Scientific, Ethical, and Economic Aspects of Farm Animal Welfare

CAST

Council for Agricultural Science and Technology
4420 West Lincoln Way, Ames, IA 50014-3447, USA
Phone: (515) 292-2125
Email: cast@cast-science.org
Web: www.cast-science.org

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Task Force

Candace Croney, Cochair, Department of Comparative Pathobiology/Department of Animal Sciences, Purdue University, West Lafayette, Indiana

Joy Mench, Cochair, Department of Animal Science, University of California–Davis

William Muir, Cochair, Department of Animal Sciences, Purdue University, West Lafayette, Indiana

Raymond Anthony, Department of Philosophy, University of Alaska Anchorage

Gail Golab, Animal Welfare Division, American Veterinary Medical Association, Schaumburg, Illinois

Charles Hofacre, Department of Population Health, University of Georgia, Athens

Michael Hulet, Department of Animal Science, Pennsylvania State University, University Park

Anna K. Johnson, Department of Animal Science, Iowa State University, Ames

Jayson L. Lusk, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana

Nicole Olynk Widmar, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana

Allan P. Schinckel, Department of Animal Sciences, Purdue University, West Lafayette, Indiana

Jan Shearer, Department of Veterinary Diagnostic and Production Animal Medicine, Iowa State University, Ames

Janice Swanson, Department of Animal Science, Michigan State University, East Lansing

Yvonne Vizzier Thaxton, Center for Food Animal Wellbeing, University of Arkansas, Fayetteville

Gary Varner, Department of Philosophy and Humanities, Texas A&M University, College Station

Task Force Contributor

Susanne Hermesch, Animal Genetics and Breeding Unit, University of New England, Armidale, Australia

Task Force Reviewers

Mary M. Beck, Department of Poultry Science, Mississippi State University, Mississippi State

Michael Engler, Cactus Feeders, Amarillo, Texas

Arlene Garcia-Marquez, Department of Animal and Food Sciences, Texas Tech University, Lubbock

Paul Siegel, Department of Animal and Poultry Sciences, Virginia Tech, Blacksburg

Jason Watters, San Francisco Zoological Society and Department of Animal Science, University of California, Davis

CAST Liaison

Robert Evans, Elanco Animal Health, Harrisonburg, Virginia

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Foreword

Recognizing the need for an update to CAST's 1997 landmark report on the well-being of agricultural animals, the CAST Board of Directors authorized preparation of a new report on the scientific, ethical, and economic aspects of farm animal welfare.

Three eminent scientists agreed to share the role of cochair: Dr. Candace Croney, Department of Animal Sciences, Purdue University, West Lafayette, Indiana; Dr. Joy Mench, Department of Animal Science, University of California–Davis; and Dr. William Muir, Department of Animal Sciences, Purdue University, West Lafayette, Indiana. A highly qualified group of scientists served as task force members. The group included individuals with expertise in agricultural economics, animal behavior, animal genetics, animal science, animal welfare science, animal well-being, philosophy, population health, poultry science, and veterinary medicine.

The task force prepared an initial draft of the report and reviewed and revised all subsequent drafts. A member of the CAST Board of Representatives served as the project liaison. The CAST Board of Directors reviewed the final draft, and the authors reviewed the proofs. The CAST staff provided editorial and structural suggestions and published the report. The task force authors are responsible for the report's scientific content.

On behalf of CAST, we thank the cochairs and task force members who gave of their time and expertise to prepare this report as a contribution by the scientific community to public understanding of the issue. We also thank the employers of the scientists, who made the time of these individuals available at no cost to CAST. The members of CAST deserve special recognition because the unrestricted contributions they have made in support of CAST also have financed the preparation and publication of this report.

This report is being distributed widely; recipients include Members of Congress, the White House, the U.S. Department of Agriculture, the Congressional Research Service, the Food and Drug Administration, the Environmental Protection Agency, and the U.S. Agency for International Development. Additional recipients include media personnel and institutional members of CAST. The report may be reproduced in its entirety without permission. If copied in any manner, credit to the authors and to CAST would be appreciated.

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Kent Schescke
Executive Vice President

Melissa Sly
Director of Council Operations

Interpretive Summary

Since the publication of the 1997 CAST task force report on the well-being of agricultural animals, myriad discoveries and improvements have been made in the respective areas of science involved in research on animal welfare. In 1997, six high-priority research areas needed for scientific advancement were identified. These were: "(1) bioethics and conflict resolution, (2) responses of individual animals to the production environment, (3) stress, (4) social behavior and space requirements, (5) cognition, and (6) alternative production practices and systems" (CAST 1997). In the interim between the 1997 publication and the current report, the priorities, state of the science, challenges, and approaches to addressing agricultural animal welfare have evolved considerably. First, the title change from animal well-being (the term more commonly used in the United States) to animal welfare is in keeping with growing global consensus on scientific terminology and definitions. Setting the stage here is the now widely accepted World Organisation for Animal Health (OIE) definition of animal welfare, which clarifies that welfare is a property of the individual animal, and refers to the animal's state as scientifically assessed by examining its health, comfort, nutritional status, safety, behavior, and experience of mental states such as pain, fear, and distress (OIE 2008).

Increased collaboration has occurred between scientists and philosophers to address agricultural bioethics in an effort to facilitate conflict resolution. A Multistate Research Coordinating Committee and Information Exchange Group (NCCC 209) on Agricultural Bioethics, consisting of philosophers and scientists with expertise in various agricultural domains was developed and operated between the late 1990s and 2014 (Reynnells 2004). In addition to coordinating annual symposia at the annual conference of the American Society for Animal Science, the multidisciplinary team produced a U.S. Department of Agriculture–National Institute of Food and Agriculture-funded grant proposal to create a standardized curriculum on agricultural animal bioethics. Further, there has been a notable increase in the number of agricultural and animal scientist-led publications exploring the bioethical implications of contemporary animal agriculture (Croney et al. 2012).

Since the last CAST task force report on agricultural animal well-being, there has also been a steadily increasing emphasis on regulation of animal welfare in the United States. This is occurring via the establishment of voluntary standards like industry or retailer standards, and also involuntary standards, particularly regulation at the state level. This has created a patchwork of animal welfare standards that can limit market opportunities for particular producers. As discussed in sections 3 and 4, these factors make it imperative to better understand how animal welfare considerations affect the purchasing patterns of consumers and their behavior as voters. In addition, they highlight the need to develop uniform and transparent processes for establishing animal welfare standards.

From a scientific perspective, animal welfare has advanced far beyond initial focuses on characterizing and measuring stress responses in an effort to identify and lessen the negative effects of stressors on agricultural animals. For example, ongoing scientific investigations have yielded much more nuanced evaluations of distress and its scientific correlates as outlined in section 5. Additionally, scientific thinking has evolved to include the notion that good welfare outcomes for agricultural animals not only depend on minimizing negative states, such as distress, but also ensuring that animals experience positive states as well. Consequently, new, diverse metrics of welfare continue to be explored. Progress has been made in preference testing to explore animals' relative preferences and their strengths for various aspects of their environments and to ascertain the importance to animals of being allowed to demonstrate key behaviors in production environments (Fraser and Nicol 2011). Development of metrics of pain in agricultural animals and methods to identify and alleviate it (Coetzee et al. 2012) have been some of the most significant areas of animal welfare advancement since 1997. In addition, technological advancements such as computer imaging and sensor technologies have made it possible to noninvasively measure welfare (Mench 2018). This would permit refined assessment of animal comfort, including use of space and movement that is potentially indicative of injury or chronic welfare-reducing conditions such as lameness. Additionally, the study of cognition in agricultural animals has led to the discovery of novel methods by which to assess cognitive bias (Harding, Paul, and Mendl 2004) as an indirect measurement of animals' emotional states.

As demand for food of animal origins increases, the impetus to address agricultural animal welfare correspondingly grows. A major emerging challenge is how to meet such animal protein demands while simultaneously protecting animal welfare and developing broadly sustainable production systems. To that end, new research priorities for agricultural animal welfare (expanded upon in section 7) include

engineering of animal housing and production practices that better accommodate species-typical behaviors, along with improved understanding of the implications of globalization, antimicrobial resistance, and urban farming. Further multidisciplinary studies are needed that build on existing epidemiological, cognitive, and functional genomics approaches to understanding and addressing contemporary agricultural animal welfare challenges.

Executive Summary

It is well established that animal welfare is multifaceted and involves considering not only the biology and psychology of the animals, but also people's ethical concerns. Scientific information is essential for determining which housing and husbandry factors pose risks to animal welfare and how those risks can be managed; however, only applied ethics can help to elucidate what levels of risk the various stakeholders of animal agriculture find acceptable.

There are many conflicting values and norms in our society related to the use of animals, leading to increasing disagreement about what constitutes a "good life" for the animals in our care. Broadly speaking, applied ethicists have discussed two different approaches to this topic—one focuses on the consequences of using animals in particular ways, and the other on the morality of that use, regardless of the consequences. These two positions are reflected in the "animal welfare" and "animal rights" views, respectively. Another ethical perspective is that animals are owed a good standard of care because of the benefits we derive from them. Nevertheless, understanding both the science and the ethics of animal welfare is critical to understanding and reconciling differing perspectives about animal care and use.

As public concern about animal welfare increases, scientists continue to develop and refine methodologies to address questions about animals' quality of life. The scientific study of animal welfare is of necessity multidisciplinary, and it involves consideration of animals' behavior, health, and physiology. In essence, thoroughly evaluating animal welfare involves a complete assessment of animals' mental and physical health.

Although research is still needed on basic aspects of welfare assessment, there are also emerging metrics and methods that will further improve our ability to detect and remedy welfare problems. These include genetic approaches to understanding animals' ability to adapt to different housing and management systems; functional genomic approaches to help understand how the animal reacts to its environment; epidemiological measures to determine the incidences of welfare problems on commercial farms and the "real world" factors affecting those incidences; and automated, noninvasive tools that can allow animals' behavior, health, and physiology to be assessed rapidly and in large-scale commercial settings.

Much work remains to be done relative to thoroughly exploring the economics of animal welfare, although this field is growing. Whereas some have argued that animal welfare and profitability go hand in hand, there are various examples demonstrating that profit-maximizing outcomes for producers are not necessarily the same as animal welfare-maximizing outcomes.

The preferences and values of consumers of animal products are not uniform; therefore, there is no single animal welfare "standard" that will satisfy everyone. In addition, consumer purchases are influenced by other factors—not just animal welfare.

Evidence also indicates that there is a disconnect between shopping and voting outcomes, with consumers willing to vote to change animal production practices of which they disapprove even though they are not always willing to voluntarily pay for those changes in the marketplace.

Because animal welfare is an important social issue, it has costs not only to consumers of animal products, but to all individuals who are concerned about the treatment of animals regardless of whether or not they participate in the market for animal products. This is an important consideration when developing policies to deal with animal welfare issues, and a number of frameworks to address this consideration have been proposed, including via meat taxes, regulation, labeling, and corporate social responsibility programs.

Significant advances have been made in theoretical and applied aspects of animal welfare science. Much of the progress that has occurred has resulted from strategic targeting and funding of animal welfare research by the European Union. In comparison, the United States lags behind Europe and Canada relative to attaining the critical mass of researchers and dedicated funding needed to advance U.S. animal agriculture and to better incorporate animal welfare into sustainable production and management systems. Establishment of key research priorities is imperative, along with new approaches to systematically tackle emerging topics such as animal cognition and the genetics and genomics of animal welfare and to grow U.S. capacity in agricultural animal welfare science.

Because the study of animal welfare is by its nature multidisciplinary, information about animal behavior, health, and physiology must be integrated with animal breeding, housing, and management. In addition, related social science research addressing the political, ethical, and economic aspects of animal and food production is needed to ensure the sustainability of approaches.

Scientific inquiry is a central ingredient in promoting good policies and governance initiatives, but not all decisions

about animal welfare or animal agricultural policies are about science. Coordinated multidisciplinary approaches based on good governance are needed to ensure that all stakeholders' interests are broadly reflected in policy formation. In addition, innovative approaches are needed to improve transparency, communication, and public participation in developing research priorities, translating science to the public domain, and crafting policies and practices pertaining to animal welfare, agriculture, and food production.

In order to advance public understanding and broad application of animal welfare science, effective, coordinated communication efforts tailored to meet the needs of specific audiences are essential and should be designed in concert with ongoing research initiatives. Consumers and other members of the lay public, scientists, animal industry sector members, and policymakers require ready access to current agricultural animal welfare information to inform decision-making. In addition to translating scientific knowledge, communications should incorporate economic, social, and ethical implications of new discoveries or applications of animal welfare science. Cooperative extension can play a valuable role in better relaying knowledge about animal welfare. Prioritization of need in this area and significant investment in funding dedicated to building capacity, however, are essential to achieve this goal.

1 Introduction

Large-scale, intensive systems of agricultural animal production predominate animal agriculture in the United States. These systems continue to generate concerns and public debates about the treatment of farm animals. Animal welfare increasingly is linked to conceptions of sustainability (Broom 2010; Verdurme and Viaene 2003) and social responsibility of food production systems, and it is now used by many consumers as an indicator of food safety and quality (Harper and Makatouni 2002). The emergence of these patterns can be traced back to several factors that are well detailed (Rollin 2004). These include seminal publications detailing the treatment of agricultural animals (Harrison 2013); broad dissemination of various philosophical concepts of animal rights and welfare; the shift away from direct public involvement in animal agriculture; and the development of technological advances that have resulted in contentious discussions of animal care and husbandry practices, such as continuous, close confinement housing of farm animals.

What was proposed by Rollin in 2004 as a "new social ethic for animals" appears to be manifesting today in the emergence of multiple global and national policies positioning animal welfare as an important priority. Various European nations individually and collectively via the European Union have now passed legislation governing agricultural animal welfare (European Commission n.d.) that clearly specifies which animal care and husbandry practices may be used. Consistent with scientific advances in animal welfare science, in 2009 the Lisbon Treaty reiterated expectations for the protection and welfare of farm animals by formally acknowledging animals as "sentient beings." Evolving global concern for animal welfare as a key priority is also reflected in the World Organisation for Animal Health (OIE) Guidelines (OIE 2014) and in various codes of practice developed in countries such as Canada and Australia.

In contrast, the United States has historically had minimal agricultural animal welfare legislation beyond the 28 Hour Law and the Humane Methods of Slaughter Act, which, respectively, mandate humane conditions for transportation of livestock entering the food chain and rendering them insensible prior to killing.

The early 2000s, however, ushered in a new era of proposed legislative efforts primarily via state ballot referenda to fill in perceived gaps in agricultural animal protection. Related efforts to create support for such legislation has heightened public awareness and scrutiny of intensive animal production. The primary focus of most of the legislative proposals has been to indict established intensive production practices—such as the use of battery cages for laying hens, gestation crates for sows, and individual stalls for veal calves, the latter issue having been a source of social contention for almost two decades.

These developments have created significant pressure for the livestock and poultry industries to move toward alternative practices that emphasize group housing and greater consideration of animals' behavioral needs. In addition, practices such as nontherapeutic uses of antibiotics, the use of growth promotants, the quality of handling and transport experienced by farm animals, and animal pain have also become hot-button issues for U.S. animal production.

Collectively, these factors have culminated in the emergence of a movement toward "ethical consumerism" (Croney and Anthony 2014; Singer and Mason 2006), wherein opposition to large-scale conventional animal agriculture is expressed by some consumer segments specifically seeking out foods with specialty labels such as "organic," "locally produced," "natural," "humane," and "cage free." An unfortunate consequence, however, is increased tension between those using well-established, conventional farming practices and those promoting alternatives based on more recent studies that require practices whose impacts are not yet fully understood.

Accordingly, there is an urgent need to evaluate the implications of alternative housing and production practices on the welfare of agricultural animals. In addition, it is imperative to understand which systems and practices may optimize economic efficiencies in conjunction with ensuring positive animal welfare outcomes and public support of animal agriculture.

The purpose of this report is therefore (1) to provide an overview of current issues in animal welfare and insight into the origins of current concerns; (2) to outline the major scientific advances that have occurred in animal welfare science since the publication of the 1997 CAST Task Force Report on the welfare of agricultural animals (CAST 1997); and (3) to identify outstanding challenges and priority areas for future research, coordination, and outreach relative to agricultural animal welfare.

2 Roles of Science and Ethics in Evaluating, Understanding, and Improving Animal Welfare

Introduction

Animal welfare is multifaceted and involves consideration not only of animals' biological and psychological capacity to adjust to their living conditions, but also of human factors such as customs, norms, and values. A common response to the socio-ethical concerns being raised about contemporary animal agriculture, including concerns about animal welfare, is that "policies must be based on science." Such statements imply that science is rational, objective, and value free, whereas ethical considerations are "emotional" and perhaps meritless (Croney and Anthony 2010). Decisions about animal welfare or any of the other contentious issues facing animal agriculture, however, cannot be made on the basis of science alone (Fraser 2000; Lackey 2007; Tannenbaum 1991; Thompson 1993). The strength of scientific assessment is that it provides the information that is essential for determining the "risks" associated with particular practices (e.g., the health risks to humans and animals of using, or not using, antibiotics for animal production). The limitation of science is that it cannot decide what level of risk is acceptable to the various stakeholders that are impacted (Swanson 2003), because that decision is based on values. Thus, questions about how we should treat animals fall outside the purview of pure science and into the realm of applied ethics (Croney and Anthony 2010).

Because animal welfare is such a complex concept, it has proven difficult in the past to arrive at a consensus definition that provides a framework for scientific and ethical analysis. Many definitions have been proposed, but they are often either based mainly on terms that are also poorly defined (like stress) or are too narrow (like health) to encompass all aspects of welfare. The OIE has adopted the following definition: "Animal welfare is how an animal copes with the conditions in which it lives. An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well nourished, safe, able to express innate behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress. Good animal welfare requires disease prevention and appropriate veterinary treatment, shelter, management and nutrition, humane handling and humane euthanasia or humane slaughter. Animal welfare refers to the state of the animal; the treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane treatment" (OIE 2015).

It is notable that this definition was approved by all of the 178 OIE member countries and territories. The OIE is the World Trade Organisation reference organization for standard setting for animal health. It seems likely that this definition (or a similar one—given that the OIE is currently in the process of making some revisions to this definition) will be widely adopted as the basis for guidelines and legislation globally, as well as for global trade agreements for agricultural animal products. The OIE definition contains many of the elements of previously proposed definitions. It makes two key points that can help direct scientific and public policy efforts: (1) animal welfare is a property of the individual animal and has several dimensions; and (2) animal welfare is affected by, but not the same as, the attitudes and behaviors of humans toward animals.

Role of Science

As the OIE definition implies, science plays a critical role in obtaining information about animal welfare as it relates to animals' health, physical and physiological functioning, behavior, and subjective states, as well as in determining how to apply that understanding to improvements in housing, management, handling, and euthanasia. There have been several attempts to operationalize definitions of animal welfare into more concrete principles in order to provide a more specific scientific framework for such animal welfare assessment and improvement. The earliest example is the now well-known "Five Freedoms" (FAWC n.d.), which is used as the basis for several animal welfare food certification programs in Europe and the United States. These were recently elaborated to form the Twelve Criteria of the European Union Welfare Quality Assurance program (WQA) (Keeling et al. 2013). The OIE has also developed a set of General Principles (Fraser et al. 2013) that provide even more specificity.

All of these frameworks do have an ethical basis in that they assume there is consensus that animals have certain basic needs. They also go beyond general ethical statements, however, and provide guidance about how those needs should be met. For example, the Five Freedoms state that animals should be free "to express normal behavior by providing sufficient space, proper facilities and company of the animal's own kind." The WQA (Keeling et al. 2013) elaborates on this by stating that animals should be able to express "normal, non-harmful social behaviours" and "species-specific natural behaviours such as foraging," whereas the

OIE General Principles (Fraser et al. 2013) also highlight the importance of providing an environment that allows animals to use natural (including behavioral) methods of thermoregulation, display natural behaviors that they are motivated to perform, and make normal postural changes—an environment that also facilitates positive social behaviors while minimizing negative ones. Solid scientific information is required to address these principles and concerns in a way that actually benefits the animals.

Animal welfare science is now a well-developed field of inquiry, and there is abundant multidisciplinary literature on various aspects of behavior, health, physiology, nutrition, neurobiology, and genetics relevant to animal welfare (see, for example, Appleby et al. 2011; Grandin 2015). Much of this research has been conducted in Europe, although there has also been considerable recent research effort in North America and Australasia. Fraser and colleagues (2013) provide many examples of how this body of science forms the underpinnings for the OIE General Principles. This scientific research has led to advances not only in our understanding of the basic biology of animal welfare, but also in ways to improve animal welfare via changes in housing, husbandry, transport, and slaughter. Social sciences also have an important role to play—e.g., in determining how the attitudes of animal caretakers and managers affect their behaviors toward animals and how those behaviors in turn impact the welfare of the animals (Hemsworth and Coleman 2011).

