An HSUS Report: The Welfare of Farmed Fish at Slaughter

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Abstract

Approximately 1.3 billion fish are raised in off-shore and land-based aquaculture systems in the United States each year and slaughtered for food. Numerous methods are used to stun and/or kill farmed fish, but scientific research has found most to be inhumane. Methods such as asphyxiation on ice or air, carbon-dioxide stunning, gill-cutting (exsanguination) without prior stunning, and live chilling do not cause immediate insensibility, and studies on the physiological and behavioral responses of fish show that these slaughter practices are likely to cause suffering as animals respond with highly aversive behavior. Both percussive and electrical stunning and killing systems, if applied correctly, can induce immediate and irreversible insensibility, thereby subjecting the animals to less pain, stress, and undue suffering as compared with other methods. At present, however, no slaughter technique is without welfare problems.

Introduction

The fish farming industry has grown at a rate of approximately 8% per year since the mid-1980s.[1] Globally, the average annual per-capita fish and fishery products consumption was 16.4 kg (36.2 lb) from 2003 to 2005[2] and could increase to as much as 22.5 kg (49.6 lb) by 2030.[3] As consumption has outpaced the growth of the world's human population since the 1960s,[4] the world's fisheries are unlikely to satisfy the marketplace. As such, "the seafood industry is beginning to shift from wild harvest to aquaculture, the production of aquatic plants and animals under grower-controlled conditions."[5]

With the expanding aquaculture† industry,[6,7] there has been greater interest in farmed fish welfare and an increased awareness of the need for better management and production practices, including at slaughter.[8,9,10] The general challenge of addressing the well-being of farmed fish was elucidated by Tore Håstein of the National Veterinary Institute in Oslo, Norway and colleagues in an article published by the World Organisation for Animal Health (OIE), an intergovernmental body with 172 member countries: "One practical problem for science is how to deal with the large numbers of individuals handled in aquaculture, as the welfare of the individual animal must be protected and monitored"[11]

Examining several slaughter techniques of farmed fish, scientific research has established that many methods presently employed are inhumane,[12] including gill-cutting without prior stunning,[13,] asphyxiation in air or on ice,[14,15] carbon-dioxide stunning,[16] and live chilling.[17] Both percussive and electrical stun/kill systems provide the fewest challenges to welfare of the methods available to date.[18,19] If applied correctly, these systems can induce immediate and irreversible unconsciousness[20,21] and, therefore, insensibility to pain, stress, and undue suffering.

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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.

Legislative Protection for Fish at Slaughter

Although the slaughter of mammals and birds for human consumption is regulated by law and these laws are promulgated in many countries, including all member countries of the European Union,[‡22] most do not yet extend this protection to farmed fish.[23] According to Bert Lambooij, a researcher in the Animal Science Group at Wageningen UR, and his colleagues:

> The concept of animal welfare, which is generally accepted for mammals, is a relatively new concept for fish. It is likely that conventional harvest adversely affects the welfare of fish, particularly when the similarities in the basic structure of neurons and neuronal biochemistry to that of mammals, and the similarities in stress responses and behaviour to that of higher vertebrates are considered[24]

Steve Kestin, a researcher with the department of Clinical Veterinary Science at University of Bristol, and his colleagues posited that "[s]ince there is no reason to suppose that fish are incapable of feeling pain and distress there is a good argument for affording fish similar protection to that given to higher vertebrates."[25]

Indeed, although general sensitivity to fish welfare is not as developed as it is for avian or mammalian animals, concern for the well-being of aquatic animals is gaining both scientific and citizen interest.[26,27] In the United Kingdom, for example, where concern for farm animal welfare is more widespread than in many other developed countries, as evidenced by the prevalence of pro-farm animal legislation, policy, and consumer interest in welfare-friendly agricultural practices, the well-being of fish is now of such importance that some U.K. retailers are anticipating the inclusion of humane fish slaughter into their purchasing policies.[28]

Background on Farmed Fish Slaughter

The slaughter of farmed fish was briefly explained by Jeff Lines, leader of aquaculture engineering research at the Silsoe Research Institute, and his colleagues:

> Slaughter is generally a two-stage process. The animal is first stunned to make it insensible to pain. Death then is induced by various methods that include bleeding, stopping the heart, or preventing access to oxygen. These two stages can occur together but where they are distinct operations, the stun-to-kill time must be minimized to prevent any recovery of consciousness before death occurs.[29]

The Farm Animal Welfare Council (FAWC), an organization established to advise the U.K. government on issues regarding the welfare of farm animals,[30] recognized many fish slaughter methods as problematic on welfare grounds and called for a search to develop humane alternatives.[31] Håstein echoed FAWC's assessment and asserted that many fish slaughter methods are "appalling from an animal welfare point of view."[32] Concluded the Scientific Panel of Animal Health and Welfare of the European Food Safety Authority (EFSA): "Many existing commercial killing methods expose fish to substantial suffering over a prolonged period of time. For some species, existing methods, whilst capable of killing fish humanely, are not doing so because operators don't have the knowledge to evaluate them."[33]

Acceptable slaughter methods must render the animal insensible immediately and should be carried out without causing avoidable pain or suffering.[34] According to the Humane Slaughter Association (HSA),[§] the ideal slaughter system for fish encompass methods that do not remove the animals from water; where this cannot be avoided, fish should not be out of water for more than 15 seconds.[35] After this amount of time, the animals "show aversive behaviour."[36]

[‡] "Council Directive 98/58/EC provides the general framework for farm animal welfare and applies to all animals (including fish, reptiles and amphibians) kept for food, wool, skin, fur or other farming purposes."

[§] The HSA is a U.K. charity that was selected by the European Commission to organize and present a co-sponsored "International Training Workshop on Welfare Standards Concerning the Stunning and Killing of Animals in Slaughterhouses or for Disease Control" in 2006.

