8. New methods in trout farming to reduce the farm effluents – Case study in Denmark

8.1. Introduction – General description of the case study

Farming of rainbow trout (*Onchorhynchus mykiss*) has taken place in Denmark for more than 100 years and rainbow trout is the most dominant species in Danish aquaculture. The total annual production is about 33 000 tonnes of fresh water and about 7 000 tonnes in sea water corresponding to about 20 % of the Danish fishery consumption. However, the value of aquaculture production is about 25 % of the total value in the Danish fishery sector.

The Danish production of rainbow trout in fresh water takes place across about 250 farms. Of these, some 200 farms are run as traditional flow through systems as they have been run for decades with intake of water from a weir and with relatively limited use of energy consuming equipment (pumps etc.). The water passes through the farm by gravity and finally to a sedimentation basin (sedimentation of particulate matter) before it is returned to the watercourse. Until the 1980's the Danish production of rainbow trout in fresh water was generally without any waste water treatment.

Following increased public concern on environmental issues, such as the nutrient discharge from trout farms or the hindering of the fauna mobility along the watercourses through the weirs, a new environmental legislation was brought into force in 1989 in Denmark. Accordingly, each trout farmer was given a restricted feed quota and the quality of the feed was required to fulfil certain specifications. It became compulsory for all trout farms to construct a settling basin for removal of particulate organic matter and nutrients before water was led back to the watercourse. Farmers were also required to follow a water sampling programme in order to provide documentation of their approximate discharge of nutrients.

To adapt to this legislation a proportion of the traditional farms developed more technologically advanced farms applying various methods of water purification, reuse of water, aeration, oxygenation etc. Furthermore, a significant development took place developing efficient feeds with high nutrient utilisation, feeding technology, water treatment, reduced water intake and farming management. As a result, the amount of fish produced per kilo of feed as well as a the amount of discharged pollutants has improved significantly.

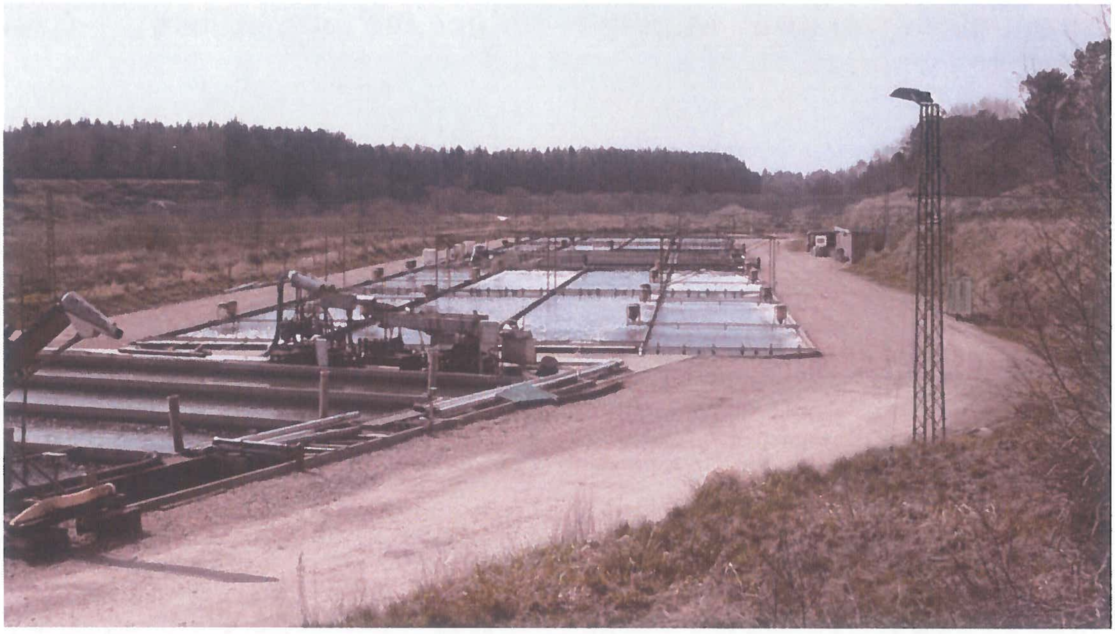
However, the environmental legislation was followed by a new legislation setting a maximum limit to the allowed intake of water from the water course. According to the legislation at least half of the water flow in the watercourse shall pass by the farm. To continue the production this legislation forces the farmers to make themselves more independent of the water course, which means to reducing the consumption of unused fresh water as well as the cleaning and re-use of water.

As a consequence of the restricted feed quotas, environmental legislation, restrictions on water intake from the water courses and EU's Water Framework Directive setting standards for water quality in the recipients, a clarification of the future conditions for trout farming in Denmark became urgently needed. During subsequent discussions between aquaculture organisations, environmental authorities and NGO's the idea of "Model fish farms" was born around the year 2000.

The model fish farm concept aims to reduce the intake of fresh water and to increase the retention of nutrients by using recirculation technology. Some of the most important parameters describing the model fish farms are summarised in Table 39 below. All data is based on the use of 100 tonnes of feed per year.

