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SCIENTIFIC OPINION

Animal welfare aspects of husbandry systems for farmed European Eel [1]

Scientific Opinion of the Panel on Animal Health and Animal Welfare

(Question No EFSA-Q-2006-150)

Adopted on 11 September 2008

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PANEL MEMBERS*

The Scientific Panel for Animal Health and Welfare (AHAW) of the European Food Safety Authority adopted the current Scientific Opinion on 11 September 2008. The Members of the AHAW Scientific Panel were:

Bo Algers, Harry J. Blokhuis, Donald M. Broom, Patrizia Costa, Mariano Domingo, Mathias Greiner, Daniel Guemene, Jörg Hartung, Frank Koenen, Christine Müller-Graf, David B. Morton, Albert Osterhaus, Dirk U. Pfeiffer, Ron Roberts, Moez Sanaa, Mo Salman, J. Michael Sharp, Philippe Vannier and Martin Wierup.

* A minority opinion was expressed from Prof. Donald Broom based on the view that the accepted Report and adopted Opinion are incomplete and that in order to answer the mandate from the European Commission, the introductory chapters on the welfare, biological functioning and farming of fish should be included (Annex II).

SUMMARY

Following a request from European Commission, the Panel on Animal Health and Welfare was asked to deliver a scientific opinion on animal welfare aspects of husbandry systems for farmed fish. Council Directive 98/58/EC concerning the protection of animals kept for farming purposes lays down minimum standards for the protection of animals, including fish. The Scientific Opinion on welfare of European eel was adopted on the 12th of September 2008.

Eel is a significant cultured species in Europe. The juvenile stock is obtained by capture from the wild as there is no closed cycle of production. Although it is a cultured species albeit captured from the wild, the European eel (*Anguilla anguilla*) is also listed as an endangered species and is subject to EU Council Regulation EC No 1100/2007 establishing measures for the recovery of the stock in view of protection and sustainable exploitation of this species. Another specific feature of eel production is that it is the only fish species that is caught in large quantities at the larval stage (glass eels) before they can make any contribution to the reproduction of the species. In addition, the existence of a human consumption market for (dead) glass eels does not favour good welfare practices as dead and animals in poor condition can still have a high market value.

It is recommended that research be supported that is directed towards completion of the eel life cycle under artificial conditions as such research has high potential impact on recovery of endangered stocks and sustainability of an important aquaculture sector.

The various life stages of eel that were considered are: glass eels and juveniles, on-growers, and marketable fish. A review of environmental conditions and factors that were identified as possibly affecting the welfare of European eel at those different life stages has been conducted. These factors are grouped as: abiotic environmental conditions, biotic factors (including behavioural interactions), food and feeding, husbandry and management, genetics, and the impact of disease and disease control measures. It is however important to realise that the environmental conditions are always defined by a range of inter-related factors. While each specific variable is described separately, there are very few occasions in reality where only a single factor is involved in any fish welfare issue relating to environmental conditions. For this reason, only ranges of acceptable levels for the various factors can be given and always these must be considered in the context of the other variables involved.

There are various methods for the capture of glass eels for farming purposes which have varying levels of welfare concern for the subsequent maintenance of the stocks in the farm. Currently, in Europe, extensive culture systems have been almost entirely replaced by the high technology high density intensive systems.

There is very little scientific literature that specifically addresses the welfare of eel under farming conditions. However, it was possible to overcome such a paucity by extrapolating from existing peer reviewed publications, and using expert opinion, in a risk assessment approach.

Major welfare issues for glass eels were identified as being: skin damage associated with consequent osmoregulatory failure, tail damage and damage to the caudal sinus associated with secondary infections, stress and demucinisation during storage and handling (post capture). These hazards occur frequently (if not invariably), affect a high proportion of the glass eel population, and are severe. Injuries and mortalities are recorded amongst fished glass eel and the number of mortalities is linked to the speed, depth and net used in active trawling. It is recommended that the capture of glass eels for farming purposes be addressed

to reduce the highly significant poor welfare of glass eels during the process. During capture and post-capture storage, temperature is a critical hazard for glass eels.

For juveniles, the most significant hazards identified are: weaning, artificial food training, parasitic infections and disease management methods (exposure to herpes virus). Ineffective weaning and artificial food training received a relatively low score in our analysis because only a small minority of farms would be affected. Nevertheless the hazard is severe, prolonged and results in death in the eels affected.

For on-growers, infectious diseases remain a significant problem during this life-stage; but this is normally less severe compared with the juvenile stage.

Among the hazards that were identified for marketable fish, rapid reduction in water temperature was seen as the most important.

For all life stages of the European eel, water pH is important, mainly to control the level of ammonia. Also for all life stages, infectious diseases are a primary source of poor welfare despite good management. The lack of efficient treatment and vaccines increases the significance of this hazard. It is recommended that research be directed toward these issues.

Where parameters have been identified as having a welfare implication for eel, it is recommended that these parameters be monitored. Without continuous recording and monitoring, the use of alarm systems, and a reliable emergency backup even relatively small failures in husbandry systems can produce disastrous outcomes in terms of welfare.

It is also recommended to develop contingency plans to protect fish welfare from exposure to rare and brutal hazards.

Key words: European eel, *Anguilla anguilla*, animal welfare, risk assessment, fish farming, husbandry system, aquaculture, environmental conditions, biotic factors, feeding, disease.

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BACKGROUND AS PROVIDED BY EUROPEAN COMMISSION

Council Directive 98/58/EC concerning the protection of animals kept for farming purposes lays down minimum standards for the protection of animals bred or kept for farming purposes, including fish.

In recent years growing scientific evidence has accumulated on the sentience of fish and the Council of Europe has in 2005 issued a recommendation on the welfare of farmed fish[2]. Upon requests from the Commission, EFSA has already issued scientific opinions which consider the transport[3] and stunning-killing[4] of farmed fish.

TERMS OF REFERENCE AS PROVIDED BY EUROPEAN COMMISSION

In view of this and in order to receive an overview of the latest scientific developments in this area the Commission requests EFSA to issue a scientific opinion on the animal welfare aspects of husbandry systems for farmed fish. Where relevant, animal health and food safety[5] aspects should also be taken into account. This scientific opinion should consider the main fish species farmed in the EU, including Atlantic salmon, gilthead sea bream, sea bass, rainbow trout, carp and European eel and aspects of husbandry systems such as water quality, stocking density, feeding, environmental structure and social behaviour.

Due to the great diversity of species it was proposed that separate scientific opinions on species or sets of similar species would be more adequate and effective. It was agreed to subdivide the initial mandate into 5 different questions in relation to Atlantic salmon, trout species, carp, sea bass and gilthead sea bream, and European eel. This Scientific Opinion refers only to the fifth question.

ACKNOWLEDGEMENTS

The European Food Safety Authority wishes to thank the members of the Working Group for the preparation of the Scientific Report which has been used as the basis of this Scientific Opinion. The Working Group was chaired by Ronald Roberts (member of the panel) and consisted of Edmund Peeler (Risk Assessor), Bernd Sures, Hans Van de Vis, and Derek Evans. This report also received special contribution from Peter Wood.

[2] Recommendation concerning farmed fish adopted by the Standing Committee of the European Convention for the protection of animals kept for farming purposes on 5 December 2005.

[3] Opinion adopted by the AHAW Panel related to the welfare of animals during transport -30 March 2004.

[4] Opinion of the AHAW Panel related to welfare aspects of the main systems of stunning and killing the main commercial species of animals- 15 June 2004.

[5] Food Safety aspects of fish welfare are addressed by a Scientific Opinion of the BIOHAZ Panel ("Food Safety aspects of Animal welfare aspects of husbandry systems for farmed fish", Question N° EFSA-Q-2008-296).

OUTCOMES FROM THE DATA PRESENTED IN THE SCIENTIFIC REPORT

1. European eel, its importance to European aquaculture, and present status of stocks

Eel is a significant cultured species in Europe. The juvenile stock is obtained by capture from the wild as there is no closed cycle of production. Although it is a cultured species albeit captured from the wild, the European eel (*Anguilla anguilla*) is also listed as an endangered species and is subject to EU Council Regulation EC No 1100/2007 establishing measures for the recovery of the stock in view of protection and sustainable exploitation of this species. Another specific feature of eel production is that it is the only fish species that is caught in large quantities at the larval stage (glass eels) before they can make any contribution to the reproduction of the species. In addition, the existence of a human consumption market for (dead) glass eels does not favour good welfare practices as dead and animals in poor condition can still have a high market value.

It is recommended that research be supported that is directed towards completion of the eel life cycle under artificial conditions as such research has high potential impact on recovery of endangered stocks and sustainability of an important aquaculture sector.

2. Overview of eel production systems in Europe

This opinion covers the welfare aspects of the capture operations and transport of the glass eels to the farm, as well as the different culture systems to which the various life stages of eels are then exposed. These systems were analysed in some detail and the various areas within eel husbandry where specific welfare risks exist have been defined and analysed in relation to the different life stages and production systems.

The scientific report, which was used as a basis for this opinion defines the systems used for culture of the European eel, and highlights areas where such systems may increase the likelihood of negative effects on the welfare of the eel.

There are various methods for the capture of glass eels for farming purposes which have varying levels of welfare concern for the subsequent maintenance of the stocks in the farm. Currently, in Europe, extensive culture systems have been almost entirely replaced by the high technology high density intensive systems.

There is very little scientific literature that specifically addresses the welfare of eel under farming conditions.

3. Identification of factors potentially affecting the welfare of European eel

The various life stages of eel that are considered in this opinion are: glass eels and juveniles, on-growers, and marketable fish.

A review of environmental conditions and factors that were identified as possibly affecting the welfare of European eel at those different life stages has been conducted.

Farming systems inevitably introduce a number of stressors to the organism. Potential stressors may include inappropriate water chemistry (NH_3 NO_2, NO_3, pH, Dissolved Oxygen, CO_2) temperature, handling, physical damage, diseases or disease treatments and inappropriate nutrition. It is impossible to avoid many of the procedures known to induce stress responses in eel farming. Netting, grading and transport are integral components of the eel farming routine and, at best, all the farmer can do is to minimize the effects of this type of stress. In general, the duration of the stress response is proportional to the duration of the stress. Thus, reducing the time-course of the event (netting, grading, transport etc.) will encourage a more rapid recovery of the fish.

Welfare factors are grouped as: abiotic environmental conditions, biotic factors (including behavioural interactions), food and feeding, husbandry and management, genetics, and the impact of disease and disease control measures. It is however important to realise that the environmental conditions are always defined by a range of inter-related factors. While each specific variable is described separately, there are very few occasions in reality where only a single factor is involved in any fish welfare issue relating to environmental conditions. For this reason, only ranges of acceptable levels for the various factors can be given and always these must be considered in the context of the other variables involved.

A review of environmental conditions and factors that may affect welfare of eels is given in the following sections.

3.1. Abiotic factors

3.1.1. Light period and intensity

Eel, like virtually all fish, react to light changes. The effect on welfare is uncertain. There is a view, supported by expert opinion, that sudden changes in light levels produce a “fright and flight” reaction.

3.1.2. Noise and vibrations

From the scientific literature review no information was found but industry experience would indicate that eels are susceptible to sudden changes in noise and to vibrations.

3.1.3. Water oxygen content

In order to ensure optimal feeding and growth water oxygen concentrations should be maintained at 100 % saturation in tank outlets. This will minimise the risk of areas of low oxygen levels developing in the system. In all culture systems the oxygen level is often the most critical factor and as such is monitored closely. However, oxygen deficiency problems leading to both mortality and impaired welfare are difficult to completely avoid unless each tank is alarmed and provided access to backup oxygenation. This can be a significant welfare issue but difficult to recognise.

3.1.4. Water temperature

Eels are naturally adapted for survival across the range of European temperature conditions. However, at temperatures below 1 to 3 C, eels were shown to enter a state of torpor.

With sudden lowering of temperature it has been observed that a percentage of the population loses its thigomotactic response. Recovery may take 2 to 4 days.

Normally, glass eels are not exposed to low temperatures. Industrial experience indicates that holding or transporting glass eels at temperatures below 4 °C can lead to significant mortality. It has been observed that there is no feed consumption below 10 C for glass eels.

Under intensive farming conditions, at temperatures below 22-24 C, advantage generally appears to be for pathogen against the host. Under intensive conditions at temperatures of 19 C appetite is very significantly suppressed.

3.1.5. Water pH

Eels tolerate a wide range of pH although extreme values reduce feeding activity and thus growth rates. Optimum pH values for the eel are reported as being between 7 and 8. Under intensive conditions, pH is maintained below 6 in order to minimise the risk of ammonia toxicity. Industrial experience indicates that for intensive systems a pH range of 4.8 to 5.8 is tolerated

3.1.6. Suspended solids

The removal of solids greater than 40 μm limits exposure of fish to the parasitic monogenean trematode *Pseudodactylogyrus* sp. by exclusion of its eggs.

3.1.7. Ammonia, nitrite and nitrate content of water

Compared with other freshwater fish species *A. anguilla* is rather tolerant to nitrite but concentrations should be below 30 mg/l. Industrial experience would indicate that levels higher than 10 mg/l should be avoided. Water nitrate levels greater than 300 mg/l create a more challenging environment for some external parasites.

3.1.8. Tank and pond design

There is no indication that specific tank or pond designs are significant in relation to eel welfare. Eels have a natural need to have mechanical contact with a solid substrate while resting (thigmotaxis). It has been shown to be important to provide adequate resting area for all of the fish in the tank at resting time.

3.1.9. Substrate of ponds

The natural substrate of a pond is normally the basis for extensive lagoons or ponds in Europe. An area concreted for the purposes of feeding or harvesting is desirable for hygiene and management.

3.1.10. Environmental pollutants

There are recommendations with regards to the safe levels of wild eel consumption because of environmental pollution. However farmed eels do not have such problems because of their reduced exposure to polluted waters.

3.2. Biotic factors

3.2.1. Behavioural interactions

After the glass eel stage, eel change from a shoaling fish into a ‘territorial’ species which can be aggressive at low densities. It is important to maintain uniformity of size within the population since cannibalism rapidly ensues when size discrepancy develops. Such uniformity should be maintained by regular grading and sorting.

3.2.2. Food and feeding

First feeding is with cod roe is one of the most critical periods in the rearing cycle at which the glass eels are transferred from the cold water storage system and introduced into the warm water juvenile system for the following twelve weeks of on-growing.

As with any carnivorous fish, the wild eels are physiologically well adapted to withstand prolonged periods of feed deprivation. Fish are normally deprived of feed for a few days prior to grading or transport in order to reduce the metabolism and thus mortality. Where eels are destined for final dispatch to market, food will normally be withheld for 2 to 3 days. On farms any change in the daily feeding routine will be to some extent stressful to the fish and is avoided if possible. .

Overfeeding, especially where demand feeders are in use, is a significant welfare issue because of the effect that wasted food disintegrating into the water column can have on the oxygen levels and water quality. Use of mechanical feeders correctly loaded for the biomass of fish avoids this risk.

3.2.3. Impact of infectious diseases on welfare

There is a large group of pathogens including numerous parasites, fungi, bacteria, and viruses infecting eel and causing disease. However, in aquaculture only a few disease agents result in disease outbreaks that, amongst other signs, decrease growth or increase mortality.

In this opinion, only selected diseases of cultured European eel were considered because of their potential significance to eel welfare (severity of effect on physiological integrity of fish, known frequency of occurrence in farming systems, and impact of preventive and/or curative measures).

3.2.4. Impact of disease control measures on welfare

When eel culture was essentially an extensive industry, the use of veterinary medicines was not a practical option because of lack of control in food intake, quantities of medicine to use, risk of re-contamination.. As the industry grew into an intensive production system, the process of eel farming allowed treatments. However, the management of recirculation systems, and particularly the filters, often restricts the way in which therapeutics can be used. Also products are generally not licensed specifically for eel, but used under the cascade system or other arrangements. Used carefully, medicinal treatments can be of value and assist in maintaining good welfare.

Currently juvenile eels are deliberately exposed to water contaminated with *Herpesvirus anguillae* in order to induce an infection which will cause some welfare issues and some mortality (2 to 25 %). Bacterial vaccines (immersion, oral) exist against the *Vibrio* pathogens of eels and can be used under the present cascade mechanism. The immersion vaccines which require high concentration of antigen in limited water volumes can lead to stress due to overcrowding foaming of the water, demucination and result in reduction of feeding. The oral vaccines have no associated significant welfare issues although efficacy may not be so high.

3.3. Husbandry and management

3.3.1. Stocking densities

The optimal stocking density is, to a large extent, dependent upon the production system in use the technical specification of the system (water flows/available oxygenation) and the life-stage of the eel being cultured. There is no published evidence that these stocking levels compromise welfare.

3.3.2. Handling

Nets cause abrasion and secondary infections especially where tails get stuck within the mesh. Eels are ideally handled with the minimum of water and are either piped or pumped out of the system without the use of nets.

4. Risk assessment approach to welfare of European eel

The risk scores based on expert advice were used to compile a risk ranking by category such as abiotic or biotic to obtain an idea which hazards are the more important for each life stage in the various production systems considered, and also to enable the comparison of the different production systems.

4.1. Glass eels

The different capture methods for glass eels (active trawling, and fixed nets) have been considered as separate production systems to allow for comparison. This life stage also includes a quarantine period referred to as post-capture storage.

Trawling and fixed nets in high currents have the following hazards, all of which received high scores:

- skin damage incurred at capture – osmo-regulatory failure within 7-10 days
- tail damage incurred at capture - damage to the caudal sinus, secondary infections
- stress, demucinisation during storage (post capture)
- stress, skin damage, demucinisation during handling (post capture)

These hazards have high scores because they occur frequently (if not invariably), affect a high proportion of the populations and are severe (severity score = 3 or 4). Inappropriate handling post capture has the highest score because the duration of the effect (skin damage and demucinisation) lasts up to 20 days (time when all affected individuals would eventually die). The damage caused to the tail results in a very high degree of mortality (however, this does not account for the high hazard score that is attributable to the effect on the eels prior to death). It is only noticed 48 hours after capture. It should also be noted that trawling results in high mortality within the first hour after capture (which has a low hazard score due to short duration of the effect). Mortality that occurs at capture (mainly due to crushing) can be considerable (order of magnitude around 50 % within a few hours following capture) but is not considered as a welfare issue in this analysis.

There can be an adverse synergistic effect of poor storage conditions following stress caused by poor capture methods which cannot be captured by the risk assessment method. Poor storage leads to exposure to air, adverse water quality, confinement leading to loss of mucous and stress. Eels are held in the storage buckets for approximately 4 hours after capture.

Low current fixed nets and hand netting resulted in two significant hazards post-capture:

- stress, demucinisation during storage
- stress, skin damage, demucinisation during handling

These hazards received the same score across all capture methods. Skin and tail damage may also result from low current fixed netting but with a lower frequency (frequency score = 1).

Table 1. Glass eel hazards ranking

trawling	fixed netting/trapp - high current	Glass-eels fixed netting/trapp - low current	Glass-eels hand netting
inappropriate handling,	inappropriate handling	inappropriate handling,	inappropriate handling
sourcing trawling (tail damage - damage caudal sinus)	sourcing fixed netting/trapp - high current (tail damage - damage caudal sinus)	storge	storge
sourcing trawling (skin damage)	sourcing fixed netting/trapp - high current (skin damage)	sourcing fixed netting/trapp - low current (tail damage) s	
storge	storge	sourcing fixed netting/trapp - low current (skin damage)	
sourcing trawling (physical damage - death in 1h)	sourcing fixed netting/trapp - high current(physical damage, death in 1h)	sourcing fixed netting/trapp - low current (physical damage, death in 1h)	

4.2. Juveniles

For this, only intensive production system was considered as it is currently the most dominant farming system in Europe. Extensive farming contribution to the European production is becoming anecdotal.

The identified hazards are weaning, artificial food training, parasitic infections and disease management methods (exposure to herpesvirus).

Infection with *Pseudodactylogyrus* ranked high as a hazard because it occurs frequently (80% of farms), affects a large proportion of the population for a long period and with severe effects. Control methods have low effectiveness. In addition, the parasite also causes a high level of mortality.

Another high ranked hazard is also disease-related. At this life stage farmers expose eels to herpesvirus (to avoid losses later in production). Infection results in stress, poor feeding and other clinical signs in a majority of the population (it had a severity score = 3), albeit with low mortality (< 20 %). Other external parasites, handling, water quality parameters also ranked relatively highly. Other ecto-parasites are generally managed effectively under normal conditions.

Ineffective weaning and artificial food training received a relatively low score because only a small minority of farms were affected and on these farms <40 % of the eels starve post weaning. Nevertheless the hazard is severe, prolonged and results in death in the eels affected.

Handling was another highly ranked hazard. Handling juveniles will cause stress, skin damage and demucinisation. As the fish at this stage are relatively robust the severity score given was low (severity score = 1).

Table 2. Juveniles hazards ranking

Juveniles
external parasites - Dactylogyrus
disease management practice – herpes virus exposure
handling
external parasites
low pH, high pH/Ammonia
uneffecitive weaning and artificial food training
Vibrio
Fungal infections, Aeromonas
rapid increase water temperature

4.3. On-growers

This stage lasts for 18 months. In accordance with the statement in the previous section (7.9.4), only intensive system was considered in this analysis.

Pseudodactylogyrus remains a significant problem during this life-stage but is less severe compared with the juvenile stage. It nevertheless remains a highly ranked hazard for on-growers. Other diseases are also highly ranked hazards, e.g. vibriosis and herpesvirus infection. Herpesvirus is present on all farms, however disease occurs on about 50 % of farms (where exposure of juveniles did not result in a sufficiently high level of 'herd immunity'). When outbreaks occur most eels are affected, and high mortalities can occur. The disease is exacerbated by poor environmental conditions.

