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NUTRIENT EMISSION AND PELAGIC ECOSYSTEM EFFECT OF SALMON AQUACULTURE IN THE NORD-MØRE REGION

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Marine Coastal Development
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Thao Nguyen Thi Mai

Abstract

The main objective of this thesis was to estimate nutrient emission rate of carbon (C), nitrogen (N) and phosphorous (P) waste from salmon farms and to evaluate the environmental impact of salmon aquaculture on planktonic ecosystems in the Nord-Møre region in the summer period from June to September in 2011. The 22 fish farms in the Nord-Møre region produced 37,114 tonnes wet weight (WW) of fish in the period. Emission rates of nutrient wastes were estimated for every month based on information about the use of feed and the mean food conversion rate of the feed in the county, together with measurable coefficients describing the elemental C, N and P composition of feed and fish and digestibility of C, N and P components of the feed. Of the total feed input, 64 % C, 59.2 % N and 75.2 % P were released into the environment in the Nord–Møre area, corresponding to 390 kg C, 38.7 kg N and 7.8 kg P per metric tonne WW of fish produced. We predicted that 42 % of feed C and 47 % of feed N were respired as CO_2 and excreted as dissolved inorganic N (DIN), respectively, and 44 % of feed P was released as solid waste. Through the measurement, the results showed that there were no significant differences among nutrient concentrations and biological variables between sampling stations and respective reference stations. Therefore, we found that there was no effect from salmon fish farm activities in the Nord-Møre area in the summer period (Jun-Sep). Furthermore, with many fish farms surrounding the 2 sampling stations, we could expect the concentration of different nutrients and plankton biomass at sampling stations (PV1 & PV2) would be higher than those at respective reference stations (BA1 & BA2). However, the results showed that the concentration of different nutrients and plankton biomass at PV1 were lower than those at BA1 (except for particulate organic carbon concentration).

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1. Introduction

1.1. General introduction

Aquaculture is the food producing sector that has grown the fastest during the last decades. This is confirmed through data published by FAO, showing that while capture production has stayed around 90 million tonnes level since 2001, aquaculture production has continued to show a strong increasing in growth at an average annual growth rate of 6.1 percent from 34.6 million tonnes in 2001 to 55.7 million tonnes in 2009 (FAO 2009a).

Over the past 20 years, the salmon farming industry has rapidly expanded. Almost 60 percent of the world's salmon is now produced via aquaculture. There are several different salmon species, but the majority of the farmed salmon is Atlantic salmon *(Salmo Salar)* with global aquaculture production of more than 1.4 million tonnes in 2010 (Fig. 1.1) (FAO 2012).

Salmon is farmed in countries around the globe, but Norway has been the largest salmon aquaculture producer in the world during the last years. In terms of volume of production, there are three other countries, aside from Norway, which are major producers, namely, Chile, the UK and Canada (Fig. 1.2) (FAO 2009b).

With that worldwide fast growth, the salmon aquaculture industry has faced environmental concerns in recent years, among them the nutrients released by cage fish farms. The increase in aquaculture production has made the industry into a leading source of nutrients and organic matter to the aquatic environment in some countries (Elliott and Partners 1999).

According to the Norwegian Directorate of Nature Management " the aquaculture industry is the greatest source of human-created emissions of phosphorus and nitrogen in many countries" (DNM 1999). WWF have estimated, for example (WWF-Scotland 2000), that Scottish salmon farms discharge the sewage waste equivalent of over 9 million people (Scotland's population is 5.1 million tonnes).

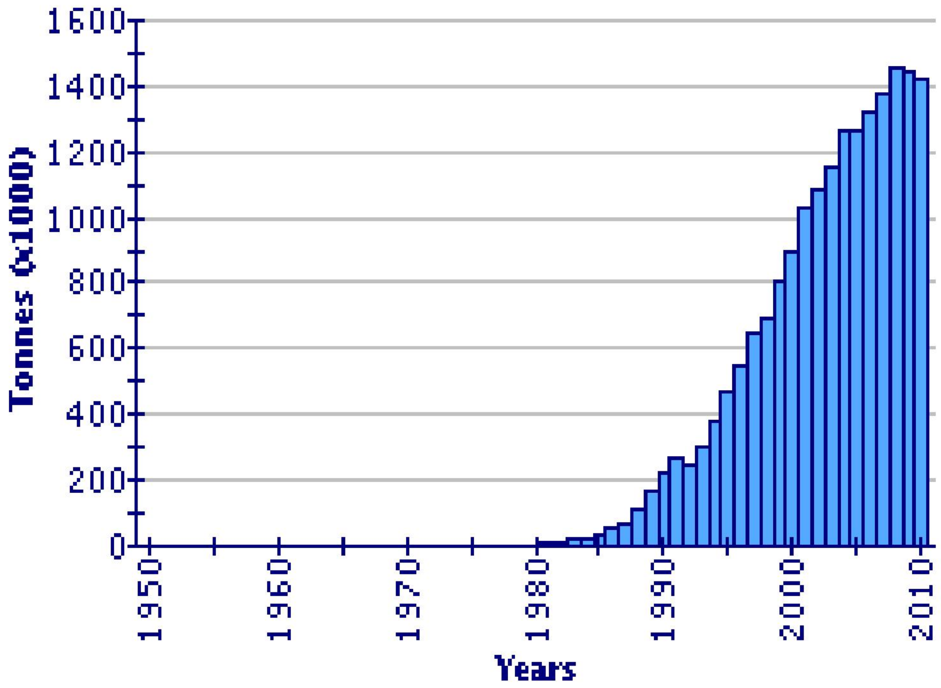

Figure 1.1. Global aquaculture production of Atlantic salmon *(Salmo salar)*

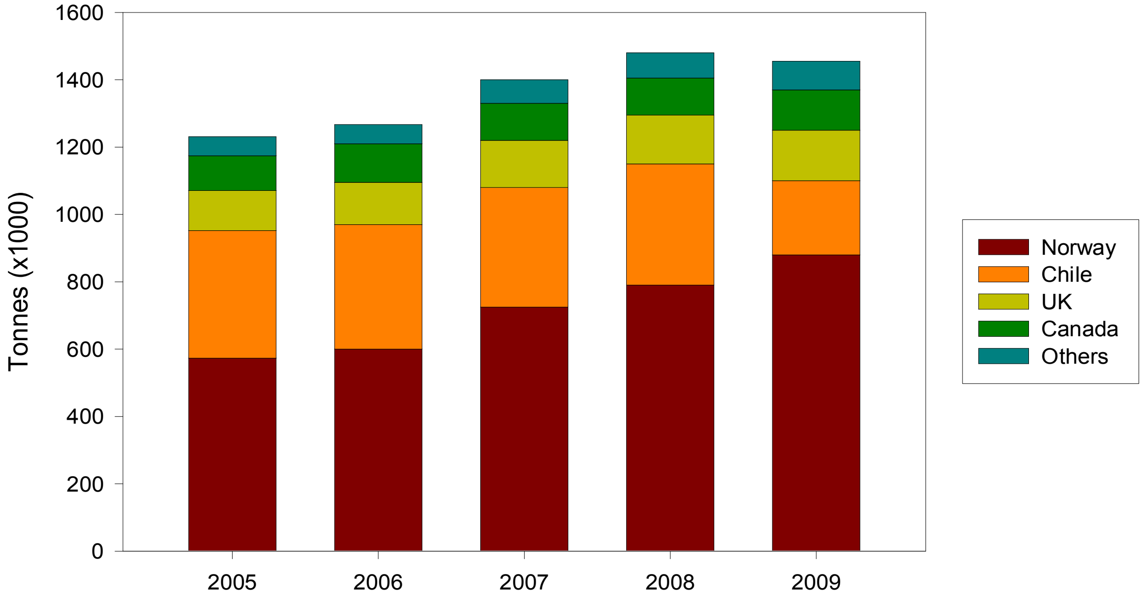

Figure1.2. World Production of Farmed Atlantic salmon

1.2. Nutrient releases from salmon aquaculture

While marine aquaculture has grown rapidly, so have concerns regarding the environmental impacts caused by the industry. The main concern is the release of solid and dissolved fish excretory products, including nutrients and these wastes may influence the marine environment (Azevedo, Podemski et al. 2011).

Composition of nutrient releases from salmon aquaculture can be divided into two group; particulate organic and dissolved waste. Individual fish release nutrients as dissolved inorganic nutrients through excretion (NH_4 and PO_4), particulate organic nutrients (PON and POP) through defecation, and dissolved organic nutrients (DON and DOP) through resuspension from the particulate fractions. Table 1 below summarizes the characteristics of the nutrient components released from cage aquaculture. On the scale of a fish farm, there will additionally be a direct loss of Feed-N and Feed-P (uneaten feed). These different waste components will affect different parts of the marine ecosystem (Olsen, Holmer et al. 2008).

1.3. Influence of salmon aquaculture on pelagic ecosystems

Following the above considerations, the different waste components form salmon cage aquaculture will affect different parts of the marine ecosystem (Table 1.1). Feed losses and the larger faeces particles will sink and affect sediments and benthic communities whereas dissolved inorganic nutrients and small faeces particles can affect the pelagic communities and the state and quality of euphotic waters. Inorganic nutrients released can affect phytoplankton in euphotic waters quite strongly in the upper mixed, illuminated layer of the water column where photosynthesis takes place. Organic dissolved nutrients are to a low extent available as nutrients for the phytoplankton (Olsen and Olsen 2008).

Number of reports on environmental impact assessment of salmon cage farming in several countries are available, among them some studies could specifically be pointed out (EAO 1996, Winsby et al. 1996, ASI 1999, Heining 2000, Nash 2001, Buschmann 2002, Crawford et al. 2002, SECRU 2002, Brooks and Mahnken 2003 a Carroll et al. 2003, Weber 2003) (Mehdi 2003).

However, all ecosystems have an inherent capacity of persistence, and smaller environmental changes are normally mitigated through adaptive responses of organisms. Major changes in ecosystem structure and function, be it reversible of irreversible changes, will only take place if the environmental signal, or the environmental interaction, is strong. For the pelagic ecosystem, nutrients may be efficiently assimilated without any harm as long as the input rate remains below a critical upper level, or the maximum assimilation capacity (Olsen, Holmer et al. 2008).

1.4. Estimation of nutrient release rate from fish farm

According to the concept of an "Ecosystem based Approach to Aquaculture" (Ecosystem Approach for Aquaculture), the fish farms should be managed as a part of the marine ecosystem. It is our understanding that wastes generated by aquaculture activity should be evaluated holistically based on nature's inherent capacity to assimilate inorganic nutrients and organic matter and the potential danger of exceeding these limits (Olsen, Holmer et al. 2008).

Mass balance model is considered as environmental management tools for the salmon cage farming industry. This model has been proposed to estimate the waste outputs from aquaculture operations. The nutrient emission from cage salmon aquaculture can be estimated by using feed use, fish production, nutrients in feed and fish, and digestibility of nutrient components as input data (Olsen and Olsen 2008).

1.5. Salmon aquaculture in the Nord-Møre region

Nordmøre (English: North-Møre) is a traditional district in the Norwegian county of Møre og Romsdal (Fig. 1.3) with the 6,059-square-kilometre area (http://en.wikipedia .org/wiki/Nordmøre). The coast of Nordmøre is one of the most favourable regions for the production of salmon, with appropriate temperatures all year round thanks to the Gulf Stream, good circulation of seawater and good access to appropriate sites (http://www.salmar.no/farming).

From Statistics Norway in 2011 (http://www.ssb.no/emner/10/05/fiskeoppdrett/arkiv/tab-2011-06-09-01.html) of ten counties, Møre og Romsdal was number three in production of salmon for food (108,026 tonnes) that contributed around 12% the total of production of salmon in Norway in 2010 (Fig. 1.4).

Table 1.1. Characteristics and fate of nutrient components released from aquaculture systems taken from Olsen and Olsen 2008

Nutrient component	Acronym	Characteristics and fate
Particulate nutrients	PON (particulate organic nitrogen) POP (particulate organic phosphorous)	Whole feed pellets, small to very small particles originating from the feed and fish faeces, and other particles generated in fish farms (e.g., fouling). Pellets and larger particles sink rapidly to the seafloor, consumed immediately by fish or other benthic organisms, or accumulated/decomposed in sediments. Small particles are suspended in the water column, consumed within days by filter feeders (mussels, zooplankton) and bacteria. Particles are not available for phytoplankton and macro algae.
Dissolved organic nutrients	DON (dissolved organic nitrogen) DOP (dissolved organic phosphorous	Molecular nutrient components (organic), mostly complex chemical compounds, released from faeces particles and feed, and other biological activity. Stable N and P components, available for phytoplankton on very long time scale, some components are very stable (>100 year lifetime). To some extent consumed by bacteria-microbial food web, can aggregate and sink (marine snow), relatively slow process
Dissolved inorganic nutrients	DIN, dissolved inorganic nitrogen (ammonium, NH_4) DIP, dissolved inorganic Phosphorous (phosphate PO_4)	Inorganic nutrients, i.e., ammonia (urea dissolves into ammonia) and phosphate Immediately taken up by phytoplankton, macro algae, and also by bacteria, used for growth, can in the worst case generate algal blooms.

