CLOSED WATERS: THE WELFARE OF FARMED ATLANTIC SALMON, RAINBOW TROUT, ATLANTIC COD & ATLANTIC HALIBUT

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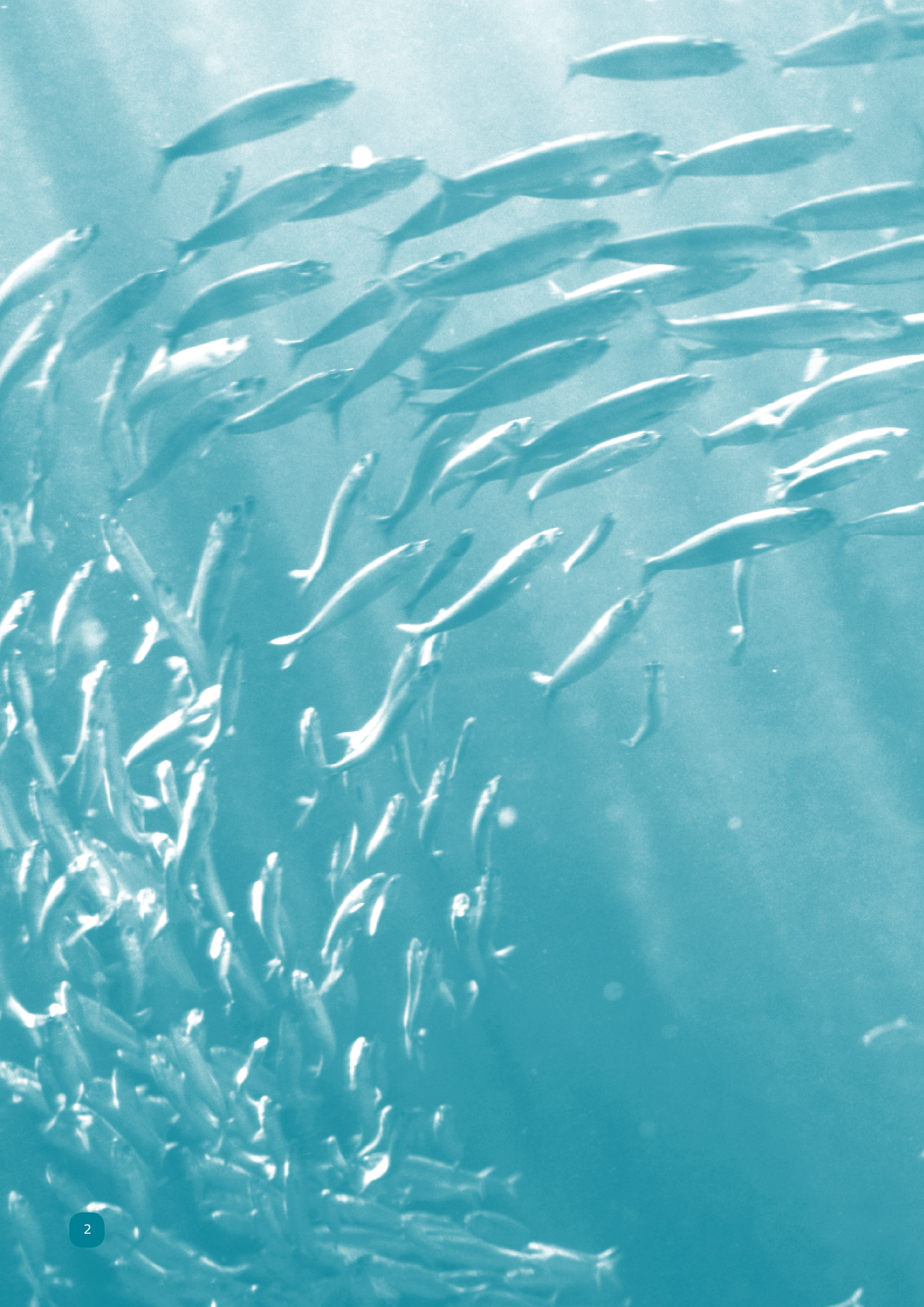
A report by Compassion in World Farming and the World Society for the Protection of Animals **2007**



CLOSED WATERS: THE WELFARE OF FARMED ATLANTIC SALMON, RAINBOW TROUT, ATLANTIC COD & ATLANTIC HALIBUT

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2007

ISBN 1 900 156 415

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Executive Summary

The vast majority of Atlantic salmon and rainbow trout are farmed intensively. We recognise that the British industry (the one with which we are most familiar) has made some progress in tackling welfare problems. Nonetheless, both in Britain and elsewhere, intensive fish farming, whereby large numbers of fish are confined in a small area, causes serious welfare problems that need to be addressed urgently to prevent further widespread suffering.

Intensive aquaculture practices frequently expose fish to a range of stressors such as stripping of broodstock, handling, vaccinations, crowding, grading, starvation, sea lice treatments and loading and transport. Although they can be alleviated to some degree by good practice, these stressors are inherent in intensive aquaculture.

Intensively farmed fish suffer from a range of welfare problems including physical injuries such as fin erosion, eye cataracts, skeletal deformities, soft tissue anomalies, increased susceptibility to disease, sea lice infestation, high mortality rates and, in some countries, often inhumane slaughter methods.

Introduction

Fish farming (aquaculture) is expanding rapidly. Indeed, fish farming is the fastest growing sector in world production of animal-derived food. Worldwide aquaculture has increased at an average compounded rate of 9.2 per cent per year since 1970, compared to 1.4 per cent for capture fisheries and 2.8 per cent for terrestrial farmed meat production.[1]

An increasing proportion of global fish production is coming from aquaculture rather than from fish caught at sea. In the last 35 years, aquaculture's contribution to total global fish production has increased from 5.3 per cent by weight in 1970 to 40.0 per cent in 2005.[2] Around 40 per cent of all fish directly consumed by humans worldwide are farmed.[3] One recent study predicts the collapse of all species of sea fish by 2048 if steep declines in fish populations continue at the present rate (collapse is defined as 90 per cent depletion).[4] This will inevitably lead to a major expansion of aquaculture.

This report focuses on the welfare of farmed Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*), the two main species farmed in Europe. It also looks at Atlantic cod (*Gadus morhua*) and Atlantic halibut (*Hippoglossus hippoglossus* L.); these species are relatively new to aquaculture, but are being increasingly farmed in Norway, Scotland and Iceland.

The production of farmed Atlantic salmon has grown dramatically since the early 1980s, with production worldwide increasing 55-fold in the two decades up to 2003 (FAO, 2006). The largest producers of Atlantic salmon are Norway, Chile, Scotland and Canada. Major producers of rainbow trout include Chile, Norway, Turkey, Denmark, France, Italy, Spain, Iran, Germany, the US, the UK, Finland and Poland. Some idea of the size of the industry can be seen from the fact that in 2004, Britain produced around 35 million Atlantic salmon and about 40 million rainbow trout for the table, making aquaculture Britain's second largest livestock sector after broiler (meat) chickens.

It is well established that fish are likely to experience pain[5], fear and psychological stress and that, like other vertebrates, they have the capacity to suffer.[6] Accordingly, it is important that their welfare is safeguarded.

Breeding methods

Invasive techniques are used to remove eggs and sperm from Atlantic salmon and rainbow trout. Female salmon are anaesthetised. A stockperson then releases the eggs by a firm stroking of the abdomen. Some facilities introduce compressed air through a needle into the abdominal cavity of the anaesthetised fish to push out the eggs. Alternatively, the salmon is killed, after which her eggs are removed surgically. Female rainbow trout are stripped manually by a stroking motion; sometimes they are sedated before stripping. Sperm is extracted from anaesthetised male salmon by stroking the abdomen.

Compassion in World Farming (CIWF) and the World Society for the Protection of Animals (WSPA) are concerned about these methods of obtaining eggs and sperm, some of which are invasive and involve removing the fish from water. That said, in Scotland fish are anaesthetised prior to stripping. We believe that this should be a normal part of best practice; our view is that all fish should be anaesthetised prior to stripping.

Stocking density

There is currently much debate about the effect of stocking density on welfare. Some argue that stocking density has no or little impact on the welfare of farmed salmon or trout. This, however, is not borne out by a careful examination of the scientific literature in this field.

The literature indicates that stocking density is important as it is one of a range of factors – including water quality, flow rate of incoming water and feeding method - that interact to determine the welfare of farmed salmon and trout. Density cannot, however, be considered in isolation from other environmental factors. Water quality, in particular, has a fundamental role in determining welfare. One of the principal concerns about high stocking density is that it can lead to deterioration of water quality.

Norwegian scientists write: "There is a legitimate public concern that fish are kept at too high densities in intensive aquaculture".[7] Similarly, a UK researcher stresses: "Stocking density is a pivotal factor affecting fish welfare in the aquaculture industry, especially where high densities in confined environments are aimed at high productivity".[8] High stocking densities can have a detrimental impact on the health and welfare of Atlantic salmon and rainbow trout. In particular, high densities can lead to:

- **increased susceptibility to disease**; moreover once disease enters a crowded enclosure, high densities facilitate its transmission [9-11]
- **increased incidence of physical injuries** such as fin erosion. Fin damage is multi-factorial in its causation; high stocking density is not the sole cause. Nonetheless fin damage is increased at higher densities in both Atlantic salmon and rainbow trout. [7, 12-14] Fin lesions increase susceptibility to pathogen infection [11, 12]
- **poor body condition** [12,14]
- **increased stress** [9,10,14]
- **reduced growth**, **feed intake and feed conversion efficiency** in rainbow trout. [12]

All the above factors are indicative of a reduced welfare status. In addition, high densities can lead to:

- **poor water quality**. An increase in stocking density can result in deterioration in water quality (e.g.: a reduction in dissolved oxygen concentrations and an increase in the level of un-ionized ammonia) as more fish are respiring and metabolising in a particular volume of water.[12] Moreover, greater fish densities result in an increase in the release of waste products into the enclosure
- **increased aggression** which leads to fin injuries, scale loss, chronic stress and subordinate fish being prevented from feeding by dominant fish. [11,12]

Rearing salmon in cages constrains their natural swimming behaviour as it deprives them of swimming the great distances that are the norm for wild salmon at sea.[15,16] That constraint is exacerbated at high densities. High densities in cages induce Atlantic salmon to swim in schools, which may not be their natural behaviour in the wild for much of their time at sea [15,16] and which may be a behavioural adaptation to reduce the stress of the high density environment in commercial cages.[17] Research is needed to examine whether any detrimental impact on the health and welfare of Atlantic salmon and rainbow trout results from the constraints placed on their natural swimming behaviour by intensive aquaculture.

In addition to the science, practical experience indicates that lower densities produce benefits in terms of better performance, better feed conversion, better quality, better health, less disease, reduced fin damage, less size variation and improved survivability.

Maximum stocking density

It is important not to stock up to a theoretical maximum but instead to provide a safety margin so as to ensure that, even when problems arise, fish continue to have good water quality and sufficient space for swimming. Farmers are not in control of all the factors – such as water quality and bad weather - that can adversely affect the fish. A safety margin is important to allow for harmful developments.

Recent research shows that above 22kg/m^3, increasing density is associated with lower welfare for caged Atlantic salmon.[14] However, in order to provide a safety margin, CIWF and WSPA believe that the maximum stocking density for Atlantic salmon in sea cages should ideally be 10kg/m^3, with farmers who achieve a high welfare status and in particular low levels of injuries, disease, parasitic attack and mortality being permitted to stock up to a maximum of 15kg/m^3.

The authors of the above study concluded that while stocking density can influence the welfare of Atlantic salmon in cages, it is only one influence on their welfare and on its own cannot be used to accurately predict or to control welfare.[14] This conclusion is what one may expect as the probability with any species (both fish and terrestrial) is that a number of factors will be involved in determining welfare.

Research shows that rainbow trout stocked at 40 and 80kg/m^3 have significantly more fin damage than those stocked at 10kg/m^3 and that growth and feed intake are greater and size variation is reduced in rainbow trout kept at around 25kg/m^3 as compared with 70 and 100kg/m^3. [13,18] In light of these studies and practical experience, CIWF and WSPA believe that the maximum stocking density for rainbow trout and for Atlantic salmon in the juvenile freshwater stages should be 20-30kg/m^3, provided that the rate and quality of water flow is high.

Low densities

Current knowledge suggests that very low densities should be avoided as they can lead to aggression. Rainbow trout should not be stocked at 10kg/m^3 or below as research has indicated certain welfare problems at this density; the authors suggest this may be due to the existence of a dominance hierarchy.[13] Salmon too should not be stocked at very low densities. The advisability of avoiding very low densities is not likely to be a problem in practice as the densities in question fall outside the range commonly used in commercial aquaculture.

The fact that welfare problems may arise at low densities indicates that fish are fundamentally unsuited to farming. Low densities do not present a problem in the wild where fish that are attacked by a con-specific are able to simply move away. However, in the confines of a cage or other enclosure, escape is not possible.

Water quality and flow rate

Good water quality is essential for the health and welfare of farmed fish. Water is the source of oxygen and also plays a vital role in disposing of wastes; it dilutes faeces and, if there is sufficient water flow, it removes faeces and uneaten feed. Dissolved oxygen is essential for fish respiration; below a certain level, asphyxia and increased mortality occur. Persistent exposure to elevated levels of carbon dioxide is likely to lead to chronic pathologies. Un-ionized ammonia is highly toxic to fish. A Council of Europe Recommendation points out that the accumulation of ammonia can be avoided by, among other things, reducing stocking density.[19]

Poor water quality can lead to both acute and chronic health and welfare problems. In particular, it can give rise to acute or chronic stress, reduced ability to control homeostasis, increased susceptibility to and incidence of disease, reduced condition factor, increased fin erosion and gill damage, reduced growth and increased mortality.[10,12,13]

A crucial factor that determines water quality and hence carrying capacity (the maximum density that is consistent with good health and welfare) is the flow rate of incoming water; this influences the provision of dissolved oxygen and the dilution and dispersal of wastes such as faeces and uneaten feed.

Health problems

An array of serious health problems are associated with intensive fish farming, although over recent years a number of issues relating to health and disease have been successfully addressed.

Håstein (2004) writes that under farming conditions, fish "may reach the outer limit of their physiological margin due to maximal exploitation and stress, making them susceptible to a wide range of diseases threatening ethical and welfare standards".[10] Stress generally reduces the ability to fight disease. Moreover, keeping large numbers of fish in crowded conditions facilitates the transmission of infectious diseases. Poppe and others (2002) point out that certain production-related or husbandry diseases have emerged concurrently with the intensification of husbandry practices.[20] These include various types of skeletal deformities, soft tissue malformations and cataracts.

Cataracts – and associated blindness – are a cause of concern in intensively farmed Atlantic salmon. [10,11] Skeletal malformations in farmed fish include spinal, head and jaw deformities. Deformities are a recurrent problem in farmed Atlantic salmon and leading Norwegian researchers stress that they "represent a challenge to the credibility of the industry, as sustained production of fish with malformations represents an ethical issue of increasing importance".[21]

Certain soft tissue anomalies have been observed in recent years in Atlantic salmon such as ventricular hypoplasia (underdevelopment of chambers that pump blood out of heart) , situs invertus of the heart (upside-down heart) and deficient septum transversum (a cardiac deformity).[10,20] These factors may lead to reduced tolerance to stress and increased mortality.[10] A proportion of farmed salmonids have developed rounder hearts than wild fish.[22] Such abnormally shaped hearts are associated with poorer cardiac function and a higher mortality rate during stressful procedures such as grading, lice treatments and transport. Poppe and others (2003) emphasise that there is a major ethical dilemma in farming fish that, due to limited cardiac capacity, are predisposed to cardiac failure during certain common, but stressful, aquaculture procedures.[22]

The incidence of several of the diseases that until recently were a major problem in aquaculture has been substantially reduced through the development of effective vaccination and improved management. Some diseases however, such as *Infectious Pancreatic Necrosis,* continue to present serious problems. Vaccination has in some cases had adverse side effects. Whilst we accept that progress has been made through vaccination, one must be careful not to use veterinary medicines to mask poor husbandry and hygiene.

Crowding, handling and grading

Fish are sometimes crowded to aid handling, for example prior to grading, counting, transport and slaughter. Crowding is undertaken in order to make it feasible to access fish; it involves gathering the fish into one section of the enclosure and leads to abnormally high stocking densities. Crowding is stressful and can lead to damage to scales, skin ulceration, eye and snout damage and bruising.[9]

Many farm activities – stripping, vaccination, tagging and marking, grading and splitting, loading prior to transport and unloading, movement to the stunning point - involve handling the fish and/ or moving them around the farm.

Handling is stressful, particularly if it entails removal from the water. It can result in scale loss, injuries to eyes and fins and muscle bruising.[10, 23] Handling can also lead to injuries to the skin, which is fishes' first line of defence against disease, and to damage to the mucous coating which secretes a protective layer over the skin and is a primary protection against pathogens and parasites.

Fish grow at varying rates. In natural conditions, smaller fish can avoid aggression by larger ones by moving away, but escape is difficult in the confined conditions of intensive farming and larger fish may bully smaller ones and prevent them from feeding or even cannibalise them. In order to minimise this, fish are periodically graded into different sizes. Fish may also be graded before slaughter to remove those not yet ready for slaughter. Grading is a stressful procedure [24] and can lead to physical injury to the fish.

Crowding, handling and grading are stressful and can cause injuries. Accordingly, they should be kept to a minimum. All farms should employ the methods used on the best farms and should keep up-to-date with developing best practice in this area. Fish should only be removed from water when absolutely necessary [8] and should not be kept out of water for more than 15 seconds unless anaesthetised.[25] Fish should not be kept crowded before slaughter for more than two hours.[25]

Transport

Juvenile fish are often transported to farms or sea cages to be fattened. On reaching slaughter weight, they are in some cases transported to the slaughter plant. Loading and transport can cause extensive stress in fish.[26,27] The capture/loading process is for most species the most stressful part of transport.[26,28,29] During transport, fish can sustain injuries from physical interaction with other fish or abrasion with the tank walls.[27] Poor conditions during transport, such as overcrowding and inadequate water quality, may result in irreparable damage to the fish and mortality.[10,30]

Transporting fish poses a significant risk of spreading disease. Because of this and the welfare problems involved, CIWF and WSPA are opposed to the transport of live fish over long distances. Transport must be kept to an absolute minimum. We concur with a Norwegian aquaculturalist's conclusion that "local production of eggs and juveniles and local processing [slaughter] is the answer".[31]

Starvation

Atlantic salmon and rainbow trout are often starved for several days, sometimes for two weeks or more, before slaughter to empty the gut. Such prolonged periods of starvation are unacceptable from the welfare viewpoint. Starvation periods should be kept as short as possible and should not exceed 72 hours.[32]

Starvation or feed reduction is also sometimes used to adapt production levels to the market situation. The purpose is to keep the fish off the market when market prices are low in the hope that prices will rise before the fish have to be sold. CIWF and WSPA believe that the use of starvation as a market-regulating mechanism should not be allowed on welfare grounds.

Tagging

So far fish have mainly been tagged for identification purposes in research. Some now advocate the tagging of farmed fish so that, in the event of escapes, it will be possible to distinguish farmed from wild fish, to monitor escapees and to trace the farms concerned. In addition, tagging may at some stage be promoted to ensure traceability from the fjord to the table.

CIWF and WSPA are opposed to any extension of tagging. The handling and restraint of fish involved in tagging are stressful and the insertion of tags can be painful and cause wounds and lead to infections.

Sea lice infestation

Intensive farming has led to sea lice infestation becoming a serious welfare problem for farmed salmon in many areas. Wild salmon range over a wide area, thereby minimising the opportunity for sea lice to find hosts. However, when thousands of salmon are kept in sea cages, they tend to attract substantial numbers of lice.

If untreated, sea lice infestation can lead to fish suffering greatly and dying. Current treatments focus on the use of in-feed or bath chemicals that have possible adverse environmental effects. More 'environmentally-friendly' methods - hydrogen peroxide and the use of wrasse to eat the lice off the salmon - have serious animal welfare drawbacks. Hydrogen peroxide is highly aversive to the fish and can cause mortalities. It is not acceptable to take wrasse from the wild and place them in cages where they suffer high mortalities due to starvation, bullying and being eaten by larger salmon.

Sea lice infestation should be controlled by improved management including careful site selection, complementary management procedures such as treating all the farms in an area at the same time, the separation of year classes and periodic fallowing of cage sites to break the cycle of parasite infection.

Algal blooms and jellyfish

Algal blooms can produce gill or nerve poisons, remove oxygen from the water and, in the worst cases, lead to mass mortality. Some jellyfish species have long trailing tentacles with stinging cells that can burn and even blind farmed fish. Unable to see properly, fish drift into the net mesh, which can result in heavy scale loss and consequent secondary infection.

Confined in cages, farmed fish are unable to evade algal blooms and jellyfish. The ethical acceptability of fish farming is called into question by the fact that it makes it impossible for fish to move away from dangers that they could avoid in the wild.

Predator control

Some farmers shoot seals and, in British Columbia and Chile, sea lions as part of predator control. Wild mammals and birds should not be shot or otherwise harmed as an anti-predator measure.

Every precaution should be taken to avoid predators gaining access to the fish through the use of anti-predator nets as well as the selective use of scarers and decoys.

Mortality

Mortality rates for salmon smolts reared in sea cages are high when compared with other farmed animals, amounting in Scotland to about 21 per cent. A leading researcher has questioned whether survival rates below 80-90 per cent can be considered acceptable for food producing animals kept under human custody (Midtlyng in Poppe and others, 2002).[20]

In Scotland, average survival rates tend to be below 80 per cent. The mortality rate for the 43 million smolts put to sea in Scotland in 2003 was 22.0 per cent [33], which means that around 9.5 million fish died after being put to sea and before slaughter. Such high mortality rates would rightly sound alarm bells in other branches of farming.

We recognise that in the wild mortality rates can be high due to predation. Farmed fish, however, are in general not subject to large-scale predation and accordingly it should be possible to keep mortality rates to a much lower level.

Biotechnology, genetic selection and genetic engineering

All-female fish and triploidy

Early sexual maturation in several species, particularly in males, presents problems for farmers. Sexually mature fish undergo changes that can reduce flesh quality. Moreover, if they escape, sexually mature fish can interbreed with wild stocks, thereby impairing their genetic integrity and reducing their chances of survival.

The industry uses sex reversal to produce batches of all-female fish, as in several species females mature later than males, thereby enabling the fish to be grown to greater weights. Sex reversal involves feeding the male sex hormone, testosterone, to young female fish.

Triploidy is a method of producing sterile fish by subjecting newly-fertilised eggs to heat or pressure shock. The resulting fish are induced to have triploid (three) sets of chromosomes instead of the usual diploid (two). The process is commonly used in conjunction with sex-reversal to produce sterile, all-female fish. Sterile female fish will not reach sexual maturity and so are able to be reared to greater weights without incurring the deterioration in flesh quality that accompanies maturation. In addition, sterile fish that escape will not endanger wild populations by inter-breeding.

Triploids are susceptible to a range of health and welfare problems, including higher levels of spinal deformities, eye cataracts, poorer growth and lower survival rates.[34-37] CIWF and WSPA believe that biotechnology techniques involving chromosome manipulation (e.g. sex reversal and triploidy) should be prohibited. We recognise that sex reversal does not entail any proven welfare problems. Nonetheless, we are concerned about it on ethical grounds and believe that the practice should be monitored to establish whether or not it has an adverse effect on welfare.

Selective breeding

Selective breeding is widely used in aquaculture to produce fish that grow more rapidly and to attain improved feed conversion rates, greater resistance to disease and delayed sexual maturation. Almost 100 per cent of the world's farmed Atlantic salmon production and about 25 per cent of the world's farmed rainbow trout production are based on stocks that have been subject to selective breeding.[38] Selectively bred salmon grow twice as fast as wild salmon.

Intense selection for fast growth or enhanced productivity has led to serious health problems in other farmed species such as meat chickens and dairy cows. We fear that farmed fish will soon begin to experience analogous health and welfare problems if the drive to accelerated growth rates continues unabated. Indeed, fast growth rates are already associated with an increased incidence of cataracts and abnormal heart shape and function.[22,39]

Genetic engineering

Genetic engineering techniques have been developed for aquaculture. These can push fish to even further extremes than traditional selective breeding. They threaten to push back the boundaries of intensification and cause yet more suffering for farmed fish. Researchers are working on fish that grow faster and larger, convert feed into flesh more efficiently, are resistant to disease, tolerant of low levels of oxygen in the water and can withstand freezing temperatures. Growth-enhanced transgenic Atlantic salmon have been produced that can grow 3-6 times faster than ordinary salmon.

Genetic engineering has led to serious health and welfare problems in fish. A major Canadian report concluded that unintended disadvantageous changes to the phenotype are the rule rather than the exception in the genetic modification of fish.[40] Expression of transgenes may have unintended adverse effects on many systems affecting the fitness of the fish, including tolerance to disease and stress.[35]

Serious deformities have been documented in coho salmon genetically engineered for accelerated growth, with abnormalities in the cranium, jaw and operculum due to excessive cartilage deposition.[41,42] This resulted in affected individuals suffering feeding and breathing difficulties and poor viability.[43] Moreover, reduced swimming abilities have been documented in growth-enhanced transgenic coho salmon.[44]

Farm escapes are already implicated in the decline of wild salmon stocks. Transgenic escapees threaten to have an even worse effect. They could displace wild fish through superior ability in securing food; they could also jeopardise wild fish by interbreeding with them, thereby undermining their genetic make-up and so producing fish less able to survive in the wild.

CIWF and WSPA are opposed to the development of genetically engineered fish for use in aquaculture.

Artificial lighting and photoperiod manipulation

Photoperiod, or the number of hours of daylight in a 24-hour period, can be manipulated, for example by the use of lamps positioned above or in the water. Such manipulation is used in Atlantic salmon to (i) vary the timing of spawning in order to obtain a supply of eggs for an increased proportion of the year, (ii) vary the timing of smoltification to produce smolts for transfer to seawater for an increased proportion of the year, (iii) reduce sexual maturation as this impairs flesh quality and (iv) increase growth. Photoperiod manipulation is used in rainbow trout to produce eggs out of season and to promote growth.

