Seasonal and Interannual Variations of Surface Nutrients and Hydrography in the Norwegian Sea

by

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Abstract

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Seasonal and interannual variations of surface nutrients and hydrography data obtained in period (1997-2010) by the Institute of Marine Research over three transects: Fugløya-Bjørnøya, Gimsøy and Svinøy located in the Norwegian Sea have been studied. The results over the Fugløya-Bjørnøya transect show good signature of the seasonal cycle of nitrate and temperature reflecting both bloom and post-bloom periods. The Gimsøy transect shows a weak seasonal cycle of nitrate and temperature in the outer part because there is no enough data during the bloom and post-bloom period. But the middle and inner part show good seasonal cycle of nitrate and temperature during the two periods. Finally, the Svinøy transect shows good seasonal cycle of nitrate and temperature during the bloom and post-bloom. The results over the three transects do not reveal much information on the interannual variations of temperature, salinity and nitrate. This due to the changes in the timing of the cruise. Also the availability of information is short over three transects.

Acknowledgements

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To my parents,

friends in Sudan,

my nephew Majzoub

Chapter 1

Introduction

Marine primary production and its seasonal and interannual variations has been the subject to extensive studies. This is because it is the foundation of the food chain of the ocean, and plays an important role in the carbon dioxide cycle, thus the climate change. Phytoplankton is the main manufacturer of pelagic marine waters, an essential part of the marine food web, thus the entire ecosystem, affecting fishery resources, nutrients cycling, trophic dynamics, and habitat conditions (Paerl et al., 2003). Additionally, plankton show strong response to environmental variations, making them good indicators of environmental disturbance (Hays et al., 2005). The important ecosystems around the world are the coastal upwelling regions, and the high latitude regions where the spring bloom is found (Mann and Lazier, 2006). The Nordic Seas are one of these important ecosystems (Mann and Lazier, 2006). The main work of my thesis concerns the Norwegian Sea, and specifically the seasonal spring bloom and its interannual variations in the Norwegian Atlantic Current (NAC) and Norwegian coastal current (NCC) along the Norwegian coast. This done by evaluating hydrographic and nutrients, using data obtained at three transects perpendicular to the Norwegian coast.

1.1 Physical Setting

The global ocean circulation is dominated by the thermohaline circulation (see Figure 1.1), also known as the Great Conveyor Belt (Broecker, 1991). It is considered as large scale processing around the world. The Nordic Seas is one of the few places where deep water is formed, is considered as key area for thermohaline circulation (Clark et al., 2002). The warm Atlantic current moves northward to high latitude, losing heat to atmosphere and become dense enough to sink down as deep cold water. In the Indian Ocean the cold water comes up through upwelling to make balance with other cold water comes down. This also happens in the Pacific Ocean. As the result these entire processing make the oceans ventilated and bring up high nutrients for the biological processes (Dorritie, 2004).

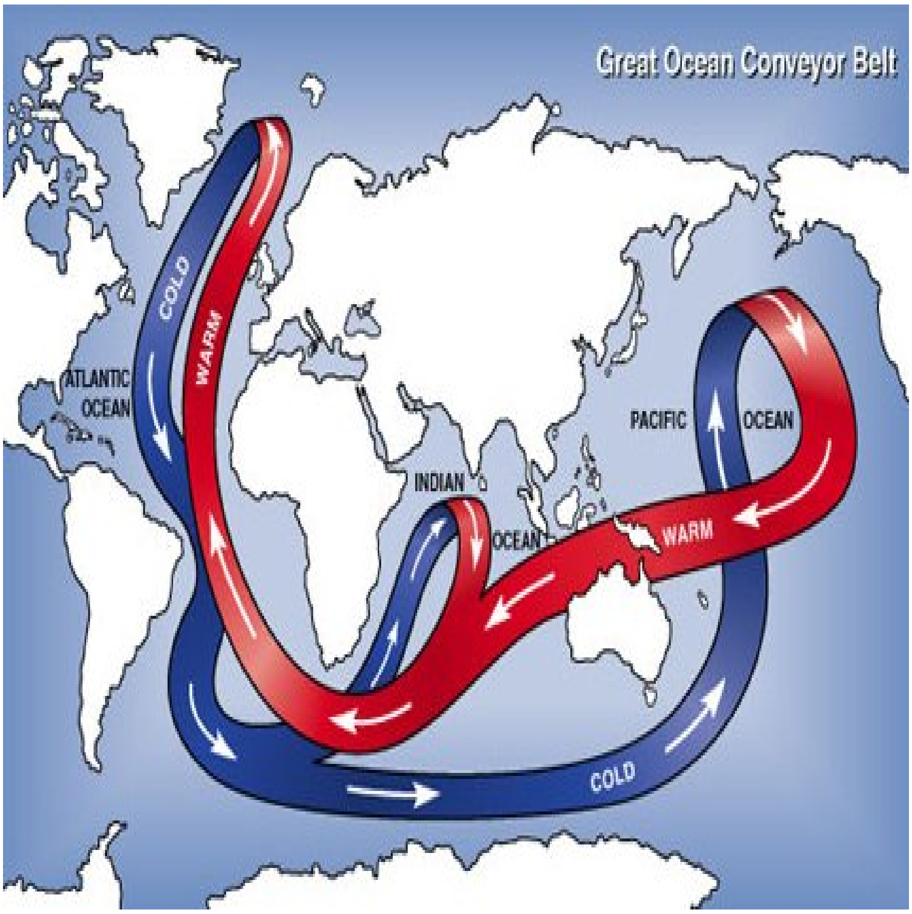


FIGURE 1.1: The thermohaline circulation, red arrows show shallower and warm water, blue arrows show deep and cold water (NESTA, 2012).

1.1.1 Bathymetry of the Nordic Seas

The bathymetry of the Nordic Seas is shown in Figure 1.2. Nordic Seas consist of three seas named according to lands boarding the region, which are Norway, Iceland, and Greenland (Blindheim and Osterhus, 2005). It connects with Arctic Ocean to the north, through the Fram Strait with a sill depth of 2600 m. To the south, the Greenland Scotland Ridge connects it to North Atlantic Ocean (Blindheim and Osterhus, 2005). The Nordic Seas contain four basins two of them are to the north and west of the mid-ocean ridge; they are named Boreas basin with depth of 3200 m and Greenland basin with depth 3400 to 3600 m in the Greenland Sea (Blindheim and Osterhus, 2005). The two other basins are found to the south in the Norwegian Sea they are named Norwegian basin with a depth of more than 2200 m deep m and Lofoten basin, about 3200 m deep (Blindheim and Osterhus, 2005).

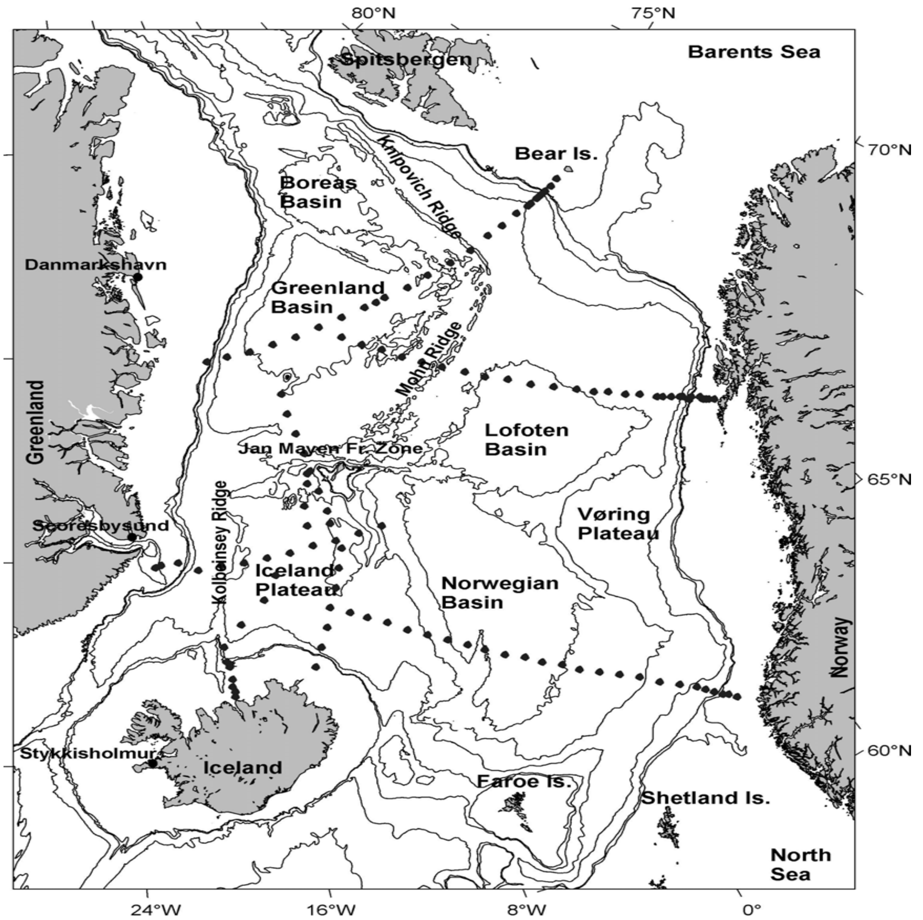


FIGURE 1.2: Bathymetry maps of the Nordic Seas from (Blindheim and Osterhus, 2005).

The Mohn ridge separates the Lofoten basin from the Greenland basin. In addition there are two plateaus, one of them is located off Greenland, to the east, and it is called the Iceland plateau, the other is called the Vøring Plateau, located eastward from the Norway, and bordered by the Lofoten basin to the north and Norwegian basin to the south (Blindheim and Osterhus, 2005).

1.1.2 Water Masses and Circulation of the Nordic Seas

In the Nordic Seas there are four main surface water masses: (i) the Atlantic water (AW) to the east which flows northwards to the Arctic Ocean, (ii) the Polar Water to the west that flows southwards from the Arctic Ocean, the mixing product between these constitutes the (iii) water mass Arctic Water (ArW), and all the way to the east, along the Norwegian Continental shelf we find (iv) Coastal Water, flowing northwards in the Norwegian Coastal Current (NCC) (Blindheim and Osterhus, 2005). In the Nordic Seas from the south to the north we have warm water known as Atlantic water with high salinity around 35 and 35.26 and temperature between 3°C and 4°C (Blindheim and Osterhus, 2005). On the other hand from south to the east of Greenland we have cold water known as polar water to the west coming from Arctic Water with salinity low than 34.2 (Blindheim and Osterhus, 2005). Moreover and between these, and result of mixing the Norwegian Sea Arctic Intermediate water is formed and flow from the south to the north with salinity below 34.89 (Blindheim and Osterhus, 2005). The current circulation track from the Atlantic Ocean northward to the Nordic Seas was dominated by the weather change (Blindheim and Osterhus, 2005). There are three location of North Atlantic Ocean inflow to the Nordic Seas (Blindheim and Osterhus, 2005). The flow over the eastern Denmark Strait is known as North Icelandic Irminger Current. The second flow across the Iceland-Faroe Ridge is known as the Faroe Current (Blindheim and Osterhus, 2005). The last flow is over the Faroe Shetland Channel Know as Atlantic Inflow (Blindheim and Osterhus, 2005). On the other hand most of waters continue into Norwegian Basin which oncoming the Vøring Plateau, its transition northwest toward Jan Mayen (Blindheim and Osterhus, 2005). Atlantic Water from the West Spitsbergen may current deflect into the northern Greenland Basin and Boreas Basin (Blindheim and Osterhus, 2005). Moreover the water masses in the Nordic seas were resulted due to their contacting with many different waters.

1.2 Biological Features

Phytoplankton is the first type of organism, a single cell in the marine food web. Through photosynthesis these organisms combine nutrients (nitrate, phosphate), and carbon dioxide into organic compounds. Primary production sustains the global marine ecosystem and its harvest-ability (Marine Odyssey, 2012). Primary production is also important for the oceans ability to store carbon dioxide. The exchange of carbon dioxide between the atmosphere and ocean depends on the concentration of CO_2 on the ocean surface (McKinley et al., 2011). Phytoplankton consumes carbon dioxide which reduces the concentration of CO_2 in the surface waters, driving a flux of CO_2 from the atmosphere and into the ocean to make equilibrium between the air and water (McKinley et al., 2011). The most important global patterns of marine primary production follow similar patterns as the quantity and distribution of light and nutrients (Mann and Lazier, 2006). There are three main types of regions, the tropical regions, the subtropical regions, and the sub-polar regions (Mann and Lazier, 2006). The oligotrophic tropical regions are where the exchange of nutrient is limited by pycnocline, which implies low rate of production in the surface layer due to low nutrients (Mann and Lazier, 2006). The other source of nitrate is nitrogen regenerated by the grazers (Mann and Lazier, 2006). The feature of oligotrophic is that appears little seasonal variability, and high stability of water column (Mann and Lazier, 2006). On the other hand trade wind at equator is carrying to west and increase the flow in the mixed layer alongside this direction (Vinogradov, 1981). In this area the Coriolis force has important role that can cause deflection of westward currents to the north whereas the westward currents in south turned to south (Mann and Lazier, 2006). These processes are known as equatorial upwelling. The water from the deep ocean is nutrients rich and phytoplankton poor (Mann and Lazier, 2006). The subtropical region appears between the sub-polar and tropical regions, and according to Longhurst et al. (1995) there are many subtropical areas, covering approximately half the area of the world ocean (Mann and Lazier, 2006). Moreover there is a short period in winter when deep mixing refills the upper layer with nutrients. The phytoplankton in the subtropical system is never light limited, is nutrients limited most of year (Mann and Lazier, 2006). The sub-polar region lies between 50°N and 70°N. When we move to northwards, the downward mixing by convection cooled water at the surface of the ocean addition to wind-driven turbulence to make deeper mixed layer in the winter season (Mann and Lazier, 2006). The turbulence induces nutrients to the euphotic zone (Mann and Lazier, 2006). Also the phytoplankton cells are sinking deeper and deeper and spend long time under the euphotic zone, while the photosynthesis is surpassed by the respiration (Mann and Lazier, 2006). Ultimately in the spring the mixed layer becomes shallower and the phytoplankton cells is trapped over the pycnocline and spend more time in the euphotic zone thus great blew up of phytoplankton that known as spring bloom (Mann and Lazier, 2006).

1.2.1 The Norwegian Sea Ecosystem

The Norwegian Sea is one of the richest and highly productive ecosystems of the world oceans (see Figure 1.3). This high productivity is due to the spring bloom which occurs through phytoplankton trapped in the shallower mixed layer rich with nutrients obtained from the deep ocean where the nutrients accumulated in the winter. In the Nordic Seas the hydrographic Features of the natural borders (Arctic and Coastal fronts in the Norwegian Sea and the Polar Front in the Barents Sea) are important matter when we going in the ecosystem composition (Fossheim et al., 2006). Also the topography effects on the ecosystem composition (Loeng and Drinkwater, 2007).

