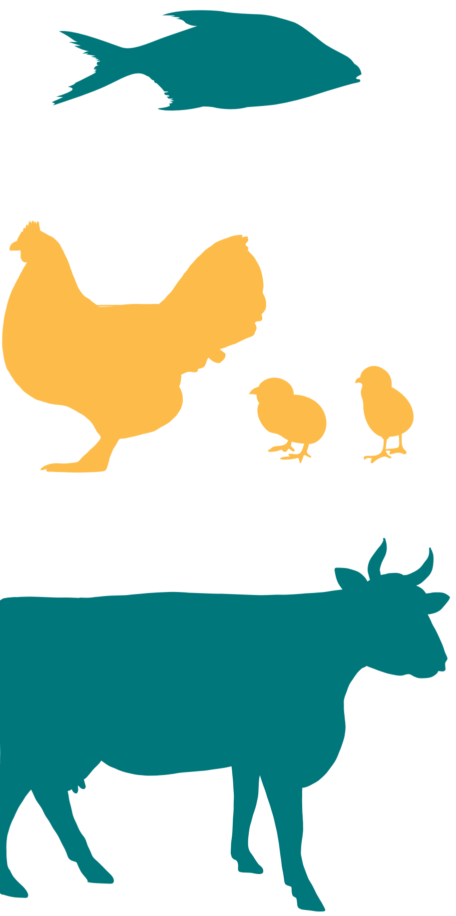
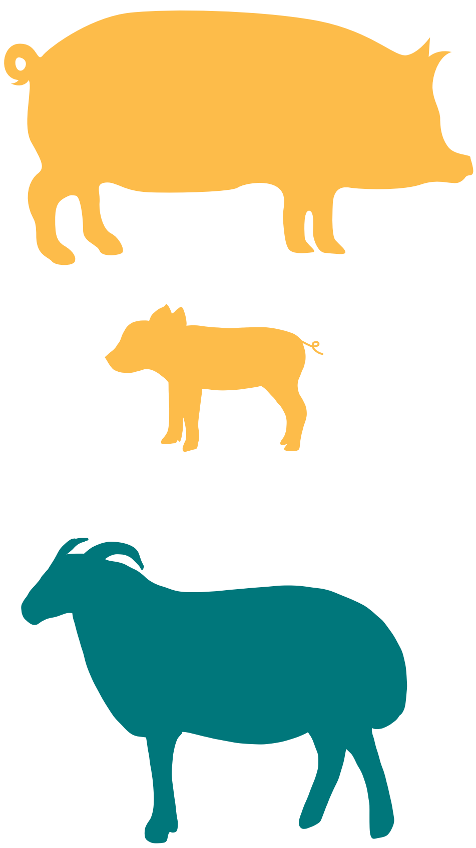


Genome editing and farmed animal breeding: social and ethical issues

NUFFIELD COUNCIL ON BIOETHICS



Genome editing and farmed animal breeding: social and ethical issues

Nuffield Council on Bioethics

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The Nuffield Council's terms of reference:

- To identify and define ethical questions raised by recent developments in biological and medical research that concern, or are likely to concern, the public interest;
- To make arrangements for the independent examination of such questions with appropriate involvement of relevant stakeholders;
- To inform and engage in policy and media debates about those ethical questions and provide informed comment on emerging issues related to or derived from NCOB's published or ongoing work; and
- To make policy recommendations to Government or other relevant bodies and to disseminate its work through published reports, briefings and other appropriate outputs.

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Acknowledgments

This report has benefitted from the contributions and advice of a great many people. The working group wishes to express its thanks, in particular, to those organisations and individuals who responded to our initial call for evidence and to the experts who attended our early fact-finding meetings. These are listed in the Appendices to the report.

Thanks are also due to the Roslin Institute in Edinburgh, for hosting a fact-finding expedition: to the research staff at the Institute for taking the time to discuss their research with the working group (Eleanor Riley, Emily Clark, Christine Tait-Burkard, Gregor Goranc, Remi Gratacap, Helen Sang, and Pam Wiener), to Tom Kirk of AbacusBio who presented findings from a willingness-to-pay study; to Leslie Penny, Head of Veterinary Services, who showed us around the veterinary hospital, and to James Nixon, the farm manager and Chris Proudfoot, the Large Animal Academic Liaison, who kindly showed us around the Roslin farm and introduced us to some of the animals, the forerunners of those for whom this report is written.

The working group is grateful to Richard Watermeyer and Gene Rowe who provided us with a review of the literature on public views about genetic modification and novel foods. We also thank former Nuffield staff member, Tom Wilson-Brown, who stepped in to provide additional research support.

Special gratitude is owed to all the participants and dialogue specialists who contributed to the public dialogue that was organised on our behalf by Basis Social and Bright Harbour, a report of which has been published separately, and to Diane Beddoes and for her advice on this initiative. Their contributions, both to our own deliberations and to the wider public debate, provide a rich and continuing source of insight.

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The Nuffield team is grateful to a number of organisations for generously inviting them to participate in meetings and initiatives in which the subject of genome editing in food and farmed animals was discussed, including: Institute of Food Science & Technology, the Food Standards Agency, the Regulatory Horizons Council, the 'What Works for Food' initiative, and the Royal Society of Biology.

The working group also wishes to thank the external readers (listed in Appendix 1) who devoted considerable energies to engaging with an earlier draft of this report and providing their valuable advice. For help in the final stages of this project we would like to thank our external copy editor, Jenny Cattermole, and indexer, Rosie Wood, and Lou Dunn who designed the cover. Finally, our gratitude goes to Nuffield colleagues Ranveig Svenning Berg and Kate Harvey, who patiently checked the references.

While the present report has benefitted in one way or another from the valuable input of all these people, the responsibility for the final content lies with the working group listed below and with the Nuffield Council on Bioethics, which has adopted this report as a report of the Council, in accordance with its established procedures.

Foreword

I first became engaged with the work of the Nuffield Council on Bioethics when I was invited to serve on the Council's first working group on genome editing in 2015. During the course of that project, I became greatly impressed by the process honed by the Council over many such endeavours, which somehow manages to reach a strong level of consensus among people with a whole range of perspectives on controversial issues of the highest importance. Given this earlier experience, it was with genuine enthusiasm that I accepted the invitation to chair the working group on the topic of genome editing of farmed animals, which generated the present report.

The question of the ethical limits of genome modification of farmed animals could hardly call more strongly for the consensus-building process for which the Nuffield Council is known. I had not imagined at the start of the project the extent to which addressing it adequately would require not only difficult ethical debate, but an understanding of the deep history of human–animal relations, and of the diverse and complex food production and distribution systems in which farmed animals play a role. Unsurprisingly, this wider framing raised a host of controversial questions. This underlined the value of having, on our working group, members with a wide range of backgrounds including farming and food systems, animal biotechnology, biological research, veterinary epidemiology, law, philosophy, social science, sociology, animal welfare, and ethics. In addition to the members of the group we discussed the issues with many more experts, to all of whom I would like to express my deep gratitude for their time and insight. I doubt whether this is exactly the report that any member of the working group would have imagined producing at the outset, but the fact that every member has been willing to sign off on it speaks again to the good will, hard work and determination to find a common position of all involved.

In order to approach the problem in hand, the working group needed to acquire a broad and shared understanding of farming systems, and I, at least, found this an eye-opening experience. Perhaps the most basic insight was into the complexity and diversity of farming systems. Farming combines knowledges, practices, environments and technologies in a huge variety of different ways and these systems are embedded in different ways in communities, societies and global value chains. The different ways that farming is organised represent different ways of solving the challenges of food supply, construct different sets of relations between the human and non-human animals involved, and have potentially significant effects, for better or worse, on a range of societal challenges. But, finally and crucially, we found much of the current set of farming systems to be ethically unacceptable and globally unsustainable and, on its current trajectory, likely only to become more so. The market incentives that have been allowed to shape the system in many industrial economies have led to intolerably low levels of animal welfare and created disastrous externalities, notably in its effects on the environment.

The low levels of animal welfare, which became a central theme of our report, are a consequence not only of the current treatment of animals, but of the long history of breeding animals for increased productivity. This has given us, for instance, chickens that grow muscle mass often faster than their legs can grow to support their weight. We recognise that new breeding technologies such as genome editing have a wide range of possible uses, some of which, in the right circumstances, might benefit both farmers and animals. Many uses doubtless remain to be discovered. But we concluded that in order safely to introduce a technology with the potential to accelerate breeding aims we would need to have procedures in place to ensure that acceptable levels of welfare, and indeed justice, were secured for the animals subject to such a technology. We were also deeply concerned that the technology not be used to adapt animals to conditions that could not conceivably provide them with a life worth living. So for example, the problem of pigs so crowded and bored that they turn to chewing one another's tails should not be solved by breeding pigs either lacking tails or so docile as not to be bothered by boredom. In the concluding part of the report, we propose a series of policies with these aims in mind, that should apply not just to genome editing, but to any technology used to direct the course of farmed animal breeding. These include full scale reform of the policies and regulation governing innovations in animal breeding, and policy informed by extensive and focused public dialogue.

I must, in conclusion, give special thanks to the hard work and dedication of the Council staff without whom this report would certainly have been impossible. Anna Wilkinson, Arzoo Ahmed, and Molly Gray, in particular, did a vast amount of background research essential to the project with great skill and thoroughness. I am grateful to the Council, which has supported the project with sage advice from its inception, and especially its Chair, Dave Archard and its Directors, first Hugh Whittall, and lately, Danielle Hamm, all of whom have been constantly available with help and advice. And I must of course thank the members of the working group whose expertise, wisdom and patience have made chairing the group an enjoyable as well as rewarding experience. Finally, I must thank Pete Mills, who has provided the main driving force behind the project. He has been the person who has kept this process on track over the years, communicating tirelessly with everyone involved, drafting and redrafting chapters, arranging meetings and expert consultations, and much more. If the report reaches, as I hope and even believe, the high standards of excellence and authority for which the Nuffield Council is known, it is above all to Pete's credit.

John Dupré

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Members of the working group were appointed for their relevant knowledge, experience, and insight. The text of the present report was agreed by the members of the working group; it does not necessarily represent the views of any individual member, their employer, or any organisation with which they may be associated. The report was adopted as a report of the Nuffield Council on Bioethics in accordance with the Council's procedures.

Terms of reference

1. To identify and examine ethical questions relating to the impact of genome editing technologies on the production, use and welfare of animals for direct human consumption (or for the production of goods for human consumption).

2. To review relevant institutional, national and international policies and provisions, and to assess their suitability in the light of the ethical questions examined.

3. To report on these matters and to make recommendations relating to policy and practice.

Table of Contents

Executive summary

1. This report was prompted by the emergence of new biological techniques for making precise, targeted alterations to DNA molecules in living cells ('genome editing') and the prospect of new breeding technologies built on them. The report considers the implications of these prospective breeding technologies in livestock and aquaculture, in the context of the broader food and farming system, particularly in relation to social and moral values. It takes a broad view, considering not only the potential implications of prospective breeding technologies for actors within food and farming systems but also implications of the innovation, diffusion, and normalisation of those technologies in the food and farming system for the societies they serve and the challenges they face.

2. The report comprises six main substantive chapters and a seventh chapter that draws out and draws together the main propositions that form the 'backbone' of the report, together with specific recommendations. This summary gives a brief overview of the content of the report.

Chapter 1 – Domestication and farmed animal breeding: from the Stone Age to the present day

3. The first chapter begins with an account of the history of the biological evolutions of, and social adaptations between, humans and non-human animals that characterise domestication up to the emergence of scientific breeding approaches and the industrialisation of farming practices. The description weaves together changes in husbandry practices with changes in the structure of social, political, and economic relations, providing a background against which ethical questions about contemporary developments in farmed animal breeding emerge. It shows the significant effect of scientific breeding practices, which emerged at the same time as the industrial revolution in eighteenth-century Britain. Combined with developments in agriculture, food preservation, processing, and distribution, these enabled the emergence of complex supply chains supporting demographic change and urbanisation in industrial nations. As a result, relationships between humans and farmed animals underwent a transformation, which we characterise as 'de-domestication', whereby farmed animals became increasingly segregated from human society and subject to new disciplines of reproductive and dietary management and environmental control.

4. The chapter describes the introduction of genetic knowledge into farmed animal breeding beginning with the description of genetic elements that explain the transmission of heritable features to successive generations. Increasing understanding of the biological mechanisms of inheritance and the ability to identify biological markers accounted for an acceleration in the development and fixing of traits that are desirable to farmers in breeding animal populations. This was supported in the twentieth century by reproductive interventions, including artificial insemination (which allows the male contribution of elite animals to be diffused widely) and management of female reproductive cycles.

5. Recombinant DNA technology and genome editing are described. In principle, these permit the inclusion or exclusion of distinct traits where a simple underlying genetic basis can be identified, in ways that may be very difficult or impossible to achieve through selective breeding (owing to the way traits are inherited together), or which would require other traits to be compromised. The limitations of these techniques are discussed. These

include technical limitations, such as editing efficiency and the current dependency on cell nuclear replacement (cloning) techniques, as well as the availability and identification of viable genetic targets for desirable traits. These limitations currently restrict the utility of genetic technologies to traits that do not involve an unmanageably large number of genes (polygenic traits) and where those genetic targets do not have multiple functions in the organism (pleiotropic genes) that could be compromised by the intervention.

6. All observable changes in characteristics of domesticated animals from the earliest archaeological records to the present time are related to evolution of genotype (whether as a result of human-imposed environmental constraints or, latterly, the deliberate selection of breeding pairs). It is therefore an open question what different significance, if any, should be attached to the possibility that changes in the genotype may potentially be controlled through direct molecular intervention. It is noted that many of the ethical distinctions that people make are rooted less in the mode of action than in the circumstances of the husbandry systems, although the potential affinity between husbandry systems and technologies is also noted.

Chapter 2 – The wider context: five societal challenges to the food and farming system

7. Chapter 2 sets out a number of 'societal challenges' to current food and farming systems. Although these challenges extend well beyond those systems, they are all challenges that have arisen, at least in part, in consequence of the way in which food and farming systems have developed, particularly in the modern period. By the same token, these challenges may be either aggravated or ameliorated by interventions in those systems. They range from locally distributed challenges, such as animal welfare in particular systems or local outbreaks of veterinary disease, to globally pervasive challenges, such as agrigenic climate change. The challenges exhibit deep systemic interconnections. The degree of integration of the global food and farming system facilitates the geographical transmission, displacement and reproduction of the challenges, and enables local events, such as innovations in breeding, to give rise to global effects. The challenges are described under five heads: (1) animal health and animal welfare; (2) human health; (3) demand and supply; (4) social, cultural, and political challenges; and (5) environmental and ecosystem challenges.

8. Infectious diseases are a major threat to farmed animals and may spread rapidly and increase in harmfulness where animals are kept at close quarters, although animals that roam freely may be more likely to come into contact with a range of disease vectors, such as wild animals. Recent years have seen a trend towards enhanced biosecurity to prevent disease, keeping animals away from potential sources of infection. Individual animals may also suffer harm from technologically intensive breeding practices (such as AI and embryo manipulation). Historical breeding strategies that have aimed at enhancing farmed animals' productivity have, in many cases, led to adverse outcomes emerging over many generations, such as a disposition to poor health and diminished capacity for enriching experiences. Many breeders have since adopted 'balanced' breeding strategies to redress this although the effectiveness of these is difficult to evaluate at present. The adverse effects of breeding have, in many cases, been compounded by husbandry systems that aim to maximise productivity and practices, such as mutilations (e.g., the surgical removal or horns or tails), that make it easier to manage animals in these systems.

9. Diet has a significant effect on human health with many non-communicable diseases being linked to the frequent consumption of certain animal products. The majority of

known human pathogens originated in animals and zoonotic disease remains a major public health threat, particularly in low-income countries, linked to contact with wild and farmed animals. The use of antimicrobials in livestock and aquaculture sectors, has been identified as a cause of antimicrobial resistance in bacteria, posing a threat to human and animal health, although steps have been taken to limit their use in recognition of this. It is increasingly recognised that the health of humans and that of farmed animals is closely linked, and that effective public health policies need to address animal and human health together.

10. Expanding populations, and sociocultural and demographic changes, place new strains on existing food and farming systems. Rising per capita income and urbanisation are associated with rising consumption of animal products, leading to so-called 'nutrition transitions', particularly in low-income countries, which are, however, most vulnerable to the effects of animal disease and climatic factors. Food security is largely dependent on integrated international supply chains to iron out local cost and supply fluctuations, although it also exposes consumers to global price instability. Power in the supply chain is unevenly distributed, so that producers generally have less influence than retailers, and poorer people in low-income countries are disproportionately vulnerable to system instabilities.

11. Urbanisation is associated with changes not only in what people prefer to eat but also in how it is processed and delivered to them, increasing the separation between human and animal lives. In some high-income countries, meat consumption is decreasing as a result of lifestyle choice and consumer preferences for meat products include those marketed for high quality and authenticity (such as local and 'organic' products). A range of social and political factors also bear on the supply chain, particularly after high profile 'food scares', which has made food safety a political issue. The nature of food production systems has also entered political consciousness, given the impact of changing husbandry systems (especially livestock intensification) on traditional employment and rural communities, and the disproportionate effects of price spikes that result from exposure to global markets.

12. Intensification of livestock farming has encouraged the intensification of crop production for animal feed, which has, in turn, led to freshwater scarcity, deforestation and habitat destruction in some parts of the world. Both the production of feed crops and the raising of animals contribute, indirectly and directly, to the emission of climate damaging greenhouse gases (carbon dioxide, methane and nitrous oxide) and environmental pollution. The extent to which these are a net contributor to environmental damage depends both on the animals farmed (the species and, to an extent, the breeds and individual genetic lines) and the husbandry system used (pasture-based systems, for example, may contribute to carbon capture). The lifecycle analysis of animal production in different systems, and of different animals in similar systems may therefore show a significantly different carbon footprint.

13. Both the interconnected nature of these challenges and the fact that they arise as effects of system configurations rather than of discrete causes means that addressing them will require transformation or rebalancing of production systems. Any intervention, including breeding interventions, may potentially ameliorate or aggravate these challenges, or ameliorate one (or more) at the expense of aggravating another (or others).

Chapter 3 – Towards a just food and farming system

14. Chapter 3 develops an ethical standard to guide and evaluate interventions in food and farming systems. It begins with the observation that, owing to circumstances of moderate scarcity, cooperation is required to secure certain of people's basic interests, for example, the opportunity for adequate nourishment. These cooperative activities become concretised in institutions of which food and farming systems are examples. It is a cardinal principle that, for any political society, its food and farming system should be arranged and governed to meet the needs of those who depend on it (see **Principle 1**).

15. Food and farming systems are arranged, managed and governed according to characteristic norms. The success of these institutions in securing people's basic interests has itself made possible growth in the size and prosperity of populations, leading to increased dependency on those very systems. However, even where it is possible to secure the basic interests of all, sometimes this is not achieved in practice. Institutions meet the standard of basic justice when the basic interests of those subject to them are respected. The challenges that impinge on or threaten to destabilise the system represent threats to basic justice.

16. Farmed animals have capacities for experiences that mean that their lives may go well or badly. We believe that sentient, non-human animals have morally relevant basic interests and come within the scope of basic justice. While we cannot say they cooperate voluntarily as moral agents in food and farming systems, they are nonetheless subject to and dependent on those systems to secure their basic interests and to provide the conditions for them to enjoy the experiences that constitute a good life. A just food and farming system is therefore one that respects the basic interests of humans and farmed animals that are subject to it (see **Principle 2**).

17. The conditions in which basic justice must be achieved are the contingent result of particular biological, environmental and social processes of evolution and co-adaptation. Addressing the challenges facing food and farming systems may require a further adaptation of these conditions. There are different ways in which these challenges might be addressed in relation to farmed animals, for example, changing the demands that are placed on farming systems, or through further adaptations of the environment or by altering animal biology. Which of these (or which combination) is desirable will depend on the initial conditions, the effective constraints on the system and choices (including moral choices) about the outcomes to be pursued.

18. Biotechnologies radically extend the power of humans to control the biological constitution of animals. While social or environmental conditions are often more tractable than biological conditions, in many cases they are not. We find no a priori reason to prefer one kind of approach over another: all bear on questions of justice and, given challenges affecting the system, all must be undertaken with caution. In determining a response it is necessary to consider both the inherent technical uncertainties of the approach and how selecting that approach may entail a commitment to a course of action that could lead to further injustices, and from which it may become increasingly difficult to disengage (see **Principle 3**).

Chapter 4 – Breeding interventions

19. Chapter 4 describes a number of prospective innovations in breeding technology that have been proposed, many of which are intended to address challenges to the food and farming system identified in Chapter 2.

20. One area where genome editing has been explored is to produce inherent changes to animals' characteristics as an alternative to surgical mutilations (such as de-horning, tail docking and castration) that are common in many farming systems. As mutilations adversely affect animal welfare, achieving the desired result through breeding interventions is claimed to be a good candidate for moral approval. However, it is important, in each case, to disentangle whether the adaptation enables the animals to live a better life in good husbandry conditions or whether it is merely intended to avert or disguise the adverse effects of poor husbandry.

21. Adaptations to produce inherent resistance to disease or tolerance for adverse environmental conditions (e.g., heat) present another class of potential genetic alterations that may benefit farmers and farmed animals. While the impact of veterinary diseases (in terms of the number of animals affected in an outbreak) may be exacerbated by intensive industrial farming, the likelihood of an outbreak occurring is mitigated by typically higher levels of biosecurity in such systems. Breeding resistance therefore offers potential advantages to both large-scale intensive and smaller scale extensive farming systems. The same is true for tolerance of environmental conditions. However, it is a cause for concern that these adaptations may perpetuate and even encourage the dense stocking of animals in industrial systems. Whether alternative strategies (e.g., vaccination of livestock or wild vectors) are available, effective, economically preferable, or morally acceptable may differ from case to case.

22. Few genome editing or biotechnological strategies have as yet been proposed for 'production traits' (understood as those that account for gross economic yield, not including reductions in costs achievable as a result of disease resistance, etc. described above). These are things like faster growth, higher finished carcass weight, the size of litters, length of reproductive cycles or efficiency of production of secondary products (e.g., milk). Many of these 'production traits' have complex underlying genetic bases. In many cases, further gains may be available by conventional selective breeding. In some species, however, historical breeding has led to significant negative outcomes for the animals and these should be redressed. They serve as a warning about the potential outcomes that future breeding practices must avoid.

23. Some applications of biotechnology have been proposed to address negative environmental impacts of farming, such as greenhouse gas emissions and reduction of biodiversity. These offer potential marginal benefits although they will not redress the substantial net contribution of animal husbandry to environmental damage without changes to the kinds of food and farming systems in use and, probably, to the overall demand for animal products (see **Recommendation 14**).

24. The examples presented in the chapter are used to explore the conjecture that the advantages of new breeding technologies such as genome editing, in terms of speed and control of genetic gain, might lead to them becoming the dominant approach for achieving breeding objectives in future. While this seems unlikely, there is clearly great potential to use these technologies for a variety of ends, or in conjunction with other breeding approaches. In this context, the possibility that applications presented as

beneficial for animal welfare might serve to establish a regulatory pathway for later applications that might lead to reduced animal welfare, for example those that simply enhance productivity traits, is a cause for concern insofar as regulation is narrowly focussed on product safety and does not adequately take animal welfare into account.

25. The examples considered suggest that it will be important to evaluate each potential application of a new breeding technology carefully, in relation to its aims and circumstances. The consideration of proposed or imagined cases in Chapter 4 helps to clarify elements of the idea of responsible breeding practices (see **Recommendation 2**).

- Farmed animals should not be bred to enhance traits merely so that they may better endure conditions of poor welfare.
- Farmed animals should not be bred in ways that diminish their inherent capacities to enjoy experiences that constitute a good life.
- Regulation of farmed animal breeding should consider the effects on the organisation of the food and farming system and on society more generally and, in particular, the need to control the potential of innovation to support damaging farming practices.

Chapter 5 – From consumers to citizens: pathways and visions

26. One of the factors that determine the configuration of the food and farming systems is the demands that are placed on it by consumers. Chapter 5 explores how the preferences of consumers are expressed through their purchasing of animal products, and how these preferences are transmitted and transformed through the value chain. It proceeds from there to consider how people express views and values about the food and farming system when they approach it as citizens who wish to influence public policy.

27. An independent review of the literature on public attitudes to genetically modified organisms and novel foods suggests that public attitudes to new breeding technologies, such as genome editing, will be complex and informed by the interaction of multiple factors, making them difficult to predict with any certainty. What existing research does suggest is that the introduction of new breeding technologies will be controversial and that people’s responses to them will be affected by how they are conceived or ‘framed’.

28. The limited evidence available about responses to genome editing as a breeding technique suggests that when people consider its use *as potential consumers* of the resulting products their preoccupations tend to be with product safety and with information that helps them to exercise choices about which products to buy. They tend to express a desire for strict regulation to secure both safety and choice. In recent public engagement about genome editing, consumers did not appear to be convinced that biotechnologies were safe and did not find it reassuring when they were presented as ways to ‘speed up’ natural processes.

29. When people consider the introduction of new breeding technologies into the national food and farming system *as citizens* they appear more concerned with effects on the food system as a whole, on farmed animals, on social justice and on the shared environment. Citizens who participated in a series of public dialogue events held alongside this inquiry expressed the strong belief that historical breeding had led to adverse outcomes for farmed animals and that many current farming practices

perpetuated poor animal welfare. Participants were much more concerned about the purposes for which the technologies (and, implicitly, alternatives to them) were to be used and whose interests they would serve than they were in their specific mode of action.

30. New breeding technologies need to be considered in the context of the range of potential approaches that exists to meet the challenges facing food and farming systems. Chapter 5 describes some of these approaches, including: radical intensification (potentially breeding animals to be more amenable to increasingly industrialised systems); exploring novel sources of protein (for example, insect and plant-based alternatives to meat); reducing food waste and developing more tightly circular food economies; and achieving general change in the dietary habits of populations (decreasing meat consumption in favour of plant-based foods).

31. While many of these approaches are consistent with each other not all are, and not all can be prioritised equally. Policy decisions are required at national level (and regional and global level) about the future of food and farming systems and the appropriate pathways to achieve it. These broach matters of national and global public interest. As a matter of principle, and for both substantive and instrumental reasons, decisions about which approach to follow should be informed by citizen engagement and public debate (see **Principle 4** and **Recommendation 1**).

Chapter 6 – Governance and compliance

32. Chapter 6 describes existing legal and regulatory controls, policy and guidance shaping the development of the food and farming system in general and its hospitability to new breeding technologies in particular, mainly from a UK perspective.

33. A significant step is to recognise sentient animals in law as deserving legal protection. Currently, there is a difference between the scrutiny given to the use of animals in scientific research and that given to their use in agriculture and aquaculture. Since the animals themselves do not differ depending on the setting in which they are placed, the increasing technical intensity of commercial breeding and, particularly, the prospective introduction of new breeding technologies (but not only this), support the case for enhanced regulation of breeding in commercial settings. Furthermore, in the current regulatory scheme, while protections for individual animals exist, insufficient attention is paid to the longitudinal effects of breeding on lines or breeds of farmed animal. This has resulted in farmed animals with phenotypes that inherently limit their ability to live lives of acceptable quality.

34. While some guidance is given to commercial breeders (for example, in Defra codes of recommendations) oversight of the cumulative effects of breeding over generations is left largely to breed societies, levy boards, industry organisations and breeders themselves. The attention it receives varies considerably between farming systems and animal species, often as a result of differences in economic organisation between sectors. 'Balanced', 'responsible' and 'sustainable' breeding objectives are generally promoted as desirable but there is little specificity, weak enforcement and a lack of reliable evidence of how these aims are being pursued and whether they are being met. Particularly in view of the prospect of new breeding technologies accelerating the attainment of breeding objectives, and making new objectives achievable, there is a need for more detailed standards, effective oversight and, where necessary, enforcement (see **Recommendation 2**).

35. The information on the basis of which commercial breeding decisions are made tends to be obscure and idiosyncratic. Breeders may rely on data that contribute to the development of breeding indices. These represent an estimation of how a given animal's progeny can be expected to differ from a specified norm in a variety of relevant respects. There is independent validation of these indices in some sectors (e.g., in dairy cattle by the Agriculture and Horticulture Development Board in the UK). In others, particularly the sectors dominated by vertically integrated commercial conglomerates, information about breeding practices is difficult to obtain, interpret, assess and compare.

36. If there is to be meaningful prospective assessment of farmed animal breeding and scrutiny of its effects on animals there is a need for standardised measures, including standards of welfare assessment (as distinct from measures of health) that can be applied between different farm settings (see **Recommendation 3**). These would benefit from validated on-farm surveillance systems (see **Recommendation 4**). The data obtained could then be fed into an independent system for collection, analysis and reporting (see **Recommendation 5**).

37. Having reliable and comparable data on the effects of breeding practices (rather than locked up in proprietary breeding systems) would provide a basis on which to make good the governance deficits identified. Governance should both promote positive objectives for breeding and guard against harmful adverse outcomes. To support this, there is a case for exploring how breeding data might be used to construct an index representing conformity with or divergence from a norm that expresses respect for basic interests and characteristics that promote the public good (see **Recommendation 6**). An independent audit system would allow such indices to be used as a tool for evaluation, improvement and governance (see **Recommendation 7**).

38. Securing a just food and farming system requires a coherent policy approach applied to the whole value chain. Consumers should be able to exercise choice as a result of labelling that provides access to reliable and meaningful information about animal welfare and other features of production and processing (see **Recommendation 8**). Retailers are able, nevertheless, to offer consumers a choice of products from animals that are responsibly bred and from those that are not. As well as producer accreditation there is therefore also a need for retailer accreditation. It is proposed that the Government should invite major retailers to subscribe to a concordat to support responsible breeding by selling animal products only from responsibly breed animals. This should ensure that, so long as all conform, none is competitively disadvantaged vis-à-vis the others (see **Recommendation 9**).

39. In the UK and EU, organisms that have been subject to direct genetic alteration are subject to special controls. Should these cease to apply to genome edited organisms or a subset of such organisms (as the Government currently proposes in England) this could potentially release an acceleration of genetic gain through new breeding technologies. Any such change in the regulatory system should only be contemplated in the context of a comprehensive review of the likely effects in the food and farming system (see **Recommendation 10**). Before changes are made there should be confidence that there is a policy context and supporting measures in place. These should be defined in relation to a coherent vision of a just food and farming system aligned with public good (see **Recommendation 11**).

40. There is already good reason for enhanced oversight of commercial breeding, though the potential of new breeding technologies to accelerate the pursuit of breeding objectives increases the strength of the argument for such measures. There is a need for an authoritative body to advise on the conformity with responsible breeding standards

and to identify, prospectively, breeds or lines that are at risk of adverse outcomes from breeding practices (see **Recommendation 12**).

41. Such a body should be able to provide anticipatory advice to commercial breeders on the conformity of their breeding strategies with responsible breeding goals (much in the way ethics committees advise on animal research), ideally informed by analysis of data that has been subject to an independent audit function (see **Recommendations 3-7**), processed in confidence if necessary. It might advise on this using a simple 'traffic light' system that divides breeding animals into three categories.

- Green – those with the capacity to live a good life in a well-managed husbandry system, when provided with a suitable environment and appropriate care.

- Amber – those in which further breeding to develop particular traits or combinations of traits may threaten their ability to live a good life, regardless of their conditions and care.

- Red – those that have been bred beyond limits compatible with an acceptable quality of life and that should therefore not be used in breeding and whose use in commercial farming should be discontinued.

42. It is products derived from animals in the 'red' category that should be proscribed via the proposed retail concordat (see **Recommendation 9**). This constraint should also apply to animal products originating outside the UK. National governments should promote responsible breeding standards and cooperate to secure similar standards internationally (see **Principle 5**). While this advice relates specifically to the effects of breeding it is equally important that acceptable standards are met in other aspects of husbandry such as the provision of suitable environments and nutrition.

43. Consideration might also be given to using the scheme to support breeding objectives that are in the public interest, making use of the intelligence about breeding effects (see **Recommendations 3-7**). This could involve redirected incentive payments to farmers, consistently with the UK Government's policy of using 'public money for public good' established by the Agriculture Act 2020, which includes improvements to animal welfare (see **Recommendation 13**).

Chapter 7 – Conclusions and recommendations

44. Chapter 7 summarises the main propositions that form the 'backbone' of the report and draws out the main conclusions and recommendations. It presents five 'guiding principles' that are relevant to the development, implementation, and governance of animal breeding technologies generally.

Principles

Principle 1 – Food security: Food and farming systems should be organised, governed, and managed to deliver, at a minimum, sufficient safe, nutritious food to meet the needs of humans and non-human animals who depend on them, now and for future generations.

Principle 2 – Basic justice: Food and farming systems should be organised and governed in a way that respects the basic interests of those whose lives they affect. This means that they should have the opportunity to live their lives in a state of safety, security, and wellbeing, with access to the experiences that constitute a good life, according to their form of life.

Principle 3 – Proportionality and caution: Policy and governance relating to farmed animal breeding should take account not only of the predicted costs and benefits of innovations but also the implications, for the food and farming system and for wider society, of their adoption, diffusion, and normalisation, having regard to the need to respond to societal challenges and taking into account the first two principles. The implications of not innovating, or of following alternative courses of action, should provide context for this consideration.

Principle 4 – Engagement and procedural justice: Where the implementation of new breeding technologies engages questions of public interest (e.g., in relation to the societal challenges affecting the food and farming system), in particular where it could have a significant bearing on the aims implied in the first two principles, those responsible for policy and governance should take steps to attend to the range of values and interests expressed by members of the public.

Principle 5 – Cooperation and solidarity: Government and public authorities should work with authorities in other jurisdictions to address societal and global challenges that cross national or political borders, including food security and nutrition, animal welfare, animal health, the emergence of zoonotic disease, biodiversity loss, ecosystem, and climate change.

45. The chapter also lays out 14 recommendations, arising from the foregoing discussion, that relate to the governance of animal breeding and the review of biotechnology regulation in the UK. These address elements across the system from consumers and retailers at one end of the supply chain to farmers and breeders at the other.

Recommendations

Recommendation 1: To inform the development of policy, law, and regulation in relation to farmed animal breeding and the introduction of new breeding technologies, public authorities should support initiatives to explore public views about these matters and their place in the future of the food and farming system. Such initiatives should explore understandings of current and proposed breeding technologies, husbandry systems, and governance, the relation between consumer choice and public interest, and the appropriate role for public authorities.

Recommendation 2: All commercial breeders of farmed animals should adopt an explicit and recognised set of breeding standards, with independent oversight. (A high-level example is Code-EFABAR, which offers certification through the European Forum of Farm Animal Breeders.) However, we recommend the development of more detailed standards that may be enforced by a national competent authority. In particular, these should seek to ensure that animals may not be bred to enhance traits merely so that they may better endure conditions of poor welfare, or in ways that diminish their inherent capacities to enjoy experiences that constitute a good life.

Recommendation 3: Support for research should include public funding for independent research to develop, validate, and integrate new measures and standards, in particular for on-farm welfare – which should include behavioural measures – as distinct from animal health.

Recommendation 4: As well as funding for the development of breeding technologies, public funding should be provided for research to develop and validate appropriate on-farm monitoring, recording, and reporting technologies, and to facilitate their adoption by farmers.

Recommendation 5: Public funding should be provided for infrastructure, training, and technical support for improved collection, integration and independent analysis of on-farm data to detect and validate the multidimensional effects of breeding and husbandry practices.

Recommendation 6: The use of breeding indices that reflect a profile of heritable characteristics, including those that are of public or social as well as economic value should be explored as a possible regulatory tool. Commercial breed developers placing animals or animal reproductive materials on the market could be required to publish these indices.

Recommendation 7: An appropriate, independent, and trustworthy body (identified or established by Defra in the UK) should monitor the longitudinal development of breeding lines (e.g., in the dimensions captured by enhanced breeding indices – see recommendation 6). This body should report on these matters to the public authority or authorities having oversight of farmed animal breeding (in the UK, the Animals in Science Committee, the Animal Welfare Committee, the Animal and Plant Health Agency and/or the proposed Animal Sentience Committee, as the case may be – see recommendation 12). The body should ideally have access to information to enable the validation of breeding effects, provided in confidence if necessary, and advise where information is lacking. We encourage breeders to facilitate scientific research using their data, leading to publication in peer-reviewed journals.

Recommendation 8: Labelling of foods containing animal products should take account of (1) scientific advice on food safety, nutrition, and other attributes of interest and (2) traceable attributes of interest to consumers, which may include circumstantial factors such as breeding practices and technologies used, husbandry systems, region of origin, and the ways in which products are processed. Use should be made of supporting technology, such as distributed ledger technology to assure traceability and quick response (QR) codes to provide access to published information.

Recommendation 9: The Government should bring the major food retailers together in order that they may collectively agree: (1) a pathway to a situation in which all animal products offered for sale come from animals that have been responsibly bred; (2) the means whereby that goal will be reached; (3) the manner in which the attainment of that goal will be overseen; (4) how this aim may be effectively backed up by retailer (rather than product) accreditation.

Recommendation 10: Any revision of the current regulatory regime for genetically modified organisms should be preceded by a thoroughgoing policy review. This should address the effects of any proposed change on the food and farming industry, and, if necessary, how these should be controlled, including their potential to encourage the use of industrial livestock systems that may adversely affect animal health, animal welfare, environmental, and other challenges.

Recommendation 11: Any review of the regulatory regime for genetically modified organisms should be carried out in the context of a publicly articulated vision for the future of the food and farming system and lead to a comprehensive policy framework (with relevant governance measures, such as are proposed in this report) to secure it.

Recommendation 12: A suitably constituted and authoritative body should oversee the effects of breeding practices in scientific research and commercial breed development. This body should advise, in particular, on any breeds or lines, whether originating from domestic or foreign breeders, which may or may not be used commercially, and on breeds or lines at risk (see recommendation 7).

Recommendation 13: Ways to encourage responsible breeding and the use of responsibly bred animals, as well as responsible husbandry practices, should be explored, for example through incentive payments to farmers in relation to the characteristics of the animals they raise (see recommendation 6).

Recommendation 14: Public support, including funding, should be provided for initiatives to develop new food sources and make more just and effective use of existing ones, and to encourage and support a voluntary change in the diet of post-industrial populations to consume animal products only when these are responsibly bred and consumed at sustainable levels, in order to promote health, to reduce environmental and ecosystem damage, and achieve climate change policy objectives.

Introduction

Origin of the inquiry

The impetus for this inquiry was the potential for development of breeding technologies that involve the precise, targeted alteration of sequences of bases in the DNA molecules of living cells (‘genome editing’). This report is the third output of a programme of work exploring the social and ethical implications of prospective genome editing technologies. It aims to elaborate and address questions first identified in our report *Genome editing: an ethical review* (2016).[1]

While possibilities of altering the genome of living beings have long been debated, new techniques, particularly the CRISPR-Cas9 system, provide a significant stepping-stone for developments in biological research and biotechnology, and bring the prospect of increased control over some inherited characteristics significantly closer. While the United Kingdom has, historically, experienced an uneasy public discourse on agricultural biotechnologies, the emergence of this new generation of genetic technologies represents a significant opportunity to examine the issues afresh.

The potential use of new breeding technologies in farmed animals raises distinctive ethical questions, concerning the treatment of sentient beings and what limits should be placed around the manipulation of their physiological and behavioural characteristics, and over how they are adapted to the conditions in which they are expected to live. These issues seem to have been less widely discussed than, for example, those involving crop plants, or even those involving human reproduction.[2] Here we aim to redress this imbalance.

Focus and scope of the inquiry

The focus of this inquiry is sentient animals that are farmed for food and other products. This includes both terrestrial livestock husbandry and aquaculture. Defining the scope of the animals under consideration presents difficulties, however. Animal sentience (which we discuss in Chapter 3) is an area of continually emerging research. It is our working assumption that not all animals are meaningfully sentient, and that not all sentient animals are sentient in the same ways. Furthermore, there may be ways other than sentience, to bring animals within the scope of moral consideration. But our report is largely concerned with the major farmed species of livestock and fish whose obvious sentience is sufficient to make their treatment a matter of moral concern.

Our decision not to consider free-living animals is also a matter of judgement given that the same species may exist on farms (and there are both tame and feral examples of all the species we discuss). And we acknowledge that genome editing strategies (e.g., for disease or population control) have been proposed in animals in the wild. Furthermore, we have not considered animals used in research (which were the subject of an earlier Nuffield Council report) or animals as potential donors of tissue and organs for medical procedures (which raise a distinctive set of issues).[3] Nor do we give separate consideration to animals used in sport,

1 Nuffield Council on Bioethics (2016) *Genome editing: an ethical review*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-an-ethical-review.

2 See: Nuffield Council on Bioethics (2018) *Genome editing and human reproduction: social and ethical issues*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-human-reproduction.

3 For animals in research, see: Nuffield Council on Bioethics (2005) *The ethics of research involving animals*, available at: https://www.nuffieldbioethics.org/publications/animal-research.

draught animals, service animals or companion animals, although many of our conclusions are equally relevant to them.

The scope of our discussions takes in animals that are subject to – and insofar as they are subject to – particular kinds of human institution, namely those characterised in the report as 'food and farming systems.' By a food and farming system we mean a set of relations involving humans and non-human animals that are orientated to the production of commodities for consumption by humans or other animals (both food and non-food products). We may speak of relatively discrete, local food and farming systems and of the global food and farming system as a whole, which may integrate so many local systems in international agri-food supply chains. The relation between local action and global outcomes is a theme of the report as this integration between the various sites and levels of production is a factor that potentially facilitates innovation, diffusion and normalisation of technologies such as genome editing.

Genome editing is one such prospective technology. While it is currently one of the most salient, it is clearly only one example of an intervention that may alter animal biology at the genomic level, one that is, furthermore, under continual development. Selective breeding remains an effective method for breeding and diffusing certain heritable changes, having been practiced more or less scientifically for many generations. As a way of achieving heritable changes in animal biology, genome editing may, in due course, also be supplemented or succeeded by other biological techniques. Accordingly, while the potential of genome editing is what has prompted our inquiry, the implications of our conclusions is inevitably broader. Indeed, it is our intention that these conclusions should be, so far as possible, 'technology-neutral'. Thus, if a new breeding technology should come along, or if similar effects should be achieved under a rubric other than that of 'genome editing', we expect our conclusions to apply equally to that new technology.

Finally, in relation to scope, in this report the reader will not find a discussion of whether it is morally acceptable for humans to eat meat or to use non-human animals instrumentally in other ways. The report does not conclude that it is morally unacceptable to eat meat or animal products (although, by the same token, it does not advocate meat-eating). It takes the present configuration of the global food and farming system, which is arranged to deliver animal products for human consumption, as the inescapable initial conditions of any future development. At the same time, it recognises that there may be a moral case for more general dietary change, particularly in urban populations in post-industrial economies.

Form of the inquiry

Rather than beginning with a discussion of a new technological development and proceeding to ask what the implications of implementing such a technology might be, we begin instead by trying to understand what factors drive or constrain the development of breeding technologies. The evolution of contemporary breeding technologies is thus located within the history of human use of farmed animals up to the present day, and the societal challenges that this history has both addressed and created. In doing so we hope to give some reflection of the variety and complexity of husbandry systems practised in other times and places, while explaining the emergence of currently dominant forms.

Among these societal challenges are moral considerations about the fair treatment of farmed animals and of humans. Unusually for a report of the Nuffield Council, the present report deals with matters that are conventionally managed by the commercial marketplace. The fact that these commercial activities give rise to societal challenges and impinge on the public interest, brings to the fore questions of public ethics (i.e., justice of systems) rather than merely of private morality (i.e., treatment of individuals). Starting with the challenges facing the food and farming system makes it possible to acknowledge that different prospective interventions may make it easier or harder to secure a just food and farming system.

In the same way that we do not take a position on the rightness or wrongness of meat eating, we do not adopt a position that is either in favour of or opposed to biotechnologies as such (though we certainly do not favour 'technological solutionism'). We appreciate that technologies or practices can help to entrench certain undesirable trajectories in the history of farming, but we also recognise that technological innovation may, in some circumstances, offer the most feasible or preferable way to respond to refractory societal challenges. We are, however, wary that short term solutions may 'lock in' undesirable systems in the long term.

There are thus really two entwined themes in the report: one is, crudely, about what humans do to non-human animals (for example, through applying breeding technologies) and the other is about what 'what humans do to animals' does to the conditions of life that humans and animals share (and therefore to the possibility of each one living a good life). Genome editing provides a way into the discussion of both of these aspects, while marking a possible moment of crisis in relation to the history of animal breeding, owing to its potential to accelerate the attainment of breeding objectives or make feasible biological changes that were previously unachievable.

Reading the report

The report is written for the interested general reader who is motivated to explore the issues discussed, either independently or professionally. Some of the discussions in the report deal with matters that are, by their nature, somewhat recondite. We have striven to present these in a way that has made sense to non-specialists. Although we have tried to keep this to a minimum, there is, unavoidably, some use of technical terminology for which we have provided a glossary at the back of the report. The report is also accompanied by a separate publication, entitled *Genome editing and farmed animal breeding: social and ethical issues – key themes, findings, and recommendations*, which provides a guide to some of the material discussed at more length in the present report.

Doubtless few readers will approach this report as a continuous whole. To enable the reader to find the sections of most interest we have provided a chapter-by-chapter summary, while to avoid missing what we regard as important contextual considerations we have supplied cross references within the text (and references to the works of others that we have found helpful or on which we rely). Our hope is to have produced an informative work that will stand as a useful reference point for important debates that are to be had about genome editing and farmed animal breeding.

Chapter 1

Domestication and farmed animal breeding

from the Stone Age to the present day

Chapter 1 – Domestication and farmed animal breeding: from the Stone Age to the present day

Chapter overview

This chapter gives a brief account of the history of biological evolution of, and social adaptations between, humans and non-human animals that characterise domestication up to the emergence of scientific breeding approaches and the industrialisation of farming practices from the eighteenth century. Combined with developments in agriculture, food preservation, processing, and distribution, these enabled the emergence of complex supply chains supporting demographic change and urbanisation in industrial nations. This has been accompanied by a transformation in the relationships between humans and farmed animals.

Increasing understanding of the biological mechanisms of inheritance and the ability to identify biological markers, combined with reproductive interventions, has led to an acceleration in the development and fixing of traits that are desirable to farmers in breeding populations. Recombinant DNA technology and genome editing potentially extend this control to the level of individual alleles, although there remain limitations.

It is an open question how this progressive extension of control should be conceived and whether the ethical response to this reflects judgements about the outcome or the mode of action.

Key points

- Humans have lived alongside farmed animals from prehistory, resulting in biological, environmental and social adaptations.
- The power to shape animals' biology to serve human ends increased significantly with the understanding of the genetic basis of heredity.
- This took place alongside social and economic transformation and industrialisation of agriculture.
- Genetic technologies offer significant potential to accelerate the attainment of breeding objectives.

Introduction

1.1 Modern human beings, *Homo sapiens*, are both descended from non-human ancestors and share many features in common with other animals. These include functional genome sequences that play similar roles in humans and other animals (and, in many cases, also in plants).[4] For most of their biological evolution, however, human beings and sentient, non-human animals did not develop in close proximity. They may, in fact, have largely avoided each other for much of prehistory. From the earliest appearance of anatomically modern human beings (approximately 200,000 years ago) until the eve of the Neolithic period (approximately 12,000 years ago), human beings' nutritional needs

[4] Zhao S, Zhang B, Yang M *et al.* (2018) Systematic profiling of histone readers in Arabidopsis thaliana *Cell Reports* **22(4)**: 1090-102.

were largely met by foraging and, occasionally, hunting.[5] Since the beginning of the Neolithic period, however, the majority of humans have followed a way of life that has supplanted foraging, one that involves pastoralism or settled farming. Indeed, the settled living arrangements that support domestication are so significant as to be a defining feature of the transition to the Neolithic from the earlier Mesolithic age.[6]

1.2 From the beginning of domestication in the Neolithic age up to the present day, humans have made use of non-human animals in a variety of ways, including as food (meat, dairy, and blood), clothing (hides and hair), transport, companions, sources of power, stores of wealth, participants in sport and religious rites, spirit helpers, sacrificial victims, totems, centrepieces of feasts, and objects of taboos.[7] For their part, the animals have received from humans food, shelter, healthcare, and protection from other predators. These arrangements have led to considerable co-adaptation between humans and non-human animals, fostering increased mutual dependency. The domestication of animals, along with the cultivation of crop plants, has led to a very considerable increase in the populations of both humans and domesticated animals, and, consequently, to the radical transformation of large areas of the physical environment.[8]

Early domestication

1.3 Domestication is a process that requires humans and non-human animals to live in close proximity and to interact for many generations.[9] Over long timescales these interactions can result in changes to the characteristic behaviours and physical features ('phenotypes') of each. Although domestication affects both humans and non-human animals, it is humans, in general, who have been able to exercise the power to establish systems of relations that serve their ends.

1.4 The shift in the balance of power between humans and non-human animals is taken to have arisen as a consequence of culture: the exceptional capacity of humans to transmit learned behaviour using language and memory.[10] It is the transmission of acquired knowledge and learned practices that makes relationships between humans and non-human animals fundamentally different from symbiotic relationships among non-humans.[11] Domestication, therefore, has both biological and cultural components, though a precise definition is notoriously difficult to settle.[12]

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5 Chan EKF, Timmermann A, Baldi BF *et al.* (2019) Human origins in a southern African palaeo-wetland and first migrations *Nature* **575**: 185-9.

6 Ucko P (1989) Foreword, in *The walking larder, patterns of domestication, pastoralism and predation* Clutton-Brock J (Editor) (London: Unwin Hyman); and Diamond J (1997) *Guns, germs and steel: the fates of human societies* (London: Vintage).

7 Russell N (2012) *Social zooarchaeology, humans and animals in prehistory* (Cambridge: Cambridge University Press).

8 For human population growth see: Our World in Data (2019) World population growth, available at: https://ourworldindata.org/world-population-growth. Although much of the world does not exhibit the visible imprint of agricultural activity, it is now beyond controversy that the atmosphere and global climate have been affected by human activity, largely as a result of the industrial revolution and transformations in systems of production of which industrial farming is a contributory part.

9 The contemporary English term 'domestication' derives from the root *domus* (Latin) or *δόμος/dómos* (Ancient Greek) meaning 'house' and apparently denoting the built setting (the root is cognate with the verb 'to build' in Proto-Indo-European languages).

10 Rindos D (1984) *The origins of agriculture: an evolutionary perspective* (New York: Academic Press).

11 Zeder MA (2012) The domestication of animals *Journal of Anthropological Research* **68(2)**: 161-90.

12 See, for example, Clutton-Brock J (1989) Introduction to domestication, in *The walking larder, patterns of domestication, pastoralism and predation*, Clutton-Brock J (Editor) (London: Unwin Hyman); Bokonyi S (1989) Definitions of animal domestication, in *The walking larder, patterns of domestication, pastoralism and predation*, Clutton-Brock J (Editor) (London: Unwin Hyman); and Ducos P (1989) Defining domestication: a clarification, in *The walking larder, patterns of domestication, pastoralism and predation*, Clutton-Brock J (Editor) (London: Unwin Hyman).

1.5 Despite the difficulty of formal definition, the process of domestication can be seen everywhere, repeated many times throughout history and still continuing today.[13] Important terrestrial domestic species (such as pigs, goats, sheep, horses, and cows) appear to have been involved in multiple and independent episodes of domestication.[14] This is confirmed by recent advances in paleogenomics, the study of ancient DNA from the archaeological record.[15] Although the pathways to domestication appear to have been diverse, it has been suggested that a number of behavioural characteristics predisposed certain animals to domestication, including group social structure, promiscuous sexual behaviour, parent–offspring bonding, flexible feeding behaviour and habitat choice, and their response to humans.[16]

1.6 Over long spans of time, domestication has had an observable effect on the characteristics of domestic animals. When humans take over protection and provisioning of animals there is a relaxation of the selective pressures that operate on free-living animals (or, rather, a replacement of those pressures by human factors). This may initially affect behaviour and physiological functions (such as the timing of reproductive cycles, the duration and volume of lactation, and speed of maturation of offspring). Controlling nutritional regimes (changing the type of fodder or bringing forward weaning) can result in biological changes that affect the size and development of domestic animals compared to free-living animals.[17]

Impacts of domestication on human societies

1.7 Domestication appears to have been associated with significant early economic and cultural transformations in human societies, being an important condition of urbanisation that took place in the early Bronze Age (mid-fourth to mid-to-late third millennium BCE).[18] Scholars have associated this development with a growth in the exploitation of 'secondary' renewable products such as milk, fibre, and traction (rather than primary products such as meat, hides, and bone).[19] These gave rise to reorganisations in the field of domestic relations, both of human–animal relations and relations that characterise human societies. These, in turn, provided the conditions for further transformations. For example, specialist handlers who worked closely with a limited number of draught livestock formed intimate and co-dependent partnerships; in the same way, the daily schedule of milking and the necessary physical proximity created relations between humans and dairy animals that improved productivity.[20] Meanwhile, the replacement of human agricultural labour (e.g., hoeing) with the use of draught animals (e.g., the ox-drawn plough) allowed the diversion of human labour into specialised crafts and large-scale building projects. As animals acquired new functions, for example as

[13] Ucko P, and Dimbleby GW (1969) Introduction: content and development of studies in domestication, in *The domestication and exploitation of plants and animals*, Ucko P, and Dimbleby GW (Editors) (London: Duckworth).

[14] Larson G, and Fuller DQ (2014) The evolution of animal domestication *Annual Review of Ecology, Evolution, and Systematics* **45**: 115-36.

[15] MacHugh DE, Larson G, and Orlando L (2017) Taming the past: ancient DNA and the study of animal domestication *Annual Review of Animal Biosciences* **5(1)**: 329-51.

[16] Zeder MA (2012) The domestication of animals *Journal of Anthropological Research* **68**: 161-90.

[17] Research comparing domestic chickens with their ancestors, red jungle fowl, has shown comparatively rapid and heritable epigenetic changes, including those associated with docility. See: Höglund A, Henriksen R, Fogelholm J *et al.* (2020) The methylation landscape and its role in domestication and gene regulation in the chicken *Nature Ecology & Evolution* **4(12)**: 1713-24.

[18] Allentuck A (2014) Temporalities of human–livestock relationships in the late prehistory of the southern Levant *Journal of Social Archaeology* **15(1)**: 94-115.

[19] Sherratt A (1983) The secondary exploitation of animals in the old world *World Archaeology* **15(1)**: 90-104.

[20] Allentuck A (2014) Temporalities of human–livestock relationships in the late prehistory of the southern Levant *Journal of Social Archaeology* **15(1)**: 94-115.

means of traction and transport, they came to be regarded as capital assets rather than merely as consumable resources.

1.8 Despite the significant asymmetries of power and the unequal distribution of benefits between humans and non-human animals, humans as well as farmed animals have been shaped by domestication.[21] Being a process that works through biological as well as cultural transmission, domestication has not left human physiology untouched. For example, although all human infants produce the enzyme lactase that allows them to digest their mothers' milk, the production of lactase tended to stop after weaning. Up to 12,000 years ago, 80 per cent of northern European adults are thought to have been lactose intolerant (poor at digesting the main carbohydrate in milk and dairy products, leading to symptoms such as bloating, abdominal cramps, diarrhoea, and nausea). Following the domestication of cattle, goats, and sheep, lactose tolerance increased rapidly, particularly among inhabitants of northern Europe, where cattle farming was established and where it remains more prevalent than in most of Asia.[22]

Modern domestication

1.9 Before the industrial revolution of the late eighteenth century (and to the present day in areas less touched by industrialisation), agriculture tended to take place within a peasant subsistence economy, typically involving cultivation of a mixture of plant and animal species. The majority of people worked in agriculture, and it remained the most common occupation in European countries into the mid-nineteenth century.[23] For most of recorded history, populations had fluctuated within relatively constant limits in response to waves of disease and food crises.[24] Agricultural productivity (or access to agricultural products) did not increase to a sufficient extent or consistently enough to support significant population increase until the modern period.[25]

Scientific breeding

1.10 Among the innovations supporting population growth and demographic change in industrialising countries in the eighteenth and nineteenth centuries were the selective breeding of livestock and new systems of arable cropping.[26] An important development was the realisation that animals differed intrinsically in quality and that the quality of animals could be improved over time. Interest in the enhancement, by breeding, of those

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[21] See, for example, Wilkins AS (2020) A molecular investigation of human self-domestication *Trends in Genetics* **36**: 227-8.

[22] In northern European populations the lactase persistence appears to be associated with a single mutation (*−13910*T*) unlike in Africa and the Middle East, where the trait is associated with several mutations. See: Gerbault P, Liebert A, Itan Y *et al.* (2011) Evolution of lactase persistence: an example of human niche construction *Philosophical Transactions of the Royal Society B: Biological Sciences* **366(1566)**: 863-77.

[23] The percentage of the population working in agriculture in England was over 70% until roughly the beginning of the seventeenth century (the proportions were almost identical in France and Germany until that point) and fell to below 50% during the first part of the eighteenth century (faster than France and Germany). See: Allen RC (2000) Economic structure and agricultural productivity in Europe, 1300-1800 *European Review of Economic History* **4**: 1-26; and The Cambridge Group for the History of Population and Social Structure (2021) *The occupational structure of Britain 1379-1911*, available at: https://www.campop.geog.cam.ac.uk/research/occupations/.

[24] Food crises are described in Thirsk J (2007) *Food in early modern England: phases, fads, fashions 1500-1760* (London: Hambledon Continuum).

[25] See: Broadberry S, Campbell BMS, and van Leeuwen B (2010) *English medieval population: reconciling time series and cross sectional evidence*, available at: https://warwick.ac.uk/fac/soc/economics/seminars/seminars/conferences/venice3/programme/english_medieval_population.pdf.

[26] The most well-known system was the Norfolk four-course rotation introduced in the nineteenth century. It has been argued that, throughout this period, improvements in arable farming were driven, to a significant degree, by the growth of the livestock sector; see: Allen R (2005) English and Welsh agriculture, 1300-1850: outputs, inputs, and income *University of Oxford, Open Access publications from University of Oxford*.

features of animals that humans found valuable developed first among the European aristocracy.[27] Enthusiasts imported horses to improve their stock by crossing them with the heavier native horses, leading to the famous Arab 'thoroughbred' lines established in the late seventeenth and early eighteenth centuries.[28]

1.11 Among farmers, it remained a common belief until the middle of the eighteenth century that the only way to increase the productivity of animals was to feed them better. It was the usual practice, therefore, to send the best animals to market, so that they could realise the best prices, and retain the poorest for breeding.[29] This practice changed from the middle of the eighteenth century with the development of experimental and controlled breeding programmes. Decisions about which particular animals to cultivate and which pairs to cross, taken on the basis of agriculturally desirable features such as growth rate, fertility, docility, adaptation to the environment, and resistance to disease, resulted in certain traits becoming more prominent in farmed animal species over time. This so-called 'look and choose' selection is the underlying mechanism of traditional animal breeding and is the process by which the particular characteristics they exhibit today were established in many species of domesticated animals.

Box 1.1: Robert Bakewell and selective breeding

The name most associated with developments in livestock breeding is that of Robert Bakewell. Bakewell was born in 1725 and took control of his family's tenancy of Dishley Grange farm in Leicestershire in 1760, at the beginning of the first industrial revolution in Britain.[30]

Bakewell adapted the method of inbreeding from racehorses to farm animals. The practice of keeping animals of both sexes together and allowing them to mate freely resulted in animals with a variety of characteristics. Bakewell's innovation was to separate males from females, allowing mating only between specifically selected animals. His method of breeding 'in-and-in', that is, breeding progeny repeatedly with closely related animals over several generations, resulted in fixed traits in those lineages that were considered desirable.

His early success was with long-wooled Lincolnshire and Leicestershire sheep. These provided mutton for the London market when culled from wool-producing flocks and fattened for market at three to four years. Bakewell bred his sheep to lay down fat earlier than other sheep, while bone and muscle were still developing. This made them succulent eating and ready for market a year sooner, on average, than other breeds. Having established the trait of early maturity, subsequent crosses with other breeds developed meat quality and fecundity. Bakewell's New Leicester breed was widely diffused, and most British sheep today have New Leicester ancestry.[31]

Bakewell also applied his principles to longhorn cattle. These met with less success as a profitable meat animal, although subsequently Mary Colpitts, her husband Charles Colling, and his brother Robert achieved success with the shorthorn using Bakewell's methods. Bakewell also experimented with heavy horses and pigs.

It was from the ideas that breeders like Bakewell and the Collings applied, that Charles Darwin later developed his ideas of natural selection. Bakewell's legacy was not only the

27 Henry VIII imported horses from Italy and Spain for his royal stud at Hampton Court and passed a law in 1535 stating that no stallion under 15 hands and no mare under 13 hands should be kept alive; see, for example, Hall S, and Clutton-Brock J (1995) *Two hundred years of British farm livestock* (London: HMSO).
28 ibid.
29 ibid.
30 Trow-Smith R (2006) *A history of British livestock husbandry, 1700-1900* (London: Routledge).
31 Hall S, and Clutton-Brock J (1995) *Two hundred years of British farm livestock* (London: HMSO).

knowledge of livestock improvement by inbreeding but also, in effect, to establish the profession of specialist breeder by selling or hiring pedigree sires to commercial farmers.[32] The knowledge developed by Bakewell and his peers was formalised and recorded in herd books, such as the *Coates Herd Book* for shorthorn cattle founded in 1822. These were adopted by cattle breeders on the model of the stud books of the breeders of racehorses.[33] Breeders also shared information and contacts through emerging agricultural societies (the Shorthorn Society was incorporated in 1875).[34] These conditions contributed to the development and diffusion of scientific approaches to breeding.

Industrialisation and complex supply chains

1.12 While selective breeding and cropping innovations made demographic shifts possible, changes in land ownership, demographic shifts, and market economic organisation were among the conditions that fostered the further transformation of agricultural systems accompanying the industrial revolution of the eighteenth century.[35] In the space of a generation the model of subsistence farming that had largely prevailed since the Stone Age was overhauled to feed the burgeoning populations of cities. This was made possible by increases in agricultural labour productivity due to greater use of draught animals, mechanisation (e.g., threshing from the 1830s) and economic reorganisation. The medieval staple of pottage (a thick soup made with seasonal cereals, pulses, greens, and herbs, and often including meat for enhanced flavour) was replaced by the 'industrial diet' that incorporated preserved and highly processed convenience foods, saving both time and money for families in which all members were obliged to work for wages.[36]

1.13 Advances in preservation, transportation, and distribution meant that the consumption of animal products could become increasingly removed from their origins. It was no longer necessary to drive animals to market and slaughter them in the streets.[37] In the course of the nineteenth century, canning of (usually processed) foods became an alternative to drying and salting.[38] By mid-century, the use of commercially produced ice had transformed the preservation of meat and dairy products, allowing them to be transported by rail and steamships a considerable distance from where they were produced.[39] The later development of mechanical refrigeration and a road transportation infrastructure

32 ibid; the authors make it clear that Bakewell was himself building on earlier work with sheep by Joseph Allom and others.

33 ibid; the first stud book for horses was founded in England in 1791.

34 ibid.

35 For urban rural population distribution up to 1800, see: Allen RC (2000) Economic structure and agricultural productivity in Europe, 1300-1800 *European Review of Economic History* **4**: 1-26. Detailed data are available via The Cambridge Group for the History of Population and Social Structure (2021) *The occupational structure of Britain 1379-1911*, available at: https://www.campop.geog.cam.ac.uk/research/occupations/.

36 Thirsk J (2007) *Food in early modern England: phases, fads, fashions 1500-1760* (London: Hambledon Continuum); and Bryant A, Bush L, and Wilk R (2013) The history of globalization and the food supply, in *The handbook of food research* Murcott A, Belasco W, and Jackson P (Editors) (London: Bloomsbury).

37 Despite public distaste and objections on the grounds of public health, this practice was nevertheless only slowly replaced throughout the nineteenth century in Western Europe by confined public abattoirs and dedicated meat markets. See: Scholliers P, and van den Eeckhout P (2013) Feeding growing cities in the nineteenth and twentieth centuries: problems, innovations, and reputations, in *The handbook of food research*, Murcott A, Belasco W, and Jackson P (Editors) (Bloomsbury: London).

38 The invention of canning was credited to Nicolas Appert, a Parisian confectioner in 1810. See: Bryant A, Bush L, and Wilk R (2013) The history of globalization and the food supply, in *The handbook of food research* Murcott A, Belasco W, and Jackson P (Editors) (London: Bloomsbury); and Hypotheses (13 February 2020) *Waste not, want not: kelp, cans and map: packaging as food preservation*, available at: https://recipes.hypotheses.org/16735.

39 Bryant A, Bush L, and Wilk R (2013) The history of globalization and the food supply, in *The handbook of food research* Murcott A, Belasco W, and Jackson P (Editors) (London: Bloomsbury).

meant that fresh meat, fish, and dairy products became cheaper and more accessible still.[40]

1.14 The industrial reorganisation of food production meant lengthening supply chains between the producer and consumers and the interposition of additional functions and entrepreneurs such as wholesalers, warehousing, distributors, and retailers with their own internal structures and external relations (facilities, packaging, quality control, management, marketing, etc.) that involve more complex value chains and increase competition.[41] The complexity of supply chains has important implications for their governance, reaching a point at which the great number of elements, their variety, and interactions exceeds the capacity of human decision makers to direct.[42]

1.15 By the end of the twentieth century, most of the final cost of food has been added in processing and retail, after the food leaves the farm.[43] It has become possible to speak of a global food system, incorporating numerous subsystems and supply chains that span the entire globe, which, through its integrated economic structure, responds constantly, if not always desirably, to fluctuations in supply and demand.[44] The local constraints of availability hitherto governing access to food in systems rooted in geography and climate have been supplanted by the constantly modulated offer of the market. Whereas demand from consumers remains a fundamental driver in this system, their influence is substantially expropriated by intermediate actors in sophisticated value chains.[45] Moreover, the international extension of supply chains means that consumers can be offered a choice between apparently similar products that have been produced using very different underlying processes.

1.16 Although food processing is ubiquitous and pervasive, it is not total. Shorter supply chains and relatively discrete food and farming systems persist in the midst of the globalised food system, allowing fresh produce to be consumed near to its source in space and time. As well as relatively discrete systems as diverse as reindeer herding in Siberia and smallholdings in sub-Saharan Africa, numerous smallholders coexist with industrial food systems in developed economies. These are an important part of the physical landscape and regional economies and, while much of their produce may find its way to food processing companies and eventually to major retailers, some reaches consumers through local outlets (e.g., butchers, farm shops, and street markets).[46]

Genetic selection of farmed animals

1.17 Discrete units of heredity were proposed in the twentieth century, as the ‘factors’ postulated in the previous century by the Moravian monk, Gregor Mendel, to explain his

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40 ibid.

41 Scholliers P, and van den Eeckhout P (2013) Feeding growing cities in the nineteenth and twentieth centuries: problems, innovations, and reputations, in *The handbook of food research*, Murcott A, Belasco W, and Jackson P (Editors) (Bloomsbury: London).

42 Serdarasan S (2013) A review of supply chain complexity drivers *Computers & Industrial Engineering* **66(3)**: 533-40

43 The Government Office for Science (2011) *The future of food and farming: challenges and choices for global sustainability*, available at: https://www.gov.uk/government/publications/future-of-food-and-farming.

44 The representation of a system (as a fluctuating field of relations within which goods, labour, capital, etc. circulate) is specifically contrasted with the representation of extractive, linear agro-industrial ‘value chains’. See: Pritchard B (2020) Food chains, in *The handbook of food research* Murcott A, Belasco W, and Jackson P (Editors) (London: Bloomsbury).

45 International Institute for Environment and Development (2004) *Food industrialisation and food power: implications for food governance*, available at: https://pubs.iied.org/sites/default/files/pdfs/migrate/9338IIED.pdf.

46 Whatmore S, Stassart P, and Renting H (2003) What’s alternative about alternative food networks? Environment **35**: 389-91; and Goodman D, DuPuis EM, and Goodman MK (2012) *Alternative food networks: knowledge, practice, and politics* (London: Routledge).

findings on the inheritance of characteristics of various strains of peas.[47] Mendelian particulate heredity was eventually recognised as a response to what had been a powerful objection to theories of Darwinian evolution: that standard theories of inheritance, which saw it as blending the traits of parents in their offspring, appeared to make the accumulation of desired variations impossible. The discrete Mendelian factors of inheritance were first named 'genes' by the Danish scientist, Wilhelm Johannsen, in 1909. The first half of the twentieth century saw impressive advances in the study of the transmission of genetic variants (mutations), most notably in research on the fruit fly, *Drosophila melanogaster*.[48] Debates about the material basis of heredity, or even whether there was one, were only finally resolved, however, with the description of the double helix structure of DNA in 1953.[49]

1.18 DNA is a large molecule present in the nucleus of every animal cell (excepting certain specific types, such as mammalian red blood cells). It consists of long series of four different subunits called nucleotides. The full complement of DNA in a cell nucleus (the organism's 'genome') is distributed among a number of chromosomes (78 in the case of chickens, 60 in cattle, and 46 in humans). Triplets of nucleotides 'code for' amino acids, the elements that make up proteins, arguably the most important functional and structural molecules in living organisms. Particular subsections of the very long DNA molecules in cell nuclei are said to 'code for' specific proteins.[50] The ability of the double helix to unwind, and for the single strands to reconstitute their complementary strands, enables these coding and, hence, hereditary information-storing molecules to replicate.

1.19 While it was formerly assumed that particular sections of DNA ('genes') could be closely identified with particular traits of which they were the cause ('genes for' traits), it is now generally understood that most traits are affected by a large number of genes (so-called polygenic traits) and that most genes are relevant to the development of many traits (pleiotropic genes). Furthermore, the expression of genes can also depend on many internal and external environmental factors. Nonetheless, a minority of so-called 'Mendelian' or 'monogenic' traits are largely dependent on the presence or absence of a particular gene variant. Several examples, such as a variant for 'polled' (hornless) cattle are discussed later in this report. And even for a variable and polygenic trait, selecting animals for reproduction that express a trait to a higher-than-average degree can produce incremental but cumulative enhancement of traits that breeders consider desirable. Moreover, even in polygenic traits there can be some variants with strong effects, so there is a continuum rather than a sharp distinction between mono- and polygenic traits. Theories of genetic inheritance allowed the use of statistical methods to achieve breeding goals, such as the 'best linear unbiased prediction' (BLUP) method developed by Charles Roy Henderson after 1949. These were based on predicting

47 Mendel's description of the laws of inheritance, published in the mid-nineteenth century, was largely ignored until its rediscovery in 1900 by three researchers, Hugo DeVries, Carl Correns and Erich von Tschermak, working independently on plant hybrids. See: Müller-Wille S, and Richmond ML (2016) Revisiting the origins of genetics, in *Heredity explored: between public domain and experimental science, 1850–1930*, Müller-Wille S, and Brandt C (Editors) (Cambridge, MA: MIT Press).

48 Kohler RE (1994) *Lord of the fly: drosophila genetics and the experimental life* (Chicago IL: University of Chicago Press).

49 Watson JD, and Crick FHC (1953) Molecular structure of nucleic acids: a structure for deoxyribose nucleic acid *Nature* **171**: 737-8.

50 The relation between these subsections, referred to as open reading frames (ORFs), and proteins is considerably more complex than this may suggest. The ORF is divided into sections called exons and introns, and after it is 'transcribed' to an RNA sequence, but before the RNA is translated into an amino acid sequence, the introns (and sometimes some of the exons) are removed and the remaining exons reassembled, often in a number of different ways. Moreover, the very complex process by which the amino acid sequence 'folds' into a functional protein may in many cases result in a number of functionally distinct end products. The relation between ORF and protein end product is thus not fixed but subordinate to the particular needs of the cell at a particular time.

random effects in offspring using pedigree and phenotypic information about progenitors.[51]

1.20 In the 1970s, techniques were developed for determining the sequence of nucleotides in DNA molecules. Dramatic increases in power and decreases in the cost of these sequencing technologies over the intervening decades have made possible detailed knowledge of the genomes of many species. For several domesticated species, this has enabled the compilation of standard reference genomes and the identification of many genes and variants of interest in farming.[52]

1.21 Where an association can be found between biological markers (such as a DNA variant) and phenotypic traits, that marker can be used to assist in the selection of individuals likely to inherit that trait, a process known as marker assisted selection. Marker assisted selection has been used since the 1980s to enable the selection and fixing of traits that would not always be passed on with high frequency (e.g., recessive traits).[53] The identification of quantitative trait loci (QTL) in the genome associated with observable, quantitatively variable traits is carried out by finding changes in individual nucleotides that are associated with sequences that are passed on with the traits of interest from generation to generation. QTL mapping shows that most of the traits of interest to breeders are polygenic, associated with thousands of genes that, individually, have a small effect.[54]

1.22 Genotyping now permits the variants of many genes in a given animal to be determined directly and their effects estimated in some cases.[55] Researchers scan and compare the genomes of many individuals with known traits to identify genetic variants (alleles) that might be fixed in the population more quickly using breeding technologies. In an attempt to accelerate variant discovery, by reducing both the use of animals and the time involved, the development of *in vitro* cell-based phenotyping platforms, including the application of surrogate readout tools, is an area of active research.

Reproductive interventions in farmed animals

1.23 Artificial insemination (AI), which involves collecting the sperm of selected male animals and depositing it manually in the reproductive tract of a female, was first used commercially in dairy cattle in the US in the 1940s. It was initially practised as a cooperative enterprise among breeders, and some of the early cooperatives subsequently evolved into major biotechnology companies.[56] The success of AI in breeding was supported by developments in theoretical and practical knowledge, including improved methods of male animal management, semen collection, evaluation, and cryopreservation, insemination procedures, detection of oestrus, and control of the

[51] Henderson CR (1975) Best linear unbiased estimation and prediction under a selection model *Biometrics* **31(2)**: 423-47.

[52] The chicken genome was first fully sequenced in 2004; see: Hillier LW, Miller W, Birney E *et al.* (2004) Sequence and comparative analysis of the chicken genome provide unique perspectives on vertebrate evolution *Nature* **432**: 695-716. The sheep genome in 2008, and cattle and pig genomes in 2009; see, for example, Archibald AL, Bolund L, Churcher C *et al.* (2010) Pig genome sequence - analysis and publication strategy *BMC Genomics* **11**: 438.

[53] Hill WG (2014) Applications of population genetics to animal breeding, from wright, fisher and lush to genomic prediction *Genetics* **196(1)**: 1-16.

[54] Schultz B, Serão N, and Ross JW (2020) Genetic improvement of livestock, from conventional breeding to biotechnological approaches, in *Animal agriculture*, Bazer FW, Lamb GC, and Wu G (Editors) (London: Academic Press).

[55] While it is certainly possible that the gene can have a robust effect, whether this is likely is an empirical question. Furthermore, even if some of the genes for a polygenic trait have significant effects, the genes are very likely also to be pleiotropic, which implies that the more of them are altered, the more likely it will be that other, probably unwanted, changes will be introduced.

[56] For example the global cooperative cattle genetics company, Genex, part of the Urus group, is continuous with the Badger Breeders Cooperative that was organised in 1940, when it had about 100 members and 12 bulls with which, that year, it inseminated 1,546 cows; see: Genex (14 May 2020) History in the making, available at: https://genex.coop/history-in-the-making/.

oestrous cycle in the female for optimum timing of insemination.[57] Oestrus detection was traditionally achieved by simple observation of the animals for behavioural signs of being in heat, but over the past 20 years this has become more challenging in dairy cows (i.e., female cattle that have borne a calf more than once).[58] As a result, alternative or additional approaches (ranging from the use of simple stick-on mounting detectors to activity monitoring and telemetry systems) have become common.[59]

1.24 Use of AI has a number of benefits for animal breeders, including minimisation of the physical stress of natural reproduction (particularly mating high bodyweight males with smaller females) and the potential to accelerate the rate at which desirable traits might be propagated through a farmed animal population by enabling 'elite' males with desirable phenotypes to sire many more offspring than could be achieved by the mating of selected animals.[60] (One bull, for example, may produce approximately 200,000 aliquots of semen for insemination per year.[61] The life of such a bull is, however, far from typical of the species, being kept in isolation and subject to routine artificial semen collection.) Of particular value to cattle farmers, is the fact that sperm can be sorted to separate or enrich samples of X and Y chromosome-bearing sperm, which give rise to female and male offspring respectively in mammals.[62] This enables the production of female calves for dairy herd replacement and avoids the birth of male calves from dairy breeds that have little economic value. In countries with modern breeding structures, more than 90 per cent of dairy cattle and nearly all turkeys are produced using AI.[63]

1.25 While AI allows the wide diffusion of a selected male contribution to reproduction, advances in both genetic profiling and embryology in the late twentieth century have allowed the female contribution to be controlled as well. The understanding of the reproductive cycle in many species and the use of hormones to regulate ovulation have allowed the production and retrieval of eggs from selected females and their controlled fertilisation in the laboratory. The development of effective *in vitro* fertilisation, embryo culture, and cryopreservation conditions and protocols for some species have meant that embryos from carefully selected male and female progenitors can be transferred to prepared surrogate hosts, potentially at large distances in time and space from their origins. *In vitro* methods still require sophisticated equipment and expertise and are therefore used primarily to establish founder populations for elite lineages in breeding programmes (e.g., in 1–2 per cent of a given cattle population) rather than as routine reproductive strategy.[64] They are, furthermore, highly invasive, require veterinary intervention and may cause discomfort and even significant pain to the animals involved.

Genetic modification

1.26 While the techniques described so far in this chapter are in widespread use in agriculture, further techniques, involving direct interventions in the genome rather than selective

57 Foote RH (2002) The history of artificial insemination: selected notes and notables *Journal of Animal Science* **80**: 1-10.
58 Yoshida C, Yusuf M, and Nakao T (2009) Duration of estrus induced after GnRH-PGF2alpha protocol in dairy heifer *Animal Science Journal* **80(6)**: 649-54
59 Crowe MA, Hostens M, and Opsomer G (2018) Reproductive management in dairy cows - the future *Irish Veterinary Journal* **71**: 1.
60 FAO and the International Atomic Energy Agency (2018) *Nuclear techniques in food and agriculture*, available at: http://www-naweb.iaea.org/nafa/aph/resources/technology-ai.html.
61 Foote RH (2002) The history of artificial insemination: selected notes and notables *Journal of Animal Science* **80**: 1-10.
62 Capel B (2017) Vertebrate sex determination: evolutionary plasticity of a fundamental switch *Nature Reviews Genetics* **18**: 675-89.
63 Niemann H, and Seamark B (2018) The evolution of farm animal biotechnology, in *Animal biotechnology 1, reproductive biotechnologies* Niemann H, and Wrezychi C (Editors) (Springer International Publishing: Springer).
64 ibid.

pressure (whether this is guided by knowledge of genetics or the results of biological testing) have been developed as a result of advances in molecular biology. These techniques have so far, with very few exceptions, only been used experimentally in animals, although some are in use in parts of the world in commercial plant breeding and arable farming.

Recombinant DNA technology

1.27 Having access to the basic cellular components of reproduction in the laboratory allows further manipulations that in many cases could not have been brought about through conventional mating, or that would have taken many generations to accomplish. Whereas genes tend to be inherited in linkage groups with other genes that are found in close proximity to them on the chromosome (linked genes), recombinant DNA technology allows the promiscuous insertion of genes from different sources. These can include genes from different organisms or species (transgenes): an example is the use of the *GFP* (green fluorescent protein) gene from the jellyfish *Aequorea victoria*, which codes for a protein that emits visible green light, to track gene expression in many scientific research contexts.[65]

1.28 The creation of a transgenic animal capable of transmitting the transgene to offspring was accomplished first in mice by injecting a sample of DNA into one of the pronuclei of a fertilised egg (zygote) *in vitro*.[66] The same technique was later used in livestock and in fish.[67] The technique of microinjection is, however, technically demanding and relatively inefficient. Furthermore, the site at which the injected DNA is integrated into the host genome cannot be controlled, which means that mutations can arise through insertion of the transgene into functional sequences, and the expression of the transgene is unpredictable.[68] Efficiency gains were made by attaching the transgene to a virus, using the genetic machinery of the virus to insert the transgene into the host genome. With this method, the size of the genetic 'payload' that can be attached to a viral vector presents a limiting factor, and targeting of insertion sites remained impossible.[69] Methods of inserting transgenes that employ gene targeting systems based on homologous recombination were subsequently applied in mouse embryonic stem (ES) cell lines that could, by reintroduction into a host embryo, give rise to chimaeric embryos (embryos containing genetic material from different kinds of organism) and, by breeding of chimaeric animals, yield mice that were genetically altered at the desired locus.[70] However, the isolation and maintenance of stem cell lines that can give rise to embryos has remained an intractable problem in large livestock and fish.[71]

Cell nuclear transfer ('cloning')

1.29 This difficulty led to the development of techniques that circumvented the process of isolating embryonic stem cells by introducing the nucleus of a modified somatic cell (a cell of the body that is not a reproductive or 'germ' cell) directly into an egg cell from

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65 See, for example, Soboleski MR, Oaks J, and Halford WP (2005) Green fluorescent protein is a quantitative reporter of gene expression in individual eukaryotic cells *Federation of American Societies for Experimental Biology Journal* **19(3)**: 440-2.

66 Costantini F, and Lacy E (1981) Introduction of a rabbit β-globin gene into the mouse germ line *Nature* **294**: 92-4.

67 Hammer RE, Pursel VG, Rexroad CE, Jr. *et al.* (1985) Production of transgenic rabbits, sheep and pigs by microinjection *Nature* **315**: 680-3.

68 The Beltsville pigs, an early transgenic application to introduce expression of human growth hormone, resulted in a range of physical abnormalities; see: Greger M (2010) Trait selection and welfare of genetically engineered animals in agriculture *Journal of Animal Science* **88(2)**: 811-4.

69 Tan W, Proudfoot C, Lillico SG, and Whitelaw CB (2016) Gene targeting, genome editing: from Dolly to editors *Transgenic Research* **25**: 273-87.

70 Capecchi MR (1989) Altering the genome by homologous recombination *Science* **244(4910)**: 1288-9.

71 ibid.

which the original nucleus had been removed. This technique was described as somatic cell nuclear transfer (SCNT) or, more popularly, cloning. Lambs cloned using embryonic cell nuclei were reported in 1996, followed by a sheep – christened Dolly – cloned using the nucleus of an adult somatic cell from a Finn Dorset ewe and the egg of a Scottish Blackface, whose birth was reported in 1997.[72]

1.30 Although the use of the cloning technique has enabled the production of transgenic livestock with gene targeted modifications, the cloning SCNT procedure has remained technically challenging and inefficient.[73] It also places a significant burden on females that produce eggs and act as surrogate hosts.[74] These factors, along with concerns about the regulatory burdens and public response to introducing cloned animals into the food system, have meant that the cloning technique has been used mostly in the development of animals for xenotransplantation and the production of pharmaceutical products rather than in agricultural applications, although there are animal breeding companies offering cloning to customers.[75] However, with improvement of cloning protocols and the potential to modify farm animal genomes more efficiently using targeted genome editing systems, a range of agricultural applications is now in view.

Genome editing

1.31 Genetic modification allows the insertion of selected genetic material to supplement the inheritance of traits that can be achieved through the assortment (limited by linkage) of gene variants in conventional breeding. However, with recombinant DNA technologies the site at which the transgene is inserted into the host genome and its consequent expression is hard to control. The process of insertion also leaves a 'footprint' in the genome of the modified organism. Genome editing, the precise, targeted alteration of a DNA sequence in a living cell, offers a way of avoiding both of these effects.[76] Research has shown that genome editing can enable the fixation of traits in livestock significantly more rapidly than genetic selection.[77] In the view of researchers from The Roslin Institute and Royal (Dick) School of Veterinary Studies at the University of Edinburgh, in 2016:

> "Until recently we have only been able to dream of the ability to change a specific base in the genome without leaving any other DNA footprint; or the ability to induce precise insertions or deletions easily and efficiently in the germline of livestock. With the advent of the genome editors this is now possible."[78]

[72] See: Campbell KH, McWhir J, Ritchie WA *et al.* (1996) Sheep cloned by nuclear transfer from a cultured cell line *Nature* **380(6569)**: 64-6; and Wilmut I, Schnieke AE, McWhir J *et al.* (1997) Viable offspring derived from fetal and adult mammalian cells *Nature* **385(6619)**: 810-3.

[73] Royal Society of Biology, responding to the working group's call for evidence (citing Hill JR (2014) Incidence of abnormal offspring from cloning and other assisted reproductive technologies *Annual Review of Animal Biosciences* **2**: 307-21); but see Genewatch UK, responding to the working group's call for evidence (citing Lewis IM, Peura TT, and Trounson AO (1998) Large-scale applications of cloning technologies for agriculture: an industry perspective *Reproduction, Fertility and Development* **10(7-8)**: 677-81) on use of cloning techniques in Australia.

