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ATINER's Conference Paper Series
WAT2015-1652

Intensification of Salmonid Aquaculture

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This paper should be cited as follows:

Bergheim, A. and Nilsen, A. (2015). **"Intensification of Salmonid Aquaculture",** Athens: ATINER'S Conference Paper Series, No: **WAT2015-1652.**

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URL Conference Papers Series: www.atiner.gr/papers.htm

ISSN: 2241-2891
20/10/2015

Intensification of Salmonid Aquaculture

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Abstract

The commercial scale production of salmon and trout has only lasted for 30 – 40 years. Over this period, a remarkable progress took place within vital fields, such as genetics, nutrition and medicines and also a revolution regarding engineering and farm management. This presentation emphasizes on the intensification attempts of the production from the fry stage to the harvest stage, made possible by the introduction of new technologies and alternative farming regimes.

Due to improved efficiency and larger farm units, the average production level at the sites, for both, has increased by 10 – 100 times in terms of numbers of smolts or tons of harvested fish per year compared with the production 2 – 3 decades ago.

In the land-based farming of smolt, the launching of oxygen (DO) injection has reduced the water consumption to 75% and even further to 90% while combining oxygenation and the stripping of carbon dioxide (CO_2) in the tanks. This combined water treatment is indicated as a 'partial recirculating aquaculture system (partial RAS)'and currently the dominating system for smolt production in Norway. A vital contribution is the development of efficient technology that removes 60 – 90% CO_2 per flow passage. Fully RAS, also including biofiltration, is rapidly expanding in most salmonid producing countries and now represents more than half of the total smolt production in Chile. Such high producing systems mean improved sustainability in terms of strongly reduced water consumption and lower effluent loading due to particle removal and sludge utilization.

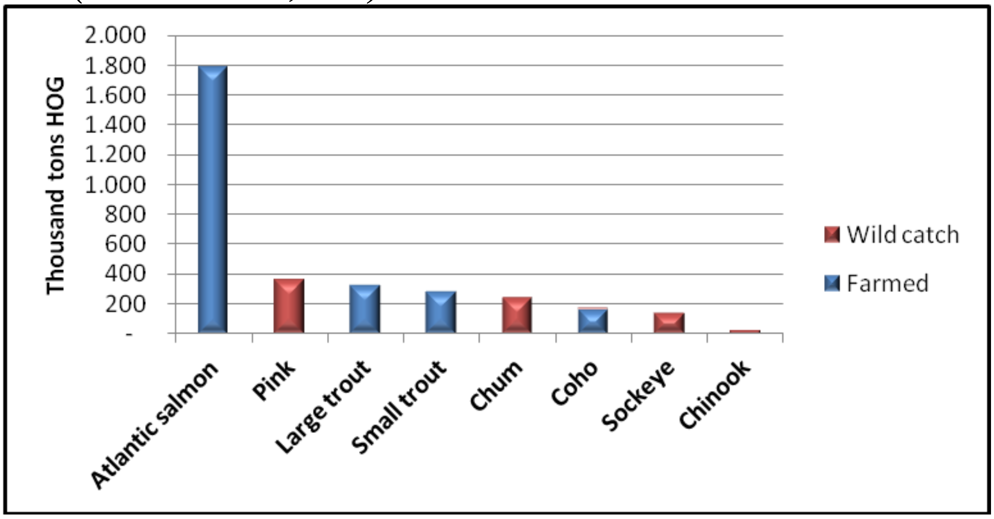
The traditional transfer of smolt (50-100 g) to sea cages is gradually being replaced by the production of the so-called super-smolt of 500 – 1,000 g in land-based RAS or in closed floating cages before stocking in open cages. This extended 'smolt stage' results in a shorter production cycle, less sea lice and a reduced discharge of feed-based wastes.

Keywords: farming systems, intensification, salmon, trout, water consumption

Introduction

Commercial production of salmonids in constructed farms was initiated in the 1960 – 70'ies. Rainbow trout was the first salmonid species to be domesticated and it dominated the aquaculture production volume until the mid-1990'ies. In 1992, the global production of the three major species amounted to approximately 300,000 metric tons (MT) of rainbow trout, 240,000 MT of Atlantic salmon and 50,000 MT of Coho salmon (Jansen and McLeary, 1996). Over the last twenty years, Atlantic salmon has become the leading aquaculture species (Figure 1).