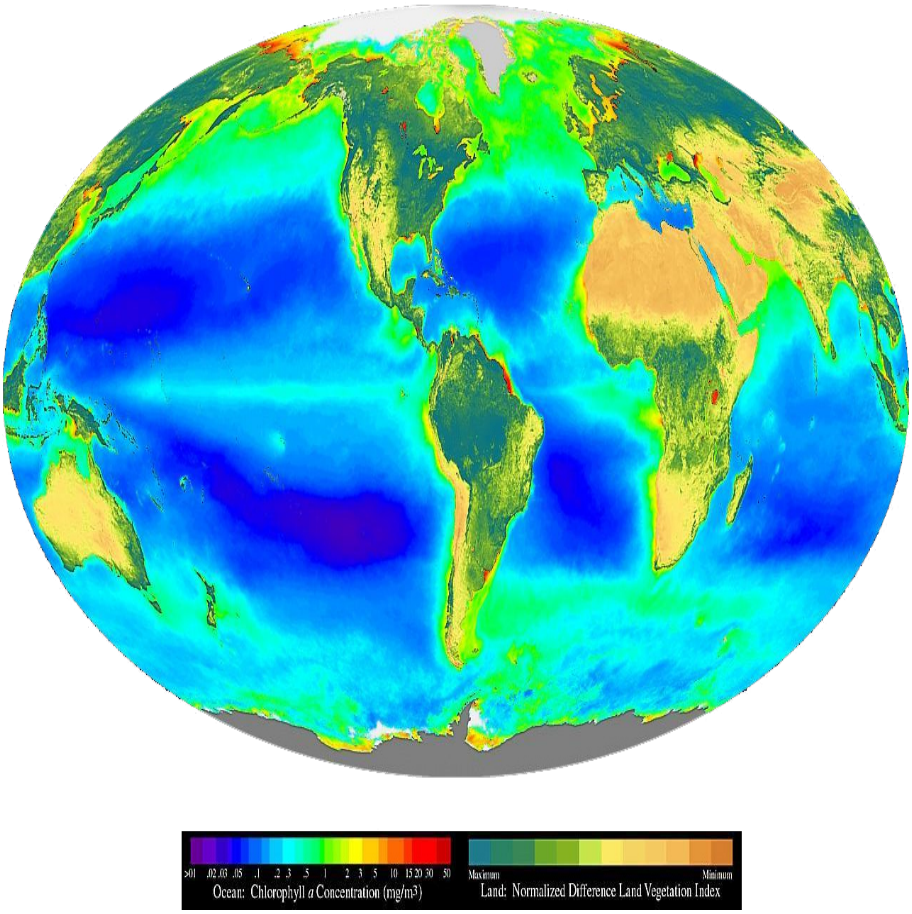


FIGURE 1.3: The global primary production include the Norwegian Sea productivity (SeaWiFS Project, 2012).

The Norwegian Sea has a short food chain that contains phytoplankton, zooplankton, and fish (Loeng and Drinkwater, 2007). The most important phytoplankton types that exist in the Norwegian Sea are diatoms, dinoflagellates and coccolithphorids (Rey, 2004). Diatoms are starting the production in early March through April (Rey, 2004). Diatoms controlls the spring bloom at the beginning of bloom.

Later the *flagellates* like *phaeocystispouchetii* that controlled the phytoplankton (Rey, 2004). The most important zooplankton group in the Norwegian Sea ecosystem are called copepods (Melle et al., 2004). The main copepod is the *Calanusfinmarchicus* and does grazing on the spring bloom (Niehoff et al., 2000). The third element of the Norwegian food chain is represented by Atlantic herring, capelin, Atlantic cod saithe and blue whiting (Rey, 2004).

1.2.2 Primary Production in the Nordic Seas

Oceans and seas on the earth contain in their interior, many of the biological systems and biodiversity, which are part of the overall system on the earth, where they have active roles in the changes of climate. There are several factors that control the process of primary productivity in the oceans, which varies with the geographic location (Sarmiento and Gruber, 2006). In the Nordic Seas the factors that dominate the primary productivity are light, temperature, and nutrients supply (Skogen et al., 2007). In addition grazing is considered one of the factors that effect on primary productivity (Skogen et al., 2007). Sea ice melting also effects primary productivity in the Nordic Seas (Skogen et al., 2007). Ryther (1956) observed that the light becomes a limiting factor for phytoplankton development in winter, thus low biomass of chlorophyll-a. The depth of the mixed layer is at its maximum in February, deeper than 100 m, till the end of April (Mann and Lazier, 2006). Johannessen and Gade (1984) assumed that the phytoplankton population was conserved low result to deep vertical mixing. There is no indication of thermal stratification in April (Mann and Lazier, 2006). The wind induces the vertical mixing (Skjoldal et al., 1993). The grazing may have a clear impact on the spring bloom in areas with delayed thermal stratification (Dale et al., 1999).

Chapter 2

Data and Methods

2.1 Hydrographic Data

The hydrographic data that were used in this thesis are temperature, salinity, and nitrate (NO_3^{-1}). In this thesis data from the years 1997-2010 were used. The data were obtained by the Norwegian Institute of Marine Research (IMR) on three of their repeat hydrography transects: The Fugløya-Bjørnøya transect in the Barents Sea, the Gimsøy transect in the Lofoten Basin, and the Svinøy transect in the Norwegian Basin. The three transects are shown on the map and perpendicular along the Norway coast (see Figure 2.1). Water samples were collected throughout the water column and then put in the polyethylene vials chloroform to prevent samples from change (Olsen, 2002). The instrument used to analyze the water samples is called Auto analyzer, and was set up to standard methods. And it is designed to determination the nutrient salts in sea water (Folkard, 1978). The basic concept of the nitrate, phosphate analysis includes reduction of the nutrient targeted Cd-column and addition of known amount from reagents have ability to produce complex compound with color that can be detected by spectrophotometer instrument at known wavelength (Grasshoff et al., 1999). The amount of produced colored compounds is proportional to the nutrient salt analyte existing in the solution (Hydes et al., 2010). As shown in (Figure 2.1) each of the three transects cover the main paths of the Atlantic water (AW) shown with bold red line beside the Norwegian Coastal Current with bold yellow line and their front with dashed orange line. Also the Atlantic water and Arctic water with bold violet line representing the Arctic front from the other side to the west. More further its shows the front of Arctic Water comes out to the west and in other time comes in to the east. At each section the average values in the upper ten meters for an outer, middle and inner part were determined. The limits between these were based on general knowledge of the hydrography aiming to capture regions dominated by Coastal and Atlantic waters for the inner and middle parts, respectively, (see Figure 2.2). In the outer parts there may be additional influence of Arctic surface waters in at the Svinøy and Gimsøy transects, and of Polar Water at the Fugløya-Bjørnøya transect. From (Table 2.1), at the Fugløya-Bjørnøya transect the outer part is north of 73°N, the middle part between 72.0°N and 73°N, and the inner part between 70.50°N and 72.0°N. On the Gimsøy transect, the outer part is north of 70.00°N, the middle part between 69.0°N and 70.00°N, and the inner part between 68.40°N and 69.0°N. On the Svinøy transect the outer part is north of 64.00°N, the middle part between 63.00°N and 64.00°N, and the inner part between 62.40°N and 63.00°N.

TABLE 2.1: limits of parts in degrees north.

Name of transect	Outer part	Middle Part	Inner Part
Fugløya–Bjørnøya	73 – 74.26	72.0 – 73.0	70.5 – 72
Gimsøy	70 – 70.41	69.0 – 70.0	68.4 – 69
Svinøy	64 – 64.70	63.0 – 64.0	62.4 – 63

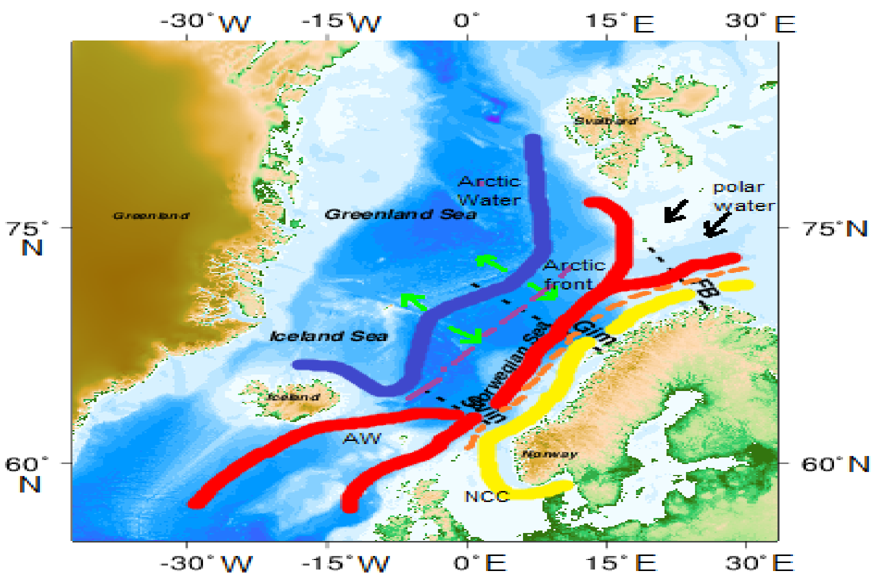


FIGURE 2.1: Map of the Nordic seas illustrating the Norwegian Sea with three transects, the yellow line shows the Norwegian Coastal Current, the orange line shows the Atlantic Water, the dashed red line shows the front between these, and the dashed black line shows the front between the Atlantic Water and the Arctic Water (Arc W).

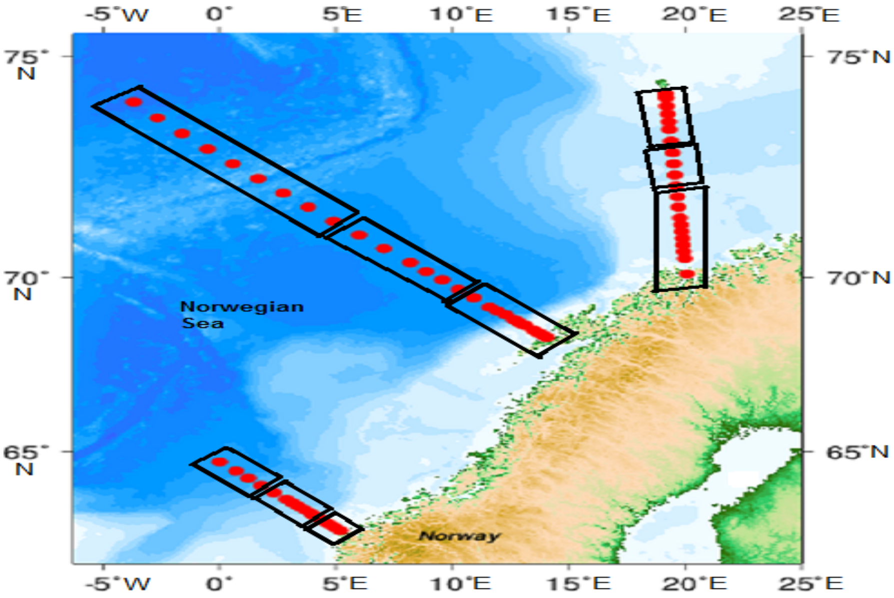


FIGURE 2.2: The Norwegian Sea including transects, Fugløya-Bjørnøya in the North, Gimsøy in the Middle, Svinøy in the south of Norway respectively. Each transect split into three boxes named from onshore to offshore, inner part, middle part, and outer part.

Figure 2.3 illustrates the spatial and temporal distribution of the data. The distribution of the stations is different from one transect to another, and every transect is divided to three parts as shown with horizontal red lines at Fugløya-Bjørnøya, horizontal orange lines at Gimsøy, and horizontal green lines at Svinøy. In the Fugløya-Bjørnøya transect the number of hydrographic measurements in the outer part is large compared with the outer in the Gimsøy and Svinøy.

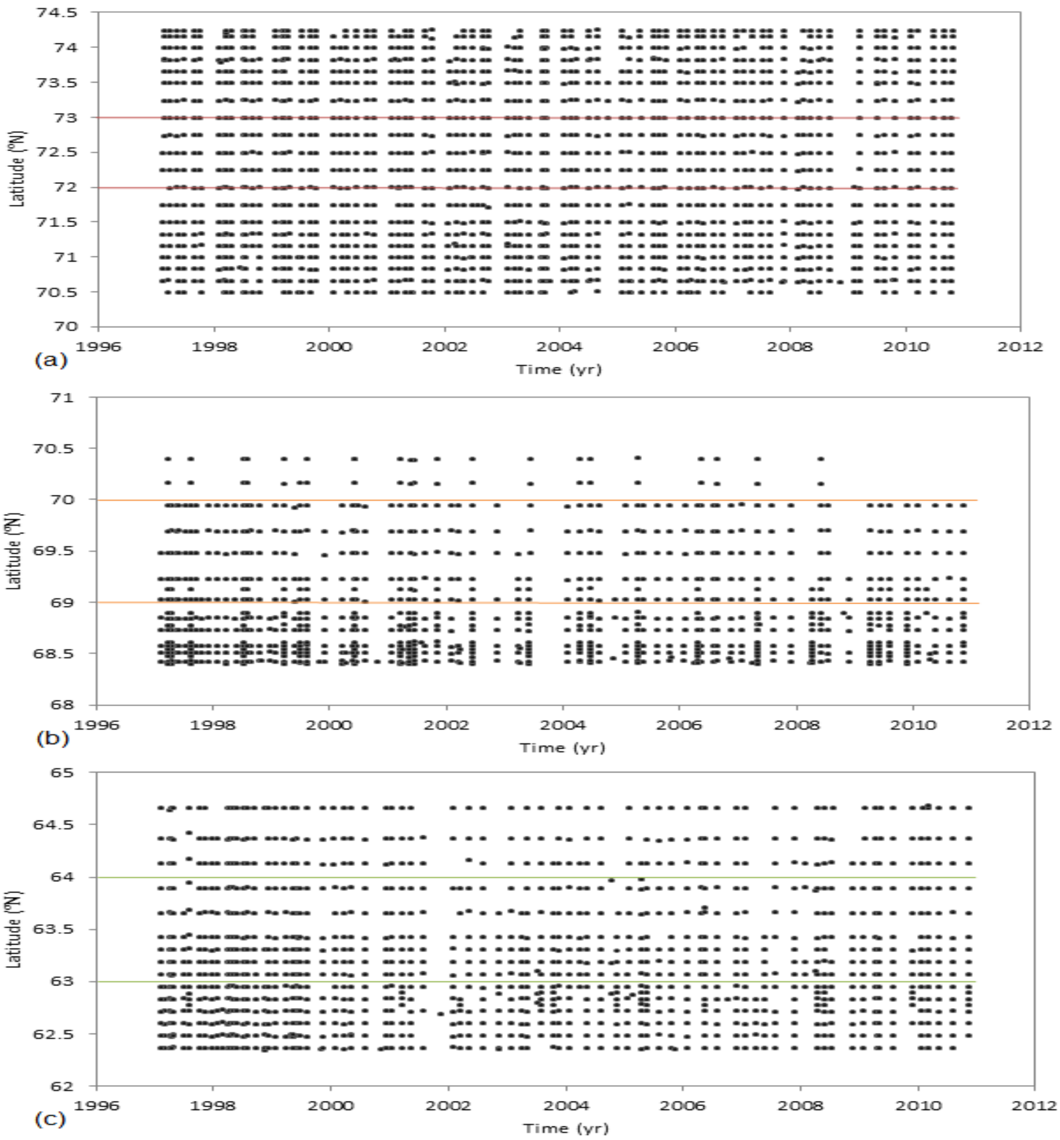


FIGURE 2.3: Temporal and spatial distribution of the stations, (a) Fugløya-Bjørnøya (b) Gimsøy and (c) Svinøy.

Chapter 3

Results and Discussion

3.1 Fugløya-Bjørnøya Transect

3.1.1 Seasonal Cycle at the Fugløya-Bjørnøya Transect

Outer Part

Definition of the phytoplankton bloom is a "high concentration of phytoplankton in an area, caused by increased reproduction; [this] often produces discoloration of the water" (Garrison, 2005). The seasonal development of temperature, salinity and nitrate at the outer part of Fugløya-Bjørnøya transect located between70.5°N and 71.0°N is shown in (Figure 3.1) where the average of hydrographic data have been taken from the outer stations for different cruises for all years have been combined on a single time axis. The data have been collected, covering for most part the time periods from the bloom until the post bloom phase. Where the bloom defined as a time of the nitrate has started to decrease in the early of spring. And the post-bloom defined as the time period following the bloom period when the nitrate is almost depleted during summer. The temperature and nutrient concentration show a clear and high repeated seasonal cycle, (see Figure 3.1). Up until day 100 low temperature indicate that winter situation prevails, with salinity quite stable at values normally above 34.7 indicating the presence of polar water and high nitrate concentrations (>9.6 μmol/kg). In the period between days 100 and 200, (see Table 3.1), the sea surface temperatures increases from 3°C to 7°C, while the waters become depleted in nitrate. During the bloom period the temperature increases, with the almost stable salinity, it indicates that the bloom caused mainly by heating. It is evidence to be the same result obtained from (Olsen et al., 2003). The lowest concentration of nitrate is found during period between days 200 and 250 (see Table 3.1), this is the post-bloom period, because most of the nutrients, including nitrate, have been consumed by phytoplankton during the bloom period. After day 250, we move to the fall situation, which will finally tend to the winter situation.