Role of Ethics

The ability to apply scientific findings about farm animal welfare may be constrained when there are conflicting values and norms related to animal use and treatment among the various stakeholders. "Animal ethics" is the subdiscipline of philosophy that seeks to determine what norms should govern our treatment of animals in various contexts. Prominent questions include the following:

- Do animals have moral standing in their own right? If so, what is the basis (or bases) of this and what ethical duties should follow?
- Is it permissible to change the natures of animals through modern biotechnologies, and when is it defensible to take the life of an animal?
- Do we have obligations to individual animals or to populations of animals and species?
- How should we balance our duties to animals relative to other duties we have (e.g., to future generations of humans and the health of the planet)?

Broadly speaking, philosophers have advocated two different approaches to making decisions about what is right or wrong when considering animal ethics. *Consequentialists*[1] think that the morality of an action or a practice depends on its consequences. Different versions of consequentialism can consider a variety of consequences, but the best-known version, *utilitarianism*, takes into account the happiness of all affected human beings and any animals that are capable of being happy. *Nonconsequentialists* think that the morality of an action or a practice depends on something other than its consequences. One prominent nonconsequentialist view is respect for individuals. In contrast to utilitarians (and consequentialists generally), such views emphasize that there are certain limits on what can be done to an individual. These limits are commonly described in terms of rights.

The basic division between consequentialist and nonconsequentialist thinking in ethics is reflected in the contemporary debate over animal welfare versus animal rights. Self-described animal welfarists tend to use consequentialist arguments (e.g., that the benefits of animal research to both humans and animals outweigh the harms to animals used in research), whereas self-described animal rightists tend to give rights-based arguments (e.g., that there are limits to what can be done to a sentient individual without that individual's consent, even if the consequences would be very good on balance).

An alternative to the consequentialist and respect for individuals approaches that some animal ethicists have taken is *contractarianism,* which some use to argue that animals are owed good husbandry in a tacit "bargain" in return for the good they do humanity. Such an approach may correspond to relational views in ethics such as the ethics of care approach (Midgley 1983). Under this view, human responsibilities toward animals are a function of the relationships or community formed with them. The greater the sense of community with certain animals (e.g., companion versus agricultural animals), the greater should be the sense of responsibility. This view encourages the development of moral virtues in humans—e.g., empathy and general dispositions related to nurturing and caring. In contrast, *biocentric* views contend that species have value in themselves and, therefore, should be protected (both from extinction and from some kinds of tampering with their genetic integrity). According to Rolston (1989), moral concern about animals need not be based around the suffering, rights, or welfare of particular individuals; it is often expressed about the extinction of species. Animals' value lies in the fact that they are members of a valued species, irrespective of their individual capacities.

Given these differing perspectives about how to think about the morality of actions involving animal use, it is not surprising that ethical questions involving "What is a good animal life?" and "What is an acceptable baseline standard for the quality of life of animals?" (Sandøe, Christiansen, and Appleby 2003) have gained currency in contemporary social consciousness. These questions reflect the increasing

[1]Italicized terms (except genus/species names and published material titles) are defined in the Glossary.

tension between the responsible use of animals for human purposes and the recognition that animals are sentient beings with capacities for pain and suffering (Anon. 1997; European Commission n.d.), and that there is thus a need to "pay full attention to the welfare requirements of animals" (European Commission n.d.).

But how should humans treat animals according to their capacities and needs, and with respect? Since such philosophical questions are central to the debate regarding animal welfare policy, it is important to understand the nature of the related philosophical disagreements, based on different values, in order to be taken seriously by people who hold different views. Understanding the philosophical literature on animal ethics can help professionals who deal with animals make critical assessments regarding the different points of view that their colleagues, members of the public, or industry actors may hold and offer measured, reasoned responses to those views. As Fraser and Preece (2004) note, commenting on the important synergy between science and ethics, "progress in animal [welfare] ethics requires both philosophically informed science to provide an empirically grounded understanding of animals, and scientifically informed philosophy to explore the ethical implications that follow."

3 Economics and Markets for Animal Welfare

Introduction

The economics of animal welfare remains a relatively nascent area of academic research; however, the field is growing (Lusk and Norwood 2011). Economic work is varied, and has focused, for example, on the costs of producing animals and animal food products in alternative systems (Chang, Lusk, and Norwood 2010; Seibert and Norwood 2011; Sumner et al. 2008), costs and benefits of policies (Allender and Richards 2010; Sumner et al. 2010), and consumer demand and willingness to pay (WTP) for improved animal welfare (Lagerkvist and Hess 2011).

There is a view in which profitability and animal welfare go hand in hand. The underlying logic is that farm animals receiving better care will be more productive, and as a result will be more profitable. Curtis (2007), for example, argued that animal performance is the best indicator of farm animal welfare. Although animal welfare and productivity can be correlated, it is typically the case that the stocking density that maximizes welfare will not equate with the stocking density that maximizes profit (see Lusk and Norwood [2011]). The result stems from the more general economic principle that the level of input usage that maximizes production or yield is not the same as the level of input usage that maximizes profits.

Citizen vs. Consumer Impacts on Markets for Animal Welfare

Additional research on the economics of animal welfare is needed to understand the extent to which rising prices resulting from the higher costs of new animal production systems will curb consumer purchases of livestock products. Of particular interest is the effect of food price increases on various segments of society.

One of the conundrums that arises in analyzing market outcomes for animal products is the so-called citizen vs. consumer conflict. The conflict is well illustrated in the case of Proposition 2 in California (Prevention of Farm Animal Cruelty Act) (California Health and Safety Code 2008). The proposition, which essentially outlawed "battery" cages for chickens in the state, passed with 63% of the vote. Fewer than 10% of eggs purchased in the state, however, come from cage-free systems (Allender and Richards 2010; Lusk 2010). Apparently, people are willing to vote for policies that ban practices that they are not willing to pay for in the marketplace. Such outcomes have been interpreted by some as an "unfunded mandate" on producers, which forces them to adopt practices for which they are unlikely to be compensated despite increases in demand and which also have the potential to affect some low-income consumers disproportionately.

The precise reason for the divergence in shopping and voting outcomes is not well understood, but a number of hypotheses have been advanced. Some examples are the following: (1) Consumers adopt a "citizen" mindset in the voting booth, paying more attention to public good aspects when voting than when in the "consumer" mindset in the grocery store. (2) A consumer's purchase only affects—at most—one animal, but a consumer's vote potentially affects many more animals. (3) Not all shoppers vote, and as a result, the characteristics of voters may diverge from the characteristics of nonvoters (if the population of voters is, for example, better educated or higher income than is the population of shoppers, the desires of voters can diverge from those of shoppers). (4) Consumers (incorrectly) believe the products they buy in the grocery store are already in compliance with proposed animal welfare laws up for vote. (5) Because the likelihood of an individual's vote being decisive is virtually nil, the cost of "expressive" voting is small.

Tastes, preferences, and values are heterogeneous. Thus, there is no single answer as to what welfare standards will meet the demands of all interested parties at any point in time. Consumer food purchasing decisions are influenced by a multitude of factors, including—but not limited to—age, household size, income, education, and information. For example, McKendree, Croney, and Widmar (2014) found that individuals reporting higher levels of concern about animal welfare were more frequently female, younger, and Democrats than those with lower levels of animal welfare concern. In addition, consumers from the midwestern region of the United States were significantly less concerned about animal welfare and more likely to have a source of information on animal welfare than those from other regions of the country. Improved understanding of consumer heterogeneity may help recognize distributional effects of policies as well as niche marketing opportunities.

Consumers also have different affinities for different livestock species. Investigating pork chops and milk, Olynk,

Tonsor, and Wolf (2010) found differences in WTP across livestock species (dairy cows versus pigs) for welfare improvements. Additionally, WTP estimates vary across products even when they are from the same species (McKendree, Croney, and Widmar 2014; Olynk and Ortega 2013). Thus, consumer preferences for animal-rearing practices are not homogenous across consumers, and even for the same consumer they may vary across animal species and products, which presents a challenge for producers who must market an entire carcass rather than just a few value-added cuts.

Reducing the Economic Externalities Associated with Animal Welfare

Conventional economic theory asserts that competitive markets efficiently allocate resources to their most valued uses, and that the prices and quantities produced by a competitive market generate the highest level of aggregate human well-being in the utilitarian sense. These ideas have led economists to set competitive market outcomes as the benchmark from which to judge the suitability of policy proposals.

One well-known situation in which the human welfare-maximizing property of competitive markets breaks down occurs when the production or consumption of a good generates an externality, which is a cost or benefit conveyed on a third party not involved in the original transaction. When externalities exist, the market price of a product will not reflect the full social costs (or benefits) of production, and consumers will consume too much (or too little) of the good. Some argue that animal welfare (or animal suffering) is an externality in the sense that farms can be thought of as producing an output, animal welfare, which is not generally factored into the price of meat. If current levels of animal welfare are perceived to be low, then the production of meat creates a negative externality. The negative externality is a "cost" imposed on third parties—e.g., those individuals who are concerned about the current state of animal production. More directly, it is sometimes argued that markets for meat, dairy, or eggs create externalities because the well-being of animals is not directly considered when setting the prices for these food products.

The externality argument provides a convenient means to analyze the effects of different types of policies while working within well-established economic theories. Consider the following four policies that have been proposed to decrease the animal welfare externality associated with meat consumption.

Meat Taxes

A traditional solution to deal with negative externalities is the use of the so-called "Pigovian tax," originally suggested by Arthur Pigou (1920) and further developed by authors such as Baumol (1972). The idea is that a tax can be levied against the good traded in the market to force producers and consumers to pay the full social cost of production. An efficiently designed Pigovian tax would increase the price of a good by exactly the amount needed to offset the social costs of the negative externality.

Several groups have proposed meat taxes. Although the proposals are often vague as to the exact size of the tax or the methods of implementation, the general idea is that a tax on meat would lessen intake of meat and therefore would result in less animal suffering. Whereas it is possible that meat taxes could partially alleviate negative externality associated with modern livestock farming practices, there are several shortcomings of the policy concept.

The effects of a meat tax are mitigated because consumer demand for meat is relatively insensitive to price changes. Most estimates suggest that a 1% increase in the price of meat would cause a 0.6 to 0.9% reduction in the quantity of meat purchased (Gallet 2010). Thus, a meat tax would probably be effective at raising revenue for the government, but it would be less effective at curbing meat consumption. More importantly, the primary effect of a meat tax would be on the quantity of animals living, not on the quality of animal lives (Cowen 2006).

A related issue is that animal welfare can instead be considered a positive externality in need of subsidy rather than a tax. As argued by Norwood and Lusk (2011), most farm animals arguably live an overall good life, which means that a positive—rather than negative—externality potentially exists for many animal products. Either way, effective Pigovian taxes require knowledge by the regulator about the size of the externality as well as the underlying demand conditions. The over-arching point is that meat taxes are a blunt instrument in improving animal welfare in the sense that the effects on animal welfare are at best indirect.

Process Regulations

A popular tactic pursued by animal advocacy organizations is to use state ballot initiatives and state-level legislation to enact regulations that seek to prohibit livestock producers from using practices such as veal crates or gestation crates. These policies target specific farm practices and seek to lessen the externality problem at its source. Process regulations are popular, in part, because of their simplicity and seemingly intuitive appeal in decreasing the externality. Unfortunately, process regulations can have counterintuitive effects. In particular, process regulations often do not completely specify the alternative systems that could be adopted. Bans on production processes cannot guarantee improvements in farm animal welfare without other regulations. It is possible that open barn systems used for chickens kept for

egg production actually achieve lower levels of hen welfare than some enhanced or enriched cage systems. Moreover, with the absence of trade restrictions, banning a practice in one state or location simply serves to change where food products come from but not how animals are raised (Sumner et al. 2008).

Meat Labels and Certification

Because taxes and process regulations provide indirect and potentially counterproductive means of improving animal welfare, many organizations have sought to develop meat labels and brands that make animal welfare claims (see section 4). Although the market for such products is growing, meat labels are unlikely to fully resolve the externality problem associated with animal welfare. One of the main reasons is that labels only affect one type of consumer who is concerned about animal welfare. Many consumers are either satisfied with current standards or do not value higher levels of animal welfare and are therefore not willing to pay for certified meat products. Vegetarians and vegans do not eat meat. Thus, even though many vegetarians and vegans may care a great deal about farm animal welfare, the existence of certified meat labels does nothing to allow them to act on their preferences (although they might persuade others to their cause through advertising, social media, etc.). Labeling thus leaves the "compassionate carnivore" to bear the responsibility of resolving the externality problem.

Economists are generally skeptical of the notion that people are sufficiently altruistic to wholly internalize the cost of the externality. In particular, one can conceptualize animal welfare as a public good (the consumption of which is nontrivial and nonexcludable), and consumers face incentives to "free-ride" off contributions of others in which they enjoy the higher level of animal welfare provided through others' purchases without having to pay for it themselves (see the discussion and examples in Norwood and Lusk [2011]). Thus, although existence of label schemes or other certifications has the potential to decrease the effects of the animal welfare externality and provide purchasing opportunities to those concerned about such issues, they are unlikely to produce outcomes that are desired by all.

A Market for Animal Welfare

As discussed in more detail in section 4, one area in which animal welfare has had significant market impacts is in corporate social responsibility (CSR). Animal welfare is perceived to be a significant component of food quality assurance in today's marketplace; thus the market for animal welfare attributes is a particular area of concern for economists, livestock producers, and livestock industries alike. Lusk (2011, 2016) suggested the possibility of a decoupled market for animal welfare as one means of allowing companies to meet CSR goals in a way that is guided by economics and market forces. Succinctly put, a market for animal welfare would consist of giving farmers property rights over an output called animal well-being units (AWBUs) and providing an institutional structure or market for AWBUs to be bought and sold independent of the market for meat.

Animal well-being units can be assigned to producers based on the living conditions on their farm (as deemed by a certifying body) and the number of animals housed. Creating a market for AWBUs would convey the opportunity, but not the obligation, to participate. Farmers and livestock producers would voluntarily choose whether or not to participate (and be audited periodically), but presumably, many would do so because they would gain access to a new market and garner an opportunity to profit. Likewise, only those citizens and nongovernmental organizations (NGOs) who have the means and the interest to do so would buy AWBUs. In this sense, a market for AWBUs would also separate rhetoric from reality. It is easy to say improvements in animal welfare should be enacted, but this is different from being willing to pay their costs. A market for AWBUs imposes the costs on the people who want them and could potentially allow companies to engage in CSR objectives in a clear and transparent manner (i.e., by buying AWBUs). This does not mean that some of the same incentives for free riding that exist with regard to meat labels wouldn't also exist with an AWBU market, only that the AWBU market would expand the pool of potential buyers to those people who currently buy little to no meat.

4 Regulation of Animal Welfare

Introduction

In the United States, although there are laws governing the transport and slaughter of livestock and prohibiting overt animal cruelty, there are few laws that directly address on-farm practices related to animal care and welfare. Consequently, the producers' desires to remain autonomous in decisions regarding best practices often conflict with social expectations about how animals should be produced and how much oversight and control there should be of production practices.

Production management practices and housing systems for farm animals have been a frequent target of legislative initiatives (Croney and Millman 2007; Mench 2008; Swanson 2008). High-density housing systems, painful procedures, use of growth-promoting substances, antibiotic use, animal handling, euthanasia, transportation, and slaughter have all drawn public scrutiny.

Approaches to Regulating Farm Animal Welfare: Voluntary and Involuntary

With the social agenda making its way through the farm gate, two regulatory approaches have been employed to provide public assurance that the welfare of food-producing animals is safeguarded. Voluntary regulation has emerged from the respective animal industries through a process of identifying and incorporating best practices into species-specific standards or guidelines, which farmers and ranchers are strongly encouraged but not required to follow. Also emerging is the strategy of involuntary regulation, and particularly passing legislation state by state either through citizen-inspired ballot initiatives or the traditional route of introducing a bill to lawmakers. Where successful, this strategy has advanced a social agenda on farm animal welfare but also resulted in a patchwork of inconsistent laws. This can be problematic for farming enterprises that span more than one state and may limit access to markets (Mench 2008; Mench, Sumner, and Rosen-Molina 2011; Swanson 2008).

Voluntary

Voluntary approaches are strongly recommended best practices. Some of the most significant improvements to farm animal welfare have happened through "conditions of doing business" between suppliers and customers (food retailers). In many instances, the conditions were precipitated by some form of social pressure (Schweikhardt and Browne 2001; Thompson et al. 2007). Companies often have a CSR plan that demonstrates their commitment to key goals and underlying values. For those involved in food production, processing, or distribution, CSR related to animal welfare often dictates how a corporation will engage its suppliers and how far down the chain its policies will reach. In some cases, that is only to the first point of contact in the supply chain (e.g., the slaughter plant). In other cases, the reach can be substantial and result in setting standards and expectations for on-farm animal care. In most cases, suppliers must provide evidence of third-party audits as a condition of doing business. Numerous food retailers and companies, such as McDonald's and Tyson, have established animal welfare programs for their supply chains.

Commodity groups, private alliances, and livestock, meat, and poultry organizations in the United States have developed voluntary guidelines for the care, handling, transport, and slaughter of livestock and poultry. In many cases, corresponding assessment and audit programs have also been developed. Quality assurance programs that were first developed for the purpose of assuring food safety and eliminating potential sources of residues in meat, milk, and egg products have evolved to include on-farm animal care, handling, transportation, and slaughter practices (e.g., beef [NCBA n.d.], pork [NPB 2009–2017], animal handling/slaughter [NAMI 2017], eggs [UEP 2016], dairy [NDFP 2017]). In an attempt to provide an independent review of standards and audits, the certification of audit instruments and training/certification of animal auditors is offered through the U.S.-based Professional Animal Auditor Certification Organization (PAACO 2016).

The other mechanism for promoting voluntary adoption of best farm animal care and management practice is marketing and labeling programs. Eggs were perhaps the first major commodity for which cartons were labelled to reflect production practices (Buller and Roe 2014; Lusk 2011). These programs typically have defined sets of standards that differ from one another in level of sophistication and tend to focus primarily on on-farm practices and expectations for slaughter. A number of NGOs, including the American Humane Association, the Animal Welfare Institute, the Global Animal Partnership, and Humane Farm Animal Care, offer

such programs. The goals are to capture consumer interest and market premiums for farmers and ranchers who are part of the program while also encouraging the continuous improvement of farm animal welfare.

As discussed elsewhere in this report, global standards are also being set by the World Organisation for Animal Health (OIE 2015). The OIE has North American representation and a resolution (Resolution 26) concerning the respective roles voluntary and involuntary regulation play in securing animal welfare (OIE 2010). From a global perspective, transnational corporations, world trade agreements, NGOs, and organizations such as the OIE will play significant roles in the continuous improvement and harmonization of animal welfare standards for agricultural animals. This will also encourage developing countries to adopt approaches to improve the care of farm animals (Fraser 2014).

Involuntary

Involuntary assurance of animal welfare requires compliance with laws, ordinances, and/or other legal vehicles describing standards or criteria for farm animal care. Laws can be passed via engagement of elected officials at the local, state, or federal level. At the time of this publication, there are 26 states, and the District of Columbia, in which citizens can engage in direct law making. In 24 states, citizen ballot initiatives and referendums can be used. Of the 24, 21 allow citizens to amend or propose statutes and 18 permit constitutional amendments (Ballotpedia n.d.; NCSL n.d.). In recent years, this law-making strategy has proved to be successful for dictating attributes of housing systems for laying hens, gestating sows, and veal calves in eight states (Smithson et al. 2014; Tonsor and Wolf 2010). A successful citizen referendum or ballot initiative can be overturned only if proved in court to be unconstitutional. The citizen ballot and referendum process has been a powerful tool for enacting farm animal welfare legislation in those states. The regulation of farm practices is often the outcome of failed attempts to produce a voluntary change in practice or a catastrophic media event, the latter of which also has the potential for market impact (Tonsor and Olynk 2011).

To date, regulations pertaining to farm animal welfare exist in 15 states (NALC n.d.). In at least 5 of the 15 states, laws were passed establishing either livestock care standards or advisory boards empowered to be the only entities allowed to develop standards on farm animal welfare. Two states, Georgia and South Carolina, have laws that prohibit local government or municipalities from passing such laws or ordinances, and in Oklahoma only the Oklahoma Department of Agriculture, Food and Forestry is empowered to establish standards.

