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Aquaculture Research Station of the Faroes

Final Report

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The potential of a semi-intensive production system to support an increased number of fish larvae by optimising the plankton season

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7th September 2011

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Authors

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Abstract

Many studies have shown that feeding reared fish larvae on a natural zooplankton diet rather than on an enriched rotifer diet, significantly enhances the juvenile growth potential, quality and health. In 2002 the Aquaculture Research Station of the Faroes (Fiskaaling) began focusing on the opportunity of rearing Faroese cod larvae on zooplankton in basins in Nesvík. To optimise the potential of the plankton production capacity in three basins at The Marine Station in Nesvík, better understanding of the underlying mechanisms in the planktonic ecosystem, is required. Thus, the aim of the experiment was to closely monitor phyto- and zooplankton abundance and community structure. Aiming to achieve a high and stable plankton production from March-April to October, optimal conditions in the basins were created by a) pumping seawater into the basin, b) a pump, making the water turbulent and c) artificial fertilisation. To determine the importance of diatom growth for the zooplankton community, silicate was added to two basins whilst the third basin received no silicate.

There was a long lag period from fertilisation to phytoplankton response. This created periodically excessive amounts of nutrients in the basins and also fluctuations in primary production and phytoplankton abundance. The oxygen concentration commonly ranged from 100 to 130%. Chl *a* was variable throughout the experimental period, commonly ranging high above the desired values of 15-20 µg L^{-1}. Some leakage occurred between the basins and thus the influence of a diatom vs. dinoflagellate community to zooplankton production could not be established. The diatoms *Skeletonema costatum*, *Leptocylindrus danicus* and *Chaetoceros* sp. dominated the phytoplankton community over prolonged periods. However in one of the basins dinoflagellates were abundant until late June. There was no relationship between the chl *a* concentration and the above mentioned parameters since, most likely, the phytoplankton production was in excess.

The species composition was markedly different from that in the sea adjacent to the basins. The copepod *Eurytemora* spp. was the dominant zooplankton species throughout the season. There was a continuous egg production of *Eurytemora* spp. during the experimental period. However, there was no relationship between the rates of egg production and chl *a* concentrations, which is probably due to the

excessive quantities of chl *a*. It is likely that three generations of *Eurytemora* spp. were produced from April to October. However, most of the time, the community consisted of all developmental stages, revealing large overlaps between the generations.

Based on optimal conditions in the basins, the systems could theoretically support a maximum of around 0.6 to 1 million cod larvae. These are significantly larger quantities compared to the approximate 180,000 cod larvae used the first time the basins were manipulated in 2006 (Kolbeinshavn *et al*., submitted).

Although phytoplankton and zooplankton concentrations showed rather large temporal variations, the basins revealed that a high plankton production cycle can be maintained from March-April to November. Together with other positive characteristics such as the dominance of a calanoid species, mixed developmental stages and stable and long-lasting fecundity, it is worth further investigation on how to achieve a more stable production of zooplankton to startfeed fish larvae.

Samandráttur

Fleiri kanningar hava víst, at fiskalarvur trívast og vaksa munandi betur, um tær fáa náttúrligt djóraæti at eta, heldur enn rotatoriur. Í 2002 fór Fiskaaling undir at menna aling av toski, har larvurnar fingu djóraæti sum var framleitt í hyljunum í Nesvík. Hetta vísti seg at bera til, men fyri at fáa størri trygd fyri at fáa so stóra framleiðslu av toskayngli sum gjørligt, var tørvur á at kenna betur plankton vistskipanina í hyljunum. Tí var farið undir hesa verkætlanina, hvørs endamál var avkannað út í æsir, hvussu nøring og vøkstur av plantu- og djóraæti í hyljunum kann stýrast og hvat kann gerast fyri halda eina javna og høga framleiðslu av æti, frá á vári til út á heystið. Frá apríl til november vórðu tríggir hyljar taðaðir ymiskt, og fylgt varð við, hvussu hetta ávirkaði gróður, nøgdir og sløg av plantuæti. Samstundis varð fylgt við nøring, sløgum, tættleikum og vøkstri av djóraæti í teimum ymisku hyljunum.

Av tí at rættiliga long tíð gekk frá tí at hyljarnir blivu taðaðir til tað sást aftur í gróðrinum, var viðhvørt ov nógv av tøðevnum í hyljunum og gróðurin kundi verða ov ójavnur. Sjógvurin í hyljunum var oftast 100-130% oxygen mettaður og nøgdirnar av plantuæti broyttust rættiliga nógv, og ofta var væl meira av plantuæti í hyljunum enn ætlað.

Oftast var mest av kiselalgunum *Skeletonema costatum*, *Leptocylindrus danicus* og *Chaetoceros* sp. Í tí eina hylinum var tó mest av dinoflagellatum ein stóran part av tíðini.

Í hyljunum vóru heilt onnur sløg av djóraæti, enn í Sundalagnum. Nógv mest var av kopepodinum *Eurytemora* spp. í øllum tíðarskeiðinum. Tey gýttu regluliga meðan royndin vardi, men einki samband var ímillum nøgdirnar av plantuæti og tal av eggum, ið gýtt vórðu. Helst er orsøkin, at nøgdirnar av plantuæti vóru størri enn tað sum kopepodarnir kláraðu at eta. Líkt er til, at tríggjar generatiónir av *Eurytemora* spp. vóru í hyljunum í tíðarskeiðinum apríl til oktober. Fyri tað mesta vóru fleiri vakstrarstig av kopepodum samstundis í hyljunum, soleiðis at meira enn ein generatión var samstundis.

Um framleiðslan av djóraæti var optimal, kundu hyljarnir teoretiskt fóðra uml. 0,6 til 1 millión toskalarvur. Hetta er munandi meir enn talið av toskalarvum, sum vórðu framleiddar í 2006, tá hyljarnir vóru taðaðir fyri fyrstu ferð (Kolbeinshavn *et al*., submitted).

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Key words

Plankton, *Eurytemora* spp., semi-intensive production system, primary production, nutrients, copepod egg production, fish larvae.

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Abstract

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1.0 Introduction

1.1 Phytoplankton and environmental influences

Phytoplankton are photoautotrophs as they use light as energy and carbon dioxide to produce new organic material. In addition to light, nutrients and turbulence/stratification have significant influence on phytoplankton growth.

In order to grow a range of nutrients are required. Nutrients that typically restrict algal growth rate are nitrogen and phosphorus. In the case of diatoms, limited availability of silicate can also lead to a restricted production rate. Phytoplankton species have different growth rates and thus the quantity of nutrients needed for growth differs between species. As a result, many different species can coexist in the same environment (Tilman *et al*., 1982).

The cell size of phytoplankton species also determines coexistence. Small cells have a larger surface area per volume compared to larger diatom cells. During low nutrient concentrations, molecular diffusion may become limited, making the diffusion-limited uptake rate per cell volume proportional to the inverse of the cell's diameter. Consequently, smaller cells have a competitive advantage when nutrient concentrations are a limited resource. Larger, actively moving phytoplankton cells significantly enhance nutrient uptake whilst swimming, although the rate is only partially compensated in a diffusion-limited environment (Kiørboe, 1993). Turbulence can increase the advective rate of nutrient supply to the cell surface and thereby the rate of nutrient uptake however only larger species tend to benefit from this scenario.

The phytoplankton biomass and composition is also strongly influenced by turbulence (Naas *et al*., 1991). In stratified waters, smaller cells are commonly found whereas in turbulent waters larger cells and colonies with limited motility may dominate. The force of gravity causes phytoplankton cells to sink. According to Stoke's law, the rate of sinking is inversely proportional to viscosity. Consequently diatoms that exhibit none or very limited movement and may form large colonies, sink faster than smaller and usually mobile cells such as dinoflagellate and smaller flagellates (Kiørboe, 1993; Tilman *et al*., 1982).

In temperate waters, diatoms are known for their ability to form immense blooms in spring, when the nutrient rich upper water column becomes warmer. Diatoms can initially grow fast as there is plentiful of nutrients as well as due to the fact that zooplankton may not have the grazing capacity to create a stable relationship during the initial bloom. During the spring bloom, silicate concentrations typically start becoming depleted and diatoms lose their competitive advantage against dinoflagellates and smaller flagellates. According to Egge and Aksnes (1992) a bloom of diatoms, as a group, can be maintained in a mesocosm environment if the silicate concentration remains above a threshold of approximately 2 µM.

1.2 Zooplankton and factors involved in a successful production

Zooplankton is a key component in the marine ecosystem, forming a link between phytoplankton and higher trophic levels. Phytoplankton is consumed by zooplankton and is thereby the primary biological factor influencing the zooplankton community structure.

Zooplankton expands over a wide taxonomic range, with copepods being the most abundant group. Copepods are an important source of food for cod larvae and other fish species. Several studies have shown that the timing and the intensity of reproduction are essential for good growth rate and survival of fish larvae (Debes *et al*., 2008a; Steingrund & Gaard, 2005; Støttrup, 2000; Voss *et al*., 2003; Burrow *et al*., 2011).

Copepods are opportunistic species, whose reproduction rate is strongly influenced by phytoplankton abundance and composition (Debes *et al*., 2008a; ICES, 2008). The ingested food is quickly transformed into energy for egg production in matured females. Once the eggs have hatched, copepods pass through six moults during the nauplii phase and usually six moults during the copepodite phase. During each development stage, copepods gradually increase in growth (fig 1.1). Their life cycle expands approximately four-six weeks, depending on species and temperature (Mauchline, 1998). In addition to temperature, salinity, oxygen and light are key factors that also influence the success of copepod cultivation (Drillet *et al*., 2011). When conditions become unfavourable, many copepod species produce resting eggs, which are dormant in the bottom sediments until the environmental conditions improve (van der Meeren *et al*., 2005).

Fig 1.1. Different developmental stages of zooplankton. The copepodite stages are identified as *Eurytemora* spp.

It is well established that zooplankton ingestion rates tend to increase with increasing phytoplankton abundance (Cowles *et al*., 1988; Dam & Lopes, 2003). However as copepods are capable of selective feeding, the quality of secondary production is further complicated by influential factors such as algae cell size and food quality (Pond *et al*., 1996). Studies have demonstrated that diatoms, in particular, are nutritious and may be beneficial for high reproductive potential (Dam & Lopes, 2003; Vargas *et al.,* 2010). However, other studies have indicated that diatoms alone as diet for egg producing copepod females may have negative effects on hatching success of the eggs, and a mixture of various genera may be needed for successful hatching and development of the nauplii (Ianora & Poulet, 1993; Jónasdóttir & Kiørboe, 1996; Jónasdóttir *et al.*, 1998; Nejstgaard *et al*., 2001; Vargas *et al*., 2006).

1.3 Diet for reared fish larvae

During the early developmental stages in coldwater marine fish such as cod (*Gadhus morhua*) and halibut (*Hippoglossus hippoglossus*), live pray is required due to underdeveloped organs and digestive track (Støttrup, 2000). Initially the larval diet consists largely of copepod eggs and naupliar stages. As larvae grow, larger food items are progressively selected, mainly constituting the copepodite stages (Gaard & Steingrund, 2001; Gaard & Reinert, 2002; Debes *et al*., 2008b; Maps *et al*., 2005).

There are two types of rearing systems which differ in the type of live pray provided for fish larvae. These are referred to as intensive and extensive/semi-intensive production systems. In an intensive production system, larvae are typically start-fed with rotifers (*Brachionus* spp.) and brine shrimps (*Artemia* spp.). On the other hand, the extensive and semi-intensive systems make use of zooplankton present in the natural environment. The latter systems are tend to be located in coastal lagoons where copepods such as *Calanus* spp., *Temora* spp., *Eurytemora* spp., *Acartia* spp. and *Centropages* spp. are abundant, and therefore commonly used are live feed for fish larvae (Evjemo *et al.,* 2003; van der Meeren *et al*., 2005).

The intensive method provides a stable food source for fish larvae as rotifers are easy to culture and *Artemia* cysts are available throughout the year. When needed, they can be induced to hatch within 24 hours prior use with little effort (Steenfeldt, 2008). The drawback of this method is the lack of nutritional value, which reduces the odds of optimal growth, development and survival compared to the extensive/semi-intensive method (van der Meeren *et al*., 2008; Shields *et al*., 1999; Steenfeldt, 2008). Substantial efforts have gone into designing enrichment diets for rotifers/*Artemia* to incorporate the lack of essential fatty acids. So far the efficacy of these methods is not comparable with the nutritional value of natural zooplankton (Evjemo *et al.*, 2003; Hamre, 2005; Imsland *et al*., 2006; Shields *et al.*, 1999).

A study conducted by Imsland *et al*. (2006) clearly demonstrates that diet for cod larvae is a key factor for juvenile growth potential, quality and adaptability to environmental changes. After 50 days, the experiment revealed that larvae fed with natural zooplankton grew up to 12 times better with less deformities compared to

larvae startfed with rotifers. Related studies by Shields *et al*. (1999), Kolbeinshavn *et al.* (submitted) and Busch *et al.* (2010) have reached similar conclusions.

Optimising the production capacity in a semi-enclosed environment should ideally prolong the production of plankton from 2 to 6 months. In turn, this increases the number of start feedings from 1 production cycle, which is common today, to 3 production cycles per year. Thus the final outcome could lead to significant benefits for fish farmers. However, at present, the disadvantage of using natural zooplankton as live feed is its unreliable quantities in production systems. Thus despite clear beneficial health effects, using rotifers and brine shrimp as live feed remains the preferred method of choice (Støttrup, 2000; Imsland *et al*., 2006).

1.4 Investigation of semi-intensive production in Nesvík's basins

Since 2002 the Aquaculture Research Station of the Faroes (Fiskaaling) has been actively involved in experimental farming of fish larvae in mesocosms at The Marine Station in Nesvík (fig 1.2).

Fig 1.2. The Marine Station in Nesvík.

From 2002 to 2006 Fiskaaling was involved in a large scale project which focused on rearing cod larvae in a semi-intensive system, startfed with natural zooplankton. Later, the larvae were transferred to net cages in Árnafirði. The results from this experiment exceeded the standard expectation, both in terms of growth and late maturation (Kolbeinshavn *et al*., submitted).

In spring 2009 two biology students from the University of the Faroe Islands worked in close association with Fiskaaling on a bachelor project, focusing on the effects of various nutrient compositions on phytoplankton cultivation in Nesvík basins (Reinert & Danielsen, 2009). It was demonstrated that low N:P ratio yielded small

phytoplankton cells and during low nutrient concentrations smaller cells became the dominating species. On some occasions nutrients did not appear limited, yet larger cells were largely absent. It was suggested that mechanical stirring might induce a change in the phytoplankton composition, favouring larger species.

1.5 Aims and objectives

The overall aim was to gain a better understanding of the underlying mechanisms in the planktonic ecosystem in Nesvík's basins. This is a prerequisite in order to understand the production capacity, and how to utilise this knowledge to optimise the production of reared fish larvae.

The objectives can be divided into two categories:

- phytoplankton and environmental parameters
- zooplankton

Regarding primary production, the goal was to achieve a relatively high and stable output from spring to autumn. Attempts were made to stimulate diatom dominance rather than a dominance consisting of small flagellates. In this association the aim was to determine the effects of different nutrient concentrations on primary production and how this potentially may affect zooplankton abundance and composition.

To become more familiar with the zooplankton community structure and its development, the aim was to observe the following processes:

- community structure and succession
- egg production of the dominant species
- zooplankton growth, stage development and mortality

2.0 Materials & methods

2.1 Study area

A mesocosm experiment was conducted at The Marine Station in Nesvík, Faroe Islands, between 12th April and 11th November 2010. The study site is located at approximately 62°13'0 N, 7°1'0 W. A map of the study location is included in appendix A.

Detailed studies were executed in three basins, referred to as the eastern, southern and northern basin. Toward the end of the experiment, samples were also collected from a fourth basin, referred to as the western basin. The enclosures, originally interconnected via 1.5 m openings, were separated into four units with wooden plates. The basins are approximately 5.5 m deep with a total volume of 18,195 m^3 (fig. 2.1). The individual volume of the basins is displayed in table 2.1. More detailed images of the first three enclosures are displayed in appendix A.

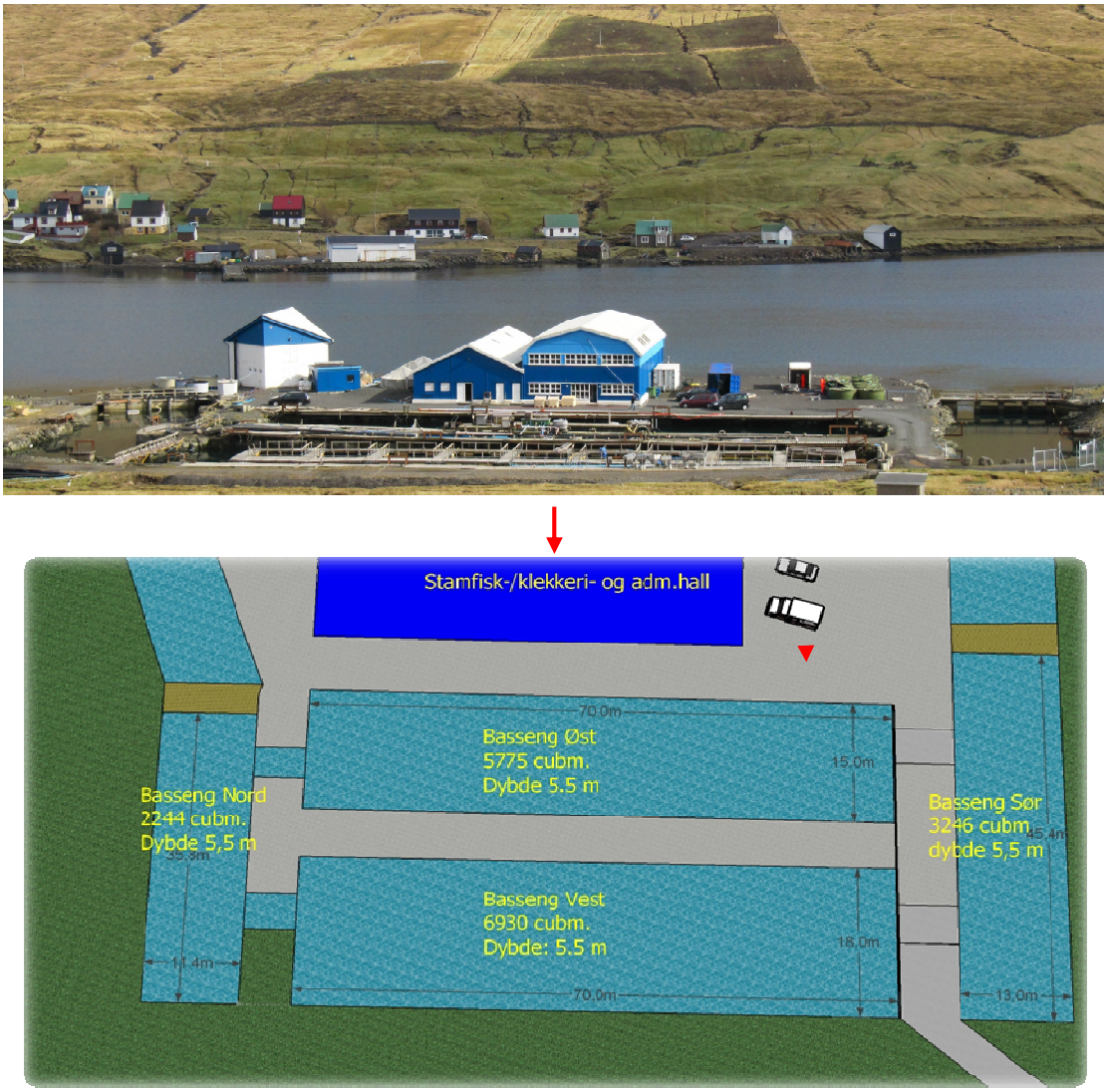

Fig. 2.1. Layout of the four basins at The Marine Station in Nesvík.

In early March 2010 the basins were drained. The eastern basin was scrubbed free from accumulated sediment, while the others remained untouched. Subsequently they were filled with seawater, pumped from 15 m depth in the fjord next to the basins. The inflowing seawater was filtered though a 100 µm net before entering the basins. Subsequently the southern, northern and eastern basins received and dispatched 0.9%, 1.0% and 1.0% of seawater each day. By 7th June and onwards the seawater renewal was 3.7% in all three basins. The seawater exiting the basins was pumped via the western basin, which had an 80 µm filter from early May to early August. Inflow and outflow of seawater (L min^{-1}) and the renewal time for each basin is presented in table 2.1.

To enhance circulation, and thereby also impeding sediment accumulation, a 5 kw pump was placed in the eastern and northern basin. The southern basin was equipped with a 1.3 kw pump. The pumps were located at approximately 4 m depth.

Table 2.1. Description of the four basins with regards to size and inflow/outflow of seawater.

		H_20 inflow/outflow (L min^{-1})			***Renewal time (days)***		
Basins	***Vol (m^3)***	***20/3 - 6/4***	***7/4 - 6/7***	***7/6- 11/11***	***20/3 - 6/4***	***7/4 - 7/6***	***7/6- 11/11***
South	3246	20	50	84	112.7	45.1	26.8
North	2244	15	50	57	103.9	31.2	27.3
East	5775	40	160	150	100.3	25.1	26.7
West	6930	75	260	291	64.4	18.5	16.5

2.2 Nutrient loading

Two types of fertilisers were used during the experiment. These were YARA (NPK 22-2-11) which was later combined with Nitrophoska (NPK 12-5-14) to increase the phosphorous content. Silicate was only added to the eastern and southern basin. The product used was called Krystazil 40 and according to the manufacture, Hjelle Kjemi, the natriumsilicate content ranged between 30% and 60% in weight.

Based on volume, the eastern basin received twice as much fertiliser compared to the other two basins and twice as much silicate compared to the southern basin. The western basin received no manipulation.

Twice a week, from 12th April to 20th April, NPK 22-2-11 was gradually discharged over one hour. Additions of silicate were scattered with a bucket. From 21st April to 21st May, nutrients were loaded continuously throughout the day during weekdays. On 22nd May and onwards, weekends were also included. Nutrient loading stopped on 11th November. Refer to tables 2.2 to 2.4 for a detailed overview of the nutrient ratio

added to each basin during the experimental period. To observe quantities of fertiliser (kg) and silicate (L) added, refer to appendix B.

Table 2.2. Amount of nitrate, ammonium, phosphate and silicate added to the eastern basin per day from 12th April to 11th November 2010.

Date	*mol NO_3^-*	*mol NH_4^+*	*mol Po_4^{3-}*	*mol Si (min*)*	*mol Si (max*)*
12/4-3/5	**15.00**	**16.43**	**0.97**	**4.36**	**8.73**
4/5-9/5	**22.50**	**24.64**	**1.45**	**10.91**	**21.82**
10/5-21/5	**47.25**	**51.75**	**3.05**	**23.03**	**46.06**
22/5-30/5	**22.61**	**24.77**	**1.46**	**11.02**	**22.04**
31/5-1/6	**15.83**	**17.34**	**1.02**	**7.72**	**15.43**
2/6-3/6	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
4/6-18/6	**15.83**	**17.34**	**1.02**	**7.72**	**15.43**
19/6-2/7	**11.25**	**12.32**	**0.73**	**5.30**	**10.61**
3/7-4/7	**7.88**	**8.63**	**0.51**	**3.71**	**7.42**
5/7-27/7	**7.22**	**7.96**	**0.54**	**3.78**	**7.56**
28/7-2/8	**8.52**	**9.39**	**0.64**	**4.46**	**8.92**
3/8-11/11	**8.31**	**9.16**	**0.63**	**4.35**	**8.70**

*****Refers to the minimum and maximum concentration of silicate in Krystazil.

Table 2.3. Amount of nitrate, ammonium, phosphate and silicate added to the southern basin per day from 12th April to 11th November 2010.

Date	*mol NO_3^-*	*mol NH_4^+*	*mol Po_4^{3-}*	*mol Si (min)*	*mol Si (max)*
12/4-3/5	**4.20**	**4.60**	**0.27**	**1.21**	**2.42**
4/5-9/5	**6.30**	**6.90**	**0.41**	**3.03**	**6.06**
10/5-18/5	**13.50**	**14.79**	**Na**	**4.24**	**8.48**
19/5-21/5	**13.50**	**14.79**	**0.87**	**6.36**	**12.73**
22/5-30/5	**6.46**	**7.07**	**0.42**	**3.05**	**6.09**
31/5-1/6	**4.52**	**4.95**	**0.29**	**2.13**	**4.27**
2/6-3/6	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
4/6-18/6	**4.52**	**4.95**	**0.29**	**2.13**	**4.27**
19/6-2/7	**3.30**	**3.61**	**0.21**	**1.52**	**3.03**
3/7-4/7	**2.31**	**2.53**	**0.15**	**1.06**	**2.12**
5/7-27/7	**2.07**	**2.28**	**0.16**	**1.05**	**2.09**
28/7-2/8	**2.44**	**2.68**	**0.18**	**1.23**	**2.47**
3/8-11/11	**2.37**	**2.61**	**0.18**	**1.20**	**2.41**

Table 2.4. Amount of nitrate, ammonium and phosphate added to the northern basin per day from 12th April to 11th November 2010.

Date	*mol NO_3*	*mol NH_4^+*	*mol Po_4^3*
12/4-3/5	**11.70**	**12.81**	**0.75**
4/5-9/5	**4.35**	**4.76**	**0.28**
10/5-21/5	**9.00**	**9.86**	**0.58**
22/5-30/5	**4.31**	**4.72**	**0.28**
31/5-1/6	**3.02**	**3.30**	**0.19**
2/6-3/6	**0.00**	**0.00**	**0.00**
4/6-18/6	**3.02**	**3.30**	**0.19**
19/6-2/7	**2.21**	**2.42**	**0.14**
3/7-4/7	**1.55**	**1.70**	**0.10**
5/7-27/7	**1.37**	**1.51**	**0.10**
28/7-2/8	**1.63**	**1.79**	**0.12**
3/8-11/11	**1.58**	**1.75**	**0.12**

The fertilisers and silicate were dissolved with freshwater (approximately 3 L) 24 hours before being transferred to tanks that were connected to the relevant basin. To prevent clogging, small pumps were installed in each tank. Due to the large amount of nutrient loading to the eastern basin, silicate and the NPK fertilisers were dissolved separately. Fig 2.2 displays the experimental setup in the eastern basin.

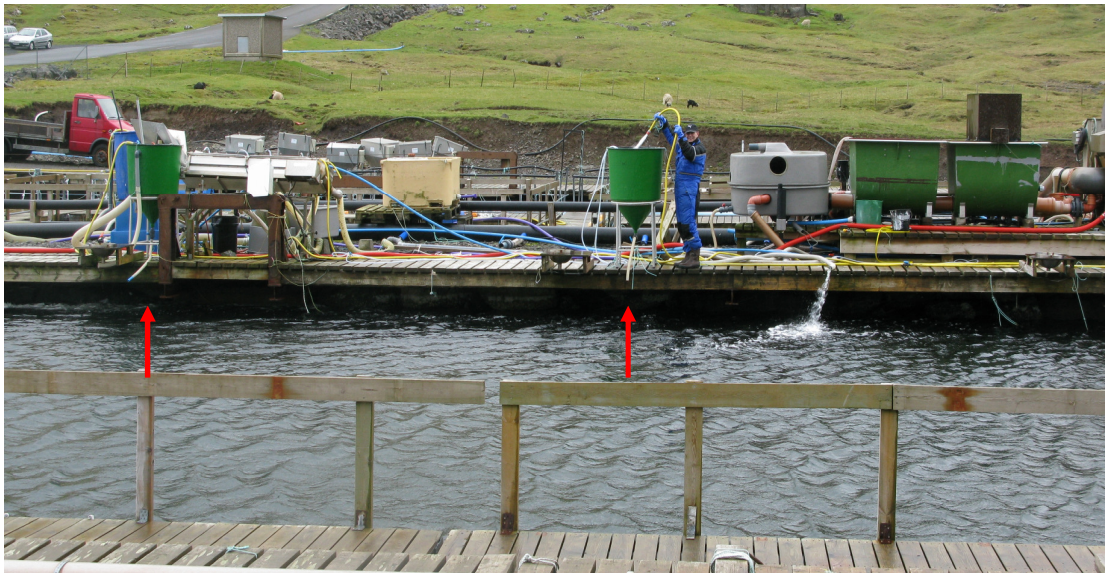

Fig. 2.2. Visualisation of the experimental setup in the eastern basin. The tank on the left hand side contained silicate while the tank on the right hand side contained the NPK fertilisers. Further to the right, inflowing seawater is discharged into the basin.