Parameter	***Model Trout Farm***
Pond material	Concrete
Water recirculation (min. %)	95
Water use (max. $l \cdot s^{-1}$)	15
Pond sludge collection	Yes
Filters for removal of particles	Yes
Bio filter	Yes
Plant lagoons	Yes

Table 39: Parameters of Danish model fish farms



A Model Trout Farm (Ejstrupholm Dambrug): In the background to the left are the plant lagoons consisting of former earthen ponds, inlet and outlet channels (Photo: DTU-Aqua)

The Model Trout Farm strategy involves significant environmental advantages, and perspectives:

- The model farms have made themselves independent of intake of water from the water courses as they catch water from drains under the production plant and/or nearby boreholes and recirculate water (up to 97% recirculation)
- The water consumption was reduced to about 0.15 l/sec/t feed or about 3 900 l per kg produced fish corresponding to 1/13 of that used in traditional flow through trout farms
- Free passage along the whole water course for the wild fauna
- A significant amount of the easy degradable substances (BOD), the total organic substances (COD), phosphorus, ammonia-N and total-N was removed by the cleaning devices inside the farm and in the plant lagoons
- Using the plant lagoons to grow commercial garden pond plants, edible crops as watercress or other species may provide a benefit as an integrated element of a model trout farm
- Stable farming conditions (water quality etc.)
- Potential increase in the trout production without corresponding increase in the environmental impact

However, implementation of the model farm technology requires extensive knowledge and experience related to:

- Biological requirements of the species to be farmed
- Extensive knowledge about the design and function of each device on the farm, e.g. mechanical filtration, bio filter, aerators, pumps etc.
- Extensive knowledge about the implications of farming fish using recirculation technology
- Skilled experience in fish farming and running systems using recirculation technology
- Adequate water quality
- High quality fish feed and feeding strategies

From an environmental as well as a commercial perspective the model fish farms are successful. Some farmers report on lower production time and, in addition to the large reduction in nutrient discharges, migration of fauna in nearby watercourses is facilitated. However, the systems need optimisation in particular with respect to lowering nitrogen discharges. Therefore, the SustainAqua Danish case study investigated different aspects/modules of the model trout farms for further optimisation:

1. Feed and feeding - Environmental impact from model trout farms
2. Energy consumption in model trout farms
3. Cultivation of pond plants in the lagoons of model farms
4. Cultivation of alternative fish species in the lagoons of model farms

8.2. *Feed and feeding - Environmental impact from model trout farms*

Feed is the most important parameter in relation to fish growth and environmental impact as well as production costs. To estimate the environmental performance of model farms it is crucial to make a precise quantification of the contribution from the feed to the production water, the so-called "contribution from production" before the water is passed on for treatment in the cleaning devices on the farm.

The different cleaning devices in operation on model farms have different cleaning efficiencies depending on the magnitude and composition of the waste components they receive. Therefore, development of an overall calculation model is required to be able to predict the environmental performance of a system in terms of waste components – nitrogen (N), phosphorus (P) and organic matter – transferred to the watercourse. The model should take relevant production parameters (feed type, amount of feed, fish production etc.), operation parameters (temperature, oxygen content etc.) and system set-up (components, flow-rates and dimensions) into account.

8.2.1. General description of the innovation

The physical form (dissolved, suspended, particulate) and chemical structure (N, P, BOD_5 [biological oxygen demand], COD [chemical oxygen demand]) of waste components can be assessed in laboratory experiments. Based on the results of these experiments a predictive laboratory based model (module of the overall calculation model) on the direct waste contribution from relevant commercial feed types applied in intensive aquaculture systems can be derived. The laboratory model is an important input for the precision of the overall calculation model.

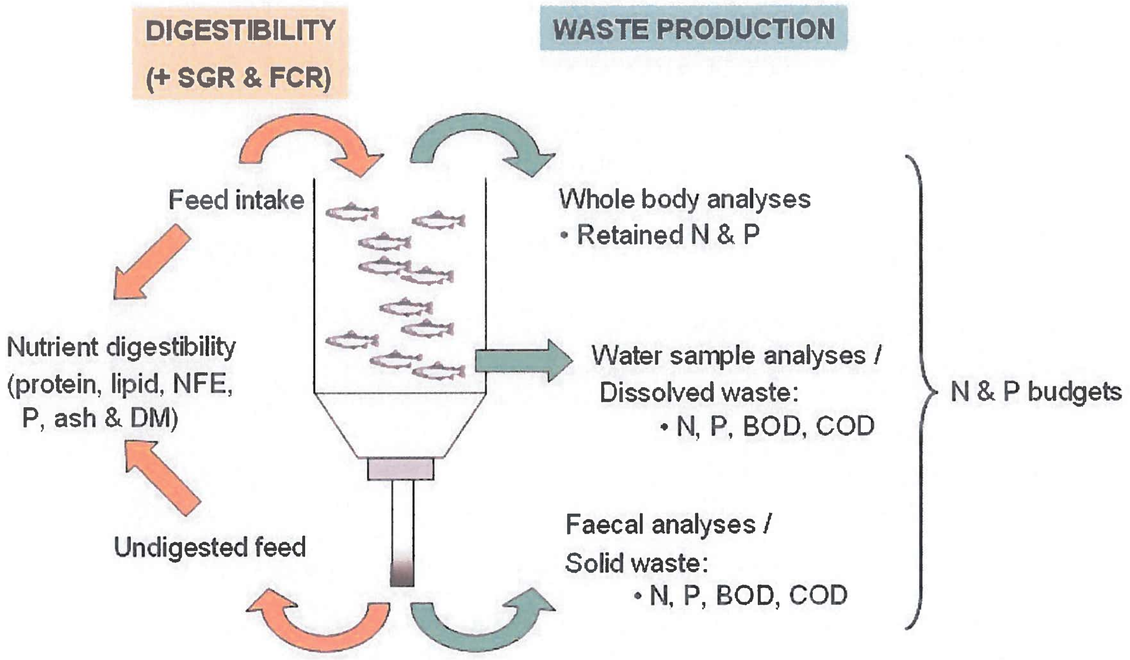


Figure 18: Set up for the assessment of the physical form and chemical structure of waste components and the direct waste contribution from relevant commercial feed types applied in intensive aquaculture systems.

