Farming of Freshwater Rainbow Trout in Denmark

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1.0 PREFACE

This publication describes the current production systems and strategies for farming of rainbow trout in fresh water in Denmark. This synthesis was conducted to support the process of global certification of rainbow trout (i.e., to contribute to the international Fresh Water Trout Aquaculture Dialogue (FTAD)).

The aim of the FTAD is to develop global, measurable, performance-based, and transparent standards that minimize negative environmental and social impacts from farming of trout in fresh water and that maintain economic sustainability of trout production.

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2.0 INTRODUCTION

Rainbow trout (*Onchorhynchus mykiss*) is the most dominant species in Danish aquaculture. The total annual production of rainbow trout is about 31,000 tons in fresh water and about 9,000 tons in seawater, corresponding to about 20% of the Danish fishery for consumption. In addition, about 300 million eyed eggs are exported. The value of the production is about 40% of the total value in the Danish fishery sector (i.e., about DKK 900 million) (Fiskeridirektoratet, 2009; Fiskeridirektoratets Akvakulturregister, 2009).

Trout farms in Denmark are regulated according to the Statuary Order for Fish Farms (Dambrugsbekendtgørelsen, 1989 and an environmental approval (Environmental Protection Act Chapter 5) for each farm. The Danish governmental strategy for aquaculture (2007–2013) aims to increase the total production of fish to 115,000 tons in 2013 and simultaneously to reduce the total nitrogen discharges from aquaculture to the environment by 40% per kg fish (Ministeriet for Fødevarer, Landbrug og Fiskeri, 2006).

The Danish production of rainbow trout in fresh water is currently taking place in about 275 farms (Fiskeridirektoratets Akvakulturregister, 2009). A number of these farms are still run as traditional flow-through systems with intake of water by gravity from a weir and with relatively low use of pump energy (Figure 1). However, an increasing number are being rebuilt into more technological farms that use recirculation technology to varying degrees. Accordingly, a significant amount of the Danish production of trout in fresh water is taking place using recirculation technology (e.g., approx. 50%; Plesner, 2010).

The driving forces behind the current changes in the strategy for Danish production of rainbow trout are strict environmental legislations and the implementation of the EU Water Framework Directive, which sets water quality standards. In Denmark, this directive is implemented through the Environmental Target Act of 2003. Furthermore, with the revision of the Water Supply Law in 1995, a maximum limit to the allowed water abstraction from the water course was introduced. According to this legislation, at least half of the median minimum rate of water flow in the water course shall pass by the farm. The median minimum rate of water flow, Q_{mm}, is defined as the median of the annual lowest average diurnal water flow for typically at least a 20 year time series. These rules are designed to prevent river stretches from experiencing very low water flow conditions during the summer that result in poor in-stream environmental conditions. Furthermore, these rules state that at any dam or weir, free passage for fish and other fauna in the water course shall be secured (e.g., by establishment of a fauna passage).

The environmental conditions that must be met for fish farming include a set of requirements to be met, such as a maximum allowable annual feed consumption; an allowed intake of water (river or ground water); statistical concentration maxima (or amounts) for nutrients and organic and suspended matter in the outlet from the fish farm; oxygen saturation in the outlet; and maximum discharge of antibiotics and chemical additives. If a farmer wants to obtain a new environmental permission with higher allowable feed consumption, it may be possible implying that there will be no further, or even less, discharge to the environment. Furthermore, the maximum allowed intake of new water might be reduced. Together, the legislation and market forces have caused a lot of farmers to strengthen their water treatment practices and to re-use the water via more advanced technologies.

As a consequence of this scenario many traditional farms have been rebuilt into model fish farms using recirculation technology with lower water intake per kg fish produced as well as reduced environmental impact. In addition, a Full Recirculated Aquaculture (FREA) system is being designed and may be implemented on a commercial scale in future aquaculture production.

In the following, the production cycle of rainbow trout will be described as well as the existing Danish production systems and management strategies applied.

Figure 1. Åstruplund traditional trout farm. Photo: Lisbeth J. Plesner.

3.0 LIFE CYCLE OF RAINBOW TROUT

3.1 Brood stock and breeding

The brood stock fish (Figure 2) in Danish trout farms normally are sexually mature at the age of 3 years. However, males often are mature in their second year. The age of sexual maturity is determined by heredity as well as by the farming conditions (e.g., feeding strategy, temperature, light conditions). This means that fish reared at an above average light regime, temperature, and feeding level may become sexually mature earlier than can be genetically foreseen.

Figure 2. Brood stock rainbow trout. Photo: Alfred Jokumsen.

Because water temperature has a significant influence on the age of maturity, it might be relevant to state the age of rainbow trout in day degrees, as we do for eggs during hatching. However, day length is an even more important trigger for the timing of sexual maturation. The time of maturation may be controlled by exposing the brood stock to specific light and temperature regimes during the last months before maturation. Exposing the brood stock to increasingly longer days from January until June (18 hours light: 6 hours darkness) with temperatures increasing from 7 to 15 °C followed by 6 months with shorter and colder days (e.g., 6 hours light: 18 hours darkness) and decreasing temperatures may speed up the time of maturation by 3–4 months. The time of maturation may be delayed by using the opposite procedure.

From the perspective of production, fish with delayed maturity are preferred because mature fish exhibit aggressive behaviour (especially males), a reduced growth rate, and reduced meat quality. However, from a breeding perspective early maturation may shorten the generation interval and thus promote breeding progress.

Systematic breeding can significantly improve the profitability of production. For example, the Norwegian salmonid breeding programme has reported progress of at least 10% per generation (Gjedrem, 2000, 2004). Breeding is a kind of product development. The best performing fish in relation to the aim of product development (i.e., the breeding goal of expressing a specific hereditable trait (e.g., growth) better in the next generation) are selected as parent fish for the next generation. The obtained breeding gains in one generation are added to the progress of the next generation (i.e., compound interest). However, the observed breeding gains are due to genetic as well as environmental conditions. Therefore, breeding work focuses on hereditable factors, while environmental effects are minimized (i.e., stabile farming conditions are maintained). It is important to keep in mind that selective breeding has long-term perspectives: It may take up to 10 years before significant results of the breeding efforts are achieved.

Some Danish farmers producing eyed eggs and fry are using specific breeding schemes aimed at specific breeding goals. To identify the selected brood stock characterized by specific traits, individual fish are PIT tagged. This means that an encapsulated chip (11.5 mm long and diameter 2.2 mm) containing a unique ID number is injected into the back of a fish close to the dorsal fin using a syringe with a hypodermic needle and a piston. The number is read by a scanner that emits a magnetic field to activate the PIT tag (Figure 3).

Figure 3. Injection of a PIT tag in the fish (left); PIT tag in the lower right corner (middle); and a scanner (right). Photo: Torben Nielsen and Alfred Jokumsen.

3.2 Hatchery

Hatcheries may be flow-through systems, but an increasing number of farmers are using recirculation technology of varying designs. The hatcheries are equipped with a number of incubators, each with a number of hatching trays (Figure 4). In hatcheries using recirculation technology, the incubators generally are supplied by gravity with aerated water from a high-level reservoir (e.g., white tank in Figure 4). The water passes through the trays to a low-level reservoir, where a pump lifts the water to a trickling filter placed just above the high-level reservoir. Other specific designs exist as well. The temperature of the hatching water is kept constant at about 7 ^{o}C by a heating element controlled by a thermostat. To prevent infective agents, the water may be sterilized by UV light.

Figure 4. Hatchery with incubators in trays. Photo: Jørgen Jøker and Alfred Jokumsen.

3.2.1 Stripping and fertilization

Based on the performance (f. ex. growth rate) of the brood stock in relation to the breeding goals, the relevant specimens are identified. At farms using a breeding scheme, each brood stock fish can be identified by the PIT tag containing the unique electronic ID number. The development of eggs and sperm in the fish is followed in the weeks before stripping. It is critical for fertilization and hatching success that the stripping of eggs takes place very close to the time of maturation.

The brood stock fish must be starved for at least 14 days prior to stripping. A mature female has a steel-grey and firm abdomen and the oviduct is visible (Figure 5).
Before stripping it is essential that all utensils (hatching units, tubing, buckets, beakers, etc.) are disinfected using iodophore, Actomar K30, or a similar disinfectant. The hatchery also must be disinfected (e.g., using formaldehyde (500 ppm) for about 1 day with ventilation, followed by iodbac (0.1%) for 1 hour).

Each individual female is anaesthetized and wiped. When a breeding scheme is being used, each fish is documented (i.e., PIT tag ID number, weight, and length are recorded). The stripping procedure is as follows: The fish is held by the tail head with the left hand. The fish is held at an angle of about 45°, with the head upward and the genital opening just outside the edge of the bucket (egg container) to avoid water, mucus, or intestinal contents from entering the bucket with the eggs. The eggs are stripped from the female by pressing carefully with the right hand thumb along the abdomen and with the other fingers following along the side of the fish. The eggs exit from the genital opening and fall into the receptacle.

Figure 5. Mature females (left) and a male (right). Photo: Alfred Jokumsen.

Breeding research has shown that a so-called partly factorial mating design promotes the optimum benefits of the crossings in relation to inbreeding, diseases, etc. (Henryon et al., 2002). This design means that the sperm from one male is used to fertilize half of the eggs from each of two females, thus each female is fertilized by two males (Figure 6). Each fertilized half of the eggs from a specific female now represents one family of full sibs, as all hatching fry have one specific mother and father. The second half of the fertilized eggs represents a separate family of full sibs. However, the two families are half-sibs, as they have the same mother but two different fathers and visa versa.

This procedure is being used by an increasing number of producers of eyed eggs and fry, and it allows researchers to follow the significant differences in performance between families of rainbow trout (Jokumsen et al., 2006a) and to make the appropriate selections of families for further on-growing. The remaining farmers are using the traditional fertilization method of mixing the eggs from several females with sperm from a few males.