2.3 Physicochemical monitoring

Monitoring of physicochemical parameters began on 12th April and finished on 11th November. From 1st October and onwards, the western basin was also included. Sampling took place three times a week around 11 am. The week commencing on 27th September, the frequency was reduced to once a week. Physicochemical parameters were sampled at 1 m and 4 m depth. In the results, the measurements at 1 and 4 m depth are combined to display an average value along with standard deviation (SD). The parameters, along with manufacturer, are listed in table 2.5. Inflowing seawater was also sampled and monitored for temperature, salinity, pH and nutrients including nitrate, ammonium, phosphate and silicate. Water samples for nutrient analyses were preserved with 12 droplets of chloroform per 100 ml of sea water. These were analysed at the Faroe Marine Research Institute.

Table 2.5. Overview of the physical and chemical parameters investigated during the experimental period and the name of instruments used.

Physicochemical parameter	***Instrument***
Oxygen	OxyGuard Handy Polaris
Temperature	WTW CAND 315
Salinity	WTW Conduktometer LF 191
pH	OxyGuard Handy PH
Nutrients (NO_3^-+ NO_2^-, NH_4^+, PO_4^{3-} & SiO_4^{2-})	Autoanalyer (Seal Analytical)

Meteorological factors including wind speed, wind direction and air temperature were recorded daily and are listed in appendix G. However these parameters have not been further dealt with.

2.4 Biological monitoring

As with the physicochemical sampling regime, the western basin was included in the sampling process on 1st October and onwards. The week commencing on 27th September, the sampling frequency was also reduced to once a week

2.4.1 Phytoplankton

Samples for chlorophyll *a* measurements were collected from each basin twice a week at 1 m and 4 m depth and measured spectrophotometrically according to Parsons *et al.* (1984). Up to 1 L of seawater was filtrated on Whatman GF/F filters however from 21st September to 8th October, MN-3 filters were used instead. The extraction was carried out with 90% acetone. The chl. *a* content was calculated using the equation by Jeffrey and Humphrey (1975).

For phytoplankton identification and semi-quantitative estimates, a net with 20 µm mesh size, was used for collection. Samples were preserved with Lugol solution. The semi-quantitative phytoplankton samples were placed in four groups based on their relative abundance. The definition of the four groups is listed in table 2.6. The raw data is presented in Appendix C.

Table 2.6. Phytoplankton score and its definition.

Phytoplankton score	***Definition of phytoplankton score***
1	present
2	frequent
3	common
4	abundant (other species nearly outcompeted)

As there was a wide variety of diatoms, the less dominant species were placed in a grouped referred to as 'other diatoms.' This group included the following species:

- *Leptocylindrus minimus*
- *Nitzschia longissima*
- *Melosira nummuloides*
- *Melosira sulcata*
- *Thalassiosira spp.*
- *Cerataulina pelagica*
- *Coscinodiscus spp.*
- *Guinardia delicatula*
- *Pseudo-nitzschia spp.*
- *Eucampia zoodiacus*
- *Proboscia spp.*
- *Dictyocha spp.*

2.4.2 Zooplankton

Zooplankton samples were collected once a week, around 10.30 am, with a net that had a mesh size of 100 µm. A Hydro-Bios flow meter was attached to the net opening, measuring the volume of water passing through. For sample preservations, formaldehyde was added to a final concentration of 4%. For identification and enumeration, subsamples of 200-300 individuals were taken out with a Motoda plankton splitter. The raw data is presented in Appendix D. The prosome length for copepods and total length for nauplii was randomly measured.

It was also attempted to collect a few samples with a water sampler (2 L) and a Schindler's trap (10 L) at 3 m depth to compare with net samples.

Due to limited amount of literature on *Eurytemora* spp., were the developmental stages identified and categorised based on number of swimming legs and urosome

(table 2.7). Images of the individual stages are shown in fig 2.3. Non-copepod species were pooled in one group, referred to as “other.”

Table 2.7. Developmental stages of *Eurytemora* spp.

Copepodite stage	*No. of paired swimming legs*	*Nno. of urosomesegments)*
CI	2	1
CII	3	2
CIII	4	2
CIV	5	3
CV – young male	5	4
Adult – male	5	5
Adult - female	5	3

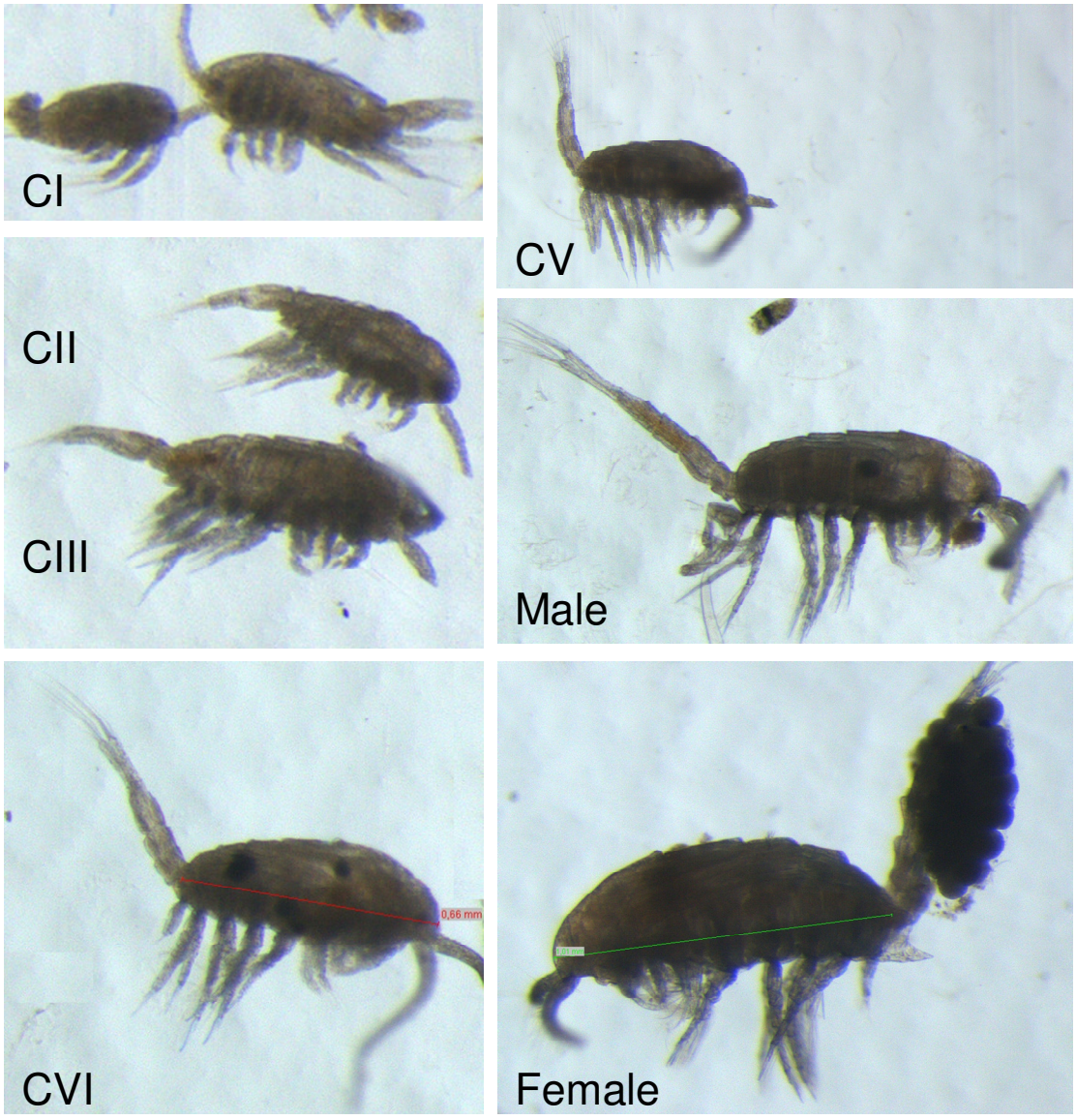

Fig 2.3. The developmental stages *of Eurytemora* spp.

2.4.3 Egg production

Observations of egg production were carried out on weekly basis. The experiments began on 14th April but the standard routine procedure was not established until 31st May. Ten replicates of egg sac bearing females from each basin were individually incubated in 500 ml bottles, containing filtered (30 µm) seawater for 24 and/or 48 hours. During the incubation period, the containers were placed in the basin of origin, maintaining *in situ* temperature and light conditions. Subsequently the samples were filtered through a 30 µm sieve and observed with an optical microscope, noting the number of eggs released and nauplii hatched.

2.4.4 Resting eggs

Collection of sediment samples took place on three different occasions which were as follows

1. before the basins were drained,
2. when the basins were nearly drained, and
3. when the basins drained and cleaned

On the first occasion a van Veen grab was used. For the following samples a cylindrical suction device was used to 'vacuum' 2 L at the bottom of the basins. Samples were sieved through 250 µm to retain larger particles and placed in a room where the temperature ranged between 10°C and 12°C. Artificial light had been set in according to April-May. Each sample was also hooked up with air flushing. A few droplets of phytoplankton culture consisting of *Nanochloropsis* and *Tetraselmis* were regularly added to the containers.

The sample was well mixed before observation. A volume between 25 ml and 100 ml of sample was collected and filtered through a 30 µm net. The remaining particles, including eggs and zooplankton, were observed under a microscope. Afterwards, the sample was transferred back to the container. Samples were regularly monitored and observed for approximately one month. During the observations, the numbers of resting eggs, nauplii and copepodite was determined. Due to the nature of the results, the data was placed in the appendix (Appendix F).

3.0 Results

3.1 The sea

3.1.1Temperature, salinity and pH

The temperature and salinity in the sea remained relative stable throughout the sampling period (fig. 3.1). At the start of the experiment the temperature was 7.8°C, gradually increasing to 11.2°C by 30th July. On the 17th September it dropped to 10°C and continued to decrease to 8.6°C.

The salinity remained relative stable throughout the sampling period, fluctuating between 33.7‰ to 34.9‰ (fig. 3.1) and the pH fluctuated within its typical range of pH 7.5 to 8.5 (fig. 3.2).

3.1.2 Nutrients

From 20th April to 8th October the nitrate concentrations fluctuated between <0.1 µM and 9.9 µM (fig. 3.3). The nitrate levels were at their lowest from 25th May to 29th June, with a maximum value of 2.8 µM. Subsequently the concentration gradually increased, peaking at 9.9 µM on 8th October.

The ammonium concentration was low throughout the experiment. The concentrations were <1 µM during the spring and from late September and onwards. During the summer the levels mainly varied between 0.5 and 2 µM (fig 3.3).

The levels of phosphate fluctuated between 0.2 µM and 0.6 µM (fig. 3.4).

The initial silicate concentration was 4.8 µM, fluctuating with a downward trend, measuring 0.8 µM on 21st May. Subsequently the concentration gradually increased, peaking at 10.1 µM on 23rd July. By 20th August the concentration had decreased again to 1.2 µM. From 31st August to 15th October the silicate concentration fluctuated between 5 µM and 9.9 µM (fig 3.4).

3.1.3 Chlorophyll **a** *and phytoplankton*

From 20th April to 21st May the concentration of chl *a* ranged between 0.9 µg L^{-1} and 5.4 µg L^{-1}. On 25th May and onwards, the chl a concentration revealed a gradual, fluctuating decease from 2.4 µg L^{-1} to 0.2 µg L^{-1} (fig. 3.5).

During most of the productive season the phytoplankton community consisted of various diatoms and dinoflagellates. Dinoflagellates (mainly *Scrippsiella trochoidea*) were consecutively present until mid August when a mixture of diatoms became more abundant (fig 3.6).

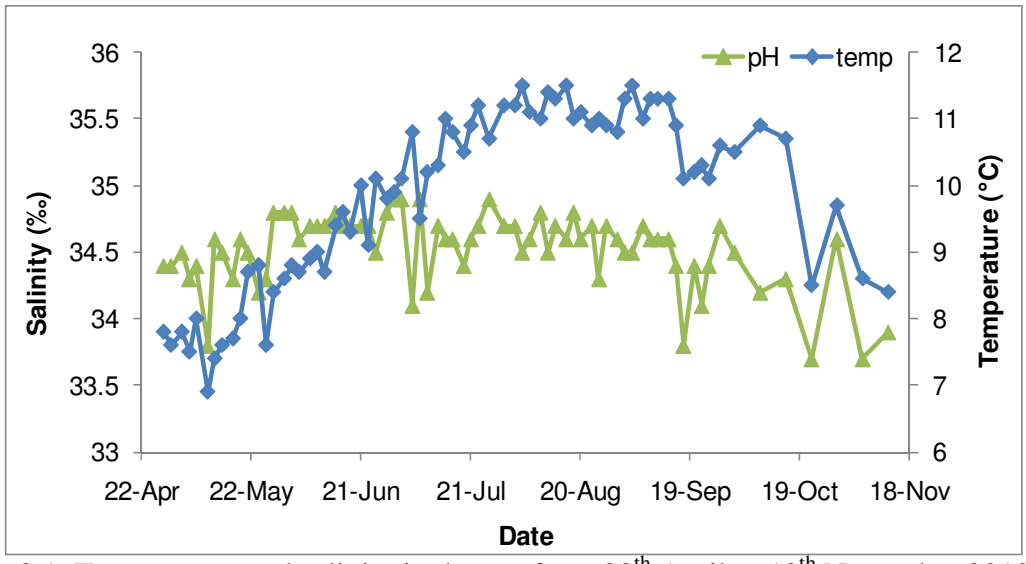

Fig. 3.1. Temperature and salinity in the sea from 28th April to 12th November 2010.

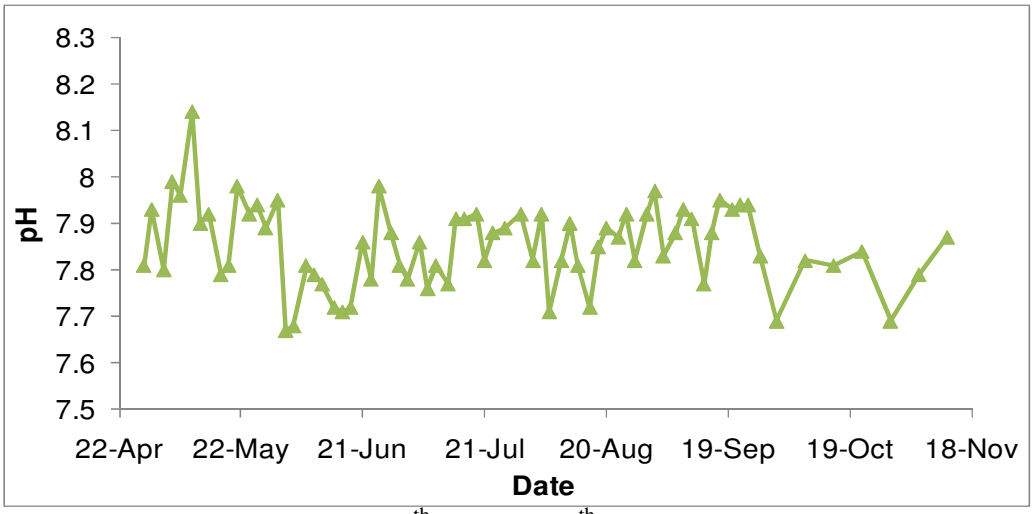

Fig. 3.2. The pH in the sea from 28th April to 12th November 2010.

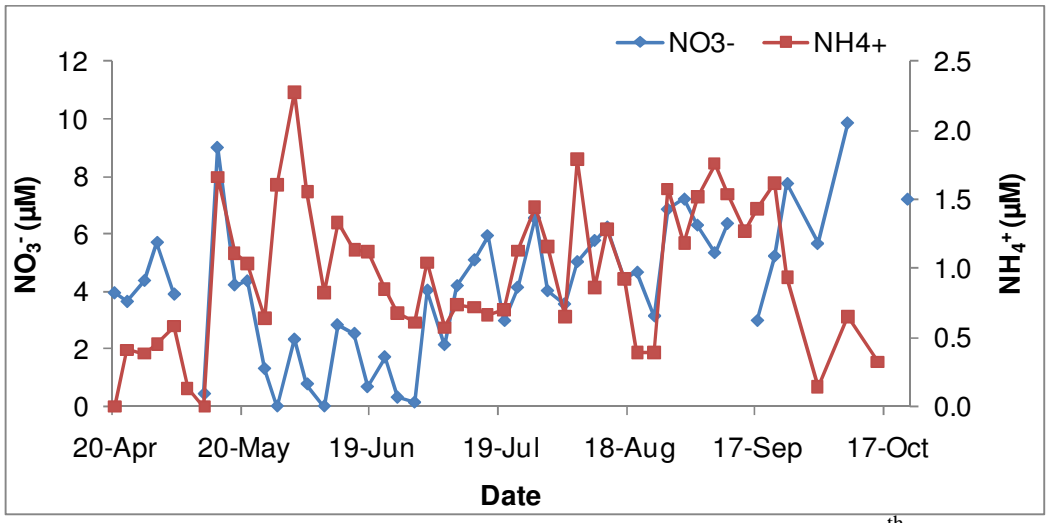

Fig. 3.3. Concentrations of nitrate and ammonium in the sea from 20th April to 15th October 2010.

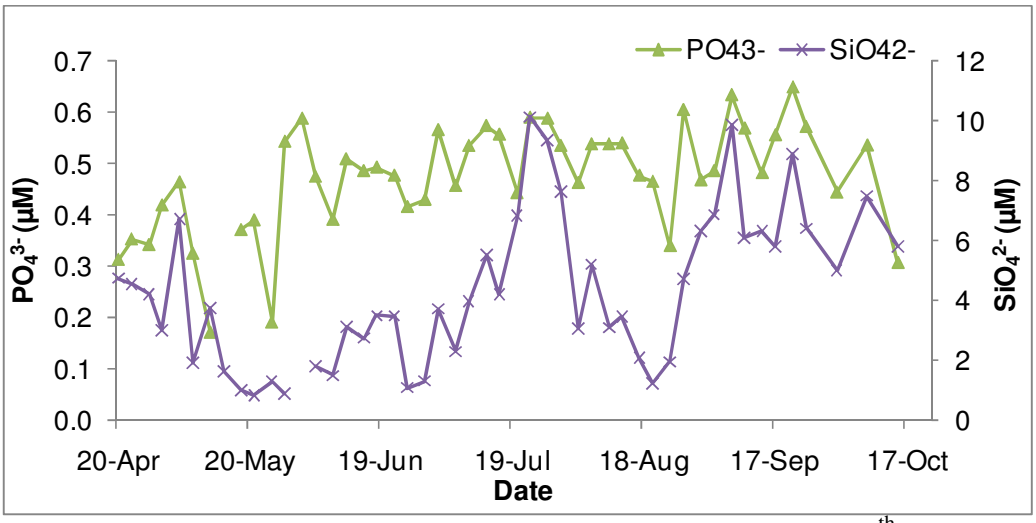

Fig. 3.4. Concentrations of phosphate and silicate in the sea from 20th April to 15th October 2010.

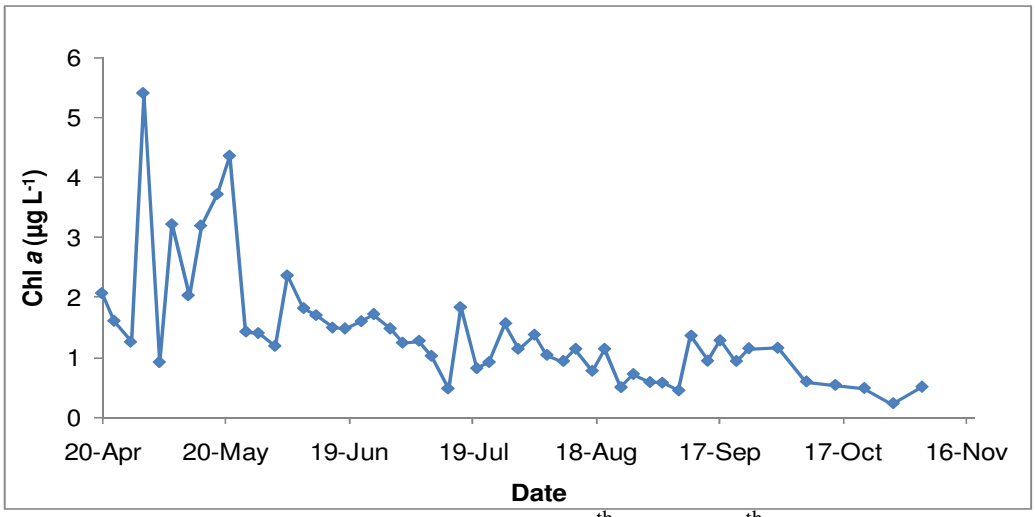

Fig 3.5. Concentration of chl *a* in the sea from 12th April to 5th November 2010.

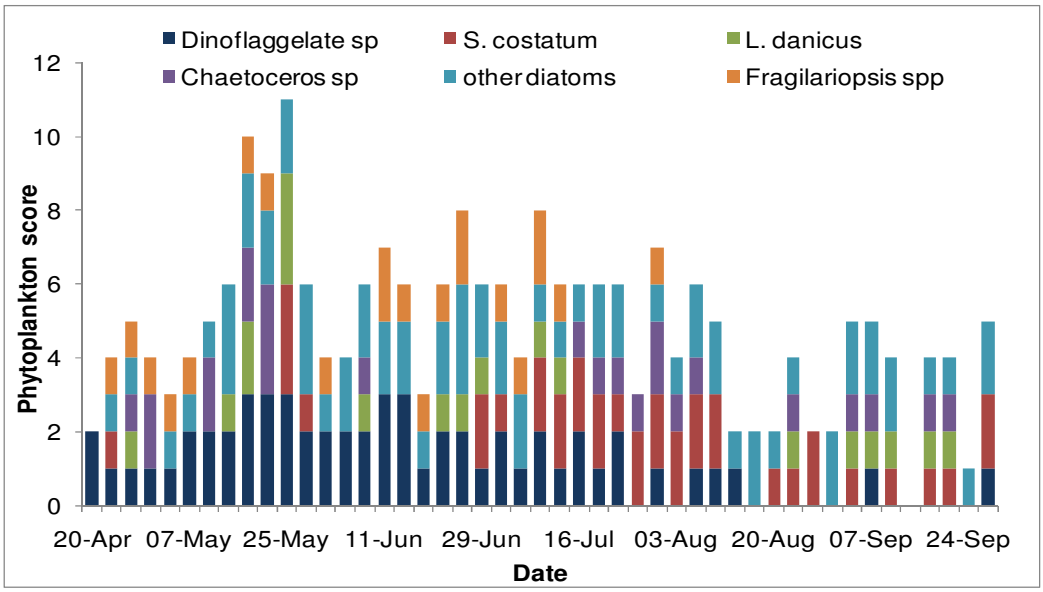

Fig. 3.6. Dominance and succession of dinoflagellate and diatom species in the sea from 20th April to 15th October.

3.2 The eastern basin

3.2.1 Temperature, salinity and pH

From the onset to the end of the experiment the temperature ranged between 5.1°C and 13.8°C, with the lowest temperature recorded during the initial and final stage of the experiment. The temperature peaked from mid July to mid August (fig. 3.7).

From mid April to mid July the salinity gradually increased from 27‰ to 31.8‰. Then it suddenly dropped to 30‰, however, by 10th September, the salinity had gradually increased to 33.0‰. Subsequently the salinity levels slowly declined to 29‰ (fig. 3.7).

The pH ranged between 7.6 and 8.6, fluctuating with a gradual decrease from mid July to the end of the experiment (fig. 3.8).

3.2.2 Nutrients

The nitrate concentration was below 7 µM until the 4th May (fig. 3.9). By 25th May the concentration had increased to 79.5 µM. On 20th July the levels had decreased again to 7 µM. Apart from three subsequent occurrences, the nitrate concentration remained above 7 µM. On five occasions, there are large discrepancies of the levels of nitrate present on 1 m and 4 m depth.

From 4th May to 14th May the ammonia concentration drastically increased from 2.1 µM to 19.9 µM (fig 3.9). By 1st June, the concentration was below 5 µM. Apart from two later occurrences, the levels ammonia remained below 5 µM.

The concentration of phosphate ranged from 0.03 µM to 1.7 µM (fig. 3.10). On 4 occasions, the phosphate levels were below 0.2 µM.

From 9th April to 15th October the levels of silicate fluctuated between 0.7 µM and 37.6 µM (fig. 3.10). The silicate concentration remained below 2 µM until the 7th May. Later, on 22nd June, the concentration had decreased again below the critical level.

3.2.3 Chlorophyll **a** *and oxygen*

The concentration of chl *a* and oxygen saturation followed a similar trend (fig. 3.11). Generally, as the concentration of chl *a* changed, the level of oxygen changed accordingly, a few days afterwards. The chl *a* concentration showed strong fluctuations throughout the experiment. From 27th April to 14th May and from 15th October to 22nd October, the concentration of chl *a* was below 15 µg L^{-1}.

The level of oxygen saturation ranged between 100 and 152%. On three occasions the level of oxygen was below 100%. The lowest recorded was on 20th August, measuring 92.5%.

3.2.4 Phytoplankton

Dinoflagellates were present from 16th April to 6th August, however most at the time they were outnumbered by diatoms (fig. 3.12). Until 28th May the diatom community was well mixed. From 1st June to 22nd June, *Fragilariopsis* spp. dominated which were gradually replaced by *Leptocylindrus danicus* and subsequently *Skelotonema costatum*. From 27th August to 24th September, the diatom community had no clear dominance but on 15th October *S. costatum* had largely replaced the other phytoplankton species.

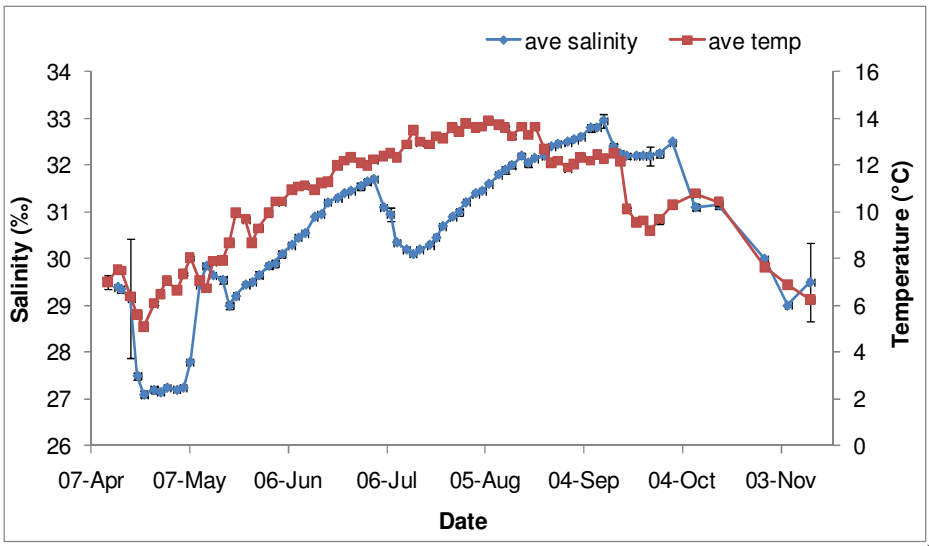

Fig 3.7. Temperature and salinity, along with SD, in the eastern basin from 12th April to 12th November 2010.

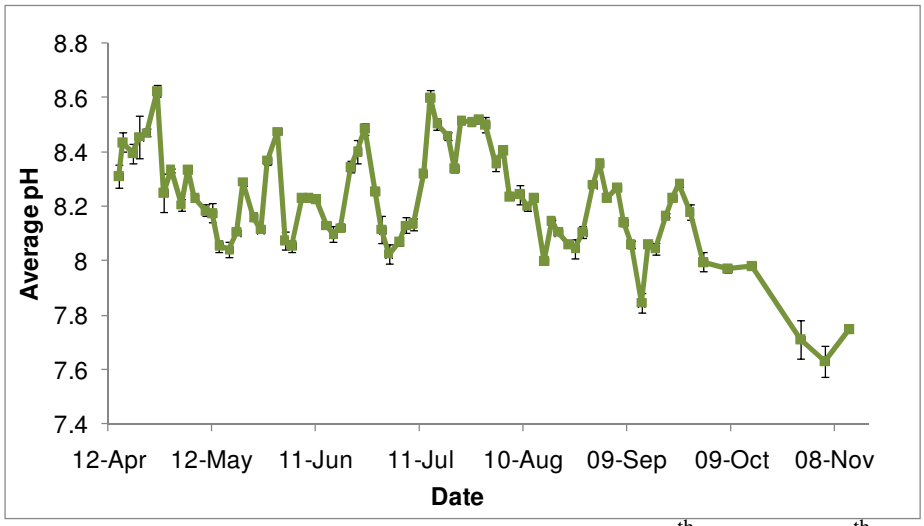

Fig. 3.8. pH, along with SD, of the eastern basin from 15th April to 12th November 2010.

