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Risk assessment principles in evaluation of animal welfare

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Abstract

Science forms a vital part of animal welfare assessment. However, many animal welfare issues are more influenced by public perception and political pressure than they are by science. The discipline of epidemiology has had an important role to play in examining the effects that management, environment and infrastructure have on animal-based measures of welfare. Standard multifactorial analyses have been used to investigate the effects of these various inputs on outcomes such as lameness. Such research has thereby established estimates of the probability of occurrence of these adverse welfare outcomes (AWOs) and given exposure to particular management inputs (welfare challenges). Welfare science has established various measures of the consequences of challenges to welfare. In this paper, a method is proposed for comparing the likely impact of different welfare challenges, incorporating both the probability of AWOs resulting from that welfare challenge, and their impacts or consequences if they do, using risk assessment principles. The rationale of this framework is explained. Its scope lies within a science-based risk assessment framework. This method does not provide objective measures or score of welfare without some context of comparison and does not provide new welfare measures but only provides a framework enabling objective comparison. Possible applications of this method include comparing the effects of specific management inputs, assigning priority to welfare challenges in order to inform allocation of resources for addressing those challenges, and comparisons of the lifetime welfare effects of management inputs or systems. The use of risk assessment methods in the animal welfare field can facilitate objective comparisons of situations that are currently assessed with some level of subjectivity. This methodology will require significant validation to determine its most productive use. The risk assessment approach could have a productive role in advancing quantitative assessment in animal welfare science.

Keywords: *animal welfare, epidemiology, impact, probability, risk assessment, welfare challenge*

Introduction

The science of animal welfare is in a rapidly developing phase. However, critics of animal welfare research and assessment have, with some justification, alluded to the lack of rigour and transparency in evaluation of animal welfare. This situation has been exacerbated by some groups promoting improvements in animal welfare which are easily labelled (for example, 'Barn-laid eggs') on the basis of emotive or anthropomorphic arguments rather than science.

There has been a proliferation of so-called welfare-friendly systems for production animals so that consumers might be assured that specific minimum standards are met, such as the provision of straw for confined dairy cattle to lie on. There is no doubt that welfare-friendly production systems have improved the welfare of many production animals. However, there are welfare challenges which are difficult or impossible to assess merely from an animal's surroundings. 'Animal-based measures' are now becoming an important aspect of the assessment of the overall welfare of animals (Whay *et al* 2003).

In spite of the acknowledged importance of using animal-based measures to assess welfare, a number of current methods for the assessment of welfare use a combination of animal-based and other indicators. Attempts to develop indices for measuring of welfare have often resulted in *ad hoc* collections of 'inputs' (infrastructure, management systems, genetics and management skills) mixed with animal-based measures or outcomes of poor welfare such as foot lesions, skin damage or displaying stereotypic behaviour (Scott *et al* 2003). Combining inputs and animal-based outcomes in welfare indices can confuse the measurement of welfare. Indices of welfare are also prone to biases arising from the personal views of experts, on whose opinions the indices are often based.

The Welfare Quality® project in Europe (Blokhuis *et al* 2003) is using some animal-based measures to develop a series of indices including welfare criteria like 'resting comfort', 'thermal comfort', 'ease of locomotion' and others, which are combined using non-additive methods into an overall index of welfare.

Indices such as these are, however, intrinsically specific to the defined system of interest. They are therefore difficult to contextualise in terms of their overall welfare impact. More generalised and broadly applicable methodologies may provide improved confidence in overall welfare assessment. If more science-based measures can be used to assess the relative importance of different inputs on welfare outcomes, then these inputs can be used with improved confidence to improve welfare outcomes.

There is a need for a methodological framework guiding and standardising welfare assessment and this need is reflected in recent international developments. The European Food Safety Authority (EFSA) has published guidelines on risk assessment for animal welfare (EFSA 2012), and the World Organization for Animal Health (OIE), which has traditionally developed international standards for animal health, now publishes international standards for animal welfare as well (OIE 2012a). Such international standards in animal welfare must be based on scientific evidence. Accordingly, improvements in our ability to analyse animal welfare under varying scenarios will assist in both the development and further refinement of standards.

