THE HUMANE SOCIETY
OF THE UNITED STATES

An HSUS Report: The Welfare of Animals in the Aquaculture Industry

Abstract

In the United States, approximately 1.3 billion fish are raised in off-shore and land-based aquaculture systems each year for food, making them the second-most commonly farmed animal domestically, following broiler chickens. The majority of farmed fish are subject to overcrowded and restrictive conditions, which, if unchecked, can quickly deteriorate water quality, cause severe stress, and result in increased mortality. Aquaculture practices and production—including handling, grading, transport, genetic manipulation, aggression from conspecifics, predation, physiological stress, and inhumane slaughter—compromise the welfare of these animals.

Introduction

If fisheries sustain their current yields, populations of wild-caught aquatic animals face uncertain futures, with predictions of global collapse by 2048 of all species currently fished.[1] “The wild harvest of seafood, man’s last major hunting and gathering activity, is at a critical point,” wrote U.S. Department of Agriculture (USDA) researcher David Harvey. “Technology has enabled harvesting to outpace the speed at which species can reproduce.”[2]

According to the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, the human population of 6.09 billion in 2000 is estimated to reach 8.2 billion by 2030.[3] Globally, the average per-capita fish and shellfish consumption each year from 2001 to 2003 was 16.4 kg (36.2 lbs)[4] and is predicted to increase to 22.5 kg (49.6 lbs) by 2030.[5] Indeed, given that consumption has outpaced the growth of the world’s human population since the 1960s,[6] the world’s fisheries are unlikely to satisfy the marketplace. “In response,” continued Harvey, “the seafood industry is beginning to shift from wild harvest to aquaculture, the production of aquatic plants and animals under grower-controlled conditions.”[2]

Absent the additional demands placed on fish supply by the increasing human population, the Food and Agriculture Organization (FAO) of the United Nations predicted in 2006 that worldwide aquaculture[*] production must nearly double in the next 25 years to satisfy current worldwide consumptive patterns for fish.[7] Since the mid-1980s, the aquaculture industry has expanded approximately 8% per year,[7] and the numbers of farmed fish are expected to continue to increase, perhaps surpassing the numbers of wild-caught animals from the world’s fisheries. Tore Håstein of Norway’s National Veterinary Institute addressed the World Organisation for Animal Health (OIE) Global Conference on Animal Welfare in 2004 and reported that aquaculture has “developed to become the fastest growing food production sector in the world and it will continue to grow in the years to come.”[8]

With the expansion of the fish farming industry comes growing concern for the well-being of increasing numbers of aquatic animals raised and killed for human consumption.[8] A review of recent scientific literature on fish welfare[8-17] and stress,[18-22] as well as debates on pain and consciousness in fish,[23-30] reflect the escalating interest in the well-being of farm-raised fish. This area of research was considered so important that both

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[*] For the purpose of this report, “aquaculture,” “aquaculture production,” and “aquaculture industry” refer exclusively to the farming of fish, not aquatic plants and other aquatic animals.

Diseases of Aquatic Organisms[31] and *Applied Animal Behaviour Science*[32] devoted entire issues to the subject of behavior and welfare of fish. Beyond the scientific community, concern for fish welfare is also receiving attention, including amongst industry. The Fisheries Society of the British Isles (FSBI) states: "In practical terms also, it is often in our selfish interest to consider the issue of animal welfare; for example…poor welfare of farmed fish often equates to poor production."[9]

With the expected growth of the human population and increased per-capita fish consumption, the aquaculture industry will likely continue to experience growth. It is therefore critical that producers act now to develop methods to ensure the health and welfare of the increasing numbers of farmed fish.

U.S. Aquaculture Industry Overview

According to the USDA's Census of Aquaculture completed in 2005, nearly 1.3 billion fish were raised for human consumption annually, with the industry dominated by five species: catfish (or channel catfish, 83.4% of cultured "food fish" by numbers), trout (11.9%), tilapia (2.8%), bass (1.3%), and salmon (0.5%).[33] The total sales value of aquaculture for food was $672 million that Census year, with the top three states accounting for 40% of the number of U.S. facilities and nearly 64% of the total sales.[33]

Top Ten U.S. States for Food Fish Aquaculture Production[33]

Rank	Number of farms	Value of sales
1	Mississippi	Mississippi
2	Alabama	Alabama
3	Arkansas	Arkansas
4	North Carolina	Idaho
5	Wisconsin	California
6	California	Washington
7	Georgia	North Carolina
8	Texas	Texas
9	Florida	Pennsylvania
10	Pennsylvania	Missouri

Across a variety of species, the steps and methods of aquaculture production are principally the same.[34-38] To obtain young, two primary systems are employed: 1) eggs and milt, a sperm-containing secretion of the testes of fish, are hand-collected from broodstock and mixed to induce fertilization or 2) broodstock spawn in captivity and fertilized eggs or swimming fry (young, post-larval fish) are subsequently collected. When starting with fertilized eggs, they are incubated until hatched. When fry begin actively searching for food, they are collected and transferred to a nursery to grow and feed until a preset time, size, or mass is reached: perhaps 2-3 months for tilapia,[34] 4-6 months for catfish[35] and trout,[36] 6-8 months for bass,[38] and 8-16 months for salmon.[37] Next, the fish are transferred from the nursery to a grow-out facility where they remain until reaching market size: 5-6 months for tilpia,[34] 15-18 months for catfish,[39] 15-20 months for trout,[36] 18-24 months for bass,[40] and 18-36 months for salmon.[37] Times for all species can vary widely by many months depending on water temperature and quality, feed quality and availability, and stocking density.[39-41]

The facilities most commonly used for aquaculture production are ponds, tanks, raceways, cages, and pens. Ponds can be natural or artificial, typically with low water refreshment. Tanks are often fiberglass with a high water turnover rate. Raceways are long, linear structures designed so water flows into one end and out the other with high turnover. Cages or pens are usually made from mesh or net screens and are submerged in larger bodies of water, often lakes or seas for species requiring saltwater.[42] The production of many farmed species requires the use of different types of facilities at different points in their lives. Farmed salmon, for example, hatch and grow as juveniles in freshwater, but after physiological adaptation to marine life, or smolting, grow-out is in seawater.

Collection of farmed fish is typically performed by netting, grading (a process similar to netting but using grates of various widths that allow fish below market size to pass through), or the draining of ponds. The animals are then transported to processing facilities for slaughter and packaging.

Given the scale of the U.S. and global aquaculture industries, and increasing concern for the welfare of farmed fish, several aspects of fish farming production practices and their impacts on the well-being of aquatic animals must be addressed.