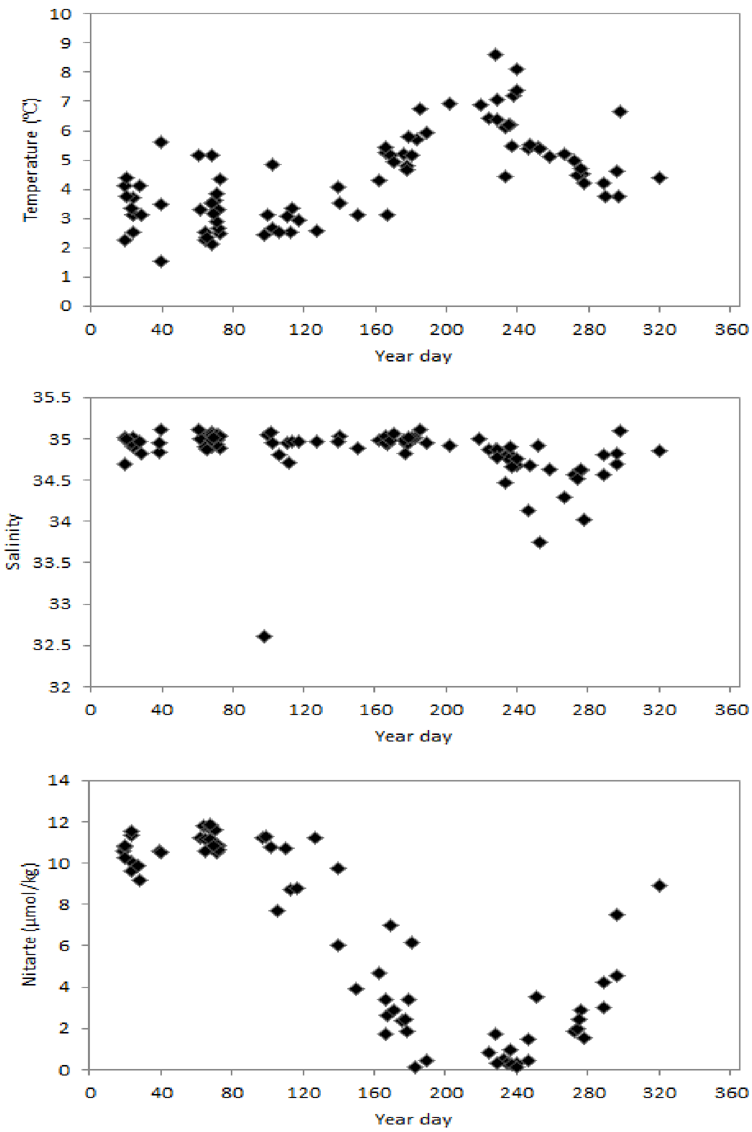


FIGURE 3.1: The average temperature, salinity and concentration of nitrate in the upper 10 m in the outer part of the Fugløya-Bjørnøya transect versus the year day.

The average value of salinity in the outer part during the bloom period is about 35 indicate that this water mass of Atlantic Water. Despite of during the post-bloom period appears two water masses, Atlantic Water and Polar Water are dominant in this period. In one year we observe salinity as low as 32.6. This is may be due to Polar Water.

Middle Part

The seasonal cycles of average temperature, salinity, and concentration of nitrate in the middle part of Fugløya-Bjørnøya transect are shown in (Figure 3.2) where the average of data from the middle stations for different cruises for all years have been combined on a single time axis. The temperature and nutrient concentrations in the middle part of Fugløya-Bjørnøya show obvious and higher repeated seasonal cycle. Up till day 127, the winter situation prevails and the water column homogenous while salinity average around 35.0. In this part of the Fugløya-Bjørnøya transect days 127 appears to demark the start of the spring bloom (see Table 3.1), and until day 200 the surface waters warm from 2.6°C to 7.0°C, while concentrations of nitrate drop from 10.0 to 4.7 μmol/kg. And through the bloom period there appears to be an overall slight decline in salinity and quite low values, down to 34.6 have been encountered in the post bloom phase, which we define as occurring between day 200 and 250 (see Table 3.1). The salinity average in the middle part is about 34.9 referred to Atlantic Water.

Inner Part

The seasonal cycle of average temperature, salinity, and concentration of nitrate in the inner part of Fugløya-Bjørnøya transect are shown in (Figure 3.3) where the average of data from the inner stations for different cruises for all years have been combined on a single time axis. The temperature and nitrate show a clear seasonal cycle as depicted in (Figure 3.3). Up until year day 140 the winter situation prevails, also we can see high values of salinity around 34.5 and nitrate around 10 μmol/kg. Days 140 to 200 demark the spring bloom, and the temperature increases, with quite stable in the salinity while nitrate increases (see Table 3.1). The period between days 200 to 250 is recognized as post-bloom period, with nitrate around 0.02 to 0.5 μmol/kg. We can see appreciably high temperatures compare to the bloom period in the three parts. Also we can observe considerably low concentration of nitrate in the post-bloom period is caused by phytoplankton productivity. The salinity in the post-bloom period is relatively low. This is perhaps due the high amounts of Coastal Water.

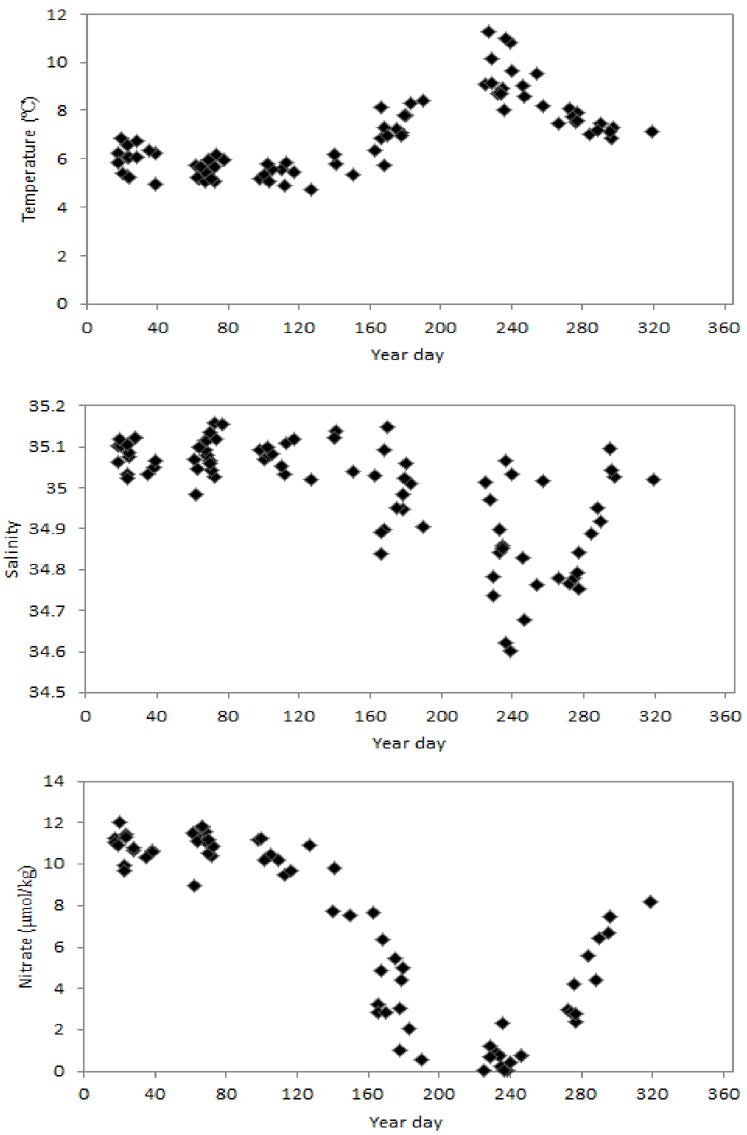


FIGURE 3.2: The average temperature, salinity and concentration of nitrate in the upper 10 m in the middle part of the Fugløya-Bjørnøya transect versus the year day.

Shortly after days 250, the fall situation prevails, in this period we can see noticeable decreases in temperature and increasing of nitrate concentration. We can summarize sequences of seasonality of three parts in Fugløya Bjørnøya transect, the bloom started in the outer part earlier than in middle part, and in the middle part earlier than in inner part with a little bit different in the mean values of temperature, salinity, and nitrate. The post-bloom sets in all parts almost at same time period. From the salinity average about 34.5 (see Figure 3.3), we can infer that water mass is referred to Norwegian Coastal Water.

Finally, in the outer part the bloom is supported by increasing up of temperature. Also the bloom in the middle part is supported by increasing of temperature and

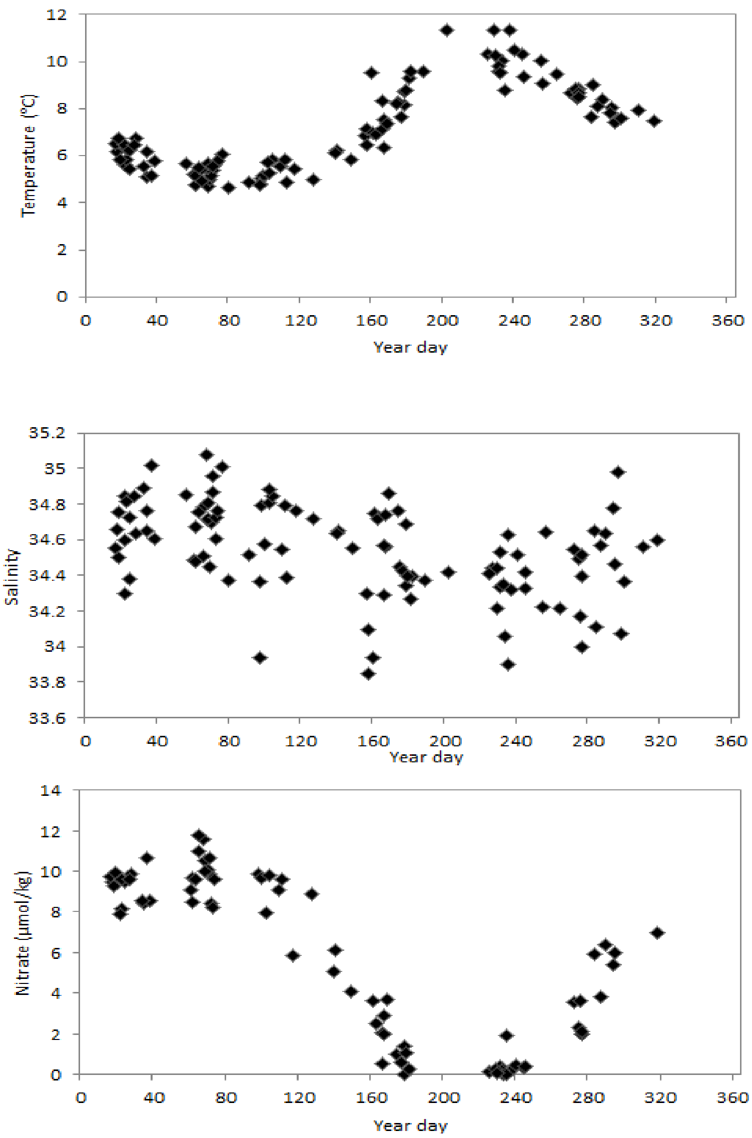


FIGURE 3.3: The average temperature, salinity and concentration of nitrate in the upper 10 m in the inner part of the Fugløya-Bjørnøya transect versus the year day.

also is affected by decreasing of salinity due to amounts of coastal water. The bloom in the inner part is supported by increasing of the temperature.

TABLE 3.1: Bloom and post-bloom periods at the three parts of Fugløya-Bjørnøya transect.

Parts	Bloom	Post–bloom
Outer	100 – 200	200 – 250
Middle	127 – 200	200 – 250
Inner	140 – 200	200 – 250

3.1.2 Interannual Variability at the Fugløya-Bjørnøya Transect

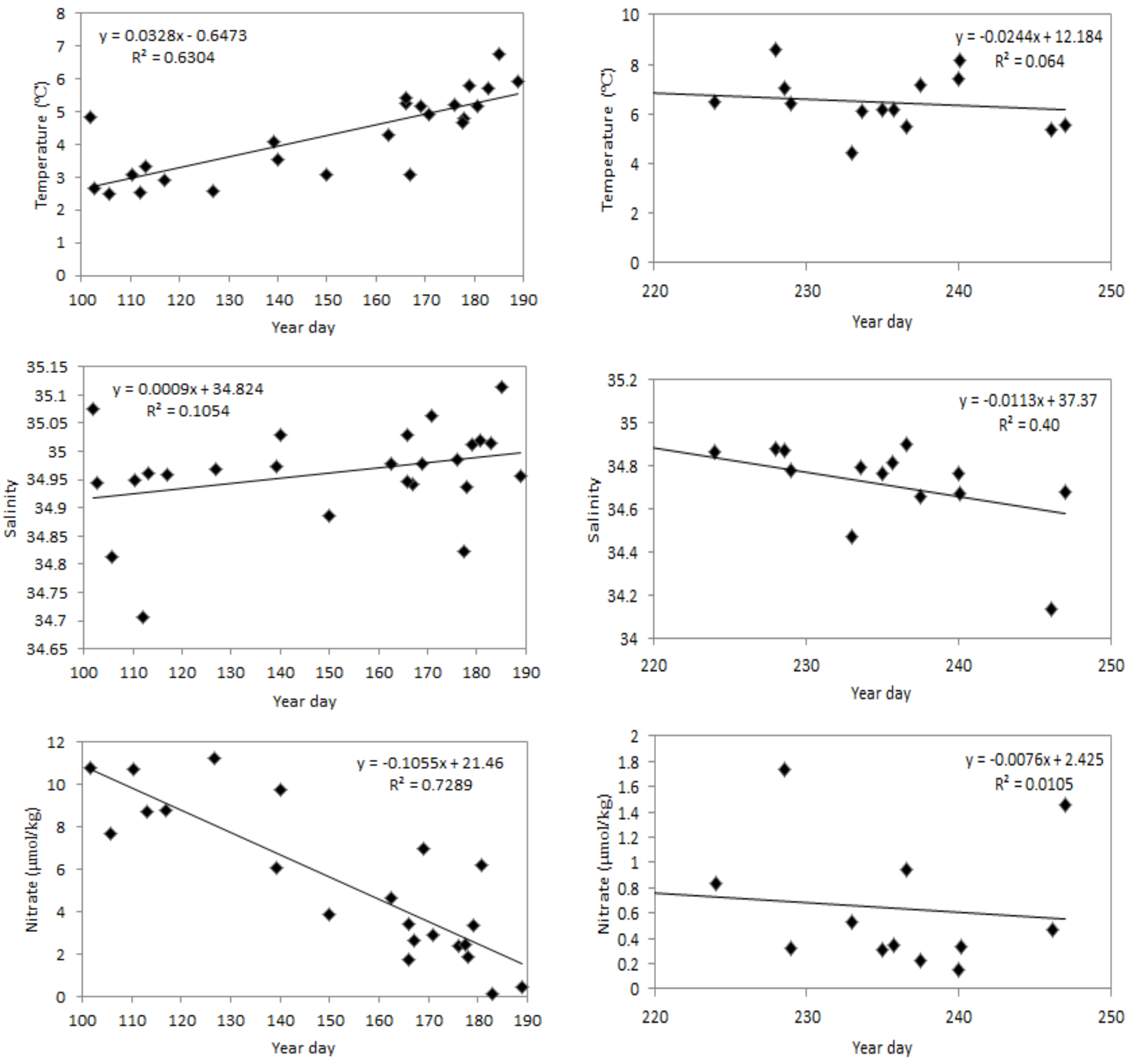
Outer Part

Hydrography and Nutrients Versus Year Day

We can see from (Figure 3.4a), in the outer part of Fugløya–Bjørnøya transect, the concentration of nitrate versus year has decreases systematically with strong correlation 0.73 during the bloom period. This indicates that the growing of bloom has increased regularly along the year. From (Figure 3.4a), it can be seen high correlation between the temperatures versus the year day is equal to 0.63 during the bloom period. This indicates that the temperature increases to create conditions suitable for growth of the phytoplankton bloom, and the bloom depends on heating. At the end, from (Figure 3.4a), the correlation of salinity versus the year day does not show any relation; result of weak correlation is equal to 0.1 in the bloom period. In view of post-bloom period in (Figure 3.4b), we find moderate correlation 0.4 of the salinity versus year day in the outer part. But the temperature and the nitrate do not show correlation 0.06 and 0.01 respectively.