Relatively little research has been undertaken on the welfare implications of photoperiod manipulation, although studies have found that artificial photoperiods affect the immune system of rainbow trout and hence their susceptibility to pathogenic microorganisms.[45] Research is needed to investigate whether any further adverse welfare implications arise from photoperiod manipulation. Such research should in particular examine:

- **if accelerated growth leads to health and welfare problems:**
  The increase in growth can be substantial; continuous light on salmon cages in winter can produce 20-30 per cent greater growth. Accelerated growth rates are a source of serious health and welfare problems in terrestrial animals. For example, fast growing broiler chickens suffer from painful leg disorders and heart problems. It cannot be presumed that fish are immune to analogous dangers
- **if continuous lighting could lead to health and eye problems:**
  Continuous lighting can lead to serious problems in terrestrial animals such as, in chickens, increased stress and fearfulness, reduced responsiveness of the immune system and eye abnormalities including blindness. It cannot be assumed that fish are not susceptible to being adversely affected by continuous lighting
- **if artificial lighting may lead to stress:**
  Atlantic salmon reduce feed intake for the first 6-12 weeks after the lights are turned on; this indicates a stress situation
- **if the transfer of smolts to sea in autumn has any adverse welfare implications:**
  The natural seaward migration of wild smolts takes place in spring. Research needs to be undertaken to investigate if the practice of placing smolts in the sea at unnatural times such as autumn has any adverse welfare implications. Wild smolts experience long summer days after migrating to the sea, but this is not the case for farmed smolts transferred to seawater in autumn. Poor growth and variable growth have been reported in smolts transferred in autumn.

CIWF and WSPA are concerned about the use of artificial lighting regimes and believe that welfare is likely to benefit if fish are kept with natural light patterns.

Housing conditions

Cage netting should be smooth and non-abrasive to prevent injuries to the snout, fins and scales. Freshwater enclosures should be constructed of materials that minimise the potential for injuries.

Biological fouling is the process whereby various organisms – such as mussels, algae and marine bacteria – settle on to and colonise a surface such as the nets of a cage. If unchecked, biological fouling can lead to very substantial reductions in water flow through cages and hence to reduced oxygen levels and increased levels of fish wastes and ammonia in the water. Cleaning of fouled nets is essential.

Feeding method

The feeding method used must minimise competition and hence aggression and ensure that all the fish have access to feed. Whilst there is widespread agreement on this principle, there is considerable debate as to the most effective spatial and temporal strategies for achieving these aims.

The quantity of feed offered is a crucial factor; the provision of sufficient feed removes the need for competition and aggression. Feeding a few large meals per day may be more effective in reducing the formation of dominance hierarchies than the provision of many small meals throughout the day. Similarly, spreading feed over as much of the water surface as possible is accepted by some as being more successful in reducing the development of aggression/bullying than delivering the feed in a highly localised area.

Thus, an effective strategy for minimising aggression is to rapidly introduce a large amount of feed into the enclosure, with the feed being spread over a large proportion of the area. Dispersing feed over a wide space in a concentrated period of time makes it hard to defend and so can help prevent monopolisation by dominant fish.

Alternatively, systems that allow the fish to determine their own feeding regime can be successful. Demand feeders for trout and feeding salmon with a 'feedback loop' that turns off the feed when the fish are satiated can work well and minimise aggression provided that the system encourages the fish to come to the feed when they choose and then, having fed, move away again.

To summarise, it is not possible to conclude that one feeding method rather than another is in all situations the best; the guiding principle is that the feeding method used must minimise competition and hence aggression and ensure that all the fish have access to feed.

Environmental enrichment

There seems to be reasonably broad recognition that environmental enrichment may be beneficial for fish welfare, but little detailed research appears to have been undertaken.

The Fisheries Society of the British Isles has said that a degree of environmental complexity may be important, depending on the species concerned.[46]

Slaughter

A range of slaughter methods are used in fish farming, some of which cause great suffering and involve the fish taking a long time to lose consciousness. Asphyxiation in air and on ice, carbon dioxide stunning and gill cutting without prior stunning should be prohibited on welfare grounds

CIWF and WSPA are pleased that the use of carbon dioxide to stun fish will be prohibited in Norway from July 2008.

In recent years, some progress has been made in introducing better systems. Mechanised percussive stunning can produce immediate unconsciousness in Atlantic salmon. Electrical stun/kill systems can produce immediate unconsciousness that lasts until death in rainbow trout provided that appropriate current magnitude, duration and frequency are used. We welcome the fact that percussive stunning is used for the slaughter of most salmon in Scotland; this method is also used in Chile and British Columbia. Also welcome is the fact that in the UK, rainbow trout farmers who supply major retailers have installed electrical stun/kill systems, although some users have experienced seasonal flesh quality difficulties and so may not be using these systems on a regular basis. In most other rainbow trout producing countries the fish are killed by asphyxiation.

Sustainability issues

Threats to wild stocks from farmed fish

Farmed Atlantic salmon jeopardise the long-term sustainability of wild salmon as a result of escapes and the transmission of sea lice from salmon farms to wild fish. Wild Atlantic salmon numbers have fallen dramatically over the last 30 years. Up to two million salmon escape each year from farms in the North Atlantic. In some Norwegian rivers and coastal areas a high proportion of salmon are of farmed origin. The detrimental impact of farmed salmon on wild fish may arise in three ways:

- competition for feed and habitat
- transfer of diseases and parasites, particularly sea lice
- interbreeding with wild fish, leading to dilution of genetic integrity and impaired survival.

Feeding wild fish to farmed fish

Salmon and trout are natural carnivores. On the farm, they are fed compound feeds based on fishmeal and fish oil. The fishmeal and oil is mainly obtained from catching so-called 'industrial' or 'feed' fish species.

It is often claimed that fish farming may take the pressure off stocks of wild-caught fish by providing an alternative. However, for carnivorous species that rely on a high degree of fishmeal and fish oil in their diet the reverse can be true. Over three tonnes of wild-caught fish are needed to produce one tonne of farmed salmon.[2,47,48] It takes 2.3 tonnes of wild fish to produce one tonne of farmed trout.[2] For marine species such as halibut and cod, it can take over three times the weight in wild fish to produce a farmed fish.[2,49] The use of wild fish to feed farmed fish is damaging in a variety of ways:

- certain wild fish species utilised as feed (including mackerel, blue whiting, sardines, anchovies, pilchards and herring) could be used for direct human consumption
- certain wild industrial stocks are being severely over-fished and their viability jeopardised in order to produce feed for farmed fish
- a decrease in wild industrial stocks entails a reduction in feed supplies for predator fish, marine mammals and seabirds.

Farming of new species

Increasingly, new species such as Atlantic cod and Atlantic halibut are being introduced into intensive fish farming. The principal European farmed species – Atlantic salmon and rainbow trout – suffer from a range of welfare problems. We do not wish to see new species being exposed to similar problems. Accordingly, we are concerned about the introduction of new species into farming; at the very least there should be a moratorium on the use of new species until farmers are able to demonstrate that humane rearing, transport and slaughter methods have been developed for that species.

Atlantic cod

High stocking densities can result in impaired welfare in cod. CIWF and WSPA believe that the maximum stocking density for cod should be 10-15kg/m^3.

Many of the factors that lead to poor welfare in farmed Atlantic salmon and rainbow trout are also present in cod farming: cod are aggressive[50] and so need to be size-graded; they can suffer from anatomical deformities such as spinal deformities[51] and a range of diseases.[52] Moreover, they are often subjected to continuous artificial lighting in order to delay maturation. In addition, a proportion of broodstock are caught from the wild. Indeed, in Iceland and Norway a proportion of the cod that are farmed (not just the broodstock) have been captured from the wild for on-growing on farms.[53,54]

Atlantic halibut

The conditions prevalent in hatcheries and on-growing farms for Atlantic halibut are in stark contrast to their natural environment.[55] There are severe problems at the juvenile production stage for halibut, resulting in a wide range of survival rates. Aggression is common in young halibut during feeding, with injuries being sustained to the eyes, fins and tails.[48] Stocking halibut at high densities appears to lead to higher stress levels, reduced feeding motivation, lower growth and stereotypic behaviour in some fish.[56]

Organic and Freedom Food standards

CIWF and WSPA have reservations about the application of the term 'organic' to caged fish. However, organic standards and those of the RSPCA's Freedom Food scheme demonstrate that it is practicable to farm fish to significantly higher standards of welfare than those of conventional intensive farming. For example, the Soil Association lays down a maximum stocking density for Atlantic salmon in saltwater net pens of 10kg/m^3 +/- 1%. The Soil Association's maximum density for trout is 20kg/m^3 +/- 2% in running freshwater operations and 10kg/m^3 +/- 1% in net pens. Also welcome is the Soil Association's prohibition on the use of triploid, all-female and genetically engineered stock. The Organic Food Federation has produced standards for farmed cod that contain a number of valuable provisions. The standards set a maximum stocking density of 15kg/m^3 which we welcome.

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CLOSED WATERS: THE WELFARE OF FARMED ATLANTIC SALMON, RAINBOW TROUT, ATLANTIC COD & ATLANTIC HALIBUT

Leading researchers have summarised the problems inherent in modern intensive aquaculture as follows:

"In aquaculture, fish have limited possibilities of performing their natural behaviour in an environment to which they are not evolutionary adapted. Although the fish in this environment try to behave 'optimally' based on available decision rules, they are likely to have difficulties in behaving efficiently."

(Kristiansen & others, 2004)

Poppe and others (2002) have pointed out that in many countries aquaculture has developed into a huge, rapidly expanding industry. Management is increasingly focused on production efficiency and maximising output and profit. The economic benefits of increasing production outweigh the economic losses of malformations and other production diseases. In this climate, the fate of individual fish is of little concern.

"Although the intensification of aquaculture practices has been profitable and enabled the farmers to increase their production within the existing facilities, they probably have had a diametrical opposite effect by reducing the water quality and thereby leading to increased chronic stress, growth impairment and health problems, all indications of reduced welfare status."

(Toften & others, 2006, referring to land-based farms)

Scope of the report

This report focuses on the welfare of certain species of farmed fish during rearing, transport and slaughter. It concentrates on the welfare of Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*), whilst looking at Atlantic cod (*Gadus morhua*) and Atlantic halibut (*Hippoglossus hippoglossus* L.) in a separate section.

The largest producers of farmed Atlantic salmon are Norway, Chile, Scotland and Canada. Major producers of farmed rainbow trout include Chile, Norway, Turkey, Denmark, France, Italy, Spain, Iran, Germany, the US, the UK, Finland and Poland.

The principal salmon species covered is the Atlantic salmon; over 90 per cent of farmed salmon production comprises Atlantic salmon (Naylor & others, 2005). However, some references are also made to the Pacific salmon: chum salmon (*Oncorhynchus keta*), pink salmon (*Oncorhynchus gorbuscha*), coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tschawytscha*). Producers of farmed Pacific salmon include Chile, Canada and New Zealand.

Rainbow trout is the 'farmer's fish' of the trout family and has been reared for the table since the late nineteenth century. The brown or sea trout (Salmo trutta) is also farmed.

Atlantic cod and Atlantic halibut are being increasingly farmed in Norway, Scotland and Iceland.

It is well established that fish are likely to experience pain (Sneddon, 2003), fear and psychological stress and that, like other vertebrates, they have the capacity to suffer (Chandroo and others, 2004). Accordingly, it is important that their welfare is safeguarded.

Size of the industry

World aquaculture (fish farming) has been expanding rapidly over recent years and this expansion is likely to continue. Indeed, fish farming is the fastest growing sector in world production of animal-derived food. Worldwide aquaculture has increased at an average compounded rate of 9.2 per cent per year since 1970, compared to 1.4 per cent for capture fisheries and 2.8 per cent for terrestrial farmed meat production (Aerni, 2004).

Over the last 35 years, aquaculture's contribution to total global fish production has increased from 5.3 per cent by weight in 1970 to 40 per cent in 2005 (Tacon, 2004; FAO, 2007). Around 40 per cent of all fish directly consumed by humans worldwide are farmed (Naylor & others, 2005). Since the mid 1980s, the yield from capture fisheries has been static, which means that, if per capita fish consumption is not reduced, the yield from aquaculture will have to increase dramatically to keep pace with the growing world population. Indeed, it has been predicted that before long the yield from aquaculture will exceed the yield of edible fish from capture fisheries (Pike, 2005). One recent study predicts the collapse of all species of sea fish by 2048 if steep declines in fish populations continue at the present rate (collapse is defined as 90 per cent depletion) (Worm and others, 2006). This will inevitably lead to a major expansion of aquaculture.

European fish farming is dominated by the production of Atlantic salmon and trout. Other species farmed in Europe include Atlantic cod, Atlantic halibut, eel, sea bass, sea bream, carp and turbot. The Norwegian and Scottish industries, for example, while still dominated by Atlantic salmon and rainbow trout now also farm Atlantic cod and Atlantic halibut and, in Scotland, sea trout.

Aquaculture is an important source of fish in the EU. Total aquaculture production in the EU-25 is about 1.3 million tonnes live weight per year, having more than doubled since 1980 (Eurostat/FAO data). Its annual value is about €3 billion. US aquaculture produces around 500,000 tonnes per year and Canada about 150,000 tonnes annually (FAO, 2007).

Fish production data is normally given in tonnes, but some idea of the scale of the industry can be seen from the fact that in 2004 Britain produced around 35 million Atlantic salmon and about 40 million rainbow trout for the table, making aquaculture Britain's second largest livestock sector after 'broiler' chickens reared for meat.

Atlantic salmon

The production of farmed Atlantic salmon has grown dramatically since the early 1980s, with production worldwide increasing 55-fold in the two decades up to 2003 (FAO data).

Worldwide, over 1.2 million tonnes of farmed Atlantic salmon are now produced annually. Around 790,000 tonnes of this was produced in the North Atlantic area in 2005; the main North Atlantic producers are Norway and Scotland, with most of the rest being produced in the Faroe Islands, Ireland, the east coast of Canada and the U.S. Outside the North Atlantic, the major producers are Chile and British Columbia.

Norway produced 582,000 tonnes of farmed Atlantic salmon in 2005 (FAO data) which amounts to around 130 million farmed salmon being produced annually. Chile's production rose more than tenfold between 1993 and 2005, standing at 374,000 tonnes in 2005 (FAO data). Scotland's production in 2004 was 158,000 tonnes, amounting to around 35 million fish (FRS, 2004); this fell to 130,000 tonnes in 2005 (FRS, 2005). In British Columbia, where Atlantic salmon comprise 77 per cent of farmed fish, even though the species is not indigenous to this area, 48,000 tonnes of farmed Atlantic salmon were produced in 2004 (82,000 tonnes were produced in Canada as a whole). **Table 1** shows annual production of Atlantic salmon in the main producing countries.

Table 1: Farmed Atlantic salmon production

COUNTRY	1983 tonnes	1993 tonnes	2003 tonnes	2004 tonnes	2005 tonnes
Worldwide	20,638	305,610	1,130,784	1,253 047	1,235,972
Norway	17,298	155,581	509,544	563,815	582,043
Chile	0	29,180	280,041	354,504	374,387
Scotland	10,337 (1)	48,691	169,736	158,000	130,000
Canada	68	23,483	90,150	82,374	83,653
Faroe Islands	90	17,660	52,526	40,985	18,962
Australia	0	3,500	15,208	16,476	16,033
Ireland	257	12,366	16,347	14,067	13,764
U.S.	0	10,750	16,315	15,127	9,401
Iceland	79	2,348	3,708	6,624	6,488

(1) Figure for 1986

Source: FAO: Fisheries Global Information System & Fisheries Research Services, Scotland

Rainbow trout

Total production of rainbow trout in Britain in 2004 was 15,374 tonnes (CEFAS, 2005; FRS, 2004). Of this, 11,274 tonnes were for the table market and 4,100 tonnes for restocking purposes. Production for the table market was evenly divided between Scotland and England and Wales; 5,858 tonnes were produced in England and Wales and 5,416 tonnes in Scotland. In addition, Northern Ireland produced 431 tonnes for the table in 2004 and 112 tonnes for restocking, giving a UK total for 2004 of 15,917 tonnes (CEFAS, 2006).

Worldwide production of rainbow trout in 2005 amounted to 486,928 tonnes (FAO, 2007). **Table 2** shows annual production of farmed rainbow trout in the main producing countries.

Table 2: Farmed rainbow trout production

COUNTRY	Production in tonnes in 2005
Worldwide	486,928
Chile	118,279
Norway	58,781
Turkey	40,250 (1)
Denmark	36,587
Iran	34,760
France	32,412
Italy	30,558
U.S.	27,504
Spain	25,959
Germany	19,343
Poland	15,700
Finland	13,693
UK	12,458
Ireland	1,614

(1): Turkey figure is for 2004

Sources: FAO, CEFAS

Wild Atlantic salmon and rainbow trout

An important feature of Atlantic salmon is their ability to live in both fresh water and, from a certain stage of their lives, in seawater. In the wild, spawning, hatching and early growth take place in rivers, but once they have transformed into smolts – a process that equips them to live in salt water - they migrate to the sea where they grow very quickly. Those from British rivers may roam the ocean as far away as Greenland and the Norwegian Sea. After spending between one and four years at sea, they return to their home river to breed. Some return after just one winter at sea; these early maturing fish are known as grilse. This movement from river to sea and back enables the fish to benefit from the conditions found in each ecosystem (Willoughby, 1999). There are fewer predators in rivers, so a reasonable proportion of fish survive the early stages of life; however the more plentiful food supply that is available in the sea is needed to achieve good adult growth.

The rainbow trout is native to North America and it is from these fish that the domestic rainbow trout farmed in Europe probably descend. Rainbow trout essentially live in freshwater, but there is a saltwater species. In rivers, some types of rainbow trout live in shallow water above gravel beds, others in the lower reaches of fast, large, rock-bottomed rivers. Whether they are river or lake-based, rainbow trout breed in rivers.

The life cycle of farmed fish

Breeding

The life cycle on a fish farm begins when eggs are stripped (removed) from the parent or 'brood' stock before being fertilised.

In the case of Atlantic salmon, female fish are removed from the water and then anaesthetised by being immersed in a tank containing anaesthetic solution. A stockperson then releases the eggs by a firm stroking motion along the abdomen. Care must be taken as hard pressure can lead to internal bleeding. Some facilities introduce compressed air through a needle into the abdominal cavity of the anaesthetised fish to push out the eggs. Once stripped of her eggs, the female is either killed or put into a tank to recover and be used again. Alternatively, the female salmon is removed from the water and killed, after which her eggs are removed surgically. In Scotland 22,188 female salmon were stripped in 2002; 15,801 were stripped in 2004, with 10,033 being stripped in 2005 (FRS, 2002, 2004 & 2005). The average ova yield per fish has increased from 4,867 in 2002 to 7,297 in 2005 (FRS, 2002 & 2005).

Female rainbow trout are removed from the water and stripped manually by a stroking motion. They are sometimes sedated before stripping. In some cases, they are stripped annually over a period of about three years.

Sperm or 'milt' is extracted from the anaesthetised male salmon by stroking the abdomen. Some males are killed after the first stripping, while others are kept alive for further use.

CIWF and WSPA are concerned about these methods of obtaining eggs and sperm, some of which are invasive and involve removing the fish from water. That said, in Scotland fish are anaesthetised prior to stripping. **We believe that this should be a normal part of best practice; our view is that all fish should be anaesthetised prior to stripping.**

Rearing in freshwater

Once they have been fertilised, the eggs are transferred to incubator trays and placed along a trough with flowing water. On hatching, the trays are removed and the young fish develop in the trough, feeding for several weeks on the contents of their yolk sac. Once this has been consumed, the tiny fish begin to swim up from the bottom of the tank and eat feed sprinkled onto the water surface.

When they have grown to be as long as one's finger, the fish - now known as *fingerlings* – are transferred for on-growing in a variety of freshwater systems.

Rainbow trout are usually reared in freshwater cages, earth ponds or raceways with a continuous flow of water. Rainbow trout is generally a much smaller fish than salmon and can be reared to a range of sizes. Many are slaughtered as 'portion-size' trout at 280-450g. Some are left to grow on to greater weights of 450-900g, while others are slaughtered at over 900g. Some rainbow trout are reared in fresh water for the first part of their life and then transferred to seawater for on-growing, usually in cages. After one year at sea, they can reach weights of 2.5-4kg.

Salmon *parr* (young salmon in freshwater) are commonly raised in freshwater cages or tanks and raceways. Freshwater cages tend to measure 12m². Parr grow rapidly through the winter and in spring undergo *smoltification*. This is a physiological pre-adaptation to life in seawater while the young fish still live in fresh water; this will equip them to survive and develop normally in the sea (Willoughby, 1999). At this point, the juveniles are known as *smolts*. Those that smoltify after one year are known as S1 smolts. Others take two years and are known as S2 smolts although these are no longer used in the Scottish industry.

Parr can be made to smolt six months early by temperature manipulation and/or the use of artificial light regimes that first 'trick' the fish into winter physiological processes (parr cannot develop into smolt without going through winter) and then mimic the increasing day length of spring. These are known as half-year smolts or S½ smolts. This intensification leads to a substantial reduction in the time needed for the salmon to reach slaughter weight. Of the smolts produced in Scotland, 35 per cent are S½ smolts, with nearly all the rest being S1 (FRS, 2005).

Rearing in seawater

Salmon smolts are transferred to sea cages in lorries, helicopters or well boats. Most cages are sited in coastal lochs or fjords, but offshore sites are now being established. Typically, a series of cages are connected to each other and to a floating metal walkway. A net is suspended from each cage to entrap the fish. Cages come in a range of shapes: square, circular, octagonal, hexagonal and rectangular. Large sea cages measure up to 24m², although in Scotland some of the smaller farms are using 15m², with much fewer fish in them. Round cages can have a circumference of 90-120 metres. A typical modern cage in Norway has a depth of 20 metres or more (the maximum would be 25 metres). Up to 50,000 or even 75,000 salmon may be confined in the largest sea cages.

Salmon are usually slaughtered after one or two years at sea, with a few being slaughtered in the year of input. Slaughter weights generally range from 4.1-4.6kg (FRS, 2004).

Stocking density

Water quality has a fundamental role in determining welfare. There is, however, currently much debate about the effect of stocking density on welfare. It is sometimes argued that stocking density has no or little impact on the welfare of farmed salmon or trout. This, however, is not borne out by a careful examination of the scientific literature in this field.

The literature indicates that stocking density is important as it is one of a range of factors – including water quality, flow rate of incoming water and feeding method - that interact to determine the welfare of farmed salmon and trout. Ellis and others (2004) concluded that stocking density is "an important factor for fish welfare, but cannot be considered in isolation from other environmental factors". As indicated above, water quality has a major effect on welfare. One of the principal concerns about high stocking density is that, in the case of rainbow trout, it has been clearly shown to have a detrimental effect on water quality parameters (Ellis & others, 2002).

Stocking density is a complex issue in fish as it involves consideration of both the behavioural need for space and the physiological need for water to provide oxygen and dilute and remove waste products (Ellis & others, 2004).

How to assess the impact of stocking density on welfare

When subjected to a stressor, fish exhibit a range of stress responses. The *primary* stress response includes the release into the bloodstream of the 'stress hormones' adrenaline and cortisol (FSBI, 2002). These induce short-term *secondary* metabolic changes. The primary and secondary responses are short-term effects of acute, short-lived stressors (FSBI, 2002).

The *tertiary* stress response, however, involves long-term reactions to a prolonged or repeated stressor. Tertiary effects include suppressed immune function and hence increased vulnerability to disease, reduced growth rates, impaired reproduction and a decrease in condition factor (Ellis & others, 2002; FSBI, 2002).

Based on the above stress responses and other considerations, studies in this field have utilised a wide range of indicators to assess whether welfare in farmed fish is impaired. These include: increased disease incidence; increased level of physical injuries, for example to fins, skin, snouts and tails; poor body condition; reduced growth; reduced feed intake; reduced feed conversion efficiency; increased aggression; increased size variation (which may result from aggression and some fish obtaining insufficient feed); and increased levels of cortisol.

Impact of stocking density on welfare

Ashley (2006) stresses: "Stocking density is a pivotal factor affecting fish welfare in the aquaculture industry, especially where high densities in confined environments are aimed at high productivity".

This report will first examine studies that consider the impact of stocking density on the welfare of farmed fish generally or on the welfare of both Atlantic salmon and rainbow trout. It will then examine studies that deal exclusively with (i) Atlantic salmon and (ii) rainbow trout.

A number of respected authorities have stressed that high densities can have an adverse impact on fish welfare:

- The UK Farm Animal Welfare Council concluded: "Stocking densities are a crucial factor affecting fish welfare". It added: "The stocking density must allow fish to show most normal behaviour." (FAWC, 1996)
- Norwegian researchers Juell and others (2003), write: "There is a legitimate public concern that fish are kept at too high densities in intensive aquaculture". They add: "Acute or chronic crowding may reduce the welfare of the fish through increased fin erosion or periods of suboptimal oxygen levels."
- In a review paper presented at a major OIE conference on animal welfare, Håstein (2004), summarising the welfare implications of high stocking densities, stated: "High densities may lead to stressful conditions, increase aggressive behaviour and a reduction in food conversion rate and growth. Furthermore, in intensive fish farming whereby a large number of individuals are kept close together, physical injuries to the skin and to the fins caused due to direct contact between the fish or the cage wall may occur. Such lesions may allow colonisation of both primary and secondary pathogens and substantially increase the risk of infection for the fish … high stocking densities may also decrease the water quality and thus accelerate other problems."

- Wall (2000), a fish veterinarian, refers to the welfare problems that can arise at high densities. He writes: "It is well recognised that high densities can lead to stress which may affect the quality of the fish. External abrasion of flanks, tails and snouts is commonly seen in this situation. Any sub-clinical or carrier disease may become an overt clinical condition … Finally, fish held at high stocking densities seem to be more susceptible to predation, particularly seals in sea cages."
- The Fisheries Society of the British Isles writes that: "There is plenty of evidence of poor welfare in salmon and trout held at very high densities, but it is not clear whether this is the result of poor water quality, high levels of aggression, simple physical damage or some other process" (FSBI, 2002).

Increased susceptibility to disease at high densities

Scientific research and practical experience indicate that at high densities, fish are more vulnerable to disease outbreaks and that once disease enters a crowded enclosure, high densities facilitate rapid transmission (Wall, 2000; Håstein, 2004). Sedgwick (1988) in his *Salmon Farming Handbook* states that most of the more dangerous diseases are density dependent.

In an overview report, the European Commission (2004) refers to the increased risk of disease transmission at high densities. The report states that increasing stocking densities compared to natural densities leads to an increase in fish interactions and that: "A secondary effect of frequent interactions between animals is the potential increase of horizontal disease transfer, either from fish to fish or through the water".

