

## **Welfare of farmed fish**

Review of the relevant scientific evidence on the welfare aspects of farmed fish during transport, the stunning and killing of farmed fish for human consumption and the killing of farmed fish for disease control purposes

***A report for the Aquatic Animal Commission of the World Organisation for Animal Health***

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## Executive summary

The primary objectives of this review are to consider how the five freedoms and other paradigms of animal welfare can be applied to fish welfare, describe the major types of transport used in aquaculture, methods used to stun and kill fish and associated handling. Welfare hazards associated with these processes were identified. The scientific literature on fish neurobiology, sentience and specifically their capacity to experience pain, fear, stress is reviewed.

Animal welfare encompasses the physical and mental wellbeing of animals, including positive experiences and emotions. Aquaculture practices frequently expose fish to stressors such as handling, vaccinations, crowding, grading, starvation, treatments, loading, and transportation, which do not exist for wild fish. Hazards (potential source of harm or damage) arising from transport, handling, stunning, and killing fish are described, and the outcomes of the hazards (e.g. physical trauma) are discussed.

The five freedoms paradigm date back to 1965 and have been influential in animal welfare thinking and management. The scope of this review is transport, handling, stunning and killing of fish. These activities may give rise to hazards which cause negative welfare states (and unpleasant or aversive experiences), which makes the concept of 'freedoms' less useful as consideration of positive affective experiences are not relevant. The reformulation of the five freedoms as domains with provisions integrates the overall welfare state of animals, emphasizing the importance of subjective experiences. The five domains model offers a useful structure to assess and grade hazard that cause negative welfare, i.e. 'suffering'. The European Food Standards Authority (EFSA) have also published a method to assess the severity of hazards which was used in their reviews of welfare aspects of killing and stunning of major aquaculture fish species.

Fish are handled during loading, unloading before and after transport and as part of the process for stunning and killing. The review describes various handling processes that give rise to hazards, such as crowding, removal from water, poor water quality, pumping through pipes, brailing, and draining ponds. These hazards may result in hypoxia, stress, and physical trauma. The key hazards associated with transport are associated with poor water quality which may cause stress, hypoxia and organ damage. Eight methods of stunning and killing fish for human consumption are reviewed, including manual and automated percussive stunning, electrical stunning, asphyxia, carbon dioxide narcosis, live chilling, gill slitting without pre-stunning, and physical brain destruction. Some of the methods can be considered as hazards, for example, gill-slitting without stunning, or live chilling, and thus is experienced by every fish. Other hazards arise when the process is not carried out effectively, e.g. mis-stunning. It is important to assess the likelihood of the hazard occurring for each method. The Humane Slaughter Association (HAS) considers only percussive and electrical stunning as acceptable methods.

The hazards associated with fish handling, transport, stunning and killing are relevant if it can be concluded that fish are sentient and capable of experiencing pain. The review of scientific literature on fish neurobiology, sentience, and pain indicates that fish have functional peripheral nociceptors and central processing of nociceptive input. The concept of animal sentience has evolved, and contemporary thinking accepts that perception of external stimuli is intrinsically linked to conscious experience. Studies demonstrate that fish are capable of learning, memory, spatial cognition, social cognition, problem-solving, and experiencing pain, fear, and stress. The accumulation of evidence from experimentation, behavioural and anatomical studies has resulted in a scientific consensus is that fish are sentient and capable of experiencing pain, stress, and fear. This position is reflected in national legislation protecting the welfare of fish used for experimentation and aquaculture. A small minority of scientists continue to argue that insufficient evidence exists, and significant doubt remains around fish sentience and their capacity to suffer. However, the question about fish sentience and the capacity for suffering is largely considered as settled and the debate has shifted to aquatic invertebrates, with increasing recognition of their welfare needs.

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## Table of Contents

Executive summary .....	i
Table of Contents .....	ii
List of Tables .....	iii
List of Figures .....	iii
List of Appendices .....	iii
Acronyms.....	iv
1. Objectives.....	1
2. Introduction.....	2
3. Five freedoms and other paradigms for animal welfare .....	3
4. Live fish transport, handling, stunning and killing .....	5
4.1. Approach.....	5
4.2. Live fish transport and handling.....	5
4.2.1. Pre-transport starvation .....	7
4.2.2. Fish handling.....	7
4.2.3. Welfare hazards associated with fish handling .....	8
4.2.4. Factors influencing welfare during transport.....	9
4.2.5. Environmental welfare hazards associated with transport.....	9
4.2.6. Closed systems.....	10
4.2.7. Open systems .....	10
4.2.8. Transport method.....	11
4.2.9. Mitigations .....	12
4.2.10. Welfare hazards associated with methods of transport .....	12
4.3. Stunning and killing methods of fish for human consumption.....	13
4.3.1. Introduction .....	13
4.3.2. Methods of stunning and killing.....	13
4.3.3. Physical brain destruction .....	15
4.3.4. Application of methods by species.....	15
4.3.5. Welfare hazards associated with stunning and killing.....	16
4.4. Stunning and killing methods for disease control purposes.....	17
4.4.1. Introduction .....	17
4.4.2. Methods of stunning and killing for disease control .....	18
5. Fish neurobiology and sentience.....	19
5.1. Literature review .....	19
5.1.1. Method .....	19
5.1.2. Philosophy and ethics of animal sentience and suffering .....	20
5.1.3. Sensory perception .....	20
5.1.4. Neurobiology .....	21
5.1.5. Sentience .....	22
5.1.6. Pain.....	23
5.1.7. Fear and stress .....	25

5.2.	Main areas of contention.....	26
5.3.	Assessment of welfare hazards and impacts.....	27
6.	Discussion .....	28
7.	Conclusion.....	29
8.	References .....	30

### List of Tables

Table 1	The original Five Freedoms and Five provisions for farm animal welfare (Webster, 1994) ....	3
Table 2	Fish welfare reviews published by the European Food Safety Authority (EFSA) (EFSA, 2009d, e, f, g, b, c) .....	6
Table 3	Welfare hazards associated with fish handling .....	8
Table 4	Welfare hazards by impacts associated with transport .....	12
Table 5	Welfare impacts associated with transport method .....	13
Table 6	Methods of stunning and killing .....	14
Table 7	Welfare hazards associated with stunning and killing method .....	16
Table 8	Welfare hazards associated with pharmacological methods of killing.....	19
Table 9	Criteria to determine whether fish (bony) experience pain.....	24
Table 10	Summary of potential welfare hazards by activity .....	27
Table 11	Summary of negative affective states by activity.....	28

### List of Figures

Figure 1.	The Five Domains model (from Mellor and Reid, 1994).....	4
Figure 2.	Stages in the transport of live fish .....	6
Figure 3.	Associations between environmental factors associated with transport and welfare impacts .....	10

### List of Appendices

[Appendix 1.](#) Tranche 1 proposal

[Appendix 2.](#) Review articles: Google Scholar and Web of Science searches

[Appendix 3.](#) Additional review papers identified from publications listed in Appendix 2

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## Acronyms

BTA	British Trout Association
CA	Competent Authority
DO	dissolved oxygen
EFSA	European Food standards Authority
EU	European Union
FAWC	Farm Animal Welfare Council
GS	Google Scholar
HSA	Humane slaughter association
RSPCA	Royal Society for the Protection of Cruelty against Animals
SSPO	Scottish Salmon Producers Organisation
WoS	Web of Science
WOAH	World Organisation for Animal Health

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## 1. Objectives

- Consideration of how the five freedoms (FAWC, 2009) of animal welfare can be applied to fish welfare.
- Description of the main types of transport currently used in major aquaculture production systems.
- Description of the handling and methods used to stun and kill fish
- Identification of welfare 'hazards' associated with transport, handling, stunning and killing of fish.
- Review of the scientific literature on the neurobiology and the special sense organs in fish, and their capacity to experience pain, fear, stress and expressions of sentience

### Scope:

Emergency killing for disease control or other reasons is included in the report. However, humane killing of individual fish, in the course of farming operations (i.e. sorting, grading, or background morbidity) is out of scope. Methods of killing wild fish populations is also out of scope. This review will consider the major farmed finfish species groups: salmonids, cyprinids, and tilapines.

A full description of agreed work is provided in [Appendix 1](#).

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## 2. Introduction

“The question is not, Can they *reason*? nor, Can they *talk*? but, Can they *suffer*?” (Bentham, 1789)

Animal welfare refers to the physical and mental wellbeing of an animal, encompassing all aspects of their quality of life, particularly when under human care or captivity. Our understanding of animal welfare goes beyond the absence of suffering to include positive experiences and emotions. An animal's welfare includes its physical, physiological and the mental state and is determined by both its genotype and the impact of the physical environment (Balasch and Tort, 2019). Broom (1986) defined welfare of an animal as ‘...its state as regards its attempt to cope with its environment’. Thus, failure to cope results in adverse physical (e.g. trauma) or mental (e.g. stress) outcomes, and poor welfare.

A report by the European Food Standards Authority (EFSA, 2009a) concluded that the concept of animal welfare is the same for all animals, i.e. mammals, birds and fish. However, fish welfare of fish has been less studied than the welfare of mammals or birds, and in most countries standards and guidelines to protect fish welfare has lagged behind those for other vertebrate species. The different treatment of fish has many explanations, but mainly because it was widely understood that fish could not perceive pain as nociceptors, receptors that preferentially detect potentially painful stimuli, had not been identified (Rose, 2002). However, in 2002 nociceptors were detected for the first time in the rainbow trout (*Oncorhynchus mykiss*) using electrophysiological and neuroanatomical approaches (Sneddon, 2002; Sneddon, 2003). The scientific consensus shifted and the EFSA (2009a) concluded that finfish are sentient and self-aware organisms that can feel pain and distress, experience emotions and have long-term and short-term memory. Nevertheless, the sentience of fish remains a subject of dispute (Browman et al., 2019; Diggles et al., 2024)

Aquaculture practices frequently expose fish to a range of potential stressors (e.g. handling, vaccinations, crowding, grading, starvation, treatments, loading, and transportation), which do not exist for wild fish. All farmed fish will be transported at least once and may be transported at a number of points during the production cycle as larvae, juveniles or as adults. Transport of live fish involves routines that may contribute to a significant increase in stress and the impairment of fish welfare. During harvesting, farmed fish are subjected to a unique period of frequent and intense handling operations. These practices potentially expose fish to hazards which negatively impact their welfare. This review investigates hazards which may arise from transport, handling, stunning and killing fish (for human consumption or disease control purposes). The scientific evidence that may allow for the impact of these hazards on fish welfare to be assessed is reviewed.

This review is in three main sections. The first section covers: i) the application of the ‘five freedoms’ and other paradigms for animal welfare to farmed fish. The second section reviews ii) types of live fish transport and handling, iii) methods fish killing and stunning and iv) potential welfare hazard arising from transport, handling, stunning and killing. The third section reviews the scientific basis for fish sentience, and their capacity to experience pain, free and stress.

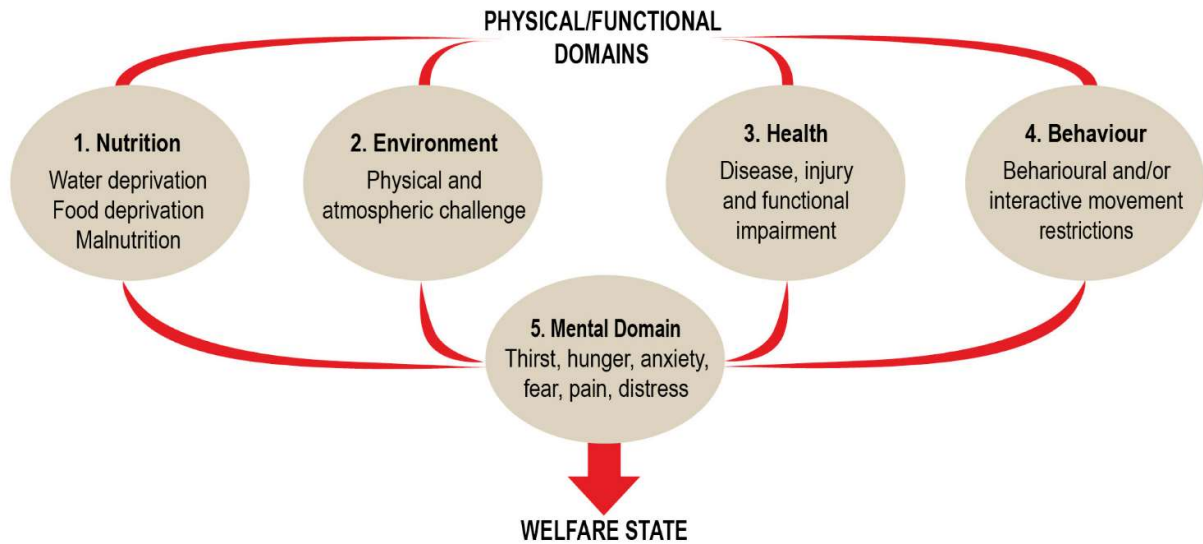
### 3. Five freedoms and other paradigms for animal welfare

The evolution of welfare standards for farmed animals starts with the rise of intensive farming methods in the late 1950s. Ruth Harrison's book 'Animal Machines' (published in 1964) described animal welfare concerns associated with intensive livestock farming. The public response led the British Government to appoint a committee to examine farm animal welfare, which resulted in the Brambell report (Brambell, 1965). The scope of the report covered major and minor farm species such as ducks and rabbits, but not fish. Brambell (1965) is credited as the originator of the five freedoms; the report stated that animals should have the freedom "to stand up, lie down, turn around, groom themselves and stretch their limbs". The UK's Farm Animal Welfare Council (FAWC) in a 1979 press release (FAWC, 1979) elaborated the five freedoms (FAWC had been established by the UK Government in the same year). Webster (1994) developed a more comprehensive set of freedoms (see Table 1), which were codified by FAWC (FAWC, 2009). The five freedoms have been profoundly influential on animal welfare thinking and management and are established as the basis for animal welfare legislation and standards across the world. Their alignment to provisions has provided practical guidance to improve animal welfare.