[74] Royal Society of Biology, responding to the working group's call for evidence.

[75] See, for example, Schnieke AE, Kind AJ, Ritchie WA *et al.* (1997) Human factor IX transgenic sheep produced by transfer of nuclei from transfected fetal fibroblasts *Science* **278**: 2130-3; McCreath KJ, Howcroft J, Campbell KH *et al.* (2000) Production of gene-targeted sheep by nuclear transfer from cultured somatic cells *Nature* **405**: 1066-9; and Tan W, Proudfoot C, Lillico SG, and Whitelaw CB (2016) Gene targeting, genome editing: from Dolly to editors *Transgenic Research* **25(3)**: 273-87.

[76] For a description of genome editing, see: Nuffield Council on Bioethics (2016) *Genome editing: an ethical review,* available at: https://www.nuffieldbioethics.org/publications/genome-editing-an-ethical-review.

[77] Bastiaansen JWM, Bovenhuis H, Groenen MAM *et al.* (2018) The impact of genome editing on the introduction of monogenic traits in livestock *Genetics, Selection, Evolution* **50(1)**: 18.

[78] Tan W, Proudfoot C, Lillico SG *et al.* (2016) Gene targeting, genome editing: from Dolly to editors *Transgenic Research* **25(3)**: 273-87.

Genome editing mechanism

1.32 A number of different genome editing systems have been developed, but all have two basic components: a guidance system (such as a specific RNA molecule) to home in on a specific DNA sequence in the target genome and an enzyme (an endonuclease such as Cas9) to cleave the strands of DNA at the target site. As a double-strand break is highly deleterious to the cell, when the break has been produced, the cell itself contributes to the process, mobilising inbuilt mechanisms to repair the break rapidly. The repair proceeds on one of two repair pathways.

1.33 One pathway rejoins the cut DNA strands without regard to the sequence of nucleotides at each end. In this pathway, the repair process may involve the insertion, substitution, or deletion of a small number of nucleotides (an 'indel') at the repair site in a way that cannot currently be controlled. This repair pathway is known as non-homologous end joining (NHEJ). It is useful because introducing an indel can disrupt or change a functional DNA sequence, allowing researchers to investigate the function of that precise sequence in the cell system or organism. The second major DNA repair pathway, homology directed repair (HDR), uses a DNA template matched to the cut section of DNA to repair the break and restore the original sequence. By supplying a specially designed template sequence with the genome editing machinery, however, HDR can also be used to add, remove, or alter prescribed DNA sequences in a controlled way.

1.34 Which pathway the cell uses to repair a break appears to depend on the stage of the cell cycle, and inserting specific sequences of DNA using the HDR pathway remains particularly challenging.[79] However, the wide diffusion and uptake of genome editing systems across the life sciences mean that this is currently a rapidly developing area of research, and the techniques are undergoing continual refinement.

Genome editing systems

1.35 The first programmable nucleases were zinc finger nucleases (ZFNs) that were derived from mammalian transcription factors (proteins in mammalian cells that bind to DNA and cause a gene to become active). The 'fingers' bind to the DNA molecule, one set for each of the corresponding sites on the two entwined strands of DNA, to effect a double-strand break at the chosen target site. A second system, using transcription activator-like effector nucleases (TALENs) derived from *Xanthomonas sp*. (a bacterium that causes disease in plants), works in a similar way.[80] Another approach makes use of meganucleases, the most specific of naturally occurring restriction endonucleases, which have a large recognition site that can be programmed, albeit with some technical difficulty, to recognise a selected target.[81] The most revolutionary discovery, however, is the one that led to the CRISPR-Cas9 genome editing system and its rapid and wide diffusion across the life sciences.

1.36 CRISPRs (clustered regularly interspaced short palindromic repeats) are part of the adaptive immune system of bacteria, comprising DNA sequences retained by bacteria from invading viruses. These enable a bacterium to recognise and therefore to defend

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79 See, for example, Paquet D, Kwart D, Chen A *et al.* (2016) Efficient introduction of specific homozygous and heterozygous mutations using CRISPR/Cas9 *Nature* **533**: 125-9.

80 Nuffield Council on Bioethics (2016) *Genome editing: an ethical review*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-an-ethical-review.

81 Smith J, Grizot S, Arnould S *et al.* (2006) A combinatorial approach to create artificial homing endonucleases cleaving chosen sequences *Nucleic Acids Research* **34(22)**: e149.

against further viral attack.[82] The Cas9 (CRISPR-associated protein 9) is a dual RNA-guided endonuclease associated with the CRISPR defence system in the bacterium *Streptococcus pyogenes*. It was first demonstrated that the system could be targeted to cleave DNA in 2012 by a team led by Jennifer Doudna and Emmanuelle Charpentier.[83] (This initial demonstration led to the award of the Nobel Prize in Chemistry to Charpentier and Doudna in 2020.) The application of CRISPR-Cas9 in eukaryotic cells (cells with an enclosed nucleus, characteristic of all plants, fungi, and animals) was demonstrated months later, in 2013.[84] This system has several advantages, including the relative ease with which it is possible to synthesise the short guide RNA sequences necessary to target the Cas9 nuclease with a high degree of specificity.[85] It is also possible to create multiple edits at several sites in the genome by direct injection into the zygote without the need for cloning.[86]

1.37 Further systems have been developed that enable researchers to edit the epigenome (the set of acquired chemical modifications to the DNA molecule that regulate gene expression in the cell) using a similar targeting system combined with an inactivated Cas9 (dCas9) that does not cleave the DNA strands. This allows the gene activity to be switched on or off in the target cells without the need to alter the DNA sequence itself. Base editing is a related system that permits direct enzymatic conversion of a base at a target site and harnesses the cell's endogenous DNA mismatch repair mechanisms to effect sequence edits. Developments in the technique mean that it is now possible to shuffle between all of the four bases (adenine, cytosine, guanine, and thymine) that comprise DNA at a specific point in the DNA molecule, in effect generating or correcting point mutations.[87] More recently still, a technique called prime editing has been described, which directly writes new genetic information into a specified DNA site without the need to introduce double-strand breaks or use a donor DNA template.[88]

Technical challenges for genome editing

1.38 Despite the rapid advances made in the genome editing field in the twenty-first century many technical challenges remain, quite apart from questions about the acceptability or desirability of its deployment in food and farming systems.[89]

1.39 The first challenge is the delivery of the editors to the target cells. Different delivery methods are available, including physical methods (microinjection, electroporation), viral delivery methods (e.g., recombinant adeno-associated virus) and, potentially, non-viral delivery methods (liposomes, polyplexes, gold particles).[90] The different editing systems

[82] Mojica FJ, Díez-Villaseñor C, García-Martínez J *et al.* (2005) Intervening sequences of regularly spaced prokaryotic repeats derive from foreign genetic elements *Journal of Molecular Evolution* **60(2)**: 174-82

[83] Jinek M, Chylinski K, Fonfara I *et al.* (2012) A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity *Science* **337(6096)**: 816-21.

[84] Cong L, Ran FA, Cox D *et al.* (2013) Multiplex genome engineering using CRISPR/Cas systems *Science* **339(6121)**: 819-23; and Mali P, Yang L, Esvelt KM *et al.* (2013) RNA-guided human genome engineering via Cas9 *Science* **339(6121)**: 823-6

[85] Hsu PD, Lander ES, and Zhang F (2014) Development and applications of CRISPR-Cas9 for genome engineering *Cell* **157(6)**: 1262-78

[86] Proudfoot C, Carlson DF, Huddart R *et al.* (2015) Genome edited sheep and cattle *Transgenic Research* **24(1)**: 147-53.

[87] Rees HA, and Liu DR (2018) Base editing: precision chemistry on the genome and transcriptome of living cells *Nature Reviews Genetics* **19**: 770-88.

[88] Anzalone AV, Randolph PB, Davis JR *et al.* (2019) Search-and-replace genome editing without double-strand breaks or donor DNA *Nature* **576**: 149-57.

[89] Petersen B (2017) Basics of genome editing technology and its application in livestock species *Reproduction in Domestic Animals* **52 Suppl 3**: 4-13.

[90] McFarlane GR, Salvesen HA, Sternberg A *et al.* (2019) On-farm livestock genome editing using cutting edge reproductive technologies *Frontiers in Sustainable Food Systems* **3(106)**.

(ZFNs, TALENs, CRISPR-Cas9, etc.) have different advantages and disadvantages with regard to efficiency of delivery, targeting, and editing.

1.40 Where the target is a cell type or organ system in a living animal, a challenge is to insert the editors into a sufficient number of cells to effect the intended change in the phenotype. Alternatively, the editors can be introduced into a single-cell zygote *in vitro* in the expectation that the edited version of the genome will be reproduced in every cell of the organism as the developing embryo divides and grows. Even using zygote injection-based genome editing, however, mosaicism (cells having different genotypes in the same organism) remains a problem in large animals.[91] Research is exploring a number of strategies to address this.[92] Securing the intended outcome is limited not only by the efficiency of editing (securing the intended edits in the target cells) but also by the efficiency of the reproductive procedures within which the editing is used (e.g., SCNT using edited, cultured cells or direct intracytoplasmic injection of genome editing reagents into the zygote).

1.41 A possible consequence of low specificity in the guidance component of the genome editing system is to cause an edit at an unintended site in the genome ('off-target effects').[93] If not detected, these could have adverse effects on the health and welfare of any resulting animal. The specificity has improved through successive generations of editing tools and the risk of off-target effects is now falling below the frequency of spontaneous mutations that occur naturally in animal genomes.[94] Another risk is the unintended integration of the repair template in the target genome.[95] This risk can be minimised by using single-strand DNA repair templates and the genome of the edited organism can be screened to identify unintended effects which can potentially be bred out using conventional strategies.[96]

1.42 As NHEJ is the predominant repair pathway for most double-strand break repairs to DNA throughout the cell cycle, a further challenge lies in harnessing the HDR repair pathway, which is only available during certain phases of the cell cycle, to fulfil the aim of inserting new genetic material.[97] Research is exploring chemical factors that may stimulate the HDR pathway and ways to promote it by suppressing the NHEJ pathway.[98]

1.43 Finally, the utility of genome editing is limited by the identification of genomic (or epigenomic) targets and the ability to target multiple sites without, in effect, scrambling the genome.[99] As many economically valuable traits in farmed animals are controlled by several genomic regions the attempt to enhance or suppress a selected trait can lead to unintended and potentially detrimental alterations in other traits as a result of

[91] Zhao J, Lai L, Ji W *et al.* (2019) Genome editing in large animals: current status and future prospects *National Science Review* **6(3)**: 402-20.
[92] Mehravar M, Shirazi A, Nazari M *et al.* (2019) Mosaicism in CRISPR/Cas9-mediated genome editing *Developmental Biology* **445(2)**: 156-62.
[93] Hennig SL, Owen JR, Lin JC *et al.* (2020) Evaluation of mutation rates, mosaicism and off target mutations when injecting Cas9 mRNA or protein for genome editing of bovine embryos *Scientific Reports* **10**: 22309.
[94] McFarlane GR, Salvesen HA, Sternberg A *et al.* (2019) On-farm livestock genome editing using cutting edge reproductive technologies *Frontiers in Sustainable Food Systems* **3(106)**.
[95] Norris AL, Lee SS, Greenlees KJ *et al.* (2020) Template plasmid integration in germline genome-edited cattle *Nature Biotechnology* **38**: 163-4.
[96] McFarlane GR, Salvesen HA, Sternberg A *et al.* (2019) On-farm livestock genome editing using cutting edge reproductive technologies *Frontiers in Sustainable Food Systems* **3(106)**.
[97] Tang X-D, Gao F, Liu M-J *et al.* (2019) Methods for enhancing clustered regularly interspaced short palindromic repeats/cas9-mediated homology-directed repair efficiency *Frontiers in Genetics* **10**.
[98] ibid.
[99] This supported by international collaborative efforts of sequencing and annotation; see, for example, Clark EL, Archibald AL, Daetwyler HD *et al.* (2020) From FAANG to fork: application of highly annotated genomes to improve farmed animal production *Genome Biology* **21(1)**: 285.

pleiotropy.[100] Nevertheless, phenotype modifications are achievable and have been demonstrated in basic research using model animals such as mice, zebrafish, the nematode worm *C. elegans*, and *Drosophila* fruit flies. Some have also been achieved in livestock. These include the modification of horned dairy cattle to produce hornless ('polled') cattle, the production of pigs modified to have inherent resistance to specific viruses, and the modification of farmed salmon to make them sterile, thereby preventing them from interbreeding with wild populations.[101] (These and other applications of genome editing are described in more detail in Chapter 4.)

Continuity or rupture?

1.44 Domestication is a set of processes that has associated effects on the genotype (the set of gene variants that are present in a given genome) and the phenotype (the ostensible form of embodiment) of farmed animals. Throughout history, from well before the hypothesis of genes or the discovery of the structure of DNA in the 1950s, humans have assumed and exercised escalating power and agency in these processes. The associated genomic and phenotypic characteristics observed in contemporary farmed animals have come about through shared environments, inbreeding within small populations, long interaction with humans, managed breeding strategies, deliberate selection of genotypes, or by a combination of these processes. However, it is often not possible to account for the specific processes that led to each particular feature of an animal's phenotype. Indeed, it is a point frequently raised in debates about the proper legal classification of genome-edited organisms and their descendants that they may not be distinguishable biologically from organisms that could have come about without deliberate intervention.[102] For some, making this distinction is highly significant; for others it reflects a prejudice that should be subjected to critique.

Box 1.2: Views from our call for evidence

In our open call for evidence (20 June – 20 September 2019) we sought views on the extent to which new breeding technologies represented a continuation of previous processes of domestication or a departure from them. We asked: "What, if any, are the ethical differences between using genome editing and using alternative methods such as traditional selective breeding methods or marker assisted selection to alter the characteristics of a breed of farmed animals?"

Several submissions suggested that the question of whether either genome editing or alternative methods of altering the genetic characteristics of animals was ethically acceptable was prior to and independent of whether there was a fundamental ethical difference between these methods. Many respondents felt that there were significant ethical problems with existing breeding methods. For example, the Royal Society for the

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[100] Schultz B, Serão N, and Ross JW (2020) Genetic improvement of livestock, from conventional breeding to biotechnological approaches, in *Animal agriculture*, Bazer FW, Lamb GC, and Wu G (Editors) (London: Academic Press).

[101] See, for example, Carlson DF, Lancto CA, Zang B *et al.* (2016) Production of hornless dairy cattle from genome-edited cell lines *Nature Biotechnology* **34(5)**: 479-81; Burkard C, Lillico SG, Reid E *et al.* (2017) Precision engineering for PRRSV resistance in pigs: Macrophages from genome edited pigs lacking CD163 SRCR5 domain are fully resistant to both PRRSV genotypes while maintaining biological function *PLOS Pathogens* **13**: e1006206; Lillico SG, Proudfoot C, King TJ *et al.* (2016) Mammalian interspecies substitution of immune modulatory alleles by genome editing *Scientific Reports* **6**: 21645; and Gratacap RL, Wargelius A, Edvardsen RB *et al.* (2019) Potential of genome editing to improve aquaculture breeding and production *Trends in Genetics* **35(9)**: 672-84. These and other applications will be discussed in more detail in subsequent chapters.

[102] See, for example, European Commission (2019) *A scientific perspective on the regulatory status of products derived from gene editing and the implications for the GMO directive*, available at: https://op.europa.eu/en/publication-detail/-/publication/a9100d3c-4930-11e9-a8ed-01aa75ed71a1/language-en; and Defra (2021) *The regulation of genetic technologies*, available at: https://consult.defra.gov.uk/agri-food-chain-directorate/the-regulation-of-genetic-technologies/.

Prevention of Cruelty to Animals (RSPCA) said: "From the perspective of the animals' experience… both of these methods are far from ideal." Stephen Harnad was more emphatic: "Both are unethical and unjustifiable." Christian Ethics of Farmed Animal Welfare warned explicitly against drawing inferences about the acceptability of genome editing on the grounds that there is no principled ethical difference between it and more established techniques: "The claim that new technological methods of breeding—using genome-editing—merely build on pre-existing methods addresses neither the pre-existing challenges to farmed animal flourishing nor the known and yet-unknown effects."

The pace of biological alteration that might be achieved by genome editing was a difference cited by many respondents. GM Freeze noted that the "potentially transformative nature of the genetic changes proposed represents a significant increase in the pace and potential impact of human-induced changes to the physiology, health and wellbeing of animals raised for food production." The pace of genetic change was also cited by the RSPCA as potentially raising "'naturalness' or integrity issues" given that use of genome editing could see the "germline altered significantly in a single step" as opposed to traditional breeding in which the germ line is altered "gradually, in a more 'natural' way." In contrast, the Royal Society of Biology (RSB) argued that achieving increased rapidity and efficiency in breeding might lead to an overall "refinement and reduction in breeding programmes", obviating the need to produce generations of animals from which to select elite individuals, and reducing the need for backcrossing to reintroduce genetic variation.

Genome editing was also said to open up a range of modifications that were not accessible by other methods: the RSB noted the potential for "a wider portfolio of targeting applications" and Ann Bruce argued that genome editing is "most attractive when addressing problems that cannot be addressed in other ways". The Scottish Episcopal Church offered the example of hornless cattle: "This could be done by selective breeding, slowly and with considerable loss of genetic merit, or by editing the existing dairy cow genome directly. The ethical difference here is that using selective breeding would delay by many years addressing an animal welfare problem, compared with doing it rapidly by genome editing." However, genome interventions were thought to be potentially more risk prone: the RSB pointed to the current understanding of animal genomes as a factor limiting the achievability of modifications while the Soil Association argued that "gene manipulation carries much more serious uncertainties and risks than selective breeding."

Some respondents pointed to the dependence of genome editing on further painful or harmful assisted reproductive procedures, in both research and development and commercial application. GeneWatch UK said: "Production of gene edited animals also requires the extensive use of hormones and surgery… where these procedures are not applied in the interests of the animal that is being treated." The RSPCA suggested that people would regard the new procedures differently given "the importance that the public places on animal welfare" and that the use of the new techniques would be "unacceptable to the public".

Integrating breeding technologies with husbandry systems

1.45 Husbandry practices vary from species to species and area to area. 'Traditional' and technologically intensive approaches are used by both large- and small-scale producers. These are sensitive to economic factors (such as the pricing of inputs and effects of scale on marginal economic advantages) and market differentiation (e.g., preferences for fresh, local produce over imported and preserved alternatives). Nevertheless, in many countries, including the UK, the combined effects of economic factors and government policies have meant that livestock production has tended to become concentrated in larger units and open to international markets.[103] Furthermore, the trend towards larger units as well as the increase in size of the units appears to be continuing.[104]

1.46 Scale is only part of the picture, however. A variety of factors may combine in different ways to give a range of possible husbandry systems. These include stocking density, housing, feed, access to pasture and enrichment materials, technological intensity, and management systems. Farms may connect in different ways with a variety of ancillary services (such as veterinary services and feed supplies), processing systems, and markets which may be local or require transportation over long distances for finishing or slaughter. In many cases, animal husbandry is vertically integrated with other elements of the value chain (e.g., feed production and breeding through to finishing, slaughter, and processing), which are all owned by a single company.

1.47 The possible combinations of features are not captured by a simple distinction between 'intensive' and 'extensive' systems. Furthermore, given the fact that these can be managed in different ways, they do not correlate neatly with animal welfare or environmental impacts. For example, although Ireland has mostly extensive, outdoor dairy farms the environmental impact of some of them is greater, by some measures, than that of more 'intensive' systems due to amount of fertiliser used and despite the high feed component for intensive systems.[105] Life cycle assessments of different systems will, therefore, depend on the standard used to calculate the various impacts. Any appraisal must consider the combination of features in any given system, how it is run in practice, and the choices and limitations of how it is assessed. Likewise, we cannot assume that extensive systems always provide better animal welfare than intensive systems.

1.48 The factors that comprise a farming system do not, however, assort with complete independence and the effects of combining different features of production systems are not straightforward. Nevertheless, as suggested above, the prevailing structure of economic incentives, leavened by national policy, tends to push towards a relatively small number of models that combine the various factors in particular ways, with some refinements due to local conditions (geography, climate, market, tradition, etc.). Large-scale intensive systems are probably more similar to each other than are other systems,

[103] It is surprisingly difficult to obtain information about the size of farms, nature of farming practices, and distribution of animals among them. It appears, however, that most livestock production in developed and emerging economies is concentrated in larger farms (with some being *very* large indeed while most farms may be much smaller). In England, for example, while over half of the 6,200 farms fattening pigs had fewer than 50 pigs in 2019, over 85% of all fattening pigs were concentrated on farms that house over 1,000 pigs; and while the figures given for 2018 show that the 'average number of pigs on holdings with >10 pigs' was 916, the data also show that over 87% of all pigs are kept on holdings where the mean pig population is over 3,000 pigs (and some may be much larger still). See: Defra (2020) *Numbers of commercial holdings and land areas/livestock numbers by size group at June each year: England (a)*, available at: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june. In the UK, this polarised distribution is especially true of pigs and chickens with more beef cattle and sheep being produced in farms closer to the modal average size; in the US, beef and dairy cattle are more concentrated than in the UK. Relevant research has also been carried out in 2017 by Compassion in World Farming to estimate number of chickens, pigs, and dairy cows permanently housed indoors in the UK based on data from pollution permits issued to farmers by the four UK Environment Agencies. See: Compassion in World Farming (2017) *UK factory farming map*, available at: https://assets.ciwf.org/factory-farm-map/

[104] The Bureau of Investigative Journalism (17 July 2017) *The rise of the "megafarm": how British meat is made*, available at: https://www.thebureauinvestigates.com/stories/2017-07-17/megafarms-uk-intensive-farming-meat; and House of Commons Library (2019) *Agriculture: historical statistics (House of Commons Library briefing paper No.3339)*, available at: https://researchbriefings.files.parliament.uk/documents/SN03339/SN03339.pdf.

[105] AgriSearch (2015) *A comparison of confinement and pasture systems for dairy cows: what does the science say?*, available at: https://pureadmin.qub.ac.uk/ws/portalfiles/portal/127810644/Arnott_et_al._2015a.pdf.

since they are less dependent on local conditions (the physical environment and inputs are more controlled, so they are reproducible almost anywhere) and determined more by market conditions. Furthermore, these systems tend to be more technologically intensive than others and more conducive to the adoption of innovations that have high up-front costs but can capitalise on economies of scale.

1.49 Many of the salient ethical distinctions between prospective genetic interventions and more 'traditional' approaches seem to be rooted in the circumstances within which the process of genetic intervention occurs (e.g., the nature and intensity of the husbandry systems or the commercial aims of those involved) and its impact on the lives of animals rather than the method by which it is achieved (whether genome editing or another technique), or even the fact that it results from deliberate human agency.[106] We will explore this further in subsequent chapters.

Conclusion: the trajectories of domestication

1.50 Living among animals has been the norm for human beings for approximately 12 millennia. Since the emergence of settled farming in the Neolithic period, domestication of plants and animals has shaped human communities, relations with others, and the material environment. It has led to the diffusion and consolidation of a way of life that is found, with local variations, throughout the contemporary world. For most of this time, relations between humans and non-human animals, both as livestock and as food, have remained familiar and domestic. Although these relations evidently have an affective dimension they have, nevertheless, routinely involved elements of violence, albeit violence that has been mediated, to an extent, through cultural and social practices and norms.

1.51 In a comparatively short historical time, largely within the last two centuries, relations with non-human animals have become both more sophisticated and attenuated for most people living in industrial and post-industrial societies. The lengthening of supply chains, the interpolation of processing stages, their increasing technical complexity, specialisation, and commercialisation can be characterised by two movements that we might describe as 'hyperdomestication' (extending control over all dimensions of animal breeding on ever finer scales, including in relation to the animal's genome) and 'de-domestication' (the trend towards the concentration of farmed animals in large, specialist production units and the division of production processes into specialised functions, removing farming and food production from most people's day-to-day experience and leading to their social and affective alienation from the animals they eat and the processes through which they pass in order to be made available as food).[107] While traditional forms of agriculture have assuredly persisted alongside more industrial and intensive forms, public encounters with whole farmed animals have become increasingly rare, and often highly choreographed.[108] Though the effects of domestication on the phenotypes of farmed animals appear to be ethically important, the consideration of these cannot be separated from the field of relations among human and non-human

[106] This was also the view of participants in the public dialogue we commissioned in the course of this inquiry; see: Nuffield Council on Bioethics (2021) *Online public dialogue on genome editing in farmed animals, research by Basis Social on behalf of the Nuffield Council on Bioethics*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/public-dialogue-on-genome-editing-and-farmed-animals.

[107] The element of alienation and dissonance in attitudes to domestic animals and animal products was also evident in the findings of our public dialogue; see: ibid.

[108] During our inquiry, attempts were made to arrange a visit to an intensive commercial farm. Such a visit turned out not to be feasible for reasons that may have had to do with cost to the host and concerns about biosecurity. These reasons equally lead to the situation where most public contact with farmed animals is via family farms (e.g., through initiatives such as 'Open Farm Sunday') or in the countryside, whereas most farmed animals (in commercial production systems) are not seen by the public.

animals that constitute the food and farming system, which comprise, in large part, the conditions of their – and our – wellbeing.

Chapter 2

The wider context

five societal challenges to the food and farming system

Chapter 2 – The wider context: five societal challenges to the food and farming system

Chapter overview

This chapter sets out a number of ‘societal challenges’ that threaten the stability and sustainability of food and farming systems. The degree of integration of the global food and farming system facilitates the geographical transmission, displacement and reproduction of the challenges. The challenges are described under five heads: (1) animal health and animal welfare; (2) human health; (3) demand and supply; (4) social, cultural, and political challenges; and (5) environmental and ecosystem challenges.

Animal health and welfare challenges include veterinary diseases, effects of husbandry practices (such as breeding procedures and surgical mutilations), and the progressive effects of selective breeding on the animals’ constitutions over generations.

Human health challenges include the effects of high meat consumption on non-communicable diseases, the emergence of new human pathogens from animals and the contribution of antimicrobial use in farming to antimicrobial resistance in bacteria. It becomes evident that human and animal health are deeply interconnected.

Rising income and urbanisation is associated with increasing meat consumption, particularly in low-income countries, increasing demand globally, and increasing dependency on industrial food production delivered by global supply chains.

Consumption of animal products in some high-income countries is starting to decrease due to lifestyle choices, and preference for product quality and authenticity. Food production and food safety have become politicised, while food shortages exacerbated by integration into global markets have led to food riots in some countries.

Intensification of livestock farming has encouraged the intensification of feed production leading to indirect impacts on freshwater availability, deforestation, habitat destruction and biodiversity loss in some parts of the world. Livestock farming also contributes directly to damaging greenhouse gas emissions that vary according to the system.

Key points

- Food and farming systems contribute to and are threatened by a number of societal challenges that make the global system unsustainable in its present form.
- The challenges are interconnected so that interventions to ameliorate some may ameliorate or potentially also aggravate others.
- The health of humans and that of farmed animals is closely linked: effective public health policies need to address farmed animal and human health together.
- For many people food security is dependent on international supply chains that expose them to price instability. Power in supply chains is unevenly distributed, so that poorer people in low-income countries are disproportionately vulnerable to instabilities.
- Food safety and food systems have become politicised as a result of food scares and globalisation of supply chains and the effect on communities.
- Lifecycle evaluation of climate and environmental impacts of animal husbandry depends to a large extent on the system used and how it is managed.

Introduction

2.1 The use of technologies (including mechanisation, new varieties of arable crops, fertilisers, herbicides and pesticides, veterinary pharmaceuticals, and intensive husbandry systems) has enabled productivity gains and made possible significant increases in food production and distribution. The global food and farming system that has emerged since the eighteenth century has provided conditions for significant social and demographic changes among people and animals (e.g., urbanisation of human populations and industrialisation of agricultural production). World agriculture now produces more than in any earlier age, while at the same time creating new dependencies and drawing on depletable resources. Despite its successes there remain distressing internal inequities and external costs, representing an accumulation of displaced and deferred challenges, which, if they are not adequately managed or addressed, threaten damaging or even catastrophic consequences. The implementation of new biotechnologies represents both a promise of amelioration and a potential further hazard.

2.2 In the 2016 report, *Genome editing: an ethical review*, the Nuffield Council concluded that it was important for the ethical appraisal of new biotechnological interventions to have regard to the societal challenges that the innovation or intervention was intended to address.[109] Approaching questions of innovation from the point of view of societal challenges rather than that of a specific, proposed technological solution opens up critical and comparative questions (the rightness of the approach and, indeed, what makes an approach the right one) rather than merely instrumental ones (of how to manage the ethical, legal, and social implications of the approach taken).

2.3 The appropriate frame in which to describe and evaluate innovation is put into question because the relevant considerations are often multiple, of different kinds and magnitudes, affect different individuals and populations, and do so over different timescales. The same innovation may ameliorate some concerns but aggravate others. The challenges to food and farming systems are several and complex but, for convenience, they may be grouped under the following five headings.

- Animal health and animal welfare challenges: how selective breeding and husbandry systems have affected the condition of the non-human animals involved.
- Human health challenges: the link between the wellbeing of humans and non-human animals, both through the sharing of common environments in which infectious diseases circulate and through the direct consumption of animal products in human diets.[110]
- Challenges of demand and supply: food security, sustainability, and equity of access to food in competitive markets and the effects of demographic change (e.g., population growth).

[109] Nuffield Council on Bioethics (2016) *Genome editing: an ethical review*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-an-ethical-review.

[110] Roughly 80% of viruses that infect humans are zoonotic in origin, as well as around 50% of bacteria; see: Taylor LH, Latham SM, and Woolhouse ME (2001) Risk factors for human disease emergence *Philosophical Transactions B* **356(1411)**: 983-9.

- Social, cultural, and political challenges: the sustainability of rural livelihoods and ways of life, food cultures, and preferences, and the disagreements about the appropriate aims and mechanisms of food policy.
- Ecological challenges: the impact on ecosystems and environments (e.g., greenhouse gas production, deforestation, water use, waste, pollution, soil and environmental degradation, and loss of genetic diversity).

Animal health and animal welfare challenges

2.4 Health (being well) and welfare (doing well) are closely connected concepts, though they are not the same. Good health is often seen as a condition of many of the things that comprise welfare, but it is possible to be in good health and experience consistently poor welfare.[111] The ways in which non-human animals experience positive and negative states of health are determined by the animal's specific physiology and behaviour and these may be modified across generations through breeding. Welfare is a more elusive concept because it includes not only biological constitution and physical condition but also aspects of animals' experiences that are not described in physiological terms. Good welfare requires that animals are in good physical and mental health and that their needs are met.[112] The welfare of farmed animals is increasingly recognised in mainstream public policy debate in a growing number of countries, though some countries with significant livestock farming industries have not enacted specific animal welfare legislation.[113]

Disease threats

2.5 Infectious disease is the result of the interaction between a pathogenic agent and an animal host in an environment that facilitates transmission of the agent into the host. These three elements constitute the 'epidemiological triad'.[114] Disease threats may spread geographically by transmission vectors, often wild animals and insects, although there may also be outbreaks of endemic disease.[115] The cost or absence of treatments for many viral diseases and the existence of conditions for transmission in herds mean that the culling of potential, suspected, or actual hosts is typically used as a disease control strategy, in both domestic and wild populations. It was used, for example, in 2001 (and, with greater effect, in 2007) to contain foot-and-mouth outbreaks in the UK, and in response to the 2018 African swine fever (ASF) epidemic in China.[116] It has also been used, in wild badgers, in the UK and Republic of Ireland to prevent the transmission of the bacterium responsible for bovine tuberculosis (though the efficacy of this strategy is disputed).[117]

2.6 There is a tendency to regard biodiversity as an issue affecting wild organisms without considering the contribution of domestic animals. These latter, however, contribute to

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[111] The converse possibility – of enjoying high levels of welfare while experiencing poor health, which is evident for many humans – is less easy to demonstrate in non-human animals.
[112] Mellor DJ, and Beausoleil NG (2015) Extending the 'Five Domains' model for animal welfare assessment to incorporate positive welfare states *Animal Welfare* **24(3)**: 241-53.
[113] Buller H, Blokhuis H, Jensen P *et al.* (2018) Towards farm animal welfare and sustainability *Animals (Basel)* **8(6)**: 81.
[114] Robertson ID (2020) Disease control, prevention and on-farm biosecurity: the role of veterinary epidemiology *Engineering* **6(1)**: 20-5.
[115] OECD Trade and Agriculture Directorate (2015) *Risk management of outbreaks of livestock diseases*, available at: https://www.oecd-ilibrary.org/agriculture-and-food/risk-management-of-outbreaks-of-livestock-diseases_5jrrwdp8x4zs-en.
[116] Miguel E, Grosbois V, Caron A *et al.* (2020) A systemic approach to assess the potential and risks of wildlife culling for infectious disease control *Communications Biology* **3(1)**: 353.
[117] Ham C, Donnelly CA, Astley KL *et al.* (2019) Effect of culling on individual badger Meles meles behaviour: potential implications for bovine tuberculosis transmission *Journal of Applied Ecology* **56(11)**: 2390-9

biodiversity in a negative sense, driving out diversity and spreading biohomogeneity, which increases the risk of incubating new pathogens and transmitting them easily between receptive hosts. Breeding therefore contributes to the co-adaptation of host and disease by increasing populations with low levels of genetic diversity.

Box 2.1: Advances in veterinary medicine

There have been many important advances in veterinary medicine, for example diagnosis, treatment, vaccination, and the use of data science.[118] In diagnostics, molecular assays have been developed that can quickly diagnose a number of diseases and also help to track the diffusion and mutation of viruses. A number of developments in precision livestock farming offer objective tools for helping to detect disease and manage livestock to optimise their health.[119] One example is the development of precision technologies for behaviour monitoring and detection of lameness in sheep and cattle.[120] Another is the use of molecular diagnostics to track the diffusion of disease variants with clinical symptoms that are not easy to detect, and that make infection difficult to control.[121] For endemic infectious diseases alternative, or additional, strategies are needed.[122] Such strategies include developing increased host resilience and tolerance through breeding or genetic alteration.[123] Improvements in husbandry practices, and the diffusion of expertise among stock persons have also contributed to improvements in animal health.[124]

2.7 Pathogen control in the agricultural and aquaculture sectors depends to a large degree on farmers adopting good management practices.[125] The uptake of best practice is often inconsistent, however, and farmers do not always follow advice or enrol in control programmes.[126] Studies have found farmers' responses to be dependent on complex determinants, many of which may be highly idiosyncratic.[127] Veterinarians tend to be seen as the main authority for interpreting the generic advice from national bodies for a local context.[128] However, for some species especially, there can be a shortage of

[118] On the impact of data science, see: Hudson C, Kaler J, and Down P (2018) Using big data in cattle practice *In Practice* **40**: 396-410.

[119] Berckmans D (2014) Precision livestock farming technologies for welfare management in intensive livestock systems *Scientific and Technical Review of the Office International des Epizooties* **33(1)**: 189-96. Some, however, are concerned about the potential for precision livestock farming to entrench large-scale, industrial approaches to animal husbandry; see: Compassion in World Farming (2017) *Precision livestock farming: could it drive the livestock sector in the wrong direction?,* available at: https://www.ciwf.org.uk/research/animal-welfare/precision-livestock-farming-could-it-drive-the-livestock-sector-in-the-wrong-direction/.

[120] See: Kaler J, Mitsch J, Vázquez-Diosdado JA *et al.* (2020) Automated detection of lameness in sheep using machine learning approaches: novel insights into behavioural differences among lame and non-lame sheep *Royal Society Open Science* **7**: 190824; and Afonso JS, Bruce M, Keating P *et al.* (2020) Profiling detection and classification of lameness methods in British dairy cattle research: a systematic review and meta-analysis *Frontiers in Veterinary Science* **7**.

[121] There are claims that some variants may involve strains that have been made for use in illicit vaccines; see, for example, Techregister (6 February 2021) *Natual mutation found in African swine fever virus*, available at: https://www.techregister.co.uk/natural-mutation-found-in-african-swine-fever-virus/.

[122] Bishop SC, and Woolliams JA (2014) Genomics and disease resistance studies in livestock *Livestock Science* **166**: 190-8

[123] Ibid.

[124] For example, the prevalence of lameness is sheep was found roughly to have halved in England (from about 10% to about 5%) between 2004 and 2013 as a result of implementing best practice; see: Winter JR, Kaler J, Ferguson E *et al.* (2015) Changes in prevalence of, and risk factors for, lameness in random samples of English sheep flocks: 2004-2013 *Preventive Veterinary Medicine* **122(1-2)**: 121-8,

[125] Ritter C, Jansen J, Roche S *et al.* (2017) Invited review: determinants of farmers' adoption of management-based strategies for infectious disease prevention and control *Journal of Dairy Science* **100(5)**: 3329-47.

[126] Ibid.

[127] Toma L, Stott AW, Heffernan C *et al.* (2013) Determinants of biosecurity behaviour of British cattle and sheep farmers-a behavioural economics analysis *Preventive Veterinary Medicine* **108**: 321-33 and; Doidge C, Ruston A, Lovatt F *et al.* (2020) Farmers; perceptions of preventing antibiotic resistance on sheep and beef farms: risk, responsibility, and action *Frontiers in Veterinary Science* **7(524)**.

[128] Garforth CJ, Bailey AP, and Tranter RB (2013) Farmers' attitudes to disease risk management in England: a comparative analysis of sheep and pig farmers *Preventive Veterinary Medicine* **110(3-4)**: 456-66.

preventative veterinary advice on farms: research in England, for example, found that the majority of contact that sheep farmers have with vets is in the context of emergencies.[129] Furthermore, the relationship between farmers and vets is complex: although vets are seen as a trusted source of advice, communication between vets and farmers is not always effective.[130]

2.8 In general, the late twentieth and early twenty-first century has seen a move towards disease control through preventing infection (in particular through stringent biosecurity protocols) and a move away from treating individual infections.[131] Meanwhile, a considerable amount of work has been done in developing vaccines for animal diseases. However, for some livestock diseases, there are no effective vaccines available. Where there are vaccines, there are a number of reasons why farmers may prefer not to use them, which include their own perceptions of the imminence of the disease threat and of vaccine effectiveness, particularly in relation to the cost of vaccination.

Breeding effects

Health and welfare impacts of breeding practices

2.9 A number of human interventions in animal reproduction are apt to cause stress, discomfort, and, potentially, injury and infection to the animals involved. These include techniques involving sperm and egg collection, artificial insemination, and embryo transfer, used to increase the number of stock from elite progenitors by the establishment of surrogate pregnancies.[132] These techniques also provide a platform for genome editing and the production of animals by cell nuclear transfer (cloning).

2.10 In those countries in which cloning is used, it is generally used to produce breeding stock and descendants with certain characteristics, rather than animals for direct human consumption.[133] It is also used as a research tool and regulated in the UK accordingly.[134] The complexity and current state of refinement of cloning techniques have raised concerns about the health and welfare impacts of their use both for cloned animals and for surrogate hosts.[135] Pregnancies with cloned embryos also show a higher frequency of abnormal or difficult birth, especially in cattle, compared to controls. This, together with

[129] Kaler J, and Green LE (2013) Sheep farmer opinions on the current and future role of veterinarians in flock health management on sheep farms: a qualitative study *Preventive Veterinary Medicine* **112(3-4)**: 370-7; and Ruston A, Shortall O, Green M *et al.* (2016) Challenges facing the farm animal veterinary profession in England: a qualitative study of veterinarians' perceptions and responses *Preventive Veterinary Medicine* **127**: 84-93.

[130] Jansen J, Steuten CDM, Renes RJ *et al.* (2010) Debunking the myth of the hard-to-reach farmer: effective communication on udder health *Journal of Dairy Science* **93(3)**: 1296-306; Shortall O, Ruston A, Green M *et al.* (2016) Broken biosecurity? Veterinarians' framing of biosecurity on dairy farms in England *Preventive Veterinary Medicine* **132**: 20-31; and Shortall O, Sutherland L-A, Ruston A *et al.* (2018) True cowmen and commercial farmers: exploring vets' and dairy farmers' contrasting views of 'good farming' in relation to biosecurity *Sociologia Ruralis* **58(3)**: 583-603.

[131] Robertson ID (2020) Disease control, prevention and on-farm biosecurity: the role of veterinary epidemiology *Engineering* **6(1)**: 20-5

[132] Provision 22 of The Bovine Embryo (Collection, Production and Transfer) Regulations 1995 provides that: "No person shall collect or transfer any bovine embryo *per vaginam* unless a general or an epidural anaesthetic has first been administered to the cow." See, The Bovine Embryo (Collection, Production and Transfer) Regulations 1995, available at: https://www.legislation.gov.uk/uksi/1995/2478/contents/made. Egg collection is performed by veterinary surgeons via transvaginal ultrasound guided laparoscopy under epidural anaesthesia, possibly with mild sedation. All veterinary surgeons are regulated in the UK under the Veterinary Surgeons Act 1966, available at: https://www.legislation.gov.uk/ukpga/1966/36.

[133] European Commission (2013) *Impact assessment accompanying the document Proposal for a Directive of the European Parliament and of the Council on the cloning of animals of the bovine, porcine, ovine, caprine and equine species kept and reproduced for farming purposes (paper SWD(2013) 519 final)*, available at: https://ec.europa.eu/food/animals/animal-welfare/other-aspects-animal-welfare/cloning/animal-cloning-proposal_en.

[134] In UK jurisdictions such procedures are regulated under the Animals (Scientific Procedures) Act 1986; see: Nuffield Council on Bioethics (2005) *The ethics of research involving animals,* available at: https://www.nuffieldbioethics.org/publications/animal-research; see also Chapter 6.

[135] van der Berg JP, Kleter GA ,and Kok EJ (2019) Regulation and safety considerations of somatic cell nuclear transfer-cloned farm animals and their offspring used for food production *Theriogenology* **135**: 85-93; and Gouveia C, Huyser C, Egli D *et al.* (2020) Lessons learned from somatic cell nuclear transfer *International Journal of Molecular Sciences* **21(7)**: 2314.

the increased size of cloned offspring, makes caesarean sections more frequent in cattle carrying a clone than with conventionally established pregnancies.[136] However, no significant health differences have been found between the offspring of cloned animals and those of conventionally bred animals at maturity.[137]

2.11 Genome editing does not, in principle, require the cell reconstruction procedures involved in cloning. (It may, however, be used in combination with cloning and with other current and prospective technologies to expand the number of modifications or the number of embryos with selected genetic variants available for reproduction).[138] In mammals, genome editing does currently require *in vitro* embryology to produce founder animals with the desired traits.[139]

Health and welfare impacts of breeding strategies

2.12 In addition to the impact of breeding practices on individual animals, breeding strategies that select for phenotypic traits may have a cumulative effect, possibly over many generations, on the health and capacity for welfare of the breeding lines. Such effects might include congenital disease or disability or inherent predisposition to disease or disability. It is beyond doubt that, especially in some species, historical selective breeding of animals to increase productivity (e.g., for high yields and faster growth) has had a negative impact on health and welfare.[140] What is less clear is the extent to which this trend is continuing, or is being reversed or mitigated, by contemporary breeding practices. Breeders are increasingly recognising the need to balance the search for higher levels of productivity with concerns about health and welfare. Furthermore, selective breeding tends to focus on the consolidation and refinement of a small number of elite lines while genetic diversity and variation is important for the robustness and resilience of the breed. Thus, while it is important to consider the health and welfare of individual animals in the next generation it is also important that welfare considerations are understood to relate to the long-term health of the breeding lines.

[136] Pigs are multiparous, typically having a litter of 10–12 piglets (and 'up to 100 or more' cloned embryos may be transferred in a reproductive cycle). Studies from Japan show a significantly higher rate of still births than in conventionally bred pigs (24.4% compared to 5.6%). Of those that are born alive clones are more likely to experience morbidity and mortality before reaching maturity. In one survey, up to 22% of cloned calves, 25% of cloned piglets and 50% of cloned lambs die before weaning from problems such as cardiovascular failure, respiratory difficulties, abnormal kidney development, defective immune systems and musculoskeletal abnormalities. See also: Compassion in World Farming (2012) *Welfare of genetically modfied and cloned animals used for food*, available at: https://www.ciwf.org.uk/media/4237869/welfare_of_genetically_modified_and_cloned_animals_used_in_food.pdf.

[137] European Food Safety Authority (2012) *Update on the state of play of animal health and welfare and environmental impact of animals derived from SCNT cloning and their offspring, and food safety of products obtained from those animals*, available at: https://www.efsa.europa.eu/en/efsajournal/pub/2794.

[138] See, for example, Niu D, Hong-Jiang W, Lin L *et al.* (2017) Inactivation of porcine endogenous retrovirus in pigs using CRISPR-Cas9 *Science* **357(6357)**: 1303-7.

[139] European Food Safety Authority (2012) *Update on the state of play of animal health and welfare and environmental impact of animals derived from SCNT cloning and their offspring, and food safety of products obtained from those animals*, available at: https://www.efsa.europa.eu/en/efsajournal/pub/2794.

[140] This is particularly marked in commercial lines of chicken. For a comparison of fast and slow growing breeds, and observation on commercial viability, see: Dixon LM (2020) Slow and steady wins the race: the behaviour and welfare of commercial faster growing broiler breeds compared to a commercial slower growing breed *PLoS One* **15**: e0231006; and Rayner AC, Newberry RC, Vas J *et al.* (2020) Slow-growing broilers are healthier and express more behavioural indicators of positive welfare *Scientific Reports* **10(1)**: 15151.

Box 2.2: Welfare impacts of historical breeding in domestic species

Negative effects of historical breeding over generations have been observed in different species. Selecting only or principally for extreme production or physical traits can result in abnormalities that impair normal biological functioning.[141]

- Genetic selection for 'double-muscling' has led to greater risk of obstructed labour in beef cattle because fetal size is too large for the pelvis of the cow.[142] Some breeds may require caesarean section to give birth.[143] While negative welfare effects have become more salient in species with high reproductive rates and short generations, simply as a result of those species going through more generations of selection, adverse welfare effects of selective breeding have been observed increasingly in ruminants.[144]
- A historical objective of increasing the size of commercial pig litters has given rise to adverse effects on both sows and piglets. Sows with large litters have longer farrowing times and thus may experience more prolonged pain and have to mobilise their body reserves to produce sufficient milk, resulting in greater risk of losing body condition.[145] The requirement to spend more time lying down to suckle piglets leads to an increased frequency of shoulder sores.[146] Litter size is a major risk factor for piglet mortality owing to low birth weight, risk of crushing, and competition for access to teats and available nutrition.[147] Competition for teats may lead to damage to the teats or to other piglets. Outside the EU (where such practices are unlawful) this may be mitigated by grinding or clipping piglets' teeth, which, as well as causing pain and stress, can act as a gateway for infection.[148] Many of the causes of piglet mortality (chilling, starvation, injury, disease) may also cause suffering in the piglets that survive. Moreover, low birth weight is associated with a variety of negative long-term effects on piglet physiology and behaviour, such as increased reactivity to stress throughout the pig's lifetime.[149] Recent data show that, owing to piglet mortality, increasing litter size has become counterproductive as a breeding target.[150]
- Broiler chickens have been selected for increased muscle mass (particularly the breast muscles, pectoralis major and minor) and fast growth rates. A Canadian study

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141 Fraser D, Duncan IJH, Edwards SA *et al.* (2013) General principles for the welfare of animals in production systems: the underlying science and its application *The Veterinary Journal* **198**: 19-27.
142 Ibid.
143 See, for example, Kolkman I, De Vliegher S, Hoflack G *et al.* (2007) Protocol of the Caesarean section as performed in daily bovine practice in Belgium *Reproduction in Domestic Animals* **42(6)**: 583-9.
144 Turner SP, Conington J, and Dwyer CM (2015) Opinion paper: is there a role for breeding for welfare improvement? *Animal* **9(8)**: 1265-7.
145 Rutherford KM, Baxter EM, D'Eath RB *et al.* (2013) The welfare implications of large litter size in the domestic pig I: biological factors *Animal Welfare* **22(2)**: 199-218.
146 Ibid.
147 Danish Centre for Bioethics and Risk Assessment and Scottish Agricultural College (2011) *The ethical and welfare implications of large litter size in the domestic pig: challenges and solutions*, available at: https://curis.ku.dk/ws/files/37642367/17_Ethics_welfare_pig_litter_size.pdf; Andersen IL, Nævdal E, and Bøe KE (2011) Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs (Sus scrofa) *Behavioral Ecology and Sociobiology* **65(6)**: 1159-67; Rutherford KM, Baxter EM, D'Eath RB *et al.* (2013) The welfare implications of large litter size in the domestic pig I: biological factors *Animal Welfare* **22(2)**: 199-218; and Ocepek M, Newberry RC, and Andersen IL (2017) Trade-offs between litter size and offspring fitness in domestic pigs subjected to different genetic selection pressures *Applied Animal Behaviour Science* **193**:7-14.
148 Council Directive 2008/120/EC laying down minimum standards for the protection of pigs; EFSA Panel on Animal Health and Welfare (2007) Animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets[1] - Scientific Opinion of the Panel on Animal Health and Welfare *The EFSA Journal* **572**: 1-13; and Baxter EM, Rutherford KM, D'Eath RB *et al.* (2013) The welfare implications of large litter size in the domestic pig II: management factors *Animal Welfare* **22(2)**: 219-38.
149 Danish Centre for Bioethics and Risk Assessment and Scottish Agricultural College (2011) The ethical and welfare implications of large litter size in the domestic pig: challenges and solutions, available at: https://curis.ku.dk/ws/files/37642367/17_Ethics_welfare_pig_litter_size.pdf; Rutherford KM, Baxter EM, D'Eath RB *et al.* (2013) The welfare implications of large litter size in the domestic pig I: biological factors, *Animal Welfare* **22**: 199–218.
150 See: Camargo EG, Marques DBD, de Figueiredo EAP *et al.* (2020) Genetic study of litter size and litter uniformity in Landrace pigs *Brazilian Journal of Animal Science* **49**: e20180295.

comparing broiler chicken breeds from 1957, 1978, and 2005 at 42 days of age found, between 1957 and 2005, an increase in yield of 30 per cent and 37 per cent in the pectoralis minor, and 79 per cent and 85 per cent in the pectoralis major, in males and females, respectively.[151] This is associated with a number of muscular and skeletal disorders.[152] One study of conventional production systems found that broilers have a weekly mortality rate seven times that of layers of the same age.[153] A 2016 report by the European Commission identified three significant welfare impacts. It found that approximately 30 per cent of commercial intensively reared broilers have leg abnormalities that mainly result from selection for fast growth.[154] It found a higher frequency of sudden death caused by ascites (a build-up of fluid in the abdomen) in fast-growing broilers than in slow-growing comparators. The third impact was susceptibility to contact dermatitis, which, although it was attributed to birds being kept in poor conditions, shows moderate heritability and could be a potential target for selection. In fact, the report found reasons to believe that all three of the welfare impacts could be addressed, to some extent, through balanced selection without negatively affecting productivity and, indeed, it found some evidence that they were already being addressed in this way.

- Broilers are typically slaughtered before reaching maturity, at five to six weeks of age. Broiler breeders, the birds needed to breed the next generation, must be kept until they are sexually mature at 18 weeks. However, their fast growth characteristics potentially cause health problems and fertility problems: if allowed to grow quickly, many would die before reaching maturity or not be healthy enough to breed. A strategy that has been employed in the poultry industry is to restrict feed to slow the growth rate to approximately one-quarter to one-third of the intake of birds fed without restriction. This has been correlated with observable behaviours indicative of adverse welfare such as chronic hunger, overdrinking, increased pecking at non-feed objects and increased pacing.[155]
- Laying hens have been bred to lay a larger number of eggs than their ancestors by reducing the length of laying cycle.[156] A hen in a commercial flock can now lay approximately 500 eggs per year.[157] In 1930, a typical hen laid approximately 115 eggs per year.[158] The increase in egg production, however, causes progressive bone loss from the bird's skeleton as calcium is mobilised for egg shell formation.[159] In 2010,

[151] Zuidhof MJ, Schneider BL, Carney VL *et al.* (2014) Growth, efficiency, and yield of commercial broilers from 1957, 1978, and 2005, *Poultry Science* **93(12)**: 2970-82.
[152] Lake JA, Dekkers JCM, and Abasht B (2021) Genetic basis and identification of candidate genes for wooden breast and white striping in commercial broiler chickens *Scientific Reports* **11(1)**: 6785.
[153] Meseret S (2016) A review of poultry welfare in conventional production system *Livestock Research for Rural Development* **28(12)**.
[154] European Commission (2016) *Report from the Commission to the European Parliament and the Council on the impact of genetic selection on the welfare of chickens kept for meat production COM(2016) 182 final*, available at: https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-182-EN-F1-1.PDF; this confirms an earlier study from 2008: Knowles TG, Kestin SC, Haslam SM *et al.* (2008) Leg disorders in broiler chickens: prevalence, risk factors and prevention. *PLoS One* **3(2)**: e1545.
[155] EFSA Panel on Animal Health and Welfare (2010) Scientific opinion on welfare aspects of the management and housing of the grand-parent and parent stocks raised and kept for breeding purposes, *EFSA Journal* **8(7)**: 1667; see also: *R. (Compassion in World Farming Ltd) v. The Secretary of State for the Environment, Food and Rural Affairs* [2004] EWCA Civ. 1009, available at: https://www.casemine.com/judgement/uk/5a8ff7b360d03e7f57eb1532.
[156] Universities Federation for Animal Welfare (2021) *Keel damage in laying hens*, available at: https://www.ufaw.org.uk/why-ufaws-work-is-important/keel-damage-in-laying-hens.
[157] European Forum of Farm Animal Breeders, and Farm Animal Breeding and Reproduction Technology Platform (9 February 2021) *Online seminar: healthy and happy animals for sustainable societies*, recording available at: https://www.effab.info/webinar-series-breederstalkgreen.html.
[158] Farm Animal Welfare Council (2010) *Opinion on osteoporosis and bone fractures in laying hens,* available at: https://www.gov.uk/government/publications/fawc-opinion-on-osteoporosis-and-bone-fractures-in-laying-hens.
[159] Universities Federation for Animal Welfare (2021) *Keel damage in laying hens*, available at: https://www.ufaw.org.uk/why-ufaws-work-is-important/keel-damage-in-laying-hens.

the Farm Animal Welfare Committee (FAWC) found that genetic selection for high egg production caused osteoporosis and was a key factor in making hens vulnerable to bone fractures.[160] As egg production declines from approximately 42 weeks of age it is usual for layers to be replaced at 18 months.

- Aquaculture has received less attention than terrestrial species such as cows, pigs, and chickens despite the fact that fish are globally the most numerous farmed animals, as well as being a more affordable source of protein to people in developing countries.[161] This may be because, historically, less has been known about the sentience of fish and the apparent structural dissimilarities between fish and mammal brains. However, more recent research has found that the behaviour of fish is more complex than previously believed and that there is a significant degree of homology and functional equivalence between the brains of fish and mammals.[162] Although carp may have been bred selectively in China for centuries, fish and crustaceans have not been subject to commercial breeding programmes for as long as other farmed animals and generally remain genetically close to their wild antecedents.[163] Nonetheless, adverse breeding effects have been found in fish bred for fast growth, such as lateral spine deformities, cardiorespiratory problems, and partial deafness.[164]

2.13 Recognising these historical problems, breeders now assert that health and welfare are the major priority in 'balanced and responsible' breeding programmes, aimed at the mitigation of the effects of historical breeding for productivity traits. The 'balanced breeding' approach implies a balance between increasing productivity, such as meat yield, growth, and feed conversion, with a number of other aims, such as health and welfare, reproductive fitness, and environmental impact.[165] However, these programmes are arguably taking an approach that involves mitigating the effects of breeding for high yield rather than addressing their causes. Thus, the higher risk of osteoporosis in laying hens might be addressed, for example, by selecting for higher bone health, although with questionable effectiveness in the absence of moderation of the very high growth rates.[166] In some cases, breeders have offered to address the underlying problems rather than simply mitigating their effects, for example by offering a choice of slower growing broiler

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[160] Farm Animal Welfare Council (2010) *Opinion on osteoporosis and bone fractures in laying hens*, available at: https://www.gov.uk/government/publications/fawc-opinion-on-osteoporosis-and-bone-fractures-in-laying-hens.

[161] Business Benchmark on Farm Animal Welfare (2016) *Animal welfare in farmed fish. Investor briefing no. 23*, available at: https://www.bbfaw.com/media/1432/investor-briefing-no-23-animal-welfare-in-farmed-fish.pdf.

[162] Huntingford FA, and Kadri S (2014) Defining, assessing and promoting the welfare of farmed fish *Revue Scientifique et Technique* **33(1)**: 233-44.

[163] Gjedrem T, and Rye M (2018) Selection response in fish and shellfish: a review *Reviews in Aquaculture* **10(1)**: 168-79.

[164] Lind C, Ponzoni RW, Nguyen NH *et al.* (2012) Selective breeding in fish and conservation of genetic resources for aquaculture *Reproduction in Domestic Animals* **47(Suppl.4)**: 255-63; Robinson NA, Timmerhaus G, Baranski M *et al.* (2017) Training the salmon's genes: influence of aerobic exercise, swimming performance and selection on gene expression in Atlantic salmon *BMC Genomics* **18**: 1-19; and Reimer T, Dempster T, Wargelius A *et al.* (2017) Rapid growth causes abnormal vaterite formation in farmed fish otoliths *Journal of Experimental Biology* **220(16)**: 2965-69.

[165] For example the 'Nordic total merit system' which has improved udder health by selective breeding, see: European Forum of Farm Animal Breeders, and Farm Animal Breeding and Reproduction Technology Platform (9 February 2021) *Online seminar: healthy and happy animals for sustainable societies*, available at: https://www.effab.info/webinar-series-breederstalkgreen.html, presentation on behalf of Viking Genetics.

[166] European Forum of Farm Animal Breeders, and Farm Animal Breeding and Reproduction Technology Platform (9 February 2021) *Online seminar: healthy and happy animals for sustainable societies*, available at: https://www.effab.info/webinar-series-breederstalkgreen.html, presentation on behalf of Swedish University of Agricultural Sciences; but see: Dixon, LM (2020) Slow and steady wins the race: the behaviour and welfare of commercial faster growing broiler breeds compared to a commercial slower growing breed *PLoS ONE* **15(4)**: e0231006. See also: Rayner AC, Newberry RC, Vas J *et al.* (2020) Slow-growing broilers are healthier and express more behavioural indicators of positive welfare *Nature Scientific Reports* **10**: 15151.

lines.[167] However, these have only limited effectiveness in sectors of the industry where practices are determined largely by market demand.[168]

Box 2.3: The prospects for and effects of 'balanced breeding'

As part of this inquiry, we carried out a review of literature and available data on the longitudinal effect of balanced breeding strategies in the context of historical health and welfare outcomes. The review explored the historical effects of selective breeding programmes on farmed animal health and welfare and improvements that more recent balanced breeding strategies and the application of new breeding technologies may have achieved or may offer to address these challenges for four types of farmed animal: broiler chickens, pigs, cows, and aquaculture. Among other things, the review made the following findings.

- Breeding programmes that only or predominantly focus on production traits are likely to increase the prevalence of welfare problems among farmed animals. Balanced breeding programmes are needed for farm animal species that encompass production, health, welfare, and sustainability traits. A greater emphasis on non-production traits in breeding programmes is needed to see bigger and quicker improvements in the welfare and health of farmed animals.
- The intensity of selection and welfare consequences varies between livestock species. In some instances, health improvements have been achieved through breeding programmes, for example, addressing skeletal leg disorders in broiler chickens. However, more reliable peer-reviewed data are needed to detect the effects of including health and welfare traits in breeding programmes over time, especially in pigs and chickens.
- The discovery and development of genetic techniques have the potential to uncover the heritabilities of different welfare and health traits that could impact breeding decisions. Genetic tools will likely help in the understanding of complex traits and lead to targeted genome selection approaches that could address different phenotypes. The development of new measurement technologies could offer breeding companies the opportunity to monitor and record health and welfare traits more accurately in real time, which could influence the accuracy of breeding programme data.
- Broadening breeding goals to include health and welfare traits can positively impact societal demand for higher-welfare meat production and positively affect the selection of productivity traits simultaneously.
- Genome editing technologies have the potential to offer a new opportunity within the breeding industry to address health and welfare issues observed in multiple farmed animal species, with a primary focus likely to be on disease resistance. It may also provide a means to redress genetic variants resulting in negative welfare phenotypes. Genetic variation which is lost due to inbreeding can be reintroduced.

[167] European Forum of Farm Animal Breeders, and Farm Animal Breeding and Reproduction Technology Platform (9 February 2021) *Online seminar: healthy and happy animals for sustainable societies*, available at: https://www.effab.info/webinar-series-breederstalkgreen.html, presentation on behalf of Aviagen; see also: European Commission (2013) *Study of the impact of genetic selection on the welfare of chickens bred and kept for meat production: final report*, available at: https://ec.europa.eu/food/sites/food/files/animals/docs/aw_practice_farm_broilers_653020_final-report_en.pdf.

[168] But see: Saatkamp HW, Vissers LSM, van Horne PLM *et al.* (2019) Transition from conventional broiler meat to meat from production concepts with higher animal welfare: experiences from The Netherlands *Animals (Basel)* **9(8)**: 483.

- Genome-edited stocks will have to be carefully studied and managed to ensure the genes being modified have the intended effect and do not produce off-target effects before they spread through breeding populations.
- Welfare surveillance and standardised welfare assessments have the potential to identify welfare issues as they arise, with the possibility of incorporating them into breeding programmes as quickly as possible instead of many years later.
- Integrated centralised databases which collect data from abattoirs, health data from veterinary services, and on-farm surveillance from both the individual animal and the herd can benefit farmers, to guide daily decisions and to help detect any change in health and productivity over time. Centralised systems also provide the opportunity to compare herds and provide accessible data sources for breeding programmes. Access to this sort of information would potentially be valuable to the general public as well, and to organisations interested in animal welfare.

* The full review can be read at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering

Husbandry systems

2.14 Husbandry systems, which comprise the main features of the environment in which farmed animals live, probably account for the largest effects on welfare. These systems include features of the animals' physical environment and accommodation as well as other variables such as the stocking density, diet and feeding regime, physical interventions (e.g., dehorning, tail docking, and castration, collectively described as 'mutilations'), veterinary care, and arrangements for obtaining products (e.g., shearing, milking, reproduction, and slaughter). Although a great deal of attention has been focused on the welfare of animals in intensive production systems, all systems raise welfare concerns.[169]

Accommodation and environment

2.15 Animals may be kept outdoors or indoors for all or part of the year, or at different stages of their lives. Indoor systems both offer control and require more intervention in terms of feeding and stock management. Such systems tend to be more intensively stocked and managed than outdoor systems, although there are relatively extensive indoor systems, for example, those that meet the RSPCA Assured standards.[170] Conversely, there are also intensive outdoor systems, such as the feedlots for finishing beef cattle, common in the US, where absence of shade or the effects of precipitation can affect welfare, and aquaculture systems in sea or freshwater cages.[171]

2.16 Though all domesticated animals are descended from ancestors that lived outdoors and obtained their food from the environment, harms to livestock are not absent from outdoor systems.[172] Indoor systems where animals live for long periods, or in many cases for their whole lives, in close proximity to others present distinctive welfare challenges, however. These arise particularly in relation to pigs and poultry, which are farmed

[169] Temple D, and Manteca X (2020) Animal welfare in extensive production systems is still an area of concern *Frontiers in Sustainable Food Systems* **4(154)**: 545902.
[170] See: RSPCA (2021) *RSPCA welfare standards*, available at: https://science.rspca.org.uk/sciencegroup/farmanimals/standards.
[171] On cattle, see: Grandin MT (2016) Evaluation of the welfare of cattle housed in outdoor feedlot pens *Veterinary and Animal Science* **1-2**: 23-8.
[172] Temple D, and Manteca X (2020) Animal welfare in extensive production systems is still an area of concern *Frontiers in Sustainable Food Systems* **4(154)**: 545902.

intensively in indoor systems in the UK, as are salmon in outdoor systems, and beef cattle elsewhere. This use and type of animal housing has consequences for biosecurity through the potential for transmission among individuals or through contact with wild species and other vectors of disease.

2.17 Indoor systems allow greater surveillance and control of biosecurity, making it easier to prevent ingress of pathogens and wild disease vectors, and some systems have all but eliminated contact with humans and other species.[173] For example, chickens kept indoors are protected from contact with wild birds, which are a major vector of disease, including potential zoonoses (diseases that may cross to humans).[174] However, when this biosecurity is breached, intensive stocking and large group size are associated with increased risk of infection and pathogenicity.[175] For example, when low pathogenic avian influenza (LPAI) that circulates in wild birds is introduced to industrial poultry operations, it may be more readily converted to high pathogenic avian influenza (HPAI) in that environment.[176] Other factors related to the industrialisation of farming systems also contribute to the spread of disease: for example, the geographical spread of porcine reproductive and respiratory syndrome virus (PRRSV) in North America has been increased by the multi-site production systems used by the pig industry, which involve frequent long-distance transport.[177]

2.18 Densely stocked and confined conditions (such as chicken sheds, pig barns, and feedlots) present an increased risk of injury though contact with other animals or health problems resulting from environmental causes. Chickens kept on wet litter, for example, are susceptible to contact dermatitis (erosions of the breast, hock, and feet can develop into ulcerations and become infected).[178] Poor stock management practices are often responsible for injury or disease. These may be due to established but suboptimal conditions or behaviours (e.g., design of milking parlours and procedures) and there is scope for research to identify upgrades and improvements.[179]

2.19 If ruminants (cattle, sheep, goats, buffalo, deer, yak, etc.) are not fed on outdoor pasture (which may be permanent grassland or 'improved' through the use of chemical fertilisers) feed inputs must be carefully controlled and monitored for animal health and productivity. Whether indoors or out, animals may be fed on soymeal or cereals (e.g., wheat, barley, oats, and maize). These feed inputs may have knock-on effects on the environment in terms of land use efficiency, deforestation, biodiversity, water use, and water and air pollution, although some systems recirculate food products, for example, where livestock are fed on by-products, such as whey from milk processing, or other waste products from

173 The Guardian (8 October 2020) *Behind China's 'pork miracle': how technology is transforming rural hog farming*, available at: https://www.theguardian.com/environment/2020/oct/08/behind-chinas-pork-miracle-how-technology-is-transforming-rural-hog-farming.

174 Evidence presented at fact-finding meeting, July 2019; on risks from zoonotic diseases; see 'human health challenges', below.

175 FAO (2007) *Industrial livestock production and global health risks*, available at: https://www.researchgate.net/publication/43521028_Industrial_livestock_production_and_global_health_risks; Jones BA, Grace D, Kock R *et al.* (2013) Zoonosis emergence linked to agricultural intensification and environmental change *Proceedings of the National Academy of Sciences* **110(21)**: 8399-404; and Henritzi D, Petric PP, Lewis NS *et al.* (2020) Surveillance of European domestic pig populations identifies an emerging reservoir of potentially zoonotic swine influenza A viruses *Cell Host & Microbe* **28(4)**: 1-14.

176 Dhingra MS, Artois J, Dellicour S *et al.* (2018) Geographical and historical patterns in the emergences of novel highly pathogenic avian influenza (HPAI) H5 and H7 viruses in poultry *Frontiers in Veterinary Science* **5**: 84.

177 Shi M, Lemey P, Brar MS *et al.* (2013) The spread of Type 2 Porcine Reproductive and Respiratory Syndrome Virus (PRRSV) in North America: a phylogeographic approach *Virology* **447(1-2)**:146-54.

178 See: Dunlop MW, Moss AF, Groves PJ *et al.* (2016) The multidimensional causal factors of 'wet litter' in chicken-meat production *Science of The Total Environment* **562**: 766-76.

179 Griffiths BE, White DG, and Oikonomou G (2018) A cross-sectional study into the prevalence of dairy cattle lameness and associated herd-level risk factors in England and Wales *Frontiers in Veterinary Science* **5**: 65.

the human food system. All of this comes, however, at the expense of limiting animals' natural feeding and foraging behaviour, where animals may seek a variety of nutritional and even medicinal inputs ('zoopharmacognosy').[180] Furthermore, grazing animals, including sheep, can also offer an important contribution to conservation in some environments.

2.20 Where animals are densely stocked it may be difficult to provide access to a sufficiently enriching environment or to present opportunities for them to express normal behaviours. A 2019 report found that approximately 50 per cent of EU laying hens are kept in enriched cages (compared to 40 per cent in the UK).[181] Standards for the protection of pigs specify a minimum space allocation of 0.65m^2 for a 100kg fattening pig.[182] Gestation crates (sow stalls), which severely restrict the movement of pregnant sows, have been banned in the UK since 1999 and in many other countries. However, in much of the world pregnant sows may be kept in gestation crates during pregnancy before being placed in farrowing crates or pens a few days before giving birth, remaining there until the piglets are weaned.[183] A more general problem is that housing on older farms that was originally built for smaller breeds is often not appropriate for larger, modern animals.[184] Lack of space and stimulation can lead to stress, which, in turn, may lead to deterioration in their general state of health and a weakened immune system. This has obvious implications for animal welfare as well as for the quality of the animal produce, having a knock-on impact on farmers and consumers. High stocking density and lack of environmental stimulation may also lead to damaging behaviours such as tail biting in pigs and feather pecking in chickens. These are not always well controlled despite official guidance and rules on prevention, housing, and stocking densities.

Mutilations

2.21 Husbandry systems may involve routine surgical interventions (collectively described as 'mutilations'), for example castration of male animals and disbudding (removal of horn buds to prevent horn growth) in horned cattle, beak trimming (in chickens), and tail docking (in pigs). These are carried out to prevent aggression and injury to humans and other animals or for other purposes (e.g., castration that is carried out to avoid 'boar taint' in pork products), subject to guidelines (e.g., regarding the involvement of veterinarians for certain procedures or in animals over a certain age). Many of these interventions mitigate the consequences rather than address the husbandry-based causes of poor welfare.

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[180] See: Villalba JJ, and Provenza FD (2007) Self-medication and homeostatic behaviour in herbivores: learning about the benefits of nature's pharmacy *Animal* **1(9)**: 1360-70.

[181] Committee for the Common Organisation of the Agricultural Markets (2019) *Market situation for eggs*, available at: https://ec.europa.eu/info/food-farming-fisheries/animals-and-animal-products/animal-products/eggs_en; and British Lion eggs (2020) *Industry data*, available at: https://www.egginfo.co.uk/egg-facts-and-figures/industry-information/data. EU minimum standards for the protection of chickens kept for meat permits chickens to be stocked at 39kg/m2; see: Council Directive 2007/43/EC, available at: https://eur-lex.europa.eu/eli/dir/2007/43/oj. Some retailers, foodservice operators, and food manufacturers refuse to sell cage eggs or are committed to doing so by around 2025; see: Compassion in World Farming (2021) *Search results for cage free eggs*, available at: https://www.compassioninfoodbusiness.com/search/?q=cage+free+eggs.

[182] Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs, available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008L0120.

[183] The EU and UK have prohibited the use of barren battery cages for laying hens. The UK and Sweden have banned the use of sow stalls altogether. The EU has banned the use of sow stalls with an exception that allows their use for the first 28 days of pregnancy; see European Parliament (14 January 2013) *Implementation of ban on individual sow stalls, in force since 1 January 2013 in accordance with Directive 2008/120/EC on the protection of pigs*, available at: https://www.europarl.europa.eu/doceo/document/E-7-2013-000321_EN.html?redirect.

[184] Turner SP, Conington J, and Dwyer CM (2015) Opinion paper: is there a role for breeding for welfare improvement? *Animal* **9(8)**: 1265-67.

2.22 The UK and EU have sought to end the practice of routine tail docking in pigs.[185] The law provides that before farmers may dock tails, they must first try to prevent tail biting by improving the conditions on the farm. If the problem persists after these measures have been taken, farmers are permitted to dock the tails but only for the next batch of pigs. They must then return to trying to prevent tail biting by improving the pigs' conditions.[186] Despite this, the exception is commonly invoked: in 2018, approximately 70 per cent of finisher pigs in the UK had their tails docked.[187]

2.23 Laying hens in all systems have a tendency to peck, which, if directed to the plumage and skin of other birds, can lead to injury and death.[188] To prevent this, the majority of laying hens housed in caged, barn, and even so-called free-range systems in the UK routinely have their beaks trimmed as day-old chicks.[189] As a result of policy reviews, alternative approaches that may prevent feather pecking behaviours are now being promulgated in the industry.[190]

Transport and slaughter

2.24 The duration of livestock transportation is a significant and avoidable factor affecting welfare, and maximum durations are often specified in legislation.[191] However, while journey time can exacerbate other factors, it is far from the only condition affecting animal welfare during transport. Also important are the type of animal (species, sex, age, physical characteristics), the availability of food and water, how the animals are managed before and after transport, and the social and physical environment experienced during transport (e.g., access to other animals and the temperature).[192]

Reflections on animal health and welfare challenges

2.25 It is beyond dispute that historical breeding practices and the development of certain husbandry systems have had detrimental effects on the health and welfare of many animals. As information and understanding of these effects have diffused, there have been some improvements in the conditions in which animals have been kept and the practices to which they have been subject. In many cases the achievement of these

185 Council Directive 2008/120/EC laying down minimum rules for the protection of pigs, Annex I, Chapter I, point 8. The ban on routine tail docking was initially enacted in Council Directive 91/630/EEC, point 4 of Chapter II of the Annex. The Annex to Directive 91/630 was replaced by Commission Directive 2001/93/EC. Point 8 of Chapter I. This has now been codified in Council Directive 2008/120/EC.

186 Russell WMS, and Burch RL (1959) *The principles of humane experimental technique* (London: Methuen & Co. Limited); Stolba A, and Wood-Gush DGM (1989) The behaviour of pigs in a semi-natural environment *Animal Science* **48(2)**: 419-25; Scientific Opinion of the Panel on Animal Health and Welfare (2007) The risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems *The EFSA Journal* **611**:1-13.

187 Defra (2018) *Evidence review and behavioural research involving both farmers and vets to investigate how to promote improved compliance with pig tail docking and environmental enrichment legislation: - AW0145*, available at: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19945.

188 The Laying Hen Welfare Forum (2020) *Beak treatment – second biennial report*, available at: https://lhwf.co.uk/beak-trimming-second-biennial-report-of-laying-hen-welfare-forum/.

189 See: Defra (2015) *Beak Trimming Action Group review*, available at: https://www.gov.uk/government/publications/beak-trimming-action-group-review.

190 See: The Laying Hen Welfare Forum (2020) *Beak treatment – second biennial report*, available at: https://lhwf.co.uk/beak-trimming-second-biennial-report-of-laying-hen-welfare-forum/.

191 Federation of Veterinarians of Europe (8 July 2019) *FVE calls to prevent suffering of animals, during long distance transports, in particular under extreme temperatures*, available at: https://www.fve.org/cms/wp-content/uploads/007-Long-distance-transport-of-livestock_final.pdf.

192 Nielsen BL, Dybkjær L, and Herskin MS (2011) Road transport of farm animals: effects of journey duration on animal welfare *Animal* **5(3)**: 415-27; and Mitchell M, Martin J, and Kettlewell P (2018) *Defra final report: a review of the evidence on welfare aspects of the transport of live animals* (AW0821), available at: http://randd.defra.gov.uk/Document.aspx?Document=14994_SYSTEMATIC_REVIEW_REPORT_Final210318.pdf.

improvements has relied on legislative action. However, husbandry conditions continue to present welfare challenges: routine tail docking in pigs, while not permitted, remains widespread, as does the disbudding and dehorning of dairy cattle rather than the adoption of inherently hornless breeds, despite recommendations.[193]

2.26 Standards of welfare that are focused on individual animals may be ineffective in preventing the decline in the physical capacity to live a good life in animal breeds over generations, as the characteristics of the 'typical' animal change. As evidence of the negative impacts of selective breeding has amassed, recognition of these impacts has given rise to 'balanced' breeding programmes that take account of 'welfare' (and environmental) breeding objectives. While these programmes include selection for improved health traits, in some cases the effect is not to reverse but to mitigate the negative impacts of past breeding practices or of health-adverse husbandry conditions.[194] Thus, the response to the problem of chickens with prodigiously enlarged breasts has been to attempt to breed chickens with preternaturally strong legs; a proposed solution to the problem of contact dermatitis resulting from chickens lying in their own droppings is the selection of variants that confer inherent resistance to contact dermatitis.[195] In many cases, by constitutionally adapting the animals to their conditions, this has led only to mitigation of the adverse health effects of breeding while enabling the perpetuation of poor environmental conditions (privations of space, light/darkness, enrichment), therefore having questionable real impact on welfare.

2.27 Many people find the approach of selective breeding to fit animals to an intensive production system morally objectionable.[196] They argue that breeds with inherently low capacity for welfare should be abolished and husbandry practices modified to fit animals' behaviours and needs instead. Where the animal's constitution, its very biology, has become a question of welfare, breeding decisions cannot be ethically neutral. By the same argument, others maintain that breeding should be used to promote enhanced welfare and cases in which biotechnology can help to achieve this should be explored. We address this difference of approach in the next chapter. What is certain is that many aspects of animal welfare continue to present challenges to food and farming systems across a range of management systems.

Human health challenges

Nutrition

Protein

2.28 Many humans derive nutrients from the consumption of animals and renewable animal products (chiefly eggs and milk). Meat is a good source of energy and a range of essential nutrients for humans and many animals. It is a major source of dietary protein (although the protein requirements, especially of very young children, remain poorly

[193] Defra (2003) *Code of recommendations for the welfare of livestock: cattle,* available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69368/pb7949-cattle-code-030407.pdf.

[194] See, for example, Heringstad B, Egger-Danner C, Charfeddine N *et al.* (2018) Invited review: genetics and claw health: opportunities to enhance claw health by genetic selection *Journal of Dairy Science* **101(6)**: 4801-21.

[195] Both these examples are drawn from: European Commission (2016) *Report from the Commission to the European Parliament and the Council on the impact of genetic selection on the welfare of chickens kept for meat production COM(2016) 182 final*, available at: https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2016)182.

[196] This was a finding of the public dialogue we commissioned in the course of this inquiry; see: Nuffield Council on Bioethics (2021) *Online public dialogue on genome editing in farmed animals, research by Basis Social on behalf of the Nuffield Council on Bioethics,* available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/public-dialogue-on-genome-editing-and-farmed-animals.

understood).[197] Protein-energy malnutrition (or undernutrition), which is an energy deficit caused by a deficiency of all macronutrients, has been identified as a problem in many countries.[198] Protein inequality between geographical regions and socioeconomic groups has also been identified.[199] This has been associated with the disproportionately high impact of atmospheric carbon dioxide on the protein content of plant-based diets.[200]

2.29 The pattern of consumption of animal products follows that of domestication and is as much linked to culture as it is to the availability of environmental resources. Some cultures are linked to vegetarianism, even where domesticated animals may thrive. Others may eat few animal products because they have little access to them and may reserve them for important feasts. In some low-income countries, access to nutrient-dense foods may be limited, for example by socioeconomic or geopolitical factors, and diets low in meat may be associated with poorer health. In other areas, where plants that can be eaten by humans are unavailable, humans must eat ruminants or fish that can process foods lower down the food chain.[201]

Micronutrients and fatty acids

2.30 A number of studies have compared the nutritional value of food produced in industrial husbandry systems, characterised by a high proportion of concentrate feed, with organic and pasture-based systems characterised by roughage feed (although definitions of these systems vary). These have found, perhaps unsurprisingly, that nutrient composition of the animal product is strongly associated with feed composition.[202] Organic and free-range dairy products and meats have been found to have significantly higher content of omega-3 fatty acids and lower fats compared to industrially farmed products.[203] However, the nutritional significance and any health implications of these differences has not been demonstrated.[204] Some studies, moreover, have found no nutritional difference between 'organic' and 'conventional' methods of food production (although the definition of 'nutritional quality' excludes pesticide and insecticide residues).[205] Other studies contradict this.[206] This is an area in which further research

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197 Semba RD (2016) The rise and fall of protein malnutrition in global health *Annals of Nutrition & Metabolism* **69(2)**:79-88.

198 de Onís M, Monteiro C, Akré J *et al*. (1993) The worldwide magnitude of protein-energy malnutrition: an overview from the WHO Global Database on Child Growth *Bulletin of the World Health Organization* **71**: 703-12.

199 Harvard School of Public Health (2 August 2017) *Millions may face protein deficiency as a result of human-caused carbon dioxide emissions*, available at: https://news.harvard.edu/gazette/story/newsplus/millions-may-face-protein-deficiency-as-a-result-of-human-caused-co2-emissions/; and Medec DE, Schwartz J, and Myers SS (2017) Estimated effects of future atmospheric co2 concentrations on protein intake and the risk of protein deficiency by country and region *Environmental Health Perspectives* **125(8)**: 087002.

200 Medec DE, Schwartz J, and Myers SS (2017) Estimated effects of future atmospheric co2 concentrations on protein intake and the risk of protein deficiency by country and region *Environmental Health Perspectives* **125(8)**: 087002.

201 Godfray HCJ, Aveyard P, Garnett T *et al*. (2018) Meat consumption, health, and the environment *Science* **361(6399)**: eaam5324.

202 Mie A, Andersen HR, Gunnarsson S *et al*. (2017) Human health implications of organic food and organic agriculture: a comprehensive review *Environmental Health* **16**: 111.

203 Petracci M, Mudalal S, Babini E *et al*. (2014) Effect of white striping on chemical composition and nutritional value of chicken breast meat *Italian Journal of Animal Science*, **13(1)**: 3138; and Butler G, Ali AM, Oladokun S *et al.* (2021) Forage-fed cattle point the way forward for beef? *Future Foods* **3**: 100012.

204 Średnicka-Tober D, Barański M, Seal C *et al.* (2016) Composition differences between organic and conventional meat: a systematic literature review and meta-analysis *British Journal of Nutrition* **115(6)**: 994-1011; Mie A, Andersen HR, Gunnarsson S *et al.* (2017) Human health implications of organic food and organic agriculture: a comprehensive review *Environmental Health* **16**: 111; and Hurtado-Barroso S, Tresserra-Rimbau A, Vallverdú-Queralt A *et al*. (2019) Organic food and the impact on human health *Critical Reviews in Food Science and Nutrition* **59(4)**: 704-14.

205 Dangour AD, Lock K, Hayter A *et al.* (2010) Nutrition-related health effects of organic foods: a systematic review *American Journal of Clinical Nutrition* **92(1)**: 203-10.

206 Barański M, Średnicka-Tober D, Volakakis N *et al.* (2014) Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses *British Journal of Nutrition* **112(5)**: 794-811.

would be valuable but remains difficult, owing to a large number of potentially confounding factors.

Non-communicable diseases

2.31 Meat consumption has been rising in middle-income countries (especially China and East Asia). It is mostly low and stable in low-income countries and static or declining in high-income countries.[207] There is a large body of evidence suggesting that, in Western countries, higher consumption of red and processed meat is associated with higher risk of type 2 diabetes, cardiovascular disease, certain types of cancers (pancreas, stomach, prostate, and colorectal) and premature death.[208] The International Agency for Research on Cancer has classified processed meat as carcinogenic to humans and red meat as a probable human carcinogen (both due to colorectal cancer risks).[209] In some studies, a moderate inverse association with cancers has been associated with high consumption of poultry, possibly displacing red meat.[210] Poultry consumption, however, has also been associated with non-communicable diseases, possibly owing to the fact that much chicken is transformed into fast food and other calorie-rich, ultra-processed products.[211] Current consumption of processed meat is significantly higher, globally, than optimal levels recommended by the World Cancer Research Fund.[212] The health effects of red meat consumption remain contested, however, and difficult to research owing to multiple confounding factors.[213]

Zoonotic disease

2.32 Zoonotic diseases (zoonoses) are diseases and infections that are naturally transmitted between non-human animals and humans.[214] They are considered to be one of the most significant threats to global health and the global economy.[215] The potential scale of their effect was demonstrated by the global pandemic of COVID-19, beginning in 2019, which is caused by the zoonotic SARS-CoV-2 coronavirus.

2.33 The occurrence of zoonotic diseases in humans began to rise after the development of agriculture and the domestication of animals, when humans started living in proximity

[207] Godfray HCJ, Aveyard P, Garnett T *et al.* (2018) Meat consumption, health, and the environment *Science* **361(6399)**: eaam5324.

[208] Bouvard V, Loomis D, Guyton KZ *et al.* (2015) Carcinogenicity of consumption of red and processed meat *Lancet Oncology* **16(16)**: 1599-600; and Harvard School of Public Health (30 September 2019) *New "guidelines" say continue red meat consumption habits, but recommendations contradict evidence*, available at: https://www.hsph.harvard.edu/nutritionsource/2019/09/30/flawed-guidelines-red-processed-meat/. On the 'industrial diet' involving high proportion of processed foods, see: Bryant A, Bush L, and Wilk R (2013) The history of globalization and the food supply, in *The handbook of food research* Murcott A, Belasco W, and Jackson P (Editors) (London: Bloomsbury).