In states with laws establishing standards for animal housing, political negotiations have resulted in subtle differences in specifications, such as space allocation for animals. This lack of consistency has implications for interstate commerce. An example is the difference in space requirements and legal interpretations of best practice for laying hen housing in California, Ohio, Michigan, Washington, and Oregon. This difference led California to place restrictions on the import of eggs from hens that are not raised under the same conditions as those required for California egg producers (California Health and Safety Code 2008; Sumner et al. 2011). The problems these state regulatory inconsistencies created for U.S. egg producers prompted a joint effort between the Humane Society of the United States and the United Egg Producers to pass a federal law to establish uniform baseline expectations and standards for laying hen care and housing (HSUS 2011; U.S. Congress 2013). Although the effort was unsuccessful, it demonstrates a need for a uniform approach to be developed in the setting of regulated standards across the United States.

Once involuntary regulations are passed, there is a public expectation for compliance. To help farmers and ranchers absorb the costs of compliance, a phase-in period is often negotiated to provide time for depreciation of existing facilities (in the case of housing system changes) or implementation of other changes. To assure compliance, however, requires that a government oversight process be codeveloped with the regulation.

Advantages and Disadvantages of Voluntary/Involuntary Regulation of Animal Welfare

Voluntary and involuntary farm animal welfare regulations have advantages and disadvantages (Swanson 2008). Voluntary regulation can initiate change at a rate that can be practically adopted within the supply chain with the fewest negative impacts on markets, product price, and industry economic viability. It may allow consumers a range of product choice by stimulating special labeling and branding programs while raising the bar on animal welfare for conventionally raised commodities. When instigated from within or including the supply chain representation, voluntary regulation can expedite internalization and institutionalization of the desired practices. Disadvantages of voluntary regulation can include a lack of transparency, potential for conflict of interest, adoption of standard-setting frameworks that lack diverse stakeholder input, no public oversight, lack of third-party audits or a public reporting vehicle, increased consumer confusion, and the potential for antitrust issues depending on the organization setting the standards and its relationship to product pricing (Thompson et al. 2007).

Involuntary regulations (laws) often resonate with the public because a change will be mandated. Laws are public

and have a level of transparency that may not often be realized with voluntary regulation. It is also assumed that a government agency or similar organization will be responsible for compliance oversight, thus relieving the public of their concern. The other advantage is that a federal law can level the playing field for the affected industry. Disadvantages include issue polarization, protracted political transaction time to initiate change, negative social stigma generated toward the affected industry, the potential that politically negotiated animal welfare standards may either generate no net benefit to the animals or not be practically achievable, and the difficulty of changing involuntary law based on new scientific or practical information. Additionally, state laws can seriously disadvantage farmers and ranchers when marketing across state boundaries. It has been suggested that if a regulatory route is to be taken, it be developed in a responsive manner in which regulators work with affected industries using a strategy to institutionalize and internalize the change (Parker 2006) rather than instigating defiance.

Hybrid models do exist—for example, federally recognized codes of practice in some countries that are voluntary yet nationally recognized as setting the baseline for farm animal care and welfare. These codes (standards) are formulated within a framework that includes scientific and diverse stakeholder input, government participation and sanctioning of the process, and public transparency. For example, the Canadian Codes of Practice (NFACC 2017) are developed by a multistakeholder process for the different species of farm animals. The National Farm Animal Care Council (NFACC) is recognized by the Canadian government as the national organization through which animal care and welfare issues are addressed. The NFACC uses a consensus-building model in which the codes of practice for farm animal care standards and assessment programs are developed, revised, and maintained, and it ensures that national issues specific to agricultural animal care are addressed. The process of approving the codes is similar to involuntary processes that involve the public weighing in on proposed standards of care. Although the codes are voluntary, in a court of law they provide a recognized baseline for the care and welfare of animals.

To date neither the U.S. government nor the animal industries have established a nationally recognized process for the development of voluntary standards and assessment of farm animal care that takes a uniform approach across the various animal industries. Ironically, the scientific community working with farm animals as a part of their research and teaching programs established a national unified framework for the development of scientifically derived guidelines for farm animal care nearly 30 years ago. The Federation of Animal Science Societies' (FASS) *Guide for the Care and Use of Agricultural Animals in Research and Teaching* (FASS 2010) is used by an independent, internationally established organization that accredits animal care in research and teaching institutions, the Association for the Assessment and Accreditation of Laboratory Animal Care, International (AAALAC). The AAALAC recognizes the FASS guidelines and acts as a third-party reviewer for institutions adopting the guidelines. Public and private research institutions obtain AAALAC accreditation as an added public assurance of high-quality animal care.

It can be argued that the lack of a unified transparent process for establishing standards of care for commercial animal agriculture has precipitated the irregular patchwork of state-by-state regulations and competitive voluntary regulatory programs under which the industry currently operates. Development of a government sanctioned, consensus-building, and evidence-based standard-setting process could provide this kind of consistency as well as the transparency and assurance that the public demands.

5 Assessment of Welfare

Previous Challenges and Advancements in Welfare Assessment

Historically, the measures of animal welfare that were most palatable to animal scientists were those that were considered to be objective and easily quantified, such as animal productivity. But during the last 50 years, social forces have pushed science to define the "quality of life" of farm animals much more broadly, considering not only their biological functions but also satisfaction of their "natures" and behavioral needs. This has driven science toward a more holistic study of the functioning of animals within the environments in which they are raised and managed. For example, applied ethologists have focused on the development of scientific models, methods, and technologies to glean insight into the mental states of animals by understanding their behavior. As scientists developed methodologies to study and answer questions about animals' quality of life, new measures of animal welfare emerged and were added to traditional measures. This holistic approach is also characteristic of animal welfare science, which by its nature is multidisciplinary and includes behavioral, physiological, and health measures of welfare. The strengths and weaknesses of the principal measures of welfare have been reviewed elsewhere (e.g., Dawkins [1980]; Mason and Mendl [1993]) and will be discussed only briefly in this report.

Behavioral restriction of animals due to crowding and/or inadequate physical or social resources has probably been the most contentious farm animal welfare issue. Because of the prominence of this issue, research has focused on identifying animals' "behavioral needs"—behaviors that animals are strongly motivated to perform and that are important for physical and psychological health. One important research tool used for this purpose is preference testing. In its simplest form, preference testing involves providing the animal with a choice between various options and asking it to select the option(s) it most prefers. Preference tests have been used to evaluate environmental features such as lighting, social contact, bedding type, and flooring surfaces (Fraser and Nicol 2011). Such testing is often now combined with operant conditioning methods in order to determine the strength of the animal's preferences and thus the importance to the animal of accessing particular resources or performing particular types of behaviors.

Another research area has been the study of the causes of and methods for decreasing or preventing the performance of abnormal behaviors (Rushen and Mason 2006). These include abnormal repetitive behaviors like stereotypies (pacing, bar biting) and behaviors that lead to self-injury or injury to other animals (tail biting, cannibalism). The occurrence of such behaviors in seemingly healthy animals may be an indicator of welfare problems, and it is often related to environmental inadequacy (e.g., barrenness, unstimulating environments, abnormal social environments, feed or water restriction). Although behaviors that cause injury have obvious negative consequences for animal health and welfare, the link between stereotypies and welfare is more complex.

Whereas the development of stereotypies is often linked to environmental inadequacy, once developed, a stereotypy may act as a kind of "coping mechanism" for the individual animal (Mason and Latham 2004). Regardless, these behaviors are abnormal, and understanding their causes sufficiently in order to prevent them from developing should be considered an important research priority. The most common method evaluated is "environmental enrichment," which involves making a biologically relevant change (Newberry 1995) in the animal's environment that promotes normal behavior and normal physiological functioning. Some abnormal behaviors have a genetic component, thus suggesting that it may be possible to decrease their occurrence and/or severity via genetic selection for improved adaptation.

Physiological evaluation of animal welfare has focused mainly on the responses considered indicative of stress, such as catecholamine-related responses including heart and respiration rate, glucocorticoids (corticosterone and cortisol), body temperature, and immune responses. The stress response is a natural response to stressors—physical and psychological demands that threaten *allostasis*. In addition to helping cope with the stressor, the stress response limits the damage caused by other defensive mechanisms evoked by the stressor (Moberg 2000; Wingfield 2005). The key challenge in using these measures as indicators of welfare is to distinguish the physiological changes that have a negative effect on animal welfare from those that simply indicate normal adaptive functioning or even pleasurable positive arousal. "Negative" stress can lead to deterioration of an animal's physical and psychological health, both of which are important components of animal welfare.

Measures of stress have been used to examine and ameliorate the responses of animals to acute stressors, such as

transport. The assessment of chronic stress, however, has proved more challenging because our understanding of the interrelationships among the various components of the stress response system and how these change over time is limited. In addition, the relationship between physiological and psychological stressors is still not well understood. Resolving these challenges will be key to validating physiological measures for use as an assessment tool to evaluate animal welfare.

Presence or absence of disease is an obvious consideration in evaluating the physical health status of an animal. Diseases can be infectious (e.g., bacterial, viral, parasitic) or noninfectious (e.g., genetic, environmental). De Passillé and Rushen (2005) note that many endemic diseases are among the more serious animal welfare issues, especially for high-producing animals. As such, the incidences of such diseases are valuable measures of welfare. Examples include mastitis, lameness, milk fever, and infertility in dairy herds (Sutherland, Webster, and Sutherland 2013); bovine viral diarrhea, brucellosis, rumen acidosis, and foot rot in beef cattle (The Cattle Site n.d.); and avian influenza, ascites (pulmonary hypertension), salmonellosis, coccidiosis, fatty liver hemorrhagic syndrome, and osteoporosis in poultry (Dinev 2000–2014).

The extent to which a disease becomes a welfare problem depends on how much it contributes to a reduction in the animal's quality of life. Physical (e.g., impaired respiratory, gastrointestinal, immune, musculoskeletal, or reproductive function and/or integrity) and mental (e.g., depression, signs of pain and discomfort, the absence of normal behaviors or presence of abnormal behaviors) measures of impact, in addition to incidence, are required as part of any welfare assessment. Consideration must be given to both clinical and subclinical disease because the latter often manifests itself in early, insidious, and/or vague clinical signs, such as decreased feed conversion and/or loss of reproductive efficiency.

Related to animal health and physiological functioning, indices of productivity (growth and reproduction) are also often used to evaluate animal welfare (Curtis, 2007). The relationship between productivity and welfare, however, is inconsistent. Depression of normal productivity can occur when an animal is ill or experiencing acute or chronic stress (caused by, for example, undernutrition, aversive handling, or social stress). High productivity achieved via genetic selection for individual performance, however, without consideration for group productivity and indirect genetic effects (IGEs) (Muir and Cheng 2004; Muir and Craig 1998) can be deleterious. Some management practices can result in a situation in which productivity leads to welfare problems—e.g., health issues in high-producing animals mentioned earlier. As with health, then, it is important to evaluate productivity in the context of other measures of welfare.

Indeed, it is often important to use multiple types of measures to obtain an adequate assessment of animal welfare. One area in which this approach has been particularly successful is in the assessment of pain (Viñuela-Fernandez, Weary, and Flecknell 2011). Validated physiological and behavioral measures to assess pain have been reviewed by Weary and colleagues (2006) and Sneddon and colleagues (2014). Weary and colleagues (2006) identified four approaches useful to assessing pain using behavior: measuring pain-specific behaviors, the decline in frequency or intensity of certain behaviors, choice or preference behavior, and changes in pain thresholds. Combining behavioral measures with assessment of physiological measures (e.g., cardiovascular and respiratory responses, endocrine changes, or neurophysiological responses) has helped improve the identification and management of pain associated with routine husbandry procedures in agricultural animals.

In short, evaluating an animal's welfare essentially involves a complete assessment of the animal's physical and mental health. When both are good, the animal's welfare is good. Ensuring appropriate attention is paid to protecting both physical and mental health, however, can be a challenge because historically the scientists contributing to the pool of animal welfare knowledge and the practitioners implementing that knowledge have tended to have a primary interest in exploring or enhancing one or the other aspect of animal health—but not both. Veterinarians, animal scientists, and producers, for example, have tended to emphasize measures of physical health—including disease-free state, growth, reproduction, and productivity—when they evaluate and attempt to enhance the animal's welfare state. Ethologists and the general public have traditionally focused more on the animal's affective (mental) state and its ability to engage in species-typical behaviors when seeking welfare improvements. Nonetheless, an animal's physical and mental health are codependent and need to be assessed and managed as such if the goal is to protect and improve its welfare. This emphasizes the need to continue to conduct basic research to further validate measures of welfare, with increased emphasis on coordinated multidisciplinary approaches.

Although research emphasis is still needed on basic aspects of welfare assessment, there are also emerging methods and metrics that will be useful for further improving our ability to detect and remedy welfare problems. Three of these are highlighted in the remainder of this section: functional genomics and genetics, epidemiology, and the development of automated assessment tools. Additional high-priority areas of research are outlined in section 7.

Emerging Methods and Metrics for Assessing Animal Welfare

Functional Genomics

Understanding the extent to which animal welfare is impacted by genetics is of great importance (see section 6). The development of genomics, combined with high-throughput deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) sequencing, allows assessment of genetic differences in individuals, trait predisposition, and breed identity at the highest level of resolution possible. In addition, scientists are now able to easily and quickly quantify gene expression.

The ability to quantify RNA by the genes used to produce it, commonly referred to as the *transcriptome*, is a holistic measure of how the animal's genome and environment interact (Klopfleisch and Gruber 2012; Martin and Wang 2011; McHale et al. 2013). Since most physiological changes in an animal and the way the animal perceives the environment are mediated by RNA, the transcriptome is a powerful tool to directly assess traits critical to animal welfare (Aggrey 2010; Muir, Cheng, and Croney 2014). It could be used in two ways—first as an objective metric for classifying alternative housing conditions as similar or different in terms of the animals' similar or different transcriptome reactions, or second by clustering environments based on known classifications (e.g., extensive vs. intensive) to enable unknown or new environments to be compared to these categories (see Golub et al. [1999] for an example of use in the medical field for classification of an unknown). This would allow for informed decisions on alternative housing and equipment. The transcriptome could also be used to determine whether or not different strains of animals perceive similar environmental assaults differently, enabling them to be classified into categories such as stress resistant or susceptible (robust or not) for management and breeding purposes. Such an application was demonstrated in the classification of diseases in a medical application by Golub and colleagues (1999).

Epidemiology

As discussed earlier, traditional experimental approaches to assessing and improving animal welfare have resulted in many theoretical and practical advances. It has become apparent, however, that experimental studies need to be complemented by on-farm/on-site research because the causes of welfare problems are often multifactorial. For example, the incidence and severity of skeletal problems (e.g., lameness) in commercial broiler chickens can be affected by genetics, nutrition, lighting, stocking density, litter management, and the presence of infectious organisms in the hatchery or grow-out facility (de Jong et al. 2012; Knowles et al. 2008; Mench 2004). It is virtually impossible to study all of these factors and their interactions using traditional experimental approaches. For this reason, there is increasing interest in applying large-scale *epidemiological* approaches in order to understand and improve animal welfare in the "real world" (Mench 2018).

Unlike traditional experimental approaches that try to understand cause and effect by limiting variability due to non-experimental factors, epidemiology takes advantage of the fact that there is variation across populations (e.g., houses on a farm, farms, transport trucks, slaughter plants) and uses that variation to examine patterns. Steps required to conduct an epidemiological analysis of animal welfare include identifying the welfare problems of interest (outcomes) and the housing and/or management factors that could affect the incidence or severity of those problems (inputs or risks). The inputs and outcomes are then measured at multiple sites, and multivariate models are created to determine the relationships among them.

A variety of methods can be used to obtain data for epidemiological analysis (Mench 2018), including direct sampling (e.g., taking blood samples, conducting behavioral observations), surveys (e.g., asking farmers about management practices), or examining historical records (e.g., mortality, production, health). Examples of the ways in which epidemiological approaches have been used to study farm animal welfare problems include evaluating the factors affecting the incidence of cannibalism of the egg-laying vent in hens (Pötzch et al. 2001), piglet mortality during transport (Dewey et al. 2009), lameness in dairy cattle (Westin et al. 2016) and chickens (Knowles et al. 2008), and aversive handling by stockpersons (Simon, Hoar, and Tucker 2016). Epidemiological models are correlational and may not include some or all causative factors. As such, epidemiological models do not definitively establish the cause(s) of specific welfare problems. They do, however, provide information about the overall prevalence of welfare problems and the relative importance of each of the various risk factors evaluated that are found to affect that prevalence. These data can then inform the farmer/producer of housing and management changes that might decrease the risk of those problems occurring.

Automated and Noninvasive Animal Welfare Assessment Tools

The development, validation, and refinement of tools for more rapid assessment of animal welfare is of high priority for both experimental and commercial-scale use. Evaluation of animal behavior is a key component of assessing welfare, but behavioral studies or evaluations are often extremely time consuming because they require trained observers to characterize behaviors in detail either during live observation sessions or by coding video recordings. A host of new technologies is emerging, however, that could greatly

streamline this process, at least for certain types of behaviors under particular conditions (Mench 2018; Rushen, Chapinal, and de Passillé 2012). For example, the duration and frequency of walking and standing, as well as the number of steps taken, by dairy cattle can be estimated with reasonable accuracy (compared to video observations) using movement sensors (accelerometers) attached to the cows' legs (Nielsen et al. 2010). Another example is range use and walking, foraging, and standing behavior in free-ranging cattle, which can be determined using global positioning system technology (Anderson et al. 2012; Davis et al. 2011).

Several methods have been evaluated and used to automatically measure activity levels in chickens, including motion sensors positioned in the housing environment (Blatchford et al. 2009), image analysis (e.g., computer vision) (Dawkins et al. 2009), or body-mounted sensors that transmit location information to a base station (Daigle et al. 2014). Kinematic analysis provides a tool for rapid measurement of three-dimensional movement, and it has been used to evaluate space requirements for hens (Mench and Blatchford 2014) and lying behavior of dairy cattle with the goal of improving stall design (Ceballos et al. 2004).

Some sensing systems can provide information about animal identity, which allows individualized welfare assessments. Such sensors have been used to track the locations, movements, perching, feeding, drinking, and nesting behaviors of individual hens within a flock (Daigle et al. 2014; Freire et al. 2003; Nakarmi, Tang, and Xin 2014). This kind of information can then be used alongside other types of observations (e.g., health or physical condition) for a more comprehensive welfare assessment (Freire et al. 2003). For example, Banerjee and colleagues (2014) used body-mounted sensors to detect the force with which individual laying hens jumped and landed during flight, information that could be coupled with assessments of bone damage in those same individuals to better understand the factors associated with the common problem of keel bone breakage.

Automated systems are also being developed to assess health and physiological parameters, sometimes in combination with behavior. Automated methods that have been used to assess gait and thus lameness and foot and skeletal disorders include image monitoring/kinematics (Aydin et al. 2010; Flower, Sanderson, and Weary 2005) and accelerometery (Pastell et al. 2009). Dawkins and colleagues (2009, 2017) found that movement patterns of broilers in commercial houses determined via automated analysis of optical flow were correlated with lameness and hock-burn incidence, offering a potential nonintrusive alternative to on-farm gait scoring, since the birds do not have to be handled. Shao and Xin (2008) developed a real-time thermal image-processing system that can be used to assess thermal comfort in group-housed pigs of varying weights and sizes, which could allow caretakers to monitor and adjust thermal conditions in the house.

Noninvasive in vivo health monitoring methods also allow patterns of health changes to be tracked over time in the same individuals, and thus they can improve the ability to select individuals for breeding. Examples are ultrasound and quantitative computed tomography, both of which have been validated as noninvasive methods for assessing bone mineral density in hens (Fleming et al. 2004; Korver, Saunders-Blades, and Nadeau 2004).

6 Advances in Animal Welfare and Outstanding Challenges

Introduction

As human population growth has changed communities from predominantly agrarian to more urban, commercial agriculture has also changed the way it functions. Mergers from small farms to larger ones and to larger food companies have occurred. The increased size of operations has led to new animal welfare issues and needs for standards of handling and hauling animals, animal density, and methods of euthanasia, as well as environmental standards for production units. Consequently, major changes have occurred in thought processes about issues such as space needs to economically, humanely, and efficiently produce animals and criteria for breeding programs. Deliberation about the quality of housing environments and methods to humanely handle and transport large numbers of animals while maintaining individual animal care continually evolved. Scientific research on animal welfare has been and is key to making these changes.