Fin damage

Fin damage is multi-factorial in its causation; high stocking density is not the sole cause. Nonetheless, fin damage is increased at higher stocking densities in both Atlantic salmon and rainbow trout (Bosakowski & Wagner, 1994; Ellis & others, 2002; Juell & others, 2003; North & others, 2004; Turnbull & others, 2005). Fin damage is commonly considered a sign of unsuitable rearing conditions such as high stocking density (Alanärä & Brännäs, 1996).

Fin lesions increase susceptibility to pathogen infection (Ellis & others, 2002; Håstein, 2004). The initial injury makes the fish predisposed to infection by opportunistic pathogens, which in turn leads to further erosion. Severe erosion can reduce long-term survival (Winfree & others, 1998).

Various causes of fin damage have been identified including infection, deterioration in water quality, nips by fellow fish and abrasion with the walls of the rearing unit or fellow fish, for example incidental contact during feeding; all these factors can result from higher stocking densities (Wall, 2000; Ellis & others, 2002; Håstein, 2004).

All rayed fins are subject to damage in intensively reared rainbow trout; indeed, the fin damage can be very severe (Ellis & others, 2002). These authors stress that fin damage in salmonids is a well-documented effect of increasing stocking density. They state that initial fin damage is generally attributed to aggressive nipping or abrasion with fellow fish or the walls of the rearing unit. Once initial damage has been caused, additional erosion may result from continued nipping or abrasion and/or impaired water quality (ammonia and alkalinity) and infection. High stocking density can promote both the initial cause and also secondary infection as high density can lead to poor water quality and increased potential for pathogen transmission (Ellis & others, 2002).

Bosakowski and Wagner (1994) found that fin erosion in trout is correlated with lower alkalinities, unnatural bottom substrates (concrete or steel), higher un-ionised ammonia levels and higher densities. They pointed out that in the case of contact with unnatural bottom substrates, the abrasion may breach the fish's first line of defence, permitting invasion by opportunistic bacteria and fungi that continue to erode the fin.

The researchers concluded that crowding does have a detrimental effect on fin health; it can induce behavioural changes such as fin nipping or lead to water quality and disease problems.

They said that a management strategy to produce trout with better fin quality would include: keeping lower fish densities, using gravel or dirt bottom ponds, maintaining lower ammonia levels by reducing fish density or increasing water flow, and utilising water sources with higher alkalinities. Lower density also leads to better fin condition in steelhead trout, possibly because physical contacts are reduced by less frequent encounters (Winfree & others, 1998).

Constraint of natural swimming behaviour at high densities

It is important that the stocking density for fish takes account not just of their physiological needs but also of their behavioural needs for physical space. The Fisheries Society of the British Isles states that fish should have sufficient space to allow a degree of freedom of movement, but that the definition of 'sufficient' will be species-specific (FSBI, 2002).

Wild salmon often swim great distances in the sea; average migration rates can be 5-30km per day (Willoughby, 1999). This author refers to a study that tracked a salmon from Norway to a river in Russia 2,500km away; the journey had taken 52 days averaging 48km per day. Juell (1995) stated that cage-reared salmon "are held at artificially high densities … Their movements are restricted to a small volume of water, depriving them of the opportunity to carry out feeding and spawning migrations … In contrast to the free-ranging life of wild salmon, the swimming behaviour of farmed salmon is constrained by the cage and influenced by high densities". He stressed that Atlantic salmon must still be seen as an undomesticated species.

Willoughby (1999) in his *Manual of Salmonid Farming* points out that salmon in sea cages are "raised in unnaturally close proximity to each other in confined conditions".

Sedgwick (1988) in his *Salmon Farming Handbook* writes: "Salmon are animals genetically programmed to spend most of their lives swimming freely through the oceans. We now confine them in tanks or cages in close proximity and frequent physical contact with thousands of others. In the open sea they would probably never have come as close to any other fish of their own kind before returning to spawn."

Sufficient lateral swimming space is a basic need (Schwedler & Johnson, 1997). However, swimming activity is constrained at high densities (Håstein, 2004 referring to Begout & Lagardere, 1999).

In recent years, heart problems have been found in Atlantic salmon (Håstein, 2004). One hypothesis suggests that some of the observed heart problems are part of a 'life-style' disease due to sedentary cage life with little exercise and surplus food compared with wild fish (European Commission, 2004; Håstein, 2004).

Caged salmon typically swim in a circular school during daylight (Oppedal & others, 2001). At dusk the salmon ascend, swimming speed decreases and the schooling groups gradually disperse. Often, however, artificial lighting is used during late autumn, winter and early spring to maintain schooling behaviour during the night.

Schooling may not be the natural behaviour of wild salmon for much of their time at sea. In natural conditions, smolts form small schools during the initial part of their feeding migration, probably to reduce the high risk of predation at this stage (Juell, 1995). This author points out that the duration of schooling is unknown but that – crucially – "catch statistics give no indication of schools at later stages".

Schools are not observed at low densities in caged salmon or rainbow trout; schools only form when the stocking density is increased (Juell, 1995). Thus, it seems that the high densities that are prevalent in today's aquaculture induce caged salmon to swim in schools, a practice that may not be their natural behaviour in the wild for much of their time at sea.

Indeed, Juell and others (2006) stress that it is important to recognise that the schooling of caged salmon "is a fundamental shift in behavioural mode where the control of the behaviour is transferred from the individual to the group level". They add that it has been suggested that caged salmon keep up schooling throughout their seawater growth, contrary to their wild counterparts, "as a behavioural adaptation to reduce the stress of the high density environment in commercial cages".

In conclusion, rearing salmon in cages constrains their natural swimming behaviour as it deprives them of swimming the great distances that are the norm for wild salmon at sea. Constraint of natural swimming behaviour is exacerbated at high densities.

Lack of proper exercise may be leading to heart problems in Atlantic salmon. High densities in cages induce Atlantic salmon to swim in schools, which may not be their natural behaviour in the wild for much of their time at sea and which may be a behavioural adaptation to reduce the stress of the high density environment in commercial cages.

Research is needed to examine the health and welfare impact on Atlantic salmon and rainbow trout of the constraints placed on their natural swimming behaviour by intensive aquaculture.

Tertiary stress responses

As indicated earlier, the *tertiary* stress response involves long-term reactions to a prolonged or repeated stressor. Tertiary effects include suppressed immune function and hence increased vulnerability to disease, reduced growth rates and a decrease in condition factor (Ellis & others, 2002; FSBI, 2002).

We have already seen that there is increased vulnerability to disease at high densities. In addition, growth, feed intake (Boujard & others, 2002; Ellis & others, 2002) and feed conversion efficiency (Ellis & others, 2002) are impaired at higher densities in rainbow trout. Moreover, higher densities have an adverse effect on body condition in both Atlantic salmon and rainbow trout (Ellis & others, 2002; Turnbull & others, 2005). The fact that tertiary stress responses are present at high densities would suggest that high density is a stressor.

Atlantic salmon

Turnbull and others (2005) studied the relationship between stocking density and welfare in Atlantic salmon farmed in marine cages. They found that high stocking densities above a threshold level are associated with reduction of welfare in farmed salmon. They found that threshold to be approximately 22kg/m^3 in the conditions prevailing in their study which was carried out in commercial on-growing cages on the west coast of Scotland.

The researchers used a multivariate analysis to combine four commonly used measures of fish welfare into a single welfare score. Two of the measures were physical indicators (fin condition and body condition) and two were physiological (plasma concentrations of glucose and cortisol). The study found that the welfare score was significantly related to stocking density and, in particular, that after an inflection point of approximately 22kg/m^3 increasing density was associated with lower welfare scores. The authors concluded that while stocking density can influence the welfare of Atlantic salmon in cages, it is only one influence on their welfare and on its own cannot be used to accurately predict or to control welfare.

The finding that, above a threshold level, high stocking density is associated with reduction of welfare in farmed Atlantic salmon is important. The conclusion that stocking density is only one influence on their welfare is what one may expect as the probability with any species (both fish and terrestrial) is that a number of factors will be involved in determining welfare.

In a study of caged Atlantic salmon, Norwegian researchers found that at densities above 26.5kg/m^3 there was reduced performance in the form of a decrease in appetite, growth and condition, poorer feed conversion and an increase in eye cataracts, fin erosion, body lesions and mortality (Juell & others, 2006).

Another Norwegian study reports that juvenile Atlantic salmon exposed to high density and sub-optimal water quality showed reduced feed intake and growth in freshwater and that, in some cases, these negative effects continued after the exposure had ceased and the fish had been transferred to seawater (Toften & others, 2005). In addition, they found that the fish reared most intensively had a clear tendency to increased mortalities after *Infectious Pancreatic Necrosis* challenge. The researchers identified low specific water flow, high levels of carbon dioxide and oxygen and high fish density as risk factors. They concluded that a combination of these factors gave the lowest growth and highest mortality rates.

Fish do not distribute themselves uniformly within the cage volume. Because caged Atlantic salmon tend to school and also because they choose to occupy those areas of the cage with preferred conditions (e.g. preferred temperature, oxygen and light levels), the actual density in certain parts of the cage may be much higher than the stocking density, which is simply total biomass divided by cage volume. This makes it particularly important to avoid excessive stocking densities as the more fish that are placed in the cage, the higher will be the actual density in preferred areas, which will lead to some fish being forced into areas of the cage with suboptimal environmental conditions.

Rainbow trout

Ashley (2006) writes: "There is considerable evidence for decreasing welfare associated with high stocking densities in rainbow trout".

North and others (2006) examined rainbow trout at densities of 10, 40 and 80kg/m^3. They found that stocking density did not significantly affect mortality or growth. However, they said that the lack of a density effect on growth in their study may have been due to the maintenance of key water quality parameters above critical levels by the use of high rates of water exchange and additional aeration. In practice not all farms may be able to maintain high levels of water quality at all times at high densities.

The researchers reported that there appeared to be greater size variation in the 10kg/m^3 group, possibly indicating the presence of a stronger dominance hierarchy. Condition factor was lower in the 10kg/m^3 group than in the 40kg/m^3 treatment in one of the nine months of the programme. However, at the end of the experiment there were no significant differences in condition factor between the different density groups. Levels of cortisol were significantly higher in the 10kg/m^3 group compared with the 80kg/m^3 treatment on five of the nine monthly samples. However, the researchers pointed out that two other studies have reported increased cortisol levels with increasing density; they added that the lower cortisol levels at the higher densities in their study may be the result of an adaptive response to those high densities.

Set against the above factors, the researchers found that the 40 and 80kg/m^3 groups had significantly more fin erosion than the 10kg/m^3 group. The researchers pointed out that an increase in the prevalence of fin erosion with increased stocking density is perhaps the most consistently reported effect of stocking density on rainbow trout. They suggested that possible causes of increased fin erosion at higher density include abrasion against the sides of rearing units or conspecifics, aggressive and/or accidental nipping at feeding, handling, poor water quality and pathogen infection. They concluded that fin erosion increased with increasing density, but that the evidence for stronger dominance hierarchies in the 10kg/m^3 group indicates that low as well as high densities have the potential to adversely affect trout welfare.

Boujard and others (2002) investigated the effect of stocking density on feed intake and related factors in rainbow trout. They found that feed intake and growth are impaired at higher densities. They examined trout stocked at three different densities; final biomass at the end of the trial was around 25, 70 and 100kg/m^3 in the three groups respectively. The researchers found that density had a significant effect on final average fish body weight with the fish kept at lowest density having the greatest weight and the fish kept at the highest density weighing least.

Similarly, feed intake was greatest at the lowest density and least at the highest density. Moreover, there was a trend for greater size variation between fish at the higher densities. In conclusion, feed intake and growth are greater and size variation is reduced at around 25kg/m^3 as compared with 70 and 100kg/m^3.

A study of columnaris disease in rainbow trout found that transmission of the disease was faster at normal rearing densities than at lower densities and that, at high temperature (23°C), mortality from the disease was higher at normal than at lower densities (Suomalainen & others, 2005). This suggests that reduction of density could be used in prevention of columnaris disease.

Ellis and others (2002) reviewed the scientific literature concerning the relationship between stocking density and welfare in farmed rainbow trout. These authors examined 43 papers that studied the effects of stocking density on productivity, health, condition and stress level. They found that commonly reported effects of increasing stocking density include an increase in fin erosion and reductions in growth, feed intake, feed conversion efficiency plus body and liver condition. They concluded that such changes are indicative of a reduced welfare status.

Ellis and others (2002) refer to a range of papers that indicate that a number of welfare-related parameters are adversely affected by higher stocking densities. In particular they:

- refer to three studies that indicate that feed intake is reduced at higher stocking densities
- refer to a number of studies that have recorded a reduction in feed conversion efficiency at higher densities
- state that growth was measured in nearly all the studies examined and the majority found that higher stocking densities led to reduced growth
- refer to studies showing that higher densities have an adverse effect on body condition and hepatosomatic index (liver weight/body weight); this indicates that increasing stocking densities can potentially have a detrimental effect on nutritional status
- state that the majority of papers that assessed fin damage found that higher stocking densities had an adverse effect on fin condition
- report that certain abnormalities in gill lamellae are commonly associated with high densities
- refer to a study that found that high densities can cause prolonged leucopenia (a reduction in the number of white blood cells) in salmonids. This can lead to a weakening of the body's immune system and increased susceptibility to disease. It can also reduce clotting rate and hence protection against physical injury
- stress that increasing stocking density increases the probability of episodic mortality in cases where water supply, aeration or oxygen systems fail.

This last point was borne out in the study by North and others (2004). The researchers carried out an experiment in which two mass mortalities occurred due to plumbing failures and warned that operating at high stocking densities and relatively low water inflow rates runs an increased risk of mass mortality in the event of system failure. Clearly, elevated stocking densities necessitate a high degree of supervision and suitable back-up equipment.

In light of the above factors, Ellis and others (2002) concluded that high stocking density can reduce welfare status in rainbow trout.

The reason that high stocking density can have an adverse impact on welfare lies in the fact that such densities can lead to:

- a deterioration in water quality, and/or
- an increase in aggressive behaviour, and/or
- an increase in non-aggressive behavioural interactions such as collision and abrasion with other fish or the walls of the rearing unit (Ellis & others, 2002).

There is much debate as to whether water quality deterioration or increased aggressive behaviour is the main cause of the adverse effect of high stocking density on the welfare of rainbow trout. The weight of evidence indicates that water quality deterioration is the primary cause. However, the relative contributions of each may vary depending on the specific circumstances (Ellis, 2002).

Non-aggressive behavioural interactions may also make a significant contribution (Ellis & others, 2002). Each of these causal factors will now be examined:

Deterioration in water quality

Good water quality is essential for the health and welfare of farmed fish. Water is the source of oxygen and also plays a vital role in disposing of wastes; it dilutes faeces and, if there is sufficient water flow, it removes faeces and uneaten feed.

An increase in stocking density can result in deterioration in water quality as more fish are respiring and metabolising in a particular volume of water (Ellis & others, 2002). Increased densities can add to the amount of suspended solids in the water column; a rise in the number of fish in a given volume of water leads to an increase in both faecal production and fish movement which prevents particles from settling (Ellis & others, 2002). These authors stress that "increasing density has been clearly shown to have a detrimental effect on water quality parameters". As indicated in the section on **Water quality** (on page 31), deterioration in water quality can have serious harmful effects on welfare.

Dissolved oxygen is essential for fish respiration. Un-ionized ammonia is highly toxic to fish (CoE, 2006); trout are particularly sensitive to un-ionized ammonia (Ellis & others, 2002). Increased densities can lead to a reduction in dissolved oxygen concentrations and an increase in the level of un-ionized ammonia (Ellis & others, 2002). These authors state that there is little doubt that increasing the trout biomass in a given volume of water reduces dissolved oxygen concentrations and that high densities can reduce dissolved oxygen to below 5mg/litre. It is generally thought that the dissolved oxygen level must be at least 6mg/litre for farmed salmonids and that lower levels can produce sublethal/chronic adverse effects.

Referring to intensive tank and recycle systems, Conte (2004) writes that, if precautions are not taken, higher densities overload systems with metabolites thereby leading to stress that exceeds the threshold of pre-pathological manifestation.

Non-aggressive interactions

At higher stocking densities there may be an increase in non-aggressive interactions which can have an adverse effect on welfare. There is evidence that high densities lead to increased injuries to the fin, snout and peduncle due to collision or abrasion with the walls of the rearing unit or fish colliding with each other (Ellis & others, 2002).

Moreover, feeding may be restricted by high stocking density as this may impair visual location of feed and may also prevent access by making it difficult for fish to follow a course to the feed pellets (Ellis & others, 2002).

Relationship between stocking density and aggression in rainbow trout and Atlantic salmon

High stocking density is one factor that can lead to aggressive behaviour in salmonids; aggression results in poor welfare in terms of fin injuries, scale loss, chronic stress and subordinate fish being prevented from feeding by dominant fish (Ellis & others, 2002; European Commission, 2004).

Both the aggression and the associated social hierarchies can lead to reduced welfare for the subordinate fish. Subordinate trout have elevated plasma cortisol levels (indicative of stress) and show reduced appetite and a reduction, plus greater day-to-day variability, in feed intake (Ellis & others, 2002).

It is sometimes suggested that high densities may result in a decrease in aggression; the thinking is that dominance hierarchies may break down as at high densities it becomes very difficult for individuals to defend specific areas (Alanärä & Brännäs, 1996). However, a number of studies in rainbow trout indicate that aggression in fact *increases* with increasing density (Ellis & others, 2002). These authors point out, however, that these studies were at lower densities than are typical of aquaculture systems. Nonetheless, they conclude: "The limited evidence … indicates that both social hierarchies and nipping do persist with increasing density".

In contrast to this, low densities can lead to aggression in farmed rainbow trout. Ellis & others (2002) state that too low a stocking density for rainbow trout can have an adverse effect on welfare in a confined area as it may lead to poor feeding response and aggressive behaviour which can result in excessive mortality. As indicated earlier, North and others (2006) found greater size variation and higher cortisol levels in rainbow trout stocked at 10kg/m^3 than those stocked at higher densities. The authors suggested that a dominance hierarchy may be responsible for these welfare aspects being poorer at lower densities. However, as indicated above, Ellis and others (2002) found that aggression persists – and can increase – at higher densities.

It is thought that farmed freshwater salmon may also be more aggressive at low densities. In rivers, wild salmon are competitive, seeking to establish territories that offer feeding and environmental benefits. Farmed freshwater salmon kept at low densities behave similarly to wild salmon by establishing hierarchies and defending territories in order to gain preferential access to feed that arrives in their territory (Kadri & others, 1996). In order to inhibit the formation of hierarchies, shoaling needs to be established and this only occurs above a certain density.

In the sea, salmon are generally not aggressive. They may show aggression to protect a localised feed resource, although this is probably not common. It is unusual to see aggression in caged salmon; however, aggressive interactions have been observed at very low densities (Juell, 1995). It should, however, be noted that Turnbull and others (2004) found that salmon stocked at 9.7-14.6kg/m^3 were in better condition than those stocked at 14.7-19.6kg/m^3. The Soil Association's organic standards set a maximum density of 10kg/m^3 for caged salmon, a density that would generally be regarded as low in a commercial operation. The Soil Association has not received any feedback from organic farms to indicate that the low density of 10kg/m^3 is leading in practice to problems of aggression.

It may be that the position for freshwater trout and salmon is as follows. There may be aggression at low densities as the fish establish and defend territories; this is reduced as density increases and shoaling becomes established. However, at even higher densities, aggression is likely to persist and indeed to increase.

It should be noted that the presence of aggression and its degree are determined not just by stocking density, but also by other factors such as water quality and feeding method (Ashley, 2006). There is less likelihood of aggression if the feeding method is successful in getting feed to all the fish. If water quality in a freshwater enclosure is problematic, the best water quality may be found at the enclosure's headway with the result that fish may fight for space in this area.

Conclusion

High stocking densities can have a detrimental impact on the health and welfare of Atlantic salmon and rainbow trout. In particular, high densities can lead to increased susceptibility to disease; increased incidence of physical injuries such as fin erosion; poor body condition; increased stress; and reduced growth, feed intake and feed conversion efficiency in rainbow trout. All these factors are indicative of a reduced welfare status. In addition, high densities can lead to poor water quality and increased aggression which in turn result in impaired health and welfare.

Setting a maximum stocking density

When setting a stocking density, it is important not to stock up to a theoretical maximum, but instead to provide a safety margin so as to ensure that, even when problems arise, fish have good water quality and sufficient space for swimming. Farmers are not in control of all the factors

– such as water quality - that can adversely affect the fish; difficulties can occur when there is deterioration in environmental conditions or water quality or a change in the weather or net deformation (and hence less available space) due to changing currents or turbulent weather. A safety margin is important to allow for such adverse developments.

For example, Turnbull and others (2004) found that after an inflection point of approximately 22kg/m^3, increasing density was associated with lower welfare scores in Atlantic salmon. During this study, dissolved oxygen and water temperatures were within the recommended ranges for Atlantic salmon in sea cages for the vast majority of the time. Welfare at a density of 22kg/m^3 may be acceptable if water quality is optimal, but if water quality deteriorates, welfare may be impaired at such a relatively high density. As farmers cannot be in control of water quality at all times, stocking densities lower than the theoretical maximum should be employed.

Conte (2004), referring to intensive tank and recycle systems, emphasises the dangers of failures in the system and points out that: "The short time period between system failure and animal impairment in high-density fish culture requires strict management protocols to avoid stress-associated loss. *Because of this, producers should avoid operating at absolute maximum carrying capacity*." [*Our emphasis*.]

Another factor that suggests it is prudent not to stock at too high a density is that, in the event of a disease outbreak, the potential for disease spread is enhanced at higher densities.

Practical experience indicates that lower densities produce benefits in terms of better performance, better feed conversion, better quality, better health, less disease and less size variation. For example, one Scottish trout farm used to stock at a high density of around 35-40kg/m^3 and experienced poor fin quality plus a high level of parasites. Since substantially reducing its density to around 21-22kg/m^3, this farm has fewer disease outbreaks, less fin damage and improved survivability.

In light of the above considerations, CIWF and WSPA believe that the maximum stocking density for Atlantic salmon in sea cages should ideally be 10kg/m^3, with farmers who achieve a high welfare status and in particular low levels of injuries, disease, parasitic attack and mortality being permitted to stock up to a maximum of 15kg/m^3.

North and others (2006) found that rainbow trout stocked at 40 and 80kg/m^3 had significantly more fin damage than those stocked at 10kg/m^3. Boujard and others (2002) found that growth and feed intake are greater and size variation is reduced in rainbow trout kept at around 25kg/m^3 as compared with 70 and 100kg/m^3.

In light of these studies and practical experience, CIWF and WSPA believe that the maximum stocking density for rainbow trout and for Atlantic salmon in the juvenile freshwater stages should be 20-30kg/m^3 provided that the rate and quality of water flow is high

At our current level of understanding it appears that very low densities should be avoided as they can lead to aggression. Rainbow trout should not be stocked at 10kg/m^3 or below as North and others (2006) reported certain welfare problems at this density. Salmon should not be stocked at very low densities either. The advisability of avoiding very low densities is not likely to be a problem in practice as the densities in question fall outside the range commonly used in commercial aquaculture.

The fact that welfare problems may arise at low densities indicates that fish are fundamentally unsuited to farming. Low densities do not present a problem in the wild where fish that are attacked by a con-specific are able to simply move away. However, in the confines of a cage or other enclosure, escape is not possible.

Water quality

Good water quality and appropriate flow rates are essential for the health and welfare of farmed fish (Ellis & others, 2002; FSBI, 2002; Conte, 2004; European Commission, 2004; Håstein, 2004; Tosten & others, 2006). Water is the source of oxygen and also plays a vital role in disposing of wastes.

Water quality deterioration can lead both to acute welfare infringements and to a chronic reduction in welfare status (Ellis & others, 2002). Variation of key water quality parameters outside acceptable ranges can lead to stress, distress, impaired health and mortality (Conte, 2004).

The Fisheries Society of the British Isles has identified water quality, flow rates and temperature appropriate for the species concerned as being critical for fish welfare (FSBI, 2002). It writes that: "Water quality (in terms of dissolved oxygen, ammonia and pH) and the presence of contaminants (organic and inorganic pollutants) are probably the most critical aspects of the environment for fish welfare and also the best defined".

Conte (2004) writes: "Chemical imbalances in water cause direct harm to fish by disrupting such physiological functions as ionic regulation, gill and kidney function, or by destroying the fishes' mucous coating, which is a primary protection against pathogenic and parasitic invasion".

A crucial factor that determines water quality and hence carrying capacity (the maximum density that is consistent with good health and welfare) is the flow rate of incoming water. Because the inflow rate influences the provision of dissolved oxygen and the dilution and dispersal of wastes, it is of vital importance in determining any enclosure's carrying capacity, i.e. the biomass of fish that it can support. Although a good flow rate is important, it must not be so strong that fish have difficulty in holding their position within the water column.

For good water quality in cage systems, water must flow through the cage at a rate adequate to remove faeces and uneaten feed and replace it with cleaner water containing sufficient dissolved oxygen concentrations. Low water flow can lead to negative changes in the gills and kidneys and to reduced growth, condition factor and disease resistance in Atlantic salmon (Toften & others, 2006).

Håstein (2004) stressed that for all farmed species good water quality and reasonable water flow rates are a necessity. He said: "There is little doubt that poor water quality may lead to disturbance in the fish due to acute or chronic stress. During chronic stress, the fish may lose the ability to control homeostasis, resulting in reduced growth and resistance to disease. Furthermore, it has been shown that lowered water circulation may induce aggression in fish, cause heterogeneous growth and increased susceptibility to disease".

Reviewing the literature on rainbow trout, Ellis and others (2002) report that:

- raised un-ionised ammonia levels are correlated with an increase in fin erosion and in mortality
- low dissolved oxygen and raised un-ionised ammonia levels are commonly associated with a range of diseases
- both low dissolved oxygen levels and high levels of un-ionised ammonia can act as chronic stressors in rainbow trout, increasing plasma cortisol levels
- gill damage is a common effect of ammonia
- both chronic exposure to ammonia and insufficient dissolved oxygen lead to reduced growth rates.

Ellis and others (2002) conclude: "Water quality deterioration therefore has the potential to reduce welfare status by reducing nutritional status and causing physiological stress, injury to gills and fins and increasing susceptibility to disease".

North and others (2004) conducted an experiment designed to assess the effect of water quality deterioration on rainbow trout welfare. The researchers adjusted water inflow rates (20, 40 and

60litre/min) in tanks containing identical numbers of fish. They found a significant effect of inflow rate on growth and condition factor; in certain months of the study, average fish weight and condition factor were significantly higher at 60litre/min as compared with 20 and 40litre/min. As indicated earlier, water quality is in part determined by the amount and quality of inflow water.