[209] Godfray HCJ, Aveyard P, Garnett T *et al.* (2018) Meat consumption, health, and the environment *Science* **361(6399)**: eaam5324.

[210] Ibid.

[211] Anand SS, Hawkes C, de Souza RJ *et al.* (2015) Food consumption and its impact on cardiovascular disease: importance of solutions focused on the globalized food system: a report from the workshop convened by the World Heart Federation. *Journal of the American College of Cardiology* **66(14)**: 1590-614; and Papier K, Fensom GF, Knuppel A *et al.* (2021) Meat consumption and risk of 25 common conditions: outcome-wide analyses in 475,000 men and women in the UK Biobank study *BMC Medicine* **19**: 53.

[212] Afshin A, Sur PJ, Fay KA *et al.* (2019) Health effects of dietary risks in 195 countries, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017 *The Lancet* **393(10184)**: 1958-72; and NHS (1 October 2019) *Have controversial new guidelines put red meat 'back on the menu'?* available at: https://www.nicswell.co.uk/health-news/have-controversial-new-guidelines-put-red-meat-back-on-the-menu.

[213] Leroy F, and Cofnas N (2020) Should dietary guidelines recommend low red meat intake? *Critical Reviews in Food Science and Nutrition* **60(16)**: 2763-72.

[214] Teshome H, and Addis SA (2019) Review on principles of zoonoses prevention, control and eradication *American Journal of Biomedical Science & Research* **3(2)**: 188-97.

[215] Bird BH, and Mazet JAK (2017) Detection of emerging zoonotic pathogens: an integrated one health approach *Annual Review of Animal Biosciences* **6**: 121-39.

with large numbers of others and with other vertebrates.[216] The majority of known human pathogens are zoonotic (80 per cent of viruses, 50 per cent of bacteria, 40 per cent of fungi, 70 per cent of protozoa, and 95 per cent of parasitic worms).[217] Some human pathogens believed to have appeared as a result of domestication include diphtheria, influenza A, measles, mumps, pertussis, rotavirus, smallpox, and tuberculosis.[218]

2.34 Emergence and transmission of zoonoses are mainly the result of human behaviour, especially increasing population density, mobility, and frequency of interactions.[219] The change in land use resulting from agricultural expansion and the encroachment of humans into wild areas are likely to be the primary drivers for the emergence of zoonotic pathogens globally.[220] The transfer of zoonotic diseases is encouraged by direct human contact with wildlife and its by-products, and consumption of wild animals and game, as well as companion animals.[221] It is noted, for example, in populations that have turned to bushmeat owing to the unavailability of traditional aquatic foods as a result of overfishing. However, transmission is greatly facilitated by livestock farming with increased frequency of contact between animals, which act as intermediate hosts and reservoirs for disease.[222] The persistence of pathogens in livestock systems may also drive pathogen evolution.[223]

2.35 Zoonoses are particularly frequent in low-income countries where humans may live close to their livestock. Women, who are more often responsible for tending to animals, may be at disproportionate risk.[224] Regions characterised by rapidly intensifying livestock farming, such as East Africa, have unusually high rates of emerging infectious zoonotic diseases.[225] Areas in which there is poor public health monitoring may account for significant disease reservoirs.[226] While industrial livestock farming in high-income countries has limited this risk to those who have frequent occupational contact with

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216 Klous G, Huss A, Heederik DJJ *et al*. (2016) Human-livestock contacts and their relationship to transmission of zoonotic pathogens, a systematic review of literature *One Health* **2**: 65-76.

217 OSF Home (2020) *Post COVID-19: a solution scan of options for preventing future zoonotic epidemics*, available at: https://osf.io/5jx3g/.

218 Wolfe ND, Dunavan CP, and Diamond J *et al*. (2007) Origins of major human infectious diseases *Nature* **447(7142)**: 279-83.

219 Bird BH, and Mazet JAK (2017) Detection of emerging zoonotic pathogens: an integrated one health approach *Annual Review of Animal Biosciences* **6**: 121-39; Ahmed S, Dávila JD, Allen A *et al*. (2019) Does urbanization make emergence of zoonosis more likely? Evidence, myths and gaps *Environment and Urbanization* **31(2)**: 443-60; and OSF Home (2020) *Post COVID-19: a solution scan of options for preventing future zoonotic epidemics*, available at: https://osf.io/5jx3g/.

220 Johnson CK, Hitchens PL, Evans TS *et al.* (2015) Spillover and pandemic properties of zoonotic viruses with high host plasticity *Scientific Reports* **5**: 14830; and White RJ, and Razgour O (2020) Emerging zoonotic diseases originating in mammals: a systematic review of effects of anthropogenic land-use change *Mammal Review* **50(4)**: 336-52.

221 This mechanism is thought to be responsible for the emergence of, for example, ebolaviruses, simian retroviruses (such as Simian foamy virus and T-lymphotropic viruses) and coronaviruses such as the SARS-CoV2 coronavirus that causes COVID-19; see: Bird BH, and Mazet JAK (2017) Detection of emerging zoonotic pathogens: an integrated one health approach *Annual Review of Animal Biosciences* **6**: 121-39; and OSF Home (2020) *Post COVID-19: a solution scan of options for preventing future zoonotic epidemics,* available at: https://osf.io/5jx3g/.

222 Bayry J (2013) Emerging viral diseases of livestock in the developing world *Indian Journal of Virology* **24(3)**: 291-4; and Koopmans M (2020) *SARS-CoV-2 and the human-animal interface: outbreaks on mink farms The Lancet Infectious Diseases* **21(1)**: 18-9.

223 FAO (2007) *Industrial livestock production and global health risks*, available at: https://www.researchgate.net/publication/43521028_Industrial_livestock_production_and_global_health_risks; and Council for Agriculture, Science and Technology (2005) *Global risks of infectious animal diseases*, available at: https://www.cast-science.org/publication/global-risks-of-infectious-animal-diseases/.

224 Ahmed S, Dávila JD, Allen A *et al*. (2019) Does urbanization make emergence of zoonosis more likely? Evidence, myths and gaps *Environment and Urbanization* **31(2)**: 443-60.

225 Kemunto N, Mogoa E, Osoro E *et al.* (2018) Zoonotic disease research in East Africa *BMC Infectious Diseases* **18**: 545.

226 Lindahl JF, and Grace D (2015) The consequences of human actions on risks for infectious diseases: a review *Infection Ecology & Epidemiology* **5**: 30048.

animals, including dead ones, zoonoses have a disproportionate impact on low-income countries, which is compounded by limitations in healthcare provision.[227]

2.36 Pandemic disease is a global threat in which livestock may be a significant transmission link. In the light of the COVID-19 pandemic, renewed proposals have been made for global surveillance systems that span wildlife, livestock, and human populations.[228] The authors of one proposal note that efforts to prevent pandemic disease "must focus on dealing with the root causes of spread, reducing risky practices, improving livestock production systems, and enhancing biosecurity along the animal food chain".[229]

Antimicrobial resistance

2.37 In the livestock and aquaculture sectors, antimicrobials are used variously for therapeutic intervention, prophylaxis, metaphylaxis (treatment of a group in which infected individuals are diagnosed), biocide, animal growth promotion, feed preservation, and feed efficiency improvement.[230] (The use of antimicrobials to promote growth is prohibited in the UK and EU, although it is still permitted elsewhere.) Surveillance of antimicrobial use in agriculture and aquaculture has been variable, including in the UK.[231] Recent reports suggest that efforts to reduce the use of antimicrobials have been effective.[232] Worldwide, however, a 2015 study predicted that the consumption of antimicrobials in agriculture would rise by 67 per cent by 2030, but the rise would be disproportionately higher in some regions (chiefly driven by increasing demand for animal products in middle-income countries) and sectors (in pigs and poultry especially).[233] There are, nevertheless, some encouraging signs: for example, China has dramatically reduced antibiotic use (from approximately one-quarter of world total antibiotic use in Chinese agriculture) by improved infection control in response to disease outbreaks.[234] Worryingly, however, antimicrobials that have been prohibited for agricultural use in the majority of high-income countries remain in use in some parts of the world.[235]

2.38 The use of antimicrobials in livestock farming is now accepted as a cause of antimicrobial resistance (AMR).[236] AMR results from a change in pathogens (such as bacteria, fungi, viruses, and parasites) as a result of exposure to antimicrobial medicines (such as

[227] Klous G, Huss A, Heederik DJJ *et al*. (2016) Human-livestock contacts and their relationship to transmission of zoonotic pathogens, a systematic review of literature *One Health* **2**: 65-76; and Kemunto N, Mogoa E, Osoro E *et al*. (2018) Zoonotic disease research in East Africa *BMC Infectious Diseases* **18**: 545.

[228] Carroll D, Morzaria S, Briand S *et al.* (2021) Preventing the next pandemic: the power of a global viral surveillance network *British Medical Journal* **372**: n485.

[229] Ibid.

[230] FAO (2016) *Drivers, dynamics and epidemiology of antimicrobial resistance in animal production*, available at: http://www.fao.org/3/a-i6209e.pdf.

[231] HM Government (2019) *Tackling antimicrobial resistance 2019-2024: the UK's five-year national action plan*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/784894/UK_AMR_5_year_national_action_plan.pdf.

[232] Responsible Use of Medicines in Agriculture Alliance (2020) *Targets Task Force Report 2020*, available at: https://www.ruma.org.uk/targets-task-force-2021-2024/.

[233] Review on Antimicrobial Resistance (2015) *Antimicrobials in agriculture and the environment: reducing unnecessary use and waste*, available at: https://amr-review.org/Publications.html.

[234] Nature (21 October 2020) *How China is getting its farmers to kick their antibiotics habit*, available at: https://www.nature.com/articles/d41586-020-02889-y. For a recent study with respect to Germany, see: Lienen T, Schnitt A, Hammerl JA *et al.* (2021) Multidrug-resistant Staphylococcus cohnii and Staphylococcus urealyticus isolates from German dairy farms exhibit resistance to beta-lactam antibiotics and divergent penicillin-binding proteins *Scientific Reports* **11**: 6075; and with respect to China, see: Fu Y Yulin, Chen Y, Liu D *et al.* (2021) Abundance of tigecycline resistance genes and association with antibiotic residues in Chinese livestock farms *Journal of Hazardous Materials* **409**: 124921.

[235] Manyi-Loh C, Mamphweli S, Meyer E *et al.* (2018) Antibiotic use in agriculture and its consequential resistance in environmental sources: potential public health implications *Molecules* **23(4)**: 795.

[236] FAO (2016) *Drivers, dynamics and epidemiology of antimicrobial resistance in animal production*, available at: http://www.fao.org/3/a-i6209e.pdf; and Bennani H, Mateus A, Mays N *et al.* (2020) Overview of evidence of antimicrobial use and antimicrobial resistance in the food chain *Antibiotics* **9(2)**: 49.

antibiotics, antifungals, antivirals, antimalarials, and anthelmintics).[237] It represents a major threat to both human and animal health, mainly as a result of reducing the repertoire and effectiveness of medicines available to treat infections. This leads to increasing morbidity and mortality associated with infectious disease, and a reduction in the safety of many medical interventions such as chemotherapy, organ transplants, joint replacements, and general surgery.[238] These effects are not equally distributed. They have a disproportionate effect on those most vulnerable: the young, elderly, and sick.[239] Low- and middle-income countries have a greater burden of infectious disease generally and will be most adversely affected by antimicrobial resistant bacteria, as well as having fewer resources to respond than high-income countries.

2.39 Antimicrobial resistant bacteria are spread via human–animal, human–environment, or human–human transmission.[240] The United Nations Food and Agriculture Organization's hypothesis is that food is likely to be the most important transmission route, but there is a lack of direct evidence in this area.[241] Wastewater from agriculture provides major reservoirs of antimicrobials and antimicrobial resistant bacteria; 75–90 per cent of tested antibiotics are excreted un-metabolised and enter sewage systems and water sources where antimicrobial resistant strains of bacteria may flourish and share genetic resistance mechanisms with other bacteria.[242] In aquaculture, where antimicrobials are sometimes used in proportionally higher quantities than in livestock, they may remain in the aquatic environment, exerting selective pressure on pathogens.[243] Whereas water is an important conduit for the spread of antimicrobial residues and resistance determinants there are, as yet, no international guidelines for antimicrobial residues in water.[244]

2.40 AMR can be promoted by all types of farming systems, although there are characteristic variations in the extent and manner of antimicrobial use. Globally, the main contributory factors are poor biosecurity practices, poor oversight (e.g., by veterinarians), over-prescribing, poor prescribing, and poor adherence to treatment regimens (incorrect dosage, duration, or frequency of treatment), non-therapeutic use, use of antimicrobials purchased directly over the counter or via the internet, and the use of counterfeit or poor-quality antimicrobials.[245] However, the spread of AMR pathogens is a global threat, affecting high-income countries as well, as the pharmaceutical pipeline for antimicrobials has effectively stalled.[246] From 2000 to 2018, the proportion of medicines to which bacteria have become resistant almost tripled in chickens and pigs, and doubled in

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[237] WHO (17 November 2021) *Antimicrobial resistance*, available at: https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.

[238] Ibid.

[239] US Centres for Disease Control and Prevention (2019) *Antibiotic resistance threats in the United States*, available at: https://www.cdc.gov/drugresistance/pdf/threats-report/2019-ar-threats-report-508.pdf.

[240] Davies R, and Wales A (2019) Antimicrobial resistance on farms: a review including biosecurity and the potential role of disinfectants in resistance selection *Comprehensive Reviews in Food Science and Food Safety* **18(3)**: 753-7.

[241] FAO (2016) *Drivers, dynamics and epidemiology of antimicrobial resistance in animal production*, available at: http://www.fao.org/3/a-i6209e.pdf.

[242] Review on Antimicrobial Resistance (2015) *Antimicrobials in agriculture and the environment: reducing unnecessary use and waste*, available at: https://amr-review.org/Publications.html; and FAO (2020) *Technical brief on water, sanitation, hygiene and wastewater management to prevent infections and reduce the spread of antimicrobial resistance*, available at: https://apps.who.int/iris/bitstream/handle/10665/332243/9789240006416-eng.pdf.

[243] Review on Antimicrobial Resistance (2015) *Antimicrobials in agriculture and the environment: reducing unnecessary use and waste*, available at: https://amr-review.org/Publications.html.

[244] FAO (2016) *Drivers, dynamics and epidemiology of antimicrobial resistance in animal production*, available at: https://amr-review.org/Publications.html.

[245] FAO (2016) *The FAO action plan on antimicrobial resistance 2016-2020*, available at: http://www.fao.org/3/a-i5996e.pdf; and FAO (2016) *Drivers, dynamics and epidemiology of antimicrobial resistance in animal production*, available at: http://www.fao.org/3/a-i6209e.pdf.

[246] FAO (2020) *Technical brief on water, sanitation, hygiene and wastewater management to prevent infections and reduce the spread of antimicrobial resistance*, available at: https://apps.who.int/iris/bitstream/handle/10665/332243/9789240006416-eng.pdf.

cattle.[247] In humans, estimates from 2019 suggested that antimicrobial resistant infections accounted for approximately 700,000 deaths per year globally, but this figure could rise to 10 million by 2050.[248] Tackling antimicrobial resistance requires coordinated, multidisciplinary, and specific commitments and responses combined with a common political will at an international level and the resources to give effect to it.[249]

Reflections on human health challenges

2.41 Though humans can live without animal products, some people are dependent on them as an source of vital nutrition. For others, however, the consumption of animal products may be linked to the rise of serious non-communicable diseases, in ways that are currently becoming better understood.[250] Throughout the world, sharing environments with farmed animals presents risks of the emergence and transmission of disease.

2.42 The recognition that animal and human health and environmental conditions are not only intimately connected but that they present imminent global challenges as a result of the exceptional degree of mutual exposure and sensitivity has focused attention on inclusive public (human and non-human animal) health approaches.[251] These have been developed, especially in the twenty-first century, under the rubric 'One Health'.[252] The One Health approach specifically requires the orchestration of multiple disciplines to address problems that cross their disciplinary boundaries in order to develop norms, regulations, and policies that will benefit humans, non-human animals, and the environment for current and future generations.[253] The need for a multifaceted approach arises from the recognition that health threats emerge from a concatenation of circumstances, including rising global population (particularly in low-income countries), increased urbanisation, income inequality, migration, emerging diseases, globalisation, and climate change.[254]

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[247] Nature (20 September 2019) *Alarm as antimicrobial resistance surges among chickens, pigs and cattle*, available at: https://www.nature.com/articles/d41586-019-02861-5.

[248] British Medical Association (2019) *AMR: ambition to action*, available at: https://www.bma.org.uk/media/2045/bma-antimicrobial-resistance-briefing-ambition-in-action.pdf.

[249] Laxminarayan R, Duse A, Wattal C *et al.* (2013) Antibiotic resistance – the need for global solutions *Lancet Infectious Diseases* **13(12)**: 1057-98; British Medical Association (2019) *AMR: ambition to action*, available at: https://www.bma.org.uk/media/2045/bma-antimicrobial-resistance-briefing-ambition-in-action.pdf; FAO (2018) *Antimicrobial resistance policy review and development framework*, available at: http://www.fao.org/3/ca1486en/CA1486EN.pdf; and WHO (17 November 2021) *Antimicrobial resistance*, available at: https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.

[250] UN Nutrition (2021) *Livestock-derived foods and sustainable healthy diets*, available at: https://cgspace.cgiar.org/handle/10568/113923.

[251] Oxford Research Encyclopedia of Global Public Health (2019) *"One Health" from concept to application in the global world*, available at: https://oxfordre.com/publichealth/view/10.1093/acrefore/9780190632366.001.0001/acrefore-9780190632366-e-29.

[252] For a brief history of One Health, see: United States Department of Agriculture (2021) What is One Health?, available at: https://www.aphis.usda.gov/animal_health/one_health/downloads/one_health_info_sheet.pdf/. See also: FAO, UNICEF, UNSIC, World Bank, WHO, and OIE (2008) *Contributing to One World, One Health: a strategic framework for reducing risks of infectious diseases at the animal–human–ecosystems interface*, available at: https://www.preventionweb.net/publication/contributing-one-world-one-health-strategic-framework-reducing-risks-infectious; AVMA One Health Initiative Task Force (2008) *One Health: a new professional imperative*, available at: https://www.avma.org/sites/default/files/resources/onehealth_final.pdf; Johnson J, and Degeling C (2019) Does One Health require a novel ethical framework? *Journal of Medical Ethics* **45(4)**: 239-43; and Mackenzie JS and Jeggo M (2019) The One Health approach—why is it so important? *Tropical Medicine and Infectious Disease* **4(2)**: 88.

[253] Transdisciplinarity – the collaborative production of new problem-focused methodological and theoretical perspectives – is an essential part of the One Health concept; on transdisciplinarity, see: Mittelstrass J (2011) On Transdisciplinarity *Trames Journal of the Humanities and Social Sciences* **15(4)**: 329-38.

[254] Oxford Research Encyclopedia of Global Public Health (2019) *"One Health" from concept to application in the global world*, available at: https://oxfordre.com/publichealth/view/10.1093/acrefore/9780190632366.001.0001/acrefore-9780190632366-e-29.

Challenges of demand and supply

2.43 The global population has been predicted to rise from the present (2021) level of approximately 7.8 billion to 9.7 billion by 2050 and 11.2 billion by 2100.[255] This is mainly due to a very large expected increase in the populations of Asia, Africa, Latin America, and the Caribbean, many of whom will be concentrated in large conurbations ('megacities').[256] This rising global population is also consuming proportionately more animal produce. Global per capita consumption of livestock products has more than doubled in the past 40 years, mainly as a result of so-called 'nutrition transitions' from plant to animal products. The global increase is mainly accounted for by increased poultry consumption, but there are regional variations in preferences, for example between pork and beef.[257] The increase has been associated with rising per capita income but has been increasingly observed in poorer populations and low-income countries.[258] The pattern of demand means that meat consumption tends to rise more rapidly as income increases in lower income countries, while other products (such as former staples) show declining demand.[259] In China, urbanisation has been found to be a more important driver of changes in food consumption than income and population growth.[260]

2.44 The supply of agricultural produce is, however, precarious. Two of the most important factors affecting supply are climate change and disease. Agriculture is extremely vulnerable to the effects of climate change and climate variability.[261] Changes in temperature and precipitation threaten crops that are used for animal feed as well as the quantity and quality of available forage.[262] Temperature increases due to climate change also affect livestock directly through impacts on overall health, reproduction, milk production, and feed conversion efficiency.[263] Tropical areas are likely to experience the

[255] Gebrehiwot KA, and Gebrewahid MG (2016) The need for agricultural water management in Sub-Saharan Africa *Journal of Water Resource and Protection* **8(9)**: 835-43.

[256] Kelly M (2016) The nutrition transition in developing Asia: dietary change, drivers and health impacts, in *Eating, drinking: surviving the International Year of Global Understanding – IYGU*, Jackson P, Speiss W, and Farhana S (Editors) (Online: Springer), at page 57.

[257] Revell BJ (2015) One man's meat… 2050? Ruminations on future meat demand in the context of global warming *Journal of Agricultural Economics* **66(3)**: 573-614; Kelly M (2016) The nutrition transition in developing Asia: dietary change, drivers and health impacts, in *Eating, drinking: surviving the International Year of Global Understanding – IYGU,* Jackson P, Speiss W, and Farhana S (Editors) (London: Springer), at page 85.

[258] Baldos ULC, and Hertel TW (2015) The role of international trade in managing food security risks from climate change *Food Security* **7**: 275-90; Bodirsky LB, Rolinski S, Biewald *et al.* (2015) Global food demand scenarios for the 21st century *PLoS ONE* **10(11)**: e0139201; Shimokawa S (2015) Sustainable meat consumption in China *Journal of Integrative Agriculture* **14(6)**: 1023-32; Herroero M, Henderson B, Havlík P *et al.* (2016) Greenhouse gas mitigation potentials in the livestock sector *Nature Climate Change* **6**: 452-61; Bai Z, Ma W, Ma L *et al.* (2018) China's livestock transition: driving forces, impacts, and consequences *Science Advances* **4**: eaar8534; and Godfray HCJ, Aveyard P, Garnett T *et al.* (2018) Meat consumption, health, and the environment, *Science* **361(6399)**: eaam5324.

[259] Sans P, and Combris P (2015) World meat consumption patterns: an overview of the last fifty years (1961-2011) *Meat Science* **109**: 106-11.

[260] Huang JK, Wei W, Cui Q et al. (2017) The prospects for China's food security and imports: will China starve the world via imports? *Journal of Integrative Agriculture* **16(12)**: 2933-44.

[261] Niles MT, Lubell M, and Brown M (2014) How limiting factors drive agricultural adaptation to climate change *Agriculture, Ecosystems and Environment* **200**: 178-85; Thornton PK, Ericksen PJ, Herrero M *et al*. (2014) Climate variability and vulnerability to climate change: a review *Global Change Biology* **20(11)**: 3313-28; Hertel TW (2015) The challenges of sustainably feeding a growing planet *Food Security* **7**:185-98; and Himanen SJ, Mäkinen H, Rimhanen K *et al*. (2016) Engaging farmers in climate change adaptation planning: assessing intercropping as a means to support farm adaptive capacity *Agriculture* **6(3)**: 34.

[262] Sejian V, Bhatta R, Soren NM *et al*. (2015) Introduction to concepts of climate change impact on livestock and its adaptation and mitigation, in *Climate change impact on livestock: adaptation and mitigation*, Sejian V, Gaughan J, Baumgard L, and Prasad C (Editors) (ebook: Spinger); and Bullock JM, Dhanjal-Adams KL, Milne A *et al.* (2017) Resilience and food security: rethinking an ecological concept *Journal of Ecology* **105(4)**: 880-4.

[263] Bullock JM, Dhanjal-Adams KL, Milne A *et al*. (2017) Resilience and food security: rethinking an ecological concept *Journal of Ecology* **105(4)**: 880-4

highest negative impact on agricultural yields as a result of a decrease in precipitation.[264] Agriculture in sub-Saharan Africa is extremely vulnerable to climate change and the least well prepared and resourced to confront it, as the region tends to be more reliant on pastoralism or rain-fed agricultural systems, which are more sensitive to weather conditions.[265] While many of the poorest countries with already insecure food supplies will be most adversely affected, some geographic regions may nevertheless benefit from climate change.[266]

2.45 Higher rainfall on the other hand, resulting in increased humidity, can lead to proliferation of insect vectors and increase the prevalence and diffusion of vector-borne diseases such as bluetongue, the emergence of which, in Europe, is attributed to climate change.[267] Outbreaks of livestock disease cause considerable adverse impacts on the income of farmers and ramify through the connected parts of the economy.[268] They affect consumers (through increased prices), insurers, the exchequer (as a result of policies of culling and compensation), and can be damaging to international trade, tourism, and the environment, in addition to the harm to the animals themselves, although a full picture of these effects is often difficult to establish.[269]

Box 2.4: Estimated economic effects of an example of livestock disease

African swine fever (ASF) is a viral disease of pigs that represents an extreme threat of economic loss due to the effect on global trade and individual livelihoods of mass culling and animal movement restrictions.[270] In 2014, in the Ignalina region of Lithuania, 20,000 animals were slaughtered in order to contain an ASF virus outbreak.[271] Determining overall figures of economic loss is challenging; estimates from recent outbreaks include: US$267 million cost during a 2011 outbreak in Russia; the value of pork and pork product exports reduced by US$961 million as a consequence of a 2014 outbreak in Poland, Lithuania, Latvia, and Estonia. Losses of US$12 million in direct costs and

[264] Thornton PK, Ericksen PJ, Herrero M, and Challinor AJ (2014) Climate variability and vulnerability to climate change: a review *Global Change Biology* **20(11)**: 3313-28; Altieri MA, Nicholls CI, Henao A, and Lana MA (2015) Agroecology and the design of climate change-resilient farming systems *Agronomy for Sustainable Development* **35**: 869-90.

[265] Cooper PJM, Dimes K, Rao KPC *et al.* (2008) Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: an essential first step in adapting to future climate change? *Agriculture, Ecosystems, and Environment* **126**: 24-35; Mosnier C, Agabriel J, Lherm M *et al.* (2009) A dynamic bio-economic model to simulate optimal adjustments of suckler cow farm management to production and market shocks in France *Agricultural Systems* **102(1-3)**: 77-88; Antwi-Agyei P, Stringer LC, and Dougill AJ (2014) Livelihood adaptations to climate variability: insights from farming households in Ghana *Regional Environmental Change* **14**: 1615-26; Adenle A, Ford JD, John M *et al.* (2017) Managing climate change risks in Africa – a global perspective *Ecological Economics* **141**: 190-201; and Masipa TS (2017) The impact of climate change on food security in South Africa: current realities and challenges ahead *Jàmbá: Journal of Disaster Risk Studies* **9(1)**: a411.

[266] OECD (2016) *OECD agriculture and climate change: towards sustainable, productive and climate-friendly agricultural systems*, available at: https://www.oecd.org/agriculture/ministerial/background/notes/4_background_note.pdf.

[267] Sejian V, Bhatta R, Soren NM *et al.* (2015) Introduction to concepts of climate change impact on livestock and its adaptation and mitigation, in *Climate change impact on livestock: adaptation and mitigation,* Sejian V, Gaughan J, Baumgard L, and Prasad C (Editors) (eBook: Spinger); Bullock JM, Dhanjal-Adams KL, Milne A *et al.* (2017) Resilience and food security: rethinking an ecological concept *Journal of Ecology* **105(4)**: 880-4; Cavicchioli R, Ripple WJ, Timmis KN *et al.* (2019) Scientists' warning to humanity: microorganisms and climate change *Nature Reviews Microbiology* **17**: 569-86.

[268] Bennett R (2003) The 'direct costs' of livestock disease: the development of a system of models for the analysis of 30 endemic livestock diseases in Great Britain *Journal of Agricultural Economics* **54(1)**: 55-71; and Nieuwhof G, and Bishop S (2005) Costs of the major endemic diseases of sheep in Great Britain and the potential benefits of reduction in disease impact *Animal Science* **81(1)**: 23-9.

[269] OECD Trade and Agriculture Directorate (2015) *Risk management of outbreaks of livestock diseases*, available at: https://www.oecd-ilibrary.org/agriculture-and-food/risk-management-of-outbreaks-of-livestock-diseases_5jrrwdp8x4zs-en.

[270] Galindo I, and Alonso C (2017) African swine fever virus: a review *Viruses* **9(5)**: 103; and Sánchez-Cordón PJ, Montoya M, Reis AL *et al*. (2018) African swine fever: a re-emerging viral disease threatening the global pig industry *The Veterinary Journal* **233**: 41-8.

[271] Gallardo C, de la Torre Reoyo A, Fernández-Pinero J *et al.* (2015) African swine fever: a global view of the current challenge *Porcine Health Management* **1(1)**: 21.

US$349 million in exports are predicted if the virus is introduced into Denmark.[272] A cost to producers of more than $4 billion is predicted if ASF virus is introduced to the US.[273]

Food security, food chains, and international trade

2.46 Few countries come anywhere close to self-sufficiency in food production.[274] Engaging in international trade has obvious advantages, expanding the range and sources of products, and ironing out local cost and supply fluctuations. It also provides efficiencies, for example by enabling meat processors to achieve 'carcass balance' by finding a market for the parts of animals that domestic consumers are unwilling to eat. By the same token, however, it may support standards of production in other jurisdictions that that are not acceptable domestically.

Box 2.5: Farming in the UK after Brexit

The UK is not self-sufficient in food despite having good quality land and the highest percentage of land under agriculture among OECD counties.[275] In 2015, the UK produced 61 per cent of the food it consumed and is a net importer of beef, poultry, pork, and lamb.[276] In 2017, EU Member States provided 70 per cent of the food, feed, and drink imported to the UK (30 per cent of total UK food consumption).[277]

Prior to the withdrawal of the UK from the European Union, payments to farmers were made under the EU Common Agricultural Policy under two 'pillars' ('direct income support' and 'rural development'). Post-Brexit agricultural arrangements, contained in the Agriculture Act 2020, will be phased in over seven years from 2021. These changes will see a shift away from direct income support and towards 'public money for public goods', with farmers being incentivised to contribute towards environmental improvements on their land by targeted payments for such contributions. Hence the new approach to farmer support in England is called 'Environmental Land Management' (ELM).

- The ELM features a new environment-based approach that will pay farmers for specified 'public goods', for example improvements to air and water quality, animal welfare standards, access to the countryside, biodiversity, and flood reduction measures. At the time of writing, the final details of are yet to be resolved and 'tests and trials' are underway to evaluate the most cost-effective system design.
- The Agriculture Act 2020 does not prohibit trade deals between the UK and countries that permit the production of food to lower standards than those required of farmers in the UK. Nevertheless, the Government must report to Parliament on the consistency of any free trade agreement with the maintenance of UK levels of protection for animal health, welfare, and the environment.[278] A Trade and Agriculture Commission may be

[272] Sánchez-Cordón PJ, Montoya M, Reis AL *et al*. (2018) African swine fever: a re-emerging viral disease threatening the global pig industry *The Veterinary Journal* **233**: 41-8.
[273] Niederwerder MC, Stoian AMM, Rowland RRR *et al.* (2019) Infectious dose of African swine fever virus when consumed naturally in liquid or feed *Emerging Infectious Diseases* **25(5)**: 891-97.
[274] Beltran-Peña A, Rosa L, and D'Odorico P (2020) Global food self-sufficiency in the 21st century under sustainable intensification of agriculture *Environmental Research Letters* **15(9)**: 095004.
[275] OECD (2015) *Public goods and externalities: agri-environmental policy measures in the United Kingdom*, available at: https://www.oecd-ilibrary.org/agriculture-and-food/public-goods-and-externalities_5js08hw4drd1-en.
[276] University of Sussex Science Policy Research Unit (2017) *A food Brexit: time to get real – a Brexit briefing*, available at: https://openaccess.city.ac.uk/id/eprint/18655/.
[277] Chatham House (2019) *Food politics and policies in post-Brexit Britain*, available at: https://www.chathamhouse.org/2019/01/food-politics-and-policies-post-brexit-britain.
[278] Agriculture Act 2020, section 42, available at: https://www.legislation.gov.uk/ukpga/2020/21/section/42/enacted.

established to provide advice on these matters, without which a free trade agreement may not be concluded.[279]

2.47 Reliance on international trade, moreover, exposes a national food system to risks: the fluctuation in global markets can affect food supplies and price stability (e.g., the post-2008 financial crisis affected food prices in high-income countries).[280] Through the globalisation of food supply chains and markets, states (and consumers within different states) are effectively in competition for global food resources, which further weakens the market power of domestic producers. Livestock production is, and is likely to continue to be, a major component of the global food supply, but is under increasing pressure because of its contribution to environmental damage (see below). Global food security faces a ‘perfect storm’ of growing demand, climate change, and ecological damage.[281] Addressing the risks to food security is generally acknowledged to be one of the most pressing challenges of this century.[282]

2.48 Considerable power in the food and farming system is concentrated in the hands of major food retailers. In Europe, North America, and Australasia, a small number of supermarkets supply over 70 per cent of the food bought by consumers.[283] While there is considerable horizontal price competition between supermarkets, vertical competition (e.g., between supermarkets and farmers) is unequal, which allows the costs of horizontal competition to be passed back to producers.[284] This situation is largely a result of the exploitation of extreme disparity in economic power between retailers and farmers and has resulted in the share of returns on the value of agricultural products moving increasingly in favour of retailers at the expense of farmers over time.[285] Retailers are, nevertheless, sensitive to what they perceive to be consumer preferences, as demonstrated in the rejection of first-generation genetically modified products in the UK in the 1990s.[286]

2.49 The plight of small farmers, particularly in low-income countries, is aggravated by being squeezed between their retail customers, on one hand, and farm input suppliers on the other.[287] Over the decade to 2018, the farm ‘price–cost squeeze’ has had a significant impact in the livestock sector, particularly in dairy production where it has caused revenues to fall below the cost of production.[288] This means that subsidies may fail to

[279] Trade Act 2021, Part 3, available at: https://www.legislation.gov.uk/ukpga/2021/10/part/3.
[280] University of Sussex Science Policy Research Unit (2017) *A food Brexit: time to get real – a Brexit briefing*, available at: https://openaccess.city.ac.uk/id/eprint/18655/. On food security in the UK, see: House of Lords Select Committee on Food, Poverty, Health and the Environment (2020) *Report of Session 2019–20, Hungry for change: fixing the failures in food (HL Paper 85)*, available at: https://committees.parliament.uk/publications/1762/documents/17092/default/, at chapter 3.
[281] Sapkota TB, Vetter SH, Jat ML *et al.* (2019) Cost-effective opportunities for climate change mitigation in Indian agriculture *Science of the Total Environment* **655**: 1342-54.
[282] United Nations Department of Economic and Social Affairs (2015) *Transforming our world: the 2030 agenda for sustainable development*, available at: https://sdgs.un.org/; and Campbell BM, Vermeulen SJ, Aggarwal PK *et al.* (2016) Reducing risks to food security from climate change *Global Food Security* **11**: 34-43.
[283] Jack L, Florez-Lopez R, and Ramon-Jeronimo JM (2018) Accounting, performance measurement and fairness in UK fresh produce supply networks *Accounting, Organizations and Society* **64**: 17-30.
[284] Food Research Collaboration (2016) *Agricultural labour in the UK* available at: https://www.farminguk.com/content/knowledge/Agricultural-Workforce-in-the-UK(5677-4829-6761-769).pdf; Paparas D, Tremma O, Pickering T *et al.* (2018) Is there a significant change in the price transmission between producer and retail prices within the British Pork industry? *Turkish Economic Review* **5(2)**: 174-90.
[285] Oxfam (2018) *Fair value: case studies of business structures for a more equitable distribution of value in food supply chains* available at https://oxfamilibrary.openrepository.com/handle/10546/620452; and Czyżewski B, Matuszcak A, and Miśkiewicz R (2018) Public goods versus the farm price-cost squeeze: shaping the sustainability of the EU’s common agricultural policy *Technological and Economic Development of Economy* **25(1)**: 82-102.
[286] We discuss the relative power of retailers and consumers, and what can be done to encourage this power to be exercised responsibly in Chapters 5 and 6.
[287] Ogutu S, Ochieng DO, and Qaim M (2020) Supermarket contracts and smallholder farmers: implications for income and multidimensional poverty *Food Policy* **95**: 101940.
[288] Czyżewski B, Matuszcak A, and Miśkiewicz R (2018) Public goods versus the farm price-cost squeeze: shaping the sustainability of the EU’s common agricultural policy *Technological and Economic Development of Economy* **25(1)**: 82-102.

benefit farmers and instead be leached off by suppliers. Likewise with technology, producers may find themselves on a productivity 'treadmill' where the adoption of agricultural technologies leads to lower unit costs of production and provides early adopters with higher net returns until the technology diffuses to enough competitors to raise the aggregate supply and lower the price.[289]

2.50 Although farmers' motivations are often complex, farms are businesses. Many farmers in the UK and Ireland, especially those rearing drystock (animals reared for meat rather than milk) find it difficult to remain profitable.[290] The failure of the price mechanism in the context of unfair business practices has been identified as a pressing priority in the majority of countries.[291] Without redress or mitigation, these issues are likely to have negative impacts on food security, and reduce the employment security of farmers and farmworkers.[292] Farmers have sought to avoid the problems that arise from market competition in a number of ways, for example by organising to form production, processing, or marketing cooperatives, by adding value through pre-sale processing on the farm, producing differentiated high-value specialty products, and bypassing major retailers by selling directly to consumers or via smaller local outlets, but they meet many challenges in doing so, when faced with the expectations of consumers who have become accustomed to standardisation, convenience, and affordability.[293]

Reflections on demand and supply challenges

2.51 The food supply, both in terms of the livelihoods and the security of farmers, and the choice available to consumers, is dominated and threatened by failures of the market and the dominance of major food retailers in what operates as a global trading system. Without effective product differentiation, and in the absence of compulsion, however, incentives to reduce costs remain overriding. Producers can little afford to compromise production traits (or abandon the pursuit of productivity) or diverge from economically optimised production systems because, with higher unit production costs, they would risk simply being driven from the marketplace by price competition and replaced by others who showed no such scruple, an outcome that benefits no one. If this is a moral failure it is primarily a failure of the market, the only remedy for which may be state intervention and, where necessary, compulsion.[294]

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[289] Ibid.

[290] Gowreesunker BL, and Tassou SA (2016) The impact of renewable energy policies on the adoption of anaerobic digesters with farm-fed wastes in Great Britain *Energies* **9(12)**: 1038; Lynch J, Donnellan T, and Hanrahan K (2016) *Exploring the implications of GHG reduction targets for agriculture in the United Kingdom and Ireland*, presented at the 90th Annual Conference of the Agricultural Economics Society, Warwick, 4-6 April 2016; and O'Leary N, Tranter R, and Bennett R (2017) *Farmer attitudes predictive of profitability*, presented at the 91st Annual Conference Agricultural Economics Society, Dublin, 24-26 April 2017.

[291] Lloyd T (2017) Forty years of price transmission research in the food industry: insights, challenges and prospects *Journal of Agricultural Economics* **68(1)**: 3-21.

[292] Food Research Collaboration (2016) *Agricultural labour in the UK*, available at: https://www.farminguk.com/content/knowledge/Agricultural-Workforce-in-the-UK(5677-4829-6761-769).pdf; and Paparas D, Tremma O, Pickering T *et al.* (2018) Is there a significant change in the price transmission between producer and retail prices within the British Pork industry? *Turkish Economic Review* **5(2)**: 174-90.

[293] Brodt S, Six J, Feenstra G *et al.* (2011) Sustainable agriculture *Nature Education Knowledge* **3(10)**: 1.

[294] The Farm Animal Welfare Forum has put forward a plan to improve the welfare of chickens (layers and broilers), pigs and dairy cattle in the UK that involves switching current subsidies to a range of proposals of around £200m capital investments per year for five years (and temporary annual subsidies growing to a peak of a little over £300m pa, thereafter tailing off as new practices became accepted, raising standards and embedding regulatory change); see: Farm Animal Welfare Forum (2020) *Proposals for public goods payments for farm animal welfare*, available at: https://www.fawf.org.uk/.

Social, cultural, and political challenges

What people eat

2.52 Diet is not determined merely by the body's need for nourishment, but by a variety of factors, for example social, cultural, religious, moral, political, and economic factors. As we have observed throughout this report, the food and farming system is not distinct from wider society but embedded within it, permeated by societal values, and shaped by people's interests and preferences, shaping them in turn. What is prepared or served as food, and what anyone ends up eating, just as much as the circumstances of its consumption, has always embodied and expressed social relations and normative practices.[295]

2.53 While the global demographic movement of people into cities alters many people's relations with livestock, it also has an effect on the kind of food they eat and how that food is delivered to them.[296] There is often less time for meal preparation among city-dwelling people especially as women, who, in most cultures, have historically taken charge of food preparation, are increasingly employed outside the home.[297] The urban food supply provides for the increased consumption of animal produce as well as access to a greater variety of foods, for example processed and fortified foods, increased dining outside the home, and preference for (often processed) food that requires less time to prepare. However, the establishment of an industrialised food supply in the twentieth century, especially in the later decades, entailed the creation of mass markets and associated advertising that transcends rural/urban boundaries, resulting in very similar patterns of food consumption in urban, suburban, and rural areas of a large number of nations.[298]

2.54 In high-income countries, where choice is available and affordable, the qualitative and extra-nutritional characteristics of food such as taste and freshness, authenticity (e.g., 'heritage' breeds), novelty, provenance (e.g., protected designation of origin validation), localism, purity or 'naturalness', brand identity, and degree of processing are all dimensions of differentiation.[299] This may have the effect of reversing the increasing percentage of the price of a product that is attributable to processing and the addition of substances (known as adulteration) as opposed to the principal ingredients, so that farmers can enjoy improved returns.

[295] See: Holm L (2013) Sociology of food consumption, in *The Handbook of Food Research* Murcott A, Belasco W and Jackson P (Editors) (London: Bloomsbury).

[296] Three quarters of the world population is expected to live in urban areas by 2050; see: Shutes L, Verma M, and Kuiper M (2015) *Changing diets in a changing world: assessing the impact of urbanisation on agriculture*, presented at the 19th Annual Conference on Global Economic Analysis (Washington DC, 15-17 June 2016), available at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4920, at page 2; Kelly M (2016) The nutrition transition in developing Asia: dietary change, drivers and health impacts in *Eating, drinking: surviving the International Year of Global Understanding – IYGU,* Jackson P, Speiss W, and Farhana S (Editors) (Online: Springer), at page 85.

[297] Kelly M (2016) The nutrition transition in developing Asia: dietary change, drivers and health impacts in *Eating, drinking: surviving the International Year of Global Understanding – IYGU,* Jackson P, Speiss W, and Farhana S (Editors) (Online: Springer).

[298] Rae A (1998) The effects of expenditure growth and urbanisation on food consumption in East Asia: a note on animal products *Agricultural Economics* **18(3)**: 291-9; Hovhannisyan V, and Devadoss S (2020) Effects of urbanization on food demand in China Empirical Economics **58(2)**: 699-721; and International Food Research Policy Institute (2016) *Food systems and diets: facing the challenges of the 21st century*, available at: http://ebrary.ifpri.org/utils/getfile/collection/p15738coll5/id/5516/filename/5517.pdf, at page 73.

[299] See, generally, Murcott A, Belasco W, and Jackson P (Editors) (2013) *The Handbook of Food Research* (London: Bloomsbury), especially Chapters 12 and 14.

2.55 There is evidence that animal welfare considerations, particularly in high-income countries, are also having an effect on agri-food supply chains.[300] Preferences are expressed in relation to the farming system involved.[301] 'Organic' products have increased in popularity in high-income countries owing to perceptions of the effect that conventional agriculture has on the environment, human health, and animal welfare.[302] While the meaning of 'organic' may vary from one context to another, criteria used for the purposes of regulation and labelling in the EU include prohibition of the use of genetically modified organisms, ionising radiation, hormones, and antibiotics (except where necessary for animal health), and limiting the use of artificial fertilisers, herbicides, and pesticides.[303]

2.56 Vegetarianism is rare and, except in India, where approximately 35 per cent of people are vegetarians, it is mainly encountered as a 'lifestyle choice' associated with higher socioeconomic status and educational attainment in high-income countries.[304] Vegetarianism has not, however, reached above 10 per cent of the population in any of these countries and veganism remains rarer still, though it is increasing.[305] While infrequent incorporation of meat in the diet occurs by necessity in many regions of the world, voluntary 'flexitarianism' (often chosen as a result of health or environmental concerns) is increasing among those for whom meat is readily available and affordable.[306] However, the effect of any rise in vegetarianism in high-income countries globally is likely to be swamped, as we noted above, by rising meat consumption associated with increasing wealth in low-income countries.[307]

Food politics

2.57 Food purchasing patterns can be highly sensitive to information circulating in public and social media leading to 'food scares', which may be amplified by the complexity of ingredients, processing, and supply chains.[308]

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[300] Wilkinson J (2015) Food security and the global agrifood systems: ethical issues in historical and sociological perspective *Global Food Security* **7**: 9-14.

[301] This was borne out in the public dialogue we commissioned in the course of this inquiry; see: Nuffield Council on Bioethics (2021) *Online public dialogue on genome editing in farmed animals, research by Basis Social on behalf of the Nuffield Council on Bioethics*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/public-dialogue-on-genome-editing-and-farmed-animals.

[302] Meemken EM, and Qaim M (2018) Organic agriculture, food security, and the environment *Annual Review of Resource Economics* **10**: 39-63.

[303] European Commission (2020) *Organic production and products*, available at: https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organic-production-and-products_en.

[304] Baldos, ULC, and Hertel TW (2015) The role of international trade in managing food security risks from climate change *Food Security* **7**: 275-90; Stoll-Kleemann S, and O'Riordan T (2015) The sustainability challenges of our meat and dairy diets, *Environment: Science and Policy for Sustainable Development* **57(3)**: 34-8; Godfray, HCJ, Aveyard P, Garnett T *et al.* (2018) Meat consumption, health, and the environment *Science* **361(6399)**: eaam5324; and Leite JC, Caldeira S, Watzl B *et al.* (2020) Healthy low nitrogen footprint diets *Global Food Security* **24**: 100342.

[305] Altaş A (2017) Vegetarianism and veganism: current situation in Turkey in the light of examples in the world *Journal of Tourism and Gastronomy Studies* **5(4)**: 403-21; Morris C, Mylan J, and Beech E (2018) Substitution and food system de-animalisation: the case of non-dairy milk *The International Journal of Sociology of Agriculture and Food* **25(1)**: 42-58; and Paslakis G, Richardson C, Nöhre M *et al.* (2020) Prevalence and psychopathology of vegetarians and vegans – results from a representative survey in Germany *Nature Scientific Reports* **10**: 6840.

[306] Hicks TM, Knowles SO, and Farouk MM (2018) Global provisioning of red meat for flexitarian diets *Frontiers in Nutrition* **5**: 50; and Wageningen Economic Research (2018) *Global implications of the European food system: a food systems approach*, available at: https://scar-europe.org/images/ARCH/Documents/Global_implications_European_Food-Approach.pdf.

[307] Stoll-Kleemann S, and O'Riordan T (2015) The sustainability challenges of our meat and dairy diets *Environment: Science and Policy for Sustainable Development* **57(3)**: 34-8.

[308] See: Smith DF (2007) Food panics in history: corned beef, typhoid and "risk society" *Journal of Epidemiology and Community Health* **61(7)**: 566-70.

Box 2.6: Salmonella in eggs

A notable scare arose in response to an epidemic of salmonella in hens' eggs in the late 1980s in the UK. Between 1981 and 1991, the incidence of nontyphoidal salmonellosis in the UK rose by more than 170 per cent.[309] By the end of that decade it had been linked to raw shell eggs and prompted the Chief Medical Officer for England to advise consumers to avoid raw egg products. However, it was the statement by a junior health minister on national television in 1988 that "Most of the egg production in this country, sadly, is now infected with salmonella" that led to a rapid collapse of egg sales by 60 per cent, followed by a continuing fall of approximately 8 per cent per year over the next 10 years.[310]

The Government responded with legislative and regulatory measures including mandatory reporting of infection, movement restrictions, disinfection, and compulsory slaughter of infected flocks. This led to the culling of over 600,000 birds in 1989. The industry response was to introduce a vaccination scheme (introduced in broiler-breeder flocks in 1994 and in laying flocks in 1998) and a revival of the 'Lion Mark' stamp on shells to indicate compliance with a code of practice requiring mandatory vaccination against salmonella as well as a range of other traceability and quality control measures.[311] The damage to the egg industry was such as to require a 'relaunch' in the late 1990s by the British Egg Industry Council, following extensive market research and accompanied by a promotional campaign to restore consumer confidence.

2.58 The salmonella scare marked a significant change in the discourse on food policy. This transformed from a domain of expert-led 'managerial control' of the risks in the food system by a community of food specialists and regulators to a new 'food politics' carried on in public by divisive interest groups in which food safety became part of the public and media discourse.[312] A notable feature of this new discourse was the politicisation of the concept of risk, which was to become the privileged site of dispute in the 1990s, especially in relation to the introduction of new genetic technologies. This politicisation of risk was met, on the other side of the argument, by a tendency to 'overpromise' on the part of proponents of innovation, for example in terms of the timescale, feasibility, or reliability of innovation, contributing to a conceptual linkage between certain societal challenges, such as food security, and prospective technological solutions.[313]

2.59 This politicisation of food policy was evident in events that followed the publication of research carried out on rats that were fed transgenic potatoes in laboratory conditions in the 1990s. The potatoes had been modified to express the lectin *Galanthus nivalis* agglutinin (GNA), which is toxic to some insects. Researchers found that rats fed on the transgenic potatoes showed intestinal changes not evident in a control group fed on unmodified potatoes.[314] It was further claimed that this effect was not due to the GNA but rather to the process of genetic modification itself, specifically the use of a CaMV (cauliflower mosaic virus) promoter, already in use in a variety of genetically modified products. It was the circumstances of the publication, however, on an edition of the

[309] O'Brien SJ (2013) The "decline and fall" of nontyphoidal salmonella in the United Kingdom *Clinical Infectious Diseases* **56(5)**: 705-10.
[310] Ibid.
[311] See: British Lion Eggs (2021) *British Lion eggs*, available at: https://www.egginfo.co.uk/british-lion-eggs.
[312] Roslyng MM (2011) Challenging the hegemonic food discourse: the British media debate on risk and salmonella in eggs *Science as Culture* **20(2)**: 157-82.
[313] See: Nuffield Council on Bioethics (2012) *Emerging biotechnologies: technology, choice and the public good*, available at: https://www.nuffieldbioethics.org/publications/emerging-biotechnologies – what are called, in another register, 'sociotechnical imaginaries'.
[314] Ewen SW, and Pusztai A (1999) Effect of diets containing genetically modified potatoes expressing *Galanthus nivalis* lectin on rat small intestine *The Lancet* **354(9187)**: 1353-4.

popular UK television investigative current affairs programme, *World in Action*, and prior to formal completion of the research and academic review, that arguably contributed to the significant and enduring public controversy. This rapidly drew in opposing teams of researchers, health professionals, learned societies, and governments, few of whose reputations ultimately emerged unsullied.[315] National newspapers, still powerful bellwethers for public opinion, mounted campaigns. What became known as the 'Pusztai affair' eventually affected regulatory policy, technological innovation, and supply chains, with supermarkets withdrawing genetically modified foods from sale in response to consumer scepticism, a policy which has endured in some cases and always threatens to resurface in relation to introduction of any novel genetic technology.

Social impacts

2.60 The trend towards the industrialisation of agricultural production has changed the shape of rural and farming communities and is continuing to do so in countries with developing economies.[316] The effects on communities that have been studied in advanced national economies (albeit sometimes in remote and insulated communities) have been generally negative. A survey of research from one such country (the US) is difficult to generalise, although premonitory. The majority of the effects reported in the literature tended to be negative (family, employment, incomes, crime, health, community engagement, public services, environment, and infrastructure) while the positive effects noted in the literature were almost entirely limited to socioeconomic conditions.[317] Although the literature covers both arable and livestock industrial farming, negative environmental associations were particularly noted in connection with concentrated animal feeding operations (CAFOs).

2.61 In low-income countries, the impact of industrialisation of farming systems is often to take people from agricultural self-employment to wage labour dependency. This increases their vulnerability to spikes in food prices, because wage labour households spend a higher proportion of their income on food (and agricultural households may actually increase their income when food prices are high).[318] While intensive husbandry practices and integration into global supply chains may decrease exposure to local conditions, food price spikes generally have uneven global effects, falling hardest on the poorest. For example, the spike in 2008 had a significant effect on the poorest people around the world and led to food riots in more than 30 countries, although it had little impact on those in high-income countries where the majority of people spend a smaller proportion of their income on food.[319] The impacts are also gendered, as the replacement of domestic with

[315] The Lancet (1999) Health risks of genetically modified foods *The Lancet* **353(9167)**: 1811.

[316] FAO (2009) *The state of food and agriculture: livestock in the balance*, available at: http://www.fao.org/docrep/012/i0680e/i0680e.pdf; see also: Humane Society International (2012) *The industrialization of animal agriculture: implications for small farmers, rural communities, the environment, and animals in the developing world*, available at: https://www.hsi.org/wp-content/uploads/assets/pdfs/hsi-fa-white-papers/the_industrialization_of.pdf.

[317] Lobao L, and Stofferahn CW (2008) The community effects of industrialized farming: social science research and challenges to corporate farming laws *Agriculture and Human Values* **25**: 219-40. Although this systematic review covers 'industrialised farming' generally, many of the effects are observed specifically in relation to pig CAFOs, and may be peculiar to them (e.g., noisome atmosphere). Also, a lot of these phenomena may be characteristic of declining communities generally, regardless of the precipitating cause, albeit that that cause may be change in major source of employment.

[318] Baldos ULC, and Hertel TW (2015) The role of international trade in managing food security risks from climate change *Food Security* **7**: 275-90.

[319] Fedoroff NV (2015) Food in a future of 10 billion *Agriculture & Food Security* **4**: 11; and Valin H, Sands RD, van der Mensbrugghe D *et al.* (2014) The future of food demand: understanding differences in global economic models *Agricultural Economics* **45(1)**: 51-67.

industrial farming disempowers women in favour of men who become the wage earners, with negative knock-on effects on children.[320]

Reflections on social, cultural, and political challenges

2.62 Changes in the place of meat and animal products in human diets have accompanied social and demographic changes of industrialisation. Worldwide, the pattern is for meat consumption to rise with urbanisation and increasing income, although this has begun to reverse in post-industrial societies. If similar consumption patterns are to be followed in currently industrialising societies, the challenge will be to avoid the excesses that have already been experienced as counterproductive by post-industrial societies and their negative consequences (for public health, communities, and the welfare of farmed animals).

2.63 Changes in the nature of food and farming systems affect individuals involved and the communities in which they live as the orientation of labour is switched from the care of land and livestock to wage earning. This makes access to food increasingly subject to industrial supply chains. These may help to stabilise food supply globally, but their negative effects are likely to fall disproportionately on those with the lowest incomes, or those, even in industrialised countries, who are detached by geography from the supply chains.[321]

Environmental and ecological challenges

Feed conversion

2.64 Historical intensification of animal production has led to gains in efficiency resulting in proportionately lower numbers of animals in some regions. The US, for example, produces 60 per cent more milk with 80 per cent fewer cows now than it did in the 1940s.[322] However, they remain relatively inefficient as a nutritional resource for humans. Estimates of conversion efficiency vary: for example, some research suggests that approximately 43 per cent of the protein and 34 per cent of calories fed to animals in the form of human-edible crops enter the human food chain in the form of meat, fish, and dairy products.[323] Other research sets these figures lower.[324] The demand for grain from industrial livestock has, in turn, propelled the intensification of crop production leading to soil degradation, biodiversity loss, and air pollution.[325] The Intergovernmental Panel on Biodiversity and Ecosystems recently concluded that “Agro-industrial systems, consisting of input-intensive monocultures and industrial-scale feedlots currently dominate farming landscapes… their reliance on chemical fertilisers, pesticides, and

[320] Waring M (1990) *If women counted: a new feminist economics* (Harper Collins Publishers: San Francisco).

[321] Bruce A, Bruce DM, Fletcher I *et al.* (2021) Producing food in a fragile food system – a case study on Isle of Skye, Scotland, in *Justice and food security in a changing climate,* Schübel H, and Wallimann-Helmer I (Editors) (Wageningen Academic Publishers).

[322] Ramakutty N, Mehrabi Z, Waha K *et al.* (2018) Trends in global agricultural land use: implications for environmental health and food security *Annual Review of Plant Biology* **69**: 789-815.

[323] Berners-Lee M, Kennelly C, Watson R *et al.* (2018) Current global food production is sufficient to meet human nutritional needs in 2050 provided there is radical societal adaptation *Elementa: Science of the Anthropocene* **6**: 52.

[324] See, for example, Cassidy ES, West PC, Gerber JS *et al.* (2013) Redefining agricultural yields: from tonnes to people nourished per hectare *Environmental Research Letters.* **8(3)**: 034015.

[325] See: Tsiafouli MA, Thébault E, Sgardelis SP *et al.* (2014) Intensive agriculture reduces soil biodiversity across Europe *Global Change Biology* **21(2)**: 973-85; Lelieveld, J, JS Evans, M Fnais *et al.* (2015) The contribution of outdoor air pollution sources to premature mortality on a global scale *Nature* **525(7569)**: 367-71.

preventive use of antibiotics, systematically yields negative outcomes and vulnerabilities."[326]

Greenhouse gas emissions

2.65 Livestock production has contributed significantly to climate change through both direct and indirect greenhouse gas (GHG) emissions. Methane is emitted from enteric (intestinal) fermentation in ruminants (which is related to species and production system, but also varies considerably according to the host genome and microbiome) and from anaerobic decomposition of livestock faeces.[327] Rates of methane production per unit of output have been reduced over the last half-century in high-income countries by improvements in ruminant production systems.[328] Methane emissions have actually fallen in Europe since the beginning of the twenty-first century while increasing significantly elsewhere.[329] Carbon dioxide emissions result from the land use change and livestock production-related energy generation (e.g., fuel and fertiliser manufacture).[330] Nitrous oxide is generated by aerobic decomposition of livestock waste, fertiliser applied to feed crops, and deposition of urine into soil.[331] Methane emissions from ruminant production and nitrous oxide from animal waste and fertilisation are the largest contributors of GHG emissions in the agricultural sector.[332] Produce from beef and dairy cattle remains among the most emission intensive of foods, and is responsible for approximately 70 per cent of livestock GHG emissions in the EU.[333] However, these figures are dominated by the outputs of industrial production systems that exist to service the global appetite for affordable animal products, whereas traditional systems in many countries are much more sustainable and may offer a variety of environmental benefits.[334]

2.66 It is expected that emissions of methane and nitrous oxide from agriculture, which are significantly more environmentally damaging than carbon dioxide, will have to decrease if the world is to meet internationally agreed climate change targets.[335] However, livestock-related emissions are expected to increase significantly over the coming

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326 Intergovernmental Panel on Biodiversity and Ecosystems (2019) *The Global Assessment report on biodiversity and ecosystem services*, available at: https://www.ipbes.net/global-assessment.

327 Difford GF, Plichta DR, Løvendahl P *et al.* (2018) Host genetics and the rumen microbiome jointly associate with methane emissions in dairy cows *PLoS Genetics* **14(10)**: e1007580; and Tapio I, Snelling TJ, Strozzi F *et al.* (2017) The ruminal microbiome associated with methane emissions from ruminant livestock *Journal of Animal Science and Biotechnology* **8**: 7.

328 Pickering NK, Oddy VH, Basarab J *et al*. (2015) Animal board invited review: genetic possibilities to reduce enteric methane emissions from ruminants *Animal* **9(9)**: 1431-40.

329 Jackson RB, Saunois M, Bousquet P *et al.* (2020) Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources *Environmental Research Letters* **15(7)**: 071002.

330 Lynch J, and Pierrehumbert R (2019) Climate impacts of cultured meat and beef cattle *Frontiers in Sustainable Food Systems* **3**: 5.

331 Henry BK and Eckard R (2009) Greenhouse gas emissions in livestock production systems *Tropical Grasslands* **43(4)**: 232-8; Difford GF, Plichta DR, Løvendahl P *et al.* (2018) Host genetics and the rumen microbiome jointly associate with methane emissions in dairy cows *PLoS Genetics* **14(10)**: e1007580; Lynch J, and Pierrehumbert R (2019) Climate impacts of cultured meat and beef cattle *Frontiers in Sustainable Food Systems* **3**: 5; and Saunois M, Stavert AR, Poulter B *et al*. (2020) The global methane budget 2000-201 *Earth System Science Data* **12(3)**: 1561-623.

332 Henry, K, and Eckard R (2009) Greenhouse gas emissions in livestock production systems *Tropical Grasslands* **43(4)**: 232-8; and Jackson RB, Saunois M, Bousquet P *et al.* (2020) Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources *Environmental Research Letters* **15(7)**: 071002.

333 Bryngelsson D, Wirsenius S, Hedenus F *et al.* (2014) How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture *Food Policy* **59**: 152-64; Lynch J, and Pierrehumbert R (2019) Climate impacts of cultured meat and beef cattle *Frontiers in Sustainable Food Systems* **3**: 5; and FAO, IFAD, UNICEF, WFP, and WHO (2020) *The state of food security and nutrition in the world: transforming food systems for affordable healthy diets,* available at: https://www.fao.org/documents/card/en/c/ca9692en.

334 PASTRES (2021) *Are livestock always bad for the planet? Rethinking the protein transition and climate change debate*, available at: https://pastres.files.wordpress.com/2021/09/climate-livestock-full-report-en-web-2.pdf.

335 Bryngelsson D, Wirsenius S, Hedenus F *et al.* (2016) How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture *Food Policy* **59**: 152-64.

decades due to an increase in demand for livestock products (mainly meat and milk) unless significant steps are taken to reduce them.[336] This has led researchers to conclude that changes in the food system are needed to address global climate change and meet climate goals irrespective of action to address other sources of GHG emissions, such as fossil fuels.[337] The research shows that moving to plant-rich diets containing only moderate amounts of meat could, however, be highly effective in reducing emissions, as well as having associated human health benefits.[338]

Waste and pollution

2.67 Livestock waste (excretions, bedding material, wastewater, soil, hair, feathers, and other debris) has a number of beneficial uses (as fertiliser, fuel, etc.) but can also present a disease and pollution risk.[339] Its management, processing, recycling, and disposal are therefore important challenges for farming systems. Large-scale, intensive husbandry systems can produce extremely large volumes of animal waste, concentrated in a small area.[340] According to the USs Environmental Protection Agency, a farm with 2,500 dairy cattle produces a similar waste load to a city of 411,000 people.[341] The absolute increase and distribution of waste production has risen in step with the global increase in farmed animal production.[342]

2.68 Animal waste releases large quantities of carbon dioxide and ammonia, contributing to climate change, eutrophication of rivers and lakes, and acid rain, as well as pathogens, concentrations of unmetabolised chemicals, nutrients, and compounds, and the products of metabolism (e.g., nitrogen, phosphorus, potassium, and veterinary antibiotics).[343] Many pathogens can survive in animal waste for days or even months, often being transported long distances in rivers and other waterways.[344] Human diseases such as

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336 Bajželj B, Richards KS, Allwood JM *et al.* (2014) Importance of food-demand management for climate mitigation *Nature* **4**: 924-9; Springmann M, Clark M, Mason-D'Croz D *et al.* (2018) Options for keeping the food system within environmental limits, *Nature* **62**: 519-25; and Harmsen M, van Vuuren DP, Bodirsky BL *et al.* (2019) The role of methane in future climate strategies: mitigation potentials and climate impacts *Climatic Change* **163**: 1409-25.

337 Clark MA, Domingo NGG, Colgan K *et al.* (2020) Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets *Science* **370(6517)**: 705-8.

338 Chatham House (2015) *Changing climate, changing diets: pathways to lower meat consumption*, available at: *https://www.chathamhouse.org/2015/11/changing-climate-changing-diets-pathways-lower-meat-consumption*; Springmann M, Godfray HCJ, Rayner M *et al.* (2016) Analysis and valuation of the health and climate change cobenefits of dietary change *Proceedings of the National Academy of Sciences* **113(15)**: 4146-51; van de Kamp ME, Seves SM, and Temme EHM (2018) Reducing GHG emissions while improving diet quality: exploring the potential of reduced meat, cheese and alcoholic and soft drinks consumption at specific moments during the day *BMC Public Health* **18**: 264; Harwatt H (2019) Including animal to plant protein shifts in climate change mitigation policy: a proposed three-step strategy *Climate Policy* **19(5)**: 533-41; and FAO, IFAD, UNICEF, WFP and WHO (2020) The state of food security and nutrition in the world (2020) *Transforming food systems for affordable healthy diets*, available at: https://www.fao.org/documents/card/en/c/ca9692en.

339 Yan B, Qian Y, and Pan Y (2016) A method to estimate farmland pollution load of livestock manure nutrient in field patch scale *Fresenius Environmental Bulletin* **25(6)**: 1942-49; and Parihar SS, Saini KPS, Lakhani GP *et al.* (2019) Livestock waste management: a review *Journal of Entomology and Zoology Studies* **7(3)**: 384-93.

340 US Environmental Protection Agency (2004) *Risk assessment evaluation for concentrated animal feeding operations,* available at: https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901V0100.txt; Graham JP, and Nachman KE (2010) Managing waste from confined animal feeding operations in the United States: the need for sanitary reform *Water and Health* **8(4)**: 646-70; and Liu Y, Cui E, Neal AL *et al.* (2019) Reducing water use by alternate-furrow irrigation with livestock wastewater reduces antibiotic resistance gene abundance in the rhizosphere but not in the non-rhizosphere *Science of the Total Environment* **648**: 12-24.

341 US Environmental Protection Agency (2004) *Risk assessment evaluation for concentrated animal feeding operations,* available at: https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901V0100.txt.

342 Strokal M, Ma L, Bai Z *et al.* (2016) Alarming nutrient pollution of Chinese rivers as are result of agricultural transitions, *Environmental Systems Analysis* **11(2)**: 024014; and Yan B, Qian Y, and Pan Y (2016) A method to estimate farmland pollution load of livestock manure nutrient in field patch scale *Fresenius Environmental Bulletin* **25(6)**: 1942-49.

343 Ogbuewu IP, Odoemenam VU, Omede AA *et al.* (2012) Livestock waste and its effect on the environment *Scientific Journal of Review* **1(2)**: 17-32; Parihar SS, Saini KPS, Lakhani GP *et al.* (2019) Livestock waste management: a review *Journal of Entomology and Zoology Studies* **7(3)**: 384-93; and Savin M , Alexander J, Bierbaum G *et al.* (2021) Antibiotic-resistant bacteria, antibiotic resistance genes, and antibiotic residues in wastewater from a poultry slaughterhouse after conventional and advanced treatments *Scientific Reports* **11**: 16622.

344 Graham JP, and Nachman KE (2010) Managing waste from confined animal feeding operations in the United States: the need for sanitary reform, *Water and Health* **8(4)**: 646-70.

typhoid, dysentery, and hepatitis, as well as foot-and-mouth and swine fever, have spread along waterways, threatening downstream ecosystems and population centres.[345] Environmental damage can occur as a result of sediment deposition increasing microbial growth and leading to oxygen depletion in rivers and ecosystems.[346]

2.69 The traditional method of managing livestock waste is composting (which destroys most pathogens) and distribution over local farmland where it is recycled into the soil as fertiliser.[347] This must be done with care, however, as excessive application of manure can have negative effects on soil, including nutrient balance and physical qualities such as compaction (e.g., compaction of soil pores and shell binding of the surface).[348] Composting is less practical in the case of large, intensive systems for a number of reasons, including the fact that they are often disconnected from the sites of crop production (either for grazing or growing feed) and it is less economically viable to transport very large quantities of waste to where they would be of benefit. Waste may therefore be stored as slurry that can harbour pathogens, leading to health risks for animals and humans through ground and surface water contamination.[349] It may also be used as an energy source, feedstock additive, or processed as a commercial fertiliser.[350]

2.70 Regulations controlling the management of agricultural waste may be absent and ineffective or compliance with them variable, and incentives for preventative measures may be lacking as the full costs of the environmental damage and remediation are often not borne by polluters.[351] Once again, the negative effects of waste from large husbandry operations are expected to be most significant in low-income economies where implementation of environmental regulations and investment in effective large-scale water treatment may be limited.[352]

Water scarcity

2.71 Water scarcity is a major problem in many parts of the world. In some regions, pressure on water resources may increase to a point at which the availability of freshwater to humans is seriously threatened, especially when demand pressures are compounded by

[345] Atilgan A , Oz H, and Buyuktas K (2011) The location of manure accumulated in cattle livestock barns and its interaction with the environment *African Journal of Biotechnology* **10(77)**: 17825-30; Ogbuewu IP, Odoemenam VU, Omede AA *et al*. (2012) Livestock waste and its effect on the environment *Scientific Journal of Review* **1(2)**: 17-32; and Wen Y, Schoups G, and van de Giesen N (2017) Organic pollution of rivers: combined threats of urbanization, livestock farming and global climate change *Nature Scientific Reports* **7**: 43289.

[346] Wen Y, Schoups G, and van de Giesen N (2017) Organic pollution of rivers: combined threats of urbanization, livestock farming and global climate change *Nature Scientific Reports* **7**: 43289.

[347] Mawdsley JL, Bardgett RD, Merry RJ *et al.* (1995) Pathogens in livestock waste, their potential for movement through soil and environmental pollution *Applied Soil Ecology* **2(1)**: 1-15.

[348] Atilgan A, Oz H, and Buyuktas K (2011) The location of manure accumulated in cattle livestock barns and its interaction with the environment, *African Journal of Biotechnology* **10(77)**: 17825-30.

[349] Graham JP, and Nachman KE (2010) Managing waste from confined animal feeding operations in the United States: the need for sanitary reform *Water and Health* **8(4)**: 646-70; and US Environmental Protection Agency (2004) *Risk assessment evaluation for concentrated animal feeding operations,* available at: https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901V0100.txt.

[350] Graham JP, and Nachman KE (2010) Managing waste from confined animal feeding operations in the United States: the need for sanitary reform, *Water and Health* **8(4)**: 646-70.

[351] US Environmental Protection Agency (2004) *Risk assessment evaluation for concentrated animal feeding operations,* available at: https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901V0100.txt; and Graham JP, and Nachman KE (2010) Managing waste from confined animal feeding operations in the United States: the need for sanitary reform *Water and Health* **8(4)**: 646-70.

[352] Wen Y, Schoups G, and van de Giesen N (2017) Organic pollution of rivers: combined threats of urbanization, livestock farming and global climate change *Nature Scientific Reports* **7**: 43289.

variability in freshwater supply as a result of climate change.[353] It has been argued that limitations to freshwater supply could be the main factor constraining food production in future.[354]

2.72 Agriculture generally consumes 70 per cent of freshwater withdrawals, of which approximately one fifth is used in livestock production, although this varies considerably depending on the species, local climate, and production system. In some regions this is much higher: for example, in Botswana, livestock production accounts for almost a quarter of the country's total water use.[355] Beef accounts for approximately four-fifths of all water used in livestock production globally.[356] Of the water used, a small amount is drinking water consumed by animals but most is consumed indirectly in feed production, as well as in processing, washing, cooling, and waste management.[357] The irrigation of feed crops puts significant pressure on available water in some regions such as Asia and North Africa, although less so in Europe, North America, Latin America, and sub-Saharan Africa (where rain-fed systems are used).[358]

2.73 Competition for water resources is largely avoided in pasture-based systems that rely on precipitation for feed production. These provide additional benefits, especially in low-income economies, by making productive use of land that is unsuitable for other types of farming and mitigating food insecurity in the face of climate instability.[359] However, outdoor systems also have an impact on the way soil absorbs water, which can contribute to flooding.[360]

Deforestation

2.74 Deforestation increased exponentially in the mid-twentieth century and, despite a number of concerted reforestation initiatives, net deforestation is predicted to continue

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[353] Doreau M, Corson MS, and Wiedemann SG (2012) Water use by livestock: a global perspective for a regional issue *Animal Frontiers* **2(2)**: 9-16; Nechifor V, and Winning M (2018) Global economic and food security impacts of demand-driven water scarcity – alternative water management options for a thirsty world *Water* **10(10)**: 1442; International Livestock Research Institute (2019) *Livestock and water in developing countries: ILRI discussion paper 38,* available at: https://cgspace.cgiar.org/handle/10568/107268; and Qin Y, Mueller ND, Siebert S *et al.* (2019) Flexibility and intensity of global water use *Nature Sustainability* **2**: 515-23.

[354] Oweis T, and Peden (2008) Water and livestock, in *Livestock and global climate change: proceedings of the livestock and global climate change conference*, *Hammamet, 17-20 May 2008* Rowlinson P, Steele M, and Nefaoui A (Editors) (Cambridge: Cambridge University Press); Murphy E, de Boer IJM, van Middelaar CM *et al.* (2017) Water footprinting of dairy farming in Ireland *Journal of Cleaner Production* **140(2)**: 547-55; and Escarcha JF, Lassa JA, and Zander KK (2018) Livestock under climate change: a systematic review of impacts and adaptation *Climate* **6(3)**: 54.

[355] Wada Y, Flörke M, Hanasaki N *et al.* (2016) Modeling global water use for the 21st century: the Water Futures and Solutions (WFaS) initiative and its approaches *Geoscientific Model Development* **9**: 175-222: and Rotz AC (2020) Environmental sustainability of livestock production *Meat and Muscle Biology* **4(2)**: 1-18.

[356] Qin Y, Mueller ND, Siebert S *et al.* (2019) Flexibility and intensity of global water use *Nature Sustainability* **2**: 515-23.

[357] Kebebe EG, Oosting SJ, Haileslassie A *et al.* (2015) Strategies for improving water use efficiency of livestock production in rain-fed systems, *Animal* **9(5)**: 908-16; International Livestock Research Institute (2019) *Livestock and water in developing countries: ILRI discussion paper 38,* available at: https://hdl.handle.net/10568/107268; US Geological Survey (2018) *Estimated use of water in the United States in 2015: US Geological Survey circular 1441,* available at: https://pubs.er.usgs.gov/publication/cir1441; and Rotz AC (2020) Environmental sustainability of livestock production *Meat and Muscle Biology* **4(2)**: 1-18.

[358] FAO (2019) *Water use in livestock production systems and supply chains: guidelines for assessment – version 1*, available at: http://www.fao.org/3/ca5685en/ca5685en.pdf; and Rotz AC (2020) Environmental sustainability of livestock production *Meat and Muscle Biology* **4(2)**: 1-18.

[359] Schlink AC, Nguyen ML, and Viljoen GJ (2010) Water requirements for livestock production: a global perspective *Revue Scientifique et Technique (International Office of Epizootics)* **29(3)**: 603-19; and International Livestock Research Institute (2019) *Livestock and water in developing countries: ILRI discussion paper 38,* available at: https://hdl.handle.net/10568/107268.

[360] Chatham House (2014) *Livestock – climate change's forgotten sector: global public opinion on meat and dairy consumption*, available at: https://www.chathamhouse.org/2014/12/livestock-climate-changes-forgotten-sector-global-public-opinion-meat-and-dairy-consumption.

to increase for decades to come.[361] The drivers of deforestation are complex.[362] The most consistently significant driver, however, is the pursuit of economic returns in response to demand for products of forestry, mining, and agriculture.[363] A typical pattern involves roads being cut through forested areas, to provide access for mining and logging activities. The adjoining forest is then cleared and crops are planted on the cleared areas. As forest soils cannot usually sustain crops for more than a few seasons, the farmers move on and ranchers take over, grazing livestock on what has now become grassland.[364] A 15-year study found that, globally, 27 per cent of forest loss was due to permanent land use change for commodity production (agriculture including oil palm, mining, or energy infrastructure) while shifting agriculture accounted for 24 per cent, forestry 26 per cent, and the remainder was due to wildfire).[365]

2.75 Livestock production is implicated in tropical deforestation, which is a major factor contributing to climate change. An estimated 73 per cent of forest loss in tropical and subtropical regions is due to the conversion of forest to agricultural land, much of which is used directly or indirectly to support livestock.[366] A key driver of deforestation in South America is the production of soybeans for animal feed that is consumed mainly by pigs and poultry. Primary forests are among the most important of global ecological infrastructures, providing air-quality regulation, nutrient cycling, carbon sequestration, pollination, disease control, freshwater, shelter, storm protection, and water-quality regulation.[367] Tropical forests also support at least 75 per cent of global biodiversity.[368]

Biodiversity

2.76 Biodiversity is, by definition, not one thing and, furthermore, takes its meaning from the context. Because of this, there is no absolute value of biodiversity or equivalence between the different ways in which it is measured. Measuring the impact of livestock production on biodiversity is further complicated by the need to account for both positive and negative effects, the difficulty of linking local and global scales, and the large number of mechanisms by which biodiversity can be affected.[369]

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[361] Alvarado F, Escobar F, Williams DR *et al*. (2017) The role of livestock intensification and landscape structure in maintaining tropical biodiversity *Journal of Applied Ecology* **55(1)**: 185-94; Busch J, and Ferretti-Gallon K (2017) What drives deforestation and what stops it? A meta-analysis *Review of Environmental Economics and Policy* **11(1)**: 3-23; Curtis PG, Slay CM, Harris NL *et al*. (2018) Classifying drivers of global forest loss *Science* **361(6407)**: 1108-11; da Silva AM, and Rodgers J (2018) Deforestation across the world: causes and alternatives for mitigating *International Journal of Environmental Science and Development* **9(3)**: 67-73; and Pendrill F, Persson UM, Godar J *et al*. (2019) Deforestation displaced: trade in forest-risk commodities and the prospects for a global forest transition *Environmental Research Letters* **14(5)**: 055003.

[362] Busch J, and Ferretti-Gallon K (2017) What drives deforestation and what stops it? A meta-analysis *Review of Environmental Economics and Policy* **11(1)**: 3-23

[363] Ibid.; da Silva AM, and Rodgers J (2018) Deforestation across the world: causes and alternatives for mitigating *International Journal of Environmental Science and Development* **9(3)**: 67-73; and Curtis PG, Slay CM, Harris NL *et al*. (2018) Classifying drivers of global forest loss *Science* **361(6407)**: 1108-11.

[364] FAO (2007) *Cattle ranching and deforestation*, available at: http://www.fao.org/3/a0262e/a0262e.pdf.

[365] Curtis PG, Slay CM, Harris NL *et al.* (2018) Classifying drivers of global forest loss *Science* **361(6407)**: 1108-11.

[366] Arrieta EM, Cuchietti A, and González A (2018) Greenhouse gas emissions and energy efficiencies for soybeans and maize cultivated in different agronomic zones: a case study of Argentina *Science of the Total Environment* **625**:199-208; and United Nations (2018) *The Sustainable Development Goals report 2018*, available at: https://www.un.org/development/desa/publications/the-sustainable-development-goals-report-2018.html.

[367] da Silva AM, and Rodgers J (2018) Deforestation across the world: causes and alternatives for mitigating *International Journal of Environmental Science and Development* **9(3)**: 67-73

[368] Giam X (2017) Global biodiversity loss from tropical deforestation *Proceedings of the National Academy of Sciences* **114(23)**: 5775-7.

[369] FAO (2015) *A review of indicators and methods to assess biodiversity: application to livestock production at global scale*, available at: http://www.fao.org/3/av151e/av151e.pdf.

2.77 Habitat degradation and land use change are among the major factors causing biodiversity loss.[370] Land used for grazing and feed crops in livestock production is perhaps the largest single factor accounting for biodiversity loss.[371] Increases in livestock production have mostly been achieved through changing pastoral systems with free-range feeding to intensive systems or mixed intensive/pastoral systems. Intensive systems acquire over 90 per cent of their feed off-farm, while mixed systems acquire approximately 10 per cent of their feed from crops or crop by-products.[372] The changes in livestock production systems have caused significant increases in cropland area for feed production, a trend that is expected to continue for the foreseeable future. As a consequence, there an increasing trend of livestock production and associated intensification and expansion of crop production is to be expected.[373]

2.78 Globally, livestock grazing is the predominant anthropogenic land use, accounting for over 60 per cent of the world's agricultural lands.[374] Overgrazing has had a mainly negative effect on wildlife and modelling suggests that the mean species abundance in rangelands will continue to decline until at least 2050.[375] Grazing animals change the biophysical structures and processes of an environment through trampling and removal of vegetation.[376] Grazing on rangelands can remove biomass, damage root systems, and displace wild grazers.[377] Nutrient excretion through urination and defecation changes nutrient cycles and can cause diffuse nitrogen and phosphorus pollution, the effects of which can lead to reduced storage of carbon in soils, diminishing the ability of the ecosystem to contribute to climate regulation.

2.79 The effect of agriculture on biodiversity is, however, varied. Regions with an ancient history of livestock grazing have a unique biodiversity specifically adapted to the presence of those livestock.[378] Grazing animals can bring specific benefits for biodiversity by supporting many different species of grasses, herbs, and shrubs maintaining soil carbon. In Europe, conservation of seminatural grasslands is an important goal for biodiversity conservation and improvement, as ancient man-made systems are valued as extremely species-rich ecosystems.[379] In North American rangelands, cattle can play a similar ecological role to that of bison.[380]

Reflections on environment and ecological challenges

2.80 The environmental and ecological challenges facing the food and farming system are perhaps of the most far-reaching importance, not only for their own sake but because they constitute the conditions for the health and welfare of present and future generations

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370 Alkemade (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems *Proceedings of the National Academy of Sciences* **110(52)**: 20900-5.

371 UN Convention to Combat Desertification (2017) *Global land outlook,* available at: https://knowledge.unccd.int/publication/full-report.

372 Alkemade R, Reid RS, van den Berg M *et al.* (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems *Proceedings of the National Academy of Sciences* **110(52)**: 20900-5.

373 Ibid.

374 Dettenmaier SJ, Messmer TA, Hovick TJ *et al.* (2017) Effects of livestock grazing on rangeland biodiversity: a meta-analysis of grouse populations *Ecology and Evolution* **7(19)**: 7620-7.

375 Ibid.; Alkemade R, Reid RS, van den Berg M *et al.* (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems *Proceedings of the National Academy of Sciences* **110(52)**: 20900-5.

376 Davidson KE, Fowler MS, Skov MW *et al.* (2017) Livestock grazing alters multiple ecosystem properties and services in salt marshes: a meta-analysis *Journal of Applied Ecology* **54(5)**: 1395-405.

377 Alkemade R, Reid RS, van den Berg M *et al.* (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems *Proceedings of the National Academy of Sciences* **110(52)**: 20900-5.

378 FAO (2015) *A review of indicators and methods to assess biodiversity: application to livestock production at global scale*, available at: http://www.fao.org/3/av151e/av151e.pdf.

379 Alkemade R, Reid RS, van den Berg M *et al.* (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems *Proceedings of the National Academy of Sciences* **110(52)**: 20900-5.

380 FAO (2015) *A review of indicators and methods to assess biodiversity: application to livestock production at global scale*, available at: http://www.fao.org/3/av151e/av151e.pdf.

of humans and non-human animals. They are also the most difficult to control because they become visible slowly, and mitigating or redressing them requires concerted action over a long time period, and on a near-planetary scale.

Conclusion

2.81 Between 1980 and 2007, most of the global growth in the animal production sector took place in large, specialised monogastric (mainly pig and chicken) farms.[381] This was especially pronounced in the world's most populous countries, India and China.[382] Most commentaries agree, however, that this is not an indefinitely scalable response to the challenge of escalating demand, even if it were possible to mitigate the impacts on animal welfare, the farming sector, and the environment.

2.82 The challenges described in this chapter are evidently deeply interconnected, to the extent that the distinction between them is a result of choices about the effects to observe rather than the independence of their causes. This implies that it will not be possible to respond to one challenge without having some effect on the others. It is equally evident that the consequences of these challenging conditions are not equally distributed among the regions of the Earth; some of the greatest threats menace those in low-income economies who are already affected by multiple vulnerabilities. But the causative factors are often also global. Climate change, for example, is a global phenomenon that exacerbates local vulnerabilities.

2.83 Responding to these challenges involves not merely a limited set of steps but an implicit commitment to a pathway that will incur further costs and challenges. Thus, when we consider the sustainability of farming systems, we must consider the sustainability of the trajectory of development rather than of the repetition of the practices themselves. Two contrasting orientations may be characterised as those of further (sustainable) intensification, that is, on one hand, a commitment to indefinitely increasing productivity or, on the other, a transition towards different ways of using the available resources.[383] The first places significant faith in continual developments in technology providing the means to overcome the accumulated costs of present consumption, while the second places perhaps an equal degree of faith in the capacity for collective action for change. But these are neither mutually nor collectively exclusive options. The challenges are complex and not likely to be met by simple, even if difficult to achieve, solutions.

381 FAO (2009) *State of food and agriculture: livestock in the balance*, available at: https://www.fao.org/3/i0680e/i0680e00.htm.