Table 3. On-growers hazards ranking

On-growers
external parasites - Dactylogyrus
herpes virus disease
handling
Vibrio
low pH, high pH/Ammonia
external parasites
Aeromonas

4.4. Marketable fish

Fish are moved into marketing tanks for a few days before being sold. Three hazards were identified: handling, fasting and a rapid reduction in temperature. Handling at this stage is significantly reduced as eels have been graded prior to reaching marketable size. Eels are generally fasted during this period for 2 days; they need to be fasted for longer (5 days) if there is a problem with taint. They are kept at a cooler temperature during this period. There is a sudden drop in water temperature which is known to be stressful, behavioural changes are seen. This is the most important hazard identified for this life stage, attributable to its higher severity compared with the other two hazards.

Table 4. Marketable fish hazards ranking

Marketable fish
rapid temperate reduction
fasting
handling

4.5. Discussion

Two main categories of hazards stand out from our risk assessment analysis: those associated with the capture methods and those with infectious diseases, notably *Pseudodactylogyrus* and herpesvirus.

The capture method is critical to the health and productivity of eels in aquaculture. Trawling (as currently practised) and fixed nets in strong currents result in a high level of stress and trauma resulting in subsequent mortality both acutely and over the next 20 days. An obvious solution is to amend the current capture practices to reduce their impact on the welfare of eels, or to use capture methods identified as having fewer, less severe hazards associated with them. Two post-capture hazards were identified associated with storage and handling. Improved storage methods would be relatively easily implemented with significant improvements in both welfare and survival.

The hazards associated with diseases were identified as serious welfare related issues. Current control methods are at best only partially successful under current farming methods. Research is needed to develop improved control strategies. In the absence of a vaccine, exposure of juveniles to herpesvirus is the most effective method of controlling disease (if not infection). Nevertheless, this practice was a highly ranked hazard for juveniles. Again, research is required to develop a vaccine and other control methods.

Other hazards are arguably amenable to improved management. Most farmers successfully wean juveniles onto proprietary feed, so presumably best practice would improve the problem on affected farms. Inappropriate handling occurs at all life-stages. It leads to loss of mucous, stress and skin damage. Handling occurs frequently during the production period and was a relatively highly ranked hazard in a number of life-stages. Better handling methods, and a reduction in handling especially of juveniles, promoted through codes of practice, may therefore improve eel welfare.

There are very few welfare issues for eels at the marketable stage; one of them being the sudden drop in water temperature as they enter the marketable phase. Practices should be employed to ensure that the temperature change is gradual.

A number of the identified hazards can be reduced significantly through changes in capture method or management. Research is required before significant improvements in the disease related hazards could be realised.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations are based on the scientific literature review and the performed risk assessment.

Conclusions

1. Serious injuries occur during active trawling of glass eels with 30-40 % being killed during capture with a further 10-15 % dying later.
2. The removal of the protective mucous coat from eel can be lethal with 97 % of dead eel showing demucinisation.
3. Tail damage caused by inappropriate net mesh size can be lethal due to damage to the caudal sinus.
4. Hand netting causes little damage.
5. The value of dead glass eel is not the same disincentive to avoid poor welfare as with other farmed species
6. Sudden changes in light levels produce a fright and flight reaction in eel.
7. Expert opinion is that eel are susceptible to vibrations and sudden changes in noise.
8. Oxygen deficiency problems lead to both mortality and poor welfare can be avoided by alarming each tank and provided access to backup oxygenation.
9. Holding or transporting glass eel at temperatures below 4 °C can lead to significant mortality.
10. The removal of suspended solids greater than 40 m is beneficial for eel welfare
11. Water nitrate levels as high as 500 mg/l are tolerated and levels greater than 300 mg/l create conditions less favourable for infestation by external parasites.
12. Improper tank or pond design to facilitate the movement of fish for grading and harvesting will lead to eel having to be netted or pumped out of water which will cause significant injuries and stress, impair growth and predispose to secondary infections.
13. Farmed eels are seldom exposed to polluted waters and so not normally exposed to environmental pollutants which are a food safety concern.
14. Lack of size uniformity within the population often leads to cannibalism and so regular grading and sorting are required.
15. The life cycle of the European eel remains obscure and attempts at artificial reproduction are not well developed. Eel aquaculture is wholly dependent upon the capture of wild glass eel.
16. The European eel stock is currently considered to be under threat because fishing has placed them outside safe conservation limits.
17. The major welfare issues for glass eels were identified as: damage to the skin, tail and caudal sinus associated with secondary infections, stress and demucinisation during storage and handling. These hazards occur frequently and affect a high proportion of glass eels, and lead to very poor welfare.

18. A synergistic effect of poor storage conditions following stress caused by poor capture methods may occur.
19. Very high injuries and mortalities are recorded amongst trawled glass eel and are linked to the speed, depth and net used in active trawling.
20. During capture and post-capture storage, temperature is an important hazard for glass eels.
21. The most significant hazards identified for juveniles are: weaning, training to artificial feed, parasitic infestations, and disease management methods.
22. Ineffective weaning and artificial feed training received a relatively low score in the RA because only a small minority of farms are affected. Nevertheless the hazard is severe, prolonged and results in death of eels.
23. Infectious diseases are a significant problem for on-growers but less severe compared with the juvenile stage.
24. Rapid reduction in water temperature is the most important hazards identified for marketable fish.
25. For all life stages of the European eel, water pH is important, mainly to control the level of ammonia.
26. For all life stages, infectious diseases are a primary source of poor welfare despite good management. There is a lack of good treatment.
27. The optimum stocking density for eel has not been determined to the extent that an equation for space requirements of eel can be provided in this report.

Recommendations

28. The trawling methods for the capture of glass eel should be modified or adapted to reduce drastically the high mortality of glass eels.
29. Water nitrite concentrations should normally be below 30 mg/l.
30. Eels should be graded and sorted regularly to maintain uniformity of size in the population
31. Farms and farming sites should have handling equipment and procedures that ensure minimal impact on the welfare of eel.
32. Research should be undertaken into completing the eel life cycle under artificial conditions. Such research would allow for production of juveniles in aquaculture conditions and avoid exposure to fishing hazards leading to poor welfare.
33. The methods for the capture of glass eels should be modified or adapted to reduce drastically the high mortality of glass eels.
34. With regards to conclusions 1 - 27: Research is needed to improve efficiency and availability of veterinary medical products and vaccines.
35. It is recommended that oxygen, nitrite, nitrate, temperature should be continuously recorded and monitored. The use of alarm systems, and a reliable emergency backup is also recommended.
36. It is recommended to develop contingency plans to protect fish welfare from exposure to rare and severe welfare hazards.

37. Research should be carried out into the welfare impact of production systems and their husbandry in European eel.
38. As it is difficult to set appropriate levels of stocking density the monitoring of the conditions of the fish (such as injury, growth rate, behaviours expressed and overall health) should be used.

SCIENTIFIC REPORT OF EFSA

ANIMAL WELFARE ASPECTS OF HUSBANDRY SYSTEMS FOR FARMED EUROPEAN EEL [1]

Prepared by Working Group on Eel Welfare

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SUMMARY

The scientific report on the animal welfare aspects of husbandry systems for farmed European eel constitutes the background document to the opinion adopted by the Panel on Animal Health and Welfare on the 12th of September 2008.

Eel is a significant cultured species in Europe. The juvenile stock is obtained by capture from the wild as there is no closed cycle of production. Although it is a cultured species albeit captured from the wild, the European eel (*Anguilla anguilla*) is also listed as an endangered species and is subject to EU Council Regulation EC No 1100/2007 establishing measures for the recovery of the stock in view of protection and sustainable exploitation of this species. Another specific feature of eel production is that it is the only fish species that is caught in large quantities at the larval stage (glass eels) before they can make any contribution to the reproduction of the species. In addition, the existence of a human consumption market for (dead) glass eels does not favour good welfare practices as dead and animals in poor condition can still have a high market value.

The various life stages of eel that were considered are: glass eels and juveniles, on-growers, and marketable fish. A review of environmental conditions and factors that were identified as possibly affecting the welfare of European eel at those different life stages has been conducted. These factors are grouped as: abiotic environmental conditions, biotic factors (including behavioural interactions), food and feeding, husbandry and management, genetics, and the impact of disease and disease control measures. It is however important to realise that the environmental conditions are always defined by a range of inter-related factors. While each specific variable is described separately, there are very few occasions in reality where only a single factor is involved in any fish welfare issue relating to environmental conditions. For this reason, only ranges of acceptable levels for the various factors can be given and always these must be considered in the context of the other variables involved.

There are various methods for the capture of glass eels for farming purposes which have varying levels of welfare concern for the subsequent maintenance of the stocks in the farm. Currently, in Europe, extensive culture systems have been almost entirely replaced by the high technology high density intensive systems.

There is very little scientific literature that specifically addresses the welfare of eel under farming conditions. However, it was possible to overcome such a paucity by extrapolating from existing peer reviewed publications, and using expert opinion, in a risk assessment approach.

Key words: European eel, *Anguilla anguilla*, animal welfare, risk assessment, fish farming, husbandry system, aquaculture, environmental conditions, biotic factors, feeding, disease.

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PANEL MEMBERS

This scientific report was peer reviewed by the Members of the Scientific Panel for Animal Health and Welfare (AHAW) of the European Food Safety Authority. The scientific report was used as the basis for the scientific opinion adopted on this matter. The members of the AHAW Scientific Panel were:

Bo Algers, Harry J. Blokhuis, Donald M. Broom, Patrizia Costa, Mariano Domingo, Mathias Greiner, Daniel Guémené, Jörg Hartung, Per Have, Frank Koenen, Christine Müller-Graf, David B. Morton, Albert Osterhaus, Dirk U. Pfeiffer, Ronald Roberts, Moez Sanaa, Mo Salman, J. Michael Sharp, Philippe Vannier, Martin Wierup.

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BACKGROUND AS PROVIDED BY EUROPEAN COMMISSION

Council Directive 98/58/EC concerning the protection of animals kept for farming purposes lays down minimum standards for the protection of animals bred or kept for farming purposes, including fish.

In recent years growing scientific evidence has accumulated on the sentience of fish and the Council of Europe has in 2005 issued a recommendation on the welfare of farmed fish[2]. Upon requests from the Commission, EFSA has already issued scientific opinions which consider the transport[3] and stunning-killing[4] of farmed fish.

TERMS OF REFERENCE AS PROVIDED BY EUROPEAN COMMISSION

In view of this and in order to receive an overview of the latest scientific developments in this area the Commission requests EFSA to issue a scientific opinion on the animal welfare aspects of husbandry systems for farmed fish. Where relevant, animal health and food safety[5] aspects should also be taken into account. This scientific opinion should consider the main fish species farmed in the EU, including Atlantic salmon, gilthead sea bream, sea bass, rainbow trout, carp and European eel and aspects of husbandry systems such as water quality, stocking density, feeding, environmental structure and social behaviour.

Due to the great diversity of species it was proposed that separate scientific opinions on species or sets of similar species would be more adequate and effective. It was agreed to subdivide the initial mandate into 5 different questions in relation to Atlantic salmon, trout species, carp, sea bass and gilthead sea bream, and European eel. This Scientific Opinion refers only to the fifth question.

[2] Recommendation concerning farmed fish adopted by the Standing Committee of the European Convention for the protection of animals kept for farming purposes on 5 December 2005.

[3] Opinion adopted by the AHAW Panel related to the welfare of animals during transport -30 March 2004.

[4] Opinion of the AHAW Panel related to welfare aspects of the main systems of stunning and killing the main commercial species of animals- 15 June 2004.

[5] Food Safety aspects of fish welfare are addressed by a Scientific Opinion of the BIOHAZ Panel ("Food Safety aspects of Animal welfare aspects of husbandry systems for farmed fish", Question N° EFSA-Q-2008-296).

ASSESSMENT

1. Scope and objectives of the report

Eels are cultured to a significant degree in Europe but unlike the other major cultured or farmed species, the juvenile stock is still obtained by capture from the wild and there is no closed cycle of production as exists for the fully domesticated fish species.

Although it is a cultured species albeit captured from the wild, the European eel (*Anguilla anguilla*) is also listed as an endangered species (CITES Annex 2) and is subject to an EU Council Regulation (EC No 1100/2007) establishing measures for the recovery of the stock of the European Eel for its protection and sustainable exploitation. By 31st July 2013, 60 % of eel stock less than 12 cm in length caught annually should be reserved for restocking. Eel management should reduce anthropogenic mortalities so as to allow at least 40 % of the silver eel biomass to escape to sea.

The scope of this report is on welfare of eel caught and kept for farming purposes and so does not deal with conservation and angling issues even though they are linked. Furthermore, if eel become extinct their welfare will be irrelevant.

Since some glass eels are required for conservation and are held in farming facilities until release, the welfare of these animals is also considered in the report, for the period they are in captivity.

Another specific feature of eel production is that it is the only fish species that is caught in large quantities at the larval stage (glass eels) before they can make any contribution to the reproduction of the species. In addition, the existence of a human consumption market for (dead) glass eels does not favour good welfare practices as dead and animals in poor condition still have a high market value.

Therefore, this report covers the welfare aspects of the capture operations and transport of the glass eels to the farm, as well as the different culture systems to which the various life stages of eels are then exposed.

These systems are analysed in some detail and the various areas within eel husbandry where specific welfare risks exist have been defined and analysed in relation to the different life stages and production systems.

Since the literature on the subject is relatively limited, these welfare risks have been identified largely by reference to industrial experience and expert opinion. Identified risks were then subjected to a semi-quantitative risk assessment

The objective of the report is to define the systems used for culture of the European eel, and to highlight any areas where such systems may increase the likelihood of negative effects on the welfare of the fish.

2. Taxonomy of eels

The order Anguilliformes are an order of fish, which consists of 4 suborders, 19 families, 110 genera and 400 species distributed throughout aquatic environments of the world's temperate and tropical regions. The majority of these, often sympatric species, are to be found in the Indo-Pacific region (Tesch, 2003). The family Anguillidae has the following features in common with most of the anguilliformes: the swim bladder is connected to the gut by the pneumatic duct; pelvic fins are absent; scales (only visible in older fish) are cycloid; there are no mesocoracoid or post-temporal bones; the pre-maxillae are fused with the ethmoid; there are teeth on the maxillae; parapophyses and most neural arches are fused with the vertebrae; gill openings are narrow; and the dorsal and anal fins are very long and confluent with the greatly reduced caudal fin. Diagnostic features of the genus *Anguilla* include: i) the pectoral fin supported by 7-9 radialia; ii) the mouth is terminal, with the lower jaw slightly longer than the upper; iii) the teeth are small and arranged in several rows on the jaws and the palate; iv) a tongue is present and the lips are thick; and v) the lateral line is well developed - even more so in the maturing form (Tesch, 2003).

There are 15 species within the genus *Anguilla*, most of which originate from tropical areas in the Pacific. Exploitation is primarily focused on the temperate species: European eel - *Anguilla anguilla*, American eel - *A. rostrata*, Japanese eel - *A. japonica*, (Australian and New Zealand) shortfin eel - *A. australis*, and longfin eel - *A. dieffenbachii*. Although not considered of equal quality, these species are treated as complementary on the world market, are mixed in aquaculture, and have occasionally been released into each other's distribution area (Dekker, 2004). Only glass eels of the European eel reach a size over 6 cm, while still being transparent. Otherwise, all species are strong look-alikes, and only DNA analysis can reveal their identity. The European eel is distinguished from its very closely related neighbour, the American eel (*A. rostrata*) on the basis of vertebral count in which *A. anguilla* has 115 and *A. rostrata* 107 (Tesch, 2003).

3. Biology of eel

The European eel is a catadromous fish species, long lived (on average males 8-11 years, females 12-18 years depending upon latitude) and the life cycle involves several metamorphic changes before the final adult spawning migration to the Sargasso Sea. Reproduction, whilst still to be observed in the wild (indeed neither spawning adults nor eggs have ever been seen), is a singular event. It is the only species of fish in Europe whose juvenile stage (glass eel) can be harvested and utilized for human consumption without being given the opportunity to reproduce. The life cycle has still not been completely resolved (Fig. 1). It is usually agreed, although still debated, that recruiting eel to continental waters originate from a single panmictic spawning stock in the Sargasso Sea, an area of the Western Atlantic Ocean, 6000 km from Europe (Dannewitz et al., 2005**;** Wirth and Bernatchez, 2001). They occur in coastal areas, estuaries, lagoons, rivers, lakes, marshes and ditches; and the eel is exploited as a food source in fresh, brackish and coastal waters in almost all of Europe and along the Mediterranean coasts of Africa and Asia (Moriarty and Dekker, 1997). They can survive a wide range of environmental conditions (temperature, salinity, depth, trophic status, etc). Eels often dominate the fish fauna in lower rivers and estuaries, where it represents a considerable component of the aquatic ecosystem, and constitutes a major part of the diet of many other fish and semi-aquatic predators such as otters, cormorants and herons (Dekker, 2004).

Larvae (also known as leptocephali) of progressively larger size have been found from the Sargasso Sea up to European continental shelf waters. Transport to the continental shelf is believed to be by passive drift on the Gulf Stream aided by the willow leaf shape of the larvae and can take up to 2 years to complete (McCleave et al., 1998). Knowledge of this larval phase is extremely limited and the duration of this phase, dispersal mechanisms, and even food source are still in dispute (Dekker, 2004).

At the shelf edge, the laterally flattened leptocephalus transforms into a rounded glass eel, which has the same shape and appearance as an adult eel but is non-pigmented. Glass eels arrive along the coastal waters in winter in southern Europe, to late spring in the most northern regions, migrating into estuaries and for the major part further into fresh water using a process known as selective tidal transport (McCleave, 1980).

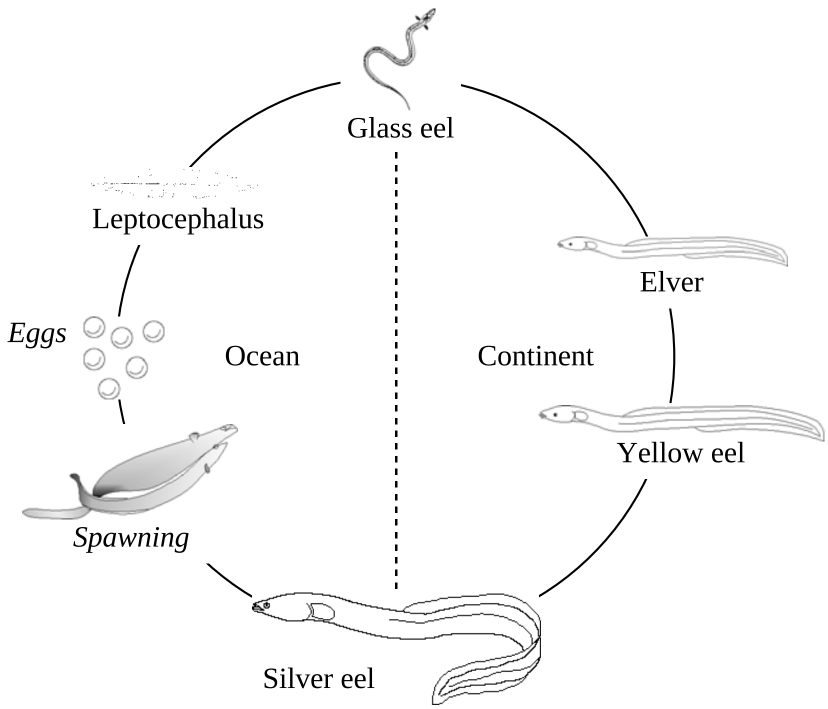

Figure 1. **The perceived life cycle of the European eel[6]. The oceanic phase of this life cycle is currently speculative.**

Following the initiation of feeding in the coastal environments the glass eels become pigmented and this migrating stage is referred to as an elver (Briand et al., 2003). Further upstream, the eel actively swim against the river flow, often in very dense numbers and are known for their ability to traverse obstacles, including using river banks to overcome obstacles. After this migration phase, the prolonged yellow eel stage begins which can last for anything from 2 to 20 years. It is during this phase that the main growth of the eel occurs though no maturation takes place. Yellow eel feed primarily on benthic invertebrates though larger eel are known to be piscivorous. This prey selection is gape limited by mouth size and habitat - riverine as opposed to lacustrine (Moriarty, 2003). Enriched water bodies and an optimum temperature of 21C produce the fastest rates of growth within yellow eels (Tesch, 2003). During winter, yellow eels become inactive below 6 °C and will spend their time in mud burrows in the bottom substrate.

At the end of this period silver eel maturation begins stimulated by body fat content and summer water temperatures (van Ginneken and Maes, 2005). The eel changes both internally and externally with the onset of gonadal maturation associated with morphological changes including an increase in ocular diameter, darkening of the skin on the dorsal surface and cessation of feeding (EELREP, 2006). The mean length of silver eels is 40 cm for males and 62 cm for females (Matthews and Evans, 2001). Their growth rate varies with latitude and associated temperature with mean age of silver eel ranging from 3 years for males and 5 years for females in Spain to 10 and 18 years respectively for silver eels in Sweden

[6] Figure from Dekker, 2000.

(Vollestad, 1992). Sex differentiation mechanisms are not fully understood and may be linked to density of eel population; the presence of high densities of eels, typical of downstream areas, produce males, and upstream areas with lower densities produce females (Roncarati et al., 1997; Dekker, 2004; Davey and Jellyman, 2005).

The final phase of the life cycle is the oceanic migration of the silver eel whose biology during this time is completely unknown. They all migrate back to the Sargasso Sea and this journey is assumed to take up to half a year, from autumn/winter to the following spring (Tesch, 2003; van Ginneken and Maes, 2005).

Attempts at the artificial production of larvae are at a very early stage with survival of fertilized embryos to only 4 days post-hatching. As yet this process is wholly dependent upon exogenous hormonal induction to induce the maturation of males and females (Palstra et al., 2004).