Pain Perception and Consciousness

Despite the current body of evidence regarding the welfare of farmed fish, some arguments persist that their ability to suffer and their conscious awareness of stimuli are yet to be determined. As such, two conflicting positions exist: one that contends that fish have the mental capacity to suffer and feel pain[26,27,43] and another that asserts that fish brains lack a key neuroanatomical structure, the neocortex—which, in humans, is associated with the generation of conscious, subjective states—so, the animals have no consciousness or capacity to feel pain.[25]

On reviewing the evidence for nociception, or the ability to perceive and transmit signals of noxious stimuli, scientists are in agreement that fish have both the appropriate nerves and pathways to sense and send potentially painful signals[8,15,23,24] and that fish share neurotransmitters responsible for pain transmission with mammals,[44] which are found in higher concentrations in brain regions receiving input from these nerves.[24] Håstein concludes, "It is beyond doubt that fish do have nosiceptors [*sic*] and thus have the possibility to register pain, although the response and way of 'showing' pain is not expressed the same way as in terrestrial animals."[8]

Lynne U. Sneddon of the University of Liverpool's School of Biological Sciences and her co-authors believe that showing physiological and behavioral responses to painful stimuli are suggestive of the perception of pain in fish.[23] Investigating the effects of noxious substances injected into the lips of trout, the researchers observed significant changes in physiology and behavior, including increased gill, or opercular, beat rate and time to resume feeding.[23] Sneddon *et al.* also reported that the fish, after being injected in their lips, rubbed their mouths against the sides of the tank and the gravel, and displayed rocking behaviors for up to 90 minutes post-injection—behaviors she feels are not simple reflexes and that were mitigated by application of an analgesic.[23,45] The scientists concluded: "If a noxious event has sufficiently adverse effects on behaviour and physiology in an animal and this experience is painful in humans, then it is likely to be painful in the animal."[23]

Arguing against the idea that fish have the ability to suffer and feel pain, James D. Rose, a professor in the Department of Zoology and Physiology at the University of Wyoming, stresses that fish lack a neo-cortex, which he contends is essential for consciousness. Though he agrees that noxious stimuli can evoke neural activity leading to physiological stress and behavioral responses, and further acknowledges that nociceptive reactions are universal in the animal kingdom, Rose distinguishes this from sentience stating that "reactivity to noxious stimuli does not imply conscious awareness."[25] His primary argument distinguishes between behavioral responses to potentially painful stimuli and conscious, painful experiences where "functions of specific regions of cerebral cortex" allow humans to be aware of pain.[25]

Among vertebrates, however, there are differences in brain areas with specific functions.[10,24] In his essay "The Evolution of Pain," Donald Broom, University of Cambridge Professor of Animal Welfare in the Department of Clinical Veterinary Medicine and Vice-Chair of Animal Welfare for the European Commission's Scientific Committee on Animal Health and Animal Welfare, cautions: "It is necessary to look for the site of any particular function rather than assuming that it will be in the same area as in man" and concludes that "it is not logical to assume that, because an area which has a certain function in man is small or absent in another group of vertebrates, the function itself is missing."[24] Evidence for the existence of nociception has been found in all vertebrates investigated, and, within the species researched, more similarities than differences exist in nociception systems, leading Broom to suggest that not only is there no basis for pain being more important for those with elevated cognitive capacity, but that "[p]ain might be a greater problem in animals with less cognitive ability."[24]

Kristopher Chandroo, a veterinarian from The University of Guelph's Aquaculture Centre, and co-authors assert that absence of structural similarities to humans in the fish brain does not exclude possible functional similarities.[27] In fact, emotions require "relatively primitive brain circuits that are conserved through evolution."[26] The researchers conclude: "Anatomical, pharmacological and behavioural data suggest that affective states of pain, fear and stress are likely to be experienced by fish in similar ways as in tetrapods. This implies that fish have the capacity to suffer, and that welfare consideration for farmed fish should take these states into account. We suggest that the concept of animal welfare can be applied legitimately to fish. It is therefore appropriate to recognize and study the welfare of farmed fish."[26]

Separate from the debate on consciousness, the complex behaviors of fish, including deliberate avoidance responses and fear,[46] indicate more than simple reflex.[17] For example, carp, after having been hooked once, learn to avoid bait for a year or more,[47] and salmon can learn predator-avoidance skills from experienced fish.[48] Additionally, fish are able to learn about and remember their environment to aid in orientation and navigation,[49] solve tasks based on mental images of their surroundings,[50] and learn from familiar conspecifics, implicating the importance of social groups.[51] After reviewing evidence documenting complex behaviors exhibited by fish, Felicity Huntingford, Professor of Functional Ecology in the Department of Environmental and Evolutionary Biology at the University of Glasgow, and co-authors conclude that "the experience of suffering may be a real possibility."[10]

John Webster, University of Bristol emeritus professor of Animal Husbandry and founding member of the Farm Animal Welfare Council, an independent advisory body established by the British government in 1979 "to keep under review the welfare of farm animals on agricultural land, at market, in transit and at the place of slaughter; and to advise the Government of any legislative or other changes that may be necessary,"[52] synthesized the discussion in a 2005 interview with *The Daily Telegraph*: "A powerful portfolio of physiological and behavioural evidence now exists to support the case that fish feel pain and that this feeling matters. In the face of such evidence, any argument to the contrary based on the claim that fish 'do not have the right sort of brain' can no longer be called scientific. It is just obstinate."[53]

The Welfare of Aquaculture Animals

Given the myriad and fundamental differences between farmed fish and other animals raised for human consumption, it follows that welfare considerations common to land-based farmed animals may not be directly applicable to aquatic farmed animals.[9] Contributing greater complexity to the farmed fish welfare discussion are the challenges of separating the different effects of individual production factors, leading to, as Huntingford *et al.* put it, "the important conclusion that, even for a particular species, gender and age of fish, we cannot guarantee the welfare by defining a simple set of husbandry conditions. This in turn emphasizes the need for sensitive on-the-spot indicators of welfare."[10]

The FSBI, the "premier Society in the British Isles, and increasingly in Europe, catering for the interests of professional fish biologists and fisheries managers"[54] and publisher of *The Journal of Fish Biology*, identifies several directly observable indices of welfare, including:[9]

- changes in skin or eye color, often indicating exposure to adverse events;
- changes in ventilation rate observed as increased opercular beating, indicating stress or exposure to environmental contaminants;
- changes in swimming performance and other behaviors, indicating injuries, the presence of parasites, or generally decreased welfare;

- reduced food intake, often indicating acute or chronic stress;
- loss of body condition or impaired growth, indicating possible chronic stress;
- morphological abnormalities resulting from the effects of adverse conditions on development;
- occurrence of injuries from aggression and slow healing, indicating possible poor immune response; and
- increased incidence of disease, indicating possible poor environmental conditions.

To align welfare issues with those commonly considered for land animals, several scientists have adapted the Brambell Committee's "Five Freedoms" to fish,[10,55] summarized as follows:

1. Freedom from hunger and thirst: Captive fish should have a nutritionally appropriate diet to avoid decreased welfare; smolting fish may become dehydrated if transferred to sea water at too young of an age, before they are able to survive.
2. Freedom from discomfort: Appropriate water conditions should be provided as fish, through the surface area of their gills, are in intimate contact with their environment. Factors to be considered include levels of dissolved oxygen, pH, and ammonia; temperature; flow rates; and the presence of pollutants.
3. Freedom from pain, injury, and disease: While many diseases of fish may be poorly understood, they are frequently caused by problems with the environment. When outbreaks occur, they can lead to high mortality rates. All attempts should be made to limit disease outbreaks, and when disease is found, it should be quickly diagnosed and treated.
4. Freedom to express normal behavior: Appropriate densities and environmental conditions to enable the fish to exhibit natural behaviors should be maintained throughout the life cycle.
5. Freedom from fear and distress: Factors that cause fear, distress, discomfort, and other welfare-impairing conditions should be minimized.

