Humane Slaughter Association
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Humane slaughter of finfish farmed around the world

Summary

Approximately 360 species of finfish are farmed worldwide and it has been estimated that at least tens of billions of individual farmed fish might be slaughtered every year, which is a far greater number than all the individuals of any other type of farmed vertebrate animal. Finfish are considered capable of experiencing fear and pain and legislation exists in some parts of the world (e.g. the EU) to protect their welfare. Unfortunately, the most common methods of slaughtering finfish (e.g. asphyxia in air or hypothermia in ice slurry) are likely to cause considerable distress. A minority of species (e.g. Atlantic salmon, rainbow trout) in a small number of, mostly European, countries are routinely stunned using higher-welfare methods but there is no one-size-fits-all set of stunning parameters for all species of fish. Funds are required for scientific research and technological development to refine, and to develop new (e.g. SPUC), humane methods of slaughter and to determine humane stunning parameters for a greater range of species of finfish, to suit their various rearing environments and to minimise handling and movement prior to death which can cause stress and chemical and physical deterioration in product quality. Funds are limited, as is legislation requiring stunning of fish at slaughter, and sophisticated stunning equipment is typically expensive, so applying scientific research to improve fish welfare in-practice will likely be a slow process, partly also because the majority of finfish are farmed in countries where the concept of how improved animal welfare can benefit product quality is in its infancy, so finfish species must be prioritised in terms of the greatest outcome. Those species produced in the greatest quantities and with the greatest value (e.g. species highly-prized for the sushi market) are good candidates, as are species produced in relatively-wealthy countries, including member states of the EU (where a great deal of scientific research into fish welfare takes place and where retailers and consumers are likely to request a higher-welfare fish product). It is important that consumers are made aware that fish are capable of suffering and that it is possible (for species with identified stunning parameters) to purchase products made from fish which are assured/certified to have been killed more humanely. Whilst much of global aquaculture is carried out by small-scale farmers, there are many large companies producing finfish for domestic and export markets and therefore offer more scope for introducing stunning. Small-scale producers can be encouraged to improve fish welfare by using any humane form of stunning available (e.g. 'priests'/mallets) and by killing the fish on-farm or, failing that, at the point of sale to the customer. Large- and small-scale producers can both improve handling and movement practices prior to slaughter and small-scale producers should be encouraged to improve storage conditions for live fish at markets. Determining humane fasting durations for fish prior to slaughter, which do not damage product quality, is another area warranting scientific research and the possibility of involving industry in sponsoring such work, along with stunning research, is a potential way of hastening fish welfare improvements. In the short-term, it is unfortunately unrealistic to introduce stunning for all aquaculture finfish; however, encouraging adoption of humane handling and stunning for species with known stunning parameters, in as many countries as possible could improve fish welfare over time and may have a positive impact on the safety of the food products (EFSA, 2009h).

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1. Introduction

This report is based on a Humane Slaughter Association (HSA) workshop entitled 'humane slaughter of finfish farmed around the world', held on 19th June 2014 in London, UK. The HSA workshop discussed the **welfare of those aquaculture finfish which, during the slaughter process, are not currently routinely rendered immediately unconscious, or unconscious without potential distress or discomfort**. The aim of the HSA workshop was to **encourage further research and development in humane slaughter of farmed finfish (particularly Actinopterygii) intended for human consumption**. This HSA workshop was **focussed on the stunning methods and stunning parameters for farmed finfish**, rather than the pre-slaughter handling and transport processes, though these are undoubtedly important for fish welfare. (This workshop did not discuss recreational angling, the capture of wild fish, the welfare of crustaceans, molluscs or any other group of invertebrates classed as 'shellfish'.)

Scientific studies investigating fish anatomy, behaviour and response to analgesics suggest that fish have the potential to experience fear and pain (e.g. Sneddon, 2003; Sneddon *et al*, 2003; Yue *et al*, 2004; Dunlop *et al*, 2006; Ashley *et al*, 2007; Reilly *et al*, 2008; Mettam, 2011; Yue Cottee, 2012). In February 2014, the UK's Farm Animal Welfare Committee stated that it supports the scientific consensus that fish can experience pain (FAWC, 2014). Across Europe, legislators are increasingly considering the welfare of fish during the various procedures that humans impose on them. For example, by 8 December 2014, the European Commission was due to submit to the European Parliament and to the Council a report on the possibility of introducing specific rules across the European Union (EU) regarding the protection of fish farmed for food, at the time of their killing.

Scientific research on fish welfare at slaughter and applied improvements in the humaneness of the slaughter procedure has, so far, mostly been undertaken in a select few countries within Europe. This is the result of certain sectors of the aquaculture industry understanding that improving animal welfare can attract consumers and can improve the quality (e.g. Roth *et al*, 2012), and potentially the safety (EFSA, 2009h), of the end-product.

Consumption of farmed fish is promoted as an alternative to mammalian and avian meat products and to capturing wild fish, the stocks of some of which are under pressure (FAO, 2014b). EU aquaculture production is mostly destined for the EU market but the EU Fish Market report (2014) estimated that in 2011 consumption of farmed fish products (not just finfish) represented 24% of total EU consumption, whilst the Federation of European Aquaculture Producers (FEAP, 2014b) reported that the EU imports approximately 65% of its capture fisheries and aquaculture sea food consumption (unfortunately official statistics do not yet differentiate between figures for capture and aquaculture finfish, of all species, EU-wide (FAO, 2015f)). In 2012, most finfish aquaculture production was in Asia, with China, India, Viet Nam and Indonesia leading production in that order (FAO, 2014a). Since 2008 Asia has produced more fish (including finfish and other seafood) through aquaculture than via wild capture fisheries. In 2012 aquaculture supplied approximately 42% of the fish (finfish and other seafood) produced globally (FAO, 2014b) and the Food and Agriculture Organization of the United Nations (FAO) estimates that finfish accounted for two-thirds of the total fish tonnage. (The FAO presents statistics for 'food fish' or 'fish' which is defined as finfish, crustaceans, molluscs, freshwater turtles, amphibians and invertebrates including sea cucumbers, sea squirts, sea urchins and jellyfish.) In 2013, aquaculture of finfish accounted for 37.5% of total global finfish production volume (FAO, 2015d); in 2011 aquaculture produced 34.2% of finfishes (FAO, 2013a). Fishcount (2014) estimated that in 2011 between 38 and 128 billion individual farmed fish were slaughtered worldwide for human consumption (currently, official data is not collected on numbers of individual finfish reared and slaughtered for human consumption). Figure 1 summarises the main global production locations of major types of farmed fish.

Figure 1. Categories of fish produced around the world. Adapted from D. Scarfe.

2. What methods of slaughter are currently available and in-use?

With regard to farmed finfish, the European Food Safety Authority (EFSA, 2004) stated '*Many existing commercial killing methods expose fish to substantial suffering over a prolonged period of time. … for many species, there is not a commercially acceptable method that can kill fish humanely*'. Slaughter methods that have been scientifically-evaluated and which are considered to compromise the welfare of farmed finfish when used without prior stunning include: asphyxia in air or amongst solid ice; hypothermia in ice slurry; gill cutting or gill pulling; immersion into ambient or chilled water containing a moderate to high concentration of carbon dioxide (sometimes with oxygen levels of 70-100% saturation: IBFC, 2017); decapitation; ammonia or salt baths; electroimmobilisation (conscious paralysis) caused by application of inappropriate electrical parameters (Robb *et al*, 2000; Lambooij *et al*, 2002a; Roth *et al* 2007; Acerete *et al*, 2009; van de Vis & Lambooij, 2016). Whenever possible, these methods should be avoided.

A definition of 'stunning' might be '*any intentionally induced process which causes loss of consciousness and sensibility without pain, including any process resulting in instantaneous death*' (European *Council Regulation 1099/2009 on the protection of animals at the time of killing*). This might involve methods that immediately render the fish unconscious or those that cause a slower, progressive loss of consciousness over a period of time and without causing pain, distress or suffering. It is important to not classify methods or equipment that are intended to stun as for 'stunning' or a 'stunner' unless the method, parameters and equipment have been scientifically validated to succeed in achieving that outcome. The World Organisation for Animal Health (OIE) publishes an *Aquatic Animal Health Code* for its 181 member countries, which includes recommendations for animal welfare when transporting, stunning and killing farmed fish for human consumption and states: '*farmed fish should be stunned before killing, and the stunning method should ensure immediate and irreversible loss of consciousness*' (OIE, 2017).

Two common methods of stunning fish, currently considered to be the most humane and globally-acceptable for food safety, are electrical and percussive stunning. Both methods are already in-use in the rainbow trout and Atlantic salmon industries, respectively, and the stunning parameters are based on scientific recommendations (e.g. Robb *et al*, 2002b). Depending on the species that electrical or percussive stunning is applied to, and the parameters used, the stun may cause death (stun-killing method) or the stun may be reversible and require a follow-up killing method, e.g. cutting of all gill arches to cause bleeding; or chilling in ice; and/or immersion in chilled deoxygenated water (produced by saturating the water with gas). (Electrically-induced cardiac arrest is known to be temporary in fish, so some electrical equipment designed to stun-kill aims to maintain fish in the electrical pathway (i.e. under tetanus) for long enough for death to occur from the heart being prevented from pumping oxygenated blood to the brain.)

3. What scientific research is required when investigating humane stunning of finfish?

Finfish have evolved many different lifestyles and so have different tolerances and utilise different behavioural repertoires for survival. After applying a treatment intended to stun a fish, relying solely on fish behaviour to interpret states of consciousness can be misleading due to variation in normal fish behaviour (e.g. aversive stimuli may trigger a variety of escape responses in different species; some may be more inclined to remain motionless whilst others may prefer to swim away) and due to the effect on the body of the type of stunning used (e.g. electrical stunning affects animals' muscles, potentially preventing, or generating, certain expressions which affects the suitability of certain behaviours for use in assessing the effectiveness of stunning). Therefore, it is essential to neurologically investigate (e.g. using electroencephalograms, EEGs) the humaneness of slaughter methods and parameters in order to be sure that the fish immediately lose consciousness on-application of the intended stunning parameters, or quickly afterwards (and without suffering) for methods that cause a progressive loss of consciousness.

Nevertheless, once validated, animal-based welfare indicators can be used in practical working environments, e.g. on-farm. The current indicators can be conservative (rhythmic breathing and eye-roll reflex) or unreliable (e.g. application of a possibly painful stimulus to the fish's body, such as a pin-prick to the tail or mouth) (Lambooij *et al*, 2010). So, more scientific research is required to identify correlations between brain activity and fish behaviour, to provide more accurate animal-based indicators of consciousness. Although some degree of generalisation is possible, there is no single set of behaviours that can be used for all species of finfish, to determine the effectiveness of stunning. It is therefore necessary to assess each type (e.g. order, family or genus), or even species, of fish on its own idiosyncrasies.

EFSA (2013) provide guidance for the performance of scientific research intended to evaluate potential stunning methods/parameters, based on assessment criteria for the eligibility, quality of reporting and quality of methodology. This guidance is designed to assist scientists/engineers when developing new stunning methods proposed for use in the EU, and to ensure a level of animal welfare at least equivalent to that of existing, legally-permitted methods. Although, at the time of writing, there were no specifically permitted stunning methods and related specifications (e.g. key parameters) for finfish in Annex I of EC Regulation 1099/2009, the principles of EFSA's (2013) scientific assessment criteria can still be applied to research on humane slaughter of fish, worldwide. Readers may also find useful, measures described in van de Vis & Lambooij (2016).

If scientists choose to evaluate stunning methods/parameters that are intended to cause an *immediate* onset of unconsciousness but which, for routine commercial slaughter, involve application of the intended stunning treatment for multiple seconds (e.g. conventional electrical stunning), then their research must objectively measure (e.g. using EEGs) the immediacy of stunning to confirm that the chosen parameters can generate unconsciousness within 100-200 milliseconds (1 second absolute maximum) of the start of application, to reduce the risk of recommending parameters/methods that initially cause conscious paralysis (e.g. painful electroimmobilisation) followed by an eventual loss of consciousness some seconds after the start of application, which would be inhumane.

In the case of electrical stunning, with poultry there can be differences in the voltage amplitude required for each sex, to generate the same current (Prinz *et al*, 2012), possibly due to differences in body tissue composition. Whether a gender-effect might apply to some species of fish is unknown but ought to be considered. Some fish species are reared as single-sex groups (e.g. portion-size rainbow trout females; male tilapias) because they reach sexual maturity later and grow faster (Bostock *et al*, 2010). If the humaneness of certain stunning parameters is only tested for one sex, then those stunning parameters may need to be verified for the other sex, for use on farms that rear mixed-sex groups.

If the same species of diadromous fish (e.g. salmonids, sturgeons, striped bass, shads, milkfish, barramundi, eels) are harvested from freshwater *and* from salt-water in different parts of the world, then separate fresh- and salt-water electrical stunning parameters may be required and therefore must be determined.

For marine species of fish stunned in sea water, the minimum electric field for *group* stunning of a particular species might be greater than the minimum electric field required to stun an individual fish of the same species/type (Lines & Kestin, 2004), which means humane stunning parameters determined in the laboratory on single fish need to also be verified as humane for use on multiple fish on-farm during commercial-scale harvest.

When trialling stunning parameters, in terms of animal welfare, there is no maximum 'power' of parameters unless product quality begins to cause concern. Researchers should begin by trialling parameters that are more likely to humanely stun 100% of the sample and then, if successful, and only if necessary, reduce the 'power' of the stunning parameters until the minimum parameters that can achieve 100% effective stunning are identified. An assessment of the effect of the minimum stunning parameters on product quality (internal and external) should also be carried out to identify whether any additional research is required to identify parameters that achieve effective stunning *and* an acceptable quality product. Publicly reporting the outcome of trials of stunning parameters (in scientific and industry journals, and/or using a system suggested on page 42 of this report, e.g. FindIT www.feap.info/Default.asp?SHORTCUT=709) will allow scientists around the world to identify what research remains to be done and to avoid unnecessarily repeating work (which is costly and contradicts the animal welfare research principles of the 3Rs – replacement, reduction and refinement). When publishing welfare and quality results, it will be critical for scientists to accurately report the common and scientific names of the species the data applies to, to avoid confusion (due to the large number of species of finfish, their synonyms and, in some cases, very similar common names).

4. What scientific research and technological development is necessary to refine existing stunners and/or produce new stunning methods and systems?

There is a need for fundamental research studies to identify different, or modified, methods of stunning, which might inform the humane killing of a wide range of fish species and improve product quality.

Electrical stunning

Electric stunning, whether dry or in-water, is typically applied to the whole body of a fish (not just the head to target the brain). A disadvantage of whole-body electrical stunning for all vertebrates, is the risk of damage to the flesh. Haemorrhaging, gill flaring and distorted or broken spines are some reasons given as to why conventional electrical stunning has not yet become widely-used within the Atlantic salmon and European sea bass industries. Some members of the Atlantic salmon industry would like to use in-water electrical stunning because of the benefits for the fish (e.g. reduced stress because fish are not emersed before stunning) but report it is difficult to find equipment (or parameters perhaps) that are suitable. Indeed, only 5% of UK Atlantic salmon were electrically stunned between 2009-2013; the rest were percussively stunned (IBFC, 2017). Similarly, electrical stunning of rainbow trout was previously trialled in Poland but abandoned due to carcase damage (IBFC, 2017).

Where conventional electrical stunning is in-use, concern for product quality can lead to a compromise between using the most humane electrical parameters for stunning and the best electrical parameters for product quality (e.g. fish: Robb *et al* 2002b; poultry: Lines *et al* 2012). For example, use of high-frequency low-amplitude currents can benefit product quality but can also lead to less than 100% of individuals experiencing effective stunning. This situation is not ideal for animal welfare (compared to the use of lower frequency (e.g. 50-100 Hz) currents), even though stunning of some fish in a given harvest is, technically, an improvement over a complete absence of stunning for all fish in that harvest. If this scenario can be avoided by developing improved electrical stunning systems that stun 100% of fish *and* produce a better product, then this is likely to be desirable to industry and lead to a dramatic applied improvement in fish welfare at slaughter.

More fundamental research is needed to determine: a) the electrical conductivities of fish tissues, particularly within the head (Lines & Kestin, 2004) and b) what proportion of an electric current (dry stunning) or electric field (in-water stunning) flows through the brain of a fish (different skull structures in different species of fish might create variation). In chickens it was predicted that, on average, only 18% of a current passed through the skull bone (Woolley *et al*, 1986). In addition, an individual animal's electrical resistance can be highly variable relative to other individuals of the same animal type/species. If it is possible to refine electrical stunners to increase the proportion of current flowing through the brain and reduce the proportion flowing through the body, this might simultaneously benefit fish welfare *and* product quality. Lines & Kestin (2004) found that the conductivity between the eyes of rainbow trout appeared to be greater than elsewhere on the trout's body.

On some fish farms, electricity is applied to a batch of fish in a container (sometimes in-water, sometimes de-waterered) in an attempt to stun them, using different shapes of electrodes (e.g. rods, metal plates), made electrically 'live' either at the start of loading fish into the container or once the container has been partially- or completely-filled with fish. Considering these varying operating practices, it is largely unknown how electricity passes through a batch of fish in physical contact with each other. Does the electric field pass through each fish's brain? Do some fish receive more or less of the electric field than others and if so, why? If less, is the electric field low enough to cause electroimmobilisation (paralysis) instead of unconsciousness? Lines & Kestin (2004) found that the magnitude of an electric field passing across an in-water stunner can vary greatly (particularly in sea water) based on the clustering pattern of multiple fishes within the stunning chamber and the conductivity of the water; greater clustering of fish leads to greater deviation in the electric field.

Exploration of novel modes of application, or types, of electrical stunning may offer advantages over conventional electrical stunning if the welfare of the fish and the quality of the product can both be improved proportionally. For example, very high amplitude currents delivered at short pulse durations may be more likely to effectively stun an animal whilst improving product quality, e.g. fish: Roth *et al* (2003); single-pulse ultra-high current (SPUC) stunning of mammals: Robins *et al* (2014). For example, to create the ideal processing scenario that enables pre-rigor mortis filleting, it is important to keep electrical stimulation to a certain minimum, e.g. a maximum of 10 seconds in Atlantic salmon (van de Vis & Lambooij, 2016; IBFC, 2017). Investigating novel approaches to stunning might be even more important as consumer preferences evolve; for example, it was reported that UK production of traditional 'table trout' (400 – 500 g whole fish) is static or in slow decline and is expected to decline further due to consumer preferences for filleted products (FEAP, 2015b); electrical stunning systems may need to be able to adjust to this change in presentation of fish at the place of sale (haemorrhages will be more visible) and for larger-size fish. In addition, if new technologies like SPUC can stun-kill, this will reduce the need to expose fish to conventional electrical pathways for prolonged durations in order to kill, which might also uphold product quality and thereby encourage adoption of stunning systems.

Percussive stunning

For some fish species, e.g. European eel, yellowtail kingfish, 'African catfish', equipment that can reliably generate an effective stun has not yet been developed (IBFC, 2017).

For species that can be more reliably effectively stunned, at present, automated percussive stunners may not be able to stun 100% of fish in a harvest because there may still be a range of sizes of fish (including deformed or sexually-mature individuals with different body shapes), despite the producer trying to rear fish that are as uniform as possible. To reduce this problem, fish can be graded prior to harvest but the associated handling (forced movement of the fish, periods of time out-of-water and drops between graders and enclosures) may be stressful for the fish and therefore is not an ideal solution. Therefore, it will be helpful if automated percussive stunners can be further developed to increase the proportion of fish successfully stunned, first-time; this might involve refining the properties (e.g. size, shape) of the knocker head and the kinetic energy provided, as well as refining fish aligning devices which automatically line-up and position fish for the percussive blow.

Percussive stunners should be designed to accurately-position and deliver *one* blow of sufficient concussive force to cause an immediate loss of consciousness or death. Manufacturers should be cautious about developing stunners whose routine operation requires multiple (e.g. two) blows to each fish's head. Fish may arrive at a stunning point in batches and typically out-of-water, putting staff under pressure to render all fish unconscious as quickly as possible to prevent distress and deterioration in product quality. 'Double-stunning' every fish will delay stunning of the other conscious fish, emersed on the stun table, awaiting stunning. If a stunner successfully stuns with one blow (which it should be designed to do), then there should be no need for routine repeated application unless double-stunning is required to reliably achieve a stun-kill.

Other potential methods of stunning

It will be particularly beneficial if research can identify methods of stun-killing fish (i.e. slaughter methods that do not rely on stunning to be followed-up by a separate killing method) which can be applied to fish in groups and in-water.

It was suggested at the HSA workshop that gas killing of fish should be investigated further. Research in this area is, so far, extremely limited. Immersion of fish into water containing high concentrations of carbon dioxide (CO_2) is considered detrimental for welfare (Erikson, 2011) but some considered that there may be potential to use gases in different ways and that some species of fish appear to react less violently than others to CO_2 (although research would need to confirm whether such behaviour was representative of a genuine lower level of suffering or simply an idiosyncratic response of that species to a stimulus that is still aversive). Gerritzen *et al* (2013) reported that, in poultry at least, '*it seems better to kill animals using* [initially low and] *gradually increasing CO_2 concentrations*'. There might also be a possibility of altering the gas delivery strategies to create more humane gas stunning scenarios for fish but exposure of poultry to initially-low CO_2 concentrations that gradually increase still appears to cause a degree of potential aversion. An investigation into the efficacy of nitrogen (N_2) as a humane killing method for Atlantic salmon recorded behaviour indicative of significant aversion (Erikson, 2011), whilst another on rainbow trout reported there was no strong aversive reaction to N_2 (Wills *et al*, 2006). Experiments are being undertaken to investigate the effects of CO_2-Argon (Ar)-N_2 mixtures for sea bass and sea bream (Roque *et al*, 2017), which are reported to appear to cause less discomfort than CO_2 alone, which is not considered humane for sea bass (EFSA, 2009a).

Chemical stun-killing methods may offer advantages for fish welfare ***if*** the fish are, thereafter, deemed safe for human consumption. Yue (2014) encouraged the investigation of AQUI-S® as a pre-slaughter sedative because it appears to reduce distress during emersion for application of the chosen method of stunning (e.g. percussive). AQUI-S® (isoeugenol) is currently the only approved aquatic anaesthetic that can be used during harvesting of fish for human consumption in Australia, Chile, Costa Rica, Faroe Islands, Honduras, Korea, New Zealand and Vietnam (AQUI-S, 2015). However, chemical methods are currently of limited-use globally because not all governments approve them from a food safety perspective. For example, in May 2008 the United States of America's Food and Drug Administration and Fish & Wildlife Service strictly prohibited all use of AQUI-S® for food fish (www.fws.gov/fisheries/aadap/aquis.htm). In addition, caution must be exercised because isoeugenol (10 mg/L) can be detected, and is responded to aversively (e.g. faster swimming), by zebrafish (Readman *et al*, 2013); consideration must be given as to whether isoeugenol may negatively affect other fish species' welfare. Ideally, for the farmers' ease and for fish welfare, chemical methods will stun-kill fish to enable a one-step slaughter process (i.e. the chemical stuns and kills the fish without further intervention or use of other stunning or killing methods afterwards). But it may be a significant challenge to identify stun-kill doses of suitable chemicals which do not compromise consumer (i.e. human) health and safety.

5. Animal welfare considerations when designing stunning equipment

For many species of fish, group stunning is likely to be preferred both for producers' ease and for animal welfare. It is also preferable for welfare to keep conscious fish immersed in water as much as possible, and may assist with creating more uniform electric fields in certain stunning containers, so it is important to encourage use of in-water (or 'wet') stunning methods and systems. In the case of electrical stunning, there may be a need to transfer fish from their rearing pen water into water that is more appropriate for stunning (e.g. of a minimum conductivity to increase the likelihood of effective stunning at a given magnitude of electric field), which may require fish to briefly pass over a de-waterer before entering the stunning system. Changes in water conductivity, and de-watering systems, must not cause fish to become distressed. For example, ideally, stunners should be designed to immediately apply the electric field as soon as fish enter the stunner's water.

If in-water electrical stunning equipment is meant to apply an electric field in a particular direction, relative to the orientation of the fish, then the equipment must be designed to ensure all fish are presented to the electrodes in the correct orientation, e.g. by constructing the stunning chamber with dimensions that only permit the intended orientation of the fish.

Electrode arrangement must account for environmental factors, particularly for wet stunners. Placement of electrodes on the dorsal (ceiling) and ventral internal sides of a stunning chamber means any air bubbles at the top will impede electrical contact and may prevent electrical flow. Positioning electrodes on the lateral internal sides of a stunning chamber is acceptable for systems fixed on land, but if the stunner is 'at-water', e.g. on a floating platform or boat, any rocking motion may cause the water to repeatedly momentarily make, and break, contact with the electrodes, causing pre-stun shocks and ineffective stunning.