4. Present status of the European eel stock.

The year 1983 saw a pan-European crash in glass eel recruitment, which has not been reversed and levels are at an historical low. The recruitment of glass eels compared with the 1980s is now between 10 % - 15 % of former levels. Local and regional environmental conditions have a marked impact on capture results that may mask short term trends. However, it would appear that the decline is continuing and major reductions in glass eel recruitment have occurred over the whole distribution area. The causes for the decline are not fully understood but are believed to be multi-factorial and include pollution, habitat loss, environmental changes, exploitation, parasitism, and other unknown factors (Stone, 2003; Sures and Knopf, 2004). ICES and EIFAC consider the European eel as being outside safe biological limits and that the current fisheries are not sustainable (ICES, 2006). Their advice is that all anthropogenic impacts should be reduced to as close to zero as is possible (ICES, 2004, 2005, 2006).

Specific structures for the management of eel stocks are now being developed at an international level (EU Council Regulation EC No 1100/2007; CITES, 2007), which will set a common objective, improve the documentation of the status, and should bring the existing, local management structures within a common framework. Eel are now listed under Appendix II of the CITES convention but the full scope of this protective measure will not come into force until March 2009.

The objective of the EU Regulation 1100/2007 on eel is to protect and restore the stock. The Regulation sets a common target for the allowing the escape of (maturing) silver eels, at 40 % of the natural escapement in the absence of anthropogenic impacts. Since current glass eel recruitment is far below earlier levels (and implicitly assumed to be due to anthropogenic impacts), return to this target level is not expected within 3-4 generations (60-80 years). Implementation of the EU Regulation will aim for sustainable management, and set limits to the level of exploitation where appropriate, and reduce the supply of glass eel and yellow and silver eel. Elaboration (2008), implementation (2009) and post-evaluation (2012) of national management plans will require substantial filling-in of current unknowns. The Regulation contains an obligation to reserve 60 % of the glass eel catch for re-stocking outdoor waters; this obligation will further reduce the market supply of live glass eels for farming. The decreasing supply of wild caught yellow and silver eel will increase the demand for aquaculture products, thus increasing the demand for seed stock glass eels.

5. Overview of eel production systems in Europe

5.1. Current production of eel in Europe

The entire aquaculture production of *A. anguilla* amounts to 10,000 metric tonnes in Europe, and 10,000 mt (metric tonnes) in Asia (ICES, 2007). However, current industry estimates suggest that European consumption of eels from aquaculture is of the order of 8,000 mt produced in Europe (value 64 million Euros) and 4,000 mt imported from Asia.

Given that the farming of eels is substantially different from other aquaculture systems in Europe, these differences have had a significant impact on how and where the industry has developed. At the present time it is not possible to reproduce eels and culture all life stages of eels in captivity despite research efforts to develop techniques for artificial induction of maturation, spawning and rearing of larvae (Palstra, et al., 2004 and 2005). Recent progresses of those persistent efforts have led to development of rearing techniques of larvae, and first success in experimental producing glass eels of Japanese eel, *Anguilla japonica* (Kagawa et al., 2005; EAS, 2007). However, the industry has to depend on wild caught juveniles (glass eels) to maintain its production stock. The successful rearing of glass eel is dependent on an intensively managed warm water system. The majority of eel farms, but not all, have a specialised unit for the rearing of juveniles from glass eels.

Glass eels are sourced from Morocco, Portugal, Spain, France and the United Kingdom. The principal area of capture is in the coastal regions adjacent to the Bay of Biscay, France (Beaulaton and Briand, 2007). In 2005 estimated landings for glass eel around Europe indicated that 80 metric tons (mt) were caught in France, 6 mt in Spain, 8 mt in UK and 16 mt taken by the black market (ICES, 2006). In 2006, it was estimated within the industry that the level of capture of glass eels for the whole of Europe was about 120 mt (approximately 360,000,000 pieces). Approximately 25 to 30 mt of this stock was utilised for culture in Europe, 60 mt shipped to Asia for aquaculture, 1 metric tonne (mt) for re-stocking purpose in Northern Europe, and the balance (29-34 mt approximately) killed in the process of capture, were retained in France, Spain and the Basque region for human consumption (known as “civelles” or “pibales” in French and “angulas” in Spanish). The exact size of the glass eel market for consumption is difficult to determine. To put it in context it should be remembered that the consumption of glass eels in Spain is an important part of culture and tradition. In the 1970s approximately 1,000 mt of glass eels were processed for consumption. In the last 15 years, significant quantities of glass eels, which would previously have been retained for human consumption in Europe, have been exported to Asia for farming purpose.

It has been reported by Philippe Boisneau[7] that more than 30 % of the French catch is not declared. There is a high probability with limited fiscal control that such catches will be diverted to personal consumption or catering; and welfare is not likely to be a high priority in this context.

It is reported that there have been some imports of American glass eels (*A. rostrata*) for farming in Europe. It is believed that this practice has now stopped and that the dominant species (>95%) of eel cultured in Europe is *A. anguilla*.

Eel culture systems can be broadly divided into extensive and intensive farming systems with intensive system estimated to make up 80 % of the production (Gousset, 1990; Ciccotti and Fontenelle, 2000; Liao et al., 2002). There has been a significant decline in the production of eel in the last decade with production continuing to fall. While there were over 50 farms in Denmark two decades ago the business has now been contracted down to just five farms

[7] Conference on eel, European parliament 22-23 March 2008 (www.fishsec.org/article.asp?CategoryID=1&ContextID=106)

although these farms have increased in volume. Such changes have also been seen throughout the rest of Europe. There has also been a very significant decline in production from extensive units and virtually all the extensive units in Italy have ceased production. All of these changes reflect a falling market demand for the end product and the influence of cheap imports of *A. anguilla* from Asia farms (Wood, pers. comm.).

5.2. Eel production systems in Europe

5.2.1. Glass eel sourcing for the purposes of farming

5.2.1.1. Capture

Where glass eel are seasonally abundant in estuaries in France, Spain, Portugal and the Severn estuary in England, fisheries have evolved to take advantage of this stage, both for consumption and for stocking to inland waters or aquaculture for on-growing.

The fishing of glass eel in France, Spain and England is legal whilst it is illegal to fish for glass eel in Portugal. The distribution of commercial glass eel fisheries around the western coast of Europe reflects the areas of highest stock densities (Dekker, 2000). There is a relatively small window of opportunity of 10 to 12 weeks for each region where this migration takes place. The principal months for capture in Europe are from November to April and the majority of the glass eels are captured on the Atlantic coastline of France (Pays de la Loire, Poitou-Charentes, Aquitaine). Individual catches are small, on average less than 2.5 kg per night per fisherman.

The information in section 5.2.1.1 was mainly obtained from the European Commission Report 98/076, edited by Willem Dekker.

During the winter glass eel migrate from the ocean towards the coast, entering estuaries as water temperatures rise above 4 °C to 6 °C. During flood tide, glass eel swim in the water column and passively drift towards the coast while during the ebb tide they hide in or near the bottom and resist being washed back to the ocean. This phase is often followed by a resting phase in the estuary and metamorphosis to the pigmented elver stage. As temperature rises to 12-15 C active migration into the rivers occurs with elvers now swimming against the current. Consequently, glass eel come into an estuary but may not be able to progress upstream due to temperature or obstruction, resulting in large concentrations of eels in early spring especially at the upstream tidal limit.

This natural migration process provides several opportunities for the development of catching methods such as:

- In estuaries glass eel are carried inland by the flood tide. Nets set in the estuary can filter the glass eel from the flood current (fixed nets).
- During ebb tide glass eel prevent being washed back to the sea by hiding in or near the bottom. Placing artificial substrates in estuaries can yield large quantities of glass eel which are hiding during this tidal phase.
- Concentrations of glass eel stopped in estuaries in high volumes of water enables active fishing of them using moving boats and towed nets by trawling.
- For those glass eel that are now in their upstream migration phase the provision of climbing substrates, with a trickling water flow attracts the glass eel which provides an opportunity to collect them in a trap.

There are a variety of passive and active methods employed to catch immigrating glass eel around Europe. In the past the vast bulk of capture was by hand netting, or the use of nets from slow moving vessels, but given the increase in demand for glass eel in the 1990s and the similar value of dead and live glass eel, methods quickly moved to the use of larger nets, hung from boats and towed at greater speeds. This has brought with it its own set of welfare problems.

5.2.1.1.1. Tela Net (fixed net) (responsible for 10 % of glass eel captures)

The commercial fishery in the river Minho (border between Spain and Portugal) applies a net locally known as a Tela for catching glass eel carried by the flood tide into the mouth of the river. The net has a wide opening (15 m) facing towards the sea; the upper surface is open and the float line is kept on the water surface using a series of large buoys. The net is anchored to the bottom (1-2 m deep) just before low tide. A boat is moored at the inland side of the net. The flood tide carries glass eel into the net where they are collected using a hand held dipnet from the boat. The net can be operated for as long as the flood tide lasts and as far upriver as the flood tide carries. Given that the glass eel are removed from the apex of the net as they arrive, there is a reduced risk of compression injuries or mortalities using this type of netting method.

5.2.1.1.2. Glass eel Fyke nets (fixed net) (responsible for 10-15 % of glass eel captures)

Fyke nets are probably the most common of all eel fishing gear but where the fishery targets the glass eel stage they are heavily modified and are composed of a fine mesh (2 mm) with relatively short wings. Glass eel swim into the fyke net, either carried by the flood tide or actively swimming their way upstream into the river. The cod end of the fyke net contains one or more chambers separated by fine meshed funnels. Because of the small mesh size glass eel fyke nets must be lifted and cleaned frequently. Damage to fyke net captured glass eel is dependent upon the length of time the net is left before being lifted and the speed of the inflowing current in which they are set as at high water flow speeds compression damage begins to be a problem. Detailed figures are not available.

5.2.1.1.3. Hand held dip nets (responsible for 10-15 % of glass eel captures)

The legal commercial glass eel fisheries in the Bristol Channel and other areas of the UK use a hand held dip net from the river bank to collect glass eel. This type of net is one of the two types legally authorised in France with ship borne active fishing gear (5.2.1.1.5). The net is of a simple box shaped design and has hardly changed with time: a long stick carries a 0.6 x 2.5 m frame covered by a shallow, fine meshed net. A fisherman holds the net from the bank into the stream and filters the glass eel from the water. Best catches are made at the end of the flood tide and into the early ebb when the glass eel concentrate near the banks as they utilize the last of the upstream flow. This type of netting produces few if any injuries or mortalities and is known to yield excellent quality glass eel for stocking or on-growing purposes (Woods, pers. comm.).

5.2.1.1.4. Active fishing gear (ship borne) (responsible for 60-70 % of glass eel captures)

The type of net used in the active capture of glass eel in estuaries varies in many respects and almost each estuary has its own special type. Two basic set ups can be distinguished; trawl nets applied at the surface sideways from the boat, and nets applied in deeper layers, underneath the boat. The surface trawls invariably consist of a rectangular frame, wider than deep, covered by a small meshed net. In some places a deep net is used (Garonne, France), in others a shallow net (Nalon, Spain). Sometimes the net is directly attached to the boat but towing from a front mounted beam also occurs. The nets applied beneath the ship usually consist of a circular hoop, with a long handle attached to the side of the boat or hand held.

Again the depth of the net can be shallow or deep. The boat carrying the net moves around the estuary actively collecting the glass eel and it is this type of fishing which causes most of injuries and mortalities to the captured glass eel.

However, given that fresh dead glass eel command a similar price for the human consumption market as that for live seed for on-growing there is little incentive for the fishermen who use these methods to alter the practice. As a consequence of this the equipment, technology and attitudes that have been adopted by the industry are still orientated towards the human consumption market. The industry has been slow to adapt and still has not adopted the technology and practices that are standard throughout the rest of aquaculture.

The compression injuries and mortalities incurred by such fishing methods are well known but poorly studied given the contentious nature of the work. Only one study from France has examined this issue in any depth (Evans, pers. comm.). This work examined the level of mortalities and injuries incurred by glass eel during active trawling for them in the Vilaine River estuary and compared these with mortalities and injuries incurred by hand netting at the same location. The results found that 30-40 % of glass eels were killed during capture and that a further 10-15 % of glass eels were sufficiently damaged that they would die over the next few days. Staining the glass eel with indigo carmine highlighted that the eels had suffered skin injuries accompanied by mucus loss in 97 % of the dead eels. The mucus in glass eel forms an epithelial barrier responsible for osmotic integrity, and healthy glass eel are perfectly adapted to cope with salinity variations (Crean et al., 2005). The study also found that mortality was linked with tail damage as about three quarters of the fish with a tail injury died over a 2 day period following their capture highlighting the importance of the caudal sinus in eels. Glass eel get caught in the outer end of the net where the mesh size is generally 1.8 to 2.0 mm suffering spinal rupture whilst many of them get their tail caught in the deepest part of the net where the mesh size is 1.3mm.

No injuries or mortalities were noted on those glass eel caught using the hand net. The conclusions from the study indicated that glass eel fished too long (nets not emptied regularly enough) and at too high a speed were the causes of the injuries and mortalities due mainly to compression injuries, mucous loss and tail damage.

5.2.1.2. Storage and transportation

From the river to the end-user, glass eels have a finite shelf life of about 3 weeks. Depending on the methods of handling, storage, temperature and time of year this shelf life can be reduced to a week or extended to five weeks.

There is a hierarchical structure by which catches are collected and consolidated.

The storage systems for glass eels are varied from simple unmonitored flow through systems to more complex monitored re-circulated systems with temperature control. They all serve the function of consolidating catches, resting glass eels and introducing a measure of quality control in the logistics chain (see Table 1).

Transport of glass eels can be by road tanker or by air freight. Transport by road is little different from transporting any other aquaculture species. The key variables are temperature, dissolved oxygen, pH and metabolic by-products. Regular monitoring and control of some of these parameters are considered as good husbandry practices and should be carried out if potential problems are to be avoided.

The transport of glass eels by air freight is different from other aquaculture species. Glass eels have the ability to survive outside water for some 30 hours providing they are kept in a cool and moist environment. This unique feature allows glass eels to be shipped over large distances which would have taken days by road but can be completed in hours by air. The key variables (e.g. temperature, oxygen, density of fish) are set at the start of the transport, as they cannot be monitored or varied during transportation and require greater precision than under other transportation methods.

5.2.2. Eel growing systems

Intensive production is largely based on stock reared from glass eels whilst the extensive systems have selected wild eels ranging in size from 5 to 150 g for production. The latter practice is changing with more of these units either establishing their own starter units for glass eels or buying juvenile eels that have been started from glass eels.

5.2.2.1. Extensive culture systems

The extensive culture systems have been established for nearly a century in those countries with warm climates in southern Europe, principally Italy and Greece. Eels were farmed in open ponds and rectangular raceways constructed from earth and/or concrete. Sizes of these ponds could vary from 0.5 to 5 hectares. These ponds are stocked with eel from 5 to 150 gm as opposed to glass eels. There is no supplementary heating and temperatures in the winter months would not be sufficient for any substantial growth. Water utilisation would be based on the amounts needed to make up pond levels as opposed to providing active flow through. Supplementary feed in the form of waste fish, paste or, latterly, specialist pelleted diets are used to complement the natural supply of food found in the ponds.

To some degree the development of eel culture in these countries was a progression of the highly developed coastal lagoon system where a range of marine species including eels were already trapped and managed. However there are practical problems in training wild eels to eat commercial diets in an extensive farm environment and a small percentage of the wild juvenile stock do not adapt and die despite all efforts.

The extensive systems do have serious limitations when it comes to the management and control of diseases. Their wild seed stocks have been identified as carrying low populations of pathogens that not only develop into disease with high morbidity and mortality during their period of adaptation but also present a significant risk to the resident population (see Dipnet, 2007 for comprehensive review). For example, HVA (*Herpesvirus anguillae*) was isolated from wild juveniles and adult eels without clinical signs (Jorgensen et al. 1994); under farming condition morbidity is high and mortality ranging between 0.5 and 10 % (Haennen et al., 2002). In the case of the nematode, *Anguillicola crassus*, the prevalence can reach 100 % of wild juveniles in inland waters. The prevalence is similar in farms but effective treatments exist (van Banning, 1991).

The extensive systems have not proved to be economically successful in the last decade. As a consequence, there are only a small number of extensive systems based in Italy and Greece which supply a niche market in Italy but the numbers are so small they are not considered in the RA.

There is a trend within some of the extensive systems to develop hybrid farms by employing some of the intensive farming water recirculation technologies to increase production and reduce pollution.

In view of the insignificant contribution of the extensive sector to the overall European production of eel, their welfare issues are only considered where there is clear indication of difference from intensive culture systems.

5.2.2.2. Intensive Culture systems.

Due to a lack of scientific research, the following section is composed from commercially available information and expert opinion.

This is a relatively new technology that was developed in the United Kingdom in the 1970s. The market price for adult eel at that time, compared with other farmed species, was relatively high.

It had already been established that the eel required a warm environment to grow effectively. Initially these intensive farms were established near industrial processes that produced large quantities of hot water effluent: e.g. electric power generators and cement manufacturers. These first generation farms were principally flow through units with access to hot water. Surprisingly this simple technology was unsuccessful as industrial hot water discharges were unstable, difficult to manage and often contaminated with deleterious pollutants. These first generation systems have either closed or adopted recirculation technology.

The current intensive systems are likely to be independent of any industrial process. They are enclosed in buildings with good thermal insulation properties. A very substantial portion of the water is filtered, treated and reused. The development of these systems is on going with special attention being paid to reducing energy consumption, labour costs, increasing production and extending the production life of these units.

Intensive eel culture systems are almost exclusively found in Northern regions of Western Europe. The majority are to be found close to the principal markets of The Netherlands, Denmark and Germany. The preferred market size for the eels varies from country to country; from 70 g (Southern Spain), to 160 g (the Netherlands), and 300 to 1,200 g (Germany and Italy).

Industrial expertise would suggest that there is a market in Europe of between 10,000 to 12,000 metric tonnes per year but the overall demand for eel in Europe for cultural and social reasons is in decline. The current trend of the European eel production is towards intensive systems over the extensive systems.

5.2.2.3. Recirculation systems

These are systems with very high investment costs requiring a high level of technical management above and beyond the daily husbandry requirement of the eels. The management of these super-intensive farms should be considered as two processes: firstly as a complex industrial process for the treatment of water and, secondly, as a husbandry unit with its own technical challenges. New filter substrates and a better understanding of the biological processes that are taking place in the filters, in conjunction with new engineering standards and cost effective electronic management solutions have allowed further intensification and increased production. However, without continuous monitoring, the use of alarm systems, and a reliable emergency backup even relatively small failures can produce disastrous outcomes.

Recirculation offers real benefits in terms of energy usage. In an insulated production unit optimal temperatures of 25 °C (Tesch, 2003) can be maintained without supplementary heating providing a stable environment for the eels. Water usage can be reduced to 10 % of system capacity per day whilst effluents can be concentrated and waste discharges into the environment controlled effectively.

The re-circulation process is one of removal of solids, nitrification to convert ammonium to nitrate, de-nitrification of nitrates to nitrogen gas and re-oxygenation of the water. (see schematic process Figure 2).

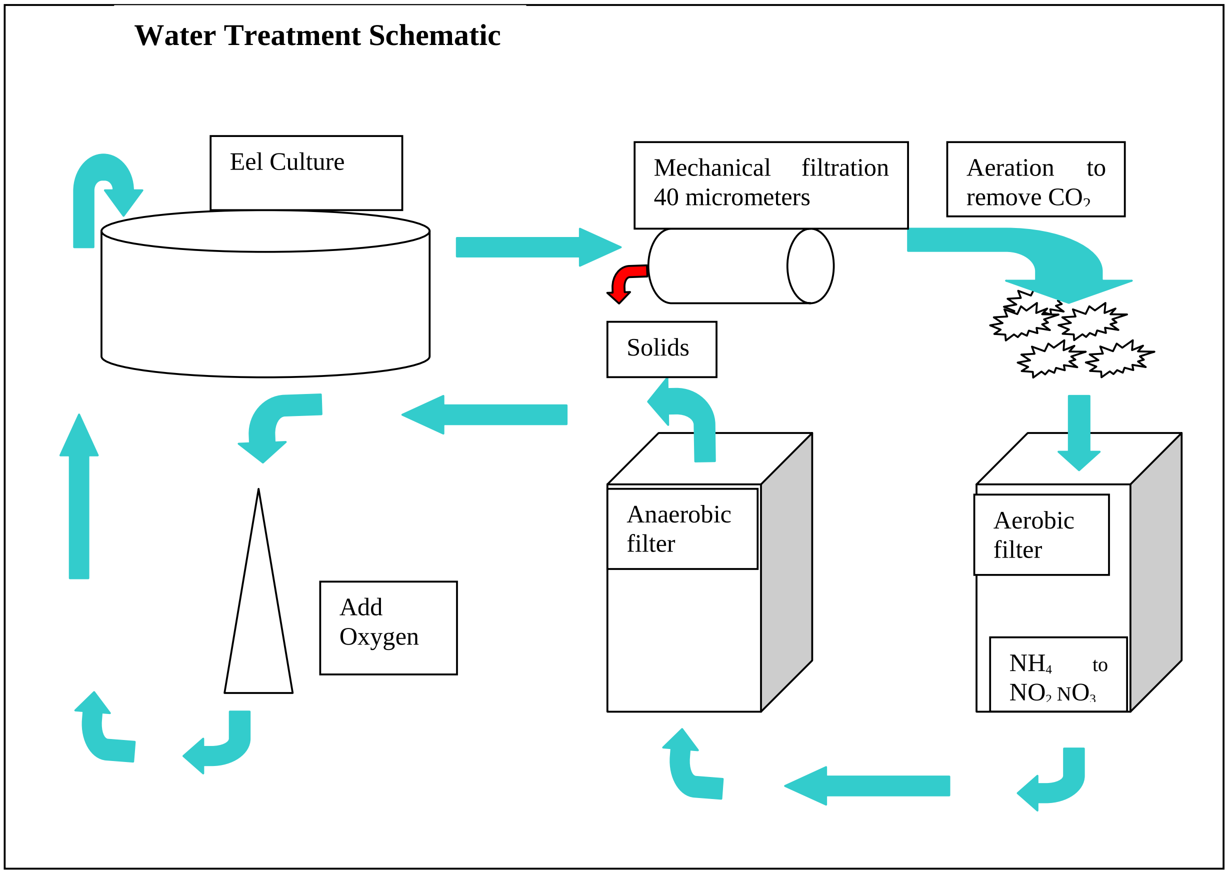

Figure 2. **Water treatment in recirculation system**[8].