8.2.2. Principles of the module

The calculation model is primarily based on data obtained through a documentation and measuring programme that was carried out at eight "model trout farms" in Denmark during 2005-2007. These model trout farms were all equipped with sludge traps, biofilters and constructed wetlands, while a few of them also had micro-sieves installed. Data for water usage, concentration of nutrients in the water at several sites within the trout farm, amounts of feed used and ingredients in feed, biomass gains etc. have been obtained from all farms and the main results have then been integrated into the overall calculation model.

Furthermore, data from traditional trout farms in Denmark (Data from By- og Landskabsstyrelsen, 2007) have been used in the model. Typically, these farms are without the facilities characterising the model trout farms, but according to Danish legislation (Bekendtgørelse om Ferskvandsdambrug) trout farms are required to have a settling basin installed immediately after the production unit(s).

By integrating data into the calculation model from both model trout farms and traditional farms with less technology, the model offers the opportunity to obtain estimates for discharges from trout farms at different technological levels. After integration of data the model has been verified and adjusted accordingly in order to correlate optimally with actual measured discharges. In this way it aimed to optimise the model as much as it was possible at the current time.

The laboratory experiments were carried out in 18 flow-through, thermoplastic tanks with a volume of 189 l. The tanks were mounted in a modified Guelph system in which the lower third of the tanks was conical and separated from the rest of the tank by a grid. This design allowed for rapid sedimentation and collection of undisturbed faecal particles in cooled, partly separated sedimentation columns.

Rainbow trout of approximately 50 g each were obtained from local Danish fish farms and transferred to DTU Aqua's research facilities in Hirtshals, Denmark. Feed consumption was recorded throughout the experiments, and faeces were collected from the sedimentation columns. The sedimentation columns were emptied daily prior to feeding, and the faecal samples were stored at -20 °C for analysis of protein, lipid, N-free extract (NFE), ash, crude fibres and P.

The three feed types used had the following average composition, as can be see in Table 40 on the right hand side:

Protein:	46.3 %
Lipid:	27.5 %
NFE:	12.6 %
Ash:	6.9 %
Crude fibres:	1.4 %
Dry matter:	94.6 %
Phosphorus:	0.98 %
Energy content:	23.8 kJ · g feed

Table 40: Composition of feed

Samples were taken for determination of the contribution of particulate N and P waste and of dissolved/suspended N and P waste, respectively. N and P retention by the fish was determined by analysing the N and P concentration in the fish at the start and at the end of the whole experiment.

A specific experiment was set up for the determination of the contribution of dissolved BOD_5 and COD waste as well as particulate BOD_5 and COD waste.

The apparent digestibility coefficient (ADC) of dietary nutrients and minerals was calculated using the following equation:

$$ADC_i = \left[\left(consumed_i - excreted_i\right)/consumed_i\right] \times 100 \qquad \text{eq. 1}$$

where *i* was the percentage of protein, lipid, NFE, P, ash or DM.

The specific growth rate (SGR, % d^{-1}) was calculated based on the biomass gain in the tanks, assuming that the juvenile fish grew exponentially within the relatively short, experimental period:

$$SGR = Ln\left(W(t_i)/W(t_0)\right)/\left(t_i - t_0\right) \times 100 \qquad \text{eq. 2}$$

where $W(t_i)$ and $W(t_0)$ were the biomass at the end (t_i) and at the start (t_0) of the trial, and (t_i - t_0) was the duration of the trial in days.

The feed conversion ratio (FCR, g g^{-1}) was calculated based on the biomass gain in the tanks, the feed amount administered and the registered feed waste during the 9 days of feeding according to:

$$FCR = feed\ consumed\ \left(t_i - t_0\right)/biomass\ gain\ \left(t_i - t_0\right) \qquad \text{eq. 3}$$

The data were subjected to one-way ANOVA analysis using Sigma Stat for Windows Version 3.10. The Holm-Sidak Test was used for pair wise comparisons where dietary treatments were significantly different. A probability of $P < 0.05$ was considered as significant in all analyses.

8.2.3. Assessment of selected SustainAqua sustainability indicators

Reduced nutrient discharge

The measured digestibility (ADC) was on average: Protein: 93.5 %; lipid: 91.2 %; NFE: 66.9 %; ash: 51.9 %; phosphorus: 64.2 %. The recorded specific growth rate (SGR) was on average: 1.97 % · d^{-1} and the average feed conversion ratio (FCR) was 0.76 (kg feed · kg weight gain). The retention of nitrogen and phosphorus by the fish was on average 49.1 % and 57.6 %, respectively (Table 41).

Dietary Component	BioMar Ecolife 20	Aller Aqua 576 BM XS	Dana Feed Dan-Ex2844	$F_{2,6}$	*P*
Protein	93.9 ± 0.4^a	92.8 ± 0.2^b	93.7 ± 0.3^a	10.81	0.010
Lipid	91.4 ± 0.6^{ab}	88.4 ± 1.8^a	93.7 ± 1.0^b	14.22	0.005
NFE	66.6 ± 1.1^a	67.2 ± 0.9^a	67.0 ± 1.0^a	0.36	0.711
Ash	46.7 ± 1.8^a	57.2 ± 0.4^b	51.7 ± 0.8^c	62.69	<0.0001
Phosphorus	60.9 ± 0.7^a	71.0 ± 0.9^b	60.6 ± 0.7^a	177.83	<0.0001
DM	84.7 ± 0.6^a	84.4 ± 0.5^a	85.6 ± 0.6^a	4.09	0.076
DM calculated[2]	85.7 ± 0.5	85.2 ± 0.5	86.3 ± 0.6	-	-

[1] Values within rows not sharing a common superscript letter were significantly different (ANOVA, Tukey HSD, $P < 0.05$).