**Table 1. The original Five Freedoms and Five provisions for farm animal welfare (Webster, 1994)**

Freedoms	Provisions
1. Freedom from thirst, hunger and malnutrition	By providing ready access to fresh water and a diet to maintain full health and vigour
2. Freedom from discomfort and exposure	By providing an appropriate environment including shelter and a comfortable resting area
3. Freedom from pain, injury, and disease	By prevention or rapid diagnosis and treatment
4. Freedom from fear and distress	By ensuring conditions and treatment which avoid mental suffering
5. Freedom to express normal behaviour	By providing sufficient space, proper facilities and company of the animal's own kind

In parallel with the publication and evolution of the five freedoms paradigm, a five domains model for animal welfare assessment was first formulated in 1994 by Mellor and Reid (1994). Originally its specific purpose was to prospectively and retrospectively assess and grade the negative impacts of research, teaching and testing procedures on sentient animals. It has been applied in a regulatory context by the New Zealand authorities for a wide range of species including fish (Mellor et al., 2020). The five domains are: i) nutrition, ii) environment, iii) health, iv) behaviour and v) mental state. Domains i), ii) and iii) considered the internal imbalances or disturbances of nutritional, environmental and health origin. The fourth domain focused on external restrictive confinement or restraint, or otherwise unusual space availability and the negative impacts of the presence or absence of other animals (including humans) (Mellor and Reid, 1994). The model requires the collation of the objective evidence from consideration of the first four domains, the subjective, emotional or affective experiences, inferred to be associated with these disturbances or restrictions, which were then assigned to the fifth domain. The fifth domain integrates the overall welfare state of the animal, understood in terms of what they were likely to experience subjectively (Figure 1).



**Figure 1. The Five Domains model (from Mellor and Reid, 1994)**

The model is premised on the understanding that physiological mechanisms are the foundation of affective experiences. The inclusion of the fifth domain (mental state) emphasises that what matter in welfare terms is the subjective experiences of the animal. The five domains model has been updated through the publication of papers that have incorporated developments in animal welfare thinking (see Mellor, 2020 for most recent revisions).

Mellor (2016) highlighted limitations of the five freedoms. The term freedom was originally intended to mean 'as free as possible' from the experiences of states described by the 'freedoms'. However, some workers in the field and activists have taken the word 'freedom' literally and regarded freedoms as completely achievable or rights (Mellor, 2016). Complete freedom is both biologically inaccurate and misleading, for example, animals must experience hunger to elicit feeding. Secondly, the emphasis on 'negatives' has become to be seen as a limitation of the five freedoms (Mellor, 2016). Mellor (2016) notes that the five freedoms paradigm did not 'differentiate between the physical/functional (malnutrition, exposure, disease and injury) and affective (thirst, hunger, discomfort, pain, fear and distress) elements of animal welfare'. This may hinder the use of the model to identify and grade different types of negative welfare impact, because 'the meaning of the notion of "degrees of impaired freedom" was inherently obscure, and therefore lacked utility'. To address these issues, Mellor (2016) uses the five domains model to reformulate the five freedoms paradigm as five provisions with associated animal welfare aims, to recognise that positive experiences or states should be promoted. The five provisions are: i) good nutrition, ii) good environment, iii) good health, iv) appropriate behaviour, and v) positive mental experiences.

The scope of this review is transport, handling, stunning and killing of fish. These activities may give rise to hazards which cause negative welfare states (and unpleasant or aversive experiences). Consideration of positive affective experiences are not relevant. The five domains model offers a useful structure to assess and grade activities that may cause negative welfare, i.e. 'suffering'. It has been recognised over recent years that generic terminology can oversimplify the assessment and regulation of animal welfare (Mellor et al., 2020). Consequently, two major categories of negative affects have been described. The first category, survival-critical negative affects, refers to experiences generated by sensory inputs that register imbalances or disruptions in the internal physical/functional state of animals. Unpleasant experiences that cannot be effectively relieved through behavioural and physiological responses may have a greater detrimental impact on the welfare state than acute but short-lived experiences. The second category, situation-related negative affects, refers to experiences generated by brain processing of sensory inputs that mainly originate from outside the body and reflect the animal's perception of its external circumstances. Affects include stress, panic, and fear.

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A five-tier scale (A to E) has been proposed (Mellor et al., 2020) to grade negative welfare impacts (i.e. hazards) according to their i) presence, ii) intensity and iii) duration. Grades A (none) and B (low) represent no and tolerably low-level impacts respectively, grade E (very severe) represents very severe negative impacts related to experienced affects variously manifesting at high to very-high intensities and/or for long to very-long durations. Grades C (mild to moderate) and D (moderate to severe) represent intermediate-level impacts related to their intensities or durations. These grades, therefore, equate to different degrees of welfare compromise, ranging from none to very severe (Mellor et al., 2020).

The five domains model has been applied to fish transport (Yang, 2024). The author concluded that transport of live fish could impact on all the Five Domains Model (Mellor et al., 2020): domain 1 (Nutrition), food deprivation: fasting fish at least 24 hours prior to transport to reduce the excretion of faeces and ammonia in water, Domain 2 (Environment), physical and environmental challenges: fish are confined in smaller tanks at high density, posing a risk of hypoxia and poor water quality, Domain 3 (Health), disease, injury, and functional impairment: handling, physical disturbance, high density in transport tanks, and poor water quality during transport may cause body injury to fish and increase the possibility of post-transport infection, Domain 4 (Behavioural Interaction), behavioural or movement restriction: confinement of fish in a transport tank may restrict their behavioural expression or increase aggression between conspecifics, leading to injury or mortality, Domain 5 (Mental Domain), the experience of anxiety, fear, and pain: there is the potential to impact fish well-being during transport, due to water deterioration, inappropriate stocking density, confinement, increased aggression, tank collision, and vehicle vibration, which can cause discomfort. In conclusion, live transport of fish affects all aspects of the Five Domains Model, impacting their nutrition, environment, health, behaviour, and mental well-being. The five domains model has been applied to the auditing of slaughter plants (Grandin, 2022) but not to killing of fish.

Whilst the five freedoms model has mainly been applied to the welfare of mammals and birds, it is a suitable paradigm for fish welfare. However, the five domains model and associated provisions provide a more appropriate basis for assessing welfare hazards than the concept of 'freedoms'.

#### **4. Live fish transport, handling, stunning and killing**

##### **4.1. Approach**

The most important types of transport currently used in aquaculture will be described for the major production system and species. The handling and methods used to stun and kill fish vary considerably with species and production system. The most commonly used methods are described. The killing of fish for disease control purposes usually takes place on farm. Methods used solely for disease control purposes (i.e. and not employed to kill fish for consumption) are described in 0 .

Reviews undertaken by EFSA (see Table 2) were a primary source for descriptions of methods for stunning and killing. Other references were identified from internet searches. In this review a hazard is defined as a potential source of harm or damage. The process whereby hazards may result in a negatively affective state (e.g. pain, stress and fear) are described. Hazards arising from handling are considered in the section of methods of transport

##### **4.2. Live fish transport and handling**

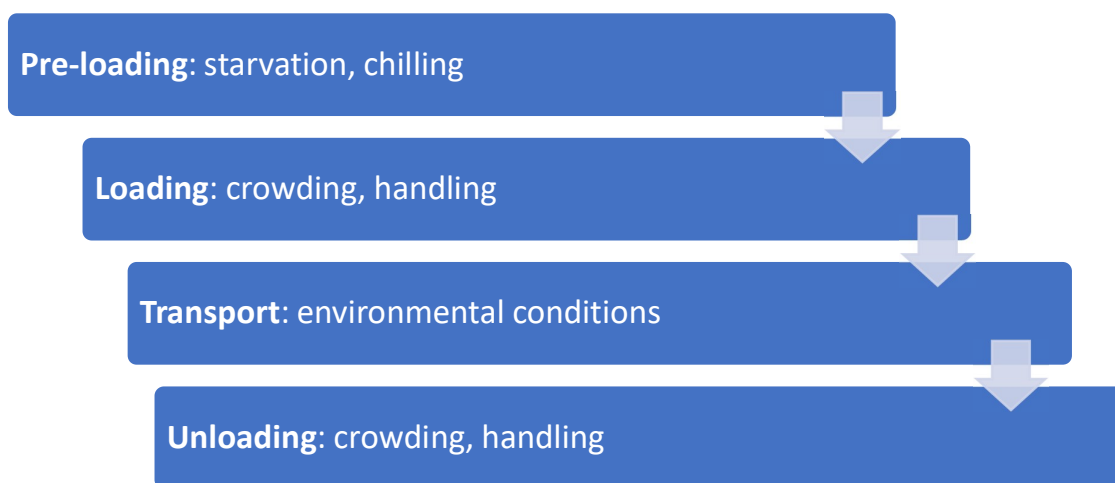
The transport of fish farmed for food is a common practice and takes place under a variety of circumstances. Within a farm fish may be transferred between ponds after grading. In many production systems broodstock farms specialise in producing juveniles which are sold to on growing farms. In salmonid systems fish are reared in freshwater and then, at smoltification, transported to marine sites. At harvest fish are often transported live to be killed at a processing plant, or for sale at a market.

Transporting live fish is often a multiple-phase operation (see Figure 2). Physical damage, suboptimal environmental conditions and stress may occur at many points during the operation from the initial preparation of the fish, handling and loading and conditions experienced during transport and finally unloading (Southgate, 2008).

There are two basic transport systems for live fish: closed and open systems. The closed system is a sealed container in which the fish's physiological needs are met for the expected duration of travel. At its simplest, this system is a sealed plastic bag partly filled with water and pressurised oxygen. The open system consists of water-filled containers, and the requirements for survival (e.g. oxygen) are met by externally. The simplest open system is small tank with an aerator stone.

**Table 2. Fish welfare reviews published by the European Food Safety Authority (EFSA) (EFSA, 2009d, e, f, g, b, c)**

	Title
1	Scientific Opinion of the Panel on Animal Health and Welfare on a request from the European Commission on welfare aspect of the main systems of stunning and killing of farmed <b>Atlantic salmon</b> . The EFSA Journal (2009) 1012, 1-77
2	Scientific Opinion of the Panel on Animal Health and Welfare on a request from the European Commission on Species-specific welfare aspects of the main systems of stunning and killing of farmed <b>carp</b> . The EFSA Journal (2009) 1013, 1-37
3	Scientific Opinion of the Panel on Animal Health and Welfare on a request from the European Commission on Species-specific welfare aspects of the main systems of stunning and killing of farmed <b>rainbow trout</b> . The EFSA Journal (2009) 1013, 1-55
4	Scientific Opinion of the Panel on Animal Health and Welfare on a request from the European Commission on welfare aspect of the main systems of stunning and killing of farmed <b>seabass and seabream</b> . The EFSA Journal (2009) 1010, 1-52
5	Scientific Opinion of the Panel on Animal Health and Welfare on a request from the European Commission on the species-specific welfare aspects of the main systems of stunning and killing of farmed <b>tuna</b> . The EFSA Journal (2009) 1072, 1-53
6	Scientific Opinion of the Panel on Animal Health and Welfare on a request from the European Commission on welfare aspect of the main systems of stunning and killing of farmed <b>turbot</b> . The EFSA Journal (2009) 1073, 1-34.



**Figure 2. Stages in the transport of live fish**

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#### 4.2.1. Pre-transport starvation

In many species withdrawal of food for some days prior to transport (or slaughter) is a common practice. A period of starvation empties the fish's gut and slows metabolism, reducing oxygen demand and waste production during transport. Feed withdrawal before transport improves the water quality during the transport, by reducing the accumulation of potential toxic metabolites (e.g. ammonia, carbon dioxide). The lower metabolic rate reduces activity and, therefore, may also reduce stress caused by handling. This practice is also thought to improve flesh quality and food hygiene (as post slaughter contamination is reduced). Farmed fish are used to receiving feed at regular and short intervals, and prolonged periods without food are likely to negatively impact their welfare. Excessive food deprivation can result in depletion of immune status, body reserves and loss of body condition, which are associated with poor welfare.

