This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773330

Valorization of aquaculture side streams
treatment of dissolved matter in wastewater

Christian Bruckner, Martiña Ferreira Novio, Johan Johansen & Hallstein Baarset

Welcome to the third part of this unit on the valorisation of aquaculture side streams, prepared by Christian Bruckner, Martiña Ferreira Novio, Johan Johansen & Hallstein Baarset. In part 3 we look in more detail at the treatment of dissolved matter in wastewater.

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Aquaculture side streams – dissolved matter

- Besides, particulate matter aquaculture wastewater contains dissolved substances as e.g. nitrogen and phosphorous compounds.
- Technologies to remove dissolved substances are based on filtration of wastewater, either supplemented with coagulants or treated with sono-electro flocculation, to precipitate dissolved matter.
- Another possibility to extract dissolved matter, particularly nitrogen and phosphorus containing compounds, is the cultivation of seaweeds in aquaculture wastewaters.

Salten Havbrukspark

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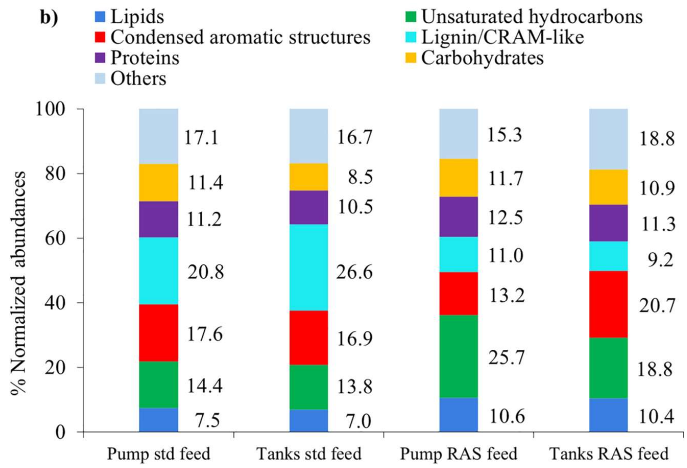
Composition of dissolved matter in recirculating aquaculture systems

Typical range values of organic and inorganic dissolved matter in RAS (mg/l)	
N-NO_3^-	2-55
N-NH_4^+	0.1-5
P-PO_4^{3-}	0.3-5
COD	20-70



Major biochemical classes of low molecular-weight organic compounds in the DOM in a salmon RAS

Aguilar-Alarcón et al. 2020. Science of the Total Environment, 749

This slide contains an overview over the most important dissolved substances in aquaculture wastewater.

Dissolved matter in Recirculated Aquaculture Systems (RAS) consists of both inorganic and organic compounds. The main Inorganic compounds are ammonia and phosphorus, released by animal excretions and uneaten feed, and nitrate which is the result of the bacterial oxidation of ammonia. Organic compounds are also released from faeces and feed. Different types of molecules can be found in the dissolved organic matter. The concentration of each type of substance varies among systems and species, but this slide shows some typical ranges.

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Recycling dissolved matter in recirculating aquaculture systems

- Biofloc technology

- Aquaponics (freshwater)

- IMTA

- Precipitation enhanced filtration

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Dissolved matter can be removed from RAS via water exchange, but there are options to use it as a side stream in circular processes as a way to use nutrients to increase the production of biomass from an aquaculture system. The most important technologies to remove dissolved matter from aquaculture waste water include:

- Biofloc technology
- Aquaponics (freshwater)
- IMTA
- Precipitation enhanced filtration

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Biofloc technology

In biofloc systems, dissolved and particulate matter are not removed from the water, but they are used to promote the growth of bacteria and microalgae, which aggregate to form flocs.

These flocs are an additional source of feed for the cultivated organisms.

Only omnivorous species with high tolerance to particulate organic matter can be reared in biofloc systems (e.g. tilapia, shrimp).

