Introduction to Recirculation Aquaculture

By Bjarne Hald Olsen, Managing Director of Billund Aquaculture

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Agenda:

1. The state of world aquaculture
2. Who are Billund Aquaculture
3. Definition of re-circulation and RAS
4. RAS - Advantage & disadvantage
5. Examples of RAS
6. Dimensioning & functioning of RAS
   - Intensive RAS
   - Semi RAS
   - Technology to minimize the water consumption
7. Managing a RAS
8. Trends within the RAS business seen from Billund Aquaculture point of view
9. Investment in RAS

1. The state of world aquaculture

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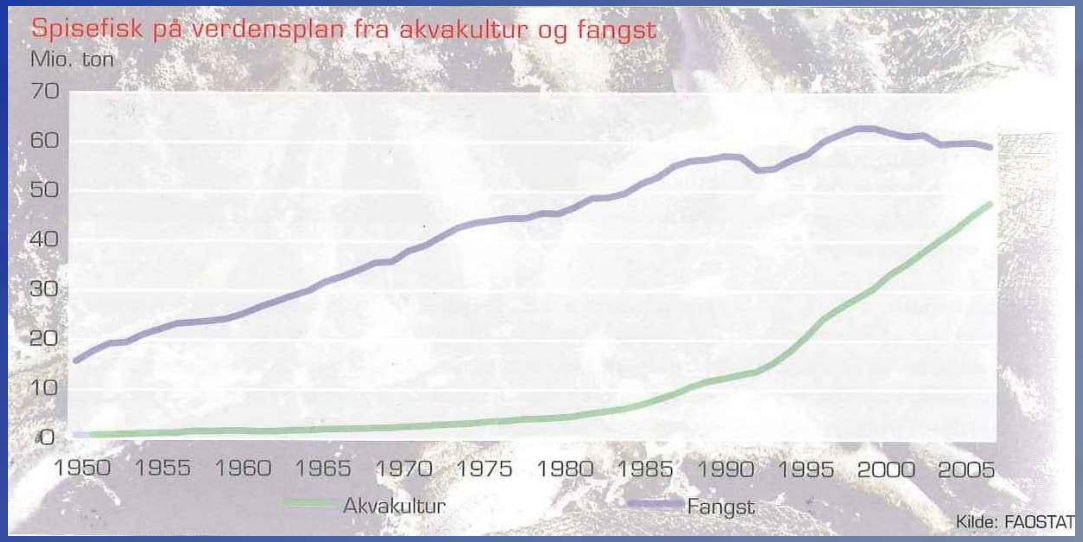
Global outlook

Aquaculture is the fastest developing sector of the global food industry with an annual rate of growth of more than 10%.

Globally, production from capture fisheries has levelled off and most of the main fishing areas have reached their maximum potential. Sustaining fisheries supplies from capture fisheries will, therefore, not be able to meet the growing global demand for aquatic food.



World aquaculture has grown tremendously during the last 50 years from a production off less than a million tonnes in the early 1950s to more than 60 million tonnes by 2007.

In order to maintain the current level of per capita consumption, global aquaculture production will need to reach 80 million tonnes by 2050.

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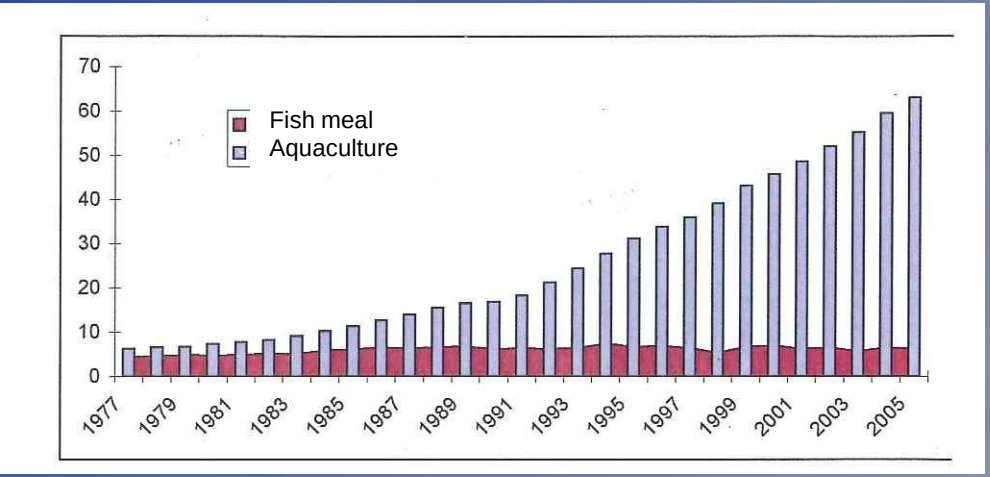
Challenges:

Aquaculture has the potential to make a significant contribution to this increasing demand for aquatic food in most regions of the world, however, in order to achieve this, the sector will face great challenges in respect to quality, access to fish feed, environment, access to water etc.

- How to produce more food from restricted resources!!
- In 2050 the world population is estimated to 9 billion people
- Still fewer people work with food production
- EU's seafood self-sufficiency: 1999: 60%; 2007: 35%!!!
- Fish feed resources
- **ENVIRONMENT**
- **ACCESS TO WATER**



2. Who are Billund Aquaculture

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Who are we:

- Billund Aquaculture is a Danish company located in Billund, Denmark and in Puerto Montt, Chile (Billund Aquaculture Chile S.A.).
- Billund Aquaculture offers more than 25 years experience in design and operation of intensive fish farms.
- The practical know-how has been obtained through our own production facilities, where we since 1984 have produced eels, sturgeons and sea bream/sea bass in our own hatcheries- and production systems. Currently we have an annual production of 300 ton of eel and 20 tons pike perch.
- Worldwide Billund Aquaculture has so far build more than 100 re-circulated systems for 24 different salt- and freshwater species in 25 different countries.

