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## 1. Introduction

The manner in which Atlantic salmon is produced is diverse, and there is a range of different production systems and strategies in operation in the industry. Thus, a standard protocol for the production of Atlantic salmon juveniles and smolts would be of limited relevance. In the following sections, a set of recommendations is presented which summarises experimental results and experiences from commercial production on how to prevent malformations in the professional production of Atlantic salmon. Some of these recommendations are justified by scientific documentation, whereas others are less well substantiated. Thus, not all the recommendations meet the standards expected from a standardised protocol as such. Nevertheless, these should be regarded as advice to be considered for both problem solving and production planning.

## 2. Background

For Atlantic salmon, malformations in freshwater juvenile production are difficult to detect and, as an additional challenge, malformations continue to develop throughout the rearing period. In commercial production, a key issue is that the full extent of malformations may not be detected until fish are approaching harvest size.

Nonetheless, a number of studies show that a significant proportion of problems may be induced in early rearing, i.e. during egg incubation and in juvenile rearing. Thus, a strategy of sorting and rejecting juveniles with deviations at an early stage, comparable to the position experienced with sea bass and seabream production, is not feasible for Atlantic salmon. The salmon markets are also increasingly sensitive to ethical issues and the prevention of malformations through biological improvements must be the preferred overall strategy.

Interaction between environmental factors giving rise to malformations is a known fact in practical production, although such phenomena are difficult to analyse, both in retrospect and in predictive models. Thus, anecdotal reports exist of successful production under environmental conditions that conflict with the recommendations that follow. Conversely, reports exist of severe malformations in fish batches produced in compliance with the same recommendations.

It is acknowledged that the knowledge on causal relations for inducing malformations in Atlantic salmon is still fragmentary and far from complete. There are, in all probability, causal relations of importance that have not yet been identified and addressed. In particular, the impact of rearing conditions in the marine environment during the grow-out stage has been studied little. Nevertheless, case reports also exist that claim significant improvements in the rate of malformations following implementation of some of the recommendation presented here.

### 3. Recommendations

The recommendations can be summarized as follows:

- **Keep freshwater rearing temperatures moderate and stable**
- **Control freshwater growth rates at a moderate and stable level, and avoid periods of maximized growth**
- **Monitor and stabilize the water quality**

Feedback from commercial production implies that, by following these key principles, while freshwater production rates may be held back the long term productivity will gain - as a result of less deformities, a sustained long-term high growth rate and, possibly, lower mortalities also .

#### 1. Temperature

Atlantic salmon is a cold water species. Although development and growth can be accelerated by the use of warmer water, side effects will include increased number of fish with skeletal malformations if the temperature change exceeds some biological limits.

The most vulnerable period is embryonic development, i.e. egg incubation. At this stage, even a short episode of temperature stress can produce lasting effects. At later stages, the effects will generally depend on the magnitude of the temperature charge, i.e. *the magnitude of the temperature increase x duration of the episode*. Thus, even though juvenile salmon may tolerate 16°C well for a limited time and without consequences for skeletal development, the same temperature applied in the long term may give severe malformations in return.

#### a) Egg incubation and yolk sac stage

- **Temperature during egg incubation must be controlled at 8°C or lower**
- **The early stages of egg incubation (before eyeing, 300-350 d°) are more vulnerable to temperature stress and requires strict temperature control**
- **Avoid rapid temperature fluctuations also when operating below 8°C.**  
**As a rule of thumb, temperature changes of 2,5°C or more within 24 hours may be expected to have impact on skeletal development**
- **Cooling of eggs towards freezing (<1°C) should be avoided during the first 100-150 d°**

The effects of increasing temperatures to 9°C or 10°C during the yolk sac stage are not expected to have dramatic consequences, but will increase the risk of inducing fusion type pathology by influencing skeletogenesis. Thus, control the temperature to 8°C as far as possible towards first feeding.

## b) First feeding and parr rearing

- Temperatures at 12°C and lower are considered optimal for skeletogenesis in first feeding fry and parr rearing
- At 14°C, increased incidence of pathology, primarily fusion type, is expected

Between 12°C and 14°C, detailed temperature recommendations can not be provided at the present time. A dose-response relation is expected, i.e. increasing incidence with increasing temperature change.

In industrialised smolt production, this rearing period is normally achieved under conditions of temperature control and using heated water - at least until biomass increase outweighs an available warm water supply.

Thus, during this stage of the production, the juveniles are at the producers' mercy with regards to temperature. However, during summer conditions, the situation may be the reverse, as ambient temperatures may reach levels of 16-20°C at some sites, without the possibilities of access to cooling water.

Optimal temperatures for growth during the juvenile stages are 15-16°C, and the use of heated water or ambient warm water to maximize growth gain is an obvious option. However, the documentation showing that this situation will increase the susceptibility to skeletal deformities is so strong that the recommendation to hold back on temperature during this period is very clear.

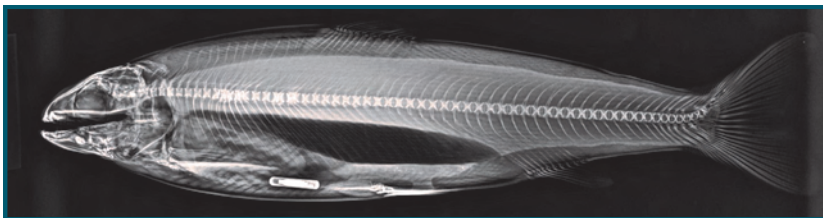


Figure 1: Radiography of Atlantic salmon parr (70g) with severe vertebral fusion, induced by high rearing temperature in early developmental stages.

