The super-sized smolt challenge

By David Owen, Blue-Unit

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In many salmon production regions, there are important advantages in producing a bigger smolt for stocking to sea cages. For example, in locations troubled by sea lice, a larger smolt could reach a size big enough to harvest just before the next wave of sea lice hits. This not only saves treatment for the fish in question, but also frees-up lice treatment resources to concentrate on the smaller fish. In Chile, a 150 g smolt is regarded to be better adapted to cope with the sea and it allows for the salmon to stay only one summer in the sea instead of two.

However, producing bigger smolts on land means that a company's recirculation systems are pushed a lot harder, giving staff some headaches. So what happens when we grow a batch of smolts a lot bigger without expanding the recirculation system?

Say we normally grow our smolts in batches of 1 million pieces to 100 g in our finely tuned recirculation system. But now we need to grow them to 150 grams. So what will happen? The farm staff will certainly put in longer hours, but is it possible to nurse the recirculation system through such an increase in intensity?

Figure 1 gives an overview of what could be expected when we increase the final stocking biomass by an extra 50 %.

A 150 gram smolt will consume less of its own body weight each day as compared to a smaller smolt, so we could reasonably assume feed delivery increasing by 30 %, rather than by the full 50 %.

A 150 gram smolt would also have a slightly worse feed conversion as compared to a 100 gram smolt, and so loading of wastes could be expected to increase by 30-35 %. This certainly holds true for dissolved nitrogenous waste (ammonia and nitrite), toxic byproducts of biological activity.

However practical experience shows that oxygen demand and carbon dioxide production would increase by much more than 30 %. A heightened gas loading is the result of an accumulation of organic matter inside a stressed recirculation system.

Accumulation of organic matter with its associated oxygen demand and carbon dioxide production is the hardest dimension within the super-sized smolt challenge. How we manage this in the water treatment system will make the difference between success and failure.

A 500 kg of feed shock to the system

Allowing a batch of 1 million pieces to grow the extra 50 grams to 150 grams in our finely tuned recirculation system would mean around an extra 500 kg of feed added to the recirculation system on any one peak day. This is quite significant and causes some shock waves around the system. Figure 2 attempts to summarise the main water quality challenges generated by our 500 kg feed shock wave.

Figure 1: Overview of what could be expected when the final stocking biomass is increased by an extra 50 %.

