Defining, assessing and promoting the welfare of farmed fish

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Summary
As currently practised, the culture of fish for food potentially raises concerns about the welfare of farmed fish, and this is a topic that has received considerable attention. As vertebrates, fish share a number of features with the birds and mammals that are more commonly farmed, so many welfare principles derived from consideration of these groups may also be applied to fish. However, fish have a long, separate evolutionary history and are also adapted to a very different, aquatic environment. For these reasons, they have a number of special features that are relevant to how welfare is defined, assessed and promoted and these are discussed. The various methods that are available to researchers for identifying and assessing good and bad welfare in fish are considered, including assessment of physical health and physiological, behavioural and genomic status. The subset of practical welfare indicators that can be used on working farms is also reviewed. Various aspects of intensive aquaculture that can potentially compromise fish welfare are outlined, as are some strategies available for mitigating such adverse effects. Finally, the paper ends by looking briefly to the future, identifying likely changes in aquaculture practices and how these might affect the welfare of farmed fish.

Keywords

Introduction
Whatever the purpose for which finfish (hereafter simply referred to as fish) are cultured, whether for the aquarium trade, scientific research or restocking (1), it is important to ensure the well-being of the fish concerned. The culture of fish for human consumption, i.e. fish farming, currently provides more than 50% of the fish we eat, is growing rapidly (approximately 9% per annum for the past three decades), and is becoming more intensive (2). The welfare of such fish, particularly those reared intensively, forms the topic of this review.

Being vertebrates, fish have many traits in common with the more familiar intensively farmed animals such as pigs and chickens. However, as an ancient group of vertebrates, and being aquatic, they differ from terrestrial animals in ways that are important when it comes to welfare. The authors therefore begin this paper with a brief account of the special features of fish, and then consider the challenging issues of what welfare means and the extent to which the term can appropriately be applied to fish. The authors conclude cautiously that the term can be meaningfully applied and so they then discuss how good and bad welfare can be identified and assessed, both during scientific research and on working fish farms. They then consider the ways in which intensive fish culture can potentially compromise fish welfare and the kinds of actions that have been and could be taken to promote the welfare of farmed fish now and in the future.
An important point to make first is that the taxonomic group Pisces has been in existence for some 500 million years, compared to 150 and 200 million for birds and mammals, respectively, and comprises about 28,500 living species, all adapted for coping with the challenge of their particular ways of life. For this reason, when it comes to defining, assessing and protecting fish welfare, it is important to avoid projecting what we know of birds and mammals onto fish or assuming that fish are in some way inferior to terrestrial animals. On the contrary, arguably their longer phylogenetic history makes them a particularly successful group. Furthermore, although the various kinds of fish have many things in common, they are phylogenetically and ecologically diverse. Legitimate generalisations can be made about fish welfare, but specific details of what promotes or detracts from good welfare will vary from species to species.

What is special about fish?

Almost all fish share a similar basic body plan with other vertebrate groups, having among many other traits an anterior, jawed skull, a spinal column and two sets of paired appendages (fins in the case of fish), all made of bone or cartilage. Also, the structure and function of the nervous system are broadly similar, with a central nervous system, consisting of a brain and spinal cord, connected to the sense organs and the muscles by a peripheral nervous system. Overall, the sense organs of fish are remarkably similar in structure and function to those of terrestrial vertebrates, as is the endocrine system, including the hormones involved in stress responses (3). Fish are also similar to other vertebrates in terms of their general behavioural capacities: they show the same kinds of learning and navigate around their environment using similar cognitive processes. Like other vertebrates, they have behavioural traits that enable them to find, capture and ingest appropriate food, to avoid becoming food themselves and, depending on the species, to fight, court and mate and, in some cases, to take care of their young (1).

On the other hand, having had a separate and longer evolutionary history than birds and mammals, and being adapted to live permanently in water, fish differ from other vertebrate groups. Some of the differences that are most relevant to the question of fish welfare are outlined in Table I. Arguably, the relatively small size and simplicity of the brain and the very different way in which it develops clearly articulated by Rose (8, 9, 10), is based on, among other things, the fact that the fish brain is small compared to that of mammals and lacks structures that underpin many higher mental processes in humans. In addition, according to this view, fish have little capacity for learning and a short memory span. While they have the mechanisms to detect and respond to harmful stimuli and potentially dangerous events, such responses, though perhaps more than simple reflexes and possibly with some emotional content (10), are thought to fall far short of what could be called feelings. However, others have argued against this view (e.g. 11, 12, 13), partly because the behaviour of fish is more complex.