Electrical stunning equipment must be designed, and fish loaded into it, in a manner that prevents fish from receiving pre-stun shocks. Any possibility for a part of a fish to come into contact with electrified water or electrodes *before the head (brain) does*, may result in a severely painful electric shock. Pre-stun shocks typically trigger an escape response, so fish might be suffering from pre-stun shocks if, at the same point(s) on a processing line, fish tend to suddenly exhibit abrupt behaviours that might indicate distress, e.g. flipping. Also, if fish display more than one contraction on entry to electrified water or electrodes, this may indicate interrupted application of the initial electric field or current flow. As well as being detrimental to fish welfare, pre-stun shocks may pose a risk of carcass damage, e.g. haemorrhages in the fillets, broken bones. To ensure all fish in a stunning container are simultaneously provided with as uniform a current/electric field as possible, electrodes should be designed to cover as much of the surface area of the stunning container as possible. For example, in a batch-style container each electrode should be wide enough to span almost the entire side of the container. Electrodes should also extend the full depth of a container. The electrodes should be positioned on the longest sides of the container, so the distance between the electrodes is as short as possible, increasing the electric field (and likelihood of an effective stun) provided to the fish. Alternatively, a mesh electrode fixed round the inner circumference of the container and an inner cylindrical electrode at the centre of the container may improve the electric field/current flow. (The available electrical power source will dictate the maximum size container and/or maximum number of fish, for effective stunning.) It must not be possible for fish to get stuck behind an electrode (i.e. in a position that would be out of the conduction pathway). The electrodes should be placed into position and then switched on before fish are loaded into the container, to reduce risk of injury to fish if electrodes are positioned after loading the container with fish. (Turning the electrical flow on prior to loading the fish reduces the risk of fish towards the bottom of the container suffering from crushing as hundreds/thousands of conscious fish are loaded atop one another, particularly in a dry batch stunner.) For dry stunning, a shallow layer of water in the bottom of the container will assist with providing a continuous conduction path for the first few fish to enter the container and will hopefully provide them with a more uniform distribution of electrical flow, reducing the risk of pre-stun shocks and ineffective stunning. Filling of a container should be as uniform as possible, which might require regular altering of the position of the chute delivering fish. For in-water pipeline stunners, the water flow rate should be considered carefully and routinely measured, to ensure the minimum recommended duration of application of electricity is achieved (i.e. that each fish takes a specified minimum amount of time to pass through the stunner in order to stun or kill); this is particularly important for species that are harvested in very large numbers and not routinely bled immediately after stunning, e.g. portion-size rainbow trout. Also, the water flow rate must not be slow enough to allow fish to swim against the flow, perhaps hovering around the entrance to the stunner where they could be at risk of pre-stun shocks. Therefore, designing wet stunners requires a careful balance of the speed of water flow. (Water flow rates can be monitored using a flowmeter or by timing how long it takes for a single, very-recently-killed fish to travel through the stunner. For this reason, pipeline stunners should be fitted with transparent pipes at the entrance and exit of the stunning system to ensure the test fish can be seen as it enters and exits the stunner.)

For good practice, an electrical stunner will ideally have a built-in ‘stop’ mechanism if it is unable to generate sufficient current/electric field to stun a given resistance of fish.

At present, dry electrical stunning and percussive stunning involve removing fish from water either completely or partially, which may be stressful (Douxfils *et al*, 2014). Such methods may also require manipulation of the fish (e.g. into single-file and/or single-layers, or orienting fish head-first into a stunner to ensure stunning is humane), which may require labour and/or a sophisticated automated separation/sorting system but, still, occasionally a fish may incorrectly enter a stunner, which, over time, may mean a large number of individual fish are improperly stunned. (In Norway, 25-30% of Atlantic salmon are oriented prior to dry electrical stunning, but for the remaining 70-75% that are not oriented there is a welfare concern, although more orienting devices are being installed as stunners are gradually replaced across Norway’s industry (IBFC, 2017).) Nevertheless, dry electrical stunners require less power than in-water electrical stunners and may allow more electrical power to be transferred to a fish’s brain to stun it. Therefore, dry electrical stunning offers an advantage/solution for species that are relatively resistant to percussion or electricity and which require a relatively high-amplitude current (or electric field) to effectively stun them. Also, it has been suggested to design dry electrical stunners that enable fish to be humanely stunned irrespective of their orientation (i.e. even if the fish enter tail-first); this would be very beneficial, however the voltage requirements can be 40% greater (van de Vis & Lambooij, 2016).

Long stun-to-stick/cut (stun-to-bleed) times may increase the risk of fish recovering consciousness after stunning; equipment designed to shorten the time between stunning and cutting to cause bleeding will improve fish welfare. Similarly, methods of cutting fish (with the intention of bleeding them) that cause a slow rate of blood loss should be replaced with more appropriate cutting methods, e.g. cutting the gill arches on both sides of the head (rather than just on one side), or cutting major arteries conveying oxygenated blood to the brain in the shortest time, or decapitating fish (e.g. Atlantic salmon: IBFC, 2017).

Wherever possible, stunning and killing equipment should be designed to be kept at, or easily-transported to, the fish rearing pens, including for species that are grown offshore in potentially rougher weather conditions. Killing fish as they leave their rearing pen may reduce the risk of causing the fish distress or injuries and may therefore be better for fish welfare and product quality, than transporting them (e.g. by road or well-boat) or moving them (e.g. using pumps) to a slaughtering point elsewhere. For example, pumps can lead to exhaustion of fish because they may resist travelling with the flow of water; after pumping, salmon may struggle to swim into an automated percussive stunner and some may be incapable of remaining upright for effective stunning (J. Lines personal communication (pers. comm.) 19 June 2014). Roth *et al* (2009) found that stunning Atlantic salmon at the rearing cage produced fillets with better quality attributes (e.g. higher pH, later onset of rigor mortis, best colour and less gaping), whilst pre-rigor-filleted fillets became lighter in colour with increasing pumping distance (up to 120 metres) from the cage; the authors concluded that, for flesh quality, pumping of conscious fish must be minimised.

The FAO (2014b) suggested that the rapid growth of inland aquaculture of finfish in less-wealthy countries reflects that it is easier to achieve than marine aquaculture (mariculture). However, the FAO (2014b) also points out that, when competing for the development of land, aquaculture often loses out to other sectors (e.g. hydroelectricity) and reported that there is a need to reduce pressure on land-use and to relocate inland aquaculture offshore (FAO, 2013b). In Turkey, European sea bass are electrically stunned offshore (IBFC, 2017). It has been suggested that offshore farming, perhaps as far as 2 km from land, of cobia and salmon is likely to become more common in the future (Bostock *et al*, 2010) and Bourne Jr. (2014) reported that the largest offshore fish farm in the world is located eight miles off the Caribbean coast of Panama where the waves may reach 20 feet or more. (The farm is capable of holding more than a million cobia in 12 cages. Although a cage could hold hundreds of thousands of cobia, they are stocked less densely, perhaps 40,000 cobia per cage.) So, means of humanely and safely slaughtering vast numbers of fish offshore are required.

Consideration of how aquaculture facilities and husbandry practices are evolving, in relation to how fish can, at the end-point, be harvested or culled humanely, must be kept in mind. Bostock *et al* (2010) identified recirculating aquaculture systems (RAS) as potential solutions to the problems of near-shore fish farming such as availability of water, environmental degradation and competition with tourism. Some types of fish rearing enclosures (e.g. tanks) might offer potential as dual-purpose rearing and in-pen stunning systems, which do not require crowding or removal of the conscious fish from the home enclosure, resulting in possibly less stress for the fish and fewer procedures and perhaps less space requirements for the farm. Of course, safety procedures would need to be robust to ensure there could not be an accidental killing of fish that are not yet ready for harvest, particularly given the long durations of rearing finfish to slaughter weight. In addition, this may not be possible for offshore fish enclosures with direct water contact with the surrounding natural environment.

6. What can be done now?

Known stunning parameters

Where parameters have been scientifically identified, their application in industry should be encouraged. Some producers may be more inclined to adopt humane stunning methods than others, depending on their customer base and whether those customers broadly share particular views on what developments are important for the product. For example, in the UK humane stunning of farmed fish is a desirable attribute and under the industry-developed Quality Trout UK scheme, '*the harvesting procedure should render the fish immediately insensible and beyond the point of recovery*' (QTUK, 2014) and under the RSPCA Assured scheme (formerly Freedom Food), 70% of Atlantic salmon was stunned in 2013 (RSPCA, 2014a). Irrespective of whether fish welfare is of a low or high priority to producers and consumers in different parts of the world, promotion of the advantages for product quality of improved fish welfare at slaughter will be a good incentive for all involved, for all fish species.

So far, scientists have identified humane stunning parameters for 17 species of farmed finfish (Table 1). Whilst the methods and parameters identified may not yet be perfect (e.g. some parameters may stun the vast majority, but not 100%, of fish sampled; dry electrical stunning is less preferable for welfare than in-water electrical stunning), they are a starting point for industry, and thereafter continuous improvements can be made. Suitable electrical stunning parameters have not yet been identified/scientifically validated for gilthead sea bream and, at present, percussive stunning is unfortunately not suitable for the scale of a typical harvest; therefore this species requires further research into large-scale stunning methods (van de Vis *et al*, 2003), hence its omission from Table 2.

Table 1. Species of finfish in aquaculture, for which humane stunning methods and parameters are known (Spence, 2014). 'African catfish' is specifically the North African catfish. Although the research on haddock was performed on wild-caught fish, haddock are listed as an aquaculture species (FAO, 2013a) and therefore the data may be transferable. Claresse® is a hybrid freshwater catfish that originates from the interbreeding of catfish from the genera *Clarias* and *Heterobranchus* (Sattari *et al*, 2010).

Common name	Scientific name	Stunning method E = electrical (dry = out of water; wet = in-water) P = percussive	Reference
Atlantic salmon	*Salmo salar*	E (dry, wet) P	Lambooij *et al* 2010; Robb & Roth 2003; Robb *et al* 2000; Roth *et al* 2007; 2003
Rainbow trout	*Onchorhynchus mykiss*	E (dry, wet) P	Lines & Kestin 2005;2004; Lines *et al* 2003; Robb *et al* 2002b; Summerfelt *et al* 2005
Arctic charr	*Salvelinus alpinus*	E (wet)	Lines & Spence 2008
European sea bass	*Dicentrarchus labrax*	E (wet)	Lambooij *et al*, 2007b
Gilthead sea bream	*Sparus auratus*	P	van de Vis *et al*, 2003
Atlantic cod	*Gadus morhua*	E (dry, wet)	Digre *et al* 2010; Erikson *et al* 2012
Haddock	*Melanogrammus aeglefinus*	E (dry)	Lambooij *et al* 2012; van de Vis & Lambooij 2011 (research on wild fish)
Yellowtail kingfish	*Seriola lalandi*	E (dry)	Llonch *et al* 2012
Nile tilapia	*Oreochromis niloticus*	E (wet)	Lambooij *et al* 2008
Common carp	*Cyprinus carpio*	E (dry, wet) P	Lambooij *et al* 2007a
Pike-perch	*Stizostedion lucioperca*	E (dry)	Llonch *et al* 2012
African catfish	*Clarias gariepinus*	E (dry, wet) P	Lambooij *et al* 2006a,b; 2004; 2003a
Claresse®	*Heteroclarias* sp.	E (dry)	Sattari *et al* 2010
European eel	*Anguilla anguilla*	E (dry, wet) P	Lambooij *et al* 2003b; 2002b,c; Robb *et al* 2002a
Common sole	*Solea solea*	E (dry)	Llonch *et al* 2012
Atlantic halibut	*Hippoglossus hippoglossus*	E (dry, wet) P	FAWC, 2014
Turbot	*Psetta maxima*	E (dry, wet) P	Morzel *et al* 2003; StunFishFirst, 2007; Tinarwo 2008

Countries producing species for which humane stunning parameters are known

Bostock *et al* (2010) identified that in 2008 Atlantic salmon was produced in 31 countries, Nile tilapia in 74 countries and common carp in 100 countries. Table 2 shows where the species shown in Table 1 were produced in the greatest quantities in 2013. There may be potential to discuss and encourage routine, widespread use of stunning for these species, in some of these countries. (Note: discussion of volumes uses both the terms 'ton' and 'tonne', depending on the term used by the referenced authors.)

Table 2. The top 50 countries in the world, producing the greatest volumes of the species listed in Table 1 (except gilthead sea bream) in 2013. (Adapted from FAO, 2015d; FEAP, 2014, 2015a). The symbol ^ indicates that the country, and all subsequent countries in the list, are producing less than 1,000 tonnes of that species per year. Members of the EU, European Economic Area (EEA) and Switzerland are part of an internal/single market and are shown in blue text. Although the Russian Federation produced more Atlantic salmon than the USA, the USA's production had a greater overall value. Although Iran produces a greater volume of rainbow trout, Chile's production has the greatest overall value.

Species	**Producer countries, in decreasing order of production.** (Total number of countries in the world listed as producers.)
Atlantic salmon	Norway, Chile, UK, Canada, Faroe Islands, Australia, Russian Federation, USA, Ireland, Iceland, France^, Sweden. (12)

Rainbow trout	Iran, Chile, Turkey, Norway, Peru, Italy, Denmark, France, China, USA, Russian Federation, Spain, Finland, UK, Poland, Sweden, Germany, Colombia, Japan, Republic of Korea, Mexico, Ecuador, Bulgaria, Romania, Bosnia & Herzegovina, Greece, South Africa, Austria, Argentina, Lebanon, Switzerland, Brazil^, Ireland, Costa Rica, Serbia, Slovakia, Canada, Slovenia, Montenegro, Israel, Lesotho, Estonia, Czech Republic, Taiwan, Croatia, Portugal, Bolivia, Venezuela, Albania, Kenya. (76)
Arctic charr	Iceland, Sweden, Norway^, Canada, Austria, Italy, Ireland, UK. (8)
European sea bass	Turkey, Greece, Spain, Egypt, Italy, Croatia, France, Tunisia, Cyprus, UK^, Portugal, Israel, Albania, Morocco, Malta, Montenegro, Slovenia, United Arab Emirates, Mauritius, Algeria. (20)
Atlantic cod	Norway, Iceland^. (2)
Haddock	No countries of production listed by FAO (2015d) but species is listed for aquaculture.
Yellowtail kingfish	Not a species listed by the FAO (2015d).
Nile tilapia	China, Indonesia, Egypt, Thailand, Philippines, Uganda, Ghana, People's Democratic Republic of Lao, Costa Rica, Ecuador, Honduras, Kenya, Zambia, Colombia, Malaysia, Paraguay, Peru, Saudi Arabia, United Republic of Tanzania, Cambodia, El Salvador, Sudan, Cote d'Ivoire, Papua New Guinea, Mali, Rwanda, Madagascar^, Jamaica, Haiti, Cameroon, Benin, Hong Kong, Senegal, Kuwait, Dominican Republic, Pakistan, Poland, UK, Burkina Faso, Republic of Fiji, Niger, Burundi, Gabon, Singapore, Congo, Vanuatu, Central African Republic, Morocco, United Arab Emirates, Sierra Leone. (74)
Common carp	China, Indonesia, Egypt, Bangladesh, Viet Nam, Russian Federation, Iran, Myanmar, Ukraine, Poland, India, Czech Republic, Iraq, Belarus, Hungary, People's Democratic Republic of Lao, Germany, Nepal, Israel, Serbia, France, Lithuania, Bulgaria, Romania, Republic of Moldova, Japan, Madagascar, Croatia, Cambodia, Thailand, Syrian Arab Republic, Sri Lanka, Armenia, Malaysia, Kenya, Uzbekistan, Uganda^, Austria, Colombia, Latvia, Papua New Guinea, Jordan, Tunisia, Bosnia & Herzegovina, Morocco, Paraguay, Taiwan, Cuba, Slovakia, Georgia. (81)
Pike-perch, or zander (genus now *Sander*)	Tunisia^, Bulgaria, Netherlands, Czech Republic, Germany, Romania, Ukraine, Hungary, Tajikistan, Croatia, Austria, Bosnia & Herzegovina, Latvia, Slovakia, Lithuania, Denmark. (15) The species was the 38th individual species with the greatest value/tonne in 2013 (Appendix 3c).
North African catfish	Nigeria, Uganda, Kenya, Hungary, Nepal, Ghana, Netherlands, Mali^, Syrian Arab Republic, Germany, Malawi, Austria, Benin, Poland, Cameroon, Cote d'Ivoire, Romania, Belarus, Saudi Arabia, Lithuania, Niger, Lebanon, Bulgaria, Guinea, Burkina Faso, Central African Republic, Democratic Republic of the Congo, South Africa, Zimbabwe, Burundi, Namibia, Sierra Leone, Tanzania, Congo, Senegal, Rwanda. (36)
Claresse®	Netherlands (FEAP, 2015a). Although FAO report the interbreeding of the parent species, the hybrid is not listed by the FAO (2015d).
European eel	Netherlands, Italy, Denmark, Germany^, Morocco, Spain, Greece, Sweden, Tunisia, Portugal. (10) (Some minor discrepancies between FAO (2015d) and FEAP (2015a) data.)
Common sole	Portugal^, Italy. (2)
Atlantic halibut	Norway, UK^, Iceland (production progressively reduced from 2004, to 0 tonnes in 2013 and 2014). (3)
Turbot	China, Spain, Portugal, France^, Netherlands, Chile, Iceland. (7)

In the European area in 2014, the major producers exceeding 100,000 tons of finfish per year were Norway, Turkey, the UK and Greece, in that order (FEAP, 2015a). Of the EU member states, the UK, Greece, Spain and Italy produced in excess of 50,000 tons in 2014 (FEAP, 2015a). In 2014, Atlantic salmon, rainbow trout, sea bass, sea bream and carp accounted for 94% of aquaculture finfish production in Europe (FEAP, 2015b) and in 2011 Atlantic salmon, trout, sea bream and sea bass were the most valuable finfish aquaculture products in the EU (EU Fish Market, 2014). In 2011 the price of farmed sea bass was 51% higher in Italy than in the EU on average (EU Fish Market, 2014). Sea bream was mostly produced by Greece, Turkey, Spain, Italy, Croatia, Cyprus, Portugal and France (in excess of 1000 tons/year and in that order) in 2014 (FEAP, 2015a); in 2013 the first four of these countries accounted for 85% of world production (IBFC, 2017). In addition, it was estimated that European sea bass and gilthead sea bream production in the Mediterranean was likely to be significantly under-reported in some geographical areas (FAO, 2012). An investigation into five fish species farmed in the European Economic Area (EEA) found that from 2009 to 2013 OIE standards for fish welfare at slaughter were not met for European sea bass or gilthead sea bream (assessed in combination) in Greece, Italy or Spain (IBFC, 2017). Six companies in Turkey and two in Greece were dry electrically stunning European sea bass and gilthead sea bream for mostly UK customers, though this was also described as 'experimental'; Italy and Spain were not stunning these species (IBFC, 2017).

In 2014, all EU producers of Atlantic salmon (Table 2) exceeded 1,000 tons per year except France (300 tons/year) (FEAP, 2015a); in 2013 Sweden produced 6 tonnes (FAO, 2015d). In 2013 Norway accounted for 56% of world production and had increased production by 35% since 2009 (IBFC, 2017). From 2009 to 2013 Atlantic salmon were dry electrically stunned by some farms in Norway (50% of market share) and percussively stunned by farms in Ireland (92-93%), Norway (automated, 50% of market; less than 5% use swim-in stunners that do not require dewatering) and by 95% of farms in the UK (IBFC, 2017). IBFC (2017) considered that for Atlantic salmon produced in the EEA, '*best practices* [based on the OIE recommendations for fish welfare at slaughter] *are mostly achieved, with a few exceptions*', e.g. 7-8% of Atlantic salmon farmed in Ireland are killed by immersion in CO_2 and some Norwegian-farmed Atlantic salmon are killed using live chilling plus moderate levels of CO_2. The UK was the only sampled country to meet OIE standards and accounted for 8% of the global market share between 2009-2013 (IBFC, 2017). In Chile and Canada, Atlantic salmon are slaughtered by percussive stunning, mainly at land-based processing plants in Chile and mainly on-farm in Canada (IBFC, 2017).

In 2013 rainbow trout had the second greatest production in the USA (out of 13 listed species or species groups), eighth greatest production in Japan (out of 15 species/groups) and in Mexico (out of 11 species/groups) and the sixth greatest production in the Republic of Korea (out of 26 species/groups). Although China and the Russian Federation are major producers, they are not major exporters (IBFC, 2017). Chile's relatively high unit production costs and cost price mean it is outcompeted in the rainbow trout export market (IBFC, 2017). In 2014 the major European producers of rainbow (or steelhead) trout were: large trout (at least 1.2 kg liveweight) – Norway, Finland, France, Denmark, Sweden, Turkey, UK, Spain, Italy, Germany (Iceland and Ireland produced at least 400 tons/year); portion-size trout (less than 1.2 kg) – Turkey, Italy, Denmark, France, Poland, Spain, UK, Germany, Greece, Austria, Ireland and Portugal (Czech Republic and Croatia produced at least 361 tons/year; Cyprus, Hungary and the Netherlands produced less than 100 tons/year) (FEAP, 2015a). In Turkey, production of rainbow trout (large and portion-size) in 2013 exceeded that of sea bass and sea bream combined (FAO, 2015d; FEAP, 2015a), though a drop in rainbow trout production and a rise in sea bass and bream production meant this was not the case in 2015, but trout production still far exceeded bream production and exceeded bass production (FAO, 2017). IBFC (2017) concluded that for rainbow trout produced in the EEA from 2009 to 2013, there was a varied level of achievement of the OIE recommendations for fish welfare at slaughter, depending on the killing method, which included asphyxia in ice (30% of market share) and in-water electrical stunning (70% market share) in Denmark; CO_2 (for large trout), ice-water chilling *prior* to electrical stunning, in-water electrical stunning and manual percussive stunning in France; in-water electrical stunning in Italy; asphyxia in ice/slurry (portion-size) or decapitation (large trout) in Poland. In Poland, OIE standards were not met for rainbow trout, but EUMOFA (2017d) has reported an increase in production of this species in Poland, particularly for portion-size 250-400 g trout. In Canada, large rainbow trout are percussively stunned, whilst portion-size rainbow trout are electrically stunned on-farm (IBFC, 2017).

In 2014 common, silver, grass and bighead carp (in that order of descending production) were produced in Europe (FEAP, 2015a). Together, the major EU producers of common carp (Poland, the Czech Republic, Hungary and Germany) accounted for 1.3% of global production of that species in 2013 (IBFC, 2017). Common carp were produced in smaller quantities (at least 41 tons/year) in Italy, Austria and Greece (FEAP, 2015a). IBFC (2017) concluded that from 2009 to 2013 OIE standards for fish welfare at slaughter were only *partly* achieved for common carp in the Czech Republic, Germany and Poland (the study did not assess other countries' practices). In-water electrical stunning (followed by decapitation, a gill cut or a percussive kill) of common carp has been reported in the Czech Republic, Germany and Poland (IBFC, 2017). In China, common carp are mostly sold to the consumer whilst still alive, or commercially killed by asphyxia (outside of processing plants) or by manual percussive stunning in restaurants when the customer orders (IBFC, 2017).

EU turbot production exceeds EU halibut production. Between 2004 and 2014, Norway consistently produced the most halibut (and in 2015) and cod within Europe (FEAP, 2015a; 2014; FAO, 2017) but in 2015 Norway's aquaculture of cod dropped very low, below that of Iceland (FAO, 2017).

Communication to the general public, of the importance of humane slaughter of fish

Communication of the scientific research investigating the capabilities of finfish to experience fear and pain, is necessary to enable the global general public to identify fish as animals that can suffer. Making consumers aware of the existence of technology for more humane slaughter of fish may encourage consumers to choose products with fish welfare in-mind (e.g. by selecting assured products/brands). To this end, the HSA is producing a short video for the public, describing fish welfare and humane slaughter. IBFC (2017) reported that competent authorities and industry believed there had been a decrease in public concern for farmed fish welfare between 2009-2013 in Denmark and that there had not been any increase in public concern in Greece, Ireland and Spain.

7. Which species might be prioritised for future scientific research and development?

The scale of farmed finfish production

In 2010 (FAO, 2012), 2012 (FAO, 2014b) and in 2014 (FAO, 2016b) the FAO registered 327, 354 and 362 individual species of farmed finfish respectively, with five hybrids each year in 2010 and 2012. Multiple additional species may be included within the FAO's 'nei' (not elsewhere included) categories of finfish (of which there were 49 in 2013) and the seven '..A' categories without specific named species. According to the FAO (2014b), between 2010 and 2012 there were no significant changes in the major species and species groups and their proportional relationships.

At least 40 species of finfish are farmed in mainland China alone, at least 30 species are farmed in Malaysia, 29 in Italy, 26 in the Republic of Korea, 24 in Bangladesh, 22 species in Indonesia and 21 in Thailand (these figures may be substantially higher, depending on the number of species included in the FAO's 'nei' categories of fish) (FAO, 2015d). The FAO (2014b) noted that for China, India and Viet Nam, the number of species produced appears to be under-reported in certain documents.