5.2.3. Eel life stages

5.2.3.1. Glass eels and juveniles

The recently captured glass eels are transferred to a starter unit. There is a short acclimatisation period to allow the glass eels to recover from the transport and to monitor any mortality (Table 1). The initial temperature of the starter unit would be between 5 to 10 °C and salinity from 0 up to 10 ppt. Within 48 hours the temperature is increased to 25-26 °C (optimum levels). Glass eels need to be trained to take dry food and the standard in industry is to use cod roe (mature ovaries of *Gadus morhua*) as a starter feed. It is introduced in small quantities as soon as temperatures reach 20 C and within a few days the glass eels learn to eat the cod roe. Daily consumption of several feeds could be between 5 and 10 % of biomass of the glass eels. As soon as the glass eels are actively feeding on the cod roe, 0.5 mm commercial eel crumb is introduced. In addition, the crumb may also be fed as a paste mixed with cod roe to aid the training process.

The management of the feed at this starter stage can be very labour-intensive with a high proportion of the feed given by hand. Constant monitoring is required to check intakes. Each farm has its own methods to ensure glass eels have equal access to the food and that the larger faster growers do not monopolise the food supply.

[8] adapted from Heinsbroeck and Kamstra, 1990.

By 40 days the glass eels should be eating 4 % dried food and weaned off the cod roe. There will now be a marked difference in individual weights. The mean weight could be 0.45 g but with the smallest individual <0.15 g and the largest >1.0 g. The glass eels are graded (see section 6.3.2) and the larger juveniles separated from the small glass eels to reduce cannibalism and competition. The small fish are then returned to the starter regime of cod roe and crumb while the larger fish continue to be reared on dried feed. It is possible that the slow growing glass eels will be graded 2-3 times returning to the starter regime each time. The juvenile population are normally transferred to on-growing production units once they attain a size of 2.5 to 10 g.

The first 10 to 12 weeks in the starter unit require intensive management and disease monitoring. Glass eels reared in a closed system, will have a similar level of immune competence. These starter systems need to be fully stocked from day 1 as the addition of a naive population of glass eels into a system already holding a resident population is contraindicated.

Survival rates of 95 % are achievable for glass eels reared in an intensive starter system over a period of 12 weeks (Richard Fordham, pers. comm.).

5.2.3.2. On-growers

Farm and tank design is optimised to reduce physical handling of the eels by using gravity and pumps whilst tanks and screens are self-cleaning. The tanks usually have a volume of 10 to 30 m^3 for stocking densities up to 250 kg/m^3.

In extensive systems, ponds are big is size, ranging from 0.1 to 5 ha for stocking densities up to 10 kg/m^3. Extensive systems offer the benefits of low capital costs but with little opportunity for management and control. For this reason eels introduced into an extensive system are likely to be greater than 10 g in weight and could be as large as 150 g. Traditionally these units depended on wild juvenile stocks but lately juvenile stocks have been sourced from glass eels. The management of disease is very difficult if not impossible. With high labour costs and the difficulties of harvesting fish, grading not carried out. As the ponds are situated outside, ambient temperatures in the winter may not be sufficient for production.

Shade is provided to protect some or all of the areas of the pond from direct sunlight. Special attention is given to providing shades or even dark areas at the point of feeding. While supplementary feeding is often provided some components of the diet are sourced within the pond’s own ecosystem. While observations do not indicate intensive systems adopting a more extensive policy it is apparent that extensive systems are now sourcing juveniles from glass eels stocks. They are adopting more efficient and intensive methods to improve management control, conserve energy and to reuse water in the production units.

The production stage while still requiring good husbandry skills is less labour input compared with glass eels and juveniles. Slightly lower temperatures 22-25 °C are acceptable and pelleted commercial diets are fed using mechanical feeders. Grading is an important feature of the production cycle to produce more even growth and reduce cannibalism. Opinions vary as to the frequency that grading is required given that there is a need to balance the benefits of grading against the drawbacks in terms of reduced growth for a period after grading due to the disturbance of the eel.

It would appear that sex ratios are dependent on densities (Roncarati et al., 1997; Dekker, 2004; Davey and Jellyman, 2005) though the exact mechanism and predictive detail is unknown. Typically in an intensive unit only 20 % of the population will exceed the 200 g size and it is assumed that these larger fish are females.

5.2.3.3. Marketable fish

For 12 to 24 hours prior to marketing, food would be withheld. Eel flesh can be tainted with ‘off-flavour’; where taint is not identified the eel continues to be held at production temperature in the system’s re-circulated water. Where taint is suspected the eel is stored in a flow through cold water system for 3-7days.

Prior to marketing, the eels would be graded, batches consolidated and placed in a cold water storage tank for a few days (<5).

Table 1. **Production systems for eel in Europe**

Life stages	Description	Production systems		
		1. intensive to super-intensive in recirculation system	2. extensive system	Essential alterations from system 1 and 2
Glass Eels (2-4 weeks)	Capture	Wild stocks. Method of capture, hand net, fixed traps, trawling. Crushed glass eels. Approximately 30% fishing mortality. Post fishing mortality 10-15 % in storage.		
	Storage	Simple open flow though systems. Re-circulated temp controlled managed systems.		
	Transport	Road transport. Tanks aeration, oxygenation. Stocking densities 20 to 200 kg per m^3. Key variables- oxygen 3-70 mg per litre, temperature 5-20 °C., pH, NH_3, Air transport. Insulated styrofoam boxes. Moist humid environment only (no free water) Temperature 5 °C, survive 30 hours. Transport parameters fixed at start. However rapid transport possible over several thousand kms with minimum mortality.		
Juveniles (10-12 weeks)		It is not possible to rear in extensive systems. Do not confuse with restocking.		
	Acclimatisation	Glass eels received at temperature 5-15 °C. Allowed to rest. Temperatures increased to 25/26 °C (production temp) in next 48 hours. Salinity 0-10 ppt.		
	Training and Starter feed	Cod roe are introduced in small quantities as soon temperatures reach 20 °C. Maximum appetite reached after 5-10 days. Daily consumption in several feeds could be between 5 and 10 % of bio mass of the glass eels. As soon as the glass eels are actively feeding on the cod roe 0.5 mm commercial eels crumb is introduced. In addition the crumb may also be fed as a paste mixed with cod roe. Oral vaccines can be administered at this stage. Well tolerated when included in paste of cod roe and crumb.		
	Weaning and Grading 40 days	The glass eels should be eating 4 % dried food and weaned off the cod roe. Marked differential in individual weights. 0.15- 1.0 g. Larger juveniles separated for the small glass eels to reduce cannibalism and competition. The small glass eels will revert to Training and Starter feed. Cyclic process may be repeated 2-3 times.		

	70-100 days	Further growth on dry food Exposure to Eel Herpes Virus (EHV)	
On-growing (18 months – 2 years)	100-500 days	Intensive System	Extensive System
	Construction	Indoors	Outdoors
		High capital cost Tanks of 10 to 30 m^3. GRP, polypropylene, concrete	Low capital cost Ponds 0.1 to 5.0 ha. Earth concrete
	Operational	Intensively managed system. High degree of control oxygen, pH, NH4, Temperature 25 °C Water reuse High stock densities 50-250 kg/m^2 Pure oxygen continual grading	Unmanaged system. Low degree of control oxygen, pH, NH_4, Temperature ambient Make up water only Low stock densities 1-20 kg/m^2 Aeration Limited grading
	Starter stock	Glass eels	Wild or cultured Juveniles
Marketable fish	Preparation for market (7 days)	24 hour fasting warm water system. Grading Consolidation of stocks in preparation for collection. Move to separate cold water system. Storage in freshwater to remove any undesirable taints from tissues.	

6. Identification of factors potentially affecting the welfare of European eel

Farming systems inevitably introduce a number of stressors to the organism. Potential stressors may include inappropriate water chemistry (NH_3 NO_2, NO_3, pH, Dissolved Oxygen, CO_2) temperature, handling, physical damage, diseases or disease treatments and inappropriate nutrition. It is impossible to avoid many of the procedures known to induce stress responses in eel farming. Netting, grading and transport are integral components of the eel farming routine and, at best, all the farmer can do is to minimize the effects of this type of stress (Pickering, 1993a). In general, the duration of the stress response is proportional to the duration of the stress. Thus, reducing the time-course of the event (netting, grading, transport etc.) will encourage a more rapid recovery of the fish (Pickering, 1993b).

A review of environmental conditions and factors that may affect welfare of eels is given in the following sections of this report.

6.1. Abiotic factors

6.1.1. Light period and intensity

Eel, like virtually all fish, react to light changes (Kezuka et al., 1988). The heart rate (as an indicator of activity) of eels depends on circadian variations which synchronize with the photoperiod (Pennec and Le Bras, 1988). The maximum level of activity is observed during the dark phase. In day light, eel would gather under shelters where they stay to protect themselves against the light. In this situation, eel activity is reduced which may affect their metabolism (Edel, 1975). Although no information is available on European eels, it can be assumed that for this species the presence of shelter also depresses total activity during the day, which thus should affect eel metabolism and growth rate. The effect on welfare is uncertain.

In extensive systems, current practice is to provide shelter from direct sunlight or too high intensity of light with feeding stations also providing shadow. Eels gather in shadow during the day and disperse at night. An observation by a working group member was that a common feature of the most successful extensive farms in China was the provision of shelter from direct sunlight.

In intensive farms, current commercial practices vary from unit to unit and generally apply to all stages of production. The management of photoperiods is in many cases coincidental to the daily operation of the production unit. Not all units are light proof. Some have skylights and external doors allowing the ingress of natural light. The consensus is to operate these units at the lowest light levels possible that are compatible with safe working practices. A significant number of units maintain these low light levels artificially 24 hours a day. There is a view, supported by expert opinion, that sudden changes in light levels produce a “fright and flight” reaction.

6.1.2. Noise and vibrations

From the scientific literature review no information was found but industry experience would indicate that eels are susceptible to sudden changes in noise and to vibrations.

6.1.3. Water oxygen content

The amount of dissolved oxygen in the water increases as atmospheric pressure rises, but decreases as temperatures rise. These physical effects have very practical consequences. When water temperature increases, fish metabolic rate increases but oxygen availability is limited at the same time. In production systems available oxygen is also consumed by micro-organisms that decompose organic matter in bottom sediments which, again, limits the availability of for fish.

Water oxygen content is variously expressed by different authorities. In order to compare these figures, the following table may be used.

Table 2. **Solubility of oxygen (mg/l) in fresh water in equilibrium with air**[9]

Temperature °C	Oxygen solubility, i.e. 100% saturation mg/l
5	12.8
10	11.3
15	10.2
20	9.2
25	8.2
30	7.5

In order to ensure optimal feeding and growth water oxygen concentrations should be > 5 mg/l although eel can withstand lower oxygen concentrations, and these conditions frequently occur in many eel habitats such as lagoons or large estuaries (Lefebvre et al., 2007). At a water temperature of approximately 10 °C eels can survive for two days and longer at oxygen concentrations between 0.5 mg/l to 3 mg/l (Lefebvre et al., 2007), whereas death occurs within a 10 hour period at a water temperature of 20 to 21 °C and an oxygen concentration of approx. 1 mg/l (Molnár, 1993).

[9] at 101.325 kPa

High oxygen concentration is necessary at intensive high feeding levels and high temperature. The demand for oxygen is approximately one kilo of oxygen for every kg of food consumed. Systems operating at 25 °C use 100 % oxygen saturation levels (Gousset, 1990) with current practice aimed at maintaining 100 % saturation at tank outlets. This will minimise the risk of areas of low oxygen levels developing in the system.

In all culture systems the oxygen level is often the most critical factor and as such is monitored closely. However, expert opinion asserts that even though intensive eel culture is now a relatively mature production system, oxygen deficiency problems leading to both mortality and impaired welfare are difficult to completely avoid unless each tank is alarmed and provided access to backup oxygenation. This can be a significant welfare issue but difficult to recognise.

6.1.4. Water temperature

Eels are naturally adapted for survival across the range of European temperature conditions. However, in the wild, mortalities are reported during cold winter periods (Tesch, 1999) as well as during temperature maxima occurring in summer months (Molnar et al., 1991). As water temperature directly affects eel growth, water temperature for eel production is usually maintained between 23 and 26 °C in intensive systems (Tesch, 1999). Experimentally, it was shown that the optimum temperature for growth is 22-23 °C (Sadler, 1979). In the same study, a critical thermal maximum was established ranging from 33 to 39 °C for fish acclimated from 14 to 29 °C At low temperatures, eels were shown to enter a state of torpor at temperatures varying from 3 °C (for fish acclimated at 29 °C) to less than 1 °C (fish acclimated at 23 °C or below).

With sudden lowering of temperature (i.e. to below 15 °C) working group experts have observed a percentage of the population loses its thigomotactic response. Recovery at these low temperatures is observed 2 to 4 days later. Normally, glass eels are not exposed to low temperatures. Industrial experience indicates that holding or transporting glass eels at temperatures below 4 °C can lead to significant mortality.

Under intensive farming conditions, it is difficult to rear juveniles below 22 °C whilst the optimum temperature for production is considered within the industry to be 24-26 °C. At lower temperatures, pathogen activity is generally more successful than the ability of eels to deal with it, whereas at 24 °C to 26 °C advantage generally appears to be with the host. Under intensive conditions at temperatures of 19 °C appetite is very significantly suppressed.

It has been observed that there is no feed consumption below 10 °C for glass eels (Elie and Daguzan, 1976).

6.1.5. Water pH

Eels tolerate a wide range of pH although extreme values reduce feeding activity and thus growth rates. Optimum pH values for the eel are reported as being between 7 and 8 (Tesch, 2003). Under intensive conditions, pH is maintained below 6 in order to minimise the risk of ammonia toxicity (Gousset, 1990). Industrial experience indicates that for intensive systems a pH range of 4.8 to 5.8 is tolerated

The direct effect of pH is less important than the indirect effect that increased pH values have on the un-ionized ammonia content in the water. In closed re-circulated systems the management of pH can be particularly demanding requiring acidification during the start up phase and the addition of alkali during the running phase. Although pH control is critical to the success of the operation, industrial experience suggests that on occasion the automatic acidification system may fail and as a result welfare issues arise due to excessive acidic or alkaline conditions leading to ammonia toxicity.

6.1.6. Suspended solids

The management of suspended solids in intensive eel culture is critical to the success of the operation not only from the perspective of the management of the production cycle but also the water treatment process. The recent introduction of cost effective mechanical drum/disc filtration systems has enabled the industry to manage suspended solids (Wood, pers.comm.). The removal of solids greater than 40 μm is typical and has the added advantage in welfare terms of controlling the prevalence of the parasitic monogenean trematode *Pseudodactylogyrus* sp. by removing its eggs from the system.

6.1.7. Ammonia, nitrite and nitrate content of water

Ammonia is the main end product of protein metabolism, often representing over 80 % of the waste nitrogen. It is excreted via the gills. This product of fish metabolism and its levels within the water column are among the most important factors affecting fish welfare. The toxicity caused by this chemical is related to the level of unionized ammonia (NH_3) and this varies depending on the pH of the water and also temperature as lower temperatures result in lower levels of unionised ammonia (Westers, 2001). According to Yamagata and Niwa (1979) and Sadler (1981), maximum concentrations of unionised ammonia should not exceed 0.05 to 0.1 mg/l. This concurs with industrial experience where levels in excess of 0.1 mg/l of unionised ammonia are avoided. If this is not achieved, there is a reduction in appetite and subsequently a gill and skin pathology, secondary infection and ultimately death (André et al., 1972).

Compared with other freshwater fish species *A. anguilla* is tolerant to nitrite, the intermediate product during nitrification. Water nitrite concentrations should be below 30 mg/l according to Yamagata and Niwa (1979) and Kamstra et al. (1996). Industrial experience would indicate that levels higher than 10 mg/l should be avoided. However it is also recognised that levels of 100 mg/l can be tolerated in the presence of salt.

Water nitrate levels (as opposed to nitrite) as high as 500 mg/l are acceptable. It has been reported that levels greater than 300 mg/l create a more challenging environment for some external parasites.

6.1.8. Tank and pond design

There is no indication that specific tank or pond designs are significant in relation to eel however, those systems which do not have adequate means of moving fish to a central harvesting point for grading or for harvesting via a channel or pipe system are of welfare concern. Without such systems, fish must be netted or pumped out of the water which expert opinion views as liable to cause significant injuries and stress that will impair growth and lead to secondary infections.

Tanks range in size depending upon the life stage grown in them (Table 1) and should be self-cleaning to expedite the removal of waste and to reduce mortality. The size of tanks for glass eels in a starter unit usually ranges from 1 to 5 m^3, and from 10 to 30 m^3 for on-growers.

Eels have a natural need to have mechanical contact with a solid substrate while resting (thigmotaxis). In very intensive systems, it has been shown to be important to provide alternative resting “hammocks” suspended within the water column as the base of the tank will not provide adequate resting area for all of the fish in the tank at resting time.

6.1.9. Substrate of ponds

The natural substrate of a pond is normally the basis for extensive lagoons or ponds in Europe. An area concreted for the purposes of feeding or harvesting is desirable for hygiene and management.

6.1.10. Environmental pollutants

In eel production systems usually a stable water flow exists, which reduces possible toxicant concentrations in the water column. Outdoor ponds may be occasionally problematic, either due to contaminants of the incoming water, via aerial spraying drift, or terrestrial run-off.

Information is available on pollutant concentrations in wild eels which are a valuable indicator species (ICES, 2007; Sures et al., 2001). Among the most important pollutants are lipophilic substances whose accumulation increases with eutrophication, such as any kind of chlorinated hydrocarbons (e.g. polychlorinated biphenyls and PCBs). As eels contain a large amount of fat they are present in relatively high concentrations in eels (Wiesmüller and Schlatterer, 1999; Belpaire, 2008), which is problematic for aspects of human consumption and for the health of affected animals.

There are recommendations with regards to the safe levels of wild eel consumption because of these issues (ICES, 2007; Belpaire, 2008). However farmed eels do not have such problems because of their reduced exposure to polluted waters (EFSA, 2004).

6.2. Biotic factors

6.2.1. Behavioural interactions

After the glass eel stage, eel change from a shoaling fish into a ‘territorial’ species which can be aggressive at low densities. It is important to maintain uniformity of size within the population since cannibalism rapidly ensues when size discrepancy develops. Such uniformity is usually maintained by regular grading and sorting.

6.2.2. Food and feeding

Initially diets for eel culture were based on waste fish, and fish meal formulated into paste. However, over the past two decades European specialist manufacturers have developed sophisticated crumb and pelleted feeds which have proved to be very satisfactory in terms of providing balanced feeds for eels containing all the necessary nutritional requirements. The quality of raw materials, the fat content and production technology has been very important in determining a satisfactory eel diet.

In today’s eel industry one of the most critical periods in the rearing cycle is the point at which the glass eels are transferred from the cold water storage system and introduced into the warm water juvenile system for the following twelve weeks of on-growing. During the first weeks of production, glass eels require extremely high standards of husbandry with particular attention to the methods that are used to introduce the glass eels to commercial diets. Live feed is not used for glass eels. First feeding is with cod roe at temperatures greater than 20 °C. Within 3-4 days the glass eels will vigorously feed on the cod roe. Over the next 14-21 days cod roe, a paste of cod roe / dry crumb and dry crumb are fed. The objective at the end of this period is to train the glass eels to eat crumb. During this process, the larger eels are separated from the smaller eels to reduce competition. Mechanical grading via a swim through or flow through grader will take place after 30-40 days. The feeding induction process is then repeated for the smaller eels which up to that time may not have been feeding actively due to competitive pressure. Despite efforts of the farmer to induce the fish to feed, those not feeding after 65 days will die.

As with any carnivorous fish, the wild eels are physiologically well adapted to withstand prolonged periods of feed deprivation. However, on farms any change in the daily feeding routine will be to some extent stressful to the fish and is avoided if possible. Fish are normally deprived of feed for a few days prior to grading or transport in order to reduce the metabolism and thus mortality. Where eels are destined for final dispatch to market, food will normally be withheld for 2 to 3 days. This is both to remove food from the gut prior to transportation and slaughter, and also to allow the metabolism and removal of molecules associated with taint.

Overfeeding, especially where demand feeders are in use, is a significant welfare issue because of the effect that wasted food disintegrating into the water column can have on the oxygen levels and water quality. Use of mechanical feeders correctly loaded for the biomass of fish avoids this risk.

6.2.3. Impact of infectious diseases on welfare

The European eel is cultured in different regions of the world (mainly Asia and Europe) under a wide range of geographic, climatic and technological conditions. As a result, there is a large group of pathogens including numerous parasites, fungi, bacteria, and viruses infecting eel and causing disease. However, in aquaculture only a few disease agents result in disease outbreaks that, amongst other signs, decrease growth or increase mortality. Commonly seen infectious diseases and their causative agents are listed in Table 3.