What does welfare mean and does the concept apply to fish?

The second section of this volume discusses the question of what welfare means when applied to animals in general. The authors revisit the topic here because much of the controversy concerning fish welfare arises from the different ways in which animal welfare can be defined. Briefly, some would propose that an animal experiences good welfare if it can adapt to its environment and is in good health, with all its biological systems functioning appropriately. According to this function-based view, an animal that is in poor health has poor welfare by definition, and vice versa. Another view proposes that to enjoy good welfare an animal must be able to lead a natural life, such that, by definition, welfare is compromised if a captive animal cannot show the full repertoire of behaviour that it would display in the wild. A third position equates good welfare with an animal being largely free from negative feelings, such as pain, fear and hunger, and having access to positive experiences, such as companionship for social animals. None of these positions is right or wrong; they simply emphasise different aspects of a complex phenomenon (4). Table II explores some implications of these different approaches to welfare with respect to two situations that farmed fish may experience; namely, poor body condition related to low nutrient intakes and involvement in fights.

The thought that an animal may be suffering is a strong driver for concern about animal welfare, so definitions based on feelings probably best address public sentiment on this matter. It is therefore important that scientists address this aspect of welfare. The question of whether fish have the capacity for suffering, which in turn depends on just how complex their cognitive and emotional capabilities are, continues to be hotly debated. The answer is important, since it will determine whether the concept of welfare defined in terms of feelings is applicable to fish, an issue that is considered in detail by Braithwaite and Ebbeson (7).

Briefly, the view that fish do not have the capacity for suffering, clearly articulated by Rose (8, 9, 10), is based on, among other things, the fact that the fish brain is small compared to that of mammals and lacks structures that underpin many higher mental processes in humans. In addition, according to this view, fish have little capacity for learning and a short memory span. While they have the mechanisms to detect and respond to harmful stimuli and potentially dangerous events, such responses, though perhaps more than simple reflexes and possibly with some emotional content (10), are thought to fall far short of what could be called feelings. However, others have argued against this view (e.g. 11, 12, 13), partly because the behaviour of fish is more complex.
than commonly recognised and also because there is a fair degree of homology and functional equivalence between the brains of fish and mammals. In particular, two parts of the forebrain involved in the generation of emotions and in learning in mammals, i.e. the amygdala and hippocampus, respectively, have anatomical and functional homologues in the brains of fish. Clearly, we need to know a great deal more about the mental and emotional life of fish before this issue can be resolved, but the authors conclude that fish have some degree of consciousness or sentience, no doubt different in kind and intensity from that of humans. In the specific context of assessing the well-being of cultured fish, the question is somewhat academic, since most of the ways that scientists can use to assess the welfare of fish held under production conditions relate to functioning rather than feeling.

Table I
Some differences between fish and other vertebrates and the environments in which they live, together with potential implications for the welfare of farmed fish (1, 3)

