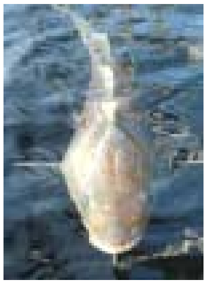

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Final Technical report (OPEL) April 2006

Optimisation of environmental conditions for cultivating marine finfish larvae

MRI Carna and Fosen AS.

Introduction

This is the final technical report for the OPEL project and its objectives are to describe the findings and achievements of the program.

The development of novel marine finfish production requires reliable and cost effective supplies of juvenile fish. This project addresses a number of key factors (water quality and feeding) involved in the cultivation process for marine larval fish with the objective of enhancing production and reducing costs.

Initially, the worldwide production of cod juveniles was somewhat of an erratic process. Some of the major problems experienced were as a result of fluctuations in water quality (temperature, salinity, total gas pressure and microbiological parameters) and feeding regime employed. In particular, the high incidences of malformed juveniles in the early days of production are thought to be as a result of these issues.

Traditionally, single use flow-through seawater systems have been employed for marine finfish larval culture. But this methodology only works best when seawater conditions are stable, production is seasonal, pumping costs low and temperature control is economic. Therefore there can be an economic and operating incentive to employ reuse systems in locations where water quality parameters are variable. Unfortunately, current knowledge on this technology in aquaculture is predominantly available for rearing adult fish, juveniles of warm water species or for freshwater organisms. By using a water reuse/ recirculation system, the water used can be treated and isolated from exterior influences, allowing the establishment of optimal larviculture conditions. Water reuse systems also reduce the volume of effluent wastewater that must be treated after use. King (2003) reported a survival rate, over the first 100 days post-hatch, of 30% in a commercial cod hatchery which used a water reuse system. Indeed, in a subsequent year, they reported a larval survival rate of 55%, which is probably the highest recorded survival rate in intensive cod hatchery production, to date.

The development of knowledge and experience in operating such water reuse systems is an important challenge for further innovation and development of a sustainable and cost effective cod industry in both regions. The goal of this project is to significantly improve cost of production and resultant quality of marine finfish juveniles through active collaboration between a commercial operation and a research organisation in the regions. The project also aim to evaluate and refine protocols for cold water larval culture and will generate a network of information exchange about marine finfish hatchery techniques.

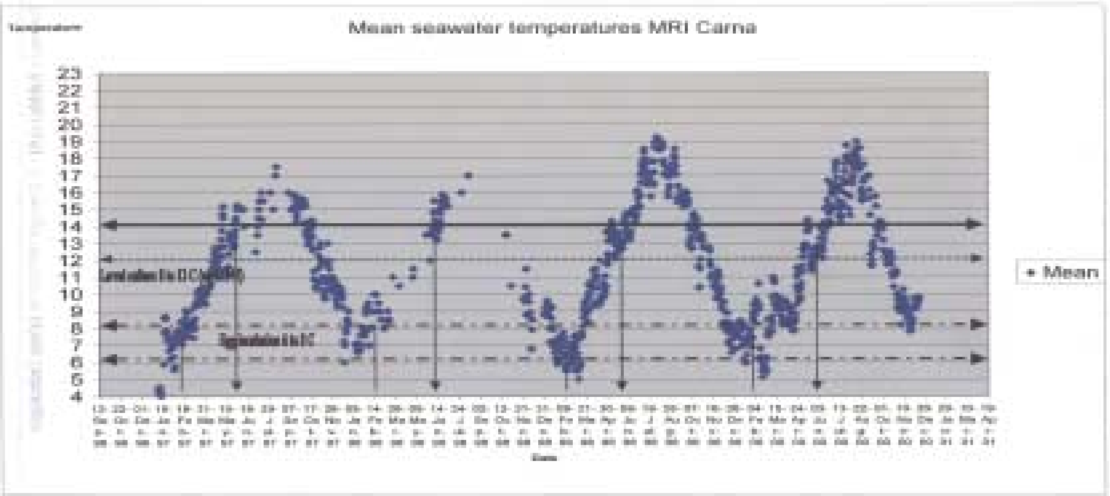
In addition to water quality issues, this technical report will describe the innovations developed for feeding live feed which traditionally has been a labour-intensive process and potentially unstable component of marine fish larval culture. A primary goal of the project therefore is the development of efficient and reliable live feed feeding systems that are essential for the consistent and economic production of juvenile fish to supply the ongrowing cage farm industry.

In the following sections, this report firstly outlines the hatchery layout of the MRI Carna finfish unit and describes in detail, water treatment and reuse systems, husbandry protocols associated with live food production, larviculture and water reuse, followed by results of water chemistry in the larval unit and biometric data on cod juveniles reared at the facility in 2005. The report will then detail water treatment and re-use systems, used or in use, at Fosen Aquasenter in 2005 and describes results obtained from water quality monitoring and overall juvenile production performance at their hatchery.

MRI Carna water re-use systems

MRI Carna is involved in the development and refining of culture systems for aquatic organisms. The laboratory currently operates a “semi-closed system” for the cultivation of cod larvae. The operation of this system involves pumping seawater from a shallow depth of only 0.5 m below chart datum, from a sheltered inlet in Mweenish Bay. The entire bay is shallow, with an average depth of only 3 m. The seawater in Mweenish Bay can be described as oceanic. Measurements of salinity of intake water at the laboratory over the duration of the OPEL project indicate a range of 32.3-35.0, with an average of 34.0. Mweenish has a short retention time of seawater which combination with its general alignment along the south-west prevailing winds gives rise the oceanic conditions. Water temperatures however, fluctuate more than other deeper bays in the region. Measurement of intake seawater at the laboratory during the period September 1996 to April 2001 show an annual range in temperature from 5.5^{o}C in February to 19^{o}C in late August (Fig. 1)

Figure 1. Temperature of incoming seawater at MRI Carna between 1996 and 2001.



These fluctuations in ambient seawater temperature, coupled with suction-pumping seawater from shallow water, in combination with the costs and practicalities of maintaining stable water temperatures and total gas saturation levels and bio-security in the laboratory were the main reasons for choosing a water reuse system. The seawater that is pumped from the bay is treated through a coarse mechanical screen filter (60 micron) through a drum filter and then its UV treated before being introduced into a seawater reuse facility purchased from Water Management Technologies (WMT). The larval reuse system in Carna consists of the following components (Table 2, Fig. 2):

Table 2 Components of water reuse unit at MRI Carna

- Ten 1.5 m diameter larval tanks
- Size 1 drum filter sump
- Hydrotech 501 drum filter (filters to 60 micron)
- 3 position drum skid
- Main bio pump
- Fractionator pump
- 2 chamber bio-blower
- Plumbing
- Integrated MCC (motor control center)
- Size 1 foam fractionator base module
- Divider wall

- Biofilter shell
- Biofilter insert kit
- Size 1UV/LHO base module
- Size 2 UV insert (5 tube)
- Size 1 LHO kit
- Recirc return pump
- 3 cartridge sock filters
- Heat exchange plates
- Chiller unit (24 hp)
- Biomedia

Fig. 2 Diagram of water reuse system (Water Management Technologies)