Temperature and Salinity Versus Nitrate

Figure 3.5 represents the correlation of nitrate versus the sea surface temperature (SST), and the sea surface salinity (SSS) during the bloom (a) and post-bloom (b) period. At the beginning, in the outer part, we can observe there is moderate relation 0.41 between the (SST) and nitrate concentration. This makes sense that temperature has caused the bloom at this time. Furthermore, the correlation between (SSS) with nitrate concentration is non-exist, 0.0063, during the bloom period (see Figure 3.5a). Afterwards in the post-bloom period (see Figure 3.5b) the relationship is non-exist, 0.063, between the nitrate and (SSS), but straight away with (SST) and the nitrate can be seen as poor correlation equal to 0.2.



(a) (b)

FIGURE 3.4: The correlations of average temperature, salinity and nitrate respectively during the (a) bloom and (b) post-bloom periods versus year day in the outer part of Fugløya-Bjørnøya transect.

Middle Part

Hydrography and Nutrients Versus Year Day

In the middle part of Fugløya-Bjørnøya transect, there are strong correlations of nitrate, and temperature versus year day, equal to 0.75 and 0.71, respectively, in the bloom period as shown in (Figure 3.6a). This indicate that, blooming is utilized nitrate and stimulate by temperature (phytoplankton bloom has caused by heating). The salinity correlation versus year day, shown in (Figure 3.6a), is weak, about 0.1 in the bloom period. The post-bloom of the middle part in Fugløya-Bjørnøya transect (see Figure 3.6b) shows that, there are no correlations

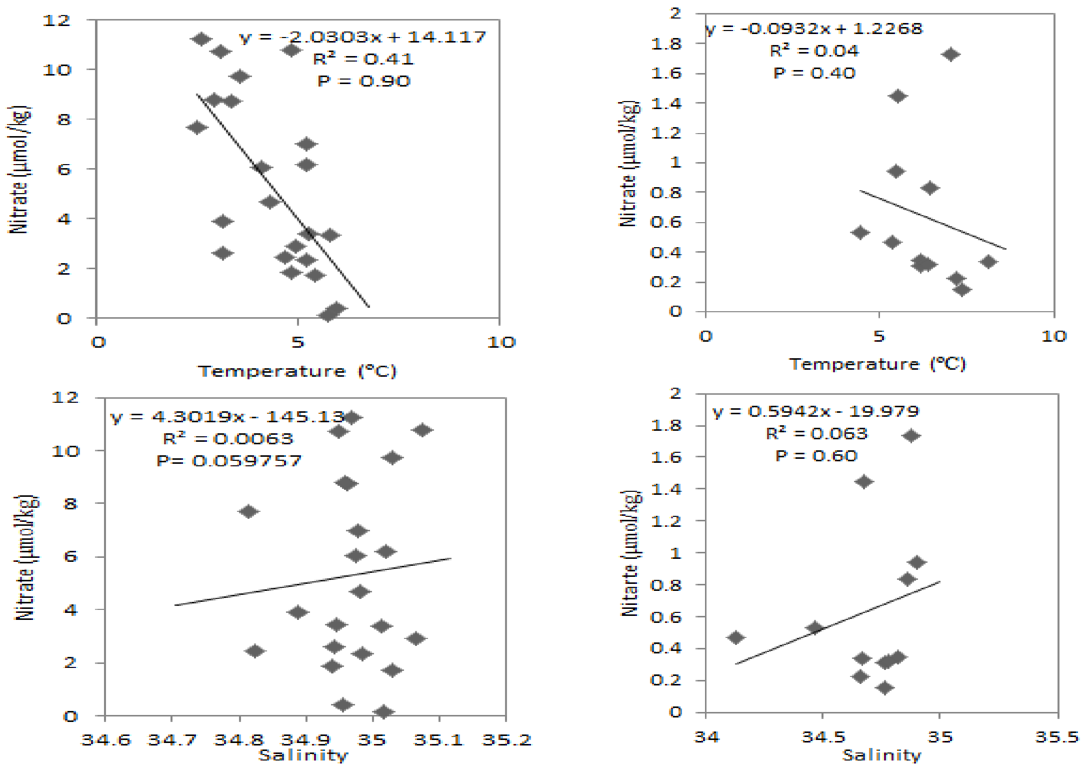
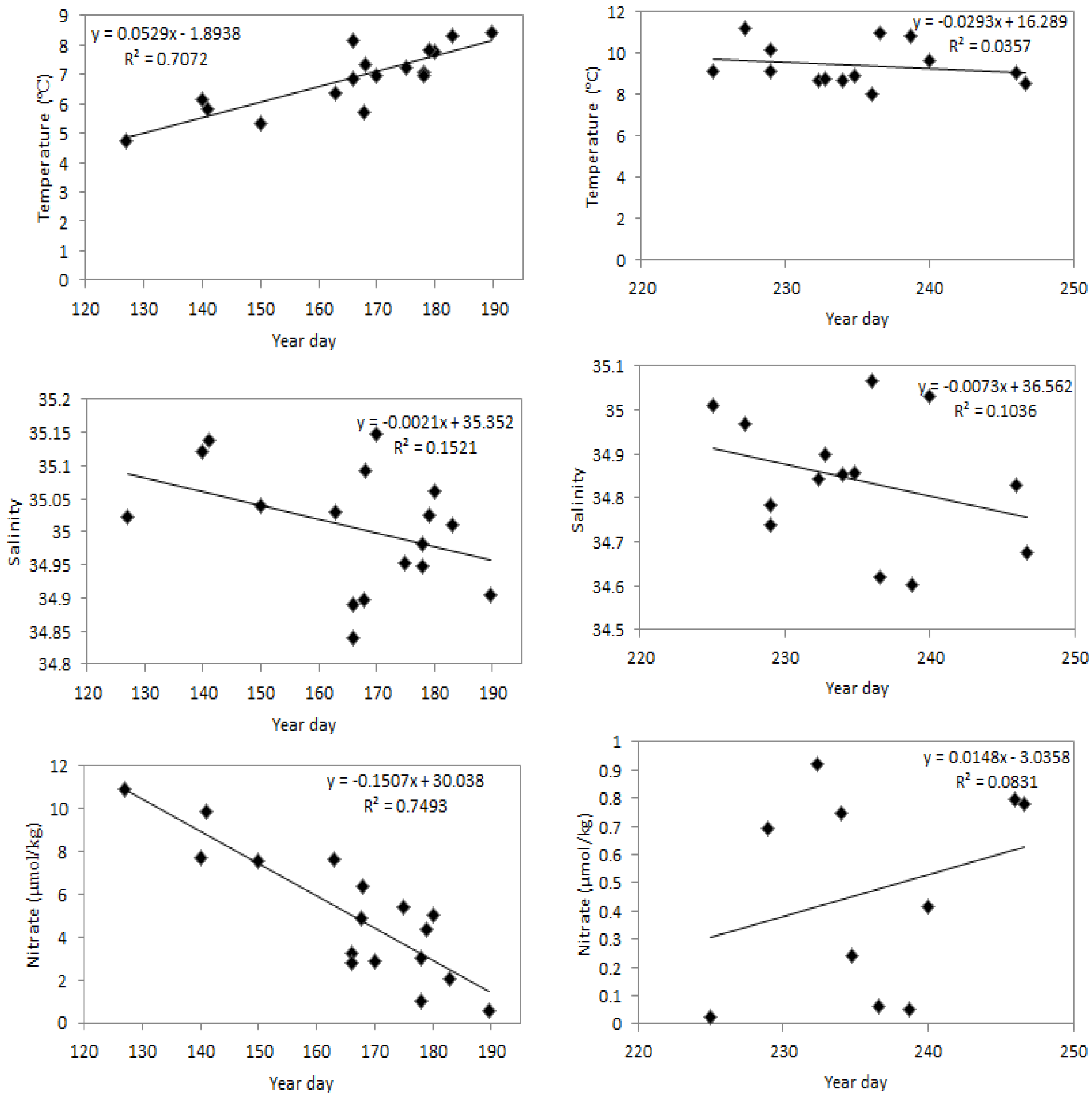


FIGURE 3.5: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the outer part of Fugløya-Bjørnøya transect, at cruises carried out during the bloom (a) and post-bloom (b) periods.

between nitrate, temperature versus year day. while the salinity versus year day (see Figure 3.6b) shows weak correlation.

Temperature and Salinity Versus Nitrate

Figure 3.7 shows correlation of nitrate versus sea surface temperature (SST), and sea surface salinity (SSS) during the bloom (a) and the post-bloom (b) periods. Firstly, from (Figure 3.7a), the correlation between nitrate and (SST) is reasonably good during the bloom period, it reaches about 0.6, this indicate that the heating have caused the bloom. The increased of the sea surface temperature (heating) leads to increase the phytoplankton productivity. This situation result of nitrate depleted by phytoplankton uptake. The correlation of (SSS) versus nitrate (see Figure 3.7b) is poor 0.3, this maybe approve that the bloom is caused by heating instead of freshening is the same as the outer part. The same scenario exactly, appeared between the (SST) and nitrate with correlation approximately 0.5 considerably moderate, associated with heating domination during the post-bloom. The correlation between nitrate and (SSS) were non-exist during the post-bloom period. It is noticed from the results of middle part that heating caused the bloom of phytoplankton.



(a) (b)

FIGURE 3.6: The correlations of average temperature, salinity and nitrate respectively during the (a) bloom and (b) post-bloom periods versus year day in the middle part of Fugløya-Bjørnøya transect.

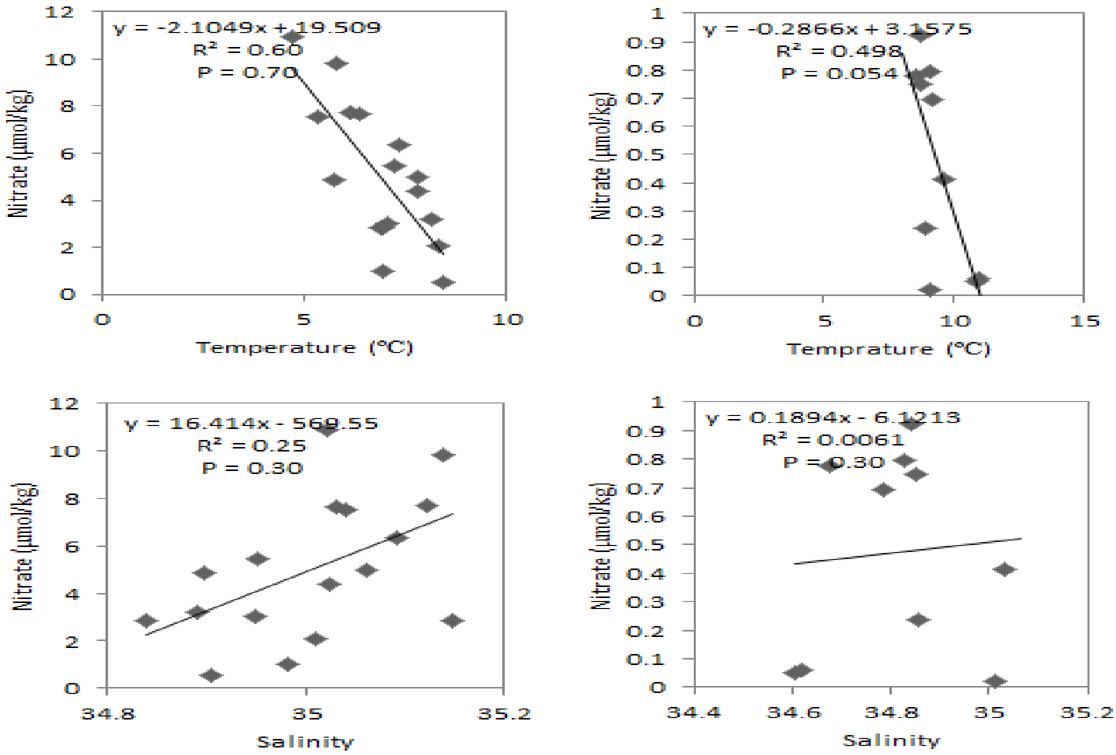


FIGURE 3.7: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the middle part of Fugløya-Bjørnøya transect, at cruises carried out during the bloom (a) and post-bloom (b) periods.

Inner Part

Hydrography and Nutrients Versus Year Day

In order to show what happened in the inner part of Fugløya-Bjørnøya transect. Figure 3.8a, nitrate and temperature show strong correlation versus year day, equal to 0.81, 0.63, respectively. Considering salinity in the inner part of Fugløya-Bjørnøya transect (see Figure 3.8a), its show non-existent correlation versus year day. During the post-bloom period in the inner part of Fugløya-Bjørnøya transect, weak correlation of Nitrate 0.3, temperature 0.11, respectively versus year day can be observed (see Figure 3.8b). The correlation between salinity and year day (see Figure 3.8b) is non-existent. This is because in the post-bloom the temperature in the highest values and then it is drop down, and nitrate at this time is approximately depleted. It could be concluded that three of the parts in Fugløya-Bjørnøya transect were plotted their hydrographic data versus year day. It should be noted that when temperature have good correlation with days of year that is means the heating is increased through year and make good suitable condition for phytoplankton bloom. Also it means bloom caused by heating. The same with when the nitrate have good correlation with year day that means nitrate has been utilized by phytoplankton bloom to show strong bloom.

Temperature and Salinity Versus Nitrate

The inner part show good correlations of sea surface temperature versus nitrate concentration 0.6, and poor correlation of sea surface salinity versus nitrate concentration 0.23 as shown in (Figure 3.9a). This it can be considered appreciable correlation for the nitrate versus temperature and evident that the heating caused the bloom in this period. during the post-bloom period, (see Figure 3.9b), temperature correlation coefficient with nitrate is poor 0.2, but it is significant. Moreover, we can see very good correlation coefficient of salinity versus nitrate 0.7. This observations indicate that the bloom caused by heating during the bloom in the inner part.