Table 3: Overview of selected infectious diseases in eel culture

Disease	Species	Taxon	Syndrome	Treatment
Parasitic infections	*Anguillicola crassus*	Nematode	Invades the swim bladder, sucks blood, causes changes of swim bladder wall ultrastructure	Formaldehyde (24 % - 60 ppm); Mebendazole
	Pseudodactylogyrus anguillae; *P. bini*	Monogenean	Invade the gills; respiratory distress	Formaldehyde (24 %) - 60 ppm; Mebendazole
	Trichodina spp.	Ciliate	Flashing; lethargy; increased mucus production; sometimes ulcers and frayed fins; respiratory distress if gills affected	Formaldehyde (24 %) - 60 ppm
	Ichthyophthirius multifiliis	Ciliate	White spots on body; becoming lethargic; attempt to remove parasites by rubbing on enclosure surfaces	NaCl (1 %)
Fungal infections	*Saprolegnia* spp.	Fungi	White to brown cottony or hairy patches on the skin, fins and gills; death may occur if gills obstructed;	NaCl (0.1 %)

			usually secondary infection following physical damage.	
	Dermocystidium anguillae	protozoan or fungus	Swellings on gills, fins or body	None - removal of infected eel
Bacterial infections	Red fin disease *Aeromonas hydrophila* / *Pseudomonas fluorescens*	Bacterium	Tail rot; fin rot; haemorrhagic septicaemia	Improved water quality; NaCl (0.5-0.9 %)
	Red eel pest *Listonella* (*Vibrio*) *anguillarum*/*vulnificus*	Bacterium	Red spots on ventral and lateral areas; swollen and dark skin lesions that ulcerate	Antibiotics
Viral infections	*Herpesvirus anguillae* (Red head)	Herpesvirus	Haemorrhages around the head and operculum initially; later spread to the whole body	Vaccination with infected fingerlings from preceding year; decreased temperature (18-20 °C); NaCl (0.1 %)

In this report, only selected diseases of cultured European eel are reviewed as they are considered to be of potential significance to eel welfare because of their: i) severity of effect on physiological integrity of fish; ii) known frequency of occurrence in farming systems; and iii) impact of preventive and/or curative measures.

6.2.3.1. Parasitic diseases

Representatives of almost all major systematic groups of parasites have been found in eel. Altogether 155 parasite species were described (Tesch, 1999) from eel species all over the world. As eels are transported worldwide and their parasites are usually not species specific rather than genus specific (see example *Anguillicola* spp.) all parasites occurring in and on the genus *Anguilla* must be considered. Due to their global trade most eel parasites have the same world-wide geographical distribution as their hosts.

Under intensive culture conditions, fish diseases have caused substantial problems. Usually monoxenous parasites are able to spread easily from fish to fish. Accordingly, the most important parasites are gill infections with monogeneans, *Pseudodactytogyrus* spp., and the ciliate *Ichthyophthirius multifiliis*. There is also one heteroxenous species, the nematode *Anguillicola crassus*, which frequently occurs in farmed eels, especially when eels are grown in outdoor ponds, allowing the larval stage to develop in copepods. Due to their importance for eel farming these three parasites are described in more detail in the specific sections below.

Swim bladder infection

In European eels two blood sucking nematodes occur in the swim bladder, the endemic nematode *Daniconema anguilla* and the invasive nematode *Anguillicola crassus*. The latter is a native parasite of the Japanese eel, *Anguillia japonica*, introduced in the early 1980s with infected European eels from Asia, most likely from Taiwan (Kirk, 2003). After the arrival of *A. crassus* it spread rapidly throughout Europe and is also described from North Africa and the USA, where it parasitizes the American eel. Although this nematode needs intermediate and probably paratenic hosts, it is one of the most successful parasitic colonizers worldwide causing serious damage to their host (Sures and Knopf, 2004). In eel farming *A. crassus* is usually only described for extensive outdoor ponds rather than for intensive production systems. This difference is related to the availability of necessary intermediate hosts, mainly copepods, which are less abundant in intensive production systems. Under outdoor farming conditions *A. crassus*, together with other adverse factors such as high water temperature, low oxygen concentrations and bacterial infections, can cause high mortality (Molnar et al., 1991; Barus et al., 1999). Treatment of eel against *A. crassus* is not practicable if they are maintained in outdoor ponds although application of e.g. Mebendazole help to control the infestation. In recirculation systems and intensive culture systems, both bath and feed treatment with Levamisole is possible (Schlotfeldt and Alderman, 1995).

Gill parasites

Important disease problems in eel farms are often caused by gill infections with the monogenean trematodes, *Pseudodactylogyrus* spp. Two species have been identified, namely *P. anguillae* and *P. bini* (Mellergaard and Dalsgaard, 1987). These parasites cause the most important disease problems in intensive production systems as their life cycle is very simple and does not rely on intermediate hosts. Adult worms shed eggs in which the larval stage develops. Some of these eggs will sediment in the basins whilst others are transferred with the water current to the filter. The eggs are fully developed within three to seven days at 20 °C to 25 °C and the hatched oncomiracidium infests the gills of another eel where it develops into an adult worm in 6 to 9 days (Mellergaard and Dalsgaard, 1987). Accordingly, *P. anguillae* and *P. bini* are persistent and highly pathogenic, and have proved to be very difficult to control. Even when present in small numbers in the gills the infestation has a marked impact on the food intake of eels, induces serious gill lesions, and then death. In heavily infected adult eels up to 700 worms were counted in one eel (Mellergaard and Dalsgaard, 1987). *Pseudodactylogyrus* spp. infections are treated with formaldehyde, in a concentration of 60 mg/l. The treatment is carried out four to five times at 2 to 3 day intervals as eggs with the developing larvae are not affected by the treatment. Formaldehyde treatment is not able to eliminate the parasite problem but may reduce it to a level at which normal production can be carried on.

White Spot (*Ichthyophthirius multifiliis*) Disease

Ichthyophthirius multifiliis is a non-specific ciliated protozoan which causes "white spot disease." This disease is a major problem to freshwater fish producers, worldwide. The disease is highly contagious and spreads rapidly from one fish to another. It can be particularly severe when fish are crowded. While many protozoans reproduce by simple division, a single *I. multifiliis* can multiply into more than a thousand new parasites. This organism is an obligate fish parasite which means that it cannot survive unless live fish are present. It is capable of causing very high mortalities within a short period of time. An outbreak of *I. multifiliis* requires immediate treatment as if left untreated this disease may result in 100 % mortality. It can be easily seen by the presence of small white spots on the skin (or gills). Prior to the appearance of white spots, fish may show signs of irritation, flashing, weakness, loss of appetite, and decreased activity. In order to prevent a disease outbreak, incoming fish should be quarantined. Chemical treatment of the disease will mainly kill free-swimming stages (tomites) which have emerged from cysts and have not yet burrowed into the skin of host fish. Accordingly, the treatment has to be repeated. For indoor systems formalin or salt should be applied to treat *I. multifiliis*.

There is the wider issue of how the control of external parasites (*I. multifiliis* and *Pseudodactylogyrus* spp.) will be managed when the ban on the use of formaldehyde solution in agriculture is implemented.

Trichodina sp.

In the wild, trichodines may occasionally occur on fish without showing clinical effects. Usually the appearance of trichodines on fish is positively associated with the trophic status of the water as they mainly feed on bacteria which are more abundant under eutrophic conditions (Palm and Dobberstein, 1999). Under intensive aquaculture conditions the ciliates may proliferate massively and have been reported to cause pathology in fish (Mellergaard and Dalsgaard, 1987; Madsen et al., 2000). Infected eels showed signs similar to those observed in *Pseudodactylogyrus* spp. infections, with haemorrhages in the mandibular and gill region and severely hyperaemic gills with increased mucus secretion. For chemical treatment of *Trichodina* sp. formaldehyde at a concentration of 20-60 mg/l can be applied. As *Trichodina* sp. reproduces only by division and does not build cysts a single treatment is sufficient.

6.2.3.2. Bacterial diseases:

Infections with *Aeromonas hydrophila* are occasionally observed but usually never reach epidemic levels. Outbreaks are often associated with poor water quality or shortly after the fish have been graded. Improvement of the environmental factors normally solves the problem. In some cases addition of salt to a concentration of 0.5-0.9 % seems to solve the problem (Mellergaard and Dalsgaard, 1987).

Vibriosis of *A. anguilla*, was the first infectious fish disease to be described, from the Camachio Lagoon, Italy by Bonaveri, in 1718 (Canestrini, 1893). *Listonella* (*Vibrio*) *anguillarum*, the commonest species involved is a halophilic Gram-negative bacillus which causes typical signs of haemorrhagic septicaemia. Once established, the disease spreads rapidly through the population, usually when the fish have been stressed by high temperatures or traumatic handling. It is characterised by severe myo-necrosis and erosion of fins, head or tail, often with haemorrhagic enteritis and bleeding from the vent (Roberts, 2001). *Vibrio vulnificus* is an emerging pathogen even where salinities are lower then 0.3 %. There are reports that this bacterium, which has zoonotic significance, is now adapted to a freshwater environment (Fouz et al., 2006). It causes high mortalities in non-vaccinated eels and is a serious welfare issue as the lesions develop over a significant period (Biosca et al., 1991). Multivalent vaccines are available and licensed in Europe and often a combination of early oral vaccination followed by immersion vaccination when the eel are more able to accept the handling trauma involved may be used (Fouz et al., 201). Obvious clinical signs of diseased eels were bleeding ventral ulcers together with haemorrhagic intestine and blood in the faeces (Fouz *et al*., 2006).

6.2.3.3. Viral diseases

Viral diseases are of growing importance for eel farming as fish viruses can cause disease or even mortality when fish are under stressful conditions The main viruses occurring in eel farms are the rhabdoviruses EVEX (Eel-Virus-European-X), and EVA (Eel-Virus-America), the birnaviridae EVE (Eel Virus European), and the herpes virus HVA (*Herpesvirus anguillae*) (van Ginneken *et al*., 2004; Dipnet, 2007 for review). Among the viruses HVA particularly is widely distributed in eels and is causing significant disease problems (van Nieuwstadt et al., 2001; van Ginneken *et al*., 2004). The disease is characterised, among other signs, by ecchymoses in the pectoral fins, operculae and head, ulcerative skin, and congested gill epithelium (Haenen et al., 2002). This virus can be isolated from many intensive production units even though clinical signs are not obvious (Nieuwstadt et al., 2001). Morbidity is reported as usually high and mortality range from 0.5 to 10 % (Haenen et al., 2002). Percentages of up to 50 % have been reported under stress situation. It can be severe in a naive population and recurrent outbreaks in infected populations continue to be a serious source of economic loss due to depressed appetite and mortality. Glass eels have been exposed to experimental autogenous vaccines as a bath with some success. Current practice is to expose juvenile population to the latent infection of the resident population early in the growing phase. This induces disease in the glass eels, and a mortality which can vary between 2 and up to 25 %. Survivors are more or less protected from further infection with HVA (Haenen, unpublished data in Dipnet, 2007, Wood, pers.comm.).

6.2.4. Impact of disease control measures on welfare

When eel culture was essentially an extensive industry, the use of veterinary medicines was not a practical option. As the industry grew into an intensive production system, the process of eel farming allowed treatments. These are generally with products that are not licensed specifically for eels, but used under the cascade system or other arrangements. Used carefully, medicinal treatments can be of value and assist in maintaining good welfare.

6.2.4.1. Treatments

As a general rule, efficacious treatment of stock in extensive systems is not practical because of lack of control in food intake, quantities of medicine to use, risk of re-contamination. In intensive systems, where the production system enables treatment, the limiting factor is the lack of availability of licensed therapeutics and approved products. Also the management of recirculation systems, and particularly the filters, often restricts the way in which therapeutics can be used.

The following treatments and their known potential effects are relevant to intensive systems (Table 5).

Solution of formaldehyde 38 % may be applied in bath procedure at 20 ppm for consecutive days, up to 10, with low impact on fish. In a bath at 150 ppm, for 2 hours, the impact is still moderate and low mortality is expected. Degradation of water quality due to impact of the chemical on biological filter is usually low. Salt (NaCl) at concentration of 5 to 10 ppt lowers risk of *Vibrio* disease.

Table 4: Selected examples of chemical treatments against infectious diseases of eels

Purpose	Treatment	Application	Comment
Trichodina	Formaldehyde 38 % solution	Single bath 20 ppm	Control good
Ichthyophthirius	Formaldehyde 38 % solution	Consecutive baths over 10 days. 20 ppm. Combined with salt up to 10 ppt	Control good
Gyrodactylus	Formaldehyde 38 % solution	Single bath 40 ppm	Control moderate
Pseudodactylogyrus	Mebendazole/Flubendazole Formaldehyde 38 % solution	- -	Treatment not effective. Drug resistance Treatment not effective
Anguillicola	Formaldehyde (24 %) Mebendazole	- -	- -
Vibrio Aeromonas	Florfenicol Oxytetracycline Flumequin	Oral Oral or Bath -	- - -

6.2.4.2. Vaccines

Currently juvenile eels are deliberately exposed to water contaminated with *Herpesvirus anguillae* (HVA) in order to induce an infection which (while causing some welfare issues and some mortality, 2 to 25 %) will allow them to develop a natural resistance to meeting the infection at the most vulnerable fast growing stage (see section 6.2.3.3). As well as causing often significant mortalities, this process causes a significant drop in food intake and growth rate but is considered the lesser evil by the industry at present in the absence of an approved commercial vaccine.

Bacterial vaccines (immersion, oral) exist against the *Vibrio* pathogens of eels and can be used under the present cascade mechanism. According to current veterinary experience, vaccines appear to work well. The immersion vaccines which require high concentration of antigen in limited water volumes can lead to stress due to overcrowding foaming of the water, demucination and result in reduction of feeding. The oral vaccines have no associated significant welfare issues although efficacy may not be so high.

6.3. Husbandry and management

6.3.1. Stocking densities

The optimal stocking density is, to a large extent, dependent upon the production system in use the technical specification of the system (water flows/available oxygenation) and the life-stage of the eel being cultured. The stocking densities in intensive systems are generally expressed on a cubic area base and extensive systems on a bottom surface area.

The figures illustrated are not specific recommendations but are only indications of densities that have been observed at stages of the production cycle. Although, stocking density impact on sex ratio is documented (see section 3), the working group has found no published evidence that these stocking levels compromise welfare.

Table 5: Typical fish densities on eel farms at different stages of their life[10].

Life stage	Density
Glass eels	5-10 kg/m^3
Eels of 5-25 g	150 kg/m^3
Eels > 150 g	250 kg/m^3

It is possible that greater stocking densities can be achieved with higher water flows and oxygen saturation levels in some intensive systems. It is well recognised that very low stocking densities are counter productive in terms of behaviour and are likely to encourage the establishment of territorial behaviour and hierarchies (Tesch, 1999).

6.3.2. Handling

Nets cause abrasion and secondary infections especially where tails get stuck within the mesh. Eels are ideally handled with the minimum of water and are either piped or pumped out of the system without the use of nets.

<u>Sorting and Grading</u>

[10] Tesch, 1999

Individual eels within a population under farmed conditions show a marked disparity of growth rates, unless graded, and this can lead to large differentials in size. In an unmanaged year class the difference in size of the individuals from the smallest to the largest eel could range from 0.5 g to over 500 g. Populations with marked differences in size have poor growth rates and a significant problem of cannibalism is often observed.

For intensive systems grading is essential to control these problems. For extensive systems with lower stocking densities the problems of differential growth and cannibalism are not so marked. While grading is possible it is much more difficult due to operational constraints such as harvesting and handling.

Prior to grading food will be withdrawn at least for a day.

During the process of grading, the eels can be held at high densities leading to low concentrations of oxygen. Eels may in some instances be transferred to the grading machine by hand netting. This is considered to be a welfare issue as they may be exposed to the risks of damage or injury to the body. However, in most farms this risk is negated by the use of on line pipes or fish pumps which keep the fish within water except for the short period when they go passively through the grader. Grading is in itself a factor affecting welfare but needs to be carried out to avoid cannibalism and reduced feed intake, and has to be carried out carefully to preserve good welfare.

Fish pumps

Expert opinion is that the movement of eels using air lift pumps or pumps using oscillating positive and negative pressure in a chamber are preferable to centrifugal pumps with recessed impellers. It has been observed that eels passing through centrifugal pumps appear to be disorientated and ataxic.

Nets and netting

Hand netting can cause particularly serious injuries to eels given the almost prehensile use they make of their tail. Nets can be abrasive and, moreover, the tails of the eels can become trapped and damaged depending upon the size of the mesh used. Hand nets should be fabricated from knotless netting utilizing a mesh size that is small enough to prevent the passage of tails.

Capture net damage is a particularly significant factor that causes post-capture mortalities in trawled glass eels (discussed previously). In the eel, the caudal sinus is a particularly important blood vascular structure which lies relatively superficially in the area of the tail and acts as a second heart helping to pump blood back along the length of the eel (Tesch, 1999). Therefore damaged tail tissue can readily compromise the sinus integrity both by direct damage to its function and also by secondary infection which will rapidly disseminate.

7. Risk assessment approach to welfare of European eel

7.1. Introduction

Poor animal welfare problems are generally the consequence of, *inter alia*, poor management, inappropriate environmental conditions, disease and interactions thereof. At present there are no standards for animal welfare risk assessment, but previous studies exist where risk assessment for animal welfare has been explored (Anonymous, 2001; EFSA, 2006). In this section, the application of risk assessment to the study of the welfare for the European eel is described.

Risk assessment is a systematic, scientific-based process to estimate the magnitude of and exposure to a hazard and includes 4 steps: hazard identification; hazard characterisation; exposure assessment and risk characterisation. In food risk assessment terminology (*Codex alimentarius*), a hazard is a biological, chemical or physical agent in, or condition of, food with the potential to cause an adverse health effect. The risk is a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard(s) in food.

Making a parallel to the *Codex alimentarius* risk assessment methodology, a hazard in animal welfare risk assessment is a factor with a potential to cause a negative animal welfare effect (adverse effect).

A risk in animal welfare is a function of the probability of occurrence and the consequences of occurrence. Four parameters were scored to assess the importance of a hazard:

1. the probability of a given target population to be exposed to a particular hazard has been scored as <u>frequency of occurrence of the hazard</u>;
2. the <u>proportion of the population affected</u>;
3. the consequences of exposure have been scored by <u>severity of the effect</u> in the individual; and
4. the <u>duration of the effect</u>.

While hazards usually relate to negative welfare impacts, the risk assessment approach could be also extended to include positive welfare consequences (resulting in risk-benefit analysis). Factors which may result in improved welfare were not considered in this analysis.

The degree of confidence in the final estimation of risk depends on the uncertainty and variability.

Information obtained from epidemiological, experimental, and laboratory animal studies have a level of uncertainty, related to, *inter alia*, the number of animals used, frequency of observations and the test characteristics. Uncertainty is increased when results are extrapolated from one situation to another (e.g. from experimental to field situations). Uncertainty also arises from incomplete knowledge. Uncertainty can be evaluated (and reduced) by carrying out further studies to obtain the necessary data or quasi-formally by using expert opinion or by simply making a judgment.

Variability is a biological phenomenon (inherent dispersion) and is not reducible. The importance of welfare hazards will inevitably vary between farms and countries and over time. Reduction in variability is not an improvement in knowledge but instead reflects a loss of information. However, it is not always easy to separate variability from uncertainty. Uncertainty combined with variability is generally referred as total uncertainty.

The methodology described in this section was based on the approach used in the previous EFSA scientific reports on welfare of fish, Atlantic salmon and trout (EFSA-Q-2006-033 and EFSA-Q-2006-147). However, for this report a slightly different approach was adopted concentrating on the most important factors. Certain hazards were only described in the text whereas for the ones considered by the working group experts as the most important a semi quantitative risk assessment was carried out based on expert opinion.

The final risk score used duration of the effect of the hazard, while in the previous reports duration of the hazard and duration of effect were used. In the present report, duration of the effect was scored as a proportion of the time span of the life stage under consideration (e.g. if the life-stage lasts 60 days and the effect of the hazard persists for 10 days the score was 1/6). In the previous fish welfare reports the denominator used was the total remaining life potential lifespan after the hazard occurred. It is therefore not appropriate to use the final risk scores to make comparisons of the importance of hazards between species.

7.2. Steps of risk assessment

For risk assessment of welfare of European eel the different production systems, as well as the different life stages were identified.

The different life stages we used were glass eels, juveniles, ongrowers and marketable. The different production systems vary depending on the life stage and are summarized in Table 2.

7.3. Hazard identification

The aim of this step is to identify causes or factors that affect animal needs and that have a potential to change the animals welfare. Although both negative and positive changes can be accessed only negative hazards were considered.

Factors potentially affecting the welfare of eel were discussed and this information was used to identify potential hazards. A list of potential categories of hazards to fish welfare and health of eel was drawn up with reference to the different life stages of the fish as well as to the different types of production systems. Only factors that were identified by the working group as the most critical from the point of view of welfare were subjected to risk assessment. These critical hazards are: netting, storage and handling of glass eels, feeding, diseases and handling of juveniles, pH, ammonia, diseases and handling of on-growers, and temperature, fasting and handling of marketable fish.

Different factors that may affect the welfare of farmed fish are for example, water temperature and stocking density. These factors may also more broadly be described as conditions that may have a direct impact on the welfare and health of eel. Subsequently, hazard (a detrimental factor) identification (clinical signs and physiological changes), its character, and the consequences of it occurring, are all important issues to be taken into account when making a risk assessment.

The list of potential hazards was established by the working group. The tables (appended to this report) were designed to cover the four stages of the risk assessment: hazard specification, hazard characterisation and exposure assessment.

Hazards may directly affect an animal or indirectly by changing the animals' environment which can also lead to animal welfare problems. The tables concentrate on single factors without interactions and only address the potential negative effects of identified factors. However, since production factors can interact and welfare problems are generally due to multiple exposures to different factors, any positive or negative interactions with other factors should be reviewed. Interactions and positive effects are described in the text if deemed necessary.

7.4. Hazard characterization

The objectives of this step are:

1. to examine and describe the consequences of an exposure to a hazard; and
2. to assess the relationship between the level of the hazard in terms of frequency and duration and the likelihood and magnitude of the adverse effect occurring at population level.

The severity of the adverse effect caused by the hazard is described and scored in the following ways. The score was based on scientific evidence of the level of physiological and behavioural responses.

Table 6. **Severity of adverse effect**

Evaluation	Score	Explanation
Limited	1	No or limited pain, malaise, frustration, fear or anxiety as evidenced by measures of the normal range of behavioural observations, physiological measures and clinical signs for >95 % of the species or strain/breed
Moderate	2	Moderate changes from normality and indicative of pain, malaise, fear or anxiety
Severe	3	Substantial changes from normality and indicative of pain, malaise, fear or anxiety.
Very severe	4	Extreme changes from normality and indicative of pain, malaise, fear or anxiety, that if persist would be incompatible with life.