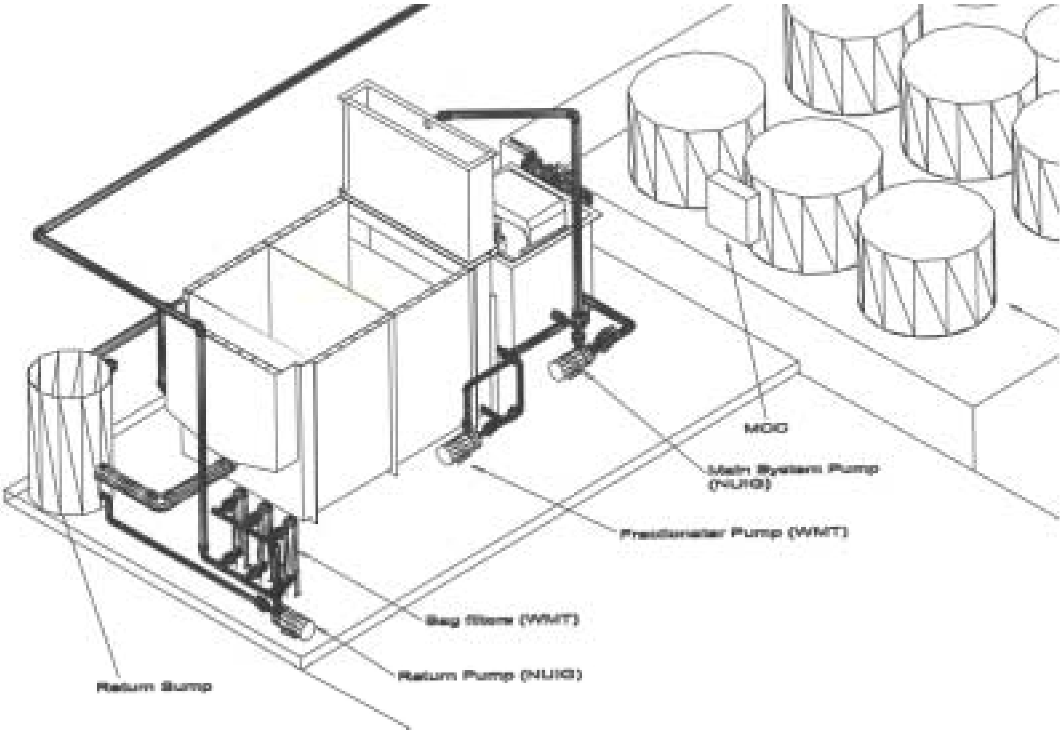


Plate 1 Water reuse system (degassing tower and bio-chambers), larval rearing tanks

The water reuse system employed at MRI Carna for marine finfish larval cultivation is a "semi-closed" system. This type of system allows for the partial removal of ammonia produced by metabolic process and also uneaten feed by dilution with new intake water.

Operations of MRI Carna water reuse system

The following is a step-by-step account of the operation of the water reuse system used at MRI Carna. Some of the components in this water reuse system were modified by MRI Carna staff to improve its performance after it was installed by WMT. The total water volume of the unit is shown in Table 3.

Table 3. Volume of components of the water re-use system

Component	Volume
Fish tanks	**15.9**
Drum tank	**0.9**
Biochamber+fractionator+LHO	**11.4**
Sump tank	**0.9**
Pipes	**1.0**
Total	**29.1**

New seawater can currently be introduced into the WMT reuse system at two separate locations (drum filter sump tank and at the top of the degassing tower). New seawater that enters the drum filter sump tank is controlled by a floating ball valve. This value ensures that a constant volume of water is retained in the WMT water re-use system. The rate of new water entering the system via the floating ball valve is regulated by a drain valve located on the sump tank of the drum filter. The rate of new water added to the system was adjusted according to a range of parameters, such as, the biomass of fish in the larval tanks, results of water quality testing (particularly ammonia and nitrite) and information on water quality in Mweenish Bay. For example, the rate of new water added was reduced following periods of heavy rain and during a dinoflagellate 'red tide' event that occurred in June of 2005. The predominant species recorded during the 'red tide' was *Karenia mikimotoi*. Water is also drained from the system from four other sources. A valve located at the bottom of the standpipe for each tank in the larval unit is briefly opened each day to flush any debris that may collect in the effluent pipework. The increase in flow of effluent water into the WMT unit can lead to water draining out through the overflow pipe, which is located in the sump of the drum filter. A small volume of water is lost along with effluent from the protein fractionator. Water used to wash the screen on the drum filter is also lost from the system. The volume of washing water varies depending on the frequency and duration of the cleaning cycle of the drum filter.

The removal of solid fish wastes and uneaten feed in water reuse systems is critical as these increase the biological oxygen demand, raises ammonia concentrations, damages fish health and fouls the biofilters in the system. At MRI Carna, the effluent seawater from the ten 1.5 m diameter larval rearing tanks flows by gravity through an automatic self-backwashing drum filter. Here it is filtered through a removable screen to either 40 or 60 µm. The smaller screen size is used during larviculture and is replaced with the 60 µm screen once fish reach an average weight of 1.0 g.

For every 1 kg of oxygen consumed by fish, they typically produce 1 kg of carbon dioxide. Carbon dioxide produced by respiration must be removed from a re-use system and this is predominantly done in a degassing column. As a general rule, carbon dioxide levels should be kept below 10 mg/L. Filtered seawater in the WMT system is pumped from the drum filter sump tank to the top of the degassing tower, where it is dispersed by jets onto trickle plates and then the seawater cascades by gravity over plastic mesh designed to maximize the exchange of water through air thus enabling excess carbon dioxide to be released. It is recommended that the carbon dioxide produced should be vented outdoors.

Although drum filters are a recommended mechanical filter in water reuse systems, as they regularly and gently remove filtered waste from effluent water, fine particulate wastes and complex organic wastes are typically not removed by mechanical filtration. These finer waste products can significantly contribute to the biological oxygen demand (BOD), turbidity and odour. A proportion of these wastes can be removed by a foam fractionator. At the base of the degassing tower in the WMT system there is a weir system where protein fractionation occurs with fine air bubbles that are incorporated into the water by venturi action. These gather as foam which float to the water surface, which then passes over the weir and drains to waste. The protein fractionator is regularly cleaned using a combination of manual brushing clean of the weir wall in combination with an automatically controlled flushing valve which passes water, pressurized to 1 bar, through a spray bar located above the weir of protein fractionator.

Seawater then passes into a major component of this seawater reuse system, two interconnected biological filtration chambers. Within these chambers are submerged fluidized biofilters containing two types of biofilm carrier media, referred to as, Kaldness Biofilm Carrier and cartwheel type biomedia. These biofilm carriers have a high surface area to volume ratio. Each piece of “Kaldness Biofilm Carrier” measures 7x10 mm. These surface area of Kaldness Biofilm Carrier is reported by the manufacturer to be 830 m^2/m^3. The manufacturer of WMT recommends the use of the two types of biomedia, as together they improve the fluidized motion of biomedia within each biochamber. Kaldness media float, while the cartwheel type media sinks and together they tend to counterbalance each other. Nitrifying bacteria living on the media oxidize unionized ammonia, which is highly toxic to fish, into nitrate, which is less toxic, in a two-step nitrification process. This involves *Nitrosomonas* spp. bacteria which convert ammonia to nitrite and then *Nitrobacter* spp. convert nitrite to nitrate. It is thought that the advantage of two chamber biofilters is that the first chamber becomes colonized by a population of predominantly *Nitrosomonas* spp. bacteria and the second by *Nitrobacter* spp. Each biochamber is supplied with vigorous aeration to maintain a fluidized motion of the biomedia. The aeration rate is set higher in the first chamber to encourage colonization by *Nitrosomonas* bacteria. The supplier of the WMT unit advises that *Nitrobacter* bacteria require more gentle aeration.

The water from the second bio-chamber passes by six ultraviolet tubes where the nitrifying bacteria and heterotrophic bacteria are killed. UV doses required to kill microorganisms can vary significant, from only 2 mWs.cm^{-2} to more than 230 mW s.cm^{-2} (at 254 nm), depending predominantly upon water turbidity and the type of target organism. The dose rate of the WMT UV unit is 400 mW s.cm^{-2} (at 254 nm).

