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SKETCHING FARM ANIMAL WELFARE

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ABSTRACT

The use of models and sketches in the life sciences has greatly expanded and trigged in scope and advanced in technique in recent decades. However, the range, type and complexity of models and sketches used in farm animal welfare is comparatively poor, despite the great scope for use of sketching in this field of research. In this paper, we review the different modeling and sketching approaches used in farm animal welfare science to date, discussing the types of questions they have been used to answer, the merits and problems associated with the method, and possible future applications of each technique. We find that the most frequently published types of sketch used in farm animal welfare are conceptual and assessment sketches; two types of sketch that are frequently (though not exclusively) based on expert opinion. Simulation, optimization, scenario, and systems modeling and sketching approaches are rarer in animal welfare, despite being commonly used in other related fields. Finally, common issues such as a lack of quantitative data to parameterize sketches, and sketch selection and validation are discussed throughout the review, with possible solutions and alternative approaches suggested.

Keywords:Animal Welfare,Optimization,Risk Assessment,Simulation,Systems Sketching,Scenario Sketching,Welfare Assessment.

1. INTRODUCTION

The use of sketches has greatly advanced in many areas of the life sciences in recent decades, but the range, complexity and type of sketches developed for use in animal welfare is comparatively poor. This is surprising given the similarities between the aims of animal welfare and those of, for example, the closely related field of animal health epidemiology, where there is great interest in using sketches (mathematical, statistical and assessment) to understand why, where, how, when and who will be affected by disease outbreaks, and to explore potential control strategies (Stochastic simulation sketching [1,2,3],decision tree sketching [4,5], and network sketching [6,7]). In the field of animalwelfare, our aims are principally to understand why, where, how, when and who will be affected by the multitude of species – specific welfare problems, and what control strategies we can put in place to prevent these problems arising. However, despite this, we do not see the same type of predictive model and sketch as is so often used in disease epidemiology being used to make predictions of welfare problems. One possible reason for this might be the relative lack of data. However, predictive disease models and sketches are often based on input data collected from largely varying sources, of varying quality and reliability and combined from multiple previously published scientific studies.

Other related areas of academic research which frequently utilize sketches, are agricultural economics and sustainability. Here, we see a range of sketches being developed to explore, for example, the potential margins associated with different farm types and practices, often incorporating elements of animal welfare (although these are usually highly simplistic). These large, multi-factor sketches are again mostly developed using input data from a large range of sources, of varying quality and reliability. For example, the use of seven, predominantly resource-based, parameters to score animal welfare in a sketch of sustainability is, perhaps, not representative of what most animal welfare academics would consider the most critical input data for a model and sketch of this type.

Given the breadth of sketching techniques available, and the objectives these models and sketches set out to meet, it is perhaps a misnomer to talk of “sketches” as if they represent one approach. In other fields, such as ecology, where sketching is far more commonly used, it is recognized that models and sketches really fall into three main types: detailed (“synthetic”), “minimal” systems, and “minimal for ideas” [8].

Here,the models and sketches are defined by what they set out to do. Detailed, or “synthetic”, models and sketches aim to produce a detailed description of the sub-components that make a system and how they interact to produce the overall working system. “Minimal” models and sketches for systems aim to explain certain types of system, but tend to ignore many characteristics of the real life system and, as such, are not designed to produce specific, detailed predictions. Finally, “minimal models and sketches for ideas” are for exploring concepts without anchoring it to a particular species or type of system. Again, this type of model and sketch, which includes some of the most famous models and sketches in ecology, such as the LotkaVolterra model and sketch, is not meant to produce testable predictions or to be applied to real life situations. We see examples of each of these types of sketch in the farm animal welfare literature and these will be discussed in section two.