A hazard is not only described by the severity of its adverse effect, but the proportion of the population affected.

Table 7. **Likelihood of effect (proportion of population affected)**

Evaluation	Score	% of population affected by the hazard
Very low	1	1-20
Low	2	21-40
Moderate	3	41-60
High	4	61-80
Very High	5	81-100

The duration of the adverse effect, i.e. the consequences of the hazard, were assessed in days and converted to a proportion of the life stage when the hazard occurred for the calculation of the final score.

A problem in scoring the “duration of adverse effect” arises when the animal dies as a consequence of a particular hazard. Death may not be considered as a primary welfare problem. If the adverse effect is fatal then the duration of the adverse effect in the period before the effect causes mortality is the key welfare issue. However, the population level of mortality might indicate a welfare problem.

7.5. Exposure Assessment

Exposure was scored as the frequency of occurrence of a hazard during the life stage of the fish (Table 9).

Table 8. **Frequency of exposure**

Evaluation	Score	Explanation
Extremely low	1	The exposure would be extremely unlikely to occur
Very low	2	The exposure would be very unlikely to occur
Low	3	The exposure would be unlikely to occur
Moderate	4	The exposure would occur with an even probability
High	5	The exposure would be very likely to occur

7.6. Uncertainty

The uncertainty value is an indication of the information is indicating the type of information available, that is whether there are different studies with differing conclusions, but also whether scientific information, published or unpublished, is available. A single combined uncertainty score (low, medium and high - Table 9) was given for the overall uncertainty of all the parameters.

Table 9. **Uncertainty score**

Score	Evaluation	Explanation
1	Low	Solid and complete data available; strong evidence in multiple references with most authors coming to the same conclusions
2	Medium	Some or only incomplete data available; evidence provided in small number of references; authors' conclusions vary from one to the other; Solid and complete data available from other species which can be extrapolated to the species considered
3	Max	Scarce or no data available; evidence provided in unpublished reports, or based on observation or personal communications; authors' conclusions vary considerably between them

7.7. Scoring process

Experts were asked individually to complete the risk tables for each hazard in each life stage. For some life stages, separate tables for different production systems needed to be completed. The scoring was based on current scientific knowledge, published data, field observation and experience of eel farming. In general, a single expert initially completed tables for groups of hazards, and the results discussed and adjusted during a group discussion.

7.8. Risk characterization

Risk characterisation integrates hazard characterisation and exposure assessment into a risk score. In the case of the fish welfare risk assessment that included a semi-quantitative risk score for each life stage in all of the production systems employed during this life stage.

This step aims to estimate the likelihood of occurrence of the adverse effect in a specific production system at a specific life stage of the fish. It aims to give information to the risk manager to evaluate a specific situation regarding maximising good welfare. The risk estimate was calculated for each hazard, and expresses its animal welfare burden in the considered population.

Risk score = (severity)*(duration of effect)*(proportion of the population affected)*(frequency of hazard)

The scores of frequency of hazard, severity and likelihood of effect were standardized to give even weighting to the scores (frequency of hazard /5; severity / 4 and likelihood of hazard / 5). The risk score was multiplied by 100 to make it easier to read.

This formula assumes the following:

- linearity of the severity scores (2 days suffering from a score 2 effect is equivalent as 1 day suffering from a score 4 effect)
- no interactions between the hazards
- that the hazards are mutually exclusive

Because the previous assumptions are not verified the risk scores have to be interpreted with caution. Secondly, the risk scoring is semi-quantitative. Thus the scores allow a ranking but do not give meaningful absolute figures (e.g. a risk score of 12 should not interpreted as being twice as important as a hazard with a score of 6).

Uncertainty scores could not be used in the risk estimate directly but are provided in the tables as an indication of the robustness of the ranking. The score may also be used to highlight areas where further research is needed to improve the certainty of the scientific data.

The risk assessment allows the relative importance of hazards in the same life stage to be assessed. Comparisons have been made between hazards in different production systems for the same life stage.

7.9. Results and discussion

7.9.1. Glass eels

The different capture methods for glass eels (active trawling, and fixed nets) have been considered as separate production systems to allow for comparison. This life stage also includes a quarantine period referred to as post-capture storage.

Trawling and fixed nets in high currents have the following hazards, all of which received high scores:

- skin damage incurred at capture – osmo-regulatory failure within 7-10 days
- tail damage incurred at capture - damage to the caudal sinus, secondary infections
- stress, demucinisation during storage (post capture)
- stress, skin damage, demucinisation during handling (post capture)

These hazards have high scores because they occur frequently (if not invariably), affect a high proportion of the populations and are severe (severity score = 3 or 4). Inappropriate handling post capture has the highest score because the duration of the effect (skin damage and demucinisation) lasts up to 20 days (time when all affected individuals would eventually die). The damage caused to the tail results in a very high degree of mortality (however, this does not account for the high hazard score that is attributable to the effect on the eels prior to death). It is only noticed 48 hours after capture. It should also be noted that trawling results in high mortality within the first hour after capture (which has a low hazard score due to short duration of the effect). Mortality that occurs at capture (mainly due to crushing) can be considerable (order of magnitude around 50 % within a few hours following capture) but is not considered as a welfare issue in this analysis.

There can be an adverse synergistic effect of poor storage conditions following stress caused by poor capture methods which cannot be captured by the risk assessment method. Poor storage leads to exposure to air, adverse water quality, confinement leading to loss of mucous and stress. Eels are held in the storage buckets for approximately 4 hours after capture.

Low current fixed nets and hand netting resulted in two significant hazards post-capture:

- stress, demucinisation during storage
- stress, skin damage, demucinisation during handling

These hazards received the same score across all capture methods. Skin and tail damage may also result from low current fixed netting but with a lower frequency (frequency score = 1).

Table 10. Glass eel hazards ranking

trawling	fixed netting/trapp - high current	Glass-eels fixed netting/trapp - low current	Glass-eels hand netting
inappropriate handling,	inappropriate handling	inappropriate handling,	inappropriate handling
sourcing trawling (tail damage - damage caudal sinus)	sourcing fixed netting/trapp - high current (tail damage - damage caudal sinus)	storge	storge
sourcing trawling (skin damage)	sourcing fixed netting/trapp - high current (skin damage)	sourcing fixed netting/trapp - low current (tail damage) s	
storge	storge	sourcing fixed netting/trapp - low current (skin damage)	
sourcing trawling (physical damage - death in 1h)	sourcing fixed netting/trapp - high current(physical damage, death in 1h)	sourcing fixed netting/trapp - low current (physical damage, death in 1h)	

7.9.2. Juveniles

For this, only intensive production system was considered as it is currently the most dominant farming system in Europe. Extensive farming contribution to the European production is becoming anecdotal.

The identified hazards are weaning, artificial food training, parasitic infections and disease management methods (exposure to herpesvirus).

Infection with *Pseudodactylogyrus* ranked high as a hazard because it occurs frequently (80% of farms), affects a large proportion of the population for a long period and with severe effects. Control methods have low effectiveness. In addition, the parasite also causes a high level of mortality.

Another high ranked hazard is also disease-related. At this life stage farmers expose eels to herpesvirus (to avoid losses later in production). Infection results in stress, poor feeding and other clinical signs in a majority of the population (it had a severity score = 3), albeit with low mortality (< 20 %). Other external parasites, handling, water quality parameters also ranked relatively highly. Other ecto-parasites are generally managed effectively under normal conditions.

Ineffective weaning and artificial food training received a relatively low score because only a small minority of farms were affected and on these farms <40 % of the eels starve post weaning. Nevertheless the hazard is severe, prolonged and results in death in the eels affected.

Handling was another highly ranked hazard. Handling juveniles will cause stress, skin damage and demucinisation. As the fish at this stage are relatively robust the severity score given was low (severity score = 1).

Table 11. **Juveniles hazards ranking**

Juveniles
external parasites - Dactylogyrus
disease management practice – herpes virus exposure
handling
external parasites
low pH, high pH/Ammonia
uneffecitive weaning and artificial food training
Vibrio
Fungal infections, Aeromonas
rapid increase water temperature

7.9.3. On-growers

This stage lasts for 18 months. In accordance with the statement in the previous section (7.9.4), only intensive system was considered in this analysis.

Pseudodactylogyrus remains a significant problem during this life-stage but is less severe compared with the juvenile stage. It nevertheless remains a highly ranked hazard for on-growers. Other diseases are also highly ranked hazards, e.g. vibriosis and herpesvirus infection. Herpesvirus is present on all farms, however disease occurs on about 50 % of farms (where exposure of juveniles did not result in a sufficiently high level of 'herd immunity'). When outbreaks occur most eels are affected, and high mortalities can occur. The disease is exacerbated by poor environmental conditions.

Table 12. **On-growers hazards ranking**

On-growers
external parasites - Dactylogyrus
herpes virus disease
handling
Vibrio
low pH, high pH/Ammonia

external parasites
Aeromonas

7.9.4. Marketable fish

Fish are moved into marketing tanks for a few days before being sold. Three hazards were identified: handling, fasting and a rapid reduction in temperature. Handling at this stage is significantly reduced as eels have been graded prior to reaching marketable size. Eels are generally fasted during this period for 2 days; they need to be fasted for longer (5 days) if there is a problem with taint. They are kept at a cooler temperature during this period. There is a sudden drop in water temperature which is known to be stressful, behavioural changes are seen. This is the most important hazard identified for this life stage, attributable to its higher severity compared with the other two hazards.

Table 13. **Marketable fish hazards ranking**

Marketable fish
rapid temperate reduction
fasting
handling

7.9.5. Discussion

Two main categories of hazards stand out from our risk assessment analysis: those associated with the capture methods and those with infectious diseases, notably *Pseudodactylogyrus* and herpesvirus.

The capture method is critical to the health and productivity of eels in aquaculture. Trawling (as currently practised) and fixed nets in strong currents result in a high level of stress and trauma resulting in subsequent mortality both acutely and over the next 20 days. An obvious solution is to amend the current capture practices to reduce their impact on the welfare of eels, or to use capture methods identified as having fewer, less severe hazards associated with them. Two post-capture hazards were identified associated with storage and handling. Improved storage methods would be relatively easily implemented with significant improvements in both welfare and survival.

The hazards associated with diseases were identified as serious welfare related issues. Current control methods are at best only partially successful under current farming methods. Research is needed to develop improved control strategies. In the absence of a vaccine, exposure of juveniles to herpesvirus is the most effective method of controlling disease (if not infection). Nevertheless, this practice was a highly ranked hazard for juveniles. Again, research is required to develop a vaccine and other control methods.

Other hazards are arguably amenable to improved management. Most farmers successfully wean juveniles onto proprietary feed, so presumably best practice would improve the problem on affected farms. Inappropriate handling occurs at all life-stages. It leads to loss of mucous, stress and skin damage. Handling occurs frequently during the production period and was a relatively highly ranked hazard in a number of life-stages. Better handling methods, and a reduction in handling especially of juveniles, promoted through codes of practice, may therefore improve eel welfare.

There are very few welfare issues for eels at the marketable stage; one of them being the sudden drop in water temperature as they enter the marketable phase. Practices should be employed to ensure that the temperature change is gradual.

A number of the identified hazards can be reduced significantly through changes in capture method or management. Research is required before significant improvements in the disease related hazards could be realised.

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GLOSSARY / ABBREVIATIONS

Glossary

Broodstock	Population of fish selected to provide genetic material for the next generation. In a modern breeding programme, broodstock populations are selected and isolated at the egg stage and grown through all the life stages separately from production stocks. Broodstock are maintained beyond the end of the ongrowing stage in order to reach sexual maturity.
Benthic	Organisms which live on, in, or near the seabed, are also known as benthic organisms.
Catadromous	Catadromous fish live in fresh water, breed in the sea.
Degree days	Average temperature in degree centigrade multiplied by the number of days.
Demucinisation	Loss of the mucous layer that covers and protect the body surface of eels
Glass eels	All stages before entering the farming process
Harvest	Harvest, in the context of eel farming, means destocking for the purpose of transfer of fish to another pond or facility or to market.
Heteroxenous	Requiring more than one host to complete the life cycle. Heteroxenous is usually opposed to monoxenous.
Hypercapnia	A condition with elevated carbon dioxide consentration in the water.
Hyperoxia	A condition with oxygen saturation above 100 % of the normal atmospheric equilibrium for a given temperature and salinity.
Hypoxia	A condition with low oxygen saturation in the water.
Juvenile	Early life stage of fish from 4 to 16 weeks approximately, beginning from glass-eel to on-grower.
Lacustrine	Lacustrine, in ichthyology, describes a population of fish which complete the bulk of their life cycle within lakes.
Paratenic	An intermediate host whose presence may be required for the completion of a parasite's life cycle but in which no development of the parasite occurs.
Panmictic	Panmixia usually refers to random mating within a breeding population. In a panmictic population all individuals are potential partners (no mating restrictions, neither genetic nor behavioural).
Riverine	Relating to a river or a river system.
Starvation	A period of food deprivation such that the animal metabolises tissues that are not food reserves but are functional tissues.
Stocking density	The number of fish per unit volume of water. This term is the reciprocal of the space allowance (the volume of water occupied per fish).
Silver eel	European eel ready for migration to the sea.
Sympatric	Sympatry is one of four theoretical models for the phenomenon of speciation. Sympatric speciation is the genetic divergence of various populations inhabiting the same geographic region, such that those populations become different species.
Thigmotaxis	Need of eels to have mechanical contact with their environment during sleep.
Trophic level	Eutrophic waters are rich in mineral and organic nutrients that promote proliferation of algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms. The trophic level reflects the degree of deterioration of the life-supporting qualities of waters, caused by excessive fertilization from effluents high in phosphorus, nitrogen, and organic growth substances.
Yellow eel	European eel in fresh water.

Abbreviations

ALOP	Appropriate Level of Protection
ALOR	Acceptable Level of Risk
DNA	Deoxyribonucleic Acid
EIFAC	European Inland Fisheries Advisory Commission
EU	European Union
FAO	Food and Agriculture Organisation of the UN
ICES	International Council for the Exploitation of the Sea
IRA	Import Risk Analysis
MT	Metric Tons
OIE	World Organization for Animal Health
PCR	Polymerase Chain Reaction
PPT	Part per Thousands
RNA	Ribonucleic Acid
MWP	Minimum Withdrawal Period
MRL	Maximum Residual Level

Animal welfare aspects of husbandry systems for European Eel [1]

MINORITY OPINION

This minority opinion from Prof. Donald M. Broom is based on the view that the accepted Report and adopted Opinion are incomplete and that in order to answer the mandate from the European Commission, the introductory chapters on the welfare, biological functioning and farming of fish should be included.

MINORITY OPINION

[1] For citation purposes: Scientific Opinion of the Panel on Animal Health and Welfare on a request from the European Commission on Animal Welfare Aspects of Husbandry Systems for Farmed European Eel. *The EFSA Journal (2008) 809,* Annex II, *1-19*

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SUMMARY

Fish are very diverse in their body form and have a wide range of sensory systems, some of which, such as electroreceptors and the lateral line system, are not shared by birds and mammals. As vertebrates, fish, birds and mammals share a similar general brain structure. Over and above this, however, comparative neuroanatomy highlights many differences among vertebrate groups; it also highlights differences in brain structure among species of fish. On the other hand, studies of brain function suggest a number of parallels between fish and other groups. Fish have nociceptors and these look like and have a similar response profile to those of birds and mammals. The question of whether fish experience the input of these receptors as pain remains controversial but experiments have shown the brain is active during such stimulation and that painkillers reduce prolonged behavioural and physiological responses. It is clear that the responses given by fish to nociceptive stimulation are more complex than simple reflexes, including significant shifts in behavioural priorities and the performance of anomalous behaviour. In this context, our working position is that juvenile and adult fish have the capacity to perceive painful stimuli and experience at least some of the adverse affective states that we associate with pain in mammals. Data suggest that the affective state of fear sometimes motivates behaviour in fish. The systems in mammals and birds that result in the production of adrenaline and cortisol have close anatomical and functional parallels in fish. Fish show physiologically and behaviourally similar freeze and flight responses and prolonged cortisol production is associated with immunosuppression.

WELFARE CONCEPTS

Attitudes to animal welfare encompass three aspects: what animals feel or experience; how animals are functioning; and how the subject animals compare with their 'natural' wild counterparts (Fraser, 1999) and these influence how animal welfare is understood. Feelings and experiences are part of animal functioning and have effects that may be assessed. However, observations on animals in the wild are not involved in welfare assessment, but give a guide as to their likely functioning when removed from the environment in which they have evolved.

Welfare is a characteristic of an individual animal and is concerned with the effects of all aspects of its genotype and environment on the individual (Duncan 1981). Broom (1986) defines welfare as follows: "the welfare of an animal is its state as regards its attempts to cope with its environment". According to this definition, an animal's welfare depends on the ease or difficulty of coping and also the extent of any failure to cope, which may lead to disease and injury. Furthermore, welfare also includes pleasurable mental states and unpleasant states such as pain, fear and frustration (Duncan 1996, Fraser and Duncan 1998). Such feelings cannot be measured directly but may be inferred from measurements of physiology and behaviour and are a component of coping systems (Cabanac 1979, Broom 1998, Panksepp 1998).

Whenever animals are overtaxed by environmental impacts, welfare is poor to some degree and aspect of animal welfare (MacIntyre et al., 2008).

When considering fish, application of these welfare concepts appear more difficult to develop and require specific consideration. There are several reasons for this. First, there is less knowledge of basic biology particularly of brain functioning in relation to awareness of pain and fear then for mammals or birds (Rose, 2002).._Fish are poikilothermic animals which live in an aquatic environment. Environmental factors have a major impact on fish biology and coping with environmental changes is a major task for fish. There are many publications, on the impact of external factors on fish physiology and behaviour: Such biological knowledge is a valuable source of information when assessing fish welfare (Iwama, 2007). In this context, the concept of 'needs' is central to discussions of animal welfare. The needs can be fulfilled by

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physiological changes and by carrying out certain behaviours. Such behavioural requirements are more difficult to evaluate as sophisticated experimental evidence is required to determine their strength (Hughes & Duncan 1988, Jensen & Toates 1993, Broom and Johnson 1993, Vestergaard 1996). Such experiments have rarely been conducted in fish even though a failure to meet such needs in some way may contribute to poor welfare.

Where welfare or health are referred to as good in this report, these words imply a state that is positive for an individual and by implication for the population as a whole, Where welfare or health are referred to as poor, a negative state is implied. The following sections will deal with the major recognisable adverse states in the fish species being studied with a review of the available scientific data and its interpretation.

CONCLUSION

The concept of welfare is relevant to all farmed animals, including farmed fish, and some aspects of fish welfare can be scientifically assessed. However, although the same methodology is relevant in studying the welfare of fish, birds and mammals, much less research has been carried out on fish.

WELFARE ASSESSMENT IN FISH

The scientific assessment of welfare is discussed by Huntingford *et al.*(2006) and and FSBI (2002).. Welfare assessment may be based upon a list of needs, for example measuring the hazards associated with the non-fulfilment of these needs. It may be assessed in various ways. Poor welfare can be assessed by how far an individual animal has deviated from what is normal for animals in a good environment (Morton and Griffiths, 1985), i.e. one that meets all of their needs. Normality is not necessarily that which is natural for wild fish and an assessment of deviation from normality must be based upon baseline studies of farmed fish in a satisfactory environment., taking into account their previous experiences e.g. (specific) rearing environment. To understand, compare and develop actions to improve fish welfare, defined protocols of welfare measures or indicators are needed.

Some welfare research involves measuring direct indicators of poor or good welfare while other research evaluates what is important to animals by studies demonstrating positive preferences and motivation (Dawkins 1990) and also aversion i.e. negative preferences and how hard an animal will work to avoid, as opposed to access, an environmental variable. Some such work on preferences and motivation has been conducted with fish, but there is not a large amount of data on these issues. Measures of physiological functioning, productivity, health and pathology and behaviour all form the basis of welfare assessment. As an example, measuring disease resistance or the functioning of the immune system offers one way of estimating the welfare "cost" of certain aquaculture conditions. Compromised immune performance can lead to disease outbreaks with associated direct negative welfare consequences. Moreover, lowered disease resistance is generally believed to be a consequence of maladaptive physiological stress, and disease challenge testing may therefore also be an indirect measure of such stress conditions.

Due to the complex causal relationships among the various needs of farmed fish and their behavioural and physiological consequences, it is impossible to find one single measurement or welfare indicator that will cover all possible welfare relevant effects of all possible rearing systems, farmed species and potential situations. Some of the methods used and evaluation of the results will be species and system specific. When the welfare of fish or other animals is assessed, sets of measures can be used, which might be physiological (Oliveira *et al.*, 1999,

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Ellis *et al.*, 2004), behavioural or pathological (see Huntingford *et al.*, 2006). Whilst a single measure could indicate poor welfare, a range of measures will usually provide a more accurate assessment of welfare because of the variety of coping mechanisms used by the animals (Koolhaas *et al.*, 1999, Huntingford and Adams 2005) and the various effects of the environment on individuals. Useful welfare indicators must to be valid reflections of welfare and repeatable. In addition to measures, which are the outputs of good husbandry, farm practices that help to ensure good welfare provide important indirect welfare indicators, independent of the condition of the fish. Such indicators of welfare through good practice include staff training, good husbandry protocols, monitoring and biosecurity systems, health plans and contingency plans. These complement measures of welfare outcomes by indicating ways by which poor welfare can be avoided.

Indicators that do not necessarily give information about individual fish are commonly used by fish farmers to assess changes at a population level. Indeed, many fish farms have strategies for real-time monitoring of such indicators, which include feed intake, growth rate and mortality. In the case of feed intake, the indicator is not the feed intake per se, but the deviation from an expected feed intake based on biomass and water temperature. Production variables of this kind have a place in welfare assessment and a failure of fish to feed and grow often indicates poor welfare. However, high performance levels (e.g. high feed intake and good growth) do not necessarily indicate good welfare. At a population level, changes in rate of mortality may be a useful indicator of poor welfare.