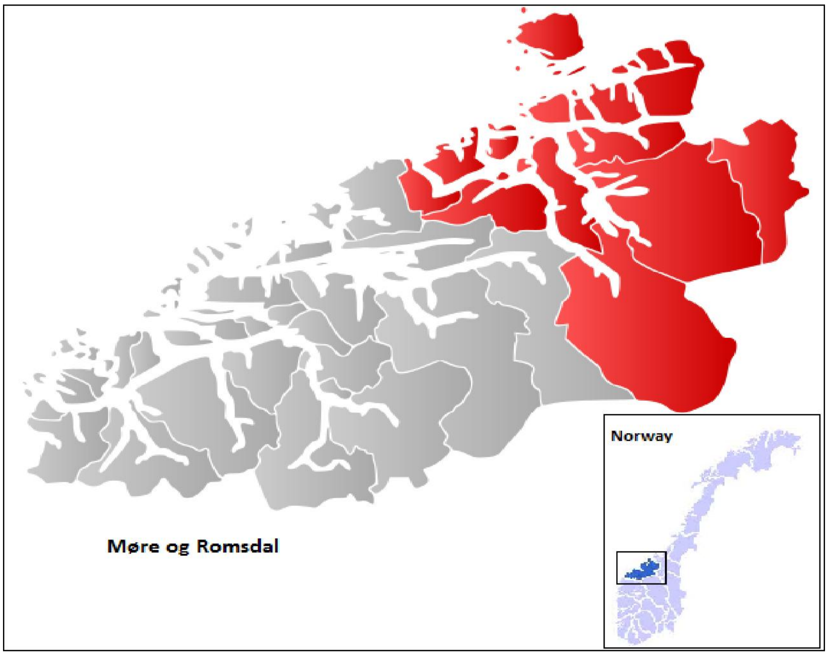

Figure 1.3. Map of the county Møre and Romsdal, with the Nord-Møre region highlighted in red color

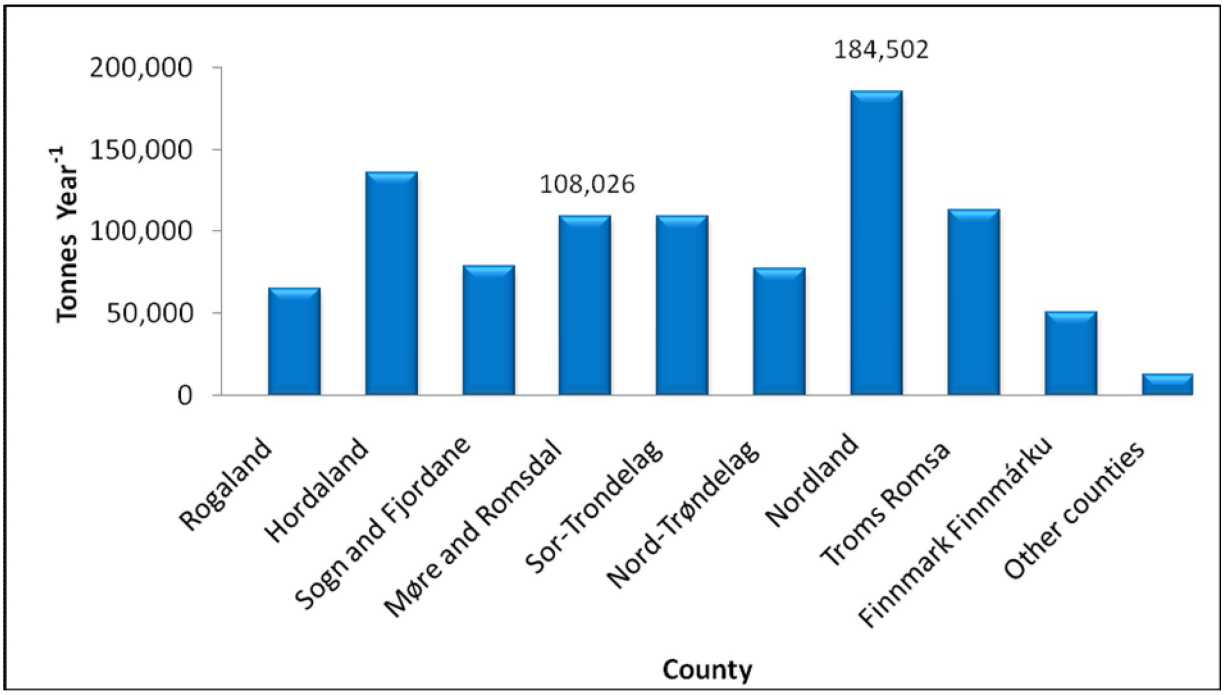

Figure 1.4. Production of salmon by county in Norway in 2010

1.6. Aim of the study

The main objective of the thesis was to estimate nutrient emissions from salmon farms and to evaluate the environmental impact of salmon aquaculture on the planktonic ecosystems in the Nord-Møre region.

The following sub-objectives were formulated:

1) Based on the information on use of feed from fish farmers, to calculate the emission rates of wastes from the individual fish farms in the Nord-Møre region.

2) To analyze samples of nutrient and chlorophyll *a* taken from two sampling stations and two reference stations in the Nord-Møre area.

3) To compare the results of the measurements with the emissions from the fish farms and question if there were differences in concentrations of nutrients and phytoplankton in sampling stations as compared with the reference stations.

2. Materials and methods

2.1. Nutrient emission from cage salmon aquaculture in the Nord-Møre area

Emission rates of nutrient wastes were calculated for every month, from June to September based on information about the use of feed at 22 difference fish farms.

2.1.1. Quantification of nutrient emission from cage salmon aquaculture

Calculating the emission rate of wastes from the individual fish farm in the Nord-Møre region was based on a mass balance model (Olsen and Olsen 2008), by using feed use, fish production elemental C, N and P composition of feed and fish and the digestibility of N and P of the feed nutrient components as input data (Fig. 2.1).

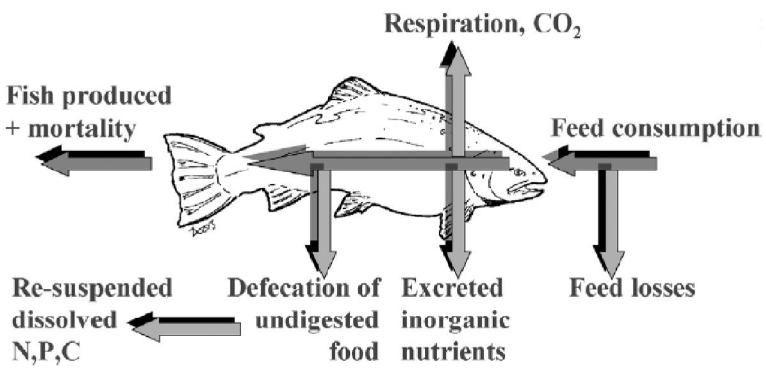

Figure 2.1. Schematic allocation pathways of C, N, and P (energy and materials) in fish. Feed losses and mortality are relevant flows on the population level.

According to Olsen and Olsen (2008), the carbon (energy) mass balance for the flow of matter through a fish can be represented by the following simple mass balance equation:

$$I = A + F = G + R + F$$

Where I is food consumed; A is assimilated food, or uptake in tissues; F is defecation; R is respiration, and G is growth and reproduction (all in terms of carbon or energy). The corresponding nutrient balance is expressed using the analogue equation below, where excretion of N and P (E_{NP}) replaces respiration.

$$I_{NP} = A_{NP} + F_{NP} = G_{NP} + E_{NP} + F_{NP}$$

The processes of respiration and excretion release inorganic carbon and excess inorganic nutrients, respectively, from fish tissues (assimilated matter) to the water. Respiration is a loss of carbon dioxide (CO_2) reflecting the metabolic costs of growth and maintenance of the organisms. The excreted N and P species are mainly inorganic nutrients wastes, i.e. urine (urea-N, PO_4) and ammonia (NH_4).

2.1.2. Food conversion ratio

The food conversion ratio (FCR) is defined as the amount of dry food consumed per wet fish biomass produced (Olsen, Holmer et al. 2008). It is a commonly used measure in the aquaculture industry to assess the efficiency of growth relative to feed used (Costa-Pierce, Olsen et al. 2007). High FCRs have been linked to poor water quality (Kelly and Elberizon 2001). Therefore, reduction of feed loss and improvements in nutrient conversion efficiency to reduce (improve) FCR is considered as a way to reduce environmental effects. To farmed Atlantic salmon, it takes between 1.1 and 1.2 kilograms of feed to grow one kilogram. In my study, FCR was set to 1.15, representative for the region.

2.1.3. Feed losses

Feed loss has long been cited as a major contributor to waste generation from commercial salmon farms. In the pioneering days of intensive salmon aquaculture, waste of feed was a significant contributor of solids exiting fish cages (Costa-Pierce, Olsen et al. 2007). Early estimates of feed loss in open cage aquaculture were around 20% (Beveridge 1987). Feed loss has been reduced significantly in recent years, in part due to improved waste pellet detection mechanisms. The level of feed uneaten by fish and lost directly to the environment was set at 3% (Cromey, Nickell et al. 2002) (Table 2.2).

2.1.4. Leaching of dissolved organic matter from waste particles

In general, the leaching rates of faecal carbon and faecal nitrogen after a few minutes immersion in sea water were about 15% (Chen, Beveridge et al. 2003). This will add to the dissolved organic carbon (DOC) and nitrogen (DON) pools of the water column. Sugiura, Merchant et al. (2006) studied P leaching from salmon faeces. They found that approximately 15% of faecal P was soluble in during minutes to hours. Phillips, Clarke et al. (1993) found the leaching from feed was about 15% of total P.

Table 2.1. Release of dissolved organic carbon (DOC), nitrogen (DON) and phosphorous (DOP) from particulate aquaculture waste

Particle type	Release rate of dissolved organic matter from faeces and feed particles	Substance released	Reference
Salmon faeces and feed wastes	ca 15% loss of C and N in 2.5 minutes, then stops (on short timescale)	DOC, DON	Chen, Beveridge et al. (2003)
Salmon faeces	ca 15% of P released in minutes to hours	DOP	Sugiura, Merchant et al. (2006)
Salmon feed	ca 15% of P released in minutes to hours	DOP	Phillips, Clarke et al. (1993)

Table 2.2. Values of model coefficients for water content of feed and fish, the assimilation efficiency of feed carbon (C), nitrogen (N) and phosphorous (P), the content of C, N and P in feed and fish

Coefficient	Value	References
Feed losses (%)	3	Corner, Brooker et al. (2006)
Water in feed (% DW)	2	Wang, Olsen et al. (2012)
Dry matter in fish (% WW)	36	Wang, Olsen et al. (2012)
Carbon (C)		
Assimilation efficiency (AE)	0.80	Cheshuk, Purser et al. (2003), Corner, Brooker et al. (2006)
C content in feed (% DW)	54.0	Wang, Olsen et al. (2012)
C content in fish (% DW)	60.6	Wang, Olsen et al. (2012)
Nitrogen (N)		
AE	0.85	Trygve Lea, Skretting AS
N content in feed (% DW)	5.80	Wang, Olsen et al. (2012)
N content in fish (% DW)	7.40	Wang, Olsen et al. (2012)
Phosphorous (P)		
AE	0.50	Bureau, Gunther et al. (2003), Reid, Liutkus et al. (2009)
P content in feed (% DW)	0.90	Wang, Olsen et al. (2012)
P content in fish (% DW)	0.64	Wang, Olsen et al. (2012)

2.2. Analyze of nutrient concentrations and chlorophyll *a* from the Nord-Møre area

2.2.1. Sampling stations

The 4 stations were established in the Nord-Møre coastal region. They were marked with dots on the map (Fig. 2.2).

Two red dots for the sampling stations were located at the fish farms with the positions following:

- PV1: Between Frei and Averøy (N63,0111°; E7,7430°)
- PV2: North West of Smøla (N63,4622°; E8,1824°)

Two blue dots for the reference stations were placed further away from the farms with the position following:

- BA1: Outside Averøy (N63, 1037°; E7,5271°)
- BA2: East of Smøla (N63,4158°; E7,7009°)

Samples were taken every week from Week 23 in June to Week 39 in September 2011, a total of 17 samplings.

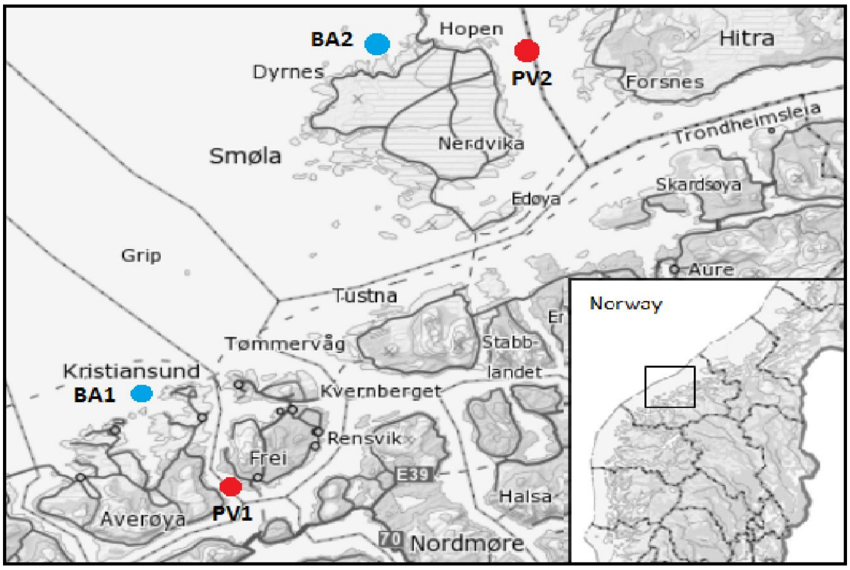

Figure 2.2. Map of sampling area in the Nord-Møre region. *Source: Norwegian Mapping Authority*

2.2.2 Analytical work

Analytical work was conducted at Trondheim Biological Station (TBS), N-7491 Trondheim, Norway. The thesis forms part of the project "Prosjekt Miljødokumentasjon Nordmøre".

Samples from 2 sampling stations and 2 reference stations were analyzed for nutrients and chlorophyll *a* (chla) after filtration through 200 µm plankton net to remove larger organisms. The procedures were as follow:

3000 ml of 200 µm net filtered water samples for analysis of chla, particulate organic carbon (POC), particulate organic nitrogen (PON) and particulate organic phosphorous (POP) were collected on 47 mm GF/F glass-fibre filters.