The challenge is to develop assessment methods which quantify, as much as possible, the effects of different parameters on the welfare of production animals. The methodological framework then needs to be the subject of general agreement, as is the case with import risk analysis, so that it can be applied consistently. These methods might then facilitate more use of quantitative measures in the science of animal welfare, leading to more straightforward and transparent analysis, and improved communication to those wishing to make decisions about aspects of animal welfare. One approach proposed is to adopt the principles of risk assessment, often used in biosecurity, to animal welfare. For example, a semi-quantitative approach for animal welfare risk assessment has been proposed by the EFSA (EFSA Panel on Animal Health and Welfare 2012). However, it is important to recognise that more than one approach may need to be explored to facilitate effective quantitatively based comparisons between different animal husbandry situations.

In this paper, we present a simple framework, based on the risk assessment concepts of probability and consequences, for comparison of the severity of welfare challenges associated with different management strategies or other inputs.

Materials and methods

Risk assessment framework for welfare assessment

We will use the terminology shown in Table 1 and will confine ourselves to animal-based indicators of welfare. Risk, in the context of risk assessment, is the probability of an event occurring, and the consequences if it does occur (the 'likely consequences' of the event). Using the welfare assessment equivalents in Table 1, the risk to the welfare of an animal can be assessed by using a measure referred to as severity of welfare challenge (SWC). This measure is comprised of the probabilities of adverse welfare outcomes (AWOs) occurring, and their welfare impacts if they do. Note that probability and consequences (or welfare impact) are independent of each other. In using the risk assessment framework for welfare assessment, we recognise that *welfare* is a positive term (or measure of well-being), having the opposite sense to *risk* (a negative measure).

The OIE's guidelines for import risk assessment (IRA) (OIE 2012b) provide an appropriate framework for consideration in welfare assessment. An import risk assessment has three components: release assessment; exposure assessment; and consequence assessment. Release assessment estimates the probability that a hazard (generally a disease) will be introduced into the importing country with the commodity in question; exposure assessment estimates the probability that animals in the importing country will be exposed to the hazard given that it has been introduced with the commodity; consequence assessment estimates the likely consequences of different outbreak scenarios, given that exposure to the hazard has occurred. The likely consequences (for a specific type of consequences) of an exposure comprise the probability of the specified consequences arising, and their magnitude if they do. Types of consequences to be considered include direct consequences (animal infection; disease and production losses; public health consequences) and indirect consequences (surveillance and control costs; compensation costs; potential trade losses; adverse consequences to the environment).

In welfare assessment, and for the purposes of this paper, the welfare equivalent of the combined release and exposure assessments is an assessment of the probability of a welfare challenge occurring to an animal or group of animals. The welfare equivalent of the OIE's consequence assessment is assessment of the SWC, given that it has occurred.

The probability that a welfare challenge will occur is an important consideration in various potential applications of welfare assessment, but in this paper we confine ourselves to comparing estimates of the severities of welfare challenges, given that those challenges have occurred; ie we confine ourselves to the welfare equivalent of the OIE's consequence assessment. In this context, the 'welfare challenge' is equivalent to the IRA 'hazard'; an 'adverse welfare outcome' is equivalent to the IRA's 'outbreak scenario', and 'welfare indicators' are measures of the magnitude of AWOs, and may be considered equivalent to the various types of consequences which should be estimated in IRA.

The OIE (2012b) has published principles which risk assessments in IRA should follow, and the following are also applicable in welfare assessment:

- Risk assessment should be flexible to deal with the complexity of real life situations. No single method is applicable in all cases. Risk assessment must be able to accommodate the variety of animal commodities, the multiple hazards that may be identified with an importation and the specificity of each disease, detection and surveillance systems, exposure scenarios and types and amounts of data and information.
- Both qualitative risk assessment and quantitative risk assessment methods are valid. Although quantitative assessment is recognised as being able to provide deeper

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Table 1 Proposed terminology for using risk assessment in animal welfare, compared to that for import risk analysis (italics).