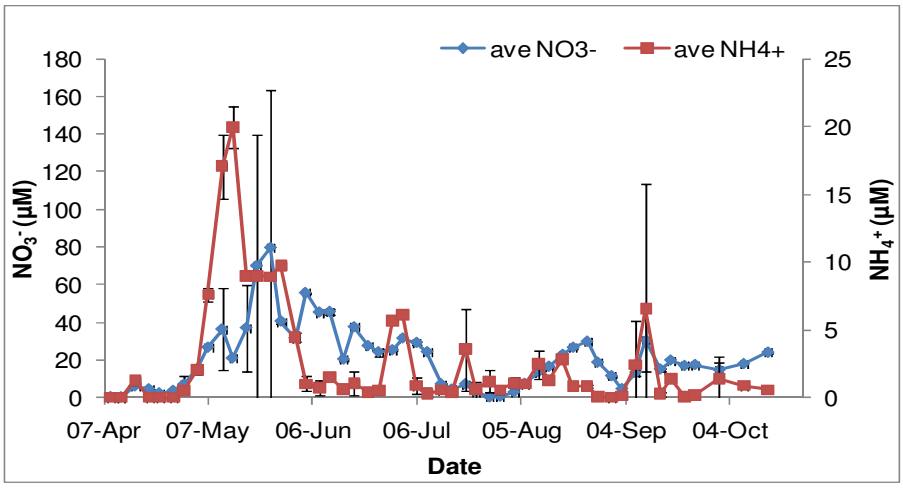

Fig 3.9. Concentrations of nitrate and ammonium, along with SD, in the eastern basin from 9th April to 15th October 2010.

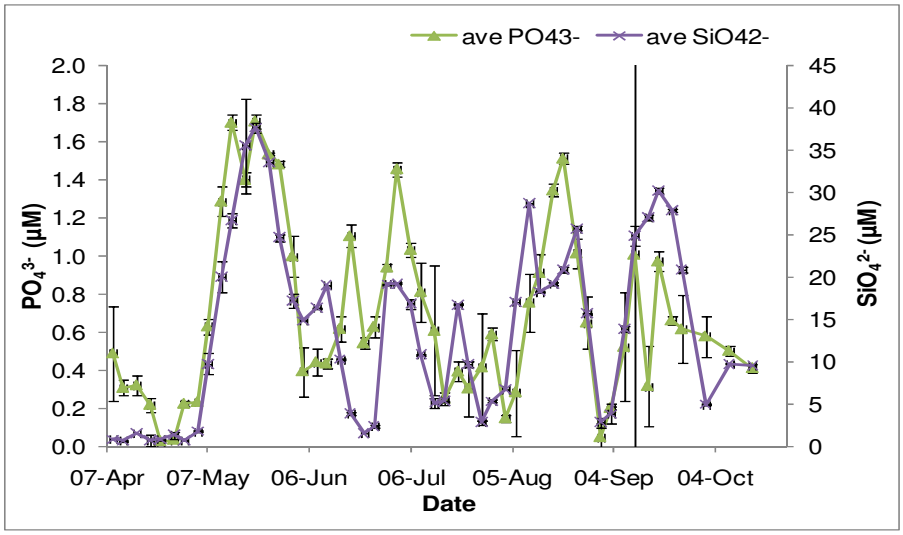

Fig 3.10. Concentrations of phosphate and silicate, along with SD, in the eastern basin from 9th April to 15th October 2010.

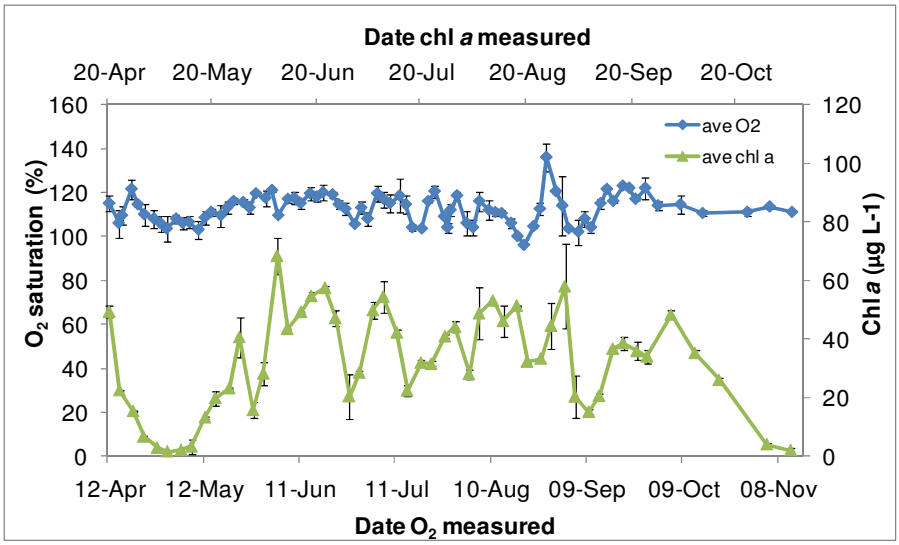

Fig 3.11. Oxygen saturation and chl *a*, along with SD, in the eastern basin from 12th April to 5th November 2010.

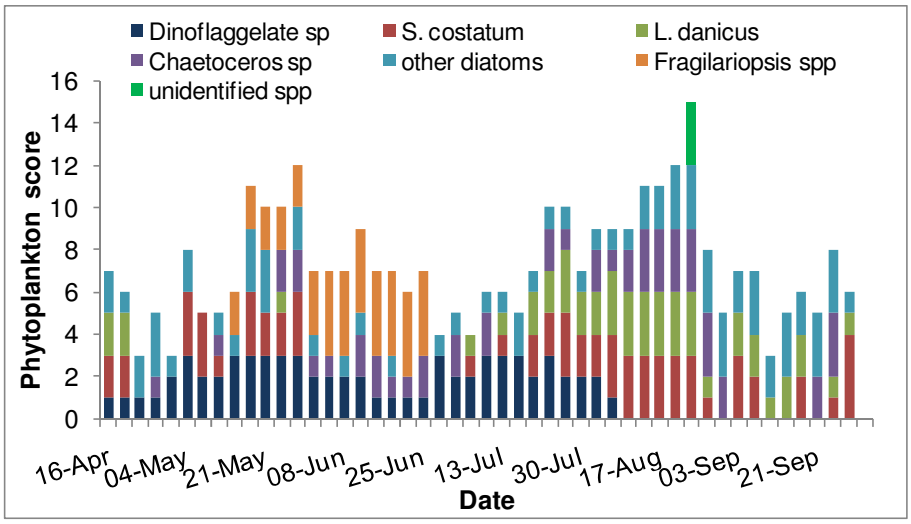

Fig. 3.12. Dominance and succession of dinoflagellate and diatom species in the eastern basin from 16th April to 15th October.

3.3 The southern basin

3.3.1 Temperature, salinity and pH

From the onset to the end of the experiment the temperature ranged between 5.0°C and 14.1°C, with the lowest temperatures recorded during the initial and final stage of the experiment (fig. 3.13). The temperature peaked from mid July to mid August.

During the initial phase of the experiment, the salinity was only around 27‰ (fig. 3.13). From 7th May to 27th September the salinity gradually increased to 32.1‰. From 28th June to 12th July the salinity dropped approximately 1 ‰ but subsequently continued to increase. After 27th September the salinity gradually decreased to roughly 28.4‰.

The pH fluctuated between 7.7 and 8.5 throughout the experiment, with the lowest values measured toward the end of the experiment (fig. 3.14).

3.3.2 Nutrients

From 12th April to 30th April the nitrate concentration was low, measuring less than 3 µM (fig. 3.15). Subsequently the concentration ranged between remained above 7 µM, peaking at 64.8 µM on 25th May. From 27th July to 3rd August, the concentration fell below 7 µM, fluctuating between <0.1 µM and 5 µM. Another drop in nitrate levels was seen from 31st August to 10th September.

The levels of ammonia peaked around the same time as the levels of nitrate (fig 3.15). The concentration remained below 5 µM except on 14th May when it reached 6.7 µM.

The phosphate concentration ranged from <0.1 µM and 2.1 µM (fig 3.16). The higher concentration values, 1.0 µM and higher, occurred from mid July and onwards.

Silicate levels fluctuated between 1.2 µM and 38.9 µM throughout the experiment. The concentration was ≤2 µM from 12th April to 23rd April (fig 3.16).

3.3.3 Chlorophyll a and oxygen

The concentration of chl *a* and oxygen saturation followed a similar trend, with strong fluctuations occurring at the same time (fig. 3.17). The chl *a* concentration ranged from 1.8 µg L^{-1} to 88.1 µg L^{-1}. The levels were below 15 µg L^{-1} on several occasions including from 27th April to 14th May, 15th June to 18th June, 16th July, 10th September, 29th October and on 5th November.

The level of oxygen saturation varied between 100% and 169%, apart on three occasions when the level was below 100% (fig. 3.17). The lowest, consecutive values recorded, were from 9th August to 25th August.

3.3.4 Phytoplankton

From 30th April to 25th June a dinoflagellate community dominated in the southern basin (fig. 3.18). On 29th June and onwards, the flagellates gradually became outcompeted by diatoms, particularly by *S. costatum* and later also by *L. danicus*. From 10th August to 15th October, no dinoflagellates were recorded.

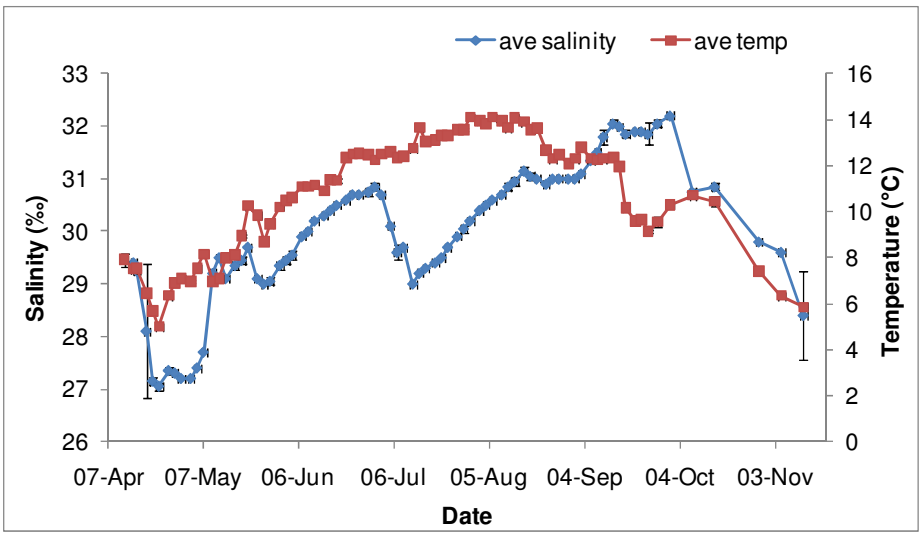

Fig. 3.13. Temperature and salinity, along with SD, in the southern basin from 12th April to 12th November 2010.

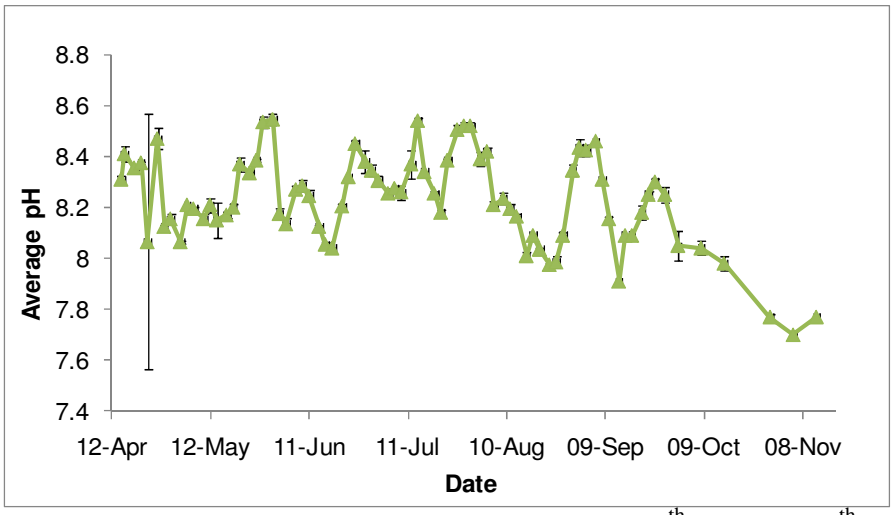

Fig. 3.14. pH along with SD, of the southern basin from 15th April to 12th November 2010.

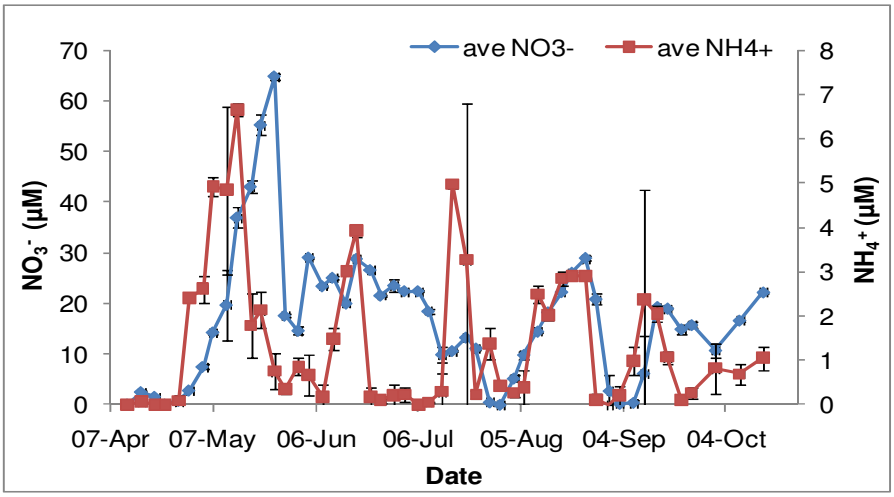

Fig. 3.15. Concentrations of nitrate and ammonium, along with SD, in the southern basin from 12th April to 15th October 2010.

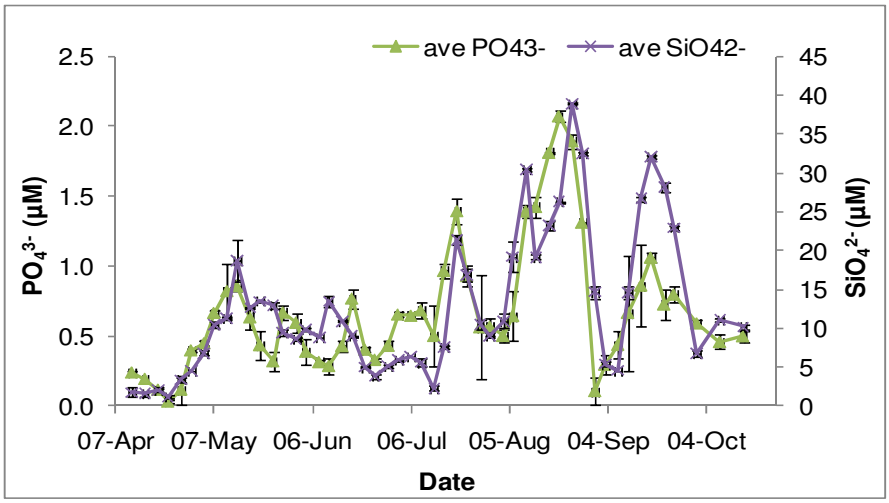

Fig. 3.16. Concentrations of phosphate and silicate, along with SD, in the southern basin from 12th April to 15th October 2010.

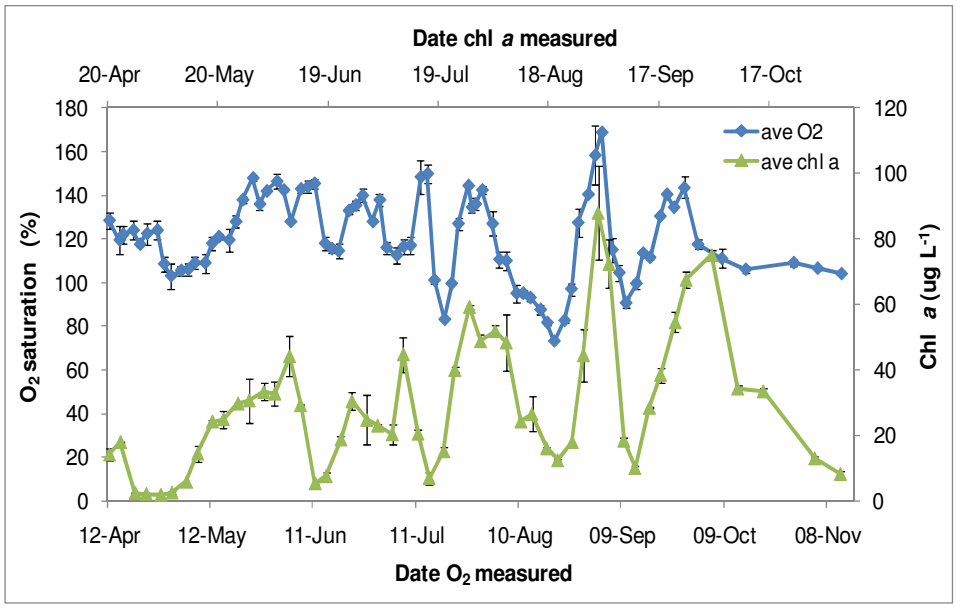

Fig. 3.17. Oxygen saturation and chl *a*, along with SD, in the southern basin from 12th April to 5th November 2010.

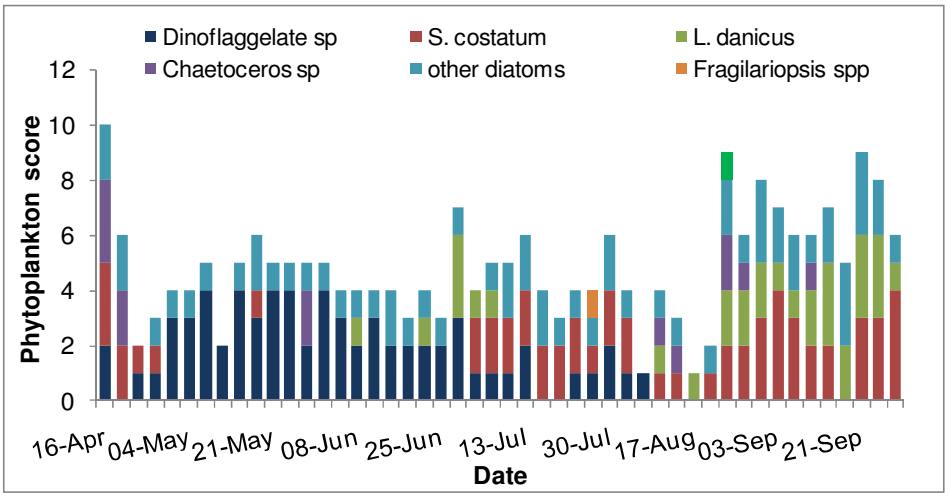

Fig. 3.18. Dominance and succession of dinoflagellate and diatom species in the southern basin from 16th April to 15th October.

3.4 The northern basin

3.4.1 Temperature, salinity and pH

The temperature ranged between 4.9°C and 14.5°C, with the lowest temperatures recorded during the initial and final stage of the experiment (fig. 3.19). The temperature peaked from mid July to mid August.

A gradual increase in salinity levels, from 29.0‰ to 32.6‰, occurred from onset to early September (fig. 3.19). In early to mid July a drop from 31.7‰ to 30.0‰

occurred, with subsequent increase. After 10th September and onwards, the salinity levels decreased again toward the initial level of approximately 29‰.

The pH ranged from 7.7 to 8.6, with the lowest values measured toward the end of the experiment (fig. 3.20). Most of the time the pH fluctuated between 8.0 and 8.4.

3.4.2 Nutrients

The concentration of nitrate ranged from <0.1 µM and 104.7 µM, reaching its peak on 25th May (fig. 3.21). Subsequently the concentration did not exceed 41.8 µM. Apart from the initial concentration, the nitrate levels were below 7 µM from 9th July to 17th August and again on 27th August to 7th September.

From 23rd April to 11th May the concentration of ammonia gradually increased from 0.25 µM to 14.7 µM (fig. 3.21). After 25th May, the levels of ammonia remained low, fluctuating between <0.1 µM and 2.5 µM.

The concentration of phosphate ranged from <0.1 µM and 1.3 µM throughout the experiment (fig. 3.22). The levels were less than 0.2 µM on 27th April and on 31st August.

The levels of silicate were below 2 µM on several occasions over a prolonged period, most notably from 12th April to 7th May, 28th May to 25th June and 3rd August to 17th August (fig. 3.22).

3.4.3 Chlorophyll a and oxygen

The chl *a* concentrations revealed large fluctuations throughout the experiment, ranging from 1.5 µg L^{-1} to 68.4 µg L^{-1} (fig. 3.23). Apart from 30th April to 18th May and from 29th October to 5th November, the chl *a* concentration remained above 15 µg L^{-1}.

The level of oxygen saturation remained above 100% except on 20th August when it measured 96% (fig. 3.23). Overall the oxygen saturation generally fluctuated between 100% and 120%.

3.4.4 Phytoplankton

Diatoms dominated from the start to the end of the experiment apart on 7th May and 11th May (fig. 3.24). The phytoplankton dominance oscillated between *S. costatum* and *L. danicus*. On 20th July *Chaetoceros* spp. increased in number however they did not outnumber *S. costatum*. From 13th August to 15th October the diatom community became more mixed. Dinoflagellate spp. were consistently present until 3rd August.

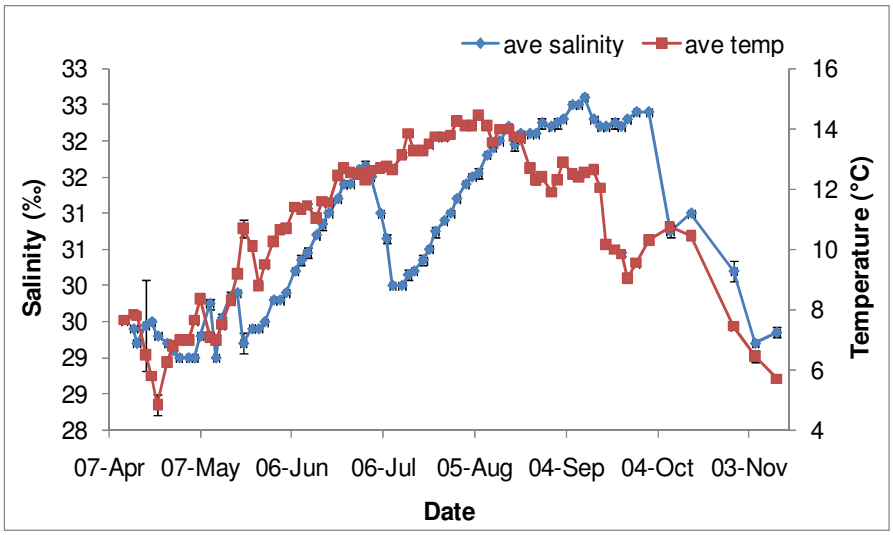

Fig. 3.19. Temperature and salinity, along with SD, in the northern basin from 12th April to 12th November 2010.

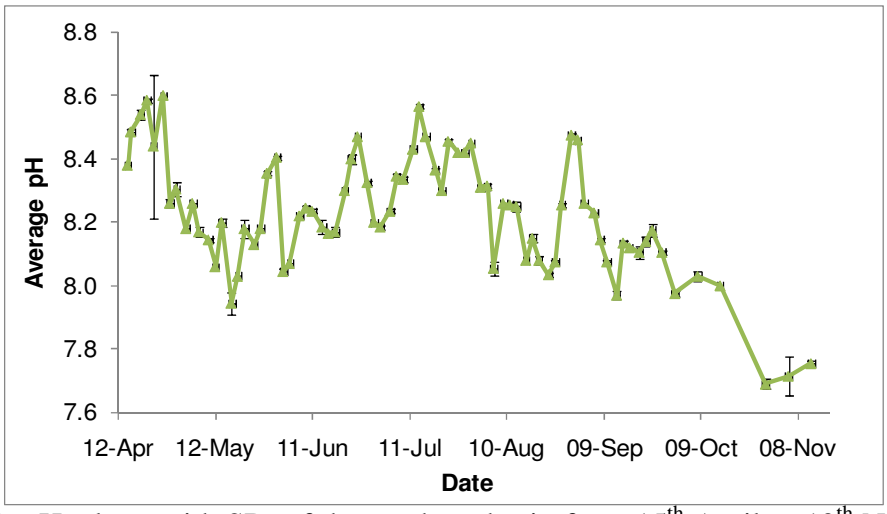

Fig. 3.20. pH, along with SD, of the northern basin from 15th April to 12th November 2010.

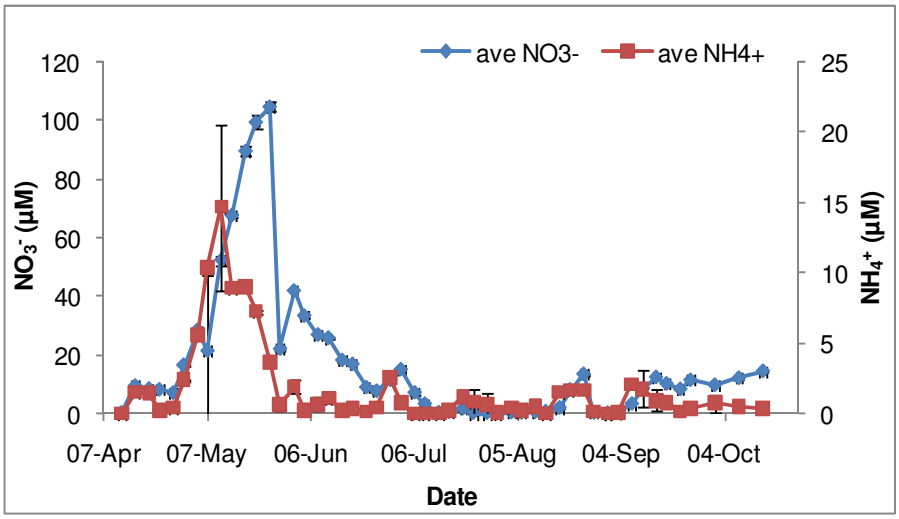

Fig. 3.21. Concentrations of nitrate and ammonium, along with SD, in the northern basin from 12th April to 15th October 2010.

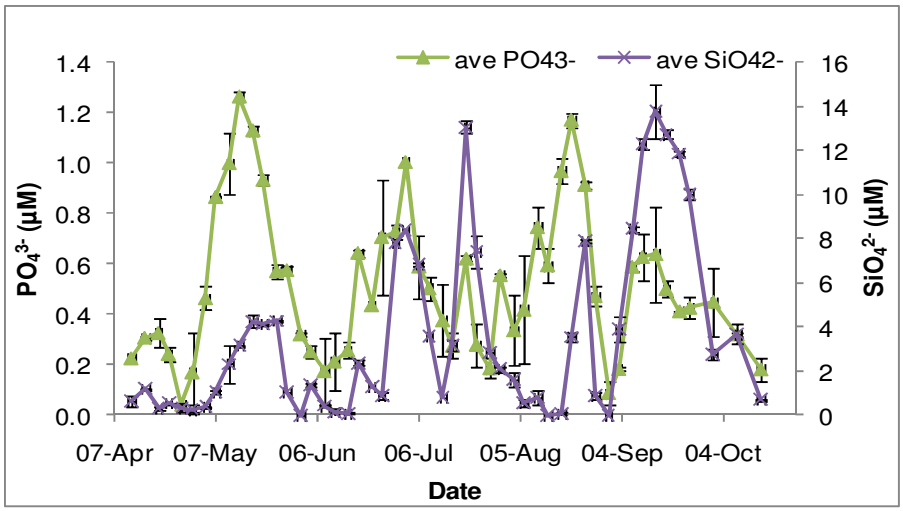

Fig. 3.22. Concentrations of phosphate and silicate, along with SD, in the northern basin from 12th April to 15th October 2010.