382 FAO (2016) *Drivers, dynamics and epidemiology of antimicrobial resistance in animal production*, available at: http://www.fao.org/3/i6209e/i6209e.pdf.

383 This paradoxical concept of sustainable intensification, originally described in the 1990s (Pretty JN (1997) The sustainable intensification of agriculture *Natural Resources Forum* **21**:247-56) has become a favourite of governments (including the UK) research institutes (the Royal Society, Oxford Martin School), international development institutions, (e.g., the FAO and World Bank) and even agribusinesses (e.g., Monsanto). There is, however, considerable debate over the relative proportions of sustainability and intensification implied in the concept, and whether it is even an oxymoron; see, for example, Loos J, Abson DJ, Chappell MJ *et al.* (2014) Putting meaning back into "sustainable intensification" *Frontiers in Ecology* and the Environment **12(6)**:356-61; Tittonell P (2014) Ecological intensification of agriculture – sustainable by nature *Current Opinion in Environmental Sustainability* **8**: 53-61; and Mahon N, Crute I, Simmons E *et al.* (2017) Sustainable intensification – 'oxymoron' or 'third-way' – a systematic review *Ecological Indicators* **74**: 73-97. Some commentators understandably see it as two different processes: "sustainable de-intensification in the industrial agriculture of the [global] north and sustainable intensification of the low-input agriculture of the south" (Struik PC, and Kuyper TW (2017) Sustainable intensification in agriculture: the richer shade of green. A review. *Agronomy for Sustainable Development* **37**: 39).

Chapter 3

Towards justice

in food and farming systems

Chapter 3 – Towards justice in food and farming systems

Chapter overview

In this chapter we propose an ethical standard to guide and evaluate interventions in food and farming systems.

People must cooperate to secure certain basic interests (such as access to nourishment) which leads to the establishment of institutions, such as food and farming systems, that are subject to characteristic norms. The success of these institutions has itself made possible growth in the size and prosperity of populations, leading to increased dependency on those very systems. However, in some cases, even though they could do so, the systems do not secure the basic interests of all those subject to them in practice.

We believe that sentient, non-human animals have morally relevant basic interests. They are dependent on food and farming systems for the conditions that enable them to live good lives.

The current arrangement of food and farming systems is the result of particular biological, environmental and social processes of evolution and co-adaptation. Further adaptations are necessary to meet the challenges currently facing food and farming systems. Which adaptations are pursued has implications for basic justice.

Some parameters have historically been more tractable than others. However, while entrenched systems have locked in certain social relations, biotechnologies have simultaneously increased the tractability of the biological features of animals. While there is no a priori reason to prefer one type of intervention to another it is necessary to consider both the technical uncertainties of the approach and how selecting that approach may entail a commitment to a course of action from which it may later become difficult to disengage.

Key points

- It is a cardinal principle for the governance of a food and farming system that it should secure the basic interests of those who depend on it insofar as they depend on it to secure those interests.
- Institutions meet the standard of basic justice when the basic interests of those subject to them are secured.
- Sentient, non-human animals have morally relevant basic interests and come within the scope of basic justice.
- The challenges that impinge on or threaten to destabilise the food and farming system represent threats to basic justice.
- There is no reason to rule out any particular kind of response but there is a need for caution, to avoid further entrenching undesirable systems or committing to undesirable outcomes.

Introduction

3.1 In Chapter 1 we offered an account of the biological and cultural co-adaptation between humans and non-human animals that is characterised as domestication. This has taken place over evolutionary timescales but has increased markedly in pace and sophistication owing to the introduction of scientific approaches to breeding since the industrial revolution. In the modern period there have been notable biological changes on the side of farmed animals whereas, on the side of humans, the changes have been largely social. This period has seen the industrialisation of much food production, its organisation around complex agri-food supply chains, and its integration into large or global markets. As a result, the majority of humans probably have little experience of the lives of the animals that they consume (a situation we have described as 'de-domestication'). On the other hand, unprecedented control is now exercised by technical specialists over the living conditions and the fundamental biology of farmed animals ('hyperdomestication').

3.2 Animal products currently form a substantial part of the global food system, particularly in high-income economies in the global North.[384] As per capita income rises, meat consumption tends to increase, and this is observed particularly among the growing middle classes of emerging economies.[385] In most countries animal products are produced for the market by commercial farmers. The predominantly commercial organisation creates the temptation to evaluate the benefits and costs of policies and interventions in economic terms, which may make it difficult to account for more diffused societal effects. Food and farming systems are, nevertheless, embedded in societies.[386] They are not only important economically, but also for basic nutritional, cultural, and social reasons: for example, they secure sources of nourishment, provide employment, organise social behaviour, and shape patterns of land, inland water, and sea use. Ensuring that food and farming systems support the fundamental interests of those who are subject to or affected by them is a matter of public interest for political societies.

3.3 As we described it in the previous chapter, the food and farming system, globally, is subject to numerous internal and external challenges that require it to adapt if it is to support the interests of those who will depend on it in future. We will discuss what implications the adoption of prospective breeding technologies might have for these challenges in subsequent chapters. In the present chapter, however, we turn from descriptive to normative questions: specifically, to the question of what values and considerations ought to guide our thinking about how food and farming systems should develop to meet the challenges they face and, therefore, about what approaches and activities should be promoted, permitted, or proscribed. Approaching these questions, we will need to take into account both the inevitable starting point (dominated by entrenched but arguably unjust and unsustainable production systems), and uncertainties or risks involved in attempting to improve existing systems or in departing from them.

384 For a summary of information about global meat and dairy production, see: Our World in Data (2019) *Meat and dairy production*, available at: https://ourworldindata.org/meat-production.

385 See: Earthscan (2003) *World agriculture: towards 2015/2030: an FAO perspective*, available at: http://www.fao.org/3/y4252e/y4252e.pdf.

386 See: Polanyi K (1944) *The great transformation: the political and economic origins of our time* (Boston MA: Beacon Press).

Food systems and justice

3.4 Access to sufficient affordable, nutritious food is a fundamental interest of all human beings. Most members of human societies are dependent on the food and farming system to provide this. The exceptions are those few who strive for a self-sufficient lifestyle 'off grid' (e.g., homesteaders, survivalists) or the many more who participate in discrete subsistence systems and have little interaction with the wider food economy (e.g., nomadic herders and pastoralists). It is estimated that upwards of a quarter of the world's population, and two-thirds of the population of rural people in low-income countries, are supported by small-scale farming, which includes shifting agriculture (often misleadingly described as 'slash and burn') and nomadic herding.[387]

3.5 It is beyond doubt, however, that the populations that expanded into the cities, from the eighteenth century in industrialised countries, could no longer be supported by a return to small-scale agriculture or pastoralism.[388] Furthermore, a widespread return to the land would mean that ways of life that depend on non-agricultural industries could no longer be supported either: the specialisation that propelled industrialisation, at the same time, led to historical developments in economic and population growth that depend on highly integrated, and now globalised food and farming systems to sustain them.[389]

Social embeddedness of food and farming systems

3.6 The question of how to arrange and govern the food and farming system that underpins the ways of life of many contemporary societies, including that of the UK, is a question of potentially existential importance for those societies. Such societies are structured to secure cooperation among their members, concretised in institutions, and governed by formal and informal norms. For such cooperation to come about in the first place, certain conditions must be present; to fail to sustain these conditions risks catastrophic consequences for large numbers of individuals.[390] Writers in the social contract tradition, particularly, have given attention to the conditions under which cooperation may be both possible and necessary.[391] These may be separated into objective and subjective circumstances.[392]

3.7 The objective circumstances are those of 'moderate scarcity' of resources, where goods are not so abundant that cooperation is superfluous, but not so scarce that interactions deteriorate into violent conflict. The subjective circumstances are that individuals have interests that are diverse and potentially conflicting (e.g., in competition for resources) but which can be voluntarily regulated or held in abeyance in accordance with recognised

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[387] See: FAO (2015) *The economic lives of smallholder farmers: an analysis based on household data from nine countries*, available at: http://www.fao.org/3/a-i5251e.pdf.

[388] A number of agrarian movements have arisen in response to globalisation; see: Borras Jr SM (2010) The politics of transnational agrarian movements *Development and Change* **41(5)**: 771-803.

[389] Comparative advantage and specialisation (of labour and other factors of production) are the basis of all trade, be it local or global, and are therefore inherent in any sort of market economy. However, there is also no doubt that the associated activities can give rise to 'negative outcomes' due to 'market failure'. Hence the ideal role of government is both to correct 'market failures' and to deliver on equity considerations such as are the focus of this chapter – although there is also scope for 'government failure' associated with these actions, too.

[390] Cf. the 'biotechnology wager' in: Nuffield Council on Bioethics (2012) *Emerging biotechnologies: technology, choice and the public good*, available at: https://www.nuffieldbioethics.org/publications/emerging-biotechnologies, at chapter 1.

[391] Writers in the social contract tradition of political theory imagine the foundation of political society as a fictional agreement by which citizens agree to give up some measure of their natural freedom in exchange for a limitation on the freedom of others, thus allowing governed, peaceful coexistence; see, for example, John Rawls, in his (1971) *A theory of justice* (Oxford: OUP, 1973), who draws on the earlier account given by David Hume in his (1777) *An enquiry concerning the principles of morals* (Oxford: Clarendon Press, 1985).

[392] The objective / subjective distinction is Rawls's; see: (1971) *A theory of justice* (Oxford: Oxford University Press, 1973), pp126-7.

norms (so that they do not erupt continually into violence).[393] These are not merely theoretical considerations: there is evidence that many conflicts around the world are precipitated by food insecurity and famine.[394]

3.8 The food and farming system supports the fundamental interests of members of society and the integrity of society itself. It follows that societies have an interest in how the system is arranged and governed. In the majority of countries, the UK included, it is arranged principally by the market. This may well be expedient, given the system's complexity, although some external regulation is desirable, for example to ensure the safety of food products offered for sale.[395] Even in the most economically developed societies, however, there are individuals whose access to essential food through the market is precarious. Although commercial food and farming systems may be capable of producing sufficient food for all, state welfare or charitable intervention is sometimes required to ensure that it reaches all members of the population.[396] Furthermore, among the principal factors threatening the system's capacity to produce sufficient food are inefficiencies such as food waste, which are themselves, to a large extent, a consequence of the structure of commercial incentives.[397]

3.9 Many people depend on farmed animals to meet their basic needs. They include people who are unable, in practice, to access sufficient protein or nutrients through plants and who are therefore dependent on meat, fish, and dairy. Many are also employed in the sector and rely on it for their livelihood. As we noted above, the food and farming system is deeply embedded in society: it affects the lives of individuals and the integrity of society in many ways. The way the system as a whole is governed must take these relations into consideration or risk undermining the very foundations on which its continuation depends.[398] **A cardinal principle is therefore that the food and farming system should be arranged and governed so that it is able to meet the needs of those who depend on it.[399]**

Moral orientation

3.10 Underlying considerations of political economy are questions of moral orientation: of the values, principles, and norms according to which the systems of relations in a society are organised, governed, and evaluated. Philosophy has hitherto offered different approaches from which to build out ethical public policy, many of which lead to coinciding conclusions or, at least, similar prescriptions. Different views about the source and

393 Martha Nussbaum emphasises the importance of these 'circumstances of justice' for Rawls; see: Nussbaum M (2006) *Frontiers of justice: disability, nationality, species membership* (Cambridge, MA: Harvard University Press, 2007).

394 See: UN WFP (2011) *Occasional paper 24 - food insecurity and violent conflict: causes, consequences, and addressing the challenges*, available at: https://www.wfp.org/publications/occasional-paper-24-food-insecurity-and-violent-conflict-causes-consequences-and-addressing-. The history of Europe since the fourteenth century suggests that the major inhibitors of population increase are famine, disease, and war.

395 Sederasan S (2013) A review of supply chain complexity drivers *Computers & Industrial Engineering* **66(3)**: 533-40.

396 See: The Trussell Trust (2021) *Latest stats*, available at: https://www.trusselltrust.org/news-and-blog/latest-stats/. Eurostat data from 2018 indicate that 33 million Europeans cannot afford a 'quality meal' (including meat, chicken, fish or a vegetarian equivalent) every second day. See: European Commission (2020) *Food loss and waste prevention*, available at: https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy/food-loss-and-waste-prevention_en.

397 See, for example, Evans D, Campbell H, and Murcott A (eds) (2013) *Waste matters: new perspectives on food and society* (Hoboken, NJ: Wiley-Blackwell); and EU Fusions (2016) *Estimates of European food waste levels*, available at: https://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf.

398 It is, perhaps, so deeply embedded that it cannot be detached from the general question of how societies are organised. It is a problem for political sovereignty, then, that, given the extent of food chain globalisation, no developed society is fully in control of its own food system.

399 See Chapter 7 (Principle 1).

ground of moral obligations may be, for this reason, less important for practical purposes than questions about the content and scope of those obligations.[400]

Basic interests

3.11 A plausible place to start is that societies comprise members who have certain interests that matter to them, some of these in a very fundamental way. For example, each individual normally has an interest in avoiding the experience of pain. For the classical utilitarian philosopher, Jeremy Bentham, the capacity to experience pleasure and pain, and the preference for the one and aversion to the other, are the cornerstones of morality and foundational for all other interests.[401] The equality of all sentient beings before these 'two sovereign masters' (as Bentham described them) has been taken, by some, to imply that having a differential regard for the suffering of individual beings based on species membership alone should be rejected as a mere prejudice.[402]

3.12 Experiences of pleasure and pain are clearly linked to capacities that arise from and remain closely connected to physiology. However, pursuing pleasure and avoiding pain do not exhaust the inventory of morally relevant interests, nor are all other interests simply reducible to them.[403] For example, individuals may experience mental anguish when they find their earnest desires frustrated; most individuals usually have a preference to go on living and to secure future states of affairs, often in sophisticated ways. Although individuals sometimes have interests in outcomes of which we would not necessarily approve, it is nonetheless morally relevant that they have those interests.

3.13 Individuals come together in groups to secure their interests, entering into sets of relations which become stabilised through institutions and societies. For some political theorists, it is a useful foundation myth of political societies that they offer a response to a primordial 'state of nature' in which the coexistence of incompatible impulses and interests threaten many with destruction.[404] 'Nature' is presented as a state of disorder and strife in which the characteristic experience of a human life was, in the famous words of one seventeenth-century theorist, "solitary, poore, nasty, brutish, and short".[405] Such views of the foundation of civil society out of chaotic nature recapitulate the cosmogonies of ancient societies (e.g., Earth-diver myths, Norse and Greek mythology). There are equally, however, traditions in which the state of nature is imagined as pleasant and harmonious.[406]

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[400] See: Toulmin S (1981) The tyranny of principles *The Hastings Center Report* **11(6)**: 31-9.

[401] This is the case for philosophers, following Jeremy Bentham, of the hedonic utilitarian persuasion; see: Bentham J (1789) Introduction to the principles of morals and legislation, in *The collected works of Jeremy Bentham, Volume 1* (1970) Burns JH, and Hart HLA (Editors) (Oxford: Clarendon Press).

[402] Singer P (1975) *Animal liberation, towards an end to man's inhumanity to animals* (London: Jonathan Cape).

[403] In setting out her list of morally relevant 'capabilities', Martha Nussbaum argues that we should adopt a 'disjunctive approach' to their moral relevance: "if a creature has either the capacity for pleasure or pain *or* the capacity of [purposive] movement from place *or* the capacity for emotion and filiation *or* the capacity for reasoning…". She nevertheless affirms that all creatures who have these capabilities also have the capacity to feel pleasure and pain, whilst acknowledging the theoretical status of supernatural or fictional beings who do not, in this way leaving the question of the significance of embodiment hanging: Nussbaum M (2006) *Frontiers of justice: disability, nationality, species membership* (Cambridge, MA: Harvard University Press, 2007), at page 362.

[404] These include seventeenth and eighteenth century political philosophers such as Thomas Hobbes, John Locke, the Baron de Montesquieu, and Jean-Jacques Rousseau, as well as contemporary thinkers such as John Rawls and Robert Nozick.

[405] Hobbes T (1651) *Leviathan* (London: JM Dent & Sons Ltd, 1973).

[406] Rousseau, for example, or the prelapsarian Eden story of the Abrahamic religions; see also: Lovejoy AO (1958) *Essays in the history of ideas* (especially chapter XVI. "Nature" as norm in Tertullian, pp308-38) (Baltimore: Johns Hopkins University Press), available at: https://muse.jhu.edu/book/67837.

3.14 Of course, individuals are born into a society that pre-exists them without having to recapitulate this foundational move themselves.[407] But they remain bound to societies because many of the interests that they have are ones that can only be secured through involvement with others.[408] Their 'form of life' is a social one.[409] For such individuals, we can say that certain conditions are required for them to live a 'good life', one in which they can secure the legitimate interests that they have according to their form of life. These include not only basic physical needs such as health, nourishment, and bodily integrity, but also opportunities to develop and exercise other capacities, and to enjoy experiences related to them. We may call these 'basic interests'.

3.15 Some political theorists have sought to elaborate lists of basic interests (or, as they are sometimes called, 'capabilities').[410] These may include the opportunity to acquire and exercise knowledge, including knowledge of a natural language, to regulate one's life according to one's conception of the good, to associate with others, and to have one's interests respected by them. Despite differences in the number, nuance, and emphasis given to these basic interests, what these approaches have in common is a commitment to the idea that the requirements for living a good life are multidimensional and 'mutually supportive', and cannot be reduced to a single, fungible quantity of 'welfare' or 'happiness', or located on the continuum of pleasure and pain. Implicit in this kind of approach is the idea that there is a threshold condition for the satisfaction of each interest, below which an individual cannot live a good life.[411] Furthermore, it recognises that the features that are valuable about a life should not be traded off, one for another, but that each one needs to be secured for a good life to be lived.[412]

Basic justice

3.16 We take as our starting point the basic interests that comprise the possibility of living a good life and the requirements they entail from others, including (but not necessarily limited to) those with whom we live in a political state and members of the same historical generation. These are requirements to secure and protect basic interests (if necessary, by reforming or creating institutions) and not to undermine them. Securing them for the moral subjects, who depend on each other for this to be achieved, is a matter of justice. This is a fairly minimal model of justice and, it will be assumed, one that is relatively uncontroversial. We may call it 'basic justice'.

3.17 It is implicit in an approach that starts from basic interests that, in political societies, a core function of the state is to secure those interests for all members of society, particularly where they are threatened by others' expansive pursuit of their own interests

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[407] It is true that individuals are all born into a society that is not of their choosing but 'consent makes any one a member of any commonwealth' albeit in circumstances in which one's options to demur may be extremely limited; see: Locke's second *Treatise on civil government*, at Chapter 8.

[408] It is in this sense that the ancient Greek philosopher Aristotle characterises humans as the 'political animal' (*politikon zōon*), the animal whose nature finds fulfillment (*eudaimonia*) in the common life of the political society (*polis*). Aristotle, *Politics* (London: Penguin Classics, 1988), 1253a.

[409] Agamben G (1995) *Homo sacer, sovereign power and bare life*, translated by Heller-Roazen D (Stanford CA: Stanford University Press, 1998).

[410] See, for example, Amartya Sen in relation to economics (see his (1992) *Inequality reexamined* (Oxford: Clarendon Press)) and Martha Nussbaum in relation to political theory (see her (2000) *Women and human development* (Cambridge: Cambridge University Press)).

[411] In the discourse on capabilities, there is some debate about whether full justice requires that everyone has equal scope to exercise their full set of capabilities or simply that no-one falls below the threshold for a decent life. The first position is broadly that of Sen (e.g., in *The idea of justice*), the second that of Nussbaum (e.g., in *Frontiers of justice*).

[412] Nussbaum M (2006) *Frontiers of justice: disability, nationality, species membership* (Cambridge, MA: Harvard University Press).

or by overweening emanations of state power.[413] It is recognised, however, that how those interests are specified and interpreted in any given social context will be subject to necessary and possibly indefinite debate. This is not so much a weakness in the normative fabric of the society as a recognition of the refreshing importance of public ethical and political discourse.

3.18 There are at least two reasons, arising from considerations of basic justice, for the state to intervene in the food and farming system specifically. The first is where the contribution of the food and farming system is necessary, given the circumstances, to secure a basic interest and the system is failing to do so. The archetype of this situation is food insecurity: where the system does not deliver sufficient food to feed the population. A second reason for state intervention is where the market-based organisation of the existing system generates externalities that actually stand in the way of securing basic interests, either at present (e.g., where it is responsible for spreading disease) or in the future (e.g., where its practices can be shown to lead to environmental degradation). A third reason, widely endorsed though also debated, is that the state has a responsibility to concern itself to some degree with the interests of non-human animals that are involved in many farming systems.

Global justice

3.19 People have basic interests wherever they happen to be in the world (and regardless of the historical generation to which they belong). Actions in some nations can have significant ramifications (positive and negative) for whether those interests are met in other parts of the world. It is therefore possible for members of one state to have duties of justice to those in other states. This may be argued for in different ways, for example on the basis that they are in the kind of cooperative and interdependent relationship that gives rise to such duties globally, or on the basis of shared characteristic or nature, which gives them a fundamental claim on one another. The idea of having obligations to those beyond our immediate society is less controversial with regard to the limited idea of 'basic justice' set out above (requiring that everyone's basic interests or capabilities are secured), than if justice is taken to require full distributional equality. The idea is simply that we owe it to our fellows to create institutions, where necessary, that protect their basic interests.[414] Even those denying that duties of justice extend beyond the state, for example, would generally allow for some basic duties to prevent serious harm to others, wherever they may be.[415] So even though we may describe it as 'justice' (rather than 'morality') it is a model of justice so pared down as to correspond to a minimal collectivised account of our core moral duties to one another.

Anthropocentrism and sentient animals

3.20 It is certain that many non-human animals display behaviours that can be described as attraction or aversion. However, distinguishing responses to experiences from mere reflexes, even very complex and highly mediated ones, and describing the content of these experiences, especially for beings that are fundamentally different from ourselves,

[413] There is room for discussion about what this requires, which is expressed in differences of emphasis and terminology. For example, Wolff and de-Shalit take the view that it is the duty of the state not only to secure freedoms but to ensure that they are realised, and prefer to speak in terms of 'functionings' (broadly, realised capabilities, which can give rise to capabilities for new functionings); see: Wolff J, and de-Shalit A (2007) *Disadvantage* (Oxford: Oxford University Press).

[414] Shue H (1980) *Basic rights, subsistence, affluence, and U.S. foreign policy* (Princeton NJ: Princeton University Press).

[415] These basic duties are often kept separate by calling them 'duties of humanity' but some key work in global justice has put pressure on this distinction by pointing to duties of individuals to work together to reform institutions which fail to protect such interests / rights. That is, rather than only states having 'duties of justice' and individuals 'duties of humanity', individuals can have duties of justice including to promote the reform of institutions or creation of just institutions.

opens up a large area for scientific and philosophical inquiry.[416] This area is the field of research into animal sentience and consciousness. Recent scholarship in this field suggests that many non-human animals are capable of experiences that are much more complex, and behaviours that are much more sophisticated, than were hitherto imagined. Many of these behaviours have the function of modifying the animal's environment and, thus, their experiences of it. The repertoire of experiences and interactions of some non-human animals, including many of the common domesticated species, suggests a complex internal life involving interests that are irreducible to attraction–aversion models.

Box 3.1: Animal sentience and consciousness

In the course of preparing this report we carried out a review of trends and the current state of research on animal sentience (understood as the capacity for consciously experiencing positive and negative affective states, such as joy, pleasure, desire, pain, and fear) and consciousness (understood as including some or all of the following: the subjective or phenomenological experience of the world and one's body, the capacity to experience a rich range of mental states, have an awareness of internal and external stimuli, and possess a sense of self, including abilities such as self-recognition, episodic memory, metacognition, and mindreading). The findings of our are summarised as follows.

- Animal sentience and consciousness are capacities that feature prominently in debates concerning the moral status of non-human animals. These aspects of the mental lives of animals offer a basis for establishing their interests and have moral relevance for assessing the mental and physical welfare implications of the human treatment of animals.
- Questions about sentience and consciousness have historically been approached through philosophical inquiry and some scientific investigation. A significant body of past research has been shaped by an interest in the study of negative emotions. The emergence of positive psychology and affective neuroscience demonstrate a shift in focus, beyond pain and suffering, towards positive states and experiences that matter to animals, and contribute to their quality of life and flourishing.
- Since there is no single test for establishing sentience or consciousness in animals, the study of these capacities is faced with several unresolved challenges on issues of definition, scope, methods of study, and interpretation of findings, as well as on the origins and distribution of consciousness across species.
- The field of animal sentience involves an emerging interdisciplinary community of researchers from different disciplines (such as comparative psychology, behavioural studies, neuroscience, animal welfare science, and philosophy); it is focused on developing the behavioural, cognitive, and neuronal criteria that could be used to attribute conscious states to animals.
- There is a growing sense that for consciousness to exist in animals, it does not need to have an equivalent form to consciousness as it is found in humans. Emerging research is moving away from assigning the same consciousness criteria to animals as are observed in humans and promoting an understanding of animal minds informed by an exploration of the distinctive ranges of affective states that animals enjoy. Research directions have shifted from asking whether any non-human animals are conscious to

[416] See: Carruthers P (1986) *Introducing persons: theories and arguments in the philosophy of mind* (London: Croom Helm).

questions of which animals it is meaningful to describe as conscious and what form their conscious experiences take.

- Many animals display cognitive and emotional complexity, as well as the propensity for positive and negative affective states. There is a growing body of research on the emotions, cognition, social interaction, and time perception across animals including cows, sheep, pigs, and chickens, as well as some invertebrates.
- New approaches proposed for characterising sentience and consciousness in animals include the development of multidimensional scales or 'distinctive profile scales' of consciousness instead of a unidimensional sliding scale for different species, on which some species are more or less conscious than others.
- There is a growing consensus among the scientific research community, in the light of conceptual and methodological developments, that animals possess a wide range of abilities for complex thinking and social behaviours, and experience feelings which matter to them (birds, fish, and other aquatic creatures included). This raises the question of what experiences comprise a 'good life', and to what extent different animals have the capacity for these experiences.

* The full review can be read at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering

3.21 Research in the field of animal sentience and consciousness gives rise to increased scepticism about the kind of normative conclusions that may be reached from an anthropocentric perspective, one that makes similarity to human experience the yardstick for all moral consideration. For example, we heard during one of our factfinding meetings how, when people habitually exploit particular animals, they tend to describe those animals as less able and less important than other animals. Thus, people have defended the idea that dogs, which are kept as pets, are more intelligent than farmed animals although farmed animals such as cattle, sheep, pigs, and goats have been found to demonstrate higher levels of cognitive function than dogs in some respects. Comparative studies on the relative intelligence of different animals show a complex picture. For example, while many primates demonstrate complex cognitive functions, there are some things that they cannot do that other species, such as certain types of fish, can do. There are many activities at which corvids and parrots are better than some primates. Current work in animal research shows that mammals, birds, and fish can all master complex behaviour and many have much higher levels of cognitive ability than previously thought.[417]

3.22 The anthropocentric perspective supports a kind of cognitive dissonance that characterises industrial de-domestication, which effectively puts 'domestic' animals (including companion animals) into a different moral category from 'industrial' animals.[418] It refocuses moral obligations from individual animals to animals homogenised as fungible commodities, and from attention to the lives of each animal to the need to meet technical criteria for welfare systematically. As Peter Roberts, the founder of Compassion

[417] Factfinding meeting on the ethical treatment of animals, 17 July 2019.

[418] Some authors point out that addressing this 'internal' inconsistency has more prospect of political traction than a frontal attack on 'external' inconsistency between treatment of humans and non-human animals (for example, through marginal case arguments); see: O'Sullivan S (2016) Animals and the politics of equity, in *The political turn in animal ethics*, Garner R, and O'Sullivan S (Editors) (London: Rowman & Littlefield). The distinction between companion animals and animals in the wild is a theme of Donaldson S, and Kymlicka W (2011) *Zoopolis: a political theory of animal rights* (Oxford: Oxford University Press).

in World Farming, has said: "Factory farming begins when we lose sight of each animal as an individual."[419]

Box 3.2: Animal welfare

Five freedoms

An influential way of understanding animal welfare has been in relation to what are known as the 'five freedoms'. The idea of the freedoms can be traced back, at least, to a report from the mid-1960s by a committee of inquiry commissioned to investigate the condition of animals in intensive husbandry systems in the UK.[420] The idea was refined by the Farm Animal Welfare Council (FAWC, which was succeeded by the Farm Animal Welfare Committee and later the current Animal Welfare Committee) in the late 1970s.[421] The freedoms were to inform the drafting of the UK's Animal Welfare Act 2006 and associated regulatory schemes.[422] They also underpin European Union and international legislation.[423] A canonical statement of the five freedoms includes both the conditions that the animal should be free from and the specific requirement that each freedom places on a person responsible for the animal.

1. **Freedom from hunger or thirst**, by ready access to freshwater and a diet to maintain full health and vigour.
2. **Freedom from discomfort**, by providing an appropriate environment including shelter and a comfortable resting area.
3. **Freedom from pain, injury, or disease**, by prevention or rapid diagnosis and treatment.
4. **Freedom to express (most) normal behaviour**, by providing sufficient space, proper facilities, and company of the animal's own kind.
5. **Freedom from fear and distress**, by ensuring conditions and treatment which avoid mental suffering.

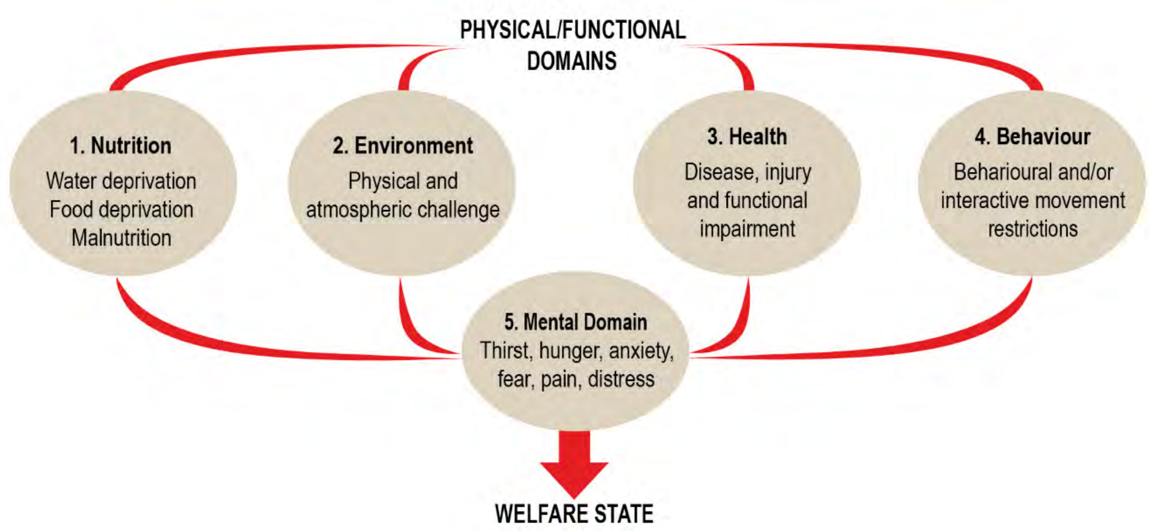
While recognising that effective regulation requires the stipulation of minimum legal standards, the FAWC, which promulgated the idea of the five freedoms in the UK, proposed that the minimum should be defined in terms of "an animal's quality of life over its lifetime on the farm, during transport, at gatherings, and at the abattoir, including the manner of its death".[424] The Council stressed that, although animals may live among others in herds and flocks, "to be concerned about welfare is to be concerned about the quality of life of individual animals".[425] They proposed classifying quality of life according to three descriptions: a life not worth living, a life worth living, and a good life.

Five domains

Although the structure of the five freedoms has provided an enduring conceptual framework for thinking about the factors relevant to animal welfare, a limitation of the model is the focus it places on negative freedoms and the emphasis on removing factors

[419] Peter Stevenson OBE, personal communication, 11 December 2020.
[420] Report of the Technical Committee to enquire into the welfare of animals kept under intensive livestock husbandry systems Cmnd. 2836, 3 December 3 1965 (London: Her Majesty's Stationery Office) known as 'The Brambell report' after the inquiry Chair, Professor Francis W Rogers Brambell.
[421] Farm Animal Welfare Council revision of the welfare codes (1979).
[422] See: Article 9(2) of the Animal Welfare Act 2006, available at: https://www.legislation.gov.uk/ukpga/2006/45/section/9. See also: McCulloch SP (2013) A critique of FAWC's five freedoms as a framework for the analysis of animal welfare *Journal of Agricultural and Environmental Ethics* **26**: 959-75.
[423] See: European Commission (2021) *Animal welfare*, available at: https://ec.europa.eu/food/animals/animal-welfare_en.
[424] Farm Animal Welfare Council (2009) *Farm animal welfare in Great Britain: past, present and future*, available at: https://www.gov.uk/government/publications/fawc-report-on-farm-animal-welfare-in-great-britain-past-present-and-future, at page iii.
[425] Ibid., at page 12.

that have an adverse impact on welfare rather than the need to enable positive experiences.[426] This has led to the elaboration of further models, within the same basic five-part framework, that link the freedoms and their associated provisions with welfare aims, and placing them within ‘five domains’ in order enable systematic identification and assessment of the instances in which welfare is compromised.[427] The advantage of the five domains approach, developed in the 1990s, is to allow a distinction to be drawn between the factors that affect animal welfare and the experience of the animal that results from these factors. The model now stresses the importance of the opportunity for animals to have positive experiences, rather than simply the need to remove factors that have a negative impact, and shows how conditions contribute to a positive welfare experience.



Source: Mellor DJ, Beausoleil NJ, Littlewood KE et al. (2020)[428]

Since it was originally proposed, the five domains model has been regularly discussed and updated, drawing on research with animals, most recently to place greater emphasis on the importance of human–animal interactions.[429]

Assessing welfare

Animal sentience and welfare are relatively rapidly developing areas of research. Recent scholarship has stressed the importance of providing animals with opportunities to have positive experiences and rewarding behaviours. These may include “environment-focused exploration and food acquisition activities as well as animal-to-animal interactive activities, all of which can generate various forms of comfort, pleasure, interest, confidence, and a sense of control.”[430] This means that suitable, stimulus-rich, and safe environmental conditions and sympathetic treatment are necessary, as are opportunities to associate with ‘congenial others’. The importance of being able to engage in

[426] Mellor DJ, and Beausoleil NJ (2015) Extending the ‘five domains’ model for animal welfare assessment to incorporate positive welfare states *Animal Welfare* **24(3)**: 241-53.

[427] Mellor DJ, and Reid CSW (1994) Concepts of animal well-being and predicting the impact of procedures on experimental animals, in *Improving the well-being of animals in the research environment*, Baker RM, Jenkin G, and Mellor DJ (Editors) (Glen Osmond, South Australia: Australian and New Zealand Council for the Care of Animals in Research and Teaching); Mellor DJ (2016) Moving beyond the “five freedoms” by updating the “five provisions” and introducing aligned “animal welfare aims” *Animals* **6(10)**: 59; and Mellor DJ (2017) Operational details of the five domains model and its key applications to the assessment and management of animal welfare *Animals* **7(8)**: 60.

[428] Mellor DJ, Beausoleil NJ, Littlewood KE *et al.* (2020) The 2020 five domains model: including human–animal interactions in assessments of animal welfare *Animals* **10(10)**:1870.

[429] Ibid.

[430] Mellor DJ (2016) Updating animal welfare thinking: moving beyond the “five freedoms” towards “a life worth living” *Animals* **6(3)**: 21.

exploration, investigation, problem solving, and play for animals' physical and mental wellbeing is contrasted with the effect of monotonous, predictable environments that "may lead to apathy and boredom, and prevent animals from experiencing a positive quality of life".[431] There still remains, however, an imbalance of research into quantitative methods of assessment of positive states compared with assessment of negative states.

Methods to assess welfare that have been proposed include behavioural measures such as locomotor play, facial expression and posture, acoustic signals, and laterality (Davidson's laterality-valence hypothesis proposed that mammals process positive and negative experiences in the left and right cerebral hemispheres, respectively) and the development of automated approaches to observation to reduce subjectivity and to support continuous measurement in a farm setting.[432] Notwithstanding the difficulty in defining reliable measures and observing them, the recognition of the importance of positive experiences has increasingly been taken up and embedded more widely.

Extending justice to non-human animals

3.23 Many non-human animals, like humans, appear to have complex experiences and behaviours that betoken fundamental interests. These may vary from species to species and from animal to animal, but they allow us to form a plausible idea of what it means for their lives to go well or to go badly. From this idea there is a further, normative step we may take to conclude that whether the lives of non-human animals go well or badly matters morally and that this moral concern should guide our treatment of them, just as it should our treatment of other humans.

3.24 Food and farming systems are artefacts of human agency (although not necessarily of deliberate or concerted human planning). Even if these systems could be described as serving some interests of non-human animals (e.g., by securing supplies of fodder or providing protection from non-human predators), and even if some animals' ancestors may have entered into them without human coercion (e.g., following the commensal pathway to domestication), it would be a stretch too far to describe animals as moral participants.[433] While the systems may have been shaped around the features of the animals involved, it is implausible to treat non-human animals as having cooperated actively in this shaping.

3.25 We can draw a helpful distinction here between being a moral agent and having moral status.[434] Moral agents must be capable of acting freely in accordance with moral values or obligations. Human beings, generally, are moral agents.[435] The notion of moral status gives shape to the common intuition that there is something that matters about certain kinds of being, such that treating them in some ways is right or good and treating them

[431] Špinka M, and Wemelsfelder F (2011) Environmental challenge and animal agency *Animal Welfare* **2**: 27-44.

[432] Whittaker AL, and Latimer-Marsh LE (2019) The role of behavioural assessment in determining 'positive' affective states in animals *CAB Reviews Perspectives in Agriculture Veterinary Science Nutrition and Natural Resources* **14(10)**.

[433] On domestication pathways, see: Zeder MA (2012) The domestication of animals *Journal of Anthropological Research* **68(2)**: 161-90.

[434] Warren MA (1997) *Moral status: obligations to persons and other living things* (New York: Oxford University Press).

[435] While the capacity for moral action is coincidental with humans, it is not necessarily essential to them. Some humans lack it: for example, babies, in whom the capacity is undeveloped; or adult sociopaths (people affected by antisocial personality disorder), in whom its development is suppressed.

in other ways is wrong or bad, and that different beings matter differently in these respects.[436]

Justice, and the margins of justice

3.26 It is a common criticism of some status-based approaches to ethical questions involving animals that they simply extend human ethical categories to animals rather than trying to conceive a morality that already includes other species.[437] Taking humans and domesticated animals as products of a dynamic field of biological and social relations allows us to relate moral status to the capacities that sentient beings have for certain kinds of experiences that are meaningful to them, rather than to their degrees of similarity or difference from human experience. This allows us to shift the focus of an ethics of animal husbandry from the hierarchical, ontological distinction between humans and non-human animals onto a dynamic and inclusive field of relations produced and dissolved by agency and circumstance. It involves not simply asking how animals should be treated in particular situations (e.g., whether instrumentalising animals is right or wrong) or how to resolve cases in which morally considerable interests conflict (e.g., assessing how many pig lives may be sacrificed to save or extend one human life), but instead asking how to arrange institutions and practices to secure and promote justice among beings with moral status.[438]

3.27 To require that our institutions do justice to farmed animals, it is not necessary that those animals be participants in the community of moral agents; it is sufficient to acknowledge that they have basic interests and that the opportunity to pursue these interests is dependent on systems that are put in place by humans and are under human control.[439] While humans depend on food and farming systems to sustain them and, in this way, to enable them to exercise social and political freedoms, the lives of farmed animals are almost entirely encompassed by the farming systems within which they live. If it matters that animal lives go well, if they have moral status, this may be thought to entail certain one-sided responsibilities on human beings to secure the conditions needed for this. **It should therefore be a principle of the organisation and governance of food and farming systems that they should be organised and governed to respect the basic interests of those whose lives they affect, giving them the opportunity to live their lives in a state of safety, security, and wellbeing, with access to the experiences that constitute a good life, according to their form of life**.[440]

3.28 These responsibilities may be qualified by supervening considerations, but such qualifications should be regarded as exceptional. However, notwithstanding that they may be set aside in certain situations, these responsibilities continue to form part of a subsisting system of norms (a 'moral fabric') for political society. In some cases, they

[436] Even if we entertain epistemological scepticism about animal sentience it seems sensible to adopt a prudential approach and suppose it, since the alternative would be to run the risk of an avoidable moral harm. See Jonathan Birch's submission to the working group's call for evidence: "We will have no guarantee that these animals are non-sentient, and reason to believe that, if sentient, they will be living lives that are appallingly circumscribed and filled with terrible suffering. So, we should err on the side of caution and not produce such animals."

[437] In their editors' introduction to their (2015) *Animal ethics and philosophy: questioning the orthodoxy* (London: Rowman and Littlefield), John Hadley and Elisa Aaltola critique 'moral extensionism': "the extension of existing moral and political theory across the species barrier to nonhuman animals", at page 2.

[438] Cochrane A, Garner R, and O'Sullivan S (2018) Animal ethics and the political *Critical Review of International Social and Political Philosophy* **21(2)**: 261-77.

[439] Donaldson and Kymlicka claim that this derives from co-citizenship and a degree of moral agency that has been overlooked by anthropomorphic constructions of moral agency; see: Donaldson S, and Kymlicka W (2011) *Zoopolis, a political theory of animal rights* (Oxford: Oxford University Press). Garner, by contrast, argues that animals deserve justice as members of the moral community, without the necessity for moral agency; see: Garner R (2013) *A theory of justice for animals* (Oxford: Oxford University Press).

[440] See Chapter 7 (Principle 2).

may be given legal form and force as obligations or duties falling on a moral agent in specific situations (as a 'person responsible for an animal', for example).[441] The content of responsibilities will vary in relation to the capacities of the animal concerned, but also according to the relations created by the institutions to which they are subject.[442] Thus, while justice entails positive responsibilities to non-human animals that are subject to human farming systems, humans may have only negative responsibilities to animals in the wild, such as not interfering with the conditions that enable them to live good lives, for example by contributing to habitat destruction or climate change.[443]

Three problems of doing justice

3.29 The development of biotechnologies brings into focus a problem that is faced by a food and farming system that aims to do justice to animals, one that was only dimly apparent in relation to selective breeding. A first dimension of this problem is that of how to arrange the system to do justice to a given set of beings: for example, the set of farmed animals that currently exist in the farming system. However, since the parameters of the system can change through time due to human action there is a second, longitudinal dimension, namely, how to take into account the interests of different cohorts of animals that could exist if one were to breed them in future.[444] To these 'same number' and 'different number' problems must be added 'different kind' problems that arise because of the theoretical potential of biotechnologies to shape the future capacities of the future animals concerned. With such a possibility, empirical lines of reasoning enter a reflexive circularity.

3.30 Such speculation opens up a range of troubling problems, albeit presently confined to the domain of science fiction. If the animal's capacities may be determined by biology and environment, and biotechnologies allow control to be exercised over these factors freely, it could, in theory, be possible to manipulate those capacities so as to ablate precisely what seems morally objectionable. One example that has been widely discussed is the possibility of using biotechnology to remove the capacity of an animal to experience pain, regardless of its circumstances.[445] But this is only to deal with the most elemental of the morally relevant experiences.[446] The logical extremity of hyperdomestication is the one emblematised by the 'dish of the day' at Milliways, the fictional 'restaurant at the end of the universe': an animal that actually wants to be eaten.[447]

[441] Section 3 of the Animal Welfare Act 2006, available at: https://www.legislation.gov.uk/ukpga/2006/45/section/3.

[442] Donaldson and Kymlicka draw a strong distinction in terms of citizenship for domestic animals; see: Donaldson S, and Kymlicka W (2011) *Zoopolis, a political theory of animal rights* (Oxford: Oxford University Press).

[443] See, for example, Cripps E (2010) Saving the polar bear, saving the world: can the capabilities approach do justice to humans, animals and ecosystems? *Res Publica* **16**: 1-22; and Palmer C (2019) The laissez-faire view: why we're not normally required to assist wild animals, in *The Routledge Handbook of Animal Ethics*, Fischer R (Editor) (New York: Routledge).

[444] A purely hedonic approach, for example, might lead to the 'repugnant conclusion' that it is preferable or, at any rate, reasonable to increase the number of beings to the point at which their lives, however bad they may be, still represent a marginal, positive net gain in welfare; see: Parfit D (1984) *Reasons and persons* (Oxford: Clarendon Press, 1987).

[445] Dr Jonathan Birch, responding to the working group's call for evidence.

[446] See the problem identified in Chapter 4, of breeding animals that are resistant to the adverse health effects of poor welfare conditions.

[447] Douglas Adams, the writer of *The hitchhiker's guide to the galaxy* radio series and novels, imagined that by the time the universe ended it would eventually have been decided "to cut through the whole tangled problem and breed an animal that actually wanted to be eaten and was capable of saying so clearly and distinctly. And here I am." The absurdity of this situation is thematised in the comic dialogue between the animal and the everyman character, Arthur Dent, and the impatient dismissal of Dent's moral scruples by his more worldly and sophisticated dining companions; see: Adams D (1980) *The restaurant at the end of the universe* (London: Pan Books Ltd.), at page 93.

Intervening in 'nature'

3.31 What is at stake here is the question of a theoretical manipulation, not just of the embodiment, but of the nature of the animal itself. Human interventions in animal reproduction might be thought to do this because they involve deliberate fixation of traits that increase the divergence of instances of that animal from current species norms, or that alter the norm for that kind of animal. The notion that each animal belongs to a particular kind, and that all kinds exist in nature (plenitude) is found at the origin of Western philosophical traditions and underwrites the 'great chain of being' of medieval Christianity that was influential in early modern thought.[448] The eighteenth century proto-scientific taxonomy of Linnaeus, informed by scholastic theories of definition, maintained this basic plan of classification. The underlying belief in the rigidity of natural kinds was shaken by the ascendency of evolutionary theory, notably following the work of Charles Darwin, popularised in the nineteenth century.[449]

3.32 Because it contributes to an animal's phenotype and therefore its physiological capacities, changes to the genome may potentially result in changes in physiological functioning. In some lines of thought the idea of the genome seems very close to – almost indiscernible from – the idea of the essence of a kind.[450] The extent to which the 'kind' of animal and its inherent capacities, interests, and behaviours result from genetic mutation and reassortment, through reproduction and selection, and in response to environmental pressures, problematises the understanding of the genome as the stable source of the organism's species nature.[451] This presents a dilemma: on one hand, if there is no more to the nature of the organism than that which is explored by biological science, and this turns out to be plastic to an arbitrary degree, then biology may disturb the normative order: every alteration can be accepted as 'natural'.[452] If the nature of an animal is, on the other hand, something metaphysical rather than physical, then it can be impervious to any distortion brought about by changes to the genome. (This is an idea that survives in religious ideas of the immortal soul and the secular idea of inalienable, imprescriptible, and inviolable dignity.)

3.33 For some people, not only the use of biotechnology but any process of domestication or selective breeding is objectionable. They may object to this because they believe that interfering with an animal for the benefit of humans constitutes something like a violation of the animal's inherent dignity. While 'full abolitionists' argue for an immediate end to the keeping of domestic animals and a separation between the world of humans and that of the remaining feral and wild animals, others accept the persistence of multi-species communities that involve both humans and non-human animals but only in ways that do not instrumentalise animals. (In effect, they hold that only the commensal pathway is a

[448] Lovejoy AO (1936) *The great chain of being: a study of the history of an idea* (Cambridge MA: Harvard University Press).

[449] Jean-Baptiste Pierre Antoine de Monet, chevalier de Lamarck (1809) *Philosophie zoologique*, cited in Gould SJ (2002) *The structure of evolutionary theory* (Cambridge MA: Harvard University Press); Darwin C (1859) *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life* (London: John Murray).

[450] This may be called 'genetic essentialism'.

[451] The extent to which the phenotype may be thought to be caused by genetic factors may be called 'genetic determinism'. For a critical explanation of genetic determinism and genetic essentialism, see: Barnes B, and Dupré J (2008) *Genomes and what to make of them* (Chicago and London: University of Chicago Press).

[452] While scientists rarely use the adjective 'natural' descriptively, it is a common token in the public discourse on science and technology. Although its significance may be disputed, ideas of the natural are often used to organise a range of concerns about biotechnologies, with the natural (usually) being valued positively. A number of these surfaced in responses to our call for evidence. See also: Nuffield Council on Bioethics (2015) *(un)natural: ideas about naturalness in public and political debates about science, technology and medicine*, available at: https://www.nuffieldbioethics.org/publications/naturalness.

legitimate route to domestication and only accept interspecies relations that continue to offer mutual benefit).[453]

3.34 We do not take this view. We acknowledge the long co-evolution of food and farming systems and the humans and non-human animals caught up in them, as complex products of biological, historical, cultural, and environmental factors. To acknowledge this process is not to valorise it but to recognise that while other worlds may have been possible, this one has become the inescapable circumstance in which decisions that shape the future must be made. It is to recognise that these circumstances represent a more or less successful, more or less durable solution to the problem of 'sufficient scarcity' that has made possible the lives of those who exist today, and the one on which they depend to have a life in the future. Most importantly, it is to recognise the possibility of agency, and the challenge of exercising it in a globally integrated food and farming system. It matters that such a system provides the conditions for beings that are subject to it to have a good life, but it also matters that those beings' inherent capabilities required to have good life are not compromised.

3.35 Evolved biological adaptations have resulted from preferential selections for conformity with farming systems (e.g., increased docility) although, as we noted above, the non-human animals involved were co-opted, rather than cooperative, in this. The history of domestication, as we have presented it, involves both biological and social adaptations, evolutions in animal breeds and developments (sometimes revolutionary) of the institutions and practices in which they have been enrolled by humans.

3.36 In the light of both the increasing power of emerging biotechnologies and the increasing dependence of populations on entrenched farming systems, it cannot easily be assumed that systems of social relations, institutions, and practices are necessarily more tractable than biology, or necessarily offer a better prospect of successfully securing justice (or of doing so without significant collateral harms). The implication of this is that it cannot be assumed that the preferred route to securing basic interests is necessarily first to adapt the food and farming system and only if no other reasonable course is available, to resort to biotechnology. On the contrary, the question of which approach should be preferred or, more likely, the extent to which each approach should be pursued, must be examined without prejudice, therefore opening up a new space of genuine ethical and political debate.

Conclusion

3.37 In this chapter, we have laid the ground for our approach to the ethical governance of food and farming systems, moving away from an anthropocentric view of what is ethically significant to one that is based on inherent and situational capacities produced and concretised in sentient beings through biological, historical, social, and cultural evolutions. Even if some claim to be sceptical about the qualitative content of animal experiences (or even, for that matter, about the content of other humans' experiences)

[453] Factfinding meeting on the ethical treatment of animals, 17 July 2019. See also: Chiesa LE (2016) Animal rights unraveled: why abolitionism collapses into welfarism and what it means for animal ethics *Georgetown Environmental Law Review* **28(557)**: 557-87. Some scholars see animals as potential participants in democratic human-animal communities; see: Meijer E (2013) Political communication with animals *Humanimalia: A Journal of Human/animal Interface Studies* **5(1)**: 28-52; Meijer E (2019) *When animals speak: toward an interspecies democracy* (New York: New York University Press). See also: Garner R (2013) *A theory of justice for animals* (Oxford: Oxford University Press).

we have reason to think that individual animals have interests that carry significant moral weight.

3.38 Whereas securing the basic interests of farmed animals depends almost entirely on farming systems, moral agents have further capacities and interests, for example as members of political societies, which may entail further moral claims and obligations. It is, however, inappropriate to treat farming systems as entirely distinct from (rather than embedded within) broader social systems and ways of life. Recognising this embeddedness is essential to make visible how farming systems externalise many of their social costs, but also to explain how social conditions can entrench practices in ways that may be difficult and slow to alter, or where it may court catastrophe to attempt to do so.

3.39 A further twist, which biotechnology makes starkly apparent, comes when we consider the evolution of the sets of relations that constitute the food and farming system dynamically, through time, and its impact on the generations of beings involved. It is not merely that farmed animals are brought into existence individually by breeding, but that their particular form of embodiment is brought into existence through breeding. These effects, which until the modern period were probably detectable only over long evolutionary timescales, have been brought under partial control by scientific breeding and significantly accelerated by biotechnology. In the response to the societal challenges facing food and farming systems, biotechnology opens up a whole new range of possibilities.[454]

3.40 Rather than setting humans and sentient, non-human animals in distinct moral universes, we place them together as morally considerable beings whose basic interests in having opportunities to live a good life, according to their form of life, are significantly affected by the food and farming systems on which, in different ways, they depend. This coexistence makes the relations and asymmetries of power relevant in the moral analysis rather than simply being foundational assumptions, entailing claims and responsibilities that arise as questions of justice.

[454] A concern of major significance for many participants in the public dialogue we commissioned in the course of this inquiry was that applying genome editing to farmed animals would lead to them being seen even more as a product or commodity and less as sentient creatures, exacerbating the cognitive disconnection between people and the food they consume; see: Nuffield Council on Bioethics (2021) *Online public dialogue on genome editing in farmed animals, research by Basis Social on behalf of the Nuffield Council on Bioethics*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/public-dialogue-on-genome-editing-and-farmed-animals.

Chapter 4

Prospective breeding interventions

Chapter 4 – Prospective breeding interventions

Chapter overview

This chapter describes a number of prospective innovations in breeding technology that have been proposed. Many of these are intended to address challenges to the food and farming system identified in Chapter 2.

Surgical mutilations (such as de-horning, tail docking, and castration) are common in many farming systems. As mutilations are harmful to animals, breeding animals that have the desired phenotype inherently has been proposed as a preferable alternative. In some cases, this may have merit, but in other cases it may serve to disguise poor husbandry practices.

Genetic adaptations for disease resistance or tolerance for adverse environmental conditions (e.g., heat) may also benefit farmers and farmed animals both in large scale intensive and smaller extensive systems, although they will need to be weighed in each case against alternatives such as vaccination. However, enhancing disease resistance would be morally unacceptable where it involves adapting animals purely so that they may endure conditions of low welfare without manifesting any associated adverse health effects.

Research in new breeding technologies is not currently focussed on traditional ‘production traits’, many of which have complex underlying genetic bases. The negative outcomes of the historical pursuit of increased yield through selective breeding should serve as a warning about outcomes that future breeding practices must avoid.

New breeding technologies may contribute to addressing negative environmental impacts of farming, such as greenhouse gas emissions and reduction of biodiversity, but to address environmental challenges effectively substantial changes to food and farming systems, probably including a reduction in overall demand for animal products, are needed.

While genome editing and other prospective breeding technologies allow step changes in genetic gain in some characteristics, they cannot achieve the same gains in all dimensions. Their potential must be assessed in each case, both in relation to the direct effects on people and animals, and the effects on the configuration of food and farming systems.

Key points

- Farmed animals should not be bred to enhance traits merely so that they may better endure conditions of poor welfare.
- Farmed animals should not be bred in ways that diminish their inherent capacities to enjoy experiences that constitute a good life.
- Regulation of farmed animal breeding should consider the effects on the organisation of the food and farming system and on society more generally and, in particular, the need to control the potential of innovation to support damaging farming practices.

Introduction

4.1 In Chapter 2, we set out a number of challenges facing the food and farming system globally. Assessments of the gravity and urgency of the challenges inevitably vary and disagreements about the most appropriate way to address them continue. What is certain is that no single kind of intervention offers a unique or sufficient response to these challenges: there is no 'magic bullet'. While technological innovations may affect certain conditions, they can only be part of any response to the global situation. In this chapter, we consider the potential contribution that prospective breeding technologies may make to the food and farming system and the lives of farmed animals within it. The principal contribution of breeding technologies is to enable breeders to make 'genetic gains' in their breeding animals. These may be in a number of dimensions; they may accelerate existing trajectories of development or enable novel combinations of traits; they may increase productivity of farming but they may, equally, incur collateral and, perhaps, unaccounted-for costs.

4.2 Applications of genome editing have been proposed in a number of domesticated animals and for a range of purposes.[455] They are organised here in relation to the primary aim of the application, for example surgical interventions (mutilations), disease resistance, environmental tolerance, etc. The examples given in the text are, naturally, illustrative rather than exhaustive, given the developing nature of the field. Our appraisal will consider prospective innovations in relation to a number of considerations, including the following: the primary aim and the challenge or challenges in relation to which it is defined; any secondary effects that may coincidentally ameliorate or aggravate other challenges; the foreseeable alternatives available and their anticipated impacts; the amenability of conditions and circumstances (such as regulatory conditions) and whether these might affect or mitigate foregoing judgements; and the interdependence of the intervention with other features of a particular system, which the intervention in question might thereby compound or entrench.

Mutilations

4.3 Mutilations are any interference with the sensitive tissues or bone structure of an animal, otherwise than for the purpose of its medical treatment.[456] Farmed animals have been subject to mutilations for a variety of reasons. These include: to identify animals (hot-iron and freeze branding, tattooing, earmarking and tagging, subcutaneous radio-frequency identification tagging); to avert injury to themselves, other animals, or stockpersons by removal of the means (disbudding, dehorning, beak trimming, tooth clipping, and grinding), the target (tail docking, desnooding, dubbing), or the impulse (castration) to injure; to prevent damage to the environment (nose ringing in pigs); to reduce risk of infection (tail docking and mulesing); to manage reproduction (castration, vasectomy, contraception, implantation); and to adjust the quality of products to fit the tastes of the

[455] See, generally: Brandt K, and Barrangou R (2019) Applications of CRISPR technologies across the food supply chain *Annual Review of Food Science and Technology* **10(1)**: 133-50; Zhao J, Lai L, Ji W *et al.* (2019) Genome editing in large animals: current status and future prospects *National Science Review* **6(3)**: 402-20; Bishop TF, and Van Eenennaam AL (2020) Genome editing approaches to augment livestock breeding programs *Journal of Experimental Biology* **223 (supplement 1)**; and Voigt CA (2020) Synthetic biology 2020–2030: six commercially-available products that are changing our world *Nature Communications* **11(1)**: 6379.

[456] This is the definition of a 'prohibited procedure' given in section 5(3) of the Animal Welfare Act 2006 for the purpose of the provisions in the section on 'mutilation', see: https://www.legislation.gov.uk/ukpga/2006/45/crossheading/prevention-of-harm.

consumer (castration of pigs to avert 'boar taint').[457] As can be seen from these examples, some of these procedures have multiple effects.

4.4 Mutilations are surgical interventions that should be carried out by professionals with appropriate training and equipment.[458] As these practices generally cause pain and the risk of complications for the animals involved, their use requires proper justification. Some more painful practices, such as hot-iron branding, have been made illegal in many jurisdictions or given way to alternatives (e.g., freeze branding, ear tagging, radio-frequency identification (RFID) tagging), though often there is no legislative requirement for potentially painful procedures to be undertaken with anaesthetic.[459]

Dehorning and disbudding

4.5 The prevention of horn growth or the removal of horns in order to minimise harm to farm workers and other animals is a common practice in livestock farming. The rate of dehorning around the world varies: in 2007, 94 per cent of US dairy operations were found to practice some form of routine horn removal on heifer calves.[460] In 2009, 81.5 per cent of EU dairy cattle were found to be dehorned.[461]

Current procedures

4.6 Horns may be prevented from growing in calves (disbudding) or removed after horn growth in more mature cattle. Dehorning of mature cattle involves the surgical removal of the horn after the horn tissue has attached to the skull, normally using a mechanical gouger, wire, or saw.[462] Disbudding is performed on calves soon after birth and involves the destruction or removal of horn-producing cells before skull attachment.[463] This is achieved by the application of either a hot iron or caustic paste to the horn buds. Across the EU, most disbudding is performed on the farm by stockpersons who have no specific formal training.[464]

4.7 Abundant behavioural, physiological, and cognitive evidence suggests that all types of dehorning and disbudding are painful to animals and apt to cause acute stress.[465]

[457] Many of these procedures have specific names that are not used in everyday speech. For example, 'desnooding' is the removal of the snood, the fleshy appendage on the top of the head of male turkeys; 'dubbing' is the surgical removal of the comb, wattles, and sometimes also the earlobes of poultry; 'mulesing' is the removal of strips of wool-growing skin from around the tail area of lambs.

[458] In the UK most are carried out by professionals recognised in accordance with the Veterinary Surgeons Act 1966 except on very young animals, where they may be carried out by those (farmers) with appropriate training, and with veterinary support.

[459] Mutilations are controlled, in the UK, by Regulations made under section 5 of the Animal Welfare Act 2006, in England, the Mutilations (Permitted Procedures) (England) Regulations 2007 (S.I 2007 No. 1100) with similar provisions in the Mutilations (Permitted Procedures) (Wales) Regulations 2007 (Wales S.I. 2007 No. 1029 (W. 96)). Hot branding was made illegal in UK jurisdictions by the Agriculture (Miscellaneous Provisions) Act 1968. Freeze branding is lawful under the Animal Welfare Act 2006 and dependent Regulations. On comparison of pain associated with hot and freeze branding, see: Lay DC, Jr., Friend TH, Randel RD *et al.* (1992) Behavioral and physiological effects of freeze or hot-iron branding on crossbred cattle *Journal of Animal Science* **70(2)**: 330-6.

[460] USDA (2007*) Dairy 2007 part i: reference of dairy cattle health and management practices in the United States, 2007*, available at: https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_allpubs.pdf.

[461] SANCO (2009) *ALCASDE final report: study on the improved methods for animal-friendly production, in particular on alternatives to the castration of pigs and on alternatives to the dehorning of cattle*, available at: https://ec.europa.eu/food/system/files/2016-10/aw_prac_farm_pigs_cast-alt_research_alcasade_final-report.pdf. (The figures for beef and suckler cattle were 38.5 and 62.5 per cent, respectively.)

[462] Robbins JA, Weary DM, Schuppli CA *et al.* (2015) Stakeholder views on treating pain due to dehorning dairy calves *Animal Welfare* **24**: 399-406.

[463] Ibid.

[464] Cozzi G, Gottardo F, Brscic M *et al.* (2015) Dehorning of cattle in the EU Member States: a quantitative survey of the current practices *Livestock Science* **179**: 4-11.

[465] Anil SS, Anil L, and Deen J (2002) Challenges of pain assessment in domestic animals *Journal of the American Veterinary Medical Association* **220(3)**: 313-9; Heinrich A, Duffield TF, Lissemore KD *et al.* (2010) The effect of meloxicam on behavior and pain sensitivity of dairy calves following cautery dehorning with a local anesthetic *Journal of Dairy Science* **93(6)**: 2450-

Amputation and hot-iron disbudding can result in infection and prolonged healing of wounds that increase the risk of sinusitis and compromise animal growth.[466] Use of pain mitigation is, however, infrequent in many parts of the world. Research suggests that fewer than 18 per cent of US dairy farms use pain relief when disbudding or dehorning.[467]

Hornless phenotypes

4.8 Horns have developed, probably along separate evolutionary pathways, in a number of animal species, including many that are domesticated such as cattle, sheep, and goats.[468] They serve a range of different functions, often connected with mate selection and establishing the position of the animal in a social hierarchy, but are also involved in feeding, sensing, temperature regulation, and even locomotion.[469] In cattle, for example, not all breeds have horns, and inherently hornless ('polled') livestock have been bred since prehistoric times according to the archaeological record. In historical times, polled cattle were numerous in some areas, for example in ancient Egypt, according to the earliest historical records.[470] Polled cattle have always been more frequent among the indigenous breeds of Scandinavia.[471]

4.9 The use of breeding animals with the polled variants is encouraged by guidance, for example from the Department for Environment, Food and Rural Affairs in England and the Declaration of Düsseldorf in North Rhine-Westphalia.[472] This is, in part, a response to public opinion, which is often found to oppose the dehorning of cattle, increasingly so in recent years.[473] In Switzerland, in 2018, sufficient support was gathered for a proposal to pay farmers to keep animals with horns to be put to a national referendum (though it was narrowly defeated in the vote).[474] Organisations promoting animal welfare continue to press for an end to dehorning.[475] Some major retailers in the US have also prioritised

7; Kupczyński R, Budny A, Śpitalniak K *et al.* (2014) Dehorning of calves – methods of pain and stress alleviation – a review *Annals of Animal Science* **14(2)**: 231-43; and Adcock SJJ, and Tucker CB (2018) The effect of disbudding age on healing and pain sensitivity in dairy calves *Journal of Dairy Science* **101(11)**: 10361-73.

466 American Veterinary Medical Foundation (2014) Welfare implications of dehorning and disbudding cattle: literature review, available at: https://www.avma.org/resources-tools/literature-reviews/welfare-implications-dehorning-and-disbudding-cattle; and Aldersey JE, Sonstegard TS, Williams JL *et al.* (2020) Understanding the effects of the bovine POLLED variants *Animal Genetics* **51(2)**: 166-76.

467 Robbins JA, Weary DM, Schuppli CA *et al.* (2015) Stakeholder views on treating pain due to dehorning dairy calves *Animal Welfare* **24(4)**: 399-406.

468 Davis EB, Brakora KA, and Lee AH (2011) Evolution of ruminant headgear: a review *Proceedings of the Royal Society B: Biological Sciences* **278(1720)**: 2857-65.

469 Ibid.; and Davis EB, Brakora KA, and Stilson KT (2014) Evolution, development and functional role of horns in cattle, in *Ecology: evolution and behaviour of wild cattle – implications for conservation*, Melletti M, Burton J (Editors) (Cambridge: Cambridge University Press).

470 Schafberg R, and Swalve HH (2015) The history of breeding for polled cattle *Livestock Science* **179**: 54-70.

471 Ibid.

472 Defra (2003) *Cattle (England): code of recommendations for the welfare of livestock* (PB7949), available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69368/pb7949-cattle-code-030407.pdf; Ministerium für Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes NRW (2012) *Düsseldorfer Erklärung*, available at: https://www.umwelt.nrw.de/fileadmin/redaktion/PDFs/landwirtschaft/Duesseldorfer_Erklaerung_zur_verstaerkten_Zucht_auf_Hornlosigkeit_Endfassung_9.5.2012.pdf [German language].

473 Co-author's unpublished research, cited in Thompson NM, Widmar NO, Schutz MM *et al.* (2017) Economic considerations of breeding for polled dairy cows versus dehorning in the United States *Journal of Dairy Science* **100(6)**: 4941-52. But see also: Kilders V, and Caputo V (2021) Is animal welfare promoting hornless cattle? Assessing consumer's valuation for milk from gene-edited cows under different information regimes *Journal of Agricultural Economics* **72(3)**: 735-59, which found that providing respondents with more information leads to an increasingly wider spread of the preference distributions, both positive and negative

474 SwissInfo.ch (25 November 2018) *No bonuses for horned cows, decide Swiss voters*, available at: https://www.swissinfo.ch/eng/november-25-vote_are-cows-with-horns-worth-a-bonus-for-the-swiss-/44564548.

475 RSPCA (2018) *Why are cattle dehorned and is it painful?*, available at: https://kb.rspca.org.au/knowledge-base/why-are-cattle-dehorned-and-is-it-painful/.

anaesthetic use or no dehorning in their animal welfare policies.[476] In fact, the proportion of horned breed beef calves born in the US decreased significantly between 1992 and 2007 (29.3 per cent to 12.4 per cent) as a consequence of producers breeding for polled animals.[477]

Persistence of horned breeds

4.10 Continued opposition to disbudding and, particularly, dehorning on welfare grounds, as well as the movement away from the use of tie-stalls, in which cattle are restrained for long periods, to loose housing and increased recreation, which is found to improve welfare, supports the search for naturally polled domestic dairy breeds.[478] Some authors speculate that continued use of horned breeds of cattle in dairy farming (that are frequently dehorned) is due to the fact that farmers and members of the public have historically considered polled cattle to be unnatural.[479] However, the overwhelming reason for not pursuing breeding strategies that favour naturally polled cattle, particularly in the most important British and European dairy breeds such as Holstein, Brown Swiss, and Fleckvieh, is the drive for increased productivity.[480] In modern dairy systems, the requirements to handle these animals (e.g., for tuberculosis testing) and transport them would present significant challenges with horned animals.[481]

4.11 Intense selection for production traits in dairy cows has suppressed hornlessness and polled sires are rare and often not deemed suitable as elite breeding stock.[482] The absence of hornless traits in commercial herds is therefore explained by the fact that the majority of cattle are bred from semen provided by a small number of specialist breeding companies and derived from a small number of elite sires. The breeding and selection of sires is increasingly based on the concept of 'genetic merit', which has generated significant gains since it was adopted in the first decade of the present century.[483] Productivity differentials and the continual genetic gains built on them are generally sufficient to offset the economic cost to farmers of disbudding or dehorning and associated veterinary care.

Genome editing for hornlessness

4.12 Several polled Bovini genotypes have been identified in cattle and yak. Genomic research has identified four genetic variants for hornlessness in cattle on bovine autosome 1 (BTA1), although it is probable that there are other variants in different populations and breeds. All the identified variants are dominant, and cattle carrying a single *POLLED* variant will be either polled or scurred (having incompletely developed

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[476] Wal-Mart, Starbucks, Nestlé, and Kroger according to *NPR The Salt* (3 August, 2015) *Wanted: more bulls with no horns*, available at: https://www.npr.org/sections/thesalt/2015/08/03/429024245/wanted-more-bulls-with-no-horns. See, for example: Walmart (2021) *Walmart policies and guidelines*, available at: https://corporate.walmart.com/policies.

[477] United States Department of Agriculture (2009) *Beef 2007-08: Part III – changes in the U.S. beef cow-calf industry, 1993–2008*, available at: https://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/downloads/beef0708/Beef0708_dr_PartIII_1.pdf.

[478] Popescu S, Borda C, Diugan EA *et al.* (2013) Dairy cows welfare quality in tie-stall housing system with or without access to exercise *Acta Veterinaria Scandinavica* **55(1)**: 43.

[479] Schafberg R, and Swalve HH (2015) The history of breeding for polled cattle *Livestock Science* **179**: 54-70.

[480] Ibid.; Thompson NM, Widmar NO, Schutz MM *et al.* (2017) Economic considerations of breeding for polled dairy cows versus dehorning in the United States *Journal of Dairy Science* **100(6)**: 4941-52.

[481] We were told that it is not feasible to farm animals with horns safely in a conventional, contemporary dairy setting (Factfinding meeting on hornless cattle, 23 May 2019) although different views have been expressed on this subject.

[482] Thompson NM, Widmar NO, Schutz MM *et al.* (2017) Economic considerations of breeding for polled dairy cows versus dehorning in the United States *Journal of Dairy Science* **100(6)**: 4941-52.

[483] García-Ruiz A, Cole JB, VanRaden PM *et al.* (2016) Changes in genetic selection differentials and generation intervals in US Holstein dairy cattle as a result of genomic selection *Proceedings of the National Academy of Sciences* **113(28)**: E3995.

horns).[484] Furthermore, and contrary to some earlier speculation, the known genetic variants associated with hornlessness do not appear to affect production performance.[485] In these circumstances, genome editing, which potentially permits the deliberate reassortment of variants that comprise the genotype, offers a promising strategy to secure a polled phenotype in an elite line without a corresponding loss of genetic merit and productivity, and without requiring a significant number of generations to achieve the result using conventional breeding techniques.[486]

4.13 Proof-of-concept research has produced live hornless cattle following knock-in of the Celtic *POLLED* variant, which gives rise to hornlessness in some breeds of beef cattle, using both TALENS and CRISPR-based genome editing systems.[487]

Box 4.1: Genome editing for hornlessness – an experiment

The first demonstration of genome editing for hornlessness was carried out by a US start-up company (Recombinetics) which has been researching this application since at least 2013.[488] Their initial communication in 2016 described the use of TALENS to introgress the *POLLED* allele into four cell lines derived from bovine embryo fibroblasts, from a cross-bred dairy bull.[489] Nuclei from these cell lines were transferred into 295 enucleated eggs, using a somatic cell nuclear transfer technique, to produce embryos. This yielded 26 suitable blastocysts that were transferred to 26 hosts, eventually yielding 5 live-born calves. Three of these were judged to be 'non-viable' and humanely killed shortly after birth. The two remaining calves were confirmed to be homozygous for the *POLLED* allele and to exhibit the polled phenotype. Initial genome analysis pronounced them clear of unexpected off-target effects or insertions other than at the intended site.[490]

The two bull calves that resulted from this initial experiment, named Spotigy and Buri, were subsequently transferred to the University of California, Davis, for evaluation and further breeding. The university researchers subsequently used Spotigy to inseminate horned Hereford dairy cows. Ten inseminations produced six calves, analysis of which confirmed that the offspring were heterozygous for the *POLLED* allele and exhibited the polled phenotype. All routine physical parameters appeared within normal limits and

[484] Aldersey JE, Sonstegard TS, Williams JL *et al.* (2020) Understanding the effects of the bovine POLLED variants *Animal Genetics* **51(2)**: 166-76.

[485] Thompson NM, Widmar NO, Schutz MM *et al.* (2017) Economic considerations of breeding for polled dairy cows versus dehorning in the United States *Journal of Dairy Science* **100(6)**: 4941-52. Polledness is, however, associated with small increase in incidence of other phenotypic characteristics, ranging from a second set of eyelashes in cattle with the Celtic or Fresian variants, to a predisposition to preputial prolapse and spiral 'corkscrew' deviation of the penis in Angus bulls and other cattle with the variant; see: Aldersey JE, Sonstegard TS, Williams JL *et al.* (2020) Understanding the effects of the bovine POLLED variants *Animal Genetics* **51(2)**: 166-76.

[486] Progressive Dairy (17 January 2014) Half of Holstein heifer calves could be polled by 2034, available at: https://www.progressivedairy.com/topics/a-i-breeding/half-of-holstein-heifer-calves-could-be-polled-by-2034; and Van Eenennaam AL, De Figueiredo Silva F, Trott JF *et al.* (2021) Genetic engineering of livestock: the opportunity cost of regulatory delay *Annual Review of Animal Biosciences* **9(1)**: 453-78.

[487] Carlson DF, Lancto CA, Zang B *et al.* (2016) Production of hornless dairy cattle from genome-edited cell lines *Nature Biotechnology* **34(5)**: 479-81; Schuster F, Aldag P, Frenzel A *et al.* (2020) CRISPR/Cas12a mediated knock-in of the polled celtic variant to produce a polled genotype in dairy cattle *Scientific Reports* **10(1)**: 13570; and Young AE, Mansour TA, McNabb BR *et al.* (2020) Genomic and phenotypic analyses of six offspring of a genome-edited hornless bull *Nature Biotechnology* **38(2)**: 225-32.

[488] Van Eenennaam AL (7 October 2019) *Blog: responsible science takes time*, available at: https://bioengineeringcommunity.nature.com/posts/54229-responsible-science-takes-time.

[489] This bull originated from the University of Minnesota dairy crossbreeding program and is known to be 62.5% Holstein, 25% Montbelliarde and 12.5% Jersey; see: Carlson DF, Lancto CA, Zang B *et al.* (2016) Production of hornless dairy cattle from genome-edited cell lines *Nature Biotechnology* **34(5)**: 479-48; and Young AE, Mansour TA, McNabb BR *et al.* (2020) Genomic and phenotypic analyses of six offspring of a genome-edited hornless bull *Nature Biotechnology* **38(2)**: 225-32.

[490] Carlson DF, Lancto CA, Zang B *et al.* (2016) Production of hornless dairy cattle from genome-edited cell lines *Nature Biotechnology* **34(5)**: 479-81.

comparable with controls following veterinary examination and follow-up over the course of 15 months. Genome sequencing and bioinformatic analysis was used to search for remarkable or unexpected findings in the genomes of the offspring. It confirmed that the *POLLED* allele was stably inherited at the expected location in the genome, and that the Mendelian error rate did not differ between the genome-edited offspring and contemporary controls.[491]

The only notable anomaly observed following the UC Davis analysis was the incorporation of the plasmid (the construct that carries the genome editing machinery) and a duplication of the repair template in one allele of the genome-edited sire (Buri), which was passed on to four of the subsequent offspring.[492] The data were subsequently reanalysed by an independent research group, who found the full length plasmid backbone had been inserted into the genome of both edited calves, as well as two copies of the repair template. This team noted that template plasmid integration errors may be under-reported or overlooked in genome editing experiments generally, and they proposed enhanced screening approaches for this method of editing.[493] The expectation is that this could be addressed by using alternative repair templates and methods.[494]

A separate team based in Germany used a CRISPR-Cas12a system (formerly CRISPR-Cpf1) to achieve polled offspring from a horned Holstein–Friesian bull. Like the Recombinetics/University of Minnesota team they integrated the Celtic *POLLED* variant from the genome of an Angus cow into fibroblasts taken from the horned bull using the CRISPR-Cas12a system; they then reconstructed embryos by somatic cell nuclear transfer using the fibroblast nuclei inserted into 70 artificially matured oocytes. These embryos were then transferred into synchronised recipients and two pregnancies established. One pregnancy was terminated on day 90 after examination of the fetus; the remaining pregnancy was carried to term resulting in a live-born calf with the polled phenotype. This calf died shortly after birth as a result of multiple organ malformations resulting in cardiovascular failure. However, despite the limitations attributed to the cloning technique, this was taken to show the feasibility of a potentially better adapted CRISPR system for introducing the *POLLED* variant.[495]

Social and ethical considerations

4.14 Removing the horns of horned cattle to facilitate the production of dairy products for human consumption seems, *prima facie*, to do a morally relevant harm to those cattle. The procedures involved cause pain and sometimes health complications for the animals, incur a cost to farmers (albeit generally lower than the concomitant gain), and involve veterinarians and farm workers in unpleasant and potentially unnecessary practices. Whether the pursuit of the polled phenotype though genome editing technology is viewed as a benefit from the point of view of animal welfare rather depends on how the practice is framed. Specifically, it depends on whether the procedure is seen as an alternative to horned cattle being allowed to keep their horns or to them being routinely disbudded or dehorned.

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491 Young AE, Mansour TA, McNabb BR *et al.* (2020) Genomic and phenotypic analyses of six offspring of a genome-edited hornless bull *Nature Biotechnology* **38(2)**: 225-32.
492 Ibid.
493 Norris AL, Lee SS, Greenlees KJ *et al.* (2020) Template plasmid integration in germline genome-edited cattle *Nature Biotechnology* **38(2)**: 163-4.
494 Young AE, Mansour TA, McNabb BR *et al.* (2020) Genomic and phenotypic analyses of six offspring of a genome-edited hornless bull *Nature Biotechnology* **38(2)**: 225-32.
495 Schuster F, Aldag P, Frenzel A *et al.* (2020) CRISPR/Cas12a mediated knock-in of the polled Celtic variant to produce a polled genotype in dairy cattle *Scientific Reports* **10(1)**: 13570.

4.15 The latter framing arises as a result of a social constraint, one that is well entrenched. Milk and milk products are a staple part of the 'Western diet'. While cheese has long been valued as a durable, portable, and nutritious food of working people, the widespread uptake of milk in its liquid form is a relatively recent adoption, largely due to the invention of pasteurisation and the encouragement of the dairy industry in the early twentieth century.[496] In fact, the overriding incentive to maintain a high level of milk production is, for many countries, such that it is difficult to envisage how husbandry systems might be modified to accommodate horned dairy cattle at scale without the associated risks of injury to cattle and farm workers. A world in which milk and milk products play a more modest or merely marginal role, as they do in many non-Western cultures, is certainly conceivable. However, this alternative is not easily or immediately accessible and there are formidable obstacles to a transition away from dairy in most Western societies. This is not to say that such a transition will not happen or that it should be resisted (indeed, there are signs that, to some degree, it is already happening).

4.16 A more immediate (though still speculative) question than the desirability or otherwise of transition away from dietary dependency on dairy produce is whether the introduction of polling biotechnology would significantly affect the prospects of such a transition, for example by helping to further entrench existing production systems. It is certainly possible that it would, insofar as it removes one of the important motives for change (i.e., the objection to dehorning). On the other hand, it is conceivable that a supervisory authority motivated by considerations of animal welfare could intervene to prohibit the use of sires other than homozygous polled sires (who would obligatorily pass on the polled trait) in commercial breeding.

4.17 The preferential use of polled sires has, in fact, been a longstanding recommendation of the UK's Department for Environment, Food and Rural Affairs.[497] However, it is one which the industry in general has consistently failed to embrace. This may be partly accounted for by the competitive structure of the breeding sector for dairy cattle.[498] In this context, a focus on the polled trait through conventional breeding would mean neglect of other commercially important criteria in conditions of continually increasing productivity through 'genetic gain'. Any breeder or farmer who voluntarily follows a course involving a relative decrease in productivity might imagine, all other things being equal, that they would be severely disadvantaged, if not driven from the market.[499]

4.18 A more effective alternative, therefore, might be the imposition of regulatory conditions or incentives on breeders to encourage or require them to breed cattle with the polled trait. It is estimated that this could take decades to achieve using conventional breeding procedures, if it is a commercial necessity simultaneously to maintain the current level of productivity (and productivity has been increasing incrementally). As a result, such a

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[496] Thirsk J (2007) *Food in early modern England: phases, fads, fashions 1500-1760* (London: Hambledon Continuum); Hettinga K, and van Valenberg H (2017) Contribution of dairy to nutrient intake in the Western diet, in *Nutrients in dairy and their implications for health and disease*, Watson RR, Collier RJ, and Preedy VR (Editors) (Academic Press), pp251-8. See also: BBC Future (6 July 2015) *How did milk become a staple food?*, available at: https://www.bbc.com/future/article/20150706-how-did-milk-become-a-staple-food.

[497] Defra (2003) *Code of recommendations for the welfare of livestock: cattle*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69368/pb7949-cattle-code-030407.pdf.

[498] Van Eenennaam AL, De Figueiredo Silva F, Trott JF *et al.* (2021) Genetic engineering of livestock: the opportunity cost of regulatory delay *Annual Review of Animal Biosciences* **9(1)**: 453-78.

[499] But see Chapter 6 for the effect of limited information on farmer behaviour, in particular fertility and feed conversion in different systems.

policy would be likely to require significant transitional financial support for domestic producers in a context of global supply chains and open borders.[500]

4.19 The major benefit of the genome editing procedure is the potential for rapid establishment of a polled, elite founder population that could disseminate the polled trait quickly throughout the commercial dairy industry, thereby eliminating the need for disbudding or dehorning, but without any associated loss of productivity.[501] Making a reasonable assumption that dairy will continue to be a major human dietary component, and a possibly optimistic one that a healthy founder population of genome-edited cattle can be efficiently produced, the question that may determine whether genome-edited cattle become the norm in the future dairy system is perhaps principally one of regulatory policy.

Regulation and the shaping of sociotechnical trajectories

4.20 The animals involved in the Minnesota experiment, both the edited bulls and their F1 offspring, were killed because, for regulatory reasons, neither they nor their descendants would be permitted to enter the food chain.[502] As a consequence, the animals had no economic value while the researchers lacked the resources, given the scope of their project funding, to keep them.

4.21 Regulation of genetically altered animals is typically cautious because of the uncertainties involved in experimentation with DNA in living beings. From the research results published so far, there is clearly some way to go to refine the technology, particularly insofar as it depends on somatic cell nuclear replacement (cloning) as an enabling technique. Even in the most competent hands this technique remains challenging, with a high rate of attrition during development. However, if the *POLLED* trait proves to be well conserved through successive generations, this would only need to be done at the tip of the breeding pyramid. The inefficiencies at the top (in terms of embryo wastage and developmental abnormalities *in utero*) need to be seen in the context of the number of live-born cattle at the bottom of the pyramid that would otherwise be expected to undergo disbudding or dehorning.

4.22 As well as the impact on the first generation of animals, regulation exists to guard against risks to consumers of animal products, and adverse consequences that are not detected at the first generation, before they are diffused through a breeding population. Though unlikely to represent a harm to members of the public, some outcomes of these early genome editing experiments were unexpected, unexplained, or uncontrolled (e.g., the congenital malformations of the German clones, Buri's cryptorchidism and the incorporation of the plasmid), which would not be expected in conventional breeding.[503] These are obstacles rather than obstructions, of a kind to be expected in scientific research, and they point the way to further refinements. The further refinements do, however, remain to be demonstrated and there must remain some uncertainty about how

[500] Despite this, it is clear that conventional breeders have already taken an interest in pursuing polled traits in their elite animal breeding programmes. See: Progressive Dairy (17 January 2014) *Half of Holstein heifer calves could be polled by 2034*, available at: https://www.progressivedairy.com/topics/a-i-breeding/half-of-holstein-heifer-calves-could-be-polled-by-2034.

[501] Carlson DF, Lancto CA, Zang B *et al.* (2016) Production of hornless dairy cattle from genome-edited cell lines *Nature Biotechnology* **34(5)**: 479-81.