#### 4.2.2. Fish handling

##### 4.2.2.1. Overview

Handling fish inevitably involves disturbance (e.g. from netting, noise or other unexpected stimuli). Fish are likely to perceive handling as a threat and exhibit an emergency response consistent with fear. The response usually involves increases in stress levels which will have an adverse effect on the welfare of the fish (and the flesh quality).

When being loaded into transport containers, fish usually exert a large amount of muscular activity which results in lactic acid build up in the muscles and blood as the blood supply cannot provide sufficient oxygen. Lactic acid results in a drop in blood pH which reduces oxygen utilization. The level of activity on loading and recovery varies between species but information on individual species is lacking. As a high level of oxygen is consumed at the beginning of the journey, additional oxygen, as much as twice the flow normally required, should be provided during loading and the first hour of hauling (Piper et al., 1982).

##### 4.2.2.2. Crowding

Removal of fish from tanks, cages or ponds usually requires 'crowding', the process of using nets or barriers to reduce the volume available to the fish. Crowding requires careful management to reduce stress and potentially physical trauma. Crowding can result in decreased DO levels due to a rapid rise in stocking density and increased muscular activity. Wall (2001) considered that crowding is one of the prime causes of poor welfare during harvest of Atlantic salmon (*Salmon salar*).

##### 4.2.2.3. Pumps and pipes

Fish pumping is achieved using centrifugal or vacuum pumping systems. The system is widely used for Atlantic salmon. From a welfare perspective a key advantage of using pumps or pipes to handle fish prior to slaughter is that the fish remain submerged in water. However, welfare hazards may arise from poorly designed or maintained equipment, or if the equipment is inexpertly operated. A low risk exists of fish being trapped or injured by the moving parts as they pass directly through the pumps. Pumping may also be achieved using airlift or venturi systems where the fish are not exposed to any moving parts. Collisions with sharp corners or interior features in the pipe through which the fish are pumped risks injury (usually due to poor design, manufacture or maintenance). During long pumped transits or if pumping is delayed, hazards arise from poor water quality or overcrowding, particularly during stoppages or if the pipe becomes blocked. A risk exists that fish get stuck in the vacuum pressure valve leading to injury and potentially death. Single chamber vacuum pumps are subject to uneven and turbulent water flow in pipes. Struggling against this turbulence quickly exhausts the fish and following a pumped transit to the slaughter plant, most salmon are too exhausted to swim properly (EFSA 2009).

#### 4.2.2.4. Brailing (wet and dry)

Brailing in fish harvesting refers to using a net, often with a crane, to lift fish from a tank or enclosure. Brails can contain from a few to several hundred kilograms of fish. The net is opened at one end to allow the fish and water to exit through a grid, which removes the water (dry brailing), into a holding tank. Dry brailing is mainly used to handle fish before stunning and slaughter. Removing fish from the water alive and conscious, inevitably resulting in stress, which increases with the time out of water. Risks to the fish from dry brailing include bruising, crushing, puncture and abrasion injuries from contact with other fish, contact with the net and contact through the net with other hard surfaces. In wet brailing where the fish and water are lifted together, fish are largely protected against these hazards. Exit from the brail may lead to tissue damage from collisions with other fish or hard surfaces (including water if dropped from a height).

#### 4.2.2.5. Draining ponds

Draining a pond to harvest fish involves using a pump or siphon to lower the water level, allowing fish to be collected by hand or with a net. This method is effective for collecting a large number of fish and is used in freshwater pond production of cyprinids or tilapia. Draining ponds presents significant welfare hazards due to crowding (see section 0), potential injuries, stress, hypoxia and potentially asphyxiation (due to low DO).

#### 4.2.2.6. Variation in handling between production systems

In large-scale salmonid aquaculture, automated systems of fish handling using pumps have been widely adopted. The majority of tilapia and cyprinid production takes place in small-scale pond production with limited equipment. In most systems carp and tilapia will be harvested (e.g. for slaughter or grading) using crowding, netting and pond drainage.

#### 4.2.3. Welfare hazards associated with fish handling

Welfare hazards associated with fish handling and their impacts are summarised in Table 3. Handling hazards arise when fish are loaded for transport and unloaded at their destination (e.g. processing plants). Handling inevitably involves crowding, netting and unavoidable disturbance which will cause a degree of stress. Poorly managed handling results in more severe impacts, notably, hypoxia and physical trauma, which in extreme circumstances may result in death.

**Table 3. Welfare hazards associated with fish handling**

Welfare hazard	Welfare impact				
	Stress	Hypoxia (stress)	Physical trauma (pain)	Exhaustion (stress)	Hunger (stress)
Pre-transport starvation	✓				✓
Crowding	✓	✓	✓		
Removal from water	✓	✓			
Pumping through pipes	✓	✓	✓	✓	
Dry brailing	✓		✓		
Wet brailing			✓		
Pond drainage	✓	✓	✓		

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#### **4.2.4. Factors influencing welfare during transport**

The physical environment, notably water quality, will largely determine the welfare of fish during transport. Water quality will be determined by the density of fish and the duration of transport. Ideally the transport water should be tested before dispatch.

##### **4.2.4.1. Water quality: carbon dioxide and ammonia**

Ammonia and CO<sub>2</sub> levels are functions water pH. Over time the CO<sub>2</sub> generated through fish respiration lowers pH (increases acidity). Elevated CO<sub>2</sub> reduces the fish's blood capacity for carrying oxygen. Optimal pH is between 7 and 8. The build of CO<sub>2</sub> is often a limiting factor in transport. Aeration of the water reduces the level of CO<sub>2</sub> if ventilation is adequate. Critical levels of CO<sub>2</sub> vary between species (and are reviewed by Berka, 1986). Cyprinids tolerate higher levels of CO<sub>2</sub> than salmonids (100 compared to 60-70 ml/litre).

The fish's protein metabolism and bacterial action on fish waste generates ammonia (NH<sub>3</sub>), and thus the level increases in transport water over time. NH<sub>3</sub> is toxic to fish and can cause damage to gills and internal organs. Decreasing the fish's metabolic rate by lowering the water temperature, and thus lessening fish activity, reduces the production of NH<sub>3</sub>. The production of NH<sub>3</sub> by bacterial action can be decreased by shipping fish after food has been withheld long enough to void the intestinal tract. The toxicity of NH<sub>3</sub> is affected by water temperature and DO levels.

##### **4.2.4.2. Water quality: dissolved oxygen (DO)**

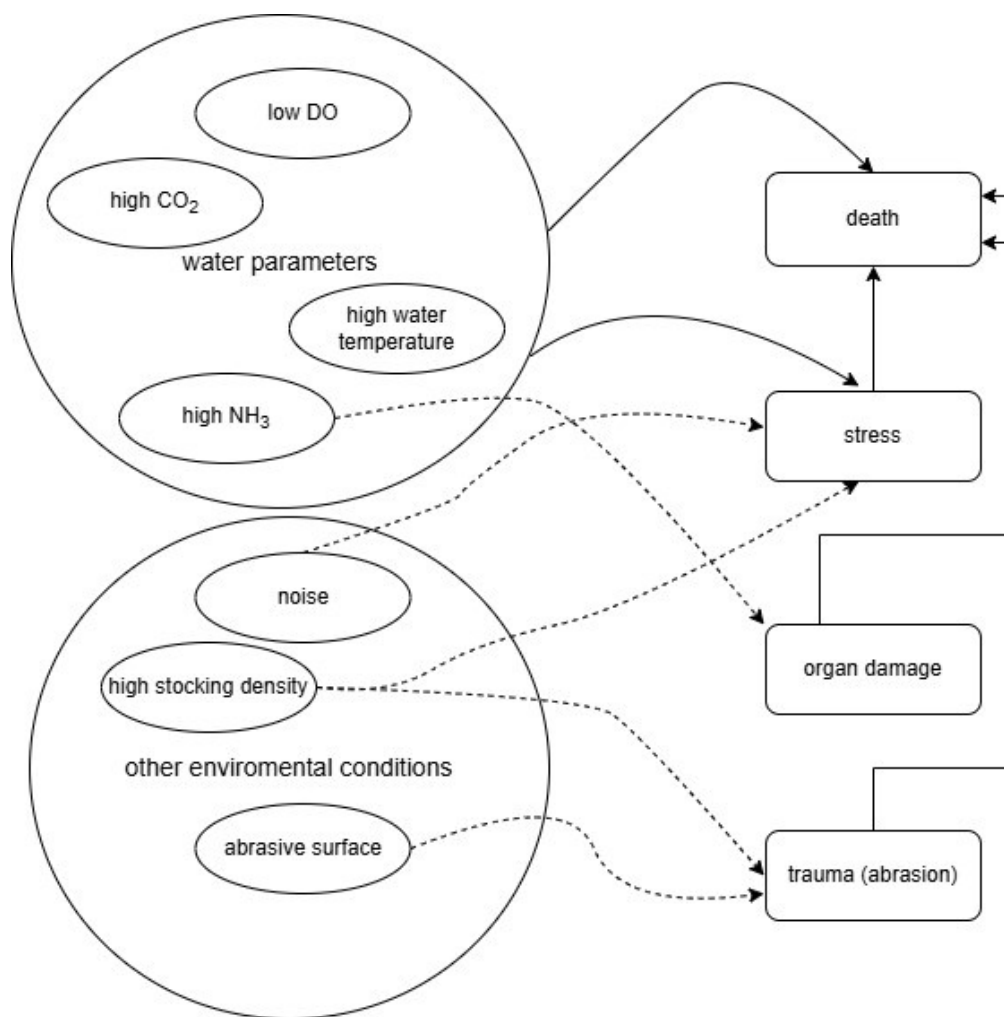
Requirements for DO vary considerably between species. For example, cyprinids tolerate considerably lower levels of DO without showing signs of distress compared with salmonid species. A high DO level has few welfare implications as fish regulate the level of oxygen absorbed. Oxygen deficit may occur if the density of fish is too high or the duration of transport is too long for the available oxygen. Fish mortality during transport will deplete DO levels as bacterial growth on the dead fish uses oxygen.

##### **4.2.4.3. Temperature control**

Optimal water temperature varies between species. Salmonids should be transported at between 6-8 °C, whilst warm water fish such as tilapines and cyprinids at 10-12 °C (Berka, 1982). Regulation of water temperature during transport impacts other water quality parameters. Low water temperature will decrease fish metabolism and keep pH high. Warmer water holds less DO than colder water.

#### **4.2.5. Environmental welfare hazards associated with transport**

The relationships between environmental conditions experienced by fish during transport to negative welfare outcomes are illustrated in Figure 3. Stress refers to both the fish's mental state and metabolic stress (due to osmoregulatory imbalance and acidosis). Some degree of mental stress will inevitably arise during a well-managed transport due to high stocking density, noise and unusual disturbance. During poorly managed transport additional welfare hazards arise due to poor water quality and physical trauma resulting, for example, from collisions between fish and with the surface of the transport container. The consequences of these hazards will vary from mild to severe, potentially resulting in death.



**Figure 3. Associations between environmental factors associated with transport and welfare impacts**

#### 4.2.6. Closed systems

Closed systems use polyethylene bags and other sealed transport units. They are used mainly for the transport of the early life-stages (e.g. fry) and ornamental fish, and to a much lesser extent for brood fish. The transport of fry in polyethylene bags with oxygen is globally widespread. It substantially reduces the total volume and weight of transport water, enables public transport to be used for fish transport, makes it possible to prolong the transport time, and is economically advantageous. The sealed units may be transported overland or by air. Guidelines and standards are available on recommended ratio of fish to water and methods of oxygenation (reviewed by Berka (1982)).

#### 4.2.7. Open systems

The open systems have many technical variants, ranging from simple containers for fish transport within the territory of a fish farm, up to specialised fish transport trucks and tank wagons. Transport longer than 30 minutes are generally undertaken in completely filled and closed tanks to minimise trauma to the fish through collisions with each other and the sides of the container. A constant supply of air or oxygen is required for even short journey in open tanks. Circulation is needed to maintain well aerated water in all parts of the tank. Well insulated tanks minimise the needs for temperature control.

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#### 4.2.8. Transport method

Open or closed systems may be employed by a large range of modes of transport; the most important methods are discussed in the sections below.

##### 4.2.8.1. Well-boats

Well-boats are purpose-built vessels for fish transport and primarily used by Atlantic salmon producers to transport smolts to sea sites or to transport harvested fish for slaughter and processing. They are also used for rainbow trout raised in the marine environment and farmed cod. Well-boats can be adapted to allow for population treatment (e.g. for fish lice). Fish are pumped into the wells of the boat, which are in the hull. Water is circulated through the wells using open valves to allow fresh seawater to enter. Modern well-boats can recirculate the water and maintain water quality, thus avoiding the discharge of water near fish farms and reducing the risk of disease spread. They are designed to enable water quality to be monitored and controlled. Operating with closed valves requires water chemistry parameters, notably DO and carbon dioxide to be monitored and appropriate levels to be maintained (e.g. by use of carbon strippers).