Sketching in farm animal welfare has mostly fallen into the frequentist statistical type, in other words, quantitative analysis of an experimentally derived, or longitudinally collected data set [9], where the main aim is to determine which abiotic and biotic factors in an animal’s environment are associated with the development of poor welfare, or change in welfare state, and which indicators can be used to determine welfare state reliably. In recent years, there has been an increasing trend to also use more statistical and engineering type methods in the formation of welfare indicators. Some of these types of studies have been reviewed and discussed previously [10].

In this review article, we focus on the other types of sketches being produced in the field of animal welfare namely, the assessment sketches, simulation, optimization, scenario, systems and conceptual sketches. This paper is not intended to provide an exhaustive review of all sketching approaches [11]. Rather, the models and sketches reviewed herein are those considered to be most promising in the field of farm animal welfare science.

We will briefly describe each type of sketch, outline the types of questions they could be used to answerhighlighting the potential drawbacks associated with the approachand provide examples from the scientific literature of their use in animal welfare research. Finally, we will discuss where the main gaps in farm animal welfare sketching lie, and suggest possible reasons why this may be and how we might go forward.

The aim of this paper is not to provide an instruction manual on using the different sketching approaches, but to open discussion between empirical and theoretical researchers, and to forearm empirical researchers with a set of questions that they can aim to answer with theoretical approaches.

2. SKETCHES IN FARM ANIMAL WELFARE

2.1 ASSESSMENT SKETCHES

2.1.1 Risk Assessment

One of the most common types of sketch used in animal welfare research, particularly at the sciencepolicy interface, is risk assessment. Risk assessment characterizes the probability of a negative event occurring and quantifies the consequences of such an event. Ultimately, it provides a means of comparing different welfare problems both at the level of the affected individual and at the population level, within and between species, based on a number of key factors [12]. They are therefore frequently utilized to produce lists of welfare priorities that are based on scientific research, for policy makers to consider. The European Food Safety Authority’s (EFSA) Panel on Animal Health and Welfare (AHAW) has, for instance, published risk assessments of welfare in dairy cows, farmed fish [11], fattening pigs [13], beef cattle and calves, broilers [14] and broiler breeders [15], in which aspects of housing, husbandry, management, stunning, slaughter and genetic selection, amongst other factors, were assessed.

In risk assessment terminology, welfare problems are caused by a series of “hazards”. The fast growth rate of standard commercial breeds of broiler chicken may be considered a potential welfare hazard with possible consequences including skeletal disorders, sudden death syndrome, ascites, high body mass and muscle disorders [16]. In risk assessment, each identified hazard is characterized based on three factors: intensity of consequences, duration of effect of consequences (either as an absolute value if comparing within a breed or species, or as a proportion of lifetime if comparing between breeds or species; see for an example) and prevalence (the proportion of affected individuals at any one time). Quantification (even in its simplest form, as categorical variables with groups including “mild”, “moderate”, or “severe”) allows consequences and their impact on the animals experiencing them to be compared. However, in this basic form of risk assessment, specific details of the hazards are not considered. A more accurate risk estimate can be obtained by also including information about the hazard itself in the calculation, such as estimates for the duration and probability of exposure to the hazard. In providing a quantitative, or even qualitative, value for each of these factors, the aim is to produce an objective estimate of risk for a series of potential welfare hazards.