[2] The digestibility of dry matter was calculated as the sum of the measured digestibility of protein, lipid, NFE and ash.

Table 41: Apparent digestibility coefficients (ADC) of protein, lipid, NFE, ash, phosphorus and dry matter (DM) (%, mean ± std. dev., n = 3) of the diets as well as the calculated digestibility of dry matter[1].

Calculations of the BOD_5 and COD contributions showed that an average of 55% of the total BOD_5 waste was recovered as dissolved/suspended waste, while an average of 45% was recovered as particulate BOD_5 waste. An average of 71% of the total COD waste was recovered in the particulate form, while 29% was recovered as dissolved/suspended COD waste, and the dissolved/suspended BOD_5/COD ratio was 0.51.

The majority of the Total N-waste was recovered as dissolved/suspended TN waste (88%), while an average of 12% was recovered in the particulate fraction. Almost all of the phosphorus P-waste was recovered as particulate waste (on average 98%), while only a very minor fraction (on average 2%) was recovered as dissolved/suspended P-waste.

8.2.4. Success factors and constraints

The results of the laboratory experiments were important inputs for the precision of the overall calculation model. By integrating data into the calculation model from both model trout farms and traditional farms with lower technology, the model offers the opportunity to obtain estimates for discharges from trout farms at different technological levels. However, it should be noticed, that the following pre-requisites prevail in order to obtain acceptable estimates upon use of the calculation model:

1. The fish species must be rainbow trout (*Oncorhynchus mykiss* Walbaum)
2. The feed used must be of good quality, i.e. contain sufficient levels of vitamins and minerals to support good growth and health and digestibility of protein and lipid must not be less than 85%.
3. If water recirculation is applied then the water must reside for at least 18.5 hours in the production unit(s) and at least 20 hours in the constructed wetland.
4. If the farm is equipped with mechanical filters (drum filters or similar) and/or bio filters, then the filters must have adequate dimensions in order to optimise water treatment.
5. The daily feed amount must not exceed 800 kg.
6. Provided that these prerequisites are fulfilled, the overall calculation model serves as a convenient tool for estimation of discharges of key nutrients from trout farms.

However, it should be emphasised that the calculation model only serves as a tool to estimate the nutrient discharges from trout farms, i.e. the model can not be used for documentation of discharges.

8.3. Energy consumption on model trout farms

The model fish farms depend on transport of water in the farm (recirculation) as well as aeration/oxygenation of the water due to the low consumption of new fresh water. Furthermore, waste gases as CO_2 and N_2 should be removed from the production water.

The most important issue in the model trout farms is the implementation of the recirculation technology, i.e. pumping water and water purification to minimise water consumption and environmental impact. This technology requires energy input and as such energy is an important parameter, which has to be considered for a sustainable production.

8.3.1. General description of the innovation

The pumping of water in the model trout farms as well as the injection of air/oxygen into the farming systems requires energy. Thus, it is important to evaluate the need of oxygen during the production and in accordance to this to adjust the injection level/energy consumption. The need of air/oxygen is highest during feeding and digestion of the feed, i.e. during the metabolic processes. Furthermore, the need for oxygen depends on fish size and on the standing stock.

8.3.2. Principles of the module

The current technologies for aeration of the water are:

- Basin aerator
- Low pressure diffuser
- Surface aerator
- Trickling filter
- Air lift pump

For efficient oxygenation/degassing it should be borne in mind that:

- The solubility of gases/water saturation increases with the pressure, i.e. water exposed to pressure may contain more oxygen/CO_2 than at the surface.
- The larger the contact surface between the gas- and the water phase, the quicker the gas is dissolved in the water, i.e. air bubbles created by diffusers with different sizes of holes, which in turn affects the magnitude of back pressure.

Basin aerator

Basin aerators may be designed as a simple diffuser placed about 50 cm above the bottom of a production unit with adequate proportions between length and depth of the basin to secure proper circulation.

Low pressure diffuser

A low pressure diffuser may have several diffuser tubes mounted on a steel frame. The diffuser has a relative low back pressure at moderate water depth, i.e. about 80 cm. The oxygenation efficiency is good at lower oxygen saturations and suitable for degassing due to the low depth of air injection.

Surface aerator

Surface aerators are often used on traditional farms. The water is thrown into the air, which creates a good contact surface with the air and mixing in the pond. The surface aerator is efficient to keep fish alive under low oxygen conditions and for degassing.

Trickling filter

In a trickling filter the water is pumped over a distribution grid on top of the filter. From there the water runs down through a filter media (for example. Bio-Blocks) providing a large contact surface for aeration (O_2) and degassing (N_2/CO_2). However, the trickling filter is energy demanding (pumping) due to the lift height requirement(often at least 1 m).

Airlift ("mammut pump")

The most common method of water transport and aeration in model trout farms is by using airlifts. The function of an airlift is both pumping and aeration of the water. The airlift consists of a well/hollow, equipped with a partition (Figure 19). On the one side (to the left in Figure 19) a number of diffusers are installed (injection of pressurised air by compressors). The driving force in an airlift is the difference in the specific gravity between the water and the air/water side. The design of the airlift determines as well its ability to manage the flow of air (avoid collapse) as the maximum head. Optimum head might be about 10 cm at a water depth of 2 m.