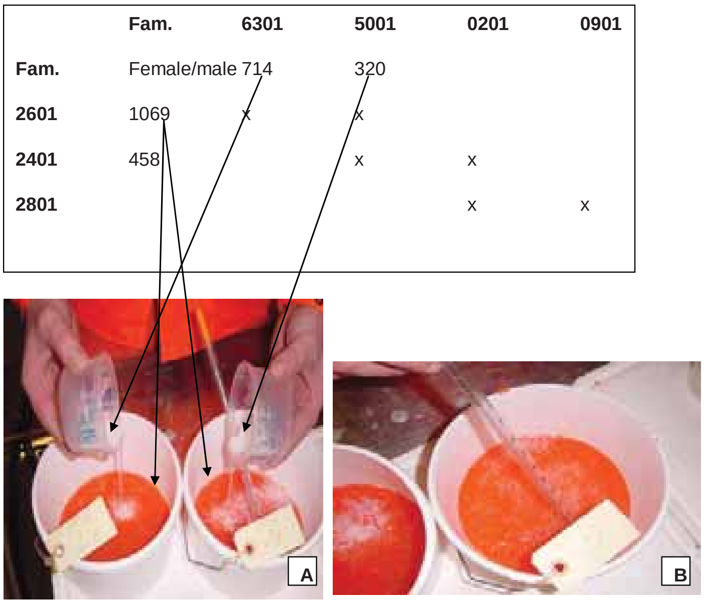
When the partly factorial design is applied, the eggs from each female are divided into two buckets (Figure 6A). The numbers of eggs/10 ml are counted. The PIT tag ID number of the female is marked on each bucket. The eggs are stored cool (4–6 ^{o}C) until fertilization. It is generally assumed that a female produces about 1500–2000 eggs/kg and about 10,000 eggs/l, depending on the size of the fish and its age. A similar procedure is followed for stripping milk (sperm) from the males. The milk is stripped into two beakers identified by PIT tag ID number (Figure 6A).

The eggs are fertilized by dry fertilization: According to the mating design, the two portions of eggs from a female are fertilized by half of the stripped milk from each of two males. The eggs are mixed with the milk (Figure 6B). Fertilization begins as soon as the milk is added to the eggs and the spermatozoa become activated and penetrate the eggs. The mixture is left for a minimum of 10 minutes at about 7 °C for the fertilization to finalise.

The fertilized eggs are rinsed carefully (preferably in physiologic saline water (0.9% salinity)) to remove surplus milk, egg shells, and other organic materials to prevent mould from growing. The eggs are left covered and undisturbed in very gentle moving fresh water for the next 1.5 hour (at 7 °C) while they are taking up water. During the water uptake period, the volume of the eggs increases by ~40%, and the eggs are very sensitive to movements/impacts during this process. For the following couple of hours, the eggs are rather robust and may be disinfected.

The specific portions of fertilized eggs (families) then are put into separate hatching trays, which each are marked with a specific family ID. The eggs are incubated at 4–9 °C, with an optimum at about 7 °C. It is critical to secure abundant water flow up through the layer of eggs. The eggs are very sensitive to light and must be protected from direct sunlight. Preferably, they should be exposed to as little light as possible (i.e., covered or use of strip light no. 82 during cleaning, etc.).

The eggs are monitored daily and the trays are lifted very carefully (2–3 cm) to create small movements around the eggs. Dead eggs are removed using a siphon. To prevent attack by fungi (e.g., *Saprolegnia*), the eggs should be treated with a fungicide (formaldehyde or similar) at regular intervals (day(s)).



	Fam.	**6301**	**5001**	**0201**	**0901**
Fam.	Female/male	714	320		
2601	1069	x	x		
2401	458		x	x	
2801				x	x

Figure 6. Partly factorial mating design: 2 portions of eggs from a selected female (no. 1069 from fam. 2601) are fertilized by milk from 2 male fish (no. 714 from family 6301 and no. 320 from family 5001, respectively) (Figure 6A). In Figure 6B the eggs and milk is mixed (dry fertilization). Photo: Alfred Jokumsen.

3.2.2 *Egg development and hatching*

Eggs of rainbow trout reach the eyed egg stage after 180–200 day degrees (i.e., 26–29 days after fertilization at 7 ^{o}C) (Figure 7). At this stage the eggs are robust and can be transferred to a container to flush away particles, dead eggs, etc. The hatching equipment is cleaned by disinfectants and thoroughly flushed before the cleaned eggs are transferred back to the trays. The eggs are treated with Actomar K30 as required and dead eggs are removed.

Figure 7. Eyed eggs in a tray and on a counting plate (left) and work at a conveyor belt for removal of dead eggs (right). Photo: Jørgen Jøker and Lisbeth J. Plesner.

The eggs hatch after about 300–350 day degrees (i.e., about 45 days after fertilization at 7 ^{o}C). During the first days after hatching, the fry are nourished by the contents of the yolk sac. When the yolk has been depleted after about 120 day degrees (about 14–20 days at 7 °C) after hatching and the mouth is fully developed, the fry swim up to inflate the swim bladder and start feeding exogenously. The fry exhibit swimming behaviour at the water surface, where they search for food. At this time, weaning with very fine dry feed (powder) can be initiated. At this stage the fry may be transferred to tanks in the fry facility and the hatching result (i.e., the survival percentage calculated as the number of swim-up fry in relation to the number of eyed eggs) may be estimated (Jokumsen et al., 2006a).

3.3 Fry

The fry facility may be a flow-through system with concrete raceways as the fish holding tanks. The water supply may be a spring, a well, or a nearby water course. However, water supplied from a spring or a bore well is preferred due to the lower risk of pathogens, the constant temperature, and the more stable supply and water quality. Some fry producers use recirculation technology to improve the production efficiency. The benefits of using recirculation technology include the possibility of higher rearing temperature and securing high and constant water quality, which can lead to better growth potential and fish health.

The fry are fed artificial granulated feed (≈ 0.5 mm) (see Section 3.5). Feeding should be initiated before the yolk sac is depleted to ensure that most fry are weaned to the dry feed. The feed is administered in excess to make sure that all fish are offered feed. The feed is administered by automatic clock feeders. It is critical that uneaten feed and faeces are removed daily to maintain hygienic conditions in the tanks. Uneaten feed and faeces are removed by vacuum or pipette or simply by the water flow.

As the fish increase in size, the pellet size and daily feed amount is adjusted accordingly (Jokumsen et al., 2006a). The fry stage lasts approximately 500 day degrees (i.e., about 10 weeks at 7 °C); by the end of this stage, the fish fry may have reached ~5 g each. At this stage the young fish are called fingerlings. During the following 2–3 months the fingerlings may grow to be about 50 g each at about 7 °C. The fingerlings may be sold from the fry and fingerling producer to production farms for on-growing to marketable size or for stocking of sea farms (when they reach ~800 g each) (Bregnballe and Jokumsen, 1985).

3.4 On-growing

Various feeding strategies are used on the farms. Some farms use computerized automatic feeding and other farms use self-demand pendulum feeders. However, the feeding strategy generally takes into consideration the specific farming conditions (e.g., water temperature, oxygen conditions, water quality).

The fish are generally fed a *restricted* amount according to a table, but it is close to *ad libitum* to optimise specific growth rate (SGR) and the feed conversion ratio (FCR).

Assuming that fish are growing exponentially, the specific growth rate (SGR) is defined as:

$$\mathrm{SGR} = (\exp((\ln W_t - \ln W_0)/(T_1 - T_0)) - 1) * 100, \qquad (1)$$

where

W_0 = biomass at the beginning of the period
W_1 = biomass at the end of the period
$T_1 - T_0$ = feeding days in the period.

The feed conversion ratio (FCR) is defined as:

$$\mathrm{FCR} = \text{feed administered (kg)/growth gain (kg)} \qquad (2)$$

According to the Danish environmental legislations, FCR must not exceed 1.0 (Dambrugs-bekendtgørelsen, 1989, 1998).

The main difference between *restricted feeding* and *ad libitum feeding* is that in restricted feeding the main focus is on the feed utilization and minimum feed loss, whereas the growth potential of the fish is the aim of *ad libitum* feeding. Restricted feeding is the most widespread strategy applied in Danish freshwater fish farms to improve the utilization of the limited feed allowances and to reduce losses to the environment (Jokumsen et al., 2006a).

When choosing the feeding strategy, it must be kept in mind that the growth in length of fish occurs in one dimension, whereas the general growth increment (meat, fat, etc.) takes place in three dimensions. For each 1 g of protein growth, 3 g of water is deposited, and fat does not bind water. This means that increased fat deposits are expected with *ad libitum* feeding (Jokumsen et al., 2006a). However, the feeding strategy used is not expected to have any influence on the ability of the fish to utilize the feed.

Most farmers currently use a computer-based feeding programme that calculates the daily feed amount per tank based on fish size, biomass, expected feed conversion, temperature, occurrence of diseases, etc.

3.5 Feed

The feed accounts for the main cost of production of rainbow trout, and therefore the feed quality and feeding strategy are of utmost importance. The feed provides the fish with energy and the required nutrients for good growth, efficient feed utilization, and good health. However, the necessary composition of the feed varies with the life stages of the fish. Furthermore, choice of the feed and the feeding strategy aims to maximize the production economy and to minimize the losses of nutrients to the environment.

The main components in the feed are protein, fat, carbohydrates, vitamins, and minerals. The quality and the composition as well as the quantitative ratio between the individual components determine the fish performance and the feed utilization. If just one of the essential nutrients (e.g., an essential amino acid) is deficient, this component will be limiting for fish growth and maybe affect fish health, the environmental impact, and ultimately the production economy.

Specific feed recipes are formulated for each life stage of the fish (fry, fingerling, on-growing, and brood stock). The choice of a specific feed type also depends on the farming conditions and the management.

Feed pellets are manufactured by extrusion. The mixture is exposed to high pressure and high temperature for a short time. This treacly mass then is pressed through the extruder nozzles to create expanded and porous pellets that may absorb relatively high amounts of oil (> 30% oil content).

The main types of fish feed are listed in Table 1, but there is no hard-and-fast boundary between designations and size categories.

Table 1. Classification of feed types with approximate composition of protein and fat and the pellet size for specific size group of fish.

Feed type	Approx. Prot./Fat content (%)	Pellet size (mm)	Fish size (g)
Starter/fry	60/14	0.5–1.5	0–10
Growing/fingerling	46/23	2.0	10–50
On-growing	43/30	3.0–9.0	50–4,000
Brood stock	50/13	9.0	1,000–4,000

According to Dambrugsbekendtgørelsen (1989), the composition of the feed must meet the following requirements:

- The gross energy content must be at least 5.8 Mcal/kg. Minimum 80% of the gross energy content must be used for the metabolism
- The nitrogen content must not exceed 9% of the dry weight of the feed
- The phosphorus content must not exceed 1.0% of the dry weight of the feed
- The content of dust must not exceed 1%.

4.0 VETERINARY HEALTH CONDITIONS

Precautions to keep the fish farm free of diseases is critical to securing fish welfare and the productivity of the farm and to reduce the risk of spreading diseases to other farms. Prevention of diseases results in reduced need for treatment with medicine and therapeutic agents and thus reduced associated environmental impact.