3.2 Gimsøy Transect

3.2.1 Seasonal Cycle at the Gimsøy Transect

Outer Part

The seasonal development of temperature, salinity and nitrate at the outer part of the Gimsøy transect shown in (Figure 3.10). Only few data have been collected, (see Figure 2.3b), covering for the most part the time periods until the post bloom phase. This is because the Gimsøy transect is normally cut short at 70.41°N, whereas we start this part at 68.4°N. Until day 120 a winter situation prevails, with salinity quite stable at values normally above 35.1 are high, indicating the presence of Atlantic Water. Nitrate concentrations 10 μmol/kg. Over the time period from day 120 to 185, (see Table 3.2) the surface temperatures increase by almost 6 degrees, from 6°C to 12°C, while the waters become depleted in nitrate. From the few data that exits in this region, the post-bloom period appears to be limited to within days 185 and 250, (see Table 3.2). The surface waters are depleted of nitrate in this time period, and in some years, lower salinities are

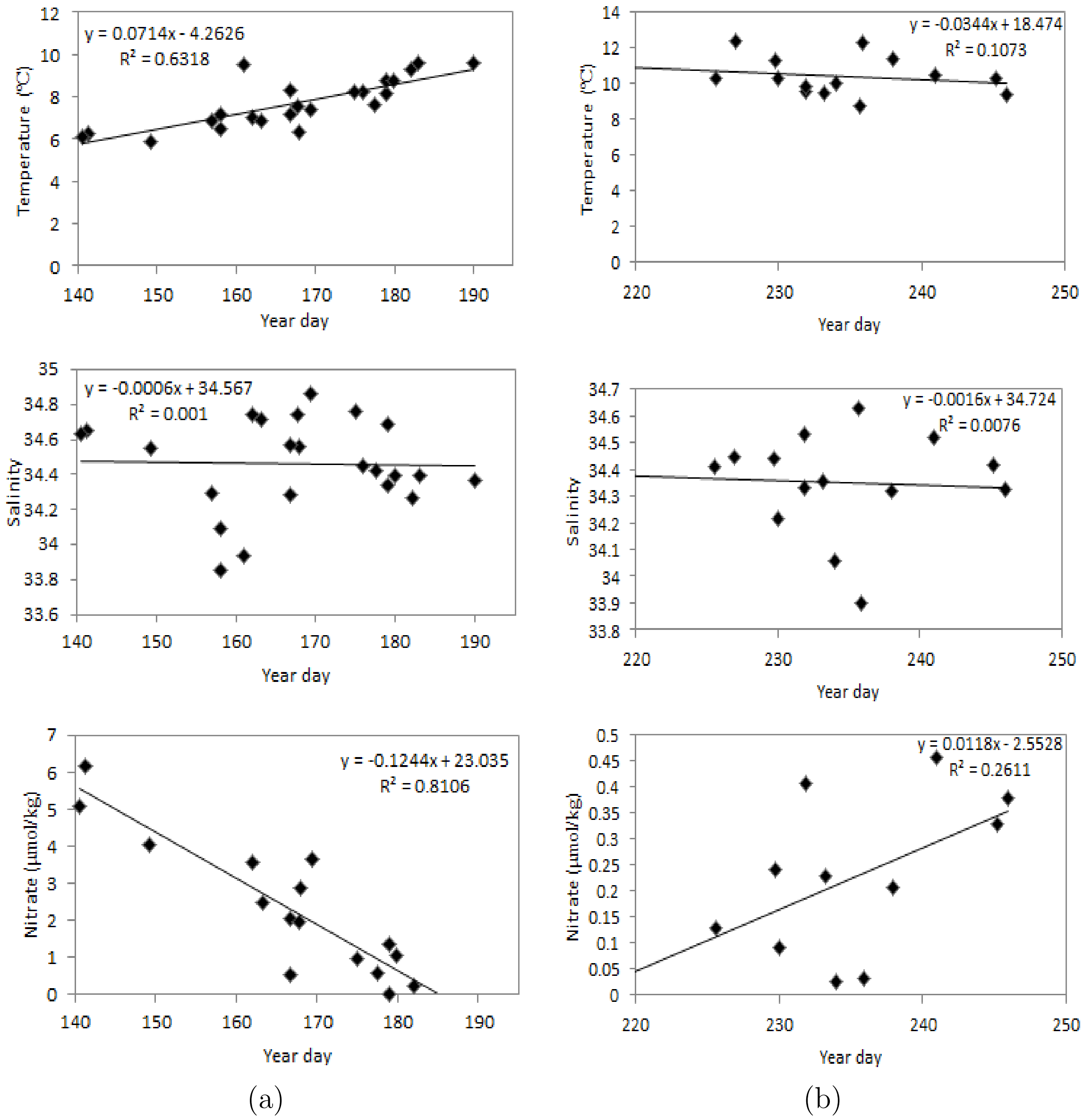
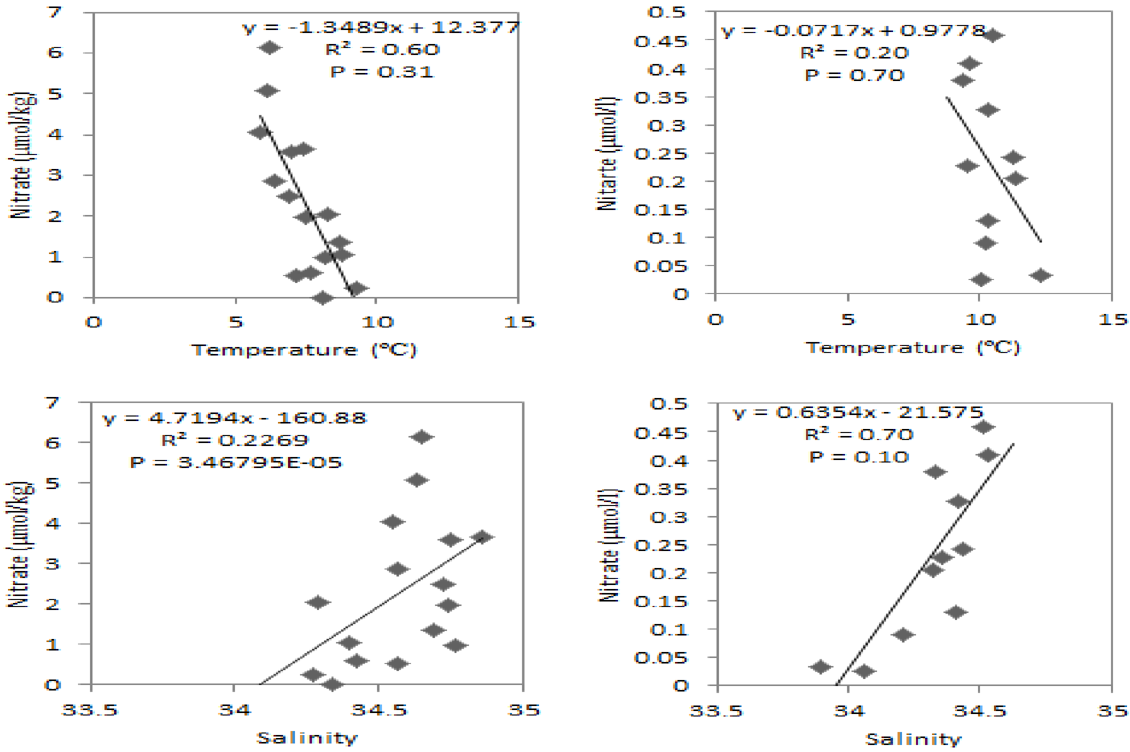


FIGURE 3.8: The correlations of average nitrate, temperature, and salinity respectively during the (a) bloom and (b) post-bloom periods versus year day in the inner part of Fugløya-Bjørnøya transect.

observed, indicating the presence of lower salinity Arctic Water. The bloom has induced by the heating over the outer part. The average value of salinity of 35.0 indicate that this water mass is Atlantic Water.

Middle

The seasonal development of average temperature, salinity and concentration of nitrate in the middle part of Gimsøy transect are shown in (Figure 3.11). Also in this part of the Gimsøy transect, day 120 appears to demark the start of the spring



(a) (b)

FIGURE 3.9: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the inner part of Fugløya-Bjørnøya transect, at cruises carried out during the bloom (a) and post-bloom (b) periods.

bloom, and until day 180, (see Table 3.2) the surface waters warms from about 6.4°C to 9.3°C, while concentrations of nitrate drops from about 8.8 μmol/kg to 1.1 μmol/kg. In one year salinity drops below 35 in winter, maybe due to the coastal water, and through the bloom period there appears to be an overall slight decline in salinity and quite low values, down to 34.5 have been encountered in the post bloom period, which we define as occurring between day 180 and 250, (see Table 3.2).

In one year we observe salinity as low as 33.2. This is maybe due the coastal water. Nutrients are not typically depleted in the post-bloom phase, nitrate concentrations seem to lie between 0 and almost 2 μmol/kg (see Figure 3.11), there is no any consequence between the salinity and temperature versus the nitrate during the post-bloom period. These explain that bloom has caused by heating also in this part. The average salinity value about 34.9 is referred as the Atlantic Water but in some years is below 34.7 might be due to the coastal water.

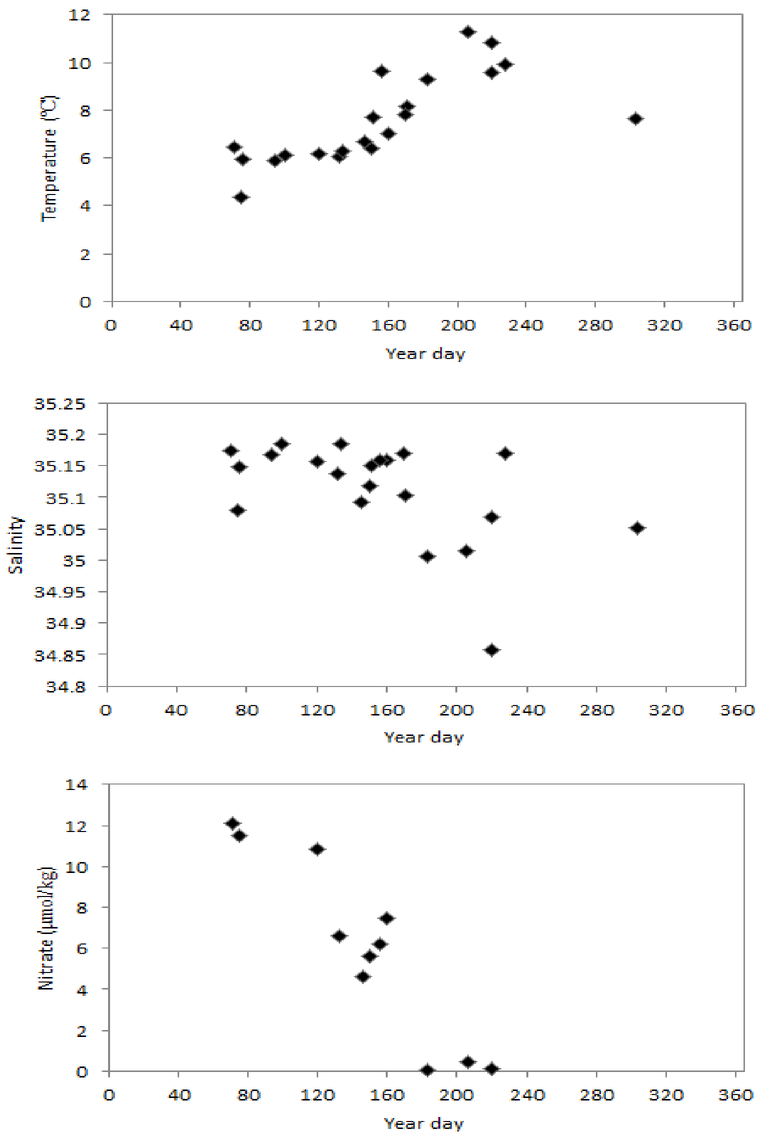


FIGURE 3.10: The average temperature, salinity and concentration of nitrate in the upper 10 m in the outer part of the Gimsøy transect versus the year day.

Inner Part

The seasonal development of average temperature, salinity and concentration of nitrate in the inner part of Gimsøy transect are showon in (Figure 3.12), where the average of hydrographic data have been taken from the inner stations for different cruises for all years and been combined on a single time axis. The temperature and nitrate show a clear seasonal cycle, illustrated in (Figure 3.12). Up until day 120 the winter state prevails with low temperature and high nutrients concentration. This is followed the spring bloom period between days 120 and 190, (see Table 3.2), when temperature rise and the nutrient concentrations begin to decrease. The rising temperatures and the stable salinity reveal that heating is the main mechanism causing the stratification of the water column that triggers the bloom (Sverdrup, 1953). As depicted in (Table 3.2), between days 190 and 250, there is a post-bloom period when the nitrate concentrations are very low. After day 250, temperatures again begin to decrease and the nutrient concentrations increase, because in this time might be there is a high amount of run-off water come from fjord and at the same time nutrient comes from vertical mixing as it moves into the fall and winter situation. Early in the fall the salinities are lower than during the rest of the year. This is explaining by high runoff water from fjords. From the salinity average about 34.0, (see Figure 3.12), we can infer that water mass is Norwegian Coastal Water.

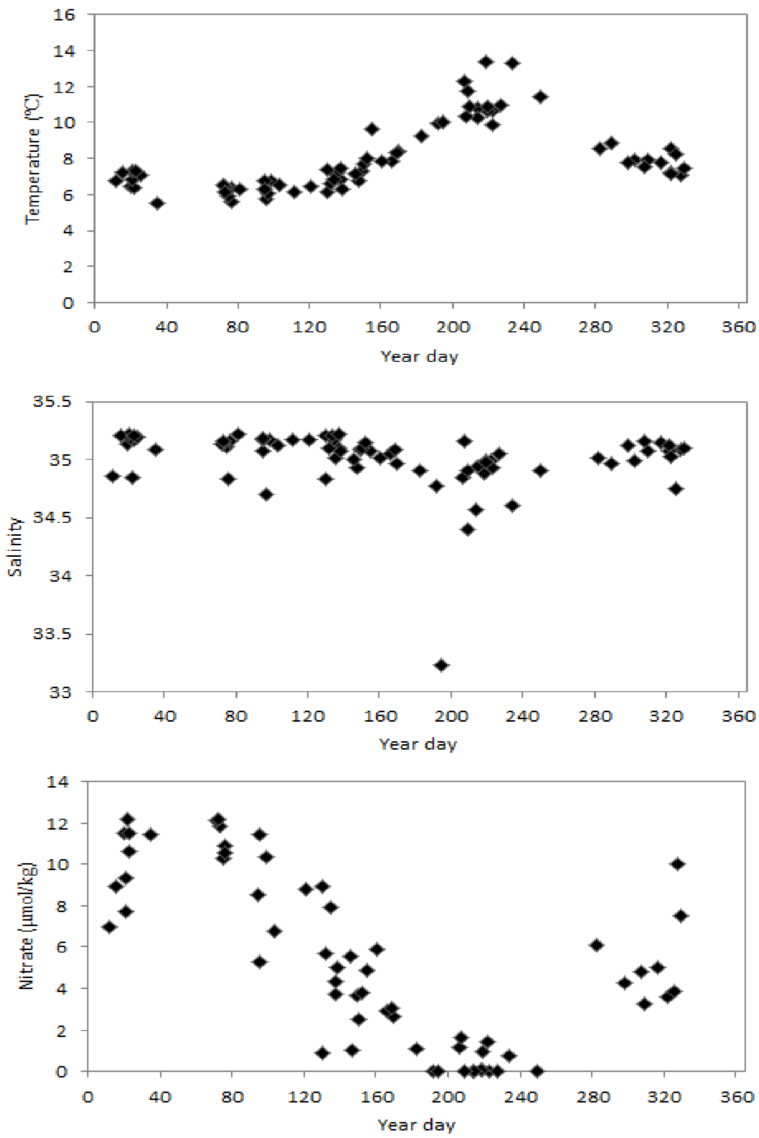


Figure 3.11: The average temperature, salinity and concentration of nitrate in the upper 10 m in the middle part of the Gimsøy transect versus the year day.