Water is re-oxygenated by a low head oxygenator located after the UV chamber. This unit functions by cascading water through a chamber within which are a series of baffles where oxygen gas is passed through. Oxygen is the primary limiting parameter governing production capacity; it is monitored regularly in all culture tanks and maintained at all times above 85% saturation (using diffusers in each rearing tank if necessary at times of very high stocking densities). The rate of oxygenation at the low head oxygenator is set to ensure the level of oxygen in the intake water to the larval tanks is between 105-115% saturation. The levels of CO_2, ammonia, salinity and the pH also have a bearing on the safe minimum and maximum dissolved oxygen concentrations. Oxygen at MRI Carna is produced by a centralised oxygen generation system. After being oxygenated, water flows into a sump tank. A proportion of water in the sump tank is pumped through a 4 L capacity titanium plate heat exchanger fitted to a 19 horsepower chiller unit that regulates the water temperature within the system. Depending on new water flow rates, the chiller can reduce the ambient temperature by 2-5^{o}C in the larval tanks. A return loop is fitted to the WMT system, whereby excess water, which is not pumped into the larval tanks, is passed back into the drum filter, where it is refiltered and reprocessed through the water re-use system. This continual re-processing of water is important for maximising the efficiency of the water re-use system.

Water required for supply to the larval tanks is passed through pressurised FSI sock filters. 5 µm socks filtered are fitted to the filters during the phase of greenwater and feeding with rotifers or *Artemia*. Following the phase of live food, the filters are replaced with 25 µm sock filters. The filter size is increased again once fish weigh on average 1 g. The sock filters are removed entirely once fish weigh on average 5 g. Sock filters are cleaned at least daily using a domestic washing machine, with non-biological washing powder as a detergent, with the machine set on white wash at 40°C. We found that this method proved less labour intensive and cleaned the filters better than washing with a cold-water power washer.

Effluent water from the reuse system is passed through sedimentation tanks and finally UV treated before being discharged back into the sea. The two principal reasons for filtering discharged water are to reduce organic loading on the surrounding aquatic environment and to improve the efficiency of effluent UV irradiator.

The water turnover rates within the larval tanks connected to the recirculation system were as follows (Table 5).

Table 4 Water turnover rates

Phase of development	Turnover every (Hours)
Greenwater	**24**
Rotifers	**12**
Feeding with *Artemia*	**5**
Co-feeding	**3**
Weaning	**1.5**

An activated carbon filter was added as an additional component to the water reuse system in September 2005. Activated carbon is a highly retentive or chelating substance and is recommended for the removal of organics and other toxic compounds, which gradually build up in water reuse systems. Before being added the carbon was rinsed thoroughly to remove fine dust particles. Approximately 10 kg (because of space constraints) of the carbon was put into four 60 µm sacks and these were placed below the trickle plates at the top of the degassing tower of the WMT system. The manufactures recommend using one gram of carbon per litre of seawater in the system and to replace with new carbon every three weeks, depending on the biological load of the system. One of the major drawbacks to using carbon is its cost (€170 per 20 kg).

Eggs and larvae

There were two inputs of eggs into the MRI Carna water reuse system from Orkney Marine Hatcheries in 2005. These arrived on the 1st and 29th of April**.** There were three sources of eggs in 2006 (broodstock reared from eggs at MRI Carna, eggs from wild cod caught off the east coast of Ireland in March 2006 and from importing eggs from Viking Fish in Scotland. All eggs were disinfected with Kickstart® and placed into 70 L capacity egg incubators with treated seawater from the water reuse system. Eggs were incubated at a temperature of between 6 and 10 °C. Stock were transferred from the egg incubators to larval tanks approximately one day prior to hatching. The practice ensured that physical trauma associated with the transfer was minimised as eggs are more tolerant of handling stress than larvae.

Plate 2 Cod egg (R. Wilkes MRI) and eggs in transport containers (note difference in stage of development between bags on the right the eggs are more developed than those in the left bag)

Live feed rotifer feeding system at MRI Carna

During the first production of cod in 2004 rotifers were manually fed six times per day seven days per week. Each morning all of the rotifer feed (a dry powder) that was required for the day was mixed in filtered freshwater and the first feed was added to the batch culture cones between 7 to 8 am and the last feed was between 8 to 9 pm. This feeding regime was both labour intensive and did not provide the rotifers with a consistently sufficient supply of feed. The addition of large quantities of feed periodically reduced oxygen levels in the cultures, sometimes to critically low levels of <1 mg O_2/L.

These fluctuations in oxygen levels can be avoided by two principal methods. One is to install an automatic oxygen control system, whereby, the oxygen level in individual tanks is monitored and the rate of oxygen supplied to each tank can be automatically adjusted. Although such systems are expensive, their use is recommended in large-scale production units. The second method of avoiding hypoxia in culture tanks is to provide regular small rations throughout the day and night, and thereby reducing the rate of oxygen consumption associated with post-prandial metabolism. This latter solution in combination with supplying a near constant rate of oxygen to tanks was adopted at MRI Carna in 2005, whereby, rotifers were manually fed three times daily (9am, 1 pm and 5pm) with 16% of the daily ration per feed. All other feeds were dispensed automatically by using peristaltic pumps, to pump the feed solution from 10 L containers stored in a fridge, into the culture tanks, via flexible silicone 6 mm diameter tubes. Each peristaltic pump was controlled by an electronic timer, which was set to feed for 15 minutes every four hours. Each feed bucket was aerated to maintain the rotifer feed in suspension. Each morning, the feed buckets and feeding tubes were flushed through with hot freshwater and washing-up liquid, then thoroughly rinsed with hot freshwater.

Fig. 3 Diagram of automatic rotifer feeding system

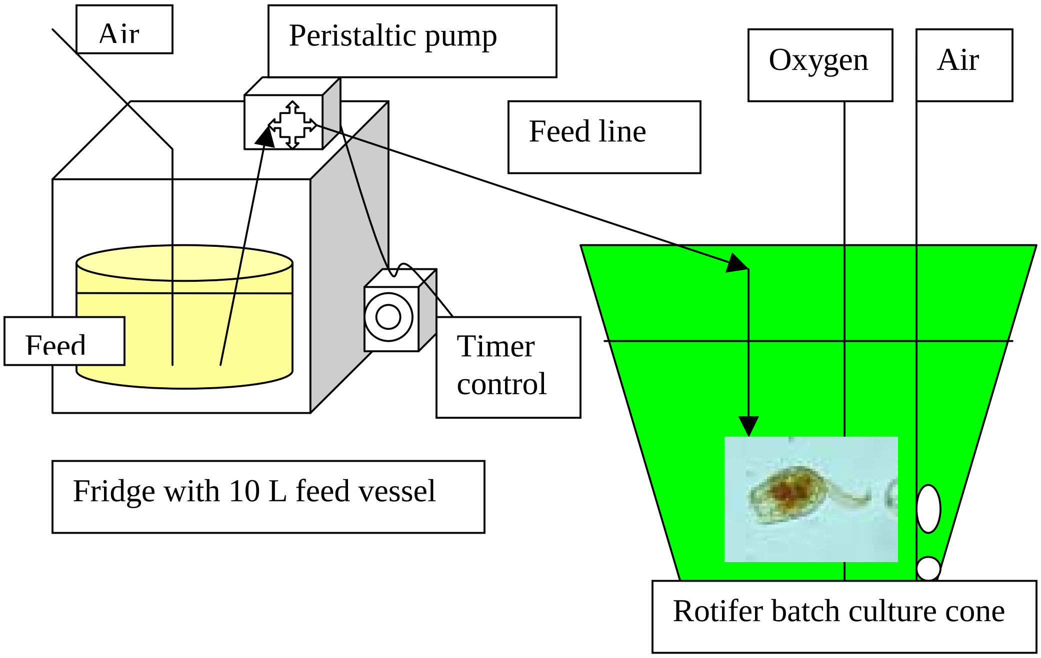


Plate 4 Rotifer batch culture and enrichment cones

Manually feeding provided a safeguard against starving rotifers in the event of a failure of the automatic feeding system. If, for instance, a peristaltic pump failed to dispense any food into the culture tank, then the rotifers in that tank would at least have been fed half of its daily food ration, by manual feeding. This protocol of manually and automatically feeding rotifers developed during this project resulted in a greatly reduced labour input and an inherently more stable production of rotifers. Oxygen levels no longer fluctuated at or below critical levels and a more consistent supply of feed was made available for rotifers. The advances developed as a result of this collaborative project directly resulted in an overall increase in live feed productivity. Indeed, between 600 and 1,000 million rotifers were reliably available each day as required by cod larvae during the epoch of rotifer feeding. This number of rotifers equated to approximately 20% of the standing stock of rotifers that were being cultured at MRI Carna in 2005.