Methods of Assessing Insensibility

A method to assess consciousness in fish is monitoring the eye roll reflex, movement of the eyes when fish are rolled from side to side. When conscious, fish will attempt to remain upright when rolled to the side and their eyes will roll relative to the head. However, when unconscious, the eyes will remain fixed relative to the head, showing no movement at all. Hence, it is accepted that insensibility is achieved in the absence of the eye roll reflex.[37]

Other acceptable non-invasive means of assessing unconsciousness include monitoring:

- self-initiated behavior, such as ability to swim normally and maintain equilibrium;
- response to stimuli, such as escape and avoidance behavior to catching or handling, pin prick, and electric stimuli; and
- clinical reflexes, such as rhythmic opercular movement indicative of breathing.[38]

These criteria are commonly used by researchers as indicators of insensibility and can easily and rapidly be employed to examine large numbers of fish, which enables producers to assess the general efficacy and level of welfare at slaughter operations.[39] However, for some methods of slaughter, behavioral indicators must be used with caution, as lack of self-initiated behavior, for example, does not necessarily indicate unconsciousness as measured by other methods.[40]

Some researchers have measured insensibility by use of electrocardiogram (ECG) techniques,[41,42] as ECG recordings that show ventricular irregularities, indicative of cardiac dysfunction, effectively monitor a fish's internal state. Electroencephalograms (EEGs) can also assess unconsciousness. Similarities in the basic neuronal biochemistry of fish with other vertebrates, including humans, support the assumption that EEG activity patterns seen in humans and other vertebrates can be used to determine when fish are rendered unconscious.[43] For example, studies of electrical stunning have found that a proper electric stun can induce epileptiform activity in the brain, indicating unconsciousness.[44] Indeed, behavioral parameters have been shown to be consistent with the EEG measurement technique in eels.[45] Dave Robb, a researcher at the Division of Food Animal Science at the University of Bristol and EWOS Innovation, and colleagues state:

> [Electroencephalography]… investigates the patency of a pathway in the brain which responds to a flash of light that stimulates the retina of the eye of an animal. When the patency of the pathway is abolished, the visual evoked responses (VERs) are absent and the animal is regarded as unresponsive to a visual stimulus. Because the pathway is simple, it is one of the last responses to an external stimulus to be lost before brain death and is thus a good indicator of the onset of profound brain failure.[46]

Many of these indicators are interrelated and synonymous with a loss of consciousness and therefore insensibility, and experimental studies often measure one or some combination of these parameters.

Farmed Fish Slaughter Methods

Addressing the welfare of farmed fish is markedly more difficult than assessing production practices and systems for other farm animals. Håstein *et al*. identifies some of the challenges:

> In contrast to terrestrial production animals, aquatic animals encompass extremely diverse, divergent and distantly related taxonomic groups, of greatly varied phylogenetic ages and linkages. They range from highly developed marine mammals to lower invertebrates, all with very different anatomies, physiologies and behaviour. For example, the evolutionary history of finfish stretches back over 450 million years…and more than 28,500 species currently exist….[47]

However, despite variances in responses and levels of aversion among fish species, scientific inquiry has successfully made determinations regarding various slaughter methods that are applicable across a variety of fish species. According to the HSA: "Traditionally, the method of [fish] slaughter was chosen for its ease of application and cost reduction. Most such traditional methods of killing fish such as live gutting, suffocation (in air or on ice)[,] hypothermia and carbon dioxide narcosis are now considered inhumane as they cause the fish to suffer unnecessary stress and pain."[48] Indeed, various methods are used to stun and slaughter fish with differing impacts on the animal's welfare. Following is an assessment on the most common techniques.

Asphyxiation in Air

Asphyxiation in air involves the removal of fish from water, whereby the animals suffocate and die. This method is extremely aversive to fish, who often show violent escape behaviors accompanied by maximum stress responses.[49] When fish are taken out of water, their gills collapse, preventing oxygen exchange with their environment.[50] The time to death in air is affected by the ambient temperature; for example, rainbow trout die after 2.6 minutes at 20ºC (68ºF), 3 minutes at 14ºC (57.2ºF), and 9.6 minutes at 2ºC (35.6ºF). As fish are poikilotherms, animals whose body temperature fluctuates according to the temperature of the environment, reducing the temperature of their bodies typically prolongs the time to anoxia (a condition in which the tissues of the body do not receive adequate amounts of oxygen) and, therefore, the time to insensibility, lengthening the period of distress or suffering.[51]

Asphyxiation on Ice and Live Chilling

Fish may also be asphyxiated by immersing them in a slurry mixture of ice and water or packed live in ice flakes. This method is commonly used on many different farmed species such as rainbow trout, gilthead sea bream, sea bass, barramundi, and channel catfish, even though temperate species take longer to lose brain function when asphyxiated in ice compared to in the air. There is no clear evidence on how aversive it is to a fish to be immersed in ice, though it has been hypothesized that this treatment could be painful.[52] Because intense, rapid cooling causes muscle paralysis, behavioral indices used to measure aversion cannot be used; however, rapid cooling has been clearly shown to initiate a stress response.[53]

Similar to the method of asphyxiation on ice, live chilling involves immersing fish in chilled water, with the intentions of causing fish either to become torpid (motionless) or stunned before slaughter.[54,55] This method of cooling muscles immobilizes the animals so they can be more easily handled.[56] However, cold shock is unacceptable as it prolongs the period of consciousness (i.e., the time to unconsciousness increases with decreasing temperatures)[57] and does not reduce the animals' ability to feel pain.[58] Fish may be exposed to water of approximately 1ºC (33.8ºF) or colder.[59,60] The chilled water often causes the fish to become sedated[61] or immobile, but may not render them insensible to pain and the effects are reversible if transferred back to normal water temperatures.[62]

Live chilling is considered by the aquaculture industry to offer benefits to carcass quality since reducing muscle temperature close to 0ºC (32ºF) eliminates significant thermal energy that would otherwise begin the muscle degradation process that begins soon after death and also increases both the time for onset of rigor mortis and the resolution of rigor.[63] That is, fish whose body temperature is significantly lowered begin normal post-death decomposition at a later time.

Rapid drops in body temperature can be very stressful to fish.[64,65] For those who are transferred from warm water, the temperature reduction and impacts on welfare may be more dramatic, as is the case with some European Atlantic salmon farms where fish are taken from seawater of temperatures as high as 15ºC (59ºF).[66] Researchers found that live chilling of salmon from warm seawater to 1ºC (33.8ºF) resulted in elevated levels of cortisol indicating that this treatment is stressful.[67]

A research team led by Bjorn Roth from the University of Bergen, Norway, observed chilled fish exhibiting non-uniform behavior upon exit of the chilling tank. Although some fish were motionless, others showed

degrees of physical activity, and all showed signs of consciousness including eye-rolling and respiratory activity upon removal from the chilling tank, as well as immediate responses such as writhing and thrashing during gill-cutting for exsanguination. The team concluded that live chilling followed by exsanguination of fish appears to be highly stressful and should not be practiced as the animals are not properly stunned.[68]

In a study of the welfare aspects of live chilling and freezing of farmed eels, Elbert Lambooij of the Institute for Animal Science and Health in the Netherlands, and colleagues found that at least 5% of fish were not successfully stunned when transferred from 18ºC (64.4ºF) water to ice water at an average temperature of 0.2ºC (32.36ºF) and were not effectively stunned until they were subsequently transferred to cold brine at -18ºC (-0.4ºF).[69] The researchers, however, do not recommend this method as unconsciousness is not induced for nearly 30 seconds.