##### 4.2.8.2. Lorries

Short duration journeys by lorry can be undertaken using closed systems, for example, sealed bags filled with water and oxygen carried in insulated containers. Long distance transport of fish by road requires an open system, usually carried out in multiple purpose-built tanks on a road haulage vehicle. The tanks (usually fibre glass) are specially designed with a sealable loading hatch and a valve/pipe discharge point. The tanks are fitted with systems to regulate water temperature and oxygen levels within the tanks. Air stones in each tank are connected to an air pump. Air is pushed through the stone creating tiny bubbles which increase the surface area of air exposed to the water, allowing for more efficient oxygen transfer from air to water. Alternatively, a compressor pumps oxygen into the tank. DO and water temperature in water is continuously monitored by the driver from within the cab. In many jurisdictions, a Government Authority may need to approve the vehicle if it is being used to transport fish for long journey, e.g. over 12 hours.

##### 4.2.8.3. Helicopter

Helicopters are used mainly for moving Atlantic salmon smolts and broodstock to cages. The duration of a journey by helicopter is short (maximum 20 minutes). Fish are transported at high densities (300-400 kg/m<sup>3</sup>) which requires the water to be supersaturated with oxygen before the fish are added and continuous oxygenation during transport. A particular issue for helicopter transport, for which there is no information, is the potential effects on the fish of rapid changes in altitude, and the forces generated during sudden movements. Physical damage to the fish may occur at loading and during transport. Hypoxia during transport may occur if the oxygen supply fails, and conversely hyper-oxygenation may lead to gas bubble disease (bubbles formed behind the cornea).

##### 4.2.8.4. Air freight

Live fish shipped by air are generally transport in closed systems. The large majority of fish transported by air are for the ornamental trade (in oxygenated polythene bags). For longer journeys reoxygenation may be required. Heat or gel packs are often used to maintain the optimal temperature.

##### 4.2.8.5. Towing cages

Sea-cages may need to be moved at points in the production cycle of marine species. For example, sea-cages of Atlantic salmon may be towed from summer sites to inshore/sheltered sites for winter, and cages may be towed to shore for harvesting. Towing cages allows for movement of large numbers of fish. From a welfare perspective the clear advantage is that the fish are not handled. Welfare issues arise if the tow speed is too high, which may cause

the cage net to deform, trapping the fish, or the fish become exhausted and crowded and against the trailing wall. The appropriate towing speed depends upon the size and species of fish. The risk of net deformation can be reduced if the nets are clean, net tensioning is considered, and directional currents are used. Other hazards which may arise are fear induced by the propeller noise may cause fear in the fish, and jellyfish swarms.

#### 4.2.9. Mitigations

Planning and monitoring are essential to be able to carry out a transport with high welfare standards. During the planning phase, specific attention must be paid to the conditions of transport, especially to the quantity and condition of the fish, preparation of the fish prior to transport, the transport system and route, the loading and unloading procedures, the post-transport procedures, and welfare-monitoring programme at each step. Planning every aspect related to live fish transportation in advance gives full control of the procedure, ensuring the best possible welfare during transport. Preparation for transport should include consideration of the fitness of the fish to be transported. Despite a high level of planning unexpected events may arise during transport. Monitoring welfare and key water quality parameters during transport is important so corrective action can be taken. For example, provisions need to be made to intervene to address adverse water quality parameters, for example, to provide supplementary oxygen.

#### 4.2.10. Welfare hazards associated with methods of transport

Welfare hazards that may arise during transport and their impacts are summarised in Table 4. Welfare impacts are categorised by transport method in Table 5.. Assessment of hazards is complicated by the inter-relationships of water quality and other parameters (e.g. stocking levels during transport). In all transport systems some degree of mental stress (i.e. distress) will inevitably arise. The other hazards may occur if transport is not adequately planned or if the equipment (i.e. containers) are unsuitable. A degree of metabolic stress due to declining water quality, and potentially hypoxia, is likely to occur over long journeys by well-boat or lorry in closed systems.

**Table 4. Welfare hazards by impacts associated with transport**

Welfare hazard	Welfare impacts				
	Stress (mental)	Stress (metabolic)	Hypoxia (stress)	Physical trauma (pain)	Exhaustion (stress)
Poor water quality	✓	✓	✓	✓ <sup>2</sup>	
High water temperature	✓	✓			
Low water temperature	✓	✓			
High density of fish	✓	✓		✓	
Abrasive surfaces				✓	
Noise	✓				
High tow speed <sup>1</sup>					✓

<sup>1</sup> applies only to towing fish cages; <sup>2</sup>organ damage if water quality extremely poor

**Table 5. Welfare impacts associated with transport method**

Transport method	Welfare impacts				
	Stress	Stress (metabolic)	Hypoxia (stress)	Physical trauma (pain)	Exhaustion (stress)
Wellboats (closed)	✓	✓	✓	✓	
Wellboats (open)	✓			✓	
Lorry (closed)	✓	✓	✓	✓	
Lorry (open)	✓			✓	
Helicopter	✓		✓	✓	
Air freight	✓	✓	✓		
Towing cages	✓			✓	✓

### 4.3. Stunning and killing methods of fish for human consumption

#### 4.3.1. Introduction

Harvesting farmed fish is essentially a three stage process: i) a period of food withdrawal, ii) the collection and movement of the fish to the point of slaughter and iii) process of stunning and killing. Welfare hazards arising from food withdrawal, handling and transport have been considered in the previous section.

#### 4.3.2. Methods of stunning and killing

It is widely accepted that for humane slaughter, fish should be stunning before exsanguination, in a way that induces unconsciousness and insensibility until the fish has died (Robb and Kestin, 2002). As fish are ectotherms it takes longer time to induce brain failure by exsanguination, compared to mammals and birds. Commonly used methods of stunning and killing considered this this section are listed in Table 6.

##### 4.3.2.1. Percussive Stunning

Percussive stunning aims to induce immediate insensibility by a single severe blow to the skull of the fish. The fish must then remain unconscious until death (e.g. by gill slitting and exsanguination). A fast, heavy blow with a solid object correctly applied to the skull produces a rapid acceleration of the head, causing the brain to collide against the inside of the skull. A disruption of normal electrical activity results from a sudden, massive increase in intra-cranial pressure followed by an equally sudden drop in pressure. The consequent damage to the nerves and blood vessels causes brain dysfunction and destruction and impaired blood circulation. Unconsciousness results and its duration depends on the severity of damage to the nervous tissue and the degree to which the blood supply is reduced. If correctly struck with sufficient force and in the correct position the stun is irreversible.

**Table 6. Methods of stunning and killing**

Method
1. Manual percussive stunning
2. Automated percussive stunning
3. Electrical stunning
4. Asphyxia (e.g. in ice/ice slurry)
5. Carbon dioxide (CO <sub>2</sub> ) narcosis & gill slitting
6. Live chilling & gill slitting
7. Gill slitting and evisceration without pre-stunning
8. Physical brain destruction

Traditionally, a priest (a heavy baton) has been used for manual fish stunning; its effectiveness depends on the skill and of the operator. Automated stunning was developed in the 1990s to achieve greater consistency. The first automated stunning machines were powered by compressed air. The operator guides the fish into the machine opening. The fish activates the trigger system resulting in the piston striking the fish's head. More recent automated models have been designed to encourage fish to swim into the entry channels where stunning takes place, obviating the need for the operator. Most automated systems have been developed for Atlantic salmon and rainbow trout. Fish can become exhausted from swimming through the system. Manual percussive stunning is generally used as a back-up method for individual fish that are ineffectively stunned by the primary automated stunning system. The duration that the fish are out of the water prior to stunning and the force used for restraint contribute to welfare hazards associated with percussive stunning.

#### **4.3.2.2. Electrical stunning**

Sufficient electrical current is passed through the brain to cause an epileptic-like fit. This results in immediate unconsciousness and insensibility to pain. Exposure to electrical stimulation is potentially painful and, therefore, should be as short as possible (e.g. one second). If the current flows for long enough (typically 30 seconds for salmon or trout) the fish will die of anoxia before the brain is able to recover sensibility, but this is rarely practical. Therefore, unlike percussive stunning, electrical stunning generally requires post-stun treatment (e.g. gill-slitting) to kill the fish. If species such as salmon, trout, charr, bass and bream are electrically stunned for a suitable duration and then placed in ice, they will die from hypoxia before recovering consciousness. The effectiveness of a stun is determined by the time take to achieve unconsciousness (ideally immediate) and its duration (sufficient to for the slaughter process). Electrical stunning can be applied to large numbers of fish simultaneously, and handling can largely be undertaken once the fish are unconscious. No adjustments are needed for under or oversized or deformed fish (unlike percussive stunning).

Systems for electrical stunning are either 'in water systems' or 'dry or semi-dry systems'. In water systems comprise a water-bath or pass through system where fish are exposed to an electric field strong enough to stun them. Stunning fish in water reduces exposure to air and light and reduces the likelihood of mechanical damage to the skin. In 'dry' or 'semi-dry' systems electrodes make direct contact with the fish when out of the water or semi-submerged. These stunning systems have a more consistent effect on the fish and can result in less electrical carcass damage. A two-stage approach is employed in some systems. The fish are shocked with a higher voltage, then maintaining a lower voltage for a period to ensure permanent insensibility.

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#### 4.3.2.3. Asphyxia

Allowing fish to die from asphyxia (lack of oxygen) in ice slurry is still widely practised. Fish are passed over a dewaterer and into ice slurry. Loss of consciousness varies between species but can take up to 22 minutes. Shuck-Paim et al (2025) used rainbow trout as a case study to investigate the welfare aspects of air asphyxia during slaughter. They estimated 10 minutes of moderate to intense pain per trout. There is a risk that fish are exsanguinated whilst still conscious as the ice can immobilise the fish (giving the appearance of unconsciousness).

#### 4.3.2.4. Live chilling (cold shock)

Live chilling is used to immobilise the fish and lower the carcass temperature to allow quicker processing (it limits contamination of the carcass compared with chilling in a gutted condition). Fish are introduced to temperatures of 2-6°C. They may initially exhibit violent movement and escape behaviour, which subsides as they become exhausted and/or immobile. After about 30 minutes they are removed from the water and their gills are cut whilst still fully conscious. Line and Spence (2012) reviewed the literature on live chilling and concluded that that 'while a fish's physical reactions may stop or slow relatively quickly after being placed in ice or ice slurry, brain activity indicates the continuation of consciousness for a substantial period'. Therefore, cold shock initially paralyses, but does not stun, the fish.

#### 4.3.2.5. Gill cut without pre-stunning

Fish are removed from water and their gills cut without any pre-stunning. Fish exhibit escape behaviour and flip their tails once out of water. Once the cut into the gills is made these reactions are dramatically increased and vigorous head shakes and tail flaps are seen for at least 30 seconds. This movement slowly subsides and after several minutes most fish stop moving

#### 4.3.2.6. Carbon dioxide narcosis

Fish are immersed in CO<sub>2</sub> saturated water (pH level 4.5). Loss of consciousness can take 7-8 minutes. On immersion fish exhibit head shaking and vigorous tail shaking for up to two minutes after immersion in the solution. Movement then subsides and the fish become still after approximately 5 minutes due to exhaustion. Fish must be exposed to high concentration solution for 7-8 minutes, otherwise recovery will begin soon after removal from the solution, and possibly before their gills are cut.

### 4.3.3. Physical brain destruction

The only farmed species for which the physical destruction of the brain is routinely used are the Atlantic and Pacific tuna (*Thunnus thynnus* and *Thunnus orientalis*, respectively). There is little available analysis of the slaughter of tuna; however, if shooting to destroy the brain while the fish is in water can be achieved quickly, reliably and accurately, a high standard of welfare at slaughter can be achieved (EFSA, 2009b). Other methods such as gaffing, hoisting and restraining conscious tuna out of water prior to killing create severe welfare hazards (EFSA, 2009b).

### 4.3.4. Application of methods by species

All methods listed in Table 6 are all used to slaughter Atlantic salmon and but automated percussive stunning (followed by gill slitting) is the most frequently used method. Catfish, pangasius, carp and tilapia are very resistant to percussive stunning due to the shape and thickness of the skull (Lambooi et al., 2007). For Nile tilapia (*Oreochromis niloticus*) and other tilapia species electrical stunning followed by use of ice slurry, decapitation, gill cutting or spiking/coring is the recommended method of stunning and killing. Tilapia farming is dominated by small-scale rural farms and the fish are typically marketed in rural areas at local markets in developing countries, either fresh or iced, with little processing (El-Sayed, 2020). There is no specific harvesting method for farmed tilapia and the information available on harvesting methods is very limited (El-Sayed, 2020). Tilapia are often reared together with other aquatic species in a polyculture, which makes it even more difficult to adopt specific harvesting techniques (El-Sayed, 2020). It is likely that the large majority of farmed tilapia are left to asphyxiate on ice slurry or exsanguinated without stunning (Lines and Spence, 2012).

The most common killing method for seabass and seabream is direct immersion in iced water where they are immobilised and eventually lose consciousness due to thermal shock and then die by asphyxia (EFSA, 2009g). The majority of carp are sold alive and killed by the end-user in homes or restaurants (EFSA, 2009e). The period from leaving the farm to killing commonly involves periods out of water and periods held in small quantities of water of poor quality. During this period, they are at risk of physical injury by being dropped on hard surfaces or from collisions with other fish during transfers. At killing, carp are commonly held out of water for a period to reduce struggling and then may be stunned by multiple percussive blows followed by bleeding or evisceration (EFSA, 2009e).