Figure 1. *Global Volume of Wild Caught and Farmed Salmon and Trout in 2013 (Marine Harvest, 2014)*



HOG: head on gutted

The global production of salmonids is dominated by the farming of Atlantic salmon in Norway, Chile, Scotland and Canada. Although Chile also produces about 200,000 MT per year, the same as Coho and New Zealand, it predominates the volume of farmed, highly valued Chinook/King salmon (approx. 15,000 MT/year). The annual production of rainbow trout is about 600,000 MT. Figure 1 also indicates that the other salmon species, Pink, Chum and Sockey, are not – or are to a little extent – farmed species. Though production of salmonids only amounts to about 5% of the global aquaculture fish volume, the value market share is several times higher due to the high price level.

Over the years, the fish farming systems have been subject to a revolutionary development. Salmon and trout producing farms some decades ago were small units only for producing a few hundred thousands of parr/smolt or about ten tons of edible fish each year. Compared to the present producing systems those small farms were rather inefficient regarding fish growth, feed utilization, etc. and were mainly based on manual work. The improved efficiency and productivity have contributed to a more environmentally friendly industry in terms of water consumption and pollution. On the other hand, the increased farm size represents a higher potential risk for accidents, e.g. at drop of water supply in land-based farms or at severe net damage in floating cages.

This survey briefly describes the major trends within salmonid aquaculture, emphasizing the consequences for the industry and the environment.

Fish Performance and Feed Quality

Genetic improvements in salmonids due to systematic breeding programs have demonstrated convincing results. Family based breeding programs in Norway started in 1975 (Gjedrem and Baranski, 2009) and the average gain, especially regarding the growth rate has been significant (Table 1). A similar growth rate gain in rainbow trout and coho salmon of 10 – 15% per generation based on selective breeding is reported (Gjedrem and Baranski, 2009). Along with growth performance, appetite level and feed utilization are clearly improved (Table 1). Significant genetic variations in resistance to harmful diseases in salmonids are demonstrated in many tests, e.g. to infectious pancreatic necrosis in rainbow trout (Wetten et al., 2011).

Over the last 10 – 15 years, an increasing number of out-of-season, or so-called 0+ - smolt, have been produced via the manipulation of photoperiod and temperature (Fitzgerald et al., 2009). This production strategy reduces the rearing time in the hatchery and allows the transfer of smolt to the sea water in the autumn thus the entire production cycle from hatching till harvest is only 2 – 3 years (Fitzgerald et al., 2009). There are no indications of reduced performance in the sea cages of out-of-season smolt transferred to the sea in autumn compared to the stocking of traditional 1-year old smolt in cages during spring (Lysfjord et al., 2004).

In modern salmon and trout farming, the so-called feed conversion ratio (FCR: kg feed/kg body gain) is in the range of 0.9 – 1.3. Thirty years ago, the average FCR in Chilean salmon farming was above 2.0, but in 2004 was gradually reduced to 1.4 due to improved feeding quality, better feeding systems, etc. (Larrain et al., 2005). Today’s feeding diets contain high quality protein and lipids (fats) at rates of 35 – 50% and 25 – 40%, respectively (Reid, 2007). Protein levels were traditionally much higher in the developing stages of intensive salmon aquaculture. The amount of protein was consequently reduced and replaced by lipids, a process called ‘protein sparing’ (Wilson, 2002). Higher fat and energy content of the diet has strongly contributed to the reduced FCR.

Table 1. *Genetic Gain in Atlantic Salmon over Five Generations of Selection (Thodesen et al. 1999)*

Trait	Improvement in selected over wild (%)
Growth rate	+113
Feed consumption	+40
Protein retention	+9
Energy retention	+14
FCR*	-20

*: FCR (kg feed/kg body weight produced)

A dominating part of the content of protein and oil of the diet was generated from wild fish, thus the growing salmon industry became a potential threat to the limited wild fish stocks. Consequently, the feeding industry has gradually replaced the fish in the salmon diets with poultry, plant based protein and oil. According to BC Salmon Facts, wild fish represented 90% of the protein and 100% of the oil in the diet in 1990, it was reduced to 30% (70% poultry and plant protein) and 45% (55% poultry and plant oil), respectively (http://www.bcsalmonfacts.ca/#!/fact/feed).