Risk analysis term	Definition
Proposed equivalent welfare analysis term	
Hazard	A potentially adverse event (a pathogenic agent in animal health)
Welfare challenge	*An event or set of circumstances with the potential to affect welfare adversely*
Consequence scenario/Outbreak scenario	One possible set of circumstances arising from exposure to a hazard
Adverse welfare outcome (AWO)	*One possible welfare outcome of exposure to a welfare challenge*
Probability	Likelihood
Probability	*Likelihood*
Consequences	The adverse effects associated with a consequence/outbreak scenario
Welfare impact	*The adverse effects on welfare associated with an Adverse welfare outcome*
Risk estimate	Estimate of risk associated with the hazard (= Probability × Consequences)
Severity of welfare challenge	*Estimate of the adverse effect on welfare associated with the welfare challenge (= Probability × Welfare impact)*
Risk assessment	The process of estimating probability, consequences and thence risk
Welfare assessment	*The process of estimating probability, welfare impact, and thence severity of welfare challenge*
Additional terms used in this paper for using risk assessment in animal welfare	
Likely impact	Probability × Welfare impact for an adverse welfare outcome
Welfare indicator	*Indicator used to assess ot measure the magnitude of the impact of an adverse welfare outcome*
Scaled welfare measure (SWM)	*Value for a welfare indicator re-scaled to a scale of zero to ten*

insights into a particular problem, qualitative methods may be more relevant when available data are limited.

• The risk assessment should be based on the best available information that is in accord with current scientific thinking. The assessment should be well-documented and supported with references to the scientific literature and other sources, including expert opinion.

• Consistency in risk assessment methods should be encouraged and transparency is essential in order to ensure fairness and rationality, consistency in decision making and ease of understanding by all the interested parties.

• Risk assessments should document the uncertainties, the assumptions made, and the effect of these on the final risk estimate.

• The risk assessment should be amenable to updating when additional information becomes available.

In risk assessment we estimate risk, and if we find the risk to be unacceptably high, we look at introducing risk management measures to reduce the risk. In welfare assessment we estimate SWC, and if we judge it to be high compared to other challenges or no challenge, then we look at different management measures to reduce the SWC. In the approach we are suggesting in this paper, any summary measure of the SWC may only be used for comparison with other SWCs estimated in the same analysis; we are not proposing any system for making absolute estimates of welfare, or for judging assessments as acceptable or unacceptable.

The approach we suggest may be applied either to the individual animal selected at random from those exposed to a management system or challenge, or alternatively to a group of animals so exposed.

In risk assessment, probability has no units, and its range is from 0 (impossible) to 1 (certain). Consequences have units (often measured on a monetary scale) and their range is from 0 (none) to a very large number. The combination of probability and consequences to give a level of risk is usually expressed multiplicatively:

$$Risk = Probability \times Consequences$$

Then, no matter how great the consequences, if the probability is negligibly small, the risk will be negligible; and if the probability is high the risk will be largely determined by the magnitude of the consequences.

In welfare assessment, for each AWO (eg lameness; reduced immune response) measured in response to a welfare challenge (a management system likely to cause high rates of one or more AWOs; eg housing pregnant sows in stalls); there is an associated probability of the AWO occurring and magnitude of the impact if it does occur. For the individual animal, probability of occurrence of the AWO is best estimated by the proportion of a homogeneously managed group that displays this AWO (ie, in the case of lameness, the proportion of a homogeneously managed group that actually suffers lameness). The magnitude of the welfare impact on the individual sow (given that it is lame) is best estimated by a measure of its magnitude (severity) among those in which the AWO occurs. This may be the average impact among lame sows in sow stalls, or other appropriate summary measure; it may be considered appropriate to use the whole range or distribution of observed welfare impacts among lame sows in stalls, in order to incorporate uncertainty and/or variability into the assessment.

Table 2 Example of a qualitative risk assessment matrix.

Likelihood of adverse event occurring	Consequences					
	Negligible	**Very low**	**Low**	**Moderate**	**High**	**Extreme**
High	Negligible	Very low	Low	Moderate	High	Extreme
Moderate	Negligible	Very low	Low	Moderate	High	Extreme
Low	Negligible	Negligible	Very low	Low	Moderate	High
Very low	Negligible	Negligible	Negligible	Very low	Low	Moderate
Extremely low	Negligible	Negligible	Negligible	Negligible	Very low	Low
Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Very low

Then, for a given welfare challenge to an individual animal:

$$SWC = \Pr(\text{AWO}) \times WI \quad (1)$$

where Pr(AWO) is the probability of the AWO occurring and *WI* is the Welfare impact of the AWO when it occurs. For an individual sow in the sow stalls example:

$$SWC = \Pr(\text{lameness}) \times WI\_lameness$$

where *WI_lameness* is the welfare impact of lameness in sow stalls.