Specific restrictions (national as well as EU legislations) are in place for the transport of farmed fish and eggs to prevent the spread of fish diseases between EU zones or compartments that are documented to be free of specific fish diseases. All Danish areas, including the sea areas, are designated as free of the American viral disease, IHN (infectious haematopoietic necrosis). Large areas and many farms are also designated as free of the Egtved disease, VHS (viral haemorrhagic septicaemia).

An extensive national eradication programme has been conducted to stamp out VHS from Denmark, especially the big river systems (the Vejle River and Skjern River catchments in the southern half of Jutland). Selected farms with high risk of infection have been emptied of fish and disinfected. The same procedure is applied to farms where VHS is diagnosed.

Based on the EU Council directive 2006/88, a categorization system was implemented. It places specific requirements on the health status of fish in a certain category (Table 2). The Danish Veterinary and Food Administration monitors all Danish fish farms via inspections and samplings each year. Based on these inspections and analyses of the samples, each farm is categorized into one of the following groups relative to certain important diseases (Table 2 and Fødevarestyrelsen, 2009). Table 2 shows the health status of fish that may be transferred into areas of a given category.

Table 2. Health categories and legal trade routes in the EU.

Category	Status	Introducing fish from	Transfer fish to
I	Free of disease	Only category I	All
II	Supervision programme	Only category I	Category III and V
III	Undefined	Category I, II and III	Category III and V
IV	Combating programme	Only category I	Category V
V	Infected	All	Category V

4.1 Antibiotics and therapeutic agents

Intensive fish production includes the risk of infection of the fish with various diseases (bacteria, viruses, parasites, fungi, etc.). Like all animal production, antibiotics and chemical additives are commonly used in trout farming. Antibiotics are approved drugs that should be prescribed by a veterinarian and administered to the fish via the feed. Some non-medicine therapeutic substances can be used without prescription and are applied to the water to improve rearing conditions.

To prevent the incidence of bacterial fish diseases, most trout fry are vaccinated (e.g., against enteric redmouth disease (ERM)) (Bruun et al., 2007). Antibiotics inhibit or kill disease-causing bacteria in fish. Diseased fish are fed with feed coated with a specific amount of a specific antimicrobial agent prescribed by a veterinarian. A treatment of 5–10 days is normally used, but the duration depends on the type of antibiotic, the disease, and the treatment prescribed. Infected fish must not be used for consumption for a period of time after treatment with antibiotics. The duration of this waiting period depends on the specific type of antibiotic, the treatment dose, and the water temperature.

The use of antibiotics includes the risk that the pathogens will develop resistance to specific antibiotics. Some antibiotics leak from the feed into the water or are excreted by the fish. Depending on the kinetics of degradation (Pedersen et al., 2010) and the design of the fish farm, some of it may end up in the recipient. Precautions must be taken at the farm level to meet specific water quality criteria (WQC) in the receiving waters (streams, rivers, lakes).

The Danish Environmental Protection Agency has assessed the WQC for each agent based on toxicological values from the international literature. The WQC are based on a precautionary approach to ensure that no living organisms are subjected to unfavourable conditions. Using formaldehyde as an example, the WQC are defined either in terms of average discharge concentrations during treatment (10 µg/l) or a maximum acute value not to be exceeded (46 µg/l) (Pedersen, 2009).

The Danish environmental laws require that all fish farms meet specific requirements in production, water treatment, management practices, and quality of discharging water from the farm so that the farms comply with the WQC. These requirements are written down in the environmental approval given for each individual farm as a prerequisite for using antibiotics and therapeutic agents.

The total amounts of antibiotics used in Danish aquaculture between 2003 and 2008 are listed in Table 3. In terms of the production of fish, the consumption of antibiotics (2003–2008) corresponded to an average of ~50 mg antibiotics (active substance)/kg produced fish (Henriksen, 2009). Research and management actions to improve treatment procedures, improve prevention by vaccination, and increase health inspections at the farms currently are under way (Bruun et al., 2007).

Table 3. Use of antibiotics* in Danish trout farms (2003–2008). The data were collected from Vetstat (Henriksen, 2009). The figures are rounded to the nearest 100 kg. The annual fish production for these years is shown in Figure 10.

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Antibiotics (kg)	2,400	1,400	1,000	1,900	1,800	1,400

***** Amoxyline, oxolinic acid, oxytetracycline, sulphadiazine, trimethoprime, florfenicol

In the future, the use of antibiotics may be decreased by the use of probiotics as a new tool to prevent the incidence of bacterial diseases. Probiotics are bacteria that do not themselves infect the host but that may impede infections by other bacteria species. The mechanisms by which probiotics impede infections by other bacteria may involve competition for nutrients or excretion of substances that inhibit or kill the other bacteria species. The use of probiotics in feed for fish may have important environmental benefits. By reducing the risk of diseases, the necessity for medication—and thereby the risk of residues left in the environment— is reduced.

Non-medicine therapeutic agents also are used for various purposes in fish farming (e.g., water treatment against ectoparasites, disinfection, pH adjustment). Table 4 provides the official figures for the amounts of therapeutic agents used in Danish fresh water farms (excluding formaldehyde) for 2003–2005. However, because of missing data and uncertainty, these figures are only rough estimates (By- og Landskabsstyrelsen, 2009).

Table 4. Survey of fish farmers' reports on the use of chemical additives (excluding formaldehyde) in 2003–2005. The figures are rounded to the nearest 100 kg.

Therapeutic agents	2003	2004	2005
Lime (*1000 kg)	1,100	800	1,000
Copper sulphate (kg)	7,700	3,400	2,100
Chloramine-T (kg)	7,100	4,900	2,500
Hydrogen peroxide (kg)*)	5,300	7,600	2,000
Sodium carbonates (kg)	3,600	9,500	2,300
Sodium chloride (kg)	41,000	31,000	63,000

* Hydrogen Peroxide (HP) is administered as sodium per carbonate (contain 33% HP)

Official reported figures for the use of formaldehyde (2003–2008) and the corresponding figures collected by the Danish Aquaculture Organisation are given in Table 5 (Henriksen, 2009). The official data contain significant uncertainty due to reporting errors and misunderstandings (By- og Landskabsstyrelsen, 2009; Henriksen, 2009).

Table 5. Use of formaldehyde (37%) in Danish trout farms (2003–2008). The "Official stat." is the figure from the fish farmers' reports. "Danish Aqua." refers to data collected by the Danish Aquaculture Organisation (Henriksen, 2009). The figures are rounded to the nearest 100 kg.

Formaldehyde (kg)	2003	2004	2005	2006	2007	2008
Official stat.	151,000	66,000	40,000	196,000	126,000	—
Danish Aqua.	110,000	101,000	103,000	149,000	142,000	157,000

The use of formaldehyde seems to have increased over time, but the more important issue is the amount discharged to the environment. Analyses have shown that the discharge per kg fish of formaldehyde is relatively lower in type 3 model trout farms (see Section 6) than in traditional farms (Sortkjær et al., 2008). This may be due to higher degradation of formaldehyde in the model farms compared with traditional Danish fish farms. This may be especially true in the biofilter and plant lagoons that have high water residence time in the production units and in the plant lagoons (Henriksen, 2009). Formaldehyde degradation also has been documented in recirculation aquaculture systems (Pedersen et al., 2010).

Formaldehyde is a hazardous substance (a carcinogen), so its use is undesirable in light of human health and the work environments. Therefore, researchers have been exploring potential alternatives. One of these is hydrogen peroxide. Experiments to date have shown that hydrogen peroxide is rapidly degradable (half-life of a few hours) compared with formaldehyde and Chloramine-T (Bruun et al., 2007). Furthermore, a model has been developed to predict discharge concentrations of selected chemicals (Bruun et al., 2007).

Agents and additives injurious to the environment are prioritised research issues, as the goal is to minimize the use and losses of substances that are potentially harmful to the environment. The research is focused on more knowledge about vaccination and the specific agents and additives (i.e., quantifying losses, environmental fate and impact, elimination kinetics/rate of degradation, and the potential for replacing current additives with substances that have less of an environmental impact).

5.0 TRADITIONAL TROUT FARMS

Traditional trout farms use flow-through systems, in which the water is taken in via a damming of the adjacent water course and water then passes through the farm by gravity (i.e., without use of or only minor use of pump energy). Originally the ponds were dug directly into the soil of river valleys close to the stream banks (Figure 8), but some traditional farms have replaced earthen ponds with tanks built of concrete or another waterproof material.

Originally, production of rainbow trout in fresh water occurred without any wastewater treatment. Thus, the production water led directly to the water courses or lakes in which the fish farms were placed. Since the late 1980s, however, fish farms have undergone gradual but significant technological development in terms of reducing the environmental impact from trout production.

One problem inherent to traditional farms is that damming of water courses by concrete constructions (weirs) hinders fauna mobility along the water courses when no efficient fish ladder or bypass is constructed (Figure 8). In particular, this problem concerns anadromous fish species, which may be hindered in reaching their spawning sites and the sea. To facilitate their migration along the water courses, the intake of fresh water from the water courses has been reduced via implementation of various technologies (e.g., re-use of water or recirculation technology; many dams and weirs have been removed; major bypasses have been constructed (Figures 8 and 9). Furthermore, grids can be installed at both the inlet and the outlet of the trout farms to prevent intrusion of wild fauna and escapement of fish from the farms (Figures 8 and 9).

Figure 8. Bypass water passage at Løjstrup Trout Farm (left) and at Bregnholm Mølle Trout Farm with inlet and grids (right). Photo: Lisbeth J. Plesner.

In 1989, a new government order (Dambrugsbekendtgørelsen, revised in 1998) stipulated a number of rules for freshwater trout farms. All trout farms were restricted to a feed quota (the feed quotient expressed as the ratio kg feed fed/kg fish weight gain must not exceed 1.0); the quality of the feed should meet given specifications (Dambrugsbekendtgørelsen, 1989); and use of wet feed and soft pellets was banned. Furthermore, it became compulsory for all trout farms to construct a settling basin for removal of nutrients and organic and particulate matter, and farmers were required to take part in a water quality (chemistry) sampling programme (typically 2–6 samples per year in the in- and outlets) to provide documentation of their approximate discharge of nutrients (nitrogen and phosphorus) and suspended and organic matter. One consequence of the new law was that trout farmers could increase their production only by improving the feed utilization. Thus, significant developments have been made in terms of development of efficient feeds with high nutrient utilization, feeding technology (Figure 10), reduced water intake, and improved farming management (Jokumsen, 2002). Accordingly, the amount of fish produced per kg of feed improved significantly, and the relative discharge of nutrients and organic matter from the fish farms was lowered.

Figure 9. Gørklint Traditional Trout Farm with production of "gold trout". Insert the water bypass and the water inlet with grids. Photo: Lisbeth J. Plesner.

