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## Introduction

This article covers skeletal deformities in Atlantic (A.) salmon, which is a complex issue, and it is clear that no single factor can explain all cases. Unfavourable rearing temperatures and inadequate mineral supply have been established as causal factors for skeletal deformities in salmon, and the symptoms and developmental mechanisms related to these factors are approaching a more complete understanding (see other chapters in this publication). But when these factors are ruled out, there are still a number of cases that remain unexplained. Among the topics discussed most often in the more obscure cases are issues related to water quality.

## Water quality of intensive smolt production

Water quality of intensive smolt rearing is, like skeletal deformities, a complex topic. It has to be noted that, within the Norwegian industry, increasing numbers of smolts are being produced at fewer sites than before, and this trend is expected to continue. A similar trend is being observed for hatchery production in the Mediterranean—for seabass and seabream. Thus, available water resources at each specific site may become a limiting factor for production.

The preference of bigger smolt size at seawater transfer adds to this challenge, through increasing the standing biomass during critical periods prior to seawater transfer. The usual way of coping with limited water supply is to decrease the specific water flow (measured in litres  $\text{kg}^{-1} \text{min}^{-1}$ ) to the tank, and add oxygen. The resulting water quality, typical for intensive smolt rearing in flow-through installations, is characterized by high levels of dissolved  $\text{CO}_2$ , low pH and fluctuating levels of  $\text{O}_2$ , including the risk of periodic or fluctuating  $\text{O}_2$  supersaturation. Accumulation of organic compounds is no real issue in flow-through systems for salmon.

Despite extensive research efforts, few (if any) clear limits have been developed for the individual water quality parameters in A. salmon. Thus, the current regulatory guidelines given by the Norwegian Food Authority specify a set of water quality criteria that are based on a “best choice” of experiences and scientific results from a number of sources, and with no particular reference to skeletal deformities.

Nevertheless, anecdotal evidence from practical smolt production indicate that some aspect of the intensive water quality may be of relevance to vertebral pathology, in particular in cases where the water quality parameters were suboptimal and unstable.

## CO<sub>2</sub>, pH and O<sub>2</sub>

Previous research on the relation between water quality and skeletal deformities has given some indications on the nature of these effects, but so far no reliable explanation. In Nofima Marin, this has been a research topic of high importance. Results from some experiments awaiting publication are summarised below (Baeverfjord et al, unpublished results):

In a series of two experiments, the water quality of intensive smolt rearing was modelled under experimental conditions. In these experiments, biomass was built gradually as the fish grew, under constant water supply but with increasing O<sub>2</sub> supplementation, similar to a production situation. The controls were kept in flow through without O<sub>2</sub> supplementation, at a much lower fish density. In the first of these experiments, water quality was well controlled and no adverse effects on skeletal development were identified even at relatively high levels of CO<sub>2</sub>. In the second experiment, the rearing period was characterized by a series of events leading to O<sub>2</sub> and CO<sub>2</sub> fluctuations, periodic O<sub>2</sub> supersaturation, and eventually a crisis induced by severe hypoxia due to a pump breakdown.

In these fish, long term effects on skeletal development were identified, as more than 20% of fish from these groups developed severe platyspondylia when they were close to harvest size. However, due to the irregular nature of the events leading to these observations, no conclusion as to the nature of the specific causal factors was possible.

In another experiment, oxygen was supplemented at different levels through various stages of parr rearing and smoltification, with particular attention to the effect of O<sub>2</sub> supersaturation. In this experiment, platyspondylia pre-stages were observed in vertebra of post-smolts, following a four month rearing period in seawater. The effect was prominent in fish exposed to hyperoxic water during smoltification, compared to controls reared in normoxic water during the same period. However, as the experiment was terminated at a fish size of approximately 400g, the issue of further development of the condition remained unanswered.

## Hyperoxia and fish density

The potential effect of hyperoxia on vertebral deformities was pursued as part of the FineFish project. An experiment was designed, addressing two experimental factors, each at two levels and in combination, in a 2x2 design.

The factors were fish density (high and low), expected to produce differences in tank water CO<sub>2</sub> and pH, and tank water oxygen content (normoxic and hyperoxic). The experimental period was through smoltification, that is, 6 weeks of photoperiod treatment initially, followed by 6 weeks of continuous light.

# Water quality and skeletal deformities: What are the critical factors?

The high density groups were  $> 100 \text{ kg m}^{-3}$  towards seawater transfer, compared to less than half in the control groups. The tank  $\text{O}_2$  level in hyperoxic groups varied between 100% and 130% saturation. The fish were individually tagged, and were X-rayed repeatedly. Following seawater transfer, the fish were placed in a common sea cage and reared to a size of 2,1 kg, at which time they were killed and X-rayed.

In this experiment, there were no differences in the prevalence of vertebral deformities at the end of the seawater-rearing period between treatment groups, neither in response to the fish density nor to the hyperoxia. The most notable effect in the experiment was a severe growth depression in the high density groups compared to the low density groups, prior to seawater transfer. This effect was not present at harvest, but should nonetheless serve as an indicator that Atlantic salmon may be particularly sensitive to high density rearing conditions.

In summary, these experiments support the hypothesis that there is a link between water quality conditions during freshwater rearing and skeletal deformities, but they also confirm that this relationship is less straightforward than, for instance, with rearing temperature. Thus, no single parameter or set of parameters could be defined, despite extensive research efforts. On the other hand, reports from commercial production indicate a reduction of skeletal deformities, as well as a general improvement of results, in response to efforts to improve water quality.



## Recommendations

On a practical level, the following recommendations can be extracted:

- ☑ *Control biomass through controlling growth rates*
- ☑ *Avoid the higher levels of fish density ( $>50 \text{ kg m}^{-3}$ )*
- ☑ *Comply with the limitations provided by the Norwegian Food Authorities:*
  - ☑  *$\text{O}_2$  saturation in tank water  $<100\%$*
  - ☑ *Dissolved  $\text{CO}_2$  in tank water  $< 15 \text{ mg l}^{-1}$*
- ☑ *Keep water quality controlled and stable*
- ☑ *Pay particular attention to  $\text{O}_2$  saturation in the final weeks of smoltification*