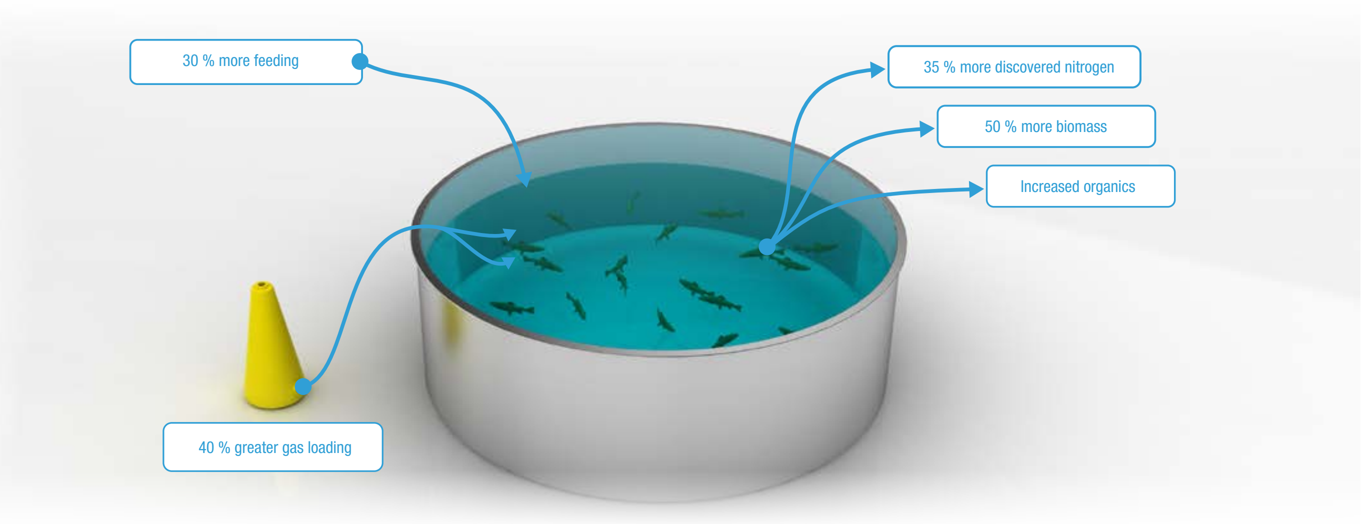
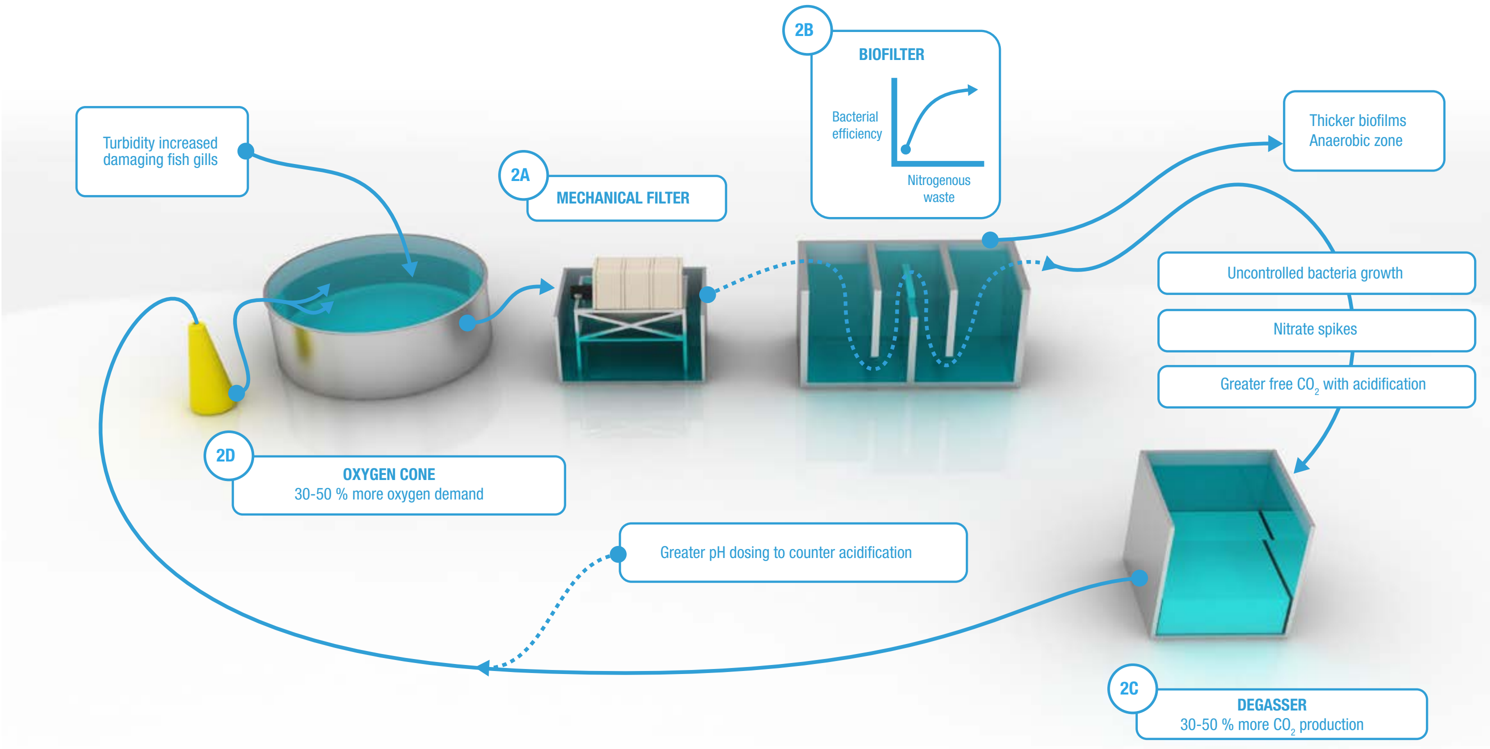