Fish reared in aquaculture systems face numerous welfare challenges. The development, implementation, and management of appropriate production practices and facilities to ensure the well-being of growing numbers of farmed fish are critical, as significant concerns with stress responses, water and environmental quality, stocking densities, disease and parasites, selective breeding, genetic selection and transgenic manipulation, nutrition and feed, external impacts, crowding, handling, netting and grading, transport, and stunning and slaughter contribute to decreased welfare.

Stress Response

Fish respond to challenges, or stressors, through their stress response. According to Thomas Schwedler, Professor in the Department of Biological Sciences at Clemson University, and Sterling Johnson, Fish Disease Specialist in the Department of Wildlife and Fisheries Science at Texas A & M University, this combined physiological and behavioral response by fish to stressful conditions is a survival mechanism in which the animals may "sacrifice long-term survival strategies to concentrate their efforts on short-term survival."[13] The stress responses can be short- or long-term and may indicate poor welfare. As welfare analysis is complex and no simple link exists between stress and welfare, the FSBI warn, "there is cause for concern about the welfare of the fish involved"[9] in the presence of a coordinated stress response influenced by specific conditions. Huntingford *et al*. address this topic in their review:[10]

> Where fish cannot escape a stressor, or where the stressful stimulus is episodic or intermittent, prolonged activation of the stress response has deleterious consequences. These include loss of appetite, impaired growth and muscle wasting, immunosuppression and suppressed reproduction. Clearly, observing such changes provides strong indications that the well-being of the fish has been significantly compromised.

The stress response in fish is very similar to responses in higher vertebrates and mammals, and is often divided into three categories: primary, secondary, and tertiary stress responses.[9,56-58]

Primary stress response is characterized by the physiological changes that occur in and between the nervous system and endocrine system. The stressor is perceived and then stimulates the release of hormones (catecholamines and cortisol) from endocrine glands. Review articles detail this chain of events in its entirety.[9,10,19,56,57] It is noteworthy that the end result is the production and release of the primary stress-induced hormone, cortisol.[57]

Secondary stress responses are those triggered by the elevated levels of hormones from the primary response. These effects include: changes in rates of turnover and secretion of other hormones and neurotransmitters; increased heart rate and blood flow to gills, improving respiratory capacity; and increased energy mobilization from stored reserves.[9,56]

Tertiary responses, or whole body responses, are typically due to repeated or long-term stressors that cannot be avoided. These effects include changes in immune function, disease resistance, growth, and reproductive health.[9] Cortisol, the primary stress-induced hormone produced and released, can suppress the immune system and increase mortality as a result.[10] Behavioral modifications may also develop as a result of stress, and these changes can develop immediately with the stressor and may be prolonged after its removal. Such altered behaviors include: feeding and appetite reduction, leading to impaired growth and fitness;[59] changes in levels of activity and swimming performance; shelter seeking; suppressed predator and stressor avoidance; and difficulties with thermoregulation and orientation.[11,18,19]

Following a stressful event, the level of plasma cortisol increases, typically proportionally to the duration and magnitude of the stressor.[9,59] If the stressful event is brief, the concentration normalizes within a few hours. When faced with chronic stress, the fish's elevated cortisol levels may persist throughout the duration of the stressor.[10] Cortisol therefore provides a measure of the deleterious effects of stress.[20] These stress responses can also be cumulative if confronted with multiple stressors.[59]

Though stress cannot be directly quantified, cortisol level measurements can be used as a proxy even though measurement methods are not consistently accurate or practical, and will not necessarily implicate the stressor involved. FSBI's aforementioned directly observable indices of welfare have also been identified by Huntingford *et al.* to assess stress, health, and welfare of farm-raised fish.[9,10] A priority of the aquaculture industry should be to identify how conditions could be improved to minimize stressors and their effects to improve the welfare of farmed fish.

Water and Environmental Quality

Water quality is considered one of the most important factors contributing to fish health and is therefore seen by industry as a limiting factor in production.[60] A fish's gills have a very large surface area so they can more easily extract oxygen from water, which also makes the animals highly sensitive to pollution and poor water quality.[9] Since fish are in such intimate contact with their environment, optimal conditions for health and welfare should include appropriate temperature, dissolved oxygen (DO), pH, salinity, the levels of organic and inorganic substances, light, among other parameters.[15] According to a 2005 review, "Science-Based Assessment of Welfare: Aquatic Animals," published in the OIE's Animal Welfare: Global Issues, Trends and Challenges, failure to provide ideal environments "may result in stress, distress, impaired health and mortality, all of which are often associated with the intensive rearing conditions that cause poor water quality."[15]

The issue of water quality affects all types of production systems. Extensive and intensive systems are differentiated in part by how the water is managed. In extensive systems, natural processes maintain water quality through currents or tides, remove carbon dioxide and ammonia via microbial activity, supply DO from the atmosphere, and dilute wastes.[11,14] Once the water can no longer negotiate the rates of oxygen consumption and waste production by the fish, it must be pumped through the system via raceways, recycled in tanks, or otherwise altered to maintain good quality; the system is then deemed intensive.[11] Net pens open to the environment are typically classified as intensive because of the stocking densities involved and the requirement of extra-environmental delivered feed.[61] In either system, however, failure to provide and maintain high water quality can rapidly deteriorate fish welfare. To avoid extreme problems with water quality, it is recommended by University of California-Davis aquaculture specialist Fred S. Conte that producers avoid operating at maximum capacity as detrimental conditions can develop rapidly in high-density intensive systems.[11]

Analysis and adjustment of water quality can improve the welfare of farmed fish. Generally, water quality deteriorates in part due to interactions between fish and water, namely respiration rates and waste production. Respiration decreases the DO content and increases carbon dioxide, and fish wastes increase levels of ammonia, nitrate, nitrite, and suspended solids.[19,60] Accumulation of nitrite in the water can alter respiration by decreasing the blood's ability to transport oxygen.[11] Hypoxia and low levels of DO trigger a stress response in fish, and altered levels of other chemicals, including ammonia and carbon dioxide, can disturb fish physiology, causing impaired gill and kidney function, and may increase respiration, which can exacerbate the effects of toxicity.[14,19,60,62] Sublethal conditions, if left for long durations, will chronically stress fish and result in reduced growth and reproductive performance, and increased susceptibility to disease and parasites.[15,60] As such, it is critical to strive for conditions that are optimal, rather than simply those that do not exceed preset toxicity limits even though such limits may be easier to assess.[14,60] Optimal water conditions can vary depending on the species, age, and size of the animals, as well as their history of exposure to dissolved gases and chemicals.[14]

