Chapter III: Environment

THE FARMED SALMONID HEALTH HANDBOOK

CHAPTER III: ENVIRONMENT

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CONTENTS

Environment

Maintaining good water quality is essential to fish health. Each farm must have a regular water monitoring program in place. This may include measuring temperature, dissolved oxygen, plankton, salinity and turbidity. The parameters measured will vary depending on whether the fish are confined to freshwater tanks or in an open marine site. On a freshwater land site, there must be adequate freshwater exchange to ensure the removal of metabolic wastes and to maintain oxygen levels. On a marine site, vigilance for phenomena such as algal blooms is essential. Appropriate monitoring must be in place to indicate when water quality is not adequate. A contingency plan must be in place in the case of an acute deterioration of water quality. This may involve stopping feeding of the fish and increasing the frequency and detail of water monitoring to establish probable cause of deterioration. Fish should be monitored closely during these events.

Under SI No. 280 of 2010 (Aquaculture (Licence Application) (Amendment) Regulations and application made under Section 10 of the Fisheries (Amendment) Act 1997 in respect of

- A seawater salmonid breeding installation, or

- Seawater fish breeding installations with an output that would exceed 100 tonnes per annum; all fish breeding installations consisting of cage rearing in lakes; all fish breeding installations upstream of drinking water intakes; other fresh-water breeding installations which would exceed 1 million smolts and with less than 1 cubic metre per second per 1 million smolts low flow diluting watershall be accompanied by an Environmental Impact Statement

Results of on-going monitoring programmes should be made available to DAFM and to the local Council Authorities in the case of the land (or lake) based operations.

3.1 Fish Requirements

As fish are in intimate contact with their aquatic environment, a reduction in the quality of the water can have serious implications for the health and welfare of the animal. The following guidelines for water parameters for farmed salmon and trout are adapted from reports published by the European Food Safety Authority[1,2] (EFSA).

[1] EFSA, 2008. Animal welfare aspects of husbandry systems for farmed Atlantic salmon. EFSA Journal 736, 1-31.
[2] EFSA, 2008. Animal welfare aspects of husbandry systems for farmed trout. EFSA Journal 796, 1-22.

3.1.1 pH

The water pH is important since fish need to maintain a constant internal pH and an acid/base balance in the blood. In seawater the pH is more stable due to the higher buffering capacity of the sea. In freshwater pH can be affected by increased carbon dioxide due to respiration. This can become a problem in recirculation systems if inadequate filtration systems are used. pH can be acutely affected by acid rain. Safe levels of water pH depend on the interaction with a range of other water quality parameters, especially aluminium and ammonia.

Sudden decreases of pH can result in gill and skin irritation in salmon and trout. Acid irritates the gills resulting in excessive mucus production and can cause reddened areas on the abdomen. Eggs can tolerate a greater range of pH, as they are partially protected by the eggshell, whereas alevins are very sensitive to extremes of pH.

As a general guide, pH levels for salmon should be above 5.4 and preferably within the range 6.0 – 8.5 in freshwater and above 7.0 in seawater. Trout are slightly more tolerant but levels below 5.0 and above 9.0 should be avoided. Rapid changes of acidity or alkalinity should be avoided for all stages of salmon and trout.

3.1.2 Temperature

Water temperature regulates the amount of dissolved oxygen that a body of water can hold. Additionally, increasing temperature facilitates the growth of many fish pathogens and increases the toxicity of many dissolved contaminants. All of these interacting factors have the capacity to compromise the health of farmed fish. As fish are cold blooded, increasing the water temperature increases the metabolic rate and hence oxygen consumption. At higher temperatures fish have a greater demand for oxygen but there is less oxygen available in the water as the temperature rises. Rapid changes in temperature can lead to severe stress.

Temperature also affects growth and development and can lead to various deformities such as abnormal heart development and skeletal deformities, particularly at the juvenile stage.

In general, salmon seem to be able to adapt to temperatures in the range of 0-20°C, provided they are supplied with well oxygenated water. The lower lethal limit is considered to be around -1°C. Temperature optimum for growth of salmon in Ireland is in the range of 12-15°C depending on stage and size.

Incubation temperatures should not exceed 8ºC from fertilisation to the eyed stage, 10°C from eyed stage to hatch and 12°C to first feeding. Salmon smolts are considered to have somewhat less tolerance than parr and ongrowing salmon, but can tolerate temperatures between 3-18ºC. Ongrowing salmon tolerate temperatures between 1-18°C, and, in Ireland, seem to display a preference for 12-14°C. At ovulation and spermatogenesis until spawning, broodfish should be held at temperatures between 8-12°C.

Trout can adapt to temperatures in the range of 0-22°C provided they are supplied with well oxygenated water. The lower lethal limit is considered to be around -1°C and the higher lethal limit is above 24°C. During the egg and alevin stages, temperatures exceeding 15°C should be avoided as should sudden temperature variations. In Ireland, temperature optimum for growth of rainbow trout is in the range of 12-14°C.