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There are currently three main issues with welfare risk assessment procedures: (1) An incorrect assumption of independence between one hazard and its consequences and another hazard and its consequences. Although it is almost certainly true that some combinations of hazards will be truly independent, in most cases there is at least some degree of non-independence between hazards and, indeed, some overlap in the types of consequences emerging from different hazards. The effects of non-independence on a risk assessment procedure are a risk score that is either over or under estimated, typically as a result of conflated prevalence information, but also, and rather less easily measurable, conflated intensity information. (2) The common use of expert opinion to quantify each of the hazard characteristics, in lieu of purely data-based estimates, is a potential source of bias and unreliability in the risk assessment process. Of course, data based estimates may also be subject to bias arising from selection, collection, analysis and interpretation of data [13]. However, just as expert opinion is gathered from numerous individuals or groups, ranging in field of expertise, data based estimates should be based on a range of studies and datasets derived from numerous sources. Doing so would reduce the impact of isolated instances of bias. Collating scientific evidence by means of systematic reviews would involve quality assessing studies whereby those at risk of bias would be excluded, and meta-analysis enables the potential effects of biases to be formally examined [17]. (3) Level of uncertainty and variability are frequently not calculated in welfare risk assessments. This makes assessing the information they contain very difficult. Did all experts agree 100% on all the scores for the hazards, or was there a large divide in opinion? Without this information, it is very difficult to assess how confident one can feel in the result. This information would routinely be given in a typical statistical analysis, in the form of standard errors, confidence intervals and sample sizes. The same should be true for risk assessment procedures. However, above all, it is particularly true when quantifying intensity of suffering. This is essentially because the strength and reliability of expert opinion is dependent on the scientific research that has been published on a subject. There is no single welfare indicator that can reliably measure welfare across different contexts and across different species. Instead, we are reliant on multiple indicators that can often give conflicting results regarding affective state. Thus a random group of experts would be expected to differ in their opinions on intensity more than they might on something more easily quantifiable, such as prevalence.

To summarize, at this stage, animal welfare risk assessment is often used as a conceptual modelling and sketching tool to allow very different welfare problems to be compared. However, it could be made more quantitative and less subjective using systematic searches and data mining tools, to extract information from the resulting large volume of peer and non-peer reviewed papers, and meta-analysis of the extracted data.

2.1.2 Welfare Assessment

Welfare assessment is typically the term given to the in situ appraisal of an animal's affective and physical states, or most commonly, to the group assessment of welfare at the herd or flock level or at the system level [18]. Welfare assessment systems can be categorized on the type of information they collect: (I) resource-based; and (II) animal based assessment systems. Resource based systems are primarily interested in the inputs provided for the animals [17]. Input factors can often be assessed with a high degree of reliability, but are perhaps more suited to informing farmers about possible prevention and solution strategies to problems, rather than identifying and assessing the health and mental well-being of the animals [18]. It has been shown that resource-based parameters alone are not sufficient to assess welfare and can be thought of as providing a “risk assessment” (or “housing condition assessment”) as opposed to a welfare assessment [14]. This could, however, be overcome by using resource-based parameters that have strong links with animal-based measures and can reliably predict welfare at the individual level [13]. Animal-based measures of physical condition and health, disease status, and behavior are also limited when used alone as they cannot conclusively identify the causes of poor welfare [18].

One approach to objective weighting of criteria is semantic modelling (SM), which was used in the development of the SOWEL, FOWEL and RICHPIG models and sketches and to assess the importance of wallowing for pig welfare. Bracke et al.[19] also demonstrated how animal welfare risk assessment might benefit from employing SM methodology. In SM, assessment criteria weightings are based on “scientific statements” (statements extracted from the literature denoting empirical observations of some aspect of welfare under particular conditions) and, in later models, include a measure of uncertainty (strength of each statement) [19]. The validity of the resulting model can then be tested through, for example, comparison with expert opinion [20, and 21], experiments designed to determine the importance of assessment criteria from the animals’ perspective,and sensitivity analysis [19]. Although a range of welfare assessment models have been developed, their widespread use in other areas of research is not apparent. Animal welfare is considered an important factor when assessing the social sustainability of farming systems. However, the assessment of animal welfare within agricultural sustainability research varies widely from the use of a limited few measures to the use of a developed model supplemented by additional criteria to behavioral observations and physiological indicators [21]. Clearly, there is need for multidisciplinary work in this area, and for increased collaboration between farm animal welfare scientists, economists and researchers in sustainability and food security.