<table>
<thead>
<tr>
<th>Special features of fish and their environment</th>
<th>Some implications for fish welfare</th>
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<tbody>
<tr>
<td><strong>Water</strong></td>
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<tr>
<td>– Water is a dense medium, so fish are constrained by hydrodynamic demands and fast swimming can be costly</td>
<td>In addition to their streamlined shape, fish secrete a layer of mucus over their skin that lubricates their movement and provides protection from external infection; the integrity of this layer is important for health</td>
</tr>
<tr>
<td>– Gases dissolve readily in water, but moving water for oxygen extraction is energetically costly</td>
<td>Extracting oxygen from and secreting carbon dioxide into water is relatively easy</td>
</tr>
<tr>
<td>– Many other chemicals readily dissolve and disperse in water</td>
<td>Water can potentially carry many harmful substances</td>
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<tr>
<td><strong>Respiration</strong></td>
<td></td>
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<tr>
<td>– The respiratory tissues of fish (the gills) have a large surface area in direct contact with water for gas exchange</td>
<td>Many ions pass readily between fish and water through the gills, making osmoregulation challenging</td>
</tr>
<tr>
<td>– Unlike air-breathing animals, the respiratory tissues of fish do not show an <em>in situ</em> immune response</td>
<td>Fish are particularly vulnerable to harmful chemicals in the water and fish can be exposed to a greater pathogen load via respiration</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
</tr>
<tr>
<td>– Fish are ectotherms, meaning that they do not maintain a constant temperature physiologically; fish body temperature follows water temperature, which can be adjusted behaviourally by tracking water of particular temperatures</td>
<td>For proper functioning, fish are dependent on exposure to an appropriate range of environmental temperatures. Access to a thermal gradient within the environment allows fish to greatly increase the efficacy of their innate immune response. At low temperatures the energetic needs of fish are reduced and periods without food are neither unnatural nor necessarily deleterious</td>
</tr>
<tr>
<td><strong>Life history</strong></td>
<td></td>
</tr>
<tr>
<td>– Many species of fish undergo, to a greater or lesser extent, dramatic changes in form and function between life-history stages</td>
<td>Each life-history stage has specific conditions that optimise welfare</td>
</tr>
<tr>
<td><strong>Immunity</strong></td>
<td></td>
</tr>
<tr>
<td>– Unlike mammals, but in common with birds, fish red blood cells are nucleated, giving them additional functions including immune responses</td>
<td>Fish have an additional line of defence against pathogens that has not yet been incorporated into disease prevention or treatment systems</td>
</tr>
<tr>
<td><strong>Sensory environment</strong></td>
<td></td>
</tr>
<tr>
<td>– The sensory environment in water is different from that in air; e.g. light attenuates quickly in water and wave length changes with depth</td>
<td>The right photic conditions are needed for visually feeding fish to detect food; e.g. zooplanktivores need ultraviolet light to capture food efficiently</td>
</tr>
<tr>
<td>– Mechano-sensory cues travel well in water and fish are very sensitive to vibration through the lateral line system</td>
<td>Fish behaviour may be disrupted by ambient sound</td>
</tr>
<tr>
<td>– Many fish are able to detect and produce electric fields and use this for orientation and communication</td>
<td>Background electrical fields may disrupt behaviour in such cases</td>
</tr>
<tr>
<td><strong>Fish density</strong></td>
<td></td>
</tr>
<tr>
<td>– Many species of fish live in large, coordinated social groups or schools</td>
<td>Relatively high fish densities may not be detrimental</td>
</tr>
<tr>
<td>– Intensive fish farming is relatively new. Strains of a few species have been reared in captivity for several generations, but the process of domestication is much less advanced than for birds and mammals</td>
<td>There has been less time for welfare-friendly traits such as lack of fear or low levels of stress responsiveness to develop</td>
</tr>
</tbody>
</table>
Table II
Some implications of defining animal welfare in terms of proper biological functioning, what is natural and what fish feel, illustrated with reference to fish in a poor state of nutrition and taking part in fights (1, 5, 6)

<table>
<thead>
<tr>
<th>Type of definition</th>
<th>Implications of each kind of definition</th>
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<tbody>
<tr>
<td><strong>Functional</strong></td>
<td></td>
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<tr>
<td>Are the fish in poor health?</td>
<td>Whether loss of appetite and depleted energy reserves should be interpreted as poor welfare depends on circumstance and on individual status. For example, failure to feed may be a sign of poor welfare in a juvenile Atlantic salmon in the summer, but not necessarily in the winter, when a subset of each cohort undergoes a period of adaptive natural anorexia. Their physiological processes are adjusted accordingly and thin fish are functioning just as they ought to be. Wild male salmon fighting to gain access to spawning females after having swum hundreds of miles up-river without feeding have markedly depleted energy reserves, may well be injured and are likely to have impaired immune function. However, these are costs incurred in the interest of gaining the fitness benefits of breeding opportunities. Natural physiological processes allow mature fish to fight and breed effectively and subsequent thinness and injury are normal consequences of these.</td>
</tr>
<tr>
<td><strong>Natural</strong></td>
<td></td>
</tr>
<tr>
<td>Can the fish engage in natural behaviour?</td>
<td>Since millions of wild fish fail to gain enough food, poor nutritional status and death from starvation occur in the wild. On a strict interpretation of a nature-based definition, these do not in themselves indicate poor welfare. Fighting is a natural behaviour in very many species of fish. Any resulting stress or injury, or the failure of losers to get food or mates, does not necessarily reflect poor welfare. Arguably, denying fish the opportunity to fight may impair their welfare.</td>
</tr>
<tr>
<td><strong>Feelings-based</strong></td>
<td></td>
</tr>
<tr>
<td>Are the fish free from negative feelings?</td>
<td>If fish are sentient, then how thin fish feel about poor nutritional status dictates whether their welfare is good or bad. Fish with low energy reserves may not feel bad if they are not motivated to feed. In juvenile Atlantic salmon displaying winter anorexia, the energy reserve threshold at which they become motivated to feed is reset downwards; a level of reserves that would generate appetite in summer does not do so in winter. Whether an animal that is stressed or injured as a result of fighting experiences poor welfare depends on whether these states generate negative feelings and emotions. The fitness consequences of winning a fight may be so high that, when in an appropriate physiological state, fish may be highly motivated to take part in contests. Again, it may be that denying fish the opportunity to do so may compromise their welfare.</td>
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</table>