Chla: The sub-samples of the 47 mm filter for chla analysis were extracted in methanol, and quantified by fluorometry on the Turner designs fluorometer (NS4767 1983). There were 2 replicate samples analyzed for chla.

POC: The sub-samples of the 47 mm filter for POC analysis were placed in fumes of hydrogen chloride (HCl 38%) for 20 minutes to remove any inorganic carbon. Then all of them were packed in 5 x 9 mm tin capsules (using steel tweezers). POC analysis was undertaken by SINTEF Fisheries and Aquaculture. There were 2 replicate samples analyzed for POC.

Dissolved Inorganic Phosphorous (DIP): 10 ml of the water that went through 47 mm GF/F glass-fibre filters (above) was analyzed for DIP. All of samples were autoclaved at 120 ^{o}C for 30 minutes and analyzed by Autoanalysator (O.I. Analytical Flow Solution IV) (NS4725 1984). 3 replicate samples were analyzed for DIP.

POP: 10 ml of H_2O was added into the 20 ml polyethylene scintillation vial that contained the sub-samples for POP analysis. 0.1 ml 4M H_2SO_4 (1 drop) and 2 ml oxidizing reagent Potassium peroxidisulphate were added into all the samples. The samples were shacked after each addition and autoclaved at 120 ^{o}C for 30 minutes. All of samples were analyzed by Autoanalysator (O.I. Analytical Flow Solution IV) (NS4725 1984). There were 2 replicate samples analyzed for POP.

DIN (Dissolved inorganic nitrogen): 8 ml of water that went through 47 mm GF/F glass-fibre filters (above) was analyzed for DIN. All of samples were autoclaved at 120 ^{o}C for 30 minutes and analyzed by Autoanalysator (O.I. Analytical Flow Solution IV. There were 3 replicate samples were analyzed for DIN.

PON: The sub-samples of the 47 mm filter for PON analysis were placed in fumes of hydrogen chloride (HCl 38%) for 20 minutes to remove any inorganic carbon. Then all of them were packed in 5 x 9 mm tin capsules (using steel tweezers). PON analysis was undertaken by SINTEF Fisheries and Aquaculture. There were 2 replicate samples analyzed for PON.

REAGENTS

Sulphuric acid, 4M

Add 220 ml of concentrated sulphuric acid to 750 ml H2O. Allow the solution to cool and adjust the volume with H2O to 1000 ml.

Oxidising reagent, Potassium peroxidisulphate (max 0.001% N)

Dissolve 25 g potassium peroxidisulphate in 500 ml H2O. Warm carefully if necessary. Store in an amber glass flask. Stable for at least 2 weeks

Routine standard solution:

1 µM phosphorus (NaH2PO4,H2O) dissolved in 3% NaCl

2.3. Data analysis and processing

All statistical analyses were performed in SigmaPlot® for Windows version 11.0 (Systat Software, Inc., 2008) with a significant level of $\alpha = 0.05$. T-tests were used for comparisons of treatments when significant differences were found. Data are presented as means ± standard error (S.E.). All tables were made in Microsoft Office Word for Windows (Microsoft Inc.). All data input were made in Microsoft Office Excel before transfer to in SigmaPlot. All graphs were made in SigmaPlot.

3. Results

3.1. Estimation of nutrient release rate from fish farms in the Nord-Møre region

The main fish farms with the feed consumption and the percentage of the total kg feed input from June to September in the Nord-Møre area are shown in Table 3.1. The value of the total kg feed consumption of main fish farms are sorted from largest to smallest. Solværet was the fish farm with the highest feed consumption (5,880,479 kg; 13.8 % of the total) and the smallest feed consumption was 1901 – Sveggvika (11,500 kg; 0.03 % of the total).

Table 3.1. The main fish farms with the highest feed consumption in the Nord-Møre area

No	Fish Farms	Latitude (N)	Longitude (E)	Total kg feed consumption (June – September)	% of the total
1	Solværet	63.255000	7.856933	5,880,479	13.8
2	Reiråklakken	63.450250	8.168853	4,847,278	11.4
3	Bremnessvaet	63.397950	8.214317	4,445,622	10.4
4	1012 - Halsbukta	63.077685	8.143622	3,978,799	9.32
5	1011 - Seglråa	63.149745	8.128550	3,580,416	8.39
6	Korsneset	62.960383	7.450150	3,367,462	7.89
7	1001 - Endreseth	63.030183	7.716150	2,648,386	6.21
8	Leite	63.035983	7.678117	2,268,861	5.32
9	1013 - Skåren	63.076733	8.193150	1,975,563	4.63
10	Gjeldsøya	63.482617	8.280283	1,891,355	4.43
11	Hjortholmen	63.457733	7.856100	1,805,026	4.23
12	Blomvikbugen	63.281766	8.453784	1,548,120	3.63
13	Hogsneset Nord	63.099517	7.670333	1,064,021	2.49
14	1002 - Hogsneset Sør	63.099517	7.670333	801,718	1.88
15	Hunnhammervika	62.863367	8.157583	764,000	1.79
16	1113 - Vullum	63.048950	8.216350	603,288	1.41
17	1111 - Bogen	63.077667	7.903450	436,719	1.02
18	1111 - Vikagjelen	63.075783	7.906067	364,810	0.85
19	Kornstad	63.142733	8.224933	161,695	0.38
20	Or	63.042092	7.849293	161,500	0.38
21	Hegerbergtrøa	62.883933	8.149917	74,000	0.17
22	1901 - Sveggvika	63.087325	7.590048	11,500	0.03

Figure 3.1 shows the geographical position of the fish farms. The size of the dots illustrates the relation size of the farms (Table 3.1).

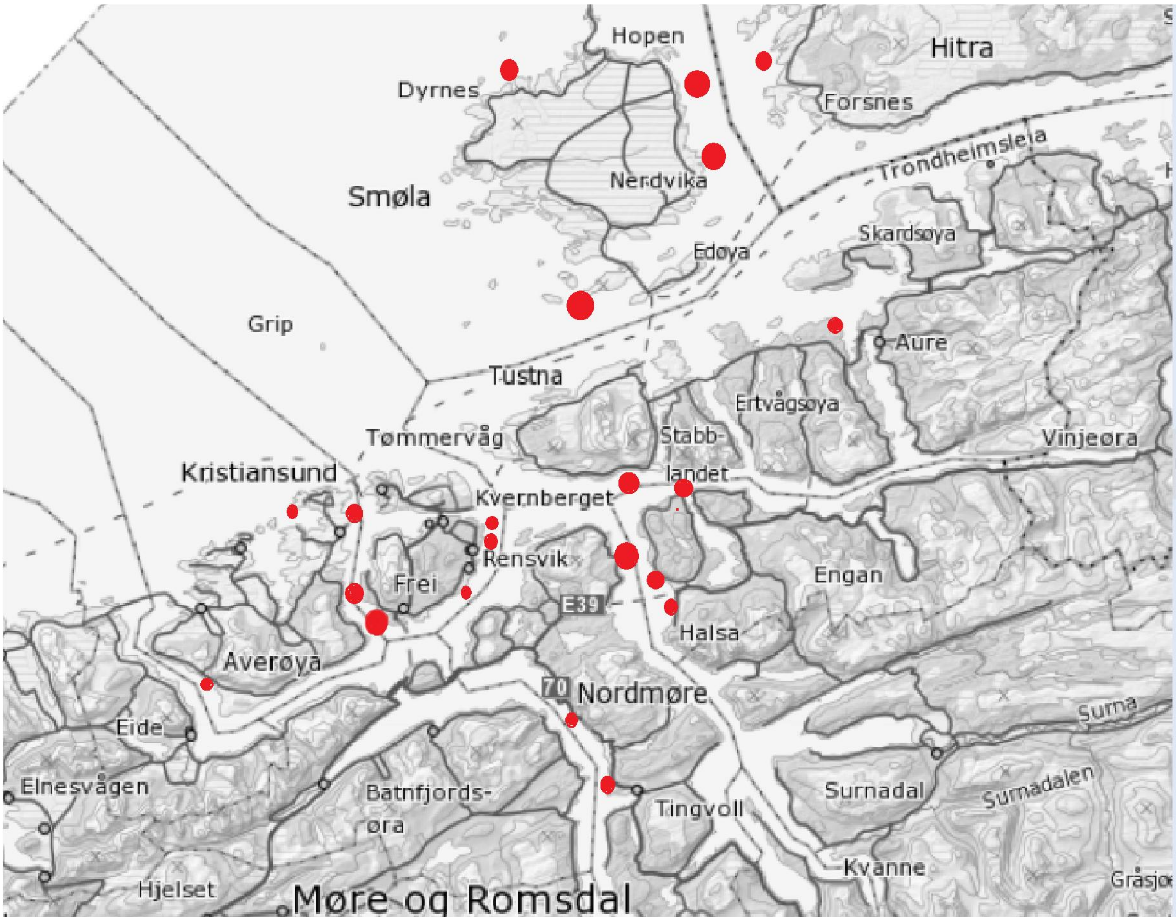

Figure 3.1. Map of the main fish farms in the Nord–Møre area

Figure 3.2 shows monthly input of feed and fish production at the main fish farms in the Nord-Møre region from June to September. Both fish production and fish feed input increased gradually from June until August where after they deceased slightly in September. Fish production ranged from 70,000 to 108,000 tonnes per month and the use of fish feed varied between 80,000 and 124,000 tonnes. The total amount of feed used (dry weight) and fish production (wet weight) in the main fish farm during this summer period was 42,681 and 37,114 tonnes, respectively (55.1 % of the year 2011).

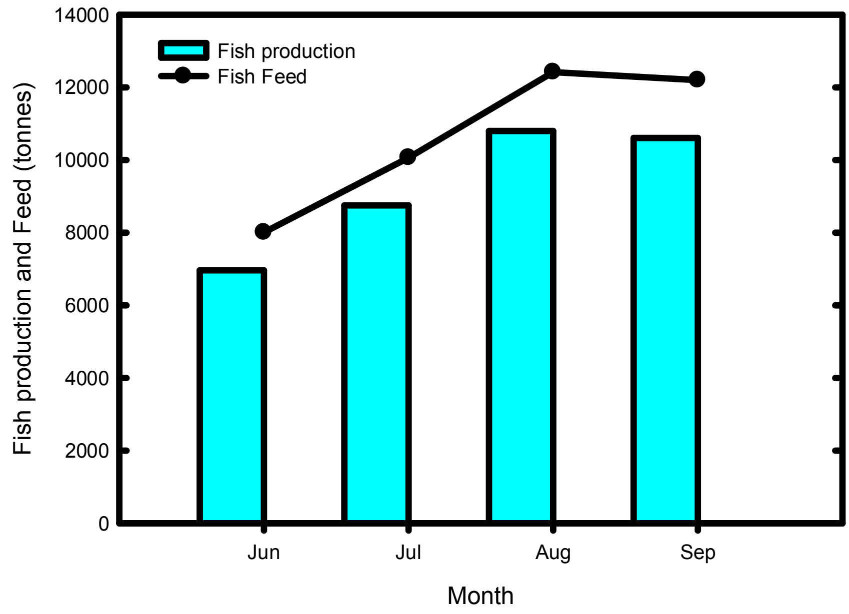

Figure 3.2. Quantity of fish production and fish feed used to cages from June to September at the main fish farms

3.1.1. Emission rates of wastes from selected individual fish farms

Based on the total feed input (Table 3.1), the emission rates of wastes from the four fish farms with the highest feed input are as follow.

Figure 3.3 shows the time course of DIN, DIP, POC, PON and POP (including feed losses and defecation) from Solværet. The emission rates of different waste components were at their maximum in July where after they decreased. The DIN losses ranged from 31.2 to 44.5 tonnes per monnth while the losses of DIP was estimated to 2.5-3.5 tonnes. The value of POC losses (feed losses and defecation) were much higher than the losses of PON and POP. The POC originating from feed losses and defecation varied between 18.7 and 26.7 and between 121 and 173 tonnes per month, respectively, while PON feed losses and defecation losses ranged only from 2.0 to 2.9 and 6.5 to 9.3 tonnes per month, respectively. POP losses were lower than PON losses. Loss of POP varied between 5.0 and 7.2 tonnes per month for defecation and between 0.3 and 0.4 tonnes for feed losses.

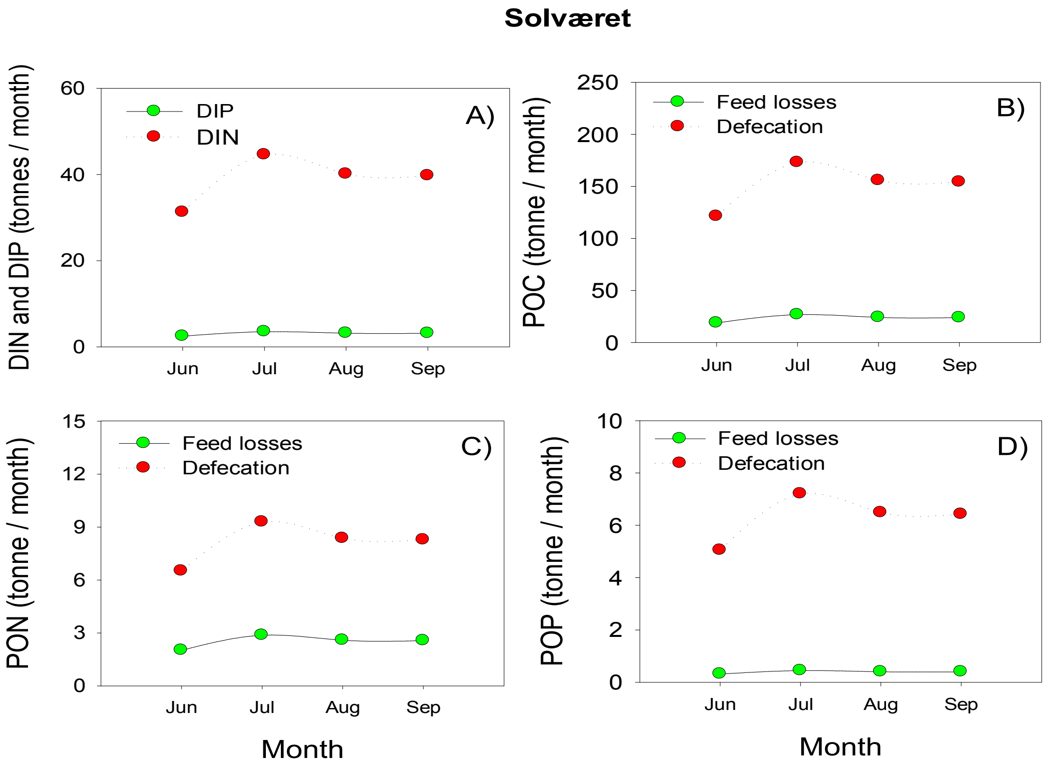

Figure 3.3. Time course of nutrient release rates at Solværet. (A): dissolved inorganic N (DIN) and P (DIP); (B): particulate organic C (POC), including POC of feed losses and POC of defecation; (C): particulate organic N (PON), including PON of feed losses and PON of defecation; and (D): particulate organic P (POP), including POP of feed losses and POP of defecation, respectively.