Tables 3a&b display the top producers of food finfish in the world in 2012 and in 2014 (FAO, 2014b; 2016b). In both years inland aquaculture of finfish accounted for a far greater liveweight volume of produce, compared to mariculture of finfish (FAO, 2016b; 2014a). (It should be noted that the FAO (2014a,b) includes inland saline production in the term 'inland aquaculture', and similarly 'mariculture' can include onshore facilities.) In Egypt there is a large amount of saline inland aquaculture, although it is unknown what proportion of this type of aquaculture is for finfish.

Table 3a. The contribution of each continent/region to global aquaculture of finfish for human consumption in 2014. Adapted from FAO (2016b).

Region:	**Asia**	**Europe**	**Americas**	**Africa**	**Oceania**
% of global volume:	87.66%	4.61%	4.20%	3.40%	0.13%

Table 3b. Farmed food fish production by top 15 producer countries in 2012 (left) and by top 25 producer countries in 2014 (right). Left: *Source: Food and Agriculture Organization of the United Nations, 2014, The State Of World Fisheries and Aquaculture 2014: Opportunities and Challenges.* Right: *Source: Food and Agriculture Organization of the United Nations, 2016, The State Of World Fisheries and Aquaculture 2016: Contributing to Food Security and Nutrition for All,* www.fao.org/fishery/en. *Reproduced with permission*.

Producer	Finfish	
	Inland aquaculture	Mariculture
	(Tonnes)	
China	23 341 134	1 028 399
India	3 812 420	84 164
Viet Nam	2 091 200	51 000
Indonesia	2 097 407	582 077
Bangladesh	1 525 672	63 220
Norway	85	1 319 033
Thailand	380 986	19 994
Chile	59 527	758 587
Egypt	1 016 629	…
Myanmar	822 589	1 868
Philippines	310 042	361 722
Brazil	611 343	…
Japan	33 957	250 472
Republic of Korea	14 099	76 307
United States of America	185 598	21 169
Top 15 subtotal	36 302 688	4 618 012
Rest of world	2 296 562	933 893
World	38 599 250	5 551 905

Note: The symbol "…" means the production data are not available or the production volume is regarded as negligibly low.

MAJOR PRODUCERS	FINFISH	
	INLAND AQUACULTURE	MARINE/ COASTAL AQUACULTURE
	(Thousand tonnes)	
China	26 029.7	1 189.7
Indonesia	2 857.6	782.3
India	4 391.1	90.0
Viet Nam	2 478.5	208.5
Philippines	299.3	373.0
Bangladesh	1 733.1	93.7
Republic of Korea	17.2	83.4
Norway	0.1	1 330.4
Chile	68.7	899.4
Egypt	1 129.9	…
Japan	33.8	238.7
Myanmar	901.9	1.8
Thailand	401.0	19.6
Brazil	474.3	…
Malaysia	106.3	64.3
Democratic People's Republic of Korea	3.8	0.1
United States of America	178.3	21.2
Ecuador	28.2	0.0
Taiwan Province of China	117.3	97.8
Iran (Islamic Republic of)	297.5	0.1
Nigeria	313.2	…
Spain	15.5	44.0
Turkey	108.2	126.1
United Kingdom	13.5	167.3
France	43.5	6.0
TOP 25 SUBTOTAL	42 041.2	5 837.5
WORLD	43 559.3	6 302.6
PERCENTAGE OF TOP 25 IN WORLD TOTAL	96.5	92.6

Note: … = production data not available or production negligible.

Earthen ponds are the predominant rearing enclosure (for freshwater and brackish water fish species), followed by cages (which hold fresh and sea water species), followed by tanks. In Indonesia mariculture accounts for approximately 22% of finfish production and depends primarily on coastal brackish-water ponds. In the Philippines, cages in marine and brackish-water account for a quarter of mariculture production (mostly milkfish) (FAO, 2014b). Freshwater production dominates China's domestic market for finfish and 38% of China's finfish mariculture production is in cages.

Although, relative to other fish farming continents, Africa accounts for a minority of global aquaculture production and the production intensity (kg/km^2) is reasonably low and contributes a low amount to the economy (0.15% GDP: FAO, 2014b), in many countries within Africa the sector is seeing some of the highest increases in annual production (2008 – 2010 mean data modified from FAO, 2012). In 2012 annual growth of aquaculture production was fastest in Africa – note though that this includes aquatic plants (FAO, 2014b). In 2010 there was rapid development of freshwater aquaculture in Nigeria, Uganda, Zambia, Ghana and Kenya and African aquaculture was 99.3% finfish by volume (FAO, 2012).

Possible priorities

Funding for scientific research to identify humane stunning parameters where these are not known and/or for development of new humane stunning methods might be most appropriately targeted at the following categories of fish:

- species with the greatest volumes of production per year (Table 4a,b; Appendix 3a) and, where data are available, the greatest numbers of individual fish farmed and slaughtered per year. (Unfortunately the FAO statistics are unable to provide estimates of the number of individual fish of each species, farmed per year. Numbers of individual fish may also be difficult to estimate because individual fish size and/or liveweight may vary with production systems and schedules, e.g. rainbow trout are harvested at 450 – 600 g in the USA, at 1-2 kg in Europe and at 3-5 kg in Canada, Chile and Scandinavia (FAO, 2015n).);

- species of high financial value (Appendices 3b & 3c), e.g. species used in the sushi and sashimi industry;

- species imported into countries that legally require a minimum standard of fish welfare at slaughter;

- species slaughtered in, or imported into, countries where the consumer and retailer demand higher-welfare rearing and harvesting methods;

- species likely to be experiencing the greatest amount of suffering during current commercial slaughter practices, e.g. species undergoing possibly the most painful killing methods, for the longest duration of time before consciousness is lost.

Table 4a. The 25 species/groups of fish produced in the largest quantities in 2012. 20 individual species are listed. Similar types of fish are identified with the same coloured text, e.g. red indicates carp species. Courtesy of D. Little.

Rank		Tonnes
1	Grass carp(=White amur)	4385467
2	Silver carp	4030822
3	Common carp	3294323
4	Bighead carp	2588001
5	Catla	2580524
6	Crucian carp	2196238
7	Nile tilapia	2107586
8	Atlantic salmon	1489126
9	Roho labeo	1299508
10	Freshwater fishes nei	1039941
11	Milkfish	807421
12	Wuchang bream	652267
13	Pangas catfishes nei	642411
14	Rainbow trout	632068
15	Tilapias nei	548195
16	Black carp	427179
17	Channel catfish	424570
18	Snakehead	397485
19	Marine fishes nei	396111
20	Mrigal carp	383121
21	Amur catfish	368416
22	Torpedo-shaped catfishes nei	345238
23	Asian swamp eel	267107
24	Mandarin fish	254697
25	Japanese eel	252503
		31810327

FAO, 2014;modified by Newton

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Table 4b. The 27 species/groups of fish produced in the largest quantities in 2015. Adapted from FAO (2017). For viewing ease, the quantities have been rounded up or down to the nearest tonne. 20 individual species are listed. Purple text indicates a species that did not feature in Table 4a but which climbed the ranks in three years. ('Nei' = not included elsewhere in FAO databases; these groups may be amalgamations of multiple species and are therefore discounted as individual species by being shown in strikethrough ~~grey~~ text, to allow identification of 20 individual species. For reader information, the discounted groups of fish are retained within the list.) FAO (2017) lists 'Crucian carp' (*Carassius carassius*) production at 2,437 tonnes in 2015; if taken together with production of the fish type ranked 6th in this table ('*Carassius* spp'), that ranking would remain the same as in Table 4a.

Number	Common name	Scientific name	Quantity (tonnes)
1	Grass carp(=White amur)	*Ctenopharyngodon idellus*	5,822,869
2	Silver carp	*Hypophthalmichthys molitrix*	5,125,461
3	Common carp	*Cyprinus carpio*	4,328,083
4	Nile tilapia	*Oreochromis niloticus*	3,930,579
5	Bighead carp	*Hypophthalmichthys nobilis*	3,402,870
~~6~~	~~..A~~	~~*Carassius* spp~~	~~2,913,160~~
7	Catla	*Catla catla*	2,764,944
~~8~~	Atlantic salmon	*Salmo salar*	2,381,576
9	~~Freshwater fishes nei~~	~~Osteichthyes~~	~~2,071,737~~
10	Roho labeo	*Labeo rohita*	1,785,900
~~11~~	~~Pangas catfishes nei~~	~~*Pangasius* spp~~	~~1,609,026~~
12	~~Tilapias nei~~	~~*Oreochromis* (=Tilapia) spp~~	~~1,243,781~~
~~13~~	Milkfish	*Chanos chanos*	1,115,095
14	~~Marine fishes nei~~	~~Osteichthyes~~	~~1,056,405~~
15	~~Torpedo-shaped catfishes nei~~	~~*Clarias* spp~~	~~849,474~~
~~16~~	Wuchang bream	*Megalobrama amblycephala*	796,830
~~17~~	Rainbow trout	*Oncorhynchus mykiss*	761,766
~~18~~	Black carp	*Mylopharyngodon piceus*	596,240
19	~~Cyprinids nei~~	~~Cyprinidae~~	~~519,845~~
20	Snakehead	*Channa argus*	495,881
21	Mrigal carp	*Cirrhinus mrigala*	467,605
22	Amur catfish	*Silurus asotus*	454,484
23	Blue-Nile tilapia, HYBRID	*Oreochromis aureus* x *O. niloticus*	445,002
24	Striped catfish	*Pangasius hypophthalmus*	419,387
25	Channel catfish	*Ictalurus punctatus*	411,790
26	Asian swamp eel	*Monopterus albus*	367,590
27	Pond loach	*Misgurnus anguillicaudatus*	367,214

Tables 4a,b and Appendix 3a show that the top three species (in terms of volume) remained the same from 2012 to 2013, to 2015. In 2008 grass and silver carp were produced in 57 and 50 countries respectively (Bostock *et al*, 2010). Fishcount (2014) estimated that 1.7 – 8.7 billion individual grass carp might be slaughtered worldwide each year. Nile tilapia increased in production and moved from 7th in 2012 to 4th in 2013, where it remained in 2015. Crucian carp as a specific species does not feature in Table 4b. Channel catfish dropped production and rank between 2012 and 2015. Blue-Nile tilapia, striped catfish and pond loach rose through the ranks of production quantities between 2012 and 2015, with striped catfish showing a 1.4-fold increase in production between 2013 and 2015. Mandarin fish increased in production marginally between 2013 and 2015, hence its drop in rank to 23rd individual species with greatest production and its omission from Table 4b. Japanese eel was ranked as the 24th individual species with the greatest production in 2015 (FAO, 2017). Appendix 3a displays the 50 individual species produced in the greatest quantities in 2013, and the FAO (2017) reported largely-similar rankings for 2015.

Although mariculture accounted for just 12.6% of finfish production by volume in 2012 and 2014 (Table 3b), the species produced (carnivores like Atlantic salmon, trouts and groupers) were typically worth more than freshwater aquaculture finfish (Table 5) – the value of the mariculture finfish industry in 2012 was 26.9% of the total finfish aquaculture industry (FAO, 2014b). In 2013 Atlantic salmon accounted for 13.7% of total aquaculture finfish value (FAO, 2015d) and the species had a greater overall value than each of the top three species of carp and Nile tilapia (Appendix 3b). (Appendix 3b displays the 50 individual species with the greatest overall value in 2013, and these rankings are largely-similar to the ranks reported by the FAO (2017) for 2015, although Atlantic salmon had reduced in value (by 7.4% but still retained rank number 1) and in value per tonne (Appendix 3c). There were also reductions in overall value for gilthead seabream (by 12.4%) and European sea bass (by 13%), which resulted in a drop in rank and in value per tonne. Turbot reduced in value by 19.6% and Africa-bighead catfish by 26.5%, whilst striped catfish increased in value by 45.5% and in rank to 25th individual species with greatest value. Chinook salmon increased in overall value by 88.4% between 2013 and 2015.)

Table 5. Values per tonne (liveweight) of types of finfish in 2013. Source: FAO (2015b); this table excludes the ‘miscellaneous’ or ‘not identified’ categories of finfishes. Tuna aquaculture takes into account only the amount produced through farming; it does not include wild-caught, then farm-fattened, tuna (data for which is classed as capture fisheries production) (FAO, 2015c).

Fish type	Value (US$) per tonne
tunas, bonitos and billfishes	20,888
flounders, halibuts and soles	6,432
river eels	5,581
salmons, trouts, smelts	5,548
cods, hakes, haddocks	5,170
sturgeons and paddlefishes	4,660
Shads	3,907
tilapias and other cichlids	1,710
carps, barbels and other cyprinids	1,446

Although the FAO-designated group ‘carps, barbels and other cyprinids’ accounted for both the greatest quantity (volume) of fish produced and the greatest value in 2013, the group’s value per tonne was the lowest of the groups listed by the FAO (Table 5). Production of carps and catfishes is typically considered to be extensive farming that is relatively easy to perform (FEAP, 2015c). Therefore, although the value of these species per tonne is relatively low, the production costs may also be relatively low. For example, production costs for grass carp were US$0.50/kg (retail prices were $0.7 – 1.0/kg) (FAO, 2015g); for crucian carp production costs are usually below $0.70/kg (FAO, 2015i); commercial-scale grow-out producers’ production costs for striped catfish are $0.83/kg (excluding capital investment costs) and achieve sale prices of $0.89/kg but profit margins are extremely narrow for household-scale grow-out farmers of striped catfish and it is anticipated that there will be consolidation and vertical integration of the striped catfish industry (FAO, 2015j). This is compared to production costs of $1.20-2.00/kg for rainbow trout (FAO, 2015n), $2.50/kg (variable) for an on-grower of Atlantic salmon (FAO, 2015l) and $5.20/kg (including various expenses) for European sea bass (FAO, 2015m).

Specific species with some of the lowest values per tonne included (in increasing values per tonne) Crucian carp, large yellow croaker, snakehead, Mozambique tilapia, grass and bighead carp, pond loach, Amur catfish, silver carp, striped catfish, common carp, blue-Nile tilapia, largemouth black bass, Africa-bighead catfish, pirapatinga, channel catfish, Wuchang bream, Nile tilapia, cobia, milkfish, catla, roho labeo and Indonesian snakehead, all below $2,000 per tonne in 2013. In 2015, Crucian carp had risen to a value of $3,111/tonne but this may be due to the introduction of a '*Carassius* spp.' classification in FAO data.

In terms of specific species, in descending order, Danube sturgeon, Pacific bluefin tuna, southern bluefin tuna, Atlantic bluefin tuna and Siberian sturgeon are the top five individual species with the greatest values per tonne *and* which have global production exceeding 100 tonnes per year (Appendix 3c). (There is slightly more movement in the rankings for the 50 individual species with the greatest value per tonne between 2013 (Appendix 3c) and 2015 (FAO, 2017). For example, southern bluefin tuna and Siberian sturgeon dramatically reduced in value per tonne and rank (3^{rd} to 11^{th} and 5^{th} to 30^{th}, respectively, excluding species produced at ≤ 100 tonnes per year worldwide). Chinook salmon dramatically increased in value per tonne and ranking, to 7^{th}. In 2015 tambatinga entered the top 50 individual species, ranked as 6^{th} greatest value per tonne if discounting species produced at ≤ 100 tonnes per year worldwide.)

Tunas should be prioritised for investigation into humane stunning methods and parameters. Pacific, southern and Atlantic bluefin tunas, and the next most-valuable species of tuna - yellowfin tuna (produced in small quantities), all belong to the same genus. Atlantic bluefin tuna production is led by Europe. EFSA (2009e) report that 90% of farmed Atlantic bluefin tuna are sold for sushi or sashimi and that tuna with high levels of lactic acid are readily-recognised in Japanese wholesale markets and are sold at a lower price or, in some cases, are deemed not to be of sufficient quality for sushi or sashimi. For farmed Atlantic bluefin tuna, the current slaughter methods kill the fish; there are no stunning methods that require follow-up killing (EFSA, 2009e). Although, in principle, outright killing offers welfare advantages compared to stunning methods that require follow-up killing, it is critical that pre-killing related operations and killing methods do not cause suffering. Unfortunately, for some of the killing methods currently used for tuna this may not be the case, e.g. if removed from the water whilst conscious, particularly by gaffing and hoisting which is likely to be painful. It has been estimated that it takes approximately 150 milliseconds for an animal to perceive the application of a possibly painful stimulus to its body (Wotton, 1996); therefore, if spiking (iki jime) killing methods take more than 0.15 seconds to penetrate the layers of skin, muscle and skull bone of the head and destroy the brain, this tissue damage could cause fish to suffer before brain activity is extinguished. Consequently, EFSA (2009e) stated the opportunity to develop new methods for slaughtering tuna should be encouraged.

The only species that are listed in Appendices 3a (50 greatest volumes), 3b (50 greatest values) and 3c (50 greatest values per tonne) are Atlantic salmon, European sea bass, gilthead sea bream, Japanese eel, Japanese amberjack, silver seabream, turbot, the bastard halibut and the Mandarin fish, *Siniperca chuatsi*. Based on these criteria, these nine species might have a higher likelihood than other species, for success in encouraging producers to adopt humane stunning at slaughter. However, there might still be challenges: in 2006 China was the largest producer of this particular species of Mandarin fish (FAO, 2015e) and was the only listed country of production in 2013 (FAO, 2015d); the product is also relatively unknown in international markets; this might make it difficult to encourage producers to adopt humane pre-slaughter stunning of *S. chuatsi*.

Of the 50 individual species listed in Appendices 3a and 3b for 2013, eight are listed in Table 1 as already having stunning parameters identified for them (the order of these species, in decreasing production quantities, in Appendix 3a is: Atlantic salmon, rainbow trout, Nile tilapia, common carp, North African catfish, gilthead sea bream (only percussive stunning), European sea bass, turbot). The order of these species, in decreasing overall value, in Appendix 3b is: Atlantic salmon, rainbow trout, Nile tilapia, common carp, European sea bass, gilthead sea bream, North African catfish, turbot. Of the 50 individual species listed in Appendix 3c, nine are listed in Table 1 (the order of these species, in decreasing values per tonne, is: common sole, Atlantic halibut, European eel, turbot, Arctic char, European sea bass, pike-perch, Atlantic salmon, gilthead sea bream). These species are therefore also priorities for introducing and encouraging humane stunning at slaughter in as many countries of production as possible.

Other species of importance in aquaculture and therefore worthy of consideration are:

- cobia (listed in Appendix 3b) and arowana (both species raised at the HSA workshop);
- brackish water: milkfish and barramundi (FAO, 2012);
- marine: amberjacks, sea breams, sea basses, croakers, grouper, drums, mullets, various flatfishes, snappers, pompano, cods and puffers (FAO, 2012).

Stunning parameters for related/similar species

The parameters required to effectively stun a fish can vary widely between species, even within the same taxonomic family or genus, and perhaps not just due to differences in the physical size of the species (e.g. electric stunning of salmonids can require different electrical parameters: Lines & Kestin 2004; Lines & Spence 2008). It may therefore be necessary to scientifically determine humane stunning parameters for each species, which is a vast undertaking in the case of finfish. Nevertheless, it may be quicker and more affordable to expand scientific knowledge of humane stunning parameters for fish by trialling and confirming whether parameters for one species that was previously subject to investigation for humane stunning (Table 1), might be suitable for other species that are either closely phylogenetically/taxonomically related and/or morphologically similar or similarly-adapted to their natural environment. This approach might address the welfare of a large number of species and individuals. (Care must be taken because some species that share similar common names may in-fact have very different evolutionary paths, may be physically dissimilar and therefore may vary in susceptibility to stunning parameters. Species that the workshop delegates considered to be quite different from one another included *Pangasius* and channel catfish; Mozambique and Nile tilapia (despite belonging to the same genus and despite a hybrid of these species currently being produced in aquaculture – Table 6); turbots and flounders. Another example of when this approach might not be feasible is for species that are relatively taxonomically isolated and might require idiosyncratic stunning parameters. For example, milkfish are the only living species in the family Chanidae (FAO, 2015a), which may warrant more thorough scientific investigation of their effective stunning. The same situation applies to cobia, which are the only member of the family Rachycentridae (Fishbase, 2017).)

<u>Species for which stunning parameters are already scientifically-determined and which might be suitable for scientifically-related species</u>

Order Salmoniformes

Rainbow trout, coho (silver) salmon and Chinook (spring or king) salmon share their genus *Oncorhynchus* so parameters that are currently recommended for rainbow trout might be worth testing for suitability for coho and Chinook salmon. Chile farms similar quantities of rainbow trout and coho salmon and Chile and New Zealand in particular farm Chinook salmon (FAO, 2015d). In 2013 Japan's 4th most produced species was coho salmon (FAO, 2015d).

Atlantic salmon share the genus *Salmo* with brown, or sea, trout (riverine form *S. trutta fario* and sea form *S. t. trutta*). Although harvested in small quantities, the sea form features in Appendix 3c and both forms feature in Appendix 4. Therefore it may be worthwhile considering investigating if parameters suitable for Atlantic salmon also suit *S. trutta*.

Order Cypriniformes and order Perciformes

Humane stunning parameters are known for common carp and for Nile tilapia (Table 1) but many other species of carp and tilapia are farmed in aquaculture. Indeed, species of carp, followed by tilapia species, dominate freshwater production (Appendix 3a). However, whilst the family Cyprinidae (which contains the common carp) comprises approximately 380 genera (FishBase, 2017), the FAO (2017) lists only that one specific *Cyprinus* species (though 'Cyprinids nei/Cyprinidae' are also listed as the 18th most produced fish type/species in Appendix 3a). The other major specific species of carp featured in Appendices 3a-c mostly belong to different genera and therefore caution may be necessary before assuming too much about each species' response to stunning parameters that are suitable for common carp, or one another. However, silver and bighead carp are both listed within the top seven species for production volume (Appendix 3a) and overall value (Appendix 3b) and they belong to the same genus and may therefore be worth investigating humane stunning parameters together. Bighead carp were produced in 28 countries in 2008 (Bostock *et al*, 2010). The commonly-used term tilapia applies to a few different genera from the Tilapiini tribe within the family Cichlidae; the FAO (2017) lists specific species from three genera. As well as Mozambique and Nile tilapia, blue tilapia belong to the same genus (though note the concern of workshop participants in the previous section) and these species account for the majority of tilapia aquaculture. The FAO also lists 'Tilapias nei/*Oreochromis* spp' as the 13th most produced fish type/species (Appendix 3a). The FAO (2014a) reported: '*Geographically tilapias are the most wide spread species for aquaculture production in the world. Close to 140 countries and territories are now recorded for farming of tilapias in FAO database*' and the range of tilapia species in aquaculture is predicted to expand in future. From 2002 to 2010, tilapia production in China increased almost ten-fold (Zhang *et al*, 2012 in D. Little presentation 19 June 2014). In 2010 72% of tilapias were raised in Asia, 19% in Africa and 9% in America (FAO, 2012). Tilapia production is expanding in Asia, South America and Africa but mostly for the domestic and regional markets, rather than international (FAO, 2014), though frozen whole tilapia and catfish from Asia have gained access to new markets in all regions of the world (FAO, 2016b). Between 2010 and 2030 it is estimated that the species predicted to grow fairly rapidly (in excess of 65%) include salmon, tilapia, carp and *Pangasius* catfish, with the fastest growth from tilapia, doubling global production (Kobayashi *et al*, 2015).

Yellowtail kingfish (stunning parameters identified) belong to the genus *Seriola*, as does Japanese amberjack which is listed within the 50 species with the greatest quantities and greatest value in 2013 (Appendices 3a and 3b). Japanese amberjack was the species produced in the greatest volume in 2013 in Japan. Also within the genus *Seriola* are greater amberjack (not listed by the FAO (2015d) but certified by the GLOBALG.A.P. fish assurance scheme) and longfin yellowtail (Appendix 3c).

Order Pleuronectiformes

Common or Dover sole (stunning parameters identified – Table 1) and Senegalese sole are classified within the genus *Solea*. Senegalese sole was the 8th individual species of fish with the greatest value per tonne in 2013 (Appendix 3c) and was produced in Spain (FAO, 2015d). Although common sole had a greater value per tonne in 2013 than Senegalese sole, aquaculture of common sole was far below that of Senegalese sole and, worldwide, did not exceed 200 tonnes in 2013 (FAO, 2015d). Most common sole are produced in Portugal, while Greece and Italy produce a very small amount (FAO, 2015d; FAO, 2016a).

Order Anguilliformes

Humane stunning parameters are already known for the European eel (*Anguilla anguilla*) but in 2011 aquaculture of the Japanese eel, *A. japonica*, created an estimated 37 times as much product, at approximately 17 times the overall value (FAO, 2013a), although in 2013 the value per tonne was approximately 2.2 times greater for the European eel (FAO, 2015d). Japanese eel is the 3rd species produced in the greatest quantities in Japan (FAO, 2015d). Extending research on eels to examine whether the same or similar parameters might also successfully stun the rest of the genus might be an appropriate starting point. In 2011 the shortfinned eel (*A. australis*), mostly produced in New Zealand, had a much lower production volume and value than the European and Japanese eel, but the value per tonne was the greatest of the three species. New Zealand's Animal Welfare (Commercial Slaughter) Code of Welfare 2010 declared that from 1 January 2015 eels must be rendered insensible for the duration of the de-sliming process, or killed before they are de-slimed; potential may therefore exist to introduce humane stunning, if it has not already been done.