In 2006, rotifers were fed predominantly on *Nannochloropsis oculata* paste. The labour required to feed with paste was reduced although it has yet to be determined whether the same level of productivity can be achieved with this feed type using cognate culture protocols.

Live feed for cod

Phytoplankton is cultured at MRI Carna using "batch" culture methodology initially developed at the Conway Laboratory. The basis of the process is that micro algae are maintained in pure culture. These cultures are used to inoculate successively larger vessels. Micro-algae stock culture or masters are grown in 250 ml flasks and as the number of cells increase to sufficiently high densities, they are inoculated asceptically into flasks such as 5 L, 10 L and 20 L until there are adequate volumes for transfer into 1,000 L tanks. There were two species of micro algae used in the cod larval cultivation process and these were *Nannochloropsis oculata* and Tahitian *Isochrysis galbana* (T. *Iso*). *Nannochloropsis* was primarily used for greening the water in the larval tanks. T. *Iso*. was used to maintain the enriched fatty acid profile of rotifers and *Artemia.* This was pumped from the 1,000 l batch culture vessels by a submersible pump into the live larval feeding system which is described in the section below “live feeding system developed during this project”.

Larval cod live feeding schedule

Feeding of larval cod is intrinsically governed by the size of their mouths. As the larvae grow larger and develop they are capable of feeding on progressively larger prey items. Initially green water (microalgae) and rotifers are added to larval tanks and as the cod grow they are then capable of feeding on the relatively larger *Artemia* nauplii. After a few days of being fed on a combination of rotifers and *Artemia* nauplii, enriched *Artemia* are added. After they metamorphose, cod are weaned onto inert diets. Many hatcheries transfer from rotifers to either *Artemia* or inert food according to the number of days post-hatch. Instead, the timing of changing feed type is governed at MRI Carna by the average total length of fish according to the table below:

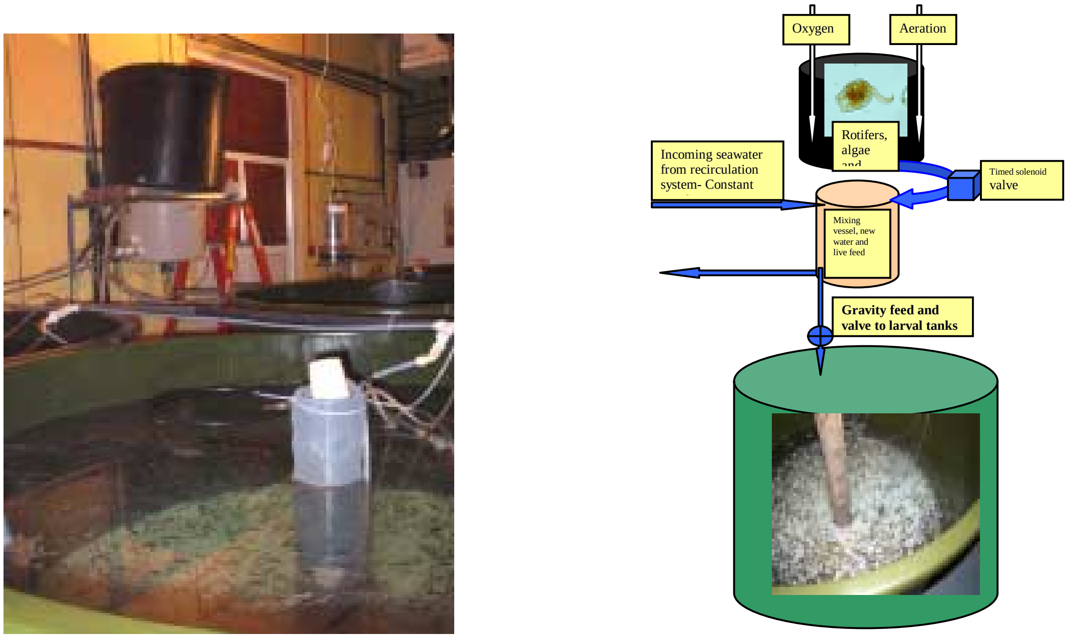
Table 6 **Feeding regime for cod at MRI Carna**

Rotifers	**From 2 days post hatch to 12 mm in length**
Artemia	**From 10 to 20 mm in length**
Gemma micro 300	**From 10 mm to 0.3 g**
Gemma 0.3	**0.15-0.5g**
Gemma 0.5	**0.3-1.0g**
Gemma 0.75	**0.8-1.5g**
Gemma 1.0	**1.0-2.0g**
Gemma 1.2	**2-20g**
Gemma 1.8	**5-20g**

Live feeding system developed during this project

During this OPEL project, an automatic system for feeding cod and other marine fish larvae was pioneered. The operation of this system involved the transfer of enriched rotifers into a 500 L capacity chill-down tank filled with 400 L of the micro alga (T. *Isochrysis galbana).* Rotifers were retained in this chill-down tank for between 4 and 20 hours. Rotifers were gently chilled from 20^{o}C to 14 ^{o}C by added freezer blocks to the tank. Oxygen and aeration was supplied to the tank to maintain adequate water quality conditions for the rotifers and algae. A pipe is connected into the base of the 500 L tank and directed into a 100 L white plastic vessel, which is located directly below the 500 L tank. Along the length of the pipe there is a solenoid valve connected to a timer. By periodically opening this valve, rotifers and algae were allowed to flow by gravity from the 500 L vessel into the 100 L vessel where they were mixed with a constant supply of seawater coming from the water reuse system. The depth of water in the 100 L tank was maintained a constant level by means of a floating ball valve. From the 100 L mixing vessel the rotifers/algae then flowed by gravity through a series of 15 mm hoses directly into the larval rearing tanks. The flow of rotifers, algae and seawater into each tank was controlled by a valve. As the larvae grew larger *Artemia* nauplii and enriched *Artemia* were added to the system and fed to each larval tank. The constant flow of water into the 100 L mixing tank and then into the feeding tubes help keep the system clean and only required manual cleaning once every three days. The 500 L chill-down tank however required cleaning on a daily basis.

Plate 5/ Fig. 4 Larval live feeding system for addition of algae, rotifers and *Artemia* to larval rearing tanks



The operation of this system greatly reduced the amount of time and labour involved in feeding cod larvae it also allowed the cod to be fed outside the normal working hours of the operators at MRI Carna. The main advantage of this gravity fed system is that rotifers are transferred into larval tanks without the need for peristaltic pumps which typically kill a proportion of rotifers by physical trauma.

Bacterial test

During the first production run of cod at MRI Carna in 2004, *Artemia* were incubated with a product called Hatch Controller, which the manufacturer claimed significantly reduced bacterial contamination in *Artemia* cultures. This product was unavailable for use in 2005. Qualitative bacterial dip tests were used in 2005 to assess the level of bacterial contamination in cultures. Levels of total viable counts were considered high and ranged from 10^3 to 10^4 per litre. Consequently, a water conditioner was added to the rotifer enrichment tanks during the last 30 minutes of enrichment at a dose rate of 50 ppm of Pyceze. *Artemia* culture tanks were also treated with Pyceze but at a higher dose rate of 150 ppm. Results of a study carried out at the research facility in Ardtoe, Scotland indicates that treatments with Pyceze results in reducing the bacterial levels in rotifer cultures by 90%.