Carbon-Dioxide Stunning

Commonly used as a stunning method, water saturation with carbon dioxide creates an acidic and hypoxic environment that eventually leads to narcosis. In response to this treatment, fish have been reported to show aversive behavior and flight reactions.[70,71,72,73] During the initial period of narcosis, fish exhibit intensely aversive behavior for a minimum of approximately 30 seconds.[74] Robb *et al*. reported that salmon react with behavior including vigorous head and tail shaking for approximately 2 minutes after being immersed in carbon dioxide-saturated water although some salmon have been recorded to show this aversive behavior for up to 9 minutes.[75] It has been reported that the high amount of activity seen during carbon-dioxide stunning routinely causes gill hemorrhaging.[76]

In addition to these behavioral responses, some fish such as rainbow trout, carp, and eels also increase mucus production, a possible sign of stress,[77,78] during carbon-dioxide narcosis.[79] In some cases, it has been observed that fish will demonstrate a "coughing" response as a means to clear excess mucus from their gills.[80] Loss of brain function by this method has been found to take 4.7 minutes for trout[81] and 6.1 minutes for salmon.[82]

Although considered an unacceptable method of slaughter by the HSA, if carbon-dioxide stunning is used, well-run systems leave fish in carbon dioxide-saturated water for a minimum of ten minutes in order to induce unconsciousness.[83] Despite this, however, it has been reported that fish are customarily removed once movement stops, typically after 2-3 minutes.[84] Thus, there is a concern that fish may be rendered immobile by the carbon dioxide before completely losing consciousness and may be bled or eviscerated while still sensible.[85,86]

Aversive behavior to carbon-dioxide stunning has been reported to cause injury and scale loss, and there is no evidence proving that carbon dioxide has any analgesic or anaesthetic effects other than narcosis, which does not imply any reduction in pain or fear.[87]

Research on alternative, less aversive gases that could be used for stunning fish in the future has the potential to greatly improve the welfare of fish at slaughter. Carmel Wills, Ph.D. candidate at the School of Food Science and Environmental Health, Dublin Institute of Technology, and colleagues investigated the use of nitrogen gas to stun rainbow trout and found this method did not cause the strong frenzied activity as seen in fish immersed in carbon dioxide-saturated water,[88] but full understanding of and further research into gas stunning methods are as of yet inconclusive.

Live Chilling with Carbon-Dioxide Stunning

Live chilling at temperatures customarily used by the aquaculture industry may immobilize fish, yet may not induce unconsciousness.[89] Thus, live-chilled fish may be fully conscious when their gills are cut.[90] A dual method has been introduced whereby fish such as salmon and trout are live-chilled in 1ºC (33.8ºF) water to immobilize them and then stunned or killed using carbon dioxide.[91]

As carbon dioxide-saturated water causes extreme aversive behavior, chilling the animals first reduces negative reactions by the animals when they are exposed to the gas. As such, this dual method may be considered by some to be a more humane way to induce the desired state of hypercapnia in fish before gill-bleeding.[92] Low temperatures, however, are thought to slow the onset of unconsciousness, giving rise to concerns that chilling may also prolong the negative effects of carbon dioxide.[93,94] As such, although live chilling does to some extent reduce the hyperactive response to carbon dioxide, it may merely be a function of cold immobilization.

However, in one particular investigation, researchers found that some live-chilled fish, prior to transfer to carbon dioxide-saturated water, recovered from their immobilized state, regained movement, and struggled to physical exhaustion.[95] Similarly, Roth *et al*. concluded that commercial use of live chilling in combination with high levels of carbon dioxide does not sufficiently stun salmon before slaughter.[96]

Bleeding without Prior Stunning

This method typically entails removing fully conscious fish from water, manually restraining them, inserting a sharp knife under their operculae, and severing all four gill arches on one side of their head.[97] Alternatively, the heart may be pierced, isthmus cut with a knife or the blood vessels in the tail severed.[98] Fish reportedly struggle intensely for an average of four minutes during this process;[99] Lambooij *et al*. found that catfish responded to noxious stimuli for a minimum of 15 minutes after gill-cutting.[100]

The Scientific Panel of Animal Health and Welfare of the European Food Safety Authority and others have stated that exsanguination without stunning is inhumane and should not be used for slaughter.[101,102] Although this method has been used commercially in the United Kingdom and in Norway,[103] behavioral and brain function measures have indeed shown that it is a slow method of slaughter as fish are not rendered immediately insensible.[104]

Percussive Stunning

With percussive stunning, fish are rapidly struck on the head, resulting in violent movement of the brain within the skull, causing concussion and cerebral dysfunction.[105] This method renders fish unconscious immediately and irreversibly if sufficient force is applied to the correct part of the head.[106] In the occasion that a fish regains consciousness due to an improper stun or there is any uncertainty whether the stun was effective, the fish should be re-stunned immediately.[107]

Manual percussive stunning presents challenges including operator fatigue that reduces accuracy and impairs welfare. Determined Håstein *et al.*: "Although percussive stunning by a hand-held club is useful from a technical point of view, the method must become automated if it is to be useful for slaughter under industrial conditions."[108] Alternative methods to traditional clubbing by slaughter workers have been explored, including a pneumatic gun originally developed for the stunning of small mammals, and these are both accurate and able to deliver the required velocity.[109]

Presently, use of semiautomatic percussive stunning devices is becoming more widespread within the salmon industry and is the most common method used in both Scotland and Chile.[110] With this system, fish are removed from the water and manually guided by operators into the opening channel of the device. When their snout touches a trigger, a quick, hard blow is delivered to the head.[111,112]

Innovations are in development that remove the human handling aspect and involve methods that do not require removing fish from water at all. New designs encourage fish to swim along the apparatus,[113] which would improve animal welfare by reducing if not eliminating stress caused by handling.