Figure 2: Challenges associated with increasing feeding by 30 %



Water leaves the fish tanks loaded with 30-35 % more faeces and feed wastes than in earlier batches. This all ends up at a fixed capacity mechanical filter that needs to work harder and suddenly needs a lot more maintenance. A drumfilter for example may even need to be increased in mesh size, say from a 40 micron to a 60 micron screen with a 30 % reduction in solids removal efficiency (Hydrotech Presentation).

Extra waste flushing past a mechanical filter (Figure 2A) adds greater pressure on the biological filters of a recirculation system. While increasing the concentration of nitrogenous wastes actually increases the efficiency of the associated bacteria (Figure 2B) (Zhu and Chen), excessive organic matter creates thick biofilms and anaerobic zones that generally reduce bacterial efficiency in the breakdown of wastes. An overloaded biofilter results in a scenario where bacteria begin to grow uncontrolled inside pipes, on tank walls and on any available surface, often forming long "lambs tails".

Organic matter adds to fish tank turbidity, which clearly damages fish gills. It is also often associated with nitrite spikes in the recirculation system. The bacteria reducing this nitrogenous waste are the least robust bacteria in the biofilter and are quickly outcompeted/damaged by the waves of heterotrophic bacteria thriving on accumulating organic matter.

While heterotrophic bacteria thriving on accumulating organic matter can directly affect the performance of degassing media by clogging water and airflow, the main problem with these fast growing bacteria is that they generate a significant demand for oxygen and produce carbon dioxide. For example, an increase in feeding by 30 % would lead to a 30-35 % increase in gas loading from the fish, PLUS a proportionally greater increase in demand for oxygen and carbon dioxide production by bacteria resulting in potentially a 50 % increase in the total gas loading!

With greater levels of nitrification (directly producing acid) combined with added carbon dioxide production (forming a weak acid[1]) there is significantly greater levels of acidification in the recirculation system at the added feed levels. A decreasing pH in itself is not a problem as it can be countered by water exchange and by dosing a strong base - $Ca(OH)_2$ (powder) or NaOH (fluid). However a decreasing pH has large implications for the concentration of toxic free carbon dioxide gas inside the water. Understanding the pH/free carbon dioxide relationship can play an important role in defying a 500 kg feed shock!

Defying feed shocks with better management

The first step in defying a feed shock is innovating to manage accumulation of organic waste. Local managers are naturally the experts to devise the best solution to manage waste, which may include foam fractionation with or without ozone, better biofilter cleaning, better fish tank hydrodynamics or improvements to the feed system.

As biomass grows and feeding increases, oxygen delivery must not be limiting. In most recirculation systems oxygen delivery usually has the scope to cover extra demands in capacity. However if not analysed before going ahead with a super-sized smolt challenge, then often inefficient methods of oxygen delivery will be adopted (e.g. greater reliance on fish tank diffusers) with a super-sized oxygen bill at the end of it.

The next critical "bottleneck" is carbon dioxide removal. Stripping of carbon dioxide is generally limited to a fixed water flow around the recirculation system, with a single pass across a degasser or aeration chamber.