Assessing the welfare of farmed fish

Assuming that the welfare of farmed fish matters, to determine if it is compromised by aquacultural practices and to monitor the effectiveness of attempts to improve it, accurate and objective ways of assessing fish welfare status are needed. Our knowledge of the effects on fish of the natural challenges they experience in the wild suggests that there are a number of approaches to this task. These approaches, most of which address welfare in terms of function rather than feelings, are listed with examples in Table III. Starting with what is perhaps the most obvious, good health is recognised as critical for fish welfare and signs of injury or infection are important indicators of poor welfare (19). So too is the status of the immune system, which reflects a fish’s ability to fight off disease (20).

It can be hard to interpret just what good or poor health indicates about welfare. Many would consider that an unhealthy fish is in a poor state of welfare by definition, as a direct result of the disease. However, the converse may not be true, as a fish that is healthy may still experience poor welfare, for example if held in an inappropriate social environment. Because stress can suppress immune function and so increase the risk of infection, a high incidence of disease and mortality can point towards underlying problems with the fish’s environment, although even fish experiencing optimal conditions may suffer from disease and serious epidemics do occur in populations of wild fish.

Physical variables such as level of nutritional reserves, rates of growth and reproductive status also provide information on the welfare of the fish concerned, because various challenges interfere with feeding, which in turn can compromise growth and reproductive development. Reduced appetite is one of a number of short-term changes induced by activation of a physiological stress response, which includes the release of the hormones adrenaline and cortisol from the inter-renal glands. Adrenaline is not an easy hormone to measure because it is released rapidly in response to handling stress, but indirect indicators of adrenaline release can be used, including faster gill ventilation and increased oxygen consumption or heart rate. Cortisol is easier to measure because handling-
induced increases are relatively slow, and elevated plasma cortisol levels thus feature prominently as an indicator of possibly impaired welfare. The relationship between such short-term responses to stress and fish welfare is complex, because they are part of a natural and adaptive response to challenge (21). There is no particular reason to suggest that the temporary physiological activation that prepares fish for activity is detrimental to welfare and in some contexts such short-term responses may be beneficial. Even so, most would agree that evidence of chronic, unavoidable stress in farmed fish indicates compromised welfare, so although a focus on stress does not fully capture the complexities of animal welfare, monitoring stress responses may give us an important part of the picture.

Since altered behaviour is an early and easily observed response to adverse conditions, monitoring behaviour is important in assessing fish welfare (22). Potential behavioural indicators of poor welfare include loss of appetite, natural signs of distress such as erratic swimming and performance of persistently repeated actions, or stereotypes. An approach that may provide a better understanding of what fish feel focuses on learned responses. For example, fish such as Atlantic salmon and Atlantic cod can be trained to associate a flashing light in one location with the imminent presentation of food somewhere else, even when there is a delay between the end of the light signal and the appearance of food. Trained fish move into the area where they have come to expect food after the light has stopped flashing but before the food has arrived, showing anticipation of the reward. The anticipation response disappears when fish are stressed and this turns out to be a particularly sensitive indicator of stress. Using computer-aided image analysis, such responses can be quantified, even in fish held at high densities, so they have the potential to provide a sensitive non-invasive indicator of welfare in intensively farmed fish (23).