Many of the main Danish water courses (about 27,000 km) have specific environmental targets that should be met. These targets are defined by the Danish Stream Fauna Index (DVFI), which expresses the composition of invertebrate species at the bottom of the water course (Friberg et al., 2006). Thus, discharges from a fish farm and damming upstream of the farm must not hinder fulfilment of the environmental quality goals downstream from a fish farm. The conditions stated in the obligatory environmental approval from the administrative authorities for each farm are set up to ensure that this goal is achieved for each specific river stretch in a water course.

In addition to a restricted feed quota, many fish farms are regulated by statistical maximal concentrations (and/or amounts) in the outlets of nutrients and organic and suspended matter and by minimum oxygen saturation levels in water discharged from the farms. Furthermore, many other national laws and EU directives must be taken into account, such as fulfilment of the Environmental Target Act, regulations about water abstraction, protection against intake of fauna with stream water, nature protection and conservation regulations, building and construction regulations, regulations about noise and smell, use of antibiotics and chemical additives, predator control, and how to use or dispose of sludge from sedimentation ponds/basins.

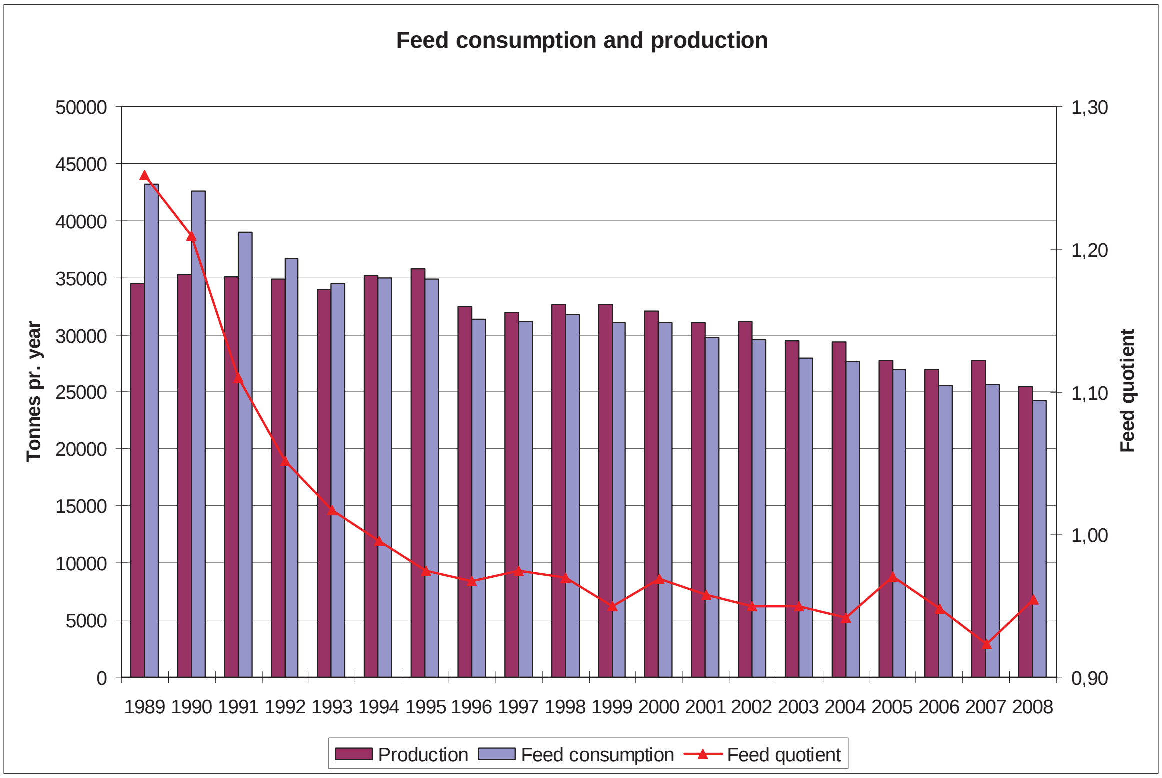


Figure 10. Development in total trout production, feed consumption, and feed quotient in Danish trout farms from 1989 to 2008. Source: By- og Landskabsstyrelsen 2009.

Taking into account local conditions, the environmental approval also includes aspects of Best Available Technology (BAT), e.g., farm construction and operating equipment, including cleaning devices, limitation of water consumption from the water course, feed composition and feeding management, process technology, oxygenation, vaccination, and use of medicine and chemical additives. In connection with achievement of the required environmental approvals, most traditional trout farms have become more technological; they use varying degrees of water cleaning treatment, re-use of water, aeration, and oxygenation to meet the requirements. No standardized techniques have been applied, as fish farmers often use locally developed solutions.

However, the framework conditions for the trout farming sector were unclear, as there was inadequate documentation of a relationship between trout farming and its direct impacts on the adjacent aquatic environment. Furthermore, there has been no documentation of the environmental effects of the different technologies applied on the fish farms. This broadly recognized fact resulted in the idea of model trout farms.

6.0 MODEL TROUT FARMS

The aims of the model fish farm were to:

- Provide documentation about the management of and environmental parameters relevant to Danish trout farms, including documentation of the specific discharge of
  - Nitrogen (ammonia, nitrate, and total nitrogen)
  - Phosphorus (dissolved and total)
  - Biochemical Oxygen Demand (BOD), which expresses the rate of oxygen uptake by micro-organisms in a sample of water at a temperature of 20 ^{0}C in the dark
  - Chemical Oxygen Demand (COD), which is a measure of the content of organic matter in water
  - Documentation and determination of the efficiencies of specific cleaning devices (micro sieves, sludge cones, biofilters, and plant lagoons)
- Reduce the intake of fresh water
- Increase the retention/transformation of organic matter and of nutrients
- Meet the environmental quality goals for the specific recipient (river, lakes, coastal areas)
- Increase the fish production without a corresponding negative environmental impact
- Facilitate administrative procedures to streamline and ease environmental approvals.

Figure 11. Ejstrupholm Model Fish Farm (type 3). The production units include two sections, each consisting of two concrete raceways. In the foreground, three concrete ponds for delivering fish are visible. In the background and to the left are the plant lagoons, which consist of the former earthen ponds overgrown with plants. Photo: Lars M. Svendsen.

Three different types of model farms were defined based on theoretical calculations of the efficiency of implementing different cleaning technologies in existing traditional farms. However, for various reasons (water abstraction, investment costs, etc.), only two types of the model trout farm were developed (Table 6, Figure 11).

Table 6. Some of the most important parameters that characterize the three types of model fish farms. All data are based on a standard module with the use of 100 tons of feed per year, a standing stock of 40 tons, an average fish size of 120 g each, and a maximum fish density of 50 kg/m^3 (Dambrugsudvalget, 2002; Modeldambrugsbekendtgørelsen, 2002).

Type of farm	**Model 1**	**Model 2**	**Model 3**
Pond material	Soil or concrete	Soil or concrete	Concrete
Water recirculation[1] (minimum %)	70	85	95
Water use (maximum l/s)	125	60	15
Fish density (maximum kg/m^3)	50	50	50
Water residence time in production unit (minimum hours)	8.9	12.3	18.5
Maximum daily feeding (kg)	800	800	800
Sludge collection in basins	Yes	Yes	Yes
Decentralized sedimentation (e.g., sludge cones)	Yes	Yes	Yes
Devices for removal of particulate matter	Yes	Yes	Yes
Biofilter	No	Yes	Yes
Plant lagoons (1440 m^2)[2]	Yes	No	Yes

[1] (Internal recirculation flow/(Internal recirculation flow + Water intake)) * 100

[2] Minimum residence time of 9 hours in plant lagoons and a maximum hydraulic load of 1 l per 48 m^2 plant lagoon; average depth 0.7–0.9 m.

In the Government Order for Model Trout Farms, which is used to regulate allowed feed consumption, removal percentages for nitrogen, phosphorus, and organic matter (BOD) were based on experiences from wastewater treatment devices in freshwater fish farms, waste water treatment plants, and theoretical considerations (Table 7).

Table 7. Assumed removal percentages (%) in the Order for Model Trout Farms for organic matter (BOD), total nitrogen, and total phosphorus (Modeldambrugs-bekendtgørelsen, 2002).

	BOD (%)	**Total nitrogen (%)**	**Total phosphorus (%)**
Traditional freshwater fish farms	20	7	20
Model trout farm, type 1	70	7	55
Model trout farm, type 2	50	15	45
Model trout farm, type 2 without micro sieves	45	11	40
Model trout farm, type 3	80	15	65
Model trout farm, type 3 without micro sieves	75	11	60

The relationship between removal percentage (R) and allowed feed consumption (F) is given by:

$$F_M = ((1-R_n)/(1-R_N))*F_T, \qquad (3)$$

where

F_M = feed allowance for a model trout farm

F_T = feed allowance according to the Statuary Order for Fish Farms (Dambrugsbekendtgørelsen, 1989) (i.e., before reconstructing a fish farm into a model trout fish farm)

R_n = removal percentages for BOD, nitrogen, and phosphorus, respectively, for a traditional trout farm

R_N = removal percentages for BOD, nitrogen, and phosphorus, respectively, for a model trout farm.

Feed allowance is regulated based on the lowest of removal percentages for BOD, nitrogen, and phosphorus, respectively.

To ensure systematic documentation of the cleaning efficiencies, a comprehensive monitoring program was conducted for a two-year period for eight type 3 model trout farms that had been recently reconstructed from traditional freshwater trout fish farms.

Balances and losses of nutrients, organic and suspended matter, removal percentages, and losses per kg produced fish, and efficiency of different water treatment devices, were thoroughly documented (Svendsen et al., 2008). During the two-year investigation period, the eight model farms participating obtained a feed allowance that was more than doubled compared with the allowance they could have obtained via the Dambrugsbekendtgørelsen (1989) because the assumed removal percentage for phosphorus was used. If they had been regulated by the assumed nitrogen removal percentage, these model farms would only have received about a 40–50% extra feed allowance compared with a traditional fish farm. However, an extra feed allowance of only 40 – 50 % was foreseen as insufficient for the trout farmers to take the risc of investment in reconstructing their fish farm. The results from the monitoring period were anticipated to be implemented in the regulation of the model farms.

Model trout farms may obtain an additional 10 ton feed allowance for each 1000 m^2 plant lagoon they establish in excess of the plant lagoon area in a standard module (Table 6). This allotment is due to the monitoring results that showed removal of 1 g nitrogen per m^2 plant lagoon per day (0.365 kg N per year) (Fjorback et al., 2003).