When multiple AWOs are considered, averaging the likely impacts of each AWO is a sensible way to combine them which does not give differential weighting to individual AWOs;

$$SWC = \frac{1}{n} \times \sum_{i=1}^{n} \Pr(AWO_i) \times WI_i \quad (2)$$

where n is the number of AWOs assessed, $\Pr(AWO_i)$ is the probability of the ith AWO occurring, and WI_i is its welfare impact when it does occur.

If the duration of a welfare impact is considered critical in an assessment, it may be appropriate to incorporate this effect by integrating the level of impact over time, and using average integrated impact for those challenged.

Methods for estimation — qualitative and quantitative

Both probabilities and impacts may be measured qualitatively (eg low; medium; high) or quantitatively (using numeric values on continuous scales) or semi-quantitatively (using scores, ranks, indices, etc). In general, it is appropriate to apply the same method to both probability and impact assessment, since the end result should only be reported using the units of the less quantitative of the two; if either impact or probability is assessed qualitatively, then SWC will be reported qualitatively. If probability is assessed quantitatively and impact semi-quantitatively, then SWC will be expressed semi-quantitatively, on an ordinal scale. As with risk assessment, there are arguments for and against each of these methods. It is possible to develop rules for combination of qualitative estimates of probabilities and impacts (eg Table 2), and mathematics may be used to combine quantitative estimates. SWC is derived by multiplicative combination of probability and impact (Equation 1). Semi-quantitative assessment involves the use of scores or ranks for probability and impact assessment. For example, probability might be estimated on a scale of 0 to 10, where 0 represents impossibility ('the event cannot occur') and 10 represents certainty ('the event will occur'). Similarly, impact might be estimated on a scale of 0 to 10, where 0 represents no impact and 10 an extremely severe impact. The multiplicative rule for SWC can still be used, yielding SWC on a scale of 0 to 100. This approach is simple and intuitive, but does not allow multiplicative combination of separate elements of the probability estimate. For example, Pr(tail abscess) might be estimated as Pr(tail biting occurs) × Pr(tail abscess/tail biting in group); this only works when quantitative probability estimates in the range 0 to 1 are used. Many variations are possible in the definition and use of scores and indices in semi-quantitative analysis.

In many welfare assessment scenarios, multiple welfare indicators, measuring multiple AWOs, are used to estimate the SWC. These impacts are generally measured on different scales (eg percent feather loss; nmol cortisol per L of plasma) and their mathematical combination is not possible without first converting them to scores. Such a system of assessment is intrinsically semi-quantitative, and information on specific AWOs will inevitably be lost when multiple welfare impacts are combined. Multiple AWOs may have different probabilities of occurring, or sometimes they may have a common probability of occurrence. In the latter scenario, a summary impact score for multiple AWOs may be combined with a quantitative estimate of the probability of the AWOs occurring. For the former scenario, where different probabilities of occurrence apply to individual AWOs, equation (2) is applied.

Developing an impact score

The SWC may be assessed by combining a range of likely impacts of AWOs (probabilities of AWOs and their impacts). Welfare indicator values (scores of severity) for each of multiple AWOs may be combined using any justifiable procedure which is transparently documented; a simple example is to take the arithmetic mean or average. This is

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the procedure followed in this paper and its accompanying paper (Fisher *et al* 2013; this issue). This effectively gives equal weight to each of the multiple indicators. Similarly, likely impacts for multiple AWOs which occur as a result of the welfare challenge may be combined or averaged in the same way, to give an overall measure of SWC.

AWOs include measures of behaviour, physiology and production (Fraser 2003). The number of AWOs used in assessing welfare will vary from one situation to another, and it is reasonable to consider incorporating at least one from each of these groups.