In their study of different slaughter methods, investigators led by Hans van de Vis, researcher at Wageningen University and Research Centre, noted that after percussive stunning, fish immediately lost the ability to perform self-initiated behavior and unconsciousness occurred after an average of 18 seconds. The researchers

posited that the EEG electrodes recording brain activity may have hindered correct application of the blow, preventing immediate loss of brain function.[114] Another research team found that when sufficient force is properly applied, the percussive stunning system renders salmon immediately insensible with a single percussive stroke to the head.[115]

Automatic percussive stunning systems have been used in the slaughter of trout, salmon,[116] turbot,[117] and catfish.[118] Lambooij *et al*. concluded through EEG readings that captive bolt stunning almost certainly eliminates pain perception and is therefore an effective and humane method of slaughter.[119]

Electrical Stunning and Killing

Stunning by use of electricity is known as electronarcosis, whereas killing by using electricity is known as electrocution. Depending on the electrical parameters, such as voltage, frequency and duration, either outcome can be induced. Electric stunning is reversible as normal brain function is disrupted for a short period only; hence electronarcosis must be immediately followed by bleeding before the animal can recover from the stun and regain consciousness. Electrocution, on the other hand, completely destroys brain function and therefore renders the animal unconscious while stopping the breathing reflex from functioning.[120]

In a study of electrical stunning of rainbow trout, investigators found that while increasing the waveform frequency decreased the stun duration, increasing current magnitude and application time increased the time that animals remained effectively stunned. Indeed, fish could be killed when higher currents were used.[121] Research has also shown that low currents resulted in fish being improperly stunned, showing physiological and behavioral signs of consciousness.[122] Similarly, if the stun duration is too short, fish can quickly regain consciousness.[123] Therefore, along with water factors, such as conductivity and temperature,[124] each of these three electrical parameters must be appropriately managed in order to ensure a proper stun.[125]

When fish are subjected to a poor stun (due to poor management or equipment malfunction) and rendered paralyzed instead of insensible, they cannot express pain or show avoidance behavior and risk being bled while conscious. The EFSA warns that electrical systems can cause suffering if not properly applied.[126] When properly applied, however, a good stun can render trout irreversibly unconscious and combinations of electrical parameters that stun trout immediately without damaging body composition have been identified.[127,128] Pre-slaughter electrical stunning has also been shown to be effective for eels,[129] salmonids,[130,131] and catfish[132] if promptly slaughtered.

The electric method has been shown to induce irreversible unconsciousness with a 1 second application of correctly selected electrical parameters[133],[134]; thus its instantaneous nature has appeal from a humane slaughter perspective. On the other hand, as quick as the application may be, fish have been reported to show violent behavioral reactions, muscle blood spots and fractured vertebrae when subjected to electricity.[135] So although the electric method may be considered more humane when compared to some other slaughter methods such as asphyxiation, it is not a method without drawbacks. Also of potential concern is that there is little publicly available information comparing the electrical stun parameters used on commercial slaughter facilities to those researchers have found to be most humane. Therefore it remains uncertain whether slaughter facilities are actually employing electrical settings conducive to producing effective stuns.

Another advantage of a well-designed and operated electrical system is that it can eliminate or significantly reduce both stressful pre-slaughter handling and the need for removal from water.[136] For example, methods such as asphyxiation in air or ice require fish to be removed from water; bleeding and percussive stunning, require fish to be removed from water and also physically restrained and handled during the process. With the electrical system, large numbers of fish can be slaughtered and processed with minimal handling.[137,138]

Although electrical stunning is by no means a universally or commonly employed method,[139] researchers including Lines *et al*. believe that "[t]he UK trout industry appears to be moving towards electric stunning as its

preferred slaughter method."[140] This is a welcome change, as the use of electricity can be a more humane and efficient alternative to other methods.[141]

Pre-Slaughter Sedation with Anesthetic

A pre-slaughter sedative with the product name AQUI-S is currently in use for salmon in Chile, Australia, Korea, Costa Rica, Honduras, and New Zealand.[142] The sedation calms the pre-slaughter stress response in fish, but does not stun or kill the animals. After the fish are sedated, they must then be properly stunned and/or killed. The sedative effect of AQUI-S does not appear to be stressful to most fish, and sedated fish show significantly less distress when they are removed from the water for stunning.[143] However, EU legislation prohibits the use of anesthetics for fish slaughter[144] as "[b]arriers to the use of this technique in UK include the cost of overcoming the legislative requirements to introducing a new medication and the possible public response to eating fish that could be perceived as having been poisoned."[145] From an animal welfare perspective, however, pre-slaughter sedation with anesthetic is worthy of investigation.

Conclusion

Wrote Håstein *et al.*:

> Various methods are used to slaughter fish…and there is no doubt that many of them can be considered totally unsatisfactory from an animal welfare point of view…The guiding principle for optimal slaughter is to avoid unnecessary stress and pain to the animal during the slaughtering process.[146]

Following this basic guideline, many of the common methods for stunning and slaughtering farmed fish are unacceptable, including asphyxiation in air[147] or on ice,[148,149,150] live chilling,[151] carbon dioxide,[152,153] live chilling with carbon-dioxide stunning,[154] and bleeding without prior stunning.[155] Given the research results and systems presently available, percussive and electrical stunning, when appropriately applied, appear to be among the least aversive methods for slaughtering fish.[156,157]

Innovations may offer alternatives, including combining methods in order to stun and kill quickly, efficiently, and without causing undue suffering. In Norway, for example, a system is reportedly in development whereby salmon are electrically stunned and, before they can regain consciousness, are quickly subjected to percussive stunning after which they undergo exsanguination by gill-cutting.[158] Prototype equipment for percussive and electrical stunning systems has recently become available, and some salmon processors, after performing trials, believe it to be economically feasible for large producers.[159]

Fish welfare is a young field but has growing interest. "In summary, …[Håstein *et al*.] believe that it is essential to improve the welfare of poikilothermic animals by…developing a more humane technology…"[160] Indeed, most research has concentrated on salmon and trout, providing little study on the impact of current slaughter methods of more newly farmed aquatic species such as cod and haddock.[161] However, additional scientific study should aid in the development and improvement of more humane slaughter methods for all intensively farmed fish, regardless of species.[162]

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[1] Food and Agriculture Organization of the United Nations. 2006. Nearly half of all fish eaten today farmed, not caught. FAONewsroom. www.fao.org/newsroom/en/news/2006/1000383/index.html. Accessed August 20, 2008.
[2]Food and Agriculture Organization of the United Nations. 2008. Appendix I - Fish and fishery products – apparent consumption. ftp://ftp.fao.org/fi/stat/summary/appIybc.pdf. Accessed September 18, 2008.
[3] FAO. 2002. World agriculture: towards 2015/2030. Food and Agriculture Organization of the United Nations. www.fao.org/docrep/004/y3557e/y3557e10.htm#q. Accessed August 20, 2008.
[4] World Health Organization. 2007. Global and regional food consumption patterns and trends, section 3.5, availability and consumption of fish. www.who.int/nutrition/topics/3_foodconsumption/en/index5.html. Accessed August 20, 2008.