#### 4.3.5. Welfare hazards associated with stunning and killing

It is useful to distinguish between hazards which are essentially inherent to the slaughter method even well properly conducted, and, therefore, invariably occur, and those that result from malfunctioning of the equipment or operator failure and should be infrequent events. In Table 7 this distinction is made in the frequency column (high frequency events are inherent and low frequency events are due to malfunction or error).

Exsanguination (and potentially evisceration) when conscious occurs in percussive and electrical stunning systems if stunning is not correctly applied, i.e. the 'mis-stun' is the hazard. If fish are live chilled and a gill cut made without stunning, then the method itself is a hazard that directly give rise to a potentially negative welfare outcomes (e.g. exsanguination when conscious resulting in pain). The hazards listed in vary considerably in severity, and the severity of some hazards, for example, handling and time out of water, depend largely on duration.

**Table 7. Welfare hazards associated with stunning and killing method**

Welfare hazard		Description and welfare impact	Frequency
<b>Manual and hand fed automated percussive stunning</b>			
1	Handling	Stress	High
2	Time out of water	Asphyxia (stress)	High
3	Mis-stun	Physical trauma, pain from exsanguination and potentially evisceration when conscious (pain)	Low
<b>Automated percussive stunning</b>			
4	Crowded swimming in the system	Exhaustion (stress)	Low
3	Mis-stun	Physical trauma, exsanguination and potentially evisceration when conscious (pain)	Low
<b>Electrical stunning (in water batch system)</b>			
5	Crowding prior to stunning	Exhaustion poor water quality (stress )	High
6	Low current or voltage (mis-stun)	Pain (from experiencing electricity); exsanguination (and possibly evisceration) when conscious (pain)	Low
7	Mis-cut	Physical trauma, exsanguination and potentially evisceration when conscious (pain)	Low

Welfare hazard		Description and welfare impact	Frequency
<b>Electrical stunning (dry system)</b>			
2	Time out of water	Asphyxia (stress)	High
5	Crowding prior to stunning	Exhaustion poor water quality (stress )	Low
6	Low current or voltage (mis-stun)	Pain (from experiencing electricity); exsanguination (and possibly evisceration) when conscious (pain)	Low
7	Mis-cut	Physical trauma (exsanguination and potentially evisceration when conscious) (pain)	Low
<b>Live chilling</b>			
8	Temperature shock	Stress	High
2	Time out of water	Asphyxia (stress)	High
9	Exsanguination	Physical trauma (exsanguination when conscious) (pain)	High
10	Evisceration	Physical trauma (evisceration when conscious) (pain)	Low
<b>Gill cut without pre-stunning</b>			
1	Handling	stress	High
2	Time out of water	Asphyxia (stress)	High
7	Mis-cut	Physical trauma (exsanguination when conscious) (pain)	Low
<b>Carbon dioxide narcosis</b>			
11	Poor water quality	Asphyxia, acidosis (stress)	High
12	Exposure to high level of CO <sub>2</sub>	Panic, release of catecholamines, low pH (below 5) acid bath, acute irritation, aversive behaviour (stress)	High
13	Exsanguination	Physical trauma (exsanguination when conscious) (pain)	High
7	Mis-cut	Physical trauma (evisceration when conscious) (pain)	Low

#### 4.4. Stunning and killing methods for disease control purposes

##### 4.4.1. Introduction

The on-farm killing of farmed fish to prevent spread of a disease or to achieve elimination (e.g. an introduced exotic diseases) from a farm, geographical zone or country and will be referred to as 'culling' in this report. This operation may involve fish at any life cycle stage. The methods for culling are limited to the equipment on farm or that can be brought onto the farm. To minimise the risk of disease spread of an introduced disease, the Competent Authority (CA) may require an infected

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population to be culled as soon as possible. A lack of equipment and time constraints may result in the use of manual percussive or an overdose of anaesthetic as killing methods. It is possible that fish of commercial size and showing no clinical signs may be slaughtered under the supervision of the CA for human consumption on farm, or transported to another facility for slaughter and processing, if the risk of disease spread is acceptably low. However, often fish culled for disease control purposes will not be suitable for human consumption. Methods of on farm culling should be included in the CA's contingency plans for disease control.

#### **4.4.2. Methods of stunning and killing for disease control**

This section considers methods of killing used primarily in the emergency slaughter of fish for disease control. The slaughter methods discussed in the previous section which may be deployed on farm for disease control purposes are: i) manual percussive stunning, ii) automated percussive stunning, iii) asphyxia (e.g. in ice/ice slurry), iv) live chilling & gill slitting, v) gill slitting and evisceration without pre-stunning. As noted above, the CA may allow fish to be moved to processing plants to be slaughtered.

##### **4.4.2.1. Pharmacological**

A number of anaesthetic agents are used to kill fish, notably metacaine, benzocaine and clove oil (active ingredient: eugenol). In many countries some agents (e.g. metacaine, also known as MS222) is licensed for the killing of fish for disease purposes. The addition of these agents to water produces general anaesthesia but their mode of action is not fully understood (Hara and Sata, 2007). Robb and Kestin (2002) found that brain activity could be detected for more than 15 minutes in Atlantic salmon after exposure to either of MS-222 or benzocaine. Some authors have suggested that exposure to MS222 and benzocaine may be stressful to fish (Kiessling et al., 2009; Zahl et al., 2009). A range of factors influence the induction time to unconsciousness and the stress response: crowding, netting water quality, life stage, water temperature, salinity, low DO and pH. Exhausted fish most likely have a longer induction time because of malfunctioning gill exchange.

##### **4.4.2.2. Maceration**

Maceration is recommended as a method of killing only for embryonic and larval forms or neonatal animals and involves the use of a mechanical device, with rotating blades or projections that cause immediate fragmentation and death. Maceration could be used to cull early life stages fish (i.e. newly hatched fish, embryonated eggs and unfertilised eggs). It may also be used to dispose of fish following stunning, which are then ensiled.

##### **4.4.4.3. Application of methods by species**

###### **4.4.2.3.1. Atlantic salmon and marine cage reared rainbow trout**

EFSA (EFSA, 2009d, f) listed pharmacological, electrical and maceration as culling methods for Atlantic salmon and sea-caged reared rainbow trout. The choice of methods is determined by the life-stage, number of fish being killed and the location: sea-cages, or land-based tanks of fry or smolt. The culling of small numbers of salmon which are easily accessible, i.e. land based systems or broodstock fish, is generally achieved by asphyxia (by reducing water flow to the tanks), or by using an overdose of anaesthetics (e.g. MS222, metacaine or benzocaine). Anaesthetics can result in permanent insensibility if applied for long enough, or the fish can be killed by bleeding or asphyxiation while insensible. Well-boats designated for emergency slaughter are needed to kill larger numbers of fish. Both pharmacological methods and electrical stunning can be carried out on well-boats. An overdose of anaesthetics is added directly to the water in tanks on the well-boat before closed transport to where the fish will be disposed of, e.g. by maceration and ensiling.

#### 4.4.2.3.2. Carp

According to EFSA (EFSA, 2009e) there are no disease control methods commonly used for carp. Methods such as pharmacological, electrical, and maceration could be used for carp, depending on life-stage, available equipment and numbers of fish to be killed. An overdose of an anaesthetic could be used to kill large numbers of carp.

#### 4.4.2.5. Seabass and seabream

EFSA (EFSA, 2009g) suggest that the following methods could be used to cull seabass or seabream: i) overdose of anaesthetic, ii) CO<sub>2</sub> or other gas mixtures, iii) maceration (for early life stages), iv) electrical stunning, v) live chilling or vi) asphyxia.

#### 4.4.2.6. Welfare hazards

Four hazards associated with pharmacological methods of killing were identified (Table 8). Crowding and exposure to chemicals are inherent to the method of killing (and, therefore, occur with high frequency). Operator error may result in insufficient levels of anaesthesia resulting stress and hypoxia.

**Table 8. Welfare hazards associated with pharmacological methods of killing**

	Welfare hazard	Description and welfare impact	Frequency
1	Crowding	Poor water quality, high density of fish resulting, exhaustion (stress) and physical trauma (pain)	High
2	Exposure to chemicals	Aversive taste/smell, irritation to skin, mucosa and gills (stress)	High
3	Poor water quality	Stress	Low
4	Insufficient level of anaesthesia	Stress (direct and due to asphyxia)	Low

## 5. Fish neurobiology and sentience

### 5.1. Literature review

#### 5.1.1. Method

Literature searches were conducted using Google Scholar (GS) and Web of Science (WoS).

Search terms in Topic: *fish AND (stress OR distress OR fear OR pain OR sentience)*

The GS search produced 2,510,000 hits, of which 194,000 were categorised as review articles. The review articles were sorted by GS on relevance. The titles of the first 200 articles were reviewed and 25 were selected for further consideration. The same search was conducted in WoS which produced 136 hits. The titles of all 136 articles were reviewed and a further two articles were selected. In addition, the EFSA (2009), which had not appeared in either search, was added to the list, making a total of 28 papers, which are listed in [Appendix 2](#). The abstracts of all 28 articles were reviewed and 21 were judged to be relevant and are reviewed below. Seventeen additional review papers were identified from the original 22 reviews and are listed in [Appendix 3](#), giving a total of 38 review papers. Other papers cited in this report (see References, section 0) were identified from the reviews.

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## 5.1.2. Philosophy and ethics of animal sentience and suffering

The question of pain and sentience in animals has been a subject of philosophical and ethical consideration since Descartes in the 17<sup>th</sup> century, who argued that animals do not experience pain and suffering because they lack consciousness (Harrison, 1992). Subsequently the work of Kant, Bentham and others shifted philosophical thought to an acknowledgement of animal's potential for sentience and moral status. Bentham was the first thinker to argue that the capacity to suffer was morally important irrespective of species (Bentham, 1789). More recently Singer (1990) argued that sentience, not species, should determine whether species are included within the 'moral circle'<sup>1</sup> and, therefore, humans have responsibility to balance the burden and benefit of their treatment. In a limited way philosophers have turned their attention specifically to fish (see Varner (2012), Lund et al (2007) and Brown (2015)). From an ethical or philosophical perspective, fish merit moral consideration if they are thought to be sentient. A judgement on fish sentience depends on an assessment of empirical evidence which is the subject of this section.

## 5.1.3. Sensory perception

### 5.1.3.1. Overview

Bony fishes inhabit a wide range of environments, and their sensory organs and capacities have evolved to suit their ecological niches, ensuring survival and interaction with their surroundings. Brown (2015) and EFSA (2009) provide detailed reviews of the sensory perception of bony fishes.

### 5.1.3.2. The Visual System

The fish eye has evolved to cope with the visual qualities of water and fish have good vision. Their eyes often include spherical lenses that allow precise focusing, a necessity in water where light refracts differently than in air. Many species possess a tapetum lucidum, a reflective layer behind the retina that enhances their ability to see in low-light conditions, such as in deep-sea environments. Most species are at least tetrachromatic and can differentiate between colours better than humans. Coral reef species, e.g. clownfish (*Amphiprioninae*), are known for their vivid colour vision, enabling them to identify mates, food, and predators. In contrast, deep-sea species, including lanternfish (*Myctophidae*), rely on bioluminescent cues and sensitivity to dim light, using specialized retinal cells packed with rods.

### 5.1.3.3. The Olfactory Sense

Olfaction plays a critical role in the life cycle of many bony fishes. Olfaction and taste (gustation) in fishes work much in the same way as in humans. Chemosensory information is used for a wide variety of behaviours including feeding, predator recognition, mate choice and navigation. Their nasal sacs, lined with sensory epithelium, detect chemicals in the water, offering abilities as precise as those seen in terrestrial mammals. The migration of salmon (*Salmo salar*) to their natal rivers to spawn relies on olfactory memory to navigate over thousands of kilometres. Studies have shown that olfactory signals can also help identify pheromones emitted by conspecifics, aiding in reproductive behaviours and social communication.

### 5.1.3.4. Hearing and Balance

The inner ear of bony fishes is a dual-purpose organ for both hearing and balance. Otoliths, calcium carbonate structures within the ear, detect sound waves and provide spatial orientation. Hearing ability varies considerably between bony fishes, depending on the environment. Two broad categories are recognised: specialists and generalists. Specialists such as carp, catfishes, mormyrids (from Africa) detect a broad frequency range of the pressure component of sound, whereas generalists may only detect the particle motion component over low frequencies (e.g. perch and salmonids).

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<sup>1</sup> A "moral circle" refers to the boundaries of our moral consideration and concern for others, including humans and non-human entities.

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#### 5.1.3.5. The Lateral Line System

In addition to having an inner ear, fishes also have a specialised system to sense vibration from all over the body: the lateral line, a defining feature of bony fishes. Disturbance in surrounding water trigger specialised cells (neuromasts) to send nerve impulses to the brain via the inner ear to be processed, enabling them to detect water movement and pressure changes. Neuromast cells are particularly sensitive in predatory fishes such as pike (*Esox lucius*), helping them detect prey movements even in turbid water. Species like schooling herring (*Clupea*) utilise the lateral line for coordinated group movements. Fish are highly responsive and potentially sensitive to sound and vibrations. However, it remains open to debate whether their behavioural response to sound and vibrations is conscious or subconscious (EFSA, 2009a).