The purpose of deriving SWC is to compare the levels of welfare associated with different welfare challenges, for example different management strategies. This may be done using a range of AWOs, or a single AWO. It will always be important, however, that for a given comparison the same AWOs are used for each challenge or management strategy; in comparing the SWCs of two different challenges, A and B, deriving a score for weight loss following challenge A, and a score for plasma cortisol level following challenge B, would clearly not be appropriate. Measurement of both indicators for both challenges is necessary for a valid comparison.

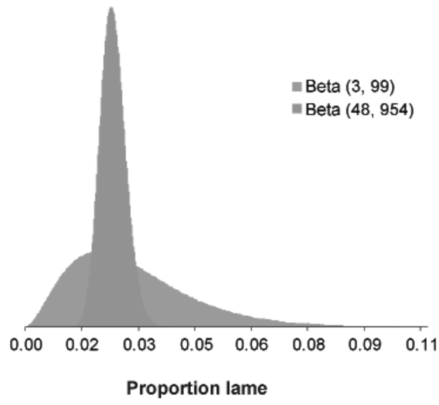
It is also important that the indicators or measures of the impact of a given AWO should be expressed on the same scale for all challenges involved in the comparison. This is necessary to take account of any differences among investigators measuring indicator values, and different conditions among studies expressed as different 'background' levels of indicators. Once we have the same indicators measured on the same scale, we propose adjusting this scale to a standardised range, zero to ten, giving a 'scaled welfare measure' (SWM) for each animal or group of animals assessed, and for each indicator. Where appropriate (ie either when they relate to a single AWO, or when all AWOs have the same probability of occurrence), individual SWMs for an animal or group may then be combined by averaging, to give a summary impact score; the average SWM for the animal or group. In this process, a system of weighting of the SWMs for each AWO could be applied, as long as the weighting process is transparently documented.

The average SWM for an animal or group of animals is then combined with the probability of the AWO(s) occurring by simple multiplication (equation [2]), to give the SWC. This process allows combination of any number of measures of an AWO, by using a standardised scaling of indicator values. A wide range of different measures of AWOs, and a range of different AWOs, may therefore be incorporated into the welfare assessment.

Uncertainty and variability

In risk assessment it is common, and important, to incorporate the effects of uncertainty and variability into the assessment, such that the distribution of possible values for the end result (the risk estimate) is well described. The same is true for welfare assessment, in which both uncertainty and variability play important roles.

Figure 1



Beta distributions illustrating uncertainty of prevalence estimate from observations on 100 sows (green) and 1,000 sows (pink).

Uncertainty is the term used to describe our lack of knowledge about some value; knowledge that could be improved by gathering more or better information. We might well be uncertain about the probability that pigs will develop lameness when housed on some novel flooring material. In assessing the SWC we should ensure that we report the likely range of values for the SWC, given that uncertainty. Also, if needed and appropriate, we will be able to gather a lot more information about the incidence of lameness as we use the flooring more. The more information we have, the less our uncertainty. Suppose that initially we only have data from 100 pigs over a suitable time-period, and two developed lameness. Ignoring our uncertainty, we estimate the probability that a pig will develop lameness under these conditions as:

$$\Pr(lameness) = 2/100$$

A better estimate of Pr(*lameness*) which incorporates our uncertainty is given by the Beta probability distribution (see Figure 1):

$$\Pr(lameness) \sim \mathrm{BETA}(3, 99)$$

Over time, we gather more information and when we have records of 47 lame pigs out of 2,000 kept on the new flooring, the uncertainty distribution for our estimate of the proportion of pigs in general developing lameness on this flooring is now much narrower, as shown in Figure 1.

The great majority of probability estimates, whether based on data or expert opinion, will involve uncertainty, and inclusion of this uncertainty in the modelling or analytical process will greatly enhance the value of the results, since they will include estimates of the level of certainty associated with the calculated SWC. By using appropriate probability distributions to represent the uncertainty associated with each probability estimate, it is straightforward with modern computer software (eg spreadsheet add-ins) to incorporate uncertainty associated with either quantitative or semi-quantitative probability estimates.

Table 3 An example of the calculation of severity of welfare challenge using probabilities and impact scores to compare welfare outcomes from two welfare challenges in dry sows.