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Billund Aquaculture has technical and biological experience in planning and construction of intensive production of all kind of warm and cold fresh- and saltwater fishes for example;

Freshwater species

- **Salmon smolt**
- **Trout**
- **Sturgeon**
- Barramundi
- Pike Perch
- Perch
- Eel
- Tilapia
- Arctic Shar
- Pike
- Carp
- Catfish
- Tench

Saltwater species:

- Sea Bass
- Sea Bream
- Cod
- Turbot
- Halibut
- Cobia
- Grouper
- Snapper
- Sole
- Yellowtail Kingfish
- Coral fish

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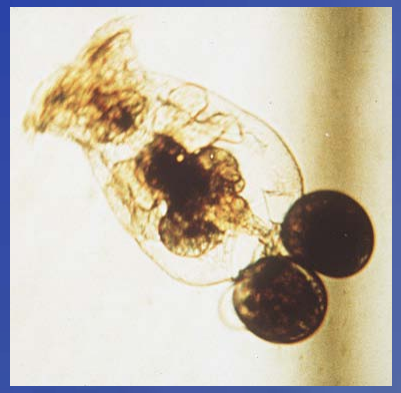
Production of live feed for marine fish larvae



Marine algae
Nannochloropsis, Isochrysis
<10 µ

rotifers
Brachionus plicatilis
120 - 250 µ

Artemia
Brine shrimp
400 - 800 µ

3. Definition of re-circulation & RAS

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Definition of re-circulation

In general, there is often confusion about what is meant by recycling and what is meant by reuse. Recycling is when the water quality is in control of the water treatment system, not by the inlet water.

RAS – Re-circulated Aquaculture System ~

Exchange of less than 10% of the total water volume per day

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Definition of re-circulation

To give a precise describing of the recirculation degree which also include the efficiency and potential of a system it is necessary with a more cost- and technical related description of the recirculation degree. In this context the water exchange per amount of feed put into the system per day is much more precise.

Water exchange/kg feed

$$\text{Water exchange per kg feed} = \frac{\text{Water exchange/day } (m^3/\text{day})}{\text{Feeding/day (kg/day)}}$$

$$\text{Water exchange per kg feed} = \frac{120\ (m^3/\text{day})}{300\ (\text{kg/day})}$$

Water exchange per kg feed = 400 l/kg feed

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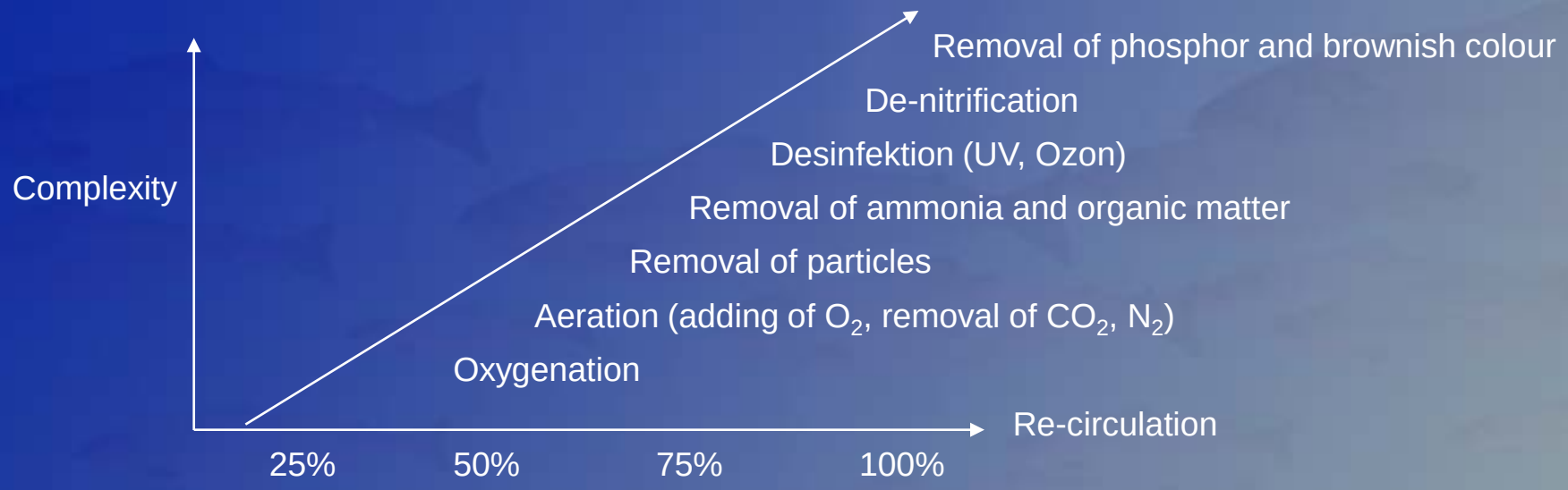
Definition of re-circulation

A traditional fish farm with ponds or tanks, has an inlet and outlet, and water is used once or a few times. If water is treated to improve quality and used again, then it is considered a re-use or recirculation system.