2.2 SIMULATION SKETCHING

The term simulation modelling and sketching is extremely broad and, in actuality, could refer to many of the kinds of sketch that will be described in the following subsections. However, in the more selective sense, a simulation sketch is one that seeks to recreate patterns observed in real life with the input of selected, often simplified, variables that are thought to be responsible (at least in part) for the production of the resultant pattern. These sketches are typically described as “stochastic”, for sketches that include one or more parameters with random values drawn from identified probability distributions; or “deterministic”, for sketches that include no random variables and no randomness. Simulation sketches can also be described as “dynamic”, if they include time as a variable, or “static” if time is not included. Dynamic models are typically represented with differential or partial differential equations. Further to this, dynamic sketches can be described as “continuous” or “discrete”, depending on whether changes in time are represented with a continuous interval, or discrete time

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steps (events), respectively.Sketches may further be described as “top-down”, where the developers start with a general overview of a system (the “big picture”), but do not have details of the component subsystems. This type of sketch tends to be formulated with a large number of differential equations. By comparison, many modern sketches are “bottom-up”, such as those used in agent-based modelling (ABM) where individual units (animals, though one could potentially also consider pens, houses or farms as separate units) are programmed to behave according to a set of probability-based rules and can interact with other units (though ABM can also be data-based or use deterministic rules [22]). The resulting emergent patterns at the global level of the sketch can then be compared with patterns observed in real life. Bottom-up, generative models such as ABMs have been used in many different fields, including disease dynamics, evolutionary and social processes and to describe financial markets [23]. In farm animal welfare, simulation modelling and sketching has been used to estimate the costs of welfare improvements for commercial pigs and the economic and welfare impacts of foot disorders and foot disorder interventions in dairy cattle. Modelling and sketching the impact of various measures on animal welfare can be difficult due to the range of factors that can interact to influence welfare and the difficulties in estimating their effects [23]. Selecting and validating the best simulation model can sometimes prove difficult. In an ideal world, all simulations would be tested using sensitivity analysis, and validated against an independent dataset after development.

2.3 OPTIMIZATION SKETCHES

As the name suggests, optimization models and sketches are developed to find the optimal solution to a defined problem and typically take the form of linear and dynamic programming in livestock science. Linear programming (LP) models reveal the optimal set of variables that maximizes (or minimizes) a particular function under specified constraints [24]. Dynamic programming (DP) models are also based on mathematical optimization, where a larger problem can be broken down into multiple smaller sub problems, which can in turn be broken down in a recursive manner. Two classic examples include Dijkstra’s shortest route algorithm, and the Tower of Hanoi recursive solution. Farm animal welfare research employing optimization models have principally focused on the economics of animal welfare. Unlike simulation models, which can be used to simulate the behavior of a system, animal ordisorder and estimate the impacts of manipulating various input factors, optimization models are designed to solve a specific problem, optimizing a particular function and identifying the best possible strategy or outcome [24].

Langford and Stott used DP to maximize dairy farmers’ economic gain through determining the optimum (financial) decision to keep or replace a heifer at each parity over a 20 – year cycle. Modelling and sketching different farm scenarios (high and low rates of infertility, mastitis and lameness) allowed estimates of the longterm effects of improving cow welfare. Several other studies have also used these models to maximize financial return at the production level. For example, LP models and sketches have been used to minimize the costs of improving pig welfare [21], to determine the most profitable body condition at which to maintain sheep and to estimate the maximum profit potential of individual sheep farms [19]. Vosough Ahmadi et al. [25] used

LP to investigate trade-offs between economics (profit) and sow welfare under different farrowing systems, and to provide a framework for designing economically feasible, high welfare systems. Other studies have used LP to estimate the price of pork produced under high welfare farrowing systems, to compare dairy farming systems and to estimate the impact of management changes on economics and animal welfare, amongst other factors [26].