Figure 3.4 shows the time course of DIN, DIP, POC, PON and POP (including feed losses and defecation) from Reiråklakken. The emission rates of different waste components increased from June, were at their maximum in August and decreased slightly in September. The DIN losses ranged from 12.3 to 40 tonnes per month while the losses of DIP was between from 1.0 to 3.1 tonnes. The value of POC losses (feed losses and defecation) were much higher than the value of PON and POP losses. The POC originating from feed losses and defecation varied between 7.4 and 23.9 and between 47.9 and 154 tonnes per month, respectively, while PON feed losses and defecation ranged only from 0.7 to 2.6 and from 2.6 to 8.3 tonnes per month, respectively. POP losses were not much lower than PON losses. The losses of POP varied between 2.0 and 6.4 tonnes per month for defecation and between 0.1 and 0.4 tonnes for feed losses.

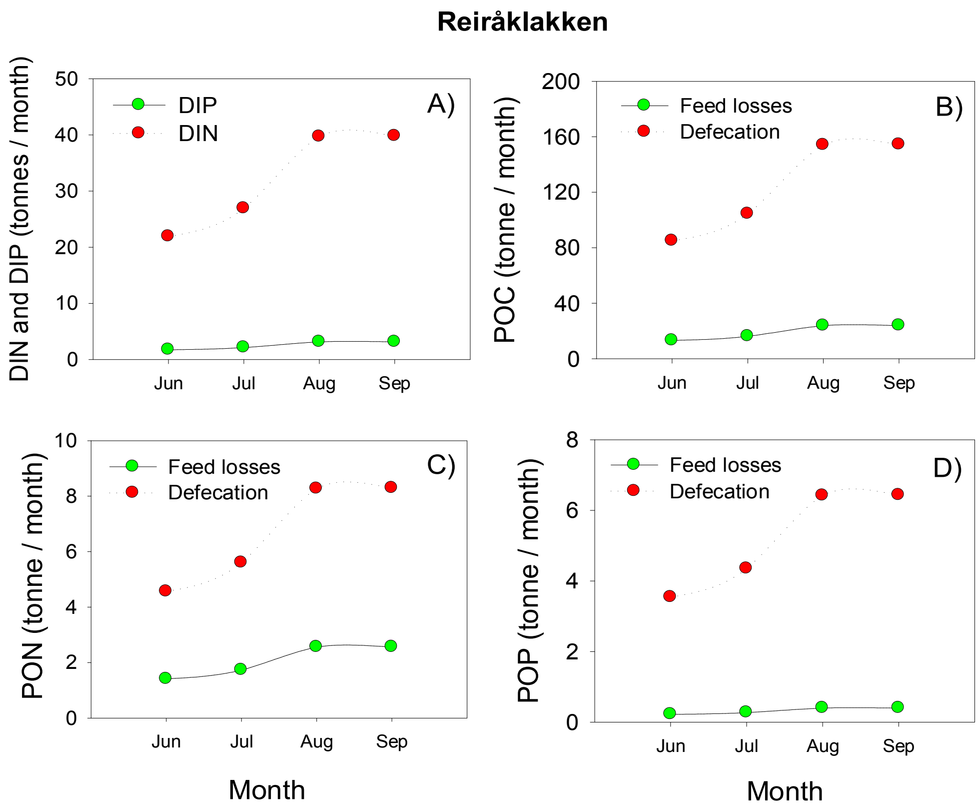

Figure 3.4. Time course of nutrient release rates at Reiråklakken. (A): dissolved inorganic N (DIN) and P (DIP); (B): particulate organic C (POC), including POC of feed losses and POC of defecation; (C): particulate organic N (PON), including PON feed losses and PON of defecation; and (D): particulate organic P (POP), including POP of feed losses and POP of defecation, respectively.

Figure. 3.5 shows the time course of DIN, DIP, POC, PON and POP (including feed losses and defecation) from Bremnessvaet. The emission rates of different waste components were at relatively constant through June to September. The DIN losses ranged from 28.0 to 30.9 tonnes per month while the losses of DIP was between from 2.2 to 2.4 tonnes. The value of POC losses (feed losses and defecation) were much higher than the value of PON and POP losses. The POC originating from feed losses and defecation varied between 16.8 and 18.5 and between 108 and 120 tonnes per month, respectively, while PON feed losses and defecation ranged only from 1.8 to 2.0 tonnes and from 5.8 to 6.4 tonnes per month, respectively. POP losses were lower than

PON losses. The POP losses varied between 4.5 and 5.0 tonnes per month for defecation and between 0.2 and 0.3 tonnes for feed losses.

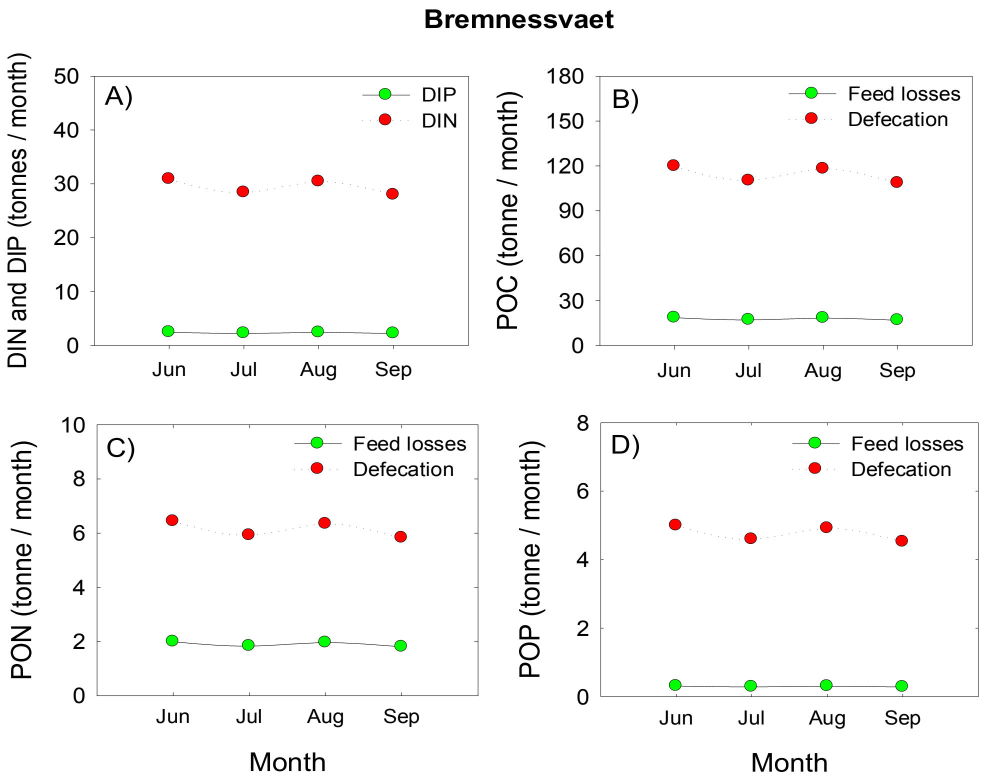

Figure 3.5. Time course of nutrient release rates at Endreseth. (A): dissolved inorganic N (DIN) and P (DIP), (B): particulate organic C (POC) including POC feed losses and POC defecation, (C): particulate organic N including PON feed losses and PON defecation, and (D): particulate organic P including POP feed losses and POP defecation, respectively.

The time course of DIN, DIP, POC, PON and POP (including feed losses and defecation) from Halsbukta is showed in Figure 3.6. The indicate emission rates of different waste components was at their maximum in August where after they decreased. The DIN losses ranged from 20.6 to 30.8 tonnes per month while the losses of DIP varied between from 1.6 to 2.4 tonnes. The value of POC losses (feed losses and defecation) were much higher the losses of PON and POP. The POC originating from feed losses and defecation varied between 12.4 and 18.5 and between 80.1 and 119 tonnes per month, respectively, while PON feed losses and defecation ranged only from

1.3 to 2.0 and from 4.3 to 6.4 tonnes, respectively. The POP losses were not much lower than the PON losses. The POP losses varied between 3.3 and 5.0 tonnes per month for defecation and between 0.2 and 0.3 tonnes for feed losses.

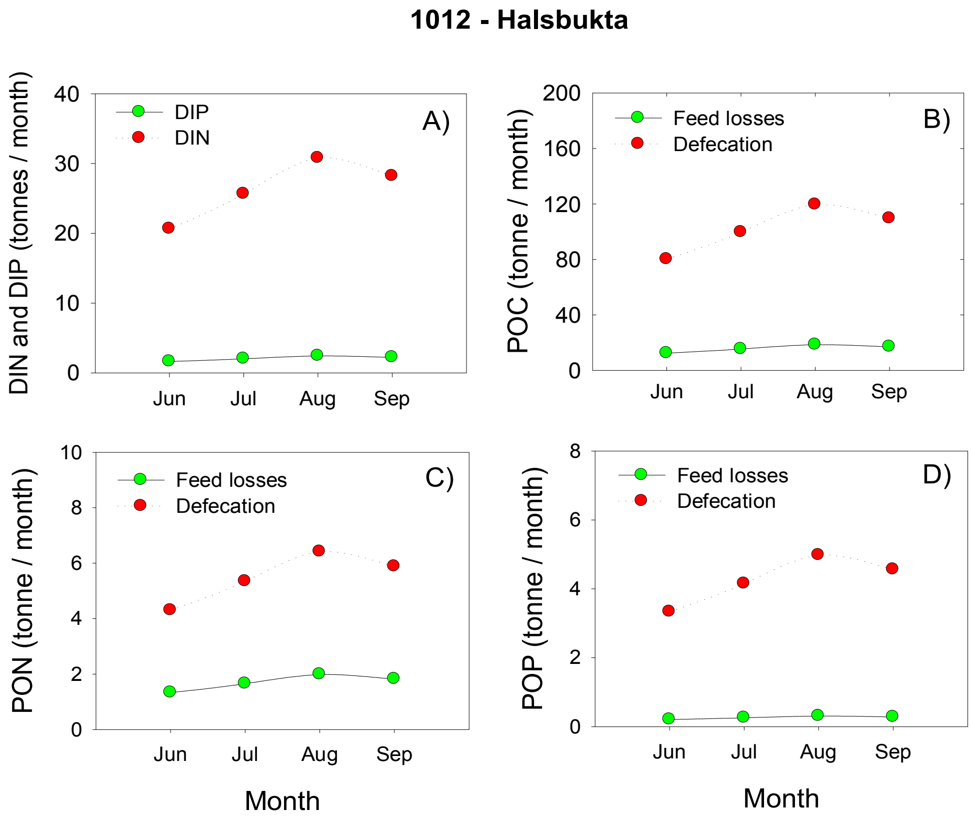

Figure 3.6. Time course of nutrient release rates at Halsbukta. (A): dissolved inorganic N (DIN) and P (DIP), (B): particulate organic C (POC), including POC of feed losses and POC of defecation; (C): particulate organic N (PON), including PON of feed losses and PON of defecation, and (D): particulate organic P (POP), including POP of feed losses and POP of defecation, respectively.

3.1.2. Monthly mean emission rates of wastes from the remaining fish farms in the Nord–Møre area

Figure 3.7 shows monthly mean emission rates of DIN, DIP, POC, PON and POP (including feed losses and defecation) from the remaining fish farms in the Nord–Møre region from June to September. The emission rates of different waste components were at their maximum in August where after they decreased in September. The DIN losses ranged from 7.3 to 10.7 tonnes per month while the DIP losses were between 0.6 and 0.8 tonnes.

The losses of POC (feed losses and defecation) were much higher than those of PON and POP. The POC originating from feed losses and defecation varied between 4.4 and 6.4 and between 28.3 and 41.7 tonnes per month, respectively, while PON feed losses and defecation ranged from 0.5 to 7.0 and from 1.5 to 2.2 tonnes per month, respectively. POP losses were not much lower than those of PON. The losses of POP varied between 1.2 and 1.7 tonnes per month for defecation and between 0.07 and 0.1 tonnes for feed losses per month.