#### 5.1.3.6. Taste

The broad distribution of taste buds across the body, including lips, fins, and skin, enables certain bottom-dwelling species like flatfish (*Pleuronectidae*) to detect food buried in sediment. This adaptation is critical in environments where visibility is limited. Taste perception aids scavengers and omnivores to discern edible substances from harmful ones, ensuring survival in diverse habitats.

#### 5.1.3.7. Electroreception

Many fish species are capable of detecting and creating electric currents in the water. Electroreception is present in select species of bony fishes, such as knifefish (*Gymnotiformes*). Electroreceptors detect weak electric fields generated by other organisms or environmental features. This capacity is vital for navigation and prey detection, particularly in murky or nocturnal settings where vision may be diminished. Many fishes can also detect and use the earth's magnetic field for both large- and small-scale navigation (magnetoception), similar to many species of migratory birds. Electroreception also plays a role in social communication among these species.

### 5.1.4. Neurobiology

#### 5.1.4.1. Peripheral nervous system

Nociception functions as an important alarm system alerting the individual to potential and actual tissue damage (Sneddon, 2017). Nociceptors were first identified in fish 2002 by Sneddon and colleagues (Sneddon, 2002; Sneddon et al., 2003). They demonstrated that that A-delta (Ad) fibres associated with fast, sharp pain and C-fibres associated with slow, burning pain are present in the trigeminal nerve of trout (Sneddon, 2002; Sneddon, 2003; Ashley et al., 2007). However, the density of C-fibres is a fraction of that found in mammals. Rose (2007) used this finding to claim that fish do not consciously suffer from pain, supporting the argument by noting that sea urchin and marine catfish spines are often found in the mouths and throats of predatory marine fishes. However, others (Woodruff, 2018a) contend that the combination of the presence of spines in the mouth of fishes and the comparative reduction in C-fibres does not necessarily imply that fish lack the capability to experience pain. They posit that evolutionary pressure on predatory fishes maximized their ability to select prey by reducing the number of nociceptors in the mouth and throat, areas supplied by the sensory branches of the trigeminal nerve. This explanation is supported by studies of other species (Woodruff, 2018a). Electrophysiological studies indicate that fish have functional peripheral nociceptors serving the body and tail. These studies also show that nociceptive input reaches the telencephalon, including the pallium. Dunlop and Laming (2005) recorded neuronal responses to pin-pricks to the body of goldfish and trout. Analysis of spike conduction velocities indicated responses to both Ad- and C-fibre activation in the cerebellum, tectum and telencephalon in trout, and in the cerebellum and tectum in goldfish (Woodruff, 2018a). The evidence presented indicates central processing of nociceptive input and pain processing in the fish telencephalon. In a review published in 2018, Sneddon (2018b) concluded that work following the detection of nociception in 2002 (Sneddon et al., 2002), has demonstrated fish nociception is 'strikingly similar to those found in mammals' and that molecular mechanisms of nociception are evolutionarily conserved. Woodruff (2018a) concurred and concluded that 'the complexity of neurophysiological activity from peripheral nerves to the pallium supports the argument by Sneddon et al. (2018b) that fishes consciously experience pain'.

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#### 5.1.4.2. Brain structure and function

The evolution of brain function in mammals resulted in many processes taking place in the multi-layered cerebral cortex (Striedter, 1997). By contrast fish have a singly laminated cortex which makes comparisons of functional anatomy complicated. In a 2002 review, Rose (2002) claimed that fish could not feel pain or were conscious. His core argument was that animals must have a multilayered cortex to experience pain, which effectively excludes all animals except human and non-human primates, although Rose (2002) only applied the argument to fish. The current consensus from a review of the literature is that parts of the fish brain, other than the cerebral cortex, have evolved the capacity for generating emotional states in fish (Huntingford et al., 2006; Sneddon et al., 2018b; Woodruff, 2018a). A key counter to Rose's argument is that the telencephalon in fish contains several brain structures that may be functionally homologous to those associated with pain and fear in higher vertebrates (Chandroo et al., 2004; Portavella et al., 2004), and known to be active after a noxious stimulus such as pin-prick stimuli in rainbow trout or goldfish (see previous section). The EFSA review (2009a) concludes that 'there is scientific evidence to support the assumption that some fish species have brain structures potentially capable of experiencing pain and fear'. However, papers presenting opposing views continued to be published. Key (2016) and Rose et al (2012) argued that 'structure determines function'. In his review, Key (2016) delineates the region of the human brain responsible for feeling painful stimuli. The principal structural features of this region are used as biomarkers to infer whether fish are, at least, anatomically capable of feeling pain. Rose (2016) concludes that fish 'lack the necessary neurocytoarchitecture, microcircuitry, and structural connectivity for the neural processing required for feeling pain'. According to Brown (2016), Key's review (2016) promoted 34 commentaries from experts, of which only three supported his position. The main criticisms of Key's work were that his approach based on pain in humans is 'selective, simplistic, misleading and outdated' (Brown, 2016). Sneddon et al (Sneddon et al., 2018a; Sneddon et al., 2018b) reject the conclusion reached by Rose (2002, 2014, 2016) that fish cannot experience pain because that cannot process pain in the same way as a mammalian brain; and argue that the fish brain is likely to be very similar in function if not structure (Woodruff, 2018a). Specifically, Sneddon et al (2018) argue that processing is not restricted to hindbrain and spinal reflexes as proposed by Rose and colleagues (Rose, 2002, 2016).

#### 5.1.5. Sentience

The concept of animal sentience has evolved over the last 30 years (Duncan, 2006). At its simplest sentience is the capacity to detect external stimuli, perceive such stimuli, and have the capacity of experience positive or negative affective states (Sneddon and Brown, 2020). Contemporary thinking now accepts that the perception of external stimuli is intrinsically linked to conscious experience of the stimuli (Dawkins, 2017; Sneddon, 2019). Sentience is fundamental to a discussion of a fish's capacity to experience pain, fear or stress, and a prerequisite for an animal species to have a welfare status (Duncan, 1996). Sentience in animals is a phenomenon that may be inferred by examination of both the cognitive abilities and neuroanatomical features (Chandroo et al., 2004). Broom (2014) considers that a sentient being has some ability to evaluate actions of others in relation to itself, remember some of its actions, assess risk and benefits (i.e. make decisions), have some feelings (positive and negative affective states), have some degree of awareness (consciousness). Experiments and observational studies have examined these criteria. If there is evidence that some or all of these criteria are met within an animal group, it must be concluded that they are sentient. On this basis, mammals are universally accepted as sentient, but sentience in fishes has been actively challenged (Sneddon et al, 2018).

Sneddon and Brown (2020) reviewed the evidence from each of the criteria set out by Broom (2014) and concluded that all are met by fish, and that fish have mental capacities on par with most other vertebrates. Specifically, they conclude that fish are sentient and capable of learning and remembering (e.g. locations of food), spatial cognition, social cognition, problem-solving, numeracy (capacity to distinguish between different numbers) and human face recognition. Brown (2015) reviewed the current state of knowledge of fish sensory perception and cognition. He concludes that fish perception and cognitive abilities often match or exceed other vertebrates. The key studies cited by Sneddon and Brown (2020) and Brown (2015) that demonstrate a fish's cognitive abilities and thus sentience (Chandroo et al., 2004) are summarised in the remainder of this section.

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A number of studies definitively demonstrate that fish are capable of learning task and memory, though this varies between species. Fish learn where and when they will be fed (time-place learning) and aggregate in expectation of a feed (Reebs, 1996; Reebs, 1999; Gómez-Laplaza and Morgan, 2005). Spatial learning has been widely studied in fishes (reviewed by Odling-Smee and Braithwaite (2003)) and is largely comparable to other vertebrates. Other studies on learning (Pepperberg and Hartsfield, 2014) have shown that cleaner wrasse fish learn to discriminate reliable food sources from unreliable ones. Goldfish learn to avoid an area where they have received an electric shock (Dunlop et al., 2006). Even when food has been previously provided in this area and the fish are strongly motivated to spend time there, they avoid it for three days, trading off their hunger against the risk of receiving another shock (Millsopp and Laming, 2008). This demonstrates complex decision-making beyond simple reflexes. Other studies demonstrating the capacity of fish for iterative learning are reviewed by Chandroo et al (2004).

Many fish species form stable groups (shoals) and become familiar with the individuals within the group. Guppies are capable of remembering the identities of number of up to 15 individuals (Griffiths and Magurran, 1997). Individual recognition and the ability to assess fighting skill through observation has been recognised in fighting fish (McGregor et al., 2001) and farmed species (Höjesjö et al., 1998). The best known example of cooperation between fish is that of cleaner wrasse and its client fish (Griffiths and Magurran, 1997), which demonstrates the capacity of the wrasse to recognise different 'clients'. The other classic example of inter-species cooperation between fish species occurs between groupers and moray eels. The grouper approaches the moray eel to initiate a cooperative hunt for prey which is mutually beneficial (Bshary et al., 2006).

Lambert et al (2022) reviewed the scientific literature for evidence of sentience in fish. The review identified 349 articles and 19 different sentience keywords, including stress, fear, anxiety and pain. They concluded that there is an abundance of evidence for fish sentience in the published scientific literature.

#### 5.1.6. Pain

Pain is defined as 'an aversive sensation and feeling associated with actual or potential tissue damage' (EFSA, 2009a). A distinction needs to be made between pain and nociception: as pain is considered a subjective experience of anguish, despair and other negative affective states (Sneddon, 2011). The question arises whether fish have the capacity to experience conscious emotional states and, specifically, pain in the same or similar way as humans.

It is universally accepted that animals, including fish, have physiological and behavioural responses to nociception similar to humans. It has been suggested that animals may behave as though they are in pain, but this reflects nociception without suffering (Allen, 2004). Allen et al. (2005) reviewed the evidence for pain in rodents and compared it with data from humans, concluding that the evidence is not conclusive. However, Shriver (2006) reviewed similar evidence and concluded that it was 'beyond a reasonable doubt' that most mammals feel pain. Sneddon (2019) came to the same conclusion: 'pain does not just involve nociception and nocifensive withdrawal but encompasses the negative affective component of pain'. However, opposition to the proposal that non-primate animals experience pain exists (e.g. Rose et al, 2014).

Nociception results in animals being motivated to avoid injury and protect themselves from further damage, and, therefore, has been conserved through evolution. Different species will exhibit pain differently, as animals have evolved to meet the demands of their environment. A key argument made by Sneddon et al (2011) is that in addition to nociception, some animals also have an associated 'aversive motivational state' similar to aspects of pain in humans. It is the 'aversive motivational state' that leads Sneddon et al (2011) to propose that some animals experience pain. The argument is that this state creates a strong and lasting motivation that increases the likelihood that the animal avoids the same situation in future. Thus pain allows for longer term protection over and above the immediate reduction in tissue damage that nociception achieves. The aversive affective component is integral to the evolutionary function of pain.

Whilst there is broad, but not universal, agreement that fish can sense pain, their capacity to experience pain as an emotional state is disputed. Given that it is not possible to definitively prove whether animals experience pain as an emotional experience, one approach to resolving the question is to apply objective criteria. Over the years several sets of criteria have been proposed (Bateson, 1991; Broom, 2001; Sneddon et al., 2014). The criteria proposed by Sneddon et al (2014) are set out in Table 9; they concluded that the criteria are met by bony fish. The evidence cited to support this conclusion is reviewed in the remainder of the section.

Table 9. Criteria to determine whether fish (bony) experience pain

	Criteria	Met <sup>1</sup>
1	Nocioceptors	✓
2	Pathways to CNS	✓
3	Central processing in brain	✓
4	Receptors for analgesic drugs	✓
5	Physiological responses	✓
6	Movement away from noxious stimuli	✓
7	Behavioural changes to norm	✓
8	Protective behaviour	✓
9	Responses reduced by analgesic drugs	✓
10	Self-administration of analgesia	✓
11	Responses with high priority over other stimuli	✓
12	Pay cost to access analgesia	✓
13	Altered behavioural choices	✓
14	Relief learning	?
15	Rubbing, limping, guarding	✓
16	Pay a cost to avoid stimulus	✓
17	Trade-offs with other requirements	✓

<sup>1</sup> conclusion made by Sneddon et al (2014)

In 5.1.4 the evidence that a neural apparatus in fish for an effective nocio-receptor system that enables the neural input to allow perception of tissue damage (criteria 1-5, Table 9) was reviewed. This system does not mean that pain (as discussed above) is a consequence. The whole animal response needs to be considered (criteria 6-17, Table 9). Studies reviewed demonstrated that: i) opercular beat rate is increased by subcutaneous injection of noxious chemical, ii) fish move away from noxious stimuli that would cause pain in mammals, iii) injection of noxious chemicals in the frontal lips resulted in the suspension of feeding, iv) fish avoid areas where they receive electrical shocks; v) fish will pay a cost to satiate hunger or pain relief, and vi) fish will rub injection sites (and the behaviour is moderated by morphine).