As a fish's body temperature is typically within a few degrees of the water temperature, any temperature increase will increase the animal's metabolic rates and demand for oxygen.[62] Water temperature conditions for farmed fish must therefore be closely monitored.[60] Staying within the optimal temperature range for a particular species and, more specifically, for genetic lines within the same species, is vital, but stress can be induced in fish when water temperature shifts dramatically even within ideal parameters.[19] This can occur when fish move in temperature-stratified waters or, if during transport, fish are moved through different environments at varying temperatures. When water temperatures increase, oxygen levels must be closely monitored as DO capacity is inversely proportional to temperature. As such, it is believed that the stress associated with increasing temperatures is due to hypoxia.[19] At the other extreme, stress induced by lower temperatures can suppress the immune system and reduce feeding, which may both be deleterious to fish welfare.[19,22]

Lighting is another environmental factor that can affect the welfare of farmed fish. Artificial lighting is used to control the photoperiod, extending daylight hours to increase growth and also to manipulate maturation.[63,64] Growth of immature fish is preferred since carcass quality degrades after sexual maturity is reached.[65,66] Aquaculture systems employ various lighting regimens, with some subjecting fish to continuous light to stimulate growth.[64,67,68] Rapid shifts in light intensity should be avoided as they can dramatically alter behavior by invoking a panic or predator type response, increasing injury through unintentional collisions, and causing mortality.[8,69] Few studies have investigated the effects on animal welfare from artificial lighting regimens, though it has been noted that artificial photoperiods can affect the immune system and disease susceptibility in some fish.[70] According to Schwedler and Johnson, fish "may require the regulation of light intensities and daily light/darkness regimes to avoid stress."[13] The FSBI lists "[a]ppropriate seasonal and daily patterns of light intensity" as "[c]ritical for fish welfare."[9] More study is needed in this area to elucidate the welfare effects of altered photoperiods and continuous lighting on farmed fish.

Stocking Density

Not unlike other industrial farm animal production systems, aquaculture facilities have increasingly stocked greater numbers of fish without making parallel increases in the size of the confinement systems. Keeping fish at high densities can have a negative impact on their health and welfare.[15,71]

Densities vary by species, age, and rearing conditions. Appropriate stocking densities should provide adequate space for proper metabolic considerations through good water quality, proper behavioral considerations, such as allowing for unimpaired swimming and social behaviors, and the limitation or control of aggression.[13,14]

Carrying capacity is a density concept that describes the ability of the system to continuously provide consistent water quality. Practically, the carrying capacity of the production system is the maximum number of fish the system can maintain in terms of management of DO, ammonia, carbon dioxide, and other water quality issues.[11,72] The appropriateness of this measure of density is questionable as it only accounts for the physiological needs of the fish and ignores spatial and behavioral requirements. As such, carrying capacity may not be optimal for disease control or welfare.[11]

Aside from the effects of high stocking densities on water quality, elevated densities can diminish the ability of fish to display natural behaviors, while increasing the exhibition of undesired ones. Given the wide variety of behaviors demonstrated by and within species at different stages in the life cycles of fish, developing a concise and broad-brushed means by which to afford aquatic animals the full range of critical natural behaviors is challenging.[19] Indeed, social behaviors vary across a wide spectrum of interactions. For example, in salmon, these behaviors change with age: Young salmon still residing in freshwater streams are solitary and will protect their feeding territory; as salmon age and begin making their migration to sea, they become more social and may begin shoaling; and, when sexually maturing, they can become aggressive.[19,73] Fish who are forced into undesired social situations face unwanted stress and diminished welfare, including higher mortality and decreased health, physiological condition, food conversion, and growth.[14] Additionally, these interactions can inhibit the ability of fish to cope with other stressors.[74]

Research has shown that the mortality of young salmon increases with density, and it is believed that social stress is a contributing factor.[75] Elevated densities have been linked with decreased disease resistance,[76] perhaps because chronic stress from aggression has been implicated in impairing immune function.[14] Aggressive interactions between fish are often based on the animals' sizes and can lead to fin, tail, and eye nipping (often referred to as cannibalism), injury from ramming, and suppressed growth.[14,77] Differences in sizes are amplified by larger fish dominating food supplies, thus growing larger, resulting in subordinate smaller fish growing slower due to competition for food at guarded feeders and higher energy requirements caused by chronic stress.[14] Indeed, high stocking densities that fail to meet behavioral requirements can stress fish and may lead to reduced growth and increased mortality.[9,11,14] Lesions that develop from aggressive behaviors can further increase the risk of infection.[8,15] Few alternatives exist for subordinate fish to avoid dominant individuals, as the confinement of aquaculture systems does not easily allow for conflict avoidance by escape.[14]

Some evidence exists that in certain species, such as tilapia and salmon, aggressive behaviors can be diminished by increasing fish densities.[14] However, it is not clear that the overall welfare of these species is improved at higher densities. As well, other welfare issues may develop at higher stocking densities such as increased bodily abrasion leading to fin damage.[12,78]

Given the complexity of stocking density issues and their effects on fish welfare for a variety of species, Tom Pottinger, Aquatic Ecotoxicology and Physiology Group Leader, and Alan Pickering, retired Professor, both with the U.K.'s Natural Environment Research Council's Centre for Ecology & Hydrology, suggest that "the aquaculture environment is inherently unsuitable for fish that are territorial or solitary animals in their natural environment, such as some salmonid fish. In these cases, agonistic interactions can be particularly stressful to the fish."[20] More investigation is needed on space (volume) preference to fully explore and address the many problems of inappropriate densities on the welfare of farmed fish.[11,79]

Disease and Parasites

A key welfare problem for farmed fish is infection by disease and parasites. In the U.S. catfish industry—the largest sector of domestic aquaculture comprising 85.8% of fish raised in 2005, farming more than 1.1 billion animals[33]—mortality due to infectious disease can approach 30% of the population.[80] Since stress can decrease immune function, high rates of disease are often warning signs of preexisting and unobserved welfare problems.[9]

The physiological links between stress and immunosuppression are thoroughly described in the aquaculture literature.[9,14,56,59] The increased levels of cortisol are implicated in the diminished capacity for macrophages (a type of white blood cell) to capture, engulf, and destroy bacteria.[14,56]Stress also decreases the numbers of white blood cells and impairs antibody production.[14,21,59,81] It has also been noted that an immune response can influence the stress response since chemicals and cells linked with immune function can affect the release of stress hormones and intermediaries,[956] leading to the possible increased susceptibility of diseased fish to other pathogens.[19] According to Gary Wedemeyer, emeritus senior scientist with the U.S. Fish and Wildlife Service's National Fisheries Research Center, "immunosuppression is particularly important because its effects can linger for some time after the other physiological changes have returned to prestress levels."[14]

Other factors aside from stress have been linked to disease.* In intensive aquaculture systems, poor water quality can lead to injuries in the gills, increasing susceptibility to bacterial infection.[14] This bacterial growth hinders the ability for the gills to exchange oxygen and carbon dioxide, and can be fatal.[14] Stressful water and environmental conditions, such as having inappropriate DO levels or stocking densities, are also correlated with two types of blood infections, furunculosis and motile *Aeromonas* septicemia (MAS), though proper management of rearing conditions can mitigate these outbreaks.[14] Unsuitable temperatures have also been shown to put catfish at high risk for enteric septicemia and rainbow trout at high risk for enteric red-mouth.[14] When MAS is present in the water, stress from social encounters between trout can be sufficient to result in MAS in defeated individuals.[82]