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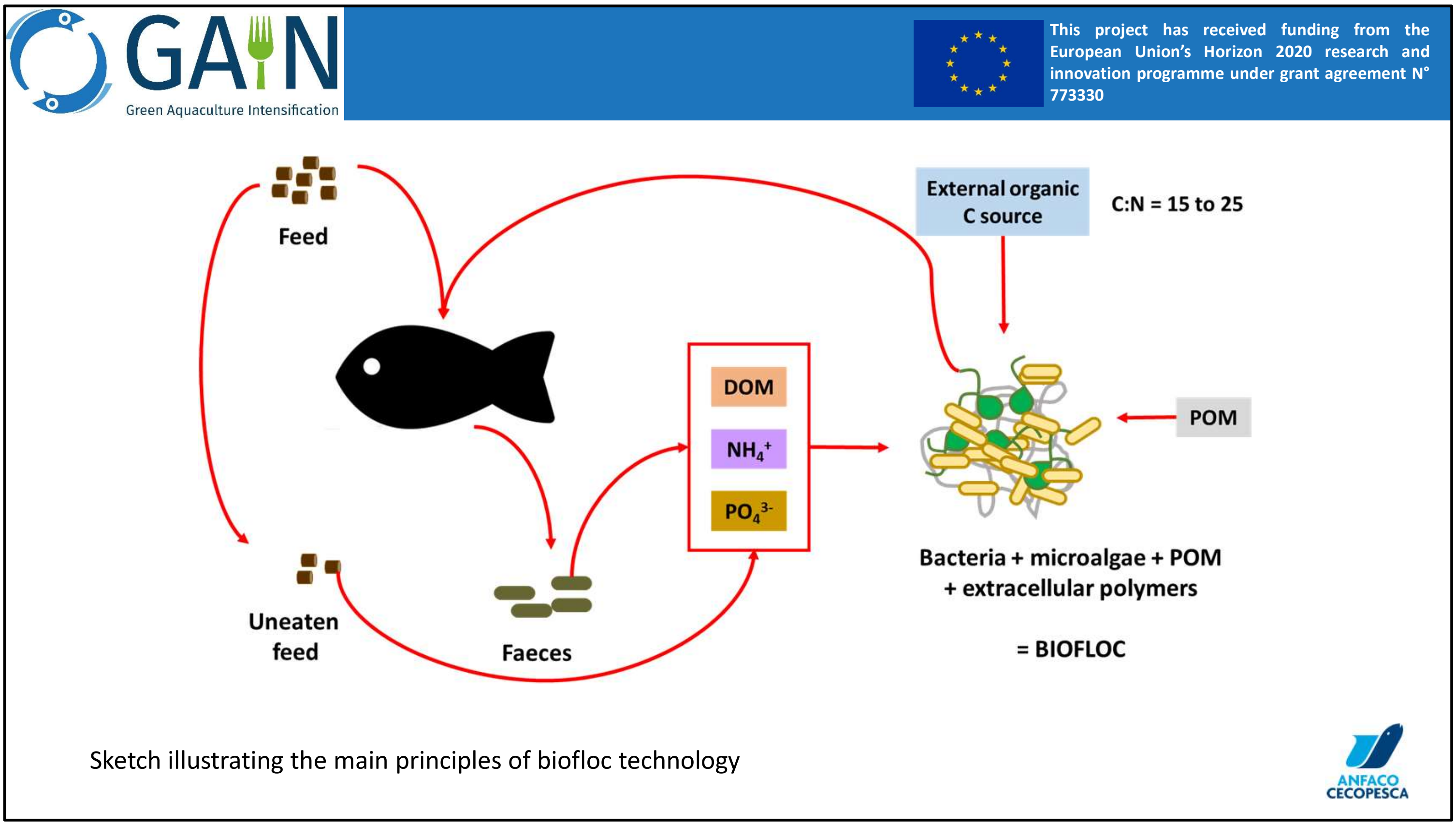
The production of microbial biomass aggregated in bioflocs, which is eventually consumed by fish or shrimp increases the efficiency of Nitrogen and Phosphate utilisation from the feeds, particularly that of protein, since Nitrogen excreted by the animals as ammonia (NH_4^+ and toxic NH_3) is transformed into microbial biomass and eaten. This enables the supply of external feed to the system to be reduced.

Biofloc technology is used in tropical areas, where tilapias and shrimp are cultured, and where temperatures are warm to sustain high growth of heterotrophic bacteria.