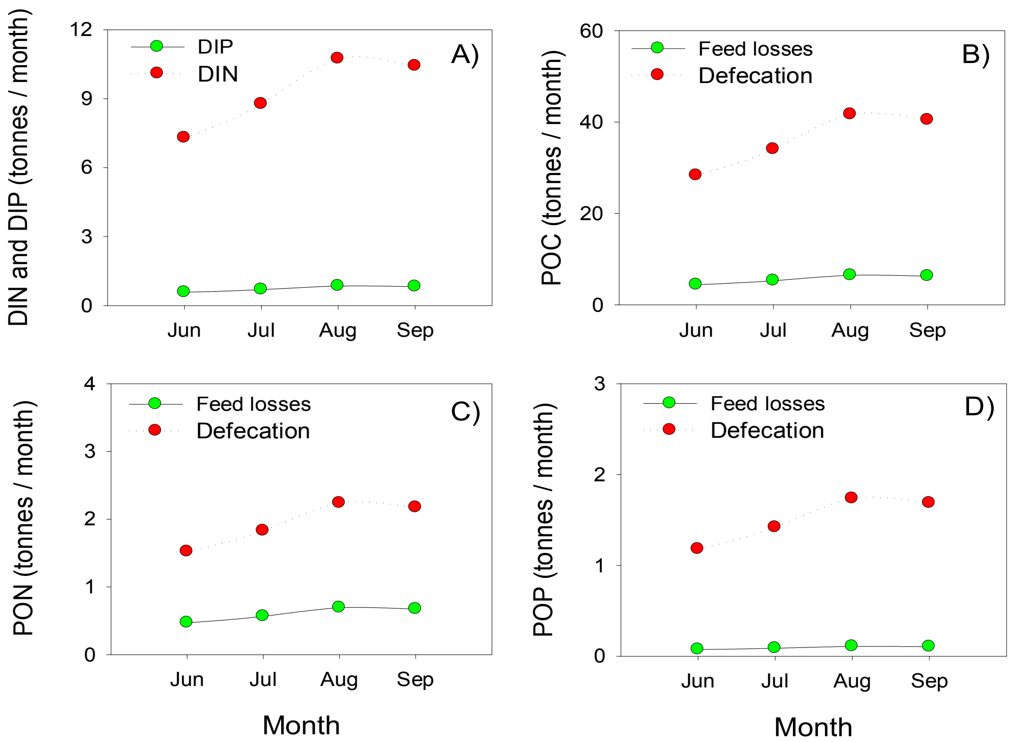

Figure 3.7. Monthly mean nutrient release rates from 18 fish farms in the Nord – Møre region from June to September. (A): dissolved inorganic N (DIN) and P (DIP); (B): particulate organic C (POC), including POC of feed losses and POC of defecation; (C): particulate organic N (PON), including PON of feed losses and PON of defecation; and (D): particulate organic P (POP), including POP of feed losses and POP of defecation, respectively.

The average N:P ratio of dissolved inorganic nutrient emission rates was found to be 12.6 and therefore well above the Redfield ratio (7.2, by weight), suggesting that DIN was in excess for phytoplankton requirements relative to DIP. The average N:P ratio of net particulate organic nutrient emission rates was found to be 1.6 and therefore much below the Redfield ratio (7.2, by weight)

3.1.3. C, N and P mass balance of the main salmon farms in the Nord–Møre area

Figure 3.8 shows C, N and P fluxes and components for the 22 fish farms (Table 3.1) producing 37,114 tonnes wet weight (WW) of fish (Fig. 3.2) in the Nord–Møre area in the summer period (Jun–Sep) in 2011. Of the total input of feed C, N and P, 64 %, 59.2 % and 75.2 %, respectively, were released to the environment as inorganic and organic wastes, corresponding to 390 kg C, 38.7 kg N and 7.8 kg P per metric tonnes WW of fish produced.

The carbon mass balance showed that 42 % of total feed C was respired by the fish, 19 % was released through defecation and 36 % was used for growth (Fig. 3.8A). Approximately 3 % of the total feed input was re-suspended from particles and became DOC.

The nitrogen mass balance indicated that 10.8 % of the input was released as PON, 40.8 % was retained in fish, and 46.5 % was lost as DIN. Approximately 3 % of the total feed used was re-suspended from particles to form DON (Fig. 3.8C).

The phosphorous mass balance (Fig. 3.8B) indicated that 24.8 % of total feed P was incorporated and harvested as fish biomass, 25.8 % was lost as DIP and 43.8 % was released as POP. Approximately 7.7 % of the total feed P was re-suspended into the water as DOP from particles.

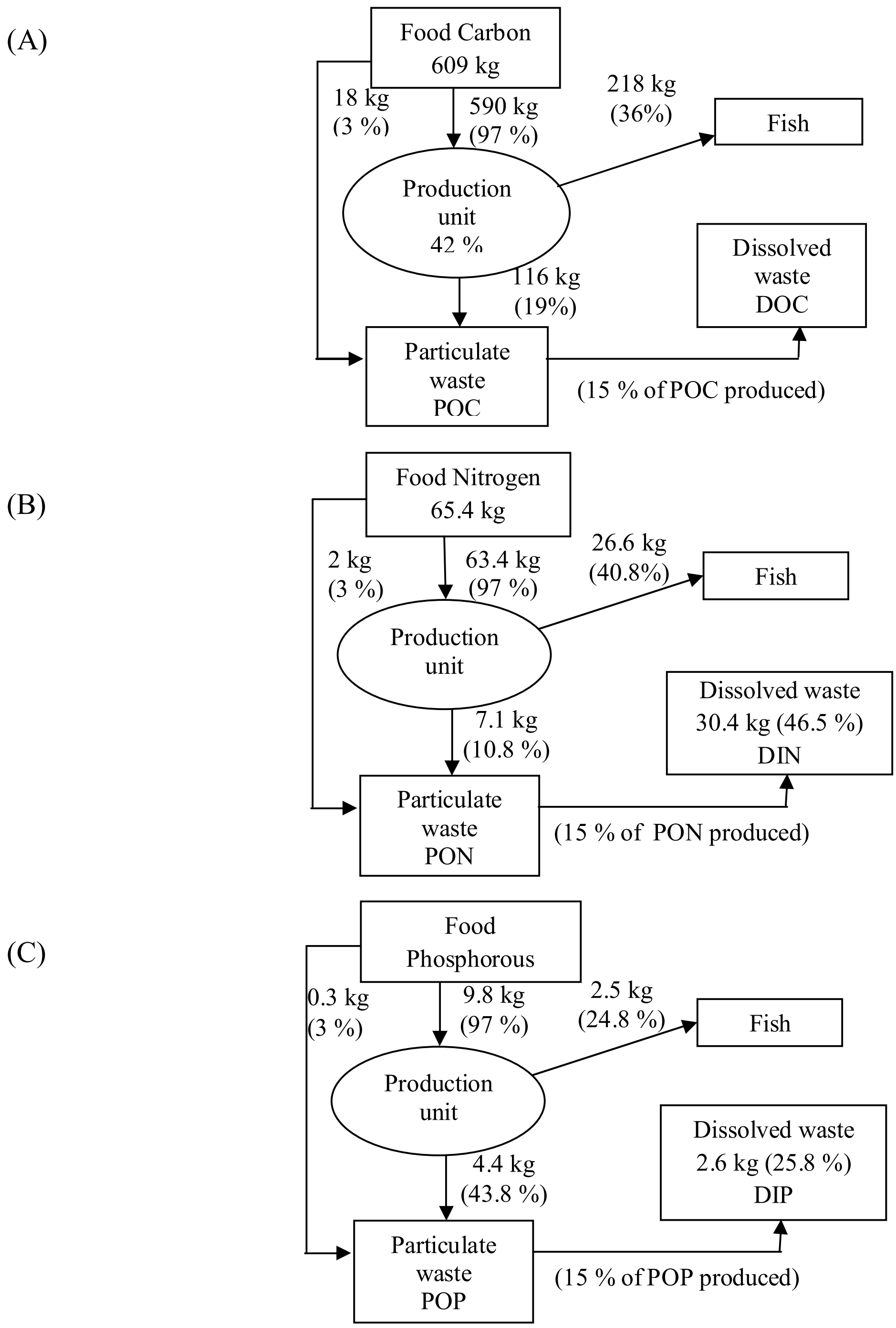

Figure 3.7. Monthly mean nutrient release rates from 18 fish farms in the Nord – Møre region from June to September; (A) C fluxes and components; (B) N fluxes and components; (C) P fluxes and components

3.2. Nutrient concentrations and plankton biomass in the Nord-Møre area

3.2.1. Chemical variables *versus* month at the 4 stations

Figure 3.9 shows dissolved inorganic nitrogen concentrations (DIN) and phosphorous concentrations (DIP) at the 4 stations during the sampling period (June – September). The concentrations of DIN and DIP at the 4 stations were low, but variable. DIN values varied between 0.2 and 5.0 µg l^{-1} at PV1 and BA1 and between 0.2 and 15.0 µg l^{-1} at PV2 and BA2, respectively, except for one higher value found at BA1 (23.7 µg l^{-1}) in July and PV2 (28.3 µg l^{-1}) in September. DIP values ranged from 0.2 to 1.5 µg l^{-1} at PV1and BA1 and from 0.2 to 2.5 µg l^{-1} at PV2 and BA2, respectively, except for one higher value found at BA1 (4.0 µg l^{-1}) in July and at PV2 (4.5 µg l^{-1}) in September.

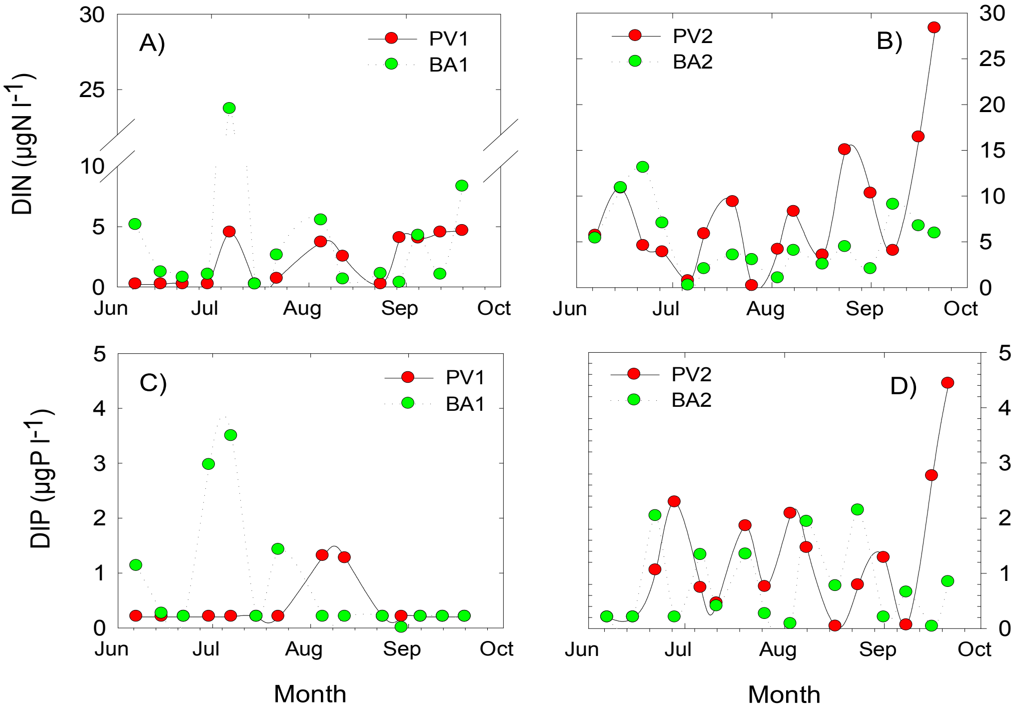

Figure 3.9. Dissolved inorganic nitrogen concentrations (DIN) and phosphorous concentrations (DIP) at 4 stations during the sampling period (June - September). (A) and (B): DIN at PV1, BA1 and PV2, BA2, respectively; (C) and (D): DIP at PV1, BA1 and at PV2, BA2, respectively.

Figure 3.10 shows particulate organic nitrogen concentrations (PON) and phosphorous concentrations (POP) at the 4 stations during the sampling period (June – September). The concentrations of PON and POP at the 4 stations were variable, but low. The PON value varied between 34.3 and 63.5 μg l^{-1} at PV1and BA1 and between 32.3 and 77.6 μg l^{-1} at PV2 and BA2, respectively, except for one higher value found at BA1 (84.6 μg l^{-1}) and PV2 (129 μg l^{-1}) in August. The POP value ranged from 5.0 to 22.6 μg l^{-1} at the 4 stations.