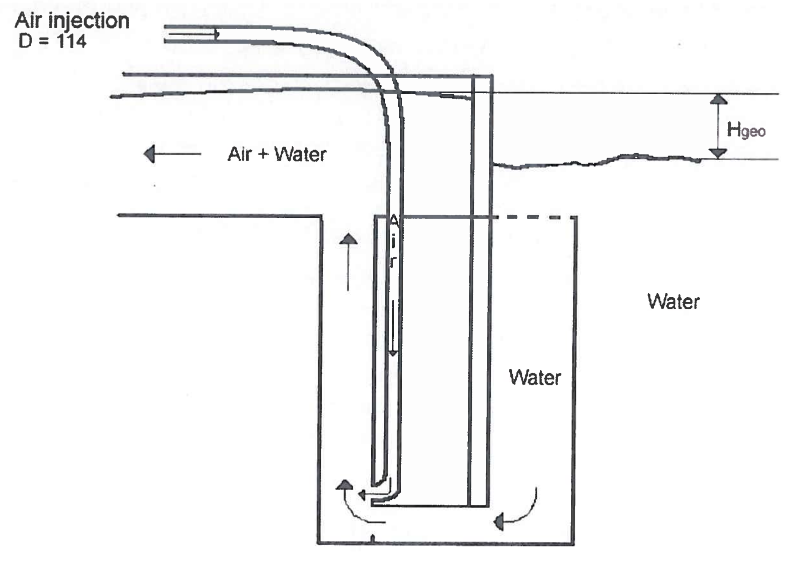


Figure 19: Sketch of the airlift (after Lokalenergi, 2008).

8.3.3. Assessment of selected SustainAqua sustainability indicators

Energy consumption

The injection of air into the farming systems is energy requiring and thus it is important to evaluate the need for air during the production and in accordance to this adjust the injection level/energy consumption. The need for air/oxygen is highest during feeding and digestion of the feed, i.e. during the metabolic processes. Further, the need for oxygen is dependent on the fish size and on the standing stock.

However, to achieve optimum utilisation of the injected air, relationships between air flow, aeration principle, choice of diffuser and water depth need to be considered so as to obtain:

- maximum contact surface between air-bubbles and water
- Air-bubbles having longest possible retention time in the water column before they reach the surface
- Lowest possible back pressure/loss of pressure in the system.

The most important factor for optimum efficiency of the airlift is the adequate relationship between the flow rate of the air and of the water. With too high an injection of air in relation to the water flow the air lift may loose efficiency, i.e. collapse. The experiments showed a direct relationship between the energy consumption and the aeration efficiency of the water. However, the energy consumption of the airlift in relation to the resulting pressure in the air delivery system needs further consideration in order to optimise the energy consumption. On average the energy consumption was estimated to 1.7 kWh/kg produced fish.

The aeration requires energy for compressing air and the coincident increase in temperature reveal a loss of energy, i.e. further energy costs. During the experiment the energy consumption by the airlift was measured to be 5 802 W for compressing the air with the addition of the energy for heating the air the total energy consumption was 10 199 W.

For comparison the corresponding energy consumption by a typical submerged propeller pump lifting the water up to 0,4 m and a total efficiency, ηtotal = 0,4 can be calculated as: Q x dp / ηtotal, where Q = 1 300 m^3/h = 0,362 m^3/s; dp = 0,25 mVs = 2 500 Pa, i.e. = 0,362 x 2 500 / 0,4 = 2 260 W.

The calculations showed that a submerged propeller pump might move the water by using only ¼ of the energy consumed by the airlift. However, using a propeller pump would require energy for aeration by an alternative method.

8.3.4. Success factors and constraints

Summarising the results of energy consumption investigations on three different model trout farms, the following can be concluded:

- Proper functioning of the airlift strongly depends on a balanced relationship between the flow rate of the air and that of the water, i.e. the rate of injection of air should be adjusted to the water flow.
- There was a linear relationship between the energy consumption by injection of the air and the resulting oxygen concentration of the water after aeration in the airlift.
- The energy costs of internal transport of water by submerged propeller pumps was 0.25 of the energy cost by using the airlift.
- Whilst, moving the water with a propeller pump is cheaper than by airlift, energy costs for aeration by another method (e.g. basin aerators) need to be added.
- A low flow of air provided more aeration efficiency related to the costs than a large air flow.
- Small air bubbles added corresponding to the target oxygen content, i.e. injection flow and long contact time between air/water are important for cost efficient aeration.
- The higher the level of air injection in the water column, the higher the air flow should be to obtain a given amount of oxygen per unit time.
- The energy costs for aeration were significantly dependent on the method of aeration, i.e. diffuser geometry.
- The loss of energy due to the significant increase in temperature by using rotary blowers should be considered.
- The cost efficient aeration process should be monitored and managed according to the current farming conditions (diurnal variation, season etc.).
- When using propeller pumps in place of airlifts the investment costs of pumps needs be considered as well as back up solutions to secure operational reliability.
- Evidently, it seemed easier to improve the energy costs of transport of water than of aeration.

8.4. Cultivation of pond plants in the lagoons of model farms

In connection to the model trout farms the former earthen ponds are often left inter-connected with the old channels and thus making up a lagoon area with wild plants.