3.1.3 Salinity

Salinity changes affect osmoregulation in fish and many species have limited tolerance. In the marine stage salmon can tolerate a wide range of salinities.

During the early stages, from eggs up to pre-smolts, Atlantic salmon are adapted to salinities below 10ppt (parts per thousand). Eggs must be kept in pure freshwater just after fertilisation to allow normal water hardening (egg swelling), but thereafter small amounts of saltwater (typically up to 1ppt) can be added in order to adjust pH, detoxify aluminium, and increase ion concentration in acid water sources. The ability to tolerate salinity above 10ppt increases with increasing body size in freshwater parr, but full osmoregulatory capacity in full strength sea-water (> 30ppt) is only achieved after full smoltification.

After sexual maturation, Atlantic salmon lose much of their ability to osmoregulate in full strength seawater and will suffer high mortality if kept in seawater throughout maturation. Sexually mature salmon broodstock must be kept in freshwater or brackish water with salinity below 10ppt. After full smoltification the optimum salinity range for Atlantic salmon is 28-33ppt.

In general, larger trout are more tolerant of higher salinities than smaller sizes. Adaptation to full strength seawater is dependant on other water parameters such as temperature and oxygen levels.

3.1.4 Oxygen

The amount of dissolved oxygen in water varies with temperature and salinity. The amount of dissolved oxygen (mg/l) at 100 % water saturation (e.g. in equilibrium with atmospheric oxygen) decreases with increasing water temperature and salinity. Often the oxygen saturation shows marked variability with time of day and during the season in farming units, due to variability in fish metabolism, algal production and consumption of oxygen as well as variability in water exchange. All life stages of salmon and trout have a high demand for oxygen. The relative oxygen consumption of salmon and trout increases with temperature, activity, feed consumption and stress level, while it decreases with increasing body size.

The dissolved oxygen concentration is considered as a key factor for welfare in salmon and trout farming. Critical levels for normal physiological functioning, feed intake and optimum growth vary for various life stages. The minimum of oxygen required varies amongst fish species, and varies also with size, age, physiological condition and health.

In general, salmon and trout will suffer impaired growth and appetite below 80% saturation. Mortality starts to occur at around 40% saturation. Dissolved oxygen levels should be maintained as close to 100% as possible for optimum appetite and growth although levels down to 70% can be tolerated.

3.1.5 Carbon Dioxide

Carbon dioxide (CO_2) is found naturally in most surface waters at levels of 1-2 mg/l and originates from diffusion from the atmosphere, microbial decomposition of organic matter and the respiration of micro-organisms, algae and aquatic plants. Naturally higher levels of CO_2 can be found in well or spring water. Within aquaculture systems, the primary source of CO_2 is fish metabolism. CO_2 is in equilibrium with the non-toxic bicarbonate ion, and its concentration depends on pH, temperature and salinity of the water, as well as the respiration of the fish and other organisms in the water.

High and medium increases in CO_2 can lead to gill lesions and can also elicit a severe stress response. Dissolved CO_2 levels can be higher in recirculation systems, particularly those with high stocking densities.

While there are reports of adverse effects on health from high levels of CO_2 there is wide disparity in the range of recommended safe levels.

3.1.6 Ammonia

Ammonia is produced as a waste product by the fish and leads to a rise in pH. Ammonia is present in 2 forms: un-ionised and ionized. Un-ionised ammonia (NH_3) is the most toxic form. Ammonia toxicity is higher at high pH and the proportion of the more toxic NH_3 form increases as salinity drops. Therefore, pH, temperature and salinity needs to known in order to estimate the toxic level of ammonia.

Ammonia affects osmoregulation and can result in fish producing an increased volume of urine in freshwater and increased drinking in saltwater. Ammonia also affects the gills by destroying the mucous layer. At sub-lethal concentrations ammonia can also impair immune function leading to increased susceptibility to infectious disease. In general the ammonia toxicity for adult Atlantic salmon held in sea-water appears to be roughly similar to that for freshwater salmon.

Ammonia levels can become critical in systems with restricted water flow, such as high stocking density fish tanks with added oxygen, during transport and in recirculated systems.

Concentrations of un-ionized ammonia higher than 0.02 mg/l for all stages of salmon and trout have been shown to cause tissue damage resulting in poor welfare. To maintain good welfare the maximum level of un-ionised ammonia (NH_3) should not exceed 0.02 mg/l for all stages.

3.1.7 Nitrite

In the presence of oxygen, ammonia is converted into nitrite which is slightly less toxic than ammonia. Nitrite breaks down red blood cells and oxidizes the iron in haemoglobin resulting in reduced oxygen carrying capacity causing listlessness. Levels of nitrite in farming systems are generally very low, with the compound rapidly converted to the significantly less toxic nitrate by nitrobacter bacteria. Nitrites are not usually a problem in aquaculture with flow-through or in adequately oxygenated water.