Order Siluriformes

North African catfish (stunning parameters identified) are classified within the genus *Clarias*, which contains approximately 60 species (FishBase, 2017). However, despite this large number of species and the

FAO category 'torpedo-shaped catfishes nei/*Clarias* spp' being listed the 16th fish species/type of greatest production (Appendix 3a) and 23rd fish species/type of the greatest value (Appendix 3b) in 2013, the only other specified species in the genus *Clarias* that are listed by the FAO (2015d) are the Philippine catfish (Appendix 3c) and the hybrid Africa-bighead catfish (Table 6).

Hybrids

Artificial, or human-induced, hybridisation is used to improve productivity traits, such as increasing growth rate. For example, hybridising the mudfish (*Clarias anguillaris*) and the African catfish (*Heterobranchus bidorsalis*) has been investigated (Diyaware & Onyila, 2014), as has hybridisation of Japanese and European eel (Müller *et al*, 2012). Aquaculture of hybrid finfishes is more common in countries with advanced aquaculture technology (FAO, 2012). Table 6 displays some of the more common hybrids being farmed. These hybrid finfish might be readily-assessed for minimum stunning parameters if humane parameters have already been determined for their parent species, which is the case for Nile tilapia, North African catfish and European eel (Table 1).

Table 6. Hybrid finfishes in aquaculture. Where the quantities column is blank, the FAO (2015d; 2017) did not list data.

'Hybrid name' or type of finfish	Parent species	Quantities (tonnes) produced, if data available	Countries of production	Comments
'Bester'	beluga sturgeon (*Huso huso*) x sterlet sturgeon (*Acipenser ruthenus*)		Asia & Europe	
	Carassius species, snakeheads & groupers		China	
	Characins		South America	
	North African catfish (*Clarias gariepinus*) x Sampa (*Heterobranchus longifilis*)		Africa & Europe.	
'Africa-bighead catfish'	*C. gariepinus* x Bighead catfish (*C. macrocephalus*)	136,265 tonnes worldwide in 2013; 113,520 in 2014; 107,730 in 2015.	Thailand	Appendix 3a, 3b
'Blue-Nile tilapia'	blue tilapia (*Oreochromis aureus*) x Nile tilapia (*O. niloticus*)	414,475 tonnes worldwide in 2013; 420,112 tonnes in 2014. 17th individual type of fish produced in the greatest volume in 2013 (Appendix 3a)	China (vast majority), Panama	Results in a high % of male offspring. The 26th individual type of fish with greatest value in 2013 (Appendix 3b).
	O. niloticus x Mozambique tilapia (*O. mossambicus*)		Philippines	Saline-resistant.
'Tambacu'	Pacu (*Piaractus mesopotamicus*) x cachama	47,163 tonnes in 2013; 32,267 tonnes in 2014 (FAO, 2016a); 30,443 in 2015	Brazil	Appendix 3a, 3b
'Tambatinga'	cachama x pirapatinga	14,265 tonnes worldwide in 2013; 8,777 tonnes in 2014 (FAO, 2016a); 12,009 tonnes in 2015 (FAO, 2017)	Brazil, Venezuela & Peru	
'Striped bass'	White bass (*Morone chrysops*) x Striped bass (*M. saxatilis*)	6,112 tonnes worldwide in 2013 & 2014; 4,169 in 2015	USA, Italy & Israel	43rd individual type of fish with greatest value/tonne in 2013 (Appendix 3c)

<u>Genera or families of fish yet to be investigated for humane stunning parameters and species within them which might be researched concurrently</u>

Order Cypriniformes

Mrigal carp, mud carp (*Cirrhinus molitorella*) and small scale mud carp (*C. microlepis*) all belong to the same genus and whilst the latter two species are produced in much smaller volumes, it might still be useful to see if stunning parameters are easily-transferred.

Although not produced in as large numbers, orangefin labeo (*Labeo calbasu*) belong to the same genus as roho labeo and are produced in Bangladesh and India.

Order Siluriformes

There are approximately 40 families of catfish and these comprise approximately 440 genera (ACSI, 2017). The striped catfish or iridescent shark-catfish (*Pangasius/Pangasianodon hypophthalmus*) is listed in Appendix 3a as the 22nd individual species produced in the greatest quantities in 2013 and in Appendix 3b and is therefore worthy of funding for scientific identification of stunning parameters. Once identified, the parameters might also be trialled for the Pangas catfish (*Pangasius pangasius*) produced in Malaysia. FishBase (2017) reports approximately 20 species belong to the genus *Pangasius*, some of which might be included in the FAO category 'Pangas catfishes nei/*Pangasius* spp' which is produced in the 11th greatest quantity and with the 13th greatest overall value (when including all fish species/types listed by the FAO, not just individual species; see Appendices 3a, 3b), in Viet Nam, Indonesia, Cambodia, Myanmar, Bangladesh and India (only 50 tonnes/year are produced in Haiti). In 2010 Viet Nam dominated *Pangasius* catfish production, though China may increase its output in coming years (FAO, 2015j).

Asia produced 73.7% of other types of catfishes, America 13.5% and Africa 12.3% (mostly North African catfish) (FAO, 2012). Although the USA is known for farming channel catfish, genus *Ictalurus*, (it was the species with the greatest production volume in the USA in 2013: FAO, 2015d), more is produced in China now. The Amur catfish (Appendix 3a, 3b) is within the genus *Silurus*, which also includes the European Wels catfish, produced in lower quantities. The yellow catfish is listed in Appendices 3a and 3b and belongs to the genus *Tachysurus*/*Pelteobagrus* within the family Bagridae. Also within this family is the Chinese longsnout catfish (*Leiocassis longirostris*) which increased in production 15-fold between 2013 and 2015 to 250,995 tonnes and was ranked as the 25th individual species produced in the greatest quantity (FAO, 2017) but both species are only produced in China (FAO, 2017).

Order Characiformes

Pirapatinga (or pirapitinga) and pacu (Brazil, Argentina, Paraguay) belong to the genus *Piaractus* and pirapatinga also features in Appendices 3a and 3b. Cachama (genus *Colossoma*) also features in Appendices 3a and 3b. The hybrids tambatinga and tambacu are a cross of these two genera and tambacu is listed within Appendices 3a and 3b. These species and hybrids might therefore be useful to assess for humane stunning. However, the countries of production (Table 6,7) might be relatively unlikely to adopt humane stunning equipment, which may make these fish less of a priority for funding for research.

Order Perciformes

Snakeheads (family Channidae) are produced in Asia (Table 7) where there may not yet be a market for humanely slaughtered fish products, but there are a few species within the genus *Channa* which could be assessed together: the snakehead (*C. argus*), the Indonesian snakehead (*C. micropeltes*), striped snakehead (*C. striata*), spotted snakehead (*C. punctata*) and the great snakehead (*C. marulius*), though the last two species are produced in very low numbers.

Barramundi (giant sea perch) and Nile perch belong to the genus *Lates* and are produced in reasonable quantities, though the latter (produced in Nigeria) did not make it into Appendices 3a-c. However, although barramundi is produced in Australia and the USA, most production is in Asia (Table 7) where it might be more difficult to instigate pre-slaughter stunning.

Snapper production is relatively low compared to other genera, but there are five species within the genus *Lutjanus* which could be assessed, four of which feature in the top 50 greatest values per tonne (Appendix 3c). Three of these species are produced in much lower quantities than the leading species, the Mangrove red snapper and John's snapper, which are mostly produced in relatively wealthy countries in Asia (Table 7).

Order Acipenseriformes

The two species of sturgeon with the highest values per tonne (Danube and Siberian) both belong to the genus *Acipenser* and might therefore be assessed concurrently. Also within that genus, and within the top 50 greatest values per tonne in 2013, are the sterlet (Belarus, Bulgaria) and starry (Spain, Bulgaria) sturgeons, the former of which is already used to produce hybrid fish (Table 6) with beluga sturgeon (a different genus, mostly produced by Spain, Bulgaria and Argentina). Bulgaria and Spain produce the majority of sturgeon.

Which countries produce the species that might be prioritised?

Table 7 provides an extensive list of the species that might be prioritised, as per the previous sections/criteria within this report. The 75 finfish chosen represent approximately 21% of the potential total number of individual species of finfish farmed worldwide. Some species listed in Table 7 (e.g. tench, European Wels catfish and Northern pike) may not have been identified in Tables 4 or 6, or in Appendices 3a, 3b and 3c, but are included because their production in relatively wealthy countries, and particularly in the EU (which may introduce specific rules for the protection of farmed fish at the time of killing), may be more likely to offer the potential to address humane stunning parameters.

Many of the carp species are produced in greater amounts in Asia than in Europe and some species are only produced in Asia. In addition, carp producers may have fewer funds for investing in humane slaughter equipment. Therefore, despite being some of the species produced in the greatest numbers, there may be limitations as to how much can be done to improve carp welfare. Tilapias are mostly produced outside the European area, snakeheads are only produced in Asia and the majority of catfish production is outside of Europe. Some species of fish are only produced in one country (e.g. Wuchang bream, yellow catfish, Chinese longsnout catfish and Mandarin fish in China), which may limit competition and desire for pre-slaughter stunning. Some species are produced in relatively-wealthy countries such as Japan and the Republic of Korea (South Korea), which might be interested in more humane, better quality products, e.g. Japanese eel, coho salmon, Japanese amberjack, silver sea bream, Ayu sweetfish, bastard halibut, Japanese jack mackerel and silver perch. Species produced in small quantities but with a relatively-high value per tonne and production in the European area (which might therefore be worth considering for investigation of humane stunning) include sea or brown trout, European whitefish, shi drum, brook trout, red porgy, sharpsnout sea bream, blackspot or red sea bream and black bullhead catfish.

Table 7. 71 species and 4 hybrids of finfish that might be prioritised for research into humane stunning parameters and the countries that produce them (FAO, 2016a; 2015e; 2015d; FEAP, 2015a; 2014). The symbol ^ indicates that country, and all subsequent countries in the list, are producing less than 1,000 tonnes of that species per year. Members of the EU, EEA and Switzerland are part of an internal/single market and are shown in blue text. Most species were chosen based on Tables 4 and 6 and Appendices 3a, 3b, 3c. From Appendix 3c, 12 individual species were chosen with production in excess of 2,000 tonnes/year (an arbitrary figure chosen by the author of this report, which just under half the species listed by the FAO fall within). Towards the bottom of the table are species which, globally, are produced in relatively low amounts (quantities less than 2,000 tonnes/year or less than 500 tonnes/year (as indicated in the species column) and listed in order of decreasing production) but which are listed within Appendix 3c (the ordinal number indicates the rank within the top 50 individual species with the greatest value per tonne in 2013, excluding species produced at ≤ 100 tonnes/year worldwide) and are produced in relatively wealthy countries.

Species	**Producer countries, in decreasing order of production.** (Total number of countries in the world listed as producers.)
Grass carp(=White amur)	China, Bangladesh, Iran, Pakistan, Myanmar, India, Russian Federation, People's Democratic Republic Lao, Nepal, Taiwan, Uzbekistan^, Iraq, Belarus, Hungary, Malaysia, Israel, Algeria, Czech Republic, Hong Kong, Poland, Bulgaria, Croatia, Cambodia, Moldova, Serbia, Tajikistan, Morocco, Romania, Argentina, Lithuania, Kyrgyzstan, Austria, Albania, Bhutan, Slovakia, Azerbaijan, Sri Lanka, Turkmenistan, Italy, Syrian Arab Republic, Ukraine, Latvia. (42)
Silver carp	China, India, Bangladesh, Iran, Pakistan, Russian Federation, Cuba, Nepal, People's Democratic Republic Lao, Myanmar, Moldova, Uzbekistan, Belarus, Hungary, Romania, Ukraine^, Sri Lanka, Armenia, Iraq, Serbia, Morocco, Poland, Israel, Cambodia, Tajikistan, Czech Republic, Albania, Thailand, Croatia, Georgia, Kyrgyzstan, Bulgaria, Hong Kong, Slovakia, Azerbaijan, Turkmenistan, Taiwan, Austria, Kazakhstan, Syrian Arab Republic, Bhutan. (41)

Bighead carp	China, Myanmar, People's Democratic Republic Lao, Iran, Malaysia, Nepal, Bulgaria, Romania, Taiwan, Moldova^, Czech Republic, Hong Kong, Croatia, Sri Lanka, Cambodia, Uzbekistan, Lithuania, Hungary, Austria, Singapore. (20)
Catla	India, Bangladesh, Myanmar, Pakistan, People's Democratic Republic Lao, Sri Lanka, Nepal, Bhutan^. (8)
Crucian carp	China, Belarus^, Taiwan, Armenia, Republic of Korea, Uzbekistan, Kazakhstan, Azerbaijan, Moldova, Latvia, Bulgaria, Estonia. (12)
Roho labeo	India, Myanmar, Bangladesh, Pakistan, People's Democratic Republic Lao, Nepal, Malaysia, Sri Lanka, Thailand, Bhutan^. (10)
Milkfish	Indonesia, Philippines, Taiwan, Singapore, Tanzania^, Guam, Palau, Kiribati, Zanzibar, Timor-Leste, Tuvalu, Northern Mariana Islands, Papua New Guinea, Nauru. (14)
Wuchang bream	China. (1)
Black carp	China, Taiwan^, Bulgaria. (3)
Snakehead	China, Republic of Korea^. (2)
Indonesian snakehead	Indonesia, Malaysia, Singapore^, Thailand. (4)
Amur catfish	China, Republic of Korea, Taiwan^. (3)
Channel catfish	China, USA, Cuba, Mexico, Russian Federation^, Bulgaria. (6)
Blue-Nile tilapia, HYBRID	China, Panama^. (2)
Mozambique tilapia	Indonesia, Malawi^, South Africa, Swaziland, Dominican Republic, Thailand, Solomon Islands. (7)
Mrigal carp	Bangladesh, India, Myanmar, Pakistan, Nepal, People's Democratic Republic Lao, Thailand^, Sri Lanka, Malaysia, Bhutan. (10)
Asian swamp eel	China, Cambodia^, Singapore. (3)
Largemouth black bass	China, Italy^, Mexico, Spain. (4)
Pond loach	China, Republic of Korea^, Taiwan. (3)
Striped catfish	Bangladesh, Thailand, Nepal^, Singapore, Vanuatu, Dominican Republic. (6). [It is likely Viet Nam's production of striped catfish is included within the FAO category 'Pangas catfishes nei' (*Pangasius* spp.), which Viet Nam is by far the lead producer of.]
Yellow catfish	China. (1)
Mandarin fish	China. (1)
Japanese eel	China, Japan, Republic of Korea, Taiwan. (4)
Pirapatinga	China, Indonesia, Colombia, Viet Nam, Myanmar, Brazil, Ecuador^, Peru, Bolivia, Malaysia, Dominican Republic. (11)
Cachama	Brazil, Venezuela, Colombia, Peru^, Bolivia, Guyana, Panama, Dominican Republic. (8)
Tambacu, HYBRID	Brazil. (1)
Gilthead sea bream	Greece, Turkey, Spain, Egypt, Tunisia, Italy, Cyprus, Croatia, Malta, Israel, Saudi Arabia, France, Portugal, Albania, United Arab Emirates, Algeria, Palestine Occupied Tr, Bosnia & Herzegovina, Montenegro, Bahrain. (20)
Coho(=Silver) salmon	Chile, Japan. (2)
Chinook(=Spring=King) salmon	New Zealand, Chile^. (2)
Silver barb	Thailand, Bangladesh, Indonesia, Myanmar, Cambodia, People's Democratic Republic Lao, Malaysia. (7)
Japanese amberjack	Japan, Republic of Korea^. (2)
Africa-bighead catfish, HYBRID	Thailand. (1)
Philippine catfish	Bangladesh, Singapore^. (2)
Snubnose pompano	China, Philippines^, Singapore, Hong Kong. (4)
Barramundi(=Giant seaperch)	Taiwan, Thailand, Malaysia, Indonesia, Australia, USA^, Singapore, Vanuatu, Cambodia, Israel, Myanmar, Brunei Darussalam, Sri Lanka, Saudi Arabia, Bulgaria. (15)
Silver seabream	Japan, Republic of Korea. (2)
Cobia	China, Taiwan, Panama^, Viet Nam and Colombia. (5)
Bastard halibut	Republic of Korea, Japan. (2)
Korean rockfish	Republic of Korea. (1)
Tiger pufferfish	China, Japan. (2)
Flathead grey mullet	Republic of Korea, Taiwan, Israel, Hong Kong^, Singapore, Greece, Italy, Tunisia, Saudi

	Arabia, Guyana. (10)
Ayu sweetfish	Japan, Taiwan, Republic of Korea^. (3)
Striped bass, HYBRID	USA, Italy^, Israel. (3)
Mangrove red snapper	Malaysia, Hong Kong^, Singapore. (3)
Greasy grouper	Malaysia. (1)
Fourfinger threadfin	Taiwan, Singapore^. (2)
Sea, or brown, trout	Italy, Germany^, France, Austria, Finland, Norway, UK, Russian Federation, Switzerland, Denmark, Bosnia & Herzegovina, Bulgaria, Romania, Czech Republic, Slovakia, Spain, Serbia, Portugal. (18)
White trevally	Japan. (1)
John's snapper	Malaysia, Singapore^. (2)
Pacific bluefin tuna	Japan, Mexico. (2)
Southern bluefin tuna	Australia. (1)
Atlantic bluefin tuna	Malta^, Croatia, Tunisia, Turkey, Spain, Italy, Greece. (7)
Yellowfin tuna	Mexico^. (1)
Danube sturgeon	Bulgaria^, Saudi Arabia, Israel, Argentina. (4)
Siberian sturgeon	Uruguay^, Spain, Argentina, Belarus, Bulgaria, Cyprus. (6)
Meagre (*Argyrosomus regius*)	Egypt, Turkey, Spain, Greece^, France, Italy, Croatia, Cyprus, Portugal (listed by FAO (2015d) but FEAP (2015a) registered 0 tonnes since 2011). (9)
Marble goby (< 2000 tonnes/year worldwide for this species & below)	Indonesia, Thailand^, Singapore, Malaysia. (4). 22nd individual species with greatest value/tonne in 2013 (excluding species produced at ≤ 100 tonnes/year worldwide) (Appendix 3c)
European whitefish	Finland, Czech Republic^. (2). 21st species. In 2014, production dropped below 1000 tonnes/year worldwide and in Finland (FAO, 2016a).
Blackhead seabream	Republic of Korea^, Taiwan. (2). 14th.
Shi drum	Greece^, Italy. (2). 29th. In 2014, the worldwide production reached 621 tonnes and Turkey was also a producer (FAO, 2016a).
Brook trout	Austria^, Czech Republic, Italy, Denmark, Slovakia, Romania, Bulgaria. (7). 33rd. In 2014 Bosnia & Herzegovina was also a producer.
Japanese jack mackerel	Japan^, Republic of Korea. (2). 17th.
Sobaity seabream	Saudi Arabia^. (1). 44th. In 2014 Bahrain was the only producer; 3 tonnes (FAO, 2016a).
Perch	Russian Federation^, Switzerland, Ireland, Italy, Ukraine, Czech Republic, Bulgaria, Romania, Latvia. (9). 48th.
Orange-spotted grouper (< 500 tonnes/year worldwide for this species & 7 more below)	Hong Kong^, Cambodia, Singapore, Brunei Darussalam, Bahrain. (5). 13th. In 2014, the worldwide production reached 596 tonnes (FAO, 2016a).
Longfin yellowtail	USA^. (1). 45th.
Malabar trevally	Taiwan^. (1). 16th.
Red porgy	Greece^. (1). 27th. In 2014 Turkey was also a producer.
Silver perch	Australia^. (1). 10th. In 2014, Taiwan was also a producer (FAO, 2016a).
Sharpsnout seabream	Greece^, Italy. (2). 28th. In 2014 Turkey was also a producer.
Blackspot(=red) seabream	Spain^. (1). 12th.
Black bullhead catfish	Italy^. (1). 31st.
Tench (*Tinca tinca*) (< 2,000 tonnes/year worldwide for this species & below)	France^, Poland, Czech Republic, Germany, Russian Federation, Spain, Italy, Latvia, Austria, Lithuania, UK, Hungary, Bulgaria. (13). [Poland in 2013 (FEAP 2014a) but not in 2014 (FEAP 2015a)]
European Wels catfish (*Silurus glanis*)	Poland^, Hungary, France, Bulgaria, Germany, Moldova, Romania, Czech Republic, Tunisia, Croatia, Belarus, Georgia, Bosnia & Herzegovina, Lithuania, Slovakia, Austria. (16). In 2014 Ukraine was also a producer.
Northern pike (*Esox lucius*)	Russian Federation^, Poland, Czech Republic, Belarus, Romania, Bulgaria, Germany, Lithuania, Hungary, Italy, Latvia, Kazakhstan, Croatia, Austria, Slovakia, Ukraine. (16)

The Federation of Veterinarians of Europe (FVE, 2013) concluded that since the EU requires imports of fish products from outside the EU, '*there is a significant potential in EU for increased production in aquaculture,* *both in terms of capacity and exploitation of new species … research must be supported and targeted towards all the different species … the particular needs of aquatic organisms during their handling, transport or slaughter must be addressed by legislation … veterinary schools should be encouraged to include in their curricula aquatic veterinary disciplines and/or training programmes, in order to ensure a high level of knowledge, skills and competencies of the graduate*'. Indeed, the European Commission is funding the introduction of certain species of farmed finfish into the EU (including some species new to the European region), such as:

1. wreckfish (*Polyprion americanus*) – not listed by the FAO (2015d);
2. grey mullet;
3. greater amberjack (*Seriola dumerili*) – not listed by the FAO (2015d);
4. meagre (certified by GLOBALG.A.P.).

The EU Diversify project (http://www.diversifyfish.eu/) has allocated funds to investigate certain aspects of the aquaculture of these species but the project proposals do not discuss humane stunning; this will need to be addressed if the species become established in the EU. Pike-perch and Atlantic halibut (stunning parameters identified - Table 1) are also included in the EU Diversify project and pike-perch might benefit from additional research into humane stunning parameters, e.g. for in-water electrical stunning.

Countries which export finfish products to, and within, the EU

Since 2013, EU member states have been required by law to spare finfish avoidable pain, distress or suffering during their killing and related operations (e.g. handling, restraining, stunning and bleeding). *Council Regulation 1099/2009* also allows member states to maintain or adopt national rules regarding the protection of fish at the time of slaughter or killing, though there are few examples. Since 1997 Germany's national legislation (which originally implemented European *Council Directive 93/119/EC on the protection of animals at the time of slaughter or killing*) has specified certain stunning/killing procedures and monitoring of states of consciousness for farmed fish (IBFC, 2017; TierschIV, 2012), e.g. prohibiting since 1999 de-sliming of conscious European eels with salt or ammonia: Anonymous, 1997 in van de Vis & Lambooij, 2016) and prohibiting the delivery of live fish to final consumers.

In 2015 EU member states imported a greater volume of farmed finfish than they exported, for all of the macro commodity groups of fish (e.g. 'groundfish', which includes cod, haddock) defined by the European Market Observatory for Fisheries and Aquaculture Products (EUMOFA). Imports of farmed finfish into the EU were dominated by 'salmonids', followed by 'freshwater fish' (Table 8). Salmonid and freshwater fish imports were mostly from aquaculture, whereas a greater proportion of the imported groundfish, tuna and tuna-like species, small pelagics, other marine fish and flat fish were wild-caught (EUMOFA, 2017a).

Table 8. Volumes of EUMOFA commodity groups of farmed finfish imported into the EU in 2015. Adapted from EUMOFA (2017a).

Farmed finfish type/EUMOFA commodity group	Volume (tonnes) imported
Salmonids	1,078,676
Freshwater fish	355,332
Other marine fish	59,556
Groundfish	14,051
Flat fish	1,168
Tuna & tuna-like species	43
Small pelagics	0

It is difficult to identify the export/import routes for specific species of farmed finfish because the FAO (2015f) do not yet differentiate between wild-caught and farmed finfish for their 'Commodities and Trade' and 'Consumption of Fish and Fishery Products' Fishery Statistical Collections and only a few countries collect such data, for only a few select species/products. Of the 97 species of finfish, aquatic invertebrates and algae that EUMOFA list as 'main commercial species', the following 19 species/types of finfish overlap with FAO farmed species records: Atlantic halibut, bluefin tuna (species not specified), carp (species not specified), cobia, cod (species not specified), eel (species not specified), European sea bass, gilthead sea bream, haddock (though no volumes in FAO data), Nile perch, *Pangasius* (species not specified), pike (species not specified), pike-perch, salmon (species not specified), sole (species not specified), tilapia (species not specified), trout (species not specified), turbot and yellowfin tuna. Two other main commercial species categories that are perhaps worthy of inclusion are 'other salmonids' and 'freshwater catfish'. In 2016, for 18 of these species/types of finfish, the EU member states leading imports from outside the EU were Sweden (619,097 tonnes), Denmark, UK, Netherlands, Spain, Italy, Germany, France, Poland and Portugal (33,522 tonnes) (EUMOFA, 2017b). This order is very similar for most of the 15 individual fish species/types shown in Table 9 (excluding cod, haddock and yellowfin tuna, which may not be valid to include), although carp is imported mostly by the UK and Lithuania.