[502] Young AE, Mansour TA, McNabb BR *et al.* (2020) Genomic and phenotypic analyses of six offspring of a genome-edited hornless bull *Nature Biotechnology* **38(2)**: 225-32. For regulatory purposes, the edits were regarded as 'unapproved animal drugs' under the FDA's guidance note 187: FDA (2017) *Guidance for industry 187 on regulation of intentionally altered genomic DNA in animals*, available at: https://www.fda.gov/regulatory-information/search-fda-guidance-documents/cvm-gfi-187-regulation-intentionally-altered-genomic-dna-animals.

[503] See: Norris AL, Lee SS, Greenlees KJ *et al.* (2020) Template plasmid integration in germline genome-edited cattle *Nature Biotechnology* **38(2)**: 163-4. See also: Martineau B (6 September 2019) *Blog: gene editing's extra DNA problem: déjà vu all over again'*, available at: https://biotechsalon.com/2019/09/06/gene-editings-extra-dna-problem-deja-vu-all-over-again/.

these will be overcome and about what other problems may yet be encountered. They underline the need for further research, and of presenting the results for regulatory scrutiny, before the technique can enter production systems.[504]

4.23 The challenge confronting the developers in this case is the investment in research and development required and the length of time required to secure regulatory clearance. More precisely, the challenge is whether the developers can produce elite polled bulls that match the estimated breeding values (EBVs) of the best horned bulls, clear the regulatory process, and get their product to market before conventional breeders can achieve a similar result (for the sake of argument, say, 15 years from the time of writing).[505] The reason regulatory delay is an important issue is that the developers of the technology will need to recover their research and development costs and the costs of meeting the regulatory requirements through sale of their product, and are likely to be outcompeted on price if conventional breeders achieve the same breeding objectives before they can bring their animals to market. The risk of this happening would be expected to dampen investment interest significantly. The advantages of genome editing are really twofold: first, the speed with which it can accomplish ‘genetic gain’ relative to conventional breeding (which is only an advantage if there exists a sufficiently fast regulatory track, which is mostly unavailable at present) and, secondly, its ability to produce novel genetic combinations that could not have come about through conventional breeding. A consequence of successful innovation, however, might be to open up a productivity gap between commercial breeders and farmers using animals bred using the new technology and those using more traditional breeding methods, with consequences for the configuration of the industry and the distribution of power in value chains, beyond what may already be observed as a result of selective breeding, especially in the major terrestrial monogastric species (i.e., chickens and pigs).

4.24 What would give social and ethical importance to the speed with which genome edited animals could be brought to market is the pressing nature of the challenges that genome editing may help to address. Challenges such as those identified in Chapter 2 are, in fact, routinely used as an argument in support of technological innovation, with references to environmental protection, food security, and the growing global population common in developers’ promotional material. Animal welfare is a significant challenge and current widespread practices of disbudding and dehorning have a negative impact on farmed animal welfare, among other things. This may account for the appeal of the *POLLED* application as a ‘demonstration case’.

4.25 The value of securing an efficient regulatory approval is not, however, limited to delivering the benefits of a particular application. Its further value may lie in establishing a pathway that could help to smooth the way for subsequent applications and normalise genome editing as a breeding technique. Given the comparative advantages over conventional breeding (of greater speed and control at the molecular level), establishing

504 While some researchers argue for a streamlining of regulatory process (for example, Van Eenennaam AL, De Figueiredo Silva F, Trott JF *et al.* (2021) Genetic engineering of livestock: the opportunity cost of regulatory delay *Annual Review of Animal Biosciences* **9(1)**: 453-78) other commentators argue that this episode has demonstrated the value of regulation (for example, Martineau B (17 February 2020) *Blog: in light of big mistakes made by developers of “poster child” GMO products like hornless cattle and golden rice, FDA is justified in requiring regulation*, available at: https://biotechsalon.com/2020/02/17/in-light-of-big-mistakes-made-by-developers-of-poster-child-gmo-products-like-hornless-cattle-and-golden-rice-fda-is-justified-in-requiring-regulation/.

505 For comparison, the first genetically modified animal approved for human consumption by the FDA in 2015, the AquAdvantage salmon, took nearly 20 years from the initial submission, while the first examples of what became the GalSafe pigs were reported in 2003. See: Phelps CJ, Koike C, Vaught TD *et al.* (2003) Production of alpha 1,3-galactosyltransferase-deficient pigs *Science* **299(5605)**: 411-4.

such a pathway could propel genome editing to become the presumptive breeding technology, not just for an initial application (e.g., polled cattle), but for the pursuit of other kinds of 'genetic gain', across the commercial breeding sector.[506] This would not just represent a gain in productivity through a given application, but lead to an *increase in the rate of productivity gain* for a range of breeding objectives (those, at least, where the underlying genetics are shown to be tractable to the technology). There is, then, something more far-reaching at stake in securing an efficient regulatory pathway: not merely the benefits available from the first 'demonstration' use but a potential technological transformation of the commercial breeding sector more generally (always assuming that there is demand in the marketplace).[507] It is these wider implications that may, however, offer a reason to be more cautious about the establishment of such a pathway.

4.26 We have given significant space to the discussion of this potential application of genome editing because it offers an instructive case study of technological development, while raising a larger question about what effect the adoption of genome editing technology may have on the food and farming system (or on the domestic production systems for distinct species). *POLLED* technology provides us with a clear and instructive thought experiment. It also invites us to consider whether regulation can be used to shape this in a way that secures a more just system, or a system that is more just than any reasonably attainable alternative. This is a question that must be borne in mind as we consider other prospective applications, and one to which we must return before we formulate our conclusions.

Tail docking

4.27 Horns are not the only features of farmed animals that are inconvenient within farming systems, giving rise to practices of routine mutilation. Tail docking (the surgical removal of an animal's tail) and mulesing (the removal of strips of wool-covered skin from the rear of sheep) are techniques used to address issues of 'breech strike' (a range of infections associated with soiling of the animals' rear area and tail) and facilitate shearing in sheep.[508] Tail docking is also used in pig husbandry as a last resort response to refractory tail biting behaviours and as a veterinary intervention in case of severe injury.[509]

Fly strike in sheep

4.28 Blowflies pose a serious threat to the health of sheep. Blowfly strike (myiasis) causes loss to sheep flocks (commonly 1–5 per cent of those affected) and represents a significant cost to farmers.[510] Incidence depends on a number of factors, including fly abundance, host susceptibility, climate, and husbandry practices, but is a common problem in a number of countries, particularly the UK, Ireland, South Africa, New Zealand, and Australia.[511] The condition is caused by the invasion of living tissue by the larvae of dipteran flies. The blowfly larvae feed on readily available nutrients on the animal's skin. In the initial stages of the infection, the larvae cause only minor irritation

506 See, however, the conclusion to this chapter.
507 We discuss public attitudes and traceability in Chapters 6 and 7.
508 French NP, Wall R, and Morgan KL (1994) Lamb tail docking: a controlled field study of the effects of tail amputation on health and productivity *The Veterinary Record* **134(18)**: 463-7; and Sheep 201: a beginner's guide to raising sheep (2018) *Docking and castrating*, available at: http://www.sheep101.info/201/dockcastrate.html.
509 See the discussion of mutilations in Chapter 2.
510 Wall R, and Lovatt F (2015) Blowfly strike: biology, epidemiology and control *In Practice* **37(4)**: 181-8.
511 Broughan JM, and Wall R (2007) Fly abundance and climate as determinants of sheep blowfly strike incidence in southwest England *Medical and Veterinary Entomology* **21(3)**: 231-8; and Lihou K, and Wall R (2019) Sheep blowfly strike: the cost of control in relation to risk *Animal* **13(10)**: 2373-8.

to the host, but the third-stage larvae (instars) have a sharp tooth with which they scratch the skin, also releasing a toxin that can cause a shock syndrome in the host, depending on the number of larvae. Female blowflies can lay over 1,000 eggs.

4.29 Fly strike is usually apparent as a discoloured, moist, and foul-smelling area infested with maggots. Strikes occur in waves, with the odour from the first strike attracting further flies. Animals affected by fly strike appear restless, dull, and reluctant to graze, and may kick at the affected area. If untreated, strike can rapidly result in increased respiratory and heart rates, ammonia toxicity, coma, and death.[512] Treatment is via topical medication, but close monitoring and veterinary treatment can be difficult, especially where identification of cases and provision of veterinary assistance is complicated by the sheep roaming over large geographic areas (e.g., in Australia). The most common form of control is preventative use of neurotoxic insecticides and, increasingly, insect growth regulators which interfere with the larval development. These are effective for approximately 12 weeks from application but timing during the fly strike season is an important factor.[513] Mechanical control (including tail docking) has been shown to be of value in reducing the incidence of fly strike but this is disputed by some researchers.[514] Research programmes have also been established to identify heritable indicator traits associated with resistance to breech strike in Merino sheep, which might in future form the basis of selection decisions to reduce the consequences.[515]

4.30 Sheep's tails protect the sensitive parts of their anus, vulva, and udder from extremes of weather and are used, to some extent, to scatter their faeces when they defecate.[516] Tail length and morphology are extremely variable and tail length highly heritable. Research has therefore been directed towards breeding sheep, such as Merinos, with desirable production characteristics using conventional breeding.[517] However, there may be insufficient variation in the breed to allow significant improvements in breech strike resistance or reductions in tail length. Crossing with short-tailed breeds, such as the Finn, offers a quicker route to these aims but also compromises the production characteristics for which Merinos have been bred. As with polled cattle, genome editing might offer the possibility of an alternative to surgical mutilations, where an underlying genetic basis for the desired phenotype can be identified. The genetic basis of taillessness in vertebrates has been described in Manx cats (a recessive allele, lethal in homozygotes) and in Chinese and Iranian breeds of sheep (traced to a missense mutation).[518]

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512 Farm Health Online (2018) *Sheep blowfly strike: a serious welfare concern*, available at: https://www.farmhealthonline.com/disease-management/sheep-diseases/sheep-blowfly-strike/.

513 Wall R, and Lovatt F (2015) Blowfly strike: biology, epidemiology and control *In Practice* **37(4)**: 181-8.

514 French NP, Wall R, and Morgan KL (1994) Lamb tail docking: a controlled field study of the effects of tail amputation on health and productivity *The Veterinary Record* **134(18)**: 463-7.

515 Ware JW, Vizard AL, and Lean GR (2000) Effects of tail amputation and treatment with an albendazole controlled-release capsule on the health and productivity of prime lambs *Australian Veterinary Journal* **78(12)**: 838-42; Greeff JC, Karlsson LJE, and Schlink AC (2014) Identifying indicator traits for breech strike in Merino sheep in a Mediterranean environment *Animal Production Science* **54(2)**: 125-40; and Government of Western Australia (23 July 2020) *Sheep indicator traits for breech strike in winter rainfall regions*, available at: https://www.agric.wa.gov.au/livestock-research-development/sheep-indicator-traits-breech-strike-winter-rainfall-regions.

516 Current domestic legislation requires that enough of the tail is left to cover the vulva and anus; see: Farmers Weekly (13 January 2020) *Tail docking lambs: advice, legislation and methods compared*, available at: https://www.fwi.co.uk/livestock/husbandry/tail-docking-lambs-advice-legislation-and-methods-compared.

517 James PJ (2006) Genetic alternatives to mulesing and tail docking in sheep: a review *Australian Journal of Experimental Agriculture* **46(1)**: 1-18.

518 Adalsteinsson S (1980) Establishment of equilibrium for the dominant lethal gene for Manx taillessness in cats *Theoretical and Applied Genetics* **57(4)**: 49-53; Buckingham KJ, McMillin MJ, Brassil MM *et al.* (2013) Multiple mutant T alleles cause haploinsufficiency of Brachyury and short tails in Manx cats *Mammalian Genome* **24(9)**: 400-8; Zhi D, Da L, Liu M *et al.* (2018) Whole genome sequencing of hulunbuir short-tailed sheep for identifying candidate genes related to the short-tail

Tail biting in pigs

4.31 A similar approach could be postulated in pigs. However, the situation with pigs is significantly different. As in other animals, pigs' tails are sensitive structures; they may be used to ward off flies and, like dogs, pigs wag their tails to express positive emotional states. All pigs have tails, although the curled tails that are familiar in domesticated species are not universal.[519] Pigs are intelligent animals that exhibit a range of sophisticated social behaviours. These include oral aggression, which may be directed towards other pigs to establish social hierarchy and in response to environmental stress. They may take the form of tail, ear, and vulva biting, and savaging of offspring. These behaviours may be exacerbated where pigs are kept in close confinement with others (see Chapter 2). The common response to persistent tail biting is surgical tail docking, an 'exceptional' practice but one that remains the norm despite efforts to abolish it through legislation in many jurisdictions, including the UK and EU.

4.32 The absence of naturally tailless breeds suggests that complex genetics and gene–environment interactions may be in play. The trait may therefore be one that is not amenable to genome editing or to transgenic modification. Tailless pigs may be of use more as a thought experiment than a practical breeding objective. But the idea of the tailless pig helps to explore the limits of the desirable uses of biotechnology. If a tailless breed of pigs were found (perhaps in the wild or as a mutation in a domestic population), would it be objectionable for farmers to cross it with domestic pigs with the aim of producing a tailless breed? All other things being equal (i.e., if there were no concomitant impact on other valued traits), there would be an incentive to do so because, while the tail, like the cow's horns, may be of some intrinsic value to the pig (perhaps having more social but less sanitary importance than the sheep's tail), it is potentially a source of pain and infection in cases of tail biting, and represents an economic cost to farmer if it has to be treated or removed.

4.33 It might be asserted that a healthy tail is a useful marker for good husbandry conditions (highlighting that where tail docking is normalised this constitutes an indictment of the management practices in the industry). Furthermore, the absence of tails to bite might merely displace or sublimate the underlying behaviour, directing it to other targets, with potentially more serious consequences. Neither breeding a tailless pig nor removing, however painlessly, the tails of living pigs addresses the underlying problem of which tail biting behaviours are an expression. Thus, even if it were achievable, using genome editing to breed the tailless pig would seem to be a morally problematic use of technology and the achievement of the same ends through conventional breeding should not be allowed to lead to a lesser vigilance or a diversion of purpose from the aim of securing higher welfare conditions in pig husbandry that would make the question of tail removal irrelevant.

Castration

4.34 Domestic animals are castrated for a variety of reasons. In sheep, castration is undertaken to prevent unwanted pregnancies, to reduce aggressive behaviour, and to prevent a particular flavour characteristic of the meat produced from uncastrated male

phenotype *G3 Genes|Genomes|Genetics* **89(2)**: 377-83; and Han J, Yang M, Guo T *et al.* (2019) Two linked TBXT (brachyury) gene polymorphisms are associated with the tailless phenotype in fat-rumped sheep *Animal Genetics* **50(6)**: 772-7.

[519] Pig behavioural genetics may offer a promising alternative route to explore; see: Canario L, Bijma P, David I *et al.* (2020) Prospects for the analysis and reduction of damaging behaviour in group-housed livestock, with application to pig breeding *Frontiers in Genetics* **11(1560)**: 611073.

lambs.[520] The procedure is used in pigs for similar reasons: to influence behavioural traits and to prevent a distinctive odour in pork known as 'boar taint' present in the meat (fat) of 'entire' males.[521] Castration also affects weight gain and the ratio of muscle to fat in a number of species.[522]

4.35 Castration is usually carried out within the first week of life, but is a painful procedure with behavioural sequelae and potential veterinary complications.[523] Under current EU legislation, male piglets can be surgically castrated without anaesthesia or analgesia up to seven days old.[524] The EU is, however, committed to moving away from surgical castration.[525] Alternatives to surgical castration involving, for example, gonadotropin-releasing hormone vaccines are in use in a number of countries (although overall global uptake has been low) and research has also been undertaken into the genetic basis of boar taint or how to avoid it by slaughtering pigs earlier or at lower weight (a more common approach in the UK and Ireland).[526]

Box 4.2: Surgical castration of swine

The biotechnology company Recombinetics has used genome editing techniques (referred to as 'precision breeding') to produce piglets that remain in a state of prepuberty for the duration of their lives, removing one of the main incentives to castrate them. The company, its agriculture division Acceligen, with breeding company Hendrix Genetics have, in fact, borrowed the compassionate sounding campaign language of interest groups in forming an 'alliance to end surgical castration of swine'.[527]

Animal health

Disease resistance

4.36 Livestock diseases account for one of the greatest risks and costs (in terms of insurance and veterinary support) to farmers and producers. These risks occur across all production systems, but their effects can be particularly devastating, in terms of the numbers of affected animals, when they take hold in large-scale intensive farming systems (see Chapter 2).[528]

[520] Farm Animal Welfare Education Centre (2018) *Welfare implications of tail docking and castration in sheep*, available at: https://www.fawec.org/en/fact-sheets/51-sheep/247-castration-taildocking-sheep.

[521] Moore KL, Mullan BP, and Dunshea FR (2017) Boar taint, meat quality and fail rate in entire male pigs and male pigs immunized against gonadotrophin releasing factor as related to body weight and feeding regime *Meat Science* **125**: 95-101.

[522] Kim S-W, Kim K-W, Park S-B *et al.* (2015) The effect of castration time on growth and carcass production of elk bulls *Journal of Animal Science and Technology* **57(1)**: 39; and Telles FG, Luna SPL, Teixeira G *et al.* (2016) Long-term weight gain and economic impact in pigs castrated under local anaesthesia *Veterinary and Animal Science* **1-2**: 36-9.

[523] Farm Animal Welfare Education Centre (2013) *Effect of castration on the welfare of pigs*, available at: https://www.fawec.org/en/fact-sheets/36-swine/113-effect-of-castration-on-the-welfare-of-pigs.

[524] *Directive 2008/120/EC*, laying down minimum standards for the protection of pigs, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0120&from=EN.

[525] European Commission (2018) *Alternatives to pig castration*, available at: https://ec.europa.eu/food/animals/animal-welfare/animal-welfare-practice/animal-welfare-farm/pigs/alternatives-pig-castration_en.

[526] Moore KL, Mullan BP, and Dunshea FR (2017) Boar taint, meat quality and fail rate in entire male pigs and male pigs immunized against gonadotrophin releasing factor as related to body weight and feeding regime *Meat Science* **s125**: 95-101.

[527] Hendrix Genetics (2018) *Alliance to end surgical swine castration*, available at: https://www.hendrix-genetics.com/en/hendrix-genetics/innovation/hendrix-genetics-innovations/alliance-end-surgical-swine-castration/.

[528] A major research programme to investigate the global burden of animal disease, including its links to agricultural productivity, smallholder household income, the empowerment of women, and the equitable provision of a safe, affordable, nutritious diet, was initiated in 2021 with funding from the Bill and Melinda Gates Foundation; see: World Organisation for Animal Health (19 January 2021) Launch of the multi-year, multi-partner Global Burden of Animal Diseases programme, available at:

African swine fever

4.37 In pigs, two of the main disease threats are from African swine fever virus (ASFv) and porcine reproductive and respiratory syndrome virus (PRRSv). ASF is a highly contagious viral disease of swine.[529] It was first identified in Kenya in the 1920s and remains endemic in most sub-Saharan countries.[530] The virus spread to Europe in the middle of the twentieth century, and later to South America and the Caribbean.[531] With the exception of Sardinia (where it remains endemic), ASF was eliminated in Europe in the 1990s through extreme control and eradication programmes.[532] In 2007, ASF again spread from Africa into the Caucasus; since then, it has spread widely in Russia and Europe and has recently led to a serious outbreaks in China from 2018.[533] Outbreaks are associated with high initial mortality.[534] Chronic forms of the disease are characterised by delayed growth, emaciation, joint swelling, skin ulcers, and lesions associated with secondary bacterial infection.[535] In the absence of an effective vaccine, infections usually require slaughter of exposed animals.[536]

4.38 In the absence of an effective vaccine against ASF, controlling the disease usually relies on early detection, strict biosecurity measures, mandatory reporting, quarantine, restriction of movement, and slaughter of infected animals.[537] Early detection is challenging, however, due to the complex epidemiology and range of clinical manifestations of the disease, many of which are similar to other viral infections.[538] This means that slaughter is widespread. (Rabobank estimated that approximately 200 million pigs, 40 per cent of the national herd, were slaughtered in the 2018 outbreak of ASF in China.[539])

Porcine reproductive and respiratory syndrome

4.39 Along with ASF, porcine reproductive and respiratory syndrome (PRRS) is one of the most significant swine diseases in the world. The disease was first identified in the early 1990s in Europe and North America but is now found worldwide.[540] The clinical presentation varies, but both of the two main strains of the virus responsible for PRRS

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https://www.oie.int/en/launch-of-the-multi-year-multi-partner-global-burden-of-animal-diseases-programme/. See also: the OIE world animal health yearbooks, and the World Animal Health Information System (2021) *OIE-WAHIS portal: animal health data*, available at: https://www.oie.int/en/what-we-do/animal-health-and-welfare/disease-data-collection/world-animal-health-information-system, that collects data on notifiable diseases.

[529] Galindo I, and Alonso C (2017) African swine fever virus: a review *Viruses* **9(5)**: 103; and Kolbasov D, Titov I, Tsybanov S *et al.* (2018) African swine fever virus, Siberia, Russia, 2017 *Emerging Infectious Disease Journal* **24(4)**: 796-98.

[530] Gallardo C, de la Torre Reoyo A, Fernández-Pinero J *et al.* (2015) African swine fever: a global view of the current challenge *Porcine Health Management* **1(1)**: 21.

[531] Galindo I, and Alonso C (2017) African swine fever virus: a review *Viruses* **9(5)**: 103.

[532] Gallardo C, de la Torre Reoyo A, Fernández-Pinero J *et al.* (2015) African swine fever: a global view of the current challenge *Porcine Health Management* **1(1)**: 21; and Galindo I, and Alonso C (2017) African swine fever virus: a review *Viruses* **9(5)**: 103.

[533] Alejo A, Matamoros T, Guerra M *et al.* (2018) A proteomic atlas of the African swine fever virus particle *Journal of Virology* **92(23)**: e01293-18 and; Kolbasov D, Titov I, Tsybanov S *et al.* (2018) African swine fever virus, Siberia, Russia, 2017 *Emerging Infectious Disease Journal* **24(4)**: 796-98. For updates, see: FAO (2021) *African swine fever in Asia & Pacific update*, available at: https://www.fao.org/ag/againfo/programmes/en/empres/ASF/situation_update.html.

[534] Sánchez-Cordón PJ, Montoya M, Reis AL *et al.* (2018) African swine fever: a re-emerging viral disease threatening the global pig industry *The Veterinary Journal* **233**: 41-8.

[535] Ibid.

[536] Galindo I, and Alonso C (2017) African swine fever virus: a review *Viruses* **9(5)**: 103.

[537] Gallardo C, de la Torre Reoyo A, Fernández-Pinero J *et al.* (2015) African swine fever: a global view of the current challenge *Porcine Health Management* **1(1)**: 21; Galindo I, and Alonso C (2017) African swine fever virus: a review *Viruses* **9(5)**: 103; and Sánchez-Cordón PJ, Montoya M, Reis AL *et al.* (2018) African swine fever: a re-emerging viral disease threatening the global pig industry *The Veterinary Journal* **233**: 41-8.

[538] Gallardo C, de la Torre Reoyo A, Fernández-Pinero J *et al.* (2015) African swine fever: a global view of the current challenge *Porcine Health Management* **1(1)**: 21.

[539] See: Pig Progress (9 August 2019) *Robobank: disease, trade issues change the global pig market*, available at: https://www.pigprogress.net/Health/Articles/2019/8/Rabobank-Disease-trade-issues-change-the-global-pig-market-459981E/.

[540] Montaner-Tarbes S, del Portillo HA, Montoya M *et al.* (2019) Key gaps in the knowledge of the porcine respiratory reproductive syndrome virus (PRRSV) *Frontiers in Veterinary Science* **6(38)**.

lead to reproductive failure for breeding sows and complex respiratory symptoms in pigs of all ages.[541] Morbidity and mortality rates for PRRS are high but vary (e.g., in one outbreak the recorded mortality rate was 100 per cent for suckling piglets, 70 per cent in nursery pigs and 20 per cent in finishing pigs; over 40 per cent of pregnant sows that were infected suffered abortion, though the mortality rate in pregnant sows was approximately 10 per cent).[542] As with ASF, progress in vaccine development for PRRS has been slow.[543] Consequently, disease management takes a similar approach, often involving culls of affected animals.[544]

Avian influenza

4.40 Birds may be affected by a variety of influenza type A viruses, including very virulent viruses causing highly pathogenic avian influenza, with flock mortality as high as 100 per cent (H5 and H7 subtypes), and variety that usually cause milder, primarily respiratory, disease.[545] The most significant to date has been the H5N1 variant that spread through domestic poultry and wild birds throughout Asia and into Europe and Africa. This has led to the death or culling of hundreds of millions of poultry.[546] A further concern that is well borne out in the case of avian flu (though it is also noted in the case of H1N1 swine flu) is the zoonotic potential of the disease to affect humans: the H1N1 'Spanish flu' pandemic that killed approximately 50 million people in 1918 was probably of avian origin.[547] Avian flu may be significantly more challenging to control than diseases affecting terrestrial species owing to the power of flight to overcome physical obstacles provided by fences and bodies of water, and the migratory habits of birds spreading over large distances (primarily ducks and geese). Avian flu has also been spread by humans, movements of domestic poultry, and other wild birds.[548] It is, however, just one of a number of grave and economically significant poultry diseases.[549]

Diseases of aquatic species

4.41 The farming of aquatic species is comparatively recent, although fish and other marine animals have formed part of the human diet since prehistoric times, and humans have industrialised the capture of wild fish, for example through trawler fishing, establishing complex and often global value chains.[550] As a result, the impact of deliberate breeding on aquatic animals (i.e., not taking into account the effects of human environmental pressures) has been focused mainly on production characteristics of certain species,

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541 Ibid.

542 Zhou L, and Yang H (2010) Porcine reproductive and respiratory syndrome in China *Virus Research* **154(1-2)**: 31-7.

543 Nan Y, Wu C, Gu G *et al.* (2017) Improved vaccine against PRRSV: current progress and future perspective *Frontiers in Microbiology* **8(1635)**.

544 OIE (2008) *PRRS: the disease, its diagnosis, prevention and control*, available at: https://www.oie.int/fileadmin/Home/eng/Our_scientific_expertise/docs/pdf/PRRS_guide_web_bulletin.pdf.

545 Alexander DJ (2007) An overview of the epidemiology of avian influenza *Vaccine* **25(30)**: 5637-44.

546 Ibid.

547 Lycett SJ, Duchatel F, and Digard P (2019) A brief history of bird flu *Philosophical Transactions of the Royal Society B: Biological Sciences* **374(1775)**: 20180257.

548 The UK, for example, hosts both resident and migratory ducks and geese, which arrive in the autumn to overwinter from colder climates. One route into Europe was Eagles smuggled to Brussels from Thailand; Alexander DJ (2007) An overview of the epidemiology of avian influenza *Vaccine* **25(30)**: 5637-44.

549 Another is Marek's disease (which is estimated to cost the global poultry industry some $2 billion/year); see: Smith J, Lipkin E, Soller M *et al.* (2020) Mapping QTL associated with resistance to avian oncogenic Marek's disease virus (mdv) reveals major candidate genes and variants *Genes* **11(9)**: 1019.

550 See, for example, Phyne J, and Mansilla J (2003) Forging linkages in the commodity chain: the case of the Chilean salmon farming industry, 1987–2001 *Sociologia Ruralis* **43(2)**: 108-27; Oosterveer P (2006) Globalization and sustainable consumption of shrimp: consumers and governance in the global space of flows *International Journal of Consumer Studies* **30(5)**: 465-76; and Nielsen M, Ankamah-Yeboah I, Staahl L *et al.* (2018) Price transmission in the trans-Atlantic northern shrimp value chain *Marine Policy* **93**: 71-9.

offering relatively rapid gain in these characteristics (see below).[551] Catfish (south-eastern US), carp (Asia-Pacific region, especially China), salmon (Canada, north-western US, Norway, Scotland), and tilapia (Asia and Pacific) are the most commonly farmed finfish, and crustaceans (shrimp, prawns) and molluscs (clams, oysters, mussels, and scallops) are also farmed. Aquaculture involves taking control of the fish's ecosystem including movement, nutrition, breeding, and waste.

4.42 While some fish (e.g., tilapia) are farmed in recirculating aquaculture systems using terrestrial tanks, many (including most farmed salmon) are farmed in open pen systems in coastal waters. The industrialisation of fish farming gives rise to a number of challenges that require further mitigation, for example fish welfare, damage from pollution of coastal environments and ecosystems with fish waste and feed, contamination owing to the introduction of chemicals (including use of veterinary medicines), and the risk of farmed fish escaping to interbreed with wild fish. The feeding systems can also be environmentally damaging, for example the use of fish waste from trawling and soya from non-sustainable sources.

4.43 Because the farming of finfish requires them to be confined together in great numbers in a bounded space, the potential for transmission and infection with disease is significantly increased. Conditions such as infestation by the parasitic sea louse *Lepeophtheirus salmonis* and the bacterial disease piscirickettsiosis are economically important conditions with high mortality rates in salmonids.

The significance of husbandry systems

4.44 Many of the diseases affecting farmed animals can be seen as diseases of industrial farming, or which industrial farming has made more prevalent and potentially catastrophic. The system in which animals are kept contributes to the risk of infection and amplification of pathogens or the degree of protection. In principle, infection is less likely where animals have less contact with each other and are able to observe social distancing, and where they are able to move away from others who may be bearers of infection. On the other hand, there is greater potential for enhancing biosecurity for animals that are segregated from the wild, where they could come into contact with potential disease vectors (e.g., housed indoors year round, or in onshore tanks in the case of fish). Housing systems also offer the capacity to monitor and treat animals more easily if they become infected. There is therefore a potential trade-off between the risk of infection and the resilience of the animal population.

4.45 A significant factor contributing to the catastrophic impact of PRRS and ASF outbreaks in pigs is the size of the production facilities.[552] Both these diseases have emerged (or re-emerged) as significant threats in the context of industrial production (PRRS was first described in 1990; ASF re-emerged in 2007, having been eradicated outside Africa in the 1990s).[553] As in the case of avian flu, while wild animals provide reservoirs and vectors of infection, the scale of the impact on animal lives is accounted for largely by the biosecurity risk (how well or poorly animals are isolated from sources of infection)

[551] See, for example, Phyne J, and Mansilla J (2003) Forging linkages in the commodity chain: the case of the Chilean salmon farming industry, 1987–2001 *Sociologia Ruralis* **43(2)**: 108-27; Oosterveer P (2006) Globalization and sustainable consumption of shrimp: consumers and governance in the global space of flows *International Journal of Consumer Studies* **30(5)**: 465-76; and Nielsen M, Ankamah-Yeboah I, Staahl L *et al.* (2018) Price transmission in the trans-Atlantic northern shrimp value chain *Marine Policy* **93**: 71-9.

[552] Resources at: European Food Safety Authority (2021) *African swine fever*, available at: https://www.efsa.europa.eu/en/topics/topic/african-swine-fever.

[553] For PRRS, see: Ohlinger VF, Pesch S, and Bischoff C (2000) History, occurrence, dynamics and current status of PRRS in Europe *Veterinary Research* **31(1)**: 86-7; for ASF, see: Sánchez-Cordón PJ, Montoya M, Reis AL *et al.* (2018) African swine fever: a re-emerging viral disease threatening the global pig industry *The Veterinary Journal* **233**: 41-8.

and the size and concentration of herds and flocks should it get through. The response to the decimation of the Chinese pork industry by ASF in 2018, which involved a substantial number of small producers, appears to involve the construction of larger and more biosecure facilities, such as the multistorey installation in Nanyang, China, which will eventually house 84,000 sows and their litters.[554]

Advances in diagnosis, prophylaxis, and treatment

4.46 Given the harm to the animals and to industry and the economic cost of conventional disease prevention and management protocols, significant research capacity has been directed towards understanding the epidemiology of these diseases and finding new prophylactic and therapeutic approaches.

Box 4.3: Detection and vaccine prevention of African swine fever virus

Molecular diagnostics have been developed for early and presymptomatic diagnosis and for tracking the diffusion and mutation of viruses, for example a multiplex RT-PCR assay for simultaneous detection of African swine fever virus (ASFv), classical swine fever virus, and atypical porcine pestivirus.[555] RT-qPCR assays for the detection of porcine respirovirus have also recently been reported.[556] Complete virus genome sequencing can help to identify genetic markers to trace the spread of virus isolates and identify virulence markers.[557] Molecular assays for ASFv have helped to identify less virulent strains in Latvia and Estonia and China, where researchers report a growing trend of lower mortality but with clinical symptoms that are harder to detect and difficult to control. There are claims that some variants may involve strains that have been made for use in illicit vaccines.[558]

The search for an effective vaccine is an active area of research. In cases such as ASFv, however, vaccine development has been limited by difficulty in acquiring scientific knowledge of the characteristics of infection and immunity. However, there are some reports of protection elicited by experimental vaccines, including live attenuated vaccines and DNA vaccines.[559] For bacterial diseases and to treat complications of viral infections, vaccines also promise to reduce the use of antimicrobials (see Chapter 2).[560]

Both vaccination and genome editing are developing fields of research. Which is likely to offer the most successful or appropriate response will depend on a range of factors, which will have to be assessed on a case-by-case basis. Whereas vaccines will require repeat delivery (at least initially) the genetic approach aims to make resistance a fixed trait of the breeding line. Whereas viruses may mutate in such a way that allows them to

[554] The Guardian (8 October 2020) *Behind China's 'pork miracle': how technology is transforming rural hog farming*, available at: https://www.theguardian.com/environment/2020/oct/08/behind-chinas-pork-miracle-how-technology-is-transforming-rural-hog-farming; and Bangkok Post (9 December 2020) *World's largest pig farm rises in China*, available at: https://www.bangkokpost.com/business/2032335/worlds-largest-pig-farm-rises-in-china.

[555] Liu H, Shi K, Sun W *et al.* (2021) Development a multiplex RT-PCR assay for simultaneous detection of African swine fever virus, classical swine fever virus and atypical porcine pestivirus *Journal of Virological Methods* **287**: 114006.

[556] Li Y, Sthal C, Bai J *et al.* (2021) Development of a real-time RT-qPCR assay for the detection of porcine respirovirus 1 *Journal of Virological Methods* **289**: 114040.

[557] Sánchez-Cordón PJ, Montoya M, Reis AL *et al.* (2018) African swine fever: a re-emerging viral disease threatening the global pig industry *The Veterinary Journal* **233**: 41-8.

[558] Reuters (5 February 2021) *Chinese researchers find natural mutation in African swine fever virus*, available at: https://www.reuters.com/article/us-china-swinefever-variant-idUSKBN2A5187.

[559] Sánchez-Cordón PJ, Montoya M, Reis AL *et al.* (2018) African swine fever: a re-emerging viral disease threatening the global pig industry *The Veterinary Journal* **233**: 41-8; and Tran XH, Le TTP, Nguyen QH *et al.* (2021) African swine fever virus vaccine candidate ASFV-G-ΔI177L efficiently protects European and native pig breeds against circulating Vietnamese field strain *Transboundary and Emerging Diseases* [published online: 28 September 2021].

[560] Hoelzer K, Bielke L, Blake DP *et al.* (2018) Vaccines as alternatives to antibiotics for food producing animals. Part 2: new approaches and potential solutions *Veterinary Research* **49(1)**: 70.

> escape a vaccine that has been designed to recognise a specific viral antigen, genetic approaches are likely to be based on biological function so may be harder for a virus to escape. There are also regulatory considerations, and questions about effectiveness and delivery and consumer perception to consider. It is therefore not possible to map the comparative benefits of the different approaches in the absence of a specific example.

4.47 As an alternative (or in addition) to vaccinating domestic herds, vaccination can potentially be delivered to wild disease reservoirs and vectors, such as wild swine in the case of ASFv or badgers in the case of bovine tuberculosis (caused by the bacterium *Mycobacterium bovis*).[561] This can be done orally, using bait, or by capturing and releasing individuals and may offer an alternative to culling.

4.48 A range of tools has been deployed, and many more are still subject to research and development, to combat veterinary and potentially zoonotic diseases. These include improved biosecurity, breeding for resilience, vaccination, therapeutics, and other measures, for example herbal supplements and faecal microbiota transplants that could help to boost immune response and improve disease resistance.[562] All of these approaches have advantages and drawbacks, for example in terms of effectiveness, cost, associated stock management requirements, collateral effects, and environmental impact. This range of tools is now potentially supplemented by biotechnologies involving genome editing.

> **Box 4.4: Gene therapy for brucellosis**
>
> In addition to vaccination, gene therapy strategies have been proposed, for example to address the risk of brucellosis, a zoonotic disease caused by the *Brucella melitensis* bacterium that leads to abortion and infertility, among other symptoms, in infected animals and humans. Brucellosis particularly affects ruminants around the Mediterranean, Africa, and Asia and, although vaccines exist, vaccination is not a fully effective method of control or eradication and entails a number of undesirable consequences, including itself provoking abortion and infertility and discharge into the environment.[563] An alternative therapeutic approach has therefore been proposed involving novel CRISPR-Cas9 lentiviral vectors, which would inactivate specific genes coding for factors that play a critical role in the intracellular replication of the brucellae bacteria.[564]

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561 Galindo I, and Alonso C (2017) African swine fever virus: a review *Viruses* **9(5)**: 103; and Benton CH, Phoenix J, Smith FAP *et al.* (2020) Badger vaccination in England: progress, operational effectiveness and participant motivations *People and Nature* **2(3)**: 761-75. See also: BBC News (5 March 2020) *Badger cull to be replaced by vaccines in bovine TB fight*, available at: https://www.bbc.co.uk/news/uk-england-51753393.

562 On dietary supplements, see: Kim K, Ji P, Song M *et al.* (2020) Dietary plant extracts modulate gene expression profiles in alveolar macrophages of pigs experimentally infected with porcine reproductive and respiratory syndrome virus *Journal of Animal Science and Biotechnology* **11(1)**: 74; on microbiomic strategies, see: Zhang J, Rodríguez F, Navas MJ *et al.* (2020) Fecal microbiota transplantation from warthog to pig confirms the influence of the gut microbiota on African swine fever susceptibility *Scientific Reports* **10(1)**: 17605.

563 Karponi G, Kritas SK, Papadopoulou G *et al.* (2019) Development of a CRISPR/Cas9 system against ruminant animal brucellosis *BMC Veterinary Research* **15(1)**: 422.

564 Ibid.

Genome editing

Identifying genetic targets

4.49 Domestic animals are highly selected for production traits that are desirable to farmers, increased homogeneity within breeds, and adaptation to conditions of modern husbandry systems. This has resulted in a reduction in genetic diversity and in environmentally driven selection for genetic characteristics such as resistance to diseases found in the wild. The disease examples described in this chapter are only a small sample of the range of diseases affecting livestock, or even of those that have significant economic importance in farming systems. They are the ones that, perhaps because of their economic importance, research capacity has been directed towards addressing with novel response strategies. These strategies usually involve identifying relevant resistance traits that appear to be heritable and investigating underlying genetic variants associated with heritability.[565]

Box 4.5: Research to identify genetic targets for breeding

Genomic research is investigating the effects on genetic diversity of domestication in fish, for example the coho salmon farmed predominantly in Chile, including in genomic regions associated with body weight and disease resistance (resistance to *Piscirickettsia salmonis*, the bacterium that causes piscirickettsiosis).[566] Research is also targeting markers of resistance, for example the higher resistance to sea lice of Pacific salmon compared to Atlantic salmon.[567]

Research is also looking at natural antibodies in chickens, which are present independently of exposure to pathogens at higher levels in some birds, allowing birds to respond more quickly when challenged by infection. Researchers have found that a predisposition to higher levels of natural antibodies appears to be heritable, making it a potential breeding target and a possible way to reduce the use of antibiotics.[568]

Research in Cameroon has identified cattle with resistance to bovine tuberculosis across breeds to identify breeding targets.[569] Further work has identified genomic loci associated with susceptibility to bovine paratuberculosis.[570]

The potential of genome editing

4.50 Where cross-breeding with resistant relatives within the same species is possible, it may not, however, be desirable from a production point of view, because the gain in resilience is likely to be bought at the cost of a loss in the productivity traits which have been selected for in the case of domestic breeds. However, in a subset of cases (those in which the underlying genetic basis is as close as possible to monogenic and in which

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[565] For example, Uemoto Y, Ichinoseki K, Matsumoto T *et al.* (2021) Genome-wide association studies for production, respiratory disease, and immune-related traits in Landrace pigs *Scientific Reports* **11(1)**: 15823.

[566] López ME, Cádiz MI, Rondeau EB *et al.* (2021) Detection of selection signatures in farmed coho salmon (Oncorhynchus kisutch) using dense genome-wide information *Scientific Reports* **11(1)**: 9685.

[567] Nofma (2021) *Harnessing cross-species variation in sea lice resistance*, available at: https://nofima.com/projects/crispresist/.

[568] See: Poultry News (20 May 2021) *Feature: the search for antibiotic-free production*, available at: https://www.poultrynews.co.uk/news/feature-the-search-for-antibiotic-free-production.html.

[569] Callaby R, Kelly R, Mazeri S *et al.* (2020) Genetic diversity of Cameroon cattle and a putative genomic map for resistance to bovine tuberculosis *Frontiers in Genetics* **11(1404)**.

[570] Canive M, Fernandez-Jimenez N, Casais R *et al.* (2021) Identification of loci associated with susceptibility to bovine paratuberculosis and with the dysregulation of the MECOM, eEF1A2, and U1 spliceosomal RNA expression *Scientific Reports* **11(1)**: 313.

identifiable pleiotropic effects are negligible), where the relevant DNA variations can be identified and characterised, genome editing technology may enable a desired variant to be introduced directly to the target species without compromising other characteristics.[571]

Box 4.6: Genome editing and transgenic approaches to disease resistance

Researchers have been able to identify the specific molecular mechanisms involved in some infections and use this knowledge to design editing strategies that block the pathogen while leaving other regions of the genome and other functions undisturbed. For example, research has identified the surface receptor (CD163) that allows the porcine reproductive and respiratory syndrome virus (PRRSv) to invade pigs' macrophage cells. Knocking out the *CD163* gene (that codes for the CD163 protein) confirmed that pigs lacking this receptor were resistant to PRRS.[572] However, the CD163 receptor has other biological functions (in homeostasis, inflammation, and the immune response) that are important to the pig, so a genome editing protocol was designed that allowed researchers to knock out only one of the nine receptor domains (domain 5, which admitted PRRSv). Subsequent experiments confirmed that the resulting animals were "completely resistant to PRRSv infection and maintained the biological functions associated with the remaining domains of CD163".[573]

In a 2016 study, it was reported that the *PRNP* gene, which is associated with bovine spongiform encephalopathy (BSE), a prion disease that can affect humans who have consumed affected animals, was successfully altered in cow zygotes using CRISPR-Cas9.[574]

Mastitis is one of the most economically significant diseases in dairy cattle and sheep.[575] Resistance to mastitis, generally the result of a given animal's immune response, has been found to be heritable and therefore to have potential as a breeding target.[576] Recent research has demonstrated the production of transgenic cloned cattle which produce a protein in their milk that can kill *Staphylococcus aureus*, a bacterium that causes mastitis (through a human lysozyme gene knock-in to the beta-casein locus, achieved using zinc finger nucleases).[577] This was previously achieved by producing transgenic cows cloned from transfected Jersey cow fetal fibroblasts, which resisted *Staphylococcus aureus* by secreting small amounts of lysostaphin in their milk.[578]

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571 See: Proudfoot C, Lillico S, and Tait-Burkard C (2019) Genome editing for disease resistance in pigs and chickens *Animal Frontiers* **9(3)**: 6-12.

572 Whitworth KM, Rowland RRR, Ewen CL *et al.* (2016) Gene-edited pigs are protected from porcine reproductive and respiratory syndrome virus *Nature Biotechnology* **34(1)**: 20-2.

573 Proudfoot C, Lillico S, and Tait-Burkard C (2019) Genome editing for disease resistance in pigs and chickens *Animal Frontiers* **9(3)**: 6-12, citing: Burkard C, Lillico SG, Reid E *et al.* (2017) Precision engineering for PRRSV resistance in pigs: macrophages from genome edited pigs lacking CD163 SRCR5 domain are fully resistant to both PRRSV genotypes while maintaining biological function *PLOS Pathogens* **13(2)**: e1006206; and Burkard C, Opriessnig T, Mileham Alan J *et al.* (2018) Pigs lacking the scavenger receptor cysteine-rich domain 5 of CD163 are resistant to porcine reproductive and respiratory syndrome virus 1 infection *Journal of Virology* **92(16)**: e00415-18.

574 Bevacqua RJ, Fernandez-Martín R, Savy V *et al.* (2016) Efficient edition of the bovine PRNP prion gene in somatic cells and IVF embryos using the CRISPR/Cas9 system *Theriogenology* **8698)**: 1886-96.e1.

575 O'Brien AC, McHugh N, Wall E *et al.* (2017) Genetic parameters for lameness, mastitis and dagginess in a multi-breed sheep population *Animal* **11(6)**: 911-9; and Martin P, Barkema HW, Brito LF *et al.* (2018) Symposium review: novel strategies to genetically improve mastitis resistance in dairy cattle *Journal of Dairy Science* **101(3)**: 2724-36.

576 Martin P, Barkema HW, Brito LF *et al.* (2018) Symposium review: novel strategies to genetically improve mastitis resistance in dairy cattle *Journal of Dairy Science* **101(3)**: 2724-36.

577 See, generally: Tait-Burkard C, Doeschl-Wilson A, McGrew MJ *et al.* (2018) Livestock 2.0 – genome editing for fitter, healthier, and more productive farmed animals *Genome Biology* **19(1)**: 204; see, more specifically: Liu X, Wang Y, Tian Y *et al.* (2014) Generation of mastitis resistance in cows by targeting human lysozyme gene to β-casein locus using zinc-finger nucleases *Proceedings of the Royal Society B: Biological Sciences* **281(1780)**: 20133368.

578 Wall RJ, Powell AM, Paape MJ *et al.* (2005) Genetically enhanced cows resist intramammary staphylococcus aureus infection *Nature Biotechnology* **23(4)**: 445-51.

Environmental tolerance

4.51 As well as improving resistance to infectious disease, breeding strategies have been employed to increase animals' tolerance to environmental challenges. Heritability has been identified in a number of so-called 'functional traits' that are of relevance to the specific conditions of some contemporary husbandry practices, and these have been targeted in breeding programmes.

4.52 More than half the cattle in the world live in hot and humid environments.[579] High temperatures can affect farmed animals by reducing their fertility and milk yield, and have a negative impact on animal welfare.[580] Research has found that preferable and harmful temperatures are similar for humans, cattle, pigs, poultry, fish, and agricultural crops.[581] Adaptation to tropical heat combined with high milk yield in dairy cattle is an objective of breeding programmes in South America and sub-Saharan Africa.[582]

Box 4.7: Genome editing for environmental adaptations

The gene *SLICK*, which is associated with a smoother coat and heat tolerance in cows, was identified in 2008 and genetic selection of heat-tolerant cows is already used on farms.[583] The precision breeding company Acceligen, for example, with funding from the Bill & Melinda Gates Foundation, is reported to be focusing on combining adaptation to tropical heat, characteristic of local breeds, with already established high milk yield from elite producers, with the possibility of adding resistance to locally prevalent diseases as required by producers in different regions (for which they are taking input from smallholders whom they assert to be their target customers).[584] In order to combine traits to achieve these objectives, the company proposes to use genome editing strategies.

Scientists in New Zealand have also used genome editing to lighten the hides of characteristically black-and-white Holstein Friesian dairy cattle in order that they may better tolerate changing climatic conditions, in view of predicted more frequent and prolonged hot temperature patterns. They achieved this by introducing a three-base-pair deletion in the pre-melanosomal protein 17 gene (*PMEL*) supposed to be the variant responsible for the semi-dominant colour dilution phenotype seen in Galloway and Highland cattle.[585]

Chickens are a globally important source of protein and therefore a focus of research. Some have implied that genome editing may provide opportunities to breed

[579] Science Daily (23 June 2017) *Scientists work to develop heat-resistant 'cow of the future'*, available at: https://www.sciencedaily.com/releases/2017/06/170623100712.htm.

[580] Charoensook R, Gatphayak K, Sharifi AR *et al.* (2012) Polymorphisms in the bovine HSP90AB1 gene are associated with heat tolerance in Thai indigenous cattle *Tropical Animal Health and Production* **44(4)**: 921-8; and Garner JB, Douglas ML, Williams SRO *et al.* (2016) Genomic selection improves heat tolerance in dairy cattle *Scientific Reports* **6(1)**: 34114.

[581] See: Asseng S, Spänkuch D, Hernandez-Ochoa IM *et al.* (2021) The upper temperature thresholds of life *The Lancet Planetary Health* **5(6)**: e378-e85.

[582] Chawala AR, Sanchez-Molano E, Dewhurst, RJ *et al.* (2021) Breeding strategies for improving smallholder dairy cattle productivity in Sub-Saharan Africa *Journal of Animal Breeding Genetics* **138**: 668-87.

[583] Garner JB, Douglas ML, Williams SRO *et al.* (2016) Genomic selection improves heat tolerance in dairy cattle *Scientific Reports* **6(1)**: 34114; Science Daily (26 August 2008) 'Slick' gene helps cattle beat the heat, available at: https://www.sciencedaily.com/releases/2008/08/080825201255.htm.

[584] CISION (24 September 2020) *Acceligen launches program for precision crossbreeding of African dairy production systems*, available at: https://www.prnewswire.com/news-releases/acceligen-launches-program-for-precision-crossbreeding-of-african-dairy-production-systems-301137450.html.

[585] Laible G, Cole SA, Brophy B *et al.* (2020) Holstein Friesian dairy cattle edited for diluted coat color as adaptation to climate change *bioRxiv*: 2020.09.15.298950.

characteristics such as improved heat tolerance or strengthen musculoskeletal characteristics such as bone health and leg strength, leading to improved locomotion and fewer complications from sedentary husbandry systems, such as contact dermatitis (also heritable).[586]

4.53 Like disease resistance, functional traits such as tolerance to adverse environmental conditions have different implications for animals in different husbandry systems. Heat tolerance, for example, could be beneficial for smallholder or subsistence farmers and cattle in tropical countries, where a farmer may need to keep many times the number of animals that a farmer in more equable conditions would need to generate the same level of produce, with the associated inefficiencies in the use of land, water, energy, and other resources. However, it might also perpetuate the concentration of cattle in feedlots, common for beef production in the US, where shade provision may be inadequate, or chickens in sedentary systems.[587]

Production traits

4.54 Breeding for production traits is perhaps the most obvious objective of selective breeding. This may be characterised as directly increasing the value of animal products by raising the value of the output in relation to the cost of the input. This simple formula draws attention to the extent to which the objectives are pursued as an optimisation of the production system that involves both the animal phenotype and physiology, the husbandry practices, and the environment, in order to increase efficiency through conversion rates of inputs to output and reduce the cost of interventions (such as veterinary interventions) and of the mitigation of environmental impacts.

4.55 While further gains in production traits remain possible through selective breeding in all the major domestic species, in many cases they have been increasingly accompanied by negative effects, such as increased incidence or severity of health conditions. These include things like mastitis in dairy cattle, lameness in beef cattle, neonatal mortality in pigs, leg problems and ascites in broiler chickens, and spinal abnormalities in salmon. These effects may require increased levels of veterinary care and medication, although increases in health problems may impact negatively on individual animals in a herd or flock before the gains in productivity from breeding for increased yield are negated by increased costs to the producer. Increased public attention has also fallen on the impact of both breeding practices and husbandry systems on the quality of animal lives and on their impact on the environment. Furthermore, in many jurisdictions, enforceable environmental standards have been applied to farms and research has, as we have noted, begun to develop operationally defined standards of animal welfare, distinct from simple measures of animal health.[588]

4.56 While there remain quantitative productivity gains that could be made through breeding, attention has also turned to other consumer defined qualities of the animal product, for example in terms of sensory qualities, such as taste and texture, or properties such as hypoallergenicity. In this context, genome editing approaches have been proposed to

[586] Hartcher KM, and Lum HK (2020) Genetic selection of broilers and welfare consequences: a review *World's Poultry Science Journal* **76(1)**: 154-67; and Park JS, Lee KY, and Han JY (2020) Precise genome editing in poultry and its application to industries *Genes* **11(10)**: 1182.

[587] Edwards-Callaway LN, Cramer MC, Cadaret CN *et al.* (2021) Impacts of shade on cattle well-being in the beef supply chain Journal of Animal Science 99(2): skaa375.

[588] See Chapter 2.

secure production traits that are desirable to producers and consumers, sometimes in innovative ways.

Increasing yield

Increasing rate of growth/maturation

4.57 One area where significant gains in yield may be achieved through genetic manipulation is in aquaculture, for example in species such as salmon and tilapia.[589] Farmed fish are only a few generations from their wild antecedents and offer producers 'unexploited optimisation potential', although the management of modified fish also presents distinct biosecurity challenges.[590] With fish farmed in sea nets, and even those farmed in land-based tanks that may be contiguous with hospitable sewerage and river systems, escape to the environment and the potential for interbreeding with wild varieties presents a concern that the prospect of a feral cow or sheep does not. The use of biotechnologies has been proposed to block the possibility of interbreeding, and the consequent threat to biodiversity, if such an escape should occur.[591]

Box 4.8: Fast-maturing transgenic salmon

Recombinant DNA technology was used to produce the AquAdvantage salmon, the first genetically modified animal to have been approved for human consumption by a national regulatory authority (the US Food and Drug Administration [FDA]). The AquAdvantage salmon is a genetically altered Atlantic salmon that contains a recombinant DNA construct composed of the growth hormone gene from Chinook salmon under the control of a promoter (a sequence of DNA that turns on the expression of a gene) from another type of fish (an ocean pout).[592] This results in a fish that can reach a stage of growth where it can be sold to market faster than its (unaltered) farmed salmon counterpart.

The FDA approved the AquAdvantage salmon as safe to eat, found the introduced DNA to be safe for the fish itself and confirmed that it gave rise to the effect claimed by the producer. They also found that it had no significant environmental or ecosystem impact. This was based on the salmon being farmed in a contained, land-based system, and the fact that the salmon are all female and effectively sterile.

The marketing approval was granted in November 2015, 20 years after an investigational new animal drug (INAD) file was first opened with the FDA's Center for Veterinary Medicine and 12 years after the submission of the first regulatory study as part of the new animal drug application (NADA 141-454).[593] While the salmon were produced using earlier generation biotechnology, the genome editing technique

[589] For summary, see: Naylor RL, Hardy RW, Buschmann AH *et al.* (2021) A 20-year retrospective review of global aquaculture *Nature* **591(7851)**: 551-63.

[590] See: European Forum of Farm Animal Breeders (26 March 2021) *Webinar: animal genome editing in the spotlight (presentation from Anna Wargelius and panel comments by Ashie Norris)*, available at: https://www.effab.info/webinar-series-breederstalkgreen.html.

[591] Gratacap RL, Wargelius A, Edvardsen RB *et al.* (2019) Potential of genome editing to improve aquaculture breeding and production *Trends in Genetics* **35(9)**: 672-84.

[592] See: US Food & Drug Administration (2020) *AquAdvantage Salmon fact sheet*, available at: https://www.fda.gov/animal-veterinary/animals-intentional-genomic-alterations/aquadvantage-salmon-fact-sheet. For more information, see: US Food & Drug Administration (2015) *Freedom of information summary: NADA 141-454 – opAFP-GHc2 rDNA construct in EO-1α lineage Atlantic salmon (AquAdvantage Salmon)*, available at: https://www.fda.gov/files/animal%20&%20veterinary/published/AquAdvantage-Salmon-FOI-Summary.pdf.

[593] See: AquaBounty Technologies (2014) *Chronology of AquAdvantage Salmon and AquaBounty Technologies*, available at: https://aquabounty.com/wp-content/uploads/2014/01/Chronology-of-AquAdvantage-Salmon-F1.pdf.

CRISPR-Cas9 has also been successfully applied to different aquaculture species for production traits, including improved reproduction and growth.[594]

Increasing yield per animal

4.58 Characteristics such as carcass size, feed conversion ratios, milk yield, and fecundity (the number of offspring or frequency of parturition) show varying degrees of heritability and may be targets for selective breeding programmes. The underlying genetic characteristics associated with these phenotypes are, however, often complex and polygenic, and not easily amenable to direct molecular control through techniques like genome editing. Furthermore, many of the contributory variants may also have pleiotropic effects, being implicated in several biological functions, so that altering them could give rise to unanticipated collateral effects in the organism.[595] Nevertheless, research continues to investigate the genetic regions associated with production traits, which may yield targets for future direct intervention.

Box 4.9: Genetic targets for meat and milk yield

Some animals carry specific genetic mutations in the *MSTN* gene, a negative regulator of muscle growth, which leads to prodigiously increased muscle size as found, for example, in the ‘double muscled’ Belgian Blue and Piedmontese cattle and Texel sheep.[596] Pigs, cows, sheep, and horses have all been subject to genome editing procedures to increase their muscle mass. In 2015, researchers at Seoul University used TALENS to edit the *MSTN* gene to produce more muscular pigs.[597] A 2016 study using CRISPR-Cas9 to knock out one *MSTN* allele produced similar results, increasing muscle size and decreasing back fat.[598] Alternations to the *MSTN* gene have also been reported using TALENS in goats in 2014, in both cows and sheep in 2015 and, using CRISPR-Cas9, in horses in 2020.[599] Knocking out the *MSTN* gene, while offering a striking proof of concept, is, however, a crude approach to increasing production yield, one that raises additional welfare concerns that are shared with naturally occurring instances (e.g., cattle may require assisted birthing), economic costs (increased veterinary care, higher feed costs, and delayed slaughter), and product quality limitations (leaner meat, with less fat marbling).

A study led by researchers at the Roslin Institute and the Centre for Tropical Livestock Genetics and Health examined how water buffalo and cattle had responded at the genomic level to selective breeding. The researchers compared the genomes of 79 water buffalo to those of 294 cattle from around the world and other domesticated species. They found that key production traits, including milk yield, disease resistance, and birth weight had developed through comparable alterations to regions of the

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[594] Li M, Yang H, Zhao J *et al.* (2014) Efficient and heritable gene targeting in tilapia by CRISPR/Cas9 *Genetics* **197(2)**: 591-9; and Kishimoto K, Washio Y, Yoshiura Y *et al.* (2018) Production of a breed of red sea bream Pagrus major with an increase of skeletal muscle mass and reduced body length by genome editing with CRISPR/Cas9 *Aquaculture* **495**: 415-27.

[595] For example, genetic studies have revealed the biological mechanism of the genetic trade-off between growth and reproduction in broilers; see: Tarsani E, Kranis A, Maniatis G *et al.* (2021) Detection of loci exhibiting pleiotropic effects on body weight and egg number in female broilers *Scientific Reports* **11(1)**: 7441.

[596] McPherron AC, and Lee S-J (1997) Double muscling in cattle due to mutations in the myostatin gene *Proceedings of the National Academy of Sciences* **94(23)**: 12457-61.

[597] Cyranoski D (2015) Super-muscly pigs created by small genetic tweak *Nature* **523(7558)**: 13-4.

[598] Bi Y, Hua Z, Liu X *et al.* (2016) Isozygous and selectable marker-free MSTN knockout cloned pigs generated by the combined use of CRISPR/Cas9 and Cre/LoxP *Scientific Reports* **6(1)**: 31729.

[599] Ni W, Qiao J, Hu S *et al.* (2014) Efficient gene knockout in goats using CRISPR/Cas9 system *PLoS One* **9(9)**: e106718; Proudfoot C, Carlson DF, Huddart R *et al.* (2015) Genome edited sheep and cattle *Transgenic Research* **24(1)**: 147-53; and Moro LN, Viale DL, Bastón JI *et al.* (2020) Generation of myostatin edited horse embryos using CRISPR/Cas9 technology and somatic cell nuclear transfer *Scientific Reports* **10(1)**: 15587.

genome in cattle and water buffalo.[600] Given the importance of water buffalo for meat, milk, as draft animals in the Indian subcontinent, and to millions of smallholders across Asia, this finding has invited the speculation that, if appropriate genetic targets can be found, "gene-editing techniques may help improve the productivity and health of agricultural animals in low- and middle-income countries and so improve the lives of those who depend on them."[601]

Diffusion of elite genetics

4.59 One of the limitations of conventional artificial insemination (AI) is the need to repeatedly collect and then disseminate the reproductive material from elite donor animals. Another is the possibility of complications arising from AI, which carries the risk of spreading venereal diseases if donor animals are not carefully screened, as well as the risk from fomites (e.g., cross-contamination from the instruments used).[602] Genome editing strategies have also enabled novel approaches to increase the diffusion of high-yielding elite animals from conventional selective breeding programmes or to reduce the wastage of resources and animal lives involved in the culling of 'unproductive' animals.

Box 4.10: 'Surrogate sires'

Genome editing has been used to create 'surrogate sires', whereby the *NANOS2* gene is edited in male pigs to make them incapable of producing their own sperm, without otherwise affecting testicular function.[603] This allows sperm precursor cells taken from elite donor pigs to be transferred into the testes of the edited animals. These grafts then produce mature gametes that can fertilise females. This process enables the radical expansion and diffusion of elite sperm lines, producing more animals with the desired phenotypes.[604] A similar technique has been applied in chickens to create surrogates for elite breeding.[605]

Sexing laying chickens in the egg

4.60 In the case of laying chickens, genome editing has been proposed as a method of avoiding the mass disposal of male hatchlings. In laying systems, male hatchlings do not have economic value since they cannot lay eggs, and the breeds that are better adapted to egg laying underperform as broiler breeds in terms of meat production. Chicks are therefore sexed after hatching and male chicks are disposed of, conventionally by

[600] Dutta P, Talenti A, Young R *et al.* (2020) Whole genome analysis of water buffalo and global cattle breeds highlights convergent signatures of domestication *Nature Communications* **11(1)**: 4739.

[601] The Beef Site (10 November 2020) *Results from domestication study could enhance livestock development*, available at: https://www.thebeefsite.com/news/55895/results-from-domestication-study-could-enhance-livestock-development/.

[602] Martins Pereira E, Silva Júnior E, da Costa E *et al.* (2021) The potential for infectious disease contamination during the artificial insemination procedure in swine, in *Success in artificial insemination - quality of semen and diagnostics employed*, Lemma A (Editor), available at: https://www.intechopen.com/chapters/40079.

[603] Park K-E, Kaucher AV, Powell A *et al.* (2017) Generation of germline ablated male pigs by CRISPR/Cas9 editing of the NANOS2 gene *Scientific Reports* **7(1)**: 40176; and Ciccarelli M, Giassetti MI, Miao D *et al.* (2020) Donor-derived spermatogenesis following stem cell transplantation in sterile NANOS2 knockout males *Proceedings of the National Academy of Sciences* **117(39)**: 24195-204.

[604] The Roslin Institute (13 January 2017) *Gene-edited pigs to help spread desirable traits*, available at: https://www.ed.ac.uk/roslin/news-events/archive/2017/gene-edited-pigs-to-help-spread-desirable-traits.

[605] Taylor L, Carlson DF, Nandi S *et al.* (2017) Efficient TALEN-mediated gene targeting of chicken primordial germ cells *Development* **144(5)**: 928-34.

maceration (although gassing with a high concentration of carbon dioxide is also a permitted approach).[606]

Box 4.11: Discerning the sex of chicken embryos

Researchers have used genome editing tools to place a marker gene on the chromosome of chicken embryos that directs male phenotypic development. This fluoresces when a laser is shone through the egg, allowing eggs containing male embryos to be disposed of immediately after laying, thereby freeing up 50 per cent of incubator space (where the eggs are maintained at 37 degrees Celsius for 22 days) and avoiding the need to dispose, after incubation, of the 50 per cent of hatchlings that are male.[607]

Other production traits

4.61 In addition to techniques to increase the quantity and sensory quality of animal products, researchers have also explored ways of using new breeding technologies to control other valued characteristics of animal products, such as allergenicity, and to produce novel chemicals that may have nutritional, medicinal, biomedical, or industrial value.

Box 4.12: Quality traits

Cows that produce milk with very low levels or none of the protein beta-lactoglobulin (BLG), a major milk allergen, have been produced. Zinc finger nucleases were used in research in New Zealand to produce cows fee of BLG in 2018.[608] In another experiment, a calf was genetically altered to express microRNAs that effectively interfered with the production of the allergen, demonstrating that the approach could be used to alter milk composition to avoid an allergic response in human consumers.[609] A similar result was obtained in goats using CRISPR-Cas9 in 2017.[610] In research from Russia reported in 2021, CRISPR-Cas 9 was used to knock out genes for BLG (*PAEP*) and the BLG-like protein gene (*LOC100848610*) in a cloned cow with a view to cloning BLG-deficient cattle.[611]

Approaches have also been developed to remove or alter protein allergens in chicken eggs. Germline molecular interventions in poultry have proved challenging owing to the difficulty in accessing poultry zygotes.[612] Researchers have recently demonstrated that CRISPR-Cas9 can be used to produce mutations in two egg white genes, *ovalbumin*

[606] On avian sex determination, see: Smith CA, Major AT, and Estermann MA (2021) The curious case of avian sex determination *Trends in Genetics* **37(6)**: 496-7.

[607] Tizard ML, Jenkins KA, Cooper CA *et al.* (2019) Potential benefits of gene editing for the future of poultry farming *Transgenic Research* **28(2)**: 87-92. See also: RSPCA (14 July 2020) *Why are male chicks culled in the egg industry and how can this be changed? With Mark Tizard from CSIRO [podcast]*, available at: https://www.rspca.org.au/media-centre/humane-food-podcast/episode-s2e5.

[608] Wei J, Wagner S, Lu D *et al.* (2015) Efficient introgression of allelic variants by embryo-mediated editing of the bovine genome *Scientific Reports* **5(1)**: 11735.

[609] Jabed A, Wagner S, McCracken J *et al.* (2012) Targeted microRNA expression in dairy cattle directs production of β-lactoglobulin-free, high-casein milk *Proceedings of the National Academy of Sciences* **109(42)**: 16811-6. As an alternative, it is possible to separate allergens from milk although this is currently expensive and has drawbacks; see, for example, Mao X, Zhang G-F, Li C *et al.* (2017) One-step method for the isolation of α-lactalbumin and β-lactoglobulin from cow's milk while preserving their antigenicity *International Journal of Food Properties* **20(4)**: 792-800.

[610] Zhou W (2017) Generation of beta-lactoglobulin knock-out goats using CRISPR/Cas9 *PloS One* **12(10)**: e0186056.

[611] Singina GN, Sergiev PV, Lopukhov AV *et al.* (2021) Production of a cloned offspring and CRISPR/Cas9 genome editing of embryonic fibroblasts in cattle *Doklady Biochemistry and Biophysics* **496(1)**: 48-51.

[612] Oishi I, Yoshii K, Miyahara D *et al.* (2016) Targeted mutagenesis in chicken using CRISPR/Cas9 system *Scientific Reports* **6(1)**: 23980. See generally: Doran TJ, Cooper CA, Jenkins KA *et al.* (2016) Advances in genetic engineering of the avian genome: "realising the promise" *Transgenic Research* **25(3)**: 307-19. See also: Schusser B, Collarini EJ, Yi H *et al.* (2013) Immunoglobulin knockout chickens via efficient homologous recombination in primordial germ cells *Proceedings of the National Academy of Sciences of the United States of America* **110(50)**: 20170-5.

and *ovomucoid*, in chicken primordial germ cells in order to produce chimaeric roosters and breeding lines containing the mutation.[613] In another experiment, researchers used PCR site-directed mutagenesis to give rise to a mutant protein in egg white that can be used in immunotherapy to induce tolerance to ovomucoid protein (Gal d 1), the dominant allergen in chicken egg white, and in the diagnosis of egg allergies.[614] The CRISPR-Cas9 system has also been used to produce hens with *ovomucoid* (*OVM*) gene mutations that laid eggs with whites lacking the ovomucoid protein.[615]

The second genetically modified animal approved for human consumption (after the AquAdvantage salmon) is a line of domestic pigs generated by the biotechnology company Revivicor. Like the salmon, the GalSafe pig was modified using transgenic technology. The meat from the pigs lacks detectable alpha-gal sugar, which is present in beef, lamb, and pork, and causes an allergic reaction in people with alpha-gal syndrome.[616] The condition is attributable to bites by an ectoparasitic tick, notably the lone star tick that is prevalent in the south-eastern US, but the disease is also prevalent in Europe.[617] The modified pigs were approved by the US Food and Drug Administration (FDA) at the end of 2020 for both human food and potential therapeutic uses as xenografts (the only animal to receive such dual approval, although three other animals had been previously approved for biomedical purposes).[618]

Environmental impact

4.62 Among the principal impacts of food and farming systems are those on the physical environment. They include impacts on soils and watercourses through pollution and fertilisation, impacts on the biosphere, including effects on biodiversity and ecosystems, impacts on the physical landscape and on human and animal geography, and impacts on the atmosphere and climate. While these effects may be detected locally, the effects of the global food and farming system contribute and combine to produce effects at a planetary scale. It is widely recognised that human activity has had decisive effects on planetary systems, which some refer to under the rubric 'Anthropocene'.[619] Whether this is dated from the agricultural revolution in the Neolithic age, the industrial revolution in modern times, or the 'Great Acceleration' in growth after the Second World War, the impacts of food and farming systems will form a significant component. As we have noted above, however, the economic structure of food systems tends to externalise the costs of control or remediation so far as possible, so that it requires some external intervention to impose an appropriate measure of accountability on producers.

[613] Oishi I, Yoshii K, Miyahara D *et al.* (2016) Targeted mutagenesis in chicken using CRISPR/Cas9 system *Scientific Reports* **6(1)**: 23980.

[614] Dhanapala P, Withanage-Dona D, Tang MLK *et al.* (2017) Hypoallergenic variant of the major egg white allergen Gal d 1 produced by disruption of cysteine bridges *Nutrients* **9(2)**: 171-82. See also: Tizard ML, Jenkins KA, Cooper CA *et al.* (2019) Potential benefits of gene editing for the future of poultry farming *Transgenic Research* **28(2)**: 87-92.

[615] Mukae T, Yoshii K, Watanobe T *et al.* (2021) Production and characterization of eggs from hens with ovomucoid gene mutation *Poultry Science* **100(2)**: 452-60.

[616] Revivicor has indicated that intends to sell meat from GalSafe pigs initially by mail order rather than in supermarkets; see: STAT News (14 December 2020) *FDA approves genetically altering pigs, to potentially make food, drugs, and transplants safer*, available at: https://www.statnews.com/2020/12/14/fda-approves-genetically-altering-pigs/.

[617] The syndrome was reported by around a fifth of people attending one German allergy unit; see: Fischer J, Huynh HN, Hebsaker J *et al.* (2020) Prevalence and impact of type I sensitization to Alpha-gal in patients consulting an allergy unit *Int Arch Allergy Immunol* **181(2)**: 119-27.

[618] See: US Food & Drug Administration (14 December 2020) *FDA approves first-of-its-kind intentional genomic alteration in line of domestic pigs for both human food, potential therapeutic uses*, available at: https://www.fda.gov/news-events/press-announcements/fda-approves-first-its-kind-intentional-genomic-alteration-line-domestic-pigs-both-human-food.

[619] See: British Geological Survey (2021) *Anthropocene*, available at: https://www.bgs.ac.uk/geology-projects/anthropocene/.

Reducing greenhouse gas emissions

4.63 According to the Food and Agriculture Organization of the United Nations (FAO), livestock production accounts for approximately 14.5 per cent of all anthropogenic greenhouse gas (GHG) emissions globally. Approximately 65 per cent of these emissions are attributable to cattle. These are generated throughout the supply chain, including via fossil fuel use in feed production, processing, and transport, through to enteric fermentation in ruminants, which represents 39 per cent of the total emissions. Beef cattle have the highest emission intensities among farmed animals (almost 300 kilograms of CO_2 equivalent per kilogram of protein produced) although there is a large variation in emission intensity within and between production systems.[620] However, while 27 per cent of livestock emissions are in the form of carbon dioxide (CO_2), 44 per cent are in the form of methane (CH_4) and the remaining 29 per cent, nitrous oxide (N_2O), which are considerably more environmentally damaging. Thus, reducing N_2O and CH_4 emissions could have a significantly disproportionate effect in reducing overall CO_2 equivalent emissions.[621]

4.64 Several strategies are being explored to reduce livestock GHG emissions, including herd management, control of dietary intake, manipulation of the microbiome, and waste management. Research has found that methane production and emissions in ruminants show significant heritability, and some have suggested that genetic selection could achieve a reduction of 10 to 20 per cent in methane production from dry matter during digestion.[622] However, the factors involved are complex.[623] Genome editing strategies have been suggested but the claims of one report that "As the individual genes responsible for the presence of these microbes are identified, it will become straightforward to use gene editing to knock out those most responsible for high methane production bacteria or increase the expression of others that favor low-methane species" seem strikingly confident.[624]

4.65 These seem to be areas in which gains are still to be had from selective breeding, though combined with herd, diet, grazing, and waste management strategies. It may be that selective breeding of livestock using genomic selection methods offers a way of reducing enteric methane emissions: genomic selection allows for the efficient selection of traits that are difficult to measure, and breeding for low methane emission has the advantage that it will not be subject to regression to pre-intervention emission levels, unlike some other interventions (e.g., some forms of rumen manipulation).[625]

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620 FAO (2013) *Tackling climate change through livestock*, available at: http://www.fao.org/3/i3437e/i3437e.pdf.

621 See Chapter 2.

622 Henry B, and Eckard R (2009) Greenhouse gas emissions in livestock production systems *TG: Tropical Grasslands* **43(4)**: 232-8; and Pickering NK, Oddy VH, Basarab J *et al.* (2015) Animal board invited review: genetic possibilities to reduce enteric methane emissions from ruminants *Animal* **9(9)**: 1431-40. See also: WIRED (9 June 2017) *Canada is using genetics to make cows less gassy*, available at: https://www.wired.com/story/canada-is-using-genetics-to-make-cows-less-gassy/. A recent study found that the cumulative effect of the rumen microbiome on cattle methane production was 13% and host genetics (heritability) was 21%. The effect of each factor was found to be mostly independent of the other; see: Difford GF, Plichta DR, Løvendahl P *et al.* (2018) Host genetics and the rumen microbiome jointly associate with methane emissions in dairy cows *PLOS Genetics* **14(10)**: e1007580. Another study found that the composition of the rumen archaeal population has a larger impact on methane production than their abundance; see: Tapio I, Snelling TJ, Strozzi F *et al.* (2017) The ruminal microbiome associated with methane emissions from ruminant livestock *Journal of Animal Science and Biotechnology* **8(1)**: 7.

623 Saborío-Montero A, López-García A, Gutiérrez-Rivas M *et al.* (2021) A dimensional reduction approach to modulate the core ruminal microbiome associated with methane emissions via selective breeding *Journal of Dairy Science* **104(7)**: 8135-51.

624 Information Technology & Innovation Foundation (2020) *Gene editing for the climate: biological solutions for curbing greenhouse emissions*, available at: https://itif.org/publications/2020/09/14/gene-editing-climate-biological-solutions-curbing-greenhouse-emissions.

625 Pickering NK, Oddy VH, Basarab J *et al.* (2015) Animal board invited review: genetic possibilities to reduce enteric methane emissions from ruminants *Animal* **9(9)**: 1431-40.

4.66 As well as breeding for low methane production, livestock could be bred for better nitrogen conversion efficiency and to urinate more frequently, or walk while urinating, in order to reduce nitrogen concentrations in the soil.[626] 'Enviropigs' with improved phosphate digestion have been proposed.[627] It is changes to the management of production systems, however, that appear to have most to contribute in relation to GHG emission management. Since this implies a high level of control of environmental factors, it has been argued that intensive production systems make it possible to capitalise on the ease of dietary modification and supplementation, while finding methane reduction strategies that work for pasture systems presents significant difficulties.[628] However, there are also claims to the contrary and more research is required in this area.

4.67 The most promising applications of biotechnology for the reduction of GHG emissions from livestock farming appear to lie not in the modification of the livestock themselves but mainly in the production and supplementation of animal feed, which can have a greater impact on biodiversity (e.g., deforestation, pasture) and water management (irrigation).[629] The most significant measures available to address environmental impacts, however, concern efficiency of livestock systems and the overall reduction of livestock in favour of plant-based foods, where possible.[630]

Biodiversity

4.68 It was noted above that, while domestication has resulted in a substantial increase in absolute numbers of animals on the planet, it has been accompanied by a significant reduction in biodiversity, both within domesticated animal populations and through pressure on wild animals and their habitats, for example where land is turned over to agricultural use, to the point where the total biological mass of the world's livestock is now more than ten times that of all wildlife combined.[631]

4.69 One of the consequences of selective breeding is reduction in genetic diversity as animals are bred to enhance and fix traits, partly as a consequence of the lack of coordination and communication among breeders aiming for common goals. Genome editing could be used to move genetic traits between lines to expand the available genetic diversity without the linkage drag associated with traditional introgression. It might even be used to remove deleterious traits from breeding stocks which have undergone intensive breeding for desired traits using a combination of traditional breeding and genomic selection.

4.70 Diversity can also be damaged by the escape of domestic breeds to interbreed with wild varieties. This is particularly a problem with fish farming. Millions of farmed salmon escape from farms each year and reproduce with wild fish, reducing the diversity of wild

[626] Henry B and Eckard R (2009) Greenhouse gas emissions in livestock production systems *TG: Tropical Grasslands* **43(4)**: 232-8.
[627] Forsberg CW, Phillips JP, Golovan SP *et al.* (2003) The Enviropig physiology, performance, and contribution to nutrient management advances in a regulated environment: the leading edge of change in the pork industry *Journal of Animal Science* **81(14)(supplement 2)**: E68-E77.
[628] Monteiro ALG, da Fonseco Faro AMC, Peres MTP *et al.* (2018) The role of small ruminants on global climate change *Acta Scientiarum Animal Sciences* **40**.
[629] Herrero M, Henderson B, Havlík P *et al.* (2016) Greenhouse gas mitigation potentials in the livestock sector *Nature Climate Change* **6(5)**: 452-61; and Rotz A, and Rotz CA (2020) Environmental sustainability of livestock production *Meat and Muscle Biology* **4(2)**: 1-18.
[630] EU Technical Expert Group on Sustainable Finance (2019) *Taxonomy technical report* available at: https://www.ecologic.eu/16796; see also Chapter 6 below.
[631] Van Oosterhout C (2021) Mitigating the threat of emerging infectious diseases; a coevolutionary perspective *Virulence* **12(1)**: 1288-95.

gene pools and diluting the traits that give wild fish advantages when dealing with predators.[632] One application of genome editing (as noted above in the case of the AquAdvantage salmon) may be to make versions of farmed salmon that are sterile and thereby unable to reproduce with wild fish populations.[633]

4.71 It should be noted that any intervention that increases productivity has the potential to reduce negative environmental impacts. For example, the development of heat-tolerant cows (see Box 4.7) has been advocated for environmental reasons, on the grounds that one heat-tolerant cow might produce the same output as several unedited cows but use a fraction of the water and energy, produce less waste, and emit less GHG. More generally, improvements in feed conversion ratios will have a similar effect. It has been noted that this may bring objectives relating to animal welfare and environmental goals into conflict. However, given the inefficiency of livestock production as a source of nutrition, more generally still, the most effective way to reduce environmental impact in many regions may be simply to reduce the numbers of livestock farmed.

Conclusions

4.72 All the applications of breeding technologies discussed in this chapter provide a prospective, though in most cases still uncertain, response to a challenge that has come about as a consequence of human action or to satisfy a human want. The appeal of these innovations is largely that the solution they offer comes at less cost than the alternative, or because the underlying problem is too difficult to address by other means, or that the responsibility for doing so can be deferred or displaced.

4.73 Some have asserted the principle that we should prefer to adapt the environment to animals rather than animals to environment.[634] However, all systems involve a degree of co-adaptation and we have argued (see Chapter 3) that, in some cases, biological parameters may be reasonable targets for intervention alongside environmental ones. Rather than judging the appropriate course in accordance with an absolute principle, we have proposed an approach based on a symmetrical conception of justice, one that includes both humans and animals in its scope.

Restricted and general objectives

4.74 Diseases in farmed animals are a contributory factor to a number of the challenges facing the food and farming system: they have a negative impact on animal welfare; they can be economically ruinous for farmers; they can affect human wellbeing directly; and both the diseases or their incautious treatment can affect human health, ecosystems, and the environment. It is tempting to see many of these as 'diseases of industrial farming', and intensive husbandry systems have undoubtedly made their effects particularly devastating. They are not restricted to industrial systems, however. Different systems, in fact, have different kinds of vulnerability: in one case it might arise from the greater

[632] Yeates SE, Einum S, Fleming IA *et al.* (2014) Assessing risks of invasion through gamete performance: farm Atlantic salmon sperm and eggs show equivalence in function, fertility, compatibility and competitiveness to wild Atlantic salmon *Evolutionary Applications* **7(4)**: 493-505.

[633] Wargelius A, Leininger S, Skaftnesmo KO *et al.* (2016) Dnd knockout ablates germ cells and demonstrates germ cell independent sex differentiation in Atlantic salmon *Scientific Reports* **6(1)**: 21284.

[634] This was, in fact, the preponderant view or participants in our public dialogue; see: Nuffield Council on Bioethics (2021) *Online public dialogue on genome editing in farmed animals: research by Basis Social on behalf of the Nuffield Council on Bioethics*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/public-dialogue-on-genome-editing-and-farmed-animals.

concentration of animals; in another, from the greater risk of exposure to vectors (other animals, especially wild ones).

4.75 In principle, the use of genome editing to confer inbuilt resistance to disease has a number of advantages. In theory, the precise control allows the inclusion of traits with a simple and well-characterised genetic basis without, in theory, disrupting other gene functions. Unlike conventional breeding, this can, in theory, be achieved directly and without a deterioration in the production traits of the breed. Once accomplished in a breeding line, the introduced traits can be fixed and passed on through conventional breeding to the founder animal's descendants. Inbuilt resistance should also help to reduce the need for veterinary treatment and handling, and the use of antimicrobials in farming, which represents a threat to humans, animals, and the wider ecosystems.[635] This is particularly relevant in the case of marine animals raised in open sea pens.[636] It could be a benefit both to small-scale outdoor systems (which are not biosecure) as well as large-scale indoor systems (where a breach of biosecurity could be catastrophic).[637] On the other hand it may perpetuate, and even encourage and increase the dense stocking of animals in industrial systems. Where innovations occur will depend on their affordability to producers of different sizes and how efficiently they may be incorporated into different systems.

4.76 The acceptability of such procedures is open to considerable debate and needs to be examined in the context of a broader discussion about the acceptability and desirability of different husbandry systems, and the consequences of any intervention for food supply, diet, health, livelihoods, and the environment. Where we find enhancing disease resistance to be morally unacceptable is where it involves adapting animals purely so that they may endure conditions of low welfare without associated adverse health effects.

Rate of genetic gain

4.77 We began this chapter with a conjecture about the potential for genome editing to become the presumptive technology for 'genetic gain', given favourable regulatory conditions. We recognised the concern that the unleashing of an 'acceleration' of breeding trajectories could aggravate those trajectories that have already been shown to have adverse effects for farmed animals, human consumers, and the environment. This represents a conceivable vision of a future state of affairs, but it may not be the most plausible one. As our itinerary has progressed through the field, we have been obliged to make a more nuanced assessment of the relationship between the nature of

[635] Genome editing also offers the potential to develop precision antimicrobials, which would have the advantage of being able to target bacteria based on their genetic sequence, rather than by the indiscriminate use of current antibiotic medicines; see: Marquardt RR and Li S (2018) Antimicrobial resistance in livestock: advances and alternatives to antibiotics *Animal Frontiers* **8(2)**: 30-7. In 2014, a number of studies reported that CRISPR-Cas9 could be used to selectively remove antimicrobial resistance genes from bacterial populations; see: Pursey E, Sünderhauf D, Gaze WH *et al.* (2018) CRISPR-Cas antimicrobials: challenges and future prospects *PLOS Pathogens* **14(6)**: e1006990.

[636] Miranda CD, Godoy FA, and Lee MR (2018) Current status of the use of antibiotics and the antimicrobial resistance in the Chilean salmon farms *Frontiers in Microbiology* **9(1284)**. Another beneficial consequence of this would be the reduction or elimination of trace elements of antibiotics in animal products, which can affect product quality. The UK Government runs a surveillance programme to ensure that these trace elements do not exceed certain levels prescribed by the European Medicines Agency, for reasons relating to human health; see: Veterinary Medicines Directorate (2018) *Residues surveillance: guidance*, available at: https://www.gov.uk/guidance/residues-surveillance. (On the other hand, some antimicrobials, e.g., ionophores, are known to reduce methane production by inhibiting hydrogen production; see: Brouček J (2018) Options to methane production abatement in ruminants: a review *Journal of Animal and Plant Sciences* **28(2)**: 348-64.)