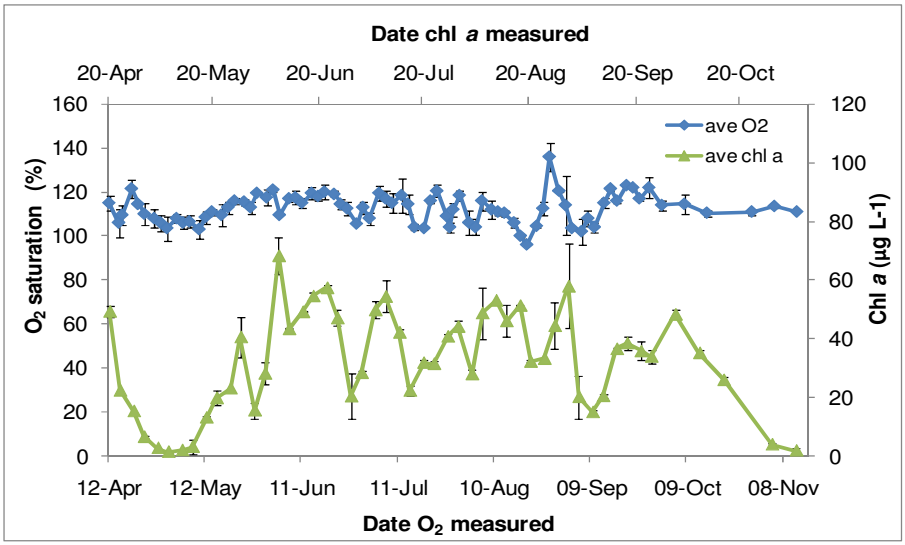

Fig. 3.23. Oxygen saturation and chl *a*, along with SD, in the northern basin from 12th April to 12th November 2010.

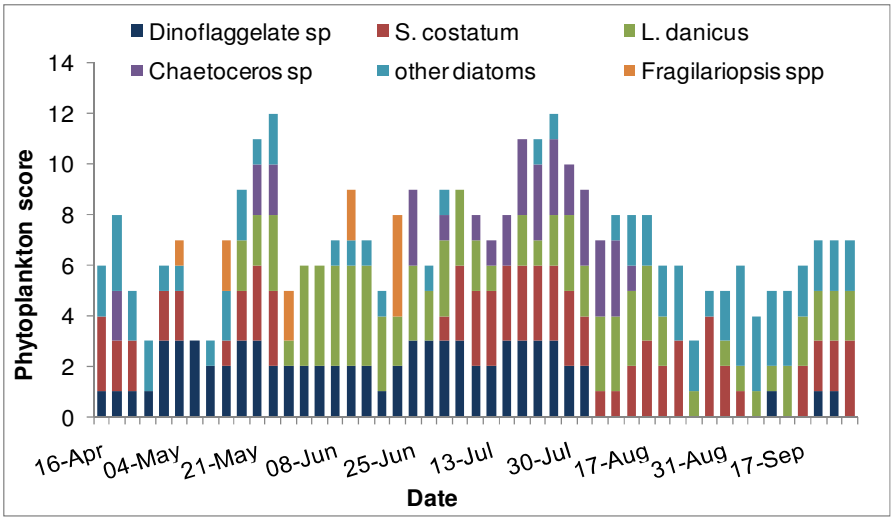

Fig. 3.24. Dominance and succession of dinoflagellate and diatom species in the northern basin from 16th April to 15th October.

3.5 The western basin

3.5.1 Temperature, salinity and pH

On 1st October, the onset of sampling in the western basin, the initial temperature was 10.0°C, which had gradually decreased to 6.1°C by 12th November (fig. 3.25). During this short period the pH varied between 7.7 and 8.0 and the salinity fluctuated from 31.8‰ to 27.7‰.

3.5.2 Nutrients

From 1st October to 5th November the nitrate concentration was high, increasing from 13.8 µM to 25µM. Meanwhile the levels of ammonia were low, ranging from 0.6 µM to 1.5 µM. The concentration of phosphate was relative stable, ranging from 0.5 µM to 0.7 µM. The silicate concentration was high however it did reveal a decreasing tendency from 21.1 µM to 9.6 µM (fig. 2.26).

3.5.3 Chlorophyll a and oxygen

The chl *a* concentration decreased from 39.9 µg L^{-1} to 1.0 µg L^{-1} (fig. 3.27). On the 15th October and onwards the levels of chl *a* were below 15 µg L^{-1}. The oxygen levels also showed a decreasing tendency, with the initial saturation level being 107%, falling to 80% by 12th November. On 8th October and onwards there is a quite large difference in oxygen saturation on 1 m and 4 m depth.

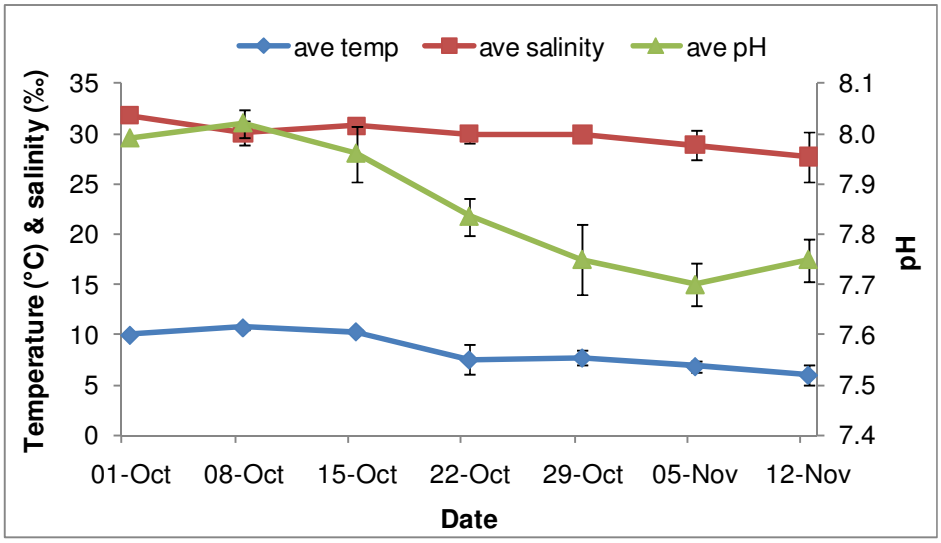

Fig. 3.25. Temperature, salinity and pH profile in the western basin, along with SD, from 1st October to 12th November 2010.

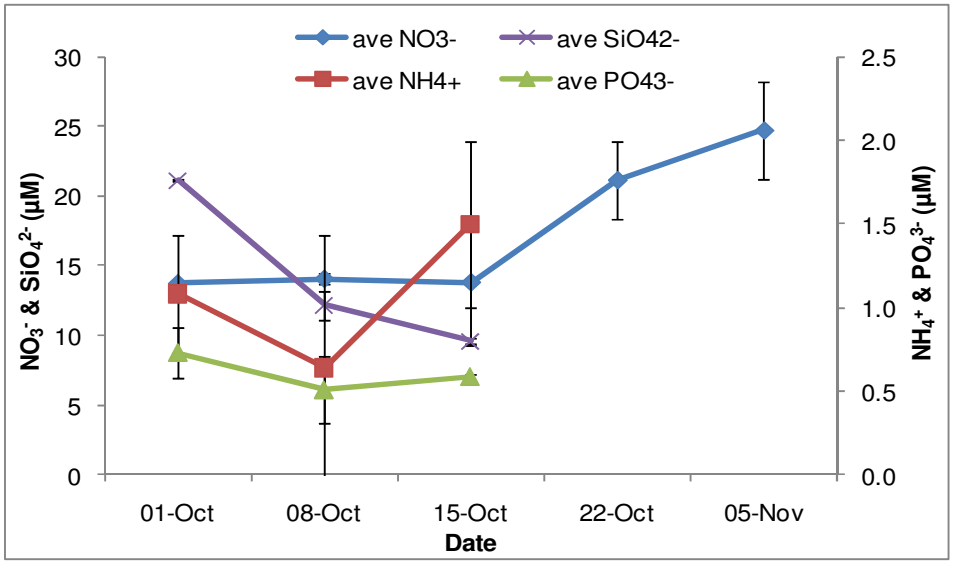

Fig 3.26. Concentrations of nitrate, ammonium, phosphate and silicate, along with SD, in the western basin from 1st October to 5th November 2010.

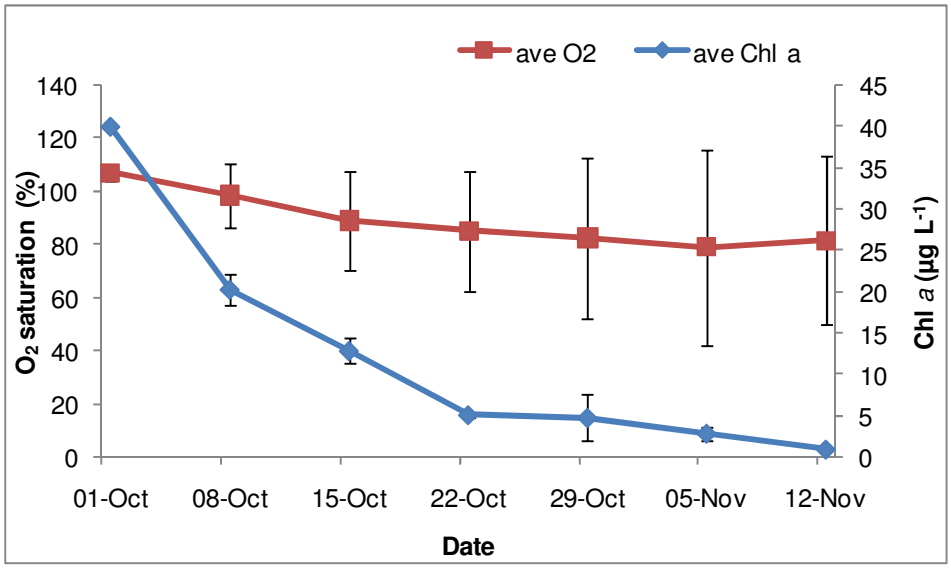

Fig 3.27. Oxygen saturation and chl *a* concentration in the western basin, along with SD, from 1st October to 12th November 2010.

3.6 Zooplankton in the eastern, southern, northern and western basin

3.6.1 Zooplankton quantity and community structure

The monthly variations in zooplankton concentrations in the eastern, southern and northern enclosures showed a high degree of variability. Less variability was seen in the western basin (fig 3.28 and 3.29). The copepod *Eurytemora* spp. was clearly the dominating species from the onset of the experiment. As *Eurytemora* spp. were present in significantly higher concentration than any other copepod species, the nauplii were assumed to belong to the same genus. Harpacoticoids were also commonly present, although in negiable concentrations (fig 3.29a). Species including decapod larvae, hydrozoans and two unknown worms were pooled into one group, referred to as "other" (fig 3.29b). There was no evident pattern of stage progression of *Eurytemora* spp. (fig 3.30 and 3.31).

3.6.2.1 Eastern basin

After the peak in early June (fig 3.28a and 3.28b), the variable quantity of *Eurytemora* spp. changed to a gradual decreasing trend until the end of the experiment. The concentration decreased from 117 nauplii L^{-1} and 38 copepodites L^{-1} to values as low as 0.067 nauplii L^{-1} and 0.057 copepodites L^{-1}. After 7th September the levels of nauplii, copodites and adults remained below 2 L^{-1}.

3.6.2.2 Southern basin

In the southern basin the quantity of *Eurytemora* spp. peaked in May 1,082 nauplii L^{-1} and 123 copepodites L^{-1} (fig 3.28a and 3.28b). Subsequently the concentration largely remained below 20 nauplii L^{-1} and 16 copepodites L^{-1}. On 21st September and onwards the concentration of nauplii and copepodites was below 2 L^{-1} and 0.7 L^{-1}, respectively.

3.6.2.3 Northern basin

The overall concentration of *Eurytemora* spp. was rather low but relative stable from May to July (fig 3.28a and 3.28b). The nauplii levels ranged from around 3.3 to 15 L^{-3} while the slightly lower quantities of copepodites varied from around 2 to 10 species L^{-3}. In August and onwards the concentrations became very low, commonly remaining below 1 L^{-3}.

3.6.2.4 Western basin

In late September to late October the concentrations of *Eurytemora* spp. ranged roughly from 20 to 50 Lm^{-3} nauplii and 10 to 26 L^{-3} copepodites. In November the quantity fell to 3 L^{-3} nauplii and 2 L^{-3} copepodites while the number of other species increased to similar levels (fig 3.29b). The pattern of each developmental stage is quite even from 29th September to 11th November in the western basin (fig 3.31).

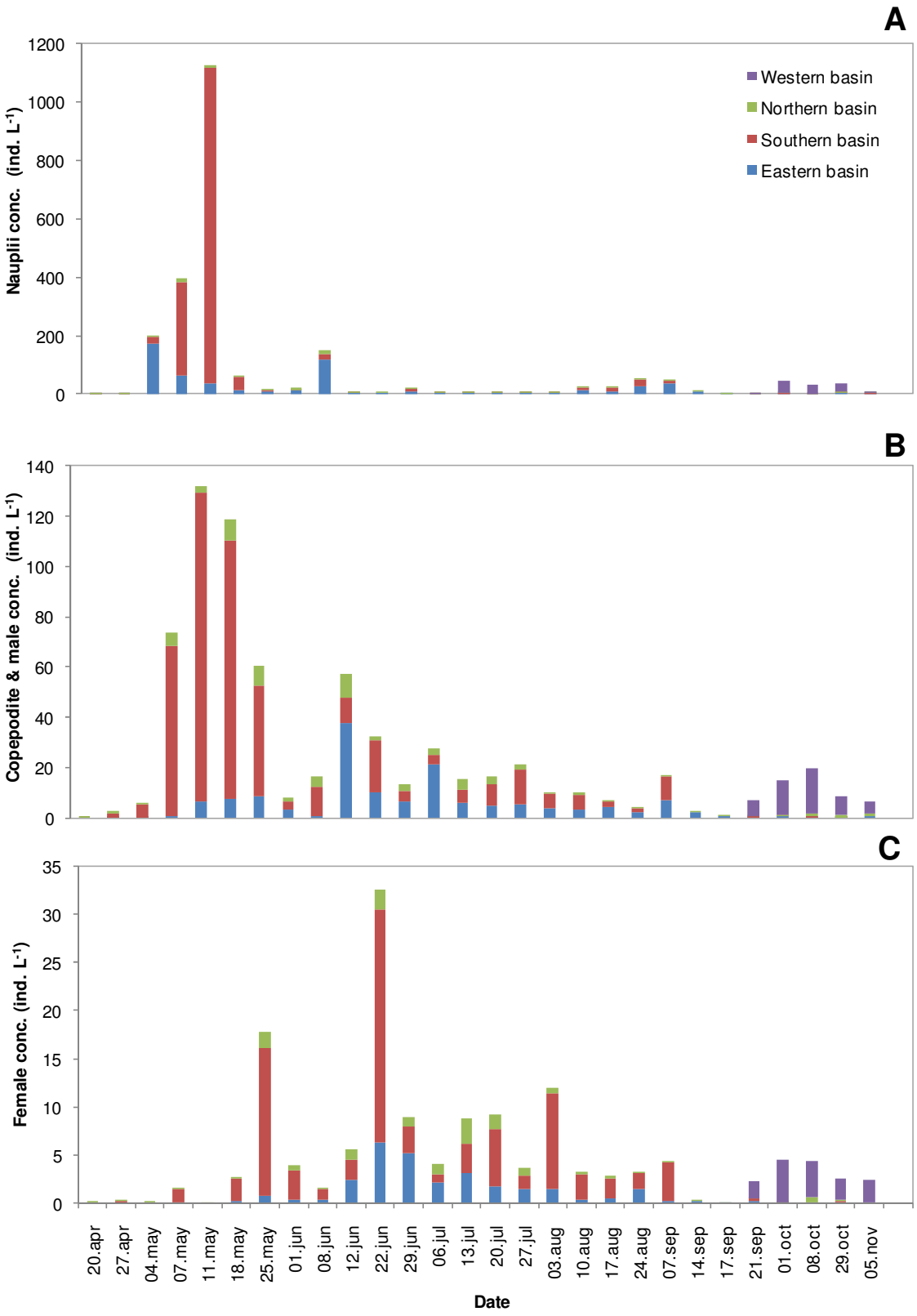

Fig 3.28. Concentration of *Eurytemora* nauplii (a), copepodites and males (b) and females (c) in the eastern, southern, northern and western basin from 20th April to 5th November 2010.

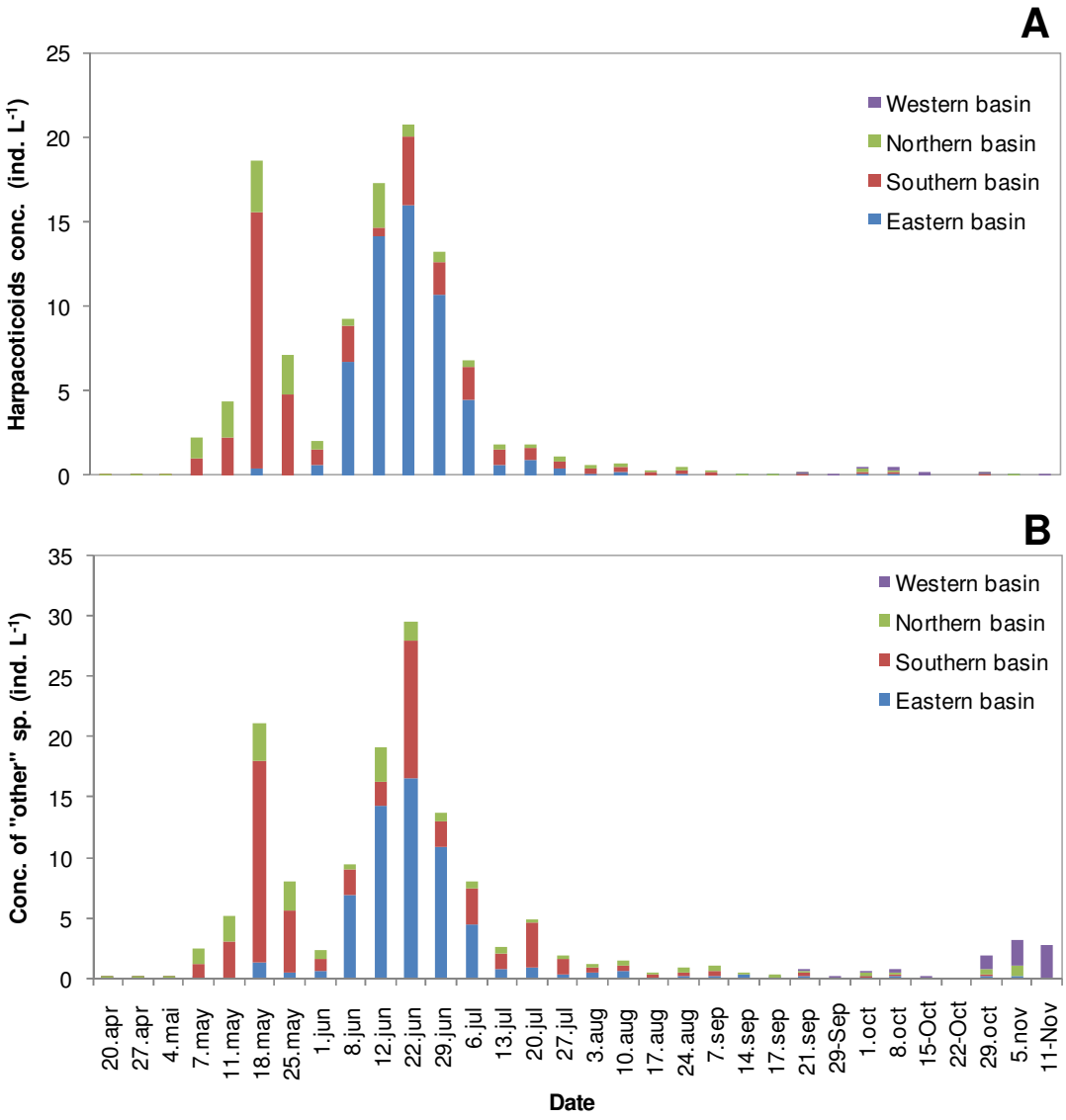

Fig 3.29. Concentration of harpacoticoids (a) and other non-copepod species (b) in the eastern, southern, northern and western basin from 20th April to 5th November 2010.

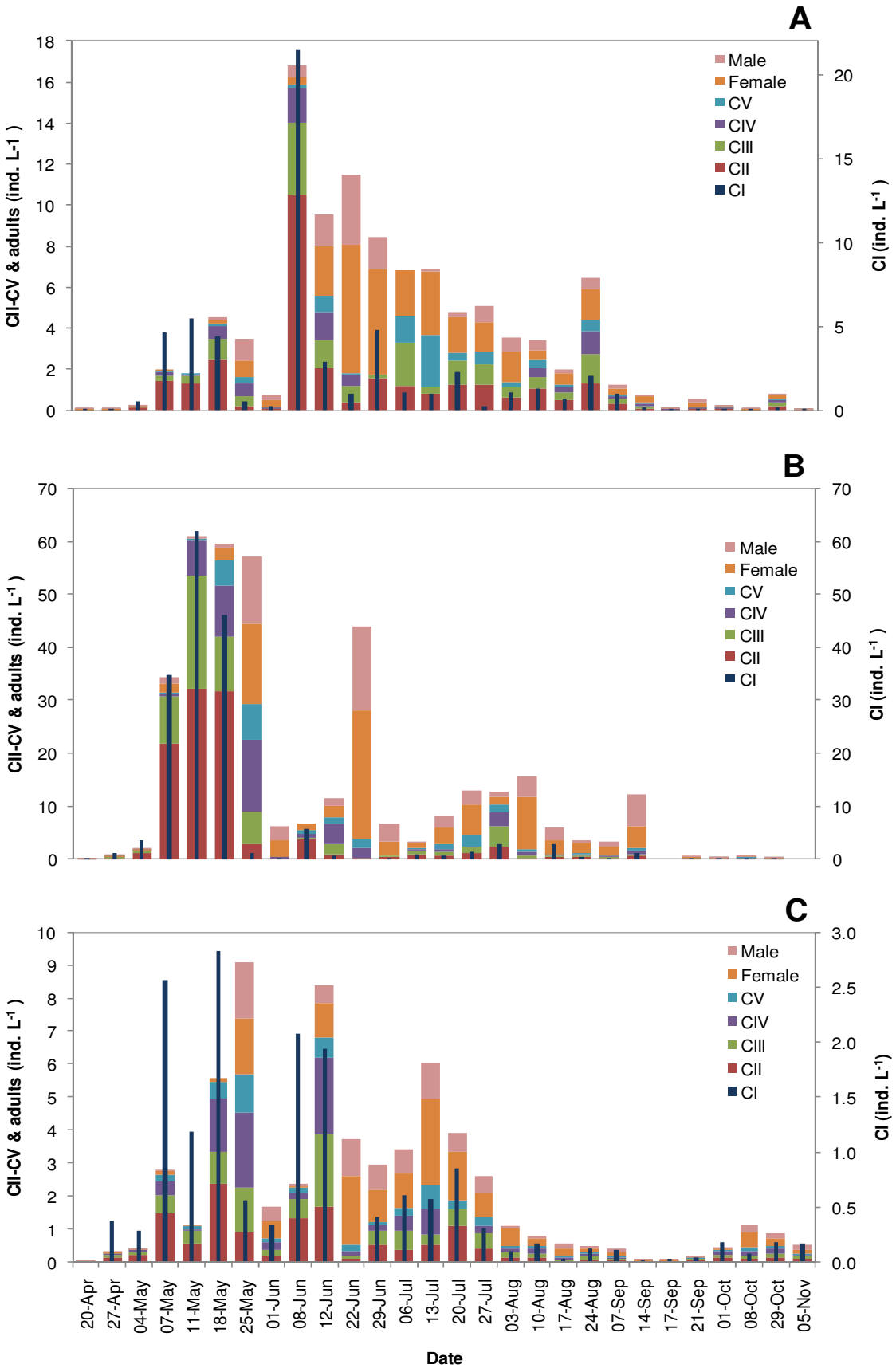

Fig 3.30. Concentration of *Eurytemora* developmental copepodites stages in the eastern (a), southern (b), northern (c) and western (d) basin from 20th April to 5th November 2010.

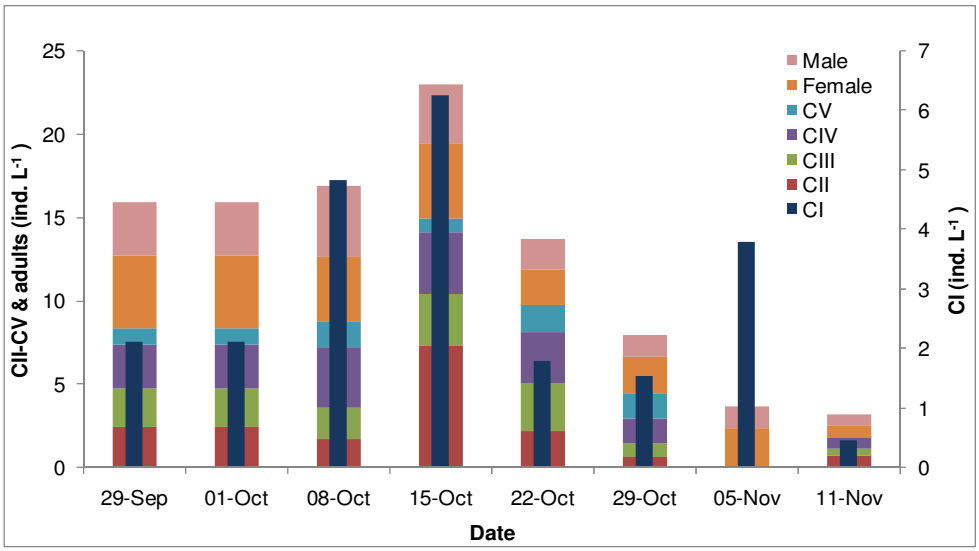

Fig 3.31. Concentration of *Eurytemora* developmental copepodites stages in the western basin from 21st September to 11th November 2010. Only a rough counting was conducted on 21st September and is therefore not included in this figure.

3.6.2 Egg production

The average egg production from 31st May 2010 to 7th October 2010 shows a similar pattern between the eastern, southern and northern basin (fig 3.32), generally ranging from 5 to 15 eggs female $^{-1}$ day $^{-1}$. However in late June to late August the production increased, fluctuating from around 15 to 30 eggs female $^{-1}$day $^{-1}$. The standard error amongst the samples is generally quite large. No females were found in the northern basin on 31st May, 3rd September and 28th September. No observations for the southern and northern basins were carried out on 26th July.

In the western basin regular observations started on 28th September 2010 and finished 11th November 2010 (fig 3.33). The production capacity is similar to the levels in September and October in the other basins. The average egg production generally ranged from around 4 to 7 eggs female^{-1} day^{-1}, except on one occasion when the average value reached 16.

Fig 3.34 reveals the difference between the mean numbers of eggs female^{-1} during 24 and 48 hours of incubation in the eastern, southern and northern basins. The average egg production is based on 9 different occasions for the eastern and northern location and 7 different occasions for the southern location. There is little difference within, but some difference exists between, the enclosures, particularly the southern enclosure.