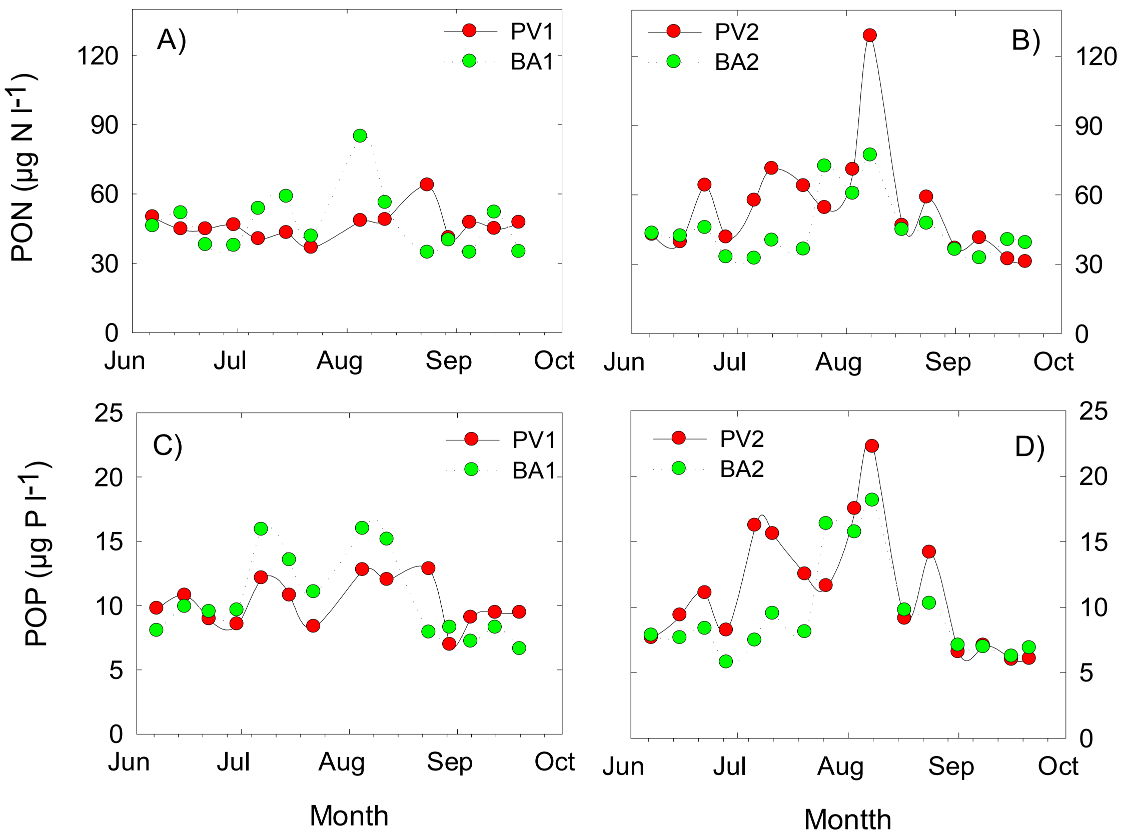

Figure 3.10. Particulate organic nitrogen concentrations (PON) and phosphorous concentrations (POP) at 4 stations during the sampling period (June - September). (A) and (B): PON at PV1, BA1 and PV2, BA2, respectively; (C) and (D): POP at PV1, BA1 and PV2, BA2, respectively.

3.2.2. Biological variables at the 4 stations from June to September

Figure 3.11 shows the chlorophyll *a* (chla) concentrations and particulate organic carbon concentrations (POC) at the 4 stations during the sampling period (June – September). The concentration of chla and POP at the 4 stations were variable and low. The chla concentrations varied between 0.3 and 2.5 µg l^{-1} at the 4 stations, except for one higher value found at R1 (3.7 µg l^{-1}) in August. The POC value ranged from 183 to 523 µg C l^{-1} at the 4 stations, except for one higher value found at PV1 (783 µg l^{-1}) in August.

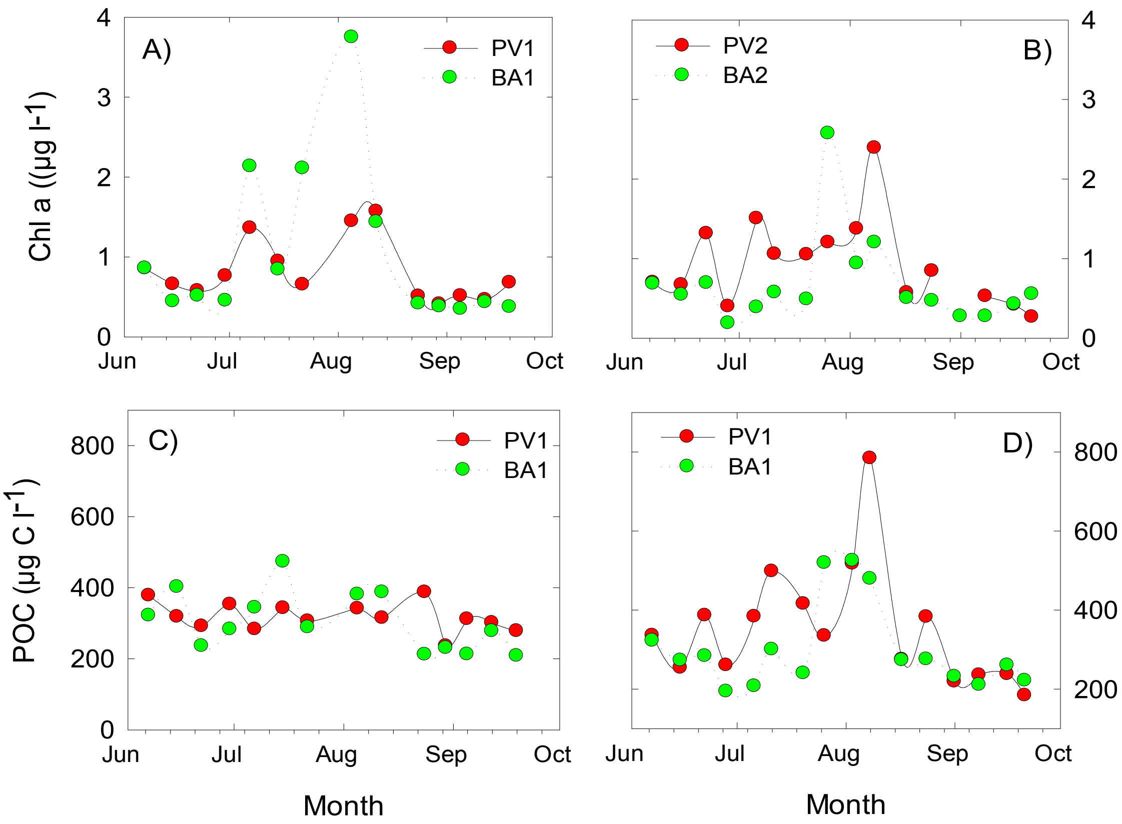

Figure 3.11. The chlorophyll a concentrations (chla) and particulate organic carbon concentrations (POC) at the 4 stations during the sampling period (June - September). (A) and (B): Chla at PV1, BA1 and PV2, BA2, respectively; (C) and (D): POC at PV1, BA1 and PV2, BA2, respectively.

3.2.3. Mean concentrations of nutrients and biological variables in summer period

Figure 3.12 shows mean concentration of difference nutrients (DIN, DIP, PON, POP), chla and POC for the 4 stations from June to September. The mean concentration of different nutrients and chla at PV1 was lower than those at BA1, except for the concentration of POC. The values at PV2 were higher than those at BA2. Moreover, most nutrient concentrations and the chla concentration at PV2 were higher than at PV1.

Figure 3.12(A) shows the mean concentration of dissolved inorganic nitrogen (DIN) for the 4 stations from June to September. There were pronounced difference in DIN among the 4 stations. The mean DIN concentration at BA1 was 87.3 % of that at PV1 while mean concentration of DIN at PV2 was 62.2 % of that at BA2. However, statistical analysis confirmed that there were no significant difference between sampling stations and reference stations (Table 3.2).

Figure 3.12(B) shows the mean concentration of dissolved inorganic phosphorous (DIP) for the 4 stations from June to September. There were pronounced difference in DIP among the 4 stations. The mean DIP concentration at BA1 was 119 % of that was PV1 while the mean concentration of DIP at PV2 was 60.8 % of that at BA2. However, statistical analysis confirmed that there were no significant difference between sampling stations and reference stations (Table 3.2).

Figure 3.12(C) and (D) show the mean concentration of particulate organic nitrogen (PON) and phosphorous (POP) for the 4 stations from June to September. It can be seen that there were small differences in PON and POP concentration between PV1 and BA1, the opposite result for PV2 and BA2. The mean PON concentration at BA1 was 2.5 % higher than that at PV1. Meanwhile the mean concentration of PON at PV2 was 21.8 % higher than that at BA2. However, statistical analysis confirmed that there was no significant difference between sampling stations and respective reference stations (Table 3.2).

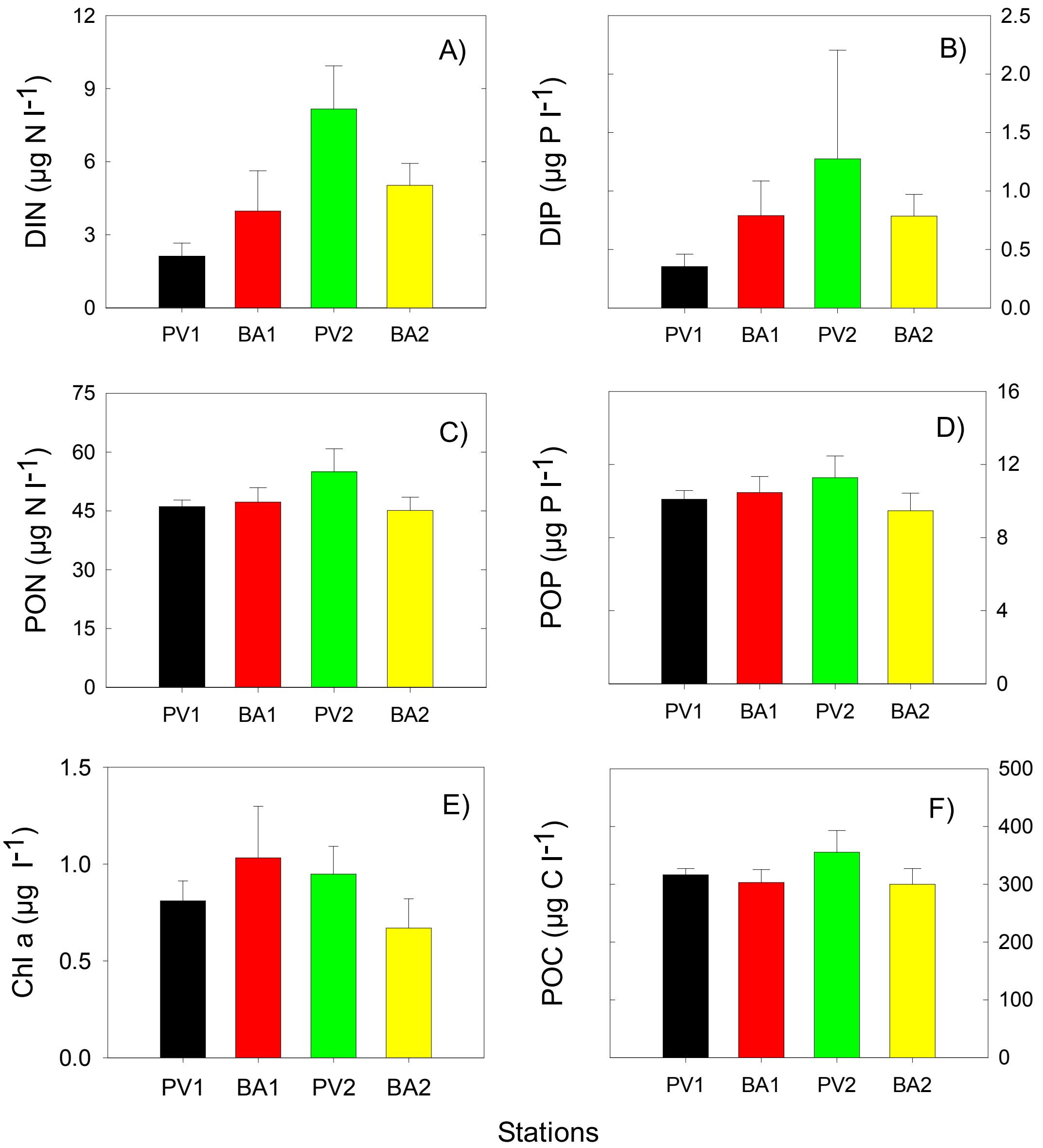

Figure 3.12. Mean nutrient concentration and chlorophyll a (chla) for the 4 stations: black bars (PV1), red bars (BA1), green bars (PV2) and yellow bars (BA2) from June to September). (A) DIN and (B) DIP: dissolved inorganic N and P; (C) PON and (D) POP: particulate organic N and P; and (E) chla and (F) POC: particulate organic C, respectively. Error bars show standard error (SE), n = 14 (PV1, BA1) and n = 16 (PV2, BA2), respectively.

Table 3.2. P-value of statistical analysis for dissolved inorganic nitrogen (DIN) and phosphorous (DIP), particulate organic nitrogen (PON) and phosphorous (POP), particulate organic nitrogen (POC) and chlorophyll a (chla) among the 4 stations from June to September

Station	Variable	P-value	Significance at 95% level
PV1 vs. BA1 PV2 vs. BA2	DIN	0.296 0.125	No No
PV1 vs. BA1 PV2 vs. BA2	DIP	0.178 0.611	No No
PV1 vs. BA1 PV2 vs. BA2	PON	0.714 0.159	No No
PV1 vs. BA1 PV2 vs. BA2	POP	0.777 0.245	No No
PV1 vs. BA1 PV2 vs. BA2	POC	0.599 0.241	No No
PV1 vs. BA1 PV2 vs. BA2	Chla	0.447 0.192	No No

Figure 3.12 (E) shows mean concentration of chla for the 4 stations from June to September. There were some differences in chla between the sampling stations and respective reference stations. The mean chla concentration at BA1was 27.2 % higher than that at PV1, at BA2 was 41.8 % higher than that at BA2. However, statistical analysis confirmed that there were no significant difference between sampling stations and respective reference stations (Table 3.2).

Figure 3.12 (F) shows the mean concentration of particulate organic carbon (POC) for the 4 stations from June to September. There was small difference between PV2 and BA2 and some difference between PV1 and BA1. The mean POC concentration at PV1 was 4.2 % higher than that at BA1, at PV2 was 18.2 % higher than that at BA2. However, statistical analysis confirmed that there were no significant differences between sampling stations and respective reference stations (Table 3.2).

Table 3.3 shows the average dissolved and particulate N:P ratios from the 4 stations (June – September). It can be seen that the dissolved and particulate N:P from the 4 stations at PV1 and

BA1 were a little bit lower than Redfield ratio (7.2 by weight). The average dissolved N:P were around 6 µgN µgP^{-1} and the average particulate N:P were approximate 5 µgN µgP^{-1} from the 4 stations.