Table 9. The EU member states (up to 10) importing from outside the EU in 2016, the greatest volumes of EUMOFA 'main commercial species' of farmed finfish, in decreasing order of volume (all columns). EUMOFA (2017b). Although *Pangasius*, pike and pike-perch are EUMOFA main commercial species, no data was listed. (Caution: although results were filtered for 'aquaculture', haddock (which according to the FAO (2017) has zero tonnage) was listed as being imported by 15 member states with a total volume of 70,322 tonnes, and the volumes for cod (518,250 tonnes) and yellowfin tuna (230,496 tonnes), all suggest wild-caught data may be included, given the decline in the farmed cod industry since wild cod stocks began recovering and given that only Mexico farms yellowfin tuna at less than 1000 tonnes per year (FAO, 2017). It is therefore possible all data presented may include wild-caught fish for all species. Nevertheless, the data indicates the popularity/value of these species for these countries.)

Species/type	**Importing EU member state (MS)** (Total number of EU member states importing)	**Volume (tonnes) imported by MS** [Total volume imported into EU]
Salmon	Sweden; Denmark; Germany; UK; Finland; France; Spain; Netherlands; Poland; Belgium (27)	519,369; 148,799; 48,544; 35,514; 20,759; 17,415; 9,413; 7,728; 6,834; 5,144 [829,990]
Freshwater catfish	Spain; Netherlands; UK; Italy; Germany; Belgium; Greece; France; Cyprus; Bulgaria (27)	20,991; 16,548; 13,442; 11,684; 9,013; 6,481; 4,050; 3,639; 1,103; 925 [109,185]
Trout	Sweden; Germany; Austria; Denmark; Romania; Poland; Netherlands; Czech Republic; Italy; Croatia (25)	12,208; 6,889; 3,216; 2,869; 2,434; 1,811; 880; 816; 444; 412 [33,169]
Gilthead sea bream	Italy; Spain; Netherlands; Germany; Portugal; Belgium; Greece; UK; Austria; France (19)	9,655; 4,467; 4,140; 3,439; 1,731; 1,368; 1,324; 733; 584; 507 [28,657]
Tilapia	Netherlands; Spain; UK; Poland; Belgium; France; Germany; Italy; Portugal; Sweden (23)	4,539; 4,422; 3,378; 3,151; 2,998; 2,900; 1,863; 1,656; 442; 422 [26,688]
Nile perch	Netherlands; Belgium; Italy; Spain; Germany; Greece; Romania; Portugal; Cyprus; France (13)	7,242; 3,372; 2,615; 2,568; 1,836; 1,474; 645; 509; 124; 63 [20,531]
European sea bass	Italy; Netherlands; Germany; Belgium; Spain; UK; Greece; Austria; France; Portugal (17)	5,481; 3,479; 2,333; 1,634; 1,623; 1,002; 693; 252; 127; 85 [16,986]
Other salmonids	UK; Netherlands; Germany; Belgium; Finland; Austria; Sweden; Ireland; Poland; France (19)	11,524; 1,561; 693; 684; 617; 469; 376; 253; 188; 152 [16,711]
Sole	Spain; UK; Portugal; Italy; Netherlands; Denmark; France; Belgium; Sweden; Germany (13)	3,383; 298; 284; 253; 103; 71; 20; 13; 2; 0.6 [4,428]
Atlantic halibut	Denmark; Sweden; UK; Spain; Germany; Netherlands; Belgium; Greece (8)	1,150; 691; 64; 33; 29; 12; 0.5; 0.2 [1,981]
Carp	UK; Lithuania; Sweden; Romania; France; Germany; Netherlands; Latvia; Ireland; Italy (12)	1,496; 295; 66; 61; 5; 4; 3; 2; 1.2; 0.5 [1,934]

Eel	Netherlands; Belgium; Germany; UK; Portugal; Italy; France; Denmark; Spain; Poland (15)	375; 296; 277; 141; 98; 48; 44; 40; 24; 21 [1,388]
Bluefin tuna	Malta; Spain; France; UK; Germany; Denmark; Sweden; Belgium; Netherlands; Poland (10)	984; 157; 35; 28; 17; 9; 6; 6; 3; 2 [1,247]
Turbot	Germany; Spain; Sweden; Denmark (4)	75; 71; 53; 31 [231]
Cobia	Netherlands; UK; Germany (3)	111; 3; 1 [115]

EUMOFA (2017b) indicates 76 'third countries' are exporting these fish species/types to the EU. Table 10 shows 10 countries exporting to the EU in 2016, the greatest volumes (of some, or all) of the more-specific 18 species/types of fish. On comparing with FAO data for 2015 (FAO, 2017), for Norway, 'other salmonids' are likely to be Arctic char and sea trout; only a small amount of cod was farmed and it was the species Norway farmed in the lowest quantities. Norway also reported farming 'finfishes nei' (FAO, 2017) which may include the species in grey at the end of the list in Table 10. Discounting cod, salmon and haddock from China's production, means tilapia and eel (most likely Japanese eel (FAO, 2017)) are likely to be the species farmed in the greatest quantities in China *and* exported to the EU; the FAO (2017) identified Nile tilapia and blue-Nile tilapia as the 6th and 11th specific species farmed in the greatest quantities in mainland China. In 2013 China produced 28,991 tonnes of rainbow trout and also 'salmonoids nei' which can include other salmoniformes (along with esociformes (pikes) and smelts) (FAO, 2015d). For Viet Nam, freshwater catfish and tilapia (species not specified (FAO, 2017)) (Table 10) fit with FAO data (2015d) but it is unclear whether Nile perch may have been included under the FAO category 'freshwater fishes nei' and whether the FAO category 'marine fishes nei' might include the other species in grey in Table 10. *Pangasius* catfish account for over half of Viet Nam's finfish production from inland aquaculture and are traded overseas (FAO, 2014b) in over 80 countries, with Europe (particularly Poland and Spain) being the most significant market at 35% by volume and 40% by value (FAO, 2015j); 301 of the 405 industrial-scale processing plants in Viet Nam are certified for export to Europe (FAO, 2015j). However, more recently, demand from the EU has reduced whilst demand from the USA remained strong (FAO, 2016b).

Table 10. Third countries exporting into the EU in 2016, in decreasing order of volume, EUMOFA main commercial species of farmed finfish, in decreasing order of volume. EUMOFA (2017b). Exporting third countries (as defined by EUMOFA) which are members of the European Economic Area (EEA) are part of an internal/single market and are shown in blue text. (Caution: although results were filtered for 'aquaculture', either wild-caught and/or imported, then further processed and re-exported products may be within the data, due to the large volumes of cod, haddock and yellowfin tuna (which are farmed in very low numbers, if at all, at present: Table 2) and due to the export of salmon from countries that are not recorded by the FAO as aquaculture salmon producers, e.g. China, Viet Nam. Where a species is missing in FAO aquaculture production data for 2015 for a given country (2017), the species is shown in grey text. The FAO (2017) did not list any aquaculture species for the Seychelles.)

Country	**EUMOFA species, in descending order of volume (tonnes), exported to EU countries in 2016**
Norway	Salmon (695,529 t), cod (178,791 t), haddock, trout (14,750 t), Atlantic halibut (1,830 t), other salmonids (413 t), turbot, bluefin tuna, sole, eel
China	Cod, salmon, tilapia (19,359 t), haddock, eel (559 t), other salmonids (449 t), sole, freshwater catfish (10 t)
Viet Nam	Freshwater catfish (108,015 t), tilapia (3,794 t), cod, salmon, haddock, other salmonids, Nile perch, eel
Iceland	Cod (102,429 t), haddock, salmon (2,469 t), trout (625 t), sole (378 t), other salmonids (92 t), Atlantic halibut, freshwater catfish
Russian Federation	Cod, haddock, salmon (324 t), freshwater catfish (103 t), other salmonids (39 t), Atlantic halibut
Faroe Islands	Salmon (39,077 t), cod, haddock, sole
Turkey	Gilthead sea bream (28,352 t), European sea bass (16,839 t), trout (15,604 t), other salmonids (483 t), bluefin tuna (25 t), yellowfin tuna, carp (3 t)

USA	Salmon (22,157 t), cod, other salmonids (11,010 t), eel, yellowfin tuna, carp (55 t), freshwater catfish (19 t)
Seychelles	Yellowfin tuna (39,061 t)
Chile	Salmon (30,841 t), trout (559 t), other salmonids (35 t)

Regarding intra-EU trade between EU member states, in 2016 Sweden exported the greatest quantity of these same 18 fish types/species (582,403 tonnes), followed by Denmark, Netherlands, Germany, Poland, Spain, Greece, UK, France and Lithuania (38,667 tonnes) (EUMOFA, 2017b). For most of the 13 individual species/types of fish in Table 11, the leading exporting member states follow a similar order, though carp export is not led by these same, major-exporting member states. Salmon was ex/imported between member states in the greatest volumes, followed by trout and gilthead sea bream. Comparing Table 11 with Table 9, shows these three species are imported to, and within, the EU in the greatest quantities, though relatively more freshwater catfish are imported from outside the EU (France imported slightly more freshwater catfish from outside the EU, than from within). France, Germany and Italy import more salmon, trout and gilthead sea bream, respectively, from within the EU than from outside the EU. More salmon and trout were traded within the EU in 2016 than imported into the EU. The UK imported more Atlantic halibut from within the EU, than from third countries. Overall, more carp is imported from within the EU, than from third countries. The Netherlands and France import more tilapia from outside the EU, than from within, whilst the Netherlands and Germany import more eel from within the EU than from third countries. Comparing Table 11 with Table 10, China and Viet Nam exported far more tilapia and freshwater catfish, respectively, to the EU than the leading EU exporter traded with other EU member states. Viet Nam also exported a similar amount of tilapia to the EU, compared to the leading intra-EU exporter which is the Netherlands. Turkey exported to the EU slightly less gilthead sea bream and trout than the leading intra-EU exporters, Greece and Denmark respectively. In 2013 50% of world production of gilthead sea bream and European sea bass was exported, including re-export (IBFC, 2017).

Table 11. EUMOFA main commercial species traded between up to six EU member states which are the species' greatest intra-EU exporting and importing countries. EUMOFA (2017b). (Caution: the data likely includes products originating from other countries, then re-exported after further processing in the listed country, e.g. Nile perch and cobia were the 12th and 18th greatest volume of species/types exported but are not farmed in the EU according to the FAO (2015d) and so were excluded from this table. Also excluded are cod, haddock and yellowfin tuna which are unlikely to be farmed in the numbers reported in EUMOFA data.)

Species/type **Total intra-EU trade**	**Ex/importing EU countries, in decreasing order of volume (tonnes) ex/imported.**
Salmon 909,206 tonnes	Exporters: Sweden (483,382 t), Denmark, Poland, Germany, UK, Lithuania (22,471 t). Importers: France (163,162 t), Germany, Poland, UK, Italy, Spain (68,862 t)
Trout 93,393 t	Exporters: Denmark (20,191 t), Sweden, Spain, Italy, France, Ireland (4,535 t). Importers: Germany (23,614 t), Poland, France, UK, Finland, Italy (4,234 t)
Gilthead sea bream 61,587 t	Exporters: Greece (40,090 t), Italy, Spain, Croatia, Netherlands, Malta (1,710 t). Importers: Italy (23,860 t), Portugal, France, Spain, Germany, Netherlands (3,289 t)
European sea bass 56,219 t	Exporters: Greece, Spain, Croatia, Netherlands, Italy, Germany. Importers: Italy, Portugal, UK, France, Spain, Netherlands
Other salmonids 36,547 t	Exporters: Poland, Germany, Denmark, Netherlands, France, Sweden. Importers: Germany, France, Italy, UK, Belgium, Spain
Freshwater catfish 20,547 t	Exporters: Netherlands (4,737 t), Belgium, Germany, Portugal, Slovenia, Poland (874 t). Importers: France (2,863 t), Hungary, Spain, Germany, Netherlands, Belgium (1,219 t)
Carp 17,954 t	Exporters: Czech Republic (10,049 t), Hungary, Croatia, Bulgaria, Poland, Lithuania (625 t). Importers: Poland (5,788 t), Germany, Romania, Slovakia, Hungary, Czech Republic (780 t)
Sole 15,230 t	Exporters: Netherlands, Spain, Belgium, Denmark, France, Germany. Importers: Italy, Spain, Netherlands, France, Germany, Belgium
Turbot 9,911 t	Exporters: Spain, Portugal, Netherlands, Denmark, Germany, France. Importers: Spain, Italy, France, Netherlands, Germany, UK

Tilapia 9,198 t	Exporters: Netherlands (4,149 t), Belgium, Poland, Germany, Denmark, Czech Republic (157 t). Importers: France (2,535 t), Germany, Netherlands, Italy, Belgium, Hungary (374 t)
Eel 4,731 t	Exporters: Denmark (1,211 t), Netherlands, France, Germany, Greece, UK (350 t). Importers: Netherlands (1,428 t), Germany, Italy, Poland, Belgium, Portugal (225 t)
Bluefin tuna 2,834 t	Exporters: Spain, Italy, Netherlands, France, Portugal, Malta. Importers: Spain, Italy, Malta, France, Portugal, UK
Atlantic halibut 2,702 t	Exporters: Denmark (1,249 t), Sweden, Spain, Portugal, Netherlands, France (75 t). Importers: UK (847 t), Denmark, Netherlands, Germany, Portugal, France (198 t)

Across all EU member states, for aquaculture, EUMOFA (2017a) reported per capita consumption in 2015 of 2.62 kg for salmonids, 0.9 kg for freshwater fish, 0.42 kg for other marine fish, 0.03 kg for tuna and tuna-like species, 0.03 kg for groundfish and 0.02 kg for flat fish. (1,000 kg = 1 tonne.) Table 12 shows some EU member states' household consumption of fresh finfish products (wild-caught *and* farmed) in 2016.

Table 12. EU household consumption of EUMOFA main commercial species of finfish (farmed and wild-caught), in decreasing order of volume, in 2016. Adapted from EUMOFA (2017c). Table excludes species which are unlikely to be farmed such as groundfish and plaice.

EU country	Species/type of finfish consumed, in decreasing order of volume
Denmark	Salmon, trout
France	Salmon, trout, gilthead sea bream
Germany	Salmon, trout, other freshwater fish, carp
Ireland	Salmon
Italy	Gilthead sea bream, European sea bass, salmon
Netherlands	Salmon, *Pangasius*, trout
Poland	Salmon, carp, trout
Portugal	Gilthead sea bream, salmon, European sea bass
Spain	Salmon, gilthead sea bream, European sea bass, miscellaneous tunas
Sweden	Salmon, other salmonids, pike-perch
UK	Salmon, miscellaneous tunas, sole, trout, European sea bass

Species likely to be suffering the most

EFSA (2009a-g) and IBFC (2017) provide information on the various slaughtering methods used for different species of fish farmed in the EU and EEA, but a global record of slaughter methods for aquaculture finfish is lacking. A global social media survey to aquaculture veterinarians, with a small number of questions (translated where necessary), was suggested at the HSA workshop as a way of finding out which slaughter methods are used for which species, in each country in order to build an inventory of current practice and monitor how it changes over time. Questions might include how long the respondent estimates it takes for each species to be gathered, duration of crowding, transfer methods, time spent out of water, time (and number of attempts) to be rendered unconscious and killed by the slaughter method used. Comparison of survey responses with scientific data could be used to gauge the likely level of suffering for each species, caused by the current killing practices and therefore which species might be prioritised for research into humane stunning. Collaborations with colleagues in Asia and Africa will be particularly useful since the aquaculture industry is largest in Asia and is growing rapidly in Africa.

8. The potential of assurance schemes to improve fish welfare at slaughter

Fish assurance schemes may offer opportunities to incorporate promotion of animal welfare and humane slaughter, alongside socially-humane and environmentally-sustainable rearing strategies. Bush *et al* (2013) reported that the greatest demand for certified aquaculture products is from North America and Europe, but currently this demand is for sustainable production rather than for reasons of animal welfare. Table 13 summarises finfish species covered by some aquaculture certification schemes. Bush *et al* (2013) identified that 4.6% of global aquaculture production (including, but not limited to, finfish) was certified under standards that are either species-specific (e.g. Aquaculture Stewardship Council, ASC) or multi-species (e.g. Global Aquaculture Alliance (GAA) and GLOBALG.A.P.). (Though the ASC are producing an Aligned Standard to harmonize commonalities between the existing standards, whilst retaining species/group-specific annexes where harmonization is not possible (ASC, 2018).) In 2015 6.3% of aquaculture production (including, but not limited to, finfish) was certified, with GLOBALG.A.P. accounting for 3%, the GAA and ASC 1% each, Friends of the Sea 1.1%, organic 0.3% and ChinaG.A.P. 0.1% (Potts *et al*, 2016). 'Salmon' accounted for 56% of this global certified production, '*Pangasius*' 10%, 'tilapia' 8%, 'trout' 6% and 'sea bream' 2%, whilst 'carp', despite its dominant production, had '*no significant certified volumes*' (Potts *et al*, 2016). IBFC (2017) reported that in 2015-16 approximately 75% of Norwegian, 85% of UK and 25% of Chilean Atlantic salmon were certified by GLOBALG.A.P. When evaluating private standards covering welfare during transport and slaughter in the EEA, IBFC (2017) described a predominance of implementation for Atlantic salmon (estimated 100% of the UK market share), followed by rainbow trout but that membership of schemes is limited for European sea bass, gilthead sea bream and particularly for common carp, though IBFC (2017) also reported that in Turkey and Greece, 99-100% of European sea bass and gilthead sea bream farms are certified by GLOBALG.A.P.

EU organic producers, European organic assurance schemes (e.g. Naturland) and third countries exporting organic aquaculture products to the EU must comply with *Commission Regulation (EC) 889/2008* as amended, which states: '*Slaughter techniques shall render fish immediately unconscious and insensible to pain*' (EC, 2018). Therefore, there may be broad future benefits of this legislation for the welfare at slaughter of many different species of organically-farmed fish (though this is limited by the availability of scientific knowledge to confirm methods and parameters for humane stunning and killing, which are lacking for the majority of fish species, and the technology to actually implement more humane slaughter). In order of decreasing global production volume, the main finfish currently certified by organic assurance schemes are 'salmon', 'carp', rainbow trout, 'trout' and 'sea bass' (Potts *et al*, 2016). In 2013 China was the leading organic producer in the world, with 59% of production (not limited to finfish), followed by Norway at 16% and Ireland with 8% (Potts *et al*, 2016). In Europe 1% of aquaculture is organic (IBFC, 2017).

Not all aquaculture standards contain guidance for fish welfare regarding humane handling or slaughter, e.g. Friends of the Sea (based in Italy), though this scheme is collaborating with the fair-fish international association (based in Switzerland) to possibly introduce welfare requirements to Friends of the Sea standards in coming years (FOS, 2018). China and Viet Nam have ChinaG.A.P. (a government-led initiative covering eel, croaker, flounder, tilapia) and VietG.A.P. (government-developed and regulatory rather than voluntary, aiming for full ASC certification and the European, USA and Japanese markets) aquaculture standards which certify products principally intended for international markets but these do not yet adhere to the general GLOBALG.A.P. aquaculture standards (Potts *et al*, 2016). Welfare during transport and humane methods of slaughter (the latter defined as: '*The standard requires practices that consider the welfare of aquatic animals in slaughter methods*') were reported to have 55% and 45%, respectively, coverage across aquaculture standards (these figures may include animals other than finfish) (Potts *et al*, 2016). Whilst the ASC standards do not require humane stunning of fish during slaughter, the ASC species scope is worth considering when identifying which species might be suitable for research into humane stunning, since other schemes which do cover humane slaughter are likely to be certifying similar species. In addition, the ASC are currently developing a fish welfare standard to link with the ASC farm standards. Similarly, other organisations are also currently developing, or collaborating on development of, standards for fish welfare, e.g. the Albert Schweitzer Foundation (based in Germany) and the Global Animal Partnership (based in the USA) (OP, 2017).

Table 13. Schemes, their species scope and examples of the standards' requirements for fish welfare at slaughter.

Certification scheme	Species covered and the schemes' welfare at slaughter/killing requirements
Aquaculture Stewardship Council (ASC). Based in the Netherlands. Most products sold in Europe.	1. 'freshwater trout' standard: originally developed for rainbow trout but includes any salmonid in freshwater. Does not include large trout in salt water (ASC, 2013); 2. 'Salmon standard': all species within *Salmo* and *Oncorhynchus* genera in all global locations (ASC, 2012c); 3. *Pangasianodon hypophthalmus* (this genus is a synonym for *Pangasius*) and *Pangasius bocourti* in all global locations (ASC, 2012a); 4. all locations and scales of internationally-traded tilapia (ASC, 2012b); 5. 'Seriola and cobia' standard: applies to *Seriola quinqueradiata*, *S. dumerili*, *S. rivoliana*, *S. lalandi* and *S. dorsalis*, and *Rachycentron canadum* for all global locations and scales (ASC, 2016). ASC are also producing standards for all production regions for 'sea bass, sea bream, and meagre' (applies to all species in the genera *Dicentrarchus*, *Sparus*, *Pagrus* and *Argyrosomus*); 'flatfish' (all species in the genera *Paralichthys*, *Scophthalmus* and *Hippoglossus*); and 'tropical marine finfish' (all species in the genera *Epinephelus* (grouper), *Mycteroperca* (grouper), *Lutjanus* (snapper), *Trachinotus* (pompano) and *Lates* (barramundi)); and for 'sturgeon; Amazonian native finfish; closed-cycle bluefin tuna; and carp' (ASC, 2018). ASC (2016): '*these requirements do not seek to address all issues relating to fish welfare (for example, harvesting of fish using humane slaughter) … outside the scope of social and environmental standards. Separate standards are available for certification of humane treatment.*'.
Global Aquaculture Alliance (GAA) Best Aquaculture Practices (BAP). Independently overseen by the Aquaculture Certification Council scheme. Based in the USA.	1. 'Salmon Farms' standard: marine cage and net pen production of Atlantic salmon, Chinook salmon, coho salmon and rainbow trout (GAA, 2017a; 2015a). Requires salmonids to be stunned instantly and humanely prior to slaughter (GAA, 2017a; 2015a) 2. 'Finfish and Crustacean Farm' standard: all finfish except those listed in the Salmon standard (GAA, 2017b; 2014). (GAA's website lists general types of fish produced under the standards (Appendix 4), but often does not specify the species (GAA, 2015b).). Requires: '*Ill and unwanted fish specimens shall be eliminated in a humane fashion, for example by dispatching them with a blow to the head.*' (GAA, 2017b; 2014)
GLOBALG.A.P. Based in Germany.	'*The GLOBALG.A.P. Aquaculture Standard applies to a diversity of fish … and extends to all hatchery-based farmed species …*' (GLOBALG.A.P., 2015a). '*It covers the entire production chain, from broodstock, … to … harvesting and processing.*' (GLOBALG.A.P., 2018a). As at 30th September 2015, of a possible 56 species of finfish that can be certified by GLOBALG.A.P. (73 species at 12th February 2018: GLOBALG.A.P. (2018b)), 25 species of finfish were listed (Appendix 4) as certified by GLOBALG.A.P. (GLOBALG.A.P., 2015c; pers. comm. GLOBALG.A.P., 15th October 2015) and 4 of these (listed below) are not listed in Appendices 3a, 3b and 3c: • Bluespotted Seabream (*Pagrus caeruleostrictus*) • Pink Dentex (*Dentex gibbous*) • Sand Steenbras (*Lithognathus mormyrus*) • White Groupers (*Epinephelus aeneus*) Requires: '*Fish are stunned using an effective stunning method and immediately become unconscious.*' AQ 13.1.4 (Level: Major must). (GLOBALG.A.P., 2017; 2016;

	2015a) '*Fish are bled immediately after stunning and remain unconscious while they bleed to death.'* AQ 13.1.5 (Level: Major must). (GLOBALG.A.P., 2017; 2016; 2015a) Fish welfare, management and husbandry > fish health and welfare > culling of fish: '*Stunning prior to killing is mandatory.'* AQ 5.2.21 (Level: Major must). (GLOBALG.A.P., 2017; 2016)
Naturland. Based in Germany. A global-oriented scheme.	'*Carp (*Cyprinus carpio*) and its accompanying species e.g. tench* Tinca*, pike* Esox*, the Cyprinidae species; salmonidae (e.g. trout (*Trutta, Oncorhynchus*), salmon (*Salmo*) and char (*Salvelinus *sp.)); whitefish Coregonus; tropical freshwater fishes e.g. milkfish* Chanos chanos*, tilapia* Oreochromis *sp., Siamese catfish* Pangasius *sp.; Perciformes (perch-like), Carangiformes (jack-like) and Gadiformes (codlike) fish*'. Requires: '*9.2 Slaughtering of fishes shall be carried out by means of incision of gills or immediate evisceration. Prior to this, fishes have to be stunned (by means of concussion, electrocution and, if need be, by natural plant anaesthetics, tropical and subtropical fish and invertebrates also by using ice, provided that it is not otherwise specified for certain species in the Special Part). … It is recommended that carp be stunned using a combination of electrical stunning followed by a blow to the head.*' (Naturland, 2017).
Quality Trout UK	Rainbow trout in UK and 'trout'. Requires: '*5.6.1. … The harvesting procedure should render the fish immediately insensible and beyond the point of recovery. Killing efficiency must be monitored to ensure fish do not regain consciousness prior to death.* *5.6.2 Where automated methods of stunning are used, a manual back-up (e.g. a priest) must be available should the system fail.*' (QTUK, 2017).
RSPCA Approved Farming, Australia	Atlantic salmon. Requires: '*10.09 Fish must be stunned prior to slaughter.* *10.10 Stunning methods using carbon dioxide are not permitted.* *10.12 Bleeding must follow within 10 seconds of stunning.*' (RSPCA, 2017).
RSPCA Assured, UK	Welfare Standards for Atlantic salmon require: '*S 1.4.2 Humane mechanical devices must be used in preference to a manual percussive blow (except for emergency killing).* *S 1.5.1 A priest or secondary stunner must be available throughout the killing process to allow a percussive blow to be administered immediately in the event of a fish not being effectively stunned. S 1.5.6 CCTV must be installed to provide clear footage of the back-up stun process.* *CF 5.0 Cleanerfish must be killed humanely using percussive/electro stunning or anaesthetic*' (RSPCA, 2018). Welfare Standards for rainbow trout require: '*S 1.4.1 Permitted stunning/killing methods for marine sourced trout are: a) an effectively applied percussive blow, b) electronarcosis followed by bleeding or, c) electrocution.* *S.1.10 A sample of fish must be examined during, and at the end of the process and checked to ensure that there are no signs of consciousness.* *S 2.15 Dry stunning methods using electricity are prohibited*' (RSPCA, 2014b).
Soil Association, UK	Currently rainbow trout and Atlantic salmon farmed in the UK and Norway and stunned electrically or percussively, but can potentially certify a variety of species including those listed by *Commission Regulation (EC) 889/2008* as amended. Require: '*AL c. Harvest and slaughter. Suffering of aquaculture animals, including at slaughter, must be kept to a minimum. You must only use slaughter techniques that render fish immediately unconscious and insensible to pain. … Guidance. The following slaughter methods do not meet this standard: ice, except for warm water shrimp; carbon dioxide; suffocation, leaving stock to die in the open air; exsanguination without stunning; operating a rolling harvest where you starve all fish in the holding facility and selectively grade a number for slaughter on a repeated basis; starving stock to modify carcass weight or quality (body composition)*' (Soil Association, 2016).