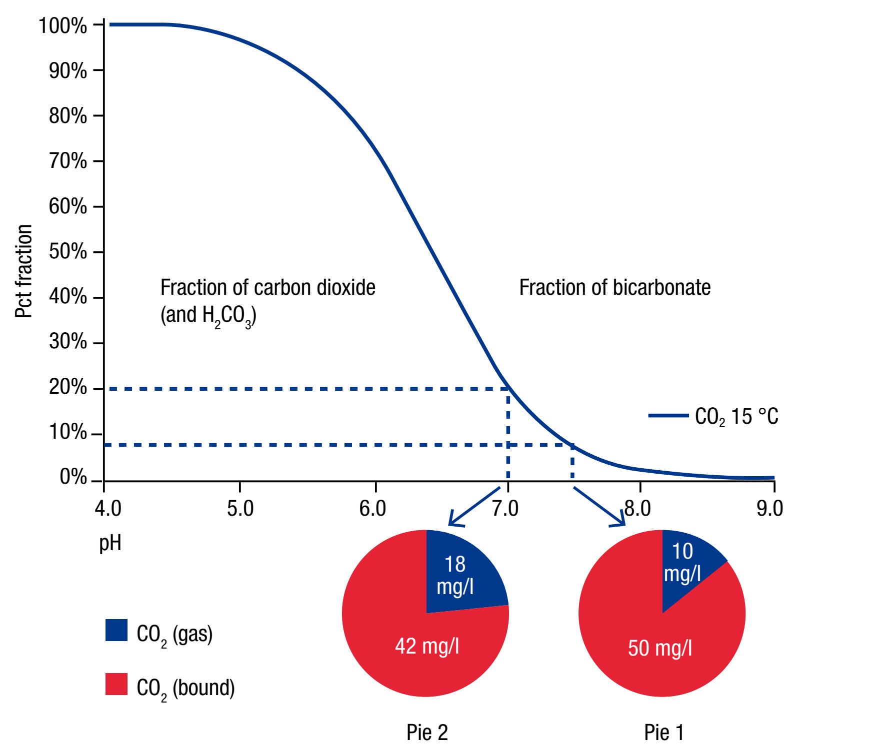
When carbon dioxide is released it dissolves into the recirculation system water as free carbon dioxide gas (free CO_2), bicarbonate and carbonate. How much remains as free CO_2 and how much binds into the water is strongly pH dependent (Figure 3).

The sum of free CO_2 and bound bicarbonate and carbonate is total inorganic carbon (or total CO_2). If the total CO_2 is 60 mg/L and the pH is 7.1, then around 15 % of total CO_2 is free CO_2 gas (Figure 3, Blue slice, Pie 1). If the pH in the system is allowed to decrease to 6.8, the total CO_2 remains at 60 mg/L but the percent fraction of free CO_2 jumps to 30 % (Figure 3 Blue slice, Pie 2).

This bit of chemistry has important implications when it is time to nurse the recirculation system through a 500 kg increase in feed intensity.

Many smolt recirculation systems operate at lower pHs and a lower total CO_2. An example in Figure 4A illustrates that this scenario results in a large drop in pH across the tank, meaning that free CO_2 nearly doubles in concentration. While this is not so good for the fish (larger fish seem more sensitive to these fluxes), it does mean a reasonable large proportion (30 %) of the carbon dioxide produced is available as free CO_2[2] to the degasser or aeration chamber to remove.

Figure 3: Carbonate System - distribution of carbon dioxide at different pH values



The figure illustrates the fraction of CO_2 gas (& H_2CO_3) at various pH levels and at 15 °C. This theoretical curve gives very high free CO_2 levels as it assumes there is nothing else affecting pH value. The reality is (especially in marine water) there are other chemicals buffering pH which effectively moves the curve to the left.

CUSTOM SOLUTIONS ON FARM

There are many wonderful examples of creative management strategies and add-on pieces of equipment that can assist a recirculation system to remove organic waste, boost oxygen or remove carbon dioxide. These solutions would vary from farm to farm with the local managers naturally being the experts to devise the best solution for a given circumstance. What is critical is the ability to understand the main processes, identify the "bottleneck", and use resources to manage the "bottleneck" as feed starts to be increased towards its peak.