Several disorders have been identified in farmed salmon, the most studied aquacultured species. Compared to their wild counterparts, reduced exercise and food surplus for pen-confined salmon have been implicated in heart deformities that lead to poor circulation, reduced stress tolerance, and increased mortality.[8,83] Cataracts are another common welfare problem in farmed salmon, believed to be caused by water temperature fluctuations, poor nutrition, rapid growth, and exposure to UV and sunlight that can lead to reduced vision, blindness, surface lesions, and impaired growth.[8,84,85] Skeletal deformities, such as shortened vertebral columns and humped backs, are increasingly identified in farmed salmon and can lead to impaired swimming performance, diminished feeding efficiency, lower stress tolerance, and overall poor welfare.[12,86]

Farmed fish are also subject to a variety of parasitic infestations.[87,88] For certain parasites, a minimum stocking density is typically needed before infestation can occur. However, Professor Christina Sommerville, Dean of Faculty of Natural Sciences and head of Parasitology at the University of Stirling's Institute of Aquaculture, notes that this threshold "is far exceeded in the fish farm environment."[87] Parasites are known to infect nearly every part of their host; they feed on scales and can infect the blood, intestines, and nearly every other organ. If left uncontrolled, parasites can cause serious health and welfare problems and increase mortality.[87,89]

Sea lice are the best known parasites infecting farmed fish and have proven since the 1960s to be particularly problematic for the farmed salmon industry.[90] Parasitic copepods (small crustaceans), sea lice feed on the skin and protective mucus of salmon, and the effects of their feeding can become severe enough to expose bones in the skull and cause death.[15,89] Financial losses due to sea lice infection of salmon can exceed 11% of the total production value due to costs associated with stress, treatment, mortalities, and lowered production.[89]

The treatments that exist for pathogens and parasites may introduce their own welfare problems. In bath treatments, for example, fish are first corralled into a smaller volume and dosed with insecticides, vaccines, antifungals, or other chemicals, before being released with the chemically treated water. Not only may surrounding ecosystems suffer potentially toxic effects,[91] but the treatments have been shown to elicit a stress response in catfish, trout, carp, and tilapia.[9,19,92-94] Bath treatments with hydrogen peroxide, though likely more environmentally friendly, have been shown in trout to increase the stress response, impair oxygen-carrying capacity by the blood, and irritate the gills.[95] Prolonged treatments with certain antiparasitics have been linked to the development of resistance, decreasing the effectiveness of the treatments.[89]

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* For a thorough review of bacterial diseases in marine systems, see Toranzo AE, Magariños B, and Romalde JL. 2005. A review of the main bacterial fish diseases in mariculture systems. Aquaculture 246:37-61.

Environmental Factors Commonly Associated with the Occurrence of Infectious and Noninfectious Fish Diseases

Fish Disease Problem	Predisposing Environmental Factors
Bacterial gill disease (*Flavobacterium* sp.)	Crowding; chronic low oxygen (4 mg/l for salmonids); elevated ammonia (more than 0.02 mg/l for salmonids); suspended particulate matter
Blue sac, hydrocele	Temperature; ammonia; crowding
Columnaris (*Flexibacter columnaris*)	Crowding or handling during warm-water periods if carrier fish are present
Environmental gill disease	Adverse rearing conditions, but contributory factors currently not well defined
Epithelial tumors, ulceration	Chronic, sublethal contaminant exposure
Fin erosion	Crowding; low level of dissolved oxygen; nutritional imbalances; chronic exposure to trace contaminants; high total suspended solids; secondary bacterial invasion
Furunculosis (*Aeromonas salmonicida*)	Low oxygen (<5 mg/l for salmonids); crowding; temperature; handling when pathogen carriers are present
Hemorrhagic septicemias, red-sore disease (*Aeromonas, Pseudomonas*)	External parasite infestations; ponds not cleaned; crowding; elevated ammonia; low oxygen; stress due to elevated water temperatures; handling after overwintering at low temperatures
Kidney disease (*Renibacterium salmoninarum*)	Water hardness less than about 100 mg/l (as $CaCO_3$); diet composition; crowding; temperature
Nephrolithiasis	Water high in phosphates and carbon dioxide
Parasite infestations	Overcrowded fry and fingerlings; low oxygen; excessive size variation among fish in ponds
Skeletal anomalies	Chronic, sublethal contaminant exposure; adverse environmental quality; PCB, heavy metals, kepone, toxaphene exposures; dietary vitamin C deficiency
Spring viremia of carp	Handling after overwintering at low temperatures
Strawberry disease (rainbow trout)	Uneaten feed; fecal matter with resultant increased saprophytic bacteria; allergic response
Sunburn	Inadequately shaded raceways; dietary vitamin imbalance may be contributory
Swim bladder stress syndrome	Oil films; hypoxia; salinity; other water quality factors
Vibriosis (*Vibrio anguillarum*)	Handling; oxygen <6 mg/l, especially at water temperatures of 10-15°C (50-59°F); salinity 10-15%
White-spot, coagulated-yolk disease	Environmental stress: air supersaturation >102-103%, temperature, metabolic wastes, chronic trace contaminant exposure

This table has been adapted from: Wedemeyer GA. 1997. Effects of rearing conditions on the health and physiological quality of fish in intensive culture. In: Iwama GK, Pickering, AD, Sumpter JP, and Schreck CB (eds.), Fish Stress and Health in Aquaculture, Society for Experiment Biology, Seminar Series 62. (Cambridge, U.K.: Cambridge University Press, pp. 35-71).

Vaccines have been used successfully against some bacterial diseases, though the welfare of the animals during handling while administering vaccines either through injection or bath treatments must be considered.[62] In-feed treatments are also becoming more commonly used,[89] though may have similar environmental problems to bath treatments.[96] Cleaner fish, animals who eat parasites off the cultured species, have also been employed.[87] Wrasse, the fish used to control sea lice, were initially effective in reducing parasitic loads, but suffered their own welfare problems, including predator attacks and high mortalities from bacterial disease and improper environmental controls.[89]

Discussing diseases, Pickering notes: "In most cases, the immediate cause of mortality in fish farms is disease and it is now well established that stressed fish are more susceptible to a wide range of diseases."[19] Many problems associated with disease and infection can be minimized by decreasing the effects of stress and providing appropriate environmental conditions for farmed fish.[14] Infections pose major welfare problems for farmed fish, and more work is needed on effective treatments that will not diminish welfare.