Nitrite concentrations of < 0.1 mg/l are adequate to protect fish health under most water quality conditions.

3.1.8 Aluminium

Aluminium toxicity can have a severely detrimental effect on fish welfare, but is generally the result of rapid reduction in pH due to external factors. Such circumstances are limited to specific locations and are not a general risk. Water treatment methods are available to reduce the problem.

Aluminium toxicity is usually associated with acid rain and acidified freshwater systems. It is well established that positively charged aluminium in acidic waters is toxic to fish due to accumulation of aluminium in fish gills.

Non-lethal concentrations of aluminium may severely affect the osmoregulatory capacity in smolting salmon, especially as there is an increasing susceptibility towards aluminium at periods with low pH during spring due to acidification.

Aluminium should be kept below 20µg/l which is the critical level smolts can tolerate. Pre-smolts and smolts are most sensitive to aluminium followed by younger stages whereas adults are the most tolerant.

3.1.9 Suspended solids

All natural waters contain some suspended solids. During spates (heavy floods) these can rise considerably. Effects such as gill surface hyperplasia, and excessive mucus generation on skin and gills are common. Furthermore, suspended organic solids can reduce oxygen availability.

In aquaculture conditions most suspended solids derived from fish e.g. faeces, are removed to prevent them becoming too high. The design of the culture system influences the amount of suspended solids and self-cleaning systems are designed to prevent this problem. Water velocity > 3cm/s prevents solids such as uneaten food from settling.

The physical characteristics and total amounts of suspended solids in water are relevant in determining the extent of possible negative effects in salmon and trout gills and skin.

3.1.10 Water flow

Water flow rate is important for determining water quality aspects such as oxygen supply and removal of metabolites in tanks and pens, self-cleaning of tanks (removal of faeces and excess feed) and also for setting up a water current speed (body lengths/min) that affects the behaviour and distribution of the salmon in the rearing unit. Too high flows can be detrimental to salmon welfare and if too low, then waste products are not removed efficiently and oxygen levels can become critically low. In farming units water speeds of 0.5 to 2.5 body lengths /sec are frequently used. Tolerance to high flow and water currents depends on life-stage and body size.

Parr prefer high water flow rates whereas fry prefer areas of low flow within rivers and these life stage requirements are normally taken into account in fish farms.

Salmon and trout should have sufficient water flow for removal of waste products and uneaten food and for oxygen provision if not otherwise provided, but the flow should not be too great for the young fish to maintain station without excessive energy usage.

3.1.11 Water depth

Water depth will affect available space, gradients in hydrostatic pressure and light, as well as time for feed to sink through the water column, all factors that can affect salmon and trout welfare. The water depth also affects the ability of the farmer to inspect and monitor the behaviour of the fish, such as feeding behaviour or behaviour indicative of diseases.

Salmon and trout need to be able to go to the surface to fill the swim bladder, and therefore require contact with air at the water surface to maintain neutral buoyancy in the water column.

During the alevin stage and until shortly after first feeding, salmon need a bottom substratum for vertical support, such as gravel, dense vegetation or artificial grass. Lack of such support will reduce survival, first feeding success and growth and may lead to deformities. The swimming depth (i.e. the vertical positioning) in sea pens depends on environmental gradients of light, temperature and salinity and is modulated by feeding response and health status. Where water depth does not allow for the direct observation of fish other methods (e.g. underwater cameras) should be used for effective monitoring.

3.2 Water Monitoring

Each marine farm must carry out water column nutrient monitoring at each site in accordance with Departmental guidelines[3]. Nutrient monitoring surveys shall be carried out monthly during the period December – March each year. A transect and the number of sampling stations on the transect shall be agreed following consultation with the Marine Environment

[3] DMNR, 2000. *Monitoring protocol for offshore finfish farms – water column monitoring.*

and Health Services Division of the Marine Institute. Water samples for nutrient analysis shall be taken at each station on the agreed transect. Samples shall be taken at the surface, mid depth and 1 metre above the bottom. Analysis should include ammonia, nitrite, nitrate and phosphate. The water quality parameters must be monitored by an approved laboratory which participates in an inter laboratory proficiency scheme.

Each freshwater farm must carry out water analysis as requested by the relevant local authority.

Water quality monitoring is especially important for hatcheries. Monitoring equipment must be maintained in good functional condition. Failure of water supply is a major consideration and back-up systems are essential until the system failure can be addressed.