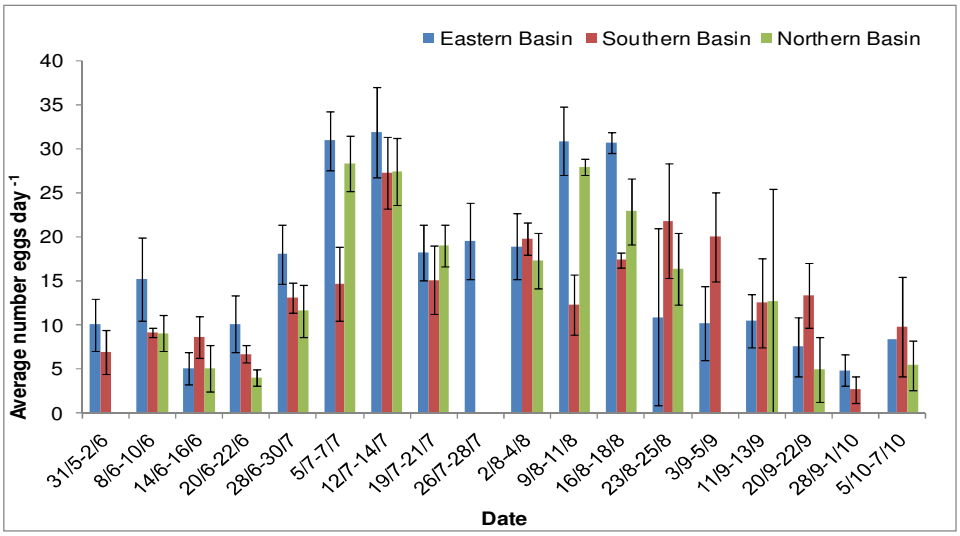

Fig 3.32. Average egg production and SE after 48 hours incubation in the eastern, southern and northern basin from 31st May to 7th October 2010.

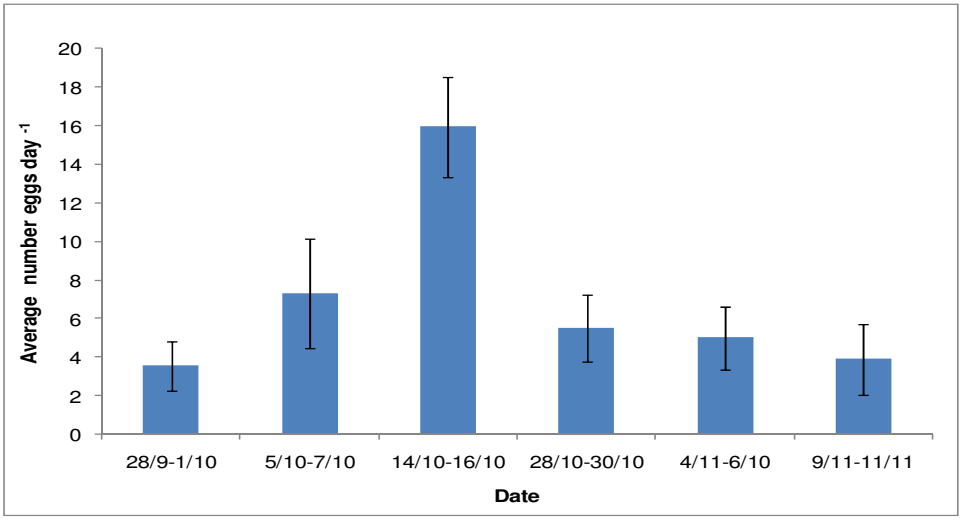

Fig 3.33. Average egg production and SE after 48 hours incubation in the western basin from 28th September to 11th November 2010.

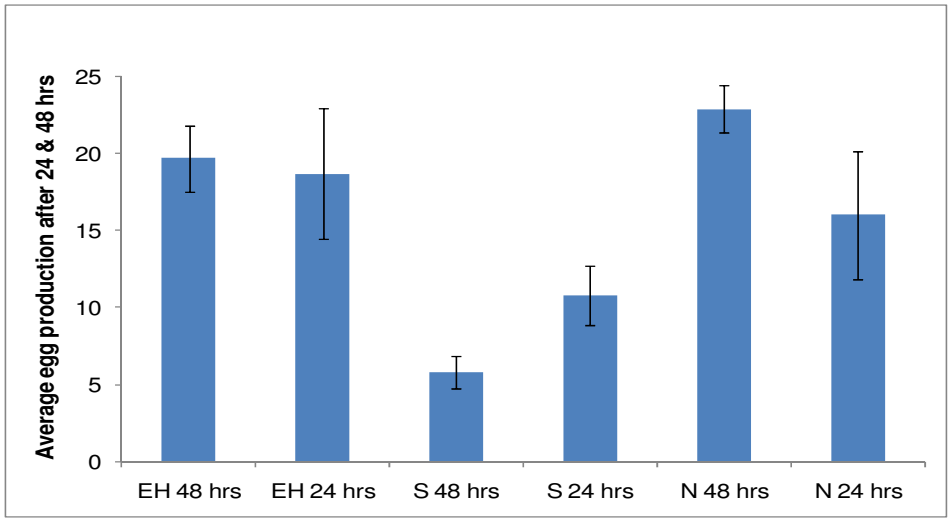

Fig 3.34. Average egg production and SE within a 24 and 48 hour period in the eastern (EH), southern (S) and northern (N) basin from 8th June to 23rd August 2010.

3.7 Net vs. Schindler's trap vs. water sampler

The amount of zooplankton was highly inconsistent between each sampling technique (fig 3.35 to fig 3.38). The largest variation of nauplii is seen in fig 4.41 between Schindler's trap and the water sampler with values ranging from 0 and 491 nauplii L^{-1}. The same figure also shows the largest variation in copepodites, with values ranging from 18 and 194 copepodites L^{-1}, when comparing the net and Schindler's trap. On 5th and 11th November, the last days of field work, samples from the western basin contained less than 50 zooplankton L^{-1}(fig 3.38).

The average of three replicates, along with standard deviation, is demonstrated in fig 3.39. Apart from the nauplii collected with Schindler's trap, each sampling method reveals a good consistency in repetitive measurements.

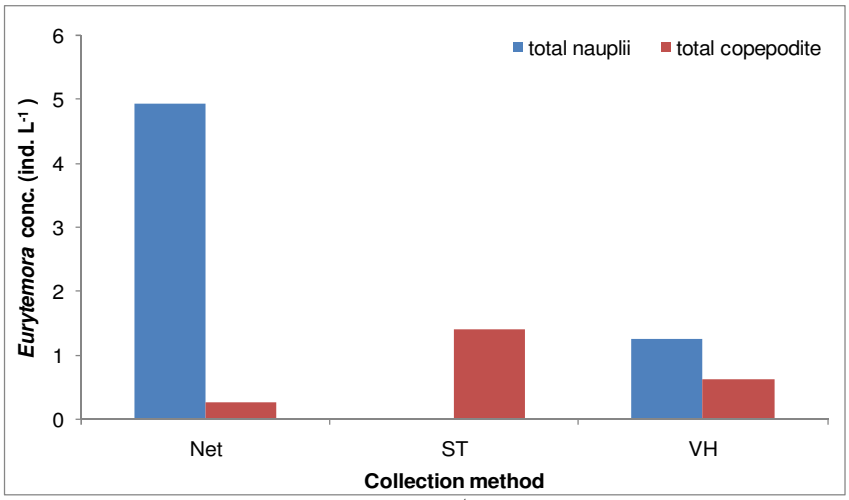

Fig 3.35. Concentration of zooplankton on 1st October in the eastern basin, collected with a net, Schindler's trap and a water sampler.

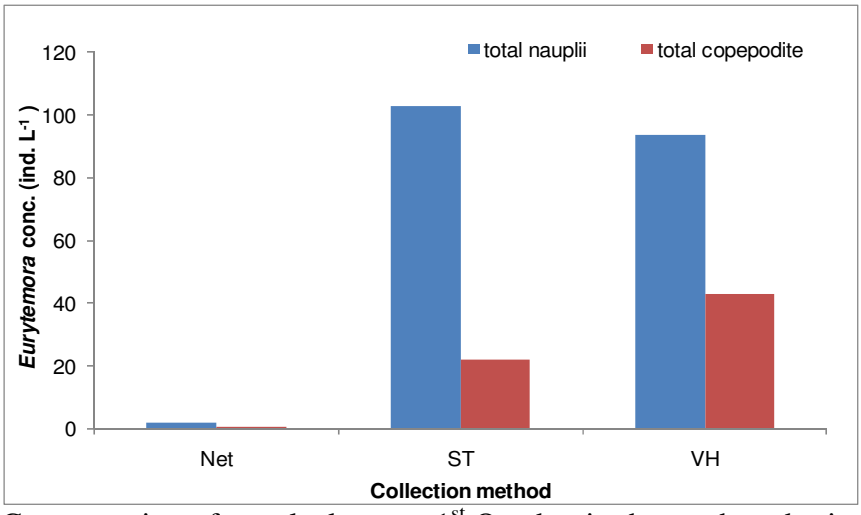

Fig 3.36. Concentration of zooplankton on 1st October in the northern basin, collected with a net, Schindler's trap and a water sampler.

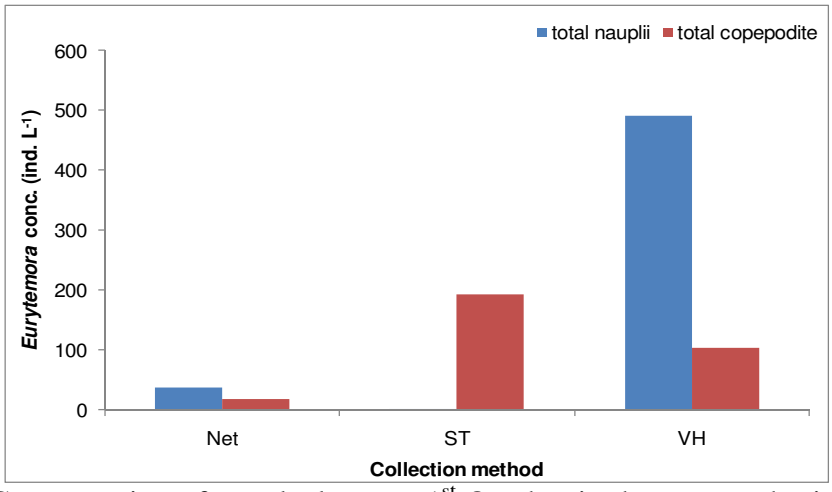

Fig 3.37. Concentration of zooplankton on 1st October in the western basin, collected with a net, Schindler's trap and a water sampler.

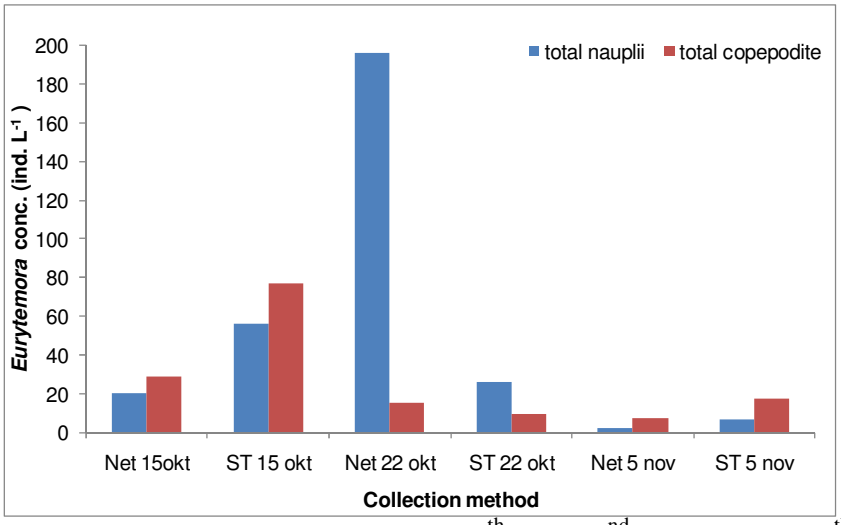

Fig 3.38. Concentration of zooplankton on 15th and 22nd October and 5th and 11th November in the western, collected with a net, Schindler's trap (ST) and a water sampler.

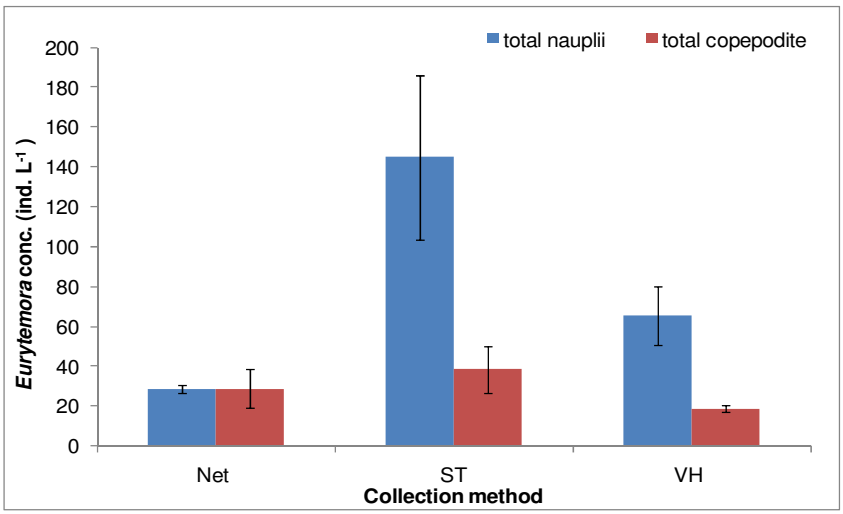

Fig 3.39. Concentration of zooplankton, along with standard deviation, on 8th October in the western basin, collected with a net, Schindler's trap and a water sampler.

4.0 Discussion

4.1 General overview

Due to the northerly location of the Faroe Islands, the level of irradiance and thus levels of primary production are very low during winter. However during spring and summer these conditions become reversed (Gaard *et al*., 2011). When nutrient supply becomes limited, phytoplankton is placed under physiological restriction in terms of growth (Debes *et al*., 2008a). In Faroese fjords, nitrate rather than phosphate tends to be the limited agent (Gaard *et al*., 2011), as common in the marine environment. However, amongst diatoms, silicate may also prevent population growth.

The majority of the diatoms that were present during the experimental period were pennate, although centric diatoms were also recorded. The sizes of the diatom cells were generally rather small, rarely exceeding 30 µm.

The maximum depth in the basins was 5.25 m. Although the *in situ* light conditions were not measured, the depth is considered to be sufficiently shallow that the critical depth extended throughout the entire water column. However, especially during periods of high phytoplankton concentrations the deepest part of the water column may well have been light limited for phytoplankton growth.

No stratification was suggested by the physicochemical parameters at 1 m and 4 m depth in the enclosures except in the western basin where the oxygen saturation and the nutrient concentration were more diverse at the measured depths (fig 3.26 and 3.27). Unlike the other three enclosures no pump was installed in the western basin as it was not originally a part of the sampling regime.

4.2 The Sea

4.2.1 Chlorophyll a

The chl *a* concentration in the sea is highest from late April to early June, measuring approximately 5.5 µg L^{-1} at its peak, indicating the occurrence of the spring bloom. The primary production in Faroese fjords and sounds usually starts in March-April and peaks in April-May, but may vary significantly between years (Gaard & Poulsen 1990, Gaard *et al*. 2011). North, in the immediate vicinity of the collection point of intake water, the depth of the sound is around 70 m. Therefore spring bloom in the sea strongly depends upon stratification of the water column (Sverdrup, 1953). Earlier studies have shown that stratification is common in the sound (Hansen 1990), induced by temperature as well as river discharge from the surrounding area. Along with stratification, the depth of the surface mixing layer is reduced. Thereby the critical depth (i.e. where total production equals total respiration) has exceeded the depth of the upper mixed layer, inducing increased phytoplankton biomass (Sverdrup, 1953).

4.2.2 Nutrients and phytoplankton

At the onset of the primary production in spring the nitrate concentrations decreased and at times they were below 2 µM (fig 3.3). Subsequently they mostly ranged between 3 µM and 8 µM. Therefore it can be assumed that primary production was not restricted due to nitrate limitations. Looking at fig 3.3 and fig 3.5, a negative correlation can be seen between chl *a* and the nitrate concentration. It should be emphasized that the intake of seawater from the fjord was at 15 m depth and therefore most likely below the depth of maximum phytoplankton concentrations and thus potential nutrient limitations.

Typical winter concentration of silicate on the Faroe Shelf is around 6 µM (Debes *et al.,* 2008a). No winter data are available in Faroese fjords, but since the primary production during winter is close to zero and since nitrate concentrations in fjords during winter are at the same level as on the shelf (Gaard *et al.* 2010), the same can be assumed to be the case for silicate.

During the spring bloom the silicate concentration gradually decreased (fig 3.4), indicating an increase in diatom production, locally or on the shelf. This is verified by the semi-quantitative measurements of phytoplankton, displayed in fig 3.6.

However in the midst of the spring bloom, from 14th May to 8th June, when diatoms became most abundant, the average silicate concentration was only 1.28 µM (SD ±0.39 µM). This is below the threshold for diatom dominance estimated by Egge and Aksnes (1992). However the phytoplankton abundance in the sea should be interpreted with caution as the number of species in a sample was often sparse. The species most notable were *Chaetoceros* sp. and *L. danicus* in addition to dinoflagellate spp. (fig 3.6). From 29th June *S. costatum* became a regular constituent of the phytoplankton community, and along with *L. danicus* and *Chaetoceros* sp., were commonly recorded thereafter. Furthermore, the nutrient concentrations may have been different at other locations in the sound, where the algae are originating from.

4.3 Physicochemical parameters in the eastern, southern and northern basin

4.3.1 Chlorophyll a, oxygen and salinity

From 12th April, the first day of fertilisation, to mid May the chl *a* concentrations gradually decreased from ≥15 µg L^{-1} to approximately 2.0 µg L^{-1} in all three basins. During this period the oxygen concentration also decreased to roughly 100%, revealing low photosynthetic activity.

The three basins had a delay of approximately one month until chl *a* increased to ≥15 µg L^{-1}. The common denominator during this period was low levels of phosphate. It took up to 25 days to achieve levels ≥0.6 µM, which Egge and Aksnes (1992) and Naas *et al.* (1991) consider being a non limiting concentration. Looking at the concentration of phosphate in the three enclosures (figs 3.10, 3.16 and 3.22), it reveals

that the levels were often below 0.3 µM until the 4th May. After this point there were no nutrient limitations in the basins, and approximately one week after sufficient phosphate concentrations, the primary production responded to the presence of nutrients. In addition to low phosphate levels, it is likely that the prolonged growth response was also a result of suppressed metabolic activity, which, according to Duarte (1990), is common when adjusting to enhanced environmental conditions.

Another common feature in the three basins during this period is the sudden drop in salinity of 1 to 2‰ (figs 3.7, 3.13 and 3.19). The lowest salinity value in the eastern and southern basin was 27 ‰ while in the northern it was 29‰. The greatest drop was seen in the eastern and southern basins. Salinity is an important abiotic factor that can place a significant amount of restraint on phytoplankton growth as primary producers have no mechanism to control osmosis (Brand, 1984). However the initial phytoplankton biomass did not show a distinctive composition compared to the later biomass and therefore was presumably not affected by the sudden salinity drop.

Primary production often reached very high values from June and onwards, as indicated by chl *a* measurements. These occurrences jeopardise the optimal growth conditions as the encounter rate between phytoplankton cells significantly increase, leading to aggregate formation and thereby increasing sedimentation rates (Egge & Jacobsen, 1997). Studies by Kahl *et al.* (2008) have shown that the sticking efficiency increases significantly with reduced physiological state, and may thus also be affected by variable growing conditions. Presence of phytoplankton aggregates was seen in the enclosures, indicating that the primary production was too high. Furthermore, the relationship between chl *a* and egg production rates indicates that the phytoplankton biomass was usually in excess for the grazing capacity of the zooplankton community (see later).

4.3.2 Nitrogen

Naas *et al*. (1991) states when the levels of nitrate become >5 µM, the nutrient is present in non-limited concentrations. The goal in this experiment was to maintain the nitrate concentration around 7 µM while levels of ammonia levels should be below toxic levels for fish.

During the phytoplankton die-off, i.e. the drop in chl *a* concentration, the concentration of ammonia increased (fig 4.1). This can be expected as decomposition leads to ammonia release. It is widely accepted that uptake of nitrate is inhibited in the presence of ammonium (Dortch, 1990). Thus as the phytoplankton biomass started to increase around mid May, ammonia is first utilised. Not until the ammonia concentration had reached sufficiently low levels, the phytoplankton started utilising nitrate. As a result, the nitrate concentration reached extremely high values toward end of May, ranging between ~65 µM and ~100 µM (fig 4.1).

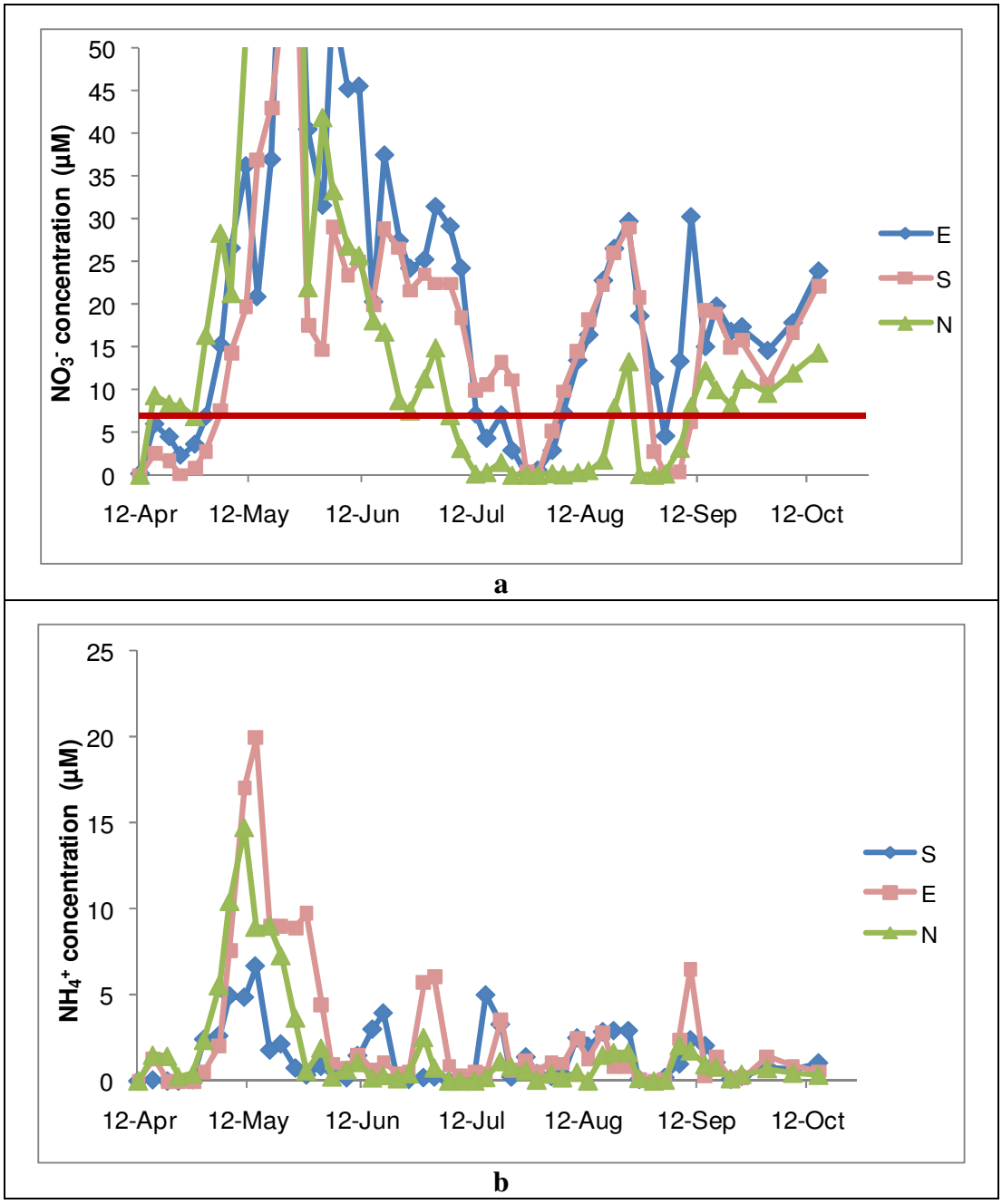

Fig 4.1. The concentration of nitrogen in the eastern, southern and northern enclosures from the onset and to the end of the experiment. Upper graph: Concentration of nitrate, highlighting the ideal concentration with a red line. Lower graph: Concentration of ammonia.

After the nitrate peak in the three basins, the quantity of nutrient loading was reduced in half. After about a week, fertilisation was further reduced. It took 4-5 weeks (early to mid July) for the nitrate concentration to reach a suitable level of around 10 µM however this was only briefly maintained.

The average nitrate concentration – characterised by wide fluctuations – after the peak was 20.0 µM (±13.1 µM) in the eastern basin, 16.1 µM (±8.6 µM) in the southern basin, and 9.3 µM (±10.1 µM) in the northern basin.

During this period and onwards the nitrogen loading remained stable around 8 µM, 2 µM and 1.5 µM in the eastern, southern and northern basins respectively (table 2.2 to 2.4), only mildly adjusted according to the changing chl *a* concentrations and oxygen saturation. Yet the levels continued to widely fluctuate from < 0.1 to 30 µM.

Only the northern basin experienced prolonged nitrogen limitations of ≤1.5 µM, which lasted from mid July to mid August. The levels of ammonia were also low during this period, yet the phytoplankton biomass remained >20 µg L^{-1}. Primary producers were probably able to maintain their growth by the recirculation of ammonium, released by decaying phytoplankton, zooplankton excretion and microbial degradation.

In the ocean there exists a clear negative pattern between chl *a* and the level of nitrate (Debes *et al.*, 2008b). The relationship between these factors in the enclosures was very poor throughout the experiment. Only the southern enclosure displayed a vague negative pattern (fig 4.2). The absence of a pattern indicates that nitrate has been in excess and only partly incorporated into primary production, which corresponds with our measurements.

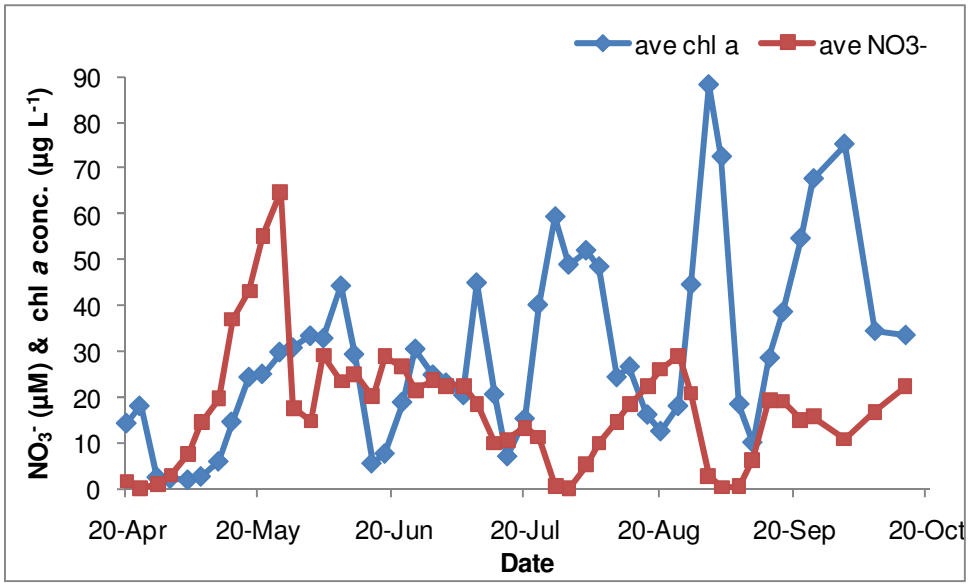

Fig 4.2. The relationship between chl *a* and nitrate in the southern enclosure.

4.3.3 Phosphate

When nutrients are not a limited resource, phytoplankton utilise nitrogen and phosphorous in a molar ratio close to 16:1 (Redfield *et al.*, 1963). According to

Jacobsen *et al.* (1995) a ratio less than 8 or greater than 20 can indicate nutrient limitations in N or P, respectively.

Although a N:P ratio of approximately 16 was regularly added to each basin, the ratio in the enclosures extended from 0 to 230, most typically being over 20. The nitrate concentration was generally far too high, occasionally due to limited phosphate resources, which contributed to a value over 20. On 5th July and onwards Nitrophoska was combined with YARA to increase phosphate availability and simultaneously lowering the supplement of nitrate.

Based on molar ratio, phosphate continued to remain largely limited in the eastern basin, even after the addition of Nitrophoska. Phosphate was also often present in limited concentrations in the southern and northern basin. The greatest improvements after adding Nitrophoska to the enclosures, was seen in the southern basin where the ratio ranged from 9 to 18 at least half of the time.

Reflecting upon the actual concentration of phosphate in fig 4.3, the addition of Nitrophoska did not show significant improvements in maintaining the phosphate concentration above 0.6 µM.