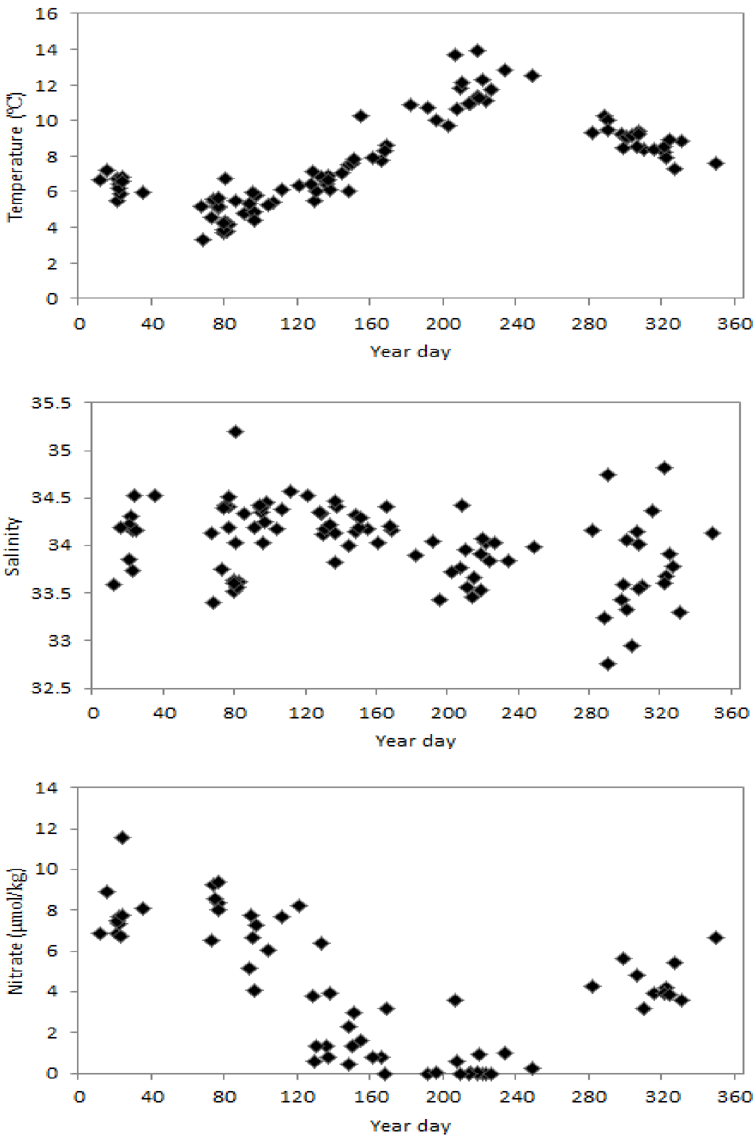


FIGURE 3.12: The average of temperature, salinity and concentration of nitrate in the upper 10 m in the inner part of the Gimsøy transect versus the year day.

TABLE 3.2: Bloom and post-bloom periods at the three parts of Gimsøy transect.

Parts	Bloom	Post–bloom
Outer	120 – 185	185 – 250
Middle	120 – 180	180 – 250
Inner	120 – 190	190 – 250

3.2.2 Interannual Variability at the Gimsøy Transect

Outer Part

Hydrography and Nutrients Versus Year Day

Figure 3.13 shows the hydrographic and nutrients data versus year day. during the bloom period (a) there is no obvious relationship between the hydrographic data and year day, also during the post-bloom (b) is similar. This is may be due to many factors, including eddies effect on the distribution of the nutrients and temperature at the sea surface (Andersson et al., 2011). This is explain why we got unsystematically changes between year day with temperature, nitrate and salinity respectively during the bloom (see Figure 3.13a) and post-bloom (see Figure 3.13b) periods. Also there is no enough data to make complete analysis.

Temperature and Salinity Versus Nitrate

Figure 3.14, do not show correlation of temperature versus nitrate during the bloom period while salinity versus nitrate show reasonably correlation about 0.5 (see Figure 3.14a). During the post-bloom period the temperature versus nitrate show strong correlation compared with salinity do not show correlation (see Figure 3.14b). At the end, it is difficult to conclude that bloom caused by freshening, whereas the further development into the post-bloom phase appears controlled by heating. Also there is no enough data to make complete analysis.

Middle Part

Hydrography and Nutrients Versus Year Day

In the middle part of Gimsøy transect is shown in (Figure 3.15a), we can see good correlation between the temperatures versus year day during the bloom period, indicate that it is increasing progressively from spring into summer due to solar heating of the sea surface. However the salinity do not show any relationship with year day in the middle part of Gimsøy transect during the bloom. And the nitrate shows weak correlation during the bloom. During the post-bloom period in the middle part nitrate, salinity and temperature also do not show any correlation

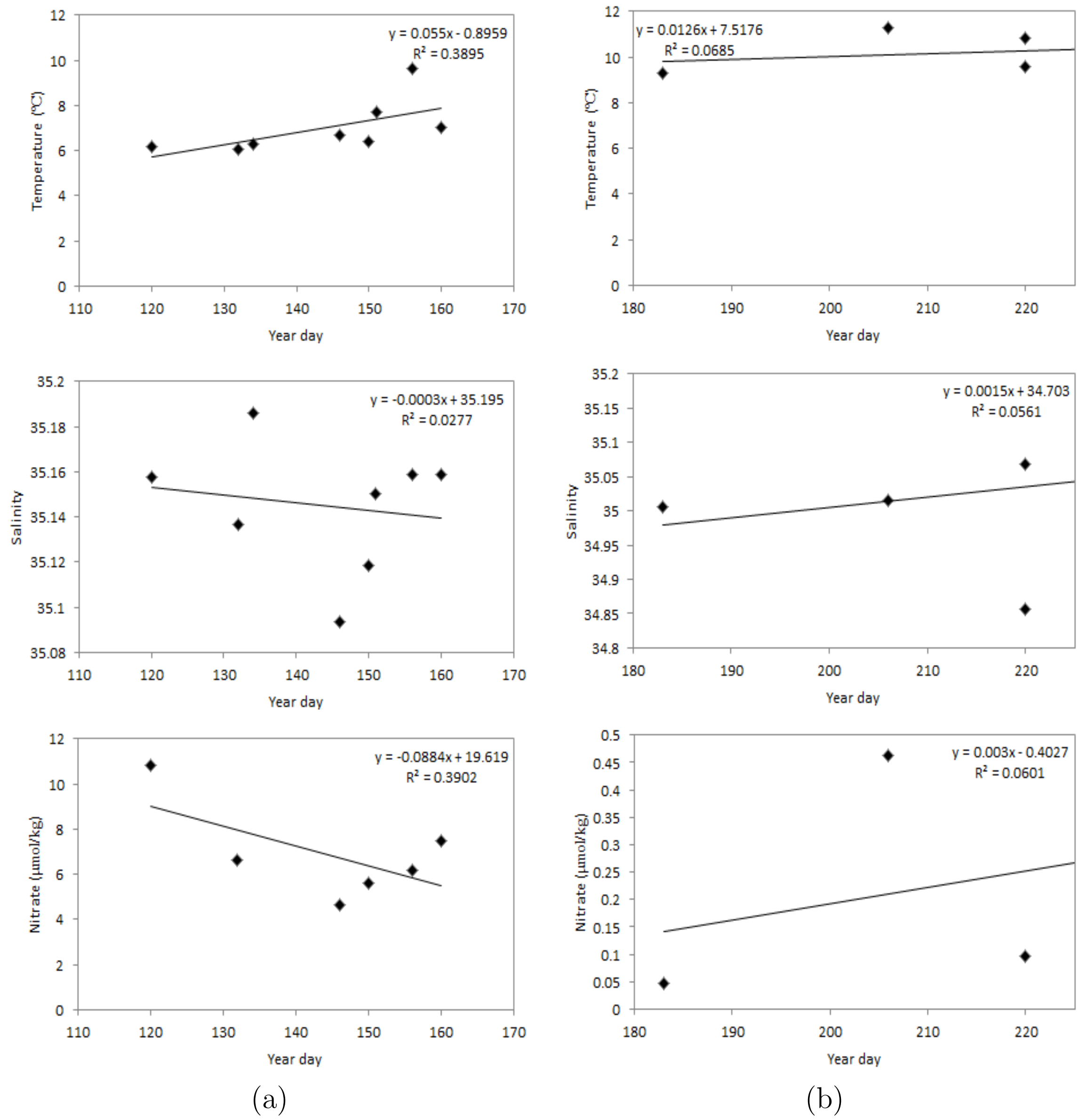
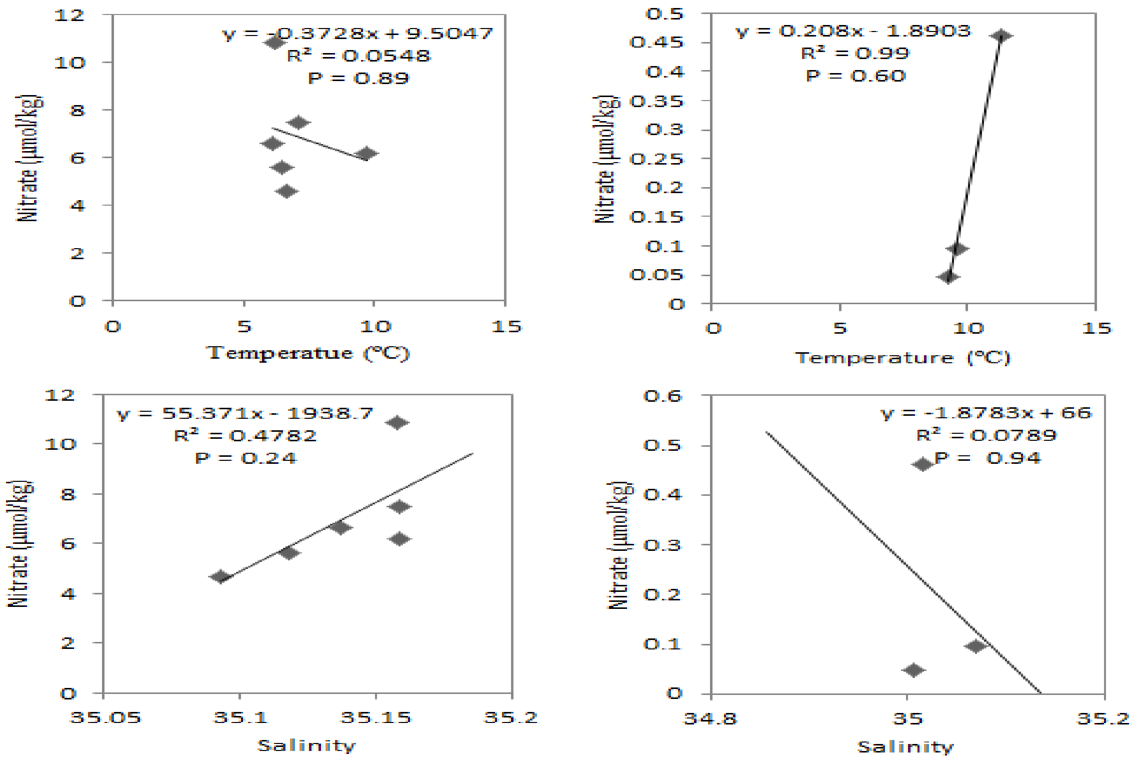


FIGURE 3.13: The correlations of average temperature, salinity and nitrate respectively during the (a) bloom and (b) post-bloom periods versus year day in the outer part of Gimsøy transect.

with year day. this reveals two regimes with high and low values of nitrate during the post-bloom . This might be result of nutrient consumed during the bloom period, and also may be due to high grazing.

Temperature and Salinity Versus Nitrate

Figure 3.16 temperature and nitrate are not correlated during the bloom period. And the nitrate versus the salinity show weak correlation coefficient about 0.44,



(a) (b)

FIGURE 3.14: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the outer part of Gimsøy transect, at cruises carried out during the bloom (a) and post-bloom (b) periods.

(see Figure 3.16a). but during the post-bloom period (see Figure 3.16b) temperature and salinity do not show any correlation. Also there are two regimes of different nitrate concentration might be caused by high grazing.

Inner Part

Hydrography and Nutrients Versus Year Day

In the inner part of Gimsøy transect shown in (Figure 3.17), illustrates the temperature, salinity and nitrate versus year day during the bloom period. The temperature and nitrate versus year day show weak correlation 0.44 and 0.25 respectively during the bloom period (see Figure 3.17a). But the salinity do not show any correlation. Also from (Figure 3.17b) we can see similar scenario of temperature, nitrate and salinity do not display correlation with year day during the post-bloom

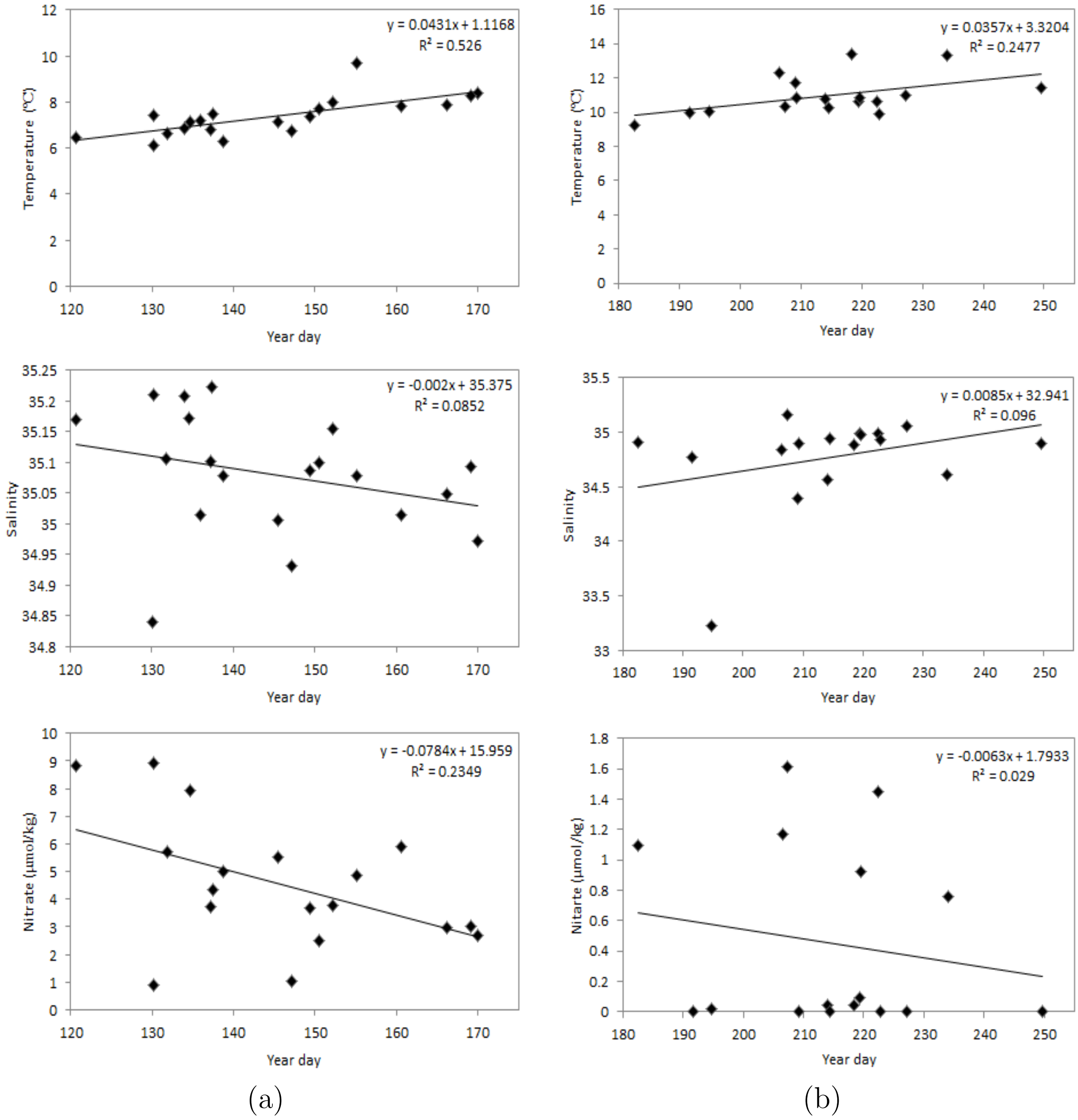


FIGURE 3.15: The correlations of average temperature, salinity and nitrate concentration respectively during the (a) bloom and (b) post-bloom periods versus year day in the middle part of Gimsøy transect.

period. I believe all these observations are results to the presence of eddies (Andersson et al., 2011), which can have an effect on the distribution of nutrient and the temperature along the year and also might be due to grazing.