[5] Harvey DJ. 2004. U.S. seafood market shifts to aquaculture. U.S. Department of Agriculture Economic Research Service, AmberWaves, April. www.ers.usda.gov/AmberWaves/april04/Findings/USSeafood.htm. Accessed August 20, 2008.
[6] Håstein T. 2004. Animal welfare issues relating to aquaculture. In: Proceedings of the Global Conference on Animal Welfare: an OIE Initiative (Paris, France: World Organization for Animal Health, pp. 212-20).
[7] Food and Agriculture Organization of the United Nations. 2006. Nearly half of all fish eaten today farmed, not caught. FAO Newsroom. www.fao.org/newsroom/en/news/2006/1000383/index.html. Accessed August 20, 2008.
[8] Southgate P and Wall T. 2001. Welfare f farmed fish at slaughter. In Practice 23:277-84.
[9] Van de Vis H, Kestin S, Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20. o
[10] Kestin SC, van de Vis JW, and Robb DHF. 2002. Protocol for assessing brain function in fish and the effectiveness of methods used to stun and kill them. The Veterinary Record 150:302–07.
[11] Håstein T, Scarfe AD, and Lund VL. 2005. Science-based assessment of welfare: aquatic animals. In: Bayvel ACD, Rahman SA, and Gavinelli A (eds.), Animal Welfare: Global Issues, Trends and Challenges. Revue Scientifique et Technique de l'Office International des Epizooties 24(2):529-47.
[12] Håstein T. 2004. Animal welfare issues relating to aquaculture. In: Proceedings of the Global Conference on Animal Welfare: an OIE Initiative, (Paris, France: World Organization for Animal Health, pp. 212-20).
[13] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[14] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[15] Kestin SC, Wotton SB, and Gregory NG. 1991. Effect of slaughter by removal from water on visual evoked activity in the brain and reflex movement of rainbow trout (*Oncorhynchus mykiss*). The Veterinary Record 128:443-6.
[16] Erikson U, Hultmann L, and Steen JE. 2006. Live chilling of Atlantic salmon (*Salmo salar*) combined with mild carbon dioxide anaesthesia. I. Establishing a method for large-scale processing of farmed fish. Aquaculture 252:183-98.
[17] Lambooij E, van de Vis JW, Kloosterboer RJ, and Pieterse C. 2002. Welfare aspects of live chilling and freezing of farmed eel (*Anguilla anguilla* L.): neurological and behavioural assessment. Aquaculture 210:159-69.
[18] Robb DHF and Roth B. 2003. Brain activity of Atlantic salmon (*Salmo salar*) following electrical stunning using various field strengths and pulse durations. Aquaculture 216:363-9.
[19] Roth B, Slinde E, and Robb DHF. 2007. Percussive stunning of Atlantic salmon (*Salmo salar*) and the relation between force and stunning. Aquacultural Engineering 36:192-7.
[20]Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[21] Robb DHF, O'Callaghan M, Lines JA, and Kestin SC. 2002. Electrical stunning of rainbow trout (*Oncorhynchus mykiss*): factors that affect stun duration. Aquaculture 205:359-71.
[22] Caporale V, Alessandrini B, Dalla Villa P, and Del Papa S. 2005. Global perspectives on animal welfare: Europe. In: Bayvel ACD, Rahman SA, and Gavinelli A (eds.), Animal Welfare: Global Issues, Trends and Challenges. Revue Scientifique et Technique de l'Office International des Epizooties 24(2):567-77.
[23] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[24] Lambooij E, Kloosterboer RJ, Pieterse C, Gerritzen MA, and van de Vis JW. 2003. Stunning of farmed African catfish (*Clarias gariepinus*) using a captive needle pistol; assessment of welfare aspects. Aquaculture Research 34:1353-8.
[25] Kestin SC, Wotton SB, and Gregory NG. 1991. Effect of slaughter by removal from water on visual evoked activity in the brain and reflex movement of rainbow trout (*Oncorhynchus mykiss*). The Veterinary Record 128:443-6.

[26] Chandroo KP, Yue S, and Moccia RD. 2004. An evaluation of current perspectives on consciousness and pain in fishes. Fish and Fisheries 5:281-95.
[27] Huntingford FA, Adams C, Braithwaite VA, et al. 2006. Current issues in fish welfare. Journal of Fish Biology 68:332-72.
[28] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[29] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[30] Farm Animal Welfare Council. 2008.What is the Farm Animal Welfare Council? www.fawc.org.uk/. Accessed October 10, 2008.
[31] Farm Animal Welfare Council. 1996. Report on the Welfare of Farmed Fish. (Tolworth: FAWC). www.fawc.org.uk/reports/fish/fishrtoc.htm. Accessed October 10, 2008.
[32] Håstein T. 2004. Animal welfare issues relating to aquaculture. In: Proceedings of the Global Conference on Animal Welfare: an OIE Initiative (Paris, France: World Organization for Animal Health, pp. 219-31).
[33] European Food Safety Authority. 2004. Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals. The EFSA Journal 45:1-29. www.efsa.europa.eu:80/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_en.pdf?ssbinary=true. Accessed October 10, 2008.
[34] Office of Public Sector Information.1995. The Welfare of Animals. (Slaughter or Killing) Regulations. Statutory Instruments number 731 (London: HMSO). www.opsi.gov.uk/si/si1995/Uksi_19950731_en_1.htm. Accessed October 10, 2008.
[35] HSA.2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.: Humane Slaughter Association).
[36] Humane Slaughter Association. Fish slaughter. www.hsa.org.uk/Information/Slaughter/Fish%20slaughter.htm. Accessed October 10, 2008.
[37] Kestin SC, van de Vis JW, and Robb DHF. 2002. Protocol for assessing brain function in fish and the effectiveness of methods used to stun and kill them. The Veterinary Record 150:302-7.
[38] Kestin SC, van de Vis JW, and Robb DHF. 2002. Protocol for assessing brain function in fish and the effectiveness of methods used to stun and kill them. The Veterinary Record 150:302-7.
[39]Kestin SC, van de Vis JW, and Robb DHF. 2002. Protocol for assessing brain function in fish and the effectiveness of methods used to stun and kill them. The Veterinary Record 150:302-7.
[40] Van de Vis H, Kestin S, and Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[41] Lambooij E, van de Vis JW, Kloosterboer RJ, and Pieterse C. 2002. Evaluation of head-only and head-to-tail electrical stunning of farmed eels (*Anguilla anguilla* L.) for the development of a humane slaughter method. Aquaculture Research 33:323-31.
[42] Lambooij E, van de Vis JW, Kloosterboer RJ, and Pieterse C. 2002. Welfare aspects of live chilling and freezing of farmed eels (*Anguilla anguilla* L.): neurological and behavioural assessment. Aquaculture 210:159-69.
[43] Lambooij E, Kloosterboer RJ, Pieterse C, Gerritzen MA, and van de Vis JW. 2003. Stunning of farmed African catfish (*Clarias gariepinus*) using a captive needle pistol; assessment of welfare aspects. Aquaculture Research 34:1353-8.
[44] Kestin S, Wotton S, and Adams S. 1995. The effect of CO2, concussion or electrical stunning of rainbow trout (*Oncorhynchus mykiss*) on fish welfare. In: Svennevig N and Krogdahl Å (eds.), Quality in Aquaculture, Special Publication 23 (Gent, Belgium: European Aquaculture Society, pp. 380-1).
[45] Lambooij E, van de Vis JW, Kloosterboer RJ, and Pieterse C. 2002. Evaluation of head-only and head-to-tail electrical stunning of farmed eels (*Anguilla anguilla* L.) for the development of a humane slaughter method. Aquaculture Research 33:323-31.
[46] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.