Sketch illustrating the main principles of biofloc technology

Bioflocs are composed mostly of heterotrophic bacteria. These bacteria, in the presence of enough Carbon, are able to uptake ammonium (NH_4^+) as a substrate for the synthesis of proteins. This removal of NH_4^+ is much faster than nitrification and is a net removal of inorganic Nitrogen from the water, unlike nitrification which converts NH_4^+ to NO_3^- (nitrate) which remains in the water and has to be washed out through water exchange. NH_4^+ is also taken up by microalgae, although these grow more slowly than heterotrophic bacteria. Phosphate is mostly removed both by microalgae and by adsorption to particulate matter.

In order to promote the growth of heterotrophic bacteria, a source of organic Carbon must be added to the water, in order to keep Carbon to Nitrogen ratios around 20. A cheap source, such as cassava, molasses, wheat bran or even straw is commonly used. A good aeration rate is also necessary to supply the whole system with enough oxygen both for fish/shrimp and heterotrophic bacteria.

If the nutrient supply to nutrient removal to bacterial growth is well balanced, NH_4^+ is fully removed from the water and the need for exchange is nearly zero.

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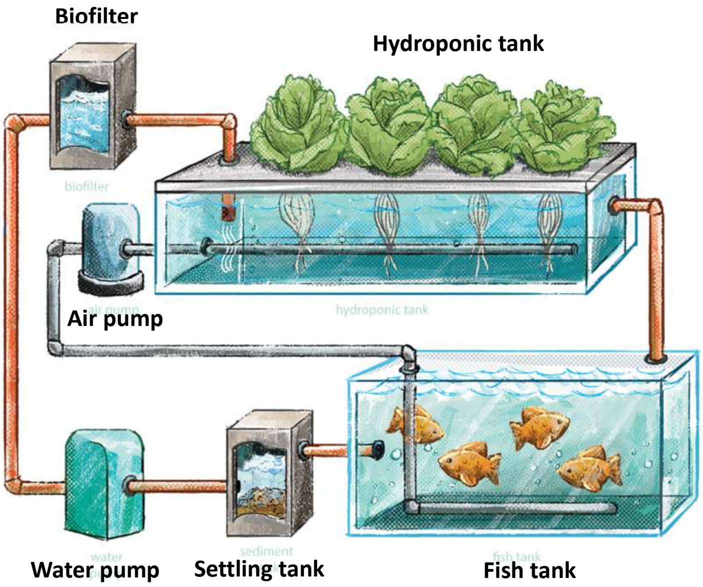
Aquaponics

In aquaponics, aquaculture is coupled to hydroponics. Plants are cultivated soilless in the effluent from the fish tanks and take up dissolved N and P from fish excreta and uneaten feed.

Plants are placed in holes made in pipes or in foam materials, so that roots float free in the water, or in inert media such as clay pellets.

Water is recirculated between the fish tanks and the hydroponic tanks.



https://ag.purdue.edu/envision/the-big-idea-hydroponics-aquaponics/

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Aquaponic systems operate in recirculation: water from fish tanks is pumped through the hydroponic tanks. A settling tank allows particulate matter, which cannot be taken up by the plants, to be sedimented out of the circuit. A biofilter is necessary for nitrification to occur and oxidise ammonium (NH_4^+) and toxic ammonia (NH_3) to nitrate (NO_3^-) which is taken up by the plants. If plants are cultivated in clay pellets, nitrifying bacteria may grow on the same pellets, thus making a separate biofilter unnecessary.

The major drawback of hydroponics is that it is a technology that has not reached economic maturity yet. Dimensioning is also an issue in terms of balancing production of fish and plants.