The following procedures should be followed:

1. The water quality parameters measured will depend on the husbandry system employed.
2. Increased vigilance is essential during high risk periods.
3. In the freshwater sites, temperature, dissolved oxygen and pH should be recorded daily. This can be done using an all-purpose probe. Probes should be of good quality, well maintained, serviced and calibrated regularly. Nitrite, nitrate and free ammonia should be measured on an infrequent basis, especially if a water quality problem is suspected. A water sample should be submitted to an appropriate laboratory for analysis of these parameters. High temperatures and biomass in the spring make it the most risky period, especially if there is a failure in oxygen delivery or a spate or flood in the river.
4. In land based tanks water can be oxygenated through mechanical means or by liquid infusion. Whatever system is in place should be monitored frequently and appropriate alarms in place in the event of oxygen failure.
5. In seawater pens temperature, oxygen (especially during summer months), salinity and turbidity should be quantified daily if possible. Zooplankton and phytoplankton monitoring should be carried out regularly to identify dangerous species where possible, either by submitting samples to an appropriate laboratory or by using a trained person on site.
6. Low oxygen in seawater pens may indicate badly fouled nets. Phytoplankton blooms may also result in de-oxygenation of water, in addition to causing toxic and physical damage to the fish.
7. A contingency plan should be put in place in case of acute deterioration in water quality.

8. A daily log of water quality parameters should be kept and monitored over time. This data should be analysed in conjunction with mortality levels and any behavioural patterns identified.

3.2.1 Contingency Plan for deteriorating water quality

This plan should detail the personnel required to apply the control measures, list their responsibilities and identify a chain of command. Such a contingency plan should include elements of:

a) How to utilise partial or complete recirculation if available and appropriate.
b) How to increase flow rates or utilise an alternative water supply where available.
c) How to aerate or oxygenate, if dangerously low oxygen levels are recorded.

3.3 Effluent & Benthic Monitoring

3.3.1 Marine

Each marine farm license states that an annual benthic (sea bed) audit must be carried out at each site, according to Departmental guidelines[4]. The benthic monitoring requirements at a fish farm are dependent on the level of biomass held at the site and the local hydrography. The following table sets out the level of benthic monitoring required based on tonnage produced and mean current speeds at the fish farm:

Table IV

Level of benthic monitoring required for different size farms at different current speeds.

	<5 cm/sec	**5-10 cm/sec**	**>10 cm/sec**
0 – 499 Tonnes	Level 1	Level 1	Level 1
500 – 999 Tonnes	Level 2	Level 1	Level 1
> 1000 Tonnes	Level 2	Level 2	Level 1

The current speed is a mean value calculated from maximum current measurements over spring and neap tidal cycles at the surface and near the bottom. The tonnage refers to the maximum biomass predicted for each site. An annual survey must be carried out at each site (production and smolt) operated by a company. All sites will be subject to one of the two levels of survey:

[4] DAFF, 2008. *Monitoring Protocol No. 1 for Offshore Finfish Farms – Benthic Monitoring.*

Level 1:

Video/photographic and visual observations and recordings should be made at the following stations:

- At a minimum of 2 sites directly beneath the pens.
- At the edges of the pens.
- Two transects at right angles to each other. Along each transect sampling stations at +/- 10m, +/- 20m, +/- 50m and + 100m from the pens.
- At a control site.

In addition to the above, the following samples / measurements shall be taken at the same stations as above. These will be used to calculate sediment quality parameters.

- A minimum of one Redox potential readings shall be made at each sampling station.
- A single sediment sample for Organic Carbon measurement.

Level 2:

In addition to the above three replicate grab samples shall be captured at each of the sampling stations. The exact location of sampling points should be agreed in advance with DAFM. The identification and abundance of macro-faunal invertebrates shall be estimated and tabulated. Identification of fauna to the level of species will be required.

An annual environmental survey will have to be conducted for each finfish culture site so that an assessment can be made of the impact of the farming operation on the seabed. The annual survey shall be carried out on behalf of the farmers by any consultant from a pool of approved consultants.

The survey should be carried out during peak biomass periods or at least within 30 days after the end of harvesting of a year class. However, it is appreciated that all sites requiring surveys at the farm most likely will be carried out in one visit therefore, the timing of the surveys should by dictated by grower sites (with greater biomass) with concurrent surveys at smolt or harvest sites. A similar timing schedule applies to each of the two survey types.

3.3.2 Freshwater

All freshwater aquaculture facilities require a *Discharge Licence* from the local Council Authorities. Permitted water discharge levels vary between local authorities.

The *Discharge Licence* sometimes stipulates the maximum allowable extraction rate as well as the frequency of water sampling.

Allowable levels of certain parameters for freshwater aquaculture are defined in SI No. 293 of 1988 – European Communities (Quality of Salmonid Waters) Regulations 1988:

BOD (Biological Oxygen Demand)	<5 mg/1
Suspended Solids	<25 mg/l
Total Ammonia	<0.3 mg/l
Un-ionised Ammonia	<0.02 mg/l