Despite being a relatively new field, there is now a significant body of animal welfare research (Fraser et al. 2013); the output of scientific publications has increased by 10 to 15% annually during the last two decades (Walker, Diez-Leon, and Mason 2014). Since the development of the field of animal welfare science was stimulated by concerns about animal production systems that restricted animal movement, applied animal behavior scientists (ethologists) initially played a major role (Fraser et al. 2013). Other disciplines increasingly contribute to the body of animal welfare research and its application (Appleby et al. 2011; Fraser 2008; Fraser et al. 2013; Mellor, Patterson-Kane, and Stafford 2009), including the disciplines of physiology, veterinary medicine, agricultural engineering/environmental design, comparative psychology, nutrition, genetics, microbiology, social sciences, and applied ethics. Research efforts have led to advances in many areas, both in terms of contributing basic knowledge about how to assess animal welfare (as discussed in section 5) and in changing housing and management. It is beyond the scope of this report to provide an exhaustive review of these research efforts, but this section provides a few selected examples of advances and challenges in four areas: housing systems, painful management practices, breeding and genetics, and handling and transport.

Housing Systems

Continuous confinement housing that results in ongoing behavioral restriction of animals has become one of the more controversial aspects of livestock production in the United States. Significant resources have consequently been allocated to investigate this topic, and particularly to develop viable alternatives to conventional cage housing used for laying hens and the standard (conventional) gestation stall used for sows.

For laying hens, early research focused on identifying those behaviors that hens were highly motivated to perform (see reviews in Appleby et al. 2002; Lay et al. 2011). These studies identified perching and nesting as being particularly important "behavioral needs" for hens. They also established the role that dust-bathing behavior plays in maintaining good feather condition, as well as the importance of providing foraging material to decrease problems with injurious feather pecking behavior. These studies were key for the development of the two alternative systems that are superseding conventional cages in North America—enriched colony cage and cage-free housing.

The enriched colony cage system was designed to maintain some of the health advantages of conventional cages, particularly by separating hens (and their eggs) from manure by housing the hens on all-wire flooring. To facilitate the performance of behaviors, the colony contains perches and a nesting area, although its configuration and size still limit dust-bathing and foraging behavior as well as long-distance movement. Cage-free systems, on the other hand, provide the hens with a litter substrate for foraging and dust bathing in addition to nests and perches, and they allow greater freedom of movement because the hens can fly.

Each of these systems has inherent advantages and disadvantages (Lay et al. 2011), but management is an important aspect of maintaining good welfare. Currently there is a great deal of research under way to define best management practices. Examples of best practices include determining how much space hens need (Mench and Blatchford 2014), how they should be reared to best prepare them for being kept in particular laying environments (Janczak and Riber 2015; Widowski and Torrey 2018), and the role of genetics in promoting hen adaptation to alternative systems (Rodenburg et al. 2008).

Although significant advancements have also been made

in understanding the welfare implications of different sow housing systems, the issue of gestation stalls has been especially problematic for U.S. pork producers in part because the scientific findings have yielded ambiguous results. For example, several studies have provided evidence that important aspects of sow welfare are protected in stalls. Individual monitoring of health and feed intake, protection of sows from injurious encounters with each other (Gonyou 2005), and caretaker safety have all been cited as benefits of the conventional gestation stall. Results also indicate infringements on other key aspects of sow welfare when sows are continuously individually stalled. Gestation stalls are by design behaviorally restrictive, constraining sows' abilities to move, exercise, engage in normal social interactions, and explore and interact with the environment (Gonyou 2005; Karlen et al. 2007), all of which potentially contribute to boredom, frustration, and other negative mental states.

The ways in which sows are fed and the interactions between housing and feeding type complicate the problem of identifying the best housing systems for sows. Because gestating sows are typically fed to nutritional needs, hunger and inter-sow aggression can present significant welfare challenges in group housing systems (Bench et al. 2013; Edwards, Brouns, and Stewart 1993; Marchant et al. 1995). Providing sows protection from each other while feeding must therefore be factored into evaluating housing and feeding systems. Significant advancements have been made in understanding the welfare benefits and risks associated with the myriad permutations of housing and feeding options available for contemporary sow housing (Bench et al. 2013; Edwards, Brouns, and Stewart 1993; Gonyou 2005; Marchant et al. 1995).

In addition, there has been considerable research on other management considerations, such as the method by which sows are introduced into groups, their stocking densities (Marchant et al. 1995), and the skill of caretakers, as well as how those impact welfare outcomes. Sow housing position papers reviewing sow behavior, performance, physiology, and health in different housing systems conclude that both individual and group housing have benefits and challenges, but that good management in any system can enhance sow welfare (AVMA 2005; Barnett et al. 2001; McGlone et al. 2004).

In terms of outstanding challenges, there is a need to modify existing or design new individual sow housing systems for breeding and gestating sows that optimize individual welfare, management/labor, lifetime productivity, and reproductive performance/efficiency for producers at all scales of production (NPB 2014). Additional evaluation of individual feeding methods in group housing systems is also necessary (Bench et al. 2013), and methods of evaluating and addressing hunger in sows are critically needed. It is particularly important to understand these conditions as they pertain to competition and aggression that can result in poor body condition in younger, lower-ranking, and smaller sows and gilts maintained in group housing systems. In addition, sow welfare in farrowing systems must be explored. Cooperation between agricultural and biological engineering and better incorporation of animal behavioral needs into housing and environmental design are necessary to optimize animal welfare.

Painful Management Practices

Painful practices are routinely performed on farm animals for a variety of reasons, including to prevent them from injuring one another or human caretakers and for production and food quality purposes such as preventing boar taint in pork or increasing marbling of beef. Pain mitigation is not routinely provided in these situations because of historical precedents, economic barriers, impracticality, uncertainty about need, uncertainty about legality of the use of analgesic drugs, or uncertainty about efficacy. Although mentioned here in the context of routine management procedures, control of animal pain, in general, is an emergent issue. Pain is a clinically important condition that adversely affects an animal's quality of life and, accordingly, must be managed. Recent research has provided information that is beginning to be applied to decrease pain associated with routine procedures, and several examples are provided here.

For pigs, castration decreases boar taint and aggression as a pig matures to a market weight. Most of the pigs reared in pork-producing countries are castrated. Except for breeding stock, male pigs are usually surgically castrated. The American Veterinary Medical Association (2013) concluded that surgical castration is a painful procedure and indicated that animal welfare would be improved if it was performed with pain management, or replaced by a less invasive procedure. In response to the need for pain mitigation, the swine industry has made several advancements during the past decade via targeted funding aimed at increasing understanding about pain in piglets, developing pain mitigation methods (NPB 2014), and identifying existing research gaps (Dzikamunhenga et al. 2014; O'Connor et al. 2014). Recommendations have been developed for three interventions—carbon dioxide/oxygen (CO_2/O_2) general anesthesia, nonsteroidal anti-inflammatory drugs (NSAIDs), and lidocaine—for use during castration. An expert panel has strongly recommended against the use of a CO_2/O_2 general anesthesia mixture, weakly recommended for the use of NSAIDs, and weakly recommended against the use of lidocaine for pain mitigation during castration of 1- to 28-day-old piglets (Dzikamunhenga et al. 2014).

In 2011, Improvest®, an immunization that uses the animals' own immune system to protect against off odors, was

approved by the Food and Drug Administration. Improvest® temporarily provides the same effect as physical castration, but much later in a pig's life, by blocking the gonadotropin-releasing factor. This decreases the levels of androstenone and skatole in mature male pigs, the primary source of "off odors" in pork.

As is the case for swine, cattle production involves management practices that raise similar issues relative to avoiding and alleviating animal pain, including castration, dehorning, ear tagging, and branding. As demonstrated by research, all of these procedures are associated with variable degrees of acute discomfort and some, such as castration and dehorning, cause prolonged pain. For example (see review in Stafford and Mellor 2011), amputation dehorning and cautery disbudding result in behavioral responses indicative of pain, as well as increased plasma cortisol levels that persist for seven to eight hours. Caustic disbudding results in a similar cortisol response but a delayed behavioral response. Administering local anesthesia prior to any of these procedures eliminates the behavioral responses, and combining local anesthesia with an NSAID (ketoprofin) virtually eliminates the cortisol response.

Studies by Coetzee and colleagues (2012) with meloxicam, an NSAID approved for use in Canada, have shown that a single oral administration of meloxicam at the rate of 1 milligram per kilogram (mg/kg) prior to castration was able to mitigate pain and also decrease the number of calves requiring treatment for bovine respiratory disease during the post-castration period. Previously, Heinrich and colleagues (2009) found a reduction in the physiological stress responses of calves to pain dehorned by cautery methods when they were pretreated with a 0.5 mg/kg intramuscular dose of meloxicam. These studies suggest that meloxicam provides benefit as a pain management tool in calves and cattle. The use of meloxicam in cattle as described here, however, constitutes extra-label use of the drug in the United States, which requires veterinary guidance.

Although there have been significant advances in understanding animal pain and methods for its alleviation, challenges remain. One important challenge associated with pain management in food animals is a lack of approved drugs for this purpose. The Animal Medicinal Drug Use Clarification Act (AMDUCA) of 1994 provides food-supply veterinarians with options for pharmaceutical management of pain in their patients, but care must be taken to ensure that requirements under AMDUCA are rigorously adhered to, including prevention of drug residues in animal product. Research and market support will assist in improving the availability of approved pain management drugs for food animals.

There is also a need for continued research on alternatives to painful procedures—e.g., alternatives to dehorning cattle such as gene editing for polledness (Tan et al. 2013). Here the development of CRISPR (clustered regularly interspaced short palindromic repeats) technology for genome editing (Jinek et al. 2012) offers unprecedented opportunity to edit genes in such a manner as to facilitate welfare by obviating the need for painful management practices. For other painful management procedures, technical and social challenges associated with the adoption of alternatives may complicate matters. As an example, immunocastration has not been embraced by the U.S. pork industry, in part because of logistics issues that might be encountered at meat packing plants relative to handling and processing animals treated with Improvest® separately from those that are untreated. In addition, concerns about worker safety and consumer acceptance of the technology exist. It is therefore important to keep in mind potential obstacles to implementing alternatives early in the research development phase and ensure that these are properly explored to avoid incurring unnecessary expense in research with no viable application as well as social contention that may otherwise occur.

Advancements and Outstanding Challenges in Genetics

In the past 60 years, intensive selection for increased meat, egg, milk, and wool production has resulted in large increases in productivity and efficiency, which will likely lead to an increased number of side effects (Rauw et al. 1998), including animal welfare issues (Rodenburg and Turner 2012). Awareness of these welfare issues and research to address them, however, has increased in the past decade, and today genetic selection is regarded as a key component to improve welfare (Fraser et al. 2013).

Selection for Robustness

Robustness is defined as the ability to combine a high production potential with resilience to stressors, allowing for unproblematic expression of a high production potential in a wide variety of environmental conditions (Knap 2005, 2012). In high-performance genotypes, fitness may be compromised when production-related processes (growth, milk or egg production) demand so many resources that coping and immune responses are decreased or compromised (Knap 2005, 2012; Prunier, Heinonen, and Quesnel 2010).

Selection for increased robustness can include selection for traits associated with fitness, including survival rates, leg structural soundness, and longevity (Ludemann, Amer, and Hermesch 2013; Merks, Mather, and Knol 2012). In some species, health-related traits like mastitis scores, measures of immune response, or measures of intensity or duration of disease symptoms may be included. Selection for a combination of disease resistance and disease tolerance has been and

continues to be researched and discussed (Doeschl-Wilson and Kyriazakis 2012a,b; Guy, Hermesch, and Thomson 2012).

In some cases, there may be genetic antagonisms among production and robustness traits. A negative trend in robustness, however, can be stopped or even reversed if the trait is measured and selected for an index that takes the economic importance of robustness into account (Knap 2005, 2012; Ludemann, Amer, and Hermesch 2013; Neeteson-van Nieuwenhoven, Knap, and Avendano 2013). Selection for measures of animal robustness—including survival, health, morbidity, uniformity, and immune function—under the commercial conditions has increased animal adaptability to a wider range of environments and produced more robust populations (Neeteson-van Nieuwenhoven, Knap, and Avendano 2013).

Selection in dairy cattle is an example of an ongoing refinement of the selection objectives (Miglior, Muir, and Van Doormaal 2005; Shook 2006; VanRaden 2004) to include welfare traits with economic value. From 1971 to 2003, the percentage relative emphasis on the nonyield traits (fitness, soundness, and reproduction) increased from 0 to 45%. It has been suggested that selection for welfare and fitness traits should be increased further to decrease the metabolic stressors placed upon higher-producing cows and to improve welfare (Fisher and Mellor 2008; Oltenacu and Algers 2005; Oltenacu and Broom 2010).

Selection for Behavioral Change

A second alternative is selection to change the behavior of animals to be better adapted to the production system (Canario et al. 2013; D'Eath et al. 2009). Under more intensive livestock production systems, animals are raised in groups and population social interactions and aggression can be altered with genetic selection to breed animals that are better suited to group housing. Divergent selection for feather pecking in layer hens has produced populations with different levels of feather pecking, aggression, and performance (Kjaer, Sørensen, and Su 2001; Su, Kjaer, and Sørensen 2005). Similar selection was conducted by Boulay and colleagues (2006) with naked-neck broilers. In both experiments, egg production and feed efficiency were lower in the high line. Selection for positive social effects by utilizing group selection or multitrait selection for productivity and positive indirect genetic social effects has improved productivity while increasing survival (Craig and Muir 1996; Muir 1996; Muir, Bijma, and Schinckel 2013).

Measuring behavior on hundreds to thousands of animals to implement a genetic selection program raises a number of practical implementation issues (D'Eath et al. 2009). More easily measured proxy traits can be used if shown to be highly related to the behavioral trait. For example, the number of skin lesions has been shown to be an acceptable proxy trait for aggression in pigs (Turner 2011; Turner et al. 2006, 2009). As pointed out by D'Eath and colleagues (2009), however, there may be unintended consequences of using proxy measurements because the underlying biological changes may not result in the desired changes in the behavioral trait. This supports the need for collaboration among geneticists and ethologists in behavioral selection procedures (D'Eath et al. 2009).

In addition, some behavioral problems occur in sudden unpredictable outbreaks (e.g., cannibalism and intense feather pecking in poultry; tail biting and flank biting in pigs) and are difficult to study (D'Eath et al. 2009). An understanding of the development of such behaviors, and associated neurobiological changes among animals during an outbreak, is needed (Brunberg et al. 2013; Zonderland et al. 2011).

Selection for Social Effects

Many modern farm animal housing systems include animals kept in groups that allow social interactions (Muir 1996; Rodenburg et al. 2010). Social interactions among individual animals including cooperation or competition affect the performance of the group of animals.

Group selection or individual selection for performance (e.g., egg production or growth) in family groups automatically includes an animal's IGE, or social effects, on the performance of others in the groups, including survival (Bijma, Muir, and Van Arendonk 2007; Bijma et al. 2007; Muir, Bijma, and Schinckel 2013). Alternatively, an animal's IGEs can be directly estimated using advanced statistical techniques (mixed model methodology) and selected against as a second trait in a multitrait selection program. Use of group selection for egg production has been evaluated in layers kept in multiple-hen cages (Craig and Muir 1996; Muir 1996; Muir and Craig 1998). Multitrait selection for growth and positive IGEs in quail has also been investigated (Muir 2005; Muir, Bijma, and Schinckel 2013). Group selection for production was shown to also cause positive changes in behavior, stress physiology, and immunology (Cheng and Muir 2005; Cheng, Freire, and Pajor 2004). Multitrait selection for growth and positive IGEs was shown to improve growth as well as survival and feed efficiency in quail (Muir 2005; Muir, Bijma, and Schinckel 2013). Similarly, individual selection in family groups was shown to be an even more robust method to bring about the same positive results (Muir, Bijma, and Schinckel 2013). In layers and in other farm animals that show aggression, selection for increased production in ways that allow positive associative effects to also be selected, such as group selection or multitrait selection for positive direct and IGEs, should be used.

Selection for improved animal welfare should continue to include a combination of selection for robustness, animal

behavior, and social effects in most species of farm animals. In general, selection for improved animal welfare results in improved animal management and overall welfare, as well as increased economic returns (Bolhuis et al. 2009; Ellen et al. 2008; Muir 2005; Muir, Bijma, and Schinckel 2013; Peeters et al. 2012; Rodenburg et al. 2009).

Animal Handling, Transport, and Euthanasia/Slaughter

Animal handling, transport, and slaughter have been intensively researched and are probably the areas in which there have been the most practical improvements in animal welfare in the last few decades. Each of these is a relatively short-term stressor for the animal, which makes implementing changes more straightforward than changing housing systems or on-farm management practices. In addition, many of these changes have economic benefits. For example, decreasing bruising during handling and transport improves not only animal welfare, but also carcass quality and yield. Improving the quality of human-animal interactions on the farm during handling has also been shown to result in increased productivity in pigs and dairy cattle (Rushen and de Passillé 2010).

Handling and Transport

Handling of animals during loading and unloading as well as transportation from the farm to the slaughter facility have long been a challenge, although research and research application have led to marked improvements. Some very simple techniques can improve the movement of animals during loading and unloading of transport trailers. These include understanding the behavioral principles involved in handling livestock (such as the influence of the handler within the animal's flight zone), minimizing overloading of crowd pens, removing visual distractions from handling facilities, providing nonslip flooring, and using low-stress moving aids instead of relying on electric prods (Grandin 2010a). Numerical scoring systems have also been developed to assess the adequacy of handling—vocalization rates of cattle and pigs being an example (Grandin 2010b,c, 2015). There has also been research across species on technical improvements to the handling and transport environments. These include improvements in the design of loading ramps for cattle and pigs (Grandin 2004, 2015) and transport vehicles for poultry (Weeks 2014), as well as development of mechanical catchers to replace hand-catching of broiler chickens (Weeks 2014) and lifters to move nonambulatory cattle (Grandin 2015). Research has also been instrumental in identifying management practices that can decrease transport stress—e.g., those related to stocking density in transport crates or trucks, provision of food and water, and improving thermal conditions (McGlone et al. 2014; Garcia et al. 2015; Grandin 2015; Tucker et al. 2015).

Even with these kinds of advances, challenges continue. Some of the most significant current challenges, reflected in the recent prevalence of undercover videos showing abusive handling on farms or during slaughter, are related to personnel training and appropriate oversight of animal caretakers. Social science research in Australia has revealed the role that understanding workers' attitudes and capabilities plays in ensuring good handling and shaping effective training programs (Hemsworth et al. 2002).

7 Emerging Topics

Since the 1990s, agricultural animal welfare has evolved from that of a "niche market" or special interest topic relevant only to developed nations to a focal issue of importance in discussions about sustainable food production systems, global food security, and food safety that impact developing nations as well. As noted previously, in the United States, consumers with little direct involvement with animal agriculture have begun to question contemporary food production methods and attend to corresponding public discussions. This shift has manifested recently in efforts to connect with and exert some control over food production via involvement in urban agriculture and participation in debates about related technologies, such as antimicrobial use. In addition, greater attention by both scientists and members of the general public to the quality of life experienced by agricultural animals has prompted scientific inquiry into underexplored aspects of their welfare, such as their cognitive abilities and subjective emotional states. Although major advancements have been made in these areas within the past decade, additional studies and coordinated approaches to develop and apply new knowledge in these areas are needed.

Role of Animal Welfare in Sustainability

Growing public awareness of the state of the environment and the food supply has turned ethically conscious eating into a mainstream trend. Government policies over the last few decades that promote efficiency (i.e., that aim to produce the most output per unit of input) have led to increased scrutiny of intensive production systems, as well as claims that these systems are not sustainable (Bovay and Sumner 2013; Fraser 2005; Singer and Mason 2006; Steinfeld et al. 2006). Public health, fair access to food, and environmental sustainability are being articulated as new goals for national food policies (Pinstrup-Andersen and Watson 2011).

Whereas the term sustainability is often used in an environmental context, it actually encompasses many other kinds of concerns, although there is no single agreed-upon definition. Sustainability has been used as shorthand for addressing conflicts or intractable problems involving climate, decreasing emissions, and other natural hazards. It has also been used in debates regarding food, water, and energy security where local, regional, national, and global scales seem to be more and more interdependent (CAST 2010, 2013). Additionally, multinational companies, including food retailers, are increasingly considering sustainability to be a core element of their social responsibility programs and thus a key driver of their purchasing decisions for many different types of products, including those from animals.

Animal welfare has emerged as one of the central concerns for ethically based consumer food preferences (Bovay and Sumner 2013; Lusk 2011). The challenge is to balance the quality of life for food animals against other sustainability considerations for food production, such as food security and affordability, food quality and safety, environmental impacts, land use planning, and the health and economic security of rural communities and agricultural workers (Niles 2013).