Conclusion

Poor water quality can lead to both acute and chronic health and welfare problems. In particular, it can give rise to acute or chronic stress, reduced ability to control homeostasis, reduced growth, reduced condition factor, increased susceptibility to and incidence of disease, increased fin erosion and gill damage and increased mortality. A crucial factor that determines water quality and hence carrying capacity is the flow rate of incoming water; this influences the provision of dissolved oxygen and the dilution and dispersal of wastes such as faeces and uneaten feed.

Water quality parameters

The parameters that affect water quality – such as dissolved oxygen, un-ionised ammonia, CO_2, pH, temperature, salinity and water flow - are closely interrelated. The acceptable range for these parameters varies from species to species. Moreover, the parameters for any particular species may vary between different life stages. Recommendations in the literature for appropriate levels for the key parameters of dissolved oxygen and un-ionised ammonia vary, often differing by a factor of two or more (Ellis, 2002).

Dissolved oxygen

Dissolved oxygen is essential for fish respiration. Low dissolved oxygen levels lead to reduced growth, poorer feed conversion and behavioural changes such as excessive respiratory ventilation (Willoughby, 1999). Below a certain level, asphyxia occurs (Ellis & others, 2002). A dissolved oxygen level of less than 3mg/litre causes increased mortality (Willoughby, 1999).

The ability of water to dissolve oxygen is determined by temperature, atmospheric pressure and salinity (Willoughby, 1999). Lower temperatures enable more oxygen to be carried in the water and thus allow more fish to be safely supported (BTA, 2002).

Trout farmers commonly seek to boost water quality and carrying capacity by using aeration or oxygenation to increase the level of dissolved oxygen, particularly in the later stages of production.

Ammonia

As indicated earlier, un-ionised ammonia is highly toxic to fish – trout are particularly sensitive. Ionised ammonia is relatively non-toxic. Willoughby (1999) states that ammonia concentration is dependent on a range of factors including how intensely a farm is managed. The Recommendation concerning farmed fish of the Standing Committee of the European Convention for the protection of animals kept for farming purposes points out that the accumulation of ammonia can be avoided by, among other things, reducing stocking density (CoE, 2006).

The level of un-ionised ammonia that will have an adverse affect on rainbow trout varies, being dependent on environmental factors such as dissolved oxygen and CO_2 levels, temperature, prior exposure, duration of exposure and the fish's stage of development (Ellis & others, 2002).

Carbon dioxide

Persistent exposure to excessive levels of CO_2 is likely to lead to chronic pathologies such as kidney damage. Fish exposed to high CO_2 levels (and reduced pH) show reduced feed intake and poor growth (Toften & others, 2006).

pH

pH is the measure of water's acidity or alkalinity. Neutral water has a pH of 7. A higher pH indicates alkalinity, a lower pH indicates acidity. Sea water has a stable pH. When pH is too low fish can suffer from acidosis which produces skin and gill irritation and reduces the blood's oxygen carrying ability. When pH is too high alkalosis can occur and produce similar effects as acidosis. Elevated pH levels can lead to an increase in the un-ionised proportion of total ammonia.

Temperature

In water temperatures just above freezing, salmonids are lethargic and expend very little energy (Willoughby, 1999). As the temperature rises, so do their activity levels and their need for oxygen and feed. Willoughby (1999) states that when temperatures move outside the normal range for the species, fish are generally unable to adapt in the way that terrestrial animals can. Higher temperatures have been linked to increased territoriality and aggression and increased fin damage (Ellis & others, 2002).

As temperatures rise, fish need more oxygen – paradoxically, as temperatures rise, the water's oxygen carrying capacity goes down and so less oxygen is available. Accordingly, at high temperatures aeration and oxygenisation become more important.

Temperature is one of the major factors inducing deformities (Baeverfjord & others, 2005). For salmon eggs, excessive temperatures during embryogenesis may lead to malformations (European Commission, 2004). In the freshwater stage, elevated temperature also appears to contribute to inducing malformations, with the incidence and severity of malformations in salmon being greater at higher temperatures (European Commission, 2004; Baeverfjord & others, 2005).

Health problems

Various serious health problems are associated with intensive fish farming. It should however be noted that, due to a greater understanding of fish health, improvements in husbandry standards and work carried out by veterinarians and others with expertise in fish health, a number of issues relating to health and disease have been successfully addressed.

Håstein (2004) writes that under farming conditions, fish "may reach the outer limit of their physiological margin due to maximal exploitation and stress, making them susceptible to a wide range of diseases threatening ethical and welfare standards". Stress generally reduces the ability to fight disease. Moreover, keeping large numbers of fish in crowded conditions clearly facilitates the transmission of infectious diseases among the fish. Poppe and others (2002) point out that certain production-related or husbandry diseases have emerged concurrently with the intensification of husbandry practices. These include cataracts plus various types of skeletal deformities and soft tissue malformations.

Cataracts

Cataracts – and associated blindness – are a recurrent problem in intensively farmed Atlantic salmon (European Commission, 2004; Håstein, 2004). Cataracts are also found in farmed sea bass and sea bream (European Commission, 2004). The fish eye is a delicate organ and one of the first to be affected by disease or stressful situations.

One study found a very high incidence of cataracts in farmed Atlantic salmon in Norway. It reported a prevalence of cataracts of around 80 per cent (Ersdal & others, 2001). Vision was impaired in nearly 30 per cent of the fish and around 5 per cent were effectively blind in one or both eyes.

Blindness in salmon leads to maladjustment, listlessness and surface lesions, while cataracts result in reduced growth due to difficulties in feeding (European Commission, 2004; Håstein, 2004).

Skeletal deformities

Skeletal malformations in farmed fish include spinal, head, jaw and opercular deformities. Baeverfjord and others (2005) state that deformities are a recurrent problem in farmed Atlantic salmon and "represent a challenge to the credibility of the industry, as sustained production of fish with malformations represents an ethical issue of increasing importance".

Vertebral column deformations are regularly observed in farmed Atlantic salmon and represent a serious problem (Fjelldal & others, 2005; Gjerde & others, 2005). One study examined four year-classes of Atlantic salmon and found an average incidence of vertebral deformities of 9.5, 7.6, 21.5 and 2.3 per cent (Gjerde & others, 2005). These problems, which affect not just salmon but many farmed species, can lead to reduced growth and elevated mortality (European Commission, 2004). Factors involved in causing skeletal deformities include inadequate nutrition, poor water quality and the use of excessive temperatures during incubation and early rearing in order to accelerate the development of the fish (Baeverfjord & others, 2005). It should be noted that the industry has been working on these problems, for example incubation temperatures have been modified and deformity due to this has been reduced.

Soft tissue anomalies

Certain soft tissue anomalies have been observed in recent years in farmed Atlantic salmon, including ventricular hypoplasia (underdevelopment of chambers that pump blood out of heart), situs invertus of the heart (upside-down heart), deficient septum transversum (a cardiac deformity) and aberrant heart morphology (Poppe & others, 2002; Håstein, 2004). These factors may lead to disturbances in blood circulation, resulting in reduced tolerance to stress and increased mortality (Håstein, 2004).

The normal triangular shape of the salmonid ventricle is associated with optimum cardiac functioning. A proportion of farmed salmonids have developed rounder hearts compared to wild fish (Poppe & others, 2003). Several Norwegian fish veterinarians report that fish with such abnormally shaped hearts have a higher mortality rate during stressful procedures such as grading, lice treatments and transport. Similar problems in farmed Atlantic salmon with abnormally shaped hearts have been found in British Columbia, where one study reported that around 20 per cent of the population at one site died from cardiac deformities following pre-slaughter grading, crowding and transport (Brocklebank & Raverty, 2002).

Those farmed fish that have aberrant heart shape and function are unable to produce the high cardiac output required to cope with energetically demanding situations, rapid growth or sub-optimal rearing conditions such as fouled nets, algal blooms and jellyfish (Poppe & others, 2003).

Poppe and others (2003) emphasise that there is a major ethical dilemma in farming fish that, due to limited cardiac capacity, are predisposed to cardiac failure during certain common, but stressful, aquaculture procedures. They conjecture that these differences in heart morphology may be due to the sedentary lifestyle of farmed fish, fast growth or selective breeding that may not take organ shape and functioning into account or a combination of these factors.

Disease

The incidence of several of the diseases that until recently were a major problem in aquaculture has been substantially reduced through the development of effective vaccination and improved management. Some diseases however, continue to present serious problems. Indeed, a leading Norwegian practitioner stresses that disease continues to be the biggest threat to the salmon farming industry (Myrseth, 2005). For example, due to *Infectious Salmon Anaemia*, salmon production in the Faroe Islands has dropped from 37,000 tonnes in 2004 to a predicted 14,000 tonnes in 2006 (Myrseth, 2005).

The disease *Infectious Pancreatic Necrosis* (IPN) caused by IPN virus has over the last 5-10 years become widespread in Scottish marine salmon farms and is also present in other areas of Atlantic salmon farming (Anon, 2003). In both Norway and Scotland, IPN has become a serious cause of acute mortality in Atlantic salmon smolts shortly after introduction to sea water; it can also cause very considerable mortality in freshwater, particularly in the vulnerable fry stages (Anon, 2003). In addition, it can result in suppression of appetite and associated reduced growth rates. IPN is found in several farmed species including cod and halibut, but especially affects salmonids. New IPN vaccines are proving successful in reducing the incidence of IPN.

Although vaccination has played a key role in reducing the incidence of certain diseases, it has in some cases had adverse side effects particularly when adjuvanted (the use of a substance to enhance a vaccine's efficacy). These include inflammatory reactions ranging from mild to severe and adhesions between organs as well as between internal organs and the peritoneal wall (Håstein, 2004). Moreover, vaccination is likely to be stressful to the fish as it involves handling and injection (Ashley, 2006). Whilst we accept that progress has been made through vaccination, one must be careful not to use veterinary medicines to mask poor husbandry and hygiene.

Increased susceptibility to parasites

Barber (2006) points out that wild fish have evolved patterns of behaviour designed to avoid or limit exposure to infective parasites. In the wild fish can avoid habitats with high parasite densities; however, fish confined in cages are unable to do so. Barber (2006) writes: "If the capacity to modify habitat choice in response to the detection of infective parasite stages is constrained [by confinement in a cage], then any adaptive behavioural control that individual fish have over their exposure to parasites may be impaired". This problem may be compounded if high cage stocking densities and/or large group sizes in cages lead to increased detectability of farmed fish by mobile parasites (Barber, 2006). Moreover, high densities in intensive rearing conditions facilitate parasite transmission among the fish (Barber, 2006).

Crowding, handling & grading

Crowding

Fish are sometimes crowded to aid handling, for example prior to grading, counting, transport and slaughter. Crowding is undertaken in order to make it feasible to access fish; it involves gathering the fish into one section of the cage or other enclosure and leads to abnormally high stocking densities. Fish are crowded prior to slaughter so that they can be delivered to the stunning point. Pre-slaughter crowding can result in significant increases in stress levels (Skjervold & others, 2001). The Humane Slaughter Association recommends that fish should not be kept crowded for more than two hours (HSA, 2005).

Crowding is a stressful procedure that may cause lesions in fish and is a prime cause of poor welfare (Wall, 2000). The main problem is often a lack of sufficient oxygen in these densely packed conditions as well as elevated levels of ammonia. The low oxygen levels can result in an increase in excitability, which can in turn lead to an even faster decrease in oxygen levels. The increase in excitability can lead to damage to scales, skin ulceration, eye and snout damage and bruising (Wall, 2000). Moreover, aggression between large and small fish is probably more frequent in the confined conditions of crowding. It is good practice to routinely monitor oxygen in the crowd. Ensuring a good water flow through the crowd, which can usually be achieved, will remove ammonia from the water and bring in oxygen, so keeping the stress levels low.

Handling

Many farm activities – stripping, vaccination, tagging and marking, grading and splitting, loading prior to transport and unloading, counting, weight sampling and transfer to the stunning point – involve handling the fish and/or moving them around the farm. Handling is stressful, particularly if it entails removal from the water. Ashley (2006) stresses that removal from the water elicits a maximal emergency physiological response and should only be carried out when absolutely necessary. Handling can, moreover, result in scale loss, injuries to eyes and fins and muscle bruising (Willoughby, 1999; Håstein, 2004). Salmon smolts are particularly vulnerable to scale loss. Handling can also lead to injuries to the skin, which is fishes' first line of defence against disease, plus can damage the mucous coating which secretes a protective layer over the skin and is a primary protection against pathogens and parasites.

Various methods are used to move fish in farms. Nets can cause abrasions and involve removal from the water, whereas pumps and pipes have the advantage of keeping the fish in water and, if well-designed, produce fewer abrasions than nets. Poorly designed pumping systems, however, can damage fish as can allowing them to drop onto hard surfaces at the point of exit from a pipe.

Grading

Fish grow at varying rates. In natural conditions, smaller fish can avoid aggression by larger ones by moving away, but in the confined conditions of intensive farming systems, larger fish may bully smaller ones and prevent them from feeding or even cannibalise them. In order to minimise this, fish are periodically graded into different sizes. In addition, as they grow larger, fish may be split into two batches to reduce the biomass in the cage. Fish may also be graded before slaughter to remove those not yet ready for slaughter. Grading is carried out on both Atlantic salmon and rainbow trout.

Grading is a stressful procedure (Dunlop & others, 2004). It can lead to physical damage to the fish and post-grading disease outbreaks; accordingly, grading should be kept to a minimum. One type of grading involves catching the fish in nets or pumping them up and then distributing them over a series of bars, with smaller fish falling through the slats. A study of rainbow trout describes how prior to and during grading, the water level in the raceway is lowered and the fish are contained in high densities. Fish are then netted out of the raceway and fed into one end of the grader where they move along a conveyor belt, falling into trays according to their size (Dunlop & others, 2004).

An alternative method is passive grading. In one such system, a sweep net is used to enclose all the fish in the cage and is then gradually lifted. The smaller fish are able to swim out through apertures in a passive grader that is inserted into the net, while the larger fish remain in the net. The benefits of passive grading are that fish are not removed from the water and a good system reduces the physical damage and stress involved in grading. Fish are often crowded for passive grading, but this can be avoided if the farmer is prepared for the grading to be a relatively slow process.

Counting

Counting is also a stressful procedure for fish (Dunlop & others, 2004). This study describes how during counting, rainbow trout are concentrated in high densities at the lower end of a raceway by the use of a barrier. They are then netted into a large barrel until a specific weight has been reached, after which they are released into the upper part of the raceway. This process continues until all the fish have been counted. Salmon are generally only counted at transfer to the farm, with the total number of fish from that point being calculated by deducting any mortalities, which are counted routinely.

Conclusion

Crowding, handling and grading are commonly used in intensive aquaculture. These procedures are stressful and can lead to injuries. Their use should be kept to a minimum and the industry should continue to develop less stressful ways of carry out these procedures. All farms should employ the methods used on the best farms and should keep up-to-date with developing best practice in this area. Fish should only be removed from water when absolutely necessary (Ashley, 2006) and should not be kept out of water for more than 15 seconds unless anaesthetised (HSA, 2005). Fish should not be kept crowded before slaughter for more than two hours (HSA, 2005).

Transport

Young rainbow trout are often transported to on-growing farms where they will be fattened to slaughter weight. Salmon smolts are transported from freshwater sites to sea cages. In some cases, slaughter weight salmon are transported from the cage to the processing (slaughter) plant; this has the disadvantage of involving an extra journey, but the potential welfare benefits of slaughter in a purpose built facility. Other salmon are slaughtered on a boat stationed adjacent to the cage, thereby dispensing with the need for transport. In some countries, however, on-farm slaughter is prohibited due to the risk of spreading disease.

There are various methods for transporting farmed fish, especially salmon: well boats, helicopters and water tanks carried on flat-bed trucks. The transport of smolts to on-growing sea cages in Norway is mainly carried out by well boats; Norway has a fleet of about 125 such boats. In well boats, fish are kept in a pool of seawater within the boat's hull. The water in a well boat is not static. It is exchanged with water from outside the boat through the well of the boat by pressure caused by the boat's motion, with pumps being used to refresh the water when it stops. Helicopters are sometimes used to move salmon smolts to sea cages. Fish are crowded into highly-oxygenated water and carried in a purpose-built tank or 'bucket' slung underneath the helicopter. Helicopters are used for very short journeys only.

Loading and transport can cause extensive stress in fish and thus may negatively affect survival (Iversen & others, 1998; Cooke & others, 2004). It takes more than 48 hours for Atlantic salmon smolts to return to pre-stress levels of plasma cortisol after the stress of capture/loading and transport (Iversen & others, 1998). During transport, fish can sustain injuries from physical interaction with other fish or from abrasion or concussion with the tank walls (Cooke & others, 2004). The capture/loading process is for most species the most stressful part of transport (Iversen & others, 1998 & 2005; EFSA, 2004a). Loading and unloading salmon when they are transported from sea cages to the slaughter facility involves pumping the fish in the UK; this is also usually the case in Norway. Netting the fish is a slower process and is likely to be poorer in welfare terms than pumping.

Poor conditions during transport, such as overcrowding and inadequate water quality due to insufficient oxygen and/or accumulation of carbon dioxide and ammonia, may result in irreparable damage to the fish and mortality (Håstein, 2004; Rosten, 2005). Transport during rough seas may lead to increased mortality in the first few weeks after transfer of Atlantic salmon smolts to sea cages (Iversen & others, 2005). Håstein (2004) adds that transportation of yearling coho salmon by truck "has been reported to cause a marked physiological stress response and reduced relative fitness as well as lower survival rate and ability to tolerate a second stressing agent". Anaesthesia or sedation, for example by metomidate or low concentrations of clove oil, can reduce transport stress (Sandodden & others, 2001; Cooke & others, 2004). Neither anaesthetic is licensed for use in fish in the EU.

Transporting fish poses a significant risk of spreading disease such as *Infectious Pancreatic Necrosis* (Anon, 2003) and *Infectious Salmon Anaemia.* Because of the danger of spreading disease, Myrseth (2005) advocates the elimination of transport of any live fish over long distances. He states that "local production of eggs and juveniles and local processing [slaughter] is the answer".

Conclusion

Due to the risk of spreading disease and the welfare problems involved, CIWF and WSPA are opposed to the transport of live fish over long distances. Transport must be kept to an absolute minimum.

Starvation

Fish are starved before transport to empty the gut, so preventing excretion of waste products and the resultant deterioration in water quality. They are also starved before slaughter to empty the gut; this is done to minimise the risk of the flesh being contaminated during gutting.

Starvation duration should be kept to a minimum as prolonged starvation is highly likely to be detrimental to welfare. Håstein (2004) points out that starvation can lead to phenomena such as eye snapping, tail biting and cannibalism, especially at high temperatures. Moreover, the immune status of fish deteriorates after just a short period of starvation (EFSA, 2004a).

Although dependent on temperature, it takes 24-72 hours to achieve gut clearance. The UK Farm Animal Welfare Council has recommended that periods in which fish are deprived of feed prior to certain management procedures or slaughter should not normally exceed 48 hours for trout and 72 hours for salmon (FAWC, 1996). Disturbingly, a 2005 survey of seven leading UK supermarkets by CIWF (*Raising the Standards)* found that the average pre-slaughter starvation period for salmon sold by six of them ranged from 6-15 days; only in the case of Marks & Spencer was the average three days. In all seven supermarkets, the maximum period was well above three days, ranging from 7-15 days. **CIWF and WSPA believe that such lengthy starvation periods are unnecessary to achieve gut clearance and are unacceptable in welfare terms. We believe that salmon and trout should not be starved before slaughter for more than 72 hours.**

Many in the industry measure starvation periods in 'degree days' (the temperature in centigrade multiplied by the number of days). This is helpful in factoring in the role of temperature in determining the length of time needed to achieve gut clearance. It may, however, lead to the sanctioning of excessive starvation periods.

Some argue that fish survive long periods of food deprivation in the wild, for example, during periods of winter scarcity or when salmon return to freshwater to spawn – and that therefore prolonged starvation has no significant impact on fish welfare. This argument is unconvincing. Wild salmon go without feed when, as sexually mature fish, they migrate to spawn. Farmed salmon are slaughtered when still sexually immature, i.e. they are forced to undergo pre-slaughter starvation at a point in their life cycle when they would not voluntarily undertake such self-deprivation. Indeed, the European Commission's report (2004) points out that fishes' natural behaviour of reducing feeding at certain times is temperature-, age-, species- and season-dependent and that depriving fish of food during non-natural periods might lead to reduced welfare.

CIWF and WSPA believe that starving farmed fish - that have previously been fed regularly - for prolonged periods is unacceptable in welfare terms.

Starvation or feed reduction is also sometimes used to adapt production levels to the market situation. The purpose is to keep the fish off the market (which involves reducing growth rates and feeding costs) when market prices are low in the hope that prices will rise before the fish have to be sold. CIWF and WSPA believe that the use of starvation as a market-regulating mechanism should not be allowed on welfare grounds.

Conclusion

Prolonged periods of starvation are unnecessary to achieve gut clearance and are unacceptable from the welfare viewpoint. Starvation periods for salmon and trout should be kept as short as possible and should not exceed 72 hours.

Tagging

To date, fish have mainly been tagged for identification purposes in research such as population studies and feeding experiments. Some now advocate the tagging of farmed fish so that, in the event of escapes, it will be possible to distinguish farmed from wild fish, to monitor escapees and to trace the farms from where they escaped. Indeed, Iceland requires 10 per cent of fish farmed in cages to be tagged (Naylor & others, 2005). In addition, tagging may at some stage be promoted to ensure traceability from the fjord to the table.

CIWF and WSPA are opposed to any extension of tagging. The handling and restraint of fish involved in tagging are stressful and the insertion of tags may be painful and cause wounds. Various tagging methods are in use, including fin clipping, external and internal tags and hot and freeze branding (Håstein & others, 2001).

Most tagging methods pose threats to fish health and welfare. Fin clipping results in increased mortality (Håstein & others, 2001). External tags are attached with threads, wires or filaments. These perforate and produce lesions in the skin and musculature, which can lead to secondary infections and algal attachments to the wounds (Håstein & others, 2001). If external tags are not properly anchored, they may result in chronic open wounds (Håstein, 2004). Coded wire-tags consist of a wire that is introduced into the snout (commonly known as 'snout tags'). These can lead to mortality due to secondary infections and reduced growth due to destruction of tissues in the snout area which impairs the ability to feed (Håstein & others, 2001).

Sea lice infestation

One of the major difficulties facing the aquaculture industry is the proliferation of sea lice in marine cage fish farms (SEPA, 2005). Although sea lice infestation in Scotland, for example, has reduced somewhat, it continues to be a serious concern.

The large number of salmon contained in cages allows sea lice to multiply substantially. Wild salmon range over a wide area, thereby minimising the opportunity for sea lice to find hosts. However, when thousands of salmon are kept in sea cages, they tend to attract substantial numbers of lice. Losses due to fish diseases are estimated to cost the Norwegian salmon industry around 700-900 million NOK a year, of which the largest item - 300-500 million NOK – is due to sea lice (Myrseth, 2005).

Sea lice infestation is a serious welfare concern in farmed salmon (Ashley, 2006). Sea lice are small crustaceans that can weaken and kill affected fish by eating their flesh (Naylor & Burke, 2005). They feed on the blood and underlying tissues of their host, causing scale loss and skin lesions. Skin is a crucial protective barrier in fish and skin damage permits the development of secondary infections. Lice damage around the head can be so severe that the bone of the living fishes' skull can be exposed. In extreme infestations, fish can suffer from osmoregulatory failure and death (SEPA, 2005). Moreover, sea lice not only inflict direct damage on the fish, but can also transmit *Infectious Salmon Anaemia* and furunculosis to the fish (Willoughby, 1999).

Wild salmon rid themselves of lice naturally as they drop off when the fish enter freshwater on migration. For farmed salmon, the solution is far less simple. A range of treatments exists for sea lice. However, most are questionable on welfare or environmental grounds. They involve bathing the fish in a chemical solution, feeding an oral pesticide or using 'cleaner' fish, such as wrasse, to eat the lice off infested fish.

Bath treatments

Infested fish are bathed in a chemical that paralyses the lice. The fish are crowded together by hauling up the cage netting before being enclosed in a 'skirt' of tarpaulin. The chemical is then applied. Both procedures cause a great deal of stress to the fish if not carried out properly. Application of the chemical can cause losses amongst the fish as they can panic and burrow into the corners of the cage (Wall, 1999).

One bath treatment seen as environmentally friendly is hydrogen peroxide. It has not been used recently in Scotland. Its environmentally-friendly credentials stem from hydrogen peroxide breaking down chemically during treatment into water and oxygen. It is, however, not welfare-friendly. Hydrogen peroxide is a well-known irritant. Fish find it very stressful and its application can cause significant mortality. As well as causing the fish to suffer, it is not fully effective at removing lice. It works by stunning the lice rather than killing them. Successful treatment relies on the crowded fish knocking against each other or rubbing against the nets to dislodge the stunned lice. Any lice that are not removed simply recover.

In-feed oral treatments

The treatment of sea lice by in-feed anti-parasitic chemicals does not entail the crowding or bathing of fish in irritant chemicals. Environmentally, in-feed treatments can be targeted more closely at the sea lice and dosing kept to a more effective minimum than bath treatments. But oral treatments are not without their problems. SEPA (2005) points out that these chemicals may be capable of damaging other marine organisms if safe concentrations are exceeded.

Cleaner fish - wrasse

Several species of wrasse, small fish that actively eat parasites off other fish, are used as an 'environmentally-friendly' way of getting rid of sea lice. However, the practice is not welfare-friendly for wrasse.

Wrasse mortality rates of 50 per cent have been reported. Some die from the stress of capture and transport to the farm (Willoughby, 1999). Others die from bullying or being eaten by salmon cage-mates, or through starvation in the winter at the low point of the sea louse life cycle.

Wrasse are only occasionally used in Scotland at present. This is partly due to their ineffectiveness, especially for larger salmon. Regrettably, their use is permitted within the UK Soil Association's organic standards. Wrasse are generally killed after each production cycle to prevent disease transfer from one salmon batch to another. This makes catching new stocks each year a necessity.

CIWF and WSPA believe that taking large numbers of wrasse out of the wild for use in fish farms where they are subjected to serious threats to their welfare is unacceptable.

Management strategies

The best long-term strategy for avoiding sea lice infestation is continued improvements in husbandry and management, including the careful selection of sites to minimise susceptibility to sea lice. Sites should have clean, fast-flowing water to reduce the likelihood of serious parasitic attack. Other positive measures include the separation of year classes, periodic fallowing of cage sites to break the cycle of parasite infection and the setting up of complementary management procedures between farms in the same loch or area. These include treating neighbouring sites at the same time to avoid cross-contamination and increase the effectiveness of treatments.