Sampling protocols

Water samples were taken from three selected points in the water reuse system at least three times per week and analysed for temperature, salinity, unionised ammonia, nitrate, nitrite, pH and carbon dioxide. Oxygen concentrations were measured in effluent water from each larval tank on a daily basis. Flow rate of intake water was adjusted to maintain oxygen saturation levels about 85%.

The sample locations were:

1 The new seawater supply (seawater that has been filtered to 60 µm and UV irradiated
2 System re-use treated water
3 Effluent water from the water re-use system

Ammonia, nitrate and nitrite were measured using a HACH DR/820 – DR/850 Datalogging colorimeter. Salinity, oxygen and temperature were measured using a WTW multimeter. pH was measured using a Hach pH meter. CO_2 analysis is carried out on a weekly basis using a HACH automatic titrator. This overall sampling protocol allowed the operators to gauge the functioning of the water reuse system and appropriate changes were made to the operation of the system base on water quality data. All the results were recorded on log sheets and some of these are summarised below:

Sampling results MRI Carna

Fig. 5 Temperature and salinity of water re-use system with the second batch of fish

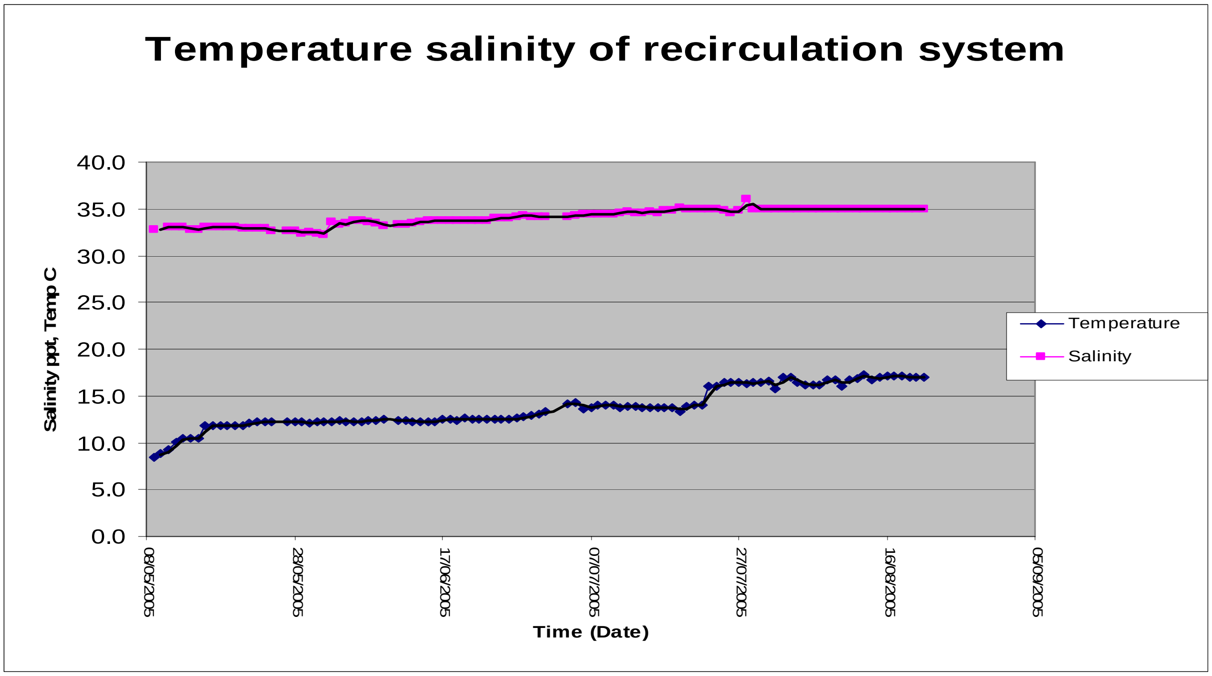


Fig. 6 Ammonia levels recorded within the WMT system during the second batch of fish