Land-Based Systems

Major Systems

Traditional flow-through (FTS) and fully recirculating (RAS) farms are presented in Figure 2 and 3, respectively. Most FTS farms had a supply of inlet water from a lake or a reservoir which led to the hatchery and fish tanks by gravitation. In former FTS-farms, aeration and the addition of lime or seawater to control dissolved oxygen and the pH were the only water treatment attempts (Figure 2), while up-to-date FTS-farms are equipped with oxygenation for the oxygen super-saturation of the tank inlet water and the removal of carbon dioxide (CO_2) from the fish stock. Due to instructions from local authorities, many farms perform end-of-pipe treatments for the removal of particles (sieving) and the further treatment of collected sludge (dewatering, stabilization) for application such as manure in agriculture or source for bioenergy (Bergheim et al., 1998, Gebauer, 2004).

Figure 2. *Sketch of a Typical, Single Flow-through Hatchery-smolt Farm (FTS) (Sketch: Yngve Ulgenes)*

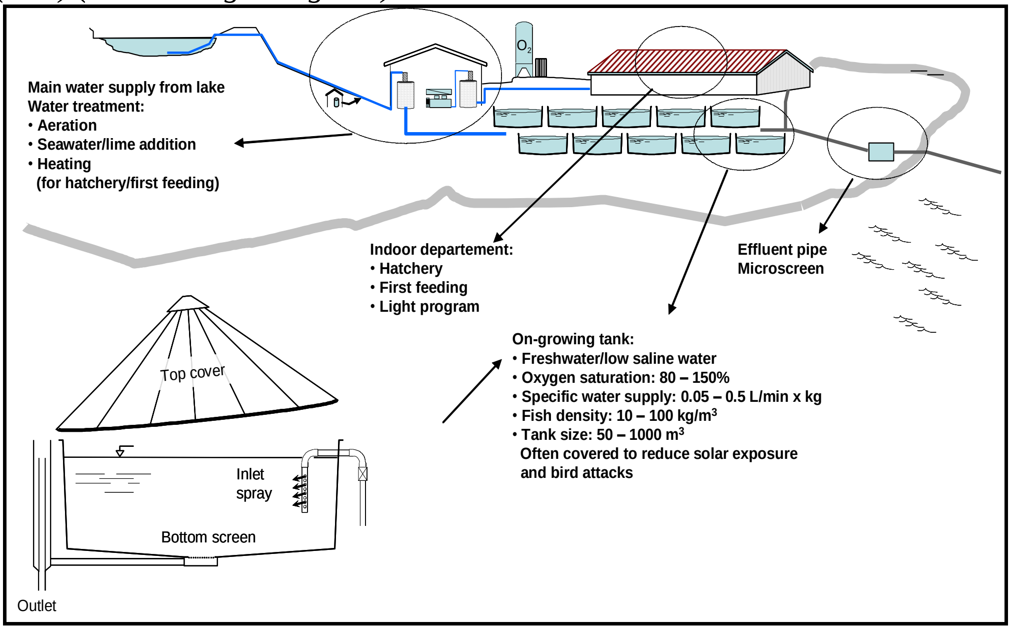
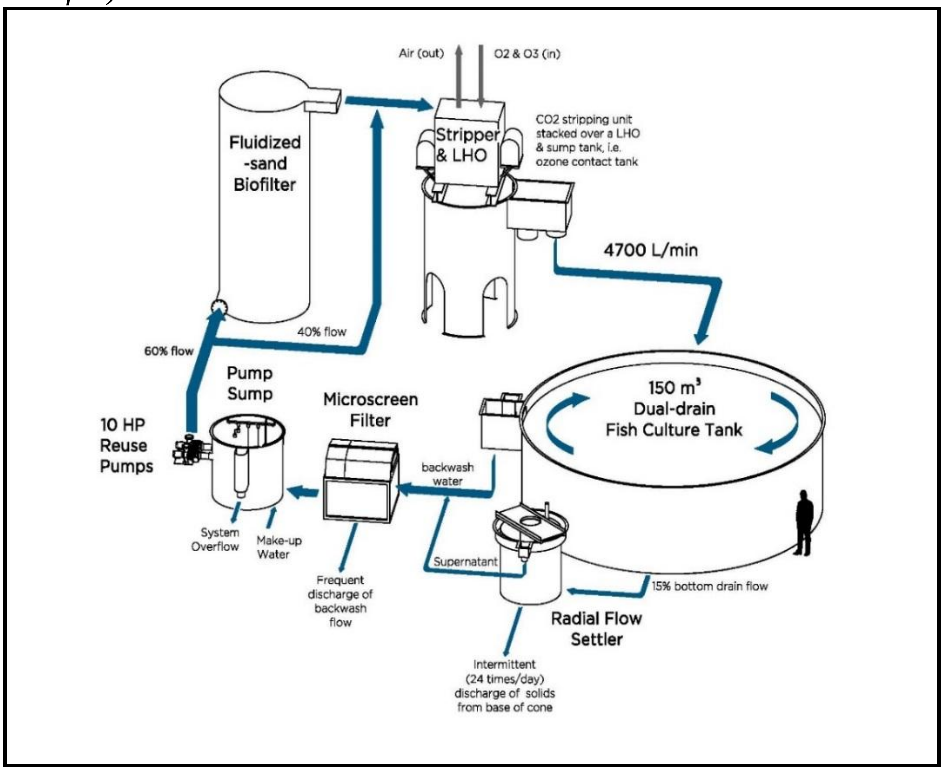