6.1 Model trout farm type 1

Model trout farms of this type are extensive farms with mechanical water treatment and re-use of water (maximum 1.25 l water/sec/ton feed/year; Table 6). A quite efficient internal conversion of nutrients occurs, and the stocking density is relatively low. Water treatment takes place partly by internal conversion processes and partly via sludge cones, micro sieves (or contact filters), plant lagoons, and sludge basins (cf. Table 6 and Figure 12). Biofilters are not required.

Figure 12. Bregnholm Mølle Model Trout Farm (type 1) with a micro sieve inserted in the right corner. Photo: Lisbeth J. Plesner.

Many traditional fish farms have chosen to convert into the model trout farm type 1 due to rather low costs of reconstruction and the possibility of obtaining the extra 10 tons feed per extra 1000 m^2 plant lagoons established (Figure 13).

Figure 13. Plant lagoon at Bregnholm Mølle Model Trout Farm (type 1). Photo: Lisbeth J. Plesner.

6.2 Model trout farm type 2

Model trout farms of this type are intensive farms with mechanical and biological water treatment and with lower water consumption and increased re-use of water compared to model farms type 1. In addition to the internal conversion of nutrients, water treatment occurs via sludge cones, micro sieves (voluntary), biofilters, and sludge basins, but no plant lagoons are required (Table 6). However, no Danish trout farm has been converted to this type, perhaps due to the high costs of conversion compared to the obtained increase in feed allowance.

6.3 Model trout farm type 3

The model farms type 3 represent the highest level of innovation with the lowest consumption of new water. The maximum value is 0.15 l water/sec/ton feed/year or 3,600 l per kg produced fish, but the current intake of fresh water in these model farms is significantly lower and the degree of recirculation has increased accordingly. Thus, the water intake is about a factor of 15–25 lower than the water consumption in traditional flow-through fish farms. Furthermore, type 3 model farms have the highest recirculation level (95%) and the most advanced application of recirculation technologies in the treatment of production water.

In general, type 3 model farms include the devices described in Figure 14 and Table 6.

Figure 14. Kongeåens Model Trout Farm (type 3). The production units include three sections, each consisting of two concrete raceways with micro sieves (mesh size 74 µm) in front of the biofilter sections (foreground). In the background to the left, the plant lagoons consisting of the former earthen ponds and the inlet and outlet channels are visible (Svendsen et al., 2008). Photo: Lars M. Svendsen.

In the established type 3 model farms, new water is supplied from upper ground water reservoirs (i.e., a bore hole (well), springs, or drains under or near to the production plant). This means that these farms, in principle, are completely independent of a water supply from a water course, and no weirs and dams are needed in the water course. Thus, they have no impact on the passage of wild fauna by the fish farm.

6.3.1 Ponds as concrete raceways

A typical raceway is 1–1.5 m deep and divided into sections, each equipped with sludge cones and aeration and separated by grids (Figure 15).

Figure 15. Sketch of a typical raceway at Hallundbæk Trout Farm. Photo: Søren Jøker.

6.3.2 Airlift pumps

There are two functions of the airlift pumps (also called mammoth pumps): To lift the water a few centimetres in order to induce water movement by gravity and to simultaneously aerate/degas the water. The internal water flow and the flow rate in raceways have been monitored in selected type 3 model trout fish farms and were about 400–700 l/s, and the velocity was approximately 0.06–0.10 ms^{-1} (Svendsen et al., 2008).

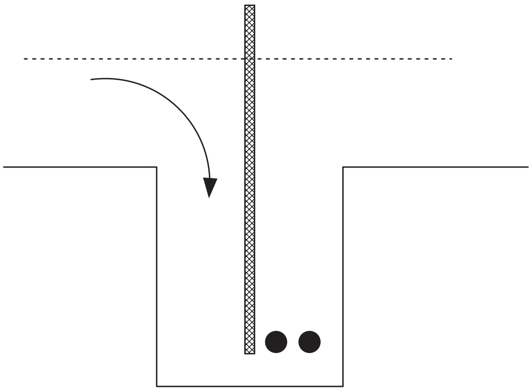


Figure 16. Sketch of an airlift/mammoth pump (Lokalenergi, 2008).

The airlift consists of a well/hollow equipped with a partition (Figure 16). On one side (to the right in Figure 16) a number of diffusers are installed, which inject pressurized atmospheric air via compressors. The driving force in an airlift is the difference in the specific gravity between the water and the air/water side. The amount of air blown into the system is determined by the required water flow and oxygen supply (Lokalenergi, 2008).
The main benefit of the airlift is its ability to move large volumes of water at a relatively low head (Lokalenergi, 2008).

6.3.3 Sludge cones, micro sieves and sludge basins

The purpose of sludge traps/cones (Figure 17) in the rear bottom of each section of the raceways is to remove particulate matter. Sludge traps quickly remove larger particles (faeces, excess feed, etc.), whereas micro sieves with mesh size ≈ 70 µm (Figure 18) are more efficient at removing fine particles. Micro sieves typically are placed at the end of each production unit just before the biofilters. Micro sieves may be installed as a supplement to the sludge traps.

Figure 17. Sludge cones are mounted at the downstream end of each raceway section across the full width of the raceway and in line with the raceway bottom. To the left, each raceway has six separate sludge cones, whereas the raceway to the right has one sludge drain along its full length, with only one discharge outlet.
Photo: Lars M. Svendsen og Lisbeth J. Plesner.

Experiences from managing sludge cones indicate the importance of emptying them regularly (at least twice per week or more and before they are filled) to optimise retention of nutrients and organic matter and to reduce leakage of dissolved nutrients and organic matter and resuspension of fine particles (Svendsen et al., 2008). The emptying process should be very short to reduce the amount of water following the sludge to the sludge basins. It might be performed automatically (via computer control) at certain intervals with a fixed, short time period or it could be triggered by a fixed degree of filling of the sludge cones. Efficient removal of organic matter during mechanical filtration is necessary for efficient functioning of the biofilters.

Figure 18. Micro sieves at Løjstrup Model Trout Farm (type 3). The micro sieves are placed just before the biofilters. Photo: Lisbeth J. Plesner.

The sludge is pumped to sludge basins/tanks for sedimentation/storage of sediments and to clear the remaining sludge water (Figure 19). High retention time in the sludge basins allows for more efficient settling of particles, which reduces the amount of nutrient and organic matter that is discharged with “cleared sludge water” from the sludge basins.

Figure 19. From the sludge cones, the sludge is transferred to sludge basins/tanks for settling of particulate matter. Left from Ejstrupholm Model Trout Farm (Photo Alfred Jokumsen) and right from Løjstrup Model Trout Farm. Photo: Lisbeth J. Plesner.

By adding a precipitant (polyaluminiumchloride or ferro iron), a major portion of the dissolved phosphorus may precipitate and settle in the sludge basins, thereby reducing losses of phosphorous from the plant lagoons. Furthermore, removal of nitrogen compounds may be improved by passing the sludge water through a biofilter before it enters the plant lagoons (Svendsen et al., 2008). In the plant lagoons the final natural removal and transformation processes is taking place. The sediment is transported as agricultural fertilizer or for production of bio gas.

6.3.4 Biofilters

The primary aim of biological filtration is to remove dissolved substances such as ammonia and dissolved organic matter, BOD, and small particles that have gotten passed the mechanical filtration. A biofilter is a medium with a large contact surface area. The biofilter may be a contact filter built of Leca or bio blocks, which also can remove organic matter (Figure 20), or a fluid filter, such as moving bed filters with several plastic beads that are kept suspended and rotating by the water flow and/or by injection of air. The surface of the biofilter medium is covered by a biofilm of autotrophic and heterotrophic bacteria, which are nourished by nutrients excreted from the fish and dissolved from the faeces. Autotrophic nitrifying bacteria convert ammonia using oxygen, whereas heterotrophic bacteria convert organic matter and also use oxygen. Therefore, adequate oxygen conditions in the biofilter are essential for optimum performance.

Figure 20. Biofilter divided into sections with bio blocks at Ejstrupholm Model trout farm (type 3). To the right of the biofilters is an ochre device for aeration of the abstracted ground water and precipitation of the ochre before the water enters the production units. Photo: Alfred Jokumsen.

In principle, two biological processes take place in the biofilters. Both processes are aerobic and thus require adequate oxygen (Figure 21):

1) Removal of organic matter by heterotrophic bacteria:

$$\text{Organic matter} + O_2 \rightarrow \text{Biomass (sludge)} + CO_2 + H_2O$$

2) Removal of ammonia by autotrophic bacteria by nitrification; this includes two processes (oxidation of ammonium (NH_4^+) and oxidation of nitrite (NO_2^-)):

$$NH_4^+ + O_2 + HCO_3^- \text{(alkalinity)} \rightarrow NO_2^- + CO_2 + H^+ + H_2O$$
$$NO_2^- + O_2 + HCO_3^- \text{(alkalinity)} \rightarrow NO_3^- + CO_2 + H^+ + H_2O$$

Using inorganic carbon for bacterial growth requires more energy than using organic carbon. Therefore, it takes much longer to activate an autotrophic biofilter (4–6 weeks) compared to a heterotrophic biofilter (a few days). As the heterotrophic bacteria grow much more quickly than the autotrophic bacteria, when adequate organic carbon is present a thick covering of heterotrophic bacteria may grow on the biofilter media (Janning, 2010). Given the fact that both processes are oxygen consuming, optimum performance of the biofilters is contingent on adequate oxygen conditions.

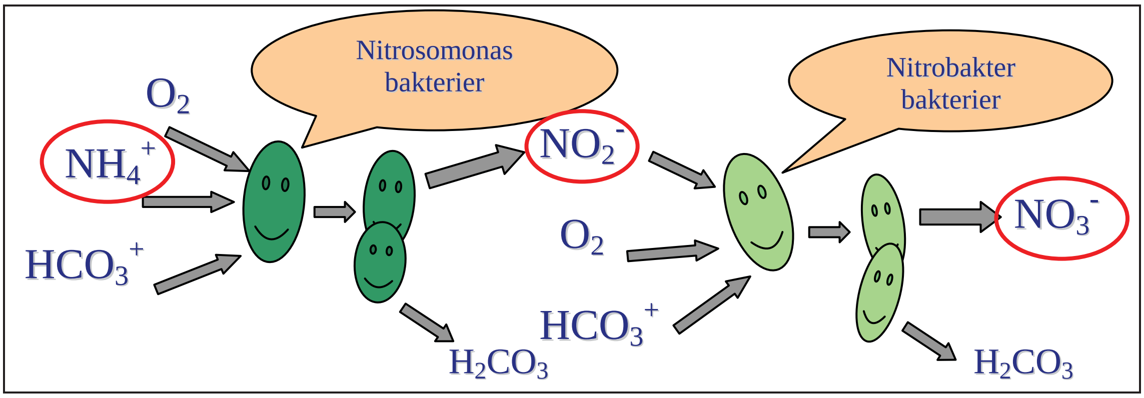


Figure 21. The nitrification process, which is executed by two groups of bacteria. (Janning, 2010).