On the occasions when the phosphate levels were below 0.3 µM did not cause a reduction in the phytoplankton biomass, which was ≥15 µg L^{-1}.

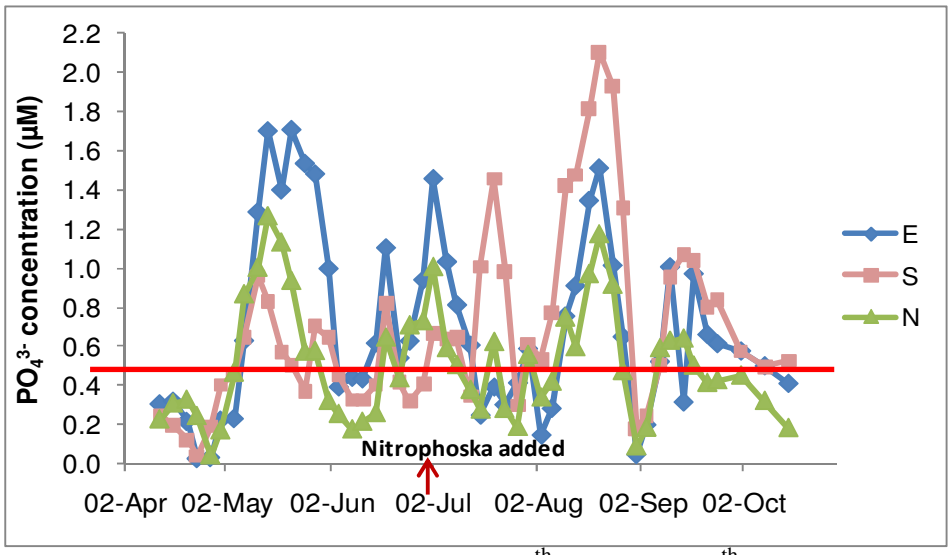

Fig 4.3. Concentration of phosphate from 12th April to 15th October 2010 in the eastern, southern and northern enclosures.

4.3.4 Silicate

From May and onwards the silicate concentration was >2 µM in the southern and eastern basin. In the northern enclosure, which received no silicate supplement, the levels fluctuated frequently below the critical concentration (fig 4.4). The pattern of

fluctuation was clearly influenced by the concentrations in the eastern basin, with a correlation factor of 0.5. This indicates that the opening between the eastern and northern basin was not sealed sufficiently to prevent leaking. Due to nutrient exchange, it can therefore not be determined how the phytoplankton composition would be under continuous silicate limitations and the effect it would have on the zooplankton community.

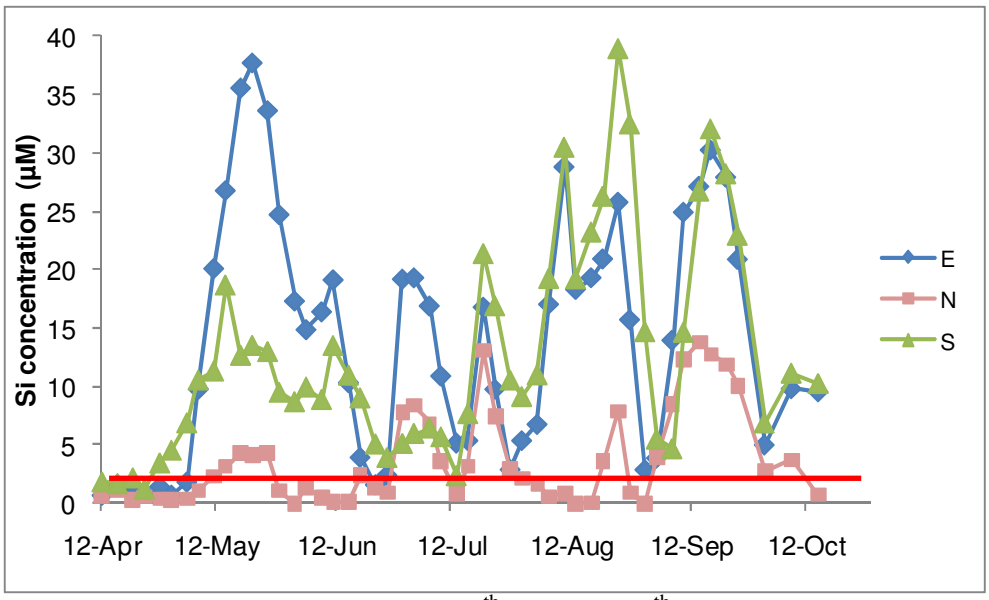

Fig 4.4. Concentration of silicate from 12th April to 15th October 2010 in the eastern, southern and northern enclosure.

The correlation factor between the eastern and southern basin was 0.63 indicating an even stronger pattern of nutrient exchange. Oscillations in nitrogen and phosphate levels in the southern and northern enclosures also corresponded to the fluctuations in the eastern basin.

4.4 Biological parameters in the eastern, southern and northern basin

4.4.1 Phytoplankton abundance and composition

There was a strong resemblance between phytoplankton species in the intake water and the enclosures (figs 3.6, 3.12, 3.18 and 3.23). For instance the flagellate community in the enclosures remained continuously present in the enclosures until early August, when the flagellates became scarce in the sea. This shows the effect that inflowing seawater can have on the phytoplankton composition in a semi-extensive system. However, the sea had a higher and more consistent dominance of phytoplankton species that fell under the category "other diatoms," whereas the enclosures had a higher concentration of *S. costatum* and *L. danicus*. This gives an indication that these diatom species had a higher growth potential compared to the

other diatoms under the same environmental conditions, and thus largely outcompeted the other species. These species, as well as *Chaetoceros* sp. are well known diatoms that form a part of phytoplankton blooms in similar environmental conditions (Aksnes *et al*., 1985; Jacobsen *et al.*, 1995; Naas *et al*., 1991; Nejstgaard *et al.*, 2001). Pictures of these phytoplankton species is shown in fig 4.5.

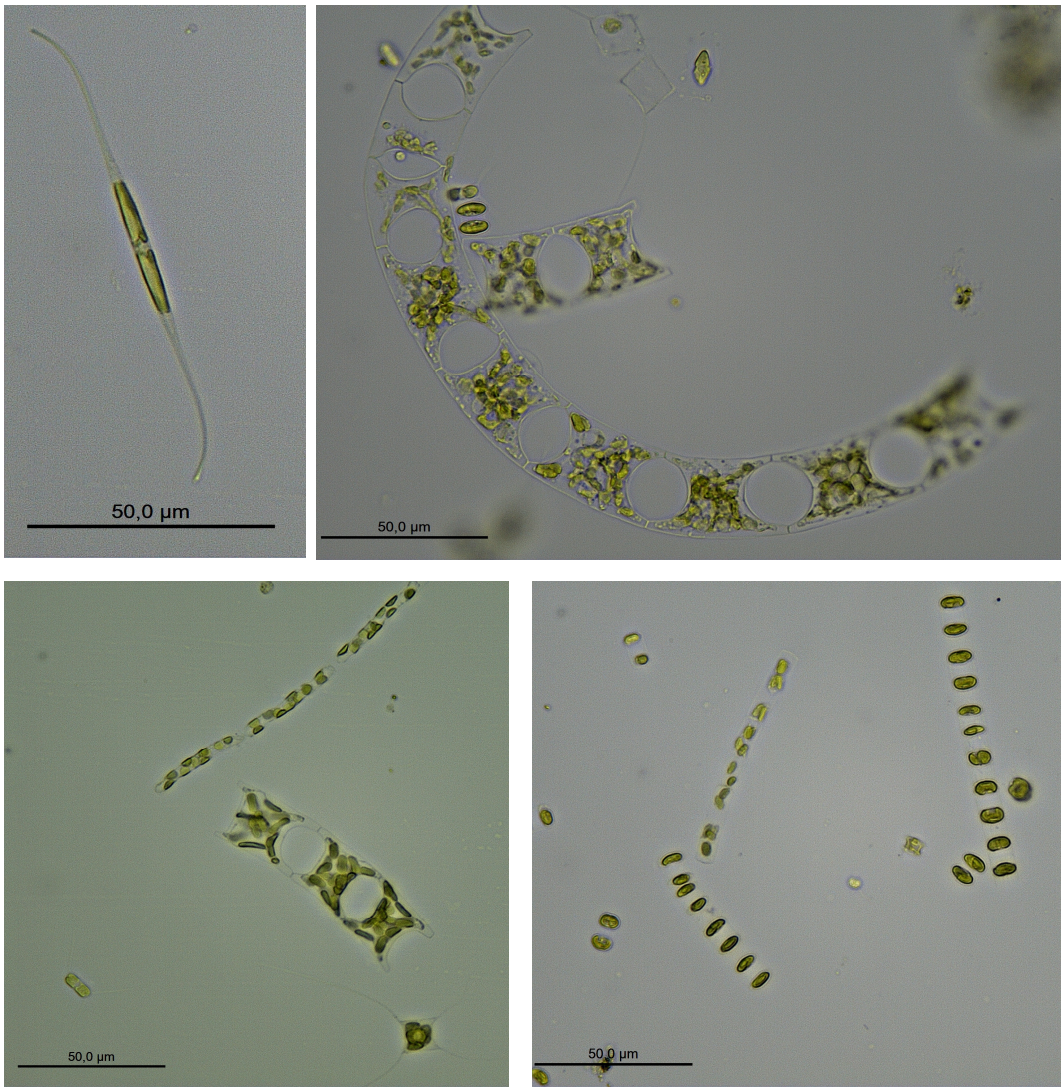

Fig 4.5. Some phytoplankton species recorded in the basins. A) *Nitzschia longissima,* b) *E. zoodiacus*, c) upper species: *L. danicus*, lower species: *Chaetoceros* sp., d) *S. costatum*.

The phytoplankton composition, which was largely dominated by diatoms throughout the sampling period, was very similar between the eastern and northern enclosure. This is unexpected as the silicate concentration in the northern basin was consecutively below 2 µM for prolonged periods. During these periods the chl *a* concentration remained within its normal fluctuations and diatoms continue to dominate. This pattern does not support the relationship between diatoms and silicate levels proposed by Egge (1998, and references herein). As mentioned previously,

silicate levels showed indication of leakage between the enclosures. In contrast to the southern basin, the source of the leakage was in the immediate vicinity where the sample collections took place in the northern enclosure. This may explain the relative high concentrations of diatoms in the northern basin during limited silicate resources.

Several studies have demonstrated that during unlimited NPS concentrations and mechanical stirring of the water column, diatoms exceed dinoflagellates in growth and become the dominant species (Egge & Aksnes, 1992; Egge, 1998; Naas *et al*., 1998). Yet despite similar conditions, the diatom growth potential was restrained and dinoflagellates dominated in the southern basin from early May to late June.

4.4.2 Nutrient and phytoplankton exchange between incoming and outgoing seawater

According to Dugdale & Goering (1967), nitrogen is a good measure of production capacity in ecosystems. For these experiments the calculations of new primary production was based on newly available nitrate and ammonium as a source of nitrogen. Thus new primary production is largely limited to this nutrient pool in the enclosures, which majority of the time received/exported daily 84, 57 and 160 L min^{-1} of seawater to/from the southern, northern and eastern basin, respectively (section 2.0, table 2.1).

A suitable method for comparing the productivity of the three basins is the ratio of production to biomass (*P/B*) (Gaard *et al*., 2011; Wassmann, 1990). The *P/B* represents the specific daily phytoplankton production by calculating the quantity of assimilated carbon (as estimated by utilized inorganic nitrogen over time) divided by the phytoplankton carbon biomass within the same water body.

Of the average nitrogen maintained from 12th April to 11th November, about 468 g C day $^{-1}$ was assimilated in new primary production in the southern basin, corresponding to a $_{Pnew}$*/B* ratio of 0.10 g C g C day $^{-1}$ (table 4.1.). The P_{new}*/B* rations in the northern and eastern basin were higher, measuring 0.21 and 0.22 g C g C day $^{-1}$, respectively. These figures indicate that the average rate of new production is high compared to the standing stock. A recent study by Gaard *et al*., (2011), revealed that Kaldbak, a Faroese fjord, had a high primary production rate, with P_{tot}*/B* ratios of ~ 0.1 – 0.3 mg C mg C^{-1} day^{-1}. Having in mind that the fjord ratios in Gaard *et al*. (2011) were based on total production while the present rations were based on the calculated new production only, the P/B ratios in the basins seem to be slightly higher. However the markedly higher primary production per volume seawater in the basins compared to the fjord, is probably mainly due to a higher biomass accumulation.

A key aspect in this experiment was to improve the current knowledge on how to support the basin via nutrient manipulations in order to maintain a high and stable level of phytoplankton. Due to the unusual long lagged phytoplankton growth, the nutrient supplement was increased. Once the phytoplankton biomass responded to the nutrients, the nitrate concentration was extremely high and despite relative low phosphate levels, the quantity of nutrient supplement was reduced. Later, a fertiliser with a lower N:P ratio was also used in order in increase the phosphate levels, whilst simultaneously reducing the nitrate concentration.

Keeping a constant level of primary production in such large systems proved to be difficult. However it is likely that reducing the fertilisation rates had a stabilising effect, in addition to reducing the excess of the phytoplankton biomass.

Table 4.1. Current biomass and newly assimilated primary production in the eastern, southern and northern enclosures from 7th June to 5th November 2010.

	Southern	Northern	Eastern
New primary production (gC/day)	468,2	690,9	2118,4
Available production to zoopl. (gC phytopl./day)	389,9	602,2	2007,3
Phytoplankton carbon (g C phytopl.)	3713,4	2890,3	9240,0
Amount of biomass vs. primary production	9,5	4,8	4,6
P/B-ratio (production/biomass)	0,10	0,21	0,22

4.4.3 Zooplankton abundance and composition in the basins

The species composition in the basins was quite different compared to the sea. On the Faroe Shelf the zooplankton community is usually dominated by copepods which were largely absent in the basins (Gaard, 1999; Debes and Eliasen, 2006). Previous studies of semi-intenstive production systems have documented overlapping trends of zooplankton species (van der Meeren & Næss, 1993; Naas *et al*., 1991). However the species diversity in the basin was low and was dominated by the copepod *Eurytemora* spp. throughout the season. *Eurytemora* spp. has previously been recorded in the basins however its quantities have not been previously investigated. The species is not commonly recorded in Faroese waters however according to Devreker *et al*. (2004) and van der Meeren *et al*. (2005) it is a common estuarine copepod that dominates in temperate estuarine environments. Harpacoitoids were the only other copepod species seen (fig 4.6a). Together with the "other" zooplankton (fig 4.6b), these were present in much lower quantities (fig 3.29a).

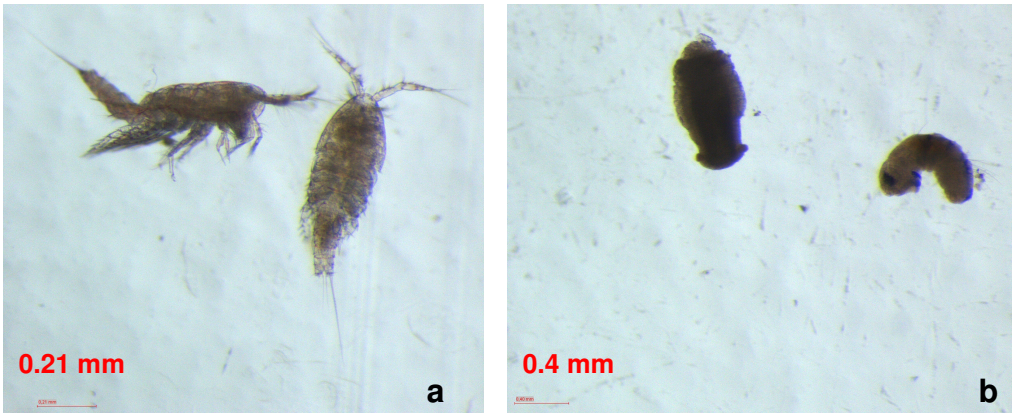

Fig 4.6. Harpacoitoids (a) and two unknown species (b), pooled together to the group referred to as "other", that were present in negligible quantities throughout the experimental period.

Resting eggs are recognised to make significant contributions to the quantity of prey stock and create an opportunity to better regulate stock density by manipulating the time of hatching (van der Meeren *et al*., 2005; Naas *et al*., 1991; Drillet, 2010). Attempts were made on finding resting eggs produced by last year's stock. However it proved difficult to distinguish their presence amongst the finer sediments. Although a few females with egg sacs were seen occasionally, most of the nauplii and copepodites stages are assumed to originate from resting eggs. The samples collected with the van Veen grab were not a good representative of the basins due to its rocky bottom however the suction device was more accurate, mainly as the collection of samples was more accessible. However as the overall level of uncertainty is rather large, the data is placed in the appendix (appendix F).

It is recommended to empty the basins between November to February however disturbing the bottom sediments any further may damage the resting eggs. Looking at fig b and c in appendix F, there is a difference between the quantities of nauplii and copepodite stages before and after the eastern basin was scrubbed. More importantly, looking at the zooplankton data (section 3.6.1) the quantities of the younger developmental stages in the eastern basin (fig 3.30a) are considerable less until early June compared to the southern basin (fig 3.30b). The abundance of *Eurytemora* spp. was however lowest in the northern basin, but the quantities were quite consistent from early May to July (figs 3.28). This indicates that resting eggs play an important role in during the initial phase by quickly establishing a zooplankton community.

The first appearance of *Eurytemora* spp. was in early spring, shortly after the start of the experiment. As they reproduced continuously throughout the season, the population was composed by mixture of all developmental stages, except from April to May when young developmental stages dominated.

Developmental time of copepod stages is strongly linked to temperature and food availability. Increasing temperature and increasing food availability decreases the stage durations. Based on temperature, which ranged from ~6-13°C, and high food concentrations, the copepod generation times is estimated to be between one and two months at the higher and lower temperature limits, respectively (Corkett & McLaren, 1970; Campbell *et al*., 2001; Gentleman *et al*., 2008). Since the temperature increased gradually during spring, and peaking in August, the generation times in late spring (around May) lasted 6-7 weeks but decreased to about 4 weeks in July-August. Thus, theoretically there should be time available for the first generation to be completed around mid June, a second generation to be completed in late July and a third generation to be completed in September. However, the observations only clarified the completion of the first generation in June. After this point, the population contained a mixture of developmental stages with large overlaps between the generations. Thus the generations could not be time-separated. This was most likely caused by the duration of the female spawning phase, making it difficult to identify whether there were two or three generations.

It is worth noting that although the egg production was relatively constant during the productive season (section 4.4.4), the abundance of nauplii and copepodites were clearly higher in spring and early summer than in late summer. Thus, either the hatching success or the survival of nauplii, in particular, has been higher during the

first two months compared to the latter phase of the experiment. The reason for this is not known. We may, however, speculate whether lower water quality may have influenced. The excessive production of phytoplankton caused high sedimentation rates and probably high fluxes of dissolved compounds from the sediment during the summer as well as high microbial activity in the water column.

4.4.4 Eurytemora reproduction

Many studies have shown a positive relationship between phytoplankton abundance and egg production rates of copepods in nature. Based on the high phytoplankton concentrations in the enclosures, the rates of egg production were expected to be high. However, the fecundity of *Eurytemora* spp. was at same level or only slightly higher than often observed during good feeding conditions in the natural environment (Campbell & Head, 2000; Stenevik *et al.*, 2007; Debes *et al.*, 2008b). On the other hand, it was more stable over time and lasted markedly longer than commonly seen in nature. The reason was the combined effect of continuously relatively high abundance of *Eurytemora* spp. females and their continuous fecundity.

There was no statistically significant relationship between chl. *a* concentrations and and *Eurytemora* egg production rates (fig 4.7 and 4.8). This is probably a result of the phytoplankton concentrations which were mainly above the saturation level for maximum ingestion rates. Thus, similar rates of egg production could probably have been reached with lower phytoplankton concentrations.

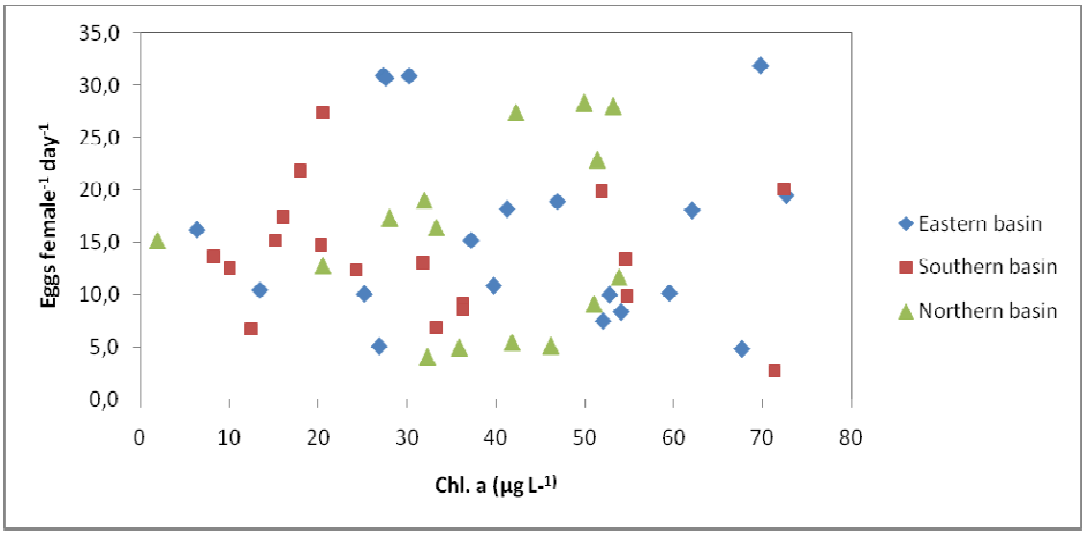

Fig 4.7. Egg production rates of *Eurytemora* spp. plotted against chl. *a* concentrations.

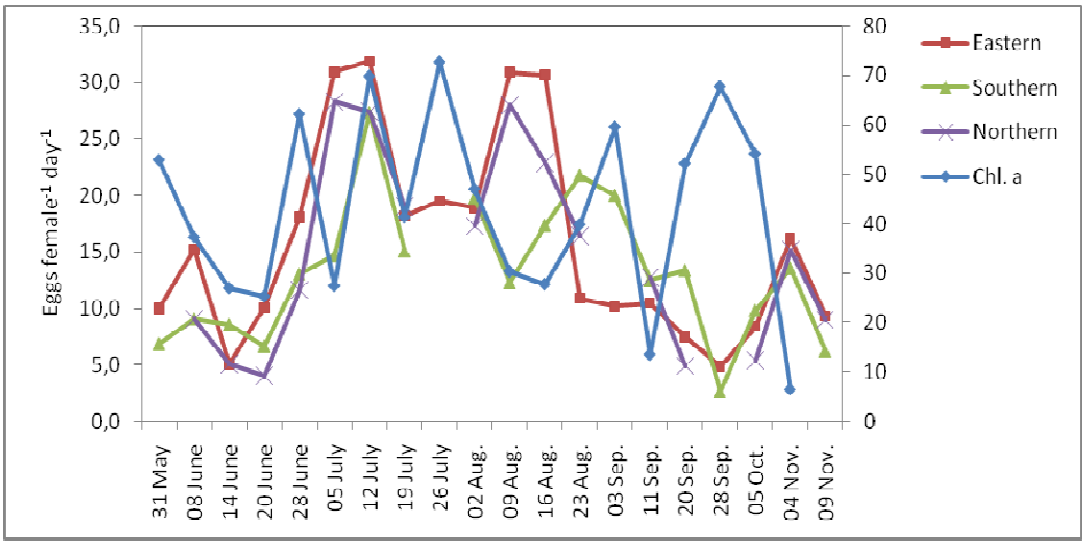

Fig 4.8. Seasonal variability in egg production rates and chl. *a* concentrations.

On average the total egg production rates from mid May to August was around 27,000, 14,000 and 40,000 eggs m^{-3} day^{-1} in the eastern, northern and southern basin, respectively (fig. 4.9). Although similar quantities occur in the natural environment, the temporal productivity in the basins is markedly higher than commonly observed during natural conditions (Gaard & Steingrund, 2001; Debes *et al.*, 2008b). The difference between the enclosures was due to different female concentrations rather than their fecundity (refer to fig 3.28c for female concentrations in the individual basins). With a total volume of about 18000 m^3 this corresponds to an egg production during the productive season about $5x10^8$ eggs per day from May to August. In September and October it decreased gradually, although the phytoplankton concentrations remained high.

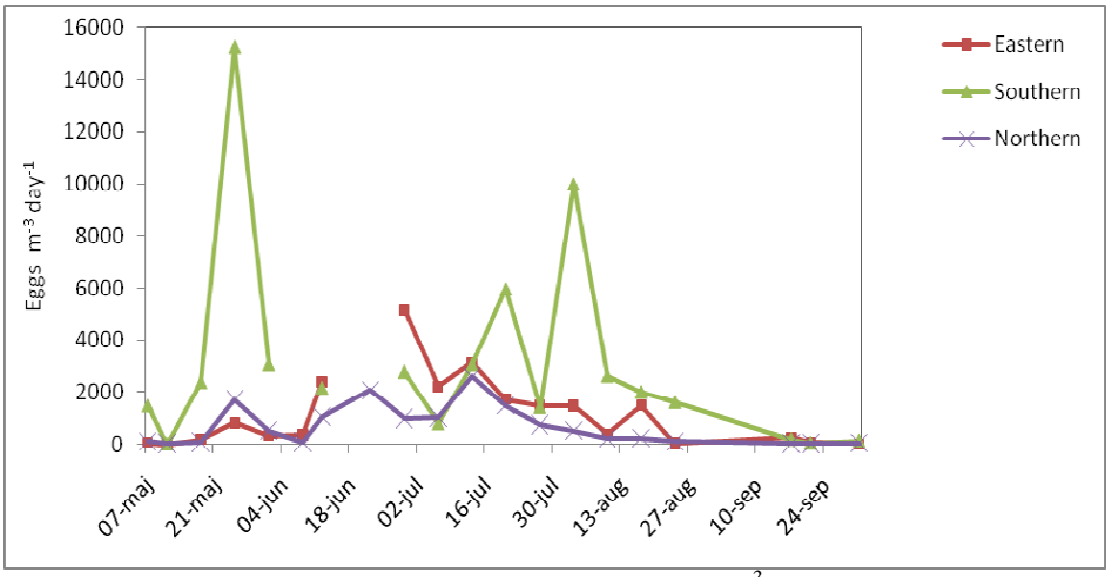

Fig 4.9. Seasonal variability in total egg production (per m^3)

Various investigations have shown that diatoms enhance the fecundity of calanoid species. During this experiment, the average rate of egg production was similar between the basins (fig 4.9), despite dinoflagellates dominated in the southern enclosure until late June. When the dinoflagellates were replaced by diatoms, the zooplankton community seemed indifferent to the change. Therefore, based on this investigation, the presence of diatoms can not be said to have had a positive or negative influence on zooplankton reproduction.

4.5 The potential of the zooplankton production used as live feed

Calanoid copepods are the principal prey for fish larvae (Drillet *et al*., 2011). Many calanoid species, including *Eurytemora* spp., have been highly praised for their nutritional quality (Shields *et al*., 1999; van der Meeren *et al*., 2008), high fecundity and short generation time (Steenfeldt, 2008; Støttrup, 2006) and are recommended candidates for aquaculture production (Drillet *et al*., 2011). Therefore the opportunity for successful rearing of fish larvae with minimal resources in Nesvík's basin looks very promising.

It is well established that creating high and stable densities of zooplankton is challenging (Busch *et al*., 2010) and the enclosures in Nesvík were not an exception. The basins showed quite a wide range from minimum to maximum production (figs 3.28 and 3.29).

According to the demand for nauplii quantities suggested by van der Meeren *et al*., (2005) and based on the average egg production rates of *Eurytemora* spp. in the basins, the production systems in Nesvík could theoretically support a maximum of 0.6 to 1 million fish larvae. These are significantly larger quantities of fish larvae compared to the approximate 180,000 cod larvae used the first time the basins were manipulated in 2006 (Kolbeinshavn *et al*., submitted).

Although all the basins showed an increased and extended plankton production capacity compared to the natural environment, the western basin showed a staggering potential in late September and onwards. As the western basin was not originally included in this project, its production capacity prior September is unknown. However it is believed that the high density of *Eurytemora* spp. was due the pumping regime of seawater (section 2.1). Since the western basin regularly received nutrients and phytoplankton produced in the other basins throughout the experimental period, and from early August, received zooplankton as well, it is likely to have caused the high quantities of *Eurytemora* spp. The zooplankton concentration in the western basin indicates that the plankton production cycle, and thus the number of start feeding of fish larvae, can theoretically be extended from spring to autumn. However further investigations are needed to support this statement.