The Scottish industry is tackling sea lice through positive management measures such as synchronised treatment and fallowing; synchronised treatments are also used in Norway. The Tripartite Working Group set up by the Scottish Executive has initiated the formation of Area Management Agreements (AMA); a major target of the AMAs is integrated pest management. Of Scotland's 278 salmon cage sites, 170 employed a fallow period in 2005, with a further 33 being fallow throughout the year (FRS, 2005).

Conclusion

Intensive farming has led to sea lice infestation becoming a serious welfare problem for farmed salmon in many areas. Wild salmon range over a wide area, thereby minimising the opportunity for sea lice to find hosts. However, when thousands of salmon are kept in sea cages, they tend to attract substantial numbers of lice.

If untreated, sea lice infestation can lead to fish suffering greatly and dying. Current treatments focus on the use of in-feed or bath chemicals that have possible adverse environmental effects. More 'environmentally-friendly' methods - hydrogen peroxide and the use of wrasse to eat the lice off the salmon - have serious animal welfare drawbacks.

Sea lice infestation should be controlled by improved management including careful site selection, complementary management procedures such as treating all the farms in an area at the same time, the separation of year classes and periodic fallowing of cage sites to break the cycle of parasite infection.

Algal blooms and jellyfish

Algal blooms contain phytoplankton, some of which can produce gill or nerve poisons while others remove oxygen from the water or act as an irritant (Willoughby, 1999). In the worst cases, algal blooms can lead to mass mortality, as has happened in Chile, Norway, Scotland, Japan, British Columbia and Washington State.

Jellyfish also present major problems. Some species have long trailing tentacles with stinging cells that can burn and even blind farmed fish (Willoughby, 1999). Unable to see properly, fish drift into the net mesh, which can result in heavy scale loss and consequent secondary infection.

Confined in cages, farmed fish are unable to evade algal blooms and jellyfish. The ethical acceptability of fish farming is called into question by the fact that it makes it impossible for fish to move away from dangers that they could avoid in the wild.

Predators and predator control

There can be few more stressful encounters for confined fish than a seal or other predator lunging through the cage netting and taking a bite. There are however, a variety of ways of preventing wildlife such as seals, birds, mink and otters from taking advantage of a free meal without resorting to the 'wild west' mentality of shooting them. Methods include sonic and visual scarers, plus nets to exclude predators from tanks and cages. Top nets to protect the water surface from birds and side and base nets (which enclose the cages in a box or curtain of net) are used to exclude predators from most if not all fish farms. Care must be taken with sonic scarers, as it has been reported that the high-pitched sound emitted by some scarers can be painful to certain marine mammals.

Poorly-fitted nets can lead to wild animals, including birds, reaching the fish. They may also become entangled and drown. There have been reports of dolphins and sharks becoming entangled in fish farms in Australia. Using smaller mesh sizes and ensuring they are properly tensioned and weighted down can avoid tangling.

Some fish farmers have seen the killing of wild animals as a legitimate part of predator control. The shooting of seals by fish farmers still takes place. In November 2005, the *Scottish Sunday Express* reported that a leading salmon farm operator in Scotland had been shooting seals at its farm near the Isle of Skye (Lambie & Mole, 2005). Earlier that year, a salmon farmer near Oban in Scotland was reported to have shot a large number of seals (Carter, 2005). In British Columbia many sea lions and seals are shot by salmon farmers, while Chile's fish farmers also kill numerous sea lions.

An organisation called British Divers Marine Life Rescue reports that some salmon farmers have used large drowning traps to catch seals (Knight, 2004). The traps are suspended around the salmon nets and are baited with live salmon. The seals enter the traps and are drowned. At one farm they found a huge monofilament net hanging below the surface and completely surrounding one of the salmon pens. The net was full of dead sea birds.

Wild mammals and birds should not be shot or otherwise harmed as an anti-predator measure. CIWF and WSPA believe that every precaution should be taken to avoid predators gaining access to the fish through the use of anti-predator nets as well as the selective use of scarers and decoys.

Both mammalian and avian predators can help spread disease. Mammalian predators and scavengers that frequent fish farms – such as seals, otters, mink, cetaceans and rodents – have the potential to act as disease vectors (Anon, 2003). The IPN virus, for example, has the ability to survive passage through the mammalian gut (Anon, 2003). Birds also regularly visit fish farms and may well act as vectors of aquatic pathogens. Piscivorous (fish-eating) birds such as corvids, herons and kingfishers that predate on rainbow trout fry infected with IPN virus can excrete live IPN virus in their faeces (McAllister & Owens, 1992). These authors suggest that this represents a significant risk of virus transmission.

Mortality

High mortality rates suggest a serious welfare problem. A leading researcher has questioned whether survival rates below 80-90 per cent can be considered acceptable for food producing animals kept under human custody (Midtlyng in Poppe & others, 2002). In meat chickens, for example, mortality rates above 5.5 per cent are generally deemed excessive.

Mortality amongst salmon smolts was found by the UK Farm Animal Welfare Council (FAWC, 1996) to be "much higher than that in other farmed animals". Mortality levels remain high for salmon smolts when compared with other farmed animals, accounting in Scotland for about 21 per cent of juveniles reared at sea (see **Table 3** opposite). The mortality rate for the 43 million smolts put to sea in Scotland in 2003 was 22.0 per cent (FRS, 2005), which means that around 9.5 million fish died after being put to sea and before slaughter. The average mortality rate in Scotland for the period 2000-2003 was 21.7 per cent (FRS, 2005). Such high mortality rates would rightly sound alarm bells in other branches of farming. Overall mortality is likely to be even worse when losses from the rest of the farmed salmon life cycle are taken into account. Wall (1999) quotes losses of ten per cent at the egg to fry stage and a further ten per cent from fry to smolt.

Premature fish deaths occur for many reasons, including disease, stress resulting from transport (particularly loading), poisoning by toxic algal blooms or hot weather causing oxygen starvation amongst the fish. Mass mortality can occur on intensive fish farms.

It is a cause for concern that the UK trout industry does not produce overall mortality figures.

We recognise that in the wild mortality rates can be high due to predation. Farmed fish, however, are in general not subject to large-scale predation and accordingly it should be possible to keep mortality rates to a much lower level.

Table 3: Salmon smolt mortality rates in Scottish sea cages 1997-2005

Year of smolt input	Smolt input (000s)	Year harvest completed	Total % of year class harvested (1)	Mortality rate (%)
1997	42,766	1999	89.6	10.4
1998	45,870	2000	69.1	30.9
1999	41,106	2001	80.6	19.4
2000	45,185	2002	77.1	22.9
2001	48,643	2003	81.6	18.4
2002	50,086	2004	76.7	23.3
2003	43,083	2005	78.0	22.0

Average mortality rate 1997-2003: 21.0%

Average mortality rate 2000-2003: 21.7%

(Years in above averages refer to year of smolt input)

(1) "**Year class**" means the fish put to sea in a given year

Source: Fisheries Research Services, Scotland

Biotechnology, genetic selection & genetic engineering

Biotechnological reproduction techniques

Biotechnology is being used in fish farming to produce all-female stock as well as triploid fish that have an extra set of chromosomes to induce sterility. These practices are widely used in the rainbow trout industry to manipulate the chromosomes of farmed fish. They are also used in salmon farming, though not in the UK.

Early sexual maturation in several species, particularly the males, presents problems for farmers. Sexually mature fish undergo changes that can reduce flesh quality. Moreover, if they escape, sexually mature fish can interbreed with wild stocks, thereby impairing their genetic integrity and reducing their chances of survival. As detailed below, the industry tries to address early maturation in various ways, i.e. through the production of all-female stocks (in several species females mature later than males) or sterile triploid fish or by the use of photoperiod manipulation to delay maturation or through selective breeding for delayed maturation.

All-female fish

Sex reversal is used to produce batches of all-female fish that will mature later than their male counterparts, thereby enabling the fish to be grown to greater weights. The process involves feeding the male sex hormone, testosterone, to young female fish (containing two X-chromosomes). This converts them into functional males. Sperm from the resulting 'males' is then used to fertilise eggs from normal females. However, because the hormone-induced 'males' are actually *genetic females*, all their sperm will contain only X-chromosomes. As none of the sperm contains male-conferring Y-chromosomes, the resulting offspring will be all females. Hormone treatment is used on the broodstock only. The offspring reared for human consumption will not have been hormone treated.

More than 31 million all-female rainbow trout ova were produced in England and Wales during 2004/2005 (CEFAS, 2005). In addition, over ten million triploid rainbow trout ova were produced. This means that 66 per cent of the rainbow trout ova were all-female and 21 per cent were triploid, with only 13 per cent being mixed sex normal diploid ova (see **Table 4** overleaf).

In Scotland, over 16 million all-female and more than 1.7 million triploid rainbow trout ova were laid down to hatch during 2005 (see **Table 5**). This means that 83 per cent of the rainbow trout ova in Scotland were all-female and 8 per cent were triploid. Nine percent were mixed sex normal diploid ova, although in 2003 and 2004 this figure had been less than one per cent (FRS, 2005).

Sex reversal has also been used for many years in Canada to produce all-female chinook salmon to avoid the early sexual maturation of the males at a size that is less than maximally profitable. Work has been undertaken to develop all-female stocks of Atlantic halibut (Hendry & others, 1999) and is now underway to develop all-female coho salmon (Henry & others, 2004). Indeed, mono-sex strains of many fish species have been developed for use in aquaculture (Henry & others, 2004).

It is also argued that, in areas where non-native fish are being farmed (e.g. Atlantic salmon in British Columbia) the use of mono-sex fish may be an effective way of preventing reproduction in the event of escapes. The thinking is that such fish, being non-native, would find no con-specifics in the wild to breed with and would disappear after one generation. This ignores the danger that they may out-compete the native species for habitats and feed and may spread parasites to them.

Table 4: Rainbow trout and brown trout ova production in England & Wales, 2004-2005

	All females (000s) and proportions (%)	**Triploid** (000s) and proportions (%)	**Mixed sex** (000s) and proportions (%)
Rainbow trout	31,654 (66%)	10,242 (21%)	6,121 (13%)
Brown trout	396 (6%)	1,074 (18%)	4,599 (76%)

Source: CEFAS

Table 5: Rainbow trout ova types laid down to hatch in Scotland during 2005

All female diploid (000s) and proportions (%)	**Triploid** (000s) and proportions (%)	**Mixed sex diploid** (000s) and proportions (%)
16,773 (83%)	1,729 (8%)	1,745 (9%)

Source: FRS

Triploid fish

Triploidy is a method of producing sterile fish by subjecting newly-fertilised eggs to heat or pressure shock. The resulting fish are induced to have triploid (three) sets of chromosomes instead of the usual diploid (two). The process is commonly used in conjunction with sex-reversal to produce sterile, all-female fish. Sterile female fish will not reach sexual maturity and so are able to be reared to greater weights without incurring the deterioration in flesh quality that accompanies maturation. In addition, sterile fish that escape will not endanger wild populations by inter-breeding. Using triploidy to produce sterile fish has therefore been advocated as a means of preventing sea cage escapees from disrupting wild salmon gene pools. However, sterility cannot prevent escaped fish from spreading disease to wild populations or dominating them in securing feed or disturbing wild nesting sites (Royal Commission, 2004).

Whilst the process of producing triploids may not have welfare effects on the fertilised eggs, it does have consequences for the health and welfare of the growing fish. Higher levels of spinal deformities have been found in triploid rainbow trout compared with diploids (Madsen & others, 2000). Triploid salmon have been shown to exhibit higher levels of runting and deformities of the mouth, gills and spine; to have reduced ability to deal with low dissolved oxygen levels and high temperatures; to have greater susceptibility to production stressors such as handling and grading; and to be more vulnerable to infection and disease compared with similar diploid stocks (Webster, 2005). Batches of triploid salmon were found suffering from eye cataracts causing blindness, whilst equivalent batches of diploid salmon remained free from the condition (Wall

& Richards, 1992). Significantly lower survival rates have been reported in triploid salmon than in diploids (Johnstone, 1992; Jhingan & others, 2003; Johnson & others, 2004). In addition, triploids tend to have poorer growth than normal fish, possibly due to the stress associated with the induction of triploidy (Johnson & others, 2004). Taranger and others (2005) reiterated that welfare problems have been noted in triploid salmonids, e.g. increased susceptibility to production disorders such as skeletal deformities and cataracts.

Studies reviewed by Willoughby (1999) suggest that triploid salmon are less able to absorb oxygen, leaving them less well equipped to cope with stressful situations. This could be a particular problem when fish are crowded together for procedures such as grading, transport and treatment for sea lice. Triploid salmon populations were found to have an increased tendency to suffer mortalities during sea lice treatment (Johnstone, 1992). They also show higher mortality levels in less oxygenated water when infected with bacterial gill disease. Triploid fish can also be anaemic, showing lower blood haemoglobin levels.

The use of triploids in salmon production world-wide has declined, almost to zero (Webster, 2005). However, there continues to be interest within the salmon farming industry in the use of triploids (Windsor, 2005).

Triploid fish, transgenic fish and sex-reversed stock are not permitted under UK organic standards.

Conclusion

The production of triploid fish has been found to cause a range of health and welfare problems in the affected fish. CIWF and WSPA believe that biotechnology techniques involving chromosome manipulation (e.g. sex reversal and triploidy) should be prohibited. We recognise that sex reversal does not entail any proven welfare problems. Nonetheless, we are concerned about it on ethical grounds and believe that the practice should be monitored to establish whether or not it has an adverse effect on welfare.

Selective breeding

Selective breeding is widely used in aquaculture to produce fish that grow more rapidly as well as to attain improved feed conversion rates, greater resistance to disease and delayed sexual maturation (Fjalestad & others, 2003). Almost 100 per cent of world production of farmed Atlantic salmon and about 25 per cent of farmed rainbow trout production are based on stocks that have been subject to selective breeding (Gjedrem & others, 2005).

The time taken by farmed salmon to reach slaughter weight has been much reduced due to genetic selection, richer feeds and artificial lighting regimes. In Norway, the time taken for an Atlantic salmon smolt to reach 4kg has been reduced from 23 to 14 months (Myrseth, 2005). This author reports that selectively bred salmon have a growth rate 113 per cent faster than wild salmon, their feed-uptake is 40 per cent greater and their feed conversion 20 per cent more efficient (Myrseth, 2005). Another study reports that the growth rate of Atlantic salmon has been doubled through selective breeding (Gjedrem & others, 2005).

Intense selection for fast growth or enhanced productivity has led to serious health problems in other farmed species. Many meat chickens suffer from painful leg disorders and succumb to heart failure as their legs and cardio-vascular system are unable to properly support the rapidly growing body (SCAHAW, 2000). Similarly, selection for high milk yields has led to a range of problems in dairy cows including lameness, mastitis, hunger, digestive disorders and production diseases.

We fear that farmed fish will soon begin to experience analogous health and welfare problems if the drive to accelerated growth rates continues unabated. Selective breeding for rapid growth is associated with an increased incidence of cataracts in farmed Atlantic salmon (Ersdal & others, 2001); one explanation advanced for this is that a relative lack of certain essential nutrients experienced during rapid growth may adversely affect the development of the lens.

Selection for rapid growth is also one of the factors that may be responsible for abnormal heart shape and function in salmonids which predisposes them to cardiac failure during stressful procedures such as grading, crowding, lice treatments and transport (Poppe & others, 2003).

Conclusion

Selective breeding is widely used in aquaculture to produce fish that grow more rapidly and to attain improved feed conversion rates, greater resistance to disease and delayed sexual maturation. Intense selection for fast growth or enhanced productivity has led to serious health problems in other farmed species such as meat chickens and dairy cows. We fear that farmed fish will soon begin to experience analogous health and welfare problems if the drive to accelerated growth rates continues unabated. Indeed, fast growth rates are already associated with an increased incidence of cataracts and abnormal heart shape and function.

Genetic engineering

Genetic engineering techniques have been developed for aquaculture. These can push fish to even further extremes than traditional selective breeding. They threaten to push back the boundaries of intensification and cause yet more suffering for farmed fish. Researchers are working on fish that grow faster and larger, convert feed into flesh more efficiently, are resistant to disease, tolerant of low levels of oxygen in the water and can withstand freezing temperatures.

Although transgenic fish are not as yet utilised on farms, they may quite soon appear on farms in certain countries. The strong interest in this area is highlighted by the fact that in Britain there were 3,532 and 4,369 licensed experiments in 2004 and 2005 respectively using normal fish for the production of genetically modified fish; moreover, the number of experiments using genetically modified fish rose from 16,000 in 2003 to nearly 32,000 in 2004 and over 38,000 in 2005 (Home Office, 2004 & 2005).

Growth hormone genes from human or animal sources have been introduced into several fish species to speed up growth rates. Dramatic increases in growth rates have been achieved experimentally in several salmonid species. Transgenic salmon with additional fish growth hormone genes have been created that are up to 11-fold heavier than normal fish after one year of growth (Dunham & Devlin, 1999). Transgenic rainbow trout have also displayed dramatic growth enhancement (Devlin & others, 1995a). Indeed, transgenic fish have shown growth performance up to 30 times higher than that of non-transgenic siblings (Devlin & others, 1995a).

Growth-enhanced transgenic Atlantic salmon have been produced with a gene construct comprising an anti-freeze protein promoter from the ocean pout linked to the growth hormone gene from chinook salmon (Fletcher & others, 2004). These fish can grow 3-6 times faster than ordinary salmon. Such fast growth rates are attractive to the industry as they reduce the time needed to raise fish to market size; transgenic Atlantic salmon reach slaughter weight a year earlier than non-transgenics (Fletcher & others, 2004). In China, transgenic common carp are being developed for faster growth and more efficient feed conversion (Fu & others, 2005).

Salmonids cannot withstand extremely cold temperatures. Thus the farming of salmonids in eastern Canada is limited to a relatively small area in the south of the region and even here winter temperatures can decline to lethal levels leading to high mortalities. Even when they are not lethal, low water temperatures result in slow growth and, in some species, reduced disease resistance (Fletcher & others, 2004). To combat these problems, researchers are working on the insertion into Atlantic salmon of antifreeze protein genes from fish that inhabit waters at sub-zero temperatures (Fletcher & others, 2004). This could lead to the development of aquaculture along the east coast of Canada and the coast of Maine in the US.

Genetic engineering has led to serious health and welfare problems in the fish. A major Canadian report concluded that unintended disadvantageous changes to the phenotype are the rule rather than the exception in the genetic modification of fish (Royal Society of Canada, 2001). Expression of transgenes may have unintended effects on many systems affecting the fitness of the fish, including tolerance to disease and stress (Jhingan & others, 2003). In one study, growth-enhanced transgenic coho salmon smolts experienced higher mortalities due to vibriosis (a bacterial disease) than non-transgenic smolts (Jhingan & others, 2003).

Serious deformities have been documented in coho salmon genetically engineered for accelerated growth, with abnormalities in the cranium, jaw and operculum due to excessive cartilage deposition (the operculum is a bony shield that protects the gill structure) (Devlin & others, 1995a & b). This resulted in affected individuals suffering feeding and breathing difficulties and poor viability (Dunham & Devlin, 1999). Moreover, reduced swimming abilities have been documented in growth-enhanced transgenic coho salmon (Kaiser, 2005). In some cases, transgenic salmon have lower disease resistance than normal fish.

Concerns about the development of transgenic fish were highlighted at an OIE conference by Håstein (2004) who stressed that any genetic engineering must be ethically based to avoid fish suffering. He stressed that "if genetic capacity, feed utilisation and feed composition all work maximally towards the same goal, the fish may rapidly be squeezed over the biological limits which leads to a situation that may be characterised as unacceptable from a welfare point of view".

Transgenic escapes

Escapes from fish farms have become a fact of life for the modern industry. Farm escapes are already implicated in the decline of wild salmon stocks. Transgenic escapees threaten to have an even worse effect. They could displace wild fish through superior ability in securing food; coho salmon genetically engineered for faster growth have a higher feeding motivation than non-transgenic fish and, if they escaped, would have a greater ability to compete for food than native wild fish (Devlin & others, 1999). Tymchuk and others (2005) concluded that transgenic salmon may have a significant impact on the survival of wild fish if they entered natural ecosystems. In addition, escaped transgenic fish could jeopardise wild fish by interbreeding with them, thereby undermining their genetic make-up and so producing fish that are less able to survive in the wild.

Research funded by the US Food and Drug Administration shows that introduction of transgenic fish into the wild could lead to rapid extinction. The study used genetically modified Japanese medaka fish (*Oruzias latipes*) as an example. The GM fish produced human growth hormone and matured faster with more eggs than non-GM relatives. The GM males had four times more opportunities to mate because of their larger size compared with non-GM males. However, the offspring showed a higher rate of mortality (30 per cent) before reaching maturity. The study concluded that "a transgene introduced into a natural population by a small number of transgenic fish will spread as a result of enhanced mating advantage, but the reduced viability of offspring will cause eventual local extinction of both populations" (Muir & Howard, 1999).

To combat the impact of transgenic escapees, the industry advocates the use of sterile transgenic triploids or transgenic fish rendered sterile through the introduction of anti-fertility genes (Aleström, 1999; Fu & others, 2005). However, the sterility of transgenic escapees would not prevent them from out-competing wild fish for food. Moreover, transgenic triploid coho salmon fry have been found to have lower resistance to a high dose of the disease vibriosis than non-transgenics (Jhingan and other, 2003). Transgenic escapees with reduced disease resistance could create reservoirs of infection which could potentially increase infection rates among non-transgenic wild populations (Jhingan and other, 2003).

In light of the widespread concerns regarding the impact of escaped transgenic fish, the Royal Commission on Environmental Pollution has recommended that "genetically modified fish should not be released or used in commercial aquaculture in the UK for the foreseeable future (Royal Commission, 2004).

Industry condemnation

We welcome the fact that Scottish Quality Salmon (SQS) has made it clear that its members are opposed to the use of transgenic salmon. However, it remains to be seen how strong industry opposition remains if transgenic salmon start to be used commercially by global competitors. Disturbingly, in its Strategic Framework for Scottish Aquaculture, the Scottish Executive keeps the door open for future use of transgenic fish, saying that "the industry considers, however, that were the public perception of transgenics to change, it could not ignore the potential of the technologies".

Transgenic fish & future welfare

There are grave concerns for the welfare of genetically engineered animals. Modern intensive farming methods already push animals toward their physiological limits or rear them under conditions that can harm their welfare.

Transgenic farm animal production threatens to open up a whole new array of welfare problems. Genetically reconstructing animals for higher performance is one route to greater intensification. The other is by inferring genetic resistance to disease, and thereby conquering nature's inbuilt limitation on how intensively farmers can keep animals and get away with it. Normally, when large numbers of animals are kept in overcrowded conditions they suffer stress, which weakens their immune system, making them susceptible to disease. Farmers are, to some degree, limited in how intensively they can farm through fear of paying the price in dead and diseased stock. Genetically-engineered disease resistance could remove this natural break and lead to animals being kept in even more stressful, poor-welfare conditions. Of course, no one wants animals to suffer disease. However, transgenic disease resistance should not be used as a way of facilitating the use of systems that further compromise the welfare of the animals involved.

Fish, in common with other farm animals, are sentient beings that can experience suffering. Genetic engineering should not be used to further relegate them to the status of 'animal machines'.

Conclusion

Genetic engineering has led to serious health and welfare problems in fish. A major Canadian report concluded that unintended disadvantageous changes to the phenotype are the rule rather than the exception in the genetic modification of fish. Expression of transgenes may have unintended adverse effects on many systems affecting the fitness of the fish, including tolerance to disease and stress.

Serious deformities have been documented in coho salmon genetically engineered for accelerated growth, with abnormalities in the cranium, jaw and operculum due to excessive cartilage deposition. This resulted in affected individuals suffering feeding and breathing difficulties and poor viability. Moreover, reduced swimming abilities have been documented in growth-enhanced transgenic coho salmon.

Farm escapes are already implicated in the decline of wild salmon stocks. Transgenic escapees threaten to have an even worse effect. They could displace wild fish through superior ability in securing food; they could also jeopardise wild fish by interbreeding with them, thereby undermining their genetic make-up and so producing fish less able to survive in the wild.

CIWF and WSPA are opposed to the development of genetically engineered fish for use in aquaculture.

Lighting manipulation

Atlantic salmon

Photoperiod, or the number of hours of daylight in a 24-hour period, can be manipulated, for example by the use of lamps positioned above or in the water. Such manipulation is used in intensive salmon farming to (i) advance or delay spawning season, (ii) modify the natural timing of smoltification and (iii) enhance productivity by increased growth and postponed sexual maturation (Juell & others, 2003).

Timing of spawning

The spawning season of broodstock is sometimes advanced or delayed by photoperiod manipulation in order to obtain a supply of eggs for an increased proportion of the year.

Timing of smoltification

Smoltification is the process whereby salmon change from freshwater fish to marine creatures. Increasing day length and light in the spring triggers the changes involved in smoltification. Photoperiod manipulation is used to accelerate or delay the timing of smoltification. This enables the industry to produce smolts ready for onward growth in sea cages at times of the year other than the natural spring smoltification. For example, photoperiod manipulation is used to produce smolts ready for transfer to seawater in autumn, i.e. 7-8 months earlier than usual (Oppedal & others, 1999). Of the 36.3 million smolts put to sea in Scotland during 2005, 39 per cent were photoperiod adjusted, i.e.: S½ and S1½ smolts (FRS, 2005).

Enhanced productivity

Continuous artificial light is used routinely in modern aquaculture during winter and spring to reduce sexual maturation and enhance growth in Atlantic salmon reared in sea cages (Oppedal & others, 2001).

Artificial photoperiods are used to delay maturation; this is desirable from an industry viewpoint as sexually mature fish have reduced flesh quality. Constant additional lighting from November significantly reduces the proportion of fish that mature in sea cages (Porter & others, 1999).

One study subjected Atlantic salmon in sea cages to artificial night time lighting from November to July (Porter & others, 1999). Only 6.1 per cent of the group exposed to the artificial lighting matured compared to 61.5 per cent of the control group kept in natural light. The researchers suggested that the effect of artificial lighting in reducing maturation is mediated through a reduction in plasma melatonin levels.

Artificial photoperiods – often involving 24 hours light and no dark - are also used to enhance growth in both fresh water and seawater (Oppedal & others, 1997 & 1999). Continuous light on salmon cages during winter can produce 20-30 per cent greater growth (Willoughby, 1999).