The nitrification process is base consuming, and acid is produced. In addition, CO_2 is produced by the heterotrophic conversion of organic matter, which leads to a drop in pH. Accordingly, to stabilize pH a base must be added (e.g.,. $NaHCO_3$). Alkalinity, pH, water temperature, concentration of oxygen, nutrient compounds, and organic matter should be monitored and controlled on a daily basis in order to optimise nitrification and transformation of organic matter in the biofilter.

Regularly flushing of the biofilter is important to optimise nitrification. Flushing mainly removes oxygen-consuming heterotrophic bacteria, which may impede the nitrification process, and other particles that reduce the flow through the biofilter. Flushing helps maintaining an optimum balance between the two groups of bacteria (Figure 22).

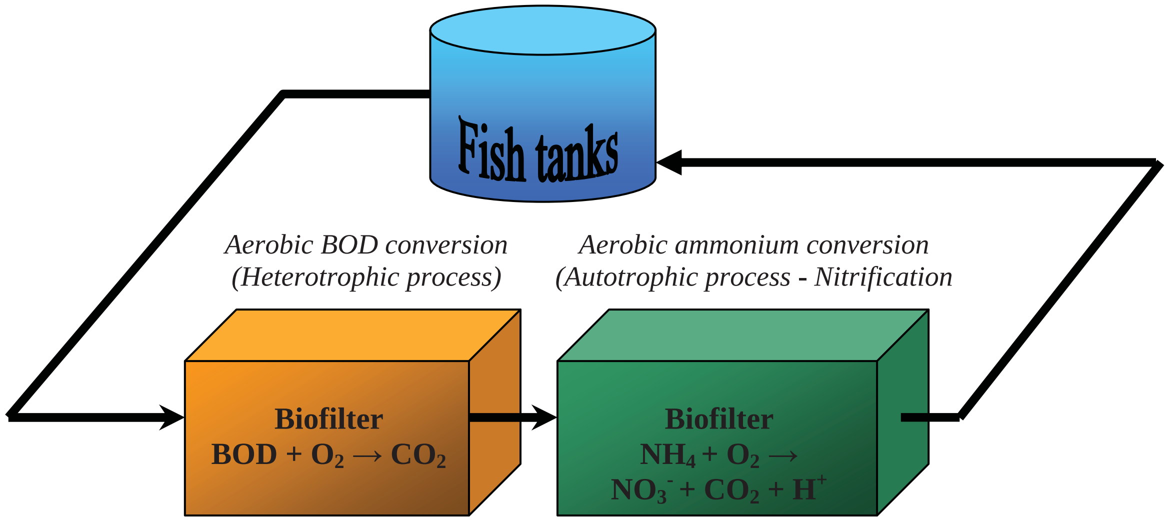


Figure 22. Sketch of the biological water treatment processes in recirculation fish farm systems (Janning, 2010).

Furthermore, by reducing the amount of particulate matter entering the biofilter, the amount of flushing required can be reduced. Experiences from the eight model trout farms indicated that flushing should be performed once per week at the minimum, but only for a short time period using a minimum amount of water (Svendsen et al., 2008). For moving bed filters, there is no obvious need for flushing, but adequate oxygen conditions are crucial for optimum filter performance.

The use of antibiotics and therapeutic agents may temporarily reduce the efficiency of the biofilter, but the biofilms are robust and they may survive treatment and disinfection procedures. However, the impact from these chemical compounds on processes in the biofilters need to be studied in greater detail. However, the design of several model farms allows the production water to bypass the biofilter during periods of treatment.

6.3.5 Plant lagoons

Plant lagoons consist of the old interconnected earthen ponds and channels, where various wild germinating plants are growing (Figure 23). In these lagoons, the ponds and channels should be connected as a meandering stream and the excess water from the production units and the sludge basins should enter as upstream as possible in the lagoon to ensure that the entire plant lagoon volume is involved in the chemical and physical removal and transformation processes.

Figure 23. Plant lagoon at Ejstrupholm Model Trout Farm.
Photo: Lars M. Svendsen and Alfred Jokumsen.

Plant lagoons are important for the conversion of nitrate into N_2; degradation of BOD; accumulation of organic matter, particulate phosphorus, nitrogen, and suspended matter; and uptake of dissolved nitrogen and phosphorus in the plant biomass. However, plant lagoons are not efficient at converting ammonia into nitrate. Due to conversion of organic matter, anaerobic conditions often occur in the bottom and near bottom areas in the lagoons and thus favour denitrification, meaning conversion of nitrate into gaseous nitrogen during consumption of organic matter according to the following process:

$$\text{Organic matter} + NO_3^- + H^+ \rightarrow CO_2 + N_2 + H_2O$$

via the following steps: $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2$.

Additionally, the residence time of the production water in the lagoons is important for the removal of nutrients and the degradation of organic matter.

Svendsen et al. (2008) reported that part of the water in the plant lagoons together with dissolved nutrients and organic matter can infiltrate the bottom of the ponds and earthen channels to reach the unsaturated zone below. Some of the infiltrating water can percolate further into the ground water, some can pass to downstream surface waters, and some can be recharged in wells and drains as new water for the fish farm, which to some extent may affect the overall cleaning efficiency of the model farm (Svendsen et al., 2008). It is assumed that most of the infiltrating nutrients and organic matter are converted, bound to particles and therefore immobilised, or returned to the fish farm as a part of new water. However, over time the infiltration capacity of the plant lagoon bottom sediment seems to be reduced due to clogging.

6.4 Environmental benefits of Model Trout Farms

The reduced and stabile water intake that characterizes the model trout farms is beneficial to the environment, but it has both advantages and disadvantages for the management of the farm (Table 8).

Table 8. Advantages and disadvantages for the water course and the fish farm of reducing the water intake to the farm, including partial or full removal of weirs and dams in the water courses.

Water course	Fish farm
Advantages: • Free water flow up/down stream and natural variations in the water flow of the water course facilitated by water bypass • No or reduced effect of damming • Free fauna passage • Reduced nutrient and organic matter losses per kg produced fish • Reduced discharge of medicines and therapeutants and reduced maximum concentrations • Improved oxygen conditions downstream of the fish farm • Reduced losses of fauna from water courses to the fish farm **Disadvantages:** • None	**Advantages:** • Stabile production conditions • Minor variations in water quality • Improved efficiency of cleaning devices • Using water from bore hole leads to fewer seasonal temperature variations • Improved control of management and production • Reduced external risk of infection with pathogens • Reduced need for medicine and therapeutants • Improved work environment **Disadvantages:** • Higher energy consumption per kg fish • Increased discharge of CO_2 • Risk of toxic levels of ammonia and risk of disagreeable taste in fish meat • Increased need of supervision and management • Increased need of back-up systems: Electricity, oxygen, pumps, etc.

The investigations of the model trout farms have shown significant reduced losses of nutrients and organic matter to rivers and streams associated with the production compared to the discharges from traditional Danish trout farms (Table 9).

Table 9: Specific discharges of N, P and BOD for 2006–2007 (kg/t produced fish) from eight intensively monitored type 3 model trout farms compared with specific discharges from Danish fresh water fish farms in 2006 (Svendsen et al., 2008).

Kg/t prod. fish	Traditional farms in 2006	Model farms type 3 2006-2007	Model farms in % of traditional farms
Total N	31.2	20	64
Total P	2.9	1.1	38
BOD	93.6	5.6	6

The recorded measurements showed that the specific discharge (kg/t fish produced) of nitrogen (N), phosphorus (P), and organic matter (measured as BOD) from the model farms amounted to 64, 38, and 6%, respectively, of the corresponding estimated discharge from traditional Danish freshwater trout farms (Table 9) (Svendsen et al., 2008).

The removal percentages (R_N) of nitrogen, phosphorus, and organic matter for the eight intensively monitored type 3 model trout farms were significantly higher (Table 10) than the assumed figures shown in Table 7 (Svendsen et al., 2008).

Table 10: Average removal percentages (R_N) from the eight intensively monitored type 3 model trout farms (Svendsen et al., 2008).

	Total nitrogen	Total phosphorus	BOD
R_N	50%	76%	93%

These documented high removal percentages may be used to make the case for higher feed allowances to the model farms, as shown in Figure 24.

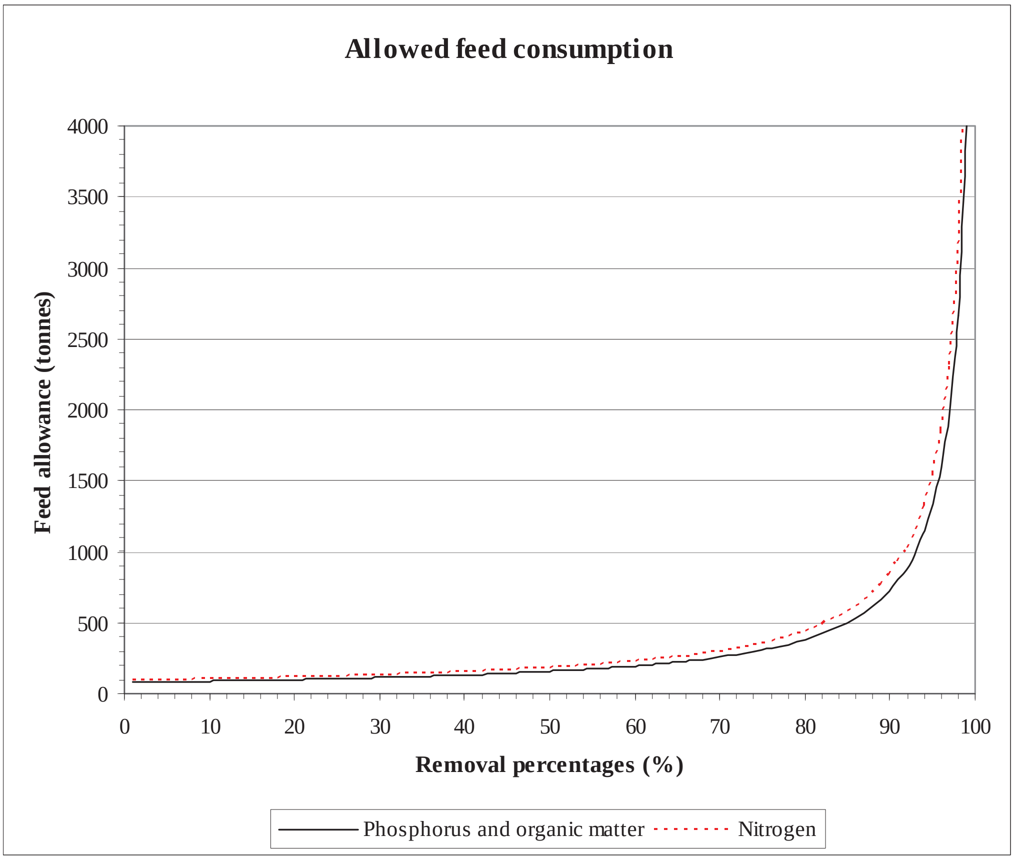


Figure 24. Based on a 100 ton feed allowance in a traditional trout farm, the figure indicates the maximum allowable feed consumption in relation to the removal percentages of N, P and BOD in the reconstructed traditional trout farms into a model trout farm.