[637] If genome-edited resistant breeds were available to support small outdoor systems, it would be perverse – almost an act of sabotage – to deny these to larger or indoor systems. If the latter kinds of systems raise problems, the solution must be something other than to give them a handicap in terms of their relative vulnerability to disease.

the 'gain' and the suitability of the approach, and a more critical assessment of their desirability. In some cases, biotechnologies may offer prodigious and rapid 'gains', in other cases 'conventional' breeding will be more effective and, in others, adaptation of the environmental conditions is the most or only effective course. Most conventional 'production traits' appear to be highly polygenic, making them refractory to genome editing strategies in most domesticated species. It seems probable that genome editing will find its initial applications in introducing additional monogenic traits to already selectively bred livestock. But we cannot generalise or predict with any great certainty what will happen in the future. How new breeding technologies are used will depend partly on the ingenuity of the technologies in relation to the constraints of biology, and partly on how their use is incentivised and controlled.

Trajectory of genetic gain

4.78 It is not merely the rate of the 'gain' that is relevant, but its orientation. It is here that the question of how biotechnologies are implicated in different visions of the future of food and farming systems becomes important. On the face of it, for example, it appears that inherent resistance to disease will benefit any pig: those reared in back yards, who may come into contact with wild vectors, and those reared in intensive herds, through which disease might spread with devastating consequences. The same may be true with heat-tolerant cows, which will be beneficial to the subsistence farmer in the global South but also to the global corporation managing feedlots in the US. The effect may, however, be asymmetrical. The efficiency gain may be greater for systems of the second type than for those of the first type, helping to entrench these through market advantage, increase the division between different parts of the industry, and lead to the atrophy of those left without a market niche. Insofar as the production of farmed animals is driven by the economic forces of the market for animal products, the strongest of the incentives that steer technology development and adoption are those of increased productivity. Though breeders now generally recognise these effects, they remain enmeshed in contradictory incentives. A failure to account for the social and environmental costs within the food and farming system effectively subsidises extractive forms of production because those costs are met by others.[638]

4.79 Animal breeding generally (in contrast to genetic interventions) is unusually lightly regulated. We have found that, historically, the incentive to pursue increased productivity has had a deleterious effect on animals, on farmers and their communities, and the environment as a result of the sort of farming practices in which it has been implicated. Conventional selective breeding and husbandry systems have already overshot a rate of productivity gain that is consistent with animals' capacity for a good life in many cases and, in many cases, stored up future harms for both humans and non-human animals in the form of unmitigated externalities. While many breeders now claim to have adopted 'balanced' breeding approaches, it is difficult to verify the effects of this because the data are lacking. In particular, there is a lack of relevant, prospectively collected longitudinal data on breeding outcomes or on the lives of animals on farms. This is perhaps not surprising, given that the incentives breeders have had to collect data have so far been largely to support their breeding strategies rather than to challenge them. Three aspects of animal breeding, in particular, require further scrutiny and management.

4.80 The first is the use of breeding to improve the resistance of animals to health conditions where the cause of ill health is the poor conditions in which they are kept or the practices to which they are subject. In this case there is a risk that breeding simply produces

[638] FAO (2017) *Full-cost accounting*, available at: http://www.fao.org/nr/sustainability/full-cost-accounting/en/.

animals that can tolerate poor conditions better without ostensible adverse health impacts, thereby masking the fact that they continue to live in unacceptable conditions. **Animals should not be bred to enhance traits merely so that they may better endure conditions of poor welfare**.[639]

4.81 The second aspect is in relation to potential intergenerational drift in the *capacities* required for living a good life as a result of successive phenotypic alteration over generations through the pursuit of breeding goals. An obvious example is grotesquely bred animals that require obstetric intervention to give birth. Another is the musculoskeletal problems in fast-growing broiler chickens, which suggest that their physiology has not evolved in step with the production traits that have been the target of breeding programmes.[640] **Animals should not be bred in ways that diminish their inherent capacities to enjoy experiences that constitute a good life**.[641]

4.82 The third aspect that requires consideration, insofar as there is an accepted need for state action to mitigate market failure, is how to decide between distinct visions of a future food and farming system that can shape coherent policy objectives, and how biotechnologies are implicated in these. **Any revision of regulation affecting new breeding technologies should be preceded by a thoroughgoing policy review that considers the effects not only on production but on the organisation of the food and farming system and on society more generally; in particular it should consider and control the potential of innovation to support damaging farming practices**.[642] This returns us, once again, to the question of securing a just food and farming system, of the role of consumers and citizens, and the need to attend to alternative, excluded, or incommensurable interests.

[639] See chapter 7 (Recommendation 2).
[640] Paxton H, Anthony NB, Corr SA *et al.* (2010) The effects of selective breeding on the architectural properties of the pelvic limb in broiler chickens: a comparative study across modern and ancestral populations *Journal of Anatomy* **217(2)**: 153-66.
[641] See chapter 7 (Recommendation 2).
[642] See chapter 7 (Principle 4 and Recommendation 10).

Chapter 5

From consumers to citizens

pathways and visions

Chapter 5 – From consumers to citizens: pathways and visions

Chapter overview

This chapter explores how food and farming systems are shaped by the demands placed on them by consumers and how policy may be informed by the views expressed by citizens when they come together to discuss the kind of food and farming system they want.

Research into public attitudes to genetically modified organisms and novel foods suggests that these attitudes are complex and informed by multiple, deeply rooted factors, but that introducing new breeding technologies will be controversial and relate to how they are framed.

When they think in the mode of potential consumers people tend to be most concerned with product safety and with information that helps them to exercise choices about which products to buy. They are not reassured about the safety of products of biotechnologies being presented as ways to 'speed up' natural processes.

When people consider new breeding technologies as citizens, they appear more concerned with effects on the food system as a whole, on farmed animals, on social justice and on the shared environment. The participants in a public dialogue held alongside our inquiry expressed the strong belief that historical breeding had led to adverse outcomes for farmed animals. Their main concerns were about the purposes for which new breeding technologies would be used and whose interests they would serve.

The chapter discusses alternative and complementary pathways to address food and farming challenges, including: radical intensification; novel sources of protein; reducing food waste; and reducing meat intake at a population level.

Key points

- When acting as consumers people focus mainly on product safety and individual choice.
- As citizens they tend to be more concerned with animal welfare and social justice.
- The technical details of breeding technologies are relatively unimportant so long as their use is properly regulated.
- The future of food and farming systems requires policy decisions at a national level that should be informed by citizen engagement and public debate.

Introduction

5.1 We began this inquiry because we found, in preparing the Nuffield Council 2016 report on genome editing technologies, that applications in farmed animals were comparatively near term (compared to many other proposed applications), raised distinctive ethical issues (owing to their effect on sentient beings), but were surprisingly little discussed in public.[643] At the same time, we recognised that public views were both important and,

[643] Nuffield Council on Bioethics (2016) *Genome editing: an ethical review*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-an-ethical-review.

potentially, very influential with regard to the adoption of agricultural biotechnologies, just as they had been in the early years of the present century. As we are now moving towards questions of governance, the subject of this chapter is the various kinds of interests that are expressed in civil society and their role in the governance of agricultural technologies.

5.2 Much of the contemporary discussion concerns how genome editing (or the products of genome editing, or a subset of these products) might be distinguished from or associated with, on one hand, genetic modification using first-generation biotechnologies and the transgenic organisms that result from it and, on the other hand, conventional breeding practices, including accelerated breeding. This is not only a question of conceptual differentiation in the sense in which, in Chapter 1, we discussed the continuity or rupture of modern breeding practices with historical processes of domestication, however. In the scheme governing the market for agricultural products, such identifications and distinctions acquire specific practical significance. They can determine which regulatory pathway different products follow (see Chapter 6) but, at a conceptual level, they can also have the effect of concealing or revealing matters that people find significant, and even of including or excluding them from public and policy discourse.

5.3 We noted in Chapter 2 that one of the challenges facing the food and farming system arises from the politicisation of public debates about food safety and about the use of genetic technologies, particularly in the UK but also in continental Europe and elsewhere.[644] This challenge has been compounded by some maladroit attempts to instrumentalise public engagement to inform policy development and to constrain it narrowly (e.g., around issues of risk), stoking mistrust and prejudice in a way that successive initiatives have had to struggle to overcome.[645]

Public attitudes to biotechnologies and novel foods

5.4 The use of biotechnologies in agriculture has been discussed over the last half-century since Boyer and Cohen demonstrated recombinant DNA techniques, and especially since products containing genetically modified plants went on sale in the 1990s. During this time, many attempts have been made to gauge public opinion and to explore the foundations and development of attitudes among non-specialists. As part of the research to inform this project, we commissioned a review of the literature on public attitudes towards genetically modified organisms (GMOs) and novel foods.[646] Our aim was to understand how much is known about public attitudes and how much of what is known might be relevant to genome editing (rather than earlier generations of biotechnology) in farmed animals (as distinct from other kinds of organism such as crop plants).

5.5 The review found that public attitudes were influenced by the interaction of multiple factors, although the purpose of the application was generally given more importance than the details of the technical processes involved. Attitudes were strongly linked to

[644] Horlick-Jones T, Walls J, Rowe G *et al.* (2006) On evaluating the GM Nation? Public debate about the commercialisation of transgenic crops in Britain *New Genetics and Society* **25(3)**: 265-88; and Macnaghten P, and Habets MGJL (2020) Breaking the impasse: towards a forward-looking governance framework for gene editing with plants *Plants, People, Planet* **2(4)**: 353-65.

[645] Wynne B (2001) Creating public alienation: expert cultures of risk and ethics on GMOs *Science as Culture* **10(4)**: 445-81; and Sciencewise-ERC subgroup on GM dialogue (2011) *Talking about GM: Approaches to public and stakeholder engagement*, available at: https://sciencewise.org.uk/wp-content/uploads/2018/12/Talking-about-GM-published.pdf.

[646] Nuffield Council on Bioethics (2020) *A review of research on public attitudes to genetically modified foods and related areas and their implications for genome editing of farmed animals,* available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering.

complexes of pre-existing values, which were often deeply entrenched. There were two main limitations in the extant literature, however. First, much of the evidence available to gauge and understand public attitudes comes from surveys that, while they capture a broad range of views from a large number of people, offer only limited opportunity to explore the foundations of people's attitudes and how they may respond to interrogation, information, and argument. The second limitation is that, inevitably, very little of the extant research directly addresses the significance of novel and distinctive aspects of biotechnologies such as genome editing.

5.6 These limitations have two consequences for our inquiry. Firstly, the value of any inferences from what is known about public attitudes would appear to depend on the very understanding that is missing: the understanding of the foundations of people's attitudes, rather than the contingent content. It is only in this light that assumptions might be made about their applicability to relevantly similar cases (novel and prospective technologies). Secondly, it seems likely that conceptual distinctions (e.g., the way in which concepts like 'genetic engineering' and 'genome editing' are distinguished) themselves have the potential to be an important area of controversy because they are a focus for arguments about relevant similarity and difference and, therefore, the extent to which they engage foundational perspectives.[647] Indeed, we have already seen this in relation to the question of conceptual continuity/discontinuity between historical and contemporary forms of domestication (discussed in Chapter 1).

5.7 Much of the available evidence concerning public attitudes, moreover, relates to the UK or European public, or the public of the global North. As we have already noted, many of the value chains and economies that comprise the food and farming system are global. As a result of political configurations of power, it may therefore exclude many of those whose interests are nevertheless engaged. These include people in other jurisdictions and, notably, non-human animals.

Box 5.1: Evidence of public attitudes to genomic technologies and novel foods

We commissioned an independent review of research into public attitudes to the use of biotechnologies in agriculture and to novel foods incorporating the products of such technologies. This confirms that a degree of public opposition and concern has persisted over at least the last 20 years, although this has been neither universal nor univocal and there is some evidence to suggest a softening of attitudes over time.

In research, members of the public have been seen consistently to question the need for and benefits of genetically modified foods, with concerns persistently raised around potential risks and 'unnaturalness'. Products that have obvious benefits for consumers have generally been seen as more acceptable than those that merely benefit producers. Applications of biotechnologies in food have tended to be perceived less positively than medical applications, and applications in crops more favourably than in animals. There is not enough evidence to distinguish degrees of approval based on the specific purpose of an innovation, however (e.g., animal welfare, human health, productivity, environment).

How an innovation is presented (e.g., the framing and terminology used) can affect approval or opposition. There are small but significant differences in attitudes to cisgenic interventions (where the alteration is to introduce to one organism a trait found in another organism of the same species) compared to transgenic interventions (where the alteration introduces a trait from a different species). Once again, however, differences in the technical processes involved appear to be much less strongly related to attitudes

[647] See: Nuffield Council on Bioethics (2016) *Genome editing: an ethical review*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-an-ethical-review.

than the nature of the application. Other factors correlated with attitudes to genetically modified foods are as follows.

- Nationality: the US and Spanish public, for example, tend to be more supportive than the majority of Europeans, Japanese, and those in developing economies (though it is not clear whether familiarity leads to support for genetically modified organisms (GMOs) or support leads to their establishment and to greater familiarity).
- Sociodemographic and economic factors: men tend to be more approving than women, younger people more so than older (perhaps reflecting differing attitudes to perceived risk); correlations of attitudes with affluence and education are unclear, however.
- Sociocultural and ideological factors: 'ecological' (rather than consumerist) worldviews, and those that value the natural environment tend to be correlated with opposition to genetic modification, although religious commitments or political affiliations do not seem to correlate.
- Technical knowledge: the conjecture that a higher level of understanding of genetic modification is correlated with greater approval is not well confirmed by the research, though this may be confounded by poor distinction between claimed knowledge and verifiable knowledge.

In terms of attitudes to products, the review notes the following.

- Novelty is a more important factor than the nature of the technical procedures involved when considering foods; there is little evidence that novel genome editing techniques are seen as importantly different from earlier techniques of genetic modification.
- Animal welfare is a theoretical concern arising in 'willingness-to-pay' studies but there is evidence of an 'attitude–behaviour gap', whereby other factors end up determining actual purchasing decisions; it remains unclear how anticipated animal welfare benefits might affect attitudes in combination with considerations such as 'unnaturalness'.

At the time of the review (early 2020) there had been relatively little research on attitudes to the use of genome editing technologies specifically, and most of this had been in relation to human biomedical interventions. In what research there was, agricultural applications tended to enjoy a lower level of approval than biomedical ones (being seen as more alike to human enhancement than therapy).

The review notes a strand of scepticism about the motivations of stakeholders and communicators among those less accepting of genetic technologies and novel foods; when seeking information spontaneously, people often do so to confirm prior attitudes rather than challenge them, and such attitudes, once formed, become well entrenched. This suggests that reflective engagement between those with divergent perspectives will be challenging when it comes to exploring novel sociotechnical possibilities. However, the review notes the potential for questions about the acceptability of biotechnology innovations to be opened up in relation to growing societal challenges such as diet, sustainability, and food security. In summary, the review offers four main conclusions.

1 Attitudes depend upon how members of the public frame the innovations (e.g., whether as technological fixes, novel foods, or the use of animals).
2 The nature of the applications is more important than the technical differences in the procedures used; findings relating to existing biotechnologies may therefore be highly pertinent to the innovations under present consideration.

3 Perceived benefits (more so, even, than risks in the absence of any significant contemporary crisis) are liable to be a critical factor for acceptance.

4 The issue of 'naturalness' and ecological viewpoints are also likely to be important.

* The full review can be read at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering.

Consumers

5.8 A recent book on the experiences of those involved in contemporary British farming reports an observation about the paradoxical behaviour of consumers. It is offered in explanation of the decisions made by a farmer whose major outputs are 'chicken and chips' (450 acres of potatoes and, at any one time, 470,000 meat chickens), produced to meet the specific requirements of major processing companies:

> "If you ask a hundred people on their way into a supermarket what they think of poultry production, the majority will say they're all in favour of free-range, organic, £8 corn-fed happy hens. If, when those same individuals emerge from the supermarket a while later, you have a look at what's in their bags, it's the ordinary £4 chicken, the 3-for-2 version, no make-up, no fancy nails."[648]

5.9 For most people, the cost of food is a significant item in their household expenditure. Changes in the cost of food disproportionately affect those on lower incomes. Nonetheless, as the proportion of household income spent on food and non-alcoholic drinks has fallen over time (on average, from approximately 40 per cent in the 1950s to approximately 10 per cent currently in the UK), what most people now spend on food represents a choice about how they value certain features of food production compared to the consumption of other goods.[649] It is tempting to ask which came first (so to speak): whether people are eating the lower priced chicken because it is an available alternative to the higher priced one, or whether it is available because there is little demand for expensive chickens. As with the chicken and the egg, however, the complex economic relationships that link products and preferences do not simply arise with one as a consequence of the other; they evolve seemingly without agency, with retailers playing the role of guardians of consumer choice.[650] What is implied in the farmer's observation (quoted above), and well confirmed by research, is not that people simply lie about their 'real' preferences.[651] It points, instead, to something more complex: an inherent inconsistency or conflict in people's interests.[652] One way of capturing this tension is between people acting as consumers, pursuing their immediate and individual interests in the world as given to them, and as citizens, notionally legislating for the kind of possible

[648] Bathurst B (2021) *Field work; what land does to people and what people do to land* (London: Profile Books).

[649] This percentage is, naturally, higher for those on the lowest incomes (around 15 per cent in 2018/19, according to the ONS Family Food 2018/19 data (see: Defra (2020) *Family Food 2018/19*, available at: https://www.gov.uk/government/statistics/family-food-201819/family-food-201819)). The Food Foundation calculates that to eat a healthy diet (following the Eatwell Guide) the poorest fifth of UK households would need to spend 40 per cent of their disposable income on food whereas the richest fifth would have to spend just 7 per cent; see: Food Foundation (2021) *The broken plate 2021: the state of the nation's food system*, available at: https://foodfoundation.org.uk/publication/broken-plate-2021.

[650] On retail power, see: Clarke I (2000) Retail power, competition and local consumer choice in the UK grocery sector *European Journal of Marketing* **34(8)**: 975-1002; on the counterproductivity of increasing options see: Iyengar SS, and Lepper MR (2000) When choice is demotivating: can one desire too much of a good thing? *Journal of personality and social psychology* **79(6)**: 995-1006.

[651] Terlau W, and Hirsch D (2015) Sustainable consumption and the attitude-behaviour-gap phenomenon - causes and measurements towards a sustainable development *Journal on Food System Dynamics* **6(3)**: 1-16.

[652] Meyer KB, and Simons J (2021) Good attitudes are not good enough: an ethnographical approach to investigate attitude-behavior inconsistencies in sustainable choice *Foods* **10(6)**: 1317.

world in which they would prefer to live. The way in which such conflicts play out in the prevailing social, political, and economic context helps both to explain and shape the evolutionary trajectory of national food and farming systems.

Consumers' attitudes to genome editing

5.10 The most substantial exploration of consumer attitudes specifically to products from genome-edited organisms (plants as well as animals) in the UK to date was carried out by Ipsos MORI on behalf of the Food Standards Agency in 2021.[653] This was carried out in the context of a UK Government consultation on the reclassification of some genome-edited organisms to remove them from the regulatory scheme for genetically modified organisms, which has been in effect across the European Union since 2001.[654] The research began from implicit assumptions that a meaningful difference could be found between genome-edited organisms and the products of recombinant DNA technology (with which they were contrasted), and that well-founded opinions would therefore require a basic understanding of the processes in question. From there it sought to examine responses to genome-edited products in terms of the perception of potential benefits and risks. The findings offer insight into the complexity of public responses to genome-edited foods, which include broader considerations such as animal welfare and the environment that spilled out of the initial frame. Perhaps the two most salient themes to emerge, however, were those of the risk of adverse or unanticipated consequences and of the effect of competing and vested interests.

5.11 In the workshops that formed part of the initiative, the question of risk often appears linked to judgements about how 'natural' or familiar a process is.[655] This conclusion may, however, merit further testing for at least two reasons, albeit ones that appear to pull in different directions. The first is that it appears to rely on an unchallenged assumption that minor or incremental genomic mutations, such as those that occur without deliberate human intervention, are relatively benign. But a simple point mutation in the genome may have a significant and possibly devastating effect on phenotype.[656] The second reason is that, in relation to risk, the appeal to what is 'natural' is often a cipher for slow evolutionary changes that have had a chance to prove themselves in real world environments, often over many generations, so that adverse consequences may come to light or be weeded out by 'natural' selection.[657] What 'speeds up nature' is, in this sense, 'unnatural'. It is therefore neither surprising nor unreasonable that, even if small alterations in the genome were reliably correlated with small changes in phenotype, and even accepting that genome-edited products and transgenic products should be

[653] Ipsos MORI (2021) *Consumer perceptions of genome edited food*, available at: https://www.food.gov.uk/research/research-projects/consumer-perceptions-of-genome-edited-food.

[654] The regulatory regime for genome edited and genetically modified organisms, and how this might be revised, is discussed in more detail in Chapter 6.

[655] Thus: "Framing genome editing as a process that 'speeds up nature', with the outcomes achieved as the same as those which occur through conventional breeding, as this research did, is likely to result in the application of the technique being perceived by the public as more natural, and therefore more acceptable." Ipsos MORI (2021) *Consumer perceptions of genome edited food*, available at: https://www.food.gov.uk/research/research-projects/consumer-perceptions-of-genome-edited-food. .

[656] See, for example, The Roslin Institute (2021) *Roslin response to UK Government consultation on gene editing*, available at: https://www.ed.ac.uk/roslin/research/roslin-response-uk-gov-consultation-gene-editing.

[657] See: Nuffield Council on Bioethics (2015) *(un)natural: ideas about naturalness in public and political debates about science, technology and medicine*, available at: https://www.nuffieldbioethics.org/publications/naturalness. See also: Comité Consultatif National d'Éthique (2020) *Opinion 133: ethical challenges of gene editing – between hope and caution*, available at: https://www.ccne-ethique.fr/en/actualites/opinion-133-ethical-challenges-gene-editing-between-hope-and-caution.

regulated separately, many participants still favoured an equivalent level of scrutiny, testing, and regulation for both, at least initially.[658]

5.12 The theme of vested and competing interests also surfaced in the workshops. There was scepticism that the use of genome editing would deliver significant public benefits rather than simply securing commercial benefits for large producers and retailers. The general response to this was to call for measures to 'empower' consumers rather than to call for direct government intervention in the industry. The envisaged measures were clear and explicit labelling, to support choice among the different products offered for sale. The exception, of particular relevance to our present inquiry, was where the genome editing technologies were applied to animals. In this case there was a recognition of the potential for commercial use of biotechnologies to have an adverse effect on the welfare of animals and of the need for robust protections against this.[659]

5.13 The finding of a preference for 'empowering' consumer choice rather than imposing further market regulation is interesting and invites further exploration of, for example, whether this outcome is an artefact of the 'consumer-orientated' framing of the workshops or whether, as some of the participants' expressed views suggest, it betokens a sense of inevitability or disempowerment.[660] It is unclear, in other words, whether consumers believe that by exercising choices in the marketplace they have the power to shape the food and farming system, or whether they simply wish to be able to detach themselves from involvement in sectors of which they do not approve.

Citizens

5.14 The kinds of question that preoccupy people as individual consumers tend to bear on how the food system is governed, for example to ensure products are checked to make sure that they are safe to eat or to enable consumers to exercise choice through accurate and informative labelling and fair pricing. When people think of themselves as citizens, it is to recognise their dependence on the actions or forbearance of others for the state and sustainability of this wider system. The questions that preoccupy people as citizens are therefore different from those in which they are interested as consumers. They are about *what kind of food system* will assure them of access to food over the long term, in a way that takes care of the natural and social environment in which they live, and protects the health and welfare of those subject to it (and, also, their descendants). In other words, questions about how to respond to the kinds of challenge that we discussed in Chapter 2.

5.15 The question of how public views are expressed, debated, and accounted for in public policy is a subject of considerable academic and political interest. We do not propose to discuss it at length here, except to make the following three points. The first is the empirical observation that the implementation of biotechnology in the food and farming system clearly matters to sections of the public, and public views about this can clearly matter very much in relation to policy.[661]

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[658] Ipsos MORI (2021) *Consumer perceptions of genome edited food,* available at: https://www.food.gov.uk/research/research-projects/consumer-perceptions-of-genome-edited-food.

[659] "Workshop participants felt that regulation for genome edited animal products must be accompanied by a review of... animal welfare regulations. This is to ensure that the new technology does not undermine protections for livestock, particularly around intensive farming." Ibid.

[660] For example, those who "were supportive based on the idea that the public have no choice but to accept new technique because conventional methods alone will not be enough to overcome challenges such as increasing populations and demand for food, climate change and food security around the world". Ibid.

[661] Weldon S, and Laycock D (2009) Public opinion and biotechnological innovation *Policy and Society* **28(4)**: 315-25.

5.16 The second point is that ignoring public views is a problem both normatively (it is arguably anti-democratic) and pragmatically (it can increase distrust between members of the public and researchers, industry and policymakers, and incubate more extreme or oppositional responses).[662] This observation is, of course, not peculiar to biotechnology, but it is particularly relevant to the implementation of technologies that raise questions of public interest.

5.17 The third point is that there are many different ways in which researchers, policymakers, and industry can engage with members of the public. All of these modes and methods of engagement have their own distinctive benefits and limitations, but all engagements have consequences. In other words, there are usually better and worse ways of engaging depending on the issue, the context, and the nature of the interests involved.[663] The form of engagement itself is therefore a politically charged question (e.g., the approach taken may silence some interests or amplify others) but failure to engage effectively can have potentially counterproductive effects (e.g., it can be captured by minority interests, it can undermine rather than encourage trust) and it can be corrosive to effective policymaking and implementation.[664]

Public deliberation on genome editing in farmed animals

5.18 Our commissioned review of public attitude research showed that most of that research has tried to identify the main factors involved in the formation and stabilisation of public attitudes, and to correlate these with their main effects.[665] Interactions between factors are recognised as important but have been difficult to interpret or inconsistent. There has been little exploration, as yet, of the basis of the observed correlations or the complex interactions between factors. In the course of the present inquiry, we therefore commissioned an online deliberative exploration of citizen perspectives on genome editing in farmed animals to explore the more foundational considerations and normative schemes that informed citizens' views of the application of prospective genome technologies. This was undertaken as a deliberate counterpoint to research that tested the attitudes of members of the public as individual *consumers* of animal products.

Box 5.2: Genome editing and farmed animals: a rapid online public dialogue

The rapid deliberative dialogue took place online (owing to the COVID-19 pandemic) during June and July 2021. It involved three evening sessions in which participants engaged with each other and with invited experts, as well as number of additional activities outside the sessions.

Over the course of the dialogue, participants progressed from sharing information about their own relationship to farming and food to thinking about how people and animals were caught up in the food and farming system, and then to the nature of the system

[662] Wynne B (2001) Creating public alienation: expert cultures of risk and ethics on GMOs *Science as Culture* **10(4)**: 445-81.
[663] Involve (2015) *Room for a view, democracy as a deliberative system*, available at: https://www.involve.org.uk/resources/publications/research/room-view-democracy-deliberative-system; and Council of Europe Committee on Bioethics (2021) *Guide to public debate on human rights and biomedicine*, available at: https://www.coe.int/en/web/bioethics/guide-on-public-debate.
[664] See: Sciencewise-ERC subgroup on GM dialogue (2011) *Talking about GM: approaches to public and stakeholder engagement* available at: https://sciencewise.org.uk/wp-content/uploads/2018/12/Talking-about-GM-published.pdf; but see: Frewer LJ, Scholderer J, and Bredahl L (2003) Communicating about the risks and benefits of genetically modified foods: The mediating role of trust *Risk Analysis* **23(6)**: 1117-33.
[665] Nuffield Council on Bioethics (2020) *A review of research on public attitudes to genetically modified foods and related areas and their implications for genome editing of farmed animals,* available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering.

more generally. As they did so, their ethical frame of reference moved from considerations of utility to the nature of responsibilities for others and for animals, and then to the characteristics of a desirable system.

The participants identified four 'domains' of issues, each of which were explored from an individual and societal perspective. They were:

- impact on humans;
- impact on animals;
- impact on farming systems; and
- impact on nature and the natural order.

A shared premise for this group of participants was that welfare standards in current intensive farming systems gave rise to significant concerns. Consequently, the claim that genome editing in farmed animals should be seen as a continuation of current selective breeding practices was more of a cause for concern than for reassurance, and did not offer a sound ethical basis for its use. Participants identified a number of 'red lines' that they felt should not be crossed.

- The major 'red lines' for participants were uses of genome editing that introduced characteristics in farmed animals that benefitted humans to the detriment of the animal.
- Given the invasive nature of genome editing, were it to be employed to achieve benefits for farmed animals (or humans), participants concluded it should not be used where a less invasive course of action could be used to achieve the same outcome.
- In any case, participants concluded that genome editing should not be used to create wholly new types of creatures or species, or to introduce human capacities or characteristics to animals.[666]

Generally, however, participants were less concerned with the details of the technique used to achieve genetic gain in farmed animals (be it genome editing or 'conventional' selective breeding) than the aims it was used to pursue. The most important of these, they found, were promoting animal welfare, sustainability, equitable access, and the quality of produce. Participants expressed significant concerns over commercial drivers for implementing genome editing in farmed animals, as well as the ability of governance and regulatory systems to control the technology in a way that meets public aspirations for the UK's future food system. The questions over which they felt innovators needed to be held to account were the following.

- Why is the technology being implemented? (Is the aim a desirable one? Is this the most appropriate way of pursing it?)
- Whose interests are being served? (Does it promote the welfare of animals and/or consumers? Or does it mostly serve the interests of producers and processors?)

* A report of this initiative can be read at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering.

5.19 One of the most significant findings of the dialogue, albeit that the exercise was limited in scope, was that people were much less interested in the details of the technology than

[666] The example used in this speculative scenario was to endow an animal with higher intellectual functions and a capacity for human speech. The dialogue did not address the question of introducing human immunological characteristics to support xenotransplantation.

the purposes for which it was to be used. Those purposes were, however, of overriding significance. Participants' concerns were, importantly, not rooted in antipathy towards or misunderstanding of biotechnologies or in an abstract sentimentality about the value of 'nature' and what is 'natural'. They were particularly concerned about the historical effects of selective breeding on animal welfare and what they saw as the effects of 'intensive' farming systems. For this reason, the claim that new breeding technologies are continuous with previous techniques of domestication did not offer the reassurance that some proponents of genome editing intend but, rather, offered a cause for redoubled concern, particularly if the new techniques could speed up the pursuit of breeding objectives.

5.20 The exploration of foundational values and considerations leads on to very different kinds of question from those about how to govern genetic technologies to provide assurance about risk of harm to health or the environment. These questions include: What technologies do 'we' (as citizens) need? What do we need them to achieve? Whose interests should they serve? These questions cannot be answered by selecting options from a menu, but require solutions that are worked out through careful deliberation. To approach these questions, it is helpful to construct and examine scenarios in which biotechnologies are implicated in different ways, in order to open a space to critique the guiding aims and visions of state and corporate policymakers and of their antagonists, and to explore alternative visions of the collective future.[667]

5.21 There was, among the participants in these dialogues, both a feeling that the food and farming system had found itself on a path that was failing to serve the public interest and an enthusiasm for 'ethical governance' of the processes used in the production of farmed animals to promote public good. If this is to be the case, the governance of breeding technologies to ensure that they do not produce obvious harms (i.e., that they do not endanger human health or farmed animal welfare) will fail to ameliorate societal challenges (and may even aggravate them, e.g., by entrenching undesirable breeding trajectories) unless it is set within a coherent policy context that orientates agricultural production systems towards the delivery of positive societal goods.

Pathways and future visions

5.22 Public discussion of biotechnologies consistently opens up for reflection the questions that policymakers must close down to enable progress through innovation.[668] This may, however, be an important signal of the need for caution about premature commitment to a preferred technological solution: a genuine concern about unexplored uncertainties, structural implications, or opportunity costs of such a commitment. In Chapter 4, we noted that there is no single kind of intervention that offers a sufficient response to all the challenges currently facing food and farming systems. We took the view that it would be important not to think simply in terms of *ad hoc* interventions to meet the most immediate

[667] The dialogues commissioned in the course of this inquiry were necessarily limited in scope and therefore merely indicative of the existence of the views that were reported. Nonetheless, they raise important questions for further examination. Among the further questions to be addressed are understandings of food regulation and of 'intensive farming' practices and 'animal welfare' and how to compare different conjunctions of features that make up alternative possible systems in nonideal circumstances (e.g., their impact on people on low incomes). The Nuffield Council on Bioethics and the Biotechnology and Biological Sciences Research Council, together with Sciencewise (the programme funded by UK Research and Innovation that aims to ensure policy is informed by the views and aspirations of the public) have been working since 2020 to develop a major public dialogue initiative to explore how responsible research and innovation in biotechnology fits with public values and interests in addressing societal challenges.

[668] Stirling A (2008) "Opening up" and "closing down": power, participation, and pluralism in the social appraisal of technology *Science, Technology & Human Values* **33(2)**: 262-94.

and pressing challenges, or simply to allow market forces to shape the industry, but rather to think about commitment to a long-term trajectory that would have implications for meeting the full range of challenges. In doing so, it is necessary to think about how local challenges and solutions are embedded both within societies and the global food system.

5.23 It is a source of controversy with regard to biotechnological innovations that that they do not conform with a vision of a desirable future state of affairs that is shared by everyone, or that they can be imagined as implicated in different ways in different visions of what is a desirable future state of affairs. In most cases, technologies are not exclusively compatible with a particular ideal. Having said that, it is important to recall our observation in Chapter 1 that technologies conform with certain conditions more readily than with others (e.g., biotechnologies may both require and consolidate certain systems and industry structures to be technically or economically viable). At the same time, it should be recognised that these conditions are human artefacts that may be controlled or influenced, to a certain extent, by deliberate interventions (e.g., regulation or subsidies to support diverse production systems).

5.24 Globally, the food and farming system may be heading towards a crisis, threatened by a number of destabilising challenges that it is ill-equipped to meet. Locally, however, even some ultimately problematic components of the system are quasi-stable or sustainable for an indefinite term, for example by meeting the costs that they themselves generate, or so long as they are able to externalise the costs that they cannot absorb. In considering interventions in the food and farming system, it is necessary continually to reflect on the relations (of relative independence or interdependence) between the local and global, and between actions and consequences in the short and long term. In particular, we should consider how the externalities generated by local systems will be accounted for in the wider system and how the pursuit of short- or medium-term objectives might close down or open up further possibilities in the longer term.

5.25 As we observed at the beginning of the present chapter, people have complex interests that can produce conflicts within individuals and between them, and they may disagree with others about the priorities for acting at a local or global level, in the short or long term.[669] The mediation of these interests through the unconstrained market is demonstrably ineffective at delivering justice. In the light of this, defining solutions to the challenges facing the food and farming system has become a collective action problem albeit one that may accommodate a range of component approaches.[670] In the following sections, we highlight some alternative visions of how challenges to the food and farming system might be addressed, including ones that go beyond the optimisation of farmed animal phenotypes and their associated husbandry systems.

Radical intensification

5.26 The assumption apparently underlying the pursuit of productivity in breeding is that, for each animal product, it should be possible to optimise the production system comprising the animal phenotype and the husbandry conditions (including the physical environment and the management of inputs and outputs). Artificial environments provide opportunities

[669] For example, the 'biotechnology wager' described in the Council's 2012 report, *Emerging biotechnologies: technology, choice and the public good*, describes a preference on the part of modern industrial democracies (in the words of the economist, Paul David) "to direct the energies of society away from redistributive struggles and towards the cooperative conquest of the 'endless frontier' of science and its commercial exploitation through technological research and development", see: Nuffield Council on Bioethics (2012) *Emerging biotechnologies: technology, choice and the public good*, available at: https://www.nuffieldbioethics.org/publications/emerging-biotechnologies.

[670] Hume D (1739) *A treatise of human nature* (Oxford, Clarendon Press, 1978), Book III, section VII.

to exert control over almost all aspects of the husbandry system. These allow, in principle, the negation of all the effects of geography, climate, diet, and exposure to pathogens. They represent, therefore, the apotheosis of farming as a system of production, one that is, in principle, reproducible almost anywhere and at scale, limited only by its dependency on ancillary services to transport feed and waste, and the availability of the means to process and distribute its products. Such systems are, by definition, technologically intensive, with biotechnology offering to adapt animal phenotypes as one of the variables of production.

Box 5.3: Intensification of husbandry systems

In 2020, Muyuan Foods Co Ltd began construction of a multistorey pig breeding facility in Nanyang, China that will eventually comprise 21 buildings and house 84,000 sows and their litters. It represents a major leap in the restructuring of the Chinese pig industry away from distributed, traditional outdoor farms, many of which were decimated by waves of disease such as the African swine fever (ASF) outbreak in 2018, which led to a spike in pork prices that large producers were able to take advantage of.[671] The new facility will be technologically intensive, piping sterilised grain for feed into an on-site feed mill to avoid contamination in transport, keeping pigs in a controlled environment with a filtered air supply, and minimising interactions between animals and handlers by using intelligent feeding systems and manure cleaning robots, as well as employing infrared cameras to detect fever among the herd. The increased biosecurity in such sites may make certain breeding objectives or biological adaptations, like ASF resistance, less important than in outdoor systems, and this might be decisive if such objectives were associated with any negative impact on productivity.

Land-based aquaculture facilities, such as those used for the AquAdvantage salmon in Prince Edward Island, Canada, maintain the fish in water that is controlled for a number of parameters, including pH level, oxygen, carbon dioxide, ammonia, nitrate and nitrite content, and within a constant temperature range and at specific maximum stocking densities. Water flow is managed to ensure a complete refresh of water in the tanks every hour, and fish are fed on controlled diets. A host of biosecurity measures are also in place to prevent the ingress of pathogens as well as the escape of fish into the wild.[672]

5.27 The characterisation of production systems as a system of relations between the animal phenotype and the husbandry conditions leaves out at least one further set of factors, namely what we described (in Chapter 3) as the basic interests of humans and non-human animals. A radical solution to the entanglement of basic interests that need to be satisfied through the institutions of food and farming systems is to use technology to remove the animal interests from this complex equation.

Box 5.4: Thought experiments on the denaturing of animals

The increased docility of farmed animals was perhaps the major effect of domestication up until the seventeenth century. New breeding technologies may allow this to be taken to greater lengths, for example breeding animals who prefer to be at close quarters with

[671] See: The Guardian (8 October 2020) *Behind China's 'pork miracle': how technology is transforming rural hog farming*, available at: https://www.theguardian.com/environment/2020/oct/08/behind-chinas-pork-miracle-how-technology-is-transforming-rural-hog-farming; and Bangkok Post (9 December 2020) *World's largest pig farm rises in China*, available at: https://www.bangkokpost.com/business/2032335/worlds-largest-pig-farm-rises-in-china.

[672] See: US Food & Drug Administration (2015) *Freedom of information summary: NADA 141-454 – opAFP-GHc2 rDNA construct in EO-1α lineage Atlantic salmon (AquAdvantage Salmon)*, available at: https://www.fda.gov/files/animal%20&%20veterinary/published/AquAdvantage-Salmon-FOI-Summary.pdf.

> others of their kind than to roam freely.[673] Some scholars have imagined (in the mode of a thought experiment) altering animals so they do not experience pain, or even feel pain as pleasure.[674] We noted above (in Chapter 3), however, that to collapse experience onto a scale of pleasure and pain is an impoverished way of appraising the multiple dimensions of morally important experiences (notwithstanding that embodiment may still be central to many or even all of them). However, a yet more radical alternative involves depriving animals of the capacity for experience so that they exist as beings that are physiologically and metabolically complex but devoid of morally relevant experiences.[675] Whether or not this is regarded as the extreme logical extension of industrial farming, it is clear that basic interests (the third element in our characterisation of production systems in addition to the two elements of animal phenotype and husbandry systems), complicate the optimisation of production systems.

Novel foods

Alternative protein sources

5.28 Alongside the search for productivity gains in the farming of existing domesticated species, researchers and industry have begun to explore alternative sources of protein that can be farmed sustainably at scale.[676] One area of current investigation is the cultivation of insects, although these have typically experienced difficulty in finding acceptance among consumers, especially in the global North.[677]

> **Box 5.5: Insects as a source of edible protein**
>
> Black soldier fly larvae, which are widely used in chicken feed and aquaculture, have been investigated as a promising source of protein for direct human consumption, since their nutritional composition, including high chitin and fat content, which has a negative effect on fermentation and digestibility for ruminants, has advantages for human health. The larvae also contain micronutrients (e.g., iron and zinc) that compare favourably to lean meat sources and a calcium content comparable to that of milk.[678] Companies are already established to develop farming systems that exploit such novel food sources. Roslin Technologies, a biotech spin-off from the University of Edinburgh, is developing breeding programmes for black soldier fly larvae, to address problems with mass breeding such as the vulnerability to disease and the accumulation of heavy metals and mycotoxins, and to make them suitable for processing into a food source for humans.[679]

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[673] Greenfield A (2021) Cloning, mitochondrial replacement and heritable genome editing: 25 years of ethical debate since Dolly *Reproduction* **162(1)**: F69-78.

[674] Practical ethics blog (6 March 2018) Oxford Uehiro Prize in Practical Ethics: why we should genetically 'disenhance' animals used in factory farms, available at: http://blog.practicalethics.ox.ac.uk/2018/03/oxford-uehiro-prize-in-practical-ethics-why-we-should-genetically-disenhance-animals-used-in-factory-farms/; on 'S&M chickens', see: The Stranger (13 April 2018) *Could engineering animals to enjoy pain end animal suffering?*, available at: https://www.thestranger.com/slog/2018/04/13/26040721/could-engineering-animals-to-enjoy-pain-end-animal-suffering.

[675] Jonathan Birch, responding to the working group's call for evidence; see also the improbable history of 'Miracle Mike', the chicken who lived for eighteen months in the US in 1945-7 after being decapitated: Modern Farmer (11 August 2014) *Here's why a chicken can live without its head*, available at: https://modernfarmer.com/2014/08/heres-chicken-can-live-without-head/.

[676] Lambert H, Elwin A, and D'Cruze N (2021) Wouldn't hurt a fly? A review of insect cognition and sentience in relation to their use as food and feed *Applied Animal Behaviour Science* **243**: 105432.

[677] Tan HSG, and House J (2018) Consumer acceptance of insects as food: integrating psychological and socio-cultural perspectives, in *Edible insects in sustainable food systems,* Halloran A, Flore R, Vantomme P *et al.* (Editors) (Springer, Cham); and Wendin K, and Nyberg M (2021) Factors influencing consumer perception and acceptability of insect-based foods *Current Opinion in Food Science* **40**: 67-71.

[678] Bessa LW, Pieterse E, Marais J *et al.* (2020) Why for feed and not for human consumption? The black soldier fly larvae *Comprehensive Reviews in Food Science and Food Safety* **19(5)**: 2747-63.

[679] See: Roslin Technologies (2021) *Our pipeline*, available at: https://roslintech.com/our-pipeline/.

Meat alternatives

5.29 An alternative to the theoretical development of livestock to reduce or remove their capacity for sentience is the production of meat alternatives, grown as cell cultures in laboratory conditions, 'from the bottom up' (i.e., by adding desirable characteristics to a culture scaffold rather than by removing capacities from an existing animal). Cultured meat began to attract significant interest and investment during the second decade of the present century.[680] The production process harnesses techniques from stem cell biology and tissue engineering to expand populations of animal cells in a growth medium and to colonise a scaffold which provides a structure similar to that of animal-produced meat.[681] 3D printing techniques can be employed to refine the structure of the finished product. There are a number of challenges awaiting further refinement, including producing output at scale from controlled bioreactors, securing food safety given the use of certain animal cell types, and making the process more efficient in terms of energy use and greenhouse gas (GHG) emissions (which may be currently no better than cattle farming, depending on the system used).[682] As with other protein sources, there are consumer acceptance issues with cultured meat, which have more to do with food safety concerns in this case, and related regulatory approvals.[683]

5.30 Another approach is the development of plant-based alternatives that are designed to mimic many of the characteristics of meat and dairy produce that are significant to consumers.

Box 5.6: Plant-based meat alternatives

Plant-based meat alternatives, which aim to reproduce the sensory experience of eating meat, also continue to be developed. These are usually based on protein from pulses and plant oils. Some of these are genetically modified to mimic meat more closely. (The 'Impossible Burger' is based on soy protein and uses iron-rich leghaemoglobin, derived from genetically modified yeast, to give the product its meaty colour, taste, and smell.[684]) 3D printing is also being used as part of the production process to render vegetable proteins into shapes and textures that resemble those of familiar meat products such as burger patties.[685] Dairy alternatives, such as chemically modified dairy-free cheese, have also been developed.[686]

5.31 The field of meat alternatives has some distance to travel in order to make significant inroads into the market for meat and meat products (its market share is currently marginal, approximately one per cent of the overall market, and mainly in developed

680 Stephens N, Sexton AE, and Driessen C (2019) Making sense of making meat: key moments in the first 20 years of tissue engineering muscle to make food *Frontiers in Sustainable Food Systems* **3**: 45.

681 Specht EA, Welch DR, Clayton EMR *et al*. (2018) Opportunities for applying biomedical production and manufacturing methods to the development of the clean meat industry *Biochemical Engineering Journal* **132**: 161-8; and Gaydhane MK, Mahanta U, Sharma CS *et al*. (2018) Cultured meat: state of the art and future *Biomanufacturing Reviews* **3(1)**.

682 Gaydhane MK, Mahanta U, Sharma CS *et al*. (2018) Cultured meat: state of the art and future *Biomanufacturing Reviews* **3(1)**; and Lynch J and Pierrehumbert R (2019) Climate impacts of cultured meat and beef cattle *Frontiers in Sustainable Food Systems* **3**: 5.

683 Bryant C, and Barnett J (2020) Consumer acceptance of cultured meat: an updated review (2018–2020) *Applied Sciences* **10(15)**: 5201.

684 See: U.S. Food & Drugs Administration (23 July 2018) *Letter to Gary L. Yingling Re: GRAS Notice No. GRN 000737*, available at: https://www.fda.gov/media/116243/download.

685 See Nova Meat (2021) *Homepage*, available at: https://www.novameat.com/.

686 Wired (22 April 2021) *The quest to make genuinely cheesy animal-free cheese,* available at: https://www.wired.co.uk/article/dairy-free-cheese.

economies). Nonetheless, it is an area of vibrant enthusiasm, rapid growth, and substantial investment, with significant scope for further research and development.[687] It can be imagined that such developments have the potential to replace meat from farmed animals in many processed products, although it is less likely that they would displace animal-sourced meat as a premium product.

Waste reduction and agroecology

5.32 As well as, or instead of, further innovation in production, there is currently strong advocacy for changes in consumption, reduction of waste, and change in the pattern of relations away from linear, often global, food chains to local circuits of production, consumption, and recycling; recognition of the social, environmental, and sanitary implications of food and food production; and an emphasis on qualitative factors rather than quantity.

5.33 Estimates of food waste vary considerably. In the UK, one study found that over 14 per cent of purchased food was avoidably wasted, but that animal produce was wasted much less than other types of food. However, other studies have found that between a third and a half of food produced globally is wasted.[688] Waste is found to be much higher in production processes in developing economies than in developed ones, suggesting that significant reduction might be achieved through investment in those systems, although in developed economies more food is wasted as a result of it being discarded by retailers and consumers.[689] Food waste occurs throughout the supply chain, however.[690]

5.34 Waste represents not merely the loss of the nutritional value of the wasted product, which has to be made up with further consumption, but also the embodied environmental costs that are involved in production, including GHG emissions and also the considerable methane emissions from decomposing food waste in landfill sites.[691] Indeed, it is claimed that we already grow enough food to feed the predicted peak world population of 10 billion (or even more), so expanding production is unnecessary to achieve food security.[692] Some go further, claiming that the perception of a crisis in food production is being used to marshal support for biotechnology innovation and intensive farming practices.[693] However, pointing to food waste is one thing; implementing effective approaches for food waste reduction is another.

5.35 More sustainable approaches, incorporating costs rather than externalising them, drive ideas of the circular economy as opposed to linear and extractive approaches.[694] These have been elaborated under a number of different rubrics (e.g., agroecology,

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687 See: Nuffield Council on Bioethics (2019) *Meat alternatives*, available at: https://www.nuffieldbioethics.org/publications/meat-alternatives/; see also: TABLE blog (14 April 2021) Introducing the Wageningen Alternative Protein Project, available at: https://tabledebates.org/blog/introducing-wageningen-alternative-protein-project.

688 See: Revell BJ (2015) One man's meat… 2050? Ruminations on future meat demand in the context of global warming *Journal of Agricultural Economics* **66(3)**: 573-614; and FAO (2021) *Food loss and food waste*, available at: https://www.fao.org/food-loss-and-food-waste/flw-data.

689 Revell BJ (2015) One man's meat… 2050? Ruminations on future meat demand in the context of global warming *Journal of Agricultural Economics* **66(3)**: 573-614.

690 High Level Panel of Experts on Food Security and Nutrition (2014) *Food losses and waste in the context of sustainable food systems*, available at: http://www.fao.org/3/a-i3901e.pdf.

691 John Hopkins Center for a Liveable Future (2015) *The importance of reducing animal product consumption and wasted food in mitigating catastrophic climate change*, available at: https://clf.jhsph.edu/publications/importance-reducing-animal-product-consumption-and-wasted-food-mitigating-catastrophic.

692 GM Freeze, responding to the working group's call for evidence.

693 Helliwell R, Hartley S, Pearce W *et al.* (2017) Why are NGOs sceptical of genome editing? *EMBO Reports* **18**: 2090-3.

694 On the circular economy, see: Ellen MacArthur Foundation (2021) *What is a circular economy?*, available at: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview; see also: Defra (2020) *Circular Economy Package policy statement*, available at: https://www.gov.uk/government/publications/circular-economy-package-policy-statement/circular-economy-package-policy-statement.

regenerative agriculture, etc.) that may be more or less hospitable to the use of biotechnologies.

Box 5.7: Agroecology

Agroecology is the application of concepts derived from the study of ecological processes to the design and management of agricultural production systems.[695] Agroecology approaches, for which local geological and climatic conditions are important factors, tend to adapt to smaller scale production systems, rather than systems that strive to reproduce optimum conditions artificially.

5.36 The approach of foregrounding how agriculture sits within environment and community goes hand-in-hand with approaches to wellbeing that recognise the dependency of human health on the health of animals and the wider ecosystem. These have been elaborated under the rubric 'One Health'.[696] Proponents of health-orientated systems oppose high-density stocking of livestock to reduce the risk of the spread of infectious disease and the amplification of pathogens, and to reduce the stress that suppresses animal immune systems.[697] For the same reasons, a health-orientated system would avoid excessive herd and flock sizes and interaction with unfamiliar animals.[698] Animal welfare can also be promoted by enabling species-typical behaviours such as rooting in pigs and dust-bathing in hens. These include parenting behaviours (e.g., avoiding early weaning of pigs), positive social behaviours (e.g., mixing with familiar animals), diet, and accommodation. The curtailment of any of these can be a cause of stress to the animals concerned.[699] Environmental controls are also important to ensure good air quality (e.g., low levels of dust, ammonia, and carbon dioxide) to reduce the risk of respiratory diseases.[700] Finally, such systems would eschew the use of animals genetically selected for very fast growth rates and high yields that are at increased risk of immunological and metabolic problems.[701]

Diet change

5.37 We noted (in Chapter 2) that while the per capita consumption of animal products appears to be falling in many developed economies, it is rising rapidly in other parts of the world and that many people in the poorest parts of the world have historically

695 See: TABLE (2019) *What is agroecology?*, available at: https://tabledebates.org/building-blocks/agroecology; see also: Dalgaard T, Hutchings NJ, and Porter JR (2003) Agroecology, scaling and interdisciplinarity *Agriculture, Ecosystems and Environment* **100(1)**: 39-51.

696 Pollock, J, Low AS, McHugh RE *et al.* (2020) Alternatives to antibiotics in a One Health context and the role genomics can play in reducing antimicrobial use *Clinical Microbiology and Infection* **26(12)**: 1617-21.

697 Pro-poor Livestock Policy Initiative (2007) *Industrial livestock production and global health risks*, available at: https://assets.publishing.service.gov.uk/media/57a08bd540f0b64974000dd6/PPLPIrep-hpai_industrialisationrisks.pdf; European Medicines Agency and European Food Safety Authority (2017) EMA and EFSA Joint Scientific Opinion on measures to reduce the need to use antimicrobial agents in animal husbandry in the European Union, and the resulting impacts on food safety (RONAFA) *EFSA Journal* **15(1)**: e04666.

698 European Commission (2015) *Guidelines for the prudent use of antimicrobials in veterinary medicine: OJEU C299/04*, available at: https://op.europa.eu/en/publication-detail/-/publication/202c8681-5813-11e5-afbf-01aa75ed71a1; and Review on Antimicrobial Resistance (2016) *Tackling drug-resistant infections globally: final report and recommendations*, available at: https://amr-review.org/Publications.html.

699 See, for example, with respect to swine: Callaway T, Morrow J, Edrington T *et al*. (2006) Social stress increases fecal shedding of Salmonella typhimurium by early weaned piglets *Current issues in intestinal microbiology* **7(2)**: 65-71.

700 European Commission (2015) *Guidelines for the prudent use of antimicrobials in veterinary medicine: OJEU C299/04*, available at: https://op.europa.eu/en/publication-detail/-/publication/202c8681-5813-11e5-afbf-01aa75ed71a1.

701 Rauw WM, Kanis E, Noordhuizen-Stassen EN *et al.* (1998) Undesirable side effects of selection for high production efficiency in farm animals: a review *Livestock Production Science* **56(1)**: 15-33.

depended on animal products as a source of essential nutrition.[702] As a result, global per capita consumption of livestock products has more than doubled in the past 40 years, mainly driven by increases in the consumption of poultry (3.6 per cent annually between 1995 and 2013), pork (2 per cent) and beef (1 per cent).

5.38 At a global level, consuming fewer animal products, especially beef, has been identified as a significant way to reduce resource use, improve health, and reduce greenhouse gas emissions by a significant amount.[703] (Moving to a completely vegan diet has been claimed to reduce greenhouse gas emissions by 25 to 75 per cent compared to average diets in developed countries, though eating fewer animals products would result in a proportionate reduction.[704]) Such shifts are unlikely to be easy to achieve at scale, however, and may result in transitional increases in injustice and inequality owing to impacts on livelihoods and food security, especially where animals are enmeshed in complex relationships with humans, for example as food, draft power, stores of wealth, and signs of status.[705]

5.39 Nonetheless, incremental diet change has been identified as a policy objective, targeted by a number of measures including education, guidelines, incentives, and prohibitions on the sale of certain products.[706] For example, the Chinese Government has issued dietary guidelines that have the explicit aim of reducing meat consumption by Chinese citizens by 50 per cent.[707] Such plans face problems both in liberal societies, where there is likely to be significant resistance to government intervention from consumers, as well as producers, processors, and distributors, and in places where food options are restricted by circumstances.[708] The UK's recent National Food Strategy independent review report, however, found significant public support for a reduction in meat consumption for health and environmental reasons.[709]

5.40 Dietary trends are not confined to preferences about the type of food to be consumed, but also include the way in which food is produced. Moving to the consumption of fewer but more expensive meat products is one possibility although, unsurprisingly, not one that has enlisted the wholehearted supported of retailers.[710] Organic products, which tend to be more expensive, have increased in popularity, mainly in developed countries, due to consumer concerns about the effects of conventional agriculture on the

[702] Burggraf, C, Kuhn L, Zhao Q *et al.* (2015) Economic growth and nutrition transition: an empirical analysis comparing demand elasticities for foods in China and Russia, *Journal of Integrative Agriculture* **14(6)**: 1008-22; and Matthew K (2016) The nutrition transition in developing Asia: dietary change, drivers and health impacts, in *Eating, drinking: surviving the International Year of Global Understanding – IYGU* Jackson P, Speiss W, and Farhana S (Editors) (Chamonix: Springer).

[703] Chatham House (2015) *Changing climate, changing diets: pathways to lower meat consumption*, available at: https://www.chathamhouse.org/2015/11/changing-climate-changing-diets-pathways-lower-meat-consumption; and WWF (2020) *Bending the curve: the restorative power of planet-based diets*, available at: https://www.worldwildlife.org/publications/bending-the-curve-the-restorative-power-of-planet-based-diets; but see: Leroy F, and Hite AH (2020) The place of meat in dietary policy: an exploration of the animal/plant divide *Meat and Muscle Biology* **4(2)**.

[704] Scherer L, and Verburg PH (2017) Mapping and linking supply- and demand-side measures in climate-smart agriculture. A review *Agronomy for Sustainable Development* **37(66)**.

[705] Revell BJ (2015) One man's meat… 2050? Ruminations on future meat demand in the context of global warming, *Journal of Agricultural Economics* **66**: 573-614.

[706] Bryngelsson D, Wirsenius S, Hedenus F *et al.* (2014) How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture *Food Policy* **59**: 152-64.

[707] The Guardian (20 June 2016) *China's plan to cut meat consumption by 50% cheered by climate campaigners,* available at: https://www.theguardian.com/world/2016/jun/20/chinas-meat-consumption-climate-change.

[708] Ibid. Engagement in support of the UK National Food Strategy review found people receptive to government intervention although strongly opposed to a blunt 'meat tax'. The review concluded that "most of the impetus to improve the food we eat will have to come from consumers, and from those who serve them", in particular supermarkets and restaurants.

[709] National Food Strategy Independent Review (2021) *The National Food Strategy: the plan*, available at: https://www.nationalfoodstrategy.org/.

[710] Trewern J, Chenoweth J, Christie I *et al.* (2021) Are UK retailers well placed to deliver 'less and better' meat and dairy to consumers? *Sustainable Production and Consumption* **28**: 154-63. See also: TABLE (2021) *Can UK retailers deliver "less and better" meat and dairy?*, available at: https://tabledebates.org/research-library/can-uk-retailers-deliver-less-and-better-meat-and-dairy.

environment and human health.[711] What makes a product 'organic' is, however, the subject of some debate, and criteria vary significantly between sectors, regions, and organisations. An authoritative definition is that used by the EU for the purposes of production and labelling legislation: the requirements are extremely detailed, but they rest on a number of principles, including a prohibition of the use of genetically modified organisms, ionising radiation, hormones, and antibiotics (except where necessary for animal health), and limiting the use of artificial fertilisers, herbicides, and pesticides.[712]

Practical problems

5.41 In this chapter, we have moved from consideration of the interests that each potential consumer has in making decisions about their own consumption, to visions of the future of the food and farming system, and how these are related to still broader visions of a desirable future state of the social and natural world. Each is potentially a site of conflict: individuals may wrestle with competing interests in, for example, price, provenance, and quality or taste and healthiness; they may disagree with each other over the place of, say, intensively reared or organically produced animals in the food system. People have complex identities: they may be both consumers and producers; all are members of communities, citizens of states, and inhabitants of a shared planet. Each individual is the site of a difficult mediation of interests, complex and indirect, between the local and the global, private and public, the present and posterity. Similar affinities and tensions are found between different individuals, or between the roles they adopt in social and political engagements, and again between communities, corporations, and political organisations. In this section we draw attention to the potential to address, and the consequences of failing to address, or to resolve, differences of aim and approach.

Plural priorities

5.42 The first issue is that of the degree of integrity required of the system in order for it to achieve global goals (such as to respond to a global challenge). Does it matter, for example, if some sectors or producers order their priorities differently or follow different priorities?[713] On one hand, the fact that certain aims are prioritised or pursued by only a subset of actors may slow or limit how well they are achieved; on the other hand, where priorities pursued by different actors are in tension with each other, it may not merely limit but actually undermine the possibility of achieving any of them.

Box 5.8: Achieving net zero

Reducing greenhouse gas (GHG) emissions, for example, is a policy priority for all emitting nations, and agriculture contributes approximately 10 per cent of the UK's emissions (a small percentage of total carbon dioxide emissions but a higher amount of methane and nitrous oxide).[714] In 2019, the UK enshrined in legislation the goal of reaching 100 per cent reduction in GHG emissions (compared to 1990 levels) by

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711 Meemken EM, and Qaim M (2018) Organic agriculture, food security, and the environment *Annual Review of Resource Economics* **10(1)**: 39-63.

712 European Commission (2020) *Organic production and products*, available at: https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organic-production-and-products_en.

713 See, for example, Muller A, Schader C, El-Hage Scialabba N *et al.* (2017) Strategies for feeding the world more sustainably with organic agriculture *Nature Communications* **8(1290)**.

714 See Chapter 2. The decision on whether to use GWP* instead of GWP100 values (to account for the relative longevity of carbon dioxide compared to methane) raised as a subject for debate ahead of the COP26 Climate Summit in November 2021.

2050.[715] The National Farmers Union (NFU) has set farmers in England and Wales the more ambitious goal of reaching net zero GHG emissions by 2040, although it is recognised that this is a national aspiration rather than an expectation that every farm will be carbon neutral.[716] Farming has great potential to contribute by reducing emissions of GHGs through greater production efficiencies and through improved land management to increase the level of carbon capture and storage in the soil and plants, including on behalf of other sectors of the economy or actors in the food supply chain.[717] Particularly with Environmental Land Management payments set to replace farming subsidies under the EU Common Agricultural Policy, it is foreseeable that many farms may turn to a different business model for land management that no longer focuses on food production.

5.43 Achieving a policy aim across the sector is complicated enough when there is only one priority, but where there are multiple, interacting priorities it becomes more difficult still. For example, improving animal welfare (which, unlike GHG emissions, cannot be traded off to achieve a 'net' neutral outcome) is often thought to be in tension with environmental remediation under the conventional options available. If we add further priorities, the challenge involved in ordering the system to produce a coherent solution is magnified accordingly. It is this kind of cognitively dismaying complexity that has persuaded some thinkers to put their faith entirely in the unimpeded processes of the market to resolve the problem of coordinating so many actors.[718] There are two fairly obvious problems with this approach, however. Firstly, the operation of the market is formally indifferent to the individual lives and livelihoods caught up in it; secondly, it tends to externalise or defer costs wherever possible, so it is an ineffective mechanism for providing public goods or meeting common challenges (market failure).

5.44 A useful distinction may be made between priorities and measures that are so strongly socially endorsed that they should be regulated for and those that are less well endorsed and should be left to the market to prioritise in response to consumer demand.[719] The views of citizens as citizens can play an important role in this. More specifically, they might contribute to producing a conception of 'the public interest' to guide, challenge, and lend legitimacy to public policy measures.[720] At the time of writing, with the emergence of genome editing, there is a historic opportunity to align public policy with the public interest for the next generation of biotechnologies (as well as for new applications of earlier technologies).

Plural pathways

5.45 As well as the question of the orientating vision (or identifying the set of priorities), there is the question of the means by which it is achieved. However, the prioritisation of ends and the choice of means to achieve them are generally not independent and may, in fact,

[715] The Climate Change Act 2008 (2050 Target Amendment) Order 2019 (S.I. 2019 No.1056), available at: https://www.legislation.gov.uk/uksi/2019/1056/contents/made amended the Climate Change Act 2008 by introducing a target for at least a 100% reduction of greenhouse gas emissions (compared to 1990 levels) in the UK by 2050.

[716] NFU (2021) *Net zero*, available at: https://www.nfuonline.com/hot-topics/net-zero/.

[717] Lynch J, Cain M, Frame D *et al.* (2021) Agriculture's contribution to climate change and role in mitigation is distinct from predominantly fossil CO2-emitting sectors *Frontiers in Sustainable Food Systems* **4**: 518039.

[718] See, for example, Hayek FA (1988) *The fatal conceit: the errors of socialism* (London: Routledge).

[719] See, in the context of animal welfare: Defra (2004) *Animal welfare, economics and policy, report on a study undertaken for the Farm & Animal Health Economics Division of Defra*, available at: https://webarchive.nationalarchives.gov.uk/ukgwa/20110318142209/http://www.defra.gov.uk/evidence/economics/foodfarm/reports/documents/animalwelfare.pdf.

[720] Mansbridge J, Bohman J, Chambers S *et al.* (2012) A systemic approach to deliberative democracy, in *Deliberate systems: deliberate democracy at the large scale,* Parkinson J and Mansbridge J (editors) (Cambridge: Cambridge University Press); see also: Owen D, and Smith G (2015) Survey article: deliberation, democracy and the systemic turn *Journal of Political Philosophy* **23(2)**: 213-34.

be more deeply connected by an underlying normative structure in a way that is partly captured by the notion of 'sociotechnical imaginaries'.[721] The critical examination of such imaginaries helps to reveal the non-obvious commitments and operations of power involved in producing a given outcome by particular means in a given set of circumstances. This helps to reveal hidden assumptions and unexamined framings of the dominant approaches and open up a potential exploration of alternative technological 'pathways' from the perspective of less privileged interests and frames.[722] It is clear, for example, that different technological pathways have different implications for the interests of those who are subject to the institutions they create, including animals, farm workers, and consumers, yet not all of these have an influence that is commensurate with their interest.

5.46 The reason that this is important is the effect that certain technological pathways have in shaping farming practices, and the agricultural sector more generally, and determining the directions in which they develop. For example, as we noted in Chapter 4, the adoption of biotechnologies may both open up new breeding possibilities and accelerate progress along trajectories of genetic gain, conceivably to the point where a rift opens between herds, flocks, or schools with 'conventional genetics' and those with 'enhanced genetics', equivalent to the development of 'breeds' with substantially different characteristics. It is only necessary to observe the way in which farming is dominated by established domestic breeds and the disappearance of their wild counterparts and ancestors (the aurochs, the tarpan, the wisent), as well as the many domestic breeds currently under threat of extinction (the Light Sussex chicken, the British Landrace pig, Vaynol cattle), to appreciate what is potentially at stake in such decisions.[723]

5.47 It is reasonable to question to what extent such extinctions matter, particularly of breeds that were created through domestication and supplanted by new domesticated breeds. (Furthermore, insofar as 'breed' is an arbitrary term, applying the concept of extinction to it is, arguably, tendentious.[724]) Attachment to the survival of particular breeds of animal is, like scepticism about particular technologies, only one source of concern about the introduction of new biotechnologies, however.

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[721] See: Harvard Kennedy School Program on Science, Technology & Society (2021) *The sociotechnical imaginaries project*, available at: https://sts.hks.harvard.edu/research/platforms/imaginaries/. Sociotechnical imaginaries are "collectively held and performed visions of desirable futures (or of resistance against the undesirable) animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology"; see: Jasanoff S (2015) Future imperfect: science, technology and the imaginations of modernity, in *Dreamscapes of modernity: sociotechnical imaginaries and the fabrication of power* Jasanoff S and Kim S-H (Editors) (Chicago: University of Chicago Press). As Kim points out: "Those visions, in turn embed and are embedded in the processes through which the meaning, roles and purposes of science and technology become closely intertwined with broader conceptions of national identity, history, and the future"; see: Kim S-H (2015) Social movements and contested sociotechnical imaginaries in South Korea, in ibid. It is perhaps now important to note the potential force of this last point, which Kim stresses in his account of biotechnology in relation to South Korean nation building, in the context of the UK's rupture with the European Union.

[722] See: The STEPS Centre (2021) *The pathways approach*, available at: https://steps-centre.org/methods/the-pathways-approach/. The STEPS centre also references sociotechnical imaginaries as a method of opening up the structure-agency relationship; see: The STEPS Centre (2021) *Methods vignettes: sociotechnical imaginaries*, available at: https://steps-centre.org/pathways-methods-vignettes/methods-vignettes-sociotechnical-imaginaries/. See also: Nuffield Council on Bioethics (2012) *Emerging biotechnologies: technology, choice and the public good,* available at: https://www.nuffieldbioethics.org/publications/emerging-biotechnologies.

[723] See: FAO (2015) *The second report on the state of the world's animal genetic resources for food and agriculture*, available at: https://www.fao.org/publications/sowangr/en/; FAO (2019) *The state of the world's biodiversity for food and agriculture*, available at: http://www.fao.org/3/CA3129EN/CA3129EN.pdf; JNCC (2021) *C9a. Animal genetic resources – effective population size of native breeds at risk*, available at: https://jncc.gov.uk/our-work/ukbi-c9a-animal-genetic-resources/. See also: Rare Breeds Survival Trust (2021) *Homepage*, available at: https://www.rbst.org.uk/. For the diversity of British livestock breeds, see: Hall SJG, and Clutton-Brock J (1995) *Two hundred years of British farm livestock* (London: HMSO).

[724] On the difficulties of the 'breed' concept, see: Langer G (2018) Possible mathematical definitions of the biological term "breed" *Archives Animal Breeding*, **61(2)**: 229-43.

5.48 It is evident from our engagement with non-specialists through the public dialogue (described above) that concerns arise not from the nature of this or that breeding technique but from what the adoption of such a breeding technique might accomplish and where adopting it might lead. This outcome is not discoverable by an anatomy of the technology but may be inferred from what is understood about how technologies are adopted, diffused, and normalised. The more important concern in the public dialogue was not that biotechnologies were different from conventional breeding practices but that they would further entrench and accelerate breeding along trajectories that were already seen as undesirable while effectively proscribing others.

5.49 More precisely, what was seen as undesirable was not simply the impact of breeding technologies within a separate and disconnected milieu of farming, but the influence this may have on society more generally.[725] The fact that this influence may be unforeseen is connected with a precautionary disposition towards biotechnology.[726] In fact, however, it is implicitly foreseen by non-specialist members of the public, much more so, on the evidence of our public dialogue, than by policymakers and regulators, who appear to be more narrowly focused on innovation governance and product safety. Governments have both a mandate to address and a function in addressing not only how to prevent direct harms to human or animal health but also how the use of technologies can support or imperil securing just outcomes for the food and farming system on which their populations largely depend.

5.50 The way to approach this, while it might involve commitment to a technological pathway, cannot be to narrow the appraisal down to manageable questions in order to exclude inconvenient uncertainties and unreconciled understandings. **To inform the development of policy, law, and regulation in this area there is a need for more initiatives to explore public views about these matters and their place in the future of the food and farming system. Such initiatives should explore understandings of current and proposed breeding technologies, husbandry systems, and governance, the relation between consumer choice and public interest, and the appropriate role for public authorities.**[727]

Conclusion

5.51 The different perspectives (of consumers immersed in a system of exchange to secure their interests and of citizens contemplating the organisation of such a system to serve their various and common interests) point to two different sorts of question that may be asked about developments in life sciences and biotechnology. One is along the lines of: What controls or limits should be placed on technological innovation in order to protect

[725] Technological determinism is a controversial matter of debate. Its most infamous expression is perhaps Marx's apothegm "The hand-mill gives you society with the feudal lord; the steam-mill society with the industrial capitalist." (Marx K (1847) *The poverty of philosophy* (London: Lawrence & Wishart, 1956); see also: Marx K (1867) *Capital volume 1* (Harmondsworth: Penguin Books Ltd, 1976)). This debate is not, thankfully, central to our argument, albeit that we acknowledge both the greater affinity of some biotechnologies with certain industrial systems (see Chapter 4) and the phenomena of technological momentum and entrenchment, which make the consequences of technology adoption difficult to escape; see: Hughes T (1994) Technological momentum, in *Does technology drive history? The dilemma of technological determinism* Marx L and Smith MR (Editors) (Cambridge, MA: MIT Press).

[726] This is a problem not only because of unforeseen harms (the limited object of many precautionary approaches) but also because of the difficulty of escaping the social effects of technological commitments (precaution in the more general sense). This is captured in the Collingridge's 'technology control dilemma'. The horns of the dilemma are: (1) limited predictability: "understanding of the interactions between technology and society is so poor that the harmful social consequences of the fully developed technology cannot be predicted with sufficient confidence to justify the imposition of controls" and (2) limited power: "by the time a technology is sufficiently well developed and diffused for its unwanted social consequences to become apparent, it is no longer easily controlled. Control may still be possible, to some degree but it has become very difficult, expensive and slow." See: Collingridge D (1980) *The social control of technology* (Milton Keynes: The Open University Press).

[727] See Chapter 7 below (Principle 4 and Recommendation 1).

those interests that are either directly or indirectly affected? There may be obvious answers to this question: threats to public safety or risk of adverse environmental impact, for example, offer good reasons to control innovation in specific ways. The other type of question is of the form: What kind of sociotechnical systems will produce or conduce to just outcomes of the system for those who are subject to it? This type of question requires a different kind of consideration, including an appraisal of what the feasible options are, what their implications and consequences might be, and for whom, in a given context.[728]

5.52 This second type of question is heard less frequently. This is possibly because it is assumed that an answer to the first question itself gives a sufficient answer to the second: that not interfering with innovation, other than to control risk and prevent harm, allows the 'invisible hand' of aggregated individual consumers' behaviours to direct the system through the marketplace. In post-industrial societies, consumers' interests in food and farming may find expression through the marketplace, owing to a range of factors including better product information and differentiation (which prevents the convergence of demand on a homogeneous or generic product). But there is a growing interest, driven more by the perspective of people as citizens, perhaps one that has become obscured by other (e.g., economic) considerations, in the quality, provenance, and conditions of production of animal-based foods, driven by a recognition of the impact of diet on health and the environment, and concerns about the condition of farmed animals.[729]

5.53 These developments may nevertheless leave the greater part of the livestock production industry unaffected. To achieve improvements across the industry and to address the challenges of injustice, the focus of governance cannot be simply to ensure that the implementation of technologies will not cause direct harms to human or animal health, although this should be an essential and indispensable condition. It must also concern how the uses to which the technologies are put can be regulated to secure just outcomes even in a context that strongly incentivises the pursuit of private interest over public benefit. While we can only move forward, collectively, from the situation in which we find ourselves, this should not be seen as a moral baseline: the fact that something is the case should not be taken as evidence that it is acceptable or just. Since even agreed moral preference for an aim is not in itself coercive, assurance must be provided instead by mechanisms and institutions to encourage coordination, while avoiding the danger that they should become counterproductive.[730]

[728] See, for example, frameworks of anticipatory governance and responsible innovation, e.g., Stilgoe J, Owen R, and Macnaghten P (2013) Developing a framework of responsible innovation *Research Policy* **42(9)**: 1568-80.

[729] On the other hand, the different power structures embodied in alternative food movements may not necessarily be more just than dominant industrial production systems. (For a justice-based critique of local food movements, see: A growing culture (23 January 2021) *Local food movements won't save the world*, available at: https://agrowingculture.medium.com/local-food-movements-wont-save-the-world-abd77031db4b.)

[730] There is also the risk of creating perverse outcomes. It was put to us that if the pursuit of subsidies for socially or environmentally beneficial activities becomes too costly or onerous, large producers may eschew them entirely and concentrate instead on maximising efficiencies, leading to a 'race to the bottom' in terms of the very factors at issue. For a pessimistic analysis, see: Thompson P (2021) Food system transformation and the role of gene technology: an ethical analysis *Ethics & International Affairs* **35(1)**: 35-49. See also: Jauernig J, Pies I, Thompson PB *et al.* (2020) Agrarian vision, industrial vision, and rent-seeking: a viewpoint *Journal of Agricultural and Environmental Ethics* **33**: 391-400. On counterproductivity generally, see: Illic I (1972) *Deschooling society* (New York: Harper & Row); see also: Illic, I (1973) *Tools for conviviality* (New York: Harper & Row).

Chapter 6

Governance and compliance

Chapter 6 – Governance and compliance

Chapter overview

This chapter describes existing legal and regulatory controls, policy and guidance governing the adoption of new breeding technologies, mainly from a UK perspective.

There is a difference between the scrutiny given to the use of animals in scientific research and that given to their use in agriculture and aquaculture. The increasing technical intensity of commercial breeding and the prospective introduction of new breeding technologies support the case for enhanced regulation of breeding in commercial settings. Furthermore, in the current regulatory scheme, while protections for individual animals exist, insufficient attention is paid to the longitudinal effects of breeding on lines or breeds of farmed animal.

The oversight of farmed animals varies considerably between farming systems and animal species, often as a result of the economic organisation of the sector. ‘Balanced’, ‘responsible’ and ‘sustainable’ breeding objectives are promoted as desirable but there is little specificity, weak enforcement and a lack of reliable evidence of how these aims are pursued and whether they are being met.

Standardised measures, including standards of welfare assessment (as distinct from measures of health) that can be applied between different farm settings are lacking. Data supporting breeding indices, which represent an estimation of how a given animal’s progeny can be expected to differ from a specified norm, could be used to assess conformity with responsible breeding standards.

Proposed changes to the regulation of some genetically altered organisms may free breeders to explore potential for rapid genetic gain. In this context there is a need for a comprehensive review of measures to ensure that breeding technologies are used responsibly and do not result in harms to farmed animals, and to coordinate measures to secure a just and sustainable food and farming system.

Key points

- There is a need for more detailed standards, better use of data and enhanced oversight of breeding to define breeding objectives and ensure that breeding technologies are used responsibly.
- Consumers should be able to benefit from meaningful labelling that includes information about animal welfare, production and processing.
- Retailers should be discouraged from selling products from animals that are not responsibly bred.
- There should be a regulatory mechanism to prevent the use of farmed animals that have been bred in ways that are incompatible with the ability to live a good life.
- Farmers should be encouraged and incentivised to raise animals that are bred in ways that promote their welfare and the public good.

Introduction

6.1 Most people rely on the food and farming system to provide the nourishment they need to sustain life; how the system is arranged and managed is fundamental to justice in societies. Throughout history, failures of the food and farming system have led to famine and wars. The food supply was, in fact, the first concern of experiments in economic planning that responded to the extreme failings and injustices of early industrial capitalism. Nevertheless, the supply of food is currently managed in most countries through commercial markets, with actors participating in international trade and global value chains.

6.2 In the present chapter, we will focus on the governance of biotechnology in livestock breeding and aquaculture. We will consider measures to promote justice in relation to the lives of farmed animals, the wellbeing of human consumers, social relations, ecosystems, and the environment, and measures both to support the effective functioning of the market and to promote beneficial developments through science and technology. Although the focus will be mainly on the UK, the global nature of the food and farming system inevitably means that some of the relevant measures will require international cooperation, particularly those relevant to the protection of the planetary environment.

Balance and sustainability in breeding

Recognising animals in law

6.3 Relationships between people and farmed animals are enmeshed with cultural norms. Different traditions both recognise different ways of relating to animals, ways that may be specific to particular species, and have different approaches to governing those relations. Attempts to secure international agreement, such as a proposed Universal Declaration of Animal Rights in 1978 and the current proposal for a Universal Declaration on Animal Welfare, have so far failed to command a working consensus.[731] More recent high-level initiatives have turned away from the more problematic recognition of animal rights towards acknowledging the significance of animal sentience.

6.4 In 1976, the Member States of the Council of Europe agreed the European Convention for the Protection of Animals kept for Farming Purposes.[732] This was incorporated into European Union law and was a source for the 1998 Council Directive 98/58/EC on the protection of animals kept for farming purposes, which contains general rules for the protection of animals of all farmed species reflecting the ‘five freedoms’.[733] In the UK, a similar scheme informs the Animal Welfare Act 2006. The consolidated version of the Treaty on the Functioning of the European Union (Lisbon Treaty) of 2008 contains an Article (hitherto a protocol to the Treaty of Amsterdam on the protection and welfare of animals) explicitly recognising animal sentience and requiring Member States to pay full

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731 On the latter, see: Europa Regina (2021) *Universal Declaration on Animal Welfare*, available at: https://europaregina.eu/business-ethics/animal-ethics/universal-declaration-on-animal-welfare/.

732 The Convention is currently in force in 33 of the Council of Europe’s 47 Member States (including the UK); see: https://www.coe.int/en/web/conventions/full-list?module=treaty-detail&treatynum=087.

733 The Directive covers animals kept for the production of food, wool, skin, or fur, or for other farming purposes, including fish, reptiles, or amphibians. For the ‘five freedoms’, see Chapter 3.

regard to the welfare requirements of animals.[734] Few countries outside Europe, however, recognise animal sentience in law.[735]

Box 6.1: The UK Animal Sentience Committee

The UK did not transpose Article 13 of the Lisbon Treaty in 2017, giving out at the time that, following the UK's withdrawal from the European Union, the Government would go further still (although this promissory note caused a negative reaction at the time). A part of the Government's answer is the Animal Welfare (Sentience) Bill.[736] The Bill makes provision for the establishment of a public authority, the Animal Sentience Committee, which "When any government policy is being or has been formulated or implemented … may produce a report containing its views on… whether, or to what extent, the government is having, or has had, all due regard to the ways in which the policy might have an adverse effect on the welfare of animals as sentient beings."[737]

In terms of governance, the Committee is to be established by the Secretary of State for Environment, Food and Rural Affairs, though its purview is potentially broad, ranging across policy areas owned by other departments. It appears that the Committee will have a relatively free hand to determine on what issues it will report (although these will no doubt be the subject of delicate negotiation) and the Secretary of State is required to lay a response to any report before Parliament within three months of publication.

It is not specified in the Bill what relationships the Committee will have with other existing bodies (e.g., Defra's advisory Animal Welfare Committee) and this will need to be worked out carefully. The Bill contains no definition of sentience or a standard for assessing sentience or its degrees, so these things will have to be determined by reference to other sources and can reflect developing understandings as they emerge from continuing research.

Controls on breeding activities

Animals in science

6.5 Animals used in scientific research were the subject of an earlier Nuffield Council report and are not within the scope of the present inquiry.[738] Nonetheless, it is useful to compare the way in which their care and use is governed in science with how it is governed in commercial breeding. Such a comparison is warranted not only because, in many cases, the animals themselves do not differ (at least in respect of their physiology and capacity

[734] "In formulating and implementing the Union's agriculture, fisheries, transport, internal market, research and technological development and space policies, the Union and the Member States shall, since animals are sentient beings, pay full regard to the welfare requirements of animals, while respecting the legislative or administrative provisions and customs of the Member States relating in particular to religious rites, cultural traditions and regional heritage." Article 13, Treaty on the Functioning of the European Union (OJ C 115/1), available at: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:12012E013&from=EN). The clause recognising animal sentience was added in for the Lisbon Treaty. This follows countries such as Austria which recognised animals as sentient (and 'not things') in domestic legislation; see section 285, Civil Code of Austria, available at: https://www.jusline.at/gesetz/abgb/paragraf/285a.

[735] Canada and New Zealand are important exceptions.

[736] The Animals (Recognition of Sentience) Bill was introduced in 2019 as a Ten Minute Rule Bill but failed to complete its passage in 2017-19 session and fell. It was reintroduced as a Government Bill in the Lords in 2021 and, at the time of writing, is set to become law in 2021. See: UK Parliament (2021) *Animal Welfare (Sentience) Bill [HL]: stages*, available at: https://bills.parliament.uk/bills/2867/stages.

[737] Animal Welfare (Sentience) Bill (as introduced), clause 2, available at: https://bills.parliament.uk/publications/41515/documents/260. The Bill was originally drawn to include only non-human vertebrates in its scope, although a regulation-making power was included to bring other animals within scope. (The non-inclusion of cephalopods and other sentient non-vertebrates provoked expressions of dissatisfaction from many quarters in debates and in committee.)

[738] Nuffield Council on Bioethics (2005) *The ethics of research involving animals*, available at: https://www.nuffieldbioethics.org/publications/animal-research.

for experience between the different settings) but also because, as breeding becomes increasingly technical, involving many specialist scientific skills, techniques, and practices (such as micromanipulation, genetic testing, embryology, genome editing), it is often indistinguishable in practice, if not in purpose, from scientific research.

6.6 In the UK, research on animals is regulated by the Animals (Scientific Procedures) Act 1986 (ASPA 1986), which is implemented by the Home Office Animals in Science Regulation Unit (ASRU). This regime, involving the licensing of individuals, programmes of research, and establishments, provides for the breeding as well as the use of animals for research. It also covers research on experimental breeding techniques, such as cloning, pioneered in large animals by the Roslin Institute in Edinburgh. A key criterion in the ASPA 1986 scheme is whether an animal will experience "a level of pain, suffering, distress or lasting harm equivalent to, or higher than, that caused by the introduction of a needle in accordance with good veterinary practice".[739] This is the criterion underlying the definition of a 'regulated procedure'. The Animals in Science Committee is an advisory non-departmental public body that advises the Secretary of State on all matters concerning the use of animals in scientific procedures. It also advises a network of local Animal Welfare and Ethical Review Bodies (AWERBs) on sharing best practice.[740] Licensing decisions with regard to research projects are made by an AWERB and the ASRU Inspector on the basis of a harm–benefit analysis.