[47] Håstein T, Scarfe AD, and Lund VL. 2005. Science-based assessment of welfare: aquatic animals. In: Bayvel ACD, Rahman SA, and Gavinelli A (eds.), Animal Welfare: Global Issues, Trends and Challenges. Revue Scientifique et Technique de l'Office International des Epizooties 24(2):529-47.
[48] Humane Slaughter Association. Fish slaughter. www.hsa.org.uk/Information/Slaughter/Fish%20slaughter.htm. Accessed October 10, 2008.
[49] Robb DHF and Kestin SC. 2002. Methods used to kill fish: field observations and literature reviewed. Animal Welfare 11:269-82.
[50] Robb DHF, O'Callaghan M, Lines JA, and Kestin SC. 2002. Electrical stunning of rainbow trout (*Oncorhynchus mykiss*): factors that affect stun duration. Aquaculture 205:359-71.
[51] Kestin SC, Wotton SB, and Gregory NG. 1991. Effect of slaughter by removal from water on visual evoked activity in the brain and reflex movement of rainbow trout (*Oncorhynchus mykiss*). The Veterinary Record 128:443-6.
[52] Robb DHF and Kestin SC. 2002. Methods used to kill fish: field observations and literature reviewed. Animal Welfare 11:269-82.
[53] Skjervold PO, Fjæra SO, Østby PB, and Einen Olai. 2001. Live-chilling and crowding stress before slaughter of Atlantic salmon (*Salmo salar*). Aquaculture 192:265-80.
[54] Roth B, Slinde E, and Robb DHF. 2006. Field evaluation of live chilling with CO_2 on stunning Atlantic salmon (*Salmo salar*) and the subsequent effect on quality. Aquaculture Research 37:799-804.
[55] Erikson U, Hultmann L, and Steen JE. 2006. Live chilling of Atlantic salmon (*Salmo salar*) combined with mild carbon dioxide anaesthesia. I. Establishing a method for large-scale processing of farmed fish. Aquaculture 252:183-98.
[56] Roth B, Slinde E, and Robb DHF.2006. Field evaluation of live chilling with CO_2 on stunning Atlantic salmon (*Salmo salar*) and the subsequent effect on quality. Aquaculture Research 37:799-804.
[57] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultureal Engineering 28:141-54.
[58] Close B, Banister K, Baumans V, et al. 1997. Recommendation for euthanasia of experimental animals: Part 2. Laboratory Animals 31:1-32.
[59] Roth B, Slinde E, and Robb DHF. 2006. Field evaluation of live chilling with CO_2 on stunning Atlantic salmon (*Salmo salar*) and the subsequent effect on quality. Aquaculture Research 37:799-804.
[60] Lambooij E, van de Vis JW, Kloosterboer RJ, and Pieterse C. 2002. Welfare aspects of live chilling and freezing of farmed eels (*Anguilla anguilla* L.): neurological and behavioural assessment. Aquaculture 210:159-69.
[61] Erikson U, Hultmann L, and Steen JE. 2006. Live chilling of Atlantic salmon (*Salmo salar*) combined with mild carbon dioxide anaesthesia. I. Establishing a method for large-scale processing of farmed fish. Aquaculture 252:183-98.
[62] Robb DHF and Kestin SC. 2002. Methods used to kill fish: field observations and literature reviewed. Animal Welfare 11:269-82.
[63] Skjervold PO, Fjæra SO, Østby PB, and Einen Olai. 2001. Live-chilling and crowding stress before slaughter of Atlantic salmon (*Salmo salar*). Aquaculture 192:265-80.
[64] Wedemeyer GA. 1997. Effects of rearing conditions on the health and physiological quality of fish in intensive culture. In: Iwama GW, Pickering AD, Sumpter JP, and Schreck CB (eds.), Fish Stress and Health in Aquaculture (Cambridge, England: Cambridge University Press, pp. 35-71).
[65] Barton BA and Peter RE. 1982. Plasma cortisol stress response in fingerling rainbow trout, *Salmo gairdneri* Richardson, to various transport conditions, anaesthesia, and cold shock. Journal of Fish Biology 20:39-51.
[66] Skjervold PO, Fjæra SO, Østby PB, and Einen Olai. 2001. Live-chilling and crowding stress before slaughter of Atlantic salmon (*Salmo salar*). Aquaculture 192:265-80.
[67] Skjervold PO, Fjæra SO, Østby PB, and Einen Olai. 2001. Live-chilling and crowding stress before slaughter of Atlantic salmon (*Salmo salar*). Aquaculture 192:265-80.
[68] Roth B, Slinde E, and Robb DHF. 2006. Field evaluation of live chilling with CO_2 on stunning Atlantic salmon (*Salmo salar*) and the subsequent effect on quality. Aquaculture Research 37:799-804.