Table 3.3. The N:P ratio between dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorous (DIP), between particulate organic nitrogen (PON) and particulate organic phosphorous (POP) (Mean ± CV)

Stations	DIN/DIP	PON/POP
	µg : µg	
PV1	5.0 ± 1.1	4.5 ± 0.9
BA1	6.0 ± 0.8	4.6 ± 0.8
PV2	6.4 ± 0.9	4.9 ± 1.0
BA2	6.4 ± 0.8	4.8 ± 0.7

Figure 3.13 shows a map of the Nord-Møre region including the main fish farms and the 4 stations. Both PV1 and PV2 were situated close to big fish farms and there were many fish farms around. BA1 and BA2 were further away from fish farms.

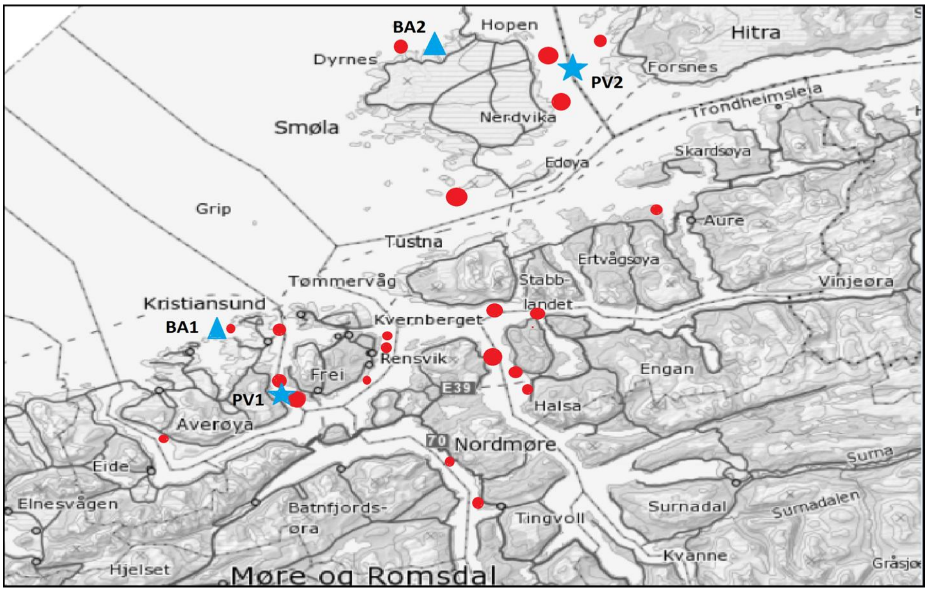

Figure 3.13. Map of Nord-Møre region with the main fish farms (red dots), the 2 sampling stations (blue stars) and the 2 reference stations (blue triangles) included

4. Discussion

4.1. Emission rates of wastes from the fish farms in the Nord-Møre region

In present study, a lower proportion of Feed-P than of Feed-N was excreted as phosphate than ammonia, respectively, whereas the relative fraction of particulate P, mainly released through defecation, was throughout higher than the fraction of particulate N from the individual fish farms and remaining fish farms in the Nord-Møre region (Fig. 3.3 – Fig. 3.7). The same result was found for emission flows of N, P and C based on the same mass balance budgets from hypothetical cage aquaculture of salmon in spite of the different chosen values for the coefficients of the model used to calculate nutrient emissions (Table 2.2) (Olsen, Holmer et al. (2008); Wang, Olsen et al. (2012)). This is not surprising as it is well known that most phosphorous (P) from salmon farming remains as particulate (organic matter) whereas most nitrogen (N) is released as the dissolved inorganic form (Soto and Norambuena 2004).

This was also the reason why the average DIN:DIP ratio of the wastes from the fish farms to open water was found to be 12.6, well above the Redfield ratio (7.2 , by weight), suggesting that DIN was in excess for phytoplankton requirements relative to DIP in inorganic nutrient wastes from the salmon farms. Contrary to this, the average PON:POP ratio of the wastes was 1.6 and therefore far lower than Redfield ratio, suggesting that POP was more limiting than PON for phytoplankton requirements. These estimation were relative similar to value obtained in previous studies (Wang, Olsen et al. 2012).

Monthly mean emission rates of wastes from salmon farms in the summer period (Jun-Sep) were at their maximum in August. This is a general trend for the defined Norwegian salmon farms, the highest growth rates correspond with the highest emission rates occur in August (Costa-Pierce, Olsen et al. 2007; Olsen, Holmer et al. 2008).

4.2. C, N and P mass balance of salmon farming in the Nord-Møre region

Of the total input of feed C, N and P, 64 %, 59.2 % and 75.2 %, respectively, were released to the environment as inorganic and organic wastes in the summer period (Jun-Sep) in 2011, corresponding to 390 kg C, 38.7 kg N and 7.8 kg P per metric tonne WW of fish produced (Fig. 3.8). These estimations were based on the mass balance model with kg dry feed per kg wet fish produced (FCR) of 1.15. These estimated values were just from the summer period, not for a year, but the released nutrient proportions over the summer period, monthly released nutrient proportions over the year as well as the released nutrient proportions in a year 2011 followed the same trend as the feed use and fish production and have the same proportions.

Of the total C input to the fish farms, 42 % was respired as CO_2 and 19 % was lost as POC (Fig. 3.8A). The predicted total release of dissolved N and total N to the environment for each tonne of fish produced were 48.4 % and 59.2 % of the input, respectively (Fig. 3.8B). These values are somewhat lower than those reported by Hall, Holby et al. (1992), who showed that between 67 and 80 % of the N added to cage systems was lost to the environment, of which the majority (50 – 60 % of total N) was lost in dissolved form (Hall, Holby et al. 1992). Another study using a mass balance model with FCR of 1.17 showed that dissolved N and total N released were 44.8 % and 61.8 % of the input, respectively (Olsen, Holmer et al. 2008).

Losses of dissolved P from the main fish farms were estimated to 33.5 % of the input (Fig. 3.8C). These values are somewhat lower than that reported by Hall et al. 1992, who estimated that 34 - 41 % of the input was lost to the environment. However, dissolved P and particulate P losses in the present study (33.5 % and 43.8 %, respectively) are still a little bit higher than those reported by Olsen, Holmer et al. 2008 (26.8 % and 42.5 %, respectively).

4.3. Measurements of concentrations of nutrient and biological variables from the Nord-Møre area

The concentrations of DIN and DIP from the 4 stations were variable but very low except for some higher values found in July for PV1, BA1 and in September for PV2, BA2 (Fig. 3.9). Although some increases were detected in the DIN and DIP concentrations between sampling and respective reference stations, there were no significant differences ($P < 0.05$) between PV1 and BA1, between PV2 and BA2 (Table 3.2). This result suggests that there were no significant ($P < 0.05$) effect on ecosystem from salmon fish farm activities. Consistent with the present study, Soto and Norambuena (2004) did not find an effect on dissolved nutrients from 29 salmon farm sites in southern Chile. Moreover, Basaran, Aksu et al. (2010) found no significant differences in DIN and DIP concentrations between control and cage stations. However, Demirak, Balci et al. (2006), who investigated dissolved nutrients in Gulluk Bay (Aegean Sea), found that major differences in DIN were explained by fish farming activities.

Concentration of PON and POP were also variable and low. Those values were at their maximum in August at the 4 stations (Fig. 3.10). Although some increase was detected in the PON and POP concentrations between the sampling stations and the respective reference stations, there were no significant differences ($P < 0.05$) (Table 3.2). Consistence with the present study, La Rosa, Mirto et al. (2002) found no significant differences between cage and control stations for suspended particulate organic matter.

No significant differences were found between sampling and respective reference stations in POC and chla concentrations ($P < 0.05$) (Table 3.2). Chla concentrations varied between 0.3 and 3.7 µg l^{-1} at 4 stations and the highest value was recorded at the 4 stations in August (Fig.3.11). In order to avoid eutrophication in the northern European waters, maximum value of 10 µg l^{-1} in chla has been recommended as an environmental quality standard (Basaran, Aksu et al. 2010). The consistence with the present study has been reported by many researchers, among them Pitta, Karakassis et al. (1998), who found that neither chla nor POC seemed to be significantly affected by the nutrient release from fish farms.

Figure 3.13 shows map of Nord-Møre region including the main fish farms and the 4 stations. It can be seen that the position of the 2 sampling stations (PV1 and PV2) were closer to big fish farms than the 2 reference stations (BA1 and BA2). Therefore, we could expect that the concentrations of different nutrients and plankton biomass at sampling stations would be higher than those at respective reference stations. However, this was not observed for PV1 and BA1. The results indicated that nutrient concentrations and plankton biomass at PV2 were higher than those at BA2. On the contrary, concentrations of nutrients and plankton biomass at BA1 were higher than PV1 (except for POC concentration) (Fig. 3.12). It is difficult to explain the reason for this. However, the reasons could be the wind and stronger mixing with deep water. Some of the other sources were supplied, hence concentrations of nutrients at BA1 went up.

4.4. Mean dissolved N:P ratio between the measurements and the emission from the fish farms

The measurements showed values of dissolved N/P ratios from the 4 stations around 6 $\mu g\ N\ \mu g\ P^{-1}$ (Table 3.5), close to the natural (Redfield, 7.2 $\mu g\ N\ \mu g\ P^{-1}$), suggesting that nitrogen acted as a main limiting nutrient to phytoplankton growth. The emissions of inorganic N/P ratios from the fish farms were very high (~12.6), but the farm emissions were not large enough to affect the ambient concentrations.

The measurement reflects both the nature and the farm emissions. With very high emissions of dissolved N/P ratios from fish farms, they were expected to change the situation of the ambient concentrations, from low N/P (N-limiting) to high N/P and possible P-limitation of phytoplankton growth. However, this was not observed in the present study. This demonstrates that the farm emissions were not the main source of nutrients, the natural was dominant, and nitrogen acted as a main limiting nutrient to phytoplankton growth. Consistent with this, many researchers, among them Ryther and Dunstan (1971), Boynton, Kemp et al. (1982), Graneli (1978), have all reported that nitrogen is the primary limiting nutrient limiting phytoplankton growth in seawater.

5. Conclusion

The mass balance proposed in the present study is a reliable method to estimate nutrient emissions from salmon farms. This model demonstrated that 64 % C, 59.2 % N and 75.2 % P of the total feed input were released into the environment in the Nord–Møre area in the summer period (Jun–Sep) in 2011. Consequently, the waste emission was 390 kg C, 38.7 kg N and 7.8 kg P per metric tonne wet weight (WW) of fish produced with total salmon production of 37,114 tonnes WW of fish. Some 42 % of feed C and 47 % of feed N were respired as CO_2 and excreted as DIN, respectively, and 44 % of feed P was released as solid waste.

Direct measurement through sampling and subsequent analysis of the water column is a method to evaluate the environmental impact of salmon aquaculture on planktonic ecosystems. The results showes that there were no significant differences ($P < 0.05$) of indicators representing the nutrient concentrations and biological variables like concentration of chlorophyll *a* and particulate carbon between sampling stations and respective reference stations. Therefore, we conclude that there was no significant ($P < 0.05$) effect from salmon fish farm activities in the Nord-Møre area in the summer period (Jun-Sep).

With many fish farms surrounding the 2 sampling stations (Fig. 3.13), we could expect the concentration of different nutrients and plankton biomass at sampling stations (PV1 & PV2) would be higher than those at respective reference stations (BA1 & BA2). However, the results showed that the concentration of different nutrients and plankton biomass at PV1 were lower than those at BA1 (except for POC concentration).

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Appendix

Appendix 1. The emission calculation from fish farms

No	Farm	Month	DIN	DIP	PON		POP		POC	
					Feed losses	Defecation	Feed losses	Defecation	Feed losses	Defecation
1	**Solværet**	Jun	31,217	2,462	2,012	6,506	312	5,048	18,733	121,141
		Jul	44,548	3,513	2,871	9,284	446	7,203	26,733	172,872
		Aug	40,100	3,162	2,585	8,357	401	6,484	24,064	155,612
		Sep	39,709	3,132	2,559	8,275	397	6,421	23,829	154,094
2	**Reiråklakken**	Jun	21,894	1,727	1,411	4,563	219	3,540	13,138	84,960
		Jul	26,889	2,121	1,733	5,604	269	4,348	16,136	104,345
		Aug	39,685	3,130	2,558	8,270	397	6,417	23,814	154,000
		Sep	39,773	3,137	2,563	8,289	398	6,431	23,867	154,340
3	**Bremnessvaet**	Jun	30,874	2,435	1,990	6,434	309	4,992	18,527	119,809
		Jul	28,382	2,238	1,829	5,915	284	4,589	17,032	110,138
		Aug	30,399	2,397	1,959	6,335	304	4,915	18,242	117,965
		Sep	27,959	2,205	1,802	5,827	280	4,521	16,778	108,497
4	**1012 - Halsbukta**	Jun	20,629	1,627	1,330	4,299	206	3,335	12,379	80,051
		Jul	25,653	2,023	1,653	5,346	257	4,148	15,394	99,547
		Aug	30,781	2,427	1,984	6,415	308	4,977	18,471	119,447
		Sep	28,201	2,224	1,818	5,877	282	4,560	16,923	109,438
5	**1011 - Seglråa**	Jun	21,923	1,729	1,413	4,569	219	3,545	13,156	85,074
		Jul	27,965	2,205	1,802	5,828	280	4,522	16,781	108,519
		Aug	23,384	1,844	1,507	4,873	234	3,781	14,032	90,743
		Sep	21,452	1,692	1,383	4,471	215	3,469	12,873	83,246
6	**Korsneset**	Jun	23,564	1,858	1,519	4,911	236	3,810	14,140	91,441
		Jul	28,943	2,283	1,866	6,032	289	4,680	17,369	112,316