Diggles et al (2024) have criticised the criteria developed by Sneddon et al, 2011, on the grounds that they are based on an 'unconventional' definition of pain. Specifically, Diggles et al (2024) reject the proposal that any behaviour in response to noxious stimuli can be interpreted as consistent with pain, and suggest that alternative explanations are not considered. However, Diggles and colleagues are in a minority. In their review, Braithwaite et al (2007) found that existing research on fish showed that not only are fish capable of nociception, but that they meet all of the criteria thought necessary for experiencing pain in a meaningful way. Braithwaite and Huntingford (2004) concluded that although a fish's

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experience of pain may not be the same as humans', it is still meaningful to them, and important to protect their welfare. Chandroo et al (2004), Schroeder (Schroeder, 2018), Sneddon (Sneddon, 2004; Sneddon, 2017; Sneddon, 2019; Sneddon, 2020), Sneddon et al (Sneddon et al., 2014) and Oidtmann and Hoffmann (Oidtmann and Hoffmann, 2001) similarly concluded based on the available evidence from anatomical, pharmacological and behavioural studies that affective states of pain, fear and stress are likely to be experienced by fish in similar ways to other vertebrates. Oidtmann and Hoffman (2001) specifically conclude that fish are capable of meeting the definition of suffering as defined in German animal welfare law. Varner (2012) reviewed the literature on pain in animals and argued by analogy that fish experience pain as they, in common with birds and mammals, have nociception, a brain, endogenous opioids, respond to analgesics and to damaging stimuli in a similar way to humans.

There is a consensus, though not universal, that behavioural and neurophysiological studies of several bony fish species demonstrate that responses, behavioural avoidance and learning from the experience of tissue damage occur in a similar way in fish and mammals. Therefore, fish fulfil the criteria for animal pain and there is the potential for pain perception in fish.

### 5.1.7. Fear and stress

Fear may be defined as a psychophysiological response to perceived danger (Chandroo et al., 2004), and is a phenomenon which acts as a powerful motivator to evade perceived threats (Jones, 1997). Three main criteria have been used to assess the capacity for fear (Fendt and Fanslow, 1999): i) the systems that control the fear response should have a common neuronal basis to neural systems underpinning human fear and anxiety, ii) a variety of threatening behaviour should generate a range of behaviours that protect against the threat, and iii) drugs that modulate fear and anxiety in humans (e.g. benzodiazepines) has similar effects in animals. Sneddon and Brown (2020) conclude that fishes meet all three criteria.

Fearful responses of fish to noxious or startling stimuli, which are manifested as vigorous, rapid escape manoeuvres are collectively defined as fast-start responses (Chandroo et al., 2004). Fast-starts are used by fish not only to escape predators but also in social interactions, and during feeding behaviour, which suggests that fast-starts are not only a reflex response but may have a motivational (i.e. voluntary) basis. Chandroo et al (2004) reviewed the extensive evidence from both observational and experimental studies and concluded that 'cognitive, neurophysiological and behavioural features of fear responses of fish suggest that they have some capacity to consciously experience fear'. Further studies published after Chandroo et al's review have supported this conclusion. Yue and colleagues demonstrated that rainbow trout learn to avoid an aversive stimulus indicating the existence of a cognitive process that underpins a capacity to experience fear (Yue et al., 2004; Yue et al., 2008). Dunlop et al (2006) showed that goldfish learn to avoid an area where they have received an electric shock even when food has been previously provided in this area. Another study demonstrated that fish trade off their hunger against the risk of receiving another shock (Millsopp and Laming, 2008). These studies demonstrate both the capacity for fear which is necessary for decision-making beyond simple reflexes. From an evolutionary perspective, defence and escape behaviours are dependent on cognitive and learning abilities related to fear. The EFSA review (2009a) concluded that defence and escape behaviours in fish are dependent on cognitive and learning abilities related to fear and that fish are able to experience fear.

In fish the physiological response to stress is adrenergic: the release of adrenaline and noradrenaline and ultimately raised blood cortisol. The response to stress is considered to be an adaptive mechanism that allows the fish to cope with stressors and maintain homeostasis, which is beneficial to its survival. If the impact of the stressors is severe or long lasting, disturbances of homeostasis can negatively impact the fish's welfare (Wendelaar Bonga, 1997). Schreck (1981) was the first to suggest psychological component to stress in fish. Most studies of psychological stress have been in a social context as many farmed species form social hierarchies. Psychological stress has been conceptualised as having three components (Chandroo et al., 2004): i) negative affective states such as fear, ii) the perception of conspecifics as threatening and iii) anticipation of the presence or actions of conspecifics.

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Subordinate fish may be psychologically affected by the presence of a dominant conspecific. Studies in Arctic charr (Winberg and Nilsson, 1993) and rainbow trout (Winberg and Lepage, 1998) have demonstrated that the threat of a conspecific can cause chronic stress. Winberg and Sneddon (2022) argued that in wild populations fish can choose whether to engage in stressful, energy demanding behaviours and when to retreat, whilst in captive situations the same options are not available. Reviews by EFSA (2009a) and Chandroo et al (2004) considered papers which monitored brain serotonergic activity in subordinate fish (e.g. Winberg et al (1996)). Increased serotonin was associated with reduced locomotor activity, findings which are similar to observations in mammals. Chandroo et al (2004) concludes that 'the neurobehavioural similarities between fish and other vertebrates with respect to social stress further supports the suggestion that fish have some capacity to experience psychological stress'.

## 5.2. Main areas of contention

Scientists who have studied sentience and pain in fish have taken two very different starting positions. A sceptical position has been adopted by Key (2016), Rose (2016) and Diggles and colleagues (Diggles, 2016; Diggles et al., 2024). They contest that a 'benefit of doubt' (i.e. precautionary) approach with respect to fish sentience would have negative financial costs to the fish farming industry and other sectors (e.g. fisheries) (see Browman et al, 2019). However, the majority of scientist argue that as it cannot be proven or disproven that fish have a subjective experience of pain, and even if some doubt persists that about sentience in fish, a precautionary approach should be adopted (Jones, 2016; Brown, 2017; Sneddon et al., 2018b). They consider that a lack of complete certainty should not be used as a reason to postpone measures to prevent potentially serious negative welfare outcomes. In support, they note that the precautionary approach is adopted in environmental and public health management. On the other side of the argument, Diggles et al (2024) have further elaborated the philosophical justification for a sceptical approach. Their paper is based on the philosophy that science advances by conjecture and refutations (Popper, 1963). They conclude that fish have not met sufficient criteria to conclude they are sentient. Essentially, Diggles et al (2024) set the bar to reject the null hypothesis (fish are not sentient) considerably higher than the large majority of scientists working in the field. Sneddon et al (2018) argued that sceptics set considerably stricter conditions for recognising sentience in fish compared with other vertebrates, which is driven largely due to potential 'costs' of recognising sentience (see Brown, 2014).

Sceptics (e.g. (Rose, 2007)) rely heavily on studies which show a lack of C fibre nociceptors in fish compared to most other vertebrates and a lack of higher cortical function. C fiber nociceptors are the most prevalent type in mammals and responsible for excruciating pain in humans, but are rare in teleosts. The relevance of this finding has been disputed by Sneddon (2015) and others (Chandroo et al., 2004; EFSA, 2009a; Brown, 2017; Woodruff, 2018b). They argue that evolutionary pressure on predatory fishes maximized their ability to select prey by reducing the number of nociceptors in the mouth and throat, areas supplied by the sensory branches of the trigeminal nerve. Rose (2002) argued that animals must have a multilayered cortex to experience pain. This theory has been widely rejected by nearly all other scientists working in field who point to evidence that the telencephalon in fish may be functionally homologous to those associated with pain and fear in higher vertebrates (Chandroo et al., 2004; Portavella et al., 2004).

Whilst a majority of researchers argue that the observed behaviours in response to noxious stimuli are reliable indicators of pain, this is rejected by others (see reviews by Diggles, Key, Rose and colleagues) who consider the observed behaviours simply reflexes or reactions to noxious stimuli. Rose et al (2012) reviewed studies of pain in fish and concluded that the results were also frequently misinterpreted and not replicable, and that claims that fish feel pain remain unsubstantiated. These conclusions have been disputed by Sneddon (2015). For example, Rose et al (2012) claim that fishes show normal feeding and activity immediately or soon after surgery, but subsequent studies have demonstrated significant changes in behaviour following surgery (Sneddon et al., 2018b). The clear majority view is that the weight of empirical evidence inevitably leads to the conclusion that fish can experience pain. Sceptics who deny that fish experience pain can be challenged to explain how pain arises in non-human primates with no evolutionary precursor (Sneddon and Brown, 2020). The consensus view is that the separation of nociception from an emotional response (pain) is outdated and that nociception and pain are both integral to the same system which functions to avoid harm (and is evolutionary ancient) (Brown, 2016). Much of the evidence for sentience comes from studies which demonstrate that fish have complex cognitive ability, comparable with other vertebrates

(Sneddon et al, 2018). Whilst, Browman et al (2019) and Diggles et al (2024) continue to challenge the evidence, an analysis of the reviews identified by this paper clearly show that they are in a small minority. Thirty-eight review papers have been considered, with 21 first authors. Ten reviews, by six lead authors were identified which argue that insufficient evidence exists to conclude that fish are sentient and can feel pain (Rose, 2002; Rose, 2007; Volpato et al., 2007; Diggles, 2016; Key, 2016; Rose, 2016; Browman et al., 2019; Hart, 2023; Diggles et al., 2024). By contrast, many papers published since 2002 present evidence for fish sentience and capacity to experience pain (discussed in the paper). Twenty-eight reviews by 15 lead authors (see [Appendix 2](#) and [3](#)) concluded that fish are sentient and can feel pain.

### 5.3. Assessment of welfare hazards and impacts

Welfare hazards identified in for handling, transport, killing and stunning (see Table 3, 4, 6 and 7) are summarised in the Tables below. Hazards are categorised by i) handling, ii) transport and iii) stunning / killing in Table 10. The welfare outcomes are similarly categorised in Table 11.

The associations between hazards and outcomes are detailed in Table 3, 4, 6 and 7. The negative affective states that may result from the identified hazards are pain, stress and fear. Based on a review of the literature, it is concluded that fish are sentient and capable of experiencing all three states (pain, stress and fear) and that no evidence was found to indicate significant differences between salmonids, cyprinids and tilapines with respect to sentience and capacity to experience negative affective states. Therefore, hazards which may result in physical trauma or tissue damage (e.g. mis-stuns, abrasive surfaces) and those that cause fear or stress (e.g. hypoxia, crowding, noise) need to be considered in welfare standards for all farmed bony fish species.

The hazards may directly or indirectly result in a negative affective state or indirectly. Hazards may also cause both pain and stress. For example, crowding fish may directly result in stress and indirectly pain due to physical trauma causing pain via contact between fish. Poor water quality during transport will directly cause stress and result in stress due to hypoxia. Extremely poor water quality can result in pain due to tissue damage. In summary, a hazard may directly result in stress or indirectly via hypoxia, exhaustion or hunger. Pain results from physical trauma from hazards associated with handling, transport or mis-stunning. Whilst slaughter methods cause pain due to trauma and tissue damage, they are considered as separate negative affective states in Table 11 in order to better understand the negative welfare impacts of different slaughter methods.

A fish may experience multiple hazards within a short space of time. For example, handling prior to transport may cause stress and physical trauma from crowding and brailing, followed by additional stress during transport due to poor quality, and further physical trauma from contact with abrasive surfaces. Stress due to one hazard may result in a fish being less well able to cope with other hazards. Thus, the negative welfare impact of combining hazards may be greater than the sum of the impact of individual hazards.

**Table 10. Summary of potential welfare hazards by activity**

Handling	Transport	Stunning/Killing
Pre-transport starvation	Poor water quality	Mis-stun (percussive or electrical)
Crowding	High water temperature	Exsanguination when conscious
Removal from water	Low water temperature	Temperature shock
Pumping through pipes	High density of fish	Exposure to high level of CO <sub>2</sub>
Dry brailing	Abrasive surfaces	Poor water quality
Wet brailing	Noise	Insufficient level of anaesthesia <sup>1</sup>
Pond drainage	High tow speed	Exposure to chemicals <sup>1</sup>

<sup>1</sup> only applies to killing for disease control purposes, i.e. culling

**Table 11. Summary of negative affective states by activity**

Negative affective state	Activity		
	Handling	Transport	Stunning and killing
Fear	✓	✓	✓
Stress	✓	✓	✓
Stress (hypoxia/asphyxia)	✓	✓	✓
Stress (exhaustion)	✓	✓	✓
Stress (hunger)	✓		
Pain (physical trauma)	✓	✓	✓
Pain (electrical shock)			✓
Pain (exsanguination/evisceration)			✓
Pain (chemical exposure)			✓

## 6. Discussion

The history of welfare standards for farmed animals reflects humanity's evolving relationship with the natural world. An understanding that animals are sentient and capable of suffering has driven the development of welfare standards and legislation for farmed terrestrial animals. The relatively recent inclusion of fish into the 'moral circle' alongside other vertebrate species can be seen as a logical step in the development of animal welfare standards and legislation. Brown (2015) speculated that the reasons why fish were excluded from the 'moral circle', and their welfare thereby disregarded, include history and tradition, and the difficulty of communicating across species boundaries. Commercial fisheries, which are rooted in ancient traditions of hunting, were considerably more important than aquaculture until relatively recently. Typically, hunting does not incorporate elements of animal care or husbandry. The apparent conceptual distance between fish and animal categories ranked 'higher' on the phylogenetic may also lead us to consider fish as inferior and non-sentient. Most importantly, a failure to recognise that fish are sentient has been the main barrier to progress in fish welfare, alongside the consequent potential costs and disbenefits to humans.