6.7 Genetic modification is a regulated procedure and subject to licensing (notwithstanding that 'protected animals' are only animals from the third trimester of gestation) if the animal will live to be a protected animal (into the third trimester or beyond) and 'may' suffer the kind of negative experiences described in section 2(1) of the Act as a result of that modification.[741] The breeding of descendants of genetically modified animals, who may also suffer such negative experiences as a result of the modification of their antecedents, is also, by that reason, a regulated procedure.[742] The regulation of genetic modification thereby 'reaches through' the generations.[743] A new line of genetically altered animals is considered to be 'established' only when transmission of the genetic alteration has been shown to be stable over at least two generations and an animal welfare assessment has concluded that the phenotype is not harmful. (In practice, any breeding of genetically altered animals is carried out subject to licence.) In these cases, breeding to maintain the line would no longer be a regulated procedure and project licence authorisation would no longer be required, allowing them to be rehomed (subject to permission from the Secretary of State) and, potentially, to enter a commercial breeding programme. By section 2(8) of the Act, 'non-experimental agricultural practices' and 'practices undertaken for the purposes of recognised animal husbandry' are not regulated procedures and are therefore exempt from the regulatory remit of ASPA 1986.[744]

739 ASPA 1986, s.2(1), available at: https://www.legislation.gov.uk/ukpga/1986/14/section/2.
740 See: Gov.uk (2021) *Animals in Science Committee*, available at: https://www.gov.uk/government/organisations/animals-in-science-committee. The AWERB network is required for each breeding, supplying and user establishment under the Animals (Scientific Procedures) Act 1986, Schedule 2C, Part 1, paragraph 6 (as amended).
741 ASPA 1986, s.3A.
742 ASPA 1986, s.3B.
743 'Genetic modification' here is wider than transgenic modification and the practices that, for example, the recent Defra consultation sought to encompass by the term 'GMO': it includes "the modification of any genetic material by virtue of which it comes into being": ASPA 1986, s.3C.
744 ASPA 1986, s.2(8), available at: https://www.legislation.gov.uk/ukpga/1986/14.

Animals on farms

6.8 For the purposes of domestic law, domestic animals are defined in the Protection of Animals Act 1911.[745] The Animal Health Act 1981 deals with biosecurity, access to inspect for disease, disease control, culling, etc., of farmed animals. Importantly, section 29 deals with control of zoonoses.[746] The Act is generally in force, but sections 37 to 39 (which deal with welfare and export) were repealed by the Animal Welfare Act 2006 (AWA 2006). AWA 2006 and associated regulations comprise the main statutory scheme providing for the treatment of farmed animals. Relevantly, the Welfare of Farmed Animals (England) Regulations 2007 provide that "Natural or artificial breeding or breeding procedures which cause, or are likely to cause, suffering or injury to any of the animals concerned, must not be practised."[747] Those Regulations also provide that "Animals may only be kept for farming purposes if it can reasonably be expected, on the basis of their genotype or phenotype, that they can be kept without any detrimental effect on their health or welfare."[748] (Similar regulations are in force for Wales, Scotland, and Northern Ireland.[749] None of these regulations applies to fish, although farmed fish fall within the scope of AWA 2006.[750])

A gap in regulation and a blind spot in oversight

6.9 Whereas the breeding of animals in scientific research (which includes the development of new techniques and new genomic variants) is regulated, and there is oversight of the welfare of individual animals on farms, there is a gap in formal oversight of the breeding of animals in agriculture and aquaculture (which may also involve scientific techniques and produce new variants). If we can assume that animals used in research and in farming are not essentially different kinds of animal (with different capacities for experience) then, if both the animals and the procedures are similar, the question must be posed: should the same scrutiny not be applied to commercial breeding? As the Royal Society said in their response to a Defra consultation on the regulation of genetic technologies in 2021: "Current rules on animal welfare focus on production systems rather than the breed itself. As there is currently no framework for assessing the welfare impacts on new breeds, the extent to which this is adequately covered by the current rules governing the use of animals in research should be evaluated."[751] Furthermore, in relation to animal reproduction, which includes procedures that facilitate breeding gains, there is a grey area between what is recognised veterinary practice and what is regarded as experimental science.[752]

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[745] This is mostly repealed but what survives are section 8 (prohibitions on poisoned grain and flesh), section 10 inspection of traps, and the definitions of 'domestic animal' in section 15(b) along with the further specifications of animals within scope in section 15(d). See: Protection of Animals Act 1911, available at: https://www.legislation.gov.uk/ukpga/Geo5/1-2/27/contents.

[746] See: Animal Health Act 1981, available at: https://www.legislation.gov.uk/ukpga/1981/22.

[747] The Farmed Animals (England) Regulations 2007 (S.I. 2007 No. 2078), Schedule 1, paragraph 28(1). Paragraph 28(2) qualifies this provision to the effect that it "does not preclude the use of natural or artificial breeding procedures that are likely to cause minimal or momentary suffering or injury or that might necessitate interventions which would not cause lasting injury."

[748] The Farmed Animals (England) Regulations 2007 (S.I. 2007 No. 2078), Schedule 1, paragraph 29.

[749] The Welfare of Farmed Animals (Wales) Regulations 2007 (S.I. 2007 No. 3070 (W. 264)); The Welfare of Farmed Animals (Scotland) Regulations 2010 (S.I. 2010 No. 388) and the Welfare of Farmed Animals Regulations (Northern Ireland) 2012 (NISR 2012 No. 156).

[750] The AWA 2006 applies to vertebrates ('protected animals' under the Act are those that are usually domesticated in the British Islands, not living in a wild state and under the control of man); section 59 provides: "Nothing in this Act applies in relation to anything which occurs in the normal course of fishing." The ASPA 1986 applies to vertebrates and cephalopods.

[751] The Royal Society (2021) *Submission to the Defra consultation on the regulation of genetic technologies*, available at: https://royalsociety.org/-/media/policy/Publications/2021/21-03-19-Royal-Society-response-to-Defra-consultation-on-genetic-technologies.pdf, at page 9.

[752] Campbell MLH (2014) Does the current regulation of assisted reproductive techniques in the UK safeguard animal welfare? *Animal Welfare* **23(1)**: 109-18; and Campbell MLH, Mellor DJ, and Sandøe PE (2014) How should the welfare of fetal and neurologically immature postnatal animals be protected? *Animal Welfare* **23(4)**: 369-79.

6.10 While the traditional 'on-farm' husbandry practices involve the deliberate selection and establishment of livestock traits in a way that could be described as 'scientific', the increasing technological intensity of breeding, particularly in the highly integrated industrial sectors, promises bolder and more experimental steps. As interventions in animal breeding for human benefit have increased in technological intensity, consideration has been given to their potential to have negative impacts on animal welfare. A foundational reference was the report of a committee of inquiry convened for that purpose under the chairmanship of the Reverend Dr Michael Banner:

> "The Banner Committee proposed three principles to be followed before any new technology was used in breeding farm animals; the first is *'harms of a certain degree and kind ought under no circumstances to be inflicted on an animal'*. What we seek to achieve here is agreement on how severe such harms can be. The second and third principles are: *'any harm to an animal, even if not absolutely impermissible, nonetheless requires justification and must be outweighed by the good which is realistically sought in so treating it'*; and *'any harm which is justified by the second principle ought, however, to be minimised as far as is reasonably possible'*."[753]

6.11 The Farm Animal Welfare Council (FAWC, reconstituted as the Farm Animal Welfare Committee from 2010 and, from 2019, the Animal Welfare Committee) had been established in 1979 to review the welfare of farmed animals and advise the UK Government of any measures that may be necessary.[754] A 2004 FAWC report contained a recommendation to establish a standing committee, to be called the Animal Breeding Committee, to be concerned with surveillance where new breeding technologies are introduced, and to report to ministers.[755] The committee was never established and nothing like the network of ethical oversight that applies to research animals through ASPA 1986 was replicated for commercial breeding.[756] While breeding companies may have their own ethics committees (e.g., as a matter of corporate social responsibility) there is no independent, nationally coordinated, and transparent (so far as commercial confidentiality would reasonably allow) system in the UK to assess, prospectively, the implications of breeding strategies.[757]

Guidance

6.12 Defra produces guidance on looking after farm animals, which restates the provision from the Welfare of Farmed Animals (England) Regulations 2000: "You must not use any breeding methods (either natural or artificial) that may cause suffering or injury to animals

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753 Extracts from Banner M (1995) Report of the committee to consider the ethical implications of the emerging technologies in the breeding of farm animals (London: HMSO), quoted in Farm Animal Welfare Council (2009) *Farm animal welfare in Great Britain: past, present and future*, available at: https://www.gov.uk/government/publications/fawc-report-on-farm-animal-welfare-in-great-britain-past-present-and-future.

754 See: Gov.uk (2014) *FAWC advice to government*, available at: https://www.gov.uk/government/collections/fawc-advice-to-government. The Council had freedom to investigate and report publicly on matters falling within its remit and maintained a connection with a network of similar European bodies. The FAW Council and FAW Committee websites are available in the National Archives respectively. NB: The powers and functions of the successive committees were not equivalent.

755 FAWC (2004) Report on the Welfare Implications of Animal Breeding and Breeding Technologies in Commercial Agriculture, available at: https://www.gov.uk/government/publications/fawc-report-on-the-welfare-implications-of-breeding-and-breeding-technologies; see also: Clark JAM, Potter M, and Harding E (2006) The welfare implications of animal breeding and breeding technologies in commercial agriculture *Livestock Science* **103(3)**: 270-81.

756 There is a Farm Animal Genetic Resources Committee, but this is mainly concerned with the preservation of rare breeds rather than the changes to commercial breeds, see: https://www.gov.uk/government/groups/farm-animal-genetic-resources-committee-fangr.

757 See: Mistra (24 May 2018) *Mistra Biotech: breeding industry needs ethical committees for genetic engineering*, available at: https://www.mistra.org/en/news/mistra-biotech-breeding-industry-needs-ethical-committees-for-genetic-engineering/.

unless it's minimal or unlikely to cause lasting injury."[758] (The standard for suffering is, as in ASPA 1986, suffering that is equivalent to or exceeds that caused by a veterinary injection.[759]) More guidance is provided in the species-specific 'codes of recommendations', which are statutory codes under AWA 2006 and contain guidance on breeding, among other matters.[760]

6.13 The Defra guidance in the species-specific codes also includes guidance on the selection of breeding animals, including to secure the welfare of the progeny.[761] Interestingly, all the guidance highlights welfare *in opposition to* production characteristics. For example, in pigs: "Breeding programmes should pay at least as much attention to improving health and welfare, as to production criteria. Therefore, the conservation or development of breeds of pigs which would limit or reduce animal welfare problems, should be encouraged."[762] Similar guidance applies to cattle and chickens, etc.[763]

6.14 As well as the species-specific codes, Defra produces a *Guide to zootechnical rules and standards*.[764] Compliance with this is overseen by the Animal and Plant Health Agency (APHA), which also licences collection and trade in bovine and porcine semen and embryos.[765] Another role of APHA is to audit recognised breed societies, of which commercial breeders are, in effect, obligate members.[766] Although there are not breed societies for all domesticated breeds and species, they occupy an important place in the industry structure for the main commercial breeds in less highly integrated sectors.[767] All breeding organisations are required to explain their breeding objectives, provide information about the selection criteria used, and give evaluation criteria relating to the objectives, among other things. The extent of APHA's oversight of breed societies is, however, limited to the health of the animals and not the objectives of the societies.

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758 The Welfare of Farmed Animals (England) Regulations 2000 (S.I. 2000 No. 1870) Sched. 1, para.28; and at: Defra (2015) *Farm animals: looking after their welfare – guidance*, available at: https://www.gov.uk/guidance/farm-animals-looking-after-their-welfare.

759 ASPA 1986, s.2(1).

760 Defra (2015) *Farm animals: looking after their welfare – guidance*, available at: https://www.gov.uk/guidance/farm-animals-looking-after-their-welfare.

761 The guidance on cattle, for example, says: "A high priority in the breeding selection policy should be to include qualities that will improve the welfare of the animals, for example, leg and foot conformation which would lessen the likelihood of lameness. You should not breed from any animals that have deformities or other weaknesses, where these could affect the general welfare of the stock. For beef cattle in particular, you should breed from animals that are more docile (less aggressive), and also animals with good muscular-skeletal structures (which can reduce lameness). Where possible, you should breed from naturally-polled cattle (i.e., those with no horns) as this avoids the need for disbudding or dehorning." Defra (2003) *Code of recommendations for the welfare of livestock: cattle*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69368/pb7949-cattle-code-030407.pdf, at paragraph 122.

762 Defra (2020) *Code of practice for the welfare of pigs*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/908108/code-practice-welfare-pigs.pdf, at paragraph 117.

763 See codes of recommendations available at: Defra (2015) *Farm animals: looking after their welfare – guidance*, available at: https://www.gov.uk/guidance/farm-animals-looking-after-their-welfare.

764 Defra (2021) *Guidance: zootechnical rules and standards*, available at: https://www.gov.uk/guidance/zootechnical-rules-and-standards.

765 The APHA Regulatory and Compliance policy makes a general framing statement that: "Through our regulatory activities, we work to prevent, control or eradicate notifiable disease and pests, uphold food safety and ensure high standards of welfare in farmed animals." See: APHA (2017) *Regulatory and compliance policy*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741996/pub-reg-comp-policy.pdf, at paragraph 1.4.

766 "Breed societies and studbooks that are officially zootech recognised by Defra or the relevant devolved authority can trade purebred breeding animals and germinal products on preferable terms. This means that animals and germinal products from recognised breeding bodies are treated the same in different countries." See: Defra (2021) *Guidance: zootechnical rules and standards*, available at: https://www.gov.uk/guidance/zootechnical-rules-and-standards. The APHA Regulatory and Compliance Policy is available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741996/pub-reg-comp-policy.pdf. See also: APHA (2021) *Bovine and boar semen collection and breeding: licence application*, available at: https://www.gov.uk/government/publications/bovine-and-boar-semen-collection-and-breeding-licence-application.

767 See: Defra (2021) *Guidance: zootechnical rules and standards*, available at: https://www.gov.uk/guidance/zootechnical-rules-and-standards.

Another gap in regulation

6.15 Although genome interventions may only be applied to a small number of founder animals (important though these are in themselves), these can be highly consequential given their diffusion through domestic populations. Furthermore, breeding companies are involved in continual development of lines, which entails continual interventions in successive generations. The long-term cumulative effects of the pursuit of commercial breeding goals are difficult to assess because of their incremental nature and the absence of reporting requirements or incentives for companies to publish data in peer-reviewed journals. In a judgment in judicial review proceedings in 2003, it was observed that the statutory scheme focuses on the effect of breeding on individual animals and *not* its accumulated effect on the constitution of breeds, so that the latter was not justiciable.[768] In fact, while breeding may have a significant effect on welfare, and while animal welfare regulations in the UK and EU contain many detailed provisions on housing, enrichment, space allocation, and other matters, there is very little provision relating to the effects of breeding. In view of our conclusion in Chapter 4, that potential intergenerational drift in the *capacities* required for living a good life as a result of the pursuit of breeding goals gives cause for concern, we regard the absence of any mechanism of oversight as a worrying omission. We discuss below how it might be redressed.

Industry self-regulation

6.16 The lack of statutory or officially mandated oversight institutions need not imply a lack of reflection or coordination among those involved in the breeding of domestic animals. At a high level, the European Forum of Farm Animal Breeders (EFFAB) has, since 2006, maintained a code of practice on responsible animal breeding (Code-EFABAR).[769] The Code, which is reviewed triennially, aims to be the standard instrument for defining and maintaining good practices for farm animal breeding and to provide transparency about animal breeding for society.[770] It sets out goals for animal breeding organisations, the way in which these goals are pursued, and rules and standards to govern the activities of breeders.

6.17 It is notable that Code-EFABAR, on its face at least, offers a more sophisticated elaboration of the 'balanced breeding' concept than simply striking a balance between productivity on one hand, and animal health and welfare on the other, one that treats breeding aims as a complex problem. In fact, a recent elaboration of the Code contains, alongside the original concept of 'responsible breeding', the more aspirational concept of 'sustainable breeding', which is defined as:

> "the extent to which farm animal breeding, as managed by professional organisations, contributes to the production of sufficient, safe, nutritious, and healthy

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[768] *R. (Compassion in World Farming Ltd) v. The Secretary of State for the Environment, Food and Rural Affairs* [2004] EWCA Civ. 1009 *per* Sedley L.J. In the judgment it is noted, with heavy irony: "What complicates the issues considerably is that the developmental peculiarities of these birds, which make diet and growth to a significant degree antithetical, are genetic. This is why much of the appellants' critique of the feeding system is in fact directed to the genotype. But the selection of genotypes is beyond the reach of the measures at issue in this appeal. It may nevertheless be for consideration whether, if the ingredients of an offence are otherwise present, the use of a genotype which makes suffering unavoidable affords a defence."

[769] See: Code-EFABAR (2020) *Code of good practice for farm animal breeding organisations*, available at: http://www.responsiblebreeding.eu/uploads/2/3/1/3/23133976/01_general_document_2020_final-code_efabar.pdf. See also: Code-EFABAR (2021) *Homepage*, available at: https://www.responsiblebreeding.eu/.

[770] See: Code-EFABAR (2020) *Code of good practice for farm animal breeding organisations*, available at: http://www.responsiblebreeding.eu/uploads/2/3/1/3/23133976/01_general_document_2020_final-code_efabar.pdf.

food whilst taking care of genetic diversity, resource efficiency, environment, animal health and animal welfare to create 'a better world' for future generations."[771]

6.18 Whereas responsible breeding takes care to guard against the undesirable downstream consequences of present action, the further concept of 'sustainable breeding' takes into account factors (such as stewardship of managing genetic diversity, the environment, and the heritage of future generations) to which it is often difficult to attach an economic weighting in conventional selection indices (see below). It embodies an awareness and sense of responsibility for the relation between local action and global outcomes.

6.19 Companies that adopt the Code may obtain certification by indicating how they meet requirements of the 6 pillars of balanced breeding, comply with the five general statements, and have in place an 'internal roadmap' for improvements and to demonstrate how Code-EFABAR has been implemented through their internal policies.[772] It also has a complaints procedure that can be used by non-members to complain about an aspect of the Code or compliance with the Code by any certified members. Complaints can be pursued through a non-conformance committee, which comprises four breeders (representing the main domestic species) and an independent chair.[773] The Code has been adopted by many of the major breeding companies.

6.20 Code-EFABAR is notable in that it covers all major domestic species (ruminants, pigs, poultry, and fish) and acknowledges the social significance of animal breeding, setting requirements that go beyond EU and national laws, linked to UN sustainable development goals. Compliance with the Code and certification is therefore, on its face, a good thing. Nevertheless, the Code is pitched at a very high level and couched in very broad language, and there are elements that could be improved or further elaborated. One area of improvement is the elision of animal health and welfare (see below) and the absence of a recognition of the constitutional capacities that are essential to sentient animals being able to live a good life. Furthermore, while the sustainable breeding objectives may be adopted ostensibly by companies (and promoted in literature and presentations), it is very difficult to verify compliance and to assess the effects of compliance (or non-compliance) with any confidence. There is therefore a danger, against which EFFAB will need to guard, of the Code being used for 'ethics washing' by less scrupulous companies. So, **while we endorse the ambition of Code-EFABAR and recommend that all commercial breed developers should adopt the Code or an equivalent, recognised set of breeding standards with independent oversight, we also recommend the development of more detailed standards that may be enforced on a clear basis of evidence by a national competent authority. These will need, in particular, to ensure that animals may not be bred to enhance traits merely so that they may better endure conditions of poor welfare, or in ways that diminish their inherent capacities to enjoy experiences that constitute a good life**.[774]

Regulatory deficits

6.21 Part of the difficulty of specifying more detailed standards for breeding and for assessing compliance is that the industry structures are different for the major domestic species. This is for a mixture of historical and economic reasons. For some, such as cattle and

[771] Ibid., at section 3.2.
[772] Ibid., at section 3.1.
[773] This procedure does not appear to have been used, however (Ana Granados Chapatte, Director of EFFAB, personal communication, 26 August 2021).
[774] See Chapter 7 (Recommendation 2).

sheep, there are many breeders and breed societies and, indeed, many animals are still bred 'on farm' by farmers who may use or share the genetic resources of their own stock. For others, such as chickens, pigs, and fish, the industries are relatively consolidated and vertically integrated, so that a few large producers dominate the supply chain. Breeders cannot necessarily be expected to pursue the aspirational goals of responsible and sustainable breeding without external encouragement, the small farmers through relative lack of agency with regard to the genetic and environmental factors and the larger, consolidated producers for reasons of economic competitiveness.[775] The governance of breeding suffers from two fundamental deficits:

a an information deficit (there are inadequate data to support pursuit of aims or to verify the actual practice and its consequences); and

b a regulatory deficit (there are inadequate mechanisms of coordination and enforcement of breeding objectives and, meanwhile, there are strong incentives to diverge from coordinated pursuit of social aims for private benefit, which is possible because of (a)).

Redressing the information deficit

6.22 There are several limitations to the availability of information and to the value of the information that is available regarding domestic species. These relate to variabilities in collection, recording, keeping, reporting, and analysis of information. The quality and richness of extant data vary between species and husbandry systems. Some of the most relevant data may also be commercially sensitive and protected by breeders. Small producers often use information differently and may practise husbandry in ways that do not depend on recording information. This makes it very difficult to assess, prospectively, the extent to which different breeding aims are actually being pursued by breeders in the development of elite breeding stock and also to assess, retrospectively, how successfully those aims have been achieved in the populations of farmed animals produced for the market (as well as any other outcomes of interest).

Breeding indices

6.23 Because many traits of interest to farmers are heritable, a number of measures are used and publicised by breeding companies that aim to represent the inherited genetic characteristics of stock (or of the genetic material taken from them) that is to be used or offered for sale. Thus, the breeder might indicate to the prospective purchaser of a laying hen how many eggs the hen can be expected to produce annually, and for how long she will continue to lay at a given rate.[776] They may also indicate the expected performance under different conditions, enabling a farmer to choose the animals that are most appropriate for their system.

6.24 A key indicator for the selection of animals is the profitable lifetime index (PLI). PLIs measure the additional profit that offspring of a given animal are predicted to earn over

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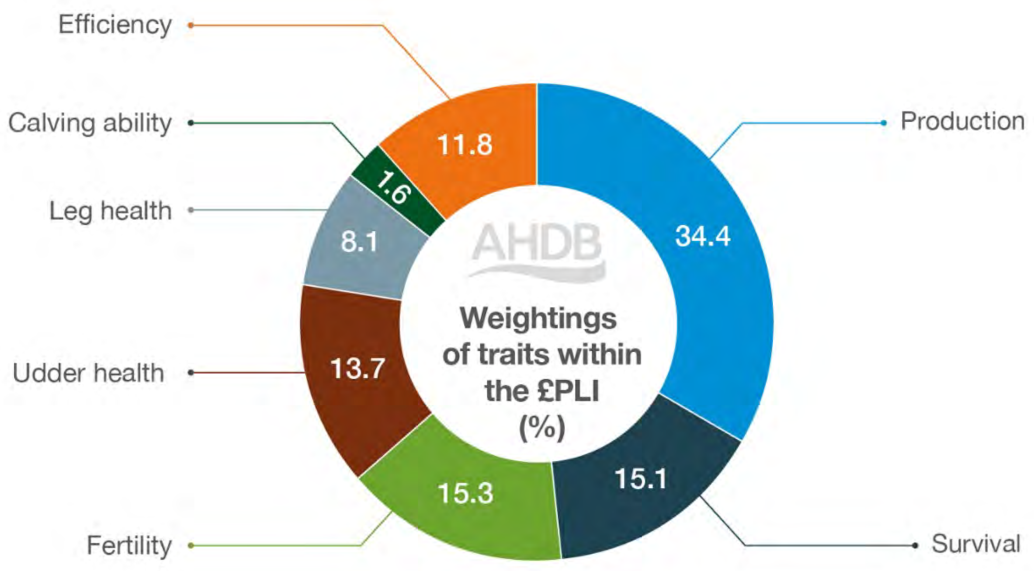
775 This is not to say that farmers are not engaged with issues of environmental conservation and restoration – far from it – but that they have little individual agency and power to affect more global issues directly.

776 See, for example, Hendrix Genetics (20 September 2019) *Reaching the mission of 500 first quality eggs*, available at: https://layinghens.hendrix-genetics.com/en/articles/reaching-mission-500-first-quality-eggs/.

their lifetime compared with offspring of an average animal (PLI=0) of that breed.[777] These indices were originally developed for production traits that had shown obvious heritability and were taken up with enthusiasm within the cooperative breeding programmes of the dairy industry. The use of indices is now common in all the major domestic species, including cattle, chickens, pigs, sheep, and fish.[778] A number of indices are used, which combine a range of weighted measures. For example, for dairy cattle, these may include production traits (fat content, feed conversion), fertility, udder health, leg health, calving ability, and longevity, among other things. Then there may be different indices for spring and autumn block calving systems. Below is a representation of the weighting of different traits in a standard dairy PLI, showing the weighting of traits according to their relative economic importance.



Source: AHDB[779]

6.25 Breeding indices (or genetic indices) can be developed for any trait of interest for which the heritability can be calculated. Breeding indices are used by companies that supply 'genetics' (in the form of reproductive material – generally semen for artificial insemination – or breeding animals), to express the extent to which a trait of interest is expected to be passed on to that animal's offspring ('predicted transmitting ability').

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[777] The dairy industry's practice of periodically re-basing genetic indices as characteristics of the 'average' animal (PLI=0) changes as a result of breeding potentially obscuring the extent of 'genetic gain' seen longitudinally, over longer time periods.

[778] For breeding indices with respect to sheep see, for example, Signet Breeding Services (2018) *Breeding indexes*, available at: https://www.signetdata.com/technical/genetic-notes/breeding-indexes/; with respect to pigs see, for example, Melnikova EE, Nikitin SA, Kabanov AV *et al.* (2020) Selection indices used in different breeding systems with pigs of maternal breeds *Russian Agricultural Sciences* **46(5)**: 503-8; with respect to chickens see, for example, Dunn IC, Woolliams JA, Wilson PW *et al.* (2019) Genetic variation and potential for genetic improvement of cuticle deposition on chicken eggs *Genetics Selection Evolution* **51(1)**: 25; with respect to salmon see, for example, Lhorente JP, Araneda M, Neira R *et al.* (2019) Advances in genetic improvement for salmon and trout aquaculture: the Chilean situation and prospects *Reviews in Aquaculture* **11(2)**: 340-53. On dairy, see: AHDB (2021) *Dairy breeding and genetics*, available at: https://ahdb.org.uk/knowledge-library/dairy-breeding-and-genetics. The beef industry has, in general, maintained a more traditional approach for longer, although efficient sexing of sperm now allows a proportion of dairy herds (usually the lower rated milkers) to be inseminated with semen from beef bull to breed calves for beef, while the higher rated are bred to dairy bulls to renew the milking herd. See, for example, Berry DP, Amer PR, Evans RD *et al.* (2019) A breeding index to rank beef bulls for use on dairy females to maximize profit *Journal of Dairy Science* **102(11)**: 10056-72.

[779] AHDB (2021) *Profitable Lifetime Index £PLI*, available at: https://ahdb.org.uk/knowledge-library/profitable-lifetime-index-pli.

Given the difference in the nature of the characteristics and their heritability, the sub-indices that comprise the overall PLI are calculated in different ways.[780] They may be calculated from information about the animal's own performance or, where that is lacking, that of its known relatives. For example, for a production trait of high heritability, 50 daughters of a dairy bull might give a reliable index for that bull; a trait of low heritability might require observation of more: perhaps 500. Genomic indices are increasingly used for many species. These allow a genetic index to be calculated from the animal's own genotype, rather than from information about its relatives, on the basis of a comparison with the genomes and known characteristics of an appropriately sized reference population.[781]

6.26 In the UK, the Agriculture and Horticulture Development Board (AHDB) collects, analyses, and publishes data from breeders, farms, and abattoirs, as well carrying out research, providing market intelligence for farmers, and setting breeding goals for the industry.[782] One of its functions is to develop and validate breeding indices.[783] The selection of traits and the measures for which data are available to validate the index are therefore of crucial importance for both the prosperity of farmers and the characteristics of the animals that populate the industry.

6.27 The breeding index is a powerful tool shaping the composition of the national herd. The selection and composition of indices is influential as much in terms of what is left out as what is included. The AHDB's introduction of a fertility index for dairy cattle in 2005 was disruptive because it provided relevant information that farmers had been missing up to that point. It changed farmers' behaviour by allowing them to form a better picture of how different genetic lines of cattle could promote their interests. The cost of veterinary treatment, and the impact on production, not to mention the value farmers place on the welfare of their animals, act as incentives to adopt indices that involve health measures (e.g., bovine tuberculosis resistance index).[784] The EnviroCow index, introduced by the AHDB in August 2021, identifies cows predicted to create the least greenhouse gas emissions in their lifetimes for each kilogram of solids-corrected milk they produce.[785] The research supporting it demonstrates a happy coincidence in certain cattle between requiring less feed input and producing less greenhouse gases, both showing the way to an input cost saving and offering to contribute to the 'net zero' industry goal.

6.28 The EnviroCow index was the result of 30 years' research by the AHDB. Breeding companies that produce their own indices will have their own priorities and approaches

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[780] See, for example, AHDB (2021) ***Health, welfare and fertility PTAs***, available at: https://ahdb.org.uk/knowledge-library/health-welfare-fertility-ptas.

[781] See, for example, AHDB (2021) *Genetic indexes: the theory*, available at: https://ahdb.org.uk/knowledge-library/genetic-indexes-theory. The dairy industry has been an enthusiastic adopter of genomic evaluations: 70% of bull semen sold in the UK is currently marketed using genomic evaluations and farmers are increasingly adopting genomic evaluations for female cows (around 15% are currently being genotyped but that proportion is increasing rapidly). In dairy, production traits tend to show moderate to high heritability (around 30% for milk production) whereas health related traits tend to show lower heritability (4-5% for mastitis resistance, for example) Traits with lower degrees of heritability require a correspondingly larger reference population to establish.

[782] Small agricultural businesses, in particular, benefit from R&D carried out by levy boards, specifically the AHDB, which is supported under statutory levies imposed by The Agriculture and Horticulture Development Board Order 2008 (https://ahdb.org.uk/levy-information), the level of which is voted for by qualifying farmers (as well as a small contribution from breeding companies in consideration of genomic assessments). The AHDB has been described as the '*Which?* for farmers'. It does not currently cover chickens or fish. The AHDB maintains links with evaluation units in other countries. While AHDB sets industry goals, it is left to farmers to interpret these and to select the traits they require.

[783] For example, when a breeder markets a bull in the UK, they are obliged to use AHDB data.

[784] In April 2021 the AHDB introduced a HealthyCow index, which highlights genetics good for health. See: AHDB (2021) *HealthyCow index*, available at: https://ahdb.org.uk/knowledge-library/healthycow-index.

[785] This EnviroCow index includes milk production, lifespan, fertility with the new feed advantage index; see: AHDB (3 August 2021) *Breeding cows to help reach net zero*, available at: https://ahdb.org.uk/news/breeding-cows-to-help-reach-net-zero.

to collecting and publishing the data that underpin them.[786] Owing to the market structure, there is no direct incentive for breeding companies either to collect data that do not serve their business objectives or to publish such data in peer-reviewed journals (although many do). Independent academic research is relatively patchy and dependent on funding and the permission of the companies, which are naturally concerned to protect information that might be commercially sensitive or that could affect their reputation.[787]

Box 6.2: Introduction of balanced breeding in the Scandinavian dairy industry

Our review of historical and more recent balanced breeding strategies (see Box 2.3) highlighted the way that the Scandinavian dairy sector has been able to make use of historical data and the cooperative industry structure to develop balanced breeding of dairy cattle. The process of transition in the Scandinavian countries from a selective breeding programme focusing predominantly on production traits to goals that include health and fitness traits for the dairy cattle industry began as early as the 1960s. This was enabled by the dairy farmers' cooperative organisational structure, which allowed the creation of integrated databases including milk recording and artificial insemination (AI) services. The integration of the two databases meant automatic pedigree control and registers were established for all recorded cows. A few years later, health data from veterinary services were also incorporated into the databases. This system was largely adopted and funded by the farmers but was also supported by representatives of the veterinary organisations and scientific researchers. The centralised databases meant it was possible to analyse trends in traits of dairy cattle, draw conclusions from past experiences, and predict future outcomes. This created the possibility of establishing total merit indexes (TMI), which include health and welfare traits alongside traditional production traits, allowing a complete re-evaluation of breeding objectives.

* The full review can be read at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering.

6.29 Relevant data comprise information not only about heritable traits but also about contingent factors that demonstrate how different animals interact with husbandry systems. For example, our research found very few standard measures for animal welfare at all (let alone longitudinally) and therefore very few available data regarding the cumulative effects of breeding for indexed traits on animal welfare (i.e., separate from data on health) in any of the major domestic species.[788] This means that it is difficult to investigate the aspect of concern we identified in Chapter 4, namely that animals may be bred to compensate for other characteristics that have a negative impact on the quality of their lives and that allow them to tolerate conditions of poor welfare without ostensible adverse health effects.[789] **The development of meaningful measures of welfare that support the assessment of how animals with different inherited**

[786] Commercial pig production, for example, which is dominated by relatively integrated production systems, relies on relatively few breeders who use differently composed indices (Craig Lewis, Chair of EFFAB, personal communication).

[787] Nuffield Council on Bioethics (2021) *Review of literature and publicly available data on the longitudinal effect of balanced breeding strategies in context of historical health and welfare outcomes*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering.

[788] Perhaps the most sophisticated on-farm welfare assessment developed for farmed animals is described by the EU funded Welfare Quality project (see: Blokhuis HJ, Veissier I, Miele M *et al.* (2010) The Welfare Quality® project and beyond: safeguarding farm animal well-being *Acta Agriculturae Scandinavica, Section A — Animal Science* **60(3)**: 129-40); however, further development is suggested to meet identified limitations (see: de Jong IC, Hindle VA, Butterworth A *et al.* (2016) Simplifying the Welfare Quality® assessment protocol for broiler chicken welfare *Animal* **10(1)**: 117-27); see also: Nuffield Council on Bioethics (2021) *Review of literature and publicly available data on the longitudinal effect of balanced breeding strategies in context of historical health and welfare outcomes*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering.

[789] This was also raised as a key issue by participants in our public dialogue (see Chapter 5).

characteristics fare in real world conditions is an area in which there is a need for further research, for which public funding should be made available.[790]

6.30 Data collection, particularly from farms, is challenging owing to the need for clear standards, appropriate surveillance, and sampling measures, particularly with free-roaming animals, and the additional burden it would place on farmers. This is particularly true of some kinds of data and for some species.[791] The information deficit makes it difficult to assess whether some breeding goals are being attained and to what extent the outcome is affected by interaction with different husbandry systems and conditions. Therefore it is difficult to validate the indices. Data collection may be improved by the adoption of more effective surveillance technologies (e.g., infrared cameras for housed animals), and by expanding and integrating the sources of data (e.g., including genomic data), including from subsequent stages of the supply chain.[792] Many of these technologies are novel and require validation before they can be relied upon, however. **We believe that the development and deployment of on-farm surveillance technologies should be encouraged and that their independent validation by a competent authority should be supported.**[793]

6.31 The adoption of properly validated surveillance technologies could provide direct benefit to farmers because it provides information about the condition and performance of individuals among their stock. It would also support precautionary surveillance by increasing the capacity to identify and respond to unanticipated, unintended, and/or adverse effects of accelerated breeding. **To secure the benefits for the industry and members of the public, the improvement of information use needs to include improved reporting mechanisms, analysis, and return of information to farmers**.[794]

Box 6.3: Livestock information

Farming (in the UK and European countries) is an industry with a high intensity of form filling through which farmers are required to engage with multiple official agencies.[795] This is inefficient both at the farm end and at the agency end. One way in which this is being addressed is through the Livestock Information Programme, a joint government–industry scheme to move the registration and tracing of livestock in England from paper to a single digital system, the Livestock Information Service (LIS). This will initially consolidate existing systems for sheep, cattle, and pigs. The LIS is intended to make disease prevention and management more effective, but it will also enable data to be used for additional purposes (it is promoted as a way of making the industry more efficient and increasing profitability).[796] It also has potential uses for further research and surveillance. For example, the Agriculture and Horticulture Development Board (AHDB)

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790 See Chapter 7 (Recommendation 3).

791 The identification of individual fish, for example, is inherently challenging. Surveillance of pigs is made difficult in the UK owing to the large minority that live outdoors all year round and farrow in moveable arks. We heard, however, how this was overcome in other systems where precision farming technologies for recording individual piglet birth weights and individual feed intake during the growth phase are in routine use, both in nucleus breeding farms and crossbred partner farms (Craig Lewis, Chair of EFFAB, personal communication).

792 In the UK, The Agriculture Act 2020 makes provisions to increase data sharing in the agri-food supply chain; see also Duncan Smith I, Villiers T, and Freeman G (2021) *Taskforce on Innovation, Growth and Regulatory Reform (TIGRR) report*, available at: https://www.gov.uk/government/publications/taskforce-on-innovation-growth-and-regulatory-reform-independent-report, at paragraph 419.

793 See Chapter 7 (Recommendation 4).

794 See Chapter 7 (Recommendation 5).

795 Duncan Smith I, Villiers T, and Freeman G (2021) *Taskforce on Innovation, Growth and Regulatory Reform (TIGRR) report*, available at: https://www.gov.uk/government/publications/taskforce-on-innovation-growth-and-regulatory-reform-independent-report.

796 See: AHDB (2021) *Livestock Information Programme*, available at https://ahdb.org.uk/livestock-information-programme.

> developed a new genetic evaluations database for beef and lamb, incorporating online data entry, calculation of inbreeding coefficient, genetic trends, and flock reporting, which could benefit from integration with LIS information.[797]

Redressing the governance deficit

6.32 While the selection and composition of indices are important, they drive behaviour principally by revealing a more efficient way of pursuing farmers' existing interests. Indices can be envisaged for features that have less direct economic significance, but they are correspondingly less likely to drive behaviour if they do not show a commercial advantage in either an absolute sense (because farmers need sufficient revenue to make at least normal profits in the medium term) or in a comparative sense, because farmers are in continuous competition for market share with other producers.

Market incentives

Value chains

6.33 Except where they are consumed directly by the hunter or farmer, a situation that is comparatively unusual in most economically developed societies, animal-based foods are sold and bought through the marketplace. From the farm to the marketplace there exists a more or less complex value chain.[798] This enables specialisation on the part of those involved in each of the intermediate processes, differentiation into a range of products, and delivery of those products to consumers, who may be at a considerable distance in space or time from the farm. At each stage, value is notionally added to the final product, with a corresponding uplift in price. For example, the average price for milk 'at the farm gate' in the UK in October 2021 was approximately 32 pence per litre.[799] The average price of milk bought in a UK supermarket is 85 pence per litre, even though supermarkets may use milk as a 'loss leader'. This is a relatively short value chain, involving farmers, milk processors, wholesalers, and retailers (such as supermarkets) and potentially extending back to feed producers and wholesalers and agrichemical suppliers.

6.34 In theory, the market sends signals to producers via the price mechanism to indicate what products are in demand and, therefore, what they should produce. In one sense, the interests of producers and consumers are directly opposed: producers want to secure the highest price and consumers the lowest. On the other hand, they share an interest in agreeing a price so that they can make a transaction that will benefit them both. Whereas producers and consumers depend on each other to accomplish a transaction, they are also dependent on the normative system that enables this (e.g., by ensuring the contractual obligations are honoured) and on the wider natural and social environment that they inhabit together (which provides the conditions for producing the goods exchanged). Producers and consumers are, equally, citizens subject to norms that regulate their interactions, which may take the form of laws, rules, customary behaviours,

[797] AHDB (2020) *Annual report and accounts 2019/20 (HC411)*, available at: https://projectblue.blob.core.windows.net/media/Default/About%20AHDB/Reports%20and%20reviews/HC411-AHDB%20ARA%202019-20_Web_Accessible.pdf, at page 7.

[798] The concept of the value chain is more or less equivalent to the 'agri-food supply chain' as defined in section 24 of the Agriculture Act 2020 (assuming that all actors extract rent for their contributions).

[799] Defra (28 October 2021) *National statistics: United Kingdom milk prices and composition of milk: October 2021*, available at: https://www.gov.uk/government/statistics/uk-milk-prices-and-composition-of-milk/united-kingdom-milk-prices-and-composition-of-milk-statistics-notice-data-for-june-2019; and AHDB (29 October 2021) *UK farmgate milk prices*, available at: https://ahdb.org.uk/dairy/uk-farmgate-milk-prices.

etc. As citizens they have an interest in securing these conditions, and in ensuring that they are just (see Chapter 3).

6.35 Value chains offer a perspective on the extraction of economic rent by actors at successive stages of the process that involves the raising of a commodity and rendering it into a product for a consumer. It is evident, however, that the rent extracted at each link in the value chain is not always or often directly proportionate to the value added by each actor in the chain. This difference betokens a related inequality of power among those actors. Individual consumers have relatively little power, but their consumption preferences inform, to an extent, how the considerable power concentrated in the hands of retailers (particularly following the 'supermarket revolution') is brought to bear.[800]

6.36 Retailers only organise consumer power to an extent, however, and usually only where doing so aligns with their own interests, which are dominated by the interest in maximising and protecting their share of the market. Retailers are able to mobilise the power of consumers because consumers themselves are, by and large, not organised. Exceptions to this are a number of (mainly single-issue) groups who campaign on aspects of the food system and ingredients (from additives to vegetarianism) and a number of loosely coordinated food 'movements' (e.g., organic food, slow food, localism) that may express preferences for alternative forms of association between producers and consumers.[801] Some campaigns, especially those promoting public health issues, have had notable success in changing what is offered by retailers and what is purchased by consumers, though this has most often been the result of intervention strategies with multiple components, sometimes involving legislative change.[802]

Informing consumers

6.37 Consumers consistently report a wish for information on which to make choices about the products they consume, and that clear and meaningful product labelling is important to them.[803] Given that public attitudes to many first-generation genetically modified (GM) products were piqued by the failure to segregate GM and non-GM commodity crops as ingredients in processed foods (on the grounds that they were substantially equivalent), it is reasonable to broach the question of labelling products from genome-edited animal

[800] See: FAO (2020) *Competition, market power, surplus creation and rent distribution in agri-food value chains: background paper for The State of Agricultural Commodity Markets (SOCO) 2020,* available at: https://www.fao.org/documents/card/en/c/cb0893en. See also: OECD Trade and Agriculture Directorate (2021) *Concentration and market power in the food chain*, available at: https://www.oecd-ilibrary.org/agriculture-and-food/concentration-and-market-power-in-the-food-chain_3151e4ca-en. Neither study finds that the concentration of power with retailers is exercised to the detriment of farmers.

[801] For example, The Food Commission, an independent NGO, lists 37 other organisations campaigning on food issues in Britain; see: http://www.foodcomm.org.uk/links/campaigning/.

[802] See, for example, a meta-analysis of measures to reduce harmful trans fats: Hyseni L, Bromley H, Kypridemos C *et al.* (2017) Systematic review of dietary trans-fat reduction interventions *Bulletin of the World Health Organization* **95(12)**: 821-830G.

[803] This finding was confirmed in relation to genome editing through the public engagement initiatives described in Chapter 5. It is also demonstrated by the popularity of services such as Open Food Facts (https://uk.openfoodfacts.org/) used by 6 million users a year. The relevant law in the EU is Regulation (EC) 1830/2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and Regulation (EC) 1946/2003 on transboundary movements of GMOs. As we concluded our inquiry the Government launched a call for evidence regarding food 'labelling for animal welfare' (available at: https://www.gov.uk/government/consultations/labelling-for-animal-welfare-call-for-evidence). Although the questionnaire does not ask about breeding methods, which may be regarded as to some extent contingent to the question of welfare, it includes a question about the content of "welfare standards that covered the whole life of the animal, including slaughter and transport, and of its parents".

lines.[804] There is a noted difficulty in distinguishing genome-edited products from conventional products analytically because, unlike in most products of recombinant DNA technologies, cases of genome editing may leave no detectable trace of the edit having been made.[805] This means that while genome-edited products may be *traced*, many of them may not be capable of being *identified* as such. The validation of labelling may therefore, in the sort of cases where an edit is within the anticipated range of natural variation, require the development of new tools or rely on verifiable chains of custody.[806] The latter may become more difficult to establish as supply chains become elongated, especially where they may cross jurisdictional boundaries between different regulatory schemes with different approaches to verification and enforcement.[807]

6.38 It is, nevertheless, possible to argue that the labelling of genome-edited products as distinct from products of 'conventional' breeding is irrational or, at least, inconsistent with the argument that, for some genome-edited organisms, they are organisms that could have come about through natural mating or recombination but for the fact that the variation was introduced by direct genomic intervention. Thus, if the product is within the anticipated range of natural genetic variation, any significance attaching to the way in which that variation came about should be irrelevant to the qualities of the product itself. Furthermore, if (as is the case with plants) products that have been developed through random mutagenesis by exposing them to radiation or chemical toxins do not require labels referring to how they came about, it would seem inconsistent to require those that have come about as a result of deliberate genetic alteration to be labelled.

6.39 Clearly, not everything within the natural range of genetic variation is harmless to animals or to consumers of animal products. Many powerful toxins, for example, exist in the wild having evolved entirely without human intervention.[808] Furthermore, without knowing a great deal about the genetics of the organism concerned, the relation between the size of a genetic alteration and the size of the effect cannot be known. Small alterations do not necessarily mean small effects. This is easily demonstrated by the fact that certain point (single base) mutations in the genome can have severe or lethal consequences for the phenotype whereas, in other cases, the disruption or ablation of long sequences within the genome has no apparent effect.[809] This suggests that the safety of genome-edited products is not guaranteed by the fact that 'they could have come about through conventional breeding'. More specific information about the nature of the alteration and its effects would be needed for this. But this is as much an argument for enhanced information about conventional breeding as it is for not including information about the products of biotechnology. In fact, all novel products placed on the market, genome-edited products included, are required to be subjected to risk assessment and appropriate analysis and testing.[810]

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804 House of Commons Select Committee on Science and Technology (1999) *Scientific advisory system: genetically modified foods: first report of session 1998-99*, available at: https://publications.parliament.uk/pa/cm199899/cmselect/cmsctech/286/28605.htm.
805 Although, see: Young AE, Mansour TA, McNabb BR *et al.* (2020) Genomic and phenotypic analyses of six offspring of a genome-edited hornless bull *Nature Biotechnology* **38(2)**: 225-32.
806 See (in relation to genome edited plants): Grohmann L, Keilwagen J, Duensing N *et al.* (2019) Detection and identification of genome editing in plants: challenges and opportunities *Frontiers in Plant Science* **10(236)**.
807 This will be a challenge for the UK in developing bilateral trading relationships with jurisdictions that do not observe the traceability and labelling requirements imposed by European Union law or equivalent instruments.
808 For example, the fugu or blowfish, eaten as a delicacy in Japan, contains the neurotoxin tetrodotoxin in the liver, eyes, ovaries and skin, potentially enough to kill about 30 human adults.
809 This point was made convincingly by The Roslin Institute's response to the Defra consultation; see: The Roslin Institute (2021) *Roslin response to UK Government consultation on gene editing*, available at: https://www.ed.ac.uk/roslin/research/roslin-response-uk-gov-consultation-gene-editing.
810 For the UK, see: FSA (2020) *Novel foods authorisation guidance*, available at: https://www.food.gov.uk/business-guidance/regulated-products/novel-foods-guidance#new-authorisations. See also FSA's helpful flowchart: FSA (2020) *Regulated products process flowchart*, available at: https://www.food.gov.uk/document/regulated-products-process-flowchart.

6.40 The argument for labelling of genetically altered animal products is not exhausted by the question of food safety, however. Food products and their production have cultural and social significance beyond the characteristics of the product, certainly beyond those that are analytically determinable in the laboratory. If this were not the case, 'Fair Trade' and 'Buy British' campaigns, and protected designation of origin schemes, would be meaningless, whereas in fact they have a significant effect on consumer behaviour. The argument for mandatory labelling needs to be restated at least as an argument for meaningful labelling. This is labelling that both enables choices that are meaningful to consumers and conveys information to which public significance can be attached (i.e., is not merely idiosyncratic). This, in turn, relies on a background of information and prior decisions that, for reasons of space and utility, cannot be described on the label itself.

6.41 Market mechanisms can be helpful, particularly where consumers give 'social' values sufficient weight, to encourage the production of public goods like public health, environmental protection, and animal welfare: goods that may be undervalued by the private interests that exert influence in the value chain, giving rise to some of the major challenges discussed in Chapter 2.[811] As the UK Government argues:

> "Consumers need to be able to make informed purchasing decisions to reflect their animal welfare preferences… Aside from the scope for more transparency, high animal welfare is a public good: it is possible for someone to derive positive value from the fact that animals are being well cared for as a result of another's purchasing decision. Those not buying animal products should be included in any assessment of public value, one person's holding of this value does not detract from another's."[812]

6.42 With the implementation of distributed ledger technologies (replicated, synchronised, and shared consensus databases, such as a blockchain), it should become increasingly straightforward to trace a growing number of foods and ingredients from origin through processing and distribution to point of sale.[813] Such technologies will enable the reliable attribution of a range of factors to individual products. Some of these will be linked to safety and health, and some to nutritional, environmental, and production standards and approaches, including the sustainability of production and provenance.[814] Societal preferences for transparency within supply chains, and the facilitation of rapid recalls of products, support the case for providing access to information about specific product attributes if and when consumers want this information.[815] This implies that it is reasonable to include labelling about breeding technologies, animal welfare, and environmental impact among a list of other traceable attributes. The use of quick response (QR) codes combined with customisable applications (apps) linking to online

[811] The strapline for the Agriculture Act 2020 was 'public money for public goods', a promise that, as direct payments were phased out, money would be redirected to promote public goods that benefit producers, consumers and wider society. See, for example, Defra (16 January 2020) *Agriculture Bill to boost environment and food production*, available at: https://www.gov.uk/government/news/agriculture-bill-to-boost-environment-and-food-production.

[812] Defra (2020) *Farming for the future: policy and progress update*¸ available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/868041/future-farming-policy-update1.pdf, at page 16. Defra rehearses this and signals an appetite for market interventions to stimulate market demand for higher welfare products in: Defra (2021) *Our action plan for animal welfare*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/985332/Action_Plan_for_Animal_Welfare.pdf.

[813] Pearson S, May D, Leontidis G *et al.* (2019) Are distributed ledger technologies the panacea for food traceability? *Global Food Security* **20**: 145-9.

[814] See, for example, Trase, a data-driven supply chain transparency initiative to provide information about environmental impact, specifically deforestation. It is based on linking intelligence about local practices to commodities, traced to geographical origin through a system called 'Spatially Explicit Information on Production to Consumption Systems' (SEI-PCS). See: Trase (2021) *Homepage*, available at: https://www.trase.earth/resources/.

[815] Qian J, Ruiz-Garcia L, Fan B *et al.* (2020) Food traceability system from governmental, corporate, and consumer perspectives in the European Union and China: a comparative review *Trends in Food Science & Technology* **99**: 402-12.

repositories of information means that it should become possible for consumers to customise label information easily at point of sale. **Labelling of foods containing animal products should take account of (1) scientific advice on food safety, nutrition, and health, and (2) traceable attributes of interest to consumers; it should make best use of available information technology to assure traceability and provide access to published information**.

6.43 Relying on consumers to govern the behaviour of the industry through the modulation of aggregate demand, however, is insufficient where it is important that conditions are met universally, across all actors and products in an industry. A just society cannot be one in which only some individuals receive justice. We have described how both farmers and members of the public often have internally inconsistent if not conflicting interests, as participants in a society that protects them and provides the conditions that allow them to flourish, and as individual actors who must secure for themselves a sufficient share of the goods available. It is therefore necessary to consider other measures, besides consumer choice, to secure standards for farming practices and for placing farm produce on the market. These measures may be of two sorts, representing the traditional levers available to governments: using the legal power of the state to proscribe what is undesirable, on the one hand, and providing incentives from the public purse to encourage what is desirable, on the other.[816]

Influencing retailers

6.44 Governments in liberal democratic states (including the UK) often emphasise the power of consumers to drive change in traditional industries.[817] However, it is evident that consumers are not the ones holding the real power, because (as we note in Chapter 5) their interests often conflict (both within and among individuals) and they do not act in a concerted way. The crude supposition is that, whatever a lot of people may believe or say about preference for high-welfare products, when presented with a choice between a high-priced meat product and low-priced alternative, their resolve may weaken. This may be a matter of rational and even moral choice. It is axiomatic, however, that if people are willing to buy a product, retailers will want to sell it to them.

6.45 Whereas there are various schemes certifying certain types of production (Soil Association, RSPCA Assured, etc.) and assuring that products stocked by retailers conform with certain standards, those retailers happily continue to sell these products alongside other, lower welfare, less healthy, and environmentally damaging products. They do this because it allows them to provide a broader range of options for their customers, which enables them to increase their revenue and defend their market share. What is missing, therefore, is an effective accreditation scheme that applies to the

[816] Both are contemplated in: Defra (2020) *Farming for the future*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/868041/future-farming-policy-update1.pdf, though their final form remains to be determined at the time of writing. Schemes for animal health are due to start from 2022 as direct payments are phased out (see page 43 of '*Farming for the future*'). See also: Defra (2021) *Our action plan for animal welfare*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/985332/Action_Plan_for_Animal_Welfare.pdf.

[817] The second of three 'strands' in the animal health and welfare pathway (alongside baseline regulatory requirements and financial incentives) is to "Tap into consumer willingness to pay for welfare enhancements by developing reforms which provide improved consumer transparency and which support improved consumer understanding." See: Defra (2020) *Farming for the future: policy and progress update*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/868041/future-farming-policy-update1.pdf, at page 16.

retailers themselves, one that judges them on the basis of the full range of products they offer to consumers.[818]

6.46 In countries like the UK and Australia, the food retail industry is dominated by a few giant companies, each of which is principally concerned to protect and increase their market share. This market structure makes it possible for these companies to have a major effect on consumption of particular goods, particularly if they are able to coordinate their behaviours. Collusion to gain advantage in the market is usually regarded as an unfair business practice. Such a mechanism, by which the major retailers agree to limit their offer to the consumer voluntarily could, however, be used to achieve socially beneficial aims that could avoid falling foul of relevant competition law. By cooperating in this way, it is unlikely that any would lose significant market share to their competitors. **We believe that the Government should explore the possibility of reaching an agreement with the retail sector to move towards the stocking of animal products only from sources that verifiably meet acceptable breeding standards**.

Box 6.4: A concordat on the selling of animal products

A real commitment to promoting the public good in relation to food production might involve earnest effort to engage and coordinate retail practice. This could involve Government inviting retailers with a qualifying annual revenue above a certain threshold level (i.e., one that would define the effective oligopoly) to agree steps they could take, as sector leaders, to work towards the use of animal products from animals that have been demonstrably bred in accordance with accepted standards (see above) and the elimination of products from those that have not.

The outcome of this process might be codified in a concordat between the Government and the retail sector.[819] Such a voluntary concordat would seem to be a proportionate approach, but one that could be backed up by the possibility of more formal measures, ranging from accreditation to penalties for non-conformity. The benefit of an approach that accredits retailers rather than just some of the products they sell would be to foreclose the possibility of them passing on the responsibility for supporting questionable husbandry practices in the name of consumer choice while, at the same time, effectively ensuring that none loses out to a competitor.

Such a scheme could link up with the setting of meaningful standards for breeding and effective oversight of compliance, with verification through audit and supported by appropriate incentives to producers, where necessary aligned with retailers' revised preferences.

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[818] Compassion in World Farming conduct an annual supermarket survey, but this system is an award (that only one retailer may win in each category) rather than a certification (that multiple retailers may attain), so failure to win is not an indictment and, while it is a valuable accolade, there is not an overriding incentive to compete. Furthermore, the data on which this is based are not publicly available. See: Compassion in World Farming (2021) *Supermarket survey*, available at: https://www.compassioninfoodbusiness.com/our-work/key-tools-for-success/supermarket-survey/#start.

[819] A possible model might be the 'concordat and moratorium on genetics and insurance' (now the 'Code on Genetic Testing and Insurance'): an agreement between the UK Government and the insurance industry (represented by the Association of British Insurers) not to use predictive genetic tests to price insurance policies (with some conditions). The concordat was renewed periodically and backed up by the threat of legislation should the industry fail to comply. Compliance has, in fact, been high (verified by an annual compliance audit) and the agreement has held now for about 20 years. See: ABI (2021) *Code on genetic testing and insurance*, available at: https://www.abi.org.uk/data-and-resources/tools-and-resources/genetics/code-on-genetic-testing-and-insurance/.

Improving the regulatory baseline

6.47 Securing access to an adequate food supply for the population, protecting human and animal health, sustaining ecosystems and biodiversity, and responding to the climate emergency are all objectives for which biotechnologies have been proposed to offer solutions. Biotechnology's detractors have argued the opposite, including that biotechnology will lead to inequalities in access to agricultural products by concentrating power in the hands of corporate actors, that it will damage ecosystems through environmental escape and contamination, and that it could even harm the health of consumers. This is the ground on which arguments for more stringent or more subtle regulation of biotechnologies have been prosecuted and, despite broad consensus that the current arrangements are not fit for purpose, securing any agreement on what should replace them is politically challenging.

GMO regulation

6.48 For 20 years or more, exacting regulatory conditions have been placed around the introduction of genetic technologies in many countries. In Europe, this is given effect through a number of legal instruments, among which is European Directive 2001/18 (the GMO Directive), duly transposed and hitherto retained in law in the UK.[820] The Directive provides for the release or marketing of 'genetically modified organisms' (GMOs) and imposes requirements for traceability and labelling of any genetically modified products that are placed on the market. It characterises a GMO as "an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination".[821] The dependency on a concept of what occurs or may occur 'naturally' has been the focus of a debate about the significance of the process by which an organism is produced rather than the characteristics of the product itself. Accepting that products, both human artefacts and naturally occurring ones, can pose a variety of risks, many, particularly in the scientific community, have long argued for a more symmetrical system of regulation that is based on the product characteristics, and has less regard to the process of production.[822]

6.49 The regulatory scheme imposed by the GMO Directive is animated by the much-discussed 'precautionary principle'.[823] This is given effect through requirements for pre-

[820] A summary of food safety regulation around the world was published by the Food Standards Agency in 2021; see: Campden BRI (Chipping Campden) Ltd (on behalf of the Food Standards Agency) (2021) *Comparing international approaches to food safety regulation of GM and novel foods*, available at: https://www.food.gov.uk/research/research-projects/comparing-international-approaches-to-food-safety-regulation-of-gm-and-novel-foods.

[821] Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC: see: Commission Declaration [2001] *Official Journal L* **106**: 1-39, Art.2(2), available at: https://eur-lex.europa.eu/eli/dir/2001/18/oj. The phrase 'in a way' is understood to refer to a process rather than an effect, as Article 2(2) further specifies what techniques are included in (Annex I A, part 1) and excluded (Annex I A, Part 2) from this definition. Article 3 makes further exemptions (specified in Annex I B), which include mutagenesis and cell fusion "on the condition that they do not involve the use of recombinant nucleic acid molecules…".

[822] See, for example, BBSRC (2015) *New techniques for genetic crop improvement: position statement*, available at: https://bbsrc.ukri.org/documents/genetic-crop-improvement-position-statement-pdf/. The UK Royal Society advocates an 'outcomes-based' approach that includes a focus on purpose of the intervention; see: Royal Society (22 March 2021) *A new approach to regulating genetic technologies*, available at: https://royalsociety.org/blog/2021/03/gmo-regulation/. A recent report on the regulation of genetic technologies from the Regulatory Horizons Council, an advisory body of the UK Department for Business, Energy & Industrial Strategy, recommends "a process-based trigger followed by product-based scrutiny": living modified organisms (as defined by the Cartagena Protocol of the Convention on Biological Diversity) would trigger regulation that would depend on the product and its intended use (though 'phenotypically and genetically similar products' should be expected to be subject to similar regulatory scrutiny); see: Regulatory Horizons Council (2021) *Report on genetic technologies*, available at: https://www.gov.uk/government/publications/regulatory-horizons-council-report-on-genetic-technologies.

[823] The principle is introduced in recital 8 and Article 1 of Directive 2001/18/EC and its application in regulation is provided for in by Article 4 and Annex II. Article 4 states: "Member States shall, in accordance with the precautionary principle, ensure that

market authorisation that require risk assessments (e.g., field trials). In some lights, these can be seen as standing in for the natural filtering of deleterious effects by evolutionary selection and the control of those effects that are injurious to human interests.[824] The unintentional effect of the requirement, it has often been remarked, is that the burdensome and expensive risk assessment process limits the use of genetic modification techniques to traits that have a high commercial value, developed by companies that can afford the substantial upfront costs associated with the pre-market approval process. Accumulated experience with genetic technologies, refinements of technique, and the existence of further layers of regulation to protect health and the environment have encouraged initiatives to streamline the regulatory process in the interest of bringing GMOs more quickly and cheaply to market.[825]

6.50 While the systematic dismantling or overhaul of this regulatory architecture would take time to achieve, working within the current scheme, some have argued that a certain subset of organisms produced by genome editing should be set outside the additional regulatory strictures applicable to GMOs, on the basis that the alterations in question are of a sort that might come about as a result of natural processes. This was tested before the European Court of Justice in a case brought by the French farmers' union, *Confédération Paysanne*, in 2018. In that instance the Court held, on a strict application of the law in force, that organisms produced by genome editing were, after all, caught by the definition in Article 1 of the Directive and did not meet the criteria of any of the specified exemptions.[826] The judgment contradicted an earlier opinion of the Advocate-General and the expectations of many EU science advisers, and has been followed by a European Commission study that has prompted a policy action aimed at adapting the risk assessment and authorisation procedures, and the labelling/traceability requirements for plants (but not animals or microorganisms) derived from targeted mutagenesis (genome editing) and cisgenesis (horizontal transfer or replication of genetic material between varieties of the same species).[827]

Box 6.5: The UK Government review of genetic technologies

Genetically modified organisms (GMOs) are defined in Part VI of the Environmental Protection Act 1990, section 106(4A) of which transposes the Directive's terminology, of being 'artificially altered' "otherwise than by a process which occurs naturally in mating or natural recombination". The section also creates 'deeming' powers, to be exercised

all appropriate measures are taken to avoid adverse effects on human health and the environment which might arise from the deliberate release or the placing on the market of GMOs." The precautionary principle originally appeared in legislation in the United Nations Conference on Environment and Development (1992) *Rio Declaration, Annex I, Principle 15*, available at: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf. Variations have since appeared in many other reports and legal instruments, and a large critical literature has developed; see: Harding R, and Fisher EC (Editors) (1999) *Perspectives on the precautionary principle* (Leichhardt: Federation Press).

[824] See: Comité Consultatif National d'Éthique (2020) *Opinion 133: ethical challenges of gene editing: between hope and caution*, available at: https://www.ccne-ethique.fr/en/actualites/opinion-133-ethical-challenges-gene-editing-between-hope-and-caution.

[825] Van Eenennaam AL, De Figueiredo Silva F, Trott JF *et al.* (2021) Genetic engineering of livestock: the opportunity cost of regulatory delay *Annual Review of Animal Biosciences* **9(1)**: 453-78.

[826] *Confédération paysanne and others v. Premier ministre and another* [2018] judgment of 25 July 2018, Case C-528/16, available at: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:62016CJ0528.

[827] Opinion of Advocate General Bobek (18 January 2018), available at: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:62016CC0528; by the Group of Chief Scientific Advisors (13 November 2018), available at: https://ec.europa.eu/info/sites/default/files/2018_11_gcsa_statement_gene_editing_1.pdf; and European Commission (2021) *Commission staff working document: study on the status of new genomic techniques under Union law and in light of the Court of Justice ruling in Case C-528/16 (final)*, available at: https://ec.europa.eu/food/document/download/5135278b-3098-4011-a286-a316209c01cd_en.

through regulations, to bring organisms within or place them outside the scope of the definition (the regulations will be subject to the negative resolution procedure).

In 2021, following the conclusion of the Brexit transition period, the UK Government launched a consultation on using these powers to remove some genome-edited organisms, specifically those that "could have been produced through traditional breeding", from the scope of retained provisions relating to GMOs.[828]

At the same time as consulting on the reclassification of some genome-edited organisms, the UK Government also sought to test opinion on whether the retained provisions of the GMO Directive could be disapplied with regard to other organisms produced by genetic technologies (including, for example, transgenic organisms). The Government's argument was that, in effect, issues of product safety can largely be dealt with under other measures, and mitigations for environmental escape should be translatable between varieties (unless they confer a breeding advantage, which can be established in the laboratory prior to farm scale rollout).

The consultation attracted well over 6,000 responses, including one from the Nuffield Council, and revealed a considerable weight of support for strict regulation, especially among individual members of the public.[829] In responding to the consultation findings, the Government presented a more nuanced and phased approach than the one set out in the consultation paper.[830] This would begin, in 2021, with regulations to facilitate field trials of genome-edited crops. If these fulfil expectations, primary legislation will follow to permit these to be brought to market. Although this may also apply to animals, the response recognises that changes relating to them may have to come later 'in light of due consideration being given to ethical questions raised in the consultation' (although microorganisms would be addressed separately).

6.51 It is clear from the public engagement initiatives discussed in Chapter 5 that members of the public still have misgivings about what they perceive as the speed and nature of genetic changes that may be brought about by genome editing in farmed animals.[831] It seems probable that similar findings emerged in the Defra consultation and that the phased approach is partly a response that allows more time for them to be addressed. It remains to be examined, for example, in what ways the expressed concerns, which, in some cases, appear to be linked to shared recollections of adverse and unanticipated consequences of earlier innovations, and which influence the implicit normative background with which many people approach the application of novel biotechnologies, are relevant and meaningful in the present case.[832] We believe that **further public deliberation is desirable to explore understandings, assumptions, and values underlying expressed public opinions about the risks of new breeding technologies**.[833]

[828] Before the official Government response to the consultation appeared, the Government's Taskforce on Innovation, Growth and Regulatory Reform published a report recommending support for the adoption of genome edited crops and an 'exemption from the GM ban' although, in common with the European Commission, it considered the question of animals too difficult to address at present; see: Duncan Smith I, Villiers T, and Freeman G (2021) *Taskforce on Innovation, Growth and Regulatory Reform (TIGRR) report*, available at: https://www.gov.uk/government/publications/taskforce-on-innovation-growth-and-regulatory-reform-independent-report.

[829] See: Nuffield Council on Bioethics (17 March 2021) *Response to Defra consultation on the regulation of genetic technologies*, available at: https://www.nuffieldbioethics.org/assets/pdfs/Nuffield-Council-response-to-Defta-regulation-of-genetic-technologies-consultation.pdf.

[830] Defra (2021) *Genetic technologies regulation: government response*, available at: https://www.gov.uk/government/consultations/genetic-technologies-regulation/outcome/genetic-technologies-regulation-government-response.

[831] This was a common finding of the FSA (Ipsos MORI) engagements and our own (Basis) public dialogues (see Chapter 5).

[832] BSE is often mentioned but also, more generally, the emergence of COVID-19 and the historical promotion of Thalidomide.

[833] See Chapter 7 (Recommendation 1).

6.52 It is equally clear that the potential health risks to consumers of genome-edited products are not the foremost concern, and that most people believe that existing product regulation provides a measure of reassurance. Of more concern are the implications for animal lives and the structure of the food and farming system, concerns that were also prominent in the 2021 Opinion of the European Group on Ethics in Science and New Technologies, *Ethics of genome editing*.[834] It was a notable finding of our public dialogue that the technical differences between genome editing and 'conventional' breeding did not raise particular concerns for participants. They were much more wary, however, of the potential of new breeding technologies to exacerbate what they saw as undesirable trends in farmed animal production. This refocuses attention from the technical procedures involved to the social and economic processes into which new biotechnologies are incorporated. It suggests that the main reason for caution is not the potential for direct harm but the insidious capacity of technologies to shape and accelerate the trajectories of food and farming systems in ways that exacerbate societal challenges, including those of animal welfare and social injustice.

6.53 The Nuffield Council has, in previous publications, distinguished the use of the *precautionary principle* as a decision tool, from a broader *precautionary approach*.[835] This is a response to a conservative use of the precautionary principle, which emphasises scientific uncertainty; it recognises that there are situations in which the status quo is unsustainable, or where maintaining the status quo involves considerable but often unacknowledged costs (externalities). In other words, the precautionary approach recognises situations in which there are significant uncertainties on all sides and threats of different kinds, potentially affecting different groups, to which different people will attach different values. Such a characterisation was given of the food and farming system in Chapter 2. The precautionary approach requires an acknowledgment that it is both impossible and inappropriate to base the adoption of technological new pathways on scientific advice alone.

6.54 We recognise that, at present, genome editing represents only a small inflection of these trajectories along undesirable pathways within food and farming systems. We acknowledge, however, the concerns that its adoption, if not appropriately controlled, could help to accelerate or lock in these trajectories. **A proportionate, cautious approach should therefore take account not only of the predicted costs and benefits of breeding innovations but also the implications of their adoption, diffusion, and normalisation for the food and farming system and for the wider society. The implications of not innovating, or of following alternative courses of action, should provide context for this consideration**.[836] GMO regulation has provided a decelerating effect on innovation while challenges to the system have continued to mount. If regulatory brakes on some genome-edited organisms, and subsequently on other uses and products of biotechnology, are to be removed, and if this is to be in the public interest, it will be important to consider first and to consider carefully the direction in which the system as a whole is pointing.

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[834] European Group on Ethics in Science and New Technologies (2021) *Ethics of genome editing*, available at: https://op.europa.eu/en/publication-detail/-/publication/6d9879f7-8c55-11eb-b85c-01aa75ed71a1/language-en.

[835] See: Nuffield Council on Bioethics (2003) *The use of GM crops in developing countries*, available at: https://www.nuffieldbioethics.org/publications/gm-crops-in-developing-countries; Nuffield Council on Bioethics (2012) *Emerging biotechnologies: technology, choice and the public good*, available at: https://www.nuffieldbioethics.org/publications/emerging-biotechnologies; and Nuffield Council on Bioethics (2016) *Genome editing: an ethical review*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-an-ethical-review.

[836] See Chapter 7 (Principle 3).

Breeds at risk

6.55 'Balanced breeding' practices have been widely promoted in the industry in response to the recognised adverse consequences of the historical pursuit of production traits through selective breeding. We believe that it is important to guard against any possibility of a return to this situation, and to forestall its occurrence in other systems and in relatively recently domesticated species. A number of domestic animal breeds already give concern that they have been bred close to (and in some cases beyond) the phenotypic limits compatible with living a good life or even a life worth living.[837]

6.56 In our conclusion to Chapter 4, we identified the need for further scrutiny and controls to ensure that animals are not bred in ways that diminish their inherent capacities to enjoy experiences that constitute a good life. We propose a notional 'traffic light' assessment of domestic species, based on the impact of directed breeding on animals' constitutional capacities for living a good life (i.e., irrespective of contingent – though unquestionably important – issues about the environmental conditions in which they are kept or the practices to which they are subject). Such an appraisal would apply to commercial breed developers and place the breeders' normal, index case (PLI=0) of each breed or line in a corresponding category, as follows.

- **Red:** those that have been bred beyond phenotypic limits that are compatible with the animals having the capacity to live a good life, regardless of the environmental conditions in which they are kept. Accordingly, animals in this category should not be used in commercial farming and, where they are used, their use should be discontinued. This category might include, for example, fast-growing lines of broiler chicken.[838]

- **Amber:** lines of concern, where further directed breeding may be acceptable to redress or compensate for any traits that give rise to concern ('balanced breeding') or where it is orthogonal to these (i.e., where it targets an unrelated trait and does not aggravate traits of concern). This category might include, for example, certain breeds of domestic pig or dairy cattle or farmed Atlantic salmon.[839]

- **Green:** where the animal's constitution is compatible with its capacity to live a good life given suitable environment and husbandry practices. This category might include a number of domesticated breeds (e.g., beef cattle and sheep, and many 'heritage' breeds) as well as animals that have been bred or altered to improve their capacities

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[837] See the FAWC report quoted earlier in this chapter: FAWC (2004) *FAWC report on the welfare implications of breeding and breeding technologies in commercial agriculture*, available at: https://www.gov.uk/government/publications/fawc-report-on-the-welfare-implications-of-breeding-and-breeding-technologies. See, also, the elaboration of the concept of 'basic justice' in Chapter 3.

[838] See, for example, Global Animal Partnership (8 September 2020) *GAP announces completion of broiler chicken study – 'in pursuit of a better broiler'*, available at: https://globalanimalpartnership.org/about/news/post/gap-announces-completion-of-university-of-guelph-research-study-in-pursuit-of-a-better-broiler/. See, in this connection, the transition to 'higher welfare' chicken for domestic consumption in the Netherlands as a result of: (1) The availability of a cost-efficient alternative to conventional production concepts, (2) a basic willingness to change within the entire value chain (including consumers), (3) initiating and triggering actions by NGOs, (4) decisive initiatives by retailers and (5) simultaneous introduction of the new concept and replacement of the conventional concept (i.e., depriving the consumer of a cheaper choice alternative). See: Saatkamp HW, Vissers LSM, van Horne PLM *et al.* (2019) Transition from conventional broiler meat to meat from production concepts with higher animal welfare: experiences from The Netherlands *Animals* **9(8)**: 483.

[839] See, for example, Lind CE, Ponzoni RW, Nguyen NH *et al.* (2012) Selective breeding in fish and conservation of genetic resources for aquaculture *Reproduction in Domestic Animals* **47(s4)**: 255-63; Lovett BA, Firth EC, Tuck ID *et al.* (2020) Radiographic characterisation of spinal curvature development in farmed New Zealand Chinook salmon Oncorhynchus tshawytscha throughout seawater production *Scientific Reports* **10(1)**: 20039; and Webster J (2021) Green milk from contented cows: is it possible? *Frontiers in Animal Science* **2(16)**: 667196.

for living good lives, including through adaptation to and impact on the environment (e.g., polled cattle, disease-resistant and environmentally adapted animals).

6.57 A difficulty is disentangling the effects of genotype and environment, since some breeds fare well in some environments but poorly in others. What we are concerned about, however, is, in the first place, breeding that results in animals that find it hard or impossible to enjoy an acceptable quality of life in any reasonably sustainable farming conditions. The effects of breeding on animals' abilities to live a good life may be demonstrated longitudinally but are made less obvious by the fact that what is an 'average' animal changes continually as a result of breeding, shifting the breed norm, as reflected in the periodic – and, in some cases, very frequent – 'rebasing' of breeding indices.[840] The concern is not, however, with whether a line of animals are now in a better or worse situation than their ancient or recent ancestors, only with whether their present phenotype allows them to enjoy a good life.

6.58 If such a scheme were to be instituted, a practical difficulty is the development of acceptable criteria or standards according to which judgements about the notional category (red, amber, or green) that a given breed or line falls into can be made.[841] Nonetheless, while clear-cut distinctions may be contested, the aims and tendencies of breeding strategies may be more clearly discerned. We believe, therefore, that this difficulty can be met by delegating this judgement to a suitably constituted body with the appropriate expertise and authority and making use of it in the right way.

6.59 In the current governance architecture in England, there is no existing body with the appropriate powers and relationships to undertake this function, albeit that the function connects with the formal remit of the Animals in Science Committee (and, by extension, the network of AWERBs) and with that of the Animal Welfare Committee and other agencies. While commercial breeders may constitute ethics committees, the use of ethics committee systems in commercial breeding is currently idiosyncratic. Such a body should, ideally, have the stature of the proposed Animal Sentience Committee, although the proposed remit of that committee, which is focused on government policy rather than industry policy and practice, would appear to preclude the functions required.[842] The constitution of an independent oversight body would, in effect, represent the delayed fulfilment of the recommendation of the 2004 FAWC report that "a Standing Committee be established for the evaluation of new and existing breeding technologies as well as

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840 For example, the dairy industry periodically 're-bases' genetic indices so the 'average cow' (PLI=0) changes over time.

841 In some species the definitions are given by the relevant breed society, but without a consistent scientific basis. For a list of breed societies, see: Defra (2021) *Lists of recognised breed societies and breeding operations*, available at: https://www.gov.uk/government/publications/lists-of-recognised-animal-breeding-organisations. An inventory of UK breeds is currently published by Defra; see: Defra (2020) *UK farm animal genetic resources (FAnGR): breed inventory results – 2020 statistics release*, available at: https://www.gov.uk/government/statistics/uk-farm-animal-genetic-resources-fangr-breed-inventory-results. NB: In 2020, experimental statistics for the genetic resources of domestic poultry animals (covering chickens, ducks, geese, and turkeys for 2019) were added, to complement the main publication.

842 In particular, it would benefit from reporting to ministers, having the power to review data and other information, engage with industry and the wider public. As such it could advise ministers on the release of animals from the ASPA regime into breeding, as well as giving needed stringency to standards such as those of Code-EFABAR and the various Defra codes of recommendations in the UK. It is hard to resist the parallel between animal breeding and human reproduction, as one of our reviewers urged, and, in particular, the function of the Human Fertilisation and Embryology Authority in controlling, prospectively, the genetic selection of future generations and the expansion of the traits that may offer a legitimate basis for selection.

for the consideration of welfare and ethical problems arising as a result of livestock breeding programmes."[843]

6.60 The case for such a body has only strengthened over time, as a result of developments in breeding practices and the prospect of new breeding technologies such as genome editing. It would ensure that the welfare of founder animals that may be bred under ASPA licence would be properly evaluated where these or their descendants may subsequently be released into commercial breeding programmes. Likewise, it would ensure similar evaluation of animals bred without an ASPA licence (e.g., in a commercial breeding programme or in another jurisdiction). Such a measure should create an incentive for commercial breed developers to submit their breeding strategies to prospective and coordinated ethics committee appraisal, in the expectation that this would provide a measure of corporate risk management for their research and development programmes. **We therefore believe that a suitably constituted and authoritative body should oversee the effects of breeding practices in scientific research and commercial breed development. This body should advise, in particular, on any breeds or lines, whether originating from domestic breeders or foreign, that may or may not be used commercially, and give guidance on breeds or lines at risk**.[844]

Breeding incentives

Protecting breeders

6.61 One way in which breeders may extract value from their activities is by licensing the intellectual property they have in the animals that they produce. Intellectual property is a type of property which protects creations of the human mind. It includes patents and trade secrets (protecting inventive products and processes), trade marks (brand names and logos), and copyright (literary and artistic works). Generally, intellectual property rights are specific to legal jurisdictions. They are characterised as 'negative' or 'monopoly' rights because they effectively restrict the freedoms of third parties to copy or use the protected creation. Intellectual property rights do not give the right-holder a positive right to exploit the protected creation. In practice, property in any genome-edited animal entering the commercial marketplace is likely to be protected by a combination of these rights, but since the technical aspects of genome-edited products are most commonly protected by patents and trade secrets, those rights are the primary focus of the present discussion.

6.62 Patents are rights granted by national governments. Applicants in Europe can choose to apply for a patent via one of two routes. The first is by application to the national intellectual property office of each state in which they want protection. The second is by means of a single application to the European Patent Office (EPO), designating any one or more of the 38 European Patent Convention (EPC) countries (including the UK). The resulting European Patent is essentially a bundle of national patent rights in the designated countries. Patents effectively give the patent-holder the exclusive right to stop others using the patented technology without their permission, usually for up to 20 years.

[843] FAWC (2004) Report on the Welfare Implications of Animal Breeding and Breeding Technologies in Commercial Agriculture, available at: https://www.gov.uk/government/publications/fawc-report-on-the-welfare-implications-of-breeding-and-breeding-technologies, at recommendation 1. At paragraph 120, the report states: "The Standing Committee, established and appointed by Ministers, could be known as the FAWC Animal Breeding Committee (FAWC ABC) and should be composed of members representing a broad spread of expertise and interests, together with lay representation and, importantly, an independent chairperson. The composition of the Committee should be wide enough to cover all major areas of interest and also have sufficient in-depth expertise to evaluate the evidence brought before it. For instance, given the Committee's remit, it would be essential to include at least one specialist in molecular genetics in the Committee membership. Additional expertise may be introduced through secondment of experts as members to assist with specific issues."

[844] See Chapter 7 (Recommendation 12).

This allows researchers to recover some of the substantial costs, for example, of developing a new trait in a farmed animal; however, exclusivity means that the price they set can be higher than in a competitive market. In return, the patentee must disclose the invention in sufficient detail to enable its practice by other skilled persons in the relevant technical field. This so-called ‘patent bargain’ is said to incentivise research and development (by allowing inventors to recover the costs of research during the period of exclusivity) while the invention disclosure requirement is said to stimulate further technological progress. By this argument, patenting is presented as an arrangement that serves the public interest.

6.63 Trade secrets arise automatically upon the creation of non-public information, ideas, or processes that have economic value. Trade secrets are protectable by law for as long as the secrecy of the information is maintained, in order to prevent someone unfairly exploiting the intellectual labour of others. Trade secrets do not offer any protection against inventions conceived by a third party independently (without any use of the trade secret). It is likely that certain genetic information, such as the association between variants and the expression of disease, as well as certain genome editing techniques, are being kept as trade secrets (with the result that no one but the holder of the secret know-how can benefit from it, at least not directly).

6.64 Because multiple researchers may be working in the same field, particularly where this has prospective commercial value, there is an incentive for them to keep research confidential so as to be the first to secure patent protection for their inventions. This sometimes leads to disputes over priority.[845] It is often observed that this incentive is in direct tension with the collaborative ethos of science.[846]

6.65 Misuse (or ‘infringement’) of patents and trade secrets, without the right-holder’s permission, are civil wrongs. The right-holder can sue the infringer for compensation and seek an injunction to stop the infringing use of the patented invention or trade secret.

Patenting in biotechnology

6.66 What protection may be obtainable for genome-edited animals (including their descendants, their reproductive material, and that of their descendants) is not a simple question. Under European patent laws, an ‘animal variety’ is excluded from patentability. However, the case law of the EPO confirms that this does not exclude patents on animals as such. It is generally accepted that an animal with a novel trait can be patented in Europe where, for example, the novel trait is present as a result of a direct technical intervention in the animal’s genome, whereas selectively bred animals, whose traits are present as a result an ‘essentially biological process’, cannot.[847] This creates an obvious incentive for breeders, who can obtain marketing exclusivity on genome-edited lines, to introduce new traits by the use of that technology. So long as that trait is valued by the market, they can extract value from sales while preventing others entering the market (or

[845] An example is the long-running dispute over the rights to CRISPR-Cas9 in eukaryotes between the Broad Institute and the University of California, Berkeley; see: *Regents of the University of California v. Broad Institute, Inc*., No. 106,115, (P.T.A.B., 10 September 2020); and *Science* (11 September 2020) The latest round in the CRISPR patent battle has an apparent victor, but the fight continues, available at: https://www.science.org/content/article/latest-round-crispr-patent-battle-has-apparent-victor-fight-continues .

[846] Merton RK (1942) Science and technology in a democratic order *Journal of Legal and Political Sociology* **1**: 115-26; see also: The University of Manchester Institute for Science, Ethics and Innovation (2009) *Who owns science? The Manchester manifesto*, available at: https://hinxtongroup.files.wordpress.com/2010/10/themanchestermanifesto.pdf.

[847] Convention on the Grant of European Patents (European Patent Convention), 17th edition (November 2020), Article 53(b), available at: https://www.epo.org/law-practice/legal-texts/epc.html; and European Patent Office (2021) *Guidelines for examination*, available at: https://www.epo.org/law-practice/legal-texts/html/guidelines/e/g_ii_5_4.htm.

extract value by licensing their intellectual property to others to use). For so long as they are able to identify 'editable' traits that are desirable to producers, and on the assumption that genome editing will allow them to fix those traits in their elite founder animals faster than conventional breeding approaches, breeders employing biotechnologies may keep ahead of conventional breeders and potentially outcompete them. The patent system may also incentivise 'evergreening': attempts to prolong patent protection beyond the initial 20-year period by filing further patents on improvements to the original edited trait or edited animal

6.67 All breeders have property rights in their animals, so that no one may use them without the breeder's agreement. Hence the breeder is able to extract value from their investment when the animal (or its reproductive material, or offspring) is sold. The application of biotechnology results in two kinds of property rights in the animal existing in parallel: property rights in the animal itself and the intellectual property embodied by the animal as a product of human ingenuity. Moreover, it is conceivable that a single animal may embody traits developed by different patent-holders, so that it may be the object of multiple property rights, where ownership is not shared but overlapping, requiring the negotiation of complex licensing arrangements to enable it to be used in breeding, for example. Furthermore, whereas ownership of conventionally bred animals, or their reproductive material, is transferred at sale, property rights in genome-edited animals may 'reach through' to successive generations in the breeding line, producing a revenue stream for the breeder. For instance, imagine a patent claim to 'a non-human animal incorporating a gene sequence resulting from genome editing whereby the expression or activity of RELA protein is reduced', meaning that the patented animal is less susceptible to serious viral infections. The act of making another animal incorporating the claimed gene sequence (through breeding of the original genome-edited animals or their descendants) would require the licence of the patent-holder.

6.68 In vertically integrated industries, producers will work with breeders using their own lines, which they will not sell to competitors. In this case, the benefit to them is not through the sale of breeding stock or licensing of their intellectual property but by competition between their products for market share. For this reason, for relatively homogeneous products, it may be predicted that the innovation in biotechnology will lead to further industry consolidation with the potential for small groups of highly desirable or valuable animals being concentrated in the hands of smaller groups of 'elite' producers.