The general standards cover a broader scope of species and might not list detailed requirements for each species; in these cases promotion of general humane handling techniques may be best. The species-specific standards are very limited in the number of species they encompass, relative to the number of species farmed, but do offer potential for specific handling techniques and stunning parameters to be listed and required. Although multi-species standards cover nearly twice as much production, they represent an increase of only 0.1% over the species-specific standards because many of the products that are potentially certifiable are produced and sold in countries with, currently, very limited interest and demand for sustainably-certified products, e.g. China (Bush *et al*, 2013). For example, the volume and the number of species of carps produced and consumed, is far greater in the 'Global South' than in the northern regions of the world, so even if carp production in the 'Global North' becomes widely certified, it won't result in the majority of carp production worldwide becoming certified in the near-future (Bush *et al*, 2013), partly also because wealthier countries still mainly trade amongst themselves (FAO, 2014b). Nevertheless, the certified species in Table 13 and Appendix 4 are a start.

Certification for exported products may be the sector most likely to require minimum stunning parameters because of the higher priority that consumers residing in some countries might place on animal welfare and because wealthier countries dominate the import of fish products, particularly in terms of volume, and the products imported are of a higher unit value. The EU, the USA and Japan are the largest importers of fish, although this figure may include reptiles, amphibians and invertebrates (FAO, 2014b). Catfish might be one fish type that this strategy could be applied to. In parts of Asia, domestic demand led to global trade opportunities and there is an increasing amount of trade between Asian countries and also now elsewhere. From 2004 Viet Nam began exporting striped river catfish or iridescent shark (*Pangasius hypophthalmus*) to Europe and the USA and, as a result, trade has risen dramatically, compared to in Bangladesh which still mostly supplies its domestic market (Belton *et al*, 2011). *Pangasius* accounts for 26% of Viet Nam's total seafood export value. Basa or cobbler are terms used to describe the products of a number of species of *Pangasius* catfishes, including *P. hypophthalmus* and *P. bocourti*. 149 countries and territories have *Pangasius* products available to buy and the EU and the USA are the main importers of *Pangasius*, followed by Japan, the Russian Federation and Egypt (FAO, 2014b). Europe imports 200,000 tonnes of product, equivalent to 600,000 tonnes of live fish, estimated to arise from the slaughter of 600 million individual fish per year (D. Little presentation 19 June 2014).

There is a need for scientific research and development to keep-up with the requirements of aquaculture standards and to identify humane stunning methods and parameters for those species covered by the schemes. In which case, assurance schemes might wish to be involved in funding such research and assisting finfish producers in adopting humane slaughter technology.

Bush *et al* (2013) warn that stakeholders in the 'Global South' (particularly small-scale producers) may not be able to participate in certified schemes due to language barriers, access, cost, time or resources and the complex requirements for administration and management of involvement in certification schemes. It will be important to ensure schemes are designed so they do not inadvertently exclude such producers from taking part. Some certification schemes are trying to bring small-scale producers into line with certification standards (GLOBALG.A.P., 2015b and GAA). Humane stunning equipment can be expensive but steps can be taken to improve handling during harvest.

9. Which sectors of industry are most likely to be able to, or wish to, employ stunning?

Despite variable cost and sale prices and variable costs of investment in more humane stunning and killing equipment, implementing improved fish welfare practices at slaughter in the EEA may potentially have only a very small effect on the cost of production (especially on larger farms), compared with operating, feed and labour costs (IBFC, 2017). The estimated effect on cost price for a farm [in a select few EEA case study countries] investing in more humane slaughter equipment to improve the welfare of Atlantic salmon, rainbow trout, and European sea bass and gilthead sea bream, was relatively small compared to investment for common carp (Table 14). Large-scale farms of Atlantic salmon in Norway and portion-size rainbow trout in Italy may even benefit from cost savings following investment in humane slaughter equipment because labour requirements are reduced. Although the sales price of rainbow trout in Italy between 2009-2013 was more than sufficient to cover all investment costs for improving fish welfare at slaughter, this was not necessarily the case for Denmark or France which have higher unit costs and require subsidies or diversification to break even. (Improving trout welfare at slaughter using in-water electrical stunning followed by manual gill cutting was considered to increase costs for small farms in these countries, though was still cheaper than percussive stunning.) Small producers benefit less from economies of scale unless they share a slaughtering/processing facility with other producers, e.g. like in Germany where common carp from multiple farms are mostly slaughtered at one central processing enterprise (though transport of conscious fish is less desirable for welfare than killing on-farm). IBFC (2017) suggest that sharing a dedicated slaughterhouse for rainbow trout might be a possible solution for small farms in Denmark and France, especially given that slaughter-ready rainbow trout are already transported by road to slaughterhouses in Denmark, France, Italy and Poland, as are other fish species in Germany and the Czech Republic (IBFC, 2017). Farming of common carp was found to generally not be profitable in Europe between 2009 – 2013, despite variation in production costs, which are approximately double those in China (IBFC, 2017). Between 2012-13 98% of global production of common carp was consumed in the country of production, making it difficult to encourage international competition that may improve welfare at slaughter practices on a larger scale. For European sea bass and gilthead sea bream, EU production is generally not profitable without subsidies or diversification (IBFC, 2017). Although Spain is not the largest EU producer of these species, it has the largest-scale farms but also higher numbers of staff (IBFC, 2017). Although in-water or dry electrical stunning followed by chilling in ice slurry was suggested as a way of improving these species welfare at slaughter, and although the extra unit costs are relatively modest as a proportion of the sales price, adoption of stunning may be problematic for low or negative income enterprises, especially without higher revenues from higher-welfare products (IBFC, 2017).

Table 14. Range of costs, depending on the enterprise/country, of adhering to improved animal welfare practices at slaughter for five species of finfish (two were combined at the data source) in a sample of EEA countries between 2009-2013. Adapted from IBFC (2017). 'Total extra investments' include pumps, in-water or dry electrical stunners or automated percussive stunners, dewatering units and decapitation robots. 'Total extra annual costs' include depreciation and maintenance, interest costs on investments (5%) and labour costs, which may be negative where improved welfare practices are anticipated to result in savings on labour. FTE = full-time employee. Investment and annual costs of in-water electrical stunning was cheaper than dry electrical stunning (17% higher annual costs) for common carp, but was the opposite for European sea bass and gilthead sea bream combined.

Species Countries sampled	**Total extra investments for fish welfare**	**Total extra annual costs**	**Effect on cost price, expressed as % of sales price**	**Minimum volume/year to achieve a cost price effect of < €0.05/kg**
Atlantic salmon Norway, UK, Ireland	€410,000 to €425,000	-€60,386 to €60,863	-0.22% to 1.47%	1,250 tonnes. 7,500 tonnes will outweigh investment costs, even at higher salary of €75,000/FTE.
Rainbow trout Italy, Denmark, France, Poland	€205,000	-€20,803 to €26,400	-2.14% to 7.68%	250-400 tonnes, depending on salary. 650 tonnes to break even at average salary of €50,000/FTE.
Common carp Poland, Czech Republic, Germany	€175,000 to €190,000	€24,675 to €28,750	2.85% to 28.45%	500 tonnes.
European sea bass & gilthead sea bream Greece, Spain, Italy	€140,000 to €195,000	€21,500 to €26,875	0.56% to 1.9%	550 tonnes.

Worldwide, most large-scale processing plants, particularly those that export fish products, are using sophisticated further processing equipment for the slaughtered fish. However, in many countries, such companies lack sophisticated stunning equipment for the live, conscious fish. Large corporations with fully-integrated farm and processing facilities may be the most likely to invest in humane stunners, to potentially have a competitive edge by addressing consumer desires and assurance scheme requirements. Seventy per cent of European sea bass and gilthead sea bream in Greece and Turkey are farmed by fully-integrated companies (IBFC, 2017). Apart from countries with an established use of fish stunners (e.g. UK, Scandinavia), companies based in other parts of the world are enquiring about stunners but few have installed them. Nevertheless, the HSA is encouraged by, for example, fish processing companies in Asia enquiring about stunners for *Pangasius* and companies in Europe enquiring about stunners for sturgeon in recent years.

However, around 80-90% of fish farmers are considered to be small-scale producers (FAO, 2013b; 2014b). In the EEA, most farms are run by small or medium size enterprises or microenterprises and family firms in coastal and rural areas, particularly for freshwater species (IBFC, 2017). Small or subsistence farmers may not employ any specific or sophisticated stunning method; some may commercially grow fish under contract for collection, transport and slaughter off-site by the contractor; other farmers may perform slaughter for local or private consumption. Some small-scale farmers may not slaughter their fish at all because the consumer prefers to take it away live. In many countries, when shopping for and inspecting potential meat products, consumers prefer to examine live animals as a guarantor of freshness (Little & Zhang, 2014 in D. Little presentation 19 June 2014). For example, when catla are sold live, their market value increases over two-fold compared to dead fish transported in ice (FAO, 2015h). Similarly, North African catfish can be sold at higher prices in live fish markets (FAO, 2015k). Common carp are sold live to consumers in Poland (75% of market share) and the Czech Republic (85% of market share), and to restaurants (70% of market share in Bavaria, but differs between regions) in Germany (IBFC, 2017). In addition, a lack of refrigeration facilities during transport of products from the farm to the place of sale, and in the consumers' homes, means live animal transport and live sales are preferred by the producer and by the consumer for product quality and food hygiene. This exposes live fish to additional stressors and risks to welfare including, ultimately, death prior to the seller's intended time of killing/selling the fish. Therefore, to minimise stressors for fish and to reduce wastage (especially post-harvest losses: FAO, 2014a), wherever possible, it will be important to encourage the sale of fish slaughtered on-farm, without the need to discount them in price at the point of sale, but this may be very difficult in certain (hot) climates. The FAO (2014b) is unable to determine the amount of fish that are marketed alive but they note that it is especially appreciated in South-East Asia and the Far East, along with niche markets in other countries. Live or 'wet' fish markets often lead to the local supply chain dominating the market and, if production is concentrated and purchase prices are reduced in order to compete, it may mean producers have fewer funds to invest in sophisticated on-farm stunning equipment. As such, promotion of more-affordable humane slaughter methods for small-scale producers is likely to be required. In some countries, once a consumer makes a purchase in a market, some fish are manually percussively stunned in the market by the seller (e.g. using a mallet). Sellers are likely to be more experienced at killing fish and so should be encouraged in all countries to kill fish before handing them over to the consumer because, for the buyer, it makes the fish easier to handle and eliminates the risk of the fish suffering further during transport to, and storage at, the buyer's home and when the buyer attempts to kill/cook the fish. Live fish in markets may also suffer due to exposure to direct sunlight and hypoxic conditions in shallow-water-filled containers with extremely limited space, often insufficient to maintain normal posture and functioning. Therefore guidance for sellers on humane handling and marketing of live fish is also required.

In addition to small-scale producers who sell their fish directly to the consumer, in some countries live fish (e.g. carp) are housed in tanks in retail establishments and either killed by the retailer at the time of sale or sold alive for the same reasons as above. For supermarkets with refrigeration/freezing facilities, fish should be slaughtered on-farm to prevent transport distress and any suffering whilst living in-store waiting for purchase. If killing is performed at a retail establishment it is essential that staff are fully trained and competent in the capture, restraint, stunning and killing techniques used and that they have appropriate, well-maintained equipment for all the stages of the slaughter process.

10. Which stunning methods are likely to be most suitable for large-scale industry and what requirements might industry have?

It is critical that scientific research focusses on stunning methods and equipment that are most likely to be used by industry. The benefits of, and desire for, stunning equipment has got to be market-led and communicated between farmers and processors. The available infrastructure in the area or country of installation is an important consideration, e.g. the output and reliability of electrical power sources.

Highly-automated group-stunning equipment often reduces labour requirements and associated costs. However, installing automated stunning equipment into an existing processing line may be costly and can require complex planning. Another key consideration when deciding how automated a system can be is whether a producer is killing large numbers of small-size fish or small numbers of large-size fish. For the former, producers tend to prefer a higher level of automation and a method that stun-kills the fish, to avoid the need for follow-up killing of each individual fish (many farms do not have sufficient staff to achieve this quickly-enough, without some fish recovering consciousness).

In-water electrical stunning allows for high throughputs and targets all fish, irrespective of size and shape (e.g. deformities, sex and stage of maturity). In-water electrical stunners also typically require low levels of maintenance because the only moving part is the water pump (J. Lines pers. comm. 19 June 2014). Pipeline in-water electrical stunners require less power and are more economical with energy, than in-water batch systems that apply electricity to a large number of fish in a container.

A major limiting factor in uptake of stunning equipment appears to be cost. Around the world, there are reports of fish farms and some processors (across a range of scales of production) self-building, or commissioning the building of, cheaper equipment (typically plugged into the mains electricity supply) which the producers believe stun their fish. Batch-style electrical stunners are often the design of choice, e.g. for rainbow trout, carp (EFSA, 2009b,c) and eel (EFSA, 2009d), and use a variety of designs of either one or two pairs of electrodes including rods and sheet metal plates, which may be left in one position or moved around the container to 'reach' fish that appear not to be under the influence of electricity. Judgement as to whether such equipment, and the parameters used, successfully stun fish is often based on behavioural indicators of consciousness alone which can be difficult to assess without training and which can be unreliable. When applied appropriately, electrical stunning is a humane method; but use of inappropriate electrical parameters can severely compromise fish welfare, sometimes causing paralysis (which can be mistaken for unconsciousness) and fish may suffer unbeknown to the producer. Whilst this clear desire of industry to improve fish welfare at slaughter is commendable, it is important that companies that develop and manufacture slaughter equipment should design stunners to use parameters that scientific research has already validated as humane, otherwise fish welfare could be compromised. Producers/manufacturers can also invite experts in animal welfare at slaughter to perform formal, specialist assessment of new equipment and parameters, to verify whether the equipment and parameters are indeed humane for the relevant species, *before* the equipment is marketed to producers or to customers who are interested in purchasing higher-welfare fish products. Some rainbow trout farms in Denmark, France and Italy, and some common carp farms in the Czech Republic, Germany and Poland, use electrical 'stunners' for which information about their construction and humaneness is 'scarce' and they are not purchased from the major/known manufacturers; therefore their design/construction is unlikely to have been scientifically assessed for its effectiveness for fish welfare and may require improvement (IBFC, 2017). For example, in the Czech Republic often no follow-up killing method is applied because '*industry considers … electricity to be sufficient for stun and kill*' but this gives cause for concern as '*from scientific literature it is known … carp cannot be killed by electricity*' (IBFC, 2017). Manufacturers should not describe equipment as a 'stunner' (or as a stun-kill system) unless that equipment has been scientifically validated as that, i.e. it is capable of routinely causing loss of consciousness without pain in the named species, and (if relevant) it is capable of reliably causing death. Self-build systems should be checked for loose electrical connections, which may increase electrical resistance (reducing current flow or electric field) and lead to intermittent power supply, potentially causing pre-stun shocks and associated meat quality problems.

In-light of this desire for cheaper stunners, it is necessary to look for low-cost means of manufacturing humane stunners that are not particularly complex (structurally and principally), which have low maintenance requirements (e.g. few moving parts), and which can be sold at an affordable price to a majority of fish farms in a range of countries. If companies with low fabrication costs are able to make effective stunning equipment at a cheaper price, this will benefit fish welfare more widely and more rapidly. Companies already experienced in producing stunning equipment might be able to collaborate with (and perhaps sponsor) a manufacturer in another region of the world, to build a humane stunner that is suitably-priced for their continent's aquaculture industries.

Companies that design stunners must be aware of potential food safety complications (e.g. *Salmonella*, *Listeria*) that might require equipment to be thoroughly disinfected between uses. EFSA (2009h) considers that the microbiological quality of the water used during in-water electrical stunning may need to be taken into account when considering food safety; this may also be dependent on the organisms present on the fish following transfer from their rearing enclosure water to the stunning water. Greater control of fish health before slaughter should be the priority and may reduce the risk of microbial contamination and still allow more humane stunning methods (like in-water stunning) to be utilised. Regular sterilisation of knives used for exsanguinating, decapitating or gutting fish (as performed by mammalian and poultry neck cutting operatives in slaughterhouses), may reduce concerns regarding microbial cross-contamination, as reported in EFSA (2009h), although no studies on fish had been published at the time of the EFSA publication.

11. What guidance is required for industry?

Guidance for the humane slaughter of Atlantic salmon and rainbow trout can already be found in existing HSA publications on farmed fish and FAWC (2014) produced a list of stunning parameters for tilapia and halibut also. In addition, van de Vis & Lambooij (2016) produced information on electrical stunning of European sea bass, European eel, common carp and turbot.

Fish producers and fish slaughter equipment manufacturers should consider starting to voluntarily operate to similar standards as required for mammals and birds protected under European *Council Regulation 1099/2009 on the protection of animals at the time of killing*. If, in future, more specific rules are required for fish in this legislation (e.g. if fish are included in Annex I) then producers and manufacturers may have to comply, e.g. by producing standard operating procedures (SOPs) for harvest. In order for producers to write their SOPs, manufacturers of fish stunners should specify the key parameters that their equipment operates at and the frequency with which the equipment must be calibrated. For example, the following parameters should be described in equipment instruction manuals:

Percussive stunners:	Target location of blow, shape and dimensions of knocker head, kinetic energy, minimum and maximum operating air pressures, minimum and maximum permissible size and/or age of fish for that type of stunner (note if any sex differences in these figures), suitable follow-up killing methods (if required), maximum duration of time between application of stun and application of a specified killing method in order to prevent recovery. 'Priests'/mallets for manual percussive stunning of fish may need to be weighted for species more resistant to percussive stunning, to increase the likelihood of an immediate stun after one blow. Ideal dimensions, materials and weights of priests for effective stunning should be described for different species, to assist operators with delivering sufficient impact energy for a successful stun or kill.

Dry electrical stunners:	Number of phases of electrical application. For each phase: waveform, minimum and maximum frequency, duty cycle, minimum voltage and minimum current, minimum duration of application, shape/dimensions of electrodes, target location of electrodes when in-contact with fish, required orientation of fish, maximum number of layers of fish atop one another (if equipment can effectively stun all fish within all layers), maximum number of fish in the stunner at any time (based on the typical resistance of that number of fish), suitable follow-up killing methods (if required), maximum duration of time between the cessation of application of the stunning treatment and the application of a specified killing method in order to prevent recovery.
In-water electrical stunners:	Number of phases of electrical application. For each phase: waveform, minimum and maximum frequency, duty cycle, minimum magnitude of electric field, minimum duration of application (or maximum water flow rate through a pipeline stunner), direction of flow of electric field and required orientation of fish, minimum and maximum water conductivity for the electrical parameters used, maximum number of fish in the stunner at any time (based on water conductivity), suitable follow-up killing methods (if required), maximum duration of time between the cessation of application of the stunning treatment and the application of a specified killing method in order to prevent recovery.

Similarly, stunners should be fitted with a digital display reporting (and recording, if manufacturers wish to follow the example of good practice requirements for mammal and poultry stunners) the relevant key parameters (e.g. air pressure for percussive stunners or current/electric field and water flow rate for in-water electrical stunners) which operatives can check to confirm the equipment is operating as intended and that stunning is likely to be effective. This will be helpful when assessing the effectiveness of stunning in combination with physically checking fish after the intended stunning treatment. The display system could also be capable of giving a clearly visible and audible warning alarm if the parameters deviate from their desired settings, giving cause for concern for animal welfare (e.g. due to equipment failure, too short an application time, or due to overloading of an electrical stunning system with too many fish creating a greater resistance than the system's voltage can overcome). Some in-water electrical stunners that calculate the electric field based on the conductivity of the water at that time, do not use volt- or ammeter displays (since the readings often differ), but rather traffic lights to indicate when the stunner can be used (green) and when not yet functioning appropriately (red). Nevertheless, it will be advantageous if traffic light systems also record key stunning parameters for operators to periodically objectively review over time.

It was suggested at the HSA workshop that, for as many species as possible, particularly those species identified as priorities for improving welfare at slaughter, research is required to identify key performance indicators of fish product quality which include traits desired by producers and consumers and which are as globally-applicable as possible (e.g. presence and severity of wounds on body (e.g. damage to eyes or gills), brightness, colour, degree of mucus (EFSA, 2009h) and presence and severity of gaping within fillets). These indicators should be assessed for different methods of handling, moving, transporting, stunning and killing fish. The outcomes should be considered in terms of whether different methods of handling and killing offer advantages for product quality and whether the outcomes vary with environmental conditions and season. Research should account for any differences in experimental (small-scale) and commercial (large) scale trials in case this affects the outcome (Roth *et al*, 2009). These research results should be communicated to industry as widely as possible, to increase awareness of any potential advantages for product quality that can be gained by improving fish welfare at harvest through more humane handling and by using stunning. This may encourage the uptake of stunning equipment and the sponsoring of further research by interested sectors of industry. The results can be used to develop an index of product quality which encourages continuous improvement, so the lowest quality indices show progressively lower levels of damage and the highest indices show continual improvement of quality over time. Such an index might be used as an international grading system for exported products. An existing similar initiative is FindIT, a platform for data management and analysis to assist European fish aquaculture in its development towards higher performance and competitiveness (FEAP, 2015b). FindIT has begun systematic collection and analysis of hatchery data across sites and companies. FindIT may provide a useful model, or even forum, for a similar database for comparing harvest procedures and outcomes on fish welfare and product quality.

12. What support and funding sources are available for further research and development?

The HSA wishes to encourage scientists and engineers to determine humane stunning parameters and develop stunning equipment that industry will use. The HSA offers funding for research or development projects aimed at improving animal welfare during transport, marketing, slaughter or killing for disease control or welfare reasons. For example, applications for 'HSA Research, Project & Travel Grants' are accepted all year round. For further details of the various HSA awards, and the application forms, please view: **www.hsa.org.uk/grants--awards/grants--awards**

In order to hasten their ability to market the finfish species they produce/certify as higher-welfare, some fish farming industries and fish assurance schemes might also be willing to sponsor research to identify humane stunning parameters and may even be willing to lead their own research and development programmes in humane slaughter because of the demonstrated economic return from good welfare and improved products. For example, the Atlantic salmon industry is interested in refining electrical stunning parameters to benefit both fish welfare and product quality.