Feed intake and growth in Atlantic salmon are controlled by a seasonal endogenous rhythm that can be advanced by the provision of additional light during winter and spring (Oppedal & others, 2001). The salmon's growth pattern is influenced by day length; the provision in winter of artificial light increases day length thereby advancing the salmon's biological clock which results in greater feed intake and growth than would normally take place in winter.

Caged salmon kept in natural light typically swim in a circular school during daylight (Oppedal & others, 2001). At dusk, however, the salmon ascend, swimming speed decreases and the schooling groups gradually disperse both vertically and horizontally. However, artificial lighting induces salmon to maintain circular schooling, daytime vertical distribution and swimming speed during the night despite the fading of natural light at dusk (Oppedal & others, 2001). Schooling behaviour in fish is dependent on visual contact (Juell & others, 2003). Hence the role of artificial light in maintaining schooling; at some point during dusk, when the artificial light is stronger than the natural light, the salmon move towards the lights and so retain schooling behaviour (Juell & others, 2003).

Sustained schooling and swimming in salmon subjected to continuous artificial lighting may contribute to their better growth performance as compared to salmon kept with natural light (Oppedal & others, 2001). It has been suggested that schooling and sustained swimming may reduce stress and improve growth efficiency (Juell, 1995; Oppedal & others, 2001). The improved growth efficiency reflects certain physiological responses to swimming activity *per se*, but it also is due to fewer aggressive confrontations when fish are in schooling groups (Juell, 1995).

One important consideration when artificial lighting is used is that sudden transitions, no matter how small, between lightness and darkness should be avoided as fish experience this as stressful (Mork & Gulbrandsen, 1994).

Impact of natural light on vertical distribution in sea cages

Research has examined how natural daily and seasonal light variations affect the vertical distribution of Atlantic salmon in sea cages and the impact of artificial light on that distribution.

High light levels result in fish swimming at greater depths (Fernö & others, 1995). In summer, Atlantic salmon generally swim deeper in the cage than in winter (Fernö & others, 1995). These researchers reported that the fish are more evenly spread out in winter and more concentrated in summer when a mean of about 50 per cent of the fish were localised in a depth interval of just one metre. Indeed, in some cases, more than 80 per cent were concentrated within a one-metre depth interval.

Caged salmon generally swim deeper during the day than at night. As indicated above, high light levels result in deeper fish distribution (Fernö & others, 1995). The fish usually descend at dawn and ascend at dusk. The researchers suggested that the vertical distribution of salmon in cages may be a trade-off between avoidance of light at the surface (greater visibility increases the risk of predation) and attraction to feed at the surface.

Following on from the conclusion that salmon in sea cages avoid strong surface light, Fernö and others (1995) suggested that they should be protected from excessive light levels by some form of shade. They noted that a positive effect on growth arising from the shading of cages from intense summer light has been reported.

The researchers pointed out that, because of the tendency in summer for salmon to be concentrated into a small proportion of the cage volume, local concentrations more than five times greater than if the fish were dispersed throughout the cage are not uncommon in the summer. The researchers stress, however: "This is not an argument for higher densities in salmon farming, as the high concentrations were restricted to a certain depth interval and the fish were more spread out in other seasons".

It should be noted that vertical distribution appears to be influenced not just by light, but by an interaction between light levels, feed availability, feeding motivation and temperature. Feed is usually dispensed at the surface and thus feed availability and feeding motivation are likely to attract salmon to the surface (Oppedal & others, 2001). Once fish are satiated, they tend to descend. With regards to temperature, fish generally have a preference for the warmest water and avoid the colder temperatures (Oppedal & others, 2001).

Impact of artificial lighting on stocking density and vertical distribution

In some circumstances artificial lighting can lead to increased density. Oppedal and others (2001) found that farmed salmon kept in natural light swim in groups during the day but at dusk, at most times of the year, they disperse both horizontally and vertically and utilise a larger part of the cage volume. However, salmon subjected to continuous artificial light tend to continue to swim in groups during the night as well as during the day. This suggests that at night natural light leads to greater dispersal and hence lower density than artificial light. In contrast to this, Juell and Fosseidengen (2004) found higher observed fish densities in salmon kept in natural light than in those subject to artificial light; the researchers pointed out, however, that the artificial lights might attract salmon towards the centre of the cage "leading to an underestimation" of density. ("Observed fish density" is the 'real' fish density, i.e. the biomass actually present in a particular part of the cage.)

Juell and others (2003) found that caged salmon lit with lamps submerged in the cage swam both at a greater depth and at lower observed fish densities, particularly at night, than salmon lit with lamps mounted above the water surface. They pointed out: "Surface lights may induce crowding of the fish at night".

The researchers said that their studies suggest that swimming depth at night relates to the position of the lamps with fish tending to gather around the point of highest light intensity. The explanation for lower fish densities at night with submerged lamps is that with these lamps fish are able to distribute themselves at both sides of the peak light intensity, whereas with lamps mounted above the water, the fish can only swim below the peak light.

Juell and Fosseidengen (2004) compared the impact of lamps submerged at 3 and 15 metres respectively. They found that salmon in cages with lamps submerged at 15m swam deeper and at lower observed fish densities, particularly at night, than salmon in cages with lamps at 3m. In a second experiment the researchers found rapid and strong changes in swimming depth and fish density in response to changes in photoperiod and lamp depth.

Juell and others (2003) and Juell and Fosseidengen (2004) suggested that, if positioning light at different depths can influence swimming depth, lamp positions could be used to avoid suboptimal water layers; for example, sea lice are generally found near the surface. They also suggested that it may be a sensible welfare precaution to use submersible lights to increase the use of cage volume and thereby reduce density. It should, however, be noted that, although deeply submerged lights lead to lower density than other artificial lights (less deeply submerged or mounted above the surface), there is evidence that at night natural light leads to greater dispersal and hence lower density than artificial light.

Rainbow trout

Photoperiod manipulation, at least in the UK industry, is used less commonly with trout than with salmon. One reason why it is used with broodstock is to produce eggs out of season. Most out of season eggs used in the UK are imported, but some are produced domestically with the aid of photoperiod manipulation.

Twenty-four hour photoperiods are sometimes used with trout, as with salmon, to increase growth. In such cases, the increased photoperiod is generally applied from autumn to spring and can increase growth by up to 25 per cent.

Welfare implications of artificial lighting

The Fisheries Society of the British Isles has identified appropriate seasonal and daily patterns of light intensity as being critical for fish welfare (FSBI, 2002). Relatively little research has been undertaken on the welfare implications of photoperiod manipulation, although studies have found that artificial photoperiods affect the immune system of rainbow trout and hence their susceptibility to pathogenic micro-organisms (Burgos & others, 2004). There appear to be a number of potential problems associated with lengthy or continuous artificial light. These include the following:

- **accelerated growth may lead to health and welfare problems:**

One purpose of artificial lighting is to increase growth. That increase can be substantial; continuous light on salmon cages during winter can produce 20-30 per cent greater growth. Genetic selection and feed composition are also used to enhance growth rate.

Accelerated growth rates are a source of serious health and welfare problems in terrestrial animals and it cannot be presumed that fish are immune to these dangers. Indeed, in its overview report on the welfare of farmed fish, the European Commission (2004) draws attention to the fact that genetic selection for high productivity has created serious welfare problems in land farmed animals. The Commission's report gives as an example broiler (meat) chickens that are selected for fast growth and high body weight and as a result show bone and cartilage disorders.

- **continuous lighting could lead to health and eye problems:**
Continuous lighting can lead to serious problems in terrestrial animals. For example, chickens kept under continuous or near-constant light suffer from increased stress and fearfulness; reduced responsiveness of the immune system; and eye abnormalities including blindness (RSPCA). As with increased growth, it cannot be assumed that fish are not susceptible to being adversely affected by continuous lighting.

- **artificial lighting may lead to stress:**
Atlantic salmon initially reduce feed intake in the first 6-12 weeks after the lights are turned on; this indicates a stress situation (Håstein, 2004).

- **lighting failure:**
A failure, or unexpected changes, in lighting may result in a panic reaction leading to mortalities and lesions due to unintentional contact with the cage net (Håstein, 2004).

- **impact on smolts of autumn transfer to sea:**
Atlantic salmon smolts have traditionally been transferred to seawater in spring in line with the timing of the natural seaward migration of wild smolts (Oppedal & others, 1999). As indicated above, however, photoperiod manipulation is now being used to produce smolts ready for transfer much earlier, in the autumn. Research needs to be undertaken to investigate if the practice of placing smolts in the sea at unnatural times has any adverse welfare implications. Wild smolt experience long summer days after migrating to the sea, but this is not the case for farmed smolt transferred to sea water in the autumn (Oppedal & others, 1999). Poor growth and variable growth have been reported in smolts transferred in the autumn; this may be due to the decrease in photoperiod experienced after transfer or to incomplete parr-smolt transformation (Oppedal & others, 1999).

- **effect on wild fish:** Willoughby (1999) points out that the effect of continuous lighting on wild fish populations is unknown.

Conclusion

CIWF and WSPA are concerned about the use of artificial lighting regimes and believe that welfare is likely to benefit if fish are kept with natural light patterns. Artificial photoperiods affect the immune system of rainbow trout and hence their susceptibility to pathogenic micro-organisms. Research is needed to investigate whether any other adverse welfare implications arise from photoperiod manipulation. Such research should in particular examine whether accelerated growth leads to health and welfare problems; whether continuous lighting could lead to health and eye problems; whether artificial lighting may lead to stress; and whether the transfer of smolts to sea in the autumn has any adverse welfare implications.

Housing conditions

One cause of fish injuries is abrasion or collision with cage nets or the wall of the rearing unit. Accordingly, cage netting should be smooth and non-abrasive to prevent injuries to the snout, fins and scales of fish, particularly during stormy conditions. Moreover, enclosures should not have any sharp corners, projections or materials that may be harmful to the fish.

One study found that rainbow trout had better fin condition in natural bottom substrates (gravel/dirt ponds) than in concrete or steel raceways (Bosakowski & Wagner, 1994). The authors concluded that this suggests that abrasion from concrete/steel may cause and/or worsen fin erosion. Other evidence, however, has not found a greater incidence of fin erosion with concrete.

Nets should be adequately tensioned and weighted to prevent distortion as this can limit the space available to the fish. Net depth should be such as to ensure that there is no contact between the net base and the sea bottom.

Biological fouling

Biological fouling (also known as bio-fouling) is the process whereby various organisms – such as mussels, algae and marine bacteria – settle on and colonise a surface such as the nets of a cage. This can be a major problem; in Norway, for example, mussels can completely cover the cage nets from the surface to a depth of 5-10 metres (Willoughby, 1999).

If unchecked, fouling can very substantially reduce the ability of water to pass through the nets. It can reduce the flow of water through the nets by 30-40 per cent and also leads to an accumulation of waste on the net bottom which prevents excess feed and faeces from passing through (Willoughby, 1999).

Fouling adversely affects fish health by reducing oxygen levels and increasing levels of fish wastes and ammonia in the water (Willoughby, 1999). Moreover, the build-up of fouling organisms with hard shells such as mussels and barnacles can result in scale loss and other damage to the fish (Willoughby, 1999).

Fouling is addressed in the following ways:

- a rotation system can be used whereby a pen is emptied of fish by getting them to swim through to another pen; alternatively a new net is placed around the fouled net which can then be untied from the cage structure. In either case, the fouled net is then suspended above the water where air and the sun dry up the fouling organisms until they fall off
- nets can be cleaned underwater by a diver
- the use of chemical anti-foulants.

Feeding method

It is important that feed is provided using methods that minimise competition, aggression and stress during feeding and also ensure that all fish have access to sufficient feed. Systems that fail to distribute feed to all the fish tend to lead to increased aggression. Moreover, uneven feed acquisition can lead to growth variation and thus to size hierarchies, thereby reinforcing dominance hierarchies (Ellis & others, 2002). Size variation among the fish necessitates more frequent grading and this is a stressful procedure.

A key factor in avoiding competition and aggression is the amount of feed provided. If sufficient feed is provided, there is no need for the fish to compete for it, whereas insufficient feed can lead to aggression and some fish getting little or no feed.

There is considerable debate as to the most appropriate spatial and temporal feeding strategies. A prevalent school of thought is that, in order to avoid the aggression and accidental nips that can occur if feed is distributed in a small area, feed should be spread over a relatively large area. Feeding in a highly localised area enables dominant fish to monopolise feed and to limit the feed intake of subordinates (Juell, 1995).

Some argue that high intensity feeding (2/3 meals per day) is preferable to the provision of a large number of small meals (low intensity feeding). The main stress takes place at feeding and high intensity feeding rather than the provision of many small meals minimises the number of times that fish experience the aggression and stress that occur as they scramble for feed.

Willoughby (1999), who summarises the literature in this area, reports that some studies have found adverse effects arising from many small feedings. This practice can lead to a hierarchy developing with the dominant fish obtaining feed first and to fish being constantly in competition for feed.

In addition, Fernö and others (1995) found that frequent feedings bring the fish to the surface more than normal and remaining close to the surface can have adverse effects on fish health; for example, strong UV light can cause damage and a greater prevalence of sea-lice is found at the surface. Another factor that may influence how often fish come to the surface is the amount of feed made available; the provision of insufficient feed will encourage fish to come to the surface in search of feed.

Despite the above reports of adverse effects of many small feedings, Willoughby (1999) reports that other researchers have found no significant difference in growth with frequent feedings and that many farms have had very good results with feeding continuously throughout the day.

Success has been reported with a system that provides feed in a small, defined area on a continuous basis. This system has not engendered dominance hierarchies and aggression; the fish can decide when to come to the feeding area and, having fed, they move away back to the lower portion of the enclosure. (Continuous systems do not generally *supply* feed continuously. Rather they make it continuously *available*; a 'feedback loop' (described below) switches the feed supply off when the fish have eaten to satiation.)

In contrast to this, support for delivering feed over a wide area in just a few large meals per day comes from Kadri and others (1996) who examined the feeding of Atlantic salmon in sea cages. The researchers stated that feeding systems on fish farms often deliver feed in a limited area of the cage at regular intervals throughout the daylight hours. They suggested that this predictability of feed supply facilitated monopolisation of the feed by dominant individuals and that feed presentation that is less predictable in time and space would make such monopolisation more difficult. They referred to a study that found that when feed is spread evenly over the water surface in a few discrete meals per day, there is much more even distribution of feed among individuals than if the same amount of feed is dispensed regularly at a single point.

Self-feeding systems (known as 'demand feeders') are often used with trout. The fish operate an electronic or mechanical device that releases pellets into the water. Farmers may either place in the hopper the quantity of feed they believe to be appropriate or the feed is provided *ad lib*. Such systems can reduce stress levels by spreading feeding across the daylight hours, although there is a substantial danger that a dominant group may prevent subordinate fish from getting sufficient access to the feeder (Alanärä & Brännäs, 1996). Fish are crepuscular feeders (i.e. they prefer to feed at dawn or dusk) and an advantage of such demand feeders is that they allow fish to feed at their preferred times, which in the summer may be after the farm staff have left. Poor results for demand feeders with Atlantic salmon have been reported (Juell, 1995; Willoughby, 1999).

Salmon are often fed with automatic systems equipped with feed monitoring devices (referred to as a 'feedback loop'). These are a form of demand feeder in that the system provides feed until the fish are satiated and then switches the feed off.

Some such systems use underwater sensors to register the passage of uneaten pellets. If the pellets have sunk to the level of the sensor it indicates that the fish are not eating them due to satiation (or disease or stress) and the system switches the feed off to avoid wastage; this has both environmental and economic benefits. A simpler system uses an underwater camera monitored by the farm staff to determine when pellets are no longer being eaten. In one system, a cone located 3-4 metres below the water surface, collects uneaten feed and recycles it by pumping it back up to the surface; this can only work if the feed is distributed in a small, defined area.

To summarise:

- **It is not possible to conclude that one feeding method rather than another is in all situations the best; the guiding principle is that the feeding method used must minimise competition and hence aggression and ensure that all the fish have access to feed. The quantity of feed that is offered is a crucial factor; the provision of sufficient feed removes the need for competition and aggression.**

- **Feeding a few large meals per day may be more effective in reducing the formation of dominance hierarchies and competition than the provision of many small meals throughout the day. Similarly, spreading feed over as much of the water surface as possible is accepted by some as being more successful in reducing the development of dominance hierarchies than delivering the feed in a limited area. Thus, an effective strategy for minimising aggression is to rapidly deliver a large amount of feed into the enclosure, with the feed being spread over a large proportion of the area. Greaves and Tuene (2001) concluded, in the case of Atlantic halibut, that dispersing feed over a wide space in a concentrated period of time makes it hard to defend and so can help prevent monopolisation by dominant or aggressive fish; this may well also be the case for other fish species.**
- **Alternatively, systems that allow the fish to determine their own feeding regime can be successful. Demand feeders and feeding with a 'feedback loop' that turns off the feed when the fish are satiated can work well and minimise aggression provided that the system encourages the fish to come to the feed when they choose and then, having fed, move away again.**

Environmental enrichment

There seems to be reasonably broad recognition that environmental enrichment may be beneficial for fish welfare, but little detailed research appears to have been undertaken. The UK Farm Animal Welfare Council has recommended that the requirements of salmon and trout for environmental stimulation should be investigated (FAWC, 1996). Similarly, the Fisheries Society of the British Isles has said that a degree of environmental complexity may be important, depending on the species concerned (FSBI, 2002).

It has been suggested that trout would benefit from appropriate objects in ponds to provide stimulation and also from some form of refuge from the activity and disturbance of a densely-stocked enclosure. One study found that rearing juvenile steelhead in enriched hatchery tanks rather than conventional tanks improved dorsal fin quality (Berejikian & Tezak, 2005). In this study the enrichment consisted of a submerged structure in the form of the tops of two Douglas-fir trees to provide an in-water structure akin to those that occur naturally in streams, overhead cover and underwater feeders.

There is growing interest among organic fish farmers in 'diverse cropping' i.e. combining the farming of fish with species or plants such as seaweeds that are capable of utilising the wastes of the fish. This would not only have benefits in terms of reduced pollution, but could provide environmental enrichment for the fish. The enhanced economic returns from this approach would enable farmers to reduce stocking densities.

Slaughter

A range of slaughter methods are used in fish farming some of which cause stress and aversion and involve the fish taking a long time to lose consciousness. In its 2004 Opinion, the Scientific Panel on Animal Health and Welfare of the European Food Safety Authority concluded: "Many commercial killing methods expose fish to substantial suffering over a prolonged period of time. For some species, existing methods, whilst capable of killing fish humanely, are not doing so because operators don't have the knowledge to evaluate them" (EFSA, 2004c).

A leading expert has said that there is no doubt that many fish slaughter methods are "appalling from an animal welfare point of view" (Håstein, 2004). Atlantic salmon are sometimes slaughtered by carbon dioxide stunning followed by gill cutting. Trout are often killed by suffocation on ice; sometimes carbon dioxide is used with trout. These methods are inhumane and their use, together with that of suffocation in air, should be prohibited.

In recent years, however, progress has been made in developing better systems. Percussive stunning which, if well-designed and properly operated, has the potential to deliver reasonable welfare for salmon, is now used in most of the Scottish salmon industry and also in British Columbia and Chile (percussive stunning involves hitting the fish on the head with a rapidly moving object). In the UK, rainbow trout farmers who supply the major retailers have installed electrical stun/kill systems, although some users have experienced seasonal flesh quality difficulties and so may not be using these systems on a regular basis. In most rainbow trout producing countries, the fish are killed by asphyxiation on ice, which is an inhumane method. A percussive stunning system similar to that developed for salmon has also been developed for the small sized rainbow trout. This is currently undergoing trials in Spain and the US.

EU legislation on welfare at slaughter extends to farmed fish. Article 3 of Directive 93/119 provides that animals (including fish) "shall be spared any avoidable excitement, pain or suffering during movement, lairaging, restraint, stunning, slaughter or killing" (Council Directive 93/119/EC). Article 7 stipulates that no person shall engage in these activities unless they have the knowledge and skill necessary to perform them humanely and efficiently. The consequences of these requirements are that fish must be slaughtered humanely by competent staff. This EU legislation has been transposed into British law by the Welfare of Animals (Slaughter or Killing) Regulations 1995.

The central principle is that, as with terrestrial farm animals, pain and suffering should be kept to a minimum during the slaughter process. To achieve this, a method should be used that either causes immediate death or immediate unconsciousness which lasts until the fish are dead; if unconsciousness is not immediate it should be induced without pain or fear or adverse behaviour.

Ideally, slaughter systems should be used that do not involve removal of fish from the water. Where this cannot be avoided, fish should never be out of water for longer than 15 seconds (HSA, 2005).

Asphyxiation in air or on ice

Asphyxiation in air involves removing the fish from the water and leaving them to die. Removal from water is highly aversive for fish; in most cases violent attempts to escape are made and maximal stress response is initiated (EFSA, 2004b). When fish are removed from water their gills collapse which largely prevents oxygen exchange with the environment (Robb & others, 2002). The time required for fish to die depends on the temperature. At 2°C, rainbow trout removed from the water take 9.6 minutes to lose brain function, 3.0 minutes at 14°C and 2.6 minutes at 20°C (Robb and others, 2002).

In 2004, the Scientific Panel on Animal Health and Welfare of the European Food Safety Authority reviewed the literature on slaughter (EFSA, 2004b). It concluded that asphyxiation in air "cannot be considered humane" and warned that loss of movement may occur well before loss of consciousness, leading to the danger that fish may be processed while still sensible. In any killing method that sometimes leads to loss of movement before unconsciousness, there is a danger that processors will mistakenly assume that the fish are unconscious and eviscerate them whilst they are still conscious.

A more commonly used alternative is for fish to be removed from water into bins or tanks containing ice where again they die of asphyxiation. In many countries, portion-sized rainbow trout (around 350-400g) are killed in this way. Temperate fish species take longer to lose brain function when left to die on ice than in air (EFSA, 2004b). As indicated above, at 2°C fish removed from water take 9.6 minutes to lose brain function compared with 3.0 minutes at 14°C. The EFSA Scientific Panel concluded that asphyxiation on ice "should not be used". The ice can immobilise the fish before loss of consciousness; this can lead to fish being bled and eviscerated while still conscious. As long ago as 1996, the UK Farm Animal Welfare Council concluded that killing trout by suffocation on ice should be prohibited (FAWC, 1996). The UK authorities have still not acted on this recommendation. CIWF's 2005 survey of leading UK supermarkets (*Raising the Standard)* found that in one retailer, all the farmed rainbow trout were still killed by asphyxiation on ice.

Both methods of allowing fish to suffocate, in air or on ice, cause immense suffering to fish and simply would not be tolerated as slaughter methods for terrestrial farm animals. CIWF and WSPA call for slaughter by suffocation to be prohibited.

Bleeding without prior stunning

Cutting the gills without prior stunning was formerly employed as a commercial slaughter method for farmed Atlantic salmon, but our understanding is that it is no longer used. This is a slow method for killing fish. Atlantic salmon killed by gill cutting without stunning take on average 4.7 minutes to lose brain function (Robb & others, 2000). This method results in violent movements for up to four minutes in Atlantic salmon which indicates that it is highly aversive (Robb & others, 2000). The EFSA Scientific Panel concluded that exsanguination without stunning "is not humane and should not be used" (EFSA, 2004b).

Where the gill arches are severed following a stunning method, all four gill arches on one side of the head should be severed in order to promote a rapid bleed out and so minimise the risk of recovery from the stun before death ensues. Where gill arches are severed without prior stunning (a practice that we believe should be prohibited), it is important to cut all eight gill arches on both sides of the head to produce as rapid an onset of unconsciousness as possible.

CIWF and WSPA call for bleeding without prior stunning to be prohibited.

Carbon dioxide

Fish are placed in a water bath saturated with carbon dioxide, a process which they find "very aversive" (EFSA, 2004b). Salmon show vigorous aversive reactions for up to two minutes after immersion in carbon dioxide (Robb & others, 2000). Similarly, trout show strong aversion for at least 30 seconds, although times of over three minutes have been recorded (Robb & others, 2002). The high activity in the carbon dioxide stunning bath routinely results in gill haemorrhage (EFSA, 2004b).

Fish immersed in carbon dioxide take a very long time to lose brain function completely. Atlantic salmon placed in carbon dioxide take on average 6.1 minutes to lose brain function, although it can take as long as nine minutes (Robb & others, 2000). For trout, loss of brain function takes 4.7 minutes (Robb & others, 2002).

Because fish stunned in carbon dioxide are rendered immobile before losing consciousness, there is a real danger that they may be bled or eviscerated while still conscious (EFSA, 2004b). Fish should be left in the carbon dioxide for at least ten minutes to cause unconsciousness in every fish (HSA, 2005). In practice, fish are often removed from the water when movement stops after 2-3 minutes (EFSA, 2004b). This means that many fish are not being left for a sufficient time in the carbon dioxide to lose consciousness and are exsanguinated whilst still conscious (EFSA, 2004b). As many fish are not bled effectively, they may still have some level of consciousness when they pass to the next stage of the operation: evisceration (EFSA, 2004b).

CIWF's 2005 *Raising the Standard Survey* of seven leading UK supermarkets found that in four of them, 33 per cent or more of the farmed Atlantic salmon were stunned with carbon dioxide.

Scientific research shows that carbon dioxide stunning is highly aversive and that the fish take a very long time to lose brain function. Accordingly, CIWF and WSPA call

for stunning and killing with carbon dioxide to be prohibited. Indeed, Norway has prohibited its use as a method for stunning fish from July 2008.

One study has found nitrogen to be an effective stunning method for rainbow trout and the strong aversive reaction reported for carbon dioxide stunning was not observed with the use of nitrogen (Wills & others, 2006).

Live chilling prior to carbon dioxide stunning or gill cutting

Live chilling is becoming more widely used prior to the slaughter of farmed Atlantic salmon and rainbow trout (Robb & Roth, 2003; Roth & others, 2006). The fish are chilled down to around 1°C before immersion in carbon dioxide or gill cutting. The aim is to sedate fish prior to slaughter in order to preserve flesh quality.

In some cases, live chilling is performed rapidly, with fish being transferred from high water temperatures to water at 1°C. This causes significant stress (Sjkervold & others, 2001) and fish may show violent movement and escape behaviour (HSA, 2005). In other cases, live chilling is carried out slowly with the rate of temperature reduction not exceeding 1.5°C per hour; this is preferable to rapid live chilling.