Tucker, Mench, and von Keyserlingk (2013) and Place (2018) provide examples of the ways in which animal welfare can align with other sustainability considerations, and where it is sometimes in conflict. For example, appropriate animal handling not only decreases stress and injury to the animals, but it can improve the quality and safety of their meat while also lessening production costs. Similarly, decreasing health problems like lameness in dairy herds would not only improve welfare, but it would have environmental benefits. In contrast, some more extensive production systems that meet consumer expectations for providing animals with space and behavioral freedom may have negative effects on the environment and food affordability. For example, egg production costs are higher and environmental impacts are typically greater for cage-free systems than for cage systems for laying hens (Mench and Rodenburg 2018). To resolve or minimize these kinds of conflicts will involve building mechanisms for sustained engagement between and among producers, industry, regulators, and the general public (Anthony 2012) and gaining a better understanding of the complexity and interrelatedness of the different aspects of the food system.

Antimicrobial Resistance

Because of concerns related to antimicrobial resistance, the use of antimicrobials in food-producing animals is a topic of much discussion. Strategies to address antimicrobial resistance include discontinuing production uses (e.g., for growth promotion and feed efficiency uses); enhanced use of other means of infectious disease prevention (e.g., improved

biosecurity measures, increased use of vaccination to prevent viral diseases that may often be followed by secondary bacterial infections); greater attention to how antimicrobials are selected and used in prevention and treatment protocols (i.e., targeted application, increased veterinary oversight); and the identification, development, and use of nonantibiotic alternatives (Hume 2011; Seal et al. 2013) for prevention, control, and treatment (e.g., organic acids in feed and water [Upadhaya, Lee, and Kim 2014], gene-encoded natural antibiotics [Linde et al. 2008], prebiotics and probiotics [Callaway et al. 2008], bacteriophages [Miller et al. 2010]).

A related emergent animal welfare problem is that increased consumer demand for meat from animals that have not been treated with antimicrobials for any purpose—production or therapeutic—has caused and may continue to cause producers and veterinarians to withhold treatment for animals intended for the consumer market. The negative impacts on animals' welfare resulting from disease that could be prevented and/or that cannot be controlled and treated are significant and unacceptable.

Global Developments and Challenges

Until recently, public concern about the welfare of food animals has been an issue mainly in the developed countries. That situation, however, is changing rapidly. A major factor affecting that change is the growing global demand for animal products, especially in Asia and South America (NRC 2015), which has been accompanied by an increasing globalization of food production (Thornton 2010). This globalization has delivered many benefits, but it has also resulted in situations in which producers who want to access international export markets are increasingly required to abide by international standards, including standards for animal welfare.

Multinational corporations have played an important role in establishing animal welfare standards globally. McDonald's, for example, requires an annual independent animal welfare audit of all slaughter plants that provide meat to the McDonald's worldwide supply chain (McDonald's 2010–2017). Other corporations have instituted global purchasing preferences related to animal welfare—such as Unilever, which announced a commitment to source only cage-free eggs in all of its products globally by 2020 (Unilever 2017). These examples of animal welfare standards or preferences are often viewed as a component of corporate sustainability and social responsibility, and they are thus treated by corporations as "precompetitive" issues rather than as marketing mechanisms. Another prominent actor in promoting global animal welfare standards is the European Union—for example, via the establishment of bilateral trade agreements that include consideration of animal welfare. As a result of such a trade agreement, Chile adopted regulations on the transport and slaughter of animals (Eurogroup for Animals 2013).

Another significant global development is the OIE's incorporation of animal welfare into its Strategic Plan. The OIE launched an international animal welfare standards-setting initiative meant to address global interest and concern in animal welfare (Stuardo Escobar et al. 2018) and to challenge member states and industry to participate more proactively in animal welfare issues. With respect to food animals, the OIE now has animal welfare standards for the transport of animals by land, sea, and air; slaughter; killing of animals for disease control purposes; beef cattle and broiler chicken production; and the farming, slaughter, killing (for disease purposes), and transport of fish.

Whereas global science-based standards like those established by the OIE can provide important principles for producing, transporting, and slaughtering animals, they must also be sensitive to local realities (Gallo and Tadich 2018; Thornber and Mellor 2018). For this reason, there has been increased focus on capacity building related to animal welfare in developing countries. The OIE has instituted capacity building programs in a number of countries focusing on improving training related to animal welfare topics, including preslaughter management and slaughter. In 2009, the Food and Agriculture Organization of the United Nations (FAO) issued a report on capacity building for animal welfare, which provided a series of recommendations that included the FAO integrating animal welfare into its existing programs, assisting in the dissemination of research findings to member countries, and developing strategic partnerships, including with the OIE. Subsequently, the FAO developed a portal, the Gateway to Farm Animal Welfare (FAO 2018), to provide information about a variety of topics ranging from standards to training resources.

Although the purpose of developing animal welfare guidelines is to promote better treatment of animals and respond to public concerns, it can result in negative economic consequences for some producers, particularly those who are smaller or less well capitalized and thus less able to absorb costs associated with compliance. On the other hand, such producers can also benefit from adopting animal welfare standards to access niche markets. For example, Namibia became Africa's largest exporter of beef to the European Union as a result of adopting an assurance scheme that included standards not only for hygiene but also for animal welfare (Bowles et al. 2005).

Giving farmers decision-making tools to manage their animals and herds, especially to prevent and address outbreaks and identify poor animal welfare, will help farmers minimize risks to themselves and their animals. Obtaining

local data is crucial in promoting successful strategies that farmers can adopt as best practices. Livestock production in developing regions and tropical countries is faced with a number of challenges to ensure sustainability (Cloete 2013). The external challenges include periods of nutrient undersupply, abundance of low-quality roughages, parasites, and disease (Cloete 2013; Petherick 2005). Selection for animals under harsher environments must include selection for fitness, including disease resistance, survival, reproduction, and heat tolerance (Bergsma and Hermesch 2012; Cardillino and Bayazoglu 2009; Goddard and Hayes 2009; McManus et al. 2009; Wang et al. 2018).

Urban Agriculture

Urban agriculture, which has been defined as "growing, processing and distribution of food and other products through intensive plant cultivation and animal husbandry in and around cities" (Bailkey and Nasr 2000), is increasing in popularity throughout North America. The drivers are varied, but they include concerns about large-scale and nonlocal food production, food safety and human health, animal welfare, and the environmental impacts of food production (Brinkley and Kingsley 2018; Butler 2012). Urban farmers range from individuals who produce food for mainly personal consumption and/or to subsidize household income to larger-scale local commercial producers (Hendrickson and Porth 2012). Livestock currently appears to make up a relatively small, although growing, sector of urban farming, with most urban animal farmers raising so-called "microlivestock"—poultry, bees, fish, rabbits, and/or sheep and goats. According to an exploratory web-based survey of 48 U.S. cities (McClintock, Pallana, and Wooten 2014), poultry (particularly chickens) are the most regulated and farmed species, kept by 90% of the 134 respondents (bee keeping was not included).

This growth in urban livestock farming raises various challenges, including those related to animal welfare. Perhaps the most significant one is a lack of evidence-based information that can be used by municipalities to set zoning regulations and reasonable standards for animal housing and care, because existing information tends to be more applicable to large-scale farming operations (Brinkley, Mench, and Kingsley 2018). A recent survey of nearly 1,500 backyard chicken owners in the United States (Elkhoraibi et al. 2014) revealed some of the other challenges faced by urban farmers. Many owners were unfamiliar with common infectious poultry diseases such as avian influenza, exotic Newcastle disease, or Marek's disease, and most had not had their chickens vaccinated. Even when owners were aware of infectious diseases, it was difficult for them to vaccinate their birds because vaccines are not sold in small enough quantities for use in small to mid-sized flocks. Biosecurity practices were very variable, and owners expressed a need for more information about biosecurity as well as more information about detecting health problems and humane methods of euthanasia/slaughter. Other challenges included a lack of processing facilities for small numbers of birds, lack of access to veterinarians with expertise in avian/poultry medicine, and difficulty obtaining nutritionally adequate feed at a reasonable cost.

Closely related to animal welfare are the issues of manure management and removal, liquid runoff, setbacks for animal housing, disposal of dead animals, and setting limits for numbers of animals (Brinkley and Kingsley 2018; Butler 2012). Testing for soil contaminants, especially in urban locations with current or past industrial activity, is important to both human and animal health. Evidence-based ordinances and standards to address these issues could minimize or eliminate nuisance complaints, improve animal and human health, and decrease food safety and environmental problems.

Assessing Animals' Mental States

Cognition

Farm animal cognition has at times presented a challenge—not just in regard to how it can be scientifically examined, but also relative to its perceived relevance and direct applicability to farm animal care. Among animal welfare scientists, the importance of animals' psychological capabilities and mental processes (cognition) is increasingly acknowledged as a significant driver of the level of welfare they experience in various environments. This parallels philosophers' growing recognition that the presence or absence of various cognitive capacities allows individuals to benefit or be harmed in various ways. Philosophers have also emphasized that the presence or absence of certain cognitive capacities in animals has important implications in terms of their moral status and therefore the obligations owed to them (e.g., DeGrazia [1996]; Regan [1983]; Singer [1993]; Varner [2012]). Consequently, various aspects of animal cognition have been studied with an eye toward understanding the specific mental capacities farm animals possess and how these may be scientifically and ethically relevant to contemporary farm animal welfare debates.

One rudimentary aspect of animal cognition—perception—warrants more research attention because the way in which animals perceive the information they acquire may significantly impact their welfare. For example, perception of a threat in the environment can cause fear, particularly when an animal is unable to do anything to avoid it, as can happen in some agricultural production systems. Prolonged

experience of fear is likely to be associated with distress and in consequence poor welfare (Dantzer 2001; Wemesfelder 1984).

The emerging study of cognitive bias in agricultural animals also warrants further investigation. It is well known that in humans, emotional states influence cognitive processes, and vice versa, in measurable ways. For instance, unhappy, anxious, or depressed people attend to threats in their environment more than happy people, are more likely to make negative judgments about ambiguous stimuli (Mendl et al. 2009), and may have decreased memories of and anticipation of positive events. This has led to methods being devised (Harding, Paul, and Mendl 2004) to evaluate cognitive bias in animals as an indirect measurement of their emotional states. Identifying the neural mechanisms underlying cognitive bias and developing tests for use of such biases in production environments should also be priority areas for further study as suggested by Mendl and colleagues (2009). It is also important to understand the factors that contribute to the development of positive and negative cognitive biases in agricultural animals and to determine the extent to which genetic and population differences exist.

The capacities for long- and short-term memory affect retention of learned associations between specific stimuli and animals' perceptions and recall of them as threatening, neutral, or positive. Thus, memory impacts animals' experiences and behavior (Croney and Newberry 2007) and is also likely to be connected with their development of positive or negative cognitive bias. Although some studies have been conducted on aspects of memory in agricultural animals (Arts, van der Staay, and Ekkel 2009; Kovalčik and Kovalčik 1986; Laughlin, Huck, and Mendl 1999; Lee, Colgate, and Fisher 2006; Mark and Watts 1971), to date these remain somewhat limited in both species and scope. Kendrick and colleagues (2001) began a promising line of research focused on facial recognition in sheep, but few studies have sufficiently explored farm animal memory and its implications. Because memory is likely to impact the quality of social interactions that group-housed animals experience, particularly as a function of their recall of encounters with familiar and unfamiliar conspecifics, memory in farm animals should be a priority area for further investigation.

Despite the link between animal cognition and welfare, many aspects of farm animal cognition thus remain poorly understood; there have also been insufficient attempts to apply these concepts to farm animal care and management. For example, there has been limited research on practical methods to engage farm animals mentally in enriching, cognitive problem-solving tasks (Manteuffel, Langbein, and Puppe 2009; Meehan and Mench 2007) that could help to mitigate undesirable behaviors, enhance their use of space, and improve their adaptability to complex environments.

Positive Welfare

Most animal welfare research has focused on assessment and amelioration of negative states such as fear, pain, and distress. There is now increasing interest, however, in the validation of measures of positive affect (reviewed in Boissy and colleagues [2007] and Yeates and Main [2008]). The primary goal is to improve the quality of life for animals by providing them with rewarding experiences, or, as Boissy and colleagues (2007) state, to give animals a "good" life rather than just a "not so bad" life. Research to validate these measures is at an early stage. Behavioral measures that have been suggested to be potential indicators of positive effect include play, anticipatory behaviors, facial expressions, vocalizations, affiliative behaviors, grooming, and exploration. Potential physiological measures include immunological function, brain imaging, and neurotransmitter (e.g., endorphins, oxytocin, or serotonin) secretion. As indicated earlier, studies of cognitive function—for example, the reward value of challenging experiences (Meehan and Mench 2007) or cognitive biases—could also provide important information about the causes and correlates of positive effect. Last, there is interest in assessing the health consequences of inducing positive emotions (Boissy et al. 2007).

8 Future Needs

Adequately addressing the challenges posed by increasing public concern about animal welfare requires new knowledge and approaches, greater inclusiveness, and improved communication between scientists, policymakers, and the public. In addition, there is need for increased national coordination of research, outreach, and policy-setting efforts. This section provides a brief overview of some areas considered to be of high priority in attaining the goals outlined within the context of other social, economic, and environmental components/aspirations.

Area 1: Increase Capacity for Scientific Research on Animal Welfare in the United States

As discussed in section 2, there have been many important theoretical and applied research gains in animal welfare science. Many of these, however, have come about because of a sustained commitment within the European Union to funding animal welfare research during the last few decades. The United States has lagged behind its European and Canadian counterparts, and the number of researchers and the knowledge base relative to public concern are now imbalanced (Johnson 2009). A recent National Academy of Sciences report (NRC 2015) identified as a priority the need to build capacity and increase funding for research in agricultural animal welfare in the United States, with a focus on U.S. production systems and management and in the context of the broader sustainability considerations affecting U.S. agriculture. Key research topics identified in the report, and elaborated here, follow.

- Development of alternatives/refinements for painful management procedures (e.g., dehorning, beak trimming, castration)
  - Cost-effective, safe, and easy-to-administer methods of pain relief
  - Environmental/genetic modifications to decrease problematic behaviors/carcass quality issues that lead to the need for these procedures
  - Refinement of current procedures that result in reductions in the severity of acute and chronic pain (e.g., determining the best age/physiological stage at which to perform the procedures, technical improvements in methodology)
- Alternatives/refinements of euthanasia (including depopulation) and slaughter methods to decrease pain and distress; validation of criteria for timely on-farm culling; genetic methods to eliminate need to euthanize male chicks (i.e., genetic control of gender)
- Improved handling and transportation to decrease injury and distress (e.g., thermal stress)
  - Identification and reduction of sources of fearfulness and injury during handling and transport
  - Development of better handling and loading methods and aids
  - Modification of transport vehicles
  - Development of improved stress measurement and mitigation methods
- Development and refinement of production systems that provide animals with more behavioral opportunities, including environmentally enriched systems and more extensive systems (e.g., loose housing, free-range or pasture-based systems), while maintaining good animal health. Specific areas of research (dependent upon species and system) may include the following:
  - Environmental and genetic modifications to decrease the impact of thermal and environmental stressors and to decrease animal stress susceptibility (e.g., heat-tolerant breeds)
  - Methods for improving range/pasture use and management
  - Development and field testing of enrichments to ensure effectiveness and safety
  - Methods for better managing animal social groups, including determination of space, social interaction, and resource provision needs, as well as genetic modifications that decrease the performance of undesirable social behaviors (e.g., excessive aggression)
- Decreasing musculoskeletal disorders (e.g., lameness in swine, meat-type poultry, cattle; osteoporosis and subsequent bone breakage in egg-laying birds) and other health and behavioral problems associated with high rates of production, including as applicable via the following:
  - Genetic selection and breeding programs
  - Modification of nutrition and/or feeding programs
  - Modification of housing/management
  - Development of effective veterinary interventions
- Development of methods for dealing with nutritionally based problems, including the following:

  - Nutritional deficiencies/imbalances in pasture-based and organic systems
  - Abnormal behaviors associated with the use of feed restriction (e.g., to prevent obesity in animals selected for high rates of intake such as broiler breeders and sows)
  - Low body condition scores due to high production demands
  - Negative health effects associated with feeding high-concentrate diets
  - Potentially negative health effects of alternative (e.g., low-cost, locally available) feedstuffs
- Developing new preventive and prophylactic strategies to maintain good animal health in alternative management systems, such as organic and antibiotic free, that prohibit the use of particular current disease prevention or treatment methods
  - Development of preventative and treatment strategies to decrease the incidence and severity of health problems, including infectious and noninfectious diseases and parasites
- Improved management methods for young/neonatal animals to improve later stress competence and adaptability via the following, for example:
  - Incubation enhancement
  - Environmental enrichment
  - Feeding strategies
  - Human-animal interactions
  - Social interactions
  - Lower stress weaning
  - Genetic selection and breeding programs
- Development and validation of outcome-based (health and behavior) welfare assessment criteria that can be measured noninvasively, including automated measurement technologies that can be used to streamline the use of these criteria for on-farm/large-scale welfare assessment

Of course, in addition to these priorities, research needs to continue on basic aspects of animal biology and psychology that are important for understanding and improving animal welfare, as well as to explore the emerging topics discussed in sections 6 and 7, such as animal cognition, genetics and genomics of animal welfare, and positive welfare. Because research funding is often limited, it will be important to develop mechanisms for prioritizing, coordinating, and systematically addressing each of these research areas. It will also be essential to have sufficient capacity to continue progress in high-priority areas. This will require taking a more broad-based and transparent approach to research and communication efforts, as discussed in the next section.

Area 2: Increase Focus on Transdisciplinary Aspects of Animal Welfare Research

As discussed earlier, animal welfare science is by its nature multidisciplinary; it involves not only the integration of information about animal behavior, health, and physiology, but it also depends on scientific input regarding breeding, housing, and management derived from related disciplines in the biological and agricultural sciences. Given the multifaceted array of political, ethical, economic, social, and food policy issues associated with animal welfare (and animal agriculture in general), it is also critical to conduct socio-ethical research to ensure that any solutions developed to address problems are sustainable (NRC 2015). Social scientists, philosophers, and ethicists can provide insights into the cultural, economic, demographic, and attitudinal variables that affect farmers' willingness to adopt sustainable practices (Blokhuis et al. 2013; Karami and Keshavarz 2010). They can also help to elucidate the values underlying the decision making of the various food system stakeholders, including the values that contribute to differing perspectives about the risks and benefits of existing and new practices and technologies in animal production (Croney and Anthony 2011).

Addressing questions about the sustainability of animal production systems will require a different way of thinking about animal science research that involves holistic, integrated approaches (NRC 2015). The Coalition for Sustainable Egg Supply project provides a working example of this research model. The project was a multidisciplinary commercial-scale research endeavor incorporating assessment of five elements of the sustainability of egg production: hen health and welfare, environment, worker health and safety, economics, and egg safety and quality (Swanson, Mench, and Karchar 2015). This project incorporated broad-based stakeholder input during both the planning and execution stages of the research, and it also involved outreach efforts and funding via the establishment of a public-private partnership (Mench, Swanson, and Arnot 2016). Similar approaches to conducting and funding research will be critical in the future for assessing and balancing sustainability considerations. Key research topics identified in the report, and for consideration here, include the following:

- Integration of relevant agricultural economics research to inform decision-making
  - Costs of new procedures/methods/tools developed to improve animal welfare
  - Implications of regulating new outcomes vs. market-based solutions
  - Consumer perceptions of and demand for new procedures/methods/tools

- Consumer willingness to pay for new procedures/tools
- Understanding the changing roles and implications of consumer ethics, values, and beliefs relative to animal welfare and sustainable agriculture

Area 3: Develop Coordinated Mechanisms for Policy Setting

Science and scientists not only have an important role in moral deliberations relating to animal welfare, but also increasingly have become integral in forming policy involving agricultural and food issues. "Good governance" is essential to help coordinate workable and socially appropriate solutions in these areas. Good governance is "the exercise of authority or management of resources through institutions, policies, traditions, cultures, and societal norms" (Pinstrup-Andersen and Watson 2011) and "involves the translation of collective moral intentions into effective and accountable institutional actions" (McDonald 2001).

Coordinated multidisciplinary approaches using good governance are necessary to ensure that all stakeholders' interests are reflected in policy formation and that the distribution of burdens and benefits among stakeholders associated with different courses of action are accounted for appropriately and justly (Thompson 2010). They can also help to ameliorate conflicting interests, make costs related to risks more evident, deliver benefits desired by society, and see to it that environmental integrity, economic resilience, and social well-being are not overlooked in the prioritization of policies and strategic initiatives (see, for example, Swanson et al. [2011]). In addition, research should be conducted to understand how various stakeholders (e.g., consumers, producers, and other food system stakeholders) integrate science, values, and preferences in decision making about the sustainability of food production (Anthony 2012; Thompson and Nardone 1999).