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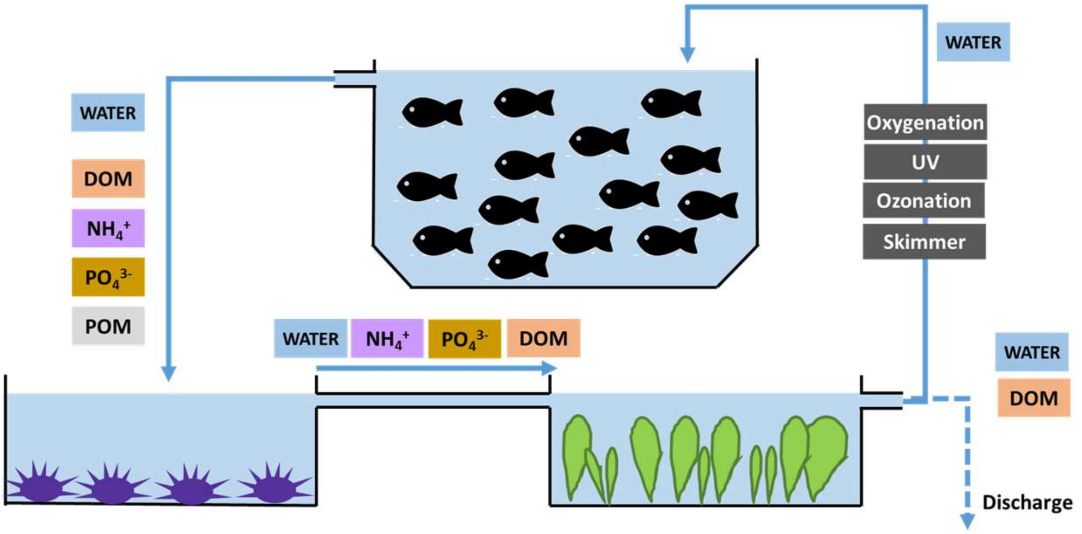
Integrated Multi-trophic Aquaculture (IMTA)



Sketch illustrating the main principles aquaponics in an IMTA system.