Live chilling sedates and may immobilise fish, but it does not induce unconsciousness (Roth & others, 2006). Accordingly, live-chilled fish will be fully conscious when their gills are cut. Equally, they will be conscious if they are immersed in carbon dioxide and, because loss of consciousness is prolonged at lower temperatures, it may take longer for live-chilled fish placed in carbon dioxide to lose consciousness (Robb & Roth, 2003). Roth & others (2006) concluded that rapid live chilling in combination with carbon dioxide appears stressful to Atlantic salmon and does not render them unconscious; the authors stressed that live chilling followed by exsanguination of the unstunned fish appears to be highly stressful and should be avoided. Because unconsciousness is not induced and because of its aversive impact, the EFSA Scientific Panel recommended that live chilling, even when carried out slowly, should not be used (EFSA, 2004 b&c).

CIWF and WSPA call for live chilling to be prohibited.

Percussive stunning

Two of the slaughter methods that have been used in the salmon industry – carbon dioxide stunning and gill cutting without stunning – are inhumane. Accordingly, we welcome the increasingly widespread use of percussive stunning in the slaughter of Atlantic salmon.

Percussive stunning involves hitting the fish on the head with a rapidly moving object. Concussion is caused by the acceleration of the brain within the skull disrupting its function (van de Vis & others, 2003). If sufficient force is applied and the correct part of the head is struck, the fish will be rendered immediately unconscious and in most cases will die without regaining consciousness (EFSA, 2004b; HSA, 2005). However, in some cases fish can recover from the stun, so fish should be bled by gill cutting following stunning within ten seconds of the stun to minimise the risk of them regaining consciousness.

Traditionally, percussive stunning is carried out manually with a club called a 'priest'. The danger is that when large numbers of fish are being slaughtered, the operator will tire and the blows may become inaccurate and miss-hits can result in bruising, eye damage and great suffering. As a result, semiautomatic percussive stunning devices have been developed (using a pneumatically driven non-penetrating captive bolt) and are becoming widespread in the salmon industry. In one stunning device, an operator holds the fish and guides it into the opening of the machine; when the snout touches a trigger, the piston delivers a hard blow to the head. Recent developments in automatic percussive stunning include methods for killing the fish in water and encouraging the fish to swim into the apparatus voluntarily without the need for an operator; this would avoid handling stress (EFSA, 2004b).

Automated percussive stunning systems can also be used in the killing of portion-sized and large trout (over 1kg), cod and flat fish.

Electrical stunning and stun/kill systems

As the systems traditionally used for the killing of most rainbow trout – asphyxiation on ice or in air and carbon dioxide stunning – are unacceptable, research has been undertaken to develop a more humane method. Electrical systems that both stun and kill small fish appear to be the best method for the slaughter of portion-sized rainbow trout. It is important that the system both stuns and kills as commercially trout are slaughtered in large numbers and, if they were only stunned, it would be impractical to cause death by bleeding in all the fish before they began to recover consciousness.

Crucially, the stun must cause immediate unconsciousness of the trout and the fish must remain unconscious until they are dead; an electrical stun of sufficient magnitude, duration and frequency leads to dysfunction of the brain, which prevents the breathing reflex from working, causing death from lack of oxygen. In order to achieve this, sufficiently high currents must be applied for a sufficient amount of time, i.e.: both current magnitude and duration of application are important (Robb & others, 2002).

If insufficient current or duration is used or if the frequency is too high, fish may be stunned for only a short period, after which they will begin to recover consciousness. Alternatively, inadequate current, duration or frequency may result in fish being paralysed rather than stunned. When paralysed, fish cannot express pain or show escape behaviour and so may be bled or eviscerated while fully conscious. The EFSA Opinion warns that electrical systems can cause substantial suffering when incorrectly applied (EFSA, 2004c).

A major concern for the industry is that electrical stunning can lead to carcase damage such as haemorrhages. To avoid this, higher frequencies can be used ('frequency' is the number of alternating cycles of current that occur per second). The frequency of mains electricity is 50 cycles per second or Hertz (Hz). Higher frequencies can avoid carcase damage, but are less effective at producing immediate insensibility and death. If a high frequency is used to avoid carcase damage, it must not be so high as to fail to stun/kill.

One major advantage of electrical stun/killing is that in a well-designed system, stressful pre-slaughter handling and restraint can be minimised or eliminated (EFSA, 2004b). In addition, the stressful event of removal from water can be avoided.

Research shows that electrical stunning can produce immediate unconsciousness in Atlantic salmon (Robb & Roth, 2003). If systems that only stun are used, the period of unconsciousness produced by the stun in Atlantic salmon must last until death results from blood loss following gill cutting. The EFSA Scientific Panel concludes that in practice this is unlikely to be achieved. Electrical stunning (with an electric field strength of 50 volts/m for three seconds) produces an average period of unconsciousness in Atlantic salmon of 4.8 minutes, although this can be as low as 44 seconds (Robb & Roth, 2003). Atlantic salmon killed by gill cutting take an average of 4.7 minutes to lose brain function (Robb & others, 2000). Accordingly, there is a real danger that the period of unconsciousness produced by stunning may be insufficient to prevent salmon from regaining consciousness before they die following gill-cutting. Accordingly, systems that both stun and kill should be used to prevent the salmon regaining consciousness. Alternatively, a system is being developed in Norway whereby salmon are stunned electrically then, before they can regain consciousness, are subject to percussive stunning after which they are bled by gill cutting.

Pre-slaughter sedation with anaesthetic

EU legislation prohibits the use of pre-slaughter anaesthetics for fish. However, an anaesthetic product called *AQUI-S* is used as a pre-slaughter sedative in salmon killing in Chile, Australia and New Zealand. Induction of sedation with *AQUI-S* does not appear to be stressful and sedated fish appear to suffer far less distress when removed from water for stunning (EFSA, 2004b).

Sedation is not a stunning or killing method; once sedated, fish must be stunned, for example by accurate percussive stunning. **CIWF and WSPA believe that further consideration should be given to the use of pre-slaughter anaesthetics as these could considerably reduce the stress involved in pre-slaughter handling.**

Bringing salmon to the surface prior to slaughter

The stress of slaughter can start well before the fish reach the stunner. Salmon can have difficulty in adapting quickly enough to being hauled to the surface of deep cages which can be 20 metres in depth. Moreover, the nets are pulled up, drawing the fish together into a confined space, adding additional stress to the fish. The longer the duration of the crowd, the more intense the stress becomes. It is therefore important that the operators are aware of this and crowd the fish prior to slaughter for as short a time as possible. The Humane Slaughter Association recommends that fish should not be kept crowded for more than two hours (HSA, 2005).

Emergency slaughter

Emergency slaughter can involve the killing of large batches of fish for disease control purposes or the euthanasia of one or more individual injured, deformed, diseased or moribund fish. Emergency slaughter must be carried out in such a way as to minimise pain and suffering. Accordingly, a method should be used that either causes immediate death or immediate unconsciousness which lasts until the fish are dead. A stunning method that produces a gradual onset of unconsciousness may only be used if the process is completely non-aversive. **CIWF and WSPA believe that the following methods are acceptable in emergency slaughter provided that they are used properly:**

- **a percussive blow followed by exsanguination** - provided that the blow is delivered with sufficient force and to the correct part of the head
- **an overdose of a non-aversive fish anaesthetic** - a lethal dose should be used with the fish being left in the solution for sufficiently long to kill them. If the concentration of anaesthetic agent is correct, surgical levels of anaesthesia are achieved in 1-2 minutes and the fish are dead in 5-10 minutes (EFSA, 2004b)
- **an electrical stun/kill system** can be used for killing trout. The current magnitude, duration and frequency should be such as to produce immediate and irreversible unconsciousness followed by death

Because they cause pain and/or suffering and entail prolonged delays until the onset of unconsciousness, the following methods should never be used in emergency slaughter: asphyxiation in air or on ice, gill-cutting without prior stunning and carbon dioxide stunning. Some argue that there may be circumstances when carbon dioxide may be the only appropriate method for emergency slaughter. However, in most cases where carbon dioxide could be used, fish could also be killed by an overdose of anaesthetic which is preferable from the welfare viewpoint (EFSA, 2004b).

Conclusion

Many farmed fish are killed by methods that have been established by scientific research to be inhumane. The following methods should be prohibited on welfare grounds: asphyxiation on ice or in air, carbon dioxide stunning and gill-cutting without prior stunning. Live chilling should also be prohibited. Further consideration should be given to the use of pre-slaughter anaesthetics as these could considerably reduce the stress involved in pre-slaughter handling. We are pleased that Norway has prohibited the use of carbon dioxide as a method for stunning fish from July 2008. We welcome the fact that percussive stunning is used for the slaughter of most salmon in Scotland; this method is also in use in Chile and British Columbia. Also welcome is the fact that in the UK, rainbow trout farmers who supply major retailers have installed electrical stun/kill systems, although some users have experienced seasonal flesh quality difficulties and so may not be using these systems on a regular basis. In most other rainbow trout producing countries, the fish are killed by asphyxiation.

Sustainability issues

Threats to wild stocks from farmed fish

Farmed Atlantic salmon jeopardise the long-term sustainability of wild salmon as a result of escapes and the transmission of sea lice from salmon farms to wild fish. Wild Atlantic salmon numbers have fallen dramatically over the last 30 years; salmon catches in the North Atlantic area have dropped by over 80 per cent between 1970 and 2000 (WWF-Norway, 2005). Wild Atlantic salmon have disappeared from much of their range and are in a precarious state in many other rivers. This fall has coincided with the growth of salmon farming which is widely recognised as an important contributory factor in the decline of wild Atlantic salmon populations.

Farmed Atlantic salmon far outnumber their wild relatives. In Norway, there are around 200 million farmed salmon, whereas the Norwegian Ministry of Environment estimated in 1999 that there were just 100,000 to 250,000 wild spawners. In Scotland, the total wild salmon catch in the salmon farming areas of the west coast was under three tonnes in 2001, whereas total farmed salmon production at that time was about 139,000 tonnes (Royal Commission, 2004).

A substantial number of fish escape from sea cages as a result of both regular, low-level leakage and periodic events such as storms. It is estimated that up to two million salmon escape each year from farms in the North Atlantic (Naylor & others, 2005). Almost half a million salmon and trout a year escape from Norwegian farms (WWF-Norway, 2005). In Scotland during 2005, there were 19 reported escapes from seawater salmon farms involving the loss of 510,840 fish (FRS, 2005). In addition, a proportion of younger salmon escape at the freshwater stage (Butler & others, 2005). In 2005, there were five reported escapes from Scottish freshwater Atlantic salmon sites involving the loss of 367,043 fish. Outside their native range, millions of Atlantic salmon have escaped on the western coasts of North and South America (Naylor & others, 2005).

A study of the River Ewe in Scotland found that since the establishment of Atlantic salmon farming in the vicinity in 1986/87, an estimated 425,000 parr and smolts, and 122,000 growers have escaped (Butler & others, 2005). Farmed fish were caught in the rod fishery in 13 out of 15 years, contributing to at least 5.8 per cent of the catch, with a maximum annual frequency of 27 per cent. The authors stress that these figures probably underestimate the prevalence of farmed salmon within the Ewe.

The maximum frequency of farmed salmon in the Ewe was lower than that found in rivers in salmon farming zones in other countries such as the River Botnsa, Iceland (69 per cent) and the Magaguadavic River, Canada (90 per cent) (Butler & others, 2005).

In some Norwegian rivers and coastal areas a high proportion of salmon are farmed fish. In several Norwegian rivers, over 20 per cent of the salmon are farmed fish; in some rivers this figure rises to over 40 per cent. In several Norwegian coastal and fjord areas farmed fish comprise around 30 per cent of the salmon; in Hardanger fjord, 86 per cent of the salmon were of farmed origin in 2003 (WWF-Norway, 2005).

The detrimental impact of farmed salmon on wild fish may arise in three ways:

- competition for feed and habitat
- transfer of diseases and parasites, particularly sea lice
- interbreeding with wild fish, leading to dilution of genetic integrity.

Competition for feed and habitat

Escaped farmed salmon tend to spawn later than their wild counterparts and, in so doing, often destroy the eggs and redds of wild fish. Farmed salmon escapees are able to out-compete wild salmon for feed and to occupy valuable habitat to the exclusion of wild fish (Fleming & others, 2000). One factor that enables them to do this is that, having been selected for rapid growth, farmed salmon are generally larger and more aggressive than wild salmon (McGinnity & others, 2003). Thus, offspring from escaped farm fish have a size advantage and potentially a competitive edge over wild juveniles (Naylor & others, 2005). The aggressiveness of escaped juvenile farmed salmon can severely stress wild juveniles, even increasing their mortality rate (Naylor & others, 2005). Farmed and hybrid fish can displace their wild counterparts to poorer habitats, again increasing mortality (Naylor & others, 2005).

Disease hazards

Disease transmission from farmed to wild fish can occur in various ways: wild fish swim near or even in and out of the cages; waste water from the cages can carry pathogens; and escaped fish can transfer disease to the wild population. Escaped fish may, for example, spread virus such as *Infectious Pancreatic Necrosis* (IPN) some distance from the farm of origin (Anon, 2003). Escaped fish that are suffering from clinical disease are vulnerable to predation. Piscine predators may become infected with the disease themselves, while mammalian and avian predators may become passive carriers of infection (Anon, 2003).

Sea lice transmission

The high levels of sea lice in some cages are leading to the transmission of lice from farms to wild salmon and sea trout and hence to substantial declines in wild salmonid populations. Indeed many studies have linked lice infestation in wild salmonids with the presence of salmon farms (Krkošek & others, 2004). Sea lice have been blamed for the collapse of wild sea trout stocks in several countries. Sea trout are particularly vulnerable to infestation by sea lice in farm cages as they tend to feed near the coast in inshore waters, i.e. close to where cages are often located.

Escaped salmon can spread sea lice. Moreover, wild salmon smolts migrating from their rivers can face a 'wall' of sea lice as they pass the farm cages on their way to the sea. In the UK, the Royal Commission on Environmental Commission has said: "Sea lice have always affected wild salmon, but intensive farming has increased the scale of the problem. It is now one of the biggest issues for salmon aquaculture in many areas of Scotland" (Royal Commission, 2004). Norway has recognised the seriousness of the problem. In order to try and reduce the impact of lice from farmed fish on wild salmon, Norway has put in place a National Action Plan Against Salmon Lice on Salmonids. This includes legal limits for the maximum mean number of lice per farmed fish, strategic regional treatments against lice and monitoring of lice infection in wild salmonids.

In 2002, around 3.5 million wild salmon failed to return to spawn in rivers in the Broughton Archipelago of British Columbia. It is feared that the migrating wild smolts were overwhelmed by the sea lice that congregate in and around the farm cages (Hume & others, 2004). One marine biologist reports that the wild smolts were covered with sea lice, with bleeding at their eyeballs and the base of the fins (Morton A. in Hume & others, 2004). She describes their 'ruined bodies' and tells of the immense scale of the suffering as the young fish were ravaged by the lice.

One study investigated infections of sea lice on juvenile pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) as they passed an isolated salmon farm during their seaward migration down two long, narrow corridors in British Columbia (Krkošek & others, 2004). The study found that maximum infection pressure near the farm was 73 times greater than ambient levels and exceeded ambient levels for 30km along the two wild salmon migration corridors. The farm-produced lice that parasitised the wild juvenile salmon reached reproductive maturity and produced a second generation of lice that re-infected the wild juveniles. This raised the infection pressure from the farm by an additional order of magnitude. The key role of salmon farms in the transmission of lice to wild salmon is highlighted by Morton and others (2004) who found a significant level of sea lice infection on wild juvenile pink and chum salmon near salmon farms, but virtually no lice on salmon in several regions of British Columbia with no salmon farms.

Genetic dilution

Wild salmon are well adapted through evolution for their complex lives. As a result of selective breeding, particularly for rapid growth, genetic changes have occurred in farmed salmon that reduce their capacity to survive in natural conditions and make them genetically distinct from their wild counterparts. In addition, farmed salmon have less of the genetic variation that is necessary for adaptability and long-term survival. Interbreeding between escaped and wild salmon produces offspring with a genetic make-up less well suited for life in the wild. As a result, these hybrid offspring have lower survival rates. Interbreeding can lead to a wild population composed completely of descendants of farmed escapees (Naylor & others, 2005). In Maine, US for example, a major reason for declines in wild stocks is seen as genetic dilution of wild Atlantic salmon populations by farm-raised fish that have trouble finding their way back to local streams to spawn (Niiler, 2000).

Fleming and others (2000) concluded that escaped farm salmon may have wide-ranging genetic effects on native salmon and that this calls into question the long-term viability of many salmon populations. McGinnity and others (2003) stressed that "interaction of farm with wild salmon results in lowered fitness, with repeated escapes causing cumulative fitness depression and potentially an extinction vortex in vulnerable populations".

In the River Ewe study referred to earlier, escaped Atlantic salmon contributed at least 27 per cent to the potential spawners in the river in 1997. Farmed fish probably spawned in three sub-catchments also used by wild fish. Smolt age of the wild fish decreased significantly; this could have been as a result of hybridisation. The researchers recommended that, as the Ewe has a depleted wild salmon population, further genetic introgression by escapees should be prevented.

Feeding wild fish to farmed fish

Salmon and trout are natural carnivores. On the farm, they are fed compound feeds based on fishmeal and fish oil. The fishmeal and oil is mainly obtained from catching so-called 'industrial' or 'feed' species of small ocean-going fish from the waters of South America and Europe. These include anchovies and sardines from Chile and Peru plus sand-eels, sprat, capelin, blue whiting and Norway pout from Europe.

Worldwide, landings of industrial fish have been fairly stable over the last 20 years at around 20-25 million tonnes per year (FAO data). In addition, over four million tonnes per year of 'trimmings' (processing waste from fish caught for human consumption) are also used as fishmeal (Shepherd & others, 2005). Over the last 20 years production of fishmeal and fish oil from industrial fish and trimmings has ranged between 6.2 and 7.4 million tonnes per year of fishmeal and 1.0 and 1.7 million tonnes of fish oil per year (Shepherd & others, 2005).

Many farmed fish, including salmonids and marine finfish, are dependent on fishmeal as the main source of dietary protein within compound aquafeeds and on fish oil as the main source of dietary lipids and essential fatty acids (Tacon, 2004). As a result, aquaculture is now the largest user of fishmeal and fish oil, with 53 per cent of global fishmeal production and 87 per cent of global fish oil production being used in aquaculture (Shepherd & others, 2005; Tacon, 2005).

It is often claimed that fish farming may take the pressure off stocks of wild-caught fish by providing an alternative. However, the reverse can be true for carnivorous species that rely on a relatively high degree of fishmeal and fish oil in their diet. Over three tonnes of wild-caught fish are needed to produce one tonne of farmed salmon (Naylor & others, 2000; Tacon, 2004; Shepherd & others, 2005). It also takes 2.3 tonnes of wild fish to produce one tonne of trout (Tacon, 2004). For marine species such as halibut and cod, it can take between 3.3 to 3.84 times the weight in wild fish to produce a farmed fish (Tacon, 2004; Naylor & Burke, 2005).

Feeding wild fish to farmed fish puts wild fisheries under pressure. This is because, in common with other animal production systems, farmed salmon and trout do not produce protein – they waste it. Fish may be less wasteful at converting feed into flesh than pigs or cattle, but they are still wasteful.

The use of wild fish to feed farmed fish is damaging in a variety of ways:

- certain of the wild fish species utilised as feed (including mackerel, blue whiting, sardines, anchovies, pilchards, capelin and herring) could be used for direct human consumption
- certain wild industrial stocks are being severely over-fished and their viability jeopardised in order to produce feed for farmed fish
- a decrease in wild industrial stocks entails a reduction in feed supplies for predator fish, marine mammals and seabirds.

Use of wild fish for direct human consumption

The use of wild-caught fish to feed farmed fish reduces stocks of wild fish that could potentially be consumed directly by people (Naylor & others, 2000). In South-East Asia, for example, small fish such as anchovy, sardines and mackerel are an important source of protein for local people.

Pressure on over-fished wild populations

Whilst the fish farming industry continues to grow rapidly in Europe and worldwide, stocks of wild-caught fish used for feed remain finite, with a number of them already classified as fully exploited, overexploited or depleted (Naylor & others, 2000). Blue whiting is being harvested unsustainably in Europe (ICES, 2004). Sand-eel, Barents Sea capelin and Norway pout are classified as having reduced reproductive capacity and steps are being taken to constrain the catch of these fish (Shepherd & others, 2005). South American pilchard and Chilean jack mackerel are classified as fully exploited or over-exploited (Tacon, 2005).

Reduction in feed supplies for other creatures

A reduction in wild stocks that are used for feed for farmed fish results in a decrease in food supplies for fish predators such as cod as well as for marine mammals and seabirds. In the North Sea, for example, falls in certain sand-eel, capelin and Norway pout stocks, largely due to over-exploitation for fishmeal, have been linked to declines in wild fish such as cod and changes in the distribution, population sizes and reproductive success of various seal and seabird colonies (Naylor & others, 2000). Likewise, in Peru, researchers have found a strong link between anchoveta stocks and the size of mammal and seabird populations (Naylor & others, 2000).

Industrial fish stocks are finite and catches will not be able to increase to meet the rising demand for feed ingredients from the rapidly growing aquaculture industry. Accordingly, research is being carried out to develop substitutes for fishmeal and fish oil as feed ingredients for aquaculture. It is predicted that substantial reductions in the fishmeal and fish oil content of farmed salmon diets will be made by 2010 (Shepherd & others, 2005). However, replacement of these ingredients for salmon and other carnivorous fish faces significant difficulties.

Particular attention has been given to the use of vegetable proteins such as soybean meal. However, carnivorous fish are not well-adapted to plant based feeds and abnormalities may occur if large amounts are included in their diet (Suontama & others, 2005). Vegetable proteins have inappropriate amino acid balance and poor digestibility for carnivorous fish (Naylor et al, 2000) and have, in some cases, compromised the fish immune system (Pike, in litt.). The use of soybean meal in diets for Atlantic salmon has resulted in severe morphological changes and inflammation-like symptoms in the distal intestine as well as reduced growth and poorer feed conversion in Atlantic salmon and rainbow trout (Frøystad & others, 2005). Digestive disturbances and growth depression have also resulted from the use of soybean meal in Atlantic salmon diets even at low inclusion levels (Refstie & others, 2005). Rainbow trout have a preference for a standard diet with fish oil to diets containing vegetable oil (Geurden & others, 2005).

Welfare implications for wild fish

Industrial feed fish are often small. The estimated average weight of the European sprat is 11g, that of sand-eels is 21g, while those of Peruvian anchovies, Japanese anchovies and capelins are 19g, 15g and 34g respectively (Mood & Brooke, 2005). The consequence of these small weights is that a huge number of feed fish are caught annually to provide fishmeal and oil. It is estimated that the number of feed fish caught per year is between 500 and 1,250 billion (Mood & Brooke, 2005).

The methods of slaughter for these fish are a long way from meeting the criteria for humane slaughter referred to in the section on slaughter above. Industrial fish will die either from crushing under the weight of fellows (in the net or in the pile of fish after landing) or from asphyxiation in air once landed. The time required for fish to die by asphyxiation varies depending on the species and the temperature. For example, rainbow trout removed from the water take 9.6 minutes to lose brain function at 2°C and 3.0 minutes at 14°C (Robb & others, 2002). Farmed seabream that are removed from the water to die of asphyxiation in air take an average of 5.5 minutes to lose brain function (van de Vis & others, 2003). It is clear that death by asphyxiation in air is a slow process. In summary, the billions of feed fish caught each year to provide fishmeal and fish oil are killed in ways that involve suffering that may often be prolonged.

Conclusion

Huge quantities of wild 'industrial' fish are caught to feed to farmed carnivorous fish such as salmon, trout, halibut and cod; this adds to the pressure on wild fish stocks and is unsustainable. Over 3 tonnes of wild-caught fish are needed to produce one tonne of farmed salmon. It takes 2.3 tonnes of wild fish to produce one tonne of farmed trout. For marine species such as halibut and cod, the ratio is over three times the weight of wild fish to produce a given amount of farmed fish.

The use of wild fish to feed farmed fish raises important sustainability issues. Some of the fish used as feed could be used for direct human consumption. In addition, the viability of certain 'industrial' fish stocks is threatened by severe overfishing. Moreover, a decrease in wild 'industrial' stocks entails a reduction in feed supplies for predator fish, marine mammals and seabirds. In view of these problems, the sustainability of intensive carnivorous fish farming should be reviewed.

Farming of new species

New species are increasingly being introduced into intensive fish farming, while the commercial potential of yet other species is currently being evaluated. The principal new species that have been introduced into Scottish aquaculture include Atlantic cod and Atlantic halibut. Other species that are either being farmed in Scotland to an, as yet, small degree or are being evaluated for their suitability for farming include Artic charr, haddock, lemon sole, lumpsucker and hake (Anon, 2005).

CIWF and WSPA oppose this development. The principal European farmed species – Atlantic salmon and rainbow trout – suffer from a range of welfare problems. We do not believe that new species should be exposed to similar problems. Because salmon and trout farms were set up before the industry had established how to rear and slaughter the fish in a humane manner, millions of salmon and trout have suffered unnecessarily over the years due to the fact that farmers have had to try to solve health and welfare problems *ad hoc*.

We are concerned about the introduction of new species into farming; at the very least there should be a moratorium on the use of such species until farmers are able to demonstrate that humane rearing, transport and slaughter methods have been developed for that species. Moreover, the farming of new species presents disease risks. A report of the Scottish Aquaculture Health Joint Working Group has concluded that as Scottish aquaculture develops over the next ten years to increase production of new species, the risk of inter-species disease interaction may also increase (Anon, 2005).

Atlantic Cod *(Gadus morhua)*

The cod is a large roundfish that in the wild can grow to 35kg. Cod is seen as an important species for aquaculture, with interest in farming cod being spurred by the severe decline in wild stocks and the high market value of farmed cod.

Farmed cod production is expected to increase rapidly in the near future; farming of Atlantic cod is already established in Norway, Scotland, Canada and Iceland. Cod farming is growing quickly in Norway. Norway produced 5,500 tonnes of farmed cod in 2005 and this is expected to rise to 37,000 tonnes per year by 2009 (Slaski, 2005; Håstein, pers. comm.). Farmed cod production in Scotland grew from 15 tonnes in 2001 to 82.1 tonnes in 2003 and an estimated 851 tonnes in 2006 (FRS, 2004 & 2005). It is predicted that Scottish production will rise to 10,000 tonnes per annum over the next few years (Slaski, 2005). Iceland produced just over 1,000 tonnes of farmed cod in 2005, with production expected to rise to almost 3,000 tonnes in 2007 (Wilhelm, 2005). Atlantic cod farming began along the Northeast coast of North America in about 2000, with around 200,000 juvenile cod being transferred to sea cages for on-growing in 2004.