Since the array of methods for assessing fish welfare all reflect something slightly different, we need some way to combine them into an integrated picture of welfare status as a whole. One approach is to use statistical analysis of relationships among the various measures to combine these into an overall welfare score. For example, Turnbull et al.
A very different approach to gaining a broad oversight of the welfare of farmed fish is potentially provided by using modern molecular tools to explore patterns of gene expression in fish exposed to different challenges (25). Information obtained from studying the complete set of RNAs encoded by the genome of (in this case) a fish held under a specific set of conditions (genome-wide transcriptomics), complemented by the huge amount of information on the functions of known genes in other organisms, can give an integrated picture of the overall response of fish to aquaculture-related challenges. For example, in seabass, discrete clusters of genes can be identified based on their specific temporal patterns of expression following confinement stress. These patterns of expression are related to rapid metabolic activation, tissue repair and remodelling, reestablishment of cellular homeostasis and immune regulation (26).

Also of interest is the expression of candidate genes whose effects are known and can confirm and extend understanding of the effects of key stressors. For example, short-term crowding in Atlantic cod is associated with up-regulation of genes involved with glucose transport and with inflammatory and antibacterial responses (27), reflecting the complex adaptive response to the challenge of high densities. The responses of candidate genes can also identify potential early warning signs of stress. For example, in young seabass acute confinement stress strikingly increases the ratio between a precursor of brain-derived neurotrophic factor (pro-BDNF) and mature BDNF, which potentially provides a reliable biomarker that could be used to detect stress in seabass (28).

Looking, in fish, for candidate genes known to be related to cognitive and emotional states in mammals offers an additional tool for addressing the difficult question of sentence in fish. As an example, comparison of candidate genes for corticoid receptors in the brains of different strains of rainbow trout (i.e. those selected for high stress responsiveness and those selected for low stress responsiveness) suggests that site-specific differences in mineralocorticoid receptor expression may be responsible for strain differences in memory and in appraisal of negative stimuli, both of which are cognitive traits that are related to sentence (29).

Many methods used by researchers for measuring fish welfare are time consuming, technically demanding, expensive and often require fish to be handled while samples are collected. In contrast, monitoring the welfare status of cultured fish requires systems that are effective, economical and practical for use under farming conditions. A range of non-invasive, relatively simple, but accurate ways of monitoring fish welfare on working farms, i.e. operational welfare indicators, are available. These include routinely gathered production indicators such as mortality, fish health, feed conversion efficiency and growth rates, as well as osmoregulatory status at critical periods, such as the transition from fresh to salt water (smolting) in salmonids. Depending on circumstances, other indicators that are observed or monitored by fish farmers include fin and body condition, body coloration (which may reflect stress levels), feed intake, ventilation rate and patterns of swimming. In this context, it is worth emphasising that good fish farmers know how to assess the well-being of their stock and have much of value to teach scientists (24).

A different, indirect approach to estimating the welfare of farmed fish, based on what is known about the effects of physical and social conditions on their well-being, is to measure not the fish themselves but the environment in which they are farmed. Water quality is particularly important in this context, and commonly measured variables include temperature and dissolved oxygen. More recently, dissolved carbon dioxide has been included, as elevated levels may not only cause discomfort, but may also indicate that stock are stressed and hyperventilating. Other variables that are monitored where appropriate include pH levels and the presence of heavy metals in the water.

### Promoting the welfare of farmed fish

A number of aquaculture practices can potentially compromise the welfare of farmed fish. The most important of these practices are summarised in Table IV. Welfare scientists, veterinarians and the aquaculture industry have worked together to develop a number of ways of mitigating the effects of these practices. One strategy is to make a careful choice of which fish to culture, since some species and strains of fish are less easily stressed and therefore more amenable to being held in captivity than others. Arguably, these are the species and strains that should be used in food aquaculture. Such suitable forms may be natural variants. For example, in many high-latitude lakes different forms of Arctic char coexist, feeding selectively on either zooplankton or large, benthic invertebrates. The plankton-feeding form is less aggressive than the benthic-feeding form (31) and arguably more suitable for culture.