After treatment by the cleaning devices (sludge traps, bio filters) of the farm, the water passes slowly through the lagoon area for further removal of nutrients by plants, i.e. final waste water treatment, before returning to the water course. The plant lagoons are important for the conversion of nitrate, BOD and precipitation of organic matter and phosphorus. However, the lagoons are not efficient in conversion of ammonia into nitrate. Due to the conversion of organic matter, anaerobic conditions may occur in bottom areas and favour denitrification, i.e. conversion of nitrate into gaseous nitrogen. Thus, anaerobic conditions in the plant lagoons may promote the removal of organic matter and nitrate.

8.4.1. General description of the innovation

The vegetation in the plant lagoons is of great importance for the cleaning process and has been investigated at Ejstrupholm. The main plant species observed in the plant lagoons with a degree of coverage of up to 80% at Ejstrupholm model trout farm were manna grass, lesser duckweed, water thyme, filamentous algae and water starwort.

These plants are interesting in relation to both removal of nutrients and transformation/ conversion of nutrients. Thus, the plants serve as surface area for micro organisms (biofilm) and they are involved in conversion of ammonia and uptake of dissolved nitrogen and phosphorus into the plant biomass. Finally, the plants influence the water currents and facilitate the sedimentation of particles.

However, apart from their function to reduce the environmental impacts from the trout production, the plant lagoons may meanwhile also be used for a secondary production of commercially high value plant species that might provide an additional income to the trout production. The market potential of different commercial plants as by-products of the fish industry has already been investigated.

8.4.2. Principles of the module

The main species studied were perennial garden pond plants, which apart from their potential of high nutrient absorption might obtain reasonable prices in the market. Nine species were investigated, four belonging to *Iridacaea,* one to *Butomaceae* and one to *Nymphaecea,* and Watercress (*Nasturtium officinale*), *Menyanthes trifoliata* and King cup (*Caltha palustris*). The investigations were performed at different sites of a plant lagoon at the Ejstrupholm model farm, Denmark. The sites selected were characterised by different water flow characteristics, nutrient load and water quality parameters.

Due to the dense native vegetation crowding out pond plants on the banks and in the ponds, special constructions, i.e. polystyrene floating frames, were used for growing the plants.

The floating garden method applicable on unused ponds of model trout farms (Photo: DTU-Aqua)

8.4.3. Success factors and constraints

The lagoons (constructed wetlands) represent a good potential to reduce nutrient discharges from the fish farm. Thus, the removal of total nitrogen was greater than 1 g per m^2 per day. However, the residence time of the water in the lagoons is important for the efficiency of removing nutrients.

The study showed that the natural vegetation in an established plant lagoon creates problems for the test plants to establish within ponds and channels as well as on the banks. Thus, it requires initially a lot of manual weeding for plants to establish. The sump plants of the *Iris* family are quite tolerant, hardy and quite easy to grow, but even these were initially crowded out by more fast growing species on the slopes and banks of the plant lagoons.

Additionally, a substantial part of the plants (rhizomes) were predated by water voles.

The plant species Watercress (*Nasturtium officinale*), *Menyanthes trifoliata* and King cup (*Caltha palustris*), which may spread fast, were grown at one of the old earthen ponds in the mid section of the plant lagoon. Some of these species survived and grew. The growth rates, however, were lower than expected, which may be related to the anaerobic conditions in the earthen ponds. One species was completely predated by water voles.

The plants studied spread easily either naturally by rhizomes or could be divided manually by division of rhizomes/ seedlings.

In addition to the vegetative reproduction the *Iris* species produced seeds. Plants grown from seeds however may have different genetic characteristics than plants multiplied by division or root shooting, which may have a negative consequence when selling due to phenotypic differences (i.e. hybrids; colour of flowers etc.)

The floating garden concept was relatively successful, and floating frames may be built into larger units covering hundreds of square meters. However, trout farms in Denmark are characterised by numerous abandoned earthen ponds, which are relatively small and narrow. Consequently, the water bodies in these areas are completely covered by natural vegetation, which may be an advantage for the nutritional retention, but renders introduction of larger units of the floating concept difficult.

In order to optimise commercial production of pond plants in the plant lagoons of the Ejstrupholm model trout farm it might be advantageous to restructure parts of the plant lagoon. This means establishing larger areas with shallow wasteland free of existing vegetation and then either use the floating garden concept or grow the plants directly in the ponds depending on the species.

Some aspects of plant pond construction should also be considered in prospective development of new farms. These considerations should also imply the combined usage of plant lagoons both for garden ponds and for a more dense and ground based vegetation like reed (*Phragmites australis*) or other repository plants. These plants may contribute to increase the low oxygen conditions in the ponds. At present most of the plant lagoons at Ejstrupholm have quite anaerobic conditions, which may reduce growth of various commercial plants. In addition to this, it should be noticed, that larger units of floating frames may hinder oxygen transport/diffusion and may create anaerobic conditions for the roots.

The study showed a good growth of some pond plant species especially belonging to *Iridacaea*, however the potential income of selling of plants may be compromised by an initial labour intensive period (weeding) and later at harvest.

8.5. Cultivation of alternative Fish Species in the lagoons of model farms

After treatment by the cleaning devices (sludge traps, bio filters) of the farm, the water passes slowly through the lagoon area for further removal of nutrients by the plants, i.e. final waste water treatment, before returning it to the water course.

8.5.1. General description of the innovation

Apart from their function to reduce the environmental impacts from the trout production, the plant lagoons may also be used for a secondary production of commercially high value juvenile fish that might provide an additional income to the trout production.

The general idea was to increase the profitability of the farm by optimising its production without harming the main trout production and the overall system operation. Furthermore, it was assumed, that new production activity should be exclusively based on the conditions prevailing in the lagoon without any external supply (e.g. feed).