Indicators at the individual level cover all measurements of individual fish in a system, either by non-invasive monitoring in free-swimming fish, or with targeted sub-sampling of fish. Examples of individual measures are fin condition and parasite load. Representative sub-samplings are difficult in large farm systems, but can work well in smaller systems. The individual indicators commonly relate to the ability of the fish to maintain a normal physiological (and possibly behavioural) state, including the ability to mount effective immune responses.

INTRODUCTION TO THE BIOLOGY AND FUNCTIONING OF FARMED FISH SPECIES

1.1. Diversity of teleost fish forms and environmental adaptations

The three major groups of fish are: Agnatha (hagfish, lampreys), Chondrichthyes (sharks, rays, sturgeons) and Actinopterygii (bony fish with teleosts being the most prevalent). Most aquaculture finfish species are teleostean fish (Evans *et al.*, 2005). There are more than twenty thousand living species of teleosts that have been evolving over 500 million years, representing every aquatic environment and a vast range of physiological and behavioural traits.

Each species has developed a set of tolerance limits for each environmental factor, and within such ranges ecological interactions are further limiting the natural distribution and habitat selection (Randall *et al.*, 2002, Helfman *et al.*, 1997). The tolerance ranges are species specific and may be wide or narrow, developing the species into opportunistic generalists or specialists designed for long-lasting natural ecological niches. Individual fish have abilities to to cope with a changing environment, including large annual changes in e.g. water temperature and food availability. As a result of such plasticity, fish have been able to inhabit every conceivable aquatic environment, from a Tibetan lake at an altitude of 5,250m to the pacific depth at –8,370m. They are also extraordinary diverse in terms of numbers of species, body forms, life-styles and physiologies. Fish genomes are more varied and plastic in comparison with other vertebrates, owing to frequent genomic changes (Cossins and Crawford, 2005).

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Teleost fish share many common morphological and physiological adaptations with other vertebrates, including many components of the neural and endocrine systems, immune system and the physiological stress cascade. However, some key systems such as the respiratory- and osmoregulatory systems differ markedly form land-living vertebrates due to the particular challenges imposed by living in water. Respiration (i.e. exchange of gases such as oxygen and carbon dioxide) takes mainly place over the gills (except in the early larval stages). The gills are also involved in uptake and excretion of ions and maintenance of osmoregulatory balance. The intimate physiological contact of all body fluid compartments and tissues through gills, skin and gastro-intestinal system with the external environment is a situation that can lead to major physiological challenges. Variations in water conditions (including oxygen levels, temperature, pathogen, salinity and water-borne pollutants) can have a direct and unavoidable impact on susceptible cells, tissues and organs. This close physiological contact is more easily defined and its impact more readily studied than in terrestrial species. Fish are sensitive sentinels of environmental challenge particularly pollution (Cossins & Crawford 2005).

Some fish species go through marked metamorphosis or habitat changes such as transfer from freshwater to sea-water that often represent critical periods with reduced capacity to withstand stressors or infectious diseases. The intimate contact with the water, including pathogens, represents a challenge in terms of barrier functions as a part of the disease defence. Breakdown of the integrity of these barriers, e.g. due to various forms of stress, may lead to increased susceptibility to infectious diseases. The development of acquired immune function often takes place after the metamorphosis from larval to juvenile form which represents a challenge on vaccination, in particular in marine farmed fish species that are exposed to a suite of pathogens from early life stages.

Fish in a natural habitat display complex swimming, feeding, anti-predator and reproductive behaviours, and such behavioural traits are linked to genotypical differences between species and individual animals, and are modified by phenotypical development and learning. In addition, several fish species undergo ontogenetic niche shifts during their lifespan, and consequent changes in behaviour, e.g. change in salmon from a territorial parr in the river to a schooling fish which migrates from freshwater to sea-water, and years later to a mature fish which migrates back to the river prior to spawning **(**McCormick *et al.*, 1998).

1.2. Environmental factors and fish physiology.

The main environmental factors which control spatio -temporal distribution of fish are temperature, salinity, light, oxygen, food, pollutants, hydrodynamics and substratum. Moreover, the physiological processes of fish are carried out under environmental conditions harsher and more restrictive in many ways than those experienced by terrrestrial animals (Wedemeyer, 1997). For example, the concentrations of the gases in the aquatic environment are highly variable compared with those in air. Oxygen depletion in water is not unusual and at times respiration can be difficult. All these reasons explain why coping with changes in environmental factors is a major ability for fish species that is relevant when considering fish welfare.

During the last 40 years, considerable research effort has been devoted to the effects of environmental factors on fish physiology-(Somero and Surarez, 2005).

Scientific information on the effects of environmental factors on physiological functions in fish, including development, growth, reproduction, excretion, osmoregulation, respiration and immunity are summarised in several text books on fish ecophysiology (Evans 1993, Rankin 1994, Bruslé and Guignard 2004). Teleost fish share with other vertebrates many common developmental pathways, physiological mechanisms and organ systems. The challenge imposed by aquatic life leads to major physiological roles for exchanging epithelia such as gills. This is not only related to the major physiological functions (i.e. respiration, osmoregulation, excretion, acid-base balance regulation) carried by the gill which then play a central role in a suite of physiological responses to environmental and internal changes but also to the huge surface exchange built up by the gill which are a major entry for many biotic or abiotic water compounds (Evans, 2005). An example of fish ecophysiologyis the study of the effect of xenoestrogen on sex differentiation on trout reared in cages (Jobling et al., 1998) which led to literature on the effect of endocrine disruptors (Sumpter and Johnson, 2005).

Literature on fish behaviour and analysis of behavioural responses exhibited by fish exposed to stressors are mostly devoted to fish in their natural environment (Schreck, Olla and davis, 1997). Fewer studies have looked at fish behaviour in production systems. Feeding behaviour (Volkoff and Peter, 2006), social interaction and hierarchies (Gilmour et al., 2005) are important in fish aquaculture.

CONCLUSION

Fish live in the aquatic environment and respond to harmful chemicals and many other stressors at intensity levels frequently far below those that can be perceived by terrestrial animals

1.3. Sensory systems in fish

Both conservation and innovation in the organisation of sensory systems occur across vertebrates. Fish perceive optical, positional, chemical, tactile, mechanosensory and electrosensory (lateral line), acoustic, and magnetic stimuli by receptors innervated by particular brain regions (Hodos & Butler 1997). Some basic patterns of sensory innervation are common to all vertebrates for the relay of sensory inputs from putative stressors in the environment to the brain, directly impacting on the fish's welfare.

The optical characteristics of water affect illumination intensity and spectral quality. This has led to evolution of the fish eye to cope with these challenges. Fish eye adaptations allow the efficient collection of light (Warrant & Lockett 2004) and other specialisations (Siebeck & Marshall 2001). They do not have eyelids or nictitating membranes and the large choroidal complexes are subject to pressure changes and to gaseous embolism. Thus the fish eye is particularly vulnerable to a variety of husbandry effects leading to poor welfare (Roberts 2001).

Sound and vibrations travel well in water and fish are highly responsive to and potentially easily disturbed by exposure to such systems. However, it is not clear whether or not salmonid fish are disturbed by such stimuli (Wysocki *et al*. 2007).

The ear of bony fish comprises three semi-circular canals, a utricle and a sacculae and lagena. The auditory receptors comprise a very variable set of sensory organs that perceive sound from the environment. The ascending auditory pathways in mammals and fish are similar. The vestibular system of vertebrates detects position and motion of the head and is important for equilibrium or balance and coordination of head, eye and body movements.

Fish have highly elaborate chemosensory detection of information from the environment including other fish. Chemicals detected by the fish and conveyed to the brain via cranial nerve I are involved in olfaction. Structural organisation of the peripheral olfactory organ is variable throughout fish species, although the ultrastructural organisation of the olfactory sensory epithelium is extremely consistent (Hara 1994). Olfactory signals such as those involved in reproduction and feeding may be processed independently through two distinct subsystems

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(Laberge & Hara 2001, Nikonov *et al.,* 2005). The neuronal components are similar to the olfactory systems of mammals except that there is no connection between respiratory structures and the olfactory system in fish. Chemical pollution and chemical signals such as alarm pheromones may often cause poor welfare in fish so consideration of the impact of olfactorily important chemicals in the fish environment can improve welfare.

The taste buds of vertebrates are the receptors of the gustatory or taste organ that may occur in the oropharyngeal cavity and elsewhere on the body surface (Hara 1994).

The lateral line system detects mechanosensory information and is found in all fishes and some amphibians but has been lost in reptiles, birds and mammals. The sensory organ consists of hair cells called neuromasts located in the lateral line canals or on the head and body. The lateral line system allows fishes to respond to water movements and other movements relatively close to the fish. This system alerts fish to prey, predators, school neighbours, water flow from environmental obstacles, and in salmon reproductive vibrations (Satou *et al.,* 1994) that facilitates orientation behaviour (Montgomery *et al.,* 1997).

Magnetoreceptors have not been identified with certainty in any animal, and the mode of transduction for the magnetic sense remains unknown. However, magnetite particles embedded in specific cells in the basal lamina within the olfactory lamellae of rainbow trout, *Oncorhynchus mykiss*, have been identified (Walker *et al.*, 1997). All fish can use their lateral line to detect local movement and electroreception is widespread in fish, including farmed species. The implications for welfare are starting to be considered (Spiess *et al.*, pers. comm.).

CONCLUSION:

Fish have a wide range of sensory systems, some of which, such as electroreceptors and the lateral line system are not shared by birds and mammals.

1.4. Comparative Brain Structure

As in all vertebrate brains, the fish brain consists of forebrain (i.e. telencephalon and diencephalon), midbrain (mesencephalon), and hindbrain (rhombencephalon). The pallium constitutes the exterior surface of the telencephalon, in mammals the neocortex is a greatly expanded part of the pallium. Thus, the general anatomy of the teleost (bony fish) brain is similar to that of other vertebrate brain, however, the fish brain is smaller relative to body size and less complex in structure than that of higher vertebrates (Kotrschal *et al.*, 1998). Moreover, among fish there is a marked inter species variation in brain anatomy, often reflecting sensory specialization, fundamental differences in embryonic development, and the degree of cell migration and proliferation and intraspecific variation in brain structure is evident (Butler 2000).

The fish brain grows continuously throughout life and appears to be highly responsive to the environmental conditions that the fish experiences as it develops (Ramage-Healey & Bass 2007, Dunlap *et al.*, 2006, Kihslinger & Nevitt 2006, Kihslinger *et al.*, 2006, Lema 2006).

In vertebrates specific brain structures have been associated with emotions and motivated behaviour. It is now indicated that the same function can be served by different structures in different groups of animals (e.g. cognitive functions in birds and mammals, Jarvis *et al.,* 2005) and structures that seem to be different may be more homologous than had previously been thought. Comparative anatomical studies have shed some light on the potential functional role of fish brain structures in relation to motivational and affective states. The issues are complex and there is considerable disagreement among specialists about the extent of commonality of

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brain function within the vertebrates. Fish do not have the extensive analytical cortex that mammals have and sensory processing is carried out in different regions of the brain according to the adaptations of the particular group of fishes. Fish do not have the extensive cerebral cortex that mammals have, this being smaller relative to body size and without the characteristic folded and layered appearance of the mammalian cortex. Additionally, sensory processing is carried out in different regions of the brain according to adaptations of the particular group of fishes (Rose 2002, Vogt 2003).

The possibility cannot be excluded that parts of the brain other than the cerebral cortex have evolved the capacity for generating negative emotional states in fish (Huntingford *et al.*, 2006). The concept of pain in vertebrates revolves around the perceived noxiousness of certain stimuli, and may have been conserved through evolution as a protective strategy.

At the level of the telencephalon, fish lack the higher cortical centres that have been demonstrated as necessary for full processing and experience of pain in mammals (Rose 2002). Extensive interconnections exist between the telencephalon, diencephalon and mesencephalon in fish (Rink & Wullimann 2004). Neural pathways that connect to various forebrain structures are of fundamental importance to consciousness and the perception of pain and fear in mammals (Willis & Westlund 1997). The pallium (the grey matter that covers the telencephalon) has thickened to various extents in different classes of vertebrates, and in mammals it consists of a laminated structure, the cerebral cortex (Striedter 1997). Unlike mammals, in the majority of modern fish species, the pallium is unlaminated (Vogt 2003), however there is evidence to suggest it has developed into a highly differentiated structure with respect to the processing of sensory information (Bradford 1995, Butler 2000). The telencephalon in fish contains several brain structures that are thought to be functionally homologous to those associated with pain and fear in higher vertebrates (Bradford 1995, Chandroo *et al.*, 2004, Portavella *et al.*, 2004), and this is known to be active during a potentially painful event (Dunlop and Laming 2004). Therefore, information about noxious stimuli, such as those resulting from tissue damage, in fish may be processed in a functionally homologous way, not yet fully characterised, to that involved in processing noxious stimuli in mammals. In mammals, the hippocampus, a telencephalic structure, is involved in memory and learning of spatial relationships whereas the amygdala, a structure which is also telencephalic, has long been known to be important in arousal and emotions, particularly fear responses (Carter 1996, Maren 2001). Recent studies have identified structures in the teleost telencephalon that appear to be homologous to the mammalian amygdala and hippocampus with alterations in fear, spatial learning and memory retrieval when these areas are lesioned (Portavella *et al.*, 2002). Another important structure in the fish brain, the hypothalamus, is thought to perform functions similar to those of the hypothalamus in other vertebrates. The hypothalamus is involved in various functions, including sexual and other social behavior, and is also responsible for the integration of both internal and external signals including those originating from those telencephalic areas that have been implicated in fear responses (Fox *et al.*, 1997, Portavella *et al.*, 2002, Chandroo *et al.*, 2004).

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CONCLUSION

Our understanding of the extent to which brain structure and function in fish are comparable with other vertebrate groups is limited. As vertebrates, fish, birds and mammals share a similar general brain structure. Over and above this, however, comparative neuroanatomy highlights many differences among vertebrate groups; it also highlights differences in brain structure among species of fish. On the other hand, studies of brain function suggest a number of parallels between fish and other groups.

1.5. Sentience

Sentience refers, among other properties, to the ability to experience pleasurable and adverse states, a key issue when considering the welfare of any animal and a focus of public concern and there are discussions of this matter in relation to fish (Broom 2006, 2007, Yue *et al.* 2008).

Animals that have some cognitive ability at a certain stage of their development, start development without such ability. Hence it is relevant to consider at what time, during the life of a fish, their perceptual and cognitive abilities develop. It is likely that fish develop some cognitive ability only when they are able to perceive external stimuli. While little is known about the development of cognitive ability, we have some evidence concerning the stage of life at which the development of responsiveness to external stimuli starts (EFSA, 2005).

1.6. Pain

Pain is defined as an aversive sensation associated with tissue damage. As non-human animals are unable to communicate the experience of pain directly, a number of criteria have been defined to provide a guide as to whether an animal might be capable of experiencing pain (Bateson 1991, Broom 2001a, b, Sneddon 2004). These criteria include: (i) the existence of functional nociceptors (ii) the presence and action of endogenous opioids and opioid receptors (iii) the activation of brain structures involved in pain processing (iv) the existence of pathways leading to higher brain structures (v) the action of analgesics in reducing nociceptive responses vi) the occurrence of avoidance learning vii) the suspension of normal behaviour associated with a noxious stimulus.

Each of these areas will be considered in turn to assess how well fish fulfil these criteria and how their functioning compares to the nociception and pain systems of higher vertebrates.

Nociception is the detection of a noxious stimulus and is usually accompanied by a reflex withdrawal response away from that stimulus immediately upon detection. Noxious stimuli are those that can or potentially could cause tissue damage so stimuli such as high mechanical pressure, extremes of temperature and chemicals, such as acids, venoms, prostaglandins and so on, excite nociceptive nerve fibres. Martin & Wickelgren (1971) and Mathews & Wickelgren (1978) identified sensory neurones in the skin and mouth of a lamprey (*Petromyzon marinus*) during heavy pressure, puncture, pinching or burning, and found that the output was like that which would be recorded in a mammalian nociceptor when responding to a painful stimuli. Studies of the rainbow trout (*Oncoryhnchus mykiss*) have shown that nociceptors are present on the trout face and are innervated by the trigeminal nerve (Sneddon 2002, 2003a). These studies on nociceptor anatomy and physiology strongly support the hypothesis that the rainbow trout has the sensory equipment for detecting potentially painful stimuli. Studies of nerve responses, nerve and other tissue regeneration, behavioural responses and effects of analgesics indicate nociceptive function in the fins of salmonid and other fish (Becerra et al 1983, Geraudie and Singer 1985, Turnbull et al 1996, Chervova 1997).

Fish have the necessary brain areas for nociceptive processing to occur (e.g. pons, medulla, thalamus; Sneddon 2004).The functional possibility for high level processing, such as that carried out in the cortex in humans, is crucial in terms of pain perception. In term of anatomy the fish brain is far smaller relative to body size and simpler in structure than of a human. Moerover, fish lack cortical structure such the neocortex, which plays a key role in the subjective experience of pain in humans (FSBI 2002; Rose 2002). However, it is not impossible that parts of the brain other than the cerebral cortex have evolved the capacity of generating negative emotional states in fish (Huntingford et al. 2006).

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In fish as in other vertebrates, nociceptive information is relayed to the brain from the periphery via two major tracts. The trigeminal tract conveys information from the head while the spinothalamic tract conveys information from the rest of the body. In fish the trigeminal has been shown to project to the thalamus as it does in other vertebrates (Goehler & Finger 1996, Finger 2000). The elasmobranch (Ebbesson & Hodde 1981) and teleost (Goehler & Finger 1996, Finger 2000) groups both have the same basic components of ascending spinal projections as higher vertebrates.

The possession of opioid receptors, endogenous opioids and enkephalins is one of the requirements to determine whether nociception can occur in an animal (Bateson 1991, Broom 2001a, b). These substances are involved in analgesia in the mammalian central nervous system and are produced in order to reduce pain internally. Met-enkephalin and leu-enkephalin are present in all vertebrates which have been tested and there are at least six opioid receptors described for teleost fish (Dores and Joss 1988, Dores *et al.*, 1989, Dores and Gorbman 1990, McDonald and Dores, 1991). Opioids elicit antinociception or analgesia through three distinct types of receptors in mammals (Newman *et al.*, 2000) and these have been identified in the zebrafish, *Danio rerio* (Stevens 2004). When goldfish are subjected to stressful conditions, there is an elevation of pro-opiomelanocortin, the precursor of the enkephalins and endorphins, just as there would be in humans (Denzer and Laudien, 1987). Goldfish which are given electric shock show agitated swimming but the threshold for this response is increased if morphine is injected and naloxone blocks the morphine effect (Jansen and Greene 1970). Work by Ehrensing *et al.*, (1982) showed that the endogenous opioid antagonist MIFI down-regulates sensitivity to opioids in both goldfish and rats. Opiate receptors and enkephalin like substances have also been found in various brain areas of goldfish, *Carassius auratus* (Finger 1981, Schulman *et al.*, 1981) and rainbow trout, *O. mykiss* (Vecino *et al.*, 1991). The distribution of enkephalins in the fish brain shows a similar pattern to that seen in higher vertebrates (Simantov *et al.*, 1977, Vecino *et al.*, 1992). In general it is clear that there are very many similarities amongst all vertebrates in their opioid systems.

A simple reflex response to a noxious stimulus can indicate nociceptive function, however, adverse affects on an animal's normal behaviour beyond a simple reflex may indicate a psychological component that is indicative of suffering, and suggests that the animal may be perceiving pain. Reflex responses occur instantaneously and within a few minutes but some of the responses of fish may be prolonged.(Sneddon 2006). A recent study investigated the behavioural response of rainbow trout that had been given subcutaneous injections of acetic acid and bee venom (algesics) to the lips (Sneddon *et al.*, 2003a). These fish showed an enhanced respiration rate for approximately 3 hours, did not feed within this period, and showed anomalous behaviours such as rubbing of the affected area on the aquarium substratum and glass and rocking from side to side on either pectoral fin (Sneddon 2003b, Sneddon *et al.*, 2003a). These, therefore, appear to represent changes in behaviour over a prolonged period as a result of nociceptive stimulation.

The ability of analgesics to modulate nociceptive responses is also indicative of pain perception since the selectively act on this system. The adverse behavioural responses seen in the rainbow trout, *O mykiss*, were quantified and when morphine was administered to fish injected with acid, there was a dramatic reduction in this rubbing behaviour as well as rocking behaviour and the enhanced respiration rate was also ameliorated (Sneddon 2003b, Sneddon *et al.*, 2003a). Further to this, acid injected fish did not show an appropriate fear response to a novel challenge supporting the idea that this painful stimulus dominates the fish attention (Sneddon *et al.*, 2003b). Studies have shown that goldfish are able to learn to avoid noxious, potentially painful stimuli such as electric shock (Portavella *et al.*, 2002, 2004). Learned avoidance of a stimulus associated with a noxious experience has also been observed in other fish species (Overmier &

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Hollis 1983, 1990) including common carp, and pike, avoiding hooks in angling trials (Beukema 1970a, b).

There are strong debates on the question of pain in fish with opposing views (Rose 2002, Derbyshire *et al.*, 2007, Sneddon 2004, 2006). For example, Derbyshire *et al.*, (2007) argue that the results from Sneddon's studies presented above can be interpreted as showing a remarkable capacity of trout to withstand oral trauma which would be expected as trout normally feed on potentially injurious prey such as crayfish, crabs and spiny fish. They also suggest that there is an important difference between knowledge about sensation and sentience (Derbyshire *et al.*, 2007). Rose (2002) argues that there are major neurobehavioral differences between fish and humans, particularly at the level of brain regions responsible for pain awareness in humans. In fish, in which the cerebral hemispheres were removed, leaving the brainstem and spinal cord intact, ome behaviour was still possible (Overmier and Hollis, 1983). Because the experience of fear and pain depends on cerebral cortical structures in mammals and these are absent in fish brains, Rose (2002) concluded that awareness of fear and pain is impossible in fish. However, evidence of an active nociceptor system in fish associated with effects of administration of noxious substances on normal behavioural repertoire has led to the inference that fish potentially have the capacity for long-term suffering (Chandroo et al. 2004, Sneddon 2006, Braithwaite and Boulcott 2007).