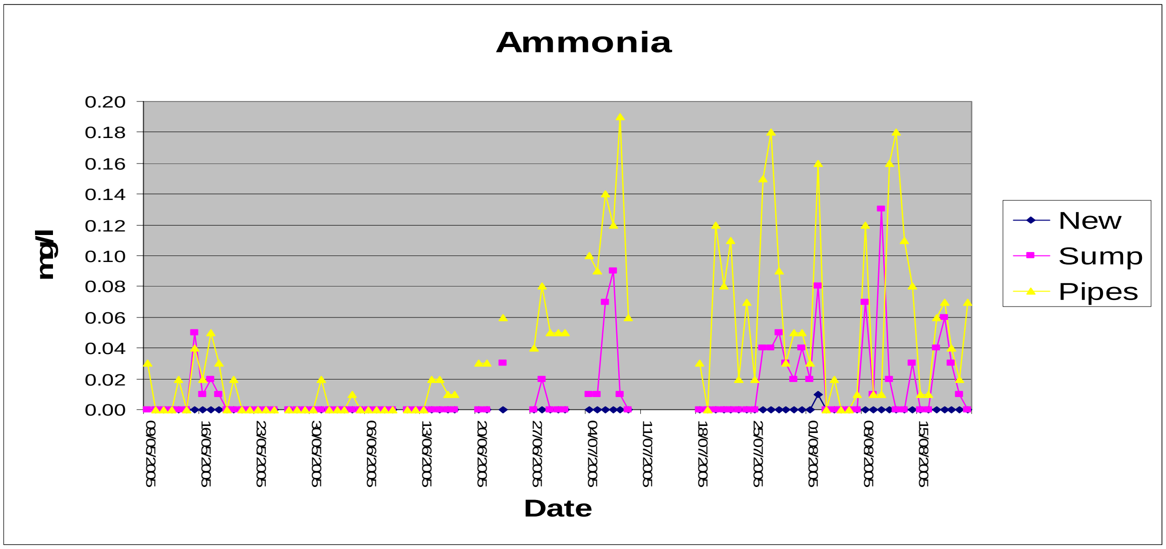


Fig. 7 Nitrite levels during the second batch of fish

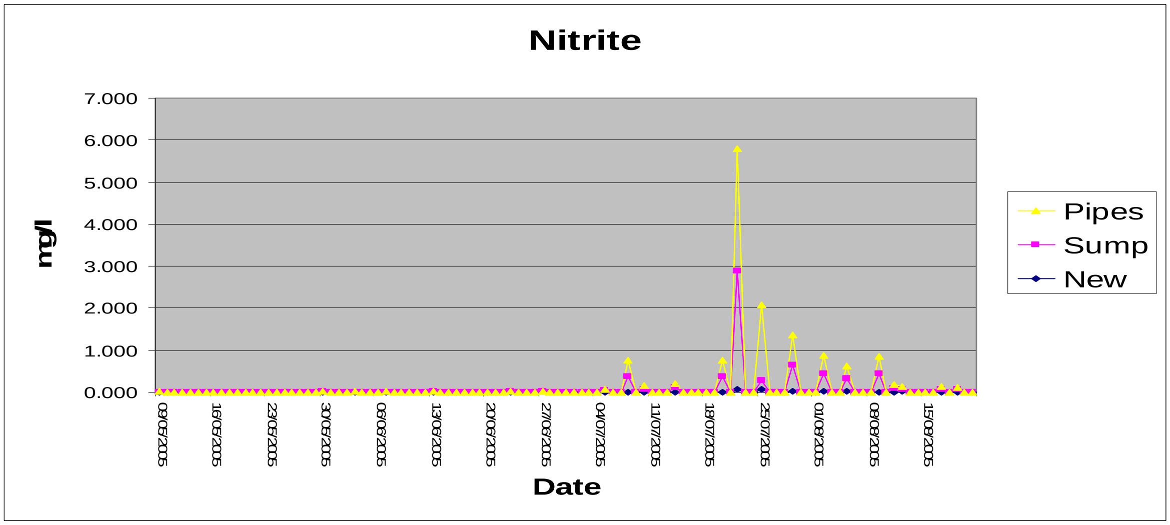


Fig. 8 Nitrate levels recorded during the second batch of fish

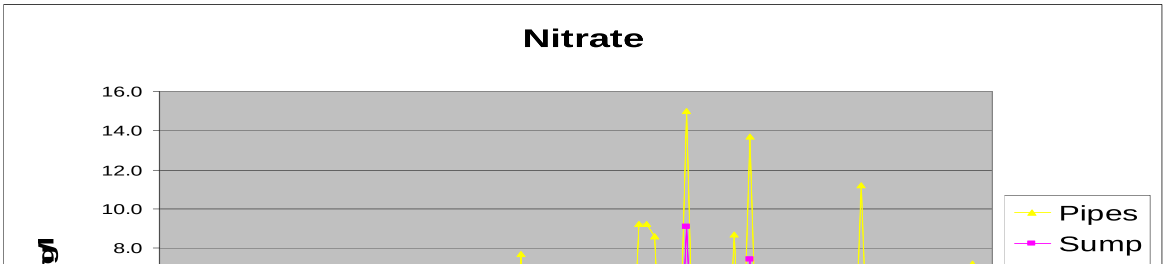


Fig. 9 Carbon dioxide levels in water re-use system

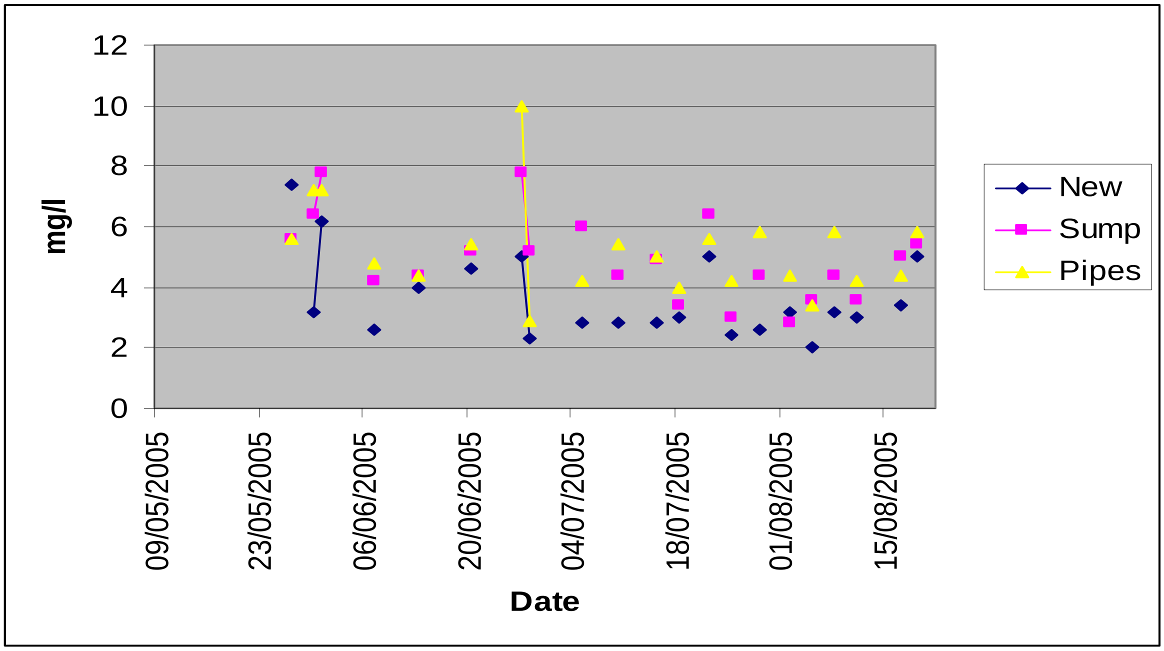
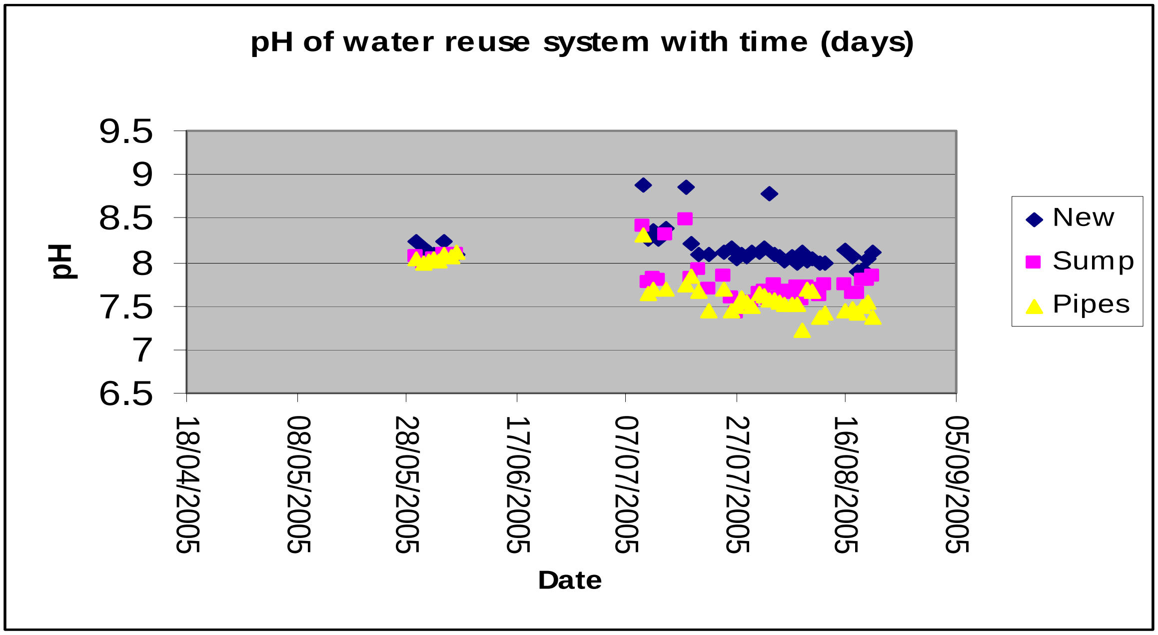


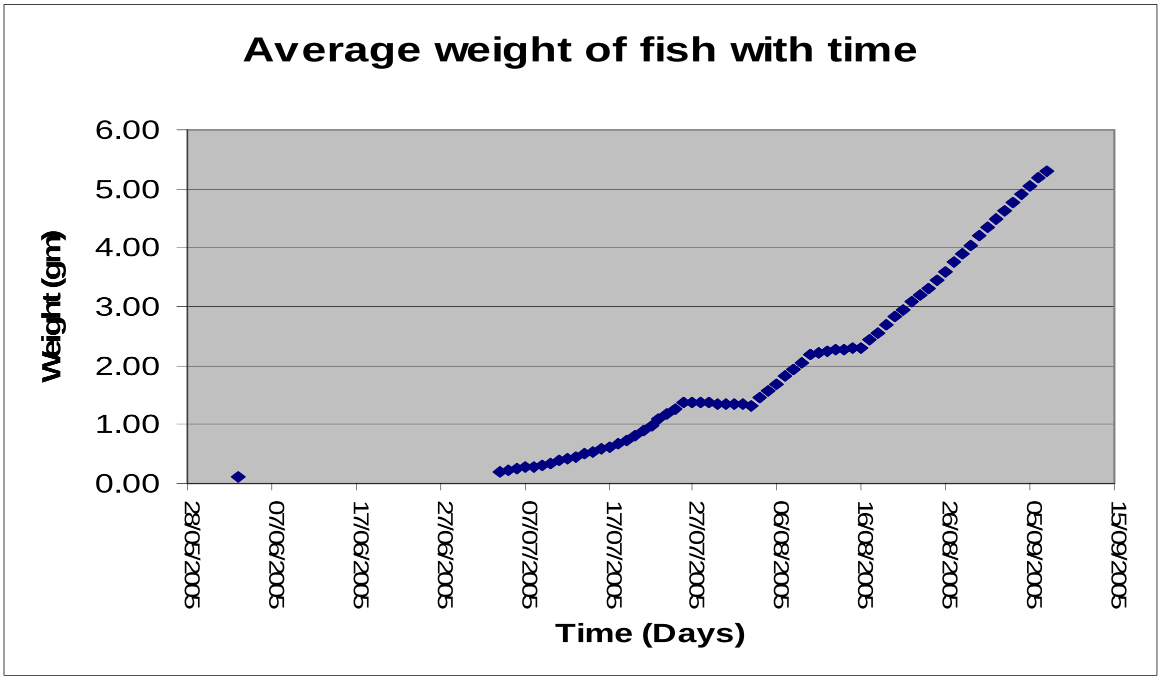
Fig. 10 pH levels in the water re-use system