		Aug	23,237	1,832	1,498	4,843	232	3,757	13,944	90,171
		Sep	13,346	1,053	860	2,781	133	2,158	8,009	51,792
7	**1001 - Endreseth**	Jun	6,759	533	436	1,409	68	1,093	4,056	26,228
		Jul	11,248	887	725	2,344	112	1,819	6,750	43,648
		Aug	24,696	1,948	1,592	5,147	247	3,993	14,820	95,834
		Sep	27,363	2,158	1,764	5,703	274	4,424	16,420	106,186
8	**Leite**	Jun	7,900	623	509	1,646	79	1,277	4,741	30,655
		Jul	11,660	920	752	2,430	117	1,885	6,997	45,247
		Aug	20,790	1,640	1,340	4,333	208	3,362	12,476	80,678
		Sep	19,675	1,552	1,268	4,100	197	3,181	11,807	76,352
9	**1013 - Skåren**	Jun	14,323	1,130	923	2,985	143	2,316	8,595	55,580
		Jul	14,910	1,176	961	3,107	149	2,411	8,947	57,858
		Aug	11,186	882	721	2,331	112	1,809	6,713	43,409
		Sep	11,847	934	764	2,469	118	1,916	7,109	45,973
10	**Gjeldsøya**	Jun	4,041	319	260	842	40	653	2,425	15,680
		Jul	9,524	751	614	1,985	95	1,540	5,715	36,960
		Aug	14,578	1,150	940	3,038	146	2,357	8,748	56,572
		Sep	19,611	1,547	1,264	4,087	196	3,171	11,768	76,100
11	**Hjortholmen**	Jun	5,116	403	330	1,066	51	827	3,070	19,852
		Jul	6,287	496	405	1,310	63	1,017	3,773	24,399
		Aug	18,051	1,424	1,163	3,762	181	2,919	10,832	70,047
		Sep	20,584	1,623	1,327	4,290	206	3,328	12,352	79,878
12	**Blomvikbugen**	Jun	5,887	464	379	1,227	59	952	3,533	22,844
		Jul	10,375	818	669	2,162	104	1,678	6,226	40,262
		Aug	14,780	1,166	953	3,080	148	2,390	8,869	57,354
		Sep	9,916	782	639	2,066	99	1,603	5,950	38,478
13	**Hogsneset Nord**	Jun	2,996	236	193	624	30	484	1,798	11,627
		Jul	3,413	269	220	711	34	552	2,048	13,246
		Aug	9,110	718	587	1,899	91	1,473	5,467	35,352
		Sep	12,630	996	814	2,632	126	2,042	7,579	49,012

14	**1002 - Hogsneset**	Jun	2,053	162	132	428	21	332	1,232	7,967
		Jul	3,166	250	204	660	32	512	1,900	12,287
		Aug	7,794	615	502	1,624	78	1,260	4,677	30,245
		Sep	8,197	646	528	1,708	82	1,325	4,919	31,809
15	**Hunnhammervika**	Jun	3,558	281	229	742	36	575	2,135	13,808
		Jul	5,437	429	350	1,133	54	879	3,263	21,098
		Aug	6,442	508	415	1,343	64	1,042	3,866	24,999
		Sep	4,775	377	308	995	48	772	2,866	18,531
16	**1113 - Vullum**	Jun	1,789	141	115	373	18	289	1,073	6,940
		Jul	2,853	225	184	595	29	461	1,712	11,072
		Aug	4,952	391	319	1,032	50	801	2,972	19,218
		Sep	6,367	502	410	1,327	64	1,029	3,821	24,706
17	**1111 - Bogen**	Jun	1,402	111	90	292	14	227	841	5,440
		Jul	2,266	179	146	472	23	366	1,360	8,794
		Aug	3,589	283	231	748	36	580	2,154	13,927
		Sep	4,297	339	277	896	43	695	2,579	16,675
18	**1111 - Vikagjelen**	Jun	705	56	45	147	7	114	423	2,737
		Jul	1,538	121	99	320	15	249	923	5,966
		Aug	2,985	235	192	622	30	483	1,792	11,585
		Sep	4,423	349	285	922	44	715	2,654	17,165
19	**Kornstad**	Jun	4,278	337	276	892	43	692	2,567	16,600
		Jul	0	0	0	0	0	0	0	0
		Aug	0	0	0	0	0	0	0	0
		Sep	0	0	0	0	0	0	0	0
20	**Or**	Jun	476	38	31	99	5	77	286	1,848
		Jul	688	54	44	143	7	111	413	2,669
		Aug	1,362	107	88	284	14	220	818	5,287
		Sep	1,746	138	113	364	17	282	1,048	6,776
21	**Hegerbergtrøa**	Jun	93	7	6	19	1	15	56	359
		Jul	450	35	29	94	4	73	270	1,745

		Aug	595	47	38	124	6	96	357	2,310
		Sep	820	65	53	171	8	133	492	3,183
22	**1901 - Sveggvika**	Jun	304	26	24	63	3	49	183	1,181
		Jul	0	0	0	0	0	0	0	0
		Aug	0	0	0	0	0	0	0	0
		Sep	0	0	0	0	0	0	0	0

Appendix 2. The main fish farms with the feed consumption in the Nord -Møre area from January to December in 2011

No	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Solværet	278,425	191,849	102,385	356,432	740,992	1,179,968	1,683,845	1,515,727	1,500,939	405,547	79,366	0
2	Reiråklakken	160,867	149,065	276,133	310,187	314,256	827,550	1,016,364	1,500,023	1,503,341	541,456	543,158	466,796
3	Bremnessvaet	312,055	272,912	293,579	420,523	772,446	1,166,993	1,072,788	1,149,030	1,056,811	181,544	256,363	131,568
4	1012 - Halsbukta	143,078	148,218	197,554	311,964	489,846	779,728	969,635	1,163,463	1,065,973	525,578	584,474	308,533
5	1011 - Seglråa	189,213	175,141	236,593	373,728	526,398	828,658	1,057,022	883,881	810,855	621,194	496,021	0
6	Korsneset	192,892	191,029	278,968	376,619	750,381	890,673	1,094,011	878,306	504,472	201,315	0	0
7	1001 - Endreseth	82,588	75,470	84,265	102,843	150,846	255,475	425,149	933,467	1,034,295	1,018,856	1,004,226	1,030,738
8	Leite	84,657	99,691	102,863	73,737	137,407	298,597	440,729	785,838	743,697	603,849	619,679	606,970
9	1013 - Skåren	101,855	141,516	181,859	263,868	370,320	541,378	563,561	422,823	447,801	146,130	89,028	66,500
10	Gjeldsøya	68,521	67,618	64,306	105,651	142,170	193,368	237,653	682,289	778,045	299,029	434,048	425,694
11	Hjortholmen	60,572	48,470	43,948	54,301	93,218	152,731	360,007	551,038	741,250	827,326	354,447	422,032
12	Blomvikbugen	92,363	72,076	68,485	73,817	133,525	222,509	392,168	558,649	374,794	105,664	338,981	312,612
13	Hogsneset Nord	46,703	44,799	46,228	70,789	88,482	113,251	129,025	344,348	477,397	502,156	365,431	412,854
14	1002 - Hogsneset Sør	33,321	28,221	28,437	47,900	62,260	77,606	119,679	294,596	309,837	344,446	211,786	292,235
15	Hunnhammervika	31,000	21,000	60,500	57,750	150,000	134,500	205,500	243,500	180,500	121,500	115,000	108,500
16	1113 - Vullum	0	0	445	27,055	59,264	67,603	107,843	187,192	240,650	288,406	219,222	235,099
17	1111 - Bogen	0	0	0	0	25,739	52,991	85,656	135,651	162,421	204,401	194,267	173,578
18	1111 - Vikagjelen	0	0	100	12,465	16,292	26,656	58,116	112,846	167,192	188,666	162,689	119,069
19	Kornstad	346,287	314,001	266,744	197,955	334,045	161,695	0	0	0	0	0	0
20	Or	0	0	0	2,500	10,500	18,000	26,000	51,500	66,000	61,000	35,000	65,000
21	Hegerbergtrøa	0	0	0	0	8,500	3,500	17,000	22,500	31,000	54,500	58,000	52,500
22	1901 - Sveggvika	143,867	189,500	193,500	162,500	222,000	11,500	0	0	0	0	0	0

Appendix 3. Nutrient concentration and plankton biomass at the 4 stations

Week	Station	Date	DIN	DIP	PON	POP	Chla	POC
			μg l-1					
23	PV1	7/6/11	0.20	0.20	49.79	9.73	0.85	377.25
24		15/6/11	0.20	0.20	44.51	10.75	0.65	317.19
25		22/6/11	0.20	0.20	44.54	8.90	0.57	290.61
26		30/6/11	0.20	0.20	46.30	8.51	0.76	352.06
27		7/7/11	4.50	0.20	40.25	12.10	1.36	281.88
28		15/7/11	0.20	0.20	42.94	10.75	0.94	341.61
29		22/7/11	0.67	0.20	36.52	8.32	0.65	305.03
31		5/8/11	3.67	1.31	48.16	12.74	1.44	340.32
32		12/8/11	2.50	1.27	48.58	11.97	1.57	313.67
34		24/8/11	0.20	0.20	63.55	12.80	0.50	386.45
35		30/8/11	4.04	0.20	40.78	6.91	0.41	235.02
36		5/9/11	4.00	0.20	47.33	9.02	0.51	310.75
37		12/9/11	4.50	0.20	44.66	9.41	0.46	300.26
38		19/9/11	4.63	0.20	47.37	9.41	0.67	277.38
23	BA1	7/6/11	5.12	1.13	45.79	8.00	0.85	320.97
24		15/6/11	1.20	0.26	51.45	9.87	0.44	401.04
25		22/6/11	0.75	0.20	37.68	9.47	0.51	234.82
26		30/6/11	1.00	2.97	37.38	9.60	0.45	282.02
27		7/7/11	23.70	3.49	53.40	15.87	2.13	343.02
28		15/7/11	0.19	0.20	58.64	13.50	0.84	472.35
29		22/7/11	2.60	1.42	41.43	11.01	2.10	287.42
31		5/8/11	5.50	0.20	84.63	15.94	3.74	380.21
32		12/8/11	0.61	0.20	56.00	15.10	1.43	386.56
34		24/8/11	1.07	0.20	34.36	7.87	0.41	211.10
35		30/8/11	0.33	0.20	39.72	8.26	0.38	229.14
36		5/9/11	4.23	0.20	34.41	7.17	0.35	211.37
37		12/9/11	1.00	0.20	51.77	8.26	0.43	277.05
38		19/9/11	8.30	0.20	34.72	6.59	0.37	207.48
23	PV2	7/6/11	5.64	0.20	42.57	7.62	0.70	334.75
24		15/6/11	10.80	0.20	39.43	9.34	0.67	252.86
25		22/6/11	4.53	1.05	63.89	11.04	1.31	385.23
26		28/6/11	3.83	2.28	41.45	8.19	0.39	259.42
27		6/7/11	0.69	0.73	57.41	16.19	1.50	382.67
28		11/7/11	5.83	0.45	71.15	15.55	1.05	497.23
29		20/7/11	9.32	1.85	63.66	12.48	1.04	414.83
30		26/7/11	0.14	0.75	54.23	11.58	1.20	333.77

31		3/8/11	4.11	2.08	70.73	17.47	1.37	516.50
32		8/8/11	8.25	1.45	128.51	22.21	2.39	783.04
33		17/8/11	3.50	0.03	46.52	9.09	0.56	274.23
34		24/8/11	15.00	0.78	58.73	14.14	0.84	381.82
35		1/9/11	10.24	1.28	36.64	6.53		218.03
36		8/9/11	4.00	0.06	41.13	7.04	0.52	234.60
37		16/9/11	16.38	2.76	32.04	5.95	0.41	236.99
38		21/9/11	28.30	4.43	30.83	6.02	0.26	182.99
39		7/6/11	5.34	0.20	43.17	7.81		321.76
24		15/6/11	10.85	0.20	41.95	7.62	0.54	271.73
25		22/6/11	13.07	2.03	45.53	8.32	0.69	282.68
26		28/6/11	7.00	0.20	32.83	5.76	0.18	193.20
27		6/7/11	0.20	1.33	32.28	7.42	0.38	206.33
28		11/7/11	2.00	0.40	40.12	9.47	0.57	299.21
29		20/7/11	3.50	1.34	36.24	8.06	0.48	239.16
30	**BA2**	26/7/11	3.00	0.26	72.19	16.32	2.57	518.18
31		3/8/11	1.00	0.08	60.35	15.68	0.94	524.32
32		8/8/11	4.00	1.93	76.92	18.11	1.20	478.06
33		17/8/11	2.50	0.76	44.71	9.73	0.50	272.14
34		24/8/11	4.40	2.13	47.37	10.24	0.46	274.64
35		1/9/11	2.00	0.20	36.10	7.04	0.27	230.87
36		8/9/11	9.02	0.65	32.47	6.91	0.27	209.65
37		16/9/11	6.68	0.03	40.31	6.21	0.42	259.17
38		21/9/11	5.89	0.84	39.00	6.85	0.55	220.79

Appendix 4. Mean nutrients and chlorophyll *a* (chla) concentration from the 4 stations (Mean, n and SE)

Station	DIN			DIP			POP			PON			Chla			POC		
	Mean	n	SE	Mean	n	SE	Mean	n	SE	Mean	n	SE	Mean	n	SE	Mean	n	SE
PV1	2.12	14	0.53	0.36	14	0.11	10.1	14	0.48	46.1	14	1.66	0.81	14	0.10	316	14	10.9
BA1	3.97	14	1.65	0.79	14	0.30	10.5	14	0.88	47.2	14	3.67	1.03	14	0.27	303	14	22.3
PV2	8.16	16	1.77	1.27	16	0.93	11.3	16	1.19	54.9	16	5.91	0.95	15	0.14	356	16	37.6
BA2	5.03	16	0.90	0.79	16	0.18	9.47	16	0.95	45.1	16	3.36	0.67	15	0.15	300	16	27.2