6.69 There is one further exclusion to patentability which may arise in the context of patents on genome-edited animals. Europe is one of few jurisdictions whose patent law includes exclusions from patentability on moral grounds (*ordre public*).[848] The European Patent Convention provides, in particular, that European patents should not be granted in respect of "processes for modifying the genetic identity of animals which are likely to cause them suffering without any substantial medical benefit to man or animal, and also animals resulting from such processes."[849] This exclusion has proved controversial in the past.[850] EPO case law establishes a three-part test to determine whether the exclusion applies: (i) likelihood of animal suffering, (ii) likelihood of associated medical benefit, and (iii) the necessary correspondence between the two in terms of the animals in question.

[848] Convention on the Grant of European Patents (European Patent Convention), 17th edition (November 2020), Article 53(a), available at: https://www.epo.org/law-practice/legal-texts/epc.html; and Directive 98/44/EC of the European Parliament and of the Council of 6 July 1998 on the legal protection of biotechnological inventions, Article 6, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31998L0044.

[849] Implementing Regulations to the Convention on the Grant of European Patents, rule 28(d), available at: https://www.epo.org/law-practice/legal-texts/epc.html.

[850] See, for example, WIPO Magazine (June 2006) *Bioethics and patent law: the case of the Oncomouse*, available at: https://www.wipo.int/wipo_magazine/en/2006/03/article_0006.html.

The EPO has ruled that this test should be applied to ensure that a patent will extend only to those animals whose suffering is balanced by a medical benefit (either to animals or humans). It is entirely possible that similar ethical objections may arise in the context of patent applications for genome-edited animals, grounded in, for example, the basic interests of animals as sentient beings together with animal welfare and health concerns. These issues are far broader than issues of patentability. While some commentators have questioned whether unelected patent examiners are well suited to act as moral guardians in relation to the acceptability of emerging technologies, others are advocating a strengthening of the existing morality exclusion to patenting, specifically, "a precautionary and deliberative process of identifying the potential risks of patenting for morality and public policy should be introduced, with an emphasis on promoting the transparent and inclusive appraisal of the implications for society of granting monopolies for technologies whose applications and effects are malleable and difficult to predict."[851]

Supporting producers

6.70 There are variations between and within different animal farming sectors with regard to how their herds, flocks, schools, etc., are developed through the diffusion of inherited traits. In some sectors, it is still common for farmers to take a traditional 'look and choose' approach, for example selecting livestock on aesthetic grounds after viewing them at markets. In other sectors, the selection of animals or reproductive materials is driven substantially by the use of breeding indices (see above). Where farmers buy in genetic material to introduce to their animals (as is common in the dairy industry in the UK) the standardised indices allow them to compare different animals, and to assess them for what they may contribute within the context of their existing herd, their environmental conditions, and husbandry system, etc. In sectors with a high level of vertical integration (such as much pig and poultry production), indices are used by commercial breed developers to develop lines for specific producers. In this case, the way breeders compile their indices may be idiosyncratic, which prevents meaningful comparison between breeders and lines, even assuming the data are shared. Thus, while indices are, in theory, descriptive, they only provide a partial profile of the animal in question, according to what are considered to be the traits of interest by breeders. Furthermore, different weightings are given to different factors in relation to the overall aims (which may be specific to a consolidated producer) and taking into account the observed heritability of the traits in question.

6.71 Many measures of animal health, resistance to disease, and greenhouse gas emission, for example, align directly with farmers' interests, since veterinary treatment, loss of animals through disease or culling, and excess feed inputs represent increases in unit production costs that it is worthwhile to avoid. There is, however, a range of non-market goods, including public goods, for which there is no direct monetary gain to be had for the producer, that may be unrepresented or underrepresented in the indices.[852] It is possible to imagine a notional index composed to promote the public interest in farmed animal breeding, which might include different components and different weightings to those conventionally used by breeders, although there is likely to be a substantial overlap. This represents a different way of framing the question of what constitute desirable characteristics. Different ways have been proposed of composing indices for

[851] Pila J (2020) Adapting the *ordre public* and morality exclusion of European patent law to accommodate emerging technologies *Nature Biotechnology* **38**: 555-7.

[852] Nielsen HM, Olesen I, Navrud S *et al.* (2011) How to consider the value of farm animals in breeding goals. a review of current status and future challenges *Journal of Agricultural and Environmental Ethics* **24(4)**: 309-30.

ruminants, for example, to achieve socially desirable outcomes such as reduced environmental impacts and animal welfare by using, for example, restricted index methodologies or adopting new approaches to calculate economic weights for traits that have no clear direct market value in existing economic indices, such as using findings from market research or weightings based on emissions modelling.[853]

6.72 While an index based on consumer market research ought to be of interest to producers, we have already discussed, in Chapter 5, how the expressed interests of consumers are not always followed through in the marketplace. This suggests that, where additional information cannot be translated into positive economic value, it might be appropriate to consider making up from the public purse any negative impact on farmers' finances from adopting different breeding aims. In some sectors, though not all, it is possible to envisage a workable incentive payment scheme that would encourage producers, particularly if it is backed up with marketing support, to adopt socially desirable breeding aims. Such a scheme follows the principle of 'public money for public good' and could be targeted using the most robust index measures that can be developed from enhanced data collections (see above). **We believe that the utility of 'public good' breeding indices to target incentive payments to farmers should be explored, including the requirement that where commercial breed developers place animals or animal reproductive materials on the market they should be required to publish 'public good' index information in an approved format**.[854]

Box 6.6: The Agriculture Act 2020 and agricultural subsides

The European Common Agricultural Policy (CAP) was introduced in 1962 to guarantee the security of Europe's food supply by setting guaranteed prices for farmers. This led to overproduction in the 1970s and 1980s, so the system was changed in the 1990s to one of direct subsidies to farmers rather than rewarding them for increasing levels of production. This, however, led to a situation where large landowners benefitted simply by virtue of owning more land. Subsidies are not generally received by the most intensive producers (e.g., of pigs, chickens, or fish) except indirectly, where they are also involved in feed production.

The Agriculture Act 2020 creates powers for ministers to develop new farm support approaches (section 1) on the principle of payment for public goods (such as improvements to animal welfare and the environment), rather than on the basis of acreage farmed (as in the CAP). It also gives ministers powers to stabilise the adverse impact of exceptional market conditions (sections 20 and 21) through financial assistance (e.g., to farmers). A part of the Act (Part 3) is also devoted to transparency and fairness in the agri-food supply chain: section 23 gives the Secretary of State wide-ranging powers to require information about any part of the chain, which might be used to improve current data collections/publications.

The Farm Animal Welfare Forum has already proposed an incentive structure for welfare for each of laying chickens, broiler chickens, pigs, and dairy cattle.[855] Furthermore, the UK Government is already understood to be considering outcome-based payments for high animal welfare.[856] There are two ways in which these could be improved: to include

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[853] Wall E, Simm G, and Moran D (2010) Developing breeding schemes to assist mitigation of greenhouse gas emissions *Animal* **4(3)**: 366-76.

[854] See Chapter 7 below (Recommendation 13).

[855] FAWF (2020) *Proposals for public goods payments for farm animal welfare – summary paper*, available at: https://www.fawf.org.uk/sites/default/files/2020-02/FAWF%20Proposals%20for%20public%20funding%20Summary%20v1.0.pdf.

[856] Defra (2020) *Farming for the future: policy and progress update*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/868041/future-farming-policy-update1.pdf.

an incentive for positive breeding objectives (to promote socially valued traits through genetics) and to include a range of priorities alongside animal welfare and environmental benefit. Having a prospective incentive structure should also provide a compass for the development of 'socially valuable' breed characteristics through research and commercial breed development programmes.

6.73 There are at least two potential difficulties with incentive schemes of this sort. The first is that they run the risk of producing unintended adverse outcomes, depending on how the economic benefits are seen by different industry actors. In the absence of any other constraint, they may split the industry between those attracted by incentives and those chasing revenue maximisation. This is likely if the level of incentive for choosing a more socially desirable genetic profile is insufficient to compensate producers for the rewards attainable by ruthless pursuit of the greatest genetic gain in systems designed for efficiency and economies of scale. It could, in other words, lead to a race to the bottom. The second difficulty is that if a penalty or hard constraint were applied it would risk doing damage to the industry and making it uncompetitive, particularly in international trade, on which many domestic producers depend. Even small and medium-sized farms may choose to follow an approach of increased productivity through wariness of future changes to farming subsidy arrangements and the potential vulnerability of being dependent on a subsidy model.

6.74 In relation to the first problem, supervision based on something like the traffic light system we have described would provide a bulwark against the most egregious effects of breeding. This could be easily confounded, however, by the effect of environmental conditions and husbandry practices in use: it is not sufficient to prevent the use of grotesque animals if producers are induced to squeeze margins by making the conditions worse for the animals they keep. It is important, therefore, that these, too, are controlled with appropriate rigour.[857]

6.75 The decision to impose constraints that affect the market system, and the way in which the consequences are managed, are matters for public policy. Farming is both socially and strategically important, as the history of agricultural subsidies attests. Nonetheless, it is clear that the way in which land is used is expected to change and must change to respond to societal challenges.[858] In this context, it would not be morally acceptable to displace these costs onto other countries that, perhaps, have less exacting standards. Given that many of the challenges to be addressed are global in nature, simply displacing them is likely to be ineffective in any case. Here, **the public good requires that countries apply the same standards to imported produce as to domestic produce to avoid 'offshoring' the social cost and continuing to aggravate global challenges facing the food system. Ethical protectionism is unlikely to be effective against global challenges and damaging to domestic businesses and consumers alike. States that take these challenges seriously therefore need to show cooperation and leadership, for example in the terms of international trade agreements and regulatory diplomacy.**[859]

[857] While we regard this as being of equal importance, we have tried to focus, in this report, on issues arising from breeding. No judgement about our views on the adequacy of any current measures should be inferred from this, however.

[858] This is recognised in the scheme of Agriculture Act 2020 in the UK.

[859] See Chapter 7 (Principle 5). In the UK, section 42 of the Agriculture Act 2020 provides that no free trade agreement that includes measures applicable to trade in agricultural products may be laid before Parliament unless the Secretary of State has first presented a report on the agreement's consistency with UK protections for human, animal or plant life or health,

Conclusion

6.76 We set out, in this inquiry, to identify and examine ethical questions relating to the impact of new breeding technologies, specifically genome editing technologies, on the production, use, and welfare of animals for human consumption. It has become very clear, as our deliberations have progressed, that the impact of those technologies and, consequently, the nature of those questions, depends only partly on the nature of the technologies themselves and what they make possible. The impact of introducing new breeding technologies depends just as much on how they engage the conditions and practices of farming systems, and the ethical questions much more on the purposes for which those technologies are used and how their use shapes the development of the system towards more acceptable states. Such states, we have argued, are ones that support and promote basic justice. This involves responding to the challenges that beset food and farming systems, which, because of the function of the food and farming system, are also challenges to securing basic justice. As an old Byzantine proverb has it:

> "He who has bread has many problems; he who lacks bread has only one problem."[860]

6.77 The way in which biotechnologies are used with farmed animals potentially has a role in relation to all of the challenges we have identified. It is unlikely, from the evidence we have considered, that genetic technologies will result in dramatic and direct increases in the production characteristics of farmed animals, although they might do so.[861] Where biotechnologies may offer productivity gains is more likely to be in areas such as reducing the burden of disease and the cost of veterinary interventions. However, biotechnologies are not the only pathway to this outcome and different approaches will serve the interests of different groups of humans and farmed animals differently. Here we recognise the need for caution, since what look like *prima facie* benefits can also serve to entrench production systems that externalise social costs. While we therefore welcome the potential for biotechnologies to bring apparent benefits of many kinds, we agree with the participants in our public dialogue that they should not be used for the benefit of people *at the expense* of the animal, so long as it is possible to meet the basic interests of both people and animals by arranging institutions and practices appropriately.

6.78 The organisation of the industries that have grown up around different domestic species has led to an unsustainable and potentially unjust distribution of costs and benefits that has given rise to the challenges we have identified in this report. There is a need to correct this trajectory.[862] It is our strong conclusion that any intervention in the breeding of farmed animals, whether a positive attempt to develop breeding science to promote desirable consequences or a regulatory constraint on such activities to avoid undesirable consequences, must be considered within the context of a broader, coherent vision of a future food and farming system. This should take account not only of the dynamics of

animal welfare and the environment. The Act (as amended by section 9 of the Trade Act 2021) requires that, in preparing this report the Secretary of State must seek advice from a Trade and Agriculture Commission, convened under powers given in section 8 of the Trade Act 2021.

860 There are many variations and attributions of this proverb: this variation occurs in Paarlberg, D (1984) *Farmers of five continents* (Lincoln NY: University of Nebraska Press).

861 For example, the AquAdvantage salmon, which incorporated a transgenic growth promoter.

862 The UK's National Food Strategy Review report sets out four goals for the food system of the future: it must make us well instead of sick, it must be resilient enough to withstand global shocks, it must help to restore nature and halt climate change so that we hand on a healthier planet to our children, and it must meet the standards the public expect, on health, environment, and animal welfare; see: National Food Strategy Independent Review (2021) *The National Food Strategy: the plan*, available at: https://www.nationalfoodstrategy.org/.

the food and farming system but also of the effect of that system on the common conditions of life for human citizens and farmed animals.

6.79 The future of farmed animal breeding needs to be seen in the wider context of the diet change that those in post-industrial and industrialising countries alike need to embrace, for the benefit of humans, animals, the planet, and future generations. This will involve a lower level of consumption of animal products overall, and, where they are consumed, the consumption of higher quality and higher welfare products, combined with the more efficient use of arable production to feed people and the development of new protein sources. It will, very probably, mean a rise in the price of animal products. But this will not be a matter of taxing consumption but of paying a fair price that reflects the true costs and reincorporates the externalities of livestock production. As our more recent forebears understood and accepted, no less than our ancient ancestors at the dawn of the agricultural revolution: eating meat and consuming animal products are to be enjoyed – by those who wish to do so – respectfully and sparingly.

Chapter 7

Conclusions and recommendations

Chapter 7 – Conclusions and recommendations

> **Chapter overview**
>
> This chapter sets out five 'guiding principles' that are relevant to the development, implementation, and governance of animal breeding technologies generally.
>
> It then summarises the main propositions and conclusions from the discussion in the previous chapters and formulates a number of recommendations.

Introduction

7.1 Eating food derived from non-human animals (and consuming other animal products) presupposes the instrumentalisation and, often, the intentional killing of animals. Although a significant number of people live flourishing lives without consuming animal products, a diet involving a greater or lesser component of animal products is still typical for the majority of people in the world. Human physiology has evolved on an omnivorous diet and, in consequence, has evolved to equip humans for an omnivorous diet. Many people depend on animals to provide important nutrients, for example by converting grass or plankton into proteins that they can digest, particularly in parts of the world that are inhospitable to plants that are edible for humans.

7.2 Our inquiry has led us to conclude that the way in which the global food and farming system is organised and run, and the internal and external challenges to which it is subject, make it morally indefensible and unsustainable in its present form. There are both immediate challenges and long-term challenges. In responding to these challenges, we recognise that short term improvements (e.g., addressing the most dysfunctional features of the current system) may serve only to entrench that system and its trajectory of development, making a later transition to a different trajectory yet more difficult to achieve. Rather than addressing distinct challenges in a piecemeal fashion, interventions in the system must, on the contrary, be guided by a coherent vision of the type of food and farming system desired, informed by a nuanced consideration of the 'opportunity costs' of alternatives foregone, and framed by a comprehensive policy context to achieve it.

7.3 The breeding of farmed animals is a component part of this vision. New breeding techniques such as genome editing have the capacity to accelerate progress towards the desired arrangement of the system, or to take it in new directions, even creating possibilities that were not accessible before. Based on our survey of current research and development, breeding technologies that make use of genome editing are not currently aimed at traditional per capita production characteristics such as increased carcass weight and fecundity, the pursuit of which has led to collateral problems in the past. They may, nonetheless, increase agricultural and aquacultural productivity in other ways (e.g., by reducing the risk of animal disease or the effects of heat), which, in turn, can address problems that arise as a result of the husbandry systems in use. But prospective breeding technologies undoubtedly have considerable though, as yet, undefined potential to achieve other outcomes.

7.4 Genome editing is only one very recently developed range of techniques in biotechnology and others may come along in the future. For this reason, our conclusions and recommendations concerning farmed animal breeding must have relevance beyond the specific techniques that are currently the most salient. Furthermore, while a range of applications is in development at present, it is not possible to predict the uses to which emerging biotechnologies may be put in future. For this reason, we have tried to make our conclusions and recommendations relevant both to those applications that are currently in development and others that can, as yet, only be imagined.

7.5 In our inquiry, we have been concerned not just with the uses that may be made of one or other breeding technology, but also with how the adoption of different technologies may affect the shape and organisation of food and farming systems and the basic interests of humans and non-human animals that are dependent on them. Correspondingly, our recommendations relate not to the transactional relations between humans, or between humans and non-human animals, but to choices about the design and management of systems, such that whatever approaches and technologies they incorporate, they may do so in a way that does justice to the lives that are entangled in them.

Guiding principles

7.6 A number of principles have emerged in the course of our inquiry that are relevant to the development, implementation, and governance of animal breeding technologies. These principles are not peculiar to genome editing, the technique that has provided the impetus for this inquiry, nor yet to biotechnology more generally. Furthermore, we are conscious that well-meaning principles can, depending on the construction of the problem to which they are applied, lead to inconsistent and even contradictory conclusions. The principles below are therefore proposed as a framework around which the elaboration of practical policy and governance may take shape, rather than as a direct guide to action.

Food security

Principle 1: Food security

Food and farming systems should be organised, governed, and managed to deliver, at a minimum, sufficient safe, nutritious food to meet the needs of humans and non-human animals who depend on them, now and for future generations.

7.7 In Chapter 3, we described theories of justice that distinguish civil society from a notional state of nature, usually presented as one of ferocious, existential competition, in which there are no recognised norms governing behaviour.[863] We also noted the very real possibility of the deterioration of societies into internal conflict or aggression against others in the event of famine and similar catastrophic events.[864] While we are sceptical about claims that any *particular* intervention in the farming system is indispensable to meet the challenges of food security and population growth, we recognise, nonetheless, that those challenges are real and must be met.[865]

[863] While a notional market society may be regarded as one of ruthless competition, it is supported by institutions that aim to solve the fundamental problem of exchange and secure the rule of law.
[864] See paragraph 3.13.
[865] See, generally, Chapter 2.

7.8 The paramount principle is therefore that the circumstances of peace and the possibility of justice should be secured and maintained by and for present and future generations.[866] In relation to food and farming systems, this means, as a minimum, ensuring a food supply that is sufficient for all sections of the population. As we noted at the start of Chapter 3, this relates to both objective factors (the resources available in relation to the size of the population they must support) and subjective factors (cooperative arrangements for extracting resources, processing commodities, and distributing products among the population). Both are important: on one hand, a superabundance of resources is insufficient if products are not made available where they are needed; on the other hand, the productivity of meagre resources can be increased significantly by technology or by regenerative forms of agriculture. The degree of control that can be exercised through institutions is limited, however, not least because, given the globalisation of markets and supply chains, no economically developed political society is fully in control of its food and farming system. The conditions of justice cannot therefore be secured completely or once and for all, but represent a continual challenge as resources, populations, and institutions all change through time.

Basic justice

> **Principle 2: Basic justice**
>
> Food and farming systems should be organised and governed in a way that respects the basic interests of those whose lives they affect. This means that they should have the opportunity to live their lives in a state of safety, security, and wellbeing, with access to the experiences that constitute a good life, according to their form of life.

7.9 We recognise that, even within economically developed and politically stable societies, severe inequality persists so that many individuals may not enjoy the conditions necessary for even an adequate quality of life. A second principle, applying to the design and governance of the cooperative institutions that are foreseen as necessary in accordance with the first principle, will therefore be needed to secure the basic interests of those who are subject to them and who depend on them. A situation in which basic interests are secured may be described as one of 'basic justice'.[867]

7.10 Food and farming systems contribute to securing basic justice by their contribution to basic interests like nutrition. Farming systems are responsible for meeting the basic needs of the non-human animals that are subject to them and also providing rewarding employment for farm workers and others in the value chain. They also have an effect, through their interactions with ecosystems and the environment, on other basic interests, such as health. Conversely, the way in which food and farming systems are organised may contribute to injustice, where the basic interests of some are not respected. This can be particularly true for the morally relevant interests of non-human animals.

7.11 The principle of securing basic justice is not indifferent to differences between species. It requires justice to be done to humans and non-human animals in a manner consistent with their form of life, and consistently with maintaining the conditions of the possibility of justice (according to the first principle). Basic justice is an organisational principle rather than a transactional one: it does not mean that priority may not be given to the interests of humans over animals where these inevitably conflict. On the other hand, it does imply that the system should be organised to minimise such conflicts as far as

[866] See paragraph 3.9.
[867] See paragraph 3.16.

possible: where justice is possible, a system is not just where only some of those subject to it receive justice.

7.12 While there is a positive duty to secure respect for the basic interests of those who are subject to food and farming systems, it is also important to recognise that these systems are embedded in the wider social and natural environment, and that these systems have an impact on those outside the population in question, such as those outside the territory and free-living animals. In this case, we consider that there is at least a negative duty not to aggravate conditions, for example by avoidable damage to habitats, in a way that makes securing the basic interests of those others more difficult.[868]

Proportionality and caution

> **Principle 3: Proportionality and caution**
>
> Policy and governance relating to farmed animal breeding should take account not only of the predicted costs and benefits of innovations but also the implications, for the food and farming system and for wider society, of their adoption, diffusion, and normalisation, having regard to the need to respond to societal challenges and taking into account the first two principles. The implications of not innovating, or of following alternative courses of action, should provide context for this consideration.

7.13 The food and farming system is dynamic, subject to a number of internal and external challenges and embedded in a broader social and environmental context. In these circumstances, simply continuing current practices (the 'status quo') is not without consequences. In fact, these may be highly undesirable and likely to exacerbate injustice as circumstances change. Among the most important purposes of governance are to ensure that innovations do not aggravate the societal challenges facing the food and farming system and that any identifiable risks are proportionate to the predicted public benefit, while ensuring that the system as a whole meets the aims implied in the first two principles (food security and basic justice).

7.14 Concerns have been expressed about the use of invasive or technological approaches to address problems that have arisen as a result of earlier developments in farming practices, or where they are used to address challenges that have organisational as well as biological responses. We conclude, however, that neither these historical considerations nor the methodological concerns are decisive objections to technological innovation: depending on the circumstances there may be cases in which altering the biology of an animal may be a more proportionate approach than addressing the environmental conditions or practices already established in the system.[869]

7.15 The question of proportionality must, however, be posed in relation to alternative approaches that are available to achieve the same legitimate aim. Two aspects of novel biotechnologies make a proportionality assessment difficult. The first is the requirement to adduce evidence in support of the suitability of the biotechnology in achieving the aim, which puts innovations – which, by definition, lack historical evidence of their effects – at

[868] See paragraph 3.28.
[869] Speed itself, for example, might provide a reason to prefer genome editing to traditional breeding.

an automatic disadvantage.[870] Whereas established practices may present identified and estimated risks, innovations are often associated with uncertainty. One reason that is often offered to prefer adapting environmental conditions rather than animal biology is a concern that novel breeding technologies may have unforeseen or irreversible consequences, and that these may not be understood or mitigated before catastrophic outcomes have become inevitable. This kind of concern has given rise to what is widely known as the 'precautionary principle'.[871] It is important, certainly, that new molecular biotechnologies should be appraised at the macromolecular and cellular levels, at the level of the individual animals, and in animal pedigrees. However, the narrowing of these considerations around product safety, which is usually stringently regulated, misses important dimensions of effect and may even amount to misdirection.

7.16 The second aspect that makes the assessment of new technologies difficult is the requirement to demonstrate that they are no more burdensome than alternatives, given that the burdens may be differently distributed, possibly among different actors, and different actors may assign radically different values to them, and to each other's positions. In fact, they may require the positing and comparison of different and incompatible futures. The scope of technology governance must not fail to take in the more general pathways for food and farming systems that particular technological innovations may help to establish and/or entrench.[872] It is this potential entrenchment of systems, configured around particular technologies through social processes of innovation, diffusion, and normalisation, carrying forward trajectories with unforeseen but potentially industry-shaping consequences, that, in our view, requires special caution.[873]

7.17 In contrast to the 'precautionary principle', which has been seen by some as a rationale for blocking certain kinds of innovation, we favour what has been called a 'precautionary procedure'. This foregrounds the need to proceed in *some* direction, even if it is with circumspection, in order to respond to present challenges; it recognises, however, that the context is complex and evolving due to local and global political, economic, climatic, and population changes that put pressure on the food and farming system, and that there is no neutral option (i.e., one that does not have consequences).[874] This offers a reason to open up the appraisal of technologies in two ways.[875] The first is to move from a limited question about a particular technology, product or practice to more general questions

[870] One of the criticisms of the precautionary principle is the demands for evidence relating to safety it may place on innovators. This is often understood as a prejudice against the technical process itself, as it is developed and used by particular actors, particularly where the 'product' in question is substantially equivalent to one that is or might be produced by an already well-established process.

[871] This principle is, at its root, an attempt to encourage anticipatory mitigations against potentially catastrophic harms concealed in the uncertainties that surround the deployment of novel technologies in complex systems. For example, a version of the principle is enshrined in the Treaty on the Functioning of the European Union, see: Official Journal of the European Union (2012) *Consolidated version of the Treaty on the Functioning of the European Union*, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A12012E%2FTXT, Article 191(2). The principle originated in the field of environmental policy; see: the United Nations Conference on Environment and Development (1992) *Rio Declaration, Annex I, Principle 15*, available at: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf. It has subsequently permeated policy relating to many fields of technology, evolving many different variants and accumulating a large and controversial literature. See: Herrero M, Thornton PK, Mason-D'Croz D *et al*. (2020) Articulating the effect of food systems innovation on the Sustainable Development Goals *Lancet Planet Health* **5(1)**: E50-62.

[872] See: Collingridge D (1980) *The social control of technology* (Milton Keynes: The Open University Press); see also: Hughes TP (1994) Technological momentum, in *Does technology drive history? The dilemma of technological determinism,* Smith MR, and Marx L (Editors) (Cambridge, Massachusetts: MIT Press).

[873] See the institutional 'virtue of caution' in: Nuffield Council on Bioethics (2012) *Emerging biotechnologies: technology, choice and the public good*, available at https://www.nuffieldbioethics.org/publications/emerging-biotechnologies.

[874] The cost of inaction, particularly for developing economies, was highlighted in the Nuffield Council on Bioethics (2003) *The use of GM crops in developing countries, a follow up discussion paper*, available at: https://www.nuffieldbioethics.org/publications/gm-crops-in-developing-countries.

[875] On the problems of the use of the precautionary principle as a 'decision rule', see: Nuffield Council on Bioethics (2014) *Submission to the House of Commons Science and Technology Committee inquiry: GM foods and application of the precautionary principle in Europe*, available at: https://www.nuffieldbioethics.org/assets/downloads/Submission_to_GM_inquiry_Nuffield_Council_on_Bioethics.pdf.

about alternative technologies, products, or practices that may be available to address a collection of interrelated societal challenges. The second is to turn from the objective of collecting more evidence of a particular kind – where this is unlikely to be decisive, given the plural ways in which it is invested with significance – to that of exploring other forms of evidence, engaging with different ways of interpreting and valuing the evidence, and different ways of constructing the challenges to be addressed or the aims to be pursued.[876]

Engagement and procedural justice

> **Principle 4: Engagement and procedural justice**
>
> Where the implementation of new breeding technologies engages questions of public interest (e.g., in relation to the societal challenges affecting the food and farming system), in particular where it could have a significant bearing on the aims implied in the first two principles, those responsible for policy and governance should take steps to attend to the range of values and interests expressed by members of the public.

7.18 The embeddedness of food and farming systems in the wider society suggests that policy and governance relating to them should be orientated by the public interest. If this is the case, efforts are needed to discern the content of the public interest. However, the relation of the public interest to the interests of members of the public is complex: it cannot be assumed that the public interest is the aggregate of individual interests, much less of the interests of any section of the public that may be motivated or encouraged to express them. In liberal democratic societies, different procedures may be adopted to discern, produce, and give effect to the public interest. Two mechanisms through which public interest may be expressed are through the selection among the programmes of political parties, for which citizens may vote in general elections, and through signals from the market as a result of economic choices made by consumers. These, though, are unlikely to be sufficient to ensure the coherence or determine the detail of public policy. Grand political programmes tend to be insufficiently detailed to survive encounters with the reality of government and, if not supplemented by continuing policy processes, can become dogmatic or paternalistic, diminishing their legitimacy. Markets, on the other hand, tend to disaggregate publics into individual consumers and recompose the public interest in ways that may serve the interests of those with power in the value chain.[877]

7.19 There are several reasons for policymakers to engage with members of the public beyond the conventional frameworks of industry or expert advisers. One is that such engagements have instrumental value: policy that fails to engage the public may be more difficult to implement, where implementation depends on public consent. Such engagement may also have a substantive benefit in relation to the third principle above, namely providing a way to explore variant forms of evidence, different ways of interpreting and valuing evidence, and of constructing the challenges to be addressed. This does not mean that the content of policy should be determined simply by 'the balance of public opinion', but that the process of governance, which applies to matters that affect the collective public interest, attend to the richness and variety of public

[876] See paragraph 6.53 above.

[877] See paragraph 6.33 ff. A number of consumer movements have, nonetheless, sought to use the market, sometimes with great success, to influence the behaviours of actors within the food system by deliberately withholding or shifting demand.

debate, reconnecting sites of debate in the public sphere with the sites of political decision making.

Cooperation and solidarity

> **Principle 5: Cooperation and solidarity**
>
> Government and public authorities should work with authorities in other jurisdictions to address societal and global challenges that cross national or political borders, including food security and nutrition, animal welfare, animal health, the emergence of zoonotic disease, biodiversity loss, ecosystem, and climate change.

7.20 The fact that food systems are rarely coextensive with any particular national jurisdiction suggests that promoting the public interest in one jurisdiction must involve cooperation with institutions in other jurisdictions. Reciprocally, the conditions of domestic production have an effect on the conditions in other jurisdictions, which, as we have said, entails at least a negative duty not to aggravate conditions in a way that makes securing the basic interests of those others more difficult (see the second principle above). Cooperation is therefore both a moral principle and a practical necessity, to secure standards and to avoid the problem of weaker standards and their effects spreading between nations, following currents of economic activity, thereby undermining efforts to maintain or raise standards domestically. This may require regulatory diplomacy and the enforcement of trade conditions to promote appropriate standards.

7.21 Given the global nature of the challenges facing food and farming systems, and the globally uneven distribution of their effects for humans and sentient, non-human animals, the principle of basic justice requires responses that transcend species, geography, and jurisdiction. At a political level this enjoins solidarity. Solidarity may be characterised as a willingness to carry costs on behalf of others.[878] This may take the form of sharing benefits of research, codesigning research objectives, facilitating technology transfer, and agreeing fair trading relations that promote high standards and discourage the ‘dumping’ of moral responsibility and economic costs on other nations.

Key propositions and recommendations

7.22 Our report contains a number of propositions and conclusions that form the backbone of our overall argument, leading to a number of recommendations that we set out below. The headings pick out the main normative claims to which we wish to draw attention.

Historical domestication has been followed by de-domestication

7.23 We have taken a long historical perspective to show how domestication (where humans and non-human animals live at close quarters) has had an effect on both farmed animals and on human societies. We observed that the modern industrialisation of farming has led to a disembedding of agricultural production systems from the societies that they support, and a growing cognitive and affective distance – which we have called ‘de-

[878] Nuffield Council on Bioethics (2011) *Solidarity: reflections on an emerging concept in bioethics*, available at: https://www.nuffieldbioethics.org/publications/solidarity. This discussion highlights how the concept of solidarity may be embodied and formalised in institutions (‘third tier’ solidarity).

domestication' – between consumers of farmed animal products and the farmed animals from which they come.[879]

Scientific breeding has led to hyperdomestication

7.24 New breeding technologies, particularly those based on knowledge of genetics, have accelerated the rate of phenotypic change in farmed animals and confirmed their increasing subjection to technological control. Prospective breeding technologies, such as genome editing, have the potential to increase this acceleration. As well as management of their feed, physical environments, and interactions, contemporary husbandry involves control over animals' reproduction that now extends down to the molecular scale – the genome – potentially allowing selection at the level of which individual alleles are passed on to the next generation. We have called this progressive refinement and combination of controlling interventions 'hyperdomestication'. Whether this represents continuity or rupture with previous breeding practices is a question of moral and political framing that may affect the response to it.[880]

The food and farming system is unsustainable on its present course

7.25 The food and farming system, globally, is highly integrated, and subject to both internal and external challenges that make it both potentially unstable and unsustainable in the long term. (We have discussed some of these challenges under the headings of 'animal health and welfare', 'human health', 'demand and supply', 'social and cultural conditions', and 'environment and ecology'.) We conclude that while changes are necessary, interventions that seek to ameliorate some conditions could potentially aggravate others. Furthermore, because the system is highly integrated, local interventions can give rise to new trajectories, potentially affecting or even transforming the system at a global scale.[881]

A just system is one that respects the basic interests of those subject to it

7.26 The food and farming system has a profound effect on the interests of all those who depend on it to answer to certain 'basic interests'. In fact, satisfying the basic interests of all depends upon their cooperation in or submission to a complex, integrated food and farming system.[882] 'Basic justice' is secured by a system or institution when it provides all those subject to it with the opportunity to have their basic interests satisfied. But the system is of such global significance that even those who do not depend on it directly are affected by its impact on their habitat, environment, economic conditions, climate, etc.

Farmed animals have morally relevant basic interests

7.27 Research is providing new insights into the experiences of non-human animals and the ways in which animals of most domesticated species are capable of having morally significant basic interests.[883] The conditions of food and farming systems determine whether and how some of the basic interests of humans and almost all of those of farmed animals are met. Although humans and non-human animals depend on each other in

[879] See: paragraph 1.51 above.
[880] See: paragraph 1.51.
[881] See: paragraph 2.3 ff.
[882] See: paragraph 3.11 ff.
[883] See: paragraph 3.20 ff.

different ways to secure their basic interests, it is possible to arrange food and farming systems in ways that are better or worse at doing justice to the humans and farmed animals involved in them.[884]

Biological and institutional changes can affect justice positively and negatively

7.28 As food and farming systems bind together the lives of humans and farmed animals in relations of dependency, it cannot be assumed that systems of social relations, institutions, and practices are necessarily more tractable than biological parameters, especially given recent developments in biotechnology. Nor can it simply be assumed that altering the former (social factors) necessarily offers a better prospect of successfully securing justice, or of doing so without significant collateral harms, than altering the latter (biological factors). The appraisal depends, at least in some cases, as much on the circumstances as on the nature of the intervention.[885]

The effect depends upon how biotechnology is implicated in the wider system

7.29 How the challenges facing food and farming systems are addressed is not, however, a matter of indifference. Biotechnology is not *merely* a tool. Technologies implicate different social and economic relations, forms of knowledge and practice, perform distinctive exclusions and inclusions, conduce to particular visions of desirable futures; the adoption of technologies can potentially change the course of entire industries or further entrench existing trajectories.[886] To attend only to factors internal to supply chains creates the potential for actors to externalise the social costs of their activities.[887] A coherent vision of the future food and farming system is needed to shape policy objectives and to assess the appropriate place for different breeding technologies.

Biotechnology has significant and exceptional implications

7.30 The capacity of biotechnology to accelerate, entrench, or transform breeding trajectories presents both opportunities and risks, through the adaptation of farmed animals to specific husbandry systems and conditions. There is a risk that breeding that does not respect animals' basic interests will produce animals that are better adapted to conditions of poor welfare, in which they are unable to live lives of good or even satisfactory quality. Improvements in robustness and resistance to disease may mean that animals can tolerate poor conditions without adverse health impacts, potentially masking the effect that living in those conditions may have on their welfare.[888]

7.31 While attention may be given to the condition of individual animals or herds, flocks, or schools, breeding creates the potential for intergenerational drift, which may cause loss of the physical capacity required for living a good life, as a result of successive phenotypic alteration over generations through the pursuit of certain kinds of genetic gain.[889] New breeding technologies have considerable power both to accelerate or reverse this.

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[884] See: paragraph 3.36 ff.
[885] See: paragraph 3.36 ff.
[886] See: paragraph 4.78 ff.
[887] See: paragraph 5.41 ff.
[888] See: paragraph 4.80.
[889] See: paragraph 4.81.

The influence of consumers on the system is limited by market processes

7.32 Where consumers do not deliberately coordinate their purchasing behaviour, their influence over farmed animal breeding through the market is limited. This allows production to become organised around private interests in the value chain and to become 'locked in' and institutionalised. While this serves some of the interests of consumers efficiently, it also tends to produce collateral effects that are detrimental to the public interest: markets fail adequately to provide public goods and externalise costs, which must then be addressed by governments. The extent to which these have not been controlled historically is demonstrated by the challenges identified in Chapter 2.

7.33 When citizens do engage, for example through participation in deliberative democratic processes, they tend to acknowledge those challenges and suggest alternative trajectories to deliver public goods.[890] Our 'rapid online deliberation' with members of the public demonstrated a significant difference between the values they expressed and the values organising the food and farming system. In view of this difference, there is good reason to explore relevant public values further using a range of quantitative and qualitative methodologies.

Recommendation 1

We recommend that, to inform the development of policy, law, and regulation in relation to farmed animal breeding and the introduction of new breeding technologies, public authorities should support initiatives to explore public views about these matters and their place in the future of the food and farming system.[891] Such initiatives should explore understandings of current and proposed breeding technologies, husbandry systems, and governance, the relation between consumer choice and public interest, and the appropriate role for public authorities.

There should be minimum standards for breeding

7.34 Public institutions have the power to shape and govern the food and farming system. As well as allowing the overall challenges to the system to become compounded, omitting to exercise this power, or failing to exercise it effectively, can allow the emergence of a range of specific harms, such as the adverse effects of breeding and breed evolution.

Recommendation 2

We recommend that all commercial breeders of farmed animals should adopt an explicit and recognised set of breeding standards, with independent oversight. (A high-level example is Code-EFABAR, which offers certification through the European Forum of Farm Animal Breeders.) However, we recommend the development of more detailed standards that may be enforced by a national competent authority.[892] In particular, these should seek to ensure that animals may not be bred to enhance traits merely so that

[890] See: paragraph 5.41.
[891] See: paragraph 5.50; see also Principles 3 and 4.
[892] See: paragraph 6.20.

they may better endure conditions of poor welfare, or in ways that diminish their inherent capacities to enjoy experiences that constitute a good life.[893]

Information and transparency can be improved

7.35 Effective intervention is hampered, on one hand, by an information deficit, so it is not possible to develop a multidimensional picture of the actual longitudinal effects of breeding practices. On the other hand, it is also hampered by a governance deficit so that, even if such information were available, the mechanisms to make use of it are lacking.[894]

Recommendation 3

We recommend that support for research should include public funding for independent research to develop, validate, and integrate new measures and standards, in particular for on-farm welfare – which should include behavioural measures – as distinct from animal health.[895]

Recommendation 4

We recommend that as well as funding for the development of breeding technologies, public funding should be provided for research to develop and validate appropriate on-farm monitoring, recording, and reporting technologies, and to facilitate their adoption by farmers.[896]

Recommendation 5

We recommend that public funding should be provided for infrastructure, training, and technical support for improved collection, integration and independent analysis of on-farm data to detect and validate the multidimensional effects of breeding and husbandry practices.[897]

Expansion of breeding indices to show full value and effects of breeding

7.36 Breeding indices are a powerful tool driving behaviours in the industry. However, they currently offer only a partial profile, which incorporates mainly traits that are considered economically valuable to producers. Additionally, not all indices are independently validated. Better use of indices incorporating traits that give a more complete profile would benefit both farmers and public policy.

Recommendation 6

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893 See: paragraphs 4.80-4.81.
894 See: paragraph 6.21.
895 See: paragraph 6.29.
896 See: paragraph 6.30.
897 See: paragraph 6.31. In the UK this could be supported by the Livestock Information Service in a way that would reduce on-farm form-filling and streamline regulation.

We recommend that the use of breeding indices that reflect a profile of heritable characteristics, including those that are of public or social as well as economic value should be explored as a possible regulatory tool. Commercial breed developers placing animals or animal reproductive materials on the market could be required to publish these indices.[898]

Recommendation 7

We recommend that an appropriate, independent, and trustworthy body (identified or established by Defra in the UK) should monitor the longitudinal development of breeding lines (e.g., in the dimensions captured by enhanced breeding indices – see recommendation 6). This body should report on these matters to the public authority or authorities having oversight of farmed animal breeding (in the UK, the Animals in Science Committee, the Animal Welfare Committee, the Animal and Plant Health Agency and/or the proposed Animal Sentience Committee, as the case may be – see recommendation 12).[899] The body should ideally have access to information to enable the validation of breeding effects, provided in confidence if necessary, and advise where information is lacking. We encourage breeders to facilitate scientific research using their data, leading to publication in peer-reviewed journals.

Labelling should provide meaningful information about animal products

7.37 What people buy can have an influence on industry behaviours; meaningful labelling can allow people to exercise informed choice in what they buy. What makes labelling fully meaningful to consumers, however, is not simply a matter of accurately representing the analytical characteristics of products.[900] Some consumers want to have confidence that they are not being deprived of information they consider relevant before buying. There is arguably also a need to enhance general understanding about the characteristics of products and the nature of production processes that may be referred to by labelling (as well as what may or may not be inferred from the absence of such information on a label).[901]

7.38 There should be oversight of labelling policy as a whole, informed by the relevant scientific and social research, and engagement with the public, stakeholders from industry, and other interest groups.[902] This should be transparent and should have the function of both understanding what information is relevant to members of the public and providing them with information about the meaning and significance of labels.[903] The arguments for transparent labelling of genome-edited products apply equally to products

[898] By ‘commercial breed developers’ we mean companies or subsidiaries whose principal business activity is the genetic development of farmed animal lines. This does not include farmers who use on-farm selective breeding to develop their own herds, flocks, schools, etc. (In some species, commercial breeders must refer to AHDB-validated indices when advertising their animals or genetic material for sale in the UK.)

[899] See: paragraph 6.60.

[900] See: paragraph 6.42.

[901] See: paragraph 6.42.

[902] In the UK, responsibility for labelling related to the socially significant aspects of food production are distributed among several agencies: the Food Standards Agency is responsible for food safety-related labelling (as well as some non-safety aspects in Wales and Northern Ireland), Defra is responsible for labelling policy and non-safety-related compositional standards, while DHSC is responsible for nutrition policy and labelling.

[903] See: paragraph 6.42.

of conventional breeding: these, too, are produced in ways that have social and cultural impact, as detailed in this report, and that may be equally relevant for consumer choice.

> **Recommendation 8**
>
> We recommend that labelling of foods containing animal products should take account of (1) scientific advice on food safety, nutrition and other attributes of interest and (2) traceable attributes of interest to consumers, which may include circumstantial factors such as breeding practices and technologies used, husbandry systems, region of origin, and the ways in which products are processed. Use should be made of supporting technology, such as distributed ledger technology to assure traceability and quick response (QR) codes to provide access to published information.[904]

Better alignment should be achieved between public and private interests

7.39 A major concentration of power in the value chain lies in the hands of retailers, whose primary incentives are to maximise market share and profits by providing choice to consumers.[905] Retailers have considerable power to set standards for how the products they offer for sale are produced. Retailers operate with international food supply chains. Any standards regarding the responsible breeding of animals from which products are offered for sale should apply regardless of the country of origin, raising, or processing, notwithstanding any challenges involved in verifying that these standards have been met.

> **Recommendation 9**
>
> We recommend that the Government bring the major food retailers together in order that they may collectively agree: (1) a pathway to a situation in which all animal products offered for sale come from animals that have been responsibly bred; (2) the means whereby that goal will be reached; (3) the manner in which the attainment of that goal will be overseen; (4) how this aim may be effectively backed up by retailer (rather than product) accreditation.[906]

Regulation of breeding technologies requires a coherent policy context

7.40 The product safety aspects of genome editing and other novel breeding technologies are unlikely to be the foremost concern, given sufficient environmental and food safety regulation.[907] While some hope that the reclassification of a subset of genetically modified organisms (GMOs) produced as a result of genome editing could facilitate the development of socially and economically valuable breeding initiatives, others express concern that the removal of the inhibitory layer of regulation for GMOs could release an acceleration of breeding practices along undesirable trajectories. They also fear that this might lead to socially undesirable effects on the configuration of sections of the farming industry.[908]

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904 See: paragraph 6.42.
905 See: paragraph 6.44.
906 See: paragraph 6.46.
907 This is an important condition, but we do not address the fitness for purpose of this domain of regulation in our report.
908 See: paragraph 6.48 ff.

Recommendation 10

We recommend that any revision of the current regulatory regime for genetically modified organisms should be preceded by a thoroughgoing policy review. This should address the effects of any proposed change on the food and farming industry, and, if necessary, how these should be controlled, including their potential to encourage the use of industrial livestock systems that may adversely affect animal health, animal welfare, environmental, and other challenges.[909]

Recommendation 11

We recommend that any review of the regulatory regime for genetically modified organisms should be carried out in the context of a publicly articulated vision for the future of the food and farming system and lead to a comprehensive policy framework (with relevant governance measures, such as are proposed in this report) to secure it.[910]

Commercial animal breeding should be controlled to prevent inherent harm

7.41 The historical effects of ungoverned breeding practices have produced some breed phenotypes that are not compatible with the capacity to live a good life. At the same time, they may have aggravated other challenges either directly (e.g., breeding animals prone to injury or disability) or by the way they have diffused and integrated into the farming industry (e.g., reducing biodiversity or incubating disease). Where harmful phenotypes persist, there is a need for redress; given the incentives bearing on the industry there is also a need to guard against these effects occurring in the future.[911] We have said that commercial breed developers should be encouraged to commit to sustainable and responsible breeding practices (see recommendation 2); however, there is also a need for more effective mechanisms to assess compliance and to hold them to account.[912]

Recommendation 12

We recommend that a suitably constituted and authoritative body should oversee the effects of breeding practices in scientific research and commercial breed development. This body should advise, in particular, on any breeds or lines, whether originating from domestic or foreign breeders, which may or may not be used commercially, and on breeds or lines at risk (see recommendation 7).[913]

Incentives should encourage responsible breeding

7.42 There is a need to restructure incentives around livestock farming and aquaculture to align with the vision of a desirable food and farming system, orientated towards securing

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[909] See: paragraphs 4.82.
[910] See: paragraph 5.50.
[911] See: paragraph 6.55 ff.
[912] See: paragraph 6.20.
[913] See: paragraph 6.60.

basic justice and promoting public good.[914] In accordance with the principle of solidarity, incentives should reflect not only local but global public good.

Recommendation 13

We recommend that ways to encourage responsible breeding and the use of responsibly bred animals, as well as responsible husbandry practices, are explored, for example through incentive payments to farmers in relation to the characteristics of the animals they raise (see recommendation 6).[915]

Future food systems must use animal products sparingly and sustainably

7.43 We have concluded that the food and farming system cannot be sustained indefinitely in its current configuration. It must therefore adapt in order to respond to the challenges it faces and to diminish the adverse effects of the societal challenges to which it contributes. A coherent vision of the place of animal products in the future food system must be articulated and pursued. Such a coherent vision must be combined with a concerted policy framework to avoid the possibility of narrowly focused, piecemeal changes having unanticipated, knock-on, and potentially undesirable effects that merely defer, displace, or externalise existing problems.[916]

Recommendation 14

We recommend public support, including funding, be provided for initiatives to develop new food sources and make more just and effective use of existing ones, and to encourage and support a voluntary change in the diet of post-industrial populations to consume animal products only when these are responsibly bred and consumed at sustainable levels, in order to promote health, to reduce environmental and ecosystem damage, and achieve climate change policy objectives.[917]

[914] See: paragraph 6.72.
[915] See: paragraph 6.72.
[916] See: paragraph 6.76 ff.
[917] See: paragraph 6.76 ff.

Appendices

Appendix 1: Method of working

Background

The Nuffield Council on Bioethics initiated this project in 2019 to explore the social and ethical issues raised by genome editing and farmed animals breeding. A working group was appointed for the project in January 2019, and the party met 16 times (in person and online) between January 2019 and November 2021.

Call for evidence

To inform the deliberations, the working group launched a call for evidence in June 2019 which took the form of a 21-question document aimed at a diverse range of organisations, stakeholders and researchers, and which received 24 submissions. For further details on the call for evidence, see Appendix 2.

Factfinding meetings

The working group held a series of roundtable meetings with a wide range of individuals and representatives of organisations, the details of which can be found below.

Factfinding meeting on hornless cattle, 23 May 2019

The purpose of the meeting on hornless cattle was to explore the technical bases of genome editing in large mammals with a particular focus on POLLED technology in cattle; the broader set of social, political, commercial and regulatory drivers and obstacles likely to influence how the technology is developed and used; and how use of POLLED technology might impact on different kinds of farming systems and animals.

- **Neil Eastham**, Partner at Bishopton Veterinary Group, and Future Farmers of Yorkshire
- **Perry Hackett**, Professor of Genetics, Cell Biology, and Development at the University of Minnesota
- **Brian Revell**, Professor Emeritus, Agricultural and Food Economics at Harper Adams University
- **Gene Rowe**, Independent Research Consultant in Science Communication and Public Engagement
- **Paul Tompkins**, farmer at South Acre Farm, Vale of York and Vice Chairman of the National Dairy Board
- **Adam Shriver**, Research Fellow at Oxford Uehiro Centre for Practical Ethics at the University of Oxford
- **Alison Van Eenennaam**, Extension Specialist: Animal Biotechnology and Genomics, Department of Animal Science, University of California Davis

Factfinding meeting on genome editing to produce disease resistant animals, 23 May 2019

The purpose of the genome editing and disease resistance meeting was to gain insights into the different technical bases for producing disease resistant animals, taking PRRS-resistant pigs and flu-resistant chickens as examples; the broader set of social, political, commercial and regulatory drivers and obstacles likely to influence how each technology is developed and used; and how cultivation of edited animals might impact different kinds of farming systems, human health and animals themselves.

- **Wendy Barclay**, Action Medical Research Chair in Virology at Imperial College London
- **Richard Bennett**, Professor in the School of Agriculture, Policy and Development at the University of Reading
- **Andy Butterworth**, Reader in Animal Science and Policy at the University of Bristol
- **Simon Lillico**, Research Fellow at The Roslin Institute, University of Edinburgh
- **Josh Milburn**, Associate Lecturer in Political Philosophy at the University of York
- **Alan Tinch**, Technical Services Director at Benchmark Breeding and Genetics

Factfinding meeting on the ethical treatment of animals, 17 July 2019

The purpose of the meeting on the ethical treatment of animals was to gain insights into different perspectives on the status of animals and human-animal relationships, including arguments relating to moral status and proper treatment of animals, and empirical understandings of human attitudes to different uses of non-human animals.

- **Donald Broom**, Emeritus Professor of Animal Welfare, University of Cambridge.
- **Alasdair Cochrane**, Senior Lecturer in Political Theory, University of Sheffield.
- **Katrien Devolder**, Senior Research Fellow, Oxford Uehiro Centre for Practical Ethics.
- **Robert Garner**, Professor in Politics and International Relations, Leicester University.
- **Rebekah Humphreys**, Lecturer in Philosophy, University of Wales, Trinity Saint David.
- **Samantha Hurn**, Associate Professor, Anthropology, University of Exeter.
- **Emma Roe**, Associate Professor in Human Geography, University of Southampton.
- **Francoise Wemelsfelder**, Senior Scientist, Scottish Rural College.

Factfinding meeting on food and farming systems, 8 November 2019

The purpose of the meeting on food and farming systems was to understand the key components of livestock farming and food systems and the potential dynamic interactions between these systems and genome editing technologies, across biotechnology research and development, animal breeding, food, production, distribution and consumption in different parts of the world.

- **Santiago Avendano**, Director of Global Genetics, Aviagen
- **Keesje Avis**, Senior Policy Officer, Nourish Scotland
- **Julian Baggini**, Food Ethics Council member and writer
- **Karl Behrendt**, Elizabeth Creak Chair in Agri-Tech Economic Modelling, Harper Adams University
- **Jude Capper**, Livestock Sustainability Consultant
- **Honor Eldridge**, Head of Policy, Sustainable Food Trust
- **Tara Garnett**, Food Climate Research Network Leader, Oxford Martin School and the Environmental Change Institute
- **Dominic Glover**, Research fellow, Institute of Development Studies
- **Carmen Hubbard**, Senior Lecturer in Agricultural Economics, Newcastle University and member of the Farm Animal Welfare Committee
- **Claire Marris**, Reader at Centre for Food Policy, City University

- **Erik Millstone**, Professor of Science Policy, SPRU, University of Sussex
- **Kirk Siderman-Wolter**, Chief Operating Officer, Agri-Epicentre

Site visit

As part of its work, the working group organised a visit to the Roslin Institute at the University of Edinburgh in September 2019. The visit included a series of presentations from researchers at the Roslin Institute, a presentation by Abacus Bio relating to public views on genome editing and farmed animals, and a farm visit (including a tour of the Large Animal Unit and Intensive Care Unit).

Evidence reviews

The working group commissioned one literature review and undertook two evidence reviews:

- A review of research on public attitudes to genetically modified foods and related areas and their implications for genome editing of farmed animals commissioned from Gene Rowe (Gene Rowe Evaluations) and Richard Watermeyer (University of Bath).
- A review of literature and publicly available data on the longitudinal effect of balanced breeding strategies in context of historical health and welfare outcomes carried out by Molly Gray.
- Animal sentience and consciousness: a review of current research carried out by Arzoo Ahmed.

External reviews

A draft version of the working party's report was circulated in September 2021 to 12 external reviewers with relevant expertise and experience. Reviewers' comments were considered at the working group's meeting in October 2021.

The reviewers were:

- **Jonathan Birch**, Associate Professor, Department of Philosophy Logic and Scientific Method, London School of Economics.
- **Ann Bruce**, Senior Lecturer, School of Social and Political Science, The University of Edinburgh
- **Madeleine Campbell**, Senior Lecturer, Royal Veterinary College
- **Penny Hawkins**, Advocacy and Policy Directorate, RSPCA
- **Craig Lewis**, Genetic Services manager for Asia and Europe, Pig Improvement Company, and Chair, European Forum of Farm Animal Breeders
- **Philip Macnaghten**, Personal Chair in Technology and International Development, Wageningen University
- **James Mills**, livestock farmer, York
- **Dominic Moran**, Professor of Agricultural and Resource Economics, University of Edinburgh
- **Anna Wargelius**, Reproduction and Developmental Biology, Institute of Marine Research

Appendix 2: Wider consultation for the report

Call for evidence

A call for evidence on genome editing and farmed animals was launched on 20 June 2019 and remained open until 20 September 2019. The aim of the call for evidence was to gather in-depth information from individuals and organisations with an existing knowledge and interest in genome editing and farm animal breeding to inform the working group's discussions.

Twenty four responses were received; five were from individuals and 19 were from organisations. All responses were circulated among the working group and considered in detail at the seventh meeting in November 2019. Further information about the call for evidence is available on the Nuffield Council's website.[918]

Questions posed

In total 21 guide questions focusing on the genome editing and farmed animals were posed and respondents were encouraged to answer as many as possible.

Section 1: Current research

Question 1: What current or planned projects of research into the use of genome editing in farmed animals do you think we ought to take into account in our inquiry?

Question 2: What kinds of innovation does genome editing make possible (or practical) that selective breeding or transgenic modification techniques do not?

Question 3: Are there biological reasons why particular (kinds of) applications in farmed animals are more or less likely to be developed and used than others?

Question 4: Are there any technical constraints or bottlenecks holding up genome editing research in this field?

Question 5: What are the expected timescales within which we might expect to see particular genome editing applications being used on farms?

Section 2: The socioeconomic context

Question 6: What are the societal, production, environmental and policy challenges to which genome editing applications in farmed animals might offer a response?

[918] Nuffield Council on Bioethics (2021) *Call for evidence*, available at: https://www.nuffieldbioethics.org/publications/genome-editing-and-farmed-animals/evidence-gathering.

Question 7: How might genome editing technologies help to address these challenges, and what practical benefits and drawbacks would genome editing applications have over existing or envisaged alternative approaches?

Question 8: What groups or organisations are likely to benefit most from the use of genome editing in farmed animals and what groups or organisations might be disadvantaged?

Question 9: What do you think are the broader social, economic and political drivers that will facilitate, impede or otherwise shape the development and use of genome editing applications in farmed animals, and what effect do you think these will have?

Question 10: How might differing regional social, economic and political drivers influence the likely development and adoption of genome editing applications in the UK, the EU and the rest of the world?

Question 11: What effect do you think public attitudes will have on innovation in this field (in the UK, the EU and internationally) and how should researchers and policy makers take account of these?

Section 3: Ethics

Question 12: Are there any categorical ethical objections to genome editing farmed animals and if so on what grounds are they based?

Question 13: What, if any, are the ethical differences between using genome editing and deliberately altering an animal's physiology in other ways, for example, by using hormones, surgical procedures or drugs?

Question 14: What, if any, are the ethical differences between using genome editing and using alternative methods such as traditional selective breeding methods, or marker assisted selection to alter the characteristics of a breed of farmed animals?

Question 15: What, if any, are the ethical differences between using genome editing, which relies on the cell's own repair mechanisms, and using genetic modification techniques that insert transgenes into organisms?

Question 16: Are some but not other applications of genome editing in farmed animals acceptable and, if so, on what does their acceptability depend (for example, improving animal welfare, meeting objectives of importance for animals or humans, etc.)?

Section 4: Law, regulation and policy

Question 17: Are there reasons to think that genome editing approaches are inherently more likely than alternative approaches to result in adverse outcomes, or to result in outcomes that are potentially more harmful; what are the major risks or uncertainties that regulation should seek to manage?

Question 18: What are the roles of policy and markets in shaping livestock farming practices and what should be the key policy objectives in this area?

Question 19: Do you think that the existing EU regulatory framework for the production and sale of GMOs is appropriate for genome editing applications in farmed animals and, if not, what alternatives might be considered?

Question 20: How might national or regional differences in policy or regulation influence the development and diffusion of genome editing applications in farmed animals internationally?

Section 5: Final

Question 21: Is there any important question that you think we should have asked or an area that we ought to have covered, or any other information that you would like to bring to our attention in order to help us with this inquiry?

List of respondents to the expert call for evidence

Individuals (5)

- Dr Jonathan Birch, Associate Professor of Philosophy, London School of Economics and Political Science
- Ann Bruce
- Stevan Harnad, Editor, *Animal Sentience*; Professor, Cognitive Sciences, Université du Québec à Montréal, McGill University and University of Southampton
- Professor Venugopal Nair OBE, Pirbright Institute, United Kingdom
- Adam J Shriver

Organisations (19)

- American Anti-Vivisection Society
- Beyond GM
- Christian Ethics of Farmed Animal Welfare Research Project, University of Chester
- Compassion in World Farming UK
- Dr Jarrod Bailey, Cruelty Free International
- Friends of the Earth Australia
- Friends of the Earth, U.S
- GE Free NZ (in Food and Environment)
- GeneWatch UK
- GM Freeze
- National Pig Association
- OGM Dangers
- Pig Veterinary Society
- Rare Breeds Survival Trust
- Royal Society of Biology
- RSPCA (Royal Society for the Prevention of Cruelty to Animals)
- Scottish Episcopal Church, Church in Society Committee
- Soil Association
- UK Research and Innovation

Appendix 3: Working group members' biographies

John Dupré (Chair)

John Dupré is Professor of Philosophy of Science and Director of Egenis, the Centre for the Study of Life Sciences (formerly the ESRC Centre for Genomics in Society), at the University of Exeter. He has worked on topics in the philosophy of biology ranging from evolutionary theory and genomics to microbiology and taxonomy. His current research focuses on the implications of seeing biology as fundamentally processual. He is an Honorary Visiting Member of the American Academy of Arts and Sciences, a Fellow of the American Association for the Advancement of Science and current President of the Philosophy of Science Association.

Rebecca Baines

Rebecca Baines is an experienced intellectual property lawyer of 20 years standing with significant expertise in the life sciences field. Rebecca has served as a partner at two leading international law firms specialising in IP disputes. She has acted for a number of global pharmaceutical companies in cross-border patent disputes. Rebecca is currently Senior Intellectual Property Counsel for international IP matters at Stryker, one of the world's leading medical technology companies. Throughout her career, Rebecca has been a regular contributor to discussions on IP issues at international life sciences conferences and in industry publications.

Elizabeth Cripps

Elizabeth Cripps is a Senior Lecturer in Political Theory at the University of Edinburgh and Associate Director of CRITIQUE: Centre for Ethics and Critical Thought. Elizabeth has published widely on climate ethics and justice, collective responsibility, and individual moral duties. She is the author of *Climate Change and the Moral Agent* and *What Climate Justice Means and Why We Should Care*. She has a degree in Philosophy, Politics and Economics (University of Oxford) and a PhD in Philosophy (University College London). Elizabeth is a former British Academy Postdoctoral Fellow, a member of the Editorial Advisory Board for *Environmental Ethics,* and a former Consultant Editor of the *British Journal of Politics and International Relations*. She has a background in journalism, working for the Financial Times group and freelancing for the Guardian.

Helen Ferrier

Helen Ferrier is Chief Science and Regulatory Affairs Adviser at the National Farmers' Union, leading the NFU's policy and advocacy work on agricultural and horticultural science and research, biotechnology, data, and food safety. Helen is a non-executive Director of the NIAB Board, chair of the Agrimetrics Advisory Board and is a member of many other groups and panels in the agrifood and research community. Before joining the NFU in 2004, Helen was a research scientist at Imperial College London, working on probabilistic modelling of dietary exposure to pesticides. She has an academic background in environment and human health, epidemiology and environmental science.

Rob Fraser

Rob Fraser is Emeritus Professor of Agricultural Economics at the University of Kent. Prior to this he was Professor of Agricultural and Resource Economics at the University of Western

Australia, and Professor of Agricultural Economics at Imperial College London. He has an international research reputation as a policy economist, specialising in both agri-environmental and invasive species policy design and evaluation. In this context, since moving to the UK in 2000 he has participated in a range of DEFRA and other funded research projects. He is a Past President of the Agricultural Economics Society (AES) and is both a Past President and a Distinguished Fellow of the Australian Agricultural and Resource Economics Society. He is also a Member of the Editorial Board of the Journal of Agricultural Economics. Since 2012 he has been a Member of DEFRA's Economic Advisory Panel.

Lynn Frewer

Lynn Frewer is chair of Food and Society at Newcastle University, (UK). Previously she was Professor of Food Safety and Consumer Behaviour at Wageningen University, (The Netherlands), and Head of Consumer Science at the Institute of Food Research at Norwich, (UK). Her research interests focus on understanding food systems, understanding and measuring societal and individual responses to risks and benefits associated with food security issues throughout the supply chain, and agri-food governance and associated policy issues. She also has interests in stakeholder and public engagement in the development and implementation of improved food security.

Andy Greenfield

Andy Greenfield is a Programme Leader in Developmental Genetics at the Medical Research Council (MRC) Harwell Institute and chaired its Animal Welfare and Ethical Review Board (AWERB) for 10 years. He was a member of the Nuffield Council on Bioethics (2014-20) and chaired its working group that reported on ethical issues surrounding genome editing in 2016. From 2009 to 2018, he was a member of the Human Fertilisation & Embryology Authority (HFEA) and, in 2014 and 2016, chaired the expert scientific panels that assessed the safety and efficacy of mitochondrial replacement techniques. From 2019-20, he was a member of the National Academies of Science International Commission on Heritable Human Genome Editing. He is currently a member of the UK's Regulatory Horizons Council.

Jasmeet Kaler

Jasmeet Kaler is Professor of Epidemiology and Precision Livestock Informatics at the School of Veterinary Medicine and Science, University of Nottingham. She graduated as vet from India and then completed her postgraduate training and research in the UK before joining Nottingham. Her research on lameness in sheep contributed to the 'best practice' for lameness in sheep in UK and impacted policy (Farm animal welfare council opinion on lameness in sheep). Her research focuses on further improving health, welfare and production of livestock systems (cattle and sheep) in a multidisciplinary setting through: (a) understanding epidemiology of endemic diseases; (b) harnessing use and development of animal behaviour monitoring and utilising various machine learning techniques to predict disease, welfare; and (c) understanding stakeholder decision making in animal health.

Anne Murcott

Anne Murcott is Professorial Research Associate, Food Studies Centre, SOAS, London, Honorary Professor at the University of Nottingham and Professor Emerita London South Bank University. She served as an expert member of the UK Food Standards Agency's (FSA) General Advisory Committee on Science between 2009 and 2016 and has been a member of the Advisory Group of Food and You, the FSA's 'flagship' social survey since its inception. In

2009 she received an honorary doctorate from the University of Uppsala. Her most recent book is *Introducing the sociology of food and eating* (Bloomsbury 2019) and a history of food packaging is in preparation, also to be published by Bloomsbury.

Peter Stevenson

Peter Stevenson is Chief Policy Advisor of Compassion in World Farming and is a qualified solicitor. He received an OBE in 2020 for services to farm animal welfare. He studied economics and law at Trinity College, University of Cambridge. He played a leading role in winning the EU bans on veal crates, battery cages and sow stalls as well as a new status for animals in EU law as sentient beings. Peter has written comprehensive legal analyses of EU legislation on farm animals and of the impact of the WTO rules on animal welfare. Peter is lead author of the FAO study reviewing animal welfare legislation in the beef, pork and poultry industries. He gave the keynote paper on pig welfare at the 2018 Congress in China of the International Pig Veterinary Society.

Bruce Whitelaw

Bruce Whitelaw is Professor of Animal Biotechnology at the University of Edinburgh and a Fellow of the Royal Society of Biology. He has a degree in Virology and PhD in molecular pathology, and has held various positions at The Roslin Institute at the University of Edinburgh, where is currently Interim Director. His research interest focuses on development and application of genetic engineering and reproductive technologies in farmed animal species. He is actively involved in knowledge exchange and the public dialogue associated with these technologies. He is Chairman of the Roslin Innovation Centre and a Director of Roslin Technologies Ltd.

Glossary

Allele: a particular version of a given gene, sometimes known as a variant. Animal cells have two alleles for each gene: one from each parent. If the two alleles are the same, the individual is homozygous for that allele; if the alleles are different, the individual is heterozygous. Alleles may be inherited in a dominant or recessive fashion and different alleles may be associated with different phenotypes (see below).

Amino acid(s): a group of 20 organic molecules that combine to form proteins. Amino acids join together in a chain to form polypeptides. Proteins consist of one or more chains of polypeptides, each of which must fold and assume a specific three-dimensional shape to be functional.

Artificial insemination (AI): a term denoting a procedure in which semen is manually deposited into the uterus of a female. The procedure is typically carried out using a catheter (tube).

Balanced breeding: breeding with the objective of balancing gain in production traits with gains in traits associated with health and welfare, environment and economy.

Base/base pair: the building blocks of deoxyribonucleic acid (DNA) whose order in a genome is synonymous with the DNA sequence of that genome. Animal genomes are composed of double-stranded DNA containing the four bases: adenine (A), guanine (G), cytosine (C) and thymine (T). The two DNA strands are antiparallel, so that As match up (pair) with Ts, and Gs with Cs.

Broiler: a type of chicken used for meat production.

Cell: the fundamental building block of many biological systems. Animals begin development as a single cell (a one-cell embryo or zygote) that divides and expands to give rise to an estimated 300 or so different cell types in a full-grown body that typically contains 10^{13}–10^{14} cells.

Cisgenic: an intervention in which modifications are made to an organism that involve replicating or inserting genome sequences (e.g., functional genes) that are found elsewhere in the same species; cf. transgenic (see below).

Citizen: the difference between ‘citizens’ and ‘members of the public’ is significant in political contexts where entitlement to representation is at stake. From a moral point of view, however, it is the public – i.e., those subject to the rules and institutions of a state rather than those belonging to a political state – that is important. Furthermore, distinctions between publics and the ‘general public’; between subgroups constituted in particular; and between sets of interests and those with an interest in the governance of a political state in general, all need to be made.

Characteristic: feature such as fur colour or meat quality that is determined by a complex interaction between genes (or their products), the environment and chance; the relative contribution of each varies for different characteristics. Also see 'trait' (below).

Chimaeric embryos: embryos containing a mixture of cells from different organisms/species.

Chromosome: segments of genomic DNA packaged with proteins and other accessory molecules. Most cells in human adults have 46 chromosomes that together constitute the nuclear genome of each cell while the number of chromosomes in animal cells ranges greatly from 254 chromosomes in hermit crabs to two in a species of roundworm.

Cloning: the process of generating an organism that is genetically identical to individuals from the same donor cell. Often done using somatic cell nuclear transfer (SCNT, see below).

Clustered regularly interspaced short palindromic repeats (CRISPR)-Cas9: a genome editing system by which an enzyme (that usually cuts DNA) can be precisely directed to a target site in the genome. With CRISPR-Cas9, the enzyme (Cas9) interacts with a guide RNA (gRNA) to direct the Cas9 to the target site in DNA. Cas9 nuclease activity then breaks both strands of the target DNA (to form a double-strand break). Repair of this DNA damage results in genome editing. Some Cas9 derivatives break only one DNA strand ('nickases'), and Cas9 has also been modified so that it lacks nuclease activity altogether ('dead' Cas9, or dCas9) and can be repurposed by fusing it to other enzymes (such as histone deacetylase) to effect site-directed epigenetic modification.

Commensal: characterisation of a long-term biological interaction in which one species gains benefits from the interaction, while the other neither benefits nor is harmed. A ‘commensal’ (noun) is an organism that benefits from the interaction.

Commercial breed developers: companies or subsidiaries whose principal business activity is the genetic development of farmed animal lines. This does not include farmers who use on-farm selective breeding to develop their own herds, flocks, schools, etc.

Consumer: someone who buys/uses items on the market. With a short and uneven history in the English language, the word’s meaning has changed over the last two centuries to a usage notably in economics where, contrasted with producer, it is a technical term. As such, it is implicitly assumed to be value neutral. Currently, however, it is far more widely used as a general shorthand that has acquired meanings extending well beyond technical usage, including specifiable desirable connotations such as ‘rationality’. This has led commentators to argue for alternatives such as the ‘public’ or ‘citizens’ in an effort to evade the ideological and political overtones it can be shown to carry.[919]

Conventional breeding: umbrella term for traditional breeding practices that do not involve direct molecular interventions in the genome (through transgenic or genome editing approaches) of the target organism. In animals this includes selection of variation, the efficient selection of difficult-to-measure traits using molecular genetic markers.

Cryopreservation: the process whereby organelles, cells, or tissues are preserved by cooling to a very low temperature (typically -80°C), often using liquid nitrogen.

Disbudding (in horned animals): the removal of horn buds from a young animal to prevent the growth of horns.

Disembedding: a term coined by the political economist, Karl Polanyi, to describe the detachment of a market from social relations and values.

DNA (deoxyribonucleic acid): the chemical comprising the genetic information in most organisms, including humans and non-human animals. A DNA molecule consists of a long chain of nucleotides.

[919] For further references and fuller discussion; see; Murcott A (2019) *Introducing the sociology of food & eating* (London: Bloomsbury), pp164-6.

Embryo: an entity during the phase of development immediately following fertilisation, up to the formation of a fetus (e.g., taken by some to begin ~11 weeks after fertilisation in humans), or it may refer to any developmental stage before birth or hatching in non-human animals.

Embryology: the discipline of biology concerned with the study of the prenatal stages of development including the formation and development of the embryo and fetus.

Embryonic stem cells (ES cells): cells derived from the inner cell mass of a blastocyst that are cultured *in vitro* and still retain the potential to give rise to every cell type in every organ of the body of an organism. Similar pluripotent stem cells can now also be derived from other early embryonic stages or by reprogramming of somatic cells *in vitro*.

Endonuclease: member of a group of proteins that can cut a strand of DNA or, much more rarely, RNA molecules into two or more shorter chains by breaking down the internal bonds.

Enzyme: a molecule (almost always a protein) that acts as a biological catalyst in living organisms to regulate biochemical processes.

Epigenetic changes: chemical modifications to genomic DNA, or the proteins associated with DNA (chromatin), that change its activity, such as how genes are expressed, without altering its nucleotide sequence. Primary examples include covalent modifications to histones such as acetylation and methylation, and to DNA, such as methylation, but there are many other epigenetic modifications. On a genome-wide scale, these modifications at any moment, in any given cell, define the epigenome. Epigenetic modifications are thought of as being relatively reversible. Also see 'Epigenome' (below).

Epigenome: the set of epigenetic changes associated with a genome; also see epigenetic (above).

Estimated breeding value (EBV): EBVs offer a measure of the genetic potential of an animal for a range of individually recorded traits (e.g., milk volume and composition, live weight, robustness, fertility, longevity, and body condition). The scores for individual animals are based on data relating to those animals and all their known relatives (parents, siblings, and progeny), controlled for effects of the environment (feeding, management, disease, climate, etc.). This gives an estimate of the genetic value of that animal for each trait, presented as an index in relation to the breed average, usually set by breed societies.

Eukaryotic: refers to any single-celled or multicellular organism whose cells are distinguished by a membrane-bound nucleus.

F1: in breeding this refers to the first filial generation of offspring that results from mating of different parental types.

Fertile Crescent: the geographical crescent-shaped region more or less bounded by the rivers Tigris and Euphrates in present day Iraq. It is often called the 'cradle of civilisation' as it is thought to be the home of some of the earliest civilisations.

Food and farming system/systems: the global system (or relatively discrete local systems) that involve non-human animals in the production of commodities for consumption or use by humans or other animals. This is not merely the infrastructure but the economic system, associated social roles and relationships, laws and regulation that shape and are shaped by the system.

Gene: the fundamental unit of inheritance. In humans and non-human animals, genes comprise nucleotide (DNA) sequences that each encode a functional product such as a protein or RNA molecule.

Genetic diversity: the degree of sequence variation in genes (alleles, variants) found within a species or a population. In humans and animals, this is commonly vast.

Genetic gain: the enhancement of a phenotype as a result of selection within a population over several cycles of breeding.

Genome: the complete complement of genetic material (DNA in humans and non-human animals) in an organism or species.

Genome editing: the precise, targeted alteration of a selected DNA sequence in a living cell or organism by modifying, deleting, replacing, or inserting DNA sequences.

Genome sequencing: technique for determining the entire sequence of nucleotides in a genome.

Genomic breeding value (GBV): GBVs offer a measure of the genetic potential of an animal for a range of individually recorded traits (e.g., milk yield, carcass and meat quality, and longevity). GBVs are calculated differently to EBVs, by compiling information on both the animal's measured performance (e.g., growth rate) on farm and any genetic marker that can be measured/detected to produce an indicator, also referred to as a 'SNP key'.

Genotype: the genetic make-up of a cell, an organism, or an individual, usually with reference to a specific characteristic under consideration.

Heritability: Heritability is a concept that describes how much of the observed variation in a trait (phenotype) is due to variation in genetic factors (e.g., as opposed to environmental or other accidental factors or interactions). It is usually expressed as a number between 0 and 1, where 1 describes obligate inheritance.

Heterozygous/heterozygosity: having different alleles of a gene; that is, the sequence of a given region inherited from one parent differs from the sequence of the corresponding region inherited from the other.

Homology directed repair (HDR): a normal cellular process by which a double-strand break in DNA is repaired via a different, matching 'template' DNA molecule. For this to occur, the DNA used in repair must contain DNA sequences that perfectly match sequences (these sequences are said to be 'homologous') on either side of the double-strand break.

Homozygous/homozygosity: possession of identical alleles of a gene; that is, identical sequences from each parent for a given genomic region (*cf.* heterozygous above).

Integrated production: (vertical) integration refers to the same company owning multiple, connected elements of the value chain, for example from breeding through to slaughter and processing.

Intensive farming: there is no standard definition of 'intensive' farming and the term is much contested. In the present report, 'intensive farming' is used to mean farming of livestock that is technologically and organisationally complex. This includes farming that involves high stocking densities (intensive use of land), and the adoption of any number of technologies (including breeding technologies), thus requiring intensive investment in capital.

Linkage group: refers to genetic loci (often on the same chromosome) that are inherited together as a group.

Liposome: a spherical vesicle made out of the same material as a cell membrane, which can be used to deliver substances to cells in the body.

Mastitis: an infection of the udder or mammary gland caused by various types of bacteria.

Monogenic trait: a characteristic whose inheritance is strongly influenced by one single gene.

Mutation: see ‘Variation’ below.

Non-homologous end joining (NHEJ): a normal cellular process by which a double-strand break in DNA is repaired by joining (ligating) the broken ends together. During NHEJ, the cell causes a template-independent genomic insertion or deletion (‘indel’) to be made at or near the site of the double-strand break. Unlike repair via the HDR pathway, the genomic sequence near a repair effected by NHEJ cannot currently be precisely controlled.

Nuclease: an enzyme which is capable of breaking the bonds between DNA bases and likely to be associated with DNA damage mechanisms.

Nucleotide: see ‘Base’ above.

Nucleus: a membrane-bound organelle found in most cells of eukaryotic organisms that contains most of the cell’s genetic material.

Oestrous cycle: the cyclical pattern of the endocrine and reproductive systems of many female mammals.

Oestrus: the part of the oestrous cycle during which a female mammal is sexually receptive and fertile.

Phenotype: the observable characteristics (structural and functional) of an organism, produced by the interaction of the organism’s genetic information and environment in which it exists.

Plasmid: small circular pieces of DNA that replicate independently from the host cell’s chromosomal DNA. Artificially designed plasmids are used in the laboratory to introduce foreign DNA into a cell.

Pleiotropic/pleiotropy: the condition of having multiple effects: a pleiotropic gene refers to the influence of one gene on many traits.

Polling/polled: (breeding for) hornlessness in horned species.

Polygenic trait/polygenicity: a trait inheritance which is influenced by many genes.

Prime editing: a genome editing technique not requiring a double-strand break to DNA. A Cas9 nickase is used to prime sequence editing by use of an RNA template attached to the guide RNA and a reverse transcriptase (which converts the RNA template to DNA) attached to the Cas9.

Production trait/characteristic: animal characteristics, such as the quantity or quality of milk, meat, fibre, eggs, draught, and other products they (or their progeny) produce, that directly contribute to the value of the animals to the farmer and are identifiable or measurable at the individual level. Production features are often quantitatively inherited, meaning they are impacted by a large number of genes, the expression of which in a given animal also reflects environmental factors.

Profitable lifetime index (PLI): is a within-breed genetic ranking index developed for the UK dairy industry and expressed as a financial value (£PLI). The £PLI indicates the additional profit that a daughter of a high £PLI bull is expected to earn over her lifetime, compared with a daughter sired by an average bull with a £PLI of zero. £PLI is calculated by using numerous traits, such as production, survival, and fertility, each weighted by economic importance. The £PLI is published by the Agriculture and Horticulture Development Board (AHDB) as part of its genetic evaluation service.

Quantitative trait locus (QTL): Quantitative traits are those that vary between individuals along a continuum, such as height and weight, rather than simply being there or not. These traits are often inherited in a polygenic fashion, meaning that sequence variants in a large number of genes (loci) – each with a small effect – influence the trait in question. These are known as quantitative trait loci (QTL). Inheritance of such traits is often complex and also commonly affected by the environment. QTL are often identified in genome-wide association studies (GWAS).

Recombinant DNA technology: techniques used to combine DNA molecules from different organisms and insert them into a host organism to produce new genetic combinations.

RNA (ribonucleic acid): a polymer of the bases A, C, G, and U, where U stands for uracil. RNA has many functions, including transfer of information from genomic DNA to the protein-synthesising machinery of cells.

Selective breeding: a process in which humans control the breeding of animals or plants by choosing and pairing only those individuals that will most likely result in offspring that exhibit or lack particular desired characteristics (traits) in future generations.

Social contract: in political theory, an unwritten agreement made among a population voluntarily to give up some degrees of freedom in exchange for limitation on (and protection from) the exercise of the freedoms of others, in order to enable peaceable coexistence.

Sociotechnical imaginary: collectively held and implemented visions of a desirable future (or resistance to the undesirable), animated by shared understandings of forms of social life and social order that can be achieved and supported by advances in science and technology. Often used to justify state investment in science and technology; in turn, advances in science and technology reaffirm the state's capacity to act as responsible stewards of the public good. Sociotechnical imaginaries serve in this respect both as the ends of policy and as instruments of legitimation.

Somatic cell: a cell of the body of a living organism that is not a reproductive or 'germ' cell.

Somatic cell nuclear transfer (SCNT): a technique in which a nucleus of a somatic cell (a cell of the body that is not a reproductive or 'germ' cell) is transferred directly to the cytoplasm of an egg cell from which the original chromosomes (nuclear DNA) have been removed.

Supply chain: the pathway from point of production to point of sale to the to the final buyer: also see 'value chain' (below).

Trait: ostensible characteristics or attributes. In the context of 'genetic trait', this means a trait that is correlated with underlying genetic factors. This can be 'recessive' or 'dominant' in the case of monogenic traits.

Transcription activator-like effector nuclease (TALEN): an alternative form of genome editing, which preceded CRISPR/Cas9, in which an endonuclease is directed to a DNA target site through interaction between the target sequence and a series of DNA-binding protein motifs attached to the nuclease. TALENs have been widely used in research but are being superseded by the CRISPR-Cas9 system, which is generally considered to be easier and quicker to use, cheaper, and considerably more efficient.

Transcription factors: proteins which bind directly or indirectly to DNA and play a role in the regulation of transcription of DNA into RNA.

Transgene/transgenic: refer to an intervention (usually performed in a single-cell embryo) in which modifications are made to the genome of an organism that involve inserting DNA sequences (e.g., functional genes) that are found in a distinct species; *cf.* cisgenic (see above)

Transgenic organism: an organism containing a sequence of DNA from another organism (a transgene), usually one that has been inserted using recombinant DNA technology. CRISPR/Cas9 genome editing can also be used to generate transgenic organisms, in which the genomic location of the transgene is under strict control, rather than through random insertion.

Ungulate: refers to a hoofed animal.

Value chain: the manner in which an enterprise alters raw materials to 'add value' via production/manufacturing processes to create finished products or services which can command a higher price than had the alterations not been effected.

Variant: sequence of a part of the genome that differs from its counterpart in other genomes, usually genomes that have a commonly encountered sequence at that position.

Viral vectors: tools commonly used to deliver genetic material into cells.

Xenotransplantation: any procedure which involves the transplantation or insertion of cells, tissues, or organs from one species to another species. This also includes the implantation of cells performed outside the body ('*ex vivo* perfusion').

Zinc finger nuclease (ZFN): an original form of genome editing, in which an endonuclease can be modified to introduce double-strand breaks at a specific DNA target site through use of an associated set of DNA-binding protein motifs (zinc fingers). ZFNs typically comprise three or four zinc finger motifs derived from mammalian transcription factors. Like TALENs, ZFNs are being superseded by the CRISPR-Cas9 system, which is generally considered to be easier and quicker to use, cheaper, and considerably more efficient.

Zygote: one-cell embryo produced by the union of sperm and egg (the gametes) at fertilisation. Zygotes are totipotent, in that through successive divisions they can give rise to an entire individual and all of the extraembryonic cell lineages required for its development *in utero.*

List of abbreviations

* denotes a corresponding entry in the Glossary.

AHDB	Agriculture and Horticulture Development Board
AI	Artificial insemination*
AMR	Antimicrobial resistance
APHA	Animal and Plant Health Agency
ASPA	Animals (Scientific Procedures) Act 1986
ASF	African swine fever
ASRU	Animals in Science Regulation Unit
AWA	Animal Welfare Act 2006
AWERB	Animal Welfare and Ethical Review Body
CRISPR	Clustered regularly interspaced short palindromic repeats*
Defra	Department for Environment, Food and Rural Affairs
DNA	Deoxyribonucleic acid*
EBV	Estimated breeding value*
EFFAB	European Forum of Farm Animal Breeders
ES	Embryonic stem*
EU	European Union
FAWC	Farm Animal Welfare Council (subsequently Farm Animal Welfare Committee)
FDA	The United States Food and Drug Administration
GBV	Genomic breeding value
GFP	Green fluorescent protein
GMO	Genetically modified organism
HDR	Homology-directed repair
LIS	Livestock Information Service
NHEJ	Non-homologous end joining*
PCR	Polymerase chain reaction

PLI	Profitable Lifetime Index*
PRRS	Porcine respiratory and reproductive syndrome
QTL	Quantitative trait locus*
RFID	Radio-frequency identification
RNA	Ribonucleic acid
RSPCA	Royal Society for the Prevention of Cruelty to Animals
RSB	Royal Society of Biology
SCNT	Somatic cell nuclear transfer*
TALEN	Transcription activator-like effector nuclease*
UK	United Kingdom
US	United States of America
ZFN	Zinc finger nuclease*

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