Growth of cod larvae

Once fish were graded, batch sample weights were measured on a weekly basis to provide information on growth rates, feeding targets and total biomass of fish within the system.

Fig. 11 Growth of cod with time



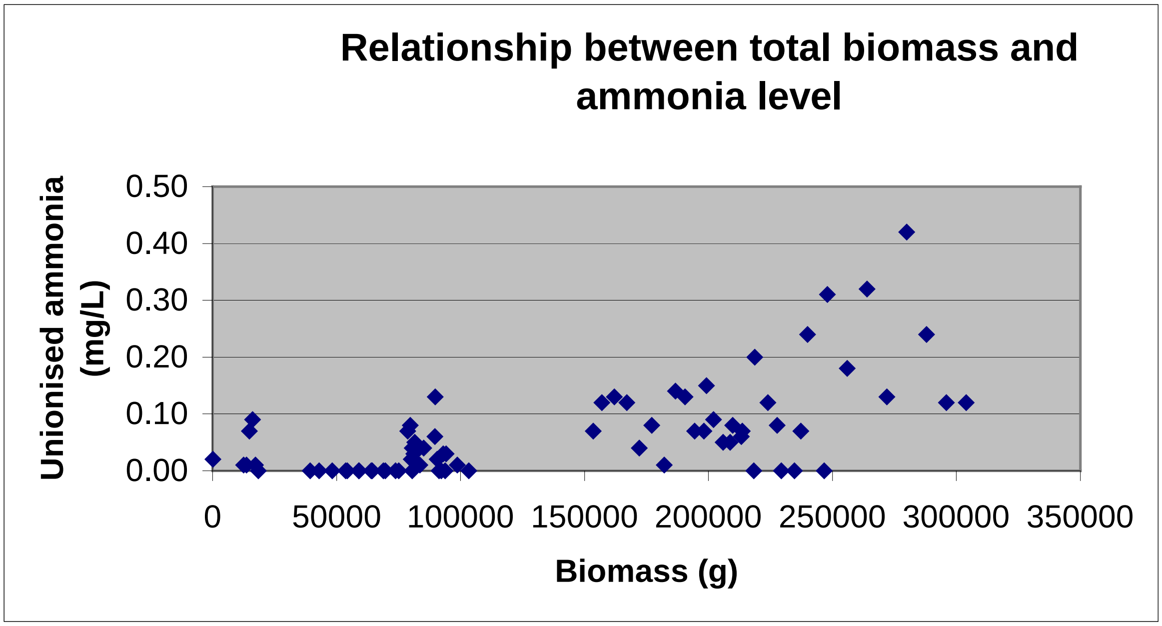
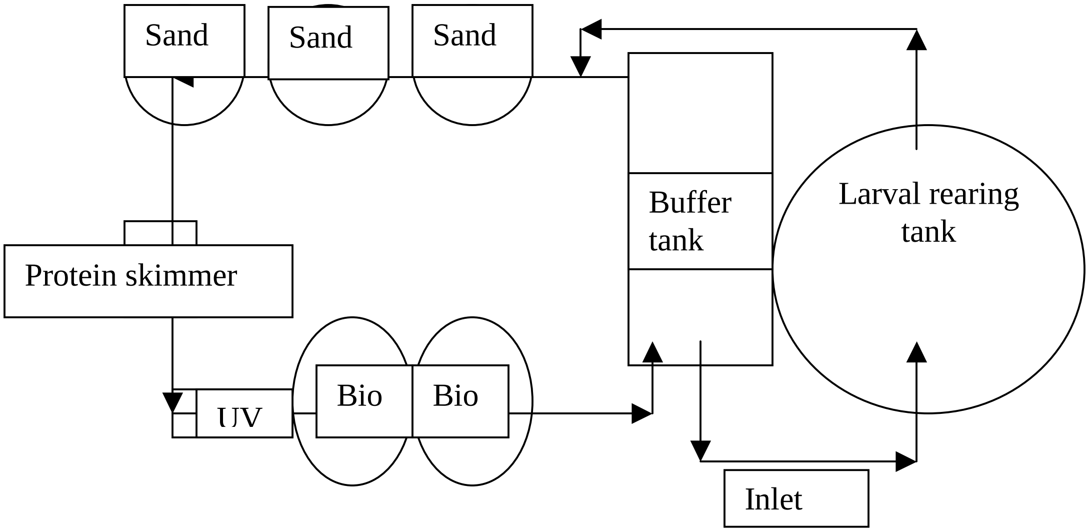


Figure 12. Demonstrates the relationship between the biomass of cod in the water reuse system and ammonia levels in the sump tank. It is noteworthy, that maximum design capacity of the WMT water reuse system is 450,000 g of fish.

Fosen As water systems

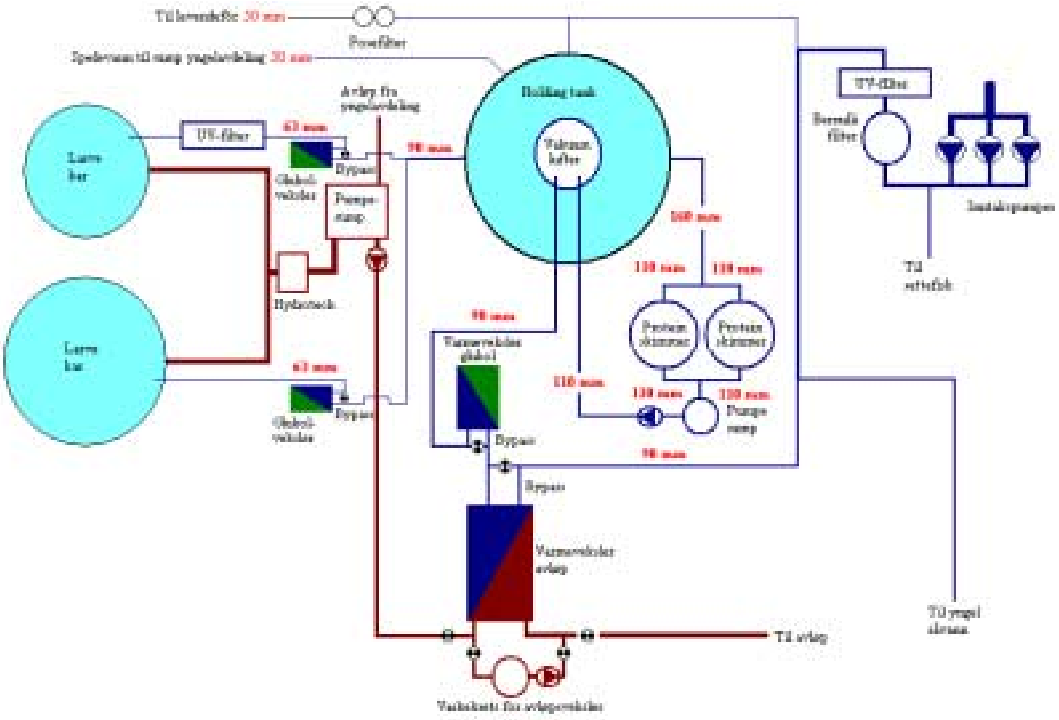
Fosens As. recycle system initially comprised a protein fractionator, UV irradiator, vacuum degasser, bio-filter and sand-filters. They operated the system with a relatively high rate of new water added to the system. Typically they operated at a rate of one exchange of new water volume per day. This equated to 20 m^3 of new water per day and a per-volume new water rate of 100%. This compares to an average new water rate of 66% at MRI Carna in 2005.