8.5.2. Principles of the case study module

Extensive production of fish larvae and juveniles should be based on the natural zooplankton production in the plant lagoons. Therefore, it was initially investigated whether the zooplankton production at various sites of the lagoon was sufficient for supplying feed for the fish larvae, e.g. perch and pike-perch larvae.

Based on the results of the zooplankton sampling it was concluded that the lagoons were less suitable for rearing fish larvae. However, production of juvenile fish in e.g. net-cages (including suitable lagoon sites) might be an attractive methodology to produce various fish species to be sold for on-growing (put-and-take-lakes, aquaria etc.)

To investigate the performance of net-cages experiments were performed both in the lagoon at the Ejstrupholm model farm and at two put-and-take lakes where water quality and zooplankton production were considered more favourable for the larvae. Perch and pike-perch larvae were used for the experiments.

8.5.3. Assessment of selected SustainAqua sustainability indicators: Nutrient, water and space utilisation efficiency

The results of the zooplankton sampling during spring (larval season) showed that the plankton concentrations were highly variable and generally below the level considered necessary for fish larvae to survive and grow. Furthermore, the water quality was unstable with periods of low oxygen and occurrence of toxic hydrogen sulphide formation. Therefore, the lagoons were considered less suitable for larval rearing.

In the succeeding net-cage experiments the cages were stocked with perch and pike-perch larvae. The results showed that production of juvenile fish in the plant lagoons of Ejstrupholm model trout farm was not feasible due to low oxygen levels and a high production of thread algae in the lagoons. Aeration of the water within the net cages was not sufficient to increase oxygen content to acceptable levels.

However, the experiments in the put-and-take lakes demonstrated that fish larvae may be reared from hatching until a size of 2-3 cm (one month) in net-cages without human interference during the production.

8.6. Summary – Success factors and constraints

Summarised, the results of the Danish Model Trout Farm case study provided valuable information and tools related to:

- Reducing nutrient and organic matter loss, i.e. reducing the environmental impacts
- Optimisation of energy costs
- Sustainability of cultivating pond plants and of growing additional, alternative juvenile fish species in the lagoon areas of the Model farms.

Specifically, the following success and limiting factors can be indicated:

- Using the plant lagoons of Ejstrupholm model farm to grow juvenile fish was not feasible due to low oxygen levels and a high production of thread algae in the lagoons. However, parallel experiments in put-and-take lakes demonstrated, that fish larvae may be reared from hatching until a size of 2-3 cm in net-cages without human interference during the production period
- Proper functioning of an airlift (pump) strongly depends on a balanced relationship between the flow rate of the air and that of the water, i.e. the rate of injection of air shall be adjusted to the water flow
- The energy costs for aeration significantly depend on the method of aeration, i.e. diffuser geometry
- The loss of energy due to the significant increase in temperature by using the rotary blowers should be considered
- Cost efficient aeration processes should be monitored and managed according to the current farming conditions (diurnal variation, season etc.)
- Increased discharge of CO_2

The principles of the model trout farm concept using the recirculation technology may be generally adapted in the European aquaculture sector.

8.7. From a case study to a fish farm: How to manage a model trout farm producing 500 t fish per year (Ejstrupholm Model Trout Farm)

8.7.1. Description of the Model Fish farm

Ejstrupholm model fish farm is located at Holtum Å (watercourse) in Mid-Jutland, Denmark. The farm is constructed with two identical production units each divided into 8 sections. Figure 20 provides a sketch of the model farm.