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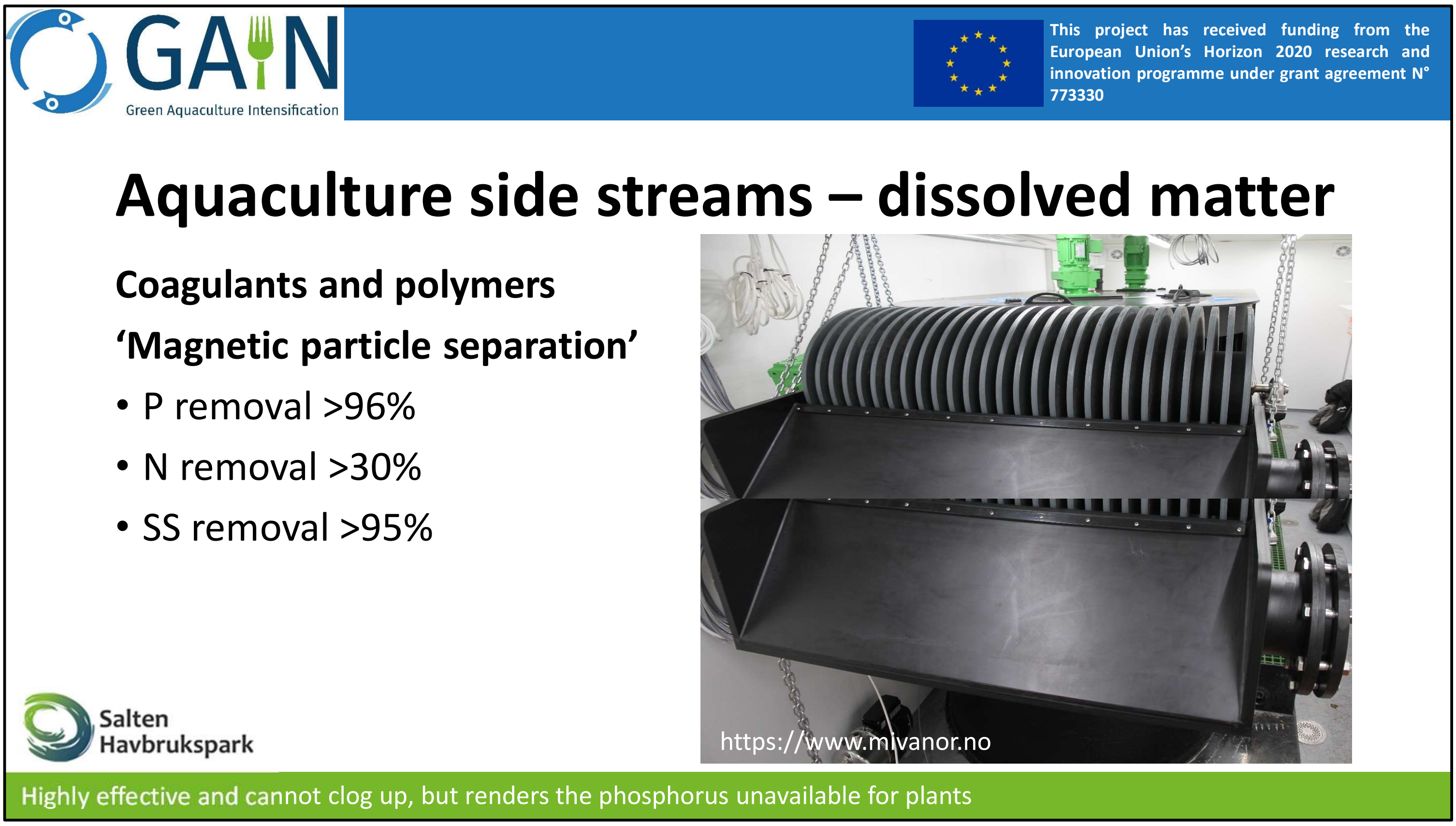
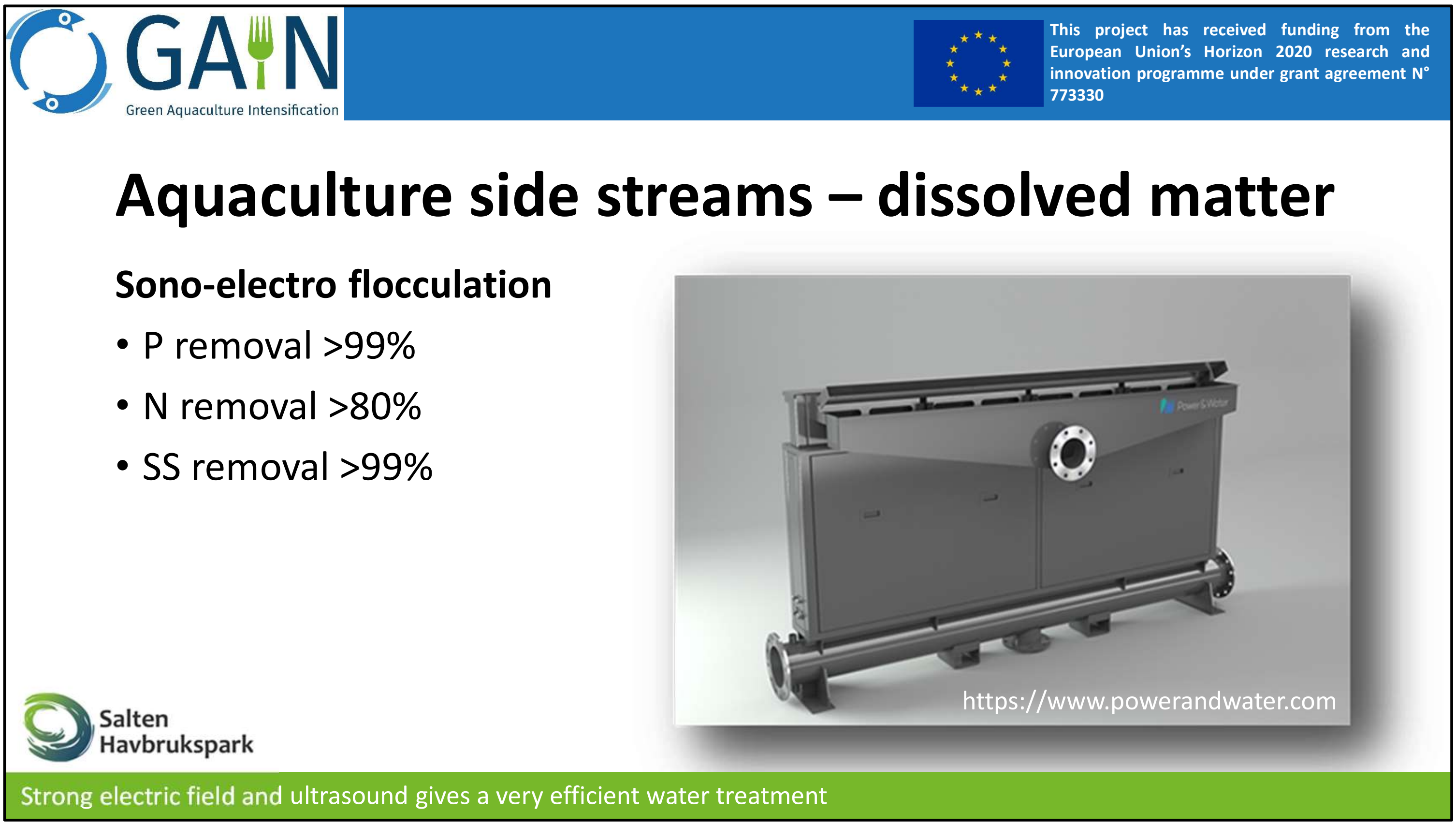
Land-based IMTA may integrate fish or shrimp (known as fed species), a filter feeder (e.g. bivalves) or detritivore feeder (e.g. echinoderms), and seaweeds. Filter and detritivore feeders are called organic extractive feeders and seaweeds are called inorganic extractive feeders, since they thrive on particulate organic matter (POM) and inorganic Nitrogen and Phosphorus respectively.