Flow through systems	30 - 50.000	Liter new water/kg fish produced
Semi RAS	3 - 5.000	Liter new water/kg fish produced
Moderate RAS	400 - 1.000	Liter new water/kg fish produced
Intensive RAS	50 - 400	Liter new water/kg fish produced

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4. RAS - Advantage & disadvantage

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Re-circulated systems - Advantages

1. Low water requirement - can utilise small water sources and/or be connected to the public water supply
2. The system can achieve optimal temperature and enables optimal and stable production all year round, independent of seasonal variation, this makes the production predictable for al 365 days
3. The required area for a given production is relative small, because a very high density and a high growth rate is possible in the controlled environment
4. Reduced risk of diseases
5. Optimal and stable production secure high and stable quality of the fish
6. Control and traceability
7. The incoming water can be treated to achieve the desired quality.
8. The effluent can be reduced to a minimum, and therefore be controlled.
9. Sludge from the system can be treated to produce a odour free fertiliser with desired dry matter content.
10. Close to market means less pollution due to transport (CO_2).
11. Fish are unable to escape from this type of system
12. The system provides a good all year round working environment

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Re-circulated systems - Disadvantages

1. The system is relatively advanced, and is dependent upon a regular power supply. It requires an emergency power generator and a security system which is in function at any time, and under all possible conditions, to secure continuous operation and good environmental conditions
2. The system requires special competence and needs a highly qualified work force
3. The system is relatively expensive to set up, and requires a minimum production capacity for an economical operation
4. Energy price

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5. Examples of RAS

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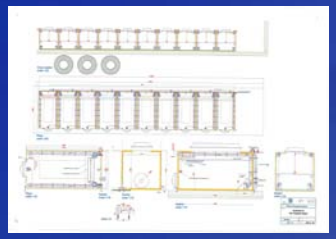
Fish transporter

Trapia Malaysia Sdn Bhd

Trapia is a Traceable Tilapia, whose origin and identity can be verified by means of DNA technology.
The company was founded in 2007 to develop and implement the company's "egg to plate" vertical integration strategy.

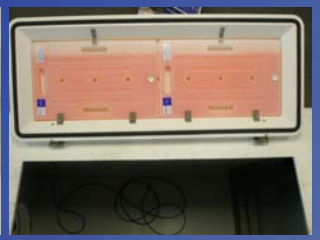
Trapia is produced using GenoMar Supreme Tilapia fingerlings to grow market size tilapia in GenoMar's own grow-out facilities. Each fingerlings used is "pre-tagged", traceable and verifiable throughout the value chain.

The company will be a major player in the tilapia industry producing up to 20,000 tonnes of tilapia in a fully integrated operation. Approximately ¾ of this production will be from contract farmers. The bulk of the production will be for the export market.











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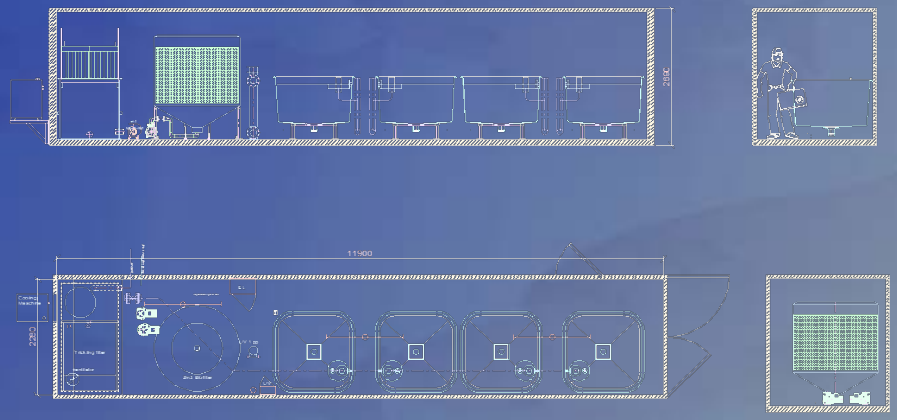
Broodstock System – 40 ft container (plug & play)



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Aqua Life

Transport of live seafood like shellfish (mussels, oyster, scallops, crayfish, and lobsters by sea from Canada to Europe. Capacity of a 40 feet container is equal to 10 tons mussels or 6 tons lobster.

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Atlantic Salmon – 20 million fish/year

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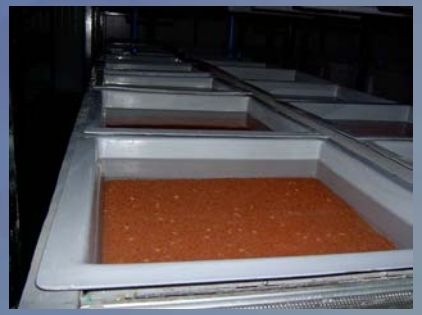
Incubation System - Salmon eggs 24.000.000/year



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Hatchery System – Salmon eggs 20.000.000/year