Alternatively, suitable fish for intensive culture may be the result of a degree of domestication or targeted selection. In
Table IV
Some possible adverse effects of husbandry practices on the welfare of farmed fish (30)

<table>
<thead>
<tr>
<th>Husbandry practice</th>
<th>Possible adverse effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding</td>
<td>Failure to provide an appropriate diet in an attractive form may result in malnutrition</td>
</tr>
<tr>
<td></td>
<td>Failure to provide the right amount of food at the right time may mean that fish do not feed well</td>
</tr>
<tr>
<td></td>
<td>Failure to make food accessible to all fish in a cage/tank may mean that some fish experience malnutrition</td>
</tr>
<tr>
<td>Stocking density</td>
<td>Stocking densities that are either too high or too low can have negative effects on welfare, depending on species and life-history stage, through interacting effects of water quality and aggression</td>
</tr>
<tr>
<td>Disease and disease treatment</td>
<td>Farmed fish are more vulnerable to disease than their wild counterparts, but disease treatments and vaccinations may themselves cause damage and stress to fish</td>
</tr>
<tr>
<td>Grading</td>
<td>Fish are graded to produce like-sized groups for efficient husbandry and potentially grow faster than companions selected for high stress responsiveness (33). Feed waste is higher and feed conversion efficiency lower in fish with a high stress response (34).</td>
</tr>
<tr>
<td>Transport</td>
<td>Transport often involves handling, crowding, vibration, poor water quality and other adverse environmental conditions</td>
</tr>
<tr>
<td>Slaughter</td>
<td>Slaughter often involves handling, crowding, exposure to alarm cues and, for some methods, pain</td>
</tr>
</tbody>
</table>

species such as brown trout and Atlantic salmon, which have been farmed intensively for a number of generations, fish from cultured strains often show weaker behavioural and physiological responses to disturbance than do their wild counterparts (1, 32). When kept in mixed groups, rainbow trout selected for low stress responsiveness grow faster than companions selected for high stress responsiveness (33). Feed waste is higher and feed conversion efficiency lower in fish with a high stress response (34).

Within species and strains, there is variation in how individual fish respond to novelty and risk, often linked to differences in stress physiology (35). Where domesticated strains are not available, one possible approach might be to identify and screen out risk-averse fish early in the production cycle. Age of first feeding is a possible selection criterion, since, in salmonids at least, this predicts responses to a potential risk in later life, e.g. the rate at which fish start feeding after being isolated (36).

A different, complementary approach is to develop husbandry practices and management systems that minimise threats to welfare. In traditional, extensive aquaculture, such systems have been in place for many years and in intensive aquaculture much effort has recently been devoted to this issue. For example, there has been an increase in the use of strippers to reduce carbon dioxide levels in tanks and in the development and deployment of land-based recirculation systems in which the water is continually treated to ensure optimal conditions for fish (37). At a different level, strategically placed underwater lights can be used to encourage fish to use more of the available space, thereby reducing crowding (38). Using interactive feeders that deliver food whenever fish are hungry rather than at pre-defined, predictable times of day creates a farm environment in which there is less competition for food, and fish that are poor competitors are able to feed and grow well (39, 40). Another method of minimising threats to welfare is to incorporate into fish feed a precursor of serotonin, which is produced naturally in the central nervous system, as this reduces levels of aggression in several species of farmed fish (41). Also, Lines and Spence (42) give examples of the development of methods of humane slaughter for fish (see also 43).

Alternatively, for each species and life-history stage, simple, but accurate, indicators of welfare can be used on working farms as ‘early warning systems’ for emerging welfare problems. The known short- and medium-term responses of fish to adverse conditions point to a number of indices that could potentially be monitored in fish in production conditions without any need for disturbing them, except perhaps by placing cameras in cages. Some of these have been discussed above, including changes in colour, ventilation rate and patterns of swimming, as well as reduced food intake, loss of body condition, damaged fins and slow growth. Recent studies have highlighted the possibility of using computer-based video analysis of the movement patterns of fish in working production cages to pick up changes that might indicate poor welfare (e.g. 44).

Thus, there are many ways in which the welfare of farmed fish can potentially be promoted, but it is important to know what the full economic consequences are likely to be. This is not simple, since it requires detailed information about the impact of the intervention upon all aspects of production, on the costs of the whole production chain and, given the possibility of a welfare premium in the marketplace, on the attitudes and behaviour of consumers. Bioeconomic models have been developed that integrate these different strands and predict the impact of any given welfare intervention on profitability across the production chain (45). For example, such modelling reveals that carbon dioxide stripping in Atlantic salmon smolt production would increase both profits and welfare, whereas, in the case of demand feeders, improved fish welfare comes at an economic cost. Such
models provide the aquaculture industry and regulatory bodies with the information needed to incorporate appropriate welfare interventions into modern, sustainable aquaculture.