An example of such "good governance" is the Canadian NFACC code of practice formation process described above. The codes (standards) are carefully formulated within a framework that includes scientific and diverse stakeholder input, government participation and sanctioning of the process, and public transparency (NFACC 2017). Similar coordinated national initiatives should be developed in the United States and include transparent and accountable processes by which decision makers are selected; formal opportunities for inclusive, productive exchange of ideas, discussion, and debate; and sufficient capacity for the governing organization (and representatives) to effectively and equitably manage its resources and implement sound policies.

Area 4: Communicating Animal Welfare

Effective communication about animal welfare is necessary to advance public understanding and improve application of the related science. Consumers should have access to information from credible sources, including the scientific community, to help them navigate the maze of choices involved in selecting their food, whereas farmers may require help in examining the social and ethical aspects of food production in order to support more efficient resource use and to produce products that consumers will find acceptable. Finally, policymakers are wrestling with how to develop and enhance sound food and agricultural policies that meet consumer demands and also promote economic expansion for the agricultural industries.

Addressing the scientific aspects of agricultural animal welfare is challenging and complicated by the need to also engage the related ethical concerns when communicating with the public (Broom 2010; Croney and Anthony 2014; Harper and Makatouni 2002; Swanson, Mench, and Karcher 2015). The wide range of interested stakeholders—including farmers, food distributors and retailers, policymakers, the media, and the general public—must be considered along with the differing perceptions and levels of knowledge about animal agriculture and animal welfare that exist. Not only must animal welfare communications be tailored to the different "publics" that exist, it is also important to identify which information is best suited for the target audience. Communicating about animal welfare is therefore not straightforward. Multiple ethical views and norms must be considered (see section 2).

McKendree, Croney, and Widmar (2014) suggest that change may be needed in the ways the U.S. livestock and poultry industries and governmental and academic institutions engage with the public on animal welfare. For example, very few members of the public appear to seek out industry or academic sites as sources of information on animal welfare. Thus, relying on traditional venues as modes of communication may be ineffective. Additionally, the purpose of the communication must be clear and targeted to the specific audiences of interest, given the topic. Different strategies are needed depending on whether the goal is to merely transfer information to the public, advocate for a particular position (e.g., engender support for certain animal production practices), reassure the public on a particular topic, or provide an opportunity for dialogue.

The Cooperative Extension System (CES) has a critical role to play in communicating information about animal welfare to this broad array of stakeholders. Although information about animal welfare is slowly being disseminated

through extension outreach, there is a need for the CES to provide more training in the basics of animal welfare for the animal agriculture industries so they can adequately address the questions and concerns of the public. Consumers also want to be informed about the trustworthiness of the sources of food they purchase, as well as the type of technology that was used to produce it and its intended and unintended consequences, including the consequences for animal welfare.

For this communication to be effective, there will need to be more extension experts who are trained in the use of a wide variety of electronic technologies. These individuals will also need to have a good understanding of both the science-ethics interface related to animal welfare (Croney et al. 2012; Pielke 2007) and the mechanisms that promote positive behavioral change. Improved capacity building relative to extension educator expertise on agricultural animal welfare is therefore necessary to ensure that cooperative extension can properly facilitate information transfer on animal welfare both to the public and traditional land-grant university audiences. As is the case for meeting the scientific/discovery needs for animal welfare, strategic coordination and funding approaches that prioritize extension and public engagement efforts on the subject are necessary. These ideally should be tied to future opportunities that are developed to advance U.S. capacity and goals toward improved agricultural animal welfare.

Appendix A: Abbreviations and Acronyms

AAALAC	Association for the Assessment and Accreditation of Laboratory Animal Care
AMDUCA	Animal Medicinal Drug Use Clarification Act
AWBU	Animal well-being units
CES	Cooperative Extension System
CO_2	Carbon dioxide
CRISPR	Clustered regularly interspaced short palindromic repeats
CSR	Corporate social responsibility
DNA	Deoxyribonucleic acid
FAO	Food and Agriculture Organization of the United Nations
FASS	Federation of Animal Science Societies
IGE	Indirect genetic effect
kg	Kilogram
mg	Milligram
NFACC	National Farm Animal Care Council
NGO	Nongovernmental organization
NSAID	Nonsteroidal anti-inflammatory drug
O_2	Oxygen
OIE	World Organisation for Animal Health
RNA	Ribonucleic acid
WQA	Welfare quality assurance
WTP	Willingness to pay

Appendix B: Glossary

Allostasis. The process by which an organism's equilibrium is maintained in response to psychological and environmental stressors.

Biocentric. The idea that species have value in themselves and, therefore, should be protected.

Consequentialists. Those who think that the morality of an action or a practice depends on its consequences.

Contractarianism. The idea that animals are owed good husbandry in return for the good they do humanity.

Epidemiological. The incidence, distribution, and control of disease in a population.

Nonconsequentialists. Those who think that the morality of an action or a practice depends on something other than its consequences.

Transcriptome. The ability to quantify RNA by the genes used to produce it.

Utilitarianism. A version of consequentialism that takes into account the happiness of all affected human beings and any animals that are capable of being happy.

Literature Cited

Aggrey, S. E. 2010. Modification of animals versus modification of the production environment to meet welfare needs. *Poultry Sci* 89:852–854.

Allender, W. J. and T. J. Richards. 2010. Consumer impact of animal welfare regulation in the California poultry industry. *J Agr Resour Econ* 35 (3): 424–442.

American Veterinary Medical Association (AVMA). 2005. A comprehensive review of housing for pregnant sows. *J Am Vet Med Assoc* 227 (10): 1580–1590, https://www.avma.org/KB/Resources/Reports/Documents/sow_housing_tfr.pdf (29 December 2014)

American Veterinary Medical Association (AVMA). 2013. *Literature Review on the Welfare Implications of Swine Castration*, https://www.avma.org/KB/Resources/LiteratureReviews/Documents/swine_castration_bgnd.pdf (29 December 2014)

Anderson, D. M., C. Winters, R. E. Estell, E. L. Fredrickson, M. Doniec, C. Detweiler, D. Rus, D. James, and B. Nolen. 2012. Characterising the spatial and temporal activities of free-ranging cows from GPS data. *Rangeland J* 34 (2): 149–161.

Anon. 1997. *Treaty of Amsterdam Amending the Treaty on European Union, the Treaties Establishing the European Communities and Certain Related Acts*. Office for Official Publications of the European Communities, Luxembourg (printed in Germany), http://www.europarl.europa.eu/topics/treaty/pdf/amst-en.pdf (30 August 2017)

Anthony, R. 2012. Building a sustainable future for animal agriculture: An environmental virtue ethic of care approach within the philosophy of technology. *J Agr Environ Ethic* (Special Supplement on Sustainable Food Production and Ethics) 25 (2): 123–144.

Appleby, M. C., J. A. Mench, I. A. S. Olsson, and B. O. Hughes (eds.). 2011. *Animal Welfare*. 2nd ed. CABI, Wallingford, United Kingdom.

Appleby, M. C., A. W. Walker, C. J. Nicol, A. C. Lindberg, R. Freire, B. O. Hughes, and H. A. Elson. 2002. Development of furnished cages for laying hens. *Brit Poultry Sci* 43 (4): 489–500.

Arts, J. W., F. J. van der Staay, and E. D. Ekkel. 2009. Working and reference memory of pigs in the spatial holeboard discrimination task. *Behav Brain Res* 205 (1): 303–306.

Aydin, A., O. Cangar, S. Eren Ozcan, C. Bahr, and D. Berckmans. 2010. Application of a fully automatic analysis tool to assess the activity of broiler chickens with different gait scores. *Comput Electron Agr* 73:194–199.

Bailkey, M. and J. Nasr. 2000. From brownfields to greenfields: Producing food in North American cities. *Comm Food Sec News* Fall 1999/Winter 2000:6, http://alivebynature.com/uploads/BrownfieldsArticle-CFSNewsFallWinter1999.pdf (18 September 2017)

Ballotpedia. n.d. States with initiative or referendum, https://ballotpedia.org/States_with_initiative_or_referendum (27 March 2018)

Banerjee, D., C. L. Daigle, B. Dong, K. Wurtz, R. C. Newberry, J. M. Siegford, and S. Biswas. 2014. Detection of jumping and landing force in laying hens using wireless wearable sensors. *Poultry Sci* 93 (11): 2724–2733.

Barnett J. L., P. H. Hemsworth, G. M. Cronin, E. C. Jongman, and G. D. Hutson. 2001. A review of the welfare issues for sows and piglets in relation to housing. *Aust J Agr Res* 52:1–28.

Baumol, W. J. 1972. On taxation and the control of externalities. *Am Econ Rev* 62:307–322.

Bench, C. J., F. C. Rioja-Lang, S. M. Hayne, and H. W. Gonyou. 2013. Group gestation sow housing with individual feeding—II: How space allowance, group size and composition, and flooring affect sow welfare. *Livest Sci* 152 (2): 218–227.

Bergsma, R. and S. Hermesch. 2012. Exploring breeding opportunities for reduced thermal sensitivity of feed intake in the lactating sow. *J Anim Sci* 90:85–98.

Bijma, P., W. A. Muir, and J. A. M. Van Arendonk. 2007. Multilevel selection 1: Quantitative genetics of inheritance and response to selection. *Genetics* 175:277–288.

Bijma, P., W. M. Muir, E. D. Ellen, J. B. Wolf, and J. A. M. Van Arendonk. 2007. Multilevel selection 2: Estimating the genetic parameters determining inheritance and response to selection. *Genetics* 175:289–299.

Blatchford, R. A., K. C. Klasing, H. L. Shivaprasad, P. S. Wakenell, G. S. Archer, and J. A. Mench. 2009. The effect of light intensity on the behavior, eye and leg health, and immune function of broiler chickens. *Poultry Sci* 88 (1): 20–28.

Blokhuis, H., I. Veissier, B. Jones, and M. Miele. 2013. The Welfare Quality® vision. Pp. 71–89. In H. Blokhuis, I. Veissier, B. Jones, and M. Miele (eds.). *Improving Farm Animal Welfare*. Wageningen Academic Publishers, The Netherlands.

Boissy, A., G. Manteuffel, M. B. Jensen, R. O. Moe, B. Spruijt, L. J. Keeling, C. Winckler, B. Forkman, I. Dimitrov, J. Langbein, M. Bakken, I. Veissier, and A. Aubert. 2007. Assessment of positive emotions in animals to improve their welfare. *Physiol Behav* 92:375–397.

Bolhuis, J. E., E. D. Ellen, G. V. Reenen, J. DeGroot, J. T. Napel, R. E. Koopmanschap, G. D. V. Reilingh, K. A. Uitdehagg, B. Kemp, and T. B. Rodenburg. 2009. Effects of genetic group selection against mortality on behavior and peripheral serotonin in domestic laying hens with trimmed and intact beaks. *Physiol Behav* 97:470–475.

Boulay, M., C. Arnould, S. Mignon-Grasteau, and H. Chapuis. 2006. Can plumage score be improved using an automatic measurement of pecking at a bunch of feathers? In *Proceedings of the 8th World Congress on Genetics Applied to Livestock Production*, Belo Horizonte, Brazil, 13–18 August 2006. 174 pp.

Bovay, J. and D. A. Sumner. 2013. Voter and consumer evaluation of restrictions on farm animal management practices. No. 150447. Paper presented at the Agricultural and Applied Economics Association and CAES Joint Annual Meeting, Washington, D.C., 4–6 August.

Bowles, D., R. Paskin, M. Gutiérrez, and A. Kasterine. 2005. Animal welfare and developing countries: Opportunities for trade in high-welfare products from developing countries. *Rev Sci Tech OIE* 24 (2): 783–790.

Brinkley, C. and J. S. Kingsley. 2018. Urban agriculture. Pp. 241–257. In J. A. Mench (ed.). *Advances in Agricultural Animal Welfare—Science and Practice*. Woodhead Press/Elsevier, United Kingdom.

Brinkley, C., J. A. Mench, and J. S. Kingsley. 2018. A method for guarding animal welfare and public health: Tracking the rise of backyard poultry ordinances. *J Commun Health* 1–8, https://doi.org/10.1007/s10900-017-0462-0 (28 March 2018)

Broom, D. M. 2010. Animal welfare: An aspect of care, sustainability, and food quality required by the public. *J Vet Med Educ* 37 (1): 83–88.

Brunberg, E., P. Jensen, A. Isaksson, and L. J. Keeling. 2013. Behavioural and brain gene expression profiling in pigs during tail biting outbreaks—Evidence of a tail biting resistant phenotype. *PLOS ONE* 3:e65136.

Buller, H. and E. Roe. 2014. Modifying and commodifying farm animal welfare: The economization of layer chickens. *J Rural Stud* 33:141–149.

Butler, W. H. 2012. Welcoming animals back to the city: Navigating the tensions of urban livestock through municipal ordinances. *J Agr Food Syst Commun Dev* 2:193–215.

California Health and Safety Code. 2008. Chapter 13.8—Farm Animal Cruelty (25990–25994). Division 20, Miscellaneous Health and Safety Provisions (24000–26217), https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=HSC&division=20.&title=&part=&chapter=13.8.&article= (26 April 2017)

Callaway, T. R., T. S. Edrington, R. C. Anderson, R. B. Harvey, K. J. Genovese, C. N. Kennedy, D. W. Venn, and D. J. Nisbet. 2008. Probiotics, prebiotics and competitive exclusion for prophylaxis against bacterial disease. *Anim Health Res Rev* 9 (2): 217–225.

Canario, L., S. Mignon-Grasteau, M. Dupont-Nivet, and F. Phocas. 2013. Genetics of behavioural adaptation of livestock to farming conditions. *Animal* 7:357–377.

Cardellino, R. A. and J. Boyazoglu. 2009. Research opportunities in the field of animal genetic resources. *Livest Sci* 120:166–173.

Ceballos, A., D. Sanderson, J. Rushen, and D. M. Weary. 2004. Improving stall design: Use of 3-D kinematics to measure space use by dairy cows when lying down. *J Dairy Sci* 87 (7): 2042–2050.

Chang, J. B., J. L. Lusk, and F. B. Norwood. 2010. The price of happy hens: A hedonic analysis of retail egg prices. *J Agr Resour Econ* 35 (3): 406–423.

Cheng, H. W. and W. M. Muir. 2005. The effects of genetic selection for survivability and productivity on chicken physiological homeostasis. *World Poultry Sci J* 61 (3): 383–397.

Cheng, H. W., R. Freire, and E. A. Pajor. 2004. Endotoxin stress responses in chickens from different genetic lines. 1. Sickness, behavioral, and physical responses. *Poultry Sci* 83:707–715.

Cloete, S. W. P. 2013. Breeding in developing countries and tropics. Pp. 1787–1795. In R. A. Meyers (ed.). *Encyclopedia of Sustainability Science and Technology*. Springer-Verlag, New York.

Coetzee, J. F., R. A. Mosher, B. KuKanich, R. Gehring, B. Robert, B. Reinbold, and B. J. White. 2012. Pharmacokinetics and effect of intravenous meloxicam in weaned Holstein calves following scoop dehorning without local anesthesia. *BMC Vet Res* 8:153.

Council for Agricultural Science and Technology (CAST). 1997. *Well-being of Agricultural Animals*. Task Force Report 130. CAST, Ames, Iowa.

Council for Agricultural Science and Technology (CAST). 2010. *Agricultural Productivity Strategies for the Future: Addressing U.S. and Global Challenges*. Issue Paper 45. CAST, Ames, Iowa.

Council for Agricultural Science and Technology (CAST). 2013. *Animal Feed vs. Human Food: Challenges and Opportunities in Sustaining Animal Agriculture Toward 2050*. Issue Paper 53. CAST, Ames, Iowa.

Cowen, T. 2006. Market failure for the treatment of animals. *Society* 43:39–44.

Craig, J. V. and W. M. Muir. 1996. Group selection for adaptation to multiple-hen cages: Beak-related mortality, feathering, and body weight responses. *Poultry Sci* 75:294–302.

Croney, C. C. and R. Anthony. 2010. Engaging science in a climate of values: Tools for animal scientists tasked with addressing ethical problems. *J Anim Sci* 88 (13): E75–E81.

Croney, C. C. and R. Anthony. 2011. Ruminating conscientiously: Scientific and socio-ethical challenges for US dairy production (invited review). *J Dairy Sci* 94 (2): 539–546.

Croney, C. and R. Anthony. 2014. Food animal production, ethics, and quality assurance. Pp. 1–10. In P. B. Thompson and D. M. Kaplan (eds.). *Encyclopedia of Food and Agricultural Ethics*. Springer Science + Business Media, Dordrecht, Netherlands.

Croney, C. C. and S. T. Millman. 2007. Board invited review: The ethical and behavioral basis for farm animal welfare legislation. *J Anim Sci* 85:556–565.

Croney, C. C. and R. C. Newberry. 2007. Group size and cognitive processes. *Appl Anim Behav Sci* 103 (3): 215–228.

Croney, C. C., M. Apley, J. L. Capper, J. A. Mench, and S. Priest. 2012. Bioethics symposium—The ethical food movement: What does it mean for the role of science and scientists in current debates about animal agriculture? *J Anim Sci* 90 (5): 1570–1582.

Curtis, S. E. 2007. Commentary: Performance indicates animal state of being—A Cinderella axiom? *Prof Anim Scientist* 23 (6): 573–583.

D'Eath, R. B., S. P. Turner, S. H. Ison, M. Farish, M. C. Jack, and A. B. Lawrence. 2009. Genetics of animal temperaments: Aggressive behavior at mixing is genetically associated with the response to handling in pigs. *Animal* 3 (11): 1544–1554.

Daigle, C. L., D. Banerjee, R. A. Montgomery, S. Biswas, and J. M. Siegford. 2014. Moving GIS research indoors: Spatiotemporal analysis of agricultural animals. *PLOS ONE* 9 (8): e104002.

Dantzer, R. 2001. Can farm animal welfare be understood without taking into account the issues of emotion and cognition? *J Anim Sci* 80 (E Suppl 1): E1–E9.

Davis, J. D., M. J. Darr, H. Xin, J. D. Harmon, and J. R. Russell. 2011. Development of a GPS herd activity and well-being kit (GPS HAWK) to monitor cattle behavior and the effect of sample interval on travel distance. *Appl Eng Agric* 27 (1): 143–150.

Dawkins, M. S. 1980. *Animal Suffering—The Science of Animal Welfare*. Springer, Netherlands. 150 pp.

Dawkins, M. S., H. J. Lee, C. D. Waitt, and S. J. Roberts. 2009. Optical flow patterns in broiler chicken flocks as automated measures of behaviour and gait. *Appl Anim Behav Sci* 119 (3): 203–209.

Dawkins, M. S., S. J. Roberts, R. J. Cain, T. Nickson, and C. A. Donnelly. 2017. Early warning of footpad dermatitis and hockburn in broiler chicken flocks using optical flow, bodyweight and water consumption. *Vet Rec* 180 (20): 499–499.

de Jong, I., C. Berg, A. Butterworth, and I. Estevez. 2012. *Scientific Report Updating the EFSA Opinions on the Welfare of Broilers and Broiler Breeders*. External scientific report, Supporting Publications 2012:EN-295. 116 pp., https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/sp.efsa.2012.EN-295 (28 March 2018)

de Passillé, A. M. and J. Rushen. 2005. Food safety and environmental issues in animal welfare. *Rev Sci Tech Off Int Epiz* 24 (2): 757–766.

DeGrazia, D. 1996. *Taking Animals Seriously: Mental Life and Moral Status*. Cambridge University Press, Cambridge/New York/Melbourne.

Dewey, C., C. Haley, T. Widowski, R. Friendship, J. Sunstrum, and K. Richardson. 2009. Using data collected for production or economic purposes to research production animal welfare: An epidemiological approach. *J Appl Anim Welf Sci* 12 (2): 105–113.

Dinev, I. 2000–2014. *Diseases of Poultry*, http://www.thepoultrysite.com/publications/6/Diseases_Of_Poultry/ (10 April 2015)

Doeschl-Wilson, A. B. and I. Kyriazakis. 2012a. The first step towards genetic selection for host tolerance to infectious pathogens. *Front Genet* 3:265, doi:10.3389/fgene.2012.00272.

Doeschl-Wilson, A. B. and I. Kyriazakis. 2012b. Should we aim for genetic improvement in host resistance or tolerance to infectious pathogens? *Front Genet* 3:272, doi:10.3389/fgene.2012.00272.

Dzikamunhenga, R. S., R. Anthony, J. F. Coetzee, S. A. Gould, A. Johnson, L. A. Karriker, J. McKean, S. T. Millman, S. R. Niekamp, and A. M. O'Connor. 2014. Pain management in the neonatal piglet during routine management procedures. Part 1: A systematic review of randomized and non-randomized intervention studies. *Anim Health Res Rev* 15 (1): 14–38.