Welfare challenge	Category of welfare effect	Adverse welfare outcome[1]	Probability	Impact score[2]	Likely impact[3]
Sow stalls	Physiological	Lameness	0.2	8	1.6
		Low immunity	0.05	6	0.15
	Behavioural	Oral stereotypies	0.5	7	3.5
		Fearfulness	0.05	5	0.25
		SWC (average of likely impacts)			1.375
Poor stockperson skills	Physiological	Lameness	0.05	8	0.4
		Low immunity	0.1	6	0.6
	Behavioural	Oral stereotypies	0.01	7	0.07
		Fearfulness	0.7	5	3.5
		SWC (average of likely impacts)			1.1425

[1] Measured using appropriate welfare indicators.
[2] Derived from appropriate welfare indicators. In this example the impact score is already a scaled welfare measure (SWM), since it is estimated on a scale of 0–10.
[3] Likely impact = Probability × Impact score.

Variability is the term used to describe variation among individuals; it cannot be reduced by acquiring more knowledge or data. In estimating probability, it is the probability itself which describes the variability of the population; some will be affected and some will not. In assessing impacts, we will generally use the mean of observed responses in a sample of the population as the expected level for the impact. The standard deviation of those observed responses is a reasonable representation of the expected variability in the population. The standard error of the mean may be thought of as representing our uncertainty about the mean impact for the population, but clearly each of these statistics comes from the same data set, and the data set contains the effects of both variability and the uncertainty arising from the fact that is derived from only a sample of the population.

Variability may be modelled in a welfare assessment using such tools as the Binomial distribution to estimate the number of exposed animals that are affected, or the Normal distribution to estimate the level of some normally distributed level of an AWO. Simulation (using multiple iterations) is then used to incorporate the effects of both uncertainty and variability into the assessment (Vose 2008).

Illustrative example

Possible applications of this method include comparing the effects of specific management inputs, prioritising for resource allocation decisions, and comparisons of the lifetime welfare effects of management systems.

The first two applications are illustrated below by hypothetical examples and the third application is developed in detail in the accompanying paper by Fisher *et al* (2013). Firstly, we compare the SWC for pregnant sows: (a) being kept in stalls for their entire pregnancy; or (b) being managed by a stockperson with poor pig-handling skills. This is an arbitrary, illustrative example of the method; it is not based on data, and thus is not an assessment of sow welfare.

The welfare challenges considered in this example are those of being managed under each of the two scenarios given above. Exposure to either (a) or (b) is a challenge to the animal's welfare. In assessing the severity of each of these welfare challenges, four AWOs are measured, two of which are physiological outcomes, and two behavioural. Lameness can be measured by a visually assessed score, and low immunity can be measured by a range of haematological parameters or physiological responses to a standard immunological challenge. For the behavioural effects, oral stereotypies, or the performing of stereotypic behaviours, can be measured by a visual index, and fearfulness may be measured by the distance which a pig will let a stockperson approach before it withdraws (flight distance) or other visually assessed behavioural traits.

In this example, each AWO has, potentially, a different probability of occurrence. Therefore, the 'likely impact' of each AWO must be calculated separately for each AWO. Likely impacts are calculated from estimates of probability and impact applicable to the AWO. The SWC is then estimated using equation (2).

In Table 3, the average SWC for each of the two challenges, using physical and behavioural AWOs, is calculated using probabilities of AWO occurrence and impact scores estimated for the individual animal. The probability estimates for individual animals displaying a particular AWO could be based on research data (the likely proportion of sows on an average farm affected by the AWO). The impact score is an estimate of the severity of the AWO on the individual sow on a scale of 0 to 10, and as such it is in itself a scaled welfare measure (SWM). This estimate

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Table 4 The calculation of Risk and Severity of Welfare Challenge using probabilities and impact scores to compare an illustrative, hypothetical, example of two welfare challenges with enterprise- and industry-level welfare effects in dry sow production.