Figure 3. *Sketch of a Recirculating Aquaculture System (RAS) for Research activities, Freshwater Institute, West Virginia, USA (Courtesy: Steve Summerfelt)*



An increasing part of the total smolt production takes place in RAS-based farms with full water treatment (O_2-injection, CO_2- and particle removal, nitrification in biofilter, and disinfection by ozone or UV-radiation), a system reviewed by Timmons and Ebeling (2010). A decade ago, only a small number of the smolt farms that produced Atlantic salmon in Europe and Chile were based on the recirculation of water (Bergheim et al., 2009), while such intensified systems were more commonly applied for the production of rainbow trout and Pacific salmon, e.g. in USA and Canada. However, no exact global figures of the distribution of FTS and RAS farms are available, but RAS-based production is supposed to represent about 50% of the Chilean and 30 - 40% of the current Atlantic salmon production.

Water Flow, Waste Load and Energy Consumption

In cold-water salmonid producing systems, the water use in traditional single-pass tanks and raceways in the 1970 – 80'ies was very high, up to 500 m^3/kg produced, while the introduction of full recirculation (> 90 – 95% recirculation rate) in the 1990'ies reduced the consumption to 3 – 5 m^3 per kg produced fish (Verdegem et al., 2006). The peak water flow in a medium sized flow-through farm (FTS) applied O_2-injection and CO_2-removal, producing 1 – 2 million smolt per year, may correspond to the domestic water consumption of approx. 70 000 persons.

The connection between the running flow and water treatment attempt is indicated in Table 2. In single flow-through systems (FTS), the introduction of oxygen injection in the water reduces the flow to around ¼. The so-called 'tank internal recirculation of water' ('partial-RAS') with additional CO_2-removal allows a further reduction (to approx. 0.1 L/kg/min), while complete recirculating systems (fully RAS incorporating biofiltration) may lower the required flow to below than 0.01 L/kg/min or to only 0.3% of the flow in FTS-based farms 30 – 40 years ago.

A survey for the sustainability of modern land-based farms in three different countries is presented in Table 3. The reduced water usage in RAS is clearly demonstrated and so is the effluent waste load in the recirculating systems due to particle removal within the system. However, efficient particle removal and sludge treatment (end-of-pipe treatment) in FTS farms may lower the outlet load to 30 – 40% of the level without such attempts (e.g. Cripps and Bergheim, 2000). In RAS, a considerable removal of organic matter takes place (e.g. Eding et al., 2006) within the biofilter unit, because of the activity of the heterotrophic bacteria.

Applied Life Cycle Assessments (LCA) to evaluate different land-based aquaculture systems clearly indicate the advantage of transferring FTS farms to RAS (Roque d'Orbcastel et al., 2009). The environmental balance of RAS is more favourable at both global and regional levels except with regards to energy use. Aeration and water treatment are the main reasons for higher energy consumption in RAS (in the range 16 – 20 kWh/kg produced fish).