### c) Smoltification

In yearling production, temperatures during smoltification are not expected to represent a problem when ambient water supply is used during a natural smoltification period for the species.

In underyearling production, smoltification must be induced — through photomanipulation or alternative procedures — and the process takes place at a different time of the year than the normal biological programming implies. Thus, in underyearling batches, smoltification is induced by giving a “winter signal”, typically during late summer, when ambient temperatures are at the highest.

In a typical photomanipulation program (6 weeks 12D:12L followed by 6 weeks 24L), the recommendation is to avoid a temperature drop from the first to the second period.

### d) Seawater rearing

There are no clear recommendations that can be given for temperature control during seawater rearing at this time. Seawater rearing is mainly done in open cages with ambient water supply, and in most cases there are no possibilities for temperature control. The temperature effects on induction of skeletal deformities during on-growing in seawater warrants further investigation.

## 2. Nutrition

Although the number of nutritional factors that may have an impact on skeletal development is high, the most robust indications point towards inadequate dietary mineral supply as the most relevant nutritional risk factor. In particular, the evidence is strong against the impact of suboptimal phosphorus (P) and zinc (Zn) supply.

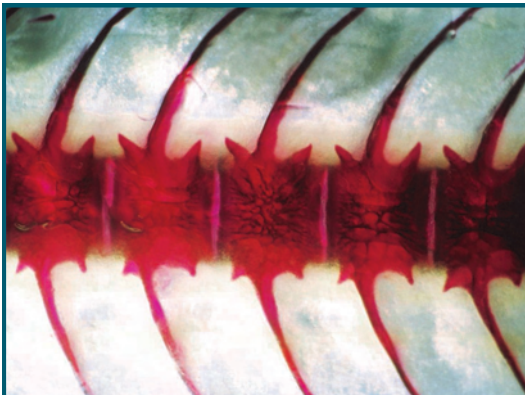


Figure 2: Hyper dense (HD) vertebrae in spinal column of salmon parr. HD vertebrae in juvenile salmon are indicative of disturbed mineralisation. (Alizarin Red staining)

In salmon farming, nearly 100% of feeds are commercial products. Thus, the nutritional quality of the feeds is to a large extent a matter of confidence and trust between feed supplier and customer, i.e. the fish producer.

The critical factor is mineralisation of skeletal structures. When mineralisation is inadequate, the actual cause can be one of several factors: Dietary supply of minerals depends not only on the concentration of the element in the feed, but also on bioavailability of the element and of the feed conversion ratio (FCR, kg feed given per kg of weight gain). The product of these three factors determines to a large extent the resulting concentration of the element in the fish, and thus the susceptibility to skeletal deformities induced by suboptimal mineral supply.

When choosing feeds:

- **Request documentation on performance ability of feeds under commercial conditions, with respect to mineralisation of skeletal structures**
- **If necessary, analyse fish mineral content and skeletal development through appropriate diagnostic procedures**

Mineralisation and development of skeletal structures can be evaluated by:

- **Analysis of mineral content of fish**
  - The most reliable parameter for evaluation on P and Zn status are whole body analyses
  - Please refer to chapter 6 in this booklet for guidelines on monitoring of mineral content in fish
- **Skeletal diagnostics**
  - X-ray diagnostics of freshwater salmon
  - Whole mount staining techniques using Alizarin Red
  - Please refer to specific guidelines for diagnostic criteria (available at [www.finefish.info](http://www.finefish.info))

### **3. Growth rates**

Growth rates in juvenile salmon are generally high. Measured as specific growth rate (SGR, % daily weight increase), values may be as much as 7-10% in early juvenile stages - when growth rates are maximized.

The most important determinant for growth rate in freshwater salmon rearing is temperature. Consequently, the specific effects of growth rate on skeletal development is difficult to separate from temperature effects under conditions that are relevant for commercial production.

Some producers maintain that SGR is the most important control parameter for skeletal malformations. Although this argument cannot be substantiated, experience from both research and commercial production support the theory that skeletal development benefits from a moderate long-term growth rate, without extreme periods, giving a smooth growth curve.

The effect may well be that a controlled growth rate will ease the pressure on nutritional balance. No matter what the mechanisms are, the best way of achieving a controlled and moderate growth rate is through temperature control.

- **Control growth rate through control of rearing temperature**
- **Avoid periods of maximized growth rates**

### **4. Water quality recommendations**

The water quality of intensive smolt production is a complex issue (see chapter 4 in this publication). Variation in tank size, quality of raw water and technical solutions for water treatment adds to the complexity. Based on a 'best choice' principle, some general recommendations are given:

- **Control biomass through controlling growth rates**
- **Avoid the higher levels of fish density (>50 kg m<sup>3</sup>)**
- **Comply with the limitations given by the Norwegian Food Authorities:**
  - O<sub>2</sub> saturation in tank water <100%
  - Dissolved CO<sub>2</sub> in tank water < 15 mg L<sup>-1</sup>
- **Keep the water quality controlled and stable**
- **Pay particular attention to O<sub>2</sub> saturation in the final weeks of smoltification**

There are other aspects of malformation control in production of Atlantic salmon juveniles that are not addressed by these recommendations, in particular related to vaccination strategies and procedures.

Please refer to other sources for further information.