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Start-feeding & Fry System








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Pre-smolt System

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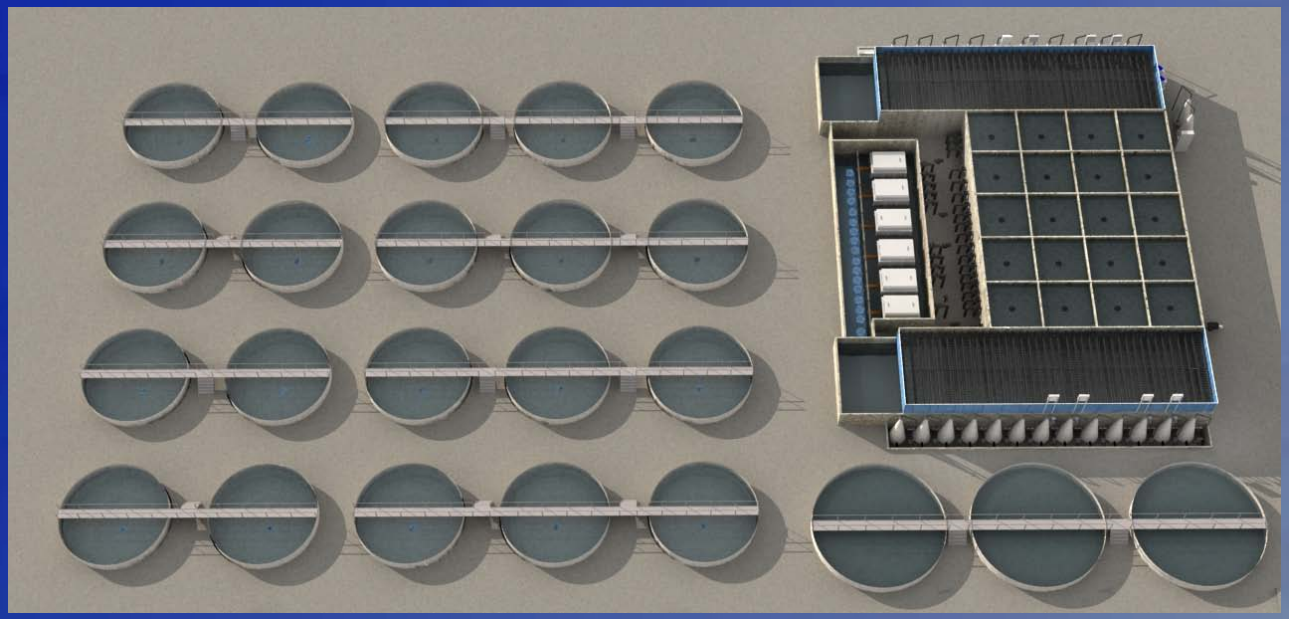
Smolt System – the world biggest biological filter capacity equal to a daily feeding of 3.500 kg



Biofilter capacity	3.500	kg feed/day
Numbers of fish tanks	23	pcs.
Size of fish tank (diameter 11	285	m^3/fish tank
Total fish tank volume	5.700	m^3
Density of fish	50	kg/m^3
Biomass in system (max.)	285	tons
Waterflow to fish tanks	9.800	m^3/h
Retention time in fish tanks	~ 35	min.

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Handling & Grading – Inside 1

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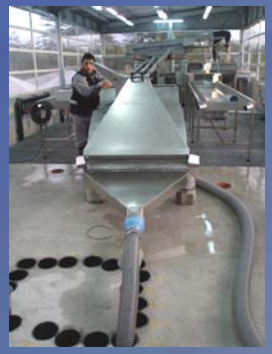
Handling & Grading - Outside







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Broodstock System

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Salmon farm – open system

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Examples of buildings







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Aquatir – Moldova – www.aquatir.md

Beluga

Russian sturgeon

Sterlet

Bester

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Aquatir - Sturgeon Facility: Live Feed-, Incubation-, Hatchery-, Startfeeding- and Juvenile System






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Aquatir - Sturgeon Facility: 2 x On-Growing Systems






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Aquatir - Sturgeon Facility: Broodstock Unit 1

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Aquatir - Sturgeon Facility: Broodstock Unit 1

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Aquatir – Products

Aquatir – Total RAS area under roof equal to 28.000 m^2

6. Dimensioning & Functioning of RAS

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Intensive RAS

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What to consider when designing a RAS

- Fish species (pelatic or flat fish laying on the bottom etc.)
- Water (fresh water, salt water)
- Water temperature (8 → 35 ^{o}C)
- Feed Conversion Rate (FCR)
- Fish feed
  - Production methods (extruded, pelletized)
  - Digestibility (dissolved and un-dissolved waste, amount of excrements)
  - Physical quality (dust)
  - Composition (Oil, Nitrogen, Phosphor, carbon hydrate)
  - Excrements (consistency)
- Management (feeding strategy, feeding levels, feed waste)

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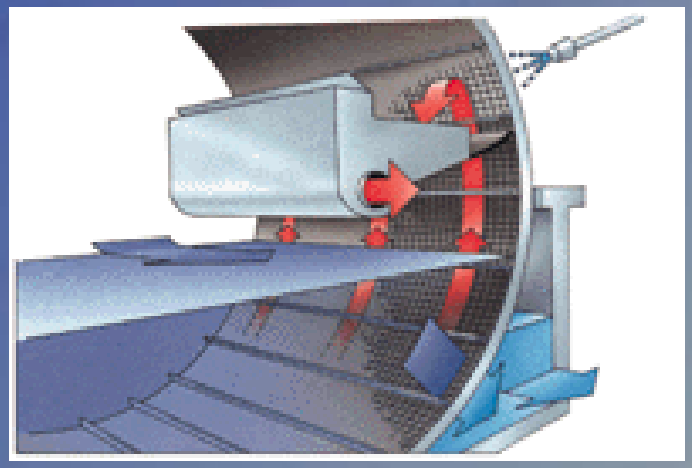
Mechanical filter - Removal of particles

Effective control of particles has an important influence for the fish health and the stability of the bio filter. High level of particles in the water can give the following consequences:

- Fish
  - Generate stress for the fish and thereby higher the risk of disease out breaks
  - Increase the risk of gill infections
- Bio filter
  - Increase in the oxygen consumption in the system
  - Increase the risk of clocking of the bio filter
  - Reduces the bio filter ability for nitrification



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Removal of particles

Nitrogen:

- Approx. 80% dissolved
- Approx. 20% solids

Phosphor:

- Approx: 30% dissolved
- Approx: 70% solids

Removal efficiency from mechanical filter (%):

	40 µm	60 µm	90 µm
Tot-P	65-84	50-80	45-75
Tot-N	25-32	20-27	15-22
Suspended Solids	60-91	55-85	50-80

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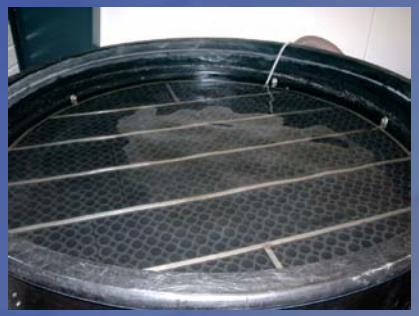
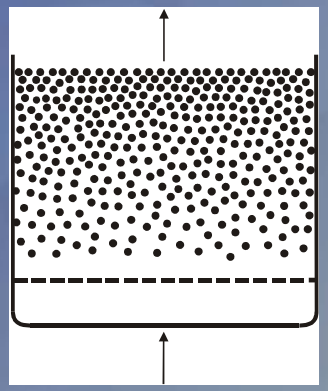
Biological filters - Submerged filters





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Submerged filters

- Advantage
  - Sedimentation of small particles in filter
  - The sludge production in the filter are removed due to back-flushing
- Disadvantage
  - Low area per cubic, specific surface (200m^2/m^3)
- Conclusion:
  - Billund Aquaculture (BA) are using submerged filters in all our systems

Rule of thumb: Retention time in biofilter 10-20 minutes
Water velocity through the biofilter ~ 25 – 50 cm/min.

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Biological filters - Moving bed filters





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Moving bed filters

- Advantage
  - Higher specific area, specific surface (600 m^2/m^3)
  - Good aeration
- Disadvantage
  - More suspended solids in the water
  - Energy consuming
- Conclusion
  - BA work with Moving bed in On-Growing facilities with fish sizes from 25 gram and up

Rule of thumb: Density of media ~ 0,95 g/cm^3
Filling rate max. 60 - 70%
Depth max. 3 m
Airflow ~ 5-7 m^3/h per m^2 bottom

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Trickling filters – Biological filtration, Aerating & de-gassing

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Trickling filters – Biological filtration, Aerating & de-gassing

- Advantage
  - Double function bio filter and aeration in one
  - Energy vice the cheapest way to aerate water
- Disadvantage
  - More solids in the water
- Conclusion
  - BA work with trickling filters in all facilities but always dimensioned to the size of Moving and Submerged filters

Rule of thumb: 25 % of total biofilter area in the trickling filter
Hydraulic surface load ~ 25 – 30 m^3/m^2/hour
Height of trickling filter minimum 1,2 m
Ventilation gas/liquid relation ~ 3-5

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Pumps

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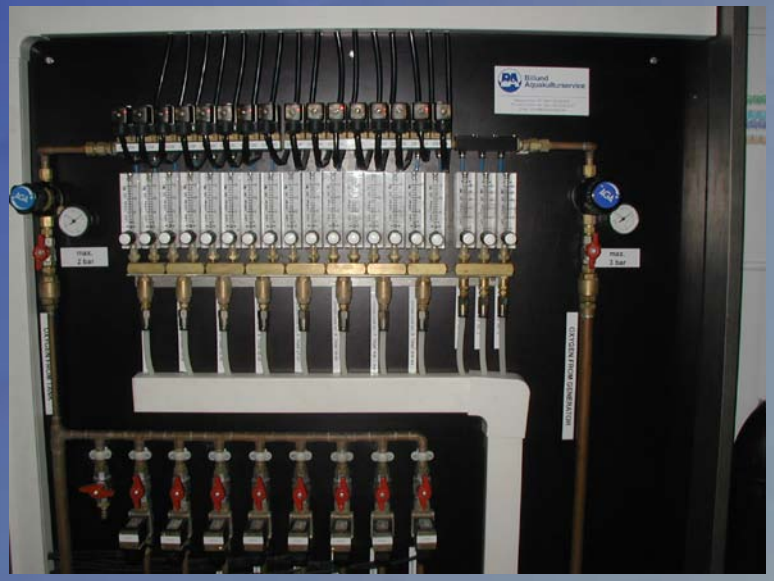
Oxygenation



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UV Treatment

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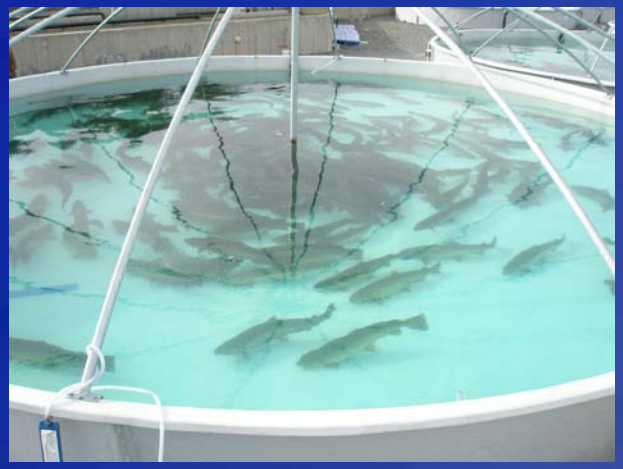
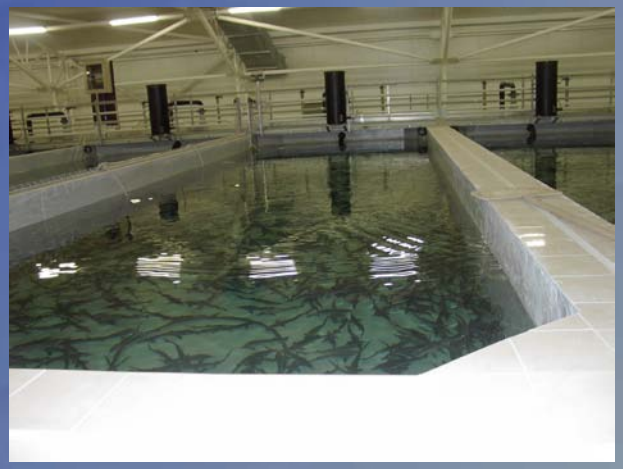
Fish tanks – variation in design, size, material etc.