4.6 Concentration of zooplankton using different sampling techniques

The selected method of collecting zooplankton samples was using a net with 100 µm mesh size as copepods typically dominate within the size range (Støttrup, 2000) and is within the size range commonly used for productivity studies (Goswami, 2004). When the little side experiment was conducted of comparing net towing, 1.5 L water sampler and Schindler's trap (10 L), the methods provided highly variable results (figs 3.35-3.39), with no evident calibration factor. The water sampler is not an ideal equipment to use for this type of study, due to its small size and the pressure created underwater. The disturbance alerts the zooplankton community, and the larger and more motile species have an advantage of escape. Towing or using Schindler's trap are better alternatives as these create less disturbance and provide a larger sample size (Terje van der Meeren, personal communication).

In contrast to the zooplankton net, which was towed horizontally through the water column, Schindler's trap, and the water sampler, is depth specific. Although variable, it is hypothesised that that this is the reason for greater diversion of the towing results from the other two sampling methods. Copepods collected with the net often showed a lower quantity, indicating that the zooplankton may be spatially distributed in the basins, which measure approximately 5.5 m in depth. It is well documented that zooplankton are influenced by light and are spatial distributed within the water column. Reassuringly, fig. 3.39 shows that the sample variation for each method is rather low, thus it can be assumed that sample consistency was achieved with the preferred method of choice.

Although it is not clearly indicated in figs 3.35-3.39, it is believed that the quantity of nauplii might well have been underestimated, as the smallest nauplii measured 110 µm in length. For a closer look at the range of nauplii sizes, refer to appendix E.

5.0 Conclusion

Copepods are an important source of food for cod larvae and are therefore an essential link between primary producers and higher trophic levels. Compared to enriched rotifers, zooplankton is of high nutritional quality and is linked with optimal juvenile growth, quality and health (Imsland *et al*., 2006; Shields *et al*. 1999; Busch *et al.,* 2010). A previous experiment by Kolbeinshavn *et al*. (submitted) showed that the basins in Nesvík may have the potential of being used as a semi-extensive plankton production system, rearing live feed for fish larvae. Larvae from these experiments were clearly superior compared to rotifer-fed larvae. Optimising the production capacity in a semi-enclosed environment should ideally increase the production of plankton from 2 to 6 months. This would allow the number of start feeding to increase from 1 to 3 times a year. Thus the final outcome could lead to significant benefits for fish farmers.

To optimise the potential of the plankton production capacity in Nesvík's basins, better understanding of the underlying mechanisms in the planktonic ecosystem, were

required. Therefore the aim of this investigation was to closely monitor phytoplankton and zooplankton abundance and community structure. Aiming to achieve a high and stable production from April to October, optimal conditions in the basins were created by a) pumping water into the basin, b) a pump, making the water turbulent and c) artificial fertilisation. To determine the importance of diatom growth for the zooplankton community, silicate was added to eastern and southern basin. No silicate was added to the northern basin.

The nitrate and phosphate levels showed large fluctuations from the desired values of 7 µM and 0.6 µM, respectively. The silicate concentration was largely ≥2 µM. Diatoms were mainly the dominating species, commonly consisting of *S. costatum* and *L. danicus*. However in the southern basin, dinoflagellates dominated until late June and were then replaced by diatoms. The shift in dominance did not affect the zooplankton density. Thus, based on this experiment, the presence of diatoms can not be said to have had a positive or negative influence on the zooplankton reproduction

The average rate of new primary production in the eastern, southern and northern enclosure was very high compared to the standing stock and was mainly contributed by the high biomass accumulation in the basins. There was no relationship between the chl *a* and the nutrient concentrations, which is probably due to the excess of phytoplankton production. Comparisons between chl *a* and egg production rates also indicated that the phytoplankton biomass was in excess for the grazing capacity of the zooplankton community. Thus, the same egg production rates most likely could have been reached with lower phytoplankton concentrations.

Eurytemora was the dominant copepod species throughout the experimental period, with densities highest around May to July. They reproduced continuously throughout the season and the population was mainly composed by a mixture of all developmental stages. The fecundity of *Eurytemora* spp. was similar to levels often seen in nature (Campbell & Head 2000; Debes *et al*. 2008b). However, it was more stable over time and lasted markedly longer than usually observed in the natural environment.

The staggering quantities of *Eurytemora* spp. in the western basin indicate that the disposal of outflowing seawater via the western basin significantly increased the production potential. According to the rates of egg production throughout the experimental period, the basins have theoretically the capacity to produce around 0.6 to 1 million fish larvae. The zooplankton concentrations in the western basin indicate that the number of start feeding of fish larvae can theoretically be extended from spring to autumn. However, further studies are needed to support this statement

Although further investigations on how to maintain a stable plankton production are also required, the enclosures revealed that a high plankton production cycle can be maintained for a prolonged period. Together with other positive characteristics such as the dominance of a calanoid species, mixed developmental stages and stable and long-lasting fecundity, the basins demonstrated good potential to be used as a semi-extensive production system to rear fish larvae.

6.0 Future recommendations

A key aspect of this study was to improve our understanding, on how to maintain a high and stable phytoplankton population via nutrient manipulations. Based on nitrate and silicate levels, the basins received too much nutrient input compared to the production capacity. An important issue leading to this situation was the phosphate levels that were below the designated threshold. The initial nutrient concentration could have been lower and rather than increasing the nutrient load to get higher phosphate levels, the fertiliser could have been replaced with another one with higher N:P ratio. Theoretically this should aid in a more stable phytoplankton production.

The nutrient concentrations were analysed approximately every other week. Whilst waiting for the results, the oxygen concentration and chl *a* were used as a guide for regulating nutrient loading. As the nutrient levels fluctuated widely on regular basis, it is recommended that nutrient analysis should take place more frequently. Palintest nutrient field kits were initially used whilst waiting for the more accurate results from the Autoanalyzer (Seal Analytical). As the field kits proved to be too unreliable for our purpose as well as time consuming, it is recommended that an alternative method should be investigated.
Semi-extensive production systems are influenced by external factors in the local environment such as light intensity, precipitation and wind. The weather conditions were noted (in descriptive terms) from April to November. Due to constant fluctuations in the basins as well as in the weather, it was difficult to see a pattern between these factors. Light intensity and average precipitation were not recorded during the experimental period. As primary production is strongly linked to light intensity and precipitation may alter the salinity in the basins, it is highly recommended that these parameters to be included in future field work.

As highlighted in section 4.6, large variations were present between Schindler's trap and the zooplankton net, which are common zooplankton sampling techniques. To determine whether zooplankton is spatially distributed within the water column, further investigations should be based on using Schindler's trap.

Several studies have noted the importance of resting eggs in semi-intensive production systems (van der Meeren *et al*., 2005); Naas *et al*., 1991; Drillet, 2010). As resting eggs contribute to the quantity of prey stock, further information can aid in a better regulation of stock density by manipulating the time of hatching. To achieve more accurate results, the method used in this experiment should be improved.

Finally, using fish larvae as a part of future experiments can provide accurate information about the potential of the basins to rear larvae on a natural zooplankton diet.

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Appendices

Appendix A - Images of the study site

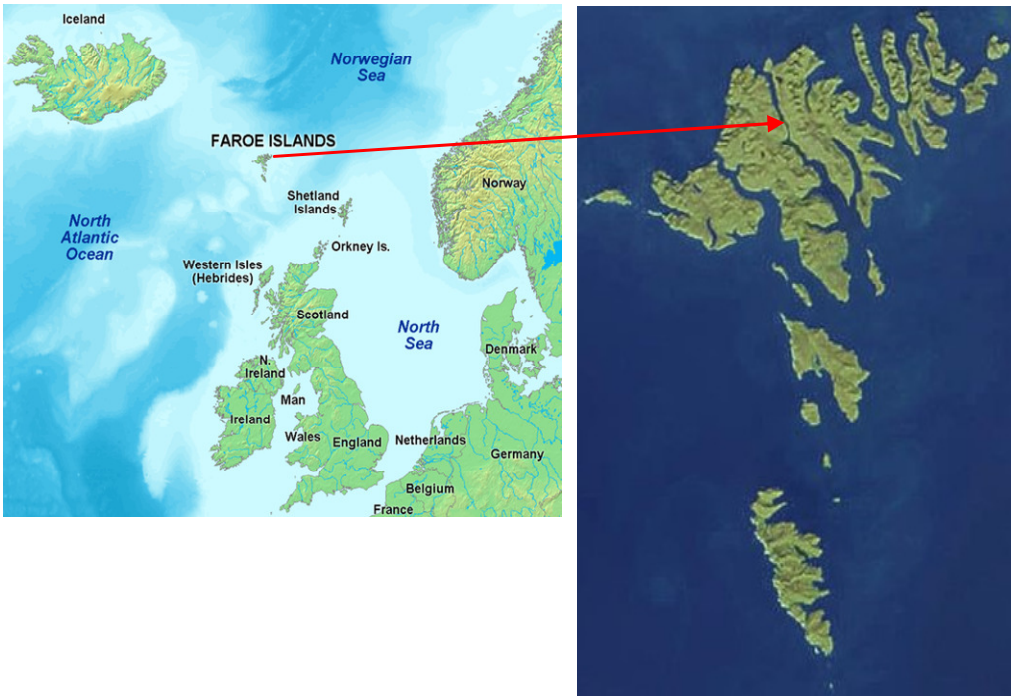

Fig 1a.Geographic location of the Faroe Islands, focusing on Nesvík where the experiment took place.

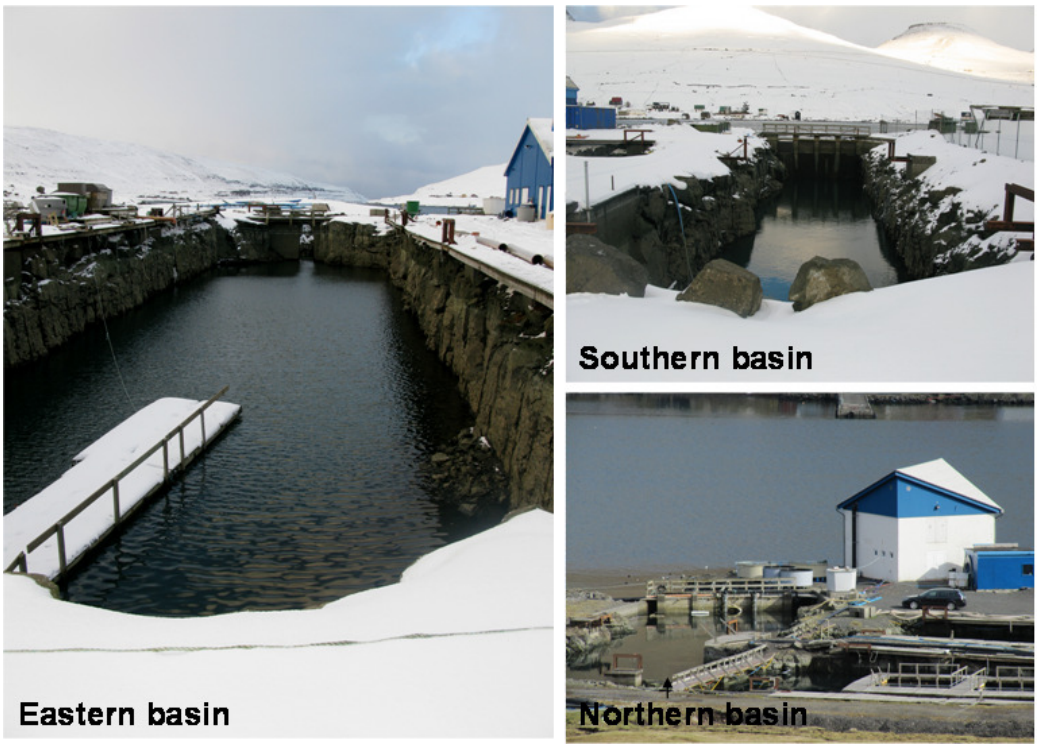

Fig 2a. A closer look at the eastern, southern and northern basin. The eastern and northern basin are being drained before the onset of the experiment.

Appendix B - Quantity of fertilisers regularly added to the basins

Table 1b. Quantity (in kg) of fertiliser NPK 22-2-11 and NPK 12-5-14 added daily in the eastern, southern and northern enclosures from 12th April to 11th November 2010.

Fertiliser (kg)	22-2-11 (kg)	12-5-14 (kg)	22-2-11 (kg)	12-5-14 (kg)	22-2-11 (kg)	12-5-14 (kg)
Date	**East**	**East**	**South**	**South**	**North**	**North**
12/4-3/5	2.000	0	0.560	0	1.560	0
4/5-9/5	3.000	0	0.840	0	0.580	0
10/5-21/5	6.300	0	1.800	0	1.200	0
22/5-30/5	3.015	0	0.861	0	0.574	0
31/5-1/6	2.111	0	0.603	0	0.402	0
2/6-3/6	0	0	0	0	0	0
4/6-18/6	2.111	0	0.603	0	0.402	0
19/6-2/7	1.500	0	0.440	0	0.295	0
3/7-4/7	1.050	0	0.308	0	0.207	0
5/7-27/7	0.884	0.150	0.253	0.043	0.168	0.029
28/7-2/8	1.043	0.177	0.298	0.051	0.199	0.034
3/8-11/11	1.017	0.173	0.290	0.049	0.194	0.033

Table 2b. Quantity (L) of silicate added daily in the eastern, southern and northern enclosures from 12th April to 11th November 2010.

	Silicate (L)		
Date	**Eastern basin**	**Southern basin**	**Northern basin**
12/4-3/5	1.440	0.400	0
4/5-9/5	3.600	1.000	0
10/5-18/5	7.600	1.400	0
19/5-21/5	7.600	2.100	0
22/5-30/5	3.637	1.005	0
31/5-1/6	2.546	0.704	0
2/6-3/6	0	0	0
4/6-18/6	2.546	0.704	0
19/6-2/7	1.750	0.500	0
3/7-4/7	1.225	0.350	0
5/7-27/7	1.248	0.345	0
28/7-2/8	1.472	0.407	0
3/8-11/11	1.435	0.397	0

Appendix C - Raw data of phytoplankton concentrations

Table 1c. Raw data of semi-quantitative phytoplankton samples from the sea, collected from 16th April to 15th October 2010.

Date	*Protoperidinium* *Dinophysis* *Dinoflaggelates*	*S. costatum*	*L. danicus*	*Chaetoceros*	*N. longissima*	*L. minimus* *Coscinodiscus*
20-apr	2					
23-apr	1	1			1	
27-apr	1		1	1		1
30-apr	1			2		
04-mai	1				1	
07-mai	2					
11-mai	2			2	1	
14-mai	2		1			2
18-mai	3		2	2		1
21-mai	3			3		2
25-mai	3	3	3			1
28-mai	2	1				
01-jun	2				1	
04-jun	2					
08-jun	2		1	1	1	
11-jun	3				1	
15-jun	3				1	
18-jun	1					
22-jun	2		1			1
25-jun	2		1		1	
29-jun	1	2	1			1
02-jul	2	1				
06-jul	1					
09-jul	2	2	1		1	
13-jul	1	2	1		1	
16-jul	2	2		1	1	
20-jul	1	2		1	1	
23-jul	2	1		1	2	
27-jul		2		1		
30-jul	1	2		2		
03-aug		2		1		
06-aug	1	2		1	1	
10-aug	1	2			1	
13-aug	1					
17-aug						
20-aug		1			1	
24-aug		1	1	1	1	
27-aug		2				
31-aug						
03-sep		1	1	1		1
07-sep	1		1	1		1
10-sep		1	1			
14-sep						
17-sep		1	1	1		1
21-sep		1	1	1		
24-sep						
15-okt	1	2				

Table 2c. Raw data of semi-quantitative phytoplankton samples from the sea, collected from 16th April to 15th October 2010.

Date	*Thalassiosira* *M. sulcate*	*Parafavella* *Dictyocha* *C. pelagica*	*Pseudo-nitzschia* *Proboscia* *G. delicatula*	*E. Zoodiacus*	*Fragilariopsis*	*M. nummuloides*
20-apr						
23-apr					1	
27-apr					1	1
30-apr					1	
04-mai		1			1	
07-mai		1	1		1	
11-mai						
14-mai	1		2			2
18-mai	1				1	
21-mai	1	1			1	
25-mai		2				
28-mai		1				
01-jun		0	1		1	
04-jun		1	2			1
08-jun		1	2			1
11-jun			1		2	1
15-jun	1	2	1		1	
18-jun			1		1	
22-jun		1	2		1	
25-jun		1	3		2	
29-jun			2			
02-jul			1		1	1
06-jul			1		1	1
09-jul	1	2			2	
13-jul					1	
16-jul						1
20-jul				2		
23-jul						
27-jul						
30-jul				1	1	
03-aug				1		
06-aug	1			2		
10-aug			1	2		
13-aug	1	1	1			
17-aug	1	1	1	2		
20-aug			1	1		
24-aug		1		1		
27-aug						
31-aug	1			2		
03-sep			1	1		
07-sep	1			1		
10-sep	1			1		1
14-sep						
17-sep				1		
21-sep	1			1		
24-sep		1		1		
15-okt	1		1	1		

Table 3c. Raw data of semi-quantitative phytoplankton samples from the northern enclosure, collected from 16th April to 15th October 2010.

Date	*Dinophysis* *Dinoflaggelate spp*	*S. costatum*	*L. danicus*	*Fragilariopsis* *L. minimus* *Chaetoceros*	*N. longissima*
16-apr	1	3			1
20-apr	1	2		2	2
23-apr	1	2			1
27-apr	1			1	2
30-apr	3	2			1
04-mai	3	2		1	
07-mai	3				
11-mai	2				
14-mai	2	1		2	1
18-mai	3	2	2		1
21-mai	3	3	2	2	1
25-mai	2	3	3	2	1
28-mai	2		1	2	
01-jun	2		4		
04-jun	2		4		
08-jun	2		4		
11-jun	2		4	2	
15-jun	2		4		
18-jun	1		3		
22-jun	2		2	4	
25-jun	3		3	3	
29-jun	3		2		
02-jul	3		3	1	
06-jul	3	3	3		
09-jul	2	3	2	1	
13-jul	2	3	1	1	
16-jul	3	3		2	
20-jul	3	3	2	3	
23-jul	3	3	1	3	
27-jul	3	3	2	3	
30-jul	2	3	3	2	
03-aug	2	2	2	3	
06-aug		1	3	3	
10-aug		1	3	3	
13-aug		2	3	1	
17-aug		3	3		
20-aug		2	2		
24-aug		3			
24-aug			1		
27-aug		4			
31-aug		2	1		1
03-sep		1	1		
07-sep			1		
10-sep	1		1		
14-sep			2		
17-sep		2	2		
21-sep	1	2	2		1
24-sep	1	2	2	1	2
15-okt		3	2		

Table 4c. Raw data of semi-quantitative phytoplankton samples from the northern enclosure, collected from 16th April to 15th October 2010.

Date	*Unidentified diatom* *Coscinodiscus*	*M. sulcate* *M. nummuloides*	*Parafavella* *Pseudo-nitzschia* *Thalassiosira*	*Dictyocha* *C. pelagica*	*E. zoodiacus* *G. delicatula*
16-apr	2				
20-apr	3				
23-apr				1	1
27-apr				1	1
30-apr					
04-mai		1			
07-mai					
11-mai		1			1
14-mai		2	1		
18-mai	1				2
21-mai	1				
25-mai	1	1	1		
28-mai					
01-jun					
04-jun					
08-jun		1			
11-jun		1			
15-jun		1			
18-jun				1	
22-jun					
25-jun					
29-jun		1		1	
02-jul				1	
06-jul					
09-jul					
13-jul					
16-jul					
20-jul					
23-jul		1		1	
27-jul				1	
30-jul					
03-aug			1		
06-aug					
10-aug		1	1		
13-aug	2		1		
17-aug	2		1		2
20-aug	2	1	1		2
24-aug	3				
24-aug					2
27-aug	1				1
31-aug	2				1
03-sep	4				1
07-sep	3				1
10-sep	3				2
14-sep	3				2
17-sep					2
21-sep	2		1	1	2
24-sep			1	1	1
15-okt		1	1		

Table 5c. Raw data of semi-quantitative phytoplankton samples from the eastern enclosure, collected from 16th April to 15th October 2010.

Date	*Protoperidinium Dinophysis Dinoflaggelates*	*S. costatum*	*L. danicus*	*Chaetoceros*	*N. longissima*
16-apr	1	2	2		1
20-apr	1	2	2		1
23-apr	1				1
27-apr	1			1	2
30-apr	2				
04-mai	3	3			1
07-mai	2	3			
11-mai	2	1		1	1
14-mai	3				1
18-mai	3	3			3
21-mai	3	2			3
25-mai	3	2	1	2	
28-mai	3	3		2	2
01-jun	2			1	1
04-jun	2			1	
08-jun	2				
11-jun	2			2	
15-jun	1			2	
18-jun	1			1	
22-jun	1			1	
25-jun	1			2	
29-jun	3				
02-jul	2			2	
06-jul	2	1	1		
09-jul	3			2	
13-jul	3	1	1		
16-jul	3				
20-jul	2	2	2		
23-jul	3	2	2	2	
27-jul	2	3	3	1	
30-jul	2	2	2		
03-aug	2	2	2	2	
06-aug	1	3	3	1	
10-aug		3	3	2	
13-aug		3	3	3	1
17-aug		3	3	3	1
20-aug		3	3	3	1
24-aug		3	3	3	2
27-aug		1	1	3	2
31-aug				2	2
03-sep		3	2		
07-sep		2	2		
10-sep			1		
14-sep			2		
17-sep		2	2		
21-sep				2	2
24-sep		1	1	3	1
15-okt		4	1		

Table 6c. Raw data of semi-quantitative phytoplankton samples from the eastern enclosure, collected from 16th April to 15th October 2010.

Date	*M. sulcate* *G. delicatula* *Coscinodiscus*	*M. nummuloides*	*Pseudo-* *nitzschia* *L. minimus* *Thalassiosira*	*Dictyocha* *E. zoodiacus*	*C. pelagica* Unidentified *Fragilariopsis*
16-apr					2
20-apr					
23-apr			2		
27-apr	1	1	2		1
30-apr	1				
04-mai			2		
07-mai					
11-mai					
14-mai		1			2
18-mai	1		1		2
21-mai					2
25-mai					2
28-mai	1				2
01-jun		1			3
04-jun					4
08-jun		1			4
11-jun		1			4
15-jun					4
18-jun		1			4
22-jun					4
25-jun					4
29-jun		1			
02-jul		1			
06-jul					
09-jul		1			
13-jul		1			
16-jul		2		1	
20-jul		1		1	
23-jul		1		1	
27-jul		1			
30-jul		1			
03-aug		1			
06-aug				1	
10-aug		1		1	
13-aug	2		1		
17-aug	2			2	
20-aug	2	1	2	2	
24-aug	3	1		2	3
27-aug	3	1	1	1	
31-aug	2	1		2	
03-sep	2			2	
07-sep	2			3	
10-sep	2			2	
14-sep	3		1	2	
17-sep	2			2	
21-sep	2			2	
24-sep	1			2	2
15-okt		1			

Table 7c. Raw data of semi-quantitative phytoplankton samples from the southern enclosure, collected from 16th April to 15th October 2010.

Date	*Dinophysis* *Dinoflaggelate*	*S. costatum*	*L. danicus*	*C. pelagica* *G. delicatula* *Chaetoceros*
16-apr	2	3		3
20-apr		2		2
23-apr	1	1		
27-apr	1	1		
30-apr	3			
04-mai	3			
07-mai	4			
11-mai	2			
14-mai	4			
18-mai	3	1		2
21-mai	4			
25-mai	4			
28-mai	2			2
01-jun	4			
04-jun	3			
08-jun	2		1	
11-jun	3			
15-jun	2			
18-jun	2			
22-jun	2		1	
25-jun	2			
29-jun	3		3	
02-jul	1	2	1	
06-jul	1	2	1	
09-jul	1	2		
13-jul	2	2		
16-jul		2		
20-jul		2		
23-jul	1	2		
27-jul	1	1		
30-jul	2	2		
03-aug	1	2		
06-aug	1			
10-aug		1	1	1
13-aug		1		1
17-aug			1	
20-aug		1		
24-aug		2	2	2
27-aug		2	2	1
31-aug		3	2	
03-sep		4	1	
07-sep		3	1	
10-sep		2	2	1
14-sep		2	3	
17-sep			2	
21-sep		3	3	
24-sep		3	3	2
15-okt		4	1	

Table 8c. Raw data of semi-quantitative phytoplankton samples from the southern enclosure, collected from 16th April to 15th October 2010.

Date	*Dictyocha N. longissima*	*Fragilariopsis L. minimus Coscinodiscus*	*M. nummuloides*	Unidentified *M. sulcate E. zoodiacus*
16-apr			1	2
20-apr	1	2		1
23-apr				
27-apr			1	
30-apr	1			
04-mai			1	
07-mai			1	
11-mai				
14-mai			1	
18-mai			1	
21-mai		1	1	
25-mai			1	
28-mai			1	
01-jun			1	
04-jun			1	
08-jun			1	
11-jun			1	
15-jun			2	
18-jun			1	
22-jun			1	
25-jun			1	1
29-jun	1		1	
02-jul				
06-jul			1	
09-jul			2	
13-jul	1		2	
16-jul			2	
20-jul	1		1	
23-jul			1	
27-jul		1	1	
30-jul			2	
03-aug			1	
06-aug				
10-aug			1	
13-aug			1	
17-aug				1
20-aug			1	
24-aug		2	2	1
27-aug	1	1		1
31-aug	2	2		2
03-sep		1	1	1
07-sep		1	1	2
10-sep		1		2
14-sep		2		2
17-sep		3		2
21-sep	2	2		2
24-sep	1		1	2
15-okt			1	

Appendix D - Raw data of zooplankton concentrations

Table 1d. Quantity (m^3) of *Eurytemora* spp. in the eastern enclosure from 20th April to 5th November 2010.

	Developmental stages of *Eurytemora* spp.									Total		
Date	**Nauplii**	**1**	**2**	**3**	**4**	**5**	**Female**	**Male**	**Unidentified**	**Nauplii**	**Copepodite**	**Total**
20-apr	2	11	8	7	10	4	30	17	2	2	72	78
27-apr	7	27	20	5	5	1	8	9	0	7	66	78
04-mai	10773	547	137	37	10	0	7	10	0	172373	737	173110
07-mai	64481	4606	1429	278	159	40	40	0	0	64481	6551	71033
11-mai	34941	5484	1290	372	74	25	0	0	0	34941	7246	42187
18-mai	11581	4434	2515	993	596	132	199	99	0	11581	8867	20448
25-mai	8272	562	199	496	629	298	827	1059	0	8272	3011	11283
01-jun	11647	251	46	40	40	20	337	258	0	11647	735	12381
08-jun	117341	21488	10463	3550	1682	187	374	561	0	117341	37743	155084
12-jun	4722	2919	2060	1374	1374	773	2404	1545	0	4722	10903	15625
22-jun	2214	963	385	770	578	96	6257	3369	96	2214	9144	11358
29-jun	9100	4808	1545	172	0	0	5151	1545	13221	9100	24896	33996
06-jul	5102	1059	1155	2118	0	1348	2214	0	0	5102	7893	12994
13-jul	4858	981	794	327	0	2522	3130	93	0	4858	7754	12612
20-jul	2087	2269	1225	1180	0	408	1724	227	0	2087	6807	8894
27-jul	3176	251	1254	1003	0	585	1463	794	0	3176	4556	7732
03-aug	2113	1050	628	512	0	243	1473	704	0	2113	3906	6020
10-aug	14073	1279	1059	574	397	485	397	485	0	14073	4191	18264
17-aug	4844	675	529	318	291	106	569	185	0	9688	2488	12176
24-aug	25375	2021	1336	1408	1083	578	1480	541	0	25375	7905	33280
07-sep	9038	993	340	208	151	57	293	189	0	36151	2042	38193
14-sep	3635	183	84	115	107	76	283	76	0	7269	848	8117
17-sep	1309	23	12	19	15	8	28	13	0	1309	106	1415
21-sep	67	64	61	35	16	13	263	186	0	67	451	519
01-okt	1232	75	51	43	19	3	56	14	0	1232	248	1480
08-okt	156	11	7	4	11	4	17	6	3	156	57	212
29-okt	1620	167	167	199	167	56	155	91	12	3240	921	4161
05-nov	154	30	14	5	4	2	7	2	0	154	62	216

Table 2d. Quantity (m^3) of zooplankton spp. in the eastern enclosure from 20th April to 5th November 2010.