Table 2. *Water Flow Limits at Different Treatment Levels in Salmon Hatcheries/Smolt Farms (Joensen, 2008)*

Technical attempts	Back-up flow limit, L/kg fish/min
FTS:	
None	2.4
Oxygen added	0.6
RAS:	
Removal of solids & CO_2	0.070
Biofiltration included	0.006

FTS: flow-through systems RAS: recirculating aquaculture systems

Table 3. *Water Use, Consumption of Electric Energy and Waste Discharge in RAS and FTS Farms for Production of Salmonids in Three Countries (Average Figures), Bergheim et al. (2013)*

Parameter	RAS		FTS	
per kg prod. fish	Norwegian	Canadian	Norwegian*	Icelandic**
Water use, m^3	0.8	0.3	22	95
Energy consumed, kWh	4.1	20	-	4.3
Waste load, g:				
Suspended solids	17	52	21	806
BOD_5	8.5	-	14	14
Total phosphorous	2.3	-	2.3	-
Total nitrogen	20	-	24	72

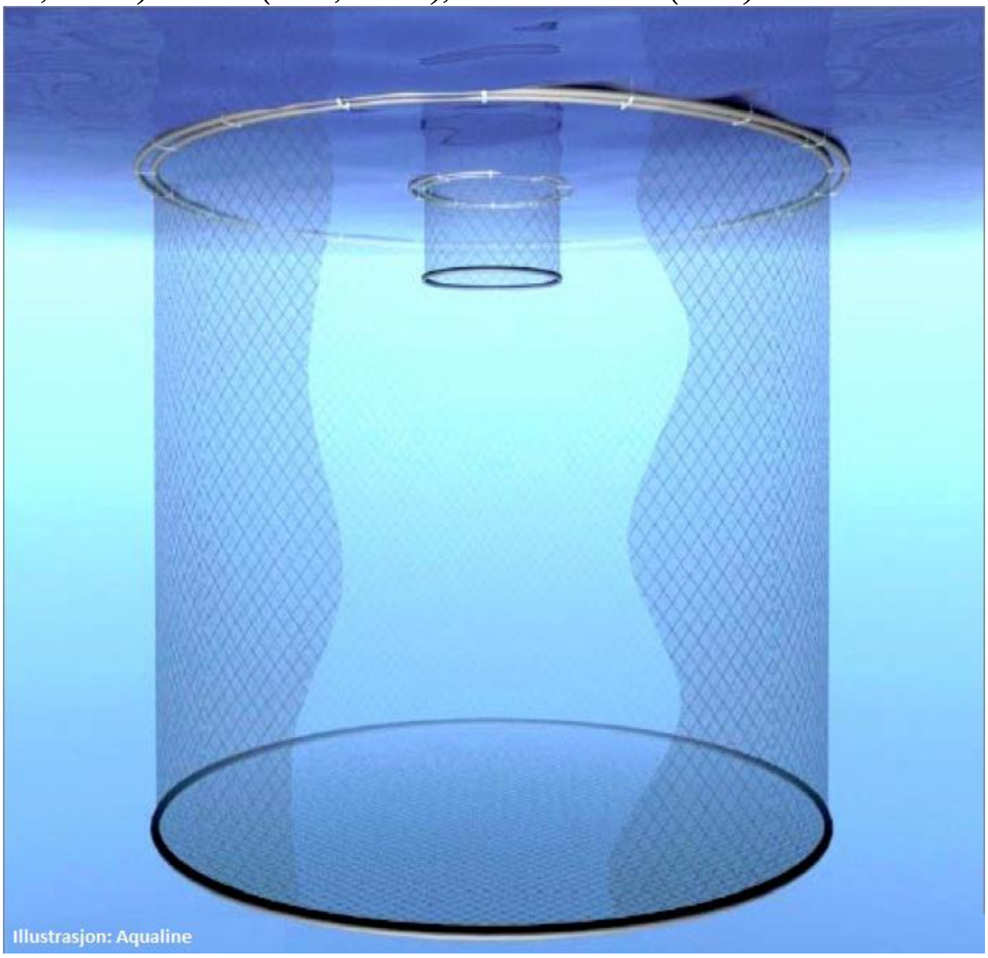
*: with end-of-pipe treatment **: without end-of-pipe treatment -: no figures

Floating Systems

Major Systems

The bulk of the global production of salmonids is based on the on-growing of post-smolt in floating open cages in seawater. At least 90% of the present biomass increase takes place in such systems. Over the years, the size of the net cages are being multiplied (Figure 4) and a large cage (Ø 160 m, 30 – 40 m deep) may be stocked with up to 200,000 salmon or rainbow trout and thus produce around 1,000 MT per year. Deep cages are considered beneficial allowing the fish stock to dwell at the most favourable depth layers regarding temperature, dissolved oxygen, occurrence of jellyfish and algae, etc.