Whether the hazards identified cause pain, stress or fear depend primarily on whether fish are judged to be sentient. In this paper key publications relevant to sentience and specifically the capacity to experience pain, stress and fear have been reviewed. Only a small number of the approximately 20,000 teleost (ray-fined bony) fish have been studied in any scientific detail as research has focused on species of importance in fisheries or aquaculture. Generalisations based on studies in a few species should carry qualifications. The subject of sentience, and specifically whether fish feel pain, has been debated in the scientific literature (see 0). Some scientists continue to argue that insufficient evidence exists to conclude that fish are sentient and can experience pain (e.g. Diggles et al, 2024). However, most scientists, from a range of disciplines, accept that the weight of empirical evidence from both observational and experimental studies clearly leads to the conclusion that fish are sentient and capable experiencing pain, stress and fear. The scientific consensus has led many countries to update animal welfare legislation to include fish.

If fish sentience is taken as a working assumption, then the inevitable sequela is that many aquacultural practices unavoidably cause some degree of pain, fear and stress. The purpose of animal welfare legislation, standards and guidance is to ensure that avoidable suffering is minimised. This review has focused welfare hazards associated on handling, transport, killing and stunning of farmed fish. Fish may be transported live at several points in the production cycle. In many production systems fish are transported live after harvest to a market or processing plants for slaughter. Handling fish is an intrinsic part of their transportation and the process of stunning and killing fish. Therefore, welfare hazards due to transport, stunning and killing need to include those arising from the associated handling. In this report, potential welfare hazards are separately identified for handling, transport and stunning/killing (for human consumption and disease control purposes).

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The five freedom paradigm has provided guiding principles for the development of animal welfare (FAWC, 2009). However, this review is focused on aquacultural practices that result in negative welfare. The five domains model with its associated provisions better lends itself for the assessment of welfare hazards which associated with handling, transport, stunning and killing of fish (Mellor, 2016). A system to grade 'animal welfare challenges' has been developed that aligns with the 5 domains model (Mellor, 2017). EFSA developed a risk assessment approach to determine the importance of hazards identified in their assessments of the welfare aspects of stunning and killing fish (see Table 2 for a full list of reviews). Hazards were scored on intensity, duration and exposure (probability that the hazard occurs).

A number of modes of transport are used for live fish. The key issue for fish welfare is the environment, most importantly water quality, during transport. Interactions between pH, temperature, DO etc., creates challenges to maintain good water quality especially for long journeys. Monitoring water quality and the capacity to intervene (e.g. by increasing DO or lowering the water temperature) will help ensure the best possible welfare. Handling fish at loading, unloading and pre-stunning are infrequent, if not unique, events in the life of a farmed fish, which inevitably will result in elevated levels of stress. Stress can be reduced by minimising contact with the fish and time out of water.

Eight methods of fish stunning and killing for human consumption are reviewed in this paper. A total of 13 potential hazards were identified; between 2 and 5 hazards were attributed to each method (see Table 7). It is important to distinguish between hazards which arise infrequently, e.g. a mis-stun, which affect a small percentage of fish, compared with hazards which are intrinsic to the slaughter method (e.g. asphyxia in slush ice). The Humane Slaughter Association (HSA) considers that only percussive stunning and electrical stunning are acceptable methods for fish slaughter (HSA, 2016) and that other methods listed in Table 6 cause unacceptable levels of suffering.

This review has focused on methods of stunning and killing practised in on commercial farms and slaughter facilities. Most of the world's farmed fish are reared in Asia where the transport, handling and killing of fish are not regulated. Cyprinid species in both Asia and Europe are often sold at markets live. Fish slaughtered at home may suffer prolonged transport without water, asphyxia, temperature shock, excessive handling, and ineffective stunning (EFSA, 2009e).

## 7. Conclusion

On the basis of a review of the literature it is reasonable to conclude that there is a consensus, if not universal, amongst scientists from a range of disciplines that fish are sentient and capable of experiencing pain, stress and fear. This position was summed up by Sneddon (2021) who wrote 'the jury has made its decision and left the building. It is clear that there is ample evidence for pain in fish'. Although scientists cannot provide a definitive answer on the level of consciousness for any non-human vertebrate, the extensive evidence of fish behavioural and cognitive sophistication and pain perception suggests that best practice would be to lend fish the same level of protection as any other vertebrate.

The acceptance that fish are sentient and capable of suffering is reflected in national legislation of many countries which protects the welfare of fish used for experimentation and aquaculture. In addition, codes of practice promoted by organisations such as the Royal Society for the Protection of Animals (RSPCA) provide standards to promote fish welfare, e.g. RSPCA (2024). Similarly, producer organisations, e.g. the British Trout Association (BTA) and Scottish Salmon Producers Organisation (SSPO) publish codes of best practice which include welfare standards against which members are audited. Transport, handling, killing and stunning are amongst the aquacultural practices most likely to give rise to welfare hazards, and, therefore, should be the focus of legislation, standards and best practice.

Now the question of fish sentience and their capacity for suffering is largely settled, the debate has shifted to aquatic invertebrates. The welfare needs of cephalopod molluscs (e.g. octopus, squid, cuttlefish) and decapod crustaceans (e.g. lobsters, crabs, shrimp) are becoming increasingly recognised. The UK Government commissioned a review of the evidence of sentience in these groups (Birch, 2021) which concluded that all cephalopod molluscs and decapod crustaceans should be regarded as sentient animals. The work was recently updated by Browning et al (2025). As a consequence of the Birch review many invertebrate animal species were recognised as sentient in UK Law in the Animal Welfare (Sentience) Act (2022).

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## **Appendix 1 -Tranche 1 proposal**

### **Tranche 1: Review of the relevant scientific evidence on the welfare aspects of farmed fish during transport, the stunning and killing of farmed fish for human consumption and the killing of farmed fish for disease control purposes**

1. The key approaches to be adopted in this review are i) keyword based systematic literature reviews (using Google Scholar and Web of Science), and ii) identification of 'welfare hazard' (defined as factors or conditions with a potential to cause a negative animal welfare effect).
2. The starting point for the review will be a consideration of how the five freedoms of animal welfare (Webster, 2001<sup>2</sup>) can be applied to fish welfare.
3. Secondly, descriptions of the major types of transport currently used in aquaculture will be described for each major production system and species. The handling and methods used to stun and kill fish vary considerably with species and production system. The currently employed methods will be described. The killing of fish for disease control purposes usually takes place on farm. Methods (e.g. anaesthetic overdose) used for disease control purposes but not to kill fish for consumption will be described.
4. The scientific literature on the neurobiology and the special sense organs in fish, and their capacity to experience pain, fear, stress and expressions of sentience, will be reviewed.
5. Based on the descriptions discussed in bullet point 3, potential 'welfare hazards' will be identified for i) transport, ii) stunning and killing for human consumption and iii) killing for disease control purpose.
6. For each potential 'hazard', the relevant scientific evidence to determine whether (and to what extent) the 'hazard' may cause adverse welfare effects will be critically reviewed. Variation between most important farmed finfish species groups (salmonid, cyprinids, tilapines) will be discussed.
7. The review will highlight i) where there is scientific consensus, ii) where it is lacking and iii) where there is a lack of evidence around specific aspects of fish welfare or for certain species.

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<sup>2</sup> Webster, 2001, [The Veterinary Journal](#), [Volume 161, Issue 3](#), May 2001, Pages 229-237

**Appendix 2 - Review articles: Google Scholar and Web of Science searches**

<b>Authors</b>	<b>Title</b>	<b>Publication</b>	<b>Vol</b>	<b>Num</b>	<b>Year</b>	<b>Relevant</b>
Balash, JC; Tort, L	Netting the stress responses in fish	Frontiers in Endocrinology	10		2019	No
Barreto, M et al;	Emerging indicators of fish welfare in aquaculture	Reviews in Aquaculture	14	1	2022	No
Braithwaite, VA; Boulcott, P;	Pain perception, aversion and fear in fish	Diseases of aquatic organisms	75	2	2007	Yes
Brown, C	Fish intelligence, sentience and ethics	Animal cognition	18	1	2015	Yes
Chandoo, K et al;	Can fish suffer?: perspectives on sentience, pain, fear and stress	Applied Animal Behaviour Science	86		2004	Yes
de Castilhos Ghisi, N et al	Fish welfare: the state of science by scientometrical analysis	Acta Scientiarum. Biological Sciences	38	3	2016	No
Diggles, B et al	Reasons to be skeptical about sentience and pain in fishes and aquatic invertebrates	Reviews in Fisheries Science & Aquaculture	32	1	2024	Yes
EFSA	Scientific Opinion of the Panel on Animal Health and Welfare on a request from European Commission on General approach to fish welfare and to the concept of sentience in fish.	The EFSA Journal	954		2009	Yes
Hart, PJB	Exploring the limits to our understanding of whether fish feel pain	Fish Biology	102	6	2023	Yes
Jones, M et al	How should we monitor welfare in the ornamental fish trade?	Reviews in Aquaculture	14	2	2022	No
Lambert, H; et al	A Kettle of Fish: A Review of the Scientific Literature for Evidence of Fish Sentience	Animals	12	9	2022	Yes
Lund, V et al;	Expanding the moral circle: farmed fish as objects of moral concern	Diseases of aquatic organisms	75	2	2007	Yes
Maia, CM	Fish welfare in farms: potential, knowledge gaps and other insights from the fair-fish database	Frontiers in Veterinary Science	11		2024	No

<b>Authors</b>	<b>Title</b>	<b>Publication</b>	<b>Vol</b>	<b>Num</b>	<b>Year</b>	<b>Relevant</b>
Oidtman, B; Hoffmann, RW;	Pain and suffering in fish	Berliner und Munchener Tierarztliche Wochenschrift	114		2001	Yes
Omeji, S. et al	Stress concept in transportation of live fishes—a review	Journal of Research in Forestry, Wildlife and Environment	9	2	2017	No
Posner, L P	Pain and distress in fish: A review of the evidence	Ilar Journal	50	4	2009	Yes
Proctor, H	Animal sentience: Where are we and where are we heading?	Animals	2	4	2012	No
Rose, J	Anthropomorphism and 'mental welfare' of fishes	Diseases of Aquatic Organisms	75	2	2007	Yes
Rose, J	The neurobehavioral nature of fishes and the question of awareness and pain	Reviews in fisheries science	10	1	2002	Yes
Schroeder, P	Pain sensitivity in fish	CABI Reviews			2018	Yes
Sneddon, L	Pain recognition in fish	Veterinary Clinics: Exotic Animal Practice	26	1	2023	Yes
Sneddon, L	Can fish experience pain?	The welfare of fish (book)			2020	Yes
Sneddon, L	Evolution of nociception and pain: evidence from fish models	Philosophical Transactions of the Royal Society B	374	1785	2019	Yes
Sneddon, L	Comparative physiology of nociception and pain	Physiology			2017	Yes
Sneddon, L	Evolution of nociception in vertebrates: comparative analysis of lower vertebrates	Brain Research Reviews	46	2	2004	Yes
Sneddon, L Brown, C	Mental capacities of fishes	Neuroethics and nonhuman animals (book)			2020	Yes
Sneddon, L et al	Defining and assessing animal pain	Animal behaviour	97		2014	Yes
Volpato, GL et al	Insights into the concept of fish welfare	Diseases of Aquatic Organisms	75	2	2007	Yes

**Appendix 3 - Additional review papers identified from publications listed in Appendix 2**

<b>Authors</b>	<b>Title</b>	<b>Publication</b>	<b>Vol</b>	<b>Num</b>	<b>Year</b>
Braithwaite, V.A., Huntingford, F.A.,	Fish and welfare: do fish have the capacity for pain perception and suffering?	Animal Welfare	13		2004
Broom, D.M	Sentience and animal welfare	CABI			2014
Brown, C.,	Fish pain: An inconvenient truth	Animal Sentience	32		2016
Browman, H.I et al	Welfare of aquatic animals: where things are, where they are going, and what it means for research, aquaculture, recreational angling, and commercial fishing	ICES Journal of Marine Science	76		2019
Diggles, B.,	Fish pain: Would it change current best practice in the real world? 1, 35.	Animal Sentience	1	35	2016
Huntingford, F.A. et al	Current issues in fish welfare.	Journal of fish biology	68		2006
Jones, R.C.,	Fish sentience and the precautionary principle.	Animal Sentience	1	10	2016
Key, B.,	Why fish do not feel pain	Animal Sentience	1		2016
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