Selective Breeding, Genetic Selection, and Transgenics

As with other farmed animals,[*] farmed fish undergo selective breeding and genetic manipulation to enhance biologically and economically favored traits, such as rapid growth rate, disease resistance, and reproductive characteristics.[66,97] In some cases, there are positive responses correlated with trait selection; for example, improvements for fry survival and disease resistance in channel catfish have been associated with selection for increased body weight after one generation.[66,98] However, the increases in growth rates for farmed fish are extraordinary in comparison to that of those in the wild, as evidenced by the dramatic differences in the growth of salmon: Genetic selection over ten years and four generations of salmon has increased their weight by more than 60%,[99] while in another study, transgenic salmon were on average 11-times heavier than their non-transgenic counterparts after only one year (one fish was 37-times heavier).[100]

Increasing production characteristics can cause serious welfare problems and should not be used to further intensify production of farmed fish. Summarized Håstein: "[I]f genetic capacity, feed utilisation and feed composition all work maximally towards the same goal, the fish may rapidly be squeezed over the biological limits which leads to a situation that may be characterised as unacceptable from a welfare point of view."[8]

Sex and ploidy, the number of chromosome sets in the nucleus, are manipulated in some fish both to increase growth rates and overall carcass yield, and to delay maturation, which is thought to result in enhanced carcass quality.[66] Sex manipulation is performed to create all-male or all-female populations depending on producer preference and cultured species. All-male populations are created by supplying the male sex hormone testosterone through a feeding regimen to young fish.[34] This is desirable for tilapia since male tilapia grow approximately twice as fast as females.[34] Using sperm from altered males (female-to-male fish) to fertilize normal females will create a population that is all-female,[101] which is desirable for salmonids since females may mature later than males[66,101] and, as previously discussed, carcass quality can degrade after sexual maturity is reached.[65,66] Artificial pressures and temperatures are employed to manipulate the number of chromosome sets in the nucleus, by placing fertilized eggs in a vessel where the pressure and temperature can be raised above normal atmospheric levels to prevent the second meiotic division.[101] This will result in three (triploid) sets of chromosomes, rather than the normal two (diploid) sets, which is advantageous since triploid females are sterile and will not reach maturity.[101,102] Mortality is approximately twice as high in triploid versus diploid salmon in fresh water,[101] and triploid salmon may also be physiologically less equipped to transport oxygen in their blood than diploid salmon, making them more easily affected by conditions of low DO.[101] As such, they should arguably not be subjected for prolonged periods to environments with poor oxygen, such as during crowding, grading, and treatments for sea lice, as this may pose increased risks and mortalities.[101] Some triploid fish are found to suffer higher occurrence of cataracts, increasing the risk of blindness and decreasing the ability to acquire feed, thereby resulting in emaciation,[85] and tetraploid fish, those with four sets of chromosomes, can suffer from spinal deformities.[8]

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[*] See www.FarmAnimalWelfare.org for reports on selective breeding and genetic manipulation for production traits.

The insertion of foreign genes to genetically engineer "transgenic" fish is another technique, along with selective breeding and polyploidy, used to enhance industry-desired traits,[66] often at the expense of the fish's welfare. Young, non-transgenic catfish exhibit better predator-avoidance skills compared to transgenic counterparts.[66] Genetically engineered salmon can show decreased swimming capacity, reducing their ability to forage and avoid predators,[66] and some exhibit severe deformities consisting of extra cartilage around the head that disrupts normal ventilation, feeding, and cartilage growth, and increases mortality.[65] Eric Hallerman, Professor and department head of Fisheries and Wildlife Sciences at Virginia Tech, and co-authors note in their review of transgenes on behavior and welfare that for growth rates, selective breeding may forgo the need for transgenesis and ultimately, many welfare issues with transgenic fish remain unanswered.[103]

Nutrition and Feed

Fish have specific dietary requirements relating to micronutrients, fats, proteins, and amino acids.[104,105] The FSBI report that "diets lacking in critical micronutrients impair welfare in many species, according to a range of indicators, such as high mortality, morphological abnormalities, poor immune function, abnormal behaviour, poor feeding, impaired sensory function and slow growth."[9] More than half of the operating budget for intensive aquaculture is feed costs, and proteins, especially from fish meal, are the most expensive component.[106] The production of one pound of some carnivorous species may require up to five pounds of wild fish,[107] and, throughout the overall aquaculture industry, dietary fish inputs exceed outputs by a factor of two to three[108]

A variety of plant sources and animal by-products have been tried as alternative feed sources to fish meal, including soybean meal, cottonseed meal, other oilseed by-products, poultry by-product meal, blood meal, hydrolyzed feather meal, meat and bone meal, and animal manures.[106] For tilapia, these alternatives have been found to generally lower growth and performance compared to use of fish meal, but their inclusion into farmed fish diets has been argued from an economical standpoint.[106] Some non-carnivorous fish species, such as carp and tilapia, may be better suited to proteins from plant-based sources. However, these alternatives may be deficient of essential amino acids, diminishing the health of some carnivorous farmed fish, including salmon.[96] Altering protein sources in feeds can cause digestion problems, irritate the intestines,[109] and cause immune depression.[110] Proper nutrition is vital, particularly before disease outbreaks, as it has been shown to increase resistance to disease and reduce mortalities.[105] Conversely, improper nutrition has been shown to compromise immune function and has also been linked with skeletal deformities.[15,111,112]

Some researchers are critical of the lack of knowledge on nutritional requirements for farmed fish in production systems and recommend further investigation.[105,108] Rune Waagbø, principal scientist at Norway's National Institute of Nutrition and Seafood Research, comments that "evaluation of nutritional impact on fish health is in its infancy….[T]he methods and criteria for optimal nutrient recommendations should be reevaluated to include health factors such as immunology and diseases resistance."[105]

In addition to the complexities of adequate nutrition for farmed fish, significant ecological and environmental impacts on wild fish stocks may be associated with the production and composition of fish feeds. These problems have been thoroughly discussed and strong recommendations have been made for the raising of only herbivorous fish.[91,96,113]

External Impacts

Unless indoors and closed to the natural environment, aquaculture production systems are open to water and/or air. Nursery and grow-out facilities are natural or artificial ponds, tanks, or raceways, or meshed or netted cages or pens typically placed in natural lakes or seas, allowing intimate contact with surrounding waters. As such, these fish farming facilities both affect their surroundings and are affected by them.

Predators pose direct and indirect threats to farmed fish in open aquaculture systems. In addition to direct predation losses, exposure to predators can increase cortisol levels and respiration in the animals.[9] Added physiological stress can be doubly detrimental as it has been linked to impaired anti-predatory behavior and significantly increased mortality.[114] Salmon recovering from handling stress initially have impaired predator-avoidance skills, although they can recover avoidance skills before hormone concentrations return to normal.[115,116] Additionally, feeding behavior is shown to decline when there is risk of predation, possibly a result of redirected visual attention from feed to an approaching predator.[117]

Some predators, such as otters and mink, can attack fish through mesh and netting, injuring and killing more fish than they consume. The resultant injuries and stress may then increase disease suceptibility.[118] The aquaculture industry uses anti-predator devices in attempts to protect stocks from birds, mink, seals, and other predators. Predators not deliberately killed risk ensnarement in nets and drowning.[118,119]

There is some indication that disease can spread both ways between wild fish and those farmed in systems open to the environment.[87] Conte notes that stressed farmed fish with suppressed immune function and sharing waters at higher densities "will often contract disease and/or parasitic infestation."[60] Conversely, sea lice from farmed fish can infect wild species in proximity, increasing mortality of those populations.[120] Since both groups, wild or cultured fish, put each other at risk of disease, closed systems have the advantage of mitigating this harmful relationship, but not without their own significant welfare problems.