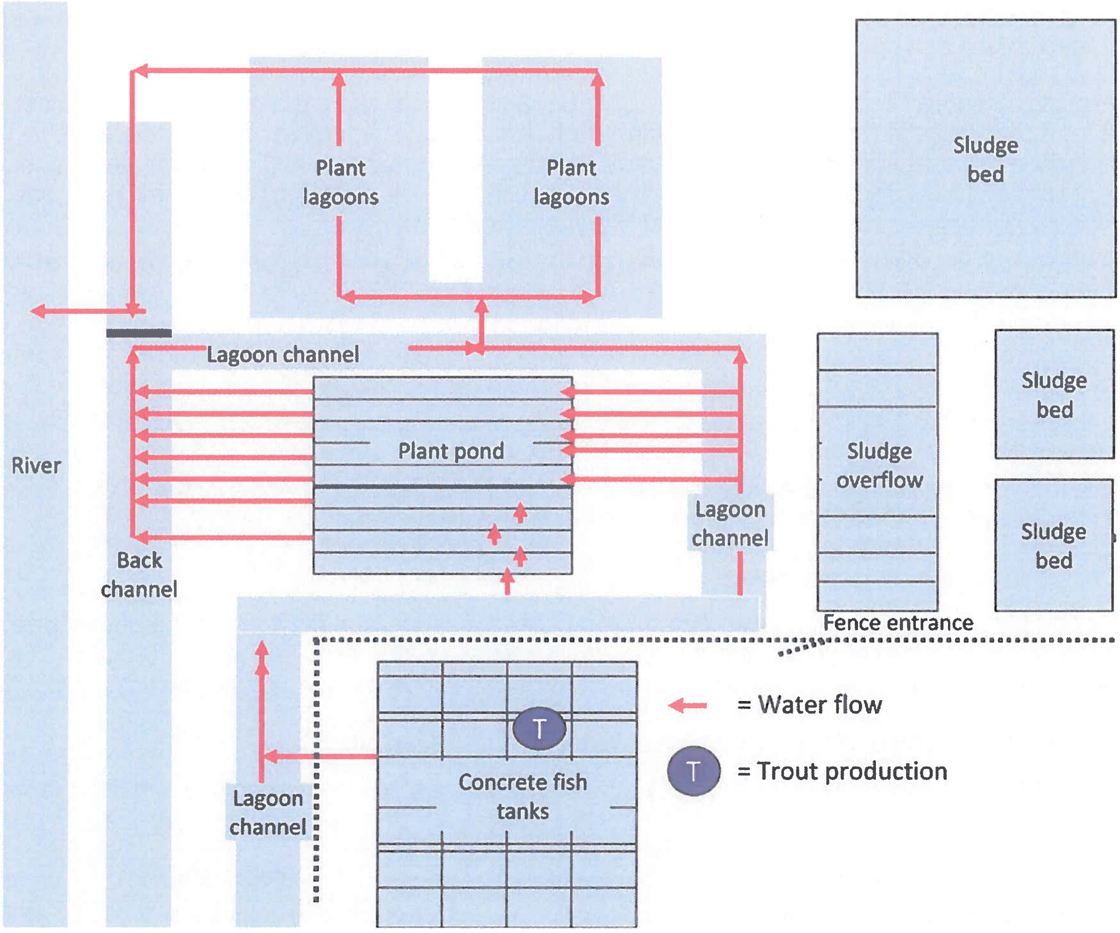


Figure 20: Sketch of Ejstrupholm Model Trout Farm. Arrows indicate direction of water flow.

The recirculation and the aeration of water is achieved by airlifts. The function of an airlift is both the pumping and aeration of water. The airlift consists of a well/hollow, equipped with a partition. On the one side of the partition, a number of diffusers are installed (injection of pressurised air by compressors). The driving force in an airlift is the difference in the specific gravity between the water and the air/water side. By a combination of the injection of air and aeration water js lifted a few centimetres and thus creating the recirculation flow.

The particulate matter from production is collected in sludge cones placed at the bottom of the production units and the sludge is pumped to sludge basins for sedimentation. The recirculated water passes through a biofilter, where the conversion of ammonia to nitrite/nitrate takes place.

The outlet water from the production units and the cleaned water from the sludge basins is passed to the plant lagoons, i.e. the former earthen ponds, which are often left inter-connected with the old channels and thus making up a lagoon area with wild plants. After treatment by the cleaning devices (sludge traps, bio filters) of the farm, the water passes slowly through the lagoon area for further removal of nutrients by the plants, i.e. final waste water treatment, before returning it to the water course.

8.7.2. Description of the farm effluents

In the table below the specific contribution from production, the net discharge and the cleaning efficiency of the cleaning devices from Ejstrupholm Model Trout Farm are compared to the average specific discharge (g nutrient per kg. produced fish) from Danish trout farms.

Nutrient	Contribution from production	Net discharge	Cleaning level, %	Average discharge Denmark	Ejstrupholm as % of avg. Denmark
Total Nitrogen	33.7	15.8	53	31.2	51
Total Phosphorus	4.3	0.39	91	2.9	13
BOD	78.7	3.2	96	93.6	3
COD	224.9	-			-

Table 42: Specific contribution from production, the net discharge (average g nutrient per kg. produced fish) and cleaning level from Ejstrupholm Model Trout Farm compared to the average specific discharge from Danish trout farms.

The results document a very high efficiency of removal of nutrients from the production water in the model trout farm. In particular, the specific discharge of phosphorus and organic matter was significantly reduced compared to the average discharge from Danish trout farms. The ammonia, phosphorus and organic matter is removed in the sludge traps and the bio filters, while the plant lagoons efficiently remove organic matter, phosphorus (especially suspended) and total-N (especially nitrate).

Calculations of the BOD_5 and COD contributions showed, that an average of 55 % of the total BOD_5 waste was recovered as dissolved/suspended waste, while an average of 45 % was recovered as particulate BOD_5 waste.

An average of 71 % of the total COD waste was recovered in the particulate form, while 29 % was recovered as dissolved/suspended COD waste, and the dissolved/suspended BOD_5/COD ratio was 0.51.

The majority of the Total N-waste was recovered as dissolved/suspended TN waste (88 %), while an average of 12 % was recovered in the particulate fraction.

Almost all of the phosphorus P-waste was recovered as particulate waste (on average 98 %), while only a very minor fraction (on average 2 %) was recovered as dissolved/suspended P-waste.

8.7.3. Water balance of the farm

The water for production is harvested from drains under the production plant and/or boreholes nearby. The water intake was about 45 l/sec. and the time of residence on the farm was about 35 hours. The energy consumption for pumping and aeration (oxygen) of the water was about 1.7 kWh/kg fish produced.

8.7.4. Pro and contra of traditional trout farms and model trout farms

Compared to traditional farming the model farm concept has the following advantages and disadvantages:

Advantages:	Disadvantages
• Water consumption reduced from about 50.000 l/kg fish to about 3.900 l/kg fish produced	• Increased need of back-up systems: Electricity, oxygen, pumps, etc.
• Independent of watercourse	• Increased discharge of CO_2
• Stable conditions for production	• Risk of accumulation of ammonia
• Minor variations in water quality	• Increased need for supervision and management
• Improved efficiency of cleaning devices	• Higher energy consumption/kg fish
• Reduced environmental impact	
• Use of water from bore hole implies less seasonal temperature variations	
• Improved control of management and production	
• Reduced external risk of infection with pathogens	
• Reduced need for medicine and therapeutics	
• Improved work environment	

Establishment costs of a Model Trout Farm as described above costs around 3 - 3,5 EURO/kg feed, i.e about 1,6 mio. EURO for a 500 ton model farm like Ejstrupholm.