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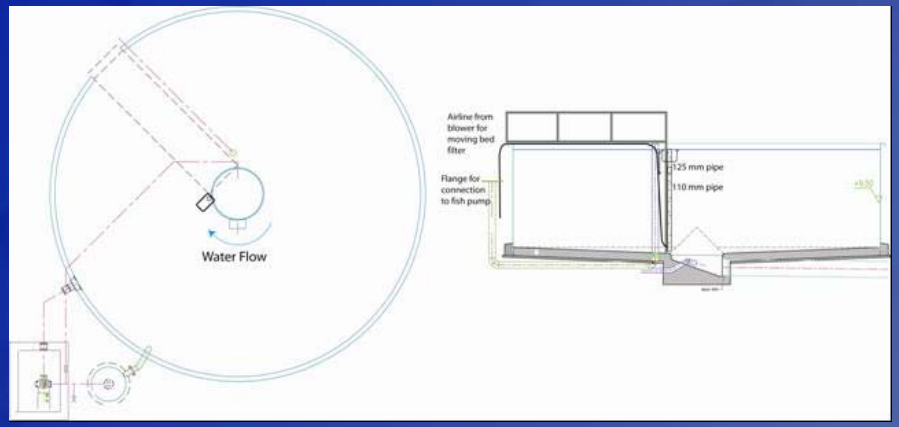
Fish tanks – Dead Fish Collector - 1



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Fish tanks – Dead Fish Collector - 2

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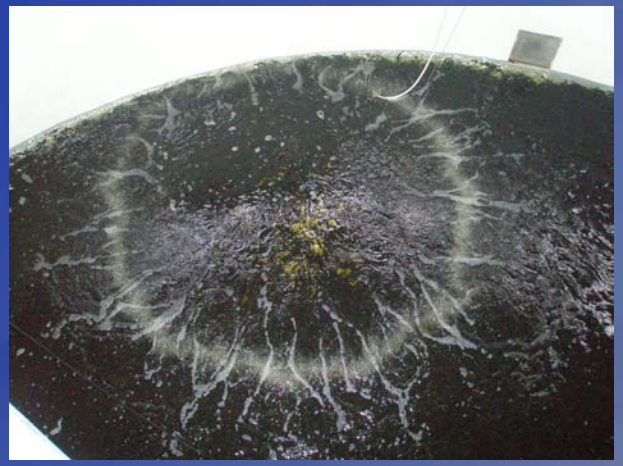
Fish tanks – emergency oxygen



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pH Regulation

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Cooling & heating

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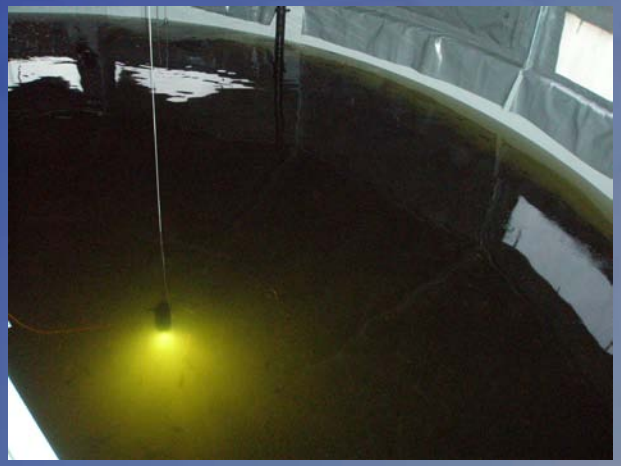
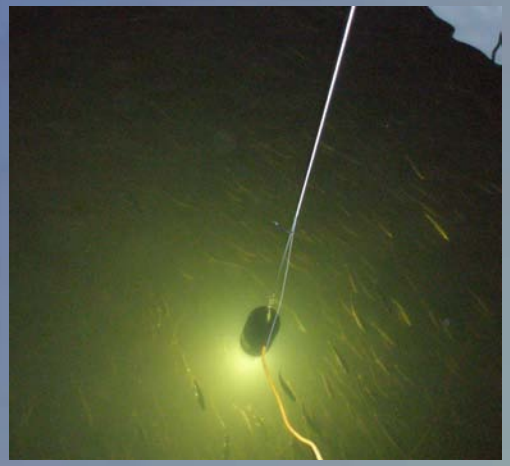
Smoltification – Salt, light and camera



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Semi RAS

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Technology to minimize the water consumption

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Definition of re-circulation