Welfare challenge	Outcome	Probability	Impact score[1]	Likely impact[2]	Risk/SWC[3]
Enterprise level					
Sow stalls	Annual cull rate > 40%	0.7	8	5.6	2.86
	Inefficient stock management	0.02	6	0.12	
Poor stockperson skills	Annual cull rate > 40%	0.05	8	0.4	2.3
	Inefficient stock management	0.7	6	4.2	
Industry level					
Sow stalls	Pork sales drop > 5%	0.3	8	2.4	1.38
	Annual staff turnover > 20%	0.05	7	0.35	
Poor stockperson skills	Pork sales drop > 5%	0.01	8	0.08	1.79
	Annual staff turnover > 20%	0.5	7	3.5	

[1] In this example the impact score is equivalent to a scaled welfare measure (SWM), since it is estimated on a scale of 0–10.
[2] Likely impact = Probability × Impact score.
[3] Risk or SWC is the average of the likely impacts for each management scenario.

could well be derived using measures described in the previous paragraph or other research which quantifies the severity of that AWO. Combination of the probability and SWM for each AWO gives the likely impact for each of the physical and behavioural effects.

For confinement in sow stalls (Table 3), the (hypothetical) estimated probability of an individual sow being lame (displaying the AWO) is 0.2 with a SWM of 8, so the likely impact derived from lameness is $0.2 \times 8 = 1.6$ (applying equation [1]). Similarly, the likely impact for the AWO of oral sterotypic behaviour is $0.5 \times 7 = 3.5$. Similar calculations are shown in Table 3 for other less probable AWO of low immunity (likely impact = 0.15) and fearfulness (likely impact = 0.25). The SWC for sow stalls (1.38) can then be compared to a similarly calculated SWC for exposure to poor stockperson skills (1.14). In reality, there are many more effects of these management scenarios making the comparison more complex. However, other AWOs, and/or other measures of the same AWO, can be handled similarly, and incorporated into the calculation of SWC.

To illustrate the application of the method for assigning priority to challenges, a similar table of estimated SWC at enterprise and industry level can be compiled (see Table 4), and considered together with the animal-level SWCs (Table 3) from the previous illustrative example. Enterprise- and industry-level outcomes which are indirect measures of welfare outcomes and risks associated with welfare issues might also be included using the same RA principles.

As with the previous example, the impact score is an estimate of the impact or consequence of the enterprise- or industry-level outcome on a scale of 0 to 10 and, as such, it is itself a scaled welfare measure (SWM). For this illustrative example (Table 4), the probability that an enterprise will have an annual sow cull rate greater than 40% is 0.7, and the impact score of 8 indicates that the impact of this on the enterprise is high. These estimates of probability and impact are likely to be based on expert opinion or industry economic data. Combination of the probability and SWM for each AWO gives a likely impact for each AWO. Calculations are made as in the previous example and average risk (equivalent to SWC) for the selected outcomes for sow stalls can then be compared to a similarly calculated average risk for poor stockperson skills.

The average SWC or risk for each of the animal, enterprise and industry levels can be considered separately so as to understand the comparative effects of the welfare challenges at these different levels. In this illustrative example, the use of sow stalls may have a higher priority at an animal and enterprise level, but a lower priority at the industry level. The outcome of such comparisons might be used to decide if resources are allocated most productively to infrastructure improvement or staff training.

Discussion

The use of quantitative assessment methods in animal welfare is likely to be improved as the body of animal welfare research grows and the complex effects of a range of inputs on AWO are more accurately defined. As the availability of these quantitative measures of the effects of animal welfare challenges increases, so will the need for a framework to use these data to compare intrinsically complex animal welfare challenges.

There are several advantages to using the risk assessment framework for evaluating animal welfare challenges. The first is that there is a logical fit of the methodology to the way that animal welfare challenges occur in reality. A welfare challenge originating in animal-, management-, or facility-based factors has a probability of causing one or more AWOs which have consequences (welfare impacts), and thus carry risks (SWCs). The data available to assess animal welfare are varied in nature, and this suits the risk assessment framework, which can cope with quantitative and qualitative data.

The EFSA panel on Animal Health and Welfare (2012) in its *Guidance on Risk Assessment for Animal Welfare* uses an example to compare two scenarios with a series of possible different welfare outcomes. The authors use an example of a series of sequential disease events, (arranged in a scenario tree) stemming from a mutually exclusive difference in management (using sexed or unsexed semen in cattle), to estimate the effects of a series of outcomes. This scenario requires a different risk calculation methodology than used as an example in this paper. Estimated welfare scores (based on expert opinion) for each outcome are added and probabilities are multiplied then the cumulative probability and welfare score outcomes are multiplied together to give an expected welfare score. These scores are then added for all outcomes of each scenario and compared. In this paper, probability and impact are multiplied to give likely impact for that welfare outcome. These are averaged within welfare effect categories and then added to give the SWC to be compared.