CONCLUSION

It has been convincingly demonstrated that fish have nociceptors and that these look like and have a similar response profile to those of birds and mammals. The question of whether fish experience the input of these receptors as pain remains controversial but experiments have shown the brain is active during this stimulation and that painkillers reduce prolonged behavioural and physiological responses. It is clear that the responses given by fish to nociceptive stimulation are more complex than simple reflexes, including significant shifts in behavioural priorities and the performance of anomalous behaviour. In this context, our working position is that juvenile and adult fish have the capacity to perceive painful stimuli and experience at least some of the adverse affective states that we associate with pain in mammals.

1.7. Fear

Fear serves a function that is fundamental to survival and is the activation of a defensive behavioural system that protects animals against actual or potentially dangerous environmental threats. In higher vertebrates, fear involves mainly the amygdaloid and hippocampal regions of the brain although other areas are also implicated. Studies in fish have shown that these responses also appear to be dependent upon cognitive mechanisms and homologous limbic brain regions in the telencephalon. The dorsomedial (Dm) telecephalon in fish has been implicated in emotional learning and is thought to be homologous to the amygdala in mammals (Bradford 1995, Butler 2000, Portavella *et al.*, 2004). In mammals the hippocampus is involved in memory and learning of spatial relationships and it is the dorsolateral (Dl) telencephalon in fish that is thought to be functionally homologous to the hippocampus. Dm lesions impaired acquisition of an avoidance response but had no effect on performance in a spatial learning task, while Dl lesions affected spatial learning but did not impair the acquisition of the avoidance response (Portavella *et al.*, 2002). Therefore Dm and Dl areas of the fish telencephalon share functional similarities with the amygdala and hippocampus, respectively, in mammals.

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Studies on fear conditioning in mammals measure levels of freezing and startle behaviour (Fendt & Fanselow 1999). In fish, a number of different behavioural responses to potentially threatening stimuli have been described and include escape responses such as fast starts (Chandroo *et al.*, 2004, Domenici & Blake 1997, Yue *et al.*, 2004) or erratic movement (Cantalupo *et al.*, 1995, Bisazza *et al.*, 1998), as well as freezing and sinking in the water (Berejikian *et al.*, 1999, 2003). Such behaviours may serve to protect the individual from the threat and a number of studies have illustrated that these behaviours can be shown in response to conditioning. Many fish species also release chemical alarm substances when injured. These are thought to act as warning signals, as conspecifics show a behavioural fright response to these chemicals (Smith 1992, Lebedeva *et al.*, 1994, Brown & Smith 1997, Berejikian *et al.*, 1999). These alarm behaviours include dashing movements, vigorous movements in the aquarium substratum, and fast swimming towards hiding places, remaining there for an extended period. These behaviours are thought to be associated with predator evasion (Hamdani *et al.*, 2000).

Learned avoidance studies not only show that a consistent suite of behaviours are produced in response to fearful stimuli in fish but they also provide evidence that the displayed behaviour is not merely a reflex response. Learning to avoid an aversive stimulus in the future implies a cognitive process of recognising that the behavioural response will lead to the desired effect of avoidance (Yue *et al.*, 2004). This may support the suggestion that an affective state such as fear may serve to motivate behaviour in fish.

Learning is thought to be mediated in part by receptors in the brain that are activated by N-methyl-D-aspartic acid (NMDA). Administration of selective antagonists of NMDA receptors impair learning mechanisms such as associative learning and conditioned fear in mammals (Miserendino *et al.*, 1990, Sanger & Joly 1991, Kim *et al.*, 1991, Maren 2001). Experiments with goldfish have shown that intracranial administration of MK-801, an NMDA receptor antagonist, blocks specific aspects of Pavlovian fear conditioning in fish (Xu & Davis 1992, Xu 1997).

CONCLUSION

Fear often depends on cognitive and learning ability and fear responses by fish are described for various situations, suggesting that the affective state of fear sometimes motivates fish.

1.8. Stress responses

Selye (1973) defined stress as “the nonspecific response of the body to any demand made upon it”. Following a period of controversial debates about the definition of stress and stressors, all recent reviews on stress in teleost fish define this term as a condition in which the homeostasis is threatened or disturbed as a result of the actions of intrinsic or extrinsic stimuli commonly defined as stressors (Wendelaar Bonga 1997, Iwama *et al.*, 1997, Barton 2002, Chrousos 1998, Wendemeyer *et al.*, 1990). The problems associated with Selye’s concept of stress are discussed by Broom and Johnson (2000) and there is debate about whether or not the concept should be limited to that which is detrimental to the fish. The response to stressors is often an adaptative mechanism that allows the fish to cope with stressors in order to maintain homeostasis. If the intensity of the stressors is overly severe or long lasting, physiological response mechanisms can become detrimental to fish welfare or maladaptative (Barton 2002, FSBI, 2002, Wendelaar Bonga 1997).

During the last 20 years, there has been extensive research devoted to the biology of stress in fish. Physiological and behavioural responses to a large variety of physical, chemical and

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biological stressors including those seen in aquaculture have been measured (for review see Wendelaar-Bonga 1997, Iwama *et al.*, 1997, Barton 2002, FBSI 2002, Conte 2004, Ashley 2007). Hypothalamic-pituitary-interenal (HPI) axis responses are generally considered as an adaptive strategy to cope with a perceived acute threat to homeostasis, for example poor water quality. Although fish are able to tolerate acute adverse water quality conditions, when they become too challenging or prolonged, fish cannot maintain homeostasis and experience chronic stress which in the long term can impair immune function, growth and reproductive function. Furthermore, chemicals may have toxic effects at the level of cell and tissue but, in addition, elicit an integrated stress response which may be specific to the toxicant.

The stress physiology of fish is directly comparable to that of higher vertebrates. Stress physiology is manifested by primary, secondary and eventually tertiary stress responses (see review Wedemeyer *et al.*, 1990, Wendelaar Bonga 1997, FSBI 2002, Ashley 2007). The primary stress response to short term potentially harmful situations involves, amongst other things, the release of catecholamines (adrenaline and noradrenaline) from the chromaffin cells into the circulating system. Simultaneously, activation of the hypothalamic-pituitary-interenal (HPI) axis is observed. The corticotrophin releasing factor (CRF) is released from the hypothalamus and acts on the pituitary resulting in the synthesis and release of adrenocorticotrophic hormone (ACTH) which in turn stimulates the synthesis and mobilisation of glucocorticoid hormones (cortisol) from the interrenal cells. Released catecholamines and cortisol will result in an activation of various physiological and behavioural mechanisms that constitute the secondary and possibly tertiary stress responses. The secondary changes include alteration of secretion of other pituitary hormones and thyroid hormones, changes in turn-over of brain neurotransmitters, mobilisation of energy by breakdown of carbohydrate and lipid reserve and by oxidation of muscle protein, improvement of respiratory capacity via increased heart stroke volume and increase blood flow to gills. As a consequence of this last effect, disruption of the hydromineral or osmoregulatory balance can be observed.

Primary and secondary stress responses are short-term effects of acute, short-lived challenges. When these responses are prolonged or repeated and fish has no way to avoiding or escape the challenge, a series of tertiary effects become apparent, including changes in immune function and disease resistance (Pickering 1992, Balm 1997), in growth (Barton *et al.*, 1987, Pickering *et al.*, 1991) and in reproduction (Pankhust and vander Kraak 1997, McCormick 1998, Schreck *et al.*, 2001).

Behavioural responses are often shown early in defence against adverse environmental changes, often triggered by the same stimuli that initiate the primary physiological stress responses. The exact behavioural response depends on the stressor in action. For example, the response to an approaching potential predator might be escape, whereas the response to an approaching competitor might be attack. The behavioural response to abiotic environmental stressors, such as inappropriate water temperature, oxygen or water current, includes a range of responses in movement pattern, spatial choice and social interactions, but these responses are poorly described in most fish species. In addition, individuals of the same species may differ in the nature and magnitude of their behavioural responses to various stressors. Such behavioural differences, together with the physiological variation with which they are associated, are referred to as coping strategies. Some individuals adopt what is called a proactive coping strategy, showing adrenaline-based fright and flight responses, while others adopt a reactive coping strategy, showing cortisol based “freeze” and hide responses (Korte *et al.*, 2005). However it is not clear to what extent these are general strategies. These differences are correlated with variation in brain serotoninergic activity (Schjolden and Winberg 2007) and are also affected by the extent of exposure to stressors.

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Chronic stress is a major factor in the health of fish (Conte, 2004). As in mammals, there is a clear link between stress and immune status arising mostly through the effects of cortisol which can suppress many aspects of the immune system (Wendelaar Bonga 1997). However, the relationship between stress and immune system goes in two directions since components of the immune system can influence stress responses through modification of the secretion of hormones (Ottaviani *et al.*, 1996, Balm 1997). While disease is not always connected to poor environmental conditions (Huntingford *et al.*, 2006), aquaculture practice presents many situations where stress and physical injury can increase susceptibility to naturally occuring pathogens (Ashley, 2007). For example, diseases associated with low temperatures over winter period have been described in a number of different species (Tort 1998b). Fin erosion is also an important problem in aquaculture which often occurs as results of aggressive interactions. Fin erosion may increase susceptibility to infections (Turnbull *et al.*, 1996). One example of the strong interaction between environmental stress and a serious infectious disease is the case of furunculosis. Many fish may carry the causative pathogen but clinical outbreaks occur normally after stressful events such as grading or transportation of fish. So predictable is the response that a predictive test for identifying carrier populations is the 'furunculosis stress test' where samples of healthy fish are injected with cortisone to identify individuals which might become clinical cases if stressed (Hiney *et al.*, 1994).

An acute stress response does not necessarily imply any harmful consequence as such a response may be important to the maintenance of homeostasis. However, mid- and long-term exposure to stressors generally leads to maladaptative effects and sometimes to chronic stress, which are associated with decreased welfare. Such effects have been described with chronic effects on growth, reproduction or immune function and disease resistance. So, while studies on stress responses do not necessarily give us a complete view of welfare in fish, deleterious effects of several components of the stress response observed after chronic exposure to stressors are indicative of poor welfare (Huntingford *et al.*, 2006, Ashley *et al.* 2007).

Measurements of the levels of both glucose and lactate in the plasma may sometimes be biomarkers of stress in fish (e.g. Arends *et al.*, 1999; Acerete *et al.*, 2004). Measures of the expression of stress related genes might also provide useful markers (e.g. Gornati *et al.*, 2004). Chronic stress has been also studied and exerts a strong effect on haematology (Montero *et al.*, 2001), metabolism (Mommsen *et al.*, 1999), neuroendocrine function (Dibastistta *et al.*, 2005b), and osmoregulation (Wendelaar Bonga, 1997). However, reliable indicators of chronic stress are still under investigation and will probably rely on a range of measurements.

Avoidance of the maladaptative consequences of prolonged stress is a central concern in aquaculture and assessments of potential methods to reduce stress responses is an active area of research (Ashley 2007). Thus, fish have been selectively bred for reduced emergency responses: High responding (HR) and low responding (LR) lines of rainbow trout have been generated by selection for consistently high or low cortisol response to a standard confinement test (Pottinger and Carrick 1999). In addition, these two strains of rainbow trout also show a divergence in sympathetic reactivity as a response to confinement (Schjolden and Winberg 2007). However, all testing was conducted under controlled laboratory conditions and the welfare and productivity of LR strains have not yet been compared under commercial conditions. Manipulation of fish diet has been also shown to play an important role in inter-renal sensitivity: For example, vitamin E added in the diet has been shown in sea bream to slow down elevation of plasma cortisol levels in response to a stressor and to increase survival rate (Montero *et al.*, 2001). In African catfish (*Clarias gariepinus*), vitamin C fed during early development induced lower inter-renal gland activity (Merchie *et al.*, 1997).

Although much research has been devoted to stress biology in fish, major questions concern the development of new techniques for non-lethal and non-invasive sampling of physiology and

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behaviour of fishes which would allow measurement of stress outside a controlled laboratory environment (Scott and Ellis 2007), including meat quality measurements (Skjervold *et al* 1999). Cumulative stress responses at different life stages and methods for evaluating stress in relationship to fish performance have not been much studied.

If stressors and failure to cope persist, the final consequence is death. Mortality rate is therefore a useful welfare indicator as mentioned in Chapter 5. In fish species, there is variation amongst species in the mortality rate in the wild. Amongst salmonids, the egg is large so mortality in alevins and fry is lower than in some species with less food reserve available. When considering the mortality rate, that which occurs in the wild is not directly relevant as farmed fish should be cared for and protected from starvation, predation and avoidable disease. Taking into account the biological functioning of the fish species, mortality rate can give information about the extent of stress and poor welfare.

CONCLUSION

In common with all vertebrates, fish possess a suite of adaptative behavioural and physiological strategies that have evolved to cope with stressors. The systems in mammals and birds that result in the production of adrenaline and cortisol have close anatomical and functional parallels in fish except that the adrenaline and cortisol production are from the more diffuse chromaffin and inter-renal tissue rather than from a discrete adrenal gland. Fish show physiologically and behaviourally similar freeze and flight responses and prolonged cortisol production is associated with immunosuppression.

NEEDS OF FISH

A need is a requirement on the part of an animal to obtain a particular resource or to respond to a particular environmental or bodily stimulus. The exact set of needs for any given species is a consequence of its biology. In general needs are associated with all of the major biological functions of the animal. In aquaculture, the fish experience only a part of the range of natural variation in environmental factors. Some factors may be less variable than in the wild, e.g. food availability, while other factors vary more than in nature, e.g. oxygen concentration. In addition, while fish in nature may swim away from adverse or sub-optimal conditions, the farmed fish spatial and temporal environment, gives few options for individual preference. Nevertheless all farmed animals have needs and good welfare depends upon these being met to a greater or lesser degree.

However, there is variation in the importance of the various needs for the welfare of the individual. Needs range from resources whose absence results in rapid death to those whose presence improves welfare for a period, but lack of which would never result in death

The following list of needs is not in order of importance and reflects current knowledge. Some needs require being satisfied only at intervals of some hours or only when fish are at certain life stage, young or adult. The causes of some problems of fish are multifactorial and may be related to more than one need. The welfare risk assessment refers to hazards that are linked to the known needs of a particular species. Those hazards or factors have been identified for each species.

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1 Need for adequate physical and chemical environmental conditions:

1A. To have access to appropriate oxygen concentration

All fish need oxygen of a certain partial pressure, the actual value varying according to species.

1B. To avoid harmful substances or environmental conditions in water

All fish need an appropriate aquatic environment. Inappropriate water conditions, for example too high salinity or carbon dioxide concentration, too much ammonia or other toxic chemicals, or suboptimal pH can harm fish.

1C. To have appropriate visual, olfactory and other environmental conditions

It may be that problems are caused to fish of particular species by inappropriate light, vibration, chemical stimuli, pressure changes, or electrical changes.

1D. To avoid extreme temperatures

Although fish are poikilotherms, adverse temperature conditions can harm fish for various reasons including impact on oxygen availability and demand, so they need to avoid them if possible. Body temperature modification in most fish, where it can occur at all, is behavioural.

1E. To osmoregulate

Fish need to maintain relative stability in the ionic composition and osmotic strength of their body fluids, for example when exposed to inappropriate salinity.

1F. To have space for movement

Fish require space to carry out various functions, such as food searching, social interactions and responses to threats, and crowding can lead to problems. The fish species vary greatly in what space they need.

2 Need to have appropriate social interactions

Some fish species shoal for much of their lives and good welfare may depend upon such behaviour. Other species are social for part of their lives or for none of their lives. Some fish need to avoid attacks by conspecifics.

3 Need to avoid predation

Many fish living in natural conditions are very vulnerable to predation. The biological functioning fish of most species is strongly adapted to maximise the chance of recognition of danger from predators and escape from it.

4 Need to feed for maintenance and growth

A variety of nutrients are needed by fish. Fish also need to avoid feed containing dietary toxins and anti-nutrients.

5 Need to maintain good health condition

Fish use various behaviours, anatomical adaptations, physiological responses and immune responses to combat pathogens. They need to avoid any physical or chemical impact that causes tissue damage.

RECOMMENDATION

Since there is evidence in fish for the range of abilities and functions associated with learning and cognition and with affective states such as pain and fear, the welfare of fish should be considered during all aspects of their husbandry.

Fish farming in Europe

World aquaculture has significantly increased during the last fifty years from a production of less than a million tonnes in the early 1950s to 59.4 million tonnes by 2004. Consumption of farmed fish is about 45.5 million metric tons whereas around 60 million tons are wild caught fish from both fresh and sea-water. The 70% of the total aquaculture production comes from the Chinese aquaculture, 22% from the Asian and the Pacific region whereas Europe contributed to approximately 4% of world farmed fish production (FAO;

http://www.fao.org/newsroom/en/news/2006/1000383/index.html).

Nevertheless Europe has the largest production of some species like Atlantic salmon, European sea bass and gilthead sea bream. Currently, Norway is the top producer in Europe, with an annual salmon production of more than 580,000 tonnes representing a 41% of increase in the production rate from 1998 to 2003. Other major producing countries of farmed fish in EEA are Spain, France and Italy. United Kingdom and Greece are also centres of fish farming activity and smaller quantities are produced in several other European countries (Table 1).

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Table 1. **Finfish aquaculture production in EEA countries in 2005**

Country	2005	% growth 1995 - 2005
Norway	652306	135.30
United Kingdom	143012	64.50
Greece	80136	268.36
Spain	57346	100.74
France	50352	-23.11
Italy	47642	-27.49
Denmark	38732	-13.41
Poland	36607	45.78
Germany	35130	-22.02
Czech Republic	20455	9.51
Ireland	15384	15.68
Finland	14355	-17.24
Hungary	13661	45.95
Netherlands	8675	213.63
Iceland	8246	136.61
Romania	7284	-63.27
Sweden	4805	-20.20
Portugal	4115	137.31
Bulgaria	2971	-31.70
Austria	2420	-17.07
Cyprus	2315	419.06
Lithuania	2013	17.44
Slovenia	1335	72.04
Switzerland	1214	4.57
Belgium	1200	41.84
Slovakia	955	-40.94
Malta	736	-18.58
Estonia	553	75.56
Latvia	542	3.24
Total	1253283	63.29

(Source: Eurostat, 2008**)**

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European finfish aquaculture species comprises a range of teleosts including salmonids like Atlantic salmon (*Salmo salar*), rainbow trout (*Oncorhynchus mykiss*) and arctic charr (*Salvelinus alpinus*), sea basses (mainly European sea bass *Dicentrarchus labrax*), sea breams (mainly gilthead sea bream *Sparus aurata*), carps (e.g. common carp, crucian carp, grass carp and silver carp), flatfish like turbot (*Psetta maxima*), halibut (*Hippoglossus hippoglossus*) and sole (*Solea vulgaris vulgaris or Solea solea*), European eel (*Anguilla anguilla*), catfish (*Clarius sp.*) and gadoids like Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (Table 2).

Table 2. **Yearly production of the main farmed fish species in EEA in tonnes**

Species	1995	2000	2005
Atlantic salmon	347 861	589 606	733 332
Rainbow trout	258 168	286 629	261 805
Gilthead seabream	17 487	58 747	71 475
Common carp	75 000	72 178	69 557
European seabass	17 000	40 869	49 202
European eel	6 819	10 658	8 202
Atlantic cod	317	169	8 115
Turbot	2 978	4 785	6 838
Catfish	1 482	3 640	6 674
Silver carp	8 851	4 909	2 568
Atlantic halibut	-	35	1 445
Grass carp	1 334	1 526	1 090
Arctic charr	531	1 028	905
Haddock			72
Sole	30	23	11

*catfish (Clarius Spp. and Silurius spp)

Source: Eurostat, 2007

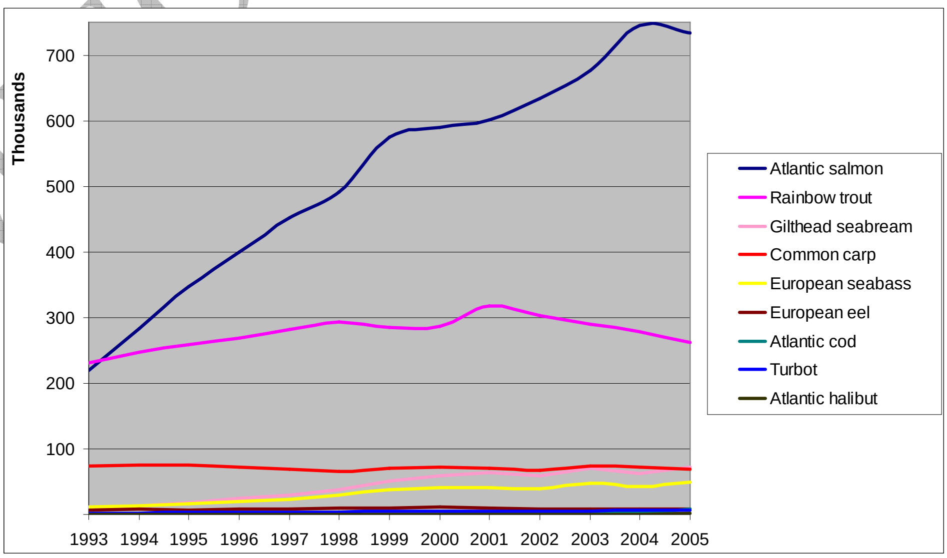

Figure 1. **Yearly production (thousands of tons) of the main farmed finfish species in EEA** (Source: Eurostat, 2007).

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