Fig. 13 Schematic for Fosen As water re-use system



The sampling programme funded by this Aquareg project has assisted in the decision making process for the system and protocol changes made at both Fosen As and MRI Carna. For example, Fosen As found that a component of their described water reuse system (sand filters) was responsible for increased the levels of the toxic compound hydrogen sulphide (H_2S). This problem was compounded by relatively high ammonia levels in the system. Expressed as unionised ammonia (NH_3), levels of over 1 mg/L were reported, which indicated the biofilter was incapable of maintaining unionised ammonia within safe levels of less than 0.2 mg/L.

As a result of the poor performance of the water reuse system, in terms of performance of cod larvae and poor water quality conditons, Fosen AS abandoned the use of the water reuse system. It was replaced with a flow-though water system, which integrated a series of water treatment elements into the intake water supply. The schematic technical drawing shown below illustrates the components of the new system.



Water is pumped from a depth of 70 m and passed through mechanical filtration, comprising a Bernoulli pressure filter, which removes particles larger than 200 µm in size. Water is then passed through a UV irradiator and then a titanium-plate heat exchanger. Heat is recovered from effluent water discharged from the larval tanks by passing through the counter-current flow of the heat exchanger. Water is typically heated to 10°C for the first 60 days post-hatch. To remove any excess dissolved nitrogen in the water as a result of heating, water is passed through a vacuum degaser. Water is fed by gravity from the degaser into two protein skimmers. Ozone is passed into the venturi inlet of each protein skimmer to disinfect the water and improve the efficiency of protein skimming. Water is then re-pressurized and pumped back into the vacuum degaser. A proportion of water is gravity fed from the degaser through a UV irradiator before being passed into the larval tanks. The second UV irradiator provides a dose rate of 60-75 mWs.cm^{-2} to ensure ozone residuals are completely destroyed before water is passed into the larval tanks. Effluent water from the larval tanks is gravity fed into a drum filter, which removes particles larger than 60 µm. Filtrate is then pumped to waste via the heat exchanger.

In Fosen Aquasenter during this project there were five batches of eggs introduced into their culture unit. Each batch comprised 6 L of eggs or approximately three million eggs. Three batches of eggs (approximately 1.5 million larvae) were subject to the intensive water treatment described, and two batches (approximately 1 million larvae) were reared in untreated seawater. Fosen As are not primarily concerned with percentage survival from egg to weaned juvenile but more with a consistent supply of good quality vigorous juveniles for transfer into sea cages.

Fig. 14 Inputs and production of fish with treated (yellow) and untreated water (blue)

	Date	Weight (g)	Nitrogen	Temp	Number
Input 1 A (water treatment)	01-Feb-05	0	92 - 99 %	8	6litre eggs
	01-Sep-05	30			150000
Input 2 (water treatment	21-Apr	0	92 - 99 %	8	6litre eggs
	01-Sep	2			150000
Input 3 (water treatment)	21-Apr-05	0	92 - 99 %	8	6litre eggs
	01-Sep-05	0.05			Poor survival
Input 1 B (no water treatment)	01-Mar-05	0	99 - 101 %	8	6litre eggs
	01-Sep-05	10			35000
Input 2 B (no water treatment)	21-Apr	0	99 - 101 %	8	6litre eggs
	01-Sep-05	0.05			1000

Initially, the water exchange rate in the larval tanks was set at a rate of two total exchanges per day. This rate was judged to balance the need to conserve live feed in the larval tanks for the optimum period, with the need to maintain adequate water quality conditions in the tanks. As the ability of juveniles to swim against water currents increased, the daily water exchange rate was incrementally increased to 15 exchanges per day around the time of weaning (approximately 30 days post hatch, depending on growth rates and water temperature). The seawater temperature was steadily increased from 7 ^{o}C during egg incubation to 12 ºC during the first week of feeding. Rotifers are fed from day two until day forty, and were weaned directly from rotifers onto inert food starting at approximately 30 days post-hatch (depending on temperature and growth rates). 'Green water', using *Nannochloropsis* paste was added to the larval rearing tanks between days 2-20 post-hatch. The photoperiod regime during larviculture was 24 hours light per day. Fosen As used several products for weaning: Gemma micro (Skretting), Aglonorse (Ewos) and Start (Dana Feed) and are currently refining feeding protocols for feeding with inert diets. Fosen typically feed juveniles on two brands of Dana feed, Wean-Ex and Dan-Ex, from 0.1 g to 50 g.

Micro algae at Fosen As

Before this Aquareg OPEL project commenced, Fosen As used inert micro-algal paste in their cod larval feeding tanks. As a result of observing the success in using live algae at other facilities and at MRI Carna, they converted over to using live micro-algae as part of their protocol for rearing cod and to facilitate this operation, they constructed a purpose built micro-algal unit.

Results

The results / production of fish indicate that during the winter period intensive water quality treatment resulted in vastly improved survival of fish compared to batches grown without water treatment. Unfortunately during the summer months the survival was not as good indicating that there is still a need to address water quality issues.

As a direct result of the first visit by MRI Carna staff to Fosen Aquasenter in November 2004, a decision was made to significantly modify design plans for the new MRI Carna water system. The initial design proved expensive both in terms of initial capital costs and also running costs. The design incorporated drum filters, several reservoir tanks and several secondary distribution pumps in the main seawater supply system. Several components in the original design were removed and replaced with two Bernoulli pressure filters, first seen in Fosen by MRI Carna staff during the first project meeting. These design alterations enabled the cost of the new MRI Carna seawater system to be reduced by approximately €100,000.

Conclusions

As a result of comparative water sampling between the two project partners, Fosen As changed from using a water reuse system which unfortunately did not work as well as anticipated to a vigorously treated flow through supply that gives good production results. Fosen As have also compared this treated flow through system with an untreated seawater supply and have found that the untreated supply yielded production batches of only 1,000 to 35,000 cod per six litres of eggs while the treated flow through system produced 150,000 fish per six litres of eggs in the first two batches. Fosen As also established a live algal production unit to augment their cod larval culture protocols.

Significant improvements were made in live feeding protocols and general husbandry techniques at MRI Carna, as a direct result of the collaboration and information exchange between the project partners. At MRI Carna, the automatic feeders provided a reliable and consistent supply of rotifers with reduced labour requirements. Standing stocks of rotifers ranging from 4-6 billion were maintained throughout the larval culture period and 600-1000 million rotifers were harvested each day. Hygiene protocols were changed during the enrichment process as a result of bacterial contamination. The automatic live feed feeding system, developed at MRI Carna during this project, significantly improved the feeding of microalgae, rotifers and *Artemia* to the larval tanks. Regular informal conversations between project partners proved important particularly regarding the re-design of the new water system at MRI Carna.

NB: In this report there are a number of commercial products named. It should be noted that this report is not an endorsement of these products.

References

King, N. 2003. Cod larval production in New Hampshire. *Hatchery International*. **Vol. 4**. Issue 3. 27-30.