[69] Lambooij E, van de Vis JW, Kloosterboer RJ, and Pieterse C. 2002. Welfare aspects of live chilling and freezing of farmed eels (*Anguilla anguilla* L.): neurological and behavioural assessment. Aquaculture 210:159-69.
[70] Robb DFH and Kestin SC. 2002. Methods used to kill fish: field observations and literature reviewed. Animal Welfare 11:269-282.
[71] Southgate P and Wall T. 2001. Welfare of farmed fish at slaughter. In Practice 23:277-84.
[72] Roth B, Moeller D, Veland JO, Imsland A, and Slinde E. 2002. The effect of stunning methods on rigor mortis and texture properties of Atlantic salmon (*Salmo salar*). Journal of Food Science 67:1462-66.
[73] Poli BM, Parisi G, Scappini F, Zampacavallo G. 2005. Fish welfare and quality as affected by pre-slaughter and slaughter management. Aquaculture International 13:29-49.
[74] Kestin S, Wotton S, and Adams.1995. The effect of CO_2 concussion or electrical stunning of rainbow trout (*Oncorhynchus mykiss*) on fish welfare. In: Svennevig N and Krogdahl Å (eds.), Quality in Aquaculture, Special Publication 23 (Gent, Belgium: European Aquaculture Society, pp. 380-1).
[75] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[76] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, p. 172. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 3, 2008.
[77] Conte FS. 2004. Stress and the welfare of cultured fish. Applied Animal Behaviour Science 86:205-23.
[78] Shephard KL. 1994. Functions for fish mucus. Reviews in Fish Biology and Fisheries 4:401-29.
[79] Erikson U, Hultmann L, and Steen JE. 2006. Live chilling of Atlantic salmon (*Salmo salar*) combined with mild carbon dioxide anaesthesia. I. Establishing a method for large-scale processing of farmed fish. Aquaculture 252:183-98.
[80] Ultsch GR and Gros G. 1979. Mucus as a diffusion barrier to oxygen: possible role in O_2 uptake at low pH in carp (*Cyprinus carpio*) gills. Comparative Biochemistry and Physiology 62A:685-9.
[81] Kestin S, Wotton S, and Adams S. 1995. The effect of CO_2 concussion or electrical stunning of rainbow trout (*Oncorhynchus mykiss*) on fish welfare. In: Svennevig N and Krogdahl Å (eds.), Quality in Aquaculture, Special Publication 23 (Gent, Belgium: European Aquaculture Society, pp. 380-1).
[82] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[83] HSA. 2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.:Humane Slaughter Association).
[84] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, p. 172. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 3, 2008.
[85] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, p 172. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 3, 2008.
[86] Van de Vis H, Kestin S, and Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[87] EFSA.2004. Report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, page 171. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed August 19, 2008.
[88] Wills CC, Zampacavallo G, Poli B-M, Proctor MRM, and Henehan GTM. 2006. Nitrogen stunning of rainbow trout. International Journal of Food Science and Technology 41:395-8.

[89] Roth B, Slinde E, and Robb DHF. 2006. Field evaluation of live chilling with CO_2 on stunning Atlantic salmon (*Salmo salar*) and the subsequent effect on quality. Aquaculture Research 37:799-804.
[90] HSA. 2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.: Humane Slaughter Association).
[91] Roth B, Slinde E, and Robb DHF. 2006. Field evaluation of live chilling with CO_2 on stunning Atlantic salmon (*Salmo salar*) and the subsequent effect on quality. Aquaculture Research 37:799-804.
[92] Erikson U, Hultmann L, and Steen JE. 2006. Live chilling of Atlantic salmon (*Salmo salar*) combined with mild carbon dioxide anaesthesia. I. Establishing a method for large-scale processing of farmed fish. Aquaculture 252:183-98.
[93] Robb DHF and Roth B. 2003. Brain activity of Atlantic salmon (*Salmo salar*) following electrical stunning using various field strengths and pulse durations. Aquaculture 216:363-69.
[94] Lambooij E, Kloosterboer RJ, Gerritzen MA, and van de Vis JW. 2006. Assessment of electrical stunning in fresh water of African Catfish (*Clarias gariepinus*) and chilling in ice water for loss of consciousness and sensibility. Aquaculture 254:388-95.
[95] Erikson U, Hultmann L, and Steen JE. 2006. Live chilling of Atlantic salmon (*Salmo salar*) combined with mild carbon dioxide anaesthesia. I. Establishing a method for large-scale processing of farmed fish. Aquaculture 252:183-98.
[96] Roth B, Slinde E, and Robb DHF. 2006. Field evaluation of live chilling with CO_2 on stunning Atlantic salmon (*Salmo salar*) and the subsequent effect on quality. Aquaculture Research 37:799-804.
[97] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[98] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, p 178. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008
[99] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[100] Lambooij E, Kloosterboer RJ, Gerritzen MA, and van de Vis JW. 2004. Head-only electrical stunning and bleeding of African catfish (*Clarias gariepus*): assessment of loss of consciousness. Animal Welfare 13:71-6.
[101] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, p 178.
www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008.
[102] Van de Vis H, Kestin S, Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[103] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[104] Kestin SC, van de Vis JW, and Robb DHF. 2002. Protocol for assessing brain function in fish and the effectiveness of methods used to stun and kill them. The Veterinary Record 150:302-07.
[105] Van de Vis H, Kestin S, Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[106] HSA. 2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.:Humane Slaughter Association).
[107] HSA. 2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.:Humane Slaughter Association).
[108] Håstein T, Scarfe AD, and Lund VL. 2005. Science-based assessment of welfare: aquatic animals. In: Bayvel ACD, Rahman SA, and Gavinelli A (eds.), Animal Welfare: Global Issues, Trends and Challenges. Revue Scientifique et Technique de l'Office International des Epizooties 24(2):529-47.