Temperature and Salinity Versus Nitrate

There is no correlation between temperature, versus nitrate (see Figure 3.18a) during the bloom. And the nitrate versus temperature during post-bloom show

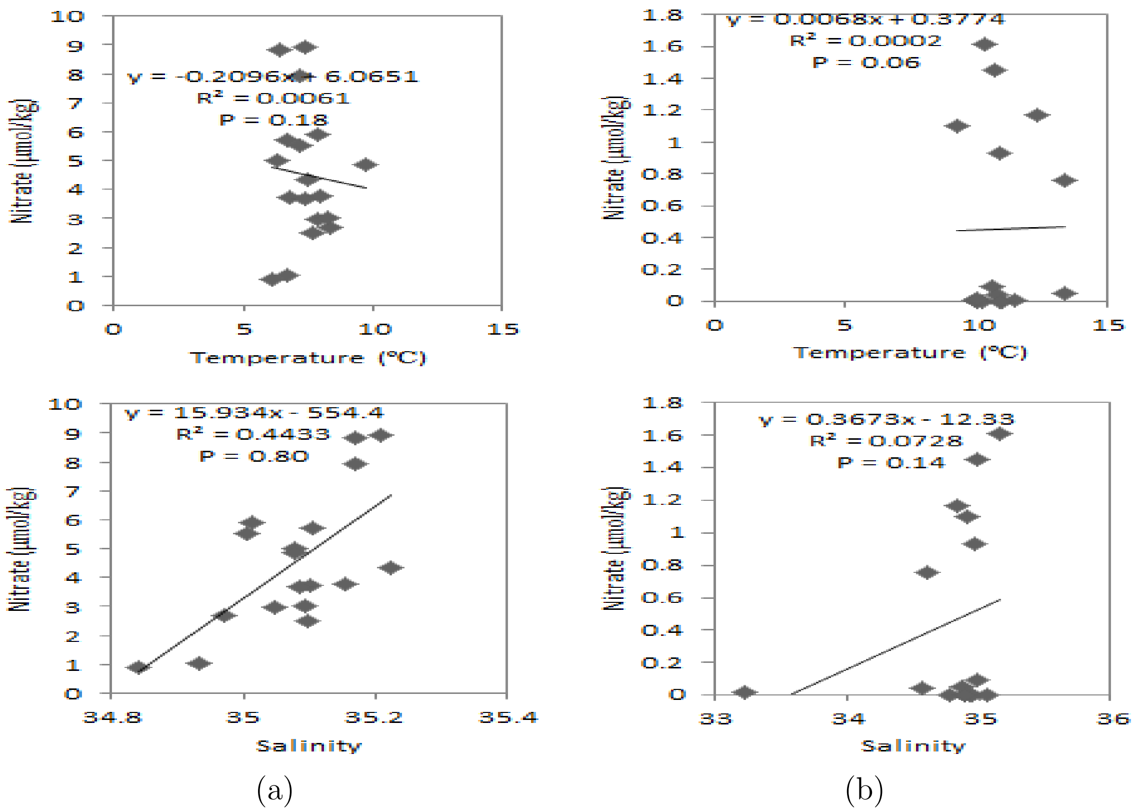


FIGURE 3.16: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the middle part of Gimsøy transect, at cruises carried out during the bloom (a) and post-bloom (b) periods.

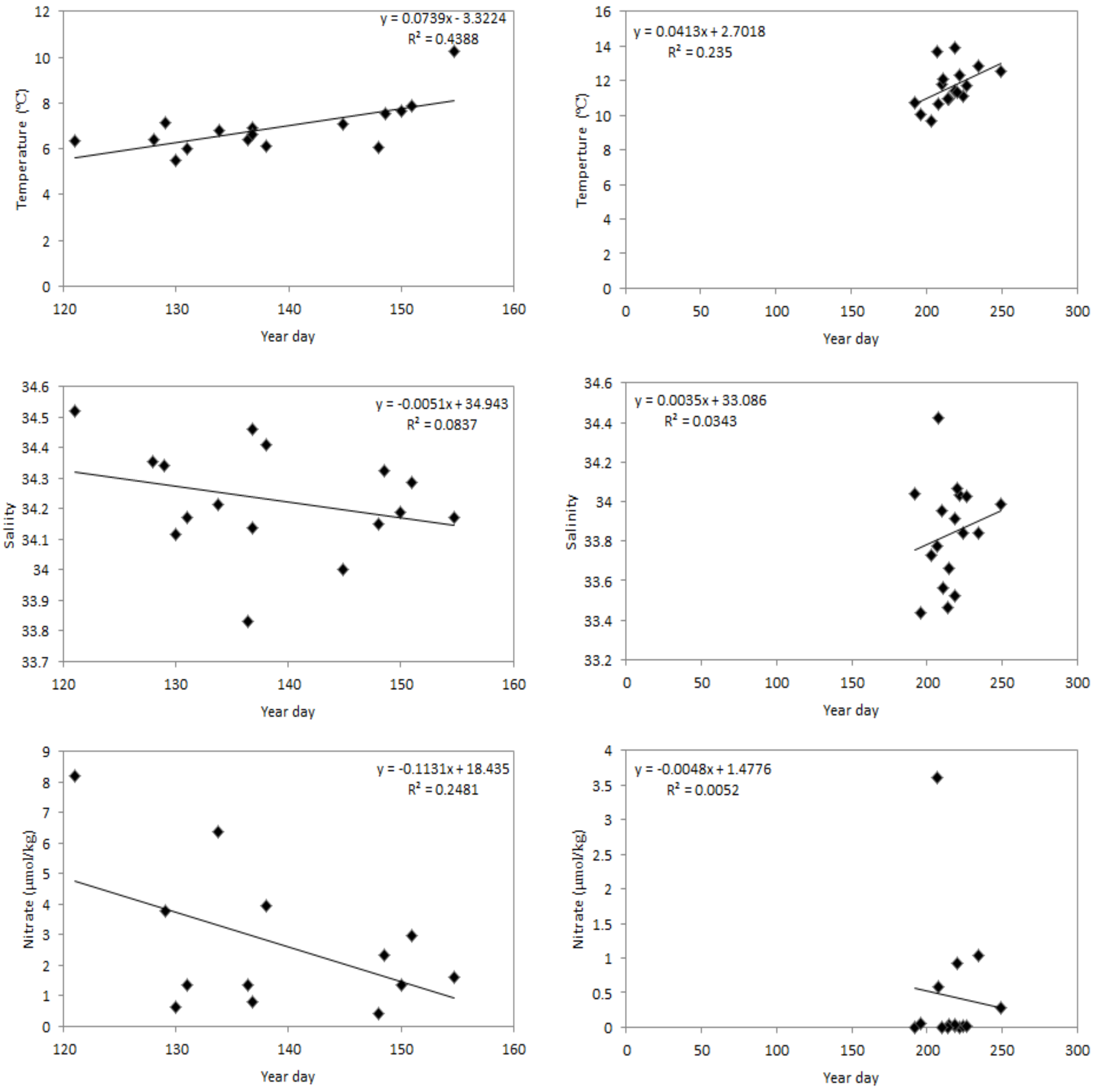
weak correlation 0.25 (see Figure 3.18b). But during the bloom the salinity versus nitrate show weak correlation 0.3. And the nitrate versus salinity during the post-bloom period do not show any correlation. There are some years during the post-bloom display low concentrations of nitrate. This is because almost all the nutrients have been consumed during the bloom period. Finally there is interannual variations but not obvious.

3.3 Svinøy Transect

3.3.1 Seasonal Cycle at the Svinøy Transect

Outer Part

The seasonal development of the temperature, salinity and nitrate shown in (Figure 3.19) at the outer part of the Svinøy transect is located between 64.0°N and



(a) (b)

FIGURE 3.17: The correlations of average temperature, salinity and nitrate respectively during the (a) bloom and (b) post-bloom periods versus year day in the inner part of Gimsøy transect.

64.7°N. The nutrients and temperature show clear seasonal cycle as depicted in (Figure 3.19). Up until day 100 the winter situation prevails with low temperatures around 5.8°C and high nitrate concentrations around 11.9 μmol/kg (see Figure 3.19). This is followed by the spring bloom period (see Table 3.3) between day 100 and day 150 when temperatures rise from 5.4°C to 7.8°C and the nitrate concentrations start to decrease from 11.9 μmol/kg to 5.2 μmol/kg. The rising temperatures and the stable salinity suggest that heating is the main mechanism causing the stratification of the water column that triggers the bloom (Sverdrup, 1953). After day 216, the nitrate concentration was zero. After day 250, the

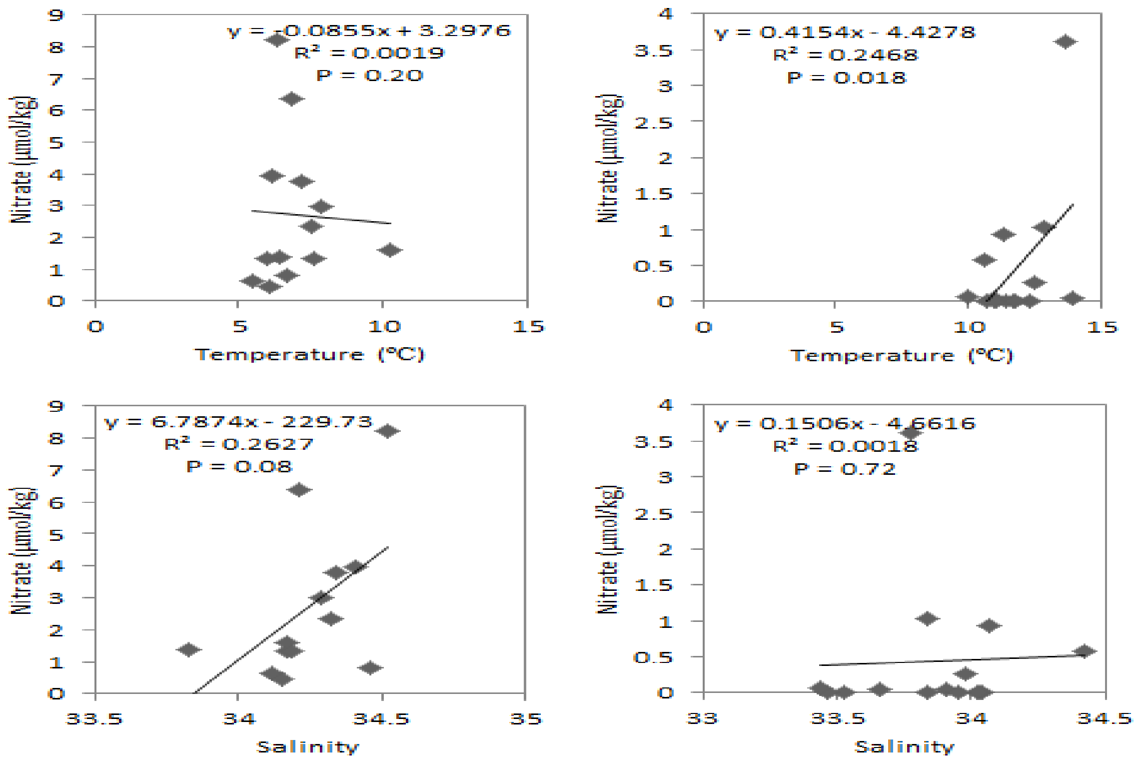


FIGURE 3.18: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the inner part of Gimsøy transect, at cruises carried out during the bloom (a) and post-bloom (b) periods.

temperatures again begin to decrease and the nutrient concentrations increase as we move into the fall and winter state. The salinity average value of about 35.1 dominated by Atlantic Water.

Middle Part

The seasonal cycle development of average temperature, salinity and concentration of nitrate in the middle part of Svinøy transect are shown in (Figure 3.20). The temperature and nutrients show a clear seasonal cycle (see Figure 3.20). Up till day 100 the winter state prevails with low temperature around 6.8°C and nutrient concentrations around 11.5 μmol/kg. This followed the spring bloom period between days 100 to 150 when temperature rise from 7.2°C to 15.0°C and nutrient concentration begin to decrease from 9.9 μmol/kg to 2.2 μmol/kg. The rising of temperature and slow dropping of salinity suggest that the heating are main mechanism caused the stratification of water column that triggers the bloom. Between days 150 to 220 (see Table 3.3), there is a post-bloom when the nutrient concentrations are near zero. there is a clear dropping of salinity during the post-bloom perid. this indicates there is water masses advection from the coastal water with average salinity about 34. After day 220 the temperatures again begin to decrease from 13.6°C to 8.2°C and the nutrient concentrations increase from 2.6 μmol/kg to 10.8 μmol/kg. The salinity average over the middle part as depicted in (Figure 3.20) appears that two water masses found are the Atlantic Water and Coastal Water.

Inner Part

The seasonal cycle of average temperature, salinity and concentration of nitrate in the inner part of Svinøy transect are shown in (Figure 3.21), where the average of data has taken from the inner stations. The temperature and nutrient concentrations show a clear seasonal cycle (see Figure 3.21). Up until day 90 the winter situation has prevailed with low temperatures and high nutrient concentrations. This is followed the spring bloom period between days 90 to 150 (see Table 3.3) when temperature rise and nutrient concentrations begin to decrease. The rising temperatures and the stable salinity suggest that the heating is the main mechanism caused the stratification of the water column that triggers the bloom (Sverdrup, 1953). Between days 150 to 220 there is a post-bloom period when the nutrient concentrations are near to zero. After day 220 the temperatures again begin to decrease and the nutrient concentrations increase as we move into the fall and winter state. Early in the fall the salinities are lower than during the rest of the year. The salinity average value of the seasonal cycle is about 33.5 clearly marking this as Norwegian Coastal Water.

Table 3.3: Bloom and post-bloom periods at the three parts of Svinøy transect.

Parts	Bloom	Post–bloom
Outer	100 – 200	200 – 250
Middle	120 – 150	150 – 220
Inner	90 – 150	150 – 220

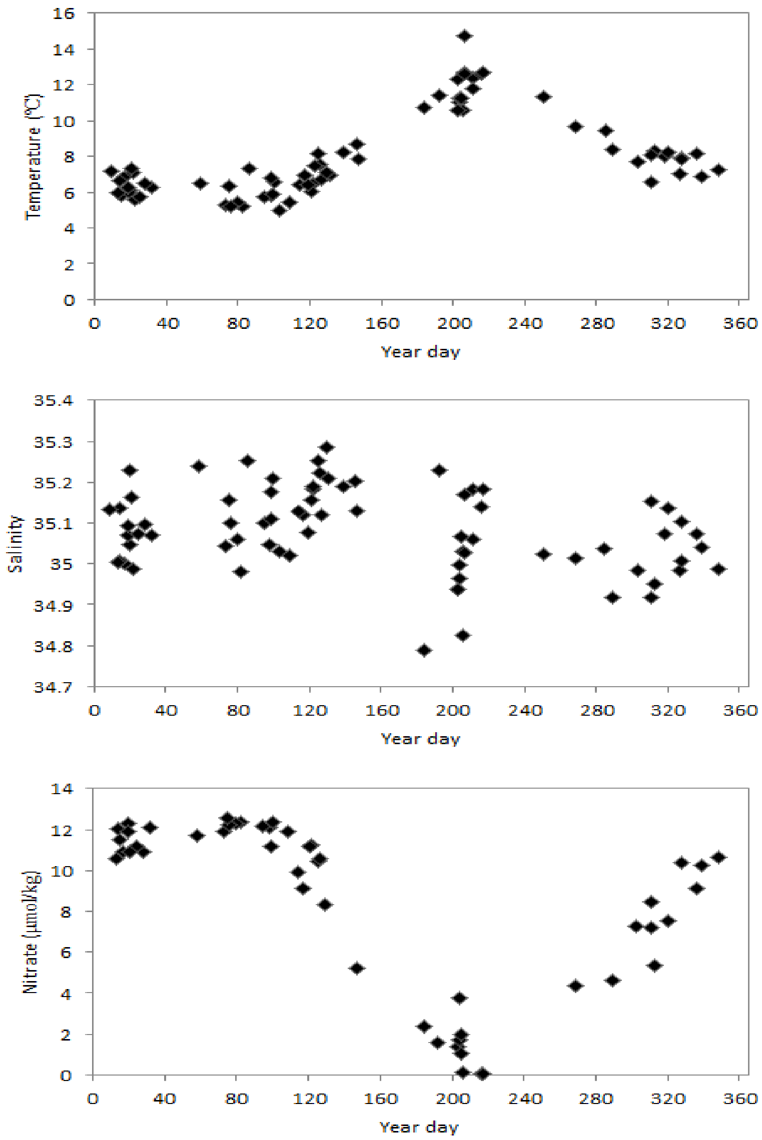


FIGURE 3.19: The average temperature, salinity and concentration of nitrate in the upper 10 m at in the outer part of the Svinøy transect versus the year day.