The infestation of a natural environment with non-native species, such as when farmed fish escape their enclosures, poses serious concerns. "In the future, farming transgenic, or genetically modified, fish may exacerbate concerns about biological pollution,"[91] concluded Rebecca Goldburg, senior scientist at Environmental Defense, and her co-authors. Damage to netpens allowing fish to escape can occur from natural storms, human error, or marine mammals.[91] Escapees may have lower survival in the wild than native species, though they can continue to compete for resources.[121] Extensive reviews are available on the problems associated with fish escapes and their effects on wildlife and predators, including interbreeding and reduced biodiversity and fitness of wild populations.[91,113,119]

Crowding, Handling, Netting, and Grading

Though typically stressful procedures themselves, crowding, handling, netting, and grading of farmed fish are performed at various stages during aquaculture production[21] often to mitigate other welfare problems. For example, as fish can grow at different rates, grading is often done to separate stock populations into uniform size in order to reduce feeding competition between disparately sized fish.[14] A large body of work has investigated the effects of these procedures on the welfare of farmed fish with hopes to alleviate the stress involved.

Prior to handling, grading, the administration of bath treatments, and transport, fish are often crowded at higher than normal densities. The animals may struggle or attempt escape, suggesting acute stress from overcrowding.[15] In addition to the deleterious effects of high stocking density discussed above, short-term crowding has also been found to increase stress[122] and depress immune function for days after the crowding event.[123,124]

Handling and netting present their own significant health and welfare concerns. The preliminary step of plunging a net into water is believed to evoke fear in some fish[46] and Conte warns, "[i]f not done correctly, excessive stress can jeopardize fish welfare."[11] In water, fish have the force of buoyancy acting against their weight, so the experience of being removed from water is considered both stressful and injurious.[11] If many fish are netted or lifted at once, the weight of the animals pressing down can injure those on the bottom, in some cases causing spine injuries.[11] Handling and netting can also harm the mucus coating and scales of the fish, elevate stress, and increase disease and parasitic susceptibility.[125,126] As netting adversely affects fish welfare, moving the animals by pumping them through transfer pipes where they remain submerged in water is an option that may be the least invasive,[11] though more work must be done in this area to assess its welfare effects.

Oxygen concentration can vary with temperature, so fish should be handled when the water is at its coldest, typically at night. Handling during high temperatures, when there is less oxygen in the water, can cause severe stress and "the associated stress often results in mortality in both the short and long-term."[11] Conte recommends:

"All fish-handling processes should be slow and deliberate so as not to increase the natural avoidance reactions of fish, which can lead to excessive activity and potential exhaustion."[11]

As discussed above, holding differing-sized fish in the same enclosure can cause aggression, fin nipping and other cannibalistic behavior, stress, depressed immune function, reduced growth, and other unwanted results and welfare assaults. To reduce these effects and improve the welfare of smaller fish, they are at times graded by size during the grow-out period.[14] This process requires collecting the fish by netting or pumping them through transfer pipes, and distributing them over a series of parallel bars of differing widths, selecting and collecting fish of similar size.[8] However, as with handling, time for grading should be kept to a minimum as it is known to be stressful, cause damage to the skin and scales, and temporarily decrease feeding rate and growth.[8,11,15]

Transport

Fish are often starved before transport to clear the gut of contents to protect water quality by eliminating the animals' need to void feces[11] and also prior to slaughter to minimize carcass contamination during gutting.[62] Claims that starvation further protects water quality by decreasing oxygen consumption and carbon dioxide production need additional evaluation, as several days of feed-withdrawal may be required to be effective to achieve these aims.[14] Many researchers note that since farmed fish are accustomed to specific feeding regimens, changes in feeding will have negative effects on welfare.[8,79] During periods of food deprivation, fish may nip at eyes and fins, cannibalistic behaviors that can cause eye damage and increased fin erosion,[8,77,127] injuries known to decrease immune capacity.[9,10,15,77] For these reasons, starvation time before transport or slaughter should be evaluated by species and environmental conditions and, if continued to be practiced, should be kept to an absolute minimum.[55,128]

When ready for transport, fish are loaded with lift nets or pumps into transport vehicles, typically trucks or boats, but at times helicopters.[8] As Håstein notes, "conditions during transport such as overcrowding, unacceptable water quality due to low oxygen, may result in irreparable damage to the fish and mortality,"[8] so construction of transport containers must address fish welfare. During transport, continuously circulated and freshly aerated water is the primary physiological need essential to promote fish health,[14,62] particularly as stressed fish can increase their oxygen consumption.[14]

Transport is known to increase concentrations of primary and secondary stress hormones in fish of varying maturity,[21,129-131] in some cases up to 15 times basal levels,[132] and is associated with increased mortalities.[132-134] Injuries sustained during transport are known to elevate susceptibility to fungal infections contributing to post-release mortality.[14] Though it may only take hours to recover from certain physiological effects associated with transport, Wedemeyer recommends "a recovery period of several days before subjecting them to additional stress from other fish culture procedures."[14] Other researchers concur on the effects of handling stress and the need to allow for proper recovery before subjection to additional handling to reduce the risk of compounding stresses and worsening mortalities.[8,55,129,135]

Various techniques to alter the hauling water have been employed to alleviate stress and decrease mortality rates during and following transport.[14] These include chilling the water,[134] or adding anesthetics[136,137] or mineral salts.[133,137] Cool water slows metabolism, reducing oxygen use and wastes, though variations in water temperatures between hauling and destination should be avoided.[14] Anesthetics added to hauling water can reduce swimming activity, thereby preventing some injuries, and suppress metabolic rates, which effectively improve water conditions by reducing oxygen use and the production of ammonia and carbon dioxide.[14] Salts provide protection from a variety of physiological conditions such as blood electrolyte loss, lowered blood pH, and ionoregulatory dysfunction.[14] Though these techniques can improve the animals' ability to cope with challenging conditions, they should not be coupled with increased densities during transport or utilized to compensate for poor water conditions.[14] To ensure the welfare of fish during crowding, handling, netting, grading, and transport, appropriate environmental conditions must be maintained and durations for each stage kept to a minimum, while ample recovery time be provided after these procedures.

Stunning and Slaughter

The production of farmed fish ends at slaughter. From the animal welfare perspective, painless slaughter is a non-negotiable goal—both for those animals who reach market weight and those culled for disease or other reasons. Many researchers agree that the optimum method of killing should avoid excessive physical activity, stress, pain, and suffering prior to slaughter, and should induce immediate insensitivity or unconsciousness throughout the slaughter process until death.[15,55,128,138-140] With all stunning methods, exsanguination by gill-cutting and bleeding should occur after the animals are fully unconsciousness and insensible to pain.