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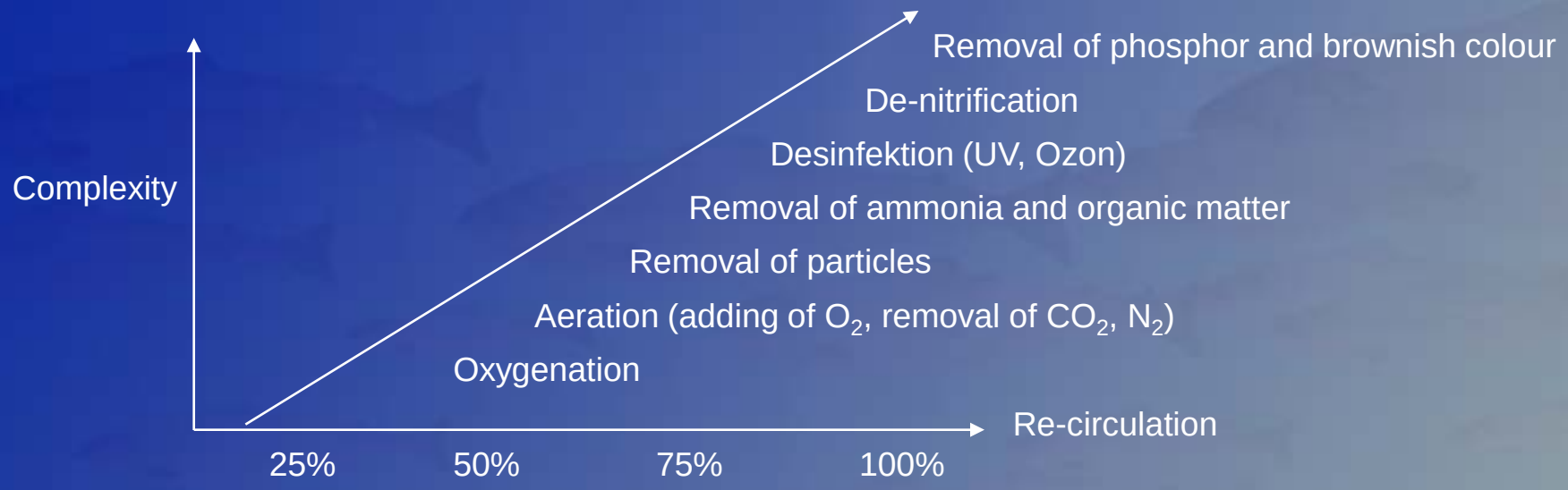

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Most common methods:

1. Removal of nitrate – De-nitrification
2. Removal of Brownish Colour
3. Removal of Phosphor and “Fine Particles”
4. Thickness of sludge

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Discharge from RAS

1. Process water from fish tanks
2. Sluicing water from mechanical filter
3. Sludge from back flushing of biological filters

Mechanical filtration

- Mesh size from 40 - 90 µm
- Average water consumption from 100 – 250 l/kg feed

Biological filtration

The sludge coming from back flushing varies according to flushing interval and, efficiency of the back flushing. The DM (dry matter) in the sludge is normally 3-4% DM.

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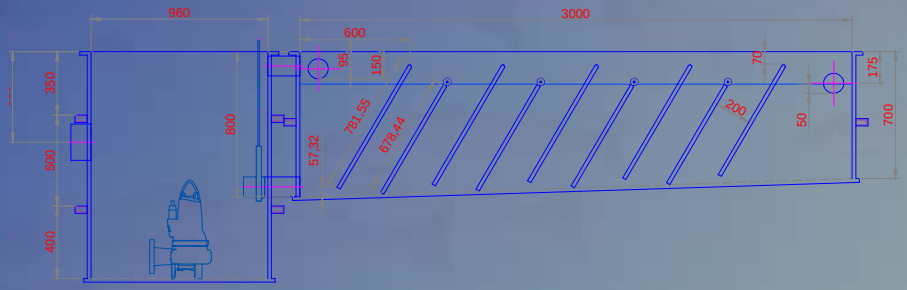
Reduction in water coming from mechanical filters



Removal of nitrate

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Nitrate removal – Moving bed:

Nitrate removal – Fixed bed:

Managing problems seen from a users point of view

- Use of external carbon (100-200 ml/kg feed)
- Inlet to filter must be with low oxygen
- Nitrite (NO_2^-) level increase in outlet from filter
- Clogging of the filter
- Discharge (outlet) from filter must be into mechanical filter

Removal of Brownish Colour

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Removal of Brownish Colour

The brownish colour is a mixture of “fine particles” and long chained macro molecules not degradable for the bacteria in the biofilter, The more intensive recirculation the more colour. The colouring of the water start to be a problem when using less than 500 liter/kg feed.

The coloring is mainly due to the fish feed:

- Raw materials (animal, blood meal, vegetable)
- Composition (Oil, Nitrogen, Phosphor, carbonhydrate)
- Digestibility (dissolved and un-dissolved waste, amount of excrements)

The brownish colour can be removed by use of ozone (5g O_3/kgfeed) and/or chemicals used for phosphor removal like ferro chloride ($FeCl_3$) and aluminum sulfate ($AlSO_4$)

Phosphor removal
&
Thickness of sludge

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Phosphor removal – solutions can be very individual

Mixer tank



Chamber 1: High turbulence → Coagulation fase

Chamber 2: Flocculation phase, small particles → bigger particles

Chamber 3: Particles ready to sediment – mixing high enough to avoid that sedimentation

Dosing: As a rule of thumb 1,4 mol iron per mol of diluted phosphor which have to be removed

In practise 120 ml $FeCl_3$ (13% iron) is used to bring the content of phosphor from 20 mg PO_4^{---}/l → 1 mg PO_4^{---}/l.