Within laboratory animal welfare science, the NC3Rs CRACK IT scheme (www.crackit.org.uk) is in-use to help apply scientific research results in-practice to benefit animals and commercial industry; something similar might be a useful initiative for improving food fish welfare at slaughter. CRACK IT is designed to enable collaboration between scientists, engineers and industry and to commercialise products developed by small and medium enterprises (Burden *et al*, 2015). Industry might act as a 'sponsor' and define the 'problem' and the ideal solution they desire (increasing the likelihood of the product's uptake once commercialised) and might also provide, in-kind, fish and other farm-related items, expertise and advice. An overseeing organisation would bring together experts to help solve the 'problem' and select the best suggested solution for project delivery and promote it to a wider audience through a relevant website. The Atlantic salmon industry's quest to refine in-water electrical stunning for routine slaughter might be such a project. Once built, another CRACK IT project might involve those manufacturers of the stunners sponsoring production of the stunner by one or two local companies at strategic points elsewhere in the world.

It was suggested that the HSA workshop featured in this report might make a useful contribution as a consortium for the EU Horizon 2020 initiative (http://ec.europa.eu/programmes/horizon2020/en), to further the case for humane slaughter of farmed fish (if a relevant call is available). (Horizon 2020, a seven-year research programme until 2020, plans to get good ideas to market faster, boost the economy, create jobs and may provide support (including financial) for institutes, universities, small businesses and international partners.)

The HSA workshop participants generally agreed that gifting stunning equipment to fish farms was unlikely to be associated with long-term use of the stunners and therefore not a cost-effective strategy.

13. Other considerations

The design of movement and handling facilities for farmed fish are very important for protecting fish welfare at harvest (Lines & Spence, 2014; 2012). Trying to improve handling systems and procedures at harvest worldwide will be extremely helpful in protecting fish welfare and, with caution, it may be possible to apply a general principle to a range of species, particularly those that share similar morphologies or lifestyles/adaptations. Guidance encouraging all farmers to plan for animal welfare when designing and building their systems is feasible and should be promoted as a means of improving fish health, product quality and saleability. Planning at the outset will avoid or reduce the need for costly refurbishments or adjustments later on.

Enforced fasting of farmed fish has been under consideration on ethical grounds for a while now. Scientific research is required to assess the various fasting conditions imposed on different species of farmed fish prior to slaughter (in varied environmental conditions and with varying farming practices) and the effects on fish welfare, and product quality and safety at the time of human consumption. (Stress can disrupt physiological processes within fish, altering their susceptibility to disease and pathogen carriage and reducing the time between death and onset of rigor mortis (EFSA, 2009h).) Food withdrawal durations intended to empty the gut (e.g. Einen *et al* (1998) noted that no residual feed was found in the gastrointestinal tracts of Atlantic salmon starved for three or more days during winter temperatures of 3-6°C) are likely to be sufficient and are unlikely to cause significant health problems for fish but the effect on welfare may be complex. Scientific research into food deprivation might be another candidate for systematic data collection and analysis across sites and companies (e.g. FindIT). Some strategies completely withhold food from fish (European sea bass and blackspot sea bream, 31-day complete starvation period at 20°C: Caruso *et al*, 2011), whilst others reduce the amount of feed provided. Consideration of how variation in the prior, routine feeding frequency might affect a species' response to enforced fasting might also be important, as will be the ambient temperature. IBFC (2017) reported for marketable (i.e. slaughter weight) Atlantic salmon that at least 90% of the market shares in Ireland, Norway and the UK fast for not more than 14 days, 9 – 21 degree days (depending on season) and 48 – 72 hours maximum, respectively. It was reported that these durations of feed deprivation are sufficient to clear the gut, except for the UK times which may not be sufficient in winter. In Denmark (100% of market share), France (100% of market share), Italy (100% of market share) and Poland (less than 50% of market share) marketable rainbow trout may be deprived of food for 2 – 7 degree days (depending on season) or for five days at 2^{o}C water temperature or 3-4 days at 15-17^{o}C, with all durations reported to clear the gut (IBFC, 2017). In Poland, Czech Republic and Germany (all 100% of market share) marketable common carp are deprived of food in only certain regions or in winter when natural food is not present in ponds (many carp are not fed supplemental food); e.g. for five days to one week at 4-6^{o}C, with all winter durations reported to clear the gut (IBFC, 2017). In Germany and Poland, holding prior to slaughter (accompanied by food deprivation) is intended '*to remove off flavour*' (IBFC, 2017). In Greece, Italy and Spain (all at least 90% of market share) marketable European sea bass and gilthead sea bream may be deprived of food for 40 and 50 degree days or 48 hours, respectively (IBFC, 2017). There is very little research on food withdrawal, and therefore very few science-based recommendations, that take account of fish health and welfare as well as product attributes; most recommendations concerning fish welfare are for Atlantic salmon and rainbow trout (e.g. López-Luna *et al*, 2014; 2013). Recommendations for feed restriction have been made on the basis that some aspects of flesh quality are considered to improve and that farms will save fish feed, and therefore money, at the end of the production cycle (Suárez *et al*, 2010). However Suárez *et al* (2010) also pointed out that severe restriction of feed by 50% or more was detrimental to the final product and reduced profitability. Mørkøre *et al* (2008) found that fasting salmon for five weeks improved certain aspects of the flesh and concluded that fasting enabled fish to cope better with acute stress during harvest. However, as Mørkøre *et al* (2008) also mentioned, this problem is likely to be more appropriately dealt with by directly addressing and removing, as much as possible, the causes of stress to fish at harvest; in terms of animal welfare, this is preferable to imposing additional possible stressors such as hunger, as a means of 'allowing fish to cope' with pre-slaughter stress. Work with sea bream found that storage post-mortem had more influence on flesh quality than starvation and also found a deterioration in quality as starvation time increased from 24 to 72 hours (at approximately 21°C) and the shortest starvation time corresponded with the longest shelf life (Alvarez *et al*, 2008). Einen & Thomassen (1998) found conflicting results in some of their analyses of the effect of starvation on the freshness of flesh and concluded that starvation of Atlantic salmon for 0 to 86 days prior to slaughter was '*a rather weak tool for changing fillet quality*'. Evidence for quality benefits from prolonged fasting is therefore mixed and possibly unreliable in commercial application. Few studies have examined the effects of feed restriction on the behaviour or external condition of fish. Given that aggression and fin damage can increase in salmon (Cañon Jones *et al*, 2010) and cod (Hatlen *et al* 2006) under feed-restriction, fasting has additional welfare implications for fish (e.g. fins are innervated) and may in-fact damage some aspects of the final product and lead to more variation in weight, especially if some individuals dominate what little food is available. Removing 'dominant' fish is unlikely to be practical or advisable (capture of one animal may stress the whole group) and additional size grading procedures will increase the number of potentially stressful procedures for all fish, again unlikely to be of benefit for welfare or quality. Recording behaviour can be challenging in aquatic environments but technology is increasingly available to assist in this task (e.g. Føre *et al*, 2011) and its application will be a welcome addition when evaluating welfare during feed restriction. Welfare measures other than just meat quality, are necessary before conclusions can be made regarding welfare status. Without a suite of measures of the effects of enforced starvation on fish, caution must be exercised when concluding their welfare status. In addition to scientific research considering the fasting of fish prior to slaughter, production of a leaner product could also perhaps be tackled by investigating potential improvements in the constituents and delivery of fish feed, the design of the growing enclosures, stocking densities and husbandry procedures (e.g. Bugeon *et al*, 2003). Research varying these factors may indicate how both fish quality and welfare can be maintained without dramatic changes in husbandry such as starving. Research must also consider the imposed feed restriction on tuna caught in the wild and then penned for farming and later slaughter.

The FAO (2014a,b) reports an increasing trend for traditionally-non-fed filter-feeding fish reared in freshwater (e.g. carp species, milkfish) to now be fed supplementary food by the farmer. It was suggested that supplementary feeding may increase the risk of disease (D. Little pers. comm. 19 June 2014) and that consideration needs to be given to how such potential diseases can be prevented, controlled and, in the unfortunate event that any condemned fish must be destroyed, how they can be humanely killed *en masse*. In-water electrical, chemical and gaseous methods of stun-killing may be most appropriate in such circumstances; electrical stunners would not require moderation of the stunning power for product quality so may be relatively easy to apply humanely.

Where wild fish (or farmed fish) are used as food, or to produce food, for other farmed fish species, humane killing of the food species is also important. However, it may be difficult to manage the welfare of finfish farmed for use as live prey for other farmed finfish. For example, mandarin fish may be stocked in polyculture with their live prey (grass, silver, bighead or crucian carp and/or Wuchang bream or tilapia fry/fingerlings); no additional food is supplied by the farm (FAO, 2015e). Where mandarin fish are reared in monoculture, live feed is provided every five days. Live, moving prey is reportedly necessary because mandarin fish do not accept static prey (FAO, 2015e; 2012). 40-45% of production costs for mandarin fish are spent on live feed and the availability of mandarin fish is limited, causing most to be sold fresh or alive; mandarin fish are highly-valued with opportunities for farmers to profit. Production costs in 2004-2005 were US$ 2.2 – 2.8 per kg. Retail prices can reach US$ 4.3 – 6.1 per kg or even $7.3/kg. In the future, working to be able to avoid feeding wild or farmed fish, or their products, to other farmed fishes may benefit environmental, species and habitat conservation initiatives (e.g. Fish Dependence, 2012), as well as farmers' profits. Bourne Jr. (2014) reported that rainbow trout have been fed mostly vegetarian diets for 12 years.

Summary of suggestions for research and development and for its application in industry

1. Assessment of each fish species or hybrid/type, for the effectiveness of stunning parameters should ideally be initially carried out using an objective means of assessing brain activity (e.g. EEGs). Scientists should confirm whether these parameters are suitable for group stunning, for each sex and for the range of sizes/ages and environmental conditions (e.g. if diadromous) under which the given species is typically harvested under commercial conditions, worldwide.
    a. Due to the sheer number of farmed fish, their synonyms and similar common names, scientists must clearly and accurately identify the species or hybrid in their peer-reviewed publications, using the common/vernacular and scientific/Latin names.

2. Assess each fish species or hybrid/type for their normal behavioural repertoire whilst conscious and the behaviours expressed during unconsciousness (as verified by measures of brain activity) and as caused by different methods of stunning.

3. Look for any associations between brain activity and behaviour to identify the most accurate animal-based welfare indicators of states of consciousness that can be used 'in the field'.

4. Determine the proportion of current or electric field that flows through a fish's brain during conventional electrical stunning when a single fish, and when multiple fish, are in a stunner.

5. Research is required to reduce the compromise between effective conventional electrical stunning and concerns for product quality. Exploration of the novel SPUC electrical stunning method may be one option to consider, in order to stun (and preferably stun-kill) as close to 100% of fish as possible, whilst maintaining acceptable meat quality. As one of the most valuable species, produced in the greatest volumes, and with predicted 100% increases in production by 2030 (IBFC, 2017), Atlantic salmon could be considered a priority species for such research, especially given industry's interest in in-water electrical stunning. Rainbow trout (large and portion-size) might also be worthwhile considering for such research, given the popularity of their meat and that OIE standards for their welfare at slaughter are only partly, or not, met in many EU member states (IBFC, 2017).

6. Carry out research to identify how electricity passes through a batch of fish in physical contact with each other in a single container, accounting for varying operational procedures (e.g. in-water, de-watered, electrode type, degree of fill of the container with fish when the current/electric field is turned on). Are all fish rendered unconscious?

7. Where possible, attempt to convert existing scientific laboratory-attained data into parameters that can be tested for suitability for use on commercial farms. For example, consider whether electrical parameters for the stunning of individual fish are also suitable for group stunning (e.g. clustered, layered multiple fish) and whether electrical parameters for dry electrical stunning can be equated into parameters for in-water electrical stunning systems (e.g. for haddock, pike-perch, yellowtail kingfish, Claresse® and common sole). Note: converted parameters must be scientifically assessed for suitability before being used routinely for slaughter.

8. Different types of gas, applied at different concentrations, over different durations, may be worthy of investigation as a stun-killing method that avoids the need to rely on immediate follow-up bleeding.

9. Determine the effect of chemical methods of stun-killing on the welfare of different types or species of fish and their effect on food safety, in case they have potential for global use during pre-slaughter handling or for stun-killing for slaughter for human consumption, or for mass culling during eradication of diseases.

10. Encourage the development of robust yet structurally-simple automated methods of slaughter that enable more reliable stunning in 100% of fish and suit farms' existing labour forces. Use in-water group stunning wherever possible to prevent emersion and/or isolation distress.

11. Encourage manufacturers of stunners to use science-based parameters for fish welfare.

12. Manufacturers should follow the example set (for mammals and poultry) by EC Regulation 1099/2009 and provide instruction manuals online with key parameters for the operation of their fish stunning equipment.

13. The design of stunning systems must account for environmental factors and fish arrangement within the stunner. For example, do fish require a higher current or electric field under certain conditions, e.g. depending on the water conductivity (in-water electrical stunners), orientation of the fish, degree of clustering and degree of layering of the fish?

14. Automated percussive stunning systems need to be refined to be capable of stunning a wider range of fish sizes encountered in a given batch and should be further refined to reduce the need for emersion and handling of conscious fish.

15. Shortening stun-to-cut times, and identifying if it is possible to improve cutting positions and techniques, for effective, rapid bleeding of stunned fish is critical to prevent recovery and protect welfare.

16. Ideally, stunning equipment should be designed to be mobile so it can be taken to fish rearing enclosures, whether inland or offshore, freshwater or marine, to reduce/avoid the need to move/transport live fish to the slaughtering point. For example, stunning fish in, or as they leave, their rearing enclosures may be ideal for animal welfare and for product quality.
    a. Designing rearing tanks that can be used for stunning may be particularly useful for animal welfare because it may limit, or eliminate, the need for crowding or handling. Such a multi-purpose tank would also be ideal for killing fish *en masse* during disease control and would reduce risks of cross-contamination.
    b. Scientists and engineers will need to design stunners that suit the industries' evolving needs. In particular, mariculture offshore rearing enclosures may require new designs of stunning equipment to cope with greater wind and wave activity and the associated health and safety requirements.
        i. Emergency protocols for humane mass killing of farmed fish in their offshore cages (e.g. for disease control) without compromising the surrounding natural environment is also a key consideration.

17. Humane stunning parameters that have already been identified for certain species should be encouraged in-place of no stunning at all, but these stunning parameters may not yet necessarily be perfect for fish welfare and are likely to require refinement to continuously improve fish welfare and product quality. For example, improving batch stun rates to achieve effective stunning in as close to 100% of fish as possible, whilst maintaining a suitable quality product.

18. The cost of stunning equipment can be prohibitive so some producers attempt to build their own stunners, which can lead to negative welfare consequences for the fish. To keep costs low and to encourage local expertise in humane slaughter of fish in less-wealthy countries, stunner manufacturers might consider sponsoring the regional or national development of stunning equipment, using science-based parameters.

19. If producers are attempting to stun fish using equipment which has not yet been formally assessed for fish welfare (either for that particular species or for any fish species), it will be helpful if industry invite animal welfare specialists to assess the fish slaughter equipment. If the equipment is considered suitable for fish welfare, it might be marketed for the same species on other farms and in other countries, subject to any necessary adjustments (e.g. related to water conductivity). (Stunning parameters may vary between species, so the equipment should only be marketed for those species it has been assessed for.)

20. Where science-based recommendations for stunning already exist for certain species of fish, encourage industry to adopt those stunning methods and to use the minimum recommended parameters. For example, in particular, equipment known to humanely stun Atlantic salmon, rainbow trout, common carp, Nile tilapia, North African catfish, European sea bass and turbot should be promoted to the public, producers and retailers (two different approaches may be necessary for the former group and the latter two groups) in major countries of production (Table 2) to encourage their uptake. These species are of key importance because they are produced in some of the greatest volumes (Appendix 3a) and with some of the greatest overall values (Appendix 3b) of all farmed finfish. Retailers might also act as

facilitators to direct interested producers' queries to the relevant contacts within specialist animal welfare organisations and to stunner manufacturers.

   a. European sea bass, particularly within the European area (mainly Turkey, Greece, Spain and Italy), should be a priority species for encouraging adoption of humane stunning at slaughter because OIE standards are not currently achieved and production is predicted to increase over the next decade (IBFC, 2017) which might enable producers to invest in more humane slaughter equipment.
   b. Turkey and Italy produce a large volume of rainbow trout and should be encouraged to use existing stunning equipment for portion-size and large (steelhead) trout. For large-scale producers, IBFC (2017) predicted relatively small costs, perhaps even cost savings, of implementing higher welfare at slaughter for this species. Rainbow trout is also a major production species in the USA.

21. A catalogue of stunning parameters and animal-based welfare indicators will be an important tool for fish farmers, stunner manufacturers and auditors.

22. Identification of general international key performance indicators of fish products can be used to develop an index of product quality and a grading system for exported products, in relation to different methods of handling, moving, transporting, stunning and killing fish, which may aid industry in choosing preferred slaughter methods. Any possible advantages for product quality that can be gained by improving fish welfare at harvest through more humane handling and by using stunning should encourage adoption of stunning and continuous improvement in general.

23. Species produced for the high-value sushi and sashimi markets are likely to be ideal candidates for introducing stunning, due to the requirements for high-quality fish meat. E.g. rainbow trout, tuna. Industry has already expressed interest in humane stunning of yellowtail kingfish in Japan (J. Lines pers. comm. 19 June 2014).

24. Species produced in, traded within, and imported to the European Union (relatively wealthy countries, with some relevant legislation and where consumers may be more willing to pay for higher-welfare fish products) may provide the best opportunities for furthering use of, and for introducing, humane stunning. For example, Germany is a leading trader of finfish and has national legislation for protecting finfish welfare at slaughter. It seems sensible to focus on salmonids (which are traded within the EU in greater quantities than imported from outside the EU), partly because of the sheer quantity of salmon and trout produced and traded within, and imported to, the EU, and their value, and partly because of the wealth of the countries leading the majority of trade, including Norway which has extensive experience in fish welfare and slaughter science. Similarly, European sea bass, *Anguilla* eels, sole and turbot are traded in greater quantities within the EU, than imported from third countries.

25. A global record of slaughter practices for each aquaculture finfish species is lacking. Wherever possible, collection of data on the current slaughter methods used and on the numbers of individuals (compared to production volumes) of each species of fish farmed/slaughtered worldwide, will help to further prioritise species for consideration for research and development for more humane slaughter. It is likely to be very difficult to collect data on the numbers of individual fish slaughtered.

26. Encourage certification/assurance schemes for farmed finfish products to adopt standards for humane slaughter and, where already in-place, encourage adoption of stunning and of specific key parameters (where known) as a pre-requisite for certain products or markets.

27. Communicate to consumers the cognitive abilities of fish and their capacity to suffer, along with the availability of stunning equipment for more humane slaughter and higher-welfare products.

28. For species that are yet to have humane stunning parameters investigated, priority species for funding for research to determine humane stunning parameters and develop stunning equipment might include those that are produced in the greatest volumes, those with the greatest financial value and those that are slaughtered in or imported into countries with minimum legal requirements for animal welfare at slaughter and/or where the consumer and retailer demand higher fish welfare. The species listed in Appendices 3a (50 greatest volumes), 3b (50 greatest values) *and* 3c (50 greatest values per tonne) are Atlantic salmon, European sea bass, gilthead sea bream, Japanese eel, Japanese amberjack, silver seabream, turbot, the bastard halibut (olive flounder) and the Mandarin fish, *Siniperca chuatsi*. Of these species, Atlantic salmon, European sea bass, gilthead sea bream and turbot are listed in Table 1 as having stunning parameters identified for them, and so their humane stunning can be further encouraged. Though, gilthead sea bream require additional research for electrical stunning parameters. The other listed species have, to the author's knowledge, not yet been considered for humane stunning; Japanese eel and Japanese amberjack might be investigated using similar parameters to those already determined for other species in the same genera.

29. Where stunning parameters/equipment have been scientifically-assessed and deemed suitable for the welfare of certain fish species, scientists should assess the parameters and equipment's suitability for closely-related species and/or with similar lifestyles. For example:
    a. Genus *Oncorhynchus*: rainbow trout parameters might be trialled for coho (silver) salmon and Chinook (spring or king) salmon
    b. Genus *Salmo*: Atlantic salmon parameters for brown, or sea, trout
    c. Genus *Solea*: common sole parameters might be trialled for Senegalese sole
    d. Genus *Seriola*: yellowtail kingfish parameters for Japanese and greater amberjack and longfin yellowtail
    e. Genus *Oreochromis*: Nile tilapia parameters for the hybrid blue-Nile tilapia (both species are exported from China to the EU in large quantities), Mozambique tilapia, blue, three spotted, tilapia shiranus, longfin, Sabaki, *O. tanganicae* (though the latter five species are produced in small quantities, but in 2015 Sabaki made it into the top 50 individual species with the greatest value per tonne, excluding species produced at ≤ 100 tonnes per year worldwide)
    f. Genus *Anguilla*: European eel parameters for Japanese eel (which China likely exports to the EU) and shortfinned eel
    g. Genus *Clarias*: north African catfish parameters for the hybrid Africa-bighead catfish and for the Philippine catfish

30. Species that might be prioritised for future research for determining stunning parameters for large-scale slaughter might include the following, with carnivorous species possibly offering the greatest opportunities due to the value of the end-product generating more profit for producers:
    a. Gilthead sea bream (order Perciformes). A greater quantity of this species is traded within the EU than imported from third countries, so might be a worthy priority, particularly as production is expected to increase over the next decade (IBFC, 2017)
    b. various species of carp (e.g. grass; silver and bighead both belong to the genus *Hypophthalmichthys*; catla; crucian; roho labeo; Wuchang bream; black; mrigal). However, a greater quantity of 'carp' is traded within the EU, than imported from third countries, so there may be a limit to what can be done to introduce humane stunning for the most commonly farmed carp species in the world, which are presumably sold domestically (non-EU) or exported to other non-EU countries where welfare demands may be less likely (Tables 4a,b).
    c. the FAO (2015d) lists 22 species/types under 'tilapias and other cichlids' (e.g. genus *Sarotherodon*) but these are produced in mostly very small quantities. Of these species, redbreast tilapia (*Tilapia rendalli*) is produced in the greatest quantities
    d. milkfish (order Gonorynchiformes)
    e. various species of catfish in the genera *Pangasius* (particularly the striped catfish *P. hypophthalmus*), *Ictalurus* (particularly channel catfish) and *Silurus* (Amur catfish and European Wels catfish). Greater quantities of freshwater catfish and tilapia are imported from third

countries into the EU, than traded between EU member states; this may make it difficult to encourage humane stunning, although the significant trade between Viet Nam and the EU may offer the most likely possibility of success

f. species of snakehead in the genus *Channa*: snakehead (*C. argus*), the Indonesian snakehead (*C. micropeltes*) and striped snakehead (*C. striata*)
g. Asian swamp eel (*Monopterus* genus, order Synbranchiformes)
h. Largemouth black bass (order Perciformes) and pond loach (order Cypriniformes)
i. various species of tuna (order Perciformes)
j. silver sea bream (genus *Pagrus*)** (order Perciformes)
k. bastard halibut (order Pleuronectiformes)
l. cobia (order Perciformes)
m. commonly farmed or valuable hybrids are also good candidates for research, e.g. striped bass production in USA and Italy
n. species currently certified under international assurance schemes (e.g. barramundi, meagre, golden pompano ('golden pompano' is not a species listed by the FAO (2015d) or www.fishbase.org but snubnose pompano is listed in Appendices 3a & 3b), bluespotted sea bream**, red porgy**, common and pink dentex (*Dentex* spp. but these are produced in very small numbers), sharpsnout sea bream, shi drum, sand steenbras, white grouper). All listed in this point belong to the order Perciformes
o. grey mullet (order Mugiliformes)
p. sturgeon from the genus *Acipenser* (Danube, Siberian, starlet, starry and Adriatic) and beluga sturgeon
q. although Mandarin fish (order Perciformes) were the only species to be listed in the 2013 top 25 species produced in the greatest volume, with greatest overall value and greatest value per tonne, the small-scale production of the species and relatively little competition between producer countries might make it difficult to encourage producers that this species should be prioritised for research and development.

31. Initially, it may be most appropriate and cost-effective to continue fish welfare at slaughter research with species of fish farmed in countries close to where the existing scientific expertise in slaughter is currently distributed and where the consumer market is most concerned with fish welfare and willing to pay a premium for higher-welfare products. This might include countries like Czech Republic, France, Italy, Norway, Poland and the UK (IBFC, 2017).

32. The HSA offers funding for research or development projects to improve fish welfare during transport, marketing, slaughter or killing for disease control or welfare reasons. For details of the various HSA awards, and the application forms, please view: **www.hsa.org.uk/grants--awards/grants--awards**

33. Sponsoring of further research to identify humane stunning parameters, and to determine pre-slaughter fasting durations (whilst also trialling alternative husbandry and feeds to reduce the need for prolonged feed restriction) that reduce risks to fish health, welfare and product quality/safety, by interested sectors of the finfish industry (producers, assurance schemes) might hasten application of scientific research results in-practice, improving fish welfare and benefitting commercial industry.