Figure 4B illustrates a scenario that the overloaded recirculation system could manage to achieve during a 500 kg feed shock. As loading to the recirculation system increases, carbon dioxide production increases while greater acidification pushes the pH downwards. Management can manage the pH higher using chemical dosing to bind more of the produced carbon dioxide. This provides the fish with a lower toxic free CO_2, makes less free CO_2 available for stripping, and allows total CO_2 to rise in the system (where production of carbon dioxide exceeds its removal).

Raising total CO_2 has the advantage of providing a greater buffer capacity in the recirculation system's water, limiting pH drops across the fish tank and limiting a corresponding free CO_2 spike. This has important positive implications for the fish. While fish can tolerate the higher free CO_2, pH drops and CO_2 spiking severely reduces appetite particularly in larger fish.

The Figure 4B scenario of higher total CO_2 concentrations also makes new water addition to the recirculation system a useful carbon dioxide removal tool. Where the total CO_2 concentration in the recirculation system is significantly higher than the total CO_2 concentration of the new inlet water, adding new inlet water would naturally dilute out carbon dioxide.

Why does the pH drop so markedly across the fish tank? Simply because the total CO_2 is an important component of alkalinity, the ability to buffer the water's pH. The higher the total CO_2, the higher the water's alkalinity is and the more resistant the water is to pH drops.

Figure 4: Scenarios relating to pH and carbon dioxide management

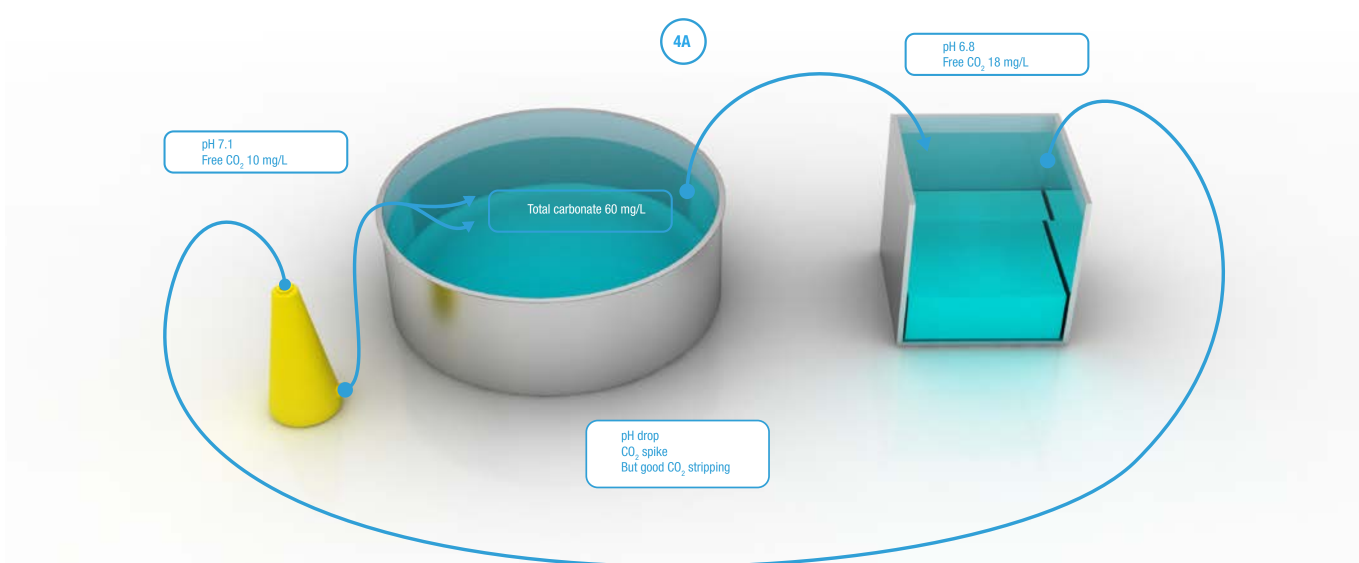


Figure 4A: Typical smolt scenario.