Although these results clearly indicate that even the removal of nitrogen has been significantly higher than expected, it is particularly necessary to improve ammonia removal to obtain a higher feed allowance (Figure 24). Based on the results shown in Table 9 for a reconstructed fish farm with a 100 tonne feed allowance during the monitoring period, the feed allowance based on nitrogen removal would be 186 tons (Table 7, formula

3 in Section 6.0); based on phosphorus removal it would be 333 tons and based on BOD removal it would be 1,143 tons.

The documented removal percentages in Table 10 are the result of combined removal and transformation of nitrogen, phosphorus, and organic matter in sludge cones, micro sieves (where applied), biofilters, sludge basins, and plant lagoons (including potential losses via water infiltrating the bottom sediment). The importance and efficiency of each treatment measure are linked to the order in which the treatments measures are situated in the water flow and to the optimisation of the operation of the individual devices. Although biofilters are most important for nitrification, sludge cones and micro sieves are very important for removing particulate matter and associated nutrients, and the plant lagoons are important for denitrification and degradation of organic matter (Figure 25). In fact, the plant lagoons in the eight type 3 model trout farms on average removed at least twice as much total nitrogen and organic matter as predicted (Svendsen et al., 2008). The overall removal efficiency can by improved by further optimisation of the operation of the treatment measures.

Figure 25. Plant lagoon at Tingkærvad Model Trout Farm (type 3). Photo: Niels Bering Ovesen.

In the biofilters, NH_4^+-N is converted into NO_3^- -N, but only a minor portion of the nitrate is denitrified into gaseous N_2 inside the production system. However, plant lagoons are important for the conversion of nitrate. Due to conversion of organic matter, anaerobic conditions may occur in bottom areas and favour denitrification into N_2 gas (Svendsen et al., 2008). Furthermore, the plant lagoons are only able to retain or transform small amounts of ammonia, which then are discharged to surface waters.

The consumption of fresh water originally was reduced to about 3,600 l water/kg produced fish in type 3 model trout farms. In a traditional flow-through farm the water consumption may be about 50,000 l/kg fish (Svendsen et al., 2008). In recent years, it has been possible to further reduce the water consumption in the type 3 model farms (Plesner, 2010). However, important potential disadvantages of the highly technological model fish farms are the increased consumption of energy (pumps for moving water around in the farm;

blowers for oxygenation, cleaning, and degassing of the water; removal of sludge from cleaning devices, etc.) and the increased discharge of CO_2. The energy consumption has been estimated to be on average 1.7 kWh/kg feed exclusive energy consumption in fry and fingerling facilities (Dansk Akvakultur, 2008).

An advantage of this type of farm is that the low water consumption makes it possible to meet the oxygen concentrations requirement in the water discharged from the farm at low cost. In addition, with low discharges/concentrations of easily degradable organic matter and ammonia from type 3 model trout farms and with improved oxygen and flow conditions, there is a tendency for improved biological stream quality downstream from the farms. This is particularly important for areas where the environmental quality targets were not met before the traditional farms were reconstructed into type 3 model trout farms (Svendsen et al., 2008).

The development of model trout farms is anticipated to increase the production of freshwater trout to 60,000 tons and to reduce the environmental impact of the farms. The investment costs to transform a traditional farm into a type 3 model trout farm is estimated to be about DKK 20 per kg feed (annual feed consumption). The use of more advanced technologies, management, and surveillance systems in type 3 model trout farms requires a higher educational level and training of personnel to ensure optimisation of productivity and a low environmental impact. Further continuous monitoring and warning systems are necessary.

7.0 FULLY RECIRCULATED AQUACULTURE FACILITY (FREA)

The governmental strategy for aquaculture aims to produce 60,000 tons of rainbow trout and to reduce the nitrogen discharge to the environment by 40% per kg produced fish (which corresponds to an average discharge of about 20 kg N per ton produced fish) (Ministeriet for Fødevarer, Landbrug og Fiskeri, 2006; Dansk Akvakultur, 2007). Achieving this goal will require more intensive technology as well as diminishing the link between production and environmental impact (Dansk Akvakultur, 2009). This challenge created the idea of FREA farms; FREA is the Danish acronym for Fully REcirculated Aquaculture indoor facility. The FREA concept includes more advanced technology and management strategies as well as less use of water compared to the current recirculated model farms (Figure 26).

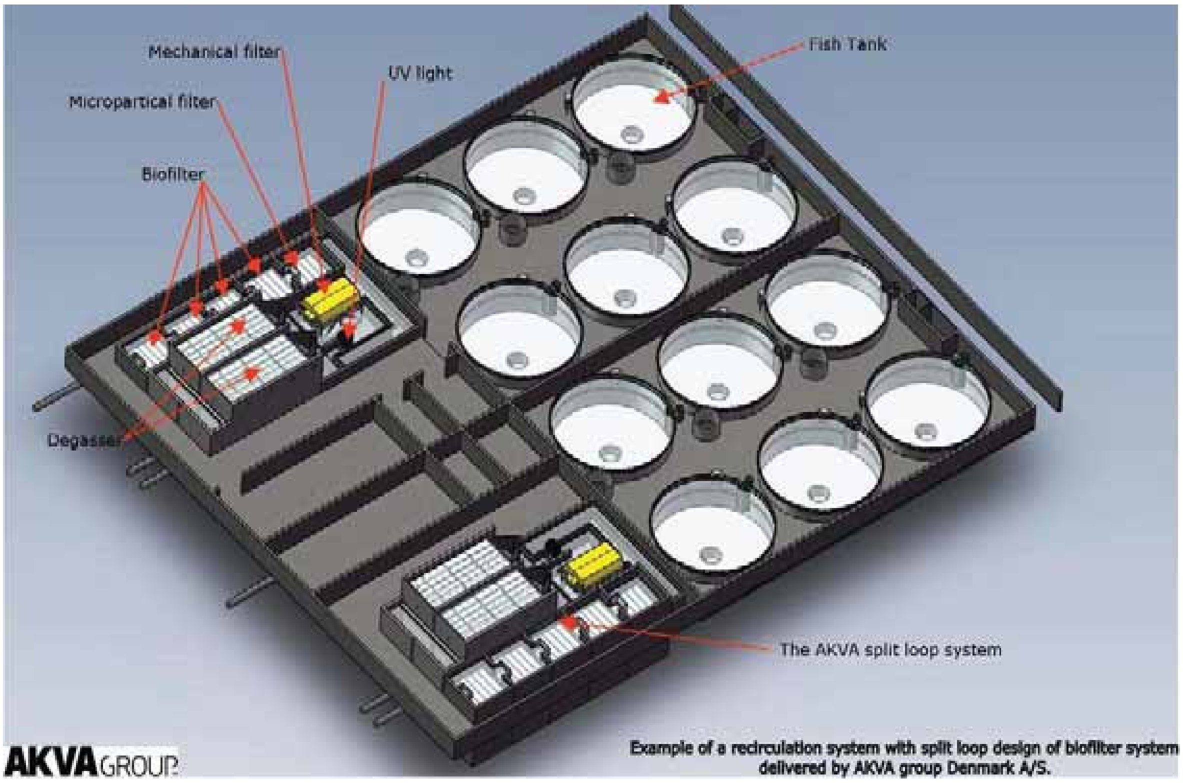


Figure 26. Sketch of a FREA fish farm. Source: AKVA group Denmark A/S.

7.1 Water supply

The water supply for a FREA farm is upper ground water (drain or bore well) and is generally assumed to have no direct influence on the drinking water reservoirs. The amount of fresh water consumed corresponds to the amount required to flush the micro sieves and biofilters, to compensate for evaporation, and to keep temperature at an appropriate level. The water exchange is supposed to be about 10% of the total water volume per day. The water is treated with UV light when necessary.

It may be possible to achieve a certain re-use of water by taking the water from drains close to the percolation area. However, due to the risk of contamination with pathogens, the water intake should be situated upstream of the facility. The facility should be placed in an area with coarse sand and gravel soils to facilitate the availability of a good quality water supply and adequate infiltration conditions for infiltrating waste water from the production units. Moreover, the facility can be located a good distance away from rivers and lakes. The water consumption per kg produced fish of a FREA farm is estimated to be about 500 l/kg fish (Dansk Akvakultur, 2007), which is approximately 7–8 times less than that of a type 3 model trout farms and 100 times less than that of a traditional farms (Svendsen et al., 2008).

7.2 Mechanical filtration

The production water from the fish tanks passes through a micro sieve (mesh size of about 40–74 µm). The micro sieve separates particulate matter > 40–60 µm, which is flushed as sludge to a sludge storage tank until it can be used as agricultural fertilizer or for production of bio gas. Excess sludge water may be returned to an anoxic biofilter (denitrification) or partly infiltrated through a root zone plant construction.

A root zone plant is a construction, which has been planted up with common reed or similar plants. The roots of these plants create the root zone. By passing the root zone the sludge water is treated, i.e. the bacterial processes around the roots of the plants converts organic matter and remove nutrients from the water.

7.3 Biological filtration

From the micro sieves the water is passed to the biofilters, where the dissolved fractions, especially NH_4^+, are converted into NO_3^-. The filter material may be either a block filter (200 m^2/m^3) or a moving bed filter (600 m^2/m^3) or a combination of the technologies. In a separate biofilter with anoxic conditions (a denitrification filter), the NO_3^- is anaerobically converted into N_2 gas via consumption of easily degradable organic matter. The discharged water from the FREA farm is passed to infiltrate through a root zone plant facility.

The recirculated water may pass a trickling filter for degassing and aeration before it enters the fish tanks. However, a portion of the aerated water from the trickling filter is pumped through an oxygen cone for oxygenation before it enters the fish tanks. In addition, pure oxygen may be added at each tank/section.