34. Promotion (e.g. using posters in market places) of suitable small-scale stunning methods and encouraging producers to kill fish either on-farm at the time of harvest or at the time of sale (rather than the customer taking live fish home) may benefit fish welfare and customers (a dead fish is easier to handle). Guidance on improved methods of storing live fish in markets may benefit welfare and prolong the lifespan of the fish in the market, which is likely to be welcomed by producers/sellers.

35. Development and communication of improved handling techniques and design of facilities that benefit the welfare of all species of fish globally, farmed on small- or large-scales, should be a major goal, even where stunning is not performed.

36. Consideration should be given to the humane killing of fish that are either caught in the wild or farmed, and intended as food for farmed fish.

Report written by: Jade Spence, Technical Officer, HSA 28 February 2018

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Appendices

<u>Appendix 1</u>

Agenda for the HSA workshop on 'humane slaughter of finfish farmed around the world', held on Thursday 19th June 2014, 10:00am – 4:00pm, in the First Floor Boardroom at the British Veterinary Association, 7 Mansfield Street, London, W1G 9NQ, UK.

09:45am: Registration. Refreshments available
10:15am: Welcome and introductions

10:15am: Presentations.

1. *Fish species for which humane stunning parameters have already been scientifically determined*. Jade Spence, HSA

2. *The most common and most valuable aquaculture species, the countries farming them and the export routes*. Professor David Little, Institute of Aquaculture

3. *Current finfish slaughter methods used in aquaculture*. Presenter requested anonymity.

4. *Humane killing of fish: developing stunning equipment*. Dr Jeff Lines, Silsoe Livestock Systems Ltd

13:00pm Discussion.

- What scientific research and technological development is required to develop humane stunning parameters and stunning systems for species of finfish currently farmed (for agricultural purposes) around the world but not routinely rendered immediately unconscious, or unconscious without potential distress/discomfort, during the slaughter process?

- Which species need to be prioritised for future scientific research and development?

- Which stunning methods are likely to be most affordable to companies with limited financial resources for animal welfare improvements?

- What funding sources are available for further necessary research and development?
    - How should resources be allocated?

Appendix 2

Delegates (including speakers) at the HSA workshop on 19th June 2014

Humane Slaughter Association
Dr Lydia Brown, Chairperson of Board of Trustees
Dr Robert Hubrecht, Chief Executive & Scientific Director
Charlie Mason, Technical Director
Jade Spence, Technical Officer
Nathan Williams, Technical Officer

John Avizienius	Deputy Head – Farm Animals, RSPCA, UK
Chris Findlay	Company Biologist, Fish Vet Group, UK
Dr Bert Lambooij	Senior Researcher, Livestock Research Wageningen UR, Netherlands
Dr Jeff Lines	Silsoe Livestock Systems Ltd, UK
Professor David Little	Institute of Aquaculture, University of Stirling, UK
Charlotte Maddocks	Aquaculture Manager, Tesco, UK
Ian Michie	Aquaculture Manager, Young's Seafood Ltd, UK
Dr Ana Roque	Researcher, Institute of Research and Technology for Food and Agriculture, Spain
Dr Bjorn Roth	Senior Researcher, Nofima AS, Norway
Dr Hans van de Vis	Senior Scientist, IMARES, Wageningen UR, Netherlands
Steve Wotton	Senior Lecturer in Farm Animal Science, University of Bristol & Farm Animal Welfare Committee, UK

Appendix 3

Appendix 3a. The 50 species of fish produced in the largest quantities (tonnes) in 2013. Adapted from FAO (2015d). For viewing ease, the quantities have been rounded up or down to the nearest tonne. 'Nei' = not included elsewhere in the FAO databases; these groups may be amalgamations of multiple species and are discounted from the list of individual species by being shown in strikethrough ~~grey~~ text, to allow identification of 50 individual species. For reader information, the discounted groups of fish are retained within the list, at their appropriate rank.

Number	Common name	Scientific name	Quantity (tonnes)
1	Grass carp(=White amur)	*Ctenopharyngodon idellus*	5,226,202
2	Silver carp	*Hypophthalmichthys molitrix*	4,591,852
3	Common carp	*Cyprinus carpio*	4,080,045
4	Nile tilapia	*Oreochromis niloticus*	3,436,526
5	Bighead carp	*Hypophthalmichthys nobilis*	3,059,555
6	Catla	*Catla catla*	2,776,074
7	Crucian carp	*Carassius carassius*	2,595,735
~~8~~	~~Freshwater fishes nei~~	~~Osteichthyes~~	~~2,120,977~~
9	Atlantic salmon	*Salmo salar*	2,087,111
10	Roho labeo	*Labeo rohita*	1,680,689
~~11~~	~~Pangas catfishes nei~~	~~*Pangasius* spp~~	~~1,657,911~~
12	Milkfish	*Chanos chanos*	1,043,936
~~13~~	~~Tilapias nei~~	~~*Oreochromis* (=Tilapia) spp~~	~~923,939~~
14	Rainbow trout	*Oncorhynchus mykiss*	814,068
15	Wuchang bream	*Megalobrama amblycephala*	730,962
~~16~~	~~Torpedo-shaped catfishes nei~~	~~*Clarias* spp~~	~~663,274~~
~~17~~	~~Marine fishes nei~~	~~Osteichthyes~~	~~621,275~~
~~18~~	~~Cyprinids nei~~	~~Cyprinidae~~	~~543,849~~
19	Black carp	*Mylopharyngodon piceus*	525,636
20	Snakehead	*Channa argus*	510,116
21	Amur catfish	*Silurus asotus*	438,736
22	Channel catfish	*Ictalurus punctatus*	419,215
23	Blue-Nile tilapia, HYBRID	*Oreochromis aureus* x *O. niloticus*	414,475
24	Mrigal carp	*Cirrhinus mrigala*	409,623
25	Asian swamp eel	*Monopterus albus*	346,143
26	Largemouth black bass	*Micropterus salmoides*	339,900
27	Pond loach	*Misgurnus anguillicaudatus*	322,207
28	Striped catfish	*Pangasius hypophthalmus*	306,077
29	Yellow catfish	*Pelteobagrus fulvidraco*	295,669
30	Mandarin fish	*Siniperca chuatsi*	284,780
31	Japanese eel	*Anguilla japonica*	227,283
32	North African catfish	*Clarias gariepinus*	213,862
33	Pirapatinga	*Piaractus brachypomus*	193,819
34	Gilthead seabream	*Sparus aurata*	173,062
35	European seabass	*Dicentrarchus labrax*	161,059
36	Coho(=Silver) salmon	*Oncorhynchus kisutch*	156,792
37	Silver barb	*Barbonymus gonionotus*	154,700

38	Japanese amberjack	*Seriola quinqueradiata*	149,766
39	Africa-bighead catfish, HYBRID	*Clarias gariepinus* x *C. macrocephalus*	136,265
~~40~~	~~Groupers nei~~	~~*Epinephelus* spp~~	~~130,435~~
41	Japanese seabass	*Lateolabrax japonicus*	129,334
~~42~~	~~Mullets nei~~	~~Mugilidae~~	~~124,986~~
43	Snubnose pompano	*Trachinotus blochii*	112,499
44	Large yellow croaker	*Larimichthys croceus*	105,230
45	Giant gourami	*Osphronemus goramy*	98,490
46	Cachama	*Colossoma macropomum*	96,036
~~47~~	~~Freshwater siluroids nei~~	~~Siluroidei~~	~~86,730~~
48	Turbot	*Psetta maxima*	76,998
49	Barramundi(=Giant seaperch)	*Lates calcarifer*	75,375
~~50~~	~~Sturgeons nei~~	~~Acipenseridae~~	~~75,014~~
51	Red drum	*Sciaenops ocellatus*	62,197
52	Silver seabream	*Pagrus auratus*	59,616
~~53~~	~~Porgies, seabreams nei~~	~~Sparidae~~	~~59,115~~
~~54~~	~~Lefteye flounders nei~~	~~Bothidae~~	~~55,600~~
55	Tambacu, HYBRID	*Piaractus mesopotamicus* x *Colossoma macropomum*	47,163
56	Cobia	*Rachycentron canadum*	43,395
57	Snakeskin gourami	*Trichogaster pectoralis*	41,509
58	Climbing perch	*Anabas testudineus*	40,616
59	Bastard halibut	*Paralichthys olivaceus*	39,445
~~60~~	~~Amberjacks nei~~	~~*Seriola* spp~~	~~36,784~~
61	Mozambique tilapia	*Oreochromis mossambicus*	34,206
62	Nilem carp	*Osteochilus hasselti*	27,718
63	Indonesian snakehead	*Channa micropeltes*	26,224

Appendix 3b. The 50 species of fish with the greatest value in 2013. Adapted from FAO (2015d). 'Nei' = not included elsewhere in the FAO databases; these groups may be amalgamations of multiple species and are discounted from the list of individual species by being shown in strikethrough ~~grey~~ text, to allow identification of 50 individual species. For reader information, the discounted groups of fish are retained within the list, at their appropriate rank.

Number	Common name	Scientific name	Value US$
1	Atlantic salmon	*Salmo salar*	12,903,515,405
2	Grass carp(=White amur)	*Ctenopharyngodon idellus*	6,689,895,334
3	Silver carp	*Hypophthalmichthys molitrix*	6,128,035,234
4	Nile tilapia	*Oreochromis niloticus*	5,772,028,832
5	Common carp	*Cyprinus carpio*	5,713,179,338
6	Catla	*Catla catla*	5,198,155,606
7	Bighead carp	*Hypophthalmichthys nobilis*	3,931,455,005
8	Rainbow trout	*Oncorhynchus mykiss*	3,454,036,976
9	Roho labeo	*Labeo rohita*	3,284,776,150
~~10~~	~~Freshwater fishes nei~~	~~Osteichthyes~~	~~3,011,544,507~~
11	Crucian carp	*Carassius carassius*	2,831,123,646
12	Mandarin fish	*Siniperca chuatsi*	2,651,301,800
~~13~~	~~Pangas catfishes nei~~	~~*Pangasius* spp~~	~~2,576,866,943~~
14	Milkfish	*Chanos chanos*	1,833,562,724
~~15~~	~~Tilapias nei~~	~~*Oreochromis* (=Tilapia) spp~~	~~1,771,727,984~~
~~16~~	~~Marine fishes nei~~	~~Osteichthyes~~	~~1,540,807,863~~
17	Japanese eel	*Anguilla japonica*	1,241,363,282
18	Black carp	*Mylopharyngodon piceus*	1,219,405,748
19	Wuchang bream	*Megalobrama amblycephala*	1,206,087,300
20	Gilthead seabream	*Sparus aurata*	1,065,027,183
21	European seabass	*Dicentrarchus labrax*	1,034,400,274
22	Japanese amberjack	*Seriola quinqueradiata*	1,027,880,528
~~23~~	~~Torpedo-shaped catfishes nei~~	~~*Clarias* spp~~	~~973,669,817~~
~~24~~	~~Cyprinids nei~~	~~Cyprinidae~~	~~965,957,538~~
25	Asian swamp eel	*Monopterus albus*	903,551,046
26	Mrigal carp	*Cirrhinus mrigala*	714,152,365
27	Channel catfish	*Ictalurus punctatus*	691,125,556
28	Turbot	*Psetta maxima*	637,955,251
29	North African catfish	*Clarias gariepinus*	630,531,490
30	Coho(=Silver) salmon	*Oncorhynchus kisutch*	630,240,899
31	Snakehead	*Channa argus*	624,154,197
32	Blue-Nile tilapia, HYBRID	*Oreochromis aureus* x *O. niloticus*	617,621,000
~~33~~	~~Groupers nei~~	~~*Epinephelus* spp~~	~~583,526,095~~
34	Amur catfish	*Silurus asotus*	579,675,368
35	Largemouth black bass	*Micropterus salmoides*	530,655,895
36	Silver seabream	*Pagrus auratus*	528,218,325
37	Snubnose pompano	*Trachinotus blochii*	450,113,905
38	Bastard halibut	*Paralichthys olivaceus*	427,864,565
39	Striped catfish	*Pangasius hypophthalmus*	426,544,199
40	Pond loach	*Misgurnus anguillicaudatus*	417,880,716
41	Yellow catfish	*Pelteobagrus fulvidraco*	384,369,700

42	Pacific bluefin tuna	*Thunnus orientalis*	357,726,945
~~43~~	~~Sturgeons nei~~	~~*Acipenseridae*~~	~~337,155,737~~
~~44~~	~~Mullets nei~~	~~*Mugilidae*~~	~~317,163,048~~
45	Pirapatinga	*Piaractus brachypomus*	316,114,212
46	Barramundi(=Giant seaperch)	*Lates calcarifer*	304,190,272
47	Giant gourami	*Osphronemus goramy*	282,336,834
48	Cachama	*Colossoma macropomum*	249,353,606
49	Silver barb	*Barbonymus gonionotus*	221,674,788
50	Africa-bighead catfish, HYBRID	*Clarias gariepinus* x *C. macrocephalus*	214,208,037
~~51~~	~~Salmonids nei~~	~~*Salmonidae*~~	~~179,301,668~~
52	Japanese seabass	*Lateolabrax japonicus*	166,234,581
~~53~~	~~Freshwater siluroids nei~~	~~*Siluroidei*~~	~~165,455,569~~
54	Korean rockfish	*Sebastes schlegeli*	163,533,655
~~55~~	~~Trouts nei~~	~~*Salmo* spp~~	~~125,982,115~~
56	Large yellow croaker	*Larimichthys croceus*	125,223,700
57	Tiger pufferfish	*Takifugu rubripes*	114,007,044
58	Tambacu, HYBRID	*Piaractus mesopotamicus* x *Colossoma macropomum*	105,810,082
59	Climbing perch	*Anabas testudineus*	91,074,371
~~60~~	~~Porgies, seabreams nei~~	~~*Sparidae*~~	~~90,449,826~~
61	Red drum	*Sciaenops ocellatus*	87,967,633
62	Ayu sweetfish	*Plecoglossus altivelis*	87,069,957
63	Snakeskin gourami	*Trichogaster pectoralis*	84,261,760

Appendix 3c. The 50 species of fish with the greatest value per tonne in 2013. Adapted from FAO (2015d). For viewing ease, the values have been rounded up or down to the nearest dollar. 'Nei' = not included elsewhere in the FAO databases; these groups may be amalgamations of multiple species and are discounted from the list of individual species by being shown in strikethrough ~~grey~~ text, to allow identification of 50 individual species. An asterisk* indicates a species that is produced in relatively very low quantities (≤ 100 tonnes worldwide per year – an arbitrary choice of the author of this report which includes 29% of the FAO listed fish types) and which may be valid to discount from the list in order to prioritise other species that are produced in greater volumes and ultimately numbers, for animal welfare research into stunning. For reader information, the discounted species/groups of fish are retained within the list, at their appropriate rank.

Number	Common name	Scientific name	Value per tonne (US$)
1	Humpback grouper*	*Cromileptes altivelis*	59,121
~~2~~	~~Pargo breams nei*~~	~~*Pagrus* spp~~	~~42,187~~
3	Spotted coralgrouper*	*Plectropomus maculatus*	32,074
~~4~~	~~Groupers, seabasses nei~~	~~Serranidae~~	~~30,030~~
5	Green humphead parrotfish*	*Bolbometopon muricatum*	28,557
6	Danube sturgeon(=Osetr)	*Acipenser gueldenstaedtii*	28,236
7	Pacific bluefin tuna	*Thunnus orientalis*	21,518
8	Huchen*	*Hucho hucho*	21,250
9	Orbicular batfish*	*Platax orbicularis*	21,166
10	Southern bluefin tuna	*Thunnus maccoyii*	19,854
11	Atlantic bluefin tuna	*Thunnus thynnus*	19,504
12	Areolate grouper*	*Epinephelus areolatus*	19,495
~~13~~	~~..A~~	~~*Solea* spp~~	~~17,545~~
14	Thai mahseer*	*Tor tambroides*	17,468
15	Common sole*	*Solea solea*	17,351
16	Giant grouper*	*Epinephelus lanceolatus*	15,641
17	Siberian sturgeon	*Acipenser baerii*	15,342
~~18~~	~~Filefishes, leatherjackets nei~~	~~Monacanthidae~~	~~15,208~~
~~19~~	~~Scorpionfishes nei~~	~~Scorpaenidae~~	~~13,840~~
20	Malabar grouper*	*Epinephelus malabaricus*	13,691
~~21~~	~~Gobies nei*~~	~~Gobiidae~~	~~13,673~~
~~22~~	~~..A*~~	~~*Hypsibarbus* spp~~	~~13,422~~
23	Ayu sweetfish	*Plecoglossus altivelis*	13,393
24	White trevally	*Pseudocaranx dentex*	13,358
25	Senegalese sole	*Solea senegalensis*	13,018
26	Atlantic halibut	*Hippoglossus hippoglossus*	12,999
27	Brown-marbled grouper*	*Epinephelus fuscoguttatus*	12,380
28	Silver perch	*Bidyanus bidyanus*	12,372
~~29~~	~~Soles nei~~	~~Soleidae~~	~~11,953~~
30	Ballan wrasse*	*Labrus bergylta*	11,953
31	European eel	*Anguilla anguilla*	11,823
32	Common dentex*	*Dentex dentex*	11,514
33	Blackspot(=red) seabream	*Pagellus bogaraveo*	11,479
~~34~~	~~Mackerels nei~~	~~Scombridae~~	~~11,471~~
35	Orange-spotted grouper	*Epinephelus coioides*	11,433
36	Sterlet sturgeon*	*Acipenser ruthenus*	11,162

37	..A*	*Brycon orbignyanus*	11,051
38	Russell's snapper*	*Lutjanus russelli*	10,998
39	Blackhead seabream	*Acanthopagrus schlegeli*	10,941
40	Bastard halibut	*Paralichthys olivaceus*	10,847
41	Trumpet emperor*	*Lethrinus miniatus*	10,414
~~42~~	~~Sciaenas nei~~	~~*Sciaena* spp~~	~~10,275~~
43	Malabar trevally	*Carangoides malabaricus*	10,070
~~44~~	~~Finfishes nei~~	~~Osteichthyes~~	~~9,559~~
45	Orfe(=Ide)*	*Leuciscus idus*	9,448
46	Japanese jack mackerel	*Trachurus japonicus*	9,322
47	Mandarin fish	*Siniperca chuatsi*	9,310
~~48~~	~~Seabasses nei*~~	~~*Dicentrarchus* spp~~	~~9,244~~
~~49~~	~~..A*~~	~~*Wallago* spp~~	~~9,191~~
50	Goldlined seabream*	*Rhabdosargus sarba*	9,167
51	Greasy grouper	*Epinephelus tauvina*	8,886
52	Silver seabream	*Pagrus auratus*	8,860
53	European whitefish	*Coregonus lavaretus*	8,754
54	Marble goby	*Oxyeleotris marmorata*	8,663
55	Yellowfin tuna	*Thunnus albacares*	8,598
56	Striped bass, HYBRID	*Morone chrysops* x *M. saxatilis*	8,436
57	White-spotted spinefoot*	*Siganus canaliculatus*	8,424
58	Spotted rose snapper*	*Lutjanus guttatus*	8,400
59	Turbot	*Psetta maxima*	8,285
~~60~~	~~Snappers nei~~	~~*Lutjanus* spp~~	~~8,264~~
61	Arctic char	*Salvelinus alpinus*	8,221
62	Black grouper*	*Mycteroperca bonaci*	8,152
~~63~~	~~Salmonids nei~~	~~Salmonidae~~	~~8,111~~
64	Starry sturgeon*	*Acipenser stellatus*	8,000
65	Red porgy	*Pagrus pagrus*	7,892
66	Sharpsnout seabream	*Diplodus puntazzo*	7,701
67	Shi drum	*Umbrina cirrosa*	7,643
68	Dotted gizzard shad*	*Konosirus punctatus*	7,605
69	Fourfinger threadfin	*Eleutheronema tetradactylum*	7,490
70	White seabream*	*Diplodus sargus*	7,417
71	American yellow perch*	*Perca flavescens*	7,170
~~72~~	~~Trouts nei~~	~~*Salmo* spp~~	~~7,054~~
73	Black bullhead	*Ameiurus melas*	6,950
74	Dorado	*Salminus brasiliensis*	6,933
75	Brook trout	*Salvelinus fontinalis*	6,888
76	Korean rockfish	*Sebastes schlegeli*	6,884
77	Japanese amberjack	*Seriola quinqueradiata*	6,863
~~78~~	~~Chars nei~~	~~*Salvelinus* spp~~	~~6,860~~
79	Croakers, drums nei*	Sciaenidae	6,640
80	Sargo breams nei*	*Diplodus* spp	6,586
81	Golden trevally*	*Gnathanodon speciosus*	6,498
82	Chinook(=Spring=King) salmon	*Oncorhynchus tshawytscha*	6,434

~~83~~	~~Snappers, jobfishes nei~~	~~Lutjanidae~~	~~6,430~~
84	European seabass	*Dicentrarchus labrax*	6,422
85	Pike-perch	*Sander lucioperca*	6,354
~~86~~	~~Sorubims nei~~	~~*Pseudoplatystoma spp*~~	~~6,262~~
87	John's snapper	*Lutjanus johnii*	6,248
88	Sea trout	*Salmo trutta*	6,233
89	Atlantic salmon	*Salmo salar*	6,182
90	Gilthead seabream	*Sparus aurata*	6,154
91	Beluga*	*Huso huso*	6,140
92	Mangrove red snapper	*Lutjanus argentimaculatus*	6,105
93	Sobaity seabream	*Sparidentex hasta*	6,002
94	Longfin yellowtail	*Seriola rivoliana*	6,000
95	Tiger pufferfish	*Takifugu rubripes*	5,889
96	Flathead grey mullet	*Mugil cephalus*	5,875
97	European perch	*Perca fluviatilis*	5,529
98	..A*	*Leporinus obtusidens*	5,526
99	Japanese eel	*Anguilla japonica*	5,462
100	Philippine catfish	*Clarias batrachus*	5,301

Appendix 4

Species of finfish (spelt as in source document) certified by two of the aquaculture assurance schemes, GAA and GLOBALG.A.P. In 2016, Canada, Chile and Australia, in that order, produce the most GAA-certified 'salmon' (GAA, 2016a). China, Costa Rica, Colombia and Ecuador, in that order, produce the most GAA-certified 'tilapia'. Vietnam is currently the main supplier of GAA-certified '*Pangasius*'. GAA-certified 'Rainbow/steelhead trout' is mainly produced in the USA, with a small amount of certification in Colombia. GAA-certified 'catfish' is mainly produced in the USA. GAA-certified 'barramundi' is mainly produced in Saudi Arabia.

Global Aquaculture Alliance (GAA) **Best Aquaculture Practices (BAP)** GAA (2015b) 'Salmon', 'tilapia', '*Pangasius*' and 'catfish' are, in that order, the finfish species certified in the greatest quantities (GAA 2016a).	**GLOBALG.A.P.** GLOBALG.A.P. (2015c); pers. comm. GLOBALG.A.P., 15th October 2015. Information relates to situation as at 30th September 2015
Barramundi	Arctic Char [*Salvelinus alpinus*]
Catfish	Atlantic Salmon [*Salmo salar*]
Pangasius	Barramundi [*Lates calcarifer*]
Pompano	Bluespotted Seabream [*Pagrus caeruleostrictus*]
Salmon	Brook Trout [*Salvelinus fontinalis*]
Tilapia	Brown Trout [*Salmo trutta fario*]
Trout	Cobia [*Rachycentron canadum*]
Carp	Coho Salmon [*Oncorhynchus kisutch*]
Cobia	Common Dentex [*Dentex dentex*]
Flounder	European Seabass [*Dicentrarchus labrax*]
Grouper	Gilthead Seabream [*Sparus aurata*]
Perch	Greater Amberjack [*Seriola dumerili*]
Seabass	Meagre [*Argyrosomus regius*]
Sea bream	Nile Tilapia [*Oreochromis niloticus*]
Seriola	Pangasius Tra [*Pangasianodon hypophthalmus*]
Striped bass (unclear if the species or the hybrid but the hybrid is produced in greater quantities (FAO, 2017) so likely the hybrid)	Pink Dentex [*Dentex gibbous*]
Turbot	Rainbow Trout [*Oncorhynchus mykiss*]
	Red Porgy [*Pagrus pagrus*]
Species below are listed at GAA (2016b):	Salmon Trout [*Salmo trutta trutta*]
Channel catfish	Sand Steenbras [*Lithognathus mormyrus*]
Golden pompano	Senegalese Sole [*Solea senegalensis*]
Rainbow trout	Sharpsnout Seabream [*Diplodus puntazzo*]
Steelhead	Shi Drum [*Umbrina cirrosa*]
	Turbot [*Scophthalmus maximus*]
	White Groupers [*Epinephelus aeneus*]