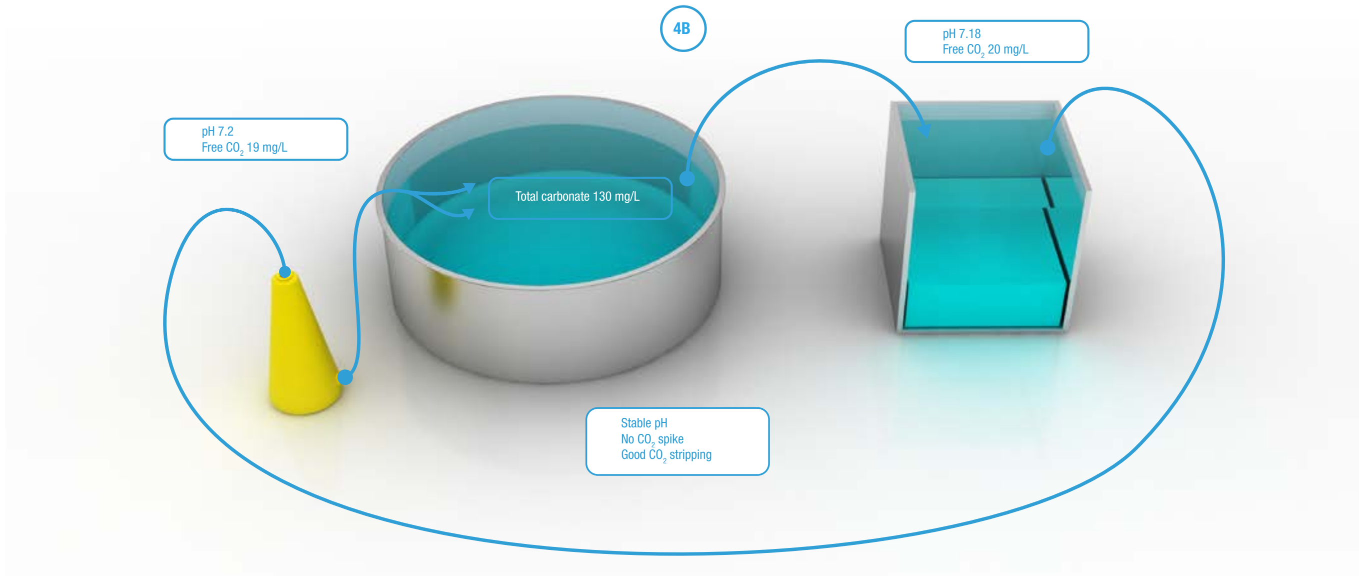


Figure 4B: Target scenario where the recirculation system has been overloaded in carbon dioxide for some time.

Success criteria for the super-sized smolt challenge

Experience shows that the worst aspect of feeding above the level that a recirculation system can cope with is that of organic matter increasing within the system causing uncontrolled bacterial growth. This leads to turbidity, nitrite spikes and significantly elevated gas loading.

The successful farm will have innovative managers that can find ways to reduce organic waste in the system, and that can understand the processes so they can for example better manage carbon dioxide. We believe that good water quality measurement combined with good management can allow for an increase in feeding by 30 % in a recirculation system for many weeks at a time. The manager must keep in mind the following key success criteria:

- Waste and feed management: consider all factors that can contribute to increasing organic loading to the system, including feed quality.
- Oxygen delivery: revise oxygen system to cope with at least 50 % greater delivery capacity.
- Carbon dioxide management: staff needs to understand the background chemistry, and use this understanding to manage on a daily basis pH and total CO_2 accumulation.

[1] Free CO_2 is in chemical equilibrium with H_2CO_3 that strongly favours CO_2 (600 times) (Summerfelt, 2004).

[2] Only free CO_2 can be removed by a degasser or aeration chamber.

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