Cod spawn naturally in farms and so, unlike salmonids, are not subject to artificial stripping. Cod fry have to be fed on live prey (rotifers and artemia) to survive. The fry are reared in tanks and then transported in trucks or well boats to sea cages or tanks where they are on-grown to slaughter weight, which in the UK is around 4.5-5kg. In Scotland the cages tend to be circular, being about 100 metres in circumference and 16 metres in depth. The technical requirements for cod hatcheries are very complex and egg and larval quality is inconsistent (Bell & others, 2005). Hatchery survival rates tend to be poor, with high mortalities often occurring during early larval development and at first feeding (Kjørsvik & Tanem, 2005).

High stocking densities may impair the welfare of cod. Feed intake and growth are significantly lower among cod stocked at 30 and 40kg/m^3 than in those stocked at 10kg/m^3(Lambert & Dutil, 2001). Reduced feed intake and growth in fish are often seen as indicative of poor welfare. The Organic Food Federation in the UK stipulates a maximum stocking density for cod of 15kg/m^3. CIWF and WSPA believe that the maximum stocking density for cod should be 10-15kg/m^3.

Many of the factors that lead to poor welfare in farmed Atlantic salmon and rainbow trout are also present in cod farming. Cod are aggressive and heterogeneous growth rates can lead to cannibalism (Höglund & others, 2005). Accordingly, frequent size-grading is needed at the nursery stage to protect smaller fish. However, grading is problematic as cod become stressed if handled too often; grading can lead to significantly lower growth rates (Lambert & Dutil, 2001). Passive grading, which can diminish the stress involved, is now being used on some cod farms.

Juvenile cod can suffer from anatomical malformations such as spinal and operculum/jaw deformities (Imsland & others, 2005); in some cases juveniles may exhibit a high frequency of abnormalities (Kjørsvik & Tanem, 2005). Up to 80 per cent of some fingerling groups of farmed cod show deformities in the neck region as a result of pressure from an abnormally large air bladder (European Commission, 2004).

A range of diseases affect cod farming. These include *Listonella anguillarum (Vibrio anguillarum)* which is associated with mortality in larvae, on-growing cod and broodstock; parasitic diseases; granulomas, for example those found with the novel disease *Francisella sp* (NVI, 2005) – granulomas are often extensive and lead to loss of performance and condition; and *Spawning Cod Inflamed Vent Syndrome* in which the vent becomes inflamed and prevents release of the next egg batch, usually leading to death of affected fish (Bricknell & others, 2005).

Like many farmed fish, cod - particularly the males - can mature earlier than desired by farmers. Such early maturation leads to reduced flesh quality and reduced growth and poses threats to wild stocks should the fish escape. Maturation in cod can be delayed by photoperiod manipulation, i.e. by exposing the fish to continuous artificial light (Kristoffersen & others, 2005). Continuous lighting is also being used to achieve increased growth rates (Kvenseth, 2005).

In addition, manipulation of day length and temperature is being used to produce eggs outside the natural spawning season (Walden, 2000).

Selective breeding programmes are being carried out to achieve faster growth in farmed cod (Wilhelm, 2005). Research indicates that selective breeding can produce increases in growth rate of around 12 per cent per generation (Kristjansson & others, 2005). Fast growth rates could lead to farmed cod being susceptible to the kind of serious welfare problems that afflict terrestrial farm animals that are pushed to high growth rates by genetic selection. The Scottish cod industry appears not to be selecting for accelerated growth at this stage. Other selective breeding goals for cod include delayed early sexual maturation and improved disease resistance.

In Iceland and Norway, a proportion of the cod that are farmed have been captured from the wild for on-growing on farms (Midling, 2005; Wilhelm, 2005). In Iceland, the number of wild juvenile cod captured for on-growing on farms has grown from 1,700 in 2001 to one million in 2004 (Ólaffson, 2005). The wild juvenile cod suffer high mortality in the first two months after arrival at the farming station; less than half survive to the next stage when they are transferred for further on-growing in sea-cages (Ólaffson, 2005). Cod aquaculture is also heavily reliant on wild caught broodstock to maintain high levels of larval production (Bell & others, 2005). The UK Organic Food Federation permits all of the broodstock in a new hatchery to be taken from the wild and up to 30 per cent of each year's replacement broodstock to be wild-caught. The use of wild-caught cod for aquaculture is unacceptable both because it further reduces severely depleted wild stocks and because wild fish are ill-equipped to adapt to the unnatural environment of aquaculture.

Experience from Norway shows that cod are more adept at escaping than salmon or trout; cod can chew their way through the net. We fear that escapes from cod farms will pose threats to already severely depleted wild stocks. Escaped farmed cod could transmit diseases, displace wild cod from spawning grounds and, through interbreeding, dilute the genetic integrity of wild populations; this can impair the adaptation that wild stocks have made to local conditions and hence weaken their ability to survive. Farmed cod are less genetically differentiated from wild cod than is the case with salmon; this would lessen, though not eliminate, the genetic impact of escapes on wild populations (Naylor & others, 2005).

A welcome development is that work is underway in Scotland to try and develop cage enhancements for cod including shelter and objects such as ropes for the fish to chew on.

Cod are subject to pre-slaughter starvation periods to ensure gut evacuation. In Scotland, these periods last 3-5 days, depending on temperature.

Turning to slaughter, in the UK cod are stunned by a percussive blow in a semi-automated system and are then bled by gill cutting.

Atlantic halibut *(Hippoglossus hippoglossus L.)*

The Atlantic halibut is a large flatfish that in the wild can live for over 50 years and can grow to over 300kg. Halibut farming has become established in the UK, Norway and Iceland. Hatchery and research programmes are also underway in Ireland, Canada, Chile and the US (Naylor & Burke, 2005). Norway produced 1,150 tonnes of farmed halibut in 2005; Scotland's production in 2005 was 272 tonnes with an estimated 423 tonnes being produced in 2006 (FRS, 2005; Håstein, pers comm.). It is predicted that UK annual production will rise to 850 tonnes by 2011 (Slaski, 2005). In 2002, Iceland produced 120 tonnes (Wilhelm, 2005).

Halibut "are essentially solitary fish and conditions prevalent in hatcheries and on-growing facilities are in stark contrast to their natural environment" (Greaves & Tuene, 2001). Halibut farming tends to be intensive, with fish being stocked at high densities in some cases and sex reversal techniques being developed to create all-female stocks; this is economically attractive to aquaculture as female halibut grow faster and mature later than males (Hendry & others, 1999).

A draft Appendix to the Council of Europe Recommendation on farmed fish states that as eggs and milt need to be collected several times and repeated administration of an anaesthetic would be detrimental to the welfare of the fish, stripping should be done manually, without anaesthetic, but with the eyes of the fish covered so that it remains calm.

Once they are passed the yolk-sac stage, the young halibut are reared in tanks. Initially they are fed live prey such as rotifers and copepods. There are major problems in this phase, resulting in a wide range of survival rates and low and unstable juvenile production (Kristiansen & others, 2004). Once they have metamorphosed into typical flatfish, they are kept in shallow tanks. Here too there can be serious problems. Aggression is common in young halibut during feeding (Greaves & Tuene, 2001). Injuries are sustained to the eyes, fins and tails. Eye injuries are a serious problem and often lead to blindness in one eye (Kristiansen & others, 2004). Aggression is mainly due to competition for food; another factor may be high stocking densities which may increase stress and induce aggression (Greaves & Tuene, 2001). Frequent grading of young fish is needed to reduce aggression.

On-growing to slaughter weight takes place in both onshore tanks and sea cages. Halibut are sedentary fish that spend most of their time resting on the bottom. Divers have observed that in the wild, single juvenile halibut lie camouflaged on the bottom, partly covered by sand, presumably rarely in contact with each other (Kristiansen & others, 2004). These authors write that "in aquaculture, densities are very high, with 100-300 per cent of the bottom area theoretically covered with fish, and high levels of contact and interactions between individuals may create stressful conditions". Densities are not always so high; for example, one UK producer stocks at a maximum of 50 per cent bottom coverage.

A study of 2-10kg halibut reared in tanks investigated low, medium and high densities (18, 54 and 112 per cent bottom coverage) (Kristiansen & others, 2004). The researchers found that food consumption and growth rates fell significantly with increasing density; indeed some fish stocked at high density had negative growth rate. Clearly, in the long run negative growth is detrimental to the fish and reflects suboptimal conditions.

They reported that the fish left the bottom more frequently at higher densities and engaged in surface swimming which may be viewed as an indication of impaired welfare in largely sedentary fish. The researchers stated that overcrowding on the bottom may increase the tendency to leave the bottom: fish that land after swimming may disturb resting fish and push them into swimming activity. They added that in the high density tanks the fish on the bottom were continually being disturbed by moving and landing fish and were thus deprived of resting periods, which may be a severe stressor.

Some fish stocked at high density engaged in almost vertical surface swimming. The researchers wrote that although the origin and function of this swimming are not clear it "may be seen as an abnormal behaviour with no functional explanation, induced by a suboptimal environment and thus, a kind of stereotypy or self-stimulation comparable to the 'pacing' behaviour of zoo animals". They added that the swimming activity could be interpreted as fish trying to move away from an unfavourable situation which, in the confines of intensive farming, they are unable to do.

The authors stressed that their study strongly indicates that the growth and welfare of halibut are best at low densities and that fish density in tanks should not exceed a critical level of bottom coverage. In conclusion, stocking halibut at high densities appears to lead to higher stress levels, reduced feeding motivation, lower growth and stereotypic behaviour in some fish.

Halibut are powerful fish and not easy to slaughter. In the UK they are stunned with a percussive blow and then bled by gill cutting. The stun is applied manually. Halibut are flatfish and asymmetric; this can make it difficult to locate the correct point for application of the blow. Moreover, because halibut are strong, considerable force is needed to deliver an effective stun. The feasibility of automated percussive stunning is being investigated; however, individual variations between halibut may make it difficult to develop automated percussive stunning. Electrical stunning is also being researched. It may be difficult to stun/kill halibut with electrical systems; accordingly, halibut would have to be stunned electrically and then immediately bled so that death occurs during the period of insensibility produced by the stun.

Organic and Freedom Food™ standards

CIWF and WSPA regret that the organic movement has moved into fish farming, as in our view, confining creatures that naturally roam over great distances in small ponds, tanks or cages is incompatible with organic principles.

That said, the organic standards and those of the RSPCA's Freedom Food™ (RSPCA, 2006) scheme demonstrate that it is practicable to farm fish to significantly higher welfare standards than those of industrial farming.

The organic and Freedom Food™ standards include a number of helpful provisions that seek to address some of the welfare problems associated with industrial production. In the UK, the Soil Association and the Organic Food Federation have set standards for salmon and trout (OFF, 2004; Soil Assoc., 2007). This report examines the Soil Association standards in some detail.

Atlantic salmon and trout

CIWF and WSPA welcome the maximum stocking densities set by the Soil Association's 2006 standards which are substantially lower than those widely used in conventional fish farms. The Soil Association lays down a maximum stocking density for Atlantic salmon in saltwater net pens of 10kg/m^3 +/-1%. The Organic Food Federation sets the same maximum density for saltwater net pens and a maximum density of 20kg/m^3 +/-2% for the juvenile freshwater stages. The Soil Association's maximum density for trout is 20kg/m^3 +/-2% in running freshwater operations and 10kg/m^3 +/-1% in net pens.

Also welcome is the Soil Association's express prohibition on the use of triploid stock, all-female stock and genetically engineered stock.

In order to reduce stress, the Soil Association provides that live fish must not be left out of the water for more than 15 seconds unless anaesthetised. It also stipulates that pre-slaughter crowding must not exceed two hours.

As we fear that photoperiod manipulation may impair welfare, we welcome the fact that the Soil Association stipulates that artificial light may only be used with fry and only to prolong the day length to a maximum of 16 hours per day. Also welcome is the Soil Association prohibition on the use of artificial light to manipulate smoltification in Atlantic salmon or to control maturation or production in finishing stock.

CIWF and WSPA are disappointed that the Soil Association permits the use of wrasse for treating sea lice as, as indicated earlier, wrasse welfare is impaired when they are used to remove sea lice from salmon. The prohibition on the use of wrasse by the RSPCA's Freedom Food™ standards is welcome.

We of course recognise that failure to treat sea lice infestation can lead to fish suffering and dying. Clearly a welfare-friendly alternative to wrasse is urgently needed. The best approach is to avoid parasite infestation, for example, through site selection (a clean site with fast-flowing water is required), separation of year classes, periodic fallowing of cage sites and the setting up of complementary management procedures between farms in the same area. Accordingly we welcome the Soil Association requirement that sites used to farm Atlantic salmon must be left fallow for at least six weeks between production cycles, although it has been suggested that a fallowing period of at least three months is needed to break the sea lice life-cycle (Porter, 2003).

We are pleased that the Soil Association standards stipulate that predators must be deterred, but cannot be killed.

In order to reduce the volume of wild caught fish used in the feed of farmed fish, the Soil Association stipulates that the aquatic ingredients in the feed must be from wild marine resources independently certified as sustainable by a recognised certification body or, failing that, must be by-products of fish caught for human consumption. The Soil Association has set a target date of 2010 by which all fishmeal and fish oil incorporated into Soil Association organic fish diets should come exclusively from Marine Stewardship-certified sources.

CIWF and WSPA believe that protracted periods of pre-slaughter starvation are unacceptable from the welfare viewpoint. The UK Farm Animal Welfare Council has recommended that pre-slaughter starvation should not normally exceed 48 hours for trout and 72 hours for salmon. In light of this, we welcome the Soil Association provision that salmon may only be starved before slaughter for up to 72 hours or 40 degree days (the temperature in centigrade multiplied by the number of days), whichever is the shorter. We are, however, opposed to the Soil Association provision that permits trout to be starved for up to seven days before slaughter; indeed, the Soil Association recognises that this starvation period is longer than ideal. Importantly, the Soil Association standards prohibit the starving of all the fish in a pen or pond if only some are to be slaughtered.

As transport can be highly stressful for fish, we welcome the Soil Association's provisions that require journeys to be kept to a minimum and that in particular place a maximum limit of six hours on road journeys and 25 minutes on helicopter journeys.

Also welcome are the provisions on slaughter that require fish to be made instantly insensible and that prohibit certain slaughter methods that have been established by scientific research to be inhumane. In particular the Soil Association prohibits suffocation in air, the use of ice, carbon dioxide and exsanguination without prior stunning. The RSPCA's Freedom Food™ standards (which apply to Atlantic salmon) only permit the use of a percussive blow for slaughter and, importantly, provide that fish must be bled within ten seconds of the blow being delivered; this minimises the risk of fish recovering consciousness from the blow.

Cod

The Organic Food Federation has produced standards for farmed cod which contain a number of valuable provisions (OFF, 2005).

The prohibition on the use of wild caught fish for on-growing on farm is highly welcome, although regrettably the standards do permit broodstock to be taken from the wild.

Also welcome is the prohibition on the use of triploid stocks, all-female stocks and genetically engineered species or strains. Disappointingly, the use of continuous lighting to prevent sexual maturity is permitted.

The standards set a maximum stocking density of 15kg/m^3,which we welcome.

In order to reduce the use of wild caught fish in the feed of farmed fish, the Organic Food Federation stipulates that at least 50 per cent of the aquatic ingredients in the feed must be by-products of fish caught for human consumption and the balance must be from wild marine resources independently certified as sustainable or approved by a recognised control body.

The Organic Food Federation standards on slaughter require cod to be made instantly insensible immediately they are taken from the water. The standards only permit two slaughter methods: concussion to the head followed by severing the gill arches and electrocution. They prohibit suffocation in air, slaughtering using ice, ice slurry or carbon dioxide and exsanguination without prior stunning.

Conclusions and recommendations

Breeding methods

CIWF and WSPA are concerned about the methods used of obtaining eggs and sperm from farmed Atlantic salmon and rainbow trout, some of which are invasive and involve removing the fish from water. That said, in Scotland fish are anaesthetised prior to stripping. We believe that this should be a normal part of best practice; our view is that all fish should be anaesthetised prior to stripping.

Water quality

Good water quality is essential for the health and welfare of farmed fish.

Relationship between stocking density and other welfare determinants

Stocking density is one of a range of factors – including water quality and flow rate of incoming water - that interact to determine the welfare of farmed salmon and trout. Density cannot, however, be considered in isolation from other environmental factors. Water quality, in particular, has a fundamental role in determining welfare. Indeed, one of the principal concerns about high stocking density is that it can lead to a deterioration in water quality.

Stocking density

High stocking densities can have a detrimental impact on the health and welfare of Atlantic salmon and rainbow trout. In particular, high densities can lead to increased incidence of physical injuries such as fin erosion; increased susceptibility to disease; poor body condition; increased stress; and reduced growth, feed intake and feed conversion efficiency in rainbow trout. All these factors are indicative of a reduced welfare status. In addition, high densities can lead to poor water quality and increased aggression.

Rearing salmon in cages constrains their natural swimming behaviour as it deprives them of swimming the great distances that are the norm for wild salmon at sea. Research is needed to examine the health and welfare impact on Atlantic salmon and rainbow trout of the constraints placed on their natural swimming behaviour by intensive aquaculture.

It is important not to stock up to a theoretical maximum but instead to provide a safety margin.

Recent research shows that above 22kg/m^3, increasing density is associated with lower welfare for caged Atlantic salmon. However, in order to provide a safety margin, CIWF and WSPA believe that the maximum stocking density for Atlantic salmon in sea cages should ideally be 10kg/m^3, with farmers who achieve a high welfare status and in particular low levels of injuries, disease, parasitic attack and mortality being permitted to stock up to a maximum of 15kg/m^3.

Research shows that rainbow trout stocked at 40 and 80kg/m^3 have significantly more fin damage than those stocked at 10kg/m^3 and that growth and feed intake are greater and size variation is reduced in rainbow trout kept at around 25kg/m^3 as compared with 70 and 100kg/m^3. In light of these studies and practical experience, CIWF and WSPA believe that the maximum stocking density for rainbow trout and for Atlantic salmon in the juvenile freshwater stages should be 20-30kg/m^3, provided that the rate and quality of water flow is high.

At our current level of understanding it appears that very low densities should be avoided as they can lead to aggression. Rainbow trout should not be stocked at 10kg/m^3 or below as research has indicated certain welfare problems at this density. Salmon should not be stocked at very low densities either. The advisability of avoiding very low densities is not likely to be a problem in practice as the densities in question fall outside the range commonly used in commercial aquaculture.

Health problems

An array of serious health problems are associated with intensive fish farming, although it should be noted that over recent years a number of issues relating to health and disease have been successfully addressed.

Håstein (2004) writes that under farming conditions, fish "may reach the outer limit of their physiological margin due to maximal exploitation and stress, making them susceptible to a wide range of diseases". Stress generally reduces the ability to fight disease. Moreover, keeping large numbers of fish in crowded conditions facilitates the transmission of infectious diseases.

Poppe & others (2002) point out that certain production-related or husbandry diseases have emerged concurrently with the intensification of husbandry practices. These include (i) various types of skeletal deformities in Atlantic salmon, (ii) cataracts in Atlantic salmon which can lead to blindness and (iii) soft tissue malformations in salmonids such as abnormally shaped hearts, which are associated with poorer cardiac function and a higher mortality rate during stressful procedures such as grading, lice treatments and transport. The production of farmed fish that suffer from skeletal malformations, cataracts or hearts with deficient cardiac capacity is ethically unacceptable.

CIWF and WSPA call on the industry to put further resources into reducing the incidence of cataracts, skeletal deformities and soft tissue malformations.

The incidence of several of the diseases that until recently were a major problem in aquaculture has been substantially reduced through vaccination and improved management. Some diseases however, such as *Infectious Pancreatic Necrosis,* continue to present serious problems. Vaccination has in some cases had adverse side effects.

Crowding, handling and grading

Crowding, handling and grading are stressful and can cause injuries. Accordingly, they should be kept to a minimum. All farms should employ the methods used on the best farms and should keep up-to-date with developing best practice in this area. Fish should only be removed from water when absolutely necessary (Ashley, 2006). The time for which fish are out of water should be kept to the minimum and should never exceed 15 seconds unless they are anaesthetised. Fish should not be kept crowded before slaughter for more than two hours.

Transport

Loading and transport can cause extensive stress, injuries and mortality in fish. Transporting fish poses a significant risk of spreading disease. Because of this and the welfare problems involved, CIWF and WSPA call for an end to the transport of live fish over long distances. Transport must be kept to an absolute minimum. We concur with Myrseth (2005) that "local production of eggs and juveniles and local processing[slaughter] is the answer".

Starvation

Starvation periods before slaughter should be kept as short as possible and should not exceed 72 hours for salmon and trout. Moreover, starvation should never be used as a market-regulating mechanism.

Tagging

We believe that there should not be any extension of tagging. The handling and restraint of fish involved in tagging are stressful and the insertion of tags can be painful and cause wounds and infections.

Sea lice infestation

Sea lice infestation should be controlled by improved management including careful site selection, complementary management procedures such as treating all the farms in an area at the same time, the separation of year classes and periodic fallowing of cage sites to break the cycle of parasite infection. Wrasse should not be used; CIWF and WSPA believe that taking wrasse out of the wild for use in fish farms where they are subjected to serious threats to their welfare is unacceptable.

Algal blooms and jellyfish

Confined in cages, farmed fish are unable to evade algal blooms and jellyfish both of which can present major welfare problems. The ethical acceptability of fish farming is called into question by the fact that it makes it impossible for fish to move away from dangers that they could avoid in the wild.

Predator control

Seals and other wild mammals and birds should not be shot or otherwise harmed as an anti-predator measure. Every precaution should be taken to avoid predators gaining access to the fish through the use of anti-predator nets as well as the selective use of scarers and decoys.

Mortality

Mortality rates in Scotland for salmon smolts in sea cages average around 21 per cent. Such high mortality rates are not acceptable for food producing animals kept under human custody and would rightly sound alarm bells in other branches of farming. Urgent steps are needed to reduce mortality rates.

Biotechnology, selective breeding and genetic engineering

Triploids are susceptible to a range of health and welfare problems including higher levels of spinal deformities and eye cataracts, poorer growth and lower survival rates. CIWF and WSPA believe that biotechnology techniques involving chromosome manipulation (e.g. sex reversal and triploidy) should be prohibited. We recognise that sex reversal does not entail any proven welfare problems. Nonetheless, we are concerned about it on ethical grounds and believe that the practice should be monitored to establish whether or not it has an adverse effect on welfare.

Intense selection for fast growth or enhanced productivity has led to serious health problems in other farmed species such as meat chickens and dairy cows. We fear that farmed fish will soon begin to experience analogous health and welfare problems if the drive to accelerated growth rates continues unabated. Accordingly, CIWF and WSPA believe that selective breeding for fast growth rates should be brought to an end.

Genetic engineering can push fish to even further biological extremes than traditional selective breeding. It threatens to introduce even greater intensification and cause yet more suffering for farmed fish. Genetic engineering has already led to serious health and welfare problems in fish. CIWF and WSPA call for an end to the development of genetically engineered fish for use in aquaculture.

Artificial lighting and photoperiod manipulation

CIWF and WSPA are concerned about the use of artificial lighting regimes and believe that welfare is likely to benefit if fish are kept with natural light patterns. Artificial photoperiods affect the immune system of rainbow trout and hence their susceptibility to pathogenic micro-organisms. Research is needed to investigate whether any other adverse welfare implications arise from photoperiod manipulation. Such research should in particular examine whether accelerated growth leads to health and welfare problems; whether continuous lighting could lead to health and eye problems; whether artificial lighting may lead to stress; and whether the transfer of smolts to sea in the autumn has any adverse welfare implications.

Housing conditions

Cage netting should be smooth and non-abrasive to prevent injuries. Freshwater enclosures should be constructed of materials that minimise the potential for injuries. Cleaning of fouled nets is essential.

Feeding method

The feeding method used must minimise competition and hence aggression and ensure that all the fish have access to feed.

Slaughter

CIWF and WSPA believe that asphyxiation in air and on ice, carbon dioxide stunning and gill cutting without prior stunning should be prohibited on welfare grounds. Live chilling should also be prohibited. In recent years some progress has been made in introducing better systems. Mechanised percussive stunning can produce immediate unconsciousness in Atlantic salmon if applied correctly. When percussive stunning is used, fish must be bled within ten seconds of the blow being delivered to minimise the risk of them recovering consciousness from the blow.

Electrical stun/kill systems can be acceptable for rainbow trout provided that they produce immediate unconsciousness that lasts until death; this requires the use of appropriate current magnitude, duration and frequency. Further consideration should be given to the use of pre-slaughter anaesthetics as these could considerably reduce the stress involved in pre-slaughter handling.

Threats to wild stocks from farmed fish

Action is needed to significantly lessen the impact of fish farming on wild fish populations. Escapes and sea lice infestation in sea cages must be reduced.

Feeding wild fish to farmed fish

The farming of carnivorous species is wasteful of resources as the production of a given weight of farmed salmon, trout, cod or halibut requires a much greater weight of wild fish to be used as feed. The use of wild fish to feed farmed fish raises important sustainability and welfare issues. Some of the fish used as feed could be used for direct human consumption. In addition, the viability of certain 'industrial' fish stocks is threatened by severe overfishing. Moreover, a decrease in wild 'industrial' stocks entails a reduction in feed supplies for predator fish, marine mammals and seabirds. In view of these problems, the sustainability of intensive carnivorous fish farming should be reviewed.

Farming of new species

The principal European farmed species – Atlantic salmon and rainbow trout – suffer from a range of welfare problems. We do not wish to see new species being exposed to similar problems. Accordingly, we are concerned about the introduction of new species into farming; at the very least there should be a moratorium on the use of new species until farmers are able to demonstrate that humane rearing, transport and slaughter methods have been developed for that species. The maximum stocking density for farmed cod should be 10-15kg/m^3. Halibut should not be stocked at high densities as this appears to lead to higher stress levels, reduced feeding motivation, lower growth and stereotypic behaviour in some fish.

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Acknowledements - Grateful thanks to the many scientists and practitioners who helped me in the preparation of this report and in particular to Dr Jimmy Turnbull and Philip Lymbery, author of CIWF's 2002 report, *In Too Deep.*

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CLOSED WATERS: THE WELFARE OF FARMED ATLANTIC SALMON, RAINBOW TROUT, ATLANTIC COD & ATLANTIC HALIBUT

Peter Stevenson

2007

ISBN 1 900 156 415

Distributed by:

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Godalming, Surrey GU7 1EZ, UK
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