Depending on the time required to induce insensitivity or achieve death, stunning and slaughter methods can be generally classified as slow or fast. David Robb, with the Norwegian aquaculture company EWOS Innovation and the Division of Food Animal Science at the University of Bristol, and co-authors describe slow methods as "generally unacceptable in terms of welfare of the fish"[140] and note faster methods that "cause a rapid loss of sensibility result in the best welfare, providing that they are carried out correctly."[139]

To gauge the effectiveness and immediacy of stunning, visual evoked responses (VERs)—responses to visual stimuli—are used, as they are one of the final measurable responses to external stimuli. Robb *et al.* state "[a]n immediate loss of VERs can be regarded as an immediate stun and therefore humane…."[140] The exhibition by fish of negative behaviors, such as excessive swimming, escape attempts, and other physical activities, is likely an indication that the stunning procedure is aversive and welfare is poor.[139] There are many prolonged and aversive methods of stunning and slaughter. Exsanguination is sometimes performed without stunning, where the gills are cut or ripped by hand and the fish are returned to water to bleed out. This method prolongs the death of fully conscious fish who have been observed as showing aversive reactions, VERs, violent head shaking, and gill movements for up to ten minutes.[140,141]

Suffocating fish in air, another slow-slaughter practice, may be the most common method used in the world.[139] Removing fish from water and asphyxiating them in air is highly aversive and causes escape behaviors and severe stress responses.[139] The time to induce loss of VERs or unconsciousness in this way varies based on temperature and its impact on metabolic rate—taking a few minutes at high temperatures and up to ten minutes at lower temperatures.[138,139,142] Loss of movement takes considerably longer, nearly 200 minutes at near-freezing temperatures (2°C [35.6°F]).[142] Some reports indicate that fish have "sensory capacity" for 15 minutes after removal from water.[8]

Asphyxiation by immersion in ice water, or ice slurry, is a method similar to suffocation in air and can diminish fish welfare and cause significant increases in stress levels.[143] As with suffocation in air, asphyxiation in ice to achieve unconsciousness can last ten minutes for some temperate species such as rainbow trout and five minutes for warm-water species such as sea bream, and may not cause death for three hours.[55,139] Given the prolonged periods needed to induce unconsciousness and the subsequent risk of gill-cutting before loss of consciousness is achieved, the ice slurry method is unacceptable.

Stunning in carbon dioxide-saturated water followed by gill-cutting is another common slaughter method. Many species exhibit extreme aversive reactions to carbon-dioxide narcosis, such as rapid swimming, escape attempts, and vigorous shaking lasting for several minutes.[139-141] Hans van de Vis, a principal at the Institute for Marine Resources and Ecosystem Studies in The Netherlands, and co-authors note that VERs continue beyond six minutes and, as it is possible for conscious states to exist after movement ceases, immobile fish may have their gills severed while conscious.[15,138] Many scientists conclude that stunning by carbon dioxide is inhumane.[15,138]

Since quicker slaughter methods may significantly decrease the time fish are conscious and suffering before death, they offer welfare benefits over slower stunning and slaughter methods. Primary fast-slaughter methods are percussive stunning, spiking, and stunning by electrocution. With percussive stunning, fish are removed from water, immobilized, and clubbed in the head.[139] The differential accelerations between the skull and brain disrupt normal function, causing immediate insensibility.[55,138,140] Spiking is similar to percussive stunning, but instead of using a club to strike the animal, a spike is driven through the brain.[139] When applied correctly and efficiently, percussive stunning and spiking cause immediate loss of movement, VERs, and consciousness without negative reactions.[8,139] Incorrect application of these methods, however, are highly aversive and may be long-lasting and painful.[140]

Stunning by electrocution can also induce unconsciousness in fish. Typically, electricity is passed through a bath containing fish, and, if the current and voltage are sufficient, loss of VERs and movement are immediate.[138,139] Fish show highly aversive reactions after the process if insufficient voltages are used, so improper stunning presents a serious welfare problem.[8,139] The possibility also arises that fish may regain consciousness after stunning, so, as with all slaughter procedures, exsanguination should rapidly follow immediate loss of consciousness.[138] To reduce the immediate effects of long-term crowding when many fish are killed at once, Peter Southgate and Tony Wall, director and founder, respectively, with the U.K.'s Fish Vet Group, recommend that slaughter should proceed as fast as possible, and, immediately before stunning, fish should not be held out of water for more than 15 seconds.[55]

Evaluating welfare at slaughter, Robb and Steve Kestin, of the Division of Farm Animal Science, Behaviour and Welfare Group in the University of Bristol's Department of Clinical and Veterinary Science, find that the slower methods of exsanguination, death in air and in ice, and carbon-dioxide narcosis rank low in terms of measured welfare, while the fast-slaughter methods of percussive stunning, spiking, and electrical stunning rank higher.[139] When discussing ethical considerations for the slaughter of farmed fish, Tony Wall with Scotland's Fish Vet Group notes:[141]

> It is important that we should step back from accepting existing fish slaughter methods and take a long cool look. Perhaps we should be developing a number of pre-harvest strategies which would enable the fish to be killed more easily and would be associated with less stress...In killing large numbers of fish it may not be possible to achieve the mammalian ideal of immediate insensibility. But, if this entails high levels of stress prior to slaughter, it may not be desirable. A low stress system prior to the point of slaughter may be just as important as the actual method used.

Research into acceptable stunning and slaughter methods is still needed to determine best practice for species and conditions. Wall describes some basic objectives the industry should strive for: increasing efficiency without compromising welfare, minimizing the pre-slaughter crowding time, minimizing fear, minimizing the time held out of water, and decreasing pain by insuring a quick stun.[141]

Conclusion

According to the FSBI, "[t]he scientific study of fish welfare lags behind that of the welfare of other vertebrates."[9] At a global animal welfare conference, Håstein identified the "need to critically review all aspects and procedures in modern fish farming in order to establish ethically acceptable farming conditions, feeding and handling regimes, transport, stunning and slaughter methods."[8] Given the billions of fish farmed domestically and globally, the need to understand the implications of aquaculture practices on those animals is critical. Indeed even despite his contention that fish are not sentient—a position highly disputed by the scientific community[26,27,43]—Rose concludes that this "in no way devalues fishes or diminishes our responsibility for respectful and responsible stewardship of them."[25]

According to Håstein *et al.*, "[a]pplying the principles of ethics and animal welfare to poikilothermic aquatic animals involves supplying the things necessary for sustaining life, optimising health and minimising visible discomfort (e.g. pain, stress and fear)."[15] The experience of multiple stressors present at every stage of aquaculture production substantially increases the stress response in fish, which, in turn, affects aspects of physiology, response to predators, and mortality as Pickering warns, "chronic mortalities occur and, to a large extent, reflect the levels of stress to which the fish are subjected."[19] Increasing mortalities are a clear indication that serious welfare problems exist, often from environmental effects, poor water quality, and infections, with some systems maintaining mortality rates of nearly 30% throughout the life cycle.[62,80]

All aspects of aquaculture production should be evaluated to minimize the stress and welfare assaults that fish face. These animals should be afforded the proper environment, water quality, and space to enable them the full range of their natural behaviors, and be protected from stress, disease, predation, negative effects of genetic selection, and inhumane slaughter.

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