The welfare of farmed fish in the future

There is little doubt that fish farming will continue and most likely expand in the future and several aspects of the way in which fish are farmed are likely to change, with possible implications for welfare (46, 47). A wider range of species is likely to be cultured, and the farming conditions that optimise welfare will need to be established for each new species and life-history stage. Depending on the location and the species concerned, production systems may well become more intensive. At one extreme these intensive systems may take the form of very large offshore cages and, at the other extreme, small units supplying fish locally.

Meeting biological needs, stock monitoring and environmental control are all increasingly challenging technologically in larger, more intensive systems, while being economically challenging in smaller-scale intensive units. Effective use of such systems will depend on technological advances, including increased use of land-based recirculation systems. Water quality can be a challenge in recirculation systems, which can be optimised if designed properly. However, a heavy reliance on technology renders back-up systems essential, as poor welfare is implicit in the event of technological failure.

Intensive fish farming will almost inevitably lead to the development of new diseases with associated welfare impairment unless suitable forms of treatment, prevention or management are developed. In intensive fish farming, veterinary care has for many years focused upon disease management, i.e. what might be called 'firefighting'. In spite of improved vaccines and other treatments and modern diagnostic tools, overall mortalities on fish farms have not been reduced in the past two decades (salmon: Kontali Analyse, unpublished data; seabass and seabream: N. Steiropoulos, personal communication). Furthermore, few veterinary courses include more than a passing reference to fish and aquaculture. As aquaculture grows rapidly, there will be an increased need for veterinary graduates who have an interest in and capacity to care for large fish populations. It is also important that the industry moves towards a paradigm of preventative fish health management, with veterinarians participating as members of fish production teams that seek to minimise losses due to disease by monitoring husbandry practices, water quality, equipment, biosecurity and other factors pertinent to fish welfare.

One way of ensuring good welfare and good production in increasingly intensive fish culture is to use selective breeding programmes to generate fish that flourish in such systems. The authors predict that, in the future, this is likely to be informed by molecular technologies (see above), which can, for example, identify biomarkers for favourable fish from an early age, streamlining and speeding up the selection process.

In terms of public relations, on the one hand there is likely to be increasing public concern about the welfare of farmed fish and the environmental impacts of aquaculture systems, a concern that may potentially be mitigated by helpful explanations provided both by farmers and researchers. On the other hand, there are early indications of beneficial changes in public attitudes, with a growing recognition that aquaculture can contribute to the provision of healthy food without depleting natural fish stocks. There is also increasing global investment in fish farming, a change that is likely to result in farmed fish being regarded even more as commodities than at present, pointing to an even greater need to ensure that their welfare is protected.

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The authors would like to thank Simon MacKenzie and Alan Dykes for discussions of the issues considered in this article and a referee for helpful comments on an earlier version of this chapter.
Definición, evaluación y fomento del bienestar de los peces de cultivo

F.A. Huntingford & S. Kadri

Resumen
La piscicultura con fines alimentarios, tal como se practica actualmente, puede generar problemas ligados al bienestar de los peces de cultivo, y este es un tema que ha merecido considerable atención. Los peces, como vertebrados que son, comparten diversos rasgos con las aves y mamíferos que más frecuentemente viven en granjas, por lo que también cabe aplicar a los peces numerosos principios de bienestar pensados para dichos grupos. Sin embargo, los peces tienen una historia evolutiva larga e independiente y además están adaptados a un medio muy distinto, el acuático. Por ello presentan una serie de características especiales que entran en juego a la hora de definir, evaluar...
y fomentar su bienestar, características que los autores enumeran y examinan. También exponen los diversos métodos de que disponen los investigadores para reconocer y determinar en los peces estados positivos y negativos de bienestar, lo que incluye la evaluación de su salud física y su estado fisiológico, comportamental y genómico. Asimismo, pasan revista al subconjunto de indicadores prácticos de bienestar que pueden utilizarse en las piscifactorías, y destacan varios aspectos de la acuicultura intensiva que pueden comprometer el bienestar de los peces, así como una serie de estrategias disponibles para mitigar esos efectos adversos. Para concluir, se refieren brevemente al futuro, señalando la evolución que presumiblemente seguirá la praxis de la acuicultura y la forma en que estos cambios podrían repercutir en el bienestar de los peces de cultivo.

**Palabras clave**


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**References**