Edwards, S. A., F. Brouns, and A. H. Stewart. 1993. Influence of feeding system on welfare and production of group housed sows. Livestock environment IV. Pp. 166–172. In E. Collins and C. Boon (eds.). *Proceedings of the 4th International Livestock and Environment Symposium*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Elkhoraibi, C., R. A. Blatchford, M. E. Pitesky, and J. A. Mench. 2014. Backyard chickens in the United States: A survey of flock owners. *Poultry Sci* 93 (11): 2920–2931.

Ellen, E. D., J. Visscher, J. A. van Arendonk, and P. Bijma. 2008. Survival of laying hens: Genetic parameters for direct and associative effects in three purebred layer lines. *Poultry Sci* 87:233–239.

Eurogroup for Animals. 2013. *The EU-Chile Free Trade Agreement—A Boost for Animal Welfare*. Eurogroup for Animals, Brussels, Belgium, http://trade.ec.europa.eu/doclib/docs/2013/december/tradoc_151962.pdf (28 March 2018)

European Commission. n.d. *Animals—Animal Welfare*, ec.europa.eu/food/animals/welfare_en (15 May 2017)

Farm Animal Welfare Committee (FAWC). n.d. Assessment of farm animal welfare—Five Freedoms and a life worth living, https://www.gov.uk/government/groups/farm-animal-welfare-committee-fawc#assessment-of-farm-animal-welfare---five-freedoms-and-a-life-worth-living (17 May 2017)

Federation of Animal Science Societies (FASS). 2010. *Guide for the Care and Use of Agricultural Animals in Research and Teaching*. 3rd ed. Federation of Animal Science Societies, Champaign, Illinois, https://

www.aaalac.org/about/Ag_Guide_3rd_ed.pdf (26 April 2017)
Fisher, M. W. and D. J. Mellor. 2008. Developing a systematic strategy incorporating ethical, animal welfare and practical principles to guide the genetic improvement of dairy cattle. *New Zeal Vet J* 56:100–106.
Fleming, R. H., D. Korver, H. A. McCormack, and C. C. Whitehead. 2004. Assessing bone mineral density in vivo: Digitized fluoroscopy and ultrasound. *Poultry Sci* 83 (2): 207–214.
Flower, F. C., D. J. Sanderson, and D. M. Weary. 2005. Hoof pathologies influence kinematic measures of dairy cow gait. *J Dairy Sci* 88:3166–3173.
Food and Agriculture Organization of the United Nations (FAO). 2018. *Gateway to Farm Animal Welfare*, http://www.fao.org/ag/againfo/themes/animal-welfare/en/ (27 March 2018)
Fraser, D. 2000. Animal ethics and animal welfare science: Bridging the two cultures. *Appl Anim Behav Sci* 65:171–189.
Fraser, D. 2005. *Animal Welfare and the Intensification of Animal Production: An Alternative Interpretation*. FAO Readings in Ethics No. 2. United Nations Food and Agriculture Organization, Rome, Italy. 32 pp.
Fraser, D. 2008. *Understanding Animal Welfare. The Science in Its Cultural Context*. Wiley-Blackwell, Hoboken, New Jersey. 336 pp.
Fraser, D. 2014. The globalization of farm animal welfare. *Rev Sci Tech Off Int Epiz* 33 (1): 33–38.
Fraser, D. and C. J. Nicol. 2011. Preference and motivation research. Pp. 183–199. In M. C. Appleby, J. A. Mench, I. A. S. Olsson, and B. O. Hughes (eds.). *Animal Welfare*, 2nd ed. CABI, Wallingford, Oxon, United Kingdom.
Fraser, D. and R. Preece. 2004. Animal ethics and the scientific study of animals: Bridging the "is" and the "ought." *Essays Philos* 5 (2): 12.
Fraser, D., I. J. Duncan, S. A. Edwards, T. Grandin, N. G. Gregory, V. Guyonnet, P. H. Hemsworth, S. M. Huertas, J. M. Huzzey, D. J. Mellor, J. A. Mench, M. Špinka, and H. R. Whay. 2013. General principles for the welfare of animals in production systems: The underlying science and its application. *Vet J* 198 (1): 19–27.
Freire, R., L. J. Wilkins, F. Short, and C. J. Nicol. 2003. Behaviour and welfare of individual laying hens in a non-cage system. *Brit Poultry Sci* 44 (1): 22–29.
Gallet, C. A. 2010. Meat meets meta: A quantitative review of the price elasticity of meat. *Am J Agr Econ* 92:258–272.
Gallo, C. S. and T. G. Taddich. 2018. Perspective from Latin America. Pp. 197–218. In J. A. Mench (ed.). *Advances in Agricultural Animal Welfare—Science and Practice*. Woodhead Press/Elsevier, United Kingdom.
Garcia, A., G. Pirner, G. Picinin, M. May, K. Guay, B. Backus, M. Sutherland, and J. McGlone. 2015. Effect of provision of feed and water during transport on the welfare of weaned pigs. *Animals* 5:407–425.
Goddard, M. E. and B. J. Hayes. 2009. Mapping genes for complex traits in domestic animals and their use in breeding programs. *Nat Rev Genet* 10:381–391.
Golub, T. R., D. K. Slonim, P. Tamayo, C. Huard, M. Gaasenbeek, J. P. Mesirov, H. Coller, M. L. Loh, J. R. Downing, M. A. Caligiuri, C. D. Bloomfield, and E. S. Lander. 1999. Molecular classification of cancer: Class discovery and class prediction by gene expression monitoring. *Science* 286:531–537.
Gonyou, H. W. 2005. Experiences with alternative methods of sow housing. *J Am Vet Med Assoc* 226:1336–3340.
Grandin, T. 2004. Principles for the design of handling facilities and transport systems. Pp. 145–166. In G. J. Benson and B. E. Rollin (eds.). *The Well-being of Farm Animals: Challenges and Solutions*. Blackwell, Ames, Iowa.
Grandin, T. (ed.). 2010a. *Improving Animal Welfare: A Practical Approach*. CABI, Wallingford, Oxfordshire, United Kingdom.
Grandin, T. 2010b. Auditing animal welfare at slaughter plants. *Meat Sci* 86:56–65.
Grandin, T. 2010c. *Recommended Animal Handling Guidelines and Audit Guide: A Systematic Approach to Animal Welfare*. American Meat Institute Foundation, Washington, D.C.
Grandin, T. 2015. *Improving Animal Welfare: A Practical Approach*. 2nd ed. CABI, Wallingford, Oxon, United Kingdom. 376 pp.
Guy, S. Z., S. Hermesch, and P. C. Thomson. 2012. Selection of pigs for improved coping with diseases and environmental challenges: Resistance or tolerance? *Front Genet* 3:281.
Harding, E. J., E. S. Paul, and M. Mendl. 2004. Animal behavior—Cognitive bias and affective state. *Nature* 427:312.
Harper, G. C. and A. Makatouni. 2002. Consumer perception of organic food production and farm animal welfare. *Brit Food J* 104:287–299.
Harrison, R. 2013. *Animal Machines* (reissue of 1964 edition). CABI, Boston, Massachusetts.
Heinrich, A., T. F. Duffield, K. D. Lissemore, E. J. Squires, and S. T. Millman. 2009. The impact of meloxicam on postsurgical stress associated with cautery dehorning. *J Dairy Sci* 92 (2): 540–547, doi:10.3168/jds.2008-1424.
Hemsworth, P. H. and G. J. Coleman. 1998. *Human-Livestock Interactions*. CABI, Wallingford, Oxon, United Kingdom.
Hemsworth, P. H. and G. J. Coleman. 2011. *Human-Livestock Interactions. The Stockperson and the Productivity and Welfare of Intensively Farmed Animals*. CABI, Wallingford, United Kingdom.
Hemsworth, P. H., G. J. Coleman, J. L. Barnett, S. Borg, and S. Dowling. 2002. The effects of cognitive behavioral intervention on the attitude and behavior of stockpersons and the behavior and productivity of commercial dairy cows. *J Anim Sci* 80 (1): 68–78.
Hendrickson, M. K. and M. Porth. 2012. *Urban Agriculture—Best Practices and Possibilities*. University of Missouri Extension, http://www.nlc.org/sites/default/files/SCI%20Documents/Report_UrbanAg_USDN_Oct2012%20%282%29.pdf (28 March 2018)
Humane Society of the United States (HSUS). 2011. HSUS and egg industry agree to promote federal standards for hens. Press release, http://www.humanesociety.org/news/press_releases/2011/07/egg_agreement.html (18 January 2015)
Hume, M. E. 2011. Historic perspective: Prebiotics, probiotics and other alternatives to antibiotics. *Poultry Sci* 90 (11): 2663–2669.
Janczak, A. M. and A. B. Riber. 2015. Review of rearing-related factors affecting the welfare of laying hens. *Poultry Sci* 94 (7): 1454–1469.
Jinek, M., K. Chylinski, I. Fonfara, M. Hauer, J. A. Doudna, and E. Charpentier. 2012. A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity. *Science* 337 (6096): 816–821, doi:10.1126/science.1225829.
Johnson, A. K. 2009. ASAS Centennial Paper: Farm animal welfare science in the United States. *J Anim Sci* 87 (6): 2175–2179.
Karami, E. and M. Keshavarz. 2010. Sociology of sustainable agriculture. Pp. 19–40. In E. Lichtfouse (ed.). *Sociology, Organic Farming, Climate Change and Soil Science*. Springer, The Netherlands.
Karlen, G. A., P. H. Hemsworth, H. W. Gonyou, E. Fabrega, A. D. Strom, and R. J. Smits. 2007. The welfare of gestating sows in conventional stalls and large groups on deep litter. *Appl Anim Behav Sci* 105 (1): 87–101.
Keeling, L. J., A. Evans, B. Forkman, and U. Kjaernes. 2013. Welfare quality principles and criteria. Pp. 91–114. In H. Blokhuis, M. Miele, I. Veissier, and B. Jones (eds.). *Improving Animal Welfare. Science and Society Working Together: The Welfare Quality Approach*. Wageningen Academic Publishers, Netherlands.
Kendrick, K. M., A. P. da Costa, A. E. Leigh, M. R. Hinton, and J. W. Peirce. 2001. Sheep don't forget a face. *Nature* 414 (6860): 165–166.
Kjaer, J. B., P. Sørensen, and G. Su. 2001. Divergent selection on feather pecking behaviour in laying hens (*Gallus gallus domesticus*). *Appl Anim Behav Sci* 71:229–239.
Klopfleisch, R. and A. D. Gruber. 2012. Transcriptome and proteome research in veterinary science: What is possible and what questions can be asked? *Sci World J* 2012 (12): 254962.
Knap, P. W. 2005. Breeding robust pigs. *Aust Agr* 45:1–11.
Knap, P. W. 2012. Pig breeding for increased sustainability. Pp. 7972–8012. In R. A. Meyers (ed.). *Encyclopedia of Sustainability Science and Technology*. Springer-Verlag, New York.
Knowles, T. G., S. C. Kestin, S. M. Haslam, S. N. Brown, L. E. Green, A. Butterworth, S. J. Pope, D. Pfeiffer, and C. J. Nicol. 2008. Leg disorders in broiler chickens: Prevalence, risk factors and prevention. *PLOS ONE* 3 (2): e1545.

Korver, D. R., J. L. Saunders-Blades, and K. L. Nadeau. 2004. Assessing bone mineral density in vivo: Quantitative computed tomography. *Poultry Sci* 83 (2): 222–229.

Kovalčik, K. and M. Kovalčik. 1986. Learning ability and memory testing in cattle of different ages. *Appl Anim Behav Sci* 15 (1): 27–29.

Lackey, R. T. 2007. Science, scientists, and policy advocacy. *Conserv Biol* 21 (1): 12–17.

Lagerkvist, C. J. and S. Hess. 2011. A meta-analysis of consumer willingness to pay for farm animal welfare. *Eur Rev Agric Econ* 38 (4): 55–78.

Laughlin, K., M. Huck, and M. Mendl. 1999. Disturbance effects of environmental stimuli on pig spatial memory. *Appl Anim Behav Sci* 64 (3): 169–180.

Lay, D. C., R. M. Fulton, P. Y. Hester, D. M. Karcher, J. B. Kjaer, J. A. Mench, B. A. Mullens, R. C. Newberry, C. J. Nicol, N. P. O'Sullivan, and R. E. Porter. 2011. Hen welfare in different housing systems. *Poultry Sci* 90 (1): 278–294.

Lee, C., S. Colegate, and A. D. Fisher. 2006. Development of a maze test and its application to assess spatial learning and memory in Merino sheep. *Appl Anim Behav Sci* 96 (1): 43–51.

Linde, A., C. R. Ross, E. G. Davis, L. Dib, F. Blecha, and T. Melgarejo. 2008. Innate immunity and host defense peptides in veterinary medicine. *J Vet Intern Med* 22 (2): 247–265.

Ludemann, C. I., P. R. Amer, and S. Hermesch. 2013. Economic weights for maternal pig traits in Australia motivate genetic improvement for robustness. *P Assoc Advmt Anim Breed Genet* 20:483–436.

Lusk, J. L. 2010. The effect of Proposition 2 on the demand for eggs in California. *J Agr Food Indust Org* 8 (1): 3–3.

Lusk, J. L. 2011. The market for animal welfare. *Agric Human Values* 28 (4): 561–575.

Lusk, J. L. 2016. *Unnaturally Delicious*. St. Martins, New York.

Lusk, J. L. and F. B. Norwood. 2011. Animal welfare economics. *Appl Econ Perspect P* 33 (4): 463–483.

Manteuffel, G., J. Langbein, and B. Puppe. 2009. Increasing farm animal welfare by positively motivated instrumental behaviour. *Appl Anim Behav Sci* 118:191–198.

Marchant, J. N., M. T. Mendl, A. R. Rudd, and D. M. Broom. 1995. The effect of agonistic interactions on the heart rate of group-housed sows. *Appl Anim Behav Sci* 46 (1): 49–56.

Mark, R. F. and W. E. Watts. 1971. Drug inhibition of memory formation in chickens. I. Long-term memory. *P Roy Soc B-Biol Sci* 178 (1053): 439–454.

Martin, J. A. and Z. Wang. 2011. Next-generation transcriptome assembly. *Nat Rev Genet* 12:671–682.

Mason, G. J. and N. R. Latham. 2004. Can't stop, won't stop: Is stereotypy a reliable welfare indicator? *Anim Welfare* 13:S57–69.

Mason, G. J. and M. Mendl. 1993. Why is there no simple way of measuring animal welfare? *Anim Welfare* 2:301–319.

McClintock, N., E. Pallana, and H. Wooten. 2014. Urban livestock ownership, management, and regulation in the United States: An exploratory survey and research agenda. *Land Use Policy* 38:426–440.

McDonald, M. 2001. Canadian governance of health research involving human subjects: Is anybody minding the store? *Health Law J* 9:1–21.

McDonald's. 2010–2017. Animal welfare auditing program. *Sourcing*, http://corporate.mcdonalds.com/mcd/sustainability/sourcing/animal-health-and-welfare/issues-we-re-focusing-on/objective-measures.html (6 September 2017)

McGlone, J., A. Johnson, A. Sapkota, and R. Kephart. 2014. Transport of market pigs: Improvements in welfare and economics. Pp. 298–314. In T. Grandin (ed.). *Livestock Handling and Transport*. CABI Publishing, Wallingford, United Kingdom.

McGlone, J. J., E. H. von Borrell, J. Deen, A. K. Johnson, D. G. Levis, M. Meunier-Salaün, J. L. Morrow, D. Reeves, J. L. Salak-Johnson, and P. L. Sundberg. 2004. Review of scientific literature comparing housing systems for gestating sows and gilts using measures of physiology, behavior, performance and health. *Prof Anim Scientist* 20:105–117.

McHale, C. M., L. P. Zhang, R. Thomas, and M. T. Smith. 2013. Analysis of the transcriptome in molecular epidemiology studies. *Environ Mol Mutagen* 54:500–517.

McKendree, M. G. S., C. C. Croney, and N. J. O. Widmar. 2014. Effects of demographic factors and information sources on United States consumer perceptions of animal welfare. *J Anim Sci* 92 (7): 3161–3173.

McManus, C., E. Prescott, G. R. Paludo, E. Bianchini, H. Louvandini, and A. S. Mariante. 2009. Heat tolerance in naturalized Brazilian cattle breeds. *Livest Sci* 120:256–264.

Meehan, C. L. and J. A. Mench. 2007. The challenge of challenge: Can problem solving opportunities enhance animal welfare? *Appl Anim Behav Sci* 102:246–261.

Mellor, D., E. Patterson-Kane, and K. J. Stafford. 2009. *The Sciences of Animal Welfare*. Wiley-Blackwell, Hoboken, New Jersey. 222 pp.

Mench, J. A. 2004. Lameness. Pp. 3–18. In C. A. Weeks and A. Butterworth (eds.). *Measuring and Auditing Broiler Welfare*. CABI Publishing, Wallingford, United Kingdom.

Mench, J. A. 2008. Farm animal welfare in the U.S.A.: Farming practices, research, education, regulation and assurance programs. *Appl Anim Behav Sci* 113:298–312.

Mench, J. A. 2018. Science in the real world: Benefits for researchers and farmers. Pp. 111–128. In J. A. Mench (ed.). *Advances in Agricultural Animal Welfare—Science and Practice*. Woodhead Publishing/Elsevier, United Kingdom.

Mench, J. A. and R. A. Blatchford. 2014. Determination of space use by laying hens using kinematic analysis. *Poultry Sci* 93 (4): 794–798.

Mench, J. A. and T. B. Rodenburg. 2018. Sustainability of laying hen housing systems. Pp. 199–226. In J. A. Mench (ed.). *Advances in Poultry Welfare*. Woodhead Press/Elsevier, United Kingdom.

Mench, J. A., D. A. Sumner, and J. T. Rosen-Molina. 2011. Sustainability of egg production in the United States: The policy and market context. *Poultry Sci* 90:229–240.

Mench, J. A., J. C. Swanson, and C. Arnot. 2016. The Coalition for Sustainable Egg Supply: A unique public-private partnership for conducting research on the sustainability of animal housing systems using a multistakeholder approach. *J Anim Sci* 94 (3): 1296–1308.

Mendl, M., O. H. P. Berman, R. M. A. Parker, and E. S. Paul. 2009. Cognitive bias as an indicator of animal emotion and welfare: Emerging evidence and underlying mechanisms. *Appl Anim Behav Sci* 118:161–181.

Merks, J. W. M., P. K. Mathur, and E. F. Knol. 2012. New phenotypes for breeding goals in pigs. *Animal* 6:535–543.

Midgley, M. 1983. *Animals and Why They Matter*. University of Georgia Press, Athens. 158 pp.

Miglior, F., B. L. Muir, and B. J. Van Doormaal. 2005. Selection indices in Holstein cattle of various countries. *Dairy Sci* 88:1255–1263.

Miller, R. W., E. J. Skinner, A. Sulakvelidze, G. F. Mathis, and C. L. Hofacre. 2010. Bacteriophage therapy for control of necrotic enteritis of broiler chickens experimentally infected with *Clostridium perfringens*. *Avian Dis* 54 (1): 33–40.

Moberg, G. P. 2000. Biological responses to stress: Implications for animal welfare. Pp. 1–22. In G. P. Moberg and J. A. Mench (eds.). *The Biology of Animal Stress: Basic Principles and Implications for Animal Welfare*. CABI, Wallingford, Oxon, United Kingdom.

Muir, W. M. 1996. Group selection for adaptation to multiple-hen cages: Selection program and direct responses. *Poultry Sci* 75:447–458.

Muir, W. M. 2005. Incorporation of competitive effects in forest tree or animal breeding programs. *Genetics* 170:1247–1259.

Muir, W. M. and H. Cheng. 2004. Breeding for productivity and welfare. Pp. 123–138. In *Welfare of the Laying Hen, No. 27*. Poultry Science Symposium Series. CABI Press, Cambridge, Massachusetts.

Muir, W. M. and J. V. Craig. 1998. Improving animal well-being through genetic selection. *Poultry Sci* 77:1781–1788.

Muir, W. M., P. Bijma, and A. Schinckel. 2013. Multilevel selection with kin and non-kin groups, experimental results with Japanese quail (*Coturnix japonica*). *Evolution* 67:1598–1606.

Muir, W. M., H. W. Cheng, and C. Croney. 2014. New selection methods for layer performance and potential impacts on behavior and management. Pp. 295–309. In *Proceeding—XIVth European Poultry Conference*, Stavanger, Norway, 23–27 June 2014.