2.4 SCENARIO SKETCHING

Scenario modelling and sketching is not really a separate type of modelling and sketchingused in farm animal welfare research, so much as a method that often overlaps with several of the approaches already discussed (simulations, optimization models and sketches). It may offer an alternative approach to forecasting whereby, rather than trying to predict future events, it compares a variety of alternative futures (or potential solutions. The effects of different scenarios on the model outcomes are estimated and then compared with the basic simulation (often reflecting the current situation). For example, in one study, three alternative future scenarios for organic dairy farming in Denmark (focusing on profit, animal welfare, and environment) were modelled and evaluated in terms of their economic and environmental impacts. Model simulations or sketch simulationsand expert knowledge were used to parameterize the scenarios [27]. Alternative cow welfare and pig performance scenarios have been investigated, using DP and LP, to estimate the effect on farmer income and on the price of pork produced under different farrowing systems, respectively.

Although farm income has risen over recent years, farming is still not a highly profitable business. Therefore, the balance of economic viability and good animal welfare is a tight line to tread. Scenario modelling provides a means of comparing alternative solutions (increased retail price of animal products, additional Common Agricultural Policy (CAP) Single Farm Payments, introduction of a national tax, complete shift to large-scale farming) in terms of their impacts on the utility (well-being) of all stakeholders (animals, farmers, retailers, consumers, citizens) and on the national economy. Scenario modelling or Scenario sketching might also be used to compare alterative future solutions that would enable the livestock industryparticularly in countries with already highly-intensive production and low welfare standards (China) to meet the increasing demand for animal products [23].Comparing multiple different possible futures may, however, be hampered by the fact that scenario sketching does not incorporate any element which could determine which of the futures is most likely, or optimal. Rather, it simply outlines what the different possible conditions could be under each of the different scenarios. It is then left open to interpretation which of the possibilities would be most ideal or most probable under current circumstances. This facet means that scenario modelling is an excellent choice for making value-free judgements within the model construct, although it also means that judgements must be made post-hoc, perhaps rather more subjectively than would be the case with other sketching methods.

2.5 SYSTEMS SKETCHING

Systems sketching is the analysis of complex systems, and investigation of how functionally different sub processes within a system integrate and interact to produce a coherent system. Unlike most other types of modelling discussed in this paper, systems modelling and sketching is almost by definitioninterdisciplinary, and is based on the underlying principle that to fully understand a system, one must understand it at different organizational levels such as at the molecular, cellular, organismal and species level, all within one model. To date, the majority of systems biology studies have focused on, for example, drug discovery, forecasting and diagnostics in plant, animal and human disease and the design of bio-products such as bio-fuels. Systems Sketching facilitates our understanding of how different parts of that system interact and enables a combination of changes, within different parts of the system, to be evaluated [28]. Developing systems models and sketches can be very time consuming and the end product is highly specific. Nonetheless, adopting a systems (or perhaps, a network) approach could provide valuable tools to improve our understanding of how animal welfare interacts with other measures of sustainability and, particularly: (1) to estimate how specific improvements in farm animal welfare would impact on the environmental, ecological and societal sustainability of the farm; (2) to estimate how improvements in the economic, environmental, ecological and/or societal sustainability of the system would impact on animal welfare; (3) to identify specific improvements in animal welfare that, if implemented, would improve overall sustainability of the farming system (leading to win-win scenarios that are more likely to be adopted); and (4) to identify combinations of factors within different parts of the system that could be changed to optimize animal welfare and overall sustainability [27].

2.6 CONCEPTUAL SKETCHES

Conceptual models and sketches allow consideration of the fundamental activities of a system without being tied to details of the physical reality of that system. Check land [25] defined a conceptual model to be "a statement of what is logically and necessarily implied by the [root] definition. It is not a recommendation of what ought to exist nor of what does exist in the real situation." Thus, economic sketches exemplify this type of approach. Conceptual models identified in the farm animal welfare scientific literature are diverse in subject matter, including human and animal willingness-to-pay (WTP) for improved animal welfare, motivation for sucking behavior in calves, stereotypy development andmaintenance under feed restriction in pigs, a quantitative genetic model of animal learning and a model to aid artificial selection for enhanced welfare in pigs. Other conceptual modelling studies have considered the impacts of farmers' perceptions, attitudes and behavior on their choice of whether toimplement welfare improvements, a matter which has generally been overlooked in other models of animal welfare. Other researchers have applied a conceptual socio-psychological model and sketch (the "theory of planned behavior") to understand farmers' decisions, and underlying motivations, to change husbandry practices, such as group housing for pregnant sows, alternatives to mule sing in sheep, and to identify interventions that might encourage farmers to implement such changes [28].Conceptual sketches can provide a theoretical basis to help guide future research, propose potential solutions, collate empirical evidence and