The methodology described in this paper is entirely consistent with the guidelines provided by the EFSA expert panel (EFSA 2012). In this paper (with a detailed case study in the accompanying, Fisher *et al* 2013), we present procedures for using quantitative measures of varied animal-based welfare indicators of multiple welfare outcomes to develop a summary measure of severity of welfare challenge, based on semi-quantitative procedures. This adds substantially to the EFSA guidelines, as well as proposing logical, descriptive terminology for the various welfare equivalents of risk assessment concepts.

In this context, it is interesting to compare the hypothetical assessment of pig welfare in this paper with that proposed by the European Food Safety Authority (EFSA Panel on Animal Health and Welfare 2007) which outlined a risk assessment approach to rank the welfare risks to dry sows. The method used followed the calculation of risk as probability by severity. However, this method did not consider combining the risk calculations for different hazards due to the same input to compare welfare outcomes for that input (eg sow stalls or 'confining sows in crates' as the paper refers to this management input). In this paper, we have combined two AWOs for physiological and behavioural welfare effect categories and added these to give an instructive example of how this calculation of an overall SWC could be calculated.

No matter what type of framework is developed to enhance the understanding of the components of animal welfare, the industries involved and the consuming public will make qualitative value judgements on the welfare of animals in particular production systems. The assessment of overall welfare using a risk assessment framework may be used as a means of enhancing the understanding of industries and consumers of the more important components of animal welfare. To maximise the value of this method, agreement is needed on rules to standardise its application. The development of consistency in its application will improve the credibility of such a methodology.

It is fundamental that science-based risk assessment should provide transparency in risk-based decision-making. This is achieved by using standardised methods of documentation, reporting, referencing and peer review. Subjective judgements are eliminated as far as is possible and only measurements based on objective scales are advocated. One disadvantage with this approach is that if an AWO which contributes to an SWC is behavioural and measures of its severity have low precision, this low precision will be reflected in the overall assessment.

There are some important limitations to the scope of this method. Risk assessment used in the way described in this paper is a method for comparison. When used in this way it cannot provide any objective measure or score of welfare without some context of comparison. It is important to understand that this method does not provide new welfare measures but only provides a framework enabling objective comparison, of existing data on complex challenges affecting the welfare of animals.

Animal welfare has recently been incorporated into the responsibilities of the OIE, which already recognises this methodology for the assessment of risks of disease introduction. This body could play a useful role in standardising the use of this methodology for welfare assessment, as it does with import risk assessment and food safety.

Another use of this method may be in the development or improvement of quality assurance (QA) systems. QA systems have been developed as a tool for animal welfare improvement (Bock 2005). Risk assessment is a method which can be used to design and enhance QA systems by comparing the effects of different inputs on SWC, leading to improved animal welfare for the benefit of animals, industries and consumers.

Effective communication of risks is a vital adjunct to risk assessment. By developing the discipline and structure of this method, the communication of elements of animal welfare risks important to the consuming public could be more effectively achieved. This clarity could improve product marketing and labelling systems giving consumers more confidence in the welfare standards behind the products they choose.

This paper introduces the application of risk assessment methodology to animal welfare assessment and its potential use for comparing specific management inputs and prioritising their use by assessing welfare challenges at animal, enterprise and industry levels. These comparisons of the SWCs caused by management decisions, will allow researchers to make more informed decisions about issues for further research, based on their likely impacts on animal welfare outcomes as well as allowing industries to prioritise funding for promoting management inputs, based on the economic and other consequences of different welfare outcomes. The accompanying paper by Fisher *et al* (2013) illustrates its application for comparing lifetime welfare under different management systems.

The OIE already provides guidelines for the use of risk assessment in animal health issues and food safety in inter-

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national trade. Using this method in the animal welfare field would give consistency across the functions of this organisation which is recognised globally as advocating the use of science to make complex decisions about the health and welfare of animals. These benefits, in addition to applications in the important areas of quality assurance and welfare communication, indicate that risk assessment will have a productive place in advancing animal welfare science.

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