7.4 Plant construction

The FREA farming facility is constructed of independent sections/units, each with a separate water supply to prevent dissemination of diseases between groups of fish and to make the “all fish in/all fish out” principle more applicable. The sections/units include a hatchery as well as separate sections/units for fry, fingerlings, and on-growing fish.

7.5 Energy balances

The aim of FREA farms is to optimise the utilization of external and internal energy supplies. External energy includes that required for pumping water, water treatment, and aeration of the water as well as that required in the buildings. Internal energy production includes the energy production of the fish, pumps, and bacteria during feed conversion as well energy produced by burning of sludge. To maintain an optimum temperature of 17–18

°C, these inputs are balanced in relation to the use of heat exchangers, insulation, outdoor temperature, and water exchange.

7.6 Environmental impact

Although a FREA farm is in principle a closed system, some loss of nutrients to the environment will occur via the water discharged to the percolation zone. The contribution from the production of nitrogen (i.e., before any water treatment) was theoretically estimated to be 38 kg N/t fish produced (Dansk Akvakultur, 2007), which is similar (40 kg N/t fish) to the results from type 3 model trout farms (Svendsen et al., 2008). A rough mass balance estimation of the nitrogen contribution indicates that about one-quarter is in the sludge fraction, about half is converted by denitrification, and the remaining portion infiltrates the root zone plant (Dansk Akvakultur, 2007).

The contribution from the production of phosphorus is theoretically estimated to be 4 kg P/t fish produced, which is similar to the 4.4 kg P/t fish found in type 3 model farms (Dansk Akvakultur, 2007; Svendsen et al., 2008). A rough mass balance estimation of the phosphorus contribution indicates that about 90% is in the sludge fraction and the remaining 10% percolates into the root zone plant (Dansk Akvakultur, 2007).

The contribution from the production of organic matter (BOD) is theoretically estimated to be 67 kg BOD/t fish produced (Dansk Akvakultur, 2007), which is lower than the results (88 kg BOD/t fish) from the type 3 model trout farms (Svendsen et al., 2008). A rough mass balance estimation of the BOD contribution indicates that about 60% is in the sludge fraction, about 35% is converted in the biofilters, and the remaining 5% percolates into the root zone plant (Dansk Akvakultur, 2007).

However, the contents of N, P, and BOD in the wastewater for the root zone constructions as well as the volumes of sludge have to be considered in relation to storage capacity and the need for land on which to distribute the sludge. Such considerations may include further nitrification and denitrification and external treatment of the sludge (Dansk Akvakultur, 2007).

7.7 Safety precautions

It is critical to take all precautions to ensure that disease agents are excluded from the FREA facility. Safety precautions include:

- The physical construction of the FREA facility shall prevent any intrusion of vectors of pathogens
- Prevent any contamination of water intake (i.e., shielding against any vectors of fish pathogens)
- Secure against intrusion of animals and birds
- Optimum bio security when introducing new material (e.g., disinfected eyed eggs, as fish may be carriers of pathogens). Preferably the FREA should have its own brood stock.

- Strict hygienic procedures for admittance to the FREA (e.g., lock for bath/wash and change to clothes and footwear exclusively for internal use). External visitors should be avoided
- Prevention of dissemination between the separate sections of the FREA facility (e.g., separate equipment, ketches, etc.)
- Strict hygienic procedures (disinfection) for lorries delivering feed and for feed storage
- Strict hygienic procedures (disinfection) for lorries collecting fish (i.e., certified disinfection)
- Strict hygienic procedures for disposal of dead fish, eggs, etc.

7.8 Management

The advanced technologies, management, comprehensive surveillance systems, working processes, and hygienic procedures in a FREA plant require well-educated and trained personnel with the competence required to achieve optimum productivity. The high degree of recirculation makes it critical to continuously monitor and control the water quality within narrow limits, and the extensive use of alarm systems is necessary for several parameters, i.e. oxygen, electricity, pump failure, water supply etc.

8.0 ORGANIC FARMING

The aim of organic farming is to create a more ethical method of sustainable production by using local resources and natural processes that help maintain the natural cycle (i.e., maintain balance in nature). Organic farming of rainbow trout in Denmark was initiated in 2001, and in 2004 a national code of practice came into effect via governmental order. Figure 27 shows one of the Danish pioneer organic trout farms.

Figure 27. Skravad Mølle organic trout farm, Hobro, Denmark.
Photo: Alfred Jokumsen.

In addition to meeting the regulations of Dambrugsbekendtgørelsen (1989) and more than 10 other regulations, the organic code of practice includes specific requirements for oxygen content, pH, nitrogen (daily/weekly measurements), veterinary control, treatment with antibiotics (once during the organic fish life), and a positive list of chemical additives. Accordingly, the use of formaldehyde, Chloramin-T, and copper sulphate are not allowed. Only the LT type of fish meal is used; no fish offal is used due to its phosphorus content and because its use would be contradictive to the Dambrugsbekendtgørelsen and Danish environmental laws (Jokumsen et al., 2006b). Furthermore, no GMO ingredients in the feed and no etoxyquine for feed preservation are allowed.

The first Danish trout with the Danish red Ø organic label that were produced in accordance with national requirements were introduced to the market in 2005 (Jokumsen et al., 2006b). The current annual production of organic rainbow trout in Denmark is about 300 t (Larsen, 2009).

Organic fish farming has been introduced in several European countries since the 1990s according to specific national codes of practice (e.g., Soil Association (UK), Naturland (DE), KRAV (S), and DEBIO (N)) (Jokumsen et al., 2006b). The various rules behind these national organic labels make the choice of product non-transparent for the consumer, and they have created distortion of competition between producers. Therefore, the International Federation of Organic Agriculture Movements (IFOAM) – EU Regional Group has agreed on a compromise for the common legal minimum criteria for organic aquaculture in all EU member states to be into effect from 1 July 2010. This EU regulation will replace the national regulations, with a transition period of 4–5 years that depends on the size of production.

This new EU regulation will have various impacts on the existing and planned Danish organic trout farms. For example, the use of closed recirculation systems will only be permitted for hatcheries and fry production. For organic on-growing production, a range of open systems, from flow through to re-use of water (e.g. types 1 and 3 model trout farms), will be permitted. Use of renewable energy is recommended where it is adequate, but it is not required. The main rules of the new EU regulation are summarized in Table 11, with a focus on rainbow trout.

Table 11. Main rules of the EU regulation for organic production of freshwater rainbow trout.

ISSUE	REGULATION
Parallel organic/conventional production	Physically separated and separate water supply
Introduction of conventional fish for organic production	1. For on-growing, minimum of $^2/_3$ of life cycle according to organic regulation 2. Use for breeding purposes after 3 months according to organic regulation 3. Beginning in 2015, all fry shall be organic (i.e., from organic brood stock)
Flow-through/recirculation systems	1. Closed recirculation systems are not permitted. 2. Recirculation (incl. heating/cooling) may be used for hatcheries and for fry production
Aeration/oxygenation	1. Only mechanical aerators are permitted and preferably they are run by renewable energy 2. Pure oxygen is only permitted in critical situations to secure fish welfare
Feed pigment	- Astaxanthin from natural sources is permitted within the physiological requirements of the fish
Fish density	- Maximum of 25 kg/m^3
Health consultancy	- Minimum one health service per year
Medication	1. Two treatments/year for life cycles > 1 year 2. Maximum of one treatment for life cycles < 1 year
Treatment against parasites	1. Two treatments/year 2. Maximum of one treatment for life cycles < 18 months
Transition period for the EU regulation to become effective	1. 1 July 2013 2. 1 July 2015 for farms producing < 200 t/year

9.0 REGULATIONS FOR DANISH FRESHWATER AQUACULTURE

The Danish production of freshwater rainbow trout has been subject to various regulations in relation to environmental impact, feed quota, use of water resource, etc. (see Section 5). Table 12 lists some of the current regulations and principles that govern Danish freshwater trout aquaculture.

Table 12. Main regulations and principles for Danish freshwater aquaculture production, (Dambrugsbekendtgørelsen, 1989, 1998; Modeldambrugsbekendtgørelsen, 2002; Miljøministeriet, 2007).

	Traditional	**Model 1**	**Model 3**
Water intake/passage; minimum % of water flow (Q_{mm})[1] in the water course that shall pass by the farm	50%		
Maximum water use; l/sec/100 tons feed/year	-	125	15
Good ecological environmental quality goals downstream of the farms, including fauna passage	Yes		
Grid inlet, maximum grid size, mm	6		
Grid outlet, maximum grid size, mm	10		
Oxygen saturation at outlet, minimum %	60	70	70
Maximum increase from inlet to outlet (calculated from Q_{mm})[2]:			
BOD, mg/l	1		
Suspended solids, mg/l	3		
Total phosphorus, mg/l	0.05		
Ammonia-N, mg/l	0.4		
Total nitrogen, mg/l	0.6		
Water Quality Criteria WQC (Conc.$_{\text{outlet}}$ – Conc.$_{\text{inlet}}$): maximum values[3]:			
Benzocaine, µg/l	7.2		
Chloramine-T, µg/l	5.8		
Chlorbutanole, µg/l	130		
Copper, µg/l	1 add (upper limit 12)[4,5]		
Formaldehyde, µg/l	9.2 add[2]		
Hydrogen peroxide, µg/l	10 add[2]		
Iodine, µg/l	10 add[2]		
Potassium permanganate, µg/l	0.84		
Amoxicilline, µg/l	0.078		
Phlorofenicol, µg/l	1.2		
Oxytetracycline, µg/l	10		
Oxolinic acid, µg/l	15		
Sulphadiazine, µg/l	4.6		
Trimethoprime, µg/l	100		
Health and welfare, health inspections	Yes		
Escape and predator control; presence of nets and grids	Yes		
FCR (Feed conversion ratio)	Maximum 1.0		
Particle filter	Yes	Yes	Yes
Biofilter	No	No	Yes
Plant lagoon	No	Yes	Yes

[1] Q_{mm} = median minimum rate of water flow = the median of the annual lowest average daily flow for typically at least a 20 year time series

[2] Increase in concentration during passage of a traditional trout farm based on the actual Q_{mm}. For the model trout farms these values have been increased wholly or partly to compensate for the reduced water intake and for the lower amount of water discharged to the water course.

[3] The figures are maximum annual average values that take into account the statistical uncertainty (i.e., in practice the individual concentration differences must be somewhat lower than the WQC to meet the environmental regulation) (Svendsen et al., 2008).

[4] In addition (add) to the background concentration

[5] Dissolved metallic concentration

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