Water is circulated from the fish tanks to the secondary species tank, where POM and/or ammonia + phosphate are removed. Dissolved organic matter (DOM) probably passes through the whole system and must be removed by skimming and ozonation before returning the water to the fish tanks in a Recirculated Aquaculture System. In flow-through systems, water may be discharged after passing through the extractive feeder tanks.



In this system, an iron containing powder is added to the waste water and the pollutants are pulled out together with the iron using magnets. The efficiency is:

- Phosphorus removal >96%,
- Nitrogen removal >30%,
- Suspended Solids removal >95%



Sono-electro flocculation is a combination of electrochemical and ultrasound technology to precipitate dissolved substances. The Efficiency is:

- Phosphorus removal >99%,
- Nitrogen removal >80%,
- Suspended Solids removal >99%

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Aquaculture side streams – dissolved matter

Seaweed cultivation in aquaculture waste water may be used to remove dissolved nitrogen and phosphorous compounds from aquaculture wastewater.

- Small, fast growing seaweeds with a certain freshwater tolerance (red-/greenalgae) are well suited aquaponics candidates.
- Together with the Thuenen institute, Germany, results from *Ulva lactuca* aquaponics pilot scale experiments were used to estimate bioremediation efficiency and economic viability of *U. lactuca* production in a downstream production system of a smolt RAS system (1300 t annual salmon production) in Nordland, Norway. Such an aquaponic system, using a mix of smolt waste water (30%) and seawater (70%) as growth medium, consists of a total area of 15.6 ha, including 9.9 ha tanks, ordered in rows of 10 tanks each (33m length, 1.5m width, 0.2 m depth) and 5.7 ha concrete paths/manoeuvring area.
- Given the light conditions in Northern Norway we expect the production plant to be in full productivity for 6 months per year (0.39 – 0.41 t (DW) d^{-1}), whereas 4 months have 30 % productivity (0.12 t (DW) d^{-1}) and 2 months are unproductive. The yearly productivity is therefore assumed to be 85 – 89 tons dry weight.
- This corresponds to a yearly nitrogen uptake of 2.7 – 2.8 tons and a phosphorous uptake of 0.16 – 0.17 tons. Given the waste water characteristics of the smolt producer Helgeland smolt Sundsfjord, 45 – 71 % of the nitrogen emissions and 3 – 6 % of the phosphorous emissions can be neutralised. Combined with the S3 filter nitrogen can be even neutralised completely, as well as 4 – 12 % of the phosphorous.

Salten Havbrukspark

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