[109] Van de Vis H, Kestin S, Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[110] Roth B, Slinde E, and Robb DHF. 2007. Percussive stunning of Atlantic salmon (*Salmo salar*) and the relation between force and stunning. Aquacultural Engineering 36:192-97.
[111] HSA. 2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.:Humane Slaughter Association).
[112] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008..
[113] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008..
[114] Van de Vis H, Kestin S, Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[115] Roth B, Slinde E, and Robb DHF. 2007. Percussive stunning of Atlantic salmon (*Salmo salar*) and the relation between force and stunning. Aquacultural Engineering 36:192-97.
[116] Southgate P and Wall T. 2001. Welfare of farmed fish at slaughter. In Practice 23:277-84.
[117] Morzel M, Sohier D, and Van de Vis H. 2002. Evaluation of slaughtering methods for turbot with respect to animal welfare and flesh quality. Journal of the Science of Food and Agriculture 82:19–28.
[118] Lambooij E, Kloosterboer RJ, Pieterse C, Gerritzen MA, and van de Vis JW. 2003. Stunning of farmed African catfish (*Clarias gariepinus*) using a captive needle pistol; assessment of welfare aspects. Aquaculture Research 34:1353-58.
[119] Lambooij E, Kloosterboer RJ, Pieterse C, Gerritzen MA, and van de Vis JW. 2003. Stunning of farmed African catfish (*Clarias gariepinus*) using a captive needle pistol; assessment of welfare aspects. Aquaculture Research 34:1353-58.
[120] HSA. 2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.: Humane Slaughter Association).
[121] Robb DHF, O'Callaghan M, Lines JA, and Kestin SC. 2002. Electrical stunning of rainbow trout (*Oncorhynchus mykiss*): factors that affect stun duration. Aquaculture 205:359-71.
[122] Kestin S, Wotton S, and Adams. 1995. The effect of CO_2, concussion or electrical stunning of rainbow trout (*Oncorhynchus mykiss*) on fish welfare. In: Svennevig N and Krogdahl Å (eds.), Quality in Aquaculture, Special Publication 23 (Gent, Belgium: European Aquaculture Society, pp. 380-1).
[123] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[124] HSA. 2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.: Humane Slaughter Association).
[125] Robb DHF, O'Callaghan M, Lines JA and Kestin SC. 2002. Electrical stunning of rainbow trout (*Oncorhynchus mykiss*): factors that affect stun duration. Aquaculture 205:359-71.
[126] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008..
[127] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[128] Kestin S, Wotton S, and Adams. 1995. The effect of CO_2, concussion or electrical stunning of rainbow trout (*Oncorhynchus mykiss*) on fish welfare. In: Svennevig N and Krogdahl Å (eds.), Quality in Aquaculture, Special Publication 23 (Gent, Belgium: European Aquaculture Society, pp. 380-1).
[129] Robb DHF, Wotton SB, and van de Vis JW. 2002. Preslaughter electrical stunning of eels. Aquaculture Research 33:37-42.

[130] Robb DHF and Roth B. 2003. Brain activity of Atlantic salmon (*Salmo salar*) following electrical stunning using various field strengths and pulse durations. Aquaculture 216:363-69.
[131] Van de Vis H, Kestin S, Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[132] Lambooij E, Kloosterboer RJ, Gerritzen MA, and van de Vis JW. 2004. Head-only electrical stunning and bleeding of African catfish (*Clarias gariepinus*): assessment of loss of consciousness. Animal Welfare 13:71-76.
[133] Kestin S, Wotton S, and Adams. 1995. The effect of CO_2, concussion or electrical stunning of rainbow trout (*Oncorhynchus mykiss*) on fish welfare. In: Svennevig N and Krogdahl Å (eds.), Quality in Aquaculture, Special Publication 23 (Gent, Belgium: European Aquaculture Society, pp. 380-1).
[134] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[135] Poli BM, Parisi G, Scappini F, and Zampacavallo G. 2005. Fish welfare and quality as affected by pre-slaughter and slaughter management. Aquaculture International 13:29-49.
[136] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, pp. 167, 168.
www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008.
[137] Robb DHF and Roth B. 2003. Brain activity of Atlantic salmon (*Salmo salar*) following electrical stunning using various field strengths and pulse durations. Aquaculture 216:363-69.
[138] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, p. 167.
www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008.
[139] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, p. 165.
www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008.
[140] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[141] Lines J and Kestin S. 2004. Electrical stunning of fish: the relationship between the electric field strength and water conductivity. Aquaculture 241:219-34.
[142] Aqui-S New Zealand Ltd. 2004. Aqui-S Anaesthetic products. www.aqui-s.com/default.aspx?Page=1528. Accessed November 4, 2008.
[143] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods.
www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 4, 2008.
[144] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods.
http://www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 5, 2008.
[145] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[146] Håstein T, Scarfe AD, and Lund VL. 2005. Science-based assessment of welfare: aquatic animals. In: Bayvel ACD, Rahman SA, and Gavinelli A (eds.), Animal Welfare: Global Issues, Trends and Challenges. Revue Scientifique et Technique de l'Office International des Epizooties 24(2):529-47.
[147] Poli BM, Parisi G, Scappini F, and Zampacavallo G. 2005. Fish welfare and quality as affected by pre-slaughter and slaughter management. Aquaculture International 13:29-49.

[148] HSA. 2005. Humane harvesting of salmon and trout: Guidance notes No. 5. (Wheathamstead, U.K.:Humane Slaughter Association).
[149] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54
[150] Van de Vis H, Kestin S, Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[151] Håstein T, Scarfe AD, and Lund VL. 2005. Science-based assessment of welfare: aquatic animals. In: Bayvel ACD, Rahman SA, and Gavinelli A (eds.), Animal Welfare: Global Issues, Trends and Challenges. Revue Scientifique et Technique de l'Office International des Epizooties 24(2):529-47.
[152] Robb DHF, Wotton SB, McKinstry JL, Sørensen NK, and Kestin SC. 2000. Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. The Veterinary Record 147:298-303.
[153] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods, p. 212.
www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 5, 2008.
[154] Roth B, Slinde E, and Robb DHF. 2006. Field evaluation of live chilling with CO_2 on stunning Atlantic salmon (*Salmo salar*) and the subsequent effect on quality. Aquaculture Research 37:799-804.
[155] European Food Safety Authority. 2004. Scientific report of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods. www.efsa.europa.eu/cs/BlobServer/Scientific_Opinion/opinion_ahaw_02_ej45_stunning_report_v2_en1,1.pdf?ssbinary=true. Accessed November 5, 2008.
[156] Lines JA, Robb DH, Kestin SC, Crook SC, and Benson T. 2003. Electric stunning: a humane slaughter method for trout. Aquacultural Engineering 28:141-54.
[157] Roth B, Slinde E, and Robb DHF. 2007. Percussive stunning of Atlantic salmon (*Salmo salar*) and the relation between force and stunning. Aquacultural Engineering 36:192-97.
[158] Stevenson P. 2007. Closed waters: the welfare of farmed Atlantic salmon, rainbow trout, Atlantic cod & Atlantic halibut (Surrey, U.K.:CIWF and WSPA).
[159] Van de Vis H, Kestin S, Robb D, et al. 2003. Is humane slaughter of fish possible for industry? Aquaculture Research 34:211-20.
[160] Håstein T, Scarfe AD, and Lund VL. 2005. In: Bayvel ACD, Rahman SA, and Gavinelli A (eds.), Science-based assessment of welfare: aquatic animals. Animal Welfare: Global Issues, Trends and Challenges. Revue Scientifique et Technique de l'Office International des Epizooties 24(2):529-47.
[161] Southgate P and Wall T. 2001. Welfare of farmed fish at slaughter. In Practice 23:277-84.
[162] Kestin SC, van de Vis JW, and Robb DHF. 2002. Protocol for assessing brain function in fish and the effectiveness of methods used to stun and kill them. The Veterinary Record 150:302-7.