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illustrate ideas of how different factors might interact. There is, therefore, scope to develop conceptual models within all areas of animal welfare research. However, unlike the other models discussed in this review, conceptual sketches, not being rooted in physical reality, can often not be explicitly tested.

3. DISCUSSION

The aim of this paper was to review the use of non-statistical sketches in farm animal welfare research. Most of the research to date has described the development, or use, of conceptual, risk and welfare assessment sketches. The use of mathematical models and sketches has been limited, despite their potential toassist us in: (1) predicting when and where welfare problems are likely to arise and who they are mostlikely to affect; (2) determining how different components of the farming system interact to influencewelfare; (3) identifying the best control strategies that we can apply to prevent welfare problems fromdeveloping; and (4) bringing together large bodies of evidence from different fields to establish linksbetween animal welfare, economics, environmental and social sustainability in livestock farming.Here, mathematical sketching could assist us in identifying, and tackling, any existing or impending conflicts between, for example, farm animal welfare, farmer livelihood, future food security andenvironmental legislation.

In a review of the literature, de Boer et al. [29] identified some potential effects of greenhouse gas (GHG) emission mitigation strategies on animal welfare, human health, emissions, land use and other sustainability factors; but highlighted that all is far from clear. They called for an amalgamation of life cycle (sustainability) assessment (LCA) and simulation models and sketches that exist across disciplines and that reflect different levels of the farming system to fully comprehend the consequences of instigating GHG mitigation strategies. The result would be akin to a complex systems model and sketch, in which component interactions (cause-effect) would be modelled throughout the entire production chain at farm, crop and animal levels. Such a modeland sketch could prove influential in policy makers' decisions. To ensure that animal welfare science can contribute to its development and that the animal welfare impacts of GHG mitigation are more fully understood, we need to use our existing knowledge to modeland sketchthe links between farm animal welfare and otheraspects of sustainability, following on from the models and sketchesthat already exist in animal welfare literature. In doing so, gaps in knowledge will be highlighted; directing future research in this area.Although numerous studies reviewed herein examined the economics of farm animal welfare, few incorporated consumer willingness-to-pay (WTP) for higher welfare standards as a factor in their models, which would be required for a complete economic evaluation of welfare improvements [18]. This may be because of the difficulties incurred in accurately estimating WTP, or due to a lack of available data. However, research into consumer WTP for welfare improvements is increasing. The values estimated in these studies could be used in future models, and to refine existing sketches, to identify potential win-win scenarios for farmer and animal. Given that it is ultimately the farmer's decision whether or not to improve the welfare of animals above that required by legislation, it may also be in our interests to better understand farmers' decision-making processes, and how the major

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supermarkets influence these. Here, agent-based modelling (previously used in agricultural and consumer behavior studies may be useful [29].

Insufficient quantitative data can cause difficulties when developing valid mathematical sketches [1] as the accuracy of model and sketchoutput depends largely on the reliability and validity of input data [23]. Input data can be collected or estimated through direct measurement, literature reviews and expert opinion. While considered the “holy grail” in medicine, meta-analysis is rarely employed in animal welfare science but, where possible, could provide more reliable estimates of input data, and of relationships between parameters, than direct measurement in a single, all-encompassing, study. As randomly controlled trials tend not to be used in animal welfare research, however, differences between studies (housing conditions, breeds, management, etc.) and study limitations must be identified and taken into consideration in the analysis.