Date	Harpacoticoid spp	Decapods	Hydrozoans	Other	Total	Total (*Eurytemora* & all other spp.)
20-apr	0	2	0	3	5	83
27-apr	1	1	0	0	1	79
04-mai	0	3	0	0	3	173113
07-mai	40	0	0	0	40	71072
11-mai	0	0	0	0	0	42187
18-mai	430	893	0	0	1324	21772
25-mai	33	430	0	33	496	11779
01-jun	615	20	0	0	635	13017
08-jun	6727	187	0	0	6913	161997
12-jun	14079	258	0	0	14337	29961
22-jun	15978	0	0	578	16556	27914
29-jun	10645	172	0	0	10817	44813
06-jul	4428	0	0	0	4428	17422
13-jul	654	47	0	0	701	13313
20-jul	908	0	0	0	908	9802
27-jul	376	0	0	0	376	8108
03-aug	51	0	0	397	448	6468
10-aug	176	0	0	397	574	18838
17-aug	26	93	0	0	119	12295
24-aug	108	144	0	0	253	33533
07-sep	9	57	38	85	189	38382
14-sep	23	153	8	115	298	8414
17-sep	27	8	32	48	115	1530
21-sep	13	224	0	3	240	759
01-okt	60	34	2	0	96	1576
08-okt	70	23	0	48	142	354
29-okt	40	119	0	64	222	4383
05-nov	21	177	0	48	246	463

Table 3d. Quantity (m^3) of *Eurytemora* spp. in the northern enclosure from 20th April to 5th November 2010.

	Developmental stages of *Eurytemora* spp.									Total		
Date	**Nauplii**	**1**	**2**	**3**	**4**	**5**	**Female**	**Male**	**Unidentified**	**Nauplii**	**Copepodite**	**Total**
20-apr	5	10	7	2	3	2	4	2	2	5	30	35
27-apr	24	373	156	51	44	11	36	29	2	24	673	698
04-mai	3416	280	211	88	64	5	5	5	0	3416	653	4069
07-mai	10396	2563	1480	541	433	180	108	72	36	10396	5342	15738
11-mai	8735	1191	550	397	61	92	31	0	0	8735	2321	11056
18-mai	4588	2823	2382	971	1588	529	88	0	0	4588	8382	12970
25-mai	5332	567	908	1361	2269	1134	1702	1702	227	5332	8168	13500
01-jun	7185	340	180	180	255	113	529	407	0	7185	1598	8782
08-jun	14777	2072	1329	570	224	121	69	69	0	14777	4385	19162
12-jun	3794	1941	1676	2206	2294	618	1059	529	0	3794	9794	13588
22-jun	3397	0	88	88	176	176	2073	1103	0	3397	2603	6000
29-jun	3259	414	529	414	199	66	993	761	199	3259	2812	6072
06-jul	940	606	376	564	460	230	1045	752	0	940	3281	4221
13-jul	3748	572	508	318	762	762	2605	1080	0	3748	5527	9275
20-jul	1128	857	1087	502	0	272	1484	564	0	1128	4200	5329
27-jul	1400	313	397	481	230	251	752	502	0	1400	2424	3824
03-aug	99	99	143	154	110	99	529	66	0	99	1136	1235
10-aug	240	167	125	125	167	84	230	84	42	240	940	1181
17-aug	161	33	33	45	79	8	240	145	0	161	438	600
24-aug	1503	128	71	95	109	28	109	66	71	1503	610	2113
07-sep	699	116	74	37	33	21	120	120	0	699	401	1100
14-sep	663	15	14	8	7	4	15	9	0	663	62	725
17-sep	454	31	9	7	7	4	20	14	0	454	78	532
21-sep	25	37	76	34	10	11	29	29	0	25	197	222
01-okt	1792	179	139	84	99	40	50	25	15	1792	606	2397
08-okt	230	78	89	104	152	115	455	230	0	230	993	1223
29-okt	2246	180	130	118	174	50	230	161	6	4492	887	5379
05-nov	245	169	109	66	60	17	122	146	0	245	543	787

Table 4d. Quantity (m^3) of zooplankton spp. in the northern enclosure from 20th April to 5th November 2010.

Date	Harpacoticoid spp	Decapods	Hydrozoans	Other	Total	Total (*Eurytemora* & all other spp.)
20-apr	1	0	0	0	1	36
27-apr	4	7	0	0	11	709
04-mai	88	5	0	0	93	4162
07-mai	1227	0	0	0	1227	16965
11-mai	2138	0	0	0	2138	13194
18-mai	3088	88	0	0	3176	16147
25-mai	2269	0	0	113	2382	15882
01-jun	567	57	0	9	633	9416
08-jun	432	0	0	35	466	19628
12-jun	2647	88	0	88	2823	16411
22-jun	662	706	132	88	1588	7588
29-jun	629	99	0	0	728	6800
06-jul	439	146	21	0	606	4827
13-jul	318	64	0	127	508	9783
20-jul	230	0	0	0	230	5559
27-jul	313	21	0	0	334	4159
03-aug	110	0	0	44	154	1390
10-aug	240	0	21	115	376	1557
17-aug	112	25	0	21	157	757
24-aug	132	43	0	184	359	2472
07-sep	83	0	12	203	298	1398
14-sep	23	11	3	41	78	804
17-sep	55	36	4	71	165	697
21-sep	47	70	0	0	117	339
01-okt	273	15	0	0	288	2685
08-okt	78	5	0	0	84	1306
29-okt	43	74	0	310	428	5807
05-nov	63	33	0	731	827	1615

Table 5d. Quantity (m^3) of *Eurytemora* spp. in the southern enclosure from 20th April to 5th November 2010.

	Developmental stages of *Eurytemora* spp.									Total		
Date	**Nauplii**	**1**	**2**	**3**	**4**	**5**	**Female**	**Male**	**Unidentified**	**Nauplii**	**Copepodite**	**Total**
20-apr	6	12	10	10	16	3	32	24	7	6	89	95
27-apr	58	1058	263	184	63	32	179	132	26	58	1805	1863
04-mai	23690	3510	1170	430	72	24	72	48	0	23690	5278	28967
07-mai	319596	34696	21746	9041	489	244	1466	1222	0	319596	67682	387278
11-mai	1082223	62034	32138	21301	6727	374	0	374	0	1082223	122572	1204796
18-mai	45264	46058	31764	10323	9529	4765	2382	794	0	45264	104822	150086
25-mai	6670	1271	2859	6035	13659	6670	15247	12706	318	6670	46058	52728
01-jun	2647	59	0	0	353	118	3059	2676	0	2647	3588	6235
08-jun	18378	5748	3781	151	832	832	1134	0	0	18378	12479	30857
12-jun	510	794	1021	1815	3857	1305	2155	1248	0	510	10947	11458
22-jun	0	0	227	0	1815	1815	24277	15882	908	0	29042	29042
29-jun	8537	265	463	199	0	0	2779	3176	397	8537	4103	12639
06-jul	550	1008	886	764	244	275	794	367	0	550	3971	4520
13-jul	1144	635	635	762	572	953	3049	2096	0	1144	6607	7750
20-jul	596	1390	1059	1257	0	2118	5956	2581	0	596	11779	12375
27-jul	3235	2765	2353	3823	2647	1471	1412	882	0	3235	14470	17706
03-aug	397	0	199	529	596	529	9992	3706	0	397	11845	12242
10-aug	7636	2810	550	183	183	61	2627	2382	0	7636	6414	14050
17-aug	11647	337	505	289	144	144	1997	578	0	11647	3417	15064
24-aug	25752	14	170	199	383	28	1602	837	14	25752	2411	28162
07-sep	7941	1155	722	289	650	578	3971	6064	0	7941	7364	15305
21-sep	241	74	71	43	57	18	191	227	0	241	454	695
01-okt	1959	86	88	73	39	17	43	39	0	1959	347	2307
08-okt	1137	140	59	86	140	59	140	108	72	1137	695	1832
29-okt	839	41	34	27	41	11	29	50	18	1678	201	1879
05-nov	528	0	0	0	0	0	0	0	0	2111	0	2111

Table 6d. Quantity (m^3) of zooplankton spp. in the southern enclosure from 20th April to 5th November 2010.

Date	Harpacoticoid spp	Decapods	Hydrozoans	Other	Total	Total (*Eurytemora* & all other spp.)
20-apr	1	2	0	2	4	99
27-apr	16	0	0	5	21	1884
04-mai	48	0	0	0	48	29015
07-mai	977	244	0	0	1222	388500
11-mai	2242	747	0	0	2990	1207785
18-mai	15088	1588	0	0	16676	166762
25-mai	4765	318	0	0	5082	57811
01-jun	882	0	0	118	1000	7235
08-jun	2118	0	0	0	2118	32974
12-jun	510	1475	0	0	1985	13443
22-jun	4084	7033	227	0	11344	40386
29-jun	1919	265	0	0	2184	14823
06-jul	1985	855	122	0	2963	7483
13-jul	889	445	0	64	1398	9148
20-jul	728	3044	0	0	3772	16147
27-jul	471	647	0	59	1176	18882
03-aug	397	0	0	132	529	12772
10-aug	305	0	0	244	550	14599
17-aug	144	24	0	0	168	15232
24-aug	227	0	43	28	298	28460
07-sep	217	0	144	144	505	15810
21-sep	78	128	0	0	206	900
01-okt	99	9	2	0	110	2417
08-okt	158	5	0	50	212	2044
29-okt	16	97	0	16	129	2008
05-nov	0	0	0	0	0	2111

Table 7d. Quantity (m^3) of *Eurytemora* spp. in the western enclosure from 21st September to 11th November 2010.

	Developmental stage of *Eurytemora* spp.									Total		
Date	**Nauplii**	**1**	**2**	**3**	**4**	**5**	**Female**	**Male**	**Unidentified**	**Nauplii**	**Copepodite**	**Total**
21-sep	529	6016	0	0	0	0	1829	0	0	529	7845	8374
29-sep	38329	2118	2435	2329	2647	953	4341	3176	0	38329	14823	53152
01-okt	38329	2118	2435	2329	2647	953	4341	3176	0	38329	14823	53152
08-okt	29510	4816	1742	1844	3586	1639	3791	4304	0	29510	17419	46929
15-okt	20391	6250	7275	3176	3689	820	4508	3484	0	20391	25719	46109
22-okt	49044	1779	2223	2859	3049	1588	2160	1842	0	49044	13659	62702
29-okt	13011	1527	672	825	1435	1527	2199	1313	0	26022	8185	34208
05-nov	2042	3800	0	0	0	0	2382	1305	0	2042	6183	8225
11-nov	3004	449	725	380	691	35	725	621	0	3004	3004	6008

Table 8d. Quantity (m^3) of zooplankton spp. in the western enclosure from 21st September to 11th November 2010.

Date	**Harpacoticoid spp**	**Decapods**	**Hydrozoans**	**Other**	**Total**	**Total (*Eurytemora* & all other spp.)**
21-sep	96	96	0	0	193	8567
29-sep	106	0	0	0	106	53258
01-okt	106	0	0	0	106	53258
08-okt	205	102	0	0	307	47236
15-okt	205	0	0	0	205	46314
22-okt	0	0	0	0	0	62702
29-okt	31	61	0	1008	1100	35307
05-nov	0	0	0	2099	2099	10323
11-nov	69	35	0	2659	2762	8770

Appendix E – Size of *Eurytemora* spp.

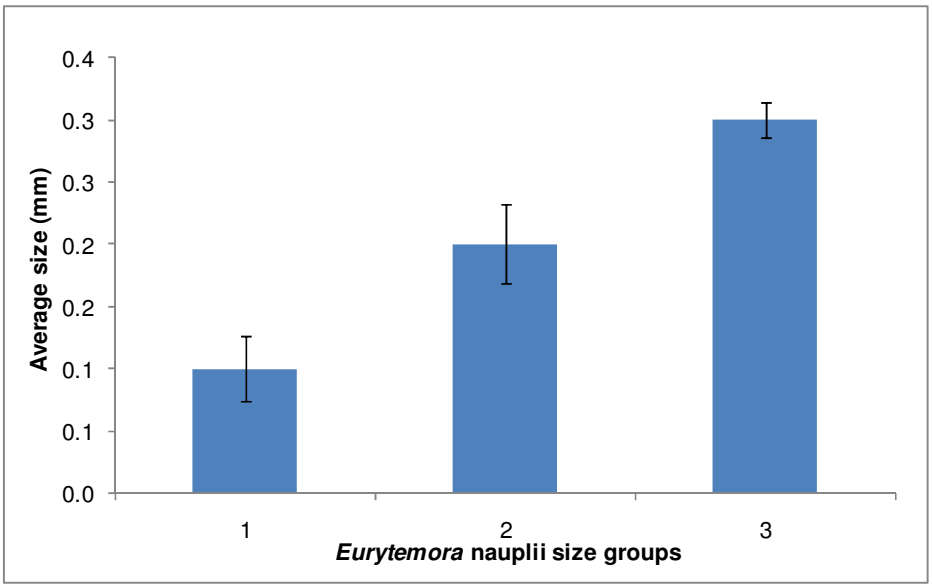

Fig 1e. The size range of 30 nauplii collected in Nesvík's basins. As the majority of the zooplankton present was *Eurytemora* spp., it is assumed that these nauplii belong to the same species.

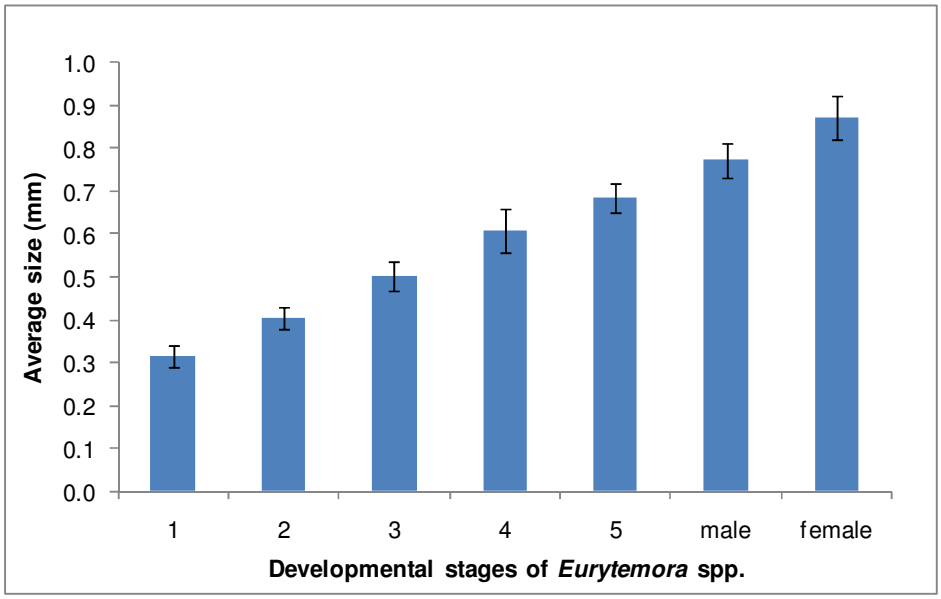

Fig 2e. Average size of the developmental stages of *Eurytemora* spp. in Nesvík's enclosures. The observations are based on at least 38 samples of each developmental stage.

Appendix F – Resting eggs

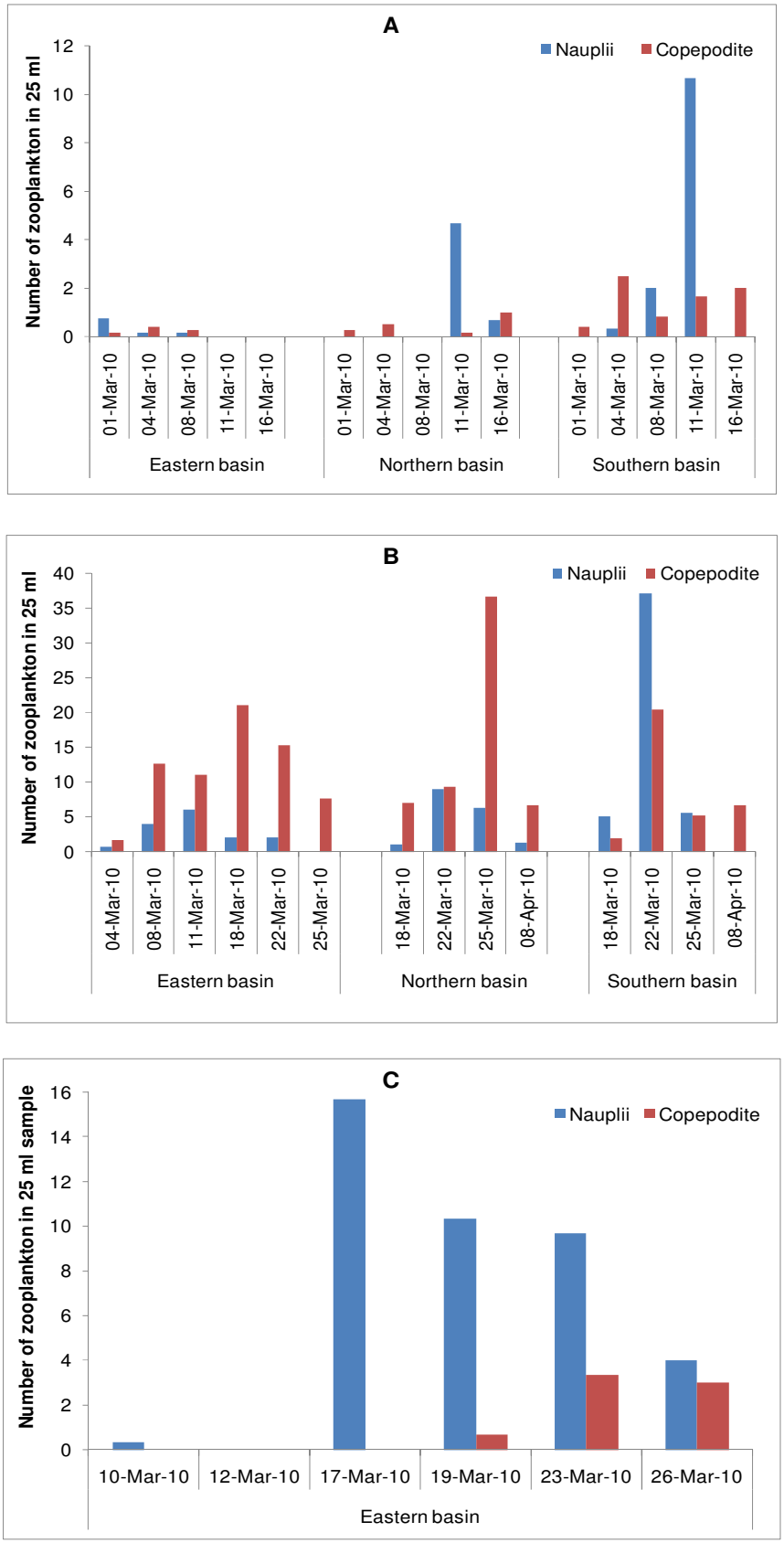

Fig 1f. Sampling for resting eggs in the eastern, southern and northern basin before the basins were drained (a), when they were nearly drained (b) and after scrubbing (c).

Appendix G – Weather conditions at the Marine Station in Nesvík

Table 1g. General weather description from 15th April to 8th October 2010.

dato	sunny	cloudy	sunny/ cloudy	rainy	dry	dato	sunny	cloudy	sunny/ cloudy	rainy	dry
15-apr			x		x	11-jun		x		x	
16-apr		x		x		12-jun		x			x
17-apr		x			x	13-jun		x			x
18-apr		x		x		14-jun		x			x
19-apr		x		x		15-jun		x			x
20-apr		x		x		16-jun		x			x
21-apr		x			x	17-jun		x		x	
22-apr		x		x		18-jun			x		x
23-apr			x		x	21-jun		x			x
26-apr		x		x		22-jun		x			x
27-apr		x			x	23-jun		x			x
28-apr		x		x		24-jun		x			x
29-apr		x			x	26-jun		x			x
30-apr		x		x		27-jun		x			x
01-mai		x			x	28-jun		x			x
02-mai	x				x	29-jun		x		x	
03-mai	x				x	30-jun		x			x
04-mai		x				01-jul		x		x	
05-mai		x				02-jul			x		x
06-mai	x				x	06-jul			x		x
07-mai		x			x	07-jul		x		x	
08-mai	x				x	08-jul		x		x	
09-mai		x		x		12-jul			x		x
10-mai		x		x		13-jul			x		x
11-mai		x		x		14-jul			x		x
12-mai		x			x	15-jul		x		x	
14-mai		x			x	16-jul			x		x
15-mai		x		x		17-jul				x	
16-mai		x		x		18-jul				x	
17-mai		x			x	19-jul		x		x	
18-mai			x	x		20-jul			x		x
19-mai		x		x		21-jul		x			x
20-mai	x				x	22-jul		x			x
21-mai	x				x	23-jul	x				x
22-mai				x		26-jul		x			x
23-mai					x	27-jul		x			x
24-mai			x		x	28-jul			x		x
25-mai				x		30-jul		x			x
26-mai				x		02-aug		x			x
27-mai			x		x	03-aug		x			x
28-mai			x		x	04-aug		x			x
29-mai			x	x		05-aug			x		x
30-mai		x		x		06-aug			x		x
31-mai		x			x	09-aug			x		x
01-jun		x			x	10-aug			x		x
02-jun		x		x		11-aug		x		x	
03-jun		x			x	12-aug		x			x
04-jun		x			x	13-aug		x			x
05-jun		x		x		14-aug			x		x

06-jun		x			x	15-aug	x			x
07-jun		x		x		16-aug	x		x	
08-jun		x		x		17-aug	x		x	
09-jun			x		x	18-aug	x		x	
10-jun			x		x	19-aug	x			x
20-aug		x			x	13-sep			x	
21-aug		x			x	14-sep		x		x
22-aug		x			x	15-sep		x		x
23-aug			x		x	16-sep			x	
24-aug			x	x		17-sep			x	
25-aug		x		x		18-sep		x		x
26-aug		x		x		19-sep		x		x
27-aug		x		x		22-sep		x		x
28-aug			x		x	23-sep		x		x
29-aug			x		x	25-sep			x	
30-aug				x		26-sep		x		x
31-aug		x			x	29-sep		x		x
01-sep		x			x	30-sep		x		x
02-sep	x					01-okt		x		x
03-sep	x					02-okt		x		x
06-sep					x	03-okt		x	x	
07-sep					x	04-okt		x	x	
08-sep					x	05-okt			x	
10-sep			x			06-okt			x	
11-sep		x				07-okt			x	
12-sep		x				08-okt		x		x

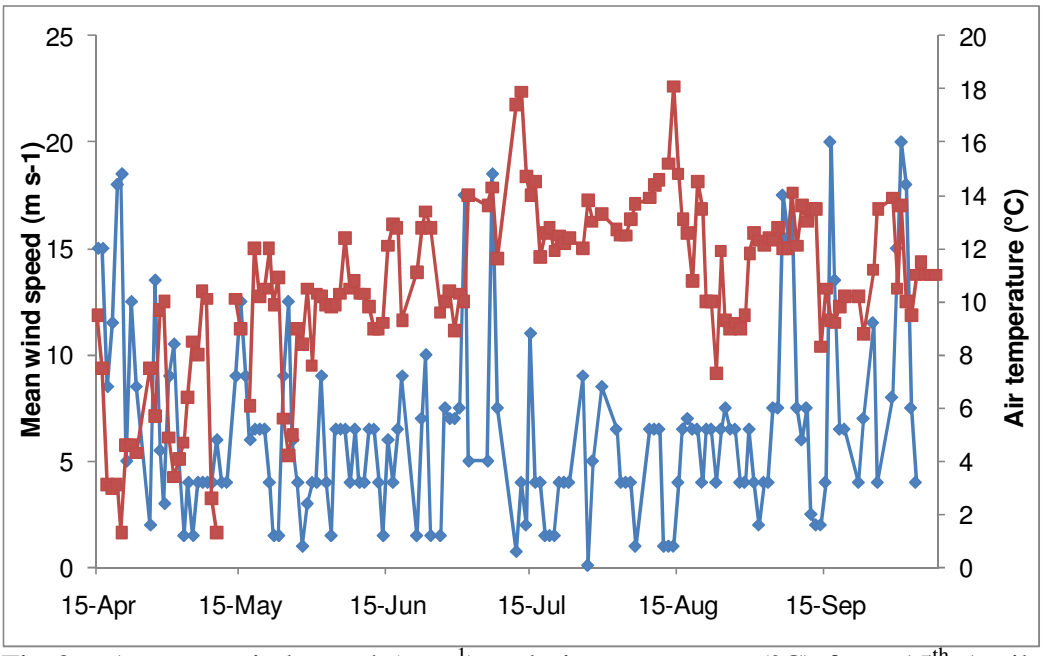

Fig 2g. Average wind speed (m s^{-1}) and air temperature (°C) from 15th April to 8th October 2010. Estimation on average wind speed is based on wind description from DMI.

Table 1g. Wind direction from 15th April to 8th October 2010.

Date	Wind direction	Date	Wind direction	Date	Wind direction
15-Apr	NW	08-Jun	NE	14-Aug	No wind
16-Apr	NW	09-Jun	NE	15-Aug	N
17-Apr	NW/N	10-Jun	NE	16-Aug	S
18-Apr	NW/N	11-Jun	N	17-Aug	SE
19-Apr	SE	12-Jun	N	18-Aug	NE
20-Apr	NW/N	13-Jun	N	19-Aug	NE
21-Apr	NW/N	14-Jun	N	20-Aug	NE
22-Apr	NW/N	15-Jun	SW	21-Aug	N
23-Apr	NW/N	16-Jun	SW	22-Aug	NW
26-Apr	SE	17-Jun	NW	23-Aug	NW
27-Apr	SE	18-Jun	N	24-Aug	N
28-Apr	SE	21-Jun	SW	25-Aug	N
29-Apr	SE	22-Jun	S	26-Aug	NW
30-Apr	NW	23-Jun	S	27-Aug	NW
01-May	N	24-Jun	SW	28-Aug	NW
02-May	N	26-Jun	S	29-Aug	NE
03-May	N	27-Jun	S	30-Aug	W
04-May	N	28-Jun	SE	31-Aug	W
05-May	N	29-Jun	N	01-Sep	S
06-May	NW	30-Jun	SE	02-Sep	SE
07-May	NW	01-Jul	SE	03-Sep	SE
08-May	N	02-Jul	SE	04-Sep	SE
09-May	N	06-Jul	SE	05-Sep	SE
10-May	N	07-Jul	SW	06-Sep	SE
11-May	NW	08-Jul	SW	07-Sep	SE
12-May	NW	12-Jul	S	08-Sep	SE
14-May	N	13-Jul	S	09-Sep	SE
15-May	N	14-Jul	SW	10-Sep	SW
16-May	N	15-Jul	S	11-Sep	S
17-May	W	16-Jul	S	12-Sep	W
18-May	N	17-Jul	SW	13-Sep	W
19-May	SE	18-Jul	S	14-Sep	N
20-May	SE	19-Jul	NE	15-Sep	N
21-May	SE	20-Jul	NE	16-Sep	N
22-May	SE	21-Jul	SE	17-Sep	N
23-May	SE	22-Jul	N	18-Sep	N
24-May	N	23-Jul	N	19-Sep	N
25-May	N	26-Jul	S	22-Sep	N
26-May	NE	27-Jul	No wind	23-Sep	NW
27-May	NE	28-Jul	NE	25-Sep	S
28-May	NE	30-Jul	N	26-Sep	S
29-May	NE	02-Aug	SE	29-Sep	SE
30-May	S	03-Aug	S	30-Sep	SE
31-May	S	04-Aug	S	01-Oct	SE
01-Jun	S	05-Aug	NE	02-Oct	S
02-Jun	SW	06-Aug	NE	03-Oct	S
03-Jun	S	09-Aug	E	04-Oct	S
04-Jun	SE	10-Aug	N	05-Oct	S
05-Jun	SE	11-Aug	N	06-Oct	S
06-Jun	SW	12-Aug	No wind	07-Oct	S
07-Jun	NE	13-Aug	No wind	08-Oct	SE