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Thickness of sludge






Polymer: High molecular organic substance, positive, negative or neutral loaded

Dosing: 5 gram per kg Dry Matter (DM)

In practice when using 100 – 150 mg $FeCl_3$ an addition equal to 0,5 mg polymer/l is used

Dry matter (DM) up to 20% can be achieved

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Storage of wastewater and sludge

7. Managing a RAS

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Success for farming fish in Re-circulation is a combination of the following ”Cocktail”

- Economic attractive
- Well tested and proven design
- Equipment of high standard
- Well education staff
- Good management

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Managing a RAS:

Moving from traditional fish farming to RAS significantly changes the daily routines and skills necessary for managing the farm. The fish farmer has now become a manager of both fish and water, and the task of managing the water and maintaining it's quality has become just as important, if not more so, than the job of looking after the fish.

The traditional pattern of doing a good day's job on the fish farm and then going home has changed into tuning a machine that runs constantly 24 hours a day!!

This require full focus on the daily routines. The most important routines and working procedures are the following:

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Daily routines

1. Visually examine the behaviour of the fish
2. Visually examine the water quality (transparency/turbidity)
3. Check hydrodynamics (flow) in tanks
4. Search for “dead water” in system and take precautions
5. Check filter sumps – no sludge must be observed
6. Check distribution of feed from feeding machines
7. Remove and register dead fish
8. Flush outlet from tanks if fitted with stand-pipes
9. Wipe of membranes of oxygen probes
10. Registration of actual oxygen concentration in tanks
11. Check water levels in pump sumps
12. Check nozzles spraying on mechanical filters
13. Registration of temperature
14. Measuring of water chemistry (ammonium/ammonia, nitrite, nitrate, pH
15. Registration of volume of new water used
16. Check pressure in oxygen cones
17. Check $NaOH/Ca(OH)_2$ for pH regulation
18. Register electricity (kWh) used
19. Read information from colleagues
20. Switch on the alarm system before leaving the farm

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Weekly or monthly

1. Clean the biological filters according to experience
2. Drain condense water from compressor
3. Check amount of remaining oxygen in oxygen tank
4. Calibration of pH-meter (stationary and handy)
5. Calibration of oxygen probes (stationary and handy)
6. Calibration of feeders
7. Check alarm systems – make alarm test
8. Check that emergency oxygen works in all tanks
9. Check all pumps and motors for failure or dissonance
10. Check emergency generators and make a test-start
11. Check ventilation in trickling filters
12. Grease the filter elements and bearings on mechanical filters
13. Rinse nozzles on mechanical filter

6-12 month

1. Clean UV sterilizer, change lamps yearly
2. Change oil and oil-filter and air-filter on compressor
3. Renew electrolyte, zinc and membrane in in oxygen probes.
4. Renew pH electrodes

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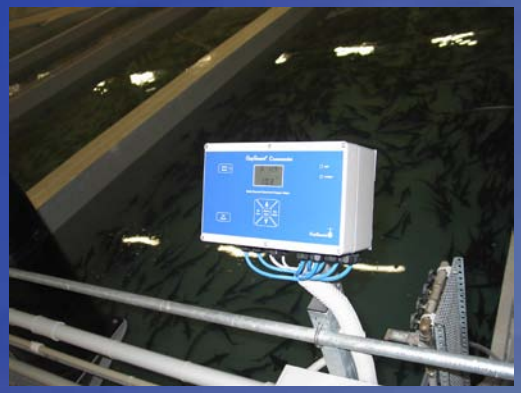
PC Monitoring and Surveillance - 1






Billund Aquaculture

PC Monitoring and Surveillance - 2



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Water chemistry

Parameter	Formula	Unit	Normal	Unfavourable Level
Temperature		^{O}C	16	>19
Oxygen	O_2	%	70-100	< 70 and > 140
Nitrogen	N_2	%	80-100	> 101
Carbon Dioxide	CO_2	mg/l	10-20	> 20
Ammonium	NH_4^+	mg/l	0-2,5 (pH dependence)	> 2,5
Ammonia	NH_3	mg/l	< 0,0125	> 0,0125
Nitrite	NO_2^-	mg/l	0-0,5	> 0,5
Nitrate	NO_3^-	mg/l	100-300	>500
pH			6,5-7,5	< 6,2 and > 8,0
Alkalinity		mmol/l	1-5	< 1
Phosphorus	PO_4^{3-}	mg/l	-	-
Suspended Solids	SS	mg/l	10-20	> 100
COD	COD	mg/L	25-100	-
BOD	BOD	mg/L	5-20	> 50
Iron	Fe^{++}	mg/L	< 0,5	> 0,5

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Water chemistry

Ammonium/ammonia

Nitrite/Nitrate

Alkalinity

Formalin

Oxygen

pH

CO_2

8. Trends within the RAS business seen from Billund Aquaculture point of view

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Trends within the RAS business:

- Salmon
  - Smolt systems up to 200 – 500 gram per fish
  - Broodstock systems
  - Grow-Out Systems for 2.500 - 5.000 tons per year of 4-5 kg salmon
- Trout
  - 3 – 6.000 tons systems
- Sturgeon
  - Meat & Caviar
  - Restocking
- Specialities

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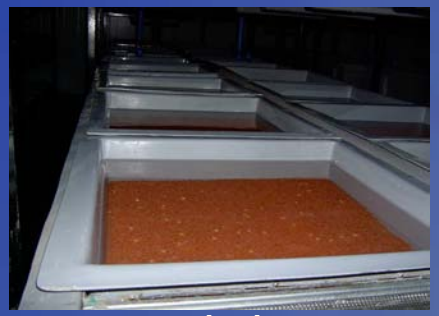
Grow-Out Systems: Example 2.500 tonnes 4-5 kg salmon

Broodstock



Incubation

Hatchery

Fry

Smolt

Grow-out

Harvest

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