Thus, there is no need to wait for the collection of “perfect” data sets to build or parameterize sketches, which may be one of the reasons behind the limited use of mathematical modelsand sketches in farm animal welfare research to date. There are, already, many scientific papers reporting experimental data on which data mining and meta-analysis techniques could be used to parameterize a modeland sketch (here, we are referring to all models, including risk assessment). Over 40 years of research has led to a wealth of experimental findings collected undervarious housing conditions and farming systems, with a range of species and breeds, using various welfare measures and reporting different welfare statuses. Indeed, it would be a shame not to make the most of this data.

It must be noted that modelling and sketching is not a precise science and, in some ways, is quite subjective. Parameterizing the model with “real” (observed) data will increase objectivity; however, it will also increase the risk of error in model and sketch output, and reduce its applicability to other datasets, if the dataset used to parameterize the model and sketch is not valid, or contains erroneous values that aren’t typically observed. Increasing modeland sketch complexity by increasing the number of parameters may result in over fitting, which can reduce the model’sand sketches predictive value. Thus, there is a trade-off between bias and variance, whereby bias decreases, and variance increases, as parameter numbers grow. It could also be said that there is a trade-off between precision and manageability, which will certainly apply to the dataset used to parameterize the model. However, as shown by Mackay and Lee, simpler models can also have the best predictive value when tested against other datasets. Model and sketch validation is vital, otherwise, the model is an untested hypothesis. Validating the model using an independent dataset (an entirely new dataset to the one used for parameterization) is generally considered the best approach. However, this is often not possible if all available data is required to build the model. In this case, techniques such as cross-validation, bootstrapping and sub-sampling can be employed [22].

Assumptions are generally used to simplify the analyses and are typically based on real data or expert opinion. It is important to consider the evidence behind sketch assumptions when interpreting sketch output and drawing

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conclusions. Models and sketches that measure animal welfare using resource-based parameters are based on the assumption that welfare can be improved through changes to the animals' environment, or other resources bestowed on them. While this is likely true, we must also be careful not to fall into the "anthropomorphic trap". For example, while high stocking density is considered a risk to welfare in broiler chickens, research suggests stocking density per se is generally of less importance than housing management. This illustrates the necessity to base sketch assumptions on scientific evidence (establish links between resource- and animal-based parameters [18]) and to incorporate other factors that might interact with environmental parameters to impact on the animal's welfare, such as quality of stockman ship and the human-animal relationship [17]. However, where such evidence-based assumptions cannot be made, this should not discourage sketch development as the sketch can be strengthened as more data becomes available. In such cases, theoretical concepts can be combined with empirical data to build a sketch, and the concepts can then be used to guide future data collection to support or refine those assumptions.

We should be working towards determining the sensitivity and specificity of individual welfare indicators and whole assessment models and sketches, and establishing non-arbitrary cut-off points for good/poor welfare. Alternatively, we could adopt and adapt methods used in formulating diagnoses in human psychiatry whereby criteria are grouped and individuals must meet a certain number of thesecriteria to be diagnosed with a particular condition. In animal welfare, this could take the form of, for example, individuals being scored against sets of criteria for good welfare, compromised welfare and severely compromised welfare (severe feed restriction, mobility score 3 (lame) [29]).

4. CONCLUSIONS

Sketching and modellingwithin animal welfare research has been largely focused on the development and use of conceptual and assessment models and sketches. While there is great scope for progressing animal welfare science through integrating our existing knowledge in the development of mathematical models and sketches, we found that the use of such techniques has been limited to date. The development of "whole systems" models and sketches will require inter-disciplinary collaborations with systems biologists, economists, and sustainability and food security experts. In return, these large-scale models and sketches may have scope to influence decision-makers and, certainly, to improve our understanding of how, and where, animal welfare improvements fit into the wider context of sustainability and food security. Preliminary work towards the development of such complex models and sketches has already begun with the more specific simulation, optimization, scenario and assessment models and sketches that have been outlined in this paper.

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