Figure 4. *Illustrative Drawing of the Volume Increase of Sea Cages from 1990 (< 1,000 m^3) to 2010 (> 65,000 m^3), Henriksen et al. (2013)*

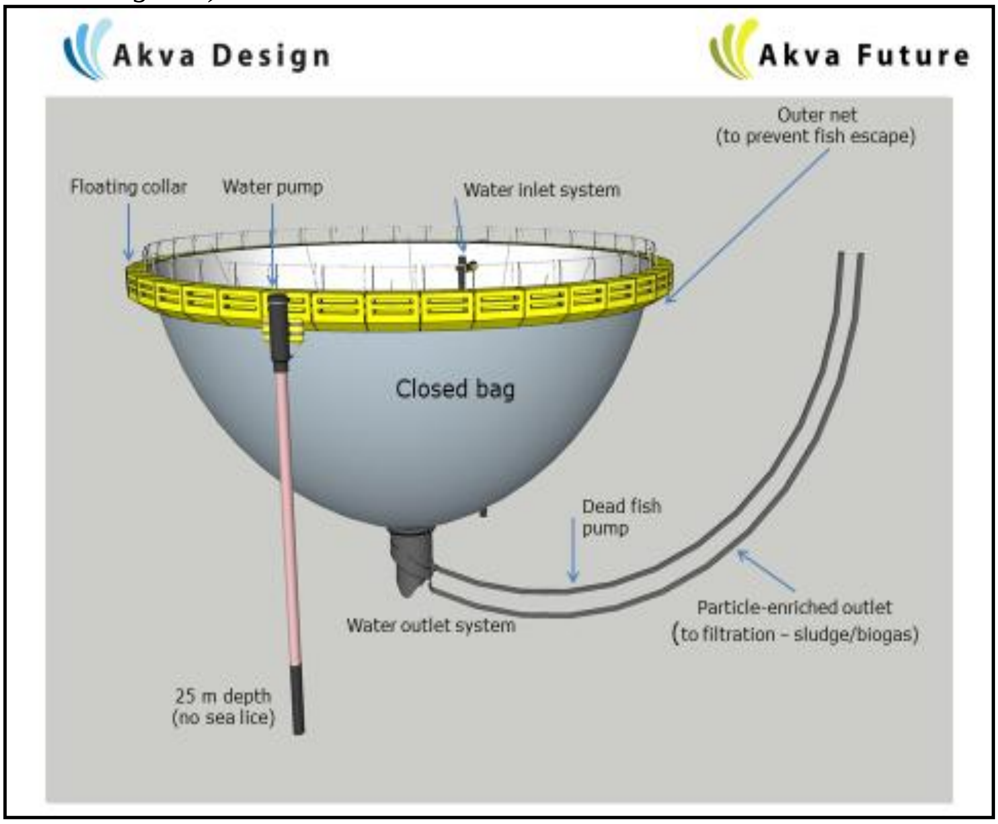


The on-growing of post-smolt from smoltification to a size of 500 – 1,000 g in closed seawater cages is a recently established alternative to the traditional transfer of smolt (*c.* 100 g) directly to open cages (Figure 5). In an ongoing study, this intermediate stage introduced, indicates the following (Nilsen et al., 2015):

- sea lice attacks, representing a serious problem for the on-growing of salmon in open cages, seem to be eliminated in closed cages
- in brackish water fjords, the potential growth rate during winter is significantly improved in closed compared to in open cages due to the higher temperature of the supplied deep-water
- effluent solid removal will efficiently prevent settling on the sea bed beneath the farm

The escalating sea lice problems are not just a heavy burden to the aquaculture, but also pose a threat to wild stocks of sea trout and salmon (Costello, 2009). The deposition of organic-rich particulate matter may degrade the sea bottom under and next to open sea cages (Carroll et al., 2003). Thus, this closed growing stage may reduce the ecological consequences of aquaculture.

Figure 5. *The Design of a Floating Closed Cage Based on Supplied Deep Water, Oxygen Injection and Outlet Water Treatment (Courtesy: Anders Næss, Akva Design AS)*



Conclusions

The aquaculture of salmonids has been through a dramatic progress since the initial domestication attempts in the 1970'ies. Significant factors, such as growth rate, feed utilization, disease control, water consumption and waste outlet are significantly improved. Salmonid aquaculture is thus far more sustainable compared to former production systems. However, the escalating size of the farms has gradually become a challenge with regard to water flow, waste load and potential risk to wild salmonid stocks.

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