Nakarmi, A. D., L. Tang, and H. Xin. 2014. Automated tracking and behavior quantification of laying hens using 3D computer vision and radio frequency identification technologies. *T ASABE* 57 (5): 1455–1472.

National Agricultural Law Center (NALC). n.d. *States' Farm Animal Confinement Statutes*, http://nationalaglawcenter.org/state-compilations/farm-animal-welfare (22 May 2017)

National Cattlemen's Beef Association (NCBA). n.d. Beef.org, www.beef.org (22 May 2017)

National Conference of State Legislatures (NCSL). n.d. Initiative and referendum states, http://www.ncsl.org/research/elections-and-campaigns/chart-of-the-initiative-states.aspx (27 March 2018)

National Dairy Farm Program (NDFP). 2017. National Dairy FARM Program homepage, http://nationaldairyfarm.com/ (22 May 2017) (formerly Dairy Producers)

National Farm Animal Care Council (NFACC). 2017. *Codes of Practice for the Care and Handling of Farm Animals*, http://www.nfacc.ca/codes-of-practice (23 May 2017)

National Pork Board (NPB). 2009–2017. *Pork Checkoff*, www.pork.org (22 May 2017)

National Pork Board (NPB). 2014. National Pork Board spring request for proposals—2014, http://old.pork.org/filelibraryrfps/2014/2014springcall.pdf (29 December 2014)

National Research Council (NRC). 2015. *Critical Role of Animal Science Research in Food Security and Sustainability*. National Academies Press, Washington, D. C.

Neeteson-van Nieuwenhoven, A. M., P. Knap, and S. Avendano. 2013. The role of sustainable commercial pig and poultry breeding for food security. *Anim Front* 3:52–57.

Newberry, R. C. 1995. Environmental enrichment: Increasing the biological relevance of captive environments. *Appl Anim Behav Sci* 44 (2–4): 229–243.

Nielsen, L. R., A. R. Pedersen, M. S. Herskin, and L. Munksgaard. 2010. Quantifying walking and standing behaviour of dairy cows using a moving average based on output from an accelerometer. *Appl Anim Behav Sci* 127 (1): 12–19.

Niles, M. T. 2013. Achieving social sustainability in animal agriculture: Challenges and opportunities to reconcile multiple sustainability goals. Pp. 193–211. In E. Kebreab (ed.). *Sustainable Animal Agriculture*. CABI, Boston, Massachusetts.

North American Meat Institute (NAMI). 2017. Animal handling.org, http://www.animalhandling.org (22 May 2017)

Norwood, F. B. and J. L. Lusk. 2011. *Compassion by the Pound: The Economics of Farm Animal Welfare*. Oxford University Press, Oxford, United Kingdom.

O'Connor, A., R. Anthony, L. Bergamasco, J. Coetzee, S. Gould, A. K. Johnson, L. A. Karriker, J. N. Marchant-Forde, G. S. Martineau, J. McKean, S. T. Millman, S. Niekamp, E. A. Pajor, K. Rutherford, M. Sprague, M. Sutherland, E. von Borell, and R. S. Dzikamunhenga. 2014. Pain management in the neonatal piglet during routine management procedures. Part 2: Grading the quality of evidence and the strength of recommendations. *Anim Health Res Rev* 15 (1): 39–62.

Oltenacu, P. A. and B. Algers. 2005. Selection for increased production and the welfare of dairy cows: Are new breeding goals needed? *AMBIO: J Human Environ* 34:311–315.

Oltenacu, P. A. and D. M. Broom. 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. *Anim Welfare* 19 (Suppl 1): 39–49.

Olynk, N. J. and D. L. Ortega. 2013. Consumer preferences for verified dairy cattle management practices in processed dairy products. *Food Control* 30 (1): 298–305.

Olynk, N. J., G. T. Tonsor, and C. A. Wolf. 2010. Consumer willingness to pay for livestock credence attribute claim verification. *J Agr Resour Econ* 35 (2): 261–280.

Parker, C. 2006. The compliance trap: The moral message in responsive regulatory enforcement. *Law Soc Rev* 40:591–622.

Pastell, M., J. Tiusanen, M. Hakojärvi, and L. Hänninen. 2009. A wireless accelerometer system with wavelet analysis for assessing lameness in cattle. *Biosyst Eng* 104 (4): 545–551.

Peeters, K., T. T. Eppink, E. D. Ellen, J. Visscher, and P. Bijma. 2012. Indirect genetic effects for survival in domestic chickens (*Gallus gallus*) are magnified in crossbred genotypes and show a parent-of-origin effect. *Genetics* 192:705–713.

Petherick, J. C. 2005. Animal welfare issues associated with extensive livestock production: The northern Australian beef cattle industry. *Appl Anim Behav Sci* 92:211–234.

Pielke, R. A. Jr. 2007. *The Honest Broker: Making Sense of Science in Policy and Politics*. Cambridge University Press, Cambridge, United Kingdom. 198 pp.

Pigou, A. C. 1920. *The Economics of Welfare*. Macmillan and Company, London, England.

Pinstrup-Andersen, P. and D. D. Watson II. 2011. *Food Policy for Developing Countries: The Role of Government in Global, National and Local Food Systems*. Cornell University Press, Ithaca, New York/London.

Place, S. E. 2018. Animal welfare and environmental issues. Pp. 69–89. In J. A. Mench (ed.). *Advances in Agricultural Animal Welfare—Science and Practice*. Woodhead Press/Elsevier, United Kingdom.

Pötzsch, C. J., K. Lewis, C. J. Nicol, and L. E. Green. 2001. A cross-sectional study of the prevalence of vent pecking in laying hens in alternative systems and its associations with feather pecking, management and disease. *Appl Anim Behav Sci* 74 (4): 259–272.

Professional Animal Auditor Certification Organization (PAACO). 2016. PAACO, https://animalauditor.org (22 May 2017)

Prunier, A., M. Heinonen, and H. Quesnel. 2010. High physiological demands in intensively raised pigs: Impact on health and welfare. *Animal* 4:886–898.

Rauw, W. M., E. Kanis, E. N. Noordhuizen-Stassen, and F. J. Grommers. 1998. Undesirable side effects of selection for high production efficiency in farm animals: A review. *Livest Prod Sci* 56:15–33.

Regan, T. 1983. *The Case for Animal Rights*. University of California Press, Berkeley/Los Angeles, California.

Reynnells, R. D. 2004. Bioethical considerations in animal production. *Poultry Sci* 83 (3): 303–306.

Rodenburg, T. B. and S. P. Turner. 2012. The role of breeding and genetics in the welfare of farm animals. *Anim Front* 2:16–21.

Rodenburg, T. B., P. Bijma, E. D. Ellen, R. Bergsma, S. De Vries, J. E. Bolhuis, and J. A. Van Arendonk. 2010. Breeding amiable animals? Improving farm animal welfare by including social effects in breeding programmes. *Anim Welfare* 19 (Suppl 1): 77–82.

Rodenburg, T. B., H. Komen, E. D. Ellen, K. A. Uitdehaag, and J. A. van Arendonk. 2008. Selection method and early-life history affect behavioural development, feather pecking and cannibalism in laying hens: A review. *Appl Anim Behav Sci* 110:217–228.

Rodenburg, T. B., K. A. Uitdehaag, E. D. Ellen, and J. Komen. 2009. The effects of selection on low mortality and brooding by a mother hen on open-field response, feather pecking and cannibalism in laying hens. *Anim Welfare* 18:427–432.

Rollin, B. E. 2004. Annual meeting keynote address: Animal agriculture and emerging social ethics for animals. *J Anim Sci* 82 (3): 955–964.

Rolston, H. 1989. *Philosophy Gone Wild: Environmental Ethics*. Prometheus Books, Buffalo, New York.

Rushen, J. and A. M. de Passillé. 2010. The importance of good stockmanship and its benefits for the animals. Pp. 50–63. In T. Grandin (ed.). *Improving Animal Welfare: A Practical Approach*. CABI, Wallingford, United Kingdom.

Rushen, J. and G. Mason (eds.). 2006. *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare*. CABI, Wallingford, Oxon, United Kingdom.

Rushen, J., N. Chapinal, and A. M. de Passillé. 2012. Automated monitoring of behavioural-based animal welfare indicators. *Anim Welfare* 21:339–350.

Sandøe, P., S. B. Christiansen, and M. Appleby. 2003. Farm animal welfare: The interaction of ethical questions and animal welfare science. *Anim Welfare* 12 (4): 469–478.

Schweikhardt, D. B. and W. P. Browne. 2001. Politics by other means: The emergence of a new politics of food in the United States. *Rev Agric Econ* 23:302–318.

Seal, B. S., H. S. Lillehoj, D. M. Donovan, and C. G. Gay. 2013. Alternatives to antibiotics: A symposium on the challenges and solutions for animal production. *Anim Health Res Rev* 14 (1): 78–87.

Seibert, L. and F. B. Norwood. 2011. Production costs and animal welfare for four stylized hog production systems. *J Appl Anim Welf Sci* 14 (1): 1–17.

Shao, B. and H. Xin. 2008. A real-time computer vision assessment and control of thermal comfort for group-housed pigs. *Comput Electron Agr* 62 (1): 15–21.

Shook, G. E. 2006. Major advances in determining appropriate selection goals. *J Dairy Sci* 89:1349–1361.

Simon, G. E., B. R. Hoar, and C. B. Tucker. 2016. Assessing cow-calf welfare. Part 2: Risk factors for beef cow health and behavior and stockperson handling. *J Anim Sci* 94 (8): 3488–3500.

Singer, P. 1993. *Practical Ethics*. 2nd ed. Cambridge University Press, Cambridge/New York/Melbourne.

Singer, P. and J. Mason. 2006. *The Way We Eat: Why Our Food Choices Matter*. 1st ed. Rodale Books, Emmaus, Pennsylvania.

Smithson, K., M. Corbin, J. L. Lusk, and F. B. Norwood. 2014. Predicting state-wide votes on ballot initiatives to ban battery cages and gestation crates. *J Agr Appl Econ* 46:107–124.

Sneddon, L. U., R. W. Elwood, S. A. Adamo, and M. C. Leach. 2014. Defining and assessing animal pain. *Animal Behav* 97:201–212.

Stafford, K. J. and D. J. Mellor. 2011. Addressing the pain associated with disbudding and dehorning in cattle. *Appl Anim Behav Sci* 135 (3): 226–231.

Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. de Haan. 2006. *Livestock's Long Shadow: Environmental Issues and Options*. FAO, Rome, Italy.

Stuardo Escobar, L., W. H. Jara, Q. N. H. Nizam, and B. Plavšić. 2018. The perspective of the World Organisation of Animal Health. Pp. 169–182. In J. A. Mench (ed.). *Advances in Agricultural Animal Welfare—Science and Practice*. Woodhead Press/Elsevier, United Kingdom.

Su, G., J. B. Kjaer, and P. Sørensen. 2005. Variance components and selection response for feather-pecking behavior in laying hens. *Poultry Sci* 84:14–21.

Sumner, D. A., H. Gow, D. Hayes, W. Matthews, B. Norwood, J. T. Rosen-Molina, and W. Thurman. 2011. Economic and market issues on the sustainability of egg production in the United States: Analysis of alternative production systems. *Poultry Sci* 90 (1): 241–250.

Sumner, D. A., W. A. Matthews, J. A. Mench, and J. T. Rosen-Molina. 2010. The economics of regulations on hen housing in California. *J Agr Appl Econ* 42 (3): 429–438.

Sumner, D. A., J. T. Rosen-Molina, W. A. Matthews, J. A. Mench, and K. R. Richter. 2008. *Economic Effects of Proposed Restrictions on Egg-laying Hen Housing in California*. University of California–Davis Agricultural Issues Center Report, July.

Sutherland, M. A., J. Webster, and I. Sutherland. 2013. Animal health and welfare issues facing organic production systems. *Animals* 3:1021–1025.

Swanson, J. C. 2003. Farm animal welfare assurance: Scientific and retailer perspectives. Pp. 195–200. In *Proceedings of the 6th Western Dairy Management Conference*, Reno, Nevada, 12–14 March 2003, http://wdmc.org/2003/Farm%20Animal%20Welfare%20Assurance-%20Scientific%20and%20Retailer%20Persp.pdf (31 August 2017)

Swanson, J. C. 2008. Bioethics—Livestock and poultry: The ethics of food animal production, processing, and marketing; The ethical aspects of regulating production. *Poultry Sci* 87:373–379.

Swanson, J. C., J. A. Mench, and D. Karcher. 2015. The coalition for sustainable egg supply project: An introduction. *Poultry Sci* 94 (3) 473–474.

Swanson, J. C., Y. Lee, P. B. Thompson, R. Bawden, and J. A. Mench. 2011. Integration: Valuing stakeholder input in setting priorities for socially sustainable egg production. *Poultry Sci* 90:2110–2121.

Tan, W., D. F. Carlson, C. A. Lancto, J. R. Garbe, D. A. Webster, P. B. Hackett, and S. C. Fahrenkrug. 2013. Efficient nonmeiotic allele introgression in livestock using custom endonucleases. *P Natl Acad Sci USA* 110:16526–16531.

Tannenbaum, J. 1991. Ethics and animal welfare: The inextricable connection. *J Am Vet Med Assoc* 198:1360–1376.

The Cattle Site. n.d. *Cattle Disease Guide*. 5m Publishing, http://www.thecattlesite.com/diseaseinfo/ (10 April 2015)

Thompson, P. B. 1993. Animals in the agrarian ideal. *J Agr Environ Ethic* 6 (Suppl 1): 36–49.

Thompson, P. B. 2010. Animal ethics and public expectations: The North American outlook. *J Vet Med Educ* 37:13–21.

Thompson, P. B. and A. Nardone. 1999. Sustainable livestock production: Methodological and ethical challenges. *Livest Prod Sci* 61:111–119.

Thompson, P., C. Harris, D. Holt, and E. A. Pajor. 2007. Livestock welfare product claims: The emerging social context. *J Anim Sci* 85:2354–2360.

Thornber, P. M. and D. J. Mellor. 2018. Perspective from Asia, Far East and Oceania, and the Middle East. Pp. 183–196. In J. A. Mench (ed.). *Advances in Agricultural Animal Welfare—Science and Practic*e. Woodhead Press/Elsevier, United Kingdom.

Thornton, P. K. 2010. Livestock production: Recent trends, future prospects. *Philos T Roy Soc B* 365:2853–2867.

Tonsor, G. T. and N. J. Olynk. 2011. Impacts of animal welfare and welfare media on meat demand. *J Agr Appl Econ* 62:59–72.

Tonsor, G. T. and C. A. Wolf. 2010. Drivers of resident support for animal care oriented ballot initiatives. *J Agr Appl Econ* 43:419–428.

Tucker, C. B., J. A. Mench, and M. A. G. von Keyserlingk. 2013. Animal welfare: An integral component of sustainability. In E. Kebreab (ed.). *Sustainable Animal Agriculture*. CABI, Boston, Massachusetts.

Tucker, C., J. Coetzee, J. Stookey, D. Thomson, T. Grandin, and K. Schwartzkopf-Genswein. 2015. Beef cattle welfare in the USA: Identification of priorities for future research. *Anim Health Res Rev* 16 (2): 107–124, doi:10.1017/S1466252315000171.

Turner, S. P. 2011. Breeding against harmful social behaviours in pigs and chickens: State of the art and the way forward. *Appl Anim Behav Sci* 134:1–9.

Turner, S. P., R. Roehe, R. B. D'Eath, S. H. Ison, M. Farish, M. C. Jack, and A. B. Lawrence. 2009. Genetic validation of postmixing skin injuries in pigs as an indicator of aggressiveness and the relationship with injuries under more stable social conditions. *J Anim Sci* 87:3076–3082.

Turner, S. P., M. S. White, S. Brotherstone, M. J. Farnworth, P. W. Knap, P. Penny, M. Mendl, and A. B. Lawrence. 2006. Heritability of postmixing aggressiveness in grower-stage pigs and its relationship with production traits. *Anim Sci* 82 (5): 615–620.

U.S. Congress. 2013. House. *Egg Products Inspection Act Amendments of 2013*. HR 1731. 113th Congress, https://www.congress.gov/bill/113th-congress/house-bill/1731 (23 May 2017)

Uniliver. 2017. Farm animal welfare. *Sustainable Living*, https://www.unilever.com/sustainable-living/what-matters-to-you/farm-animal-welfare.html (12 September 2017)

United Egg Producers (UEP). 2016. *Animal Husbandry Guidelines for U.S. Egg Laying Flocks*. 2016 ed., http://unitedegg.com/information/pdf/UEP-Animal-Welfare-Guidelines2016.pdf (22 May 2017)

Upadhaya, S. D., K. Y. Lee, and I. H. Kim. 2014. Protected organic acid blends as an alternative to antibiotics in finishing pigs. *Asian-Australas J Anim Sci* 27 (11): 1600–1607.

VanRaden, P. M. 2004. Invited review: Selection on net merit to improve lifetime profit. *J Dairy Sci* 87:3125–3131.

Varner, G. E. 2012. *Personhood, Ethics, and Animal Cognition: Situating Animals in Hare's Two-level Utilitarianism*. Oxford University Press, New York.

Verdurme, A. and J. Viaene. 2003. Exploring and modeling consumer attitudes towards genetically modified food. *Qual Market Res: Int J* 6 (2): 95–110.

Viñuela-Fernandez, I., D. M. Weary, and P. Flecknell. Pain. 2011. Pp. 64–77. In M. C. Appleby, J. A. Mench, I. A. S. Olsson, and B. O. Hughes (eds.). *Animal Welfare*, 2nd ed. CABI, Wallingford, United Kingdom.

Walker, M., M. Diez-Leon, and G. Mason. 2014. Animal welfare science: Recent publication trends and future research priorities. *Int J Comp Psych* 27 (1): 80–100.

Wang, Y., P. Saelao, K. K. Z. Mon, T-H. Kim, T. Kelly, and H. Zhou. 2018. Using genetic approaches to improve host responses to environmental

stressors. Pp. 323–338. In J. A. Mench (ed.). *Advances in Poultry Welfare*. Woodhead Press/Elsevier, United Kingdom.

Weary, D. M., L. Neil, F. C. Flower, and D. Fraser. 2006. Identifying and preventing pain in animals. *Appl Anim Behav Sci* 100:64–76.

Weeks, C. A. 2014. Poultry handling and transport. In T. Grandin (ed.). *Livestock Handling and Transport*, 3rd ed. CABI, Wallingford, Oxon, United Kingdom.

Wemesfelder, F. 1984. The question of animal awareness. Pp. 1–18. In M. W. Fox and L. D. Mickley (eds.). *Advances in Animal Welfare Science*. The Humane Society of the United States, Washington, D.C.

Westin, R., A. Vaughan, A. M. de Passillé, T. J. DeVries, E. A. Pajor, D. Pellerin, J. M. Siegford, A. Witaifi, E. Vasseur, and J. Rushen. 2016. Cow-and farm-level risk factors for lameness on dairy farms with automated milking systems. *J Dairy Sci* 99 (5): 3732–3743.

Widowski, T. and S. Torrey. 2018. Rearing young birds for adaptability. Pp. 49–76. In J. A. Mench (ed.). *Advances in Poultry Welfare*. Woodhead Press/Elsevier, United Kingdom.

Wingfield, J. C. 2005. The concept of allostasis: Coping with a capricious environment. *J Mammal* 86 (2): 248–254.

World Organisation for Animal Health (OIE). 2008. A new definition for the Terrestrial Animal Health Code: 'Animal welfare.' *Forum*, https://www.oie.int/doc/ged/D5517.PDF (28 March 2018)

World Organisation for Animal Health (OIE). 2010. *Roles of Public and Private Standards in Animal Health and Welfar*e. Res. 26, http://www.oie.int/fileadmin/Home/eng/Internationa_Standard_Setting/docs/pdf/A_RESO_2010_PS.pdf (18 January 2015)

World Organisation for Animal Health (OIE). 2014. *OIE's Achievements in Animal Welfare*, http://www.oie.int/animal-welfare/animal-welfare-key-themes/ (15 May 2017)

World Organisation for Animal Health (OIE). 2015. Animal welfare. Sec. 7. In *Terrestrial Animal Health Code*, http://www.oie.int/index.php?id=169&L=0&htmfile=titre_1.7.htm (18 January 2015)

Yeates, J. W. and D. C. J. Main. 2008. Assessment of positive welfare: A review. *Vet J* 175:293–300.

Zonderland, J. J., B. Kemp, M. B. M. Bracke, L. A. den Hartog, and H. A. M. Spoolder. 2011. Individual piglets' contribution to the development of tail biting. *Animal* 5:601–607.

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Phone: 515-292-2125
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