3.3.2 Interannual Variability at the Svinøy Transect

Outer Part

Hydrography and Nutrients Versus Year Day

Firstly, (Figure 3.22a) shows the temperature, salinity, and nitrate versus year day in the bloom and post-bloom periods. During the bloom the temperature and nitrate show good correlation versus year day. This is consequence with phytoplankton bloom production, indicate that heating has caused the mechanism

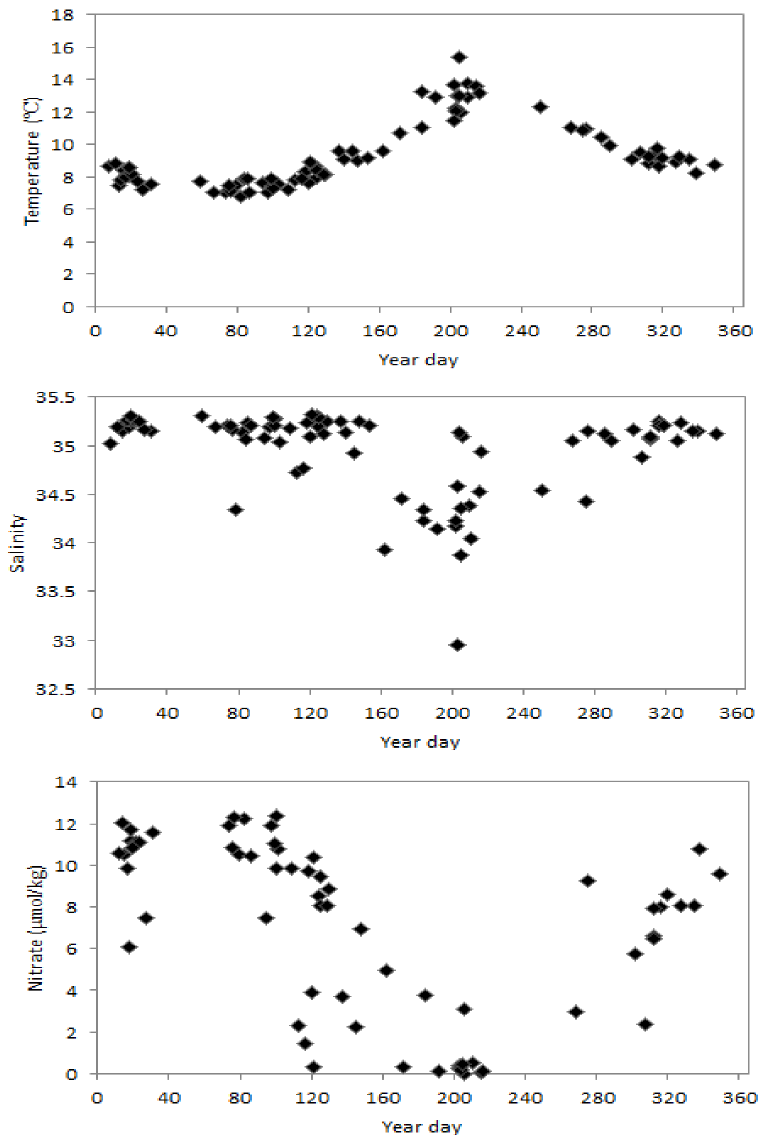


FIGURE 3.20: The average temperature, salinity and concentration of nitrate in the upper 10 m in the middle part of the Svinøy transect versus the year day.

of water stratification. The salinity shows very weak correlation with year day (see Figure 3.22a). This is suggested that there is no mixing between the Atlantic Water and Arctic Water. Moreover in the post-bloom (see Figure 3.22b) the temperature, salinity, and nitrate do not show any relation and this is might be due to low concentration of nutrient.

Temperature and Salinity Versus Nitrate

There is a clear Interannual variation in the nutrient data. The temperature versus nitrate (see Figure 3.23a) shows reasonably good correlation. This suggest that the heating is the main mechanism causing the stratification of water column

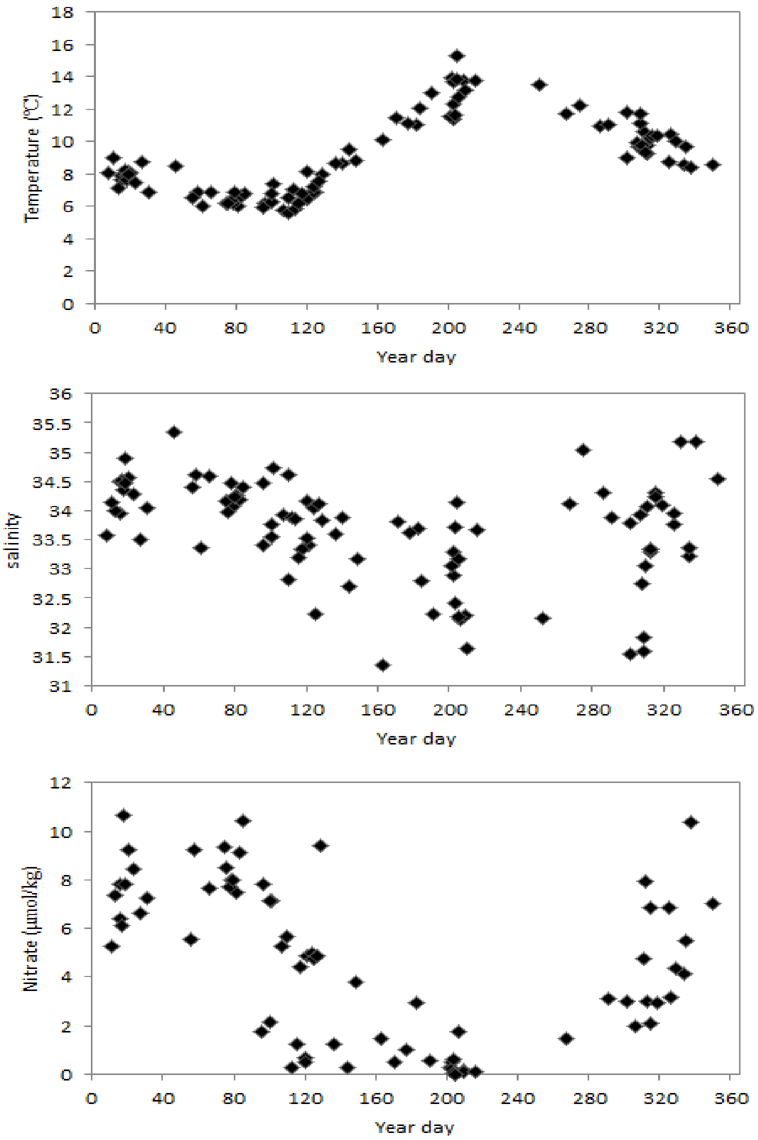


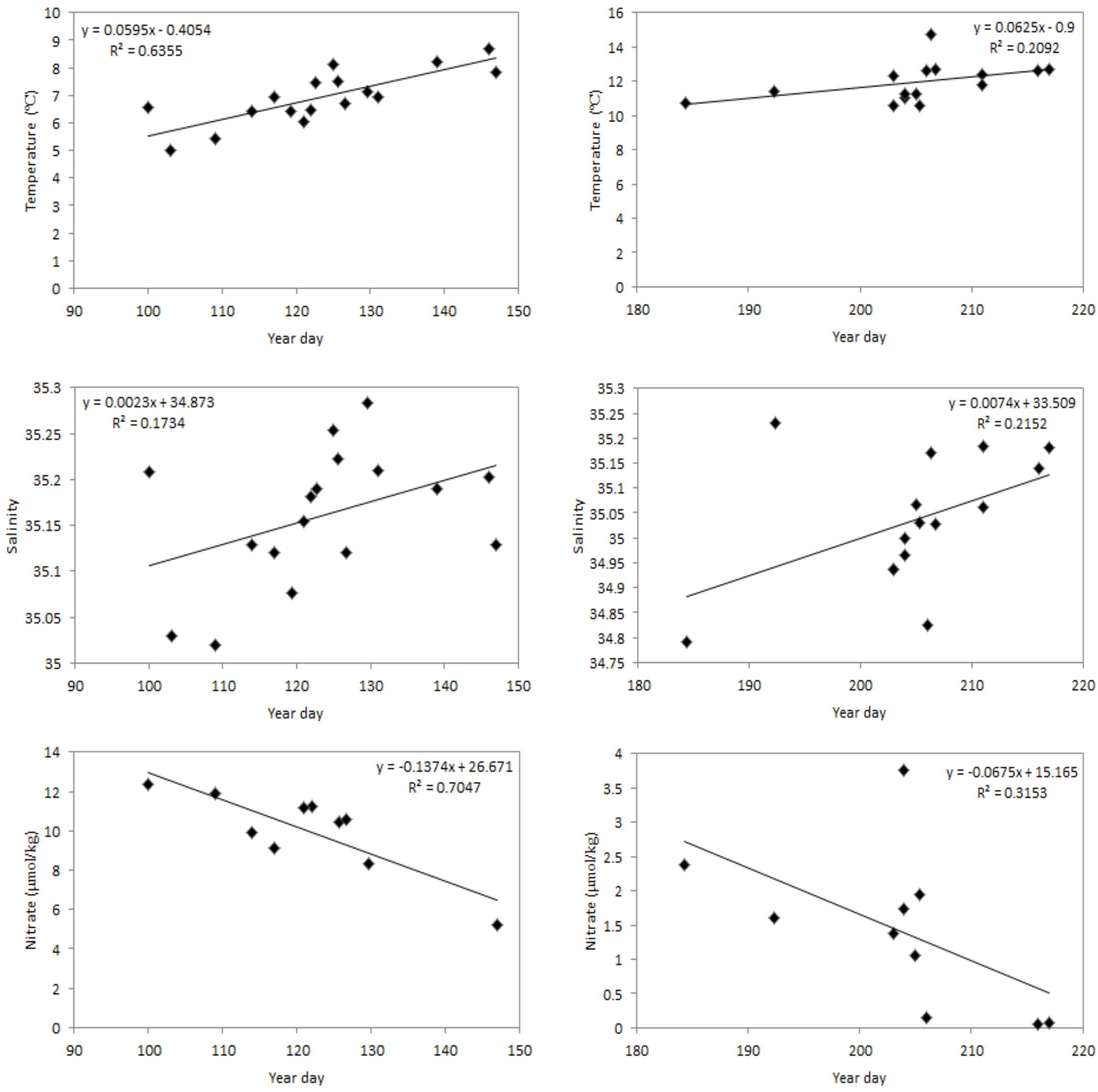
FIGURE 3.21: The average temperature, salinity and concentration of nitrate in the upper 10 m in the inner part of the Svinøy transect versus the year day.

that triggers the bloom. This is followed the post-bloom (see Figure 3.23b) where temperature also shows good correlation established the similar mechanism in the bloom period.

Middle Part

Hydrography and Nutrients Versus Year Day

During the bloom the temperature shows a reasonably good correlation versus year day (see Figure 3.24a) compared with salinity and nitrate do not show any correlation. In addition, the temperature shows also reasonably good correlation



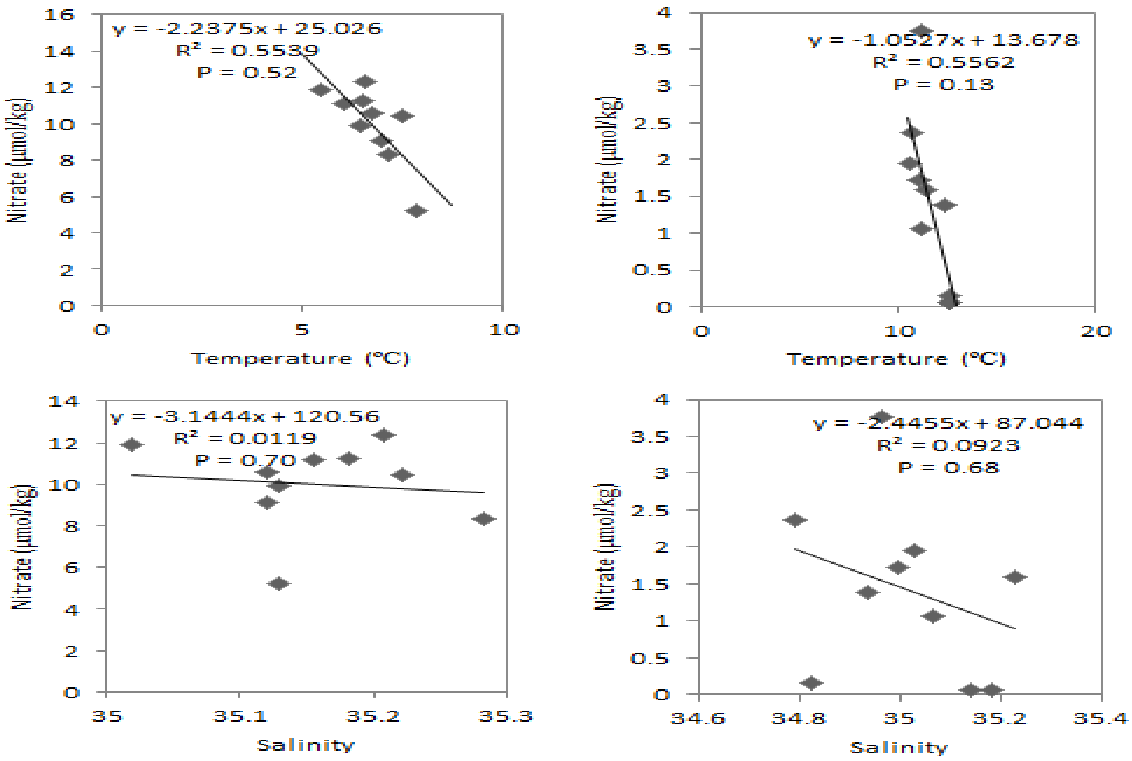
(a) (b)

FIGURE 3.22: The correlations of average temperature, salinity and nitrate respectively in the (a) bloom period and (b) post-bloom periods versus year day in the outer part of Svinøy transect.

in the post-bloom (see Figure 3.24b) compared with salinity and nitrate do not show any correlation. This suggest that heating is main the mechanism causing stratification of the water column that triggers the bloom.

Temperature and Salinity Versus Nitrate

From (Figure 3.25) in the bloom period temperature and salinity show poor correlation versus nitrate (see Figure 3.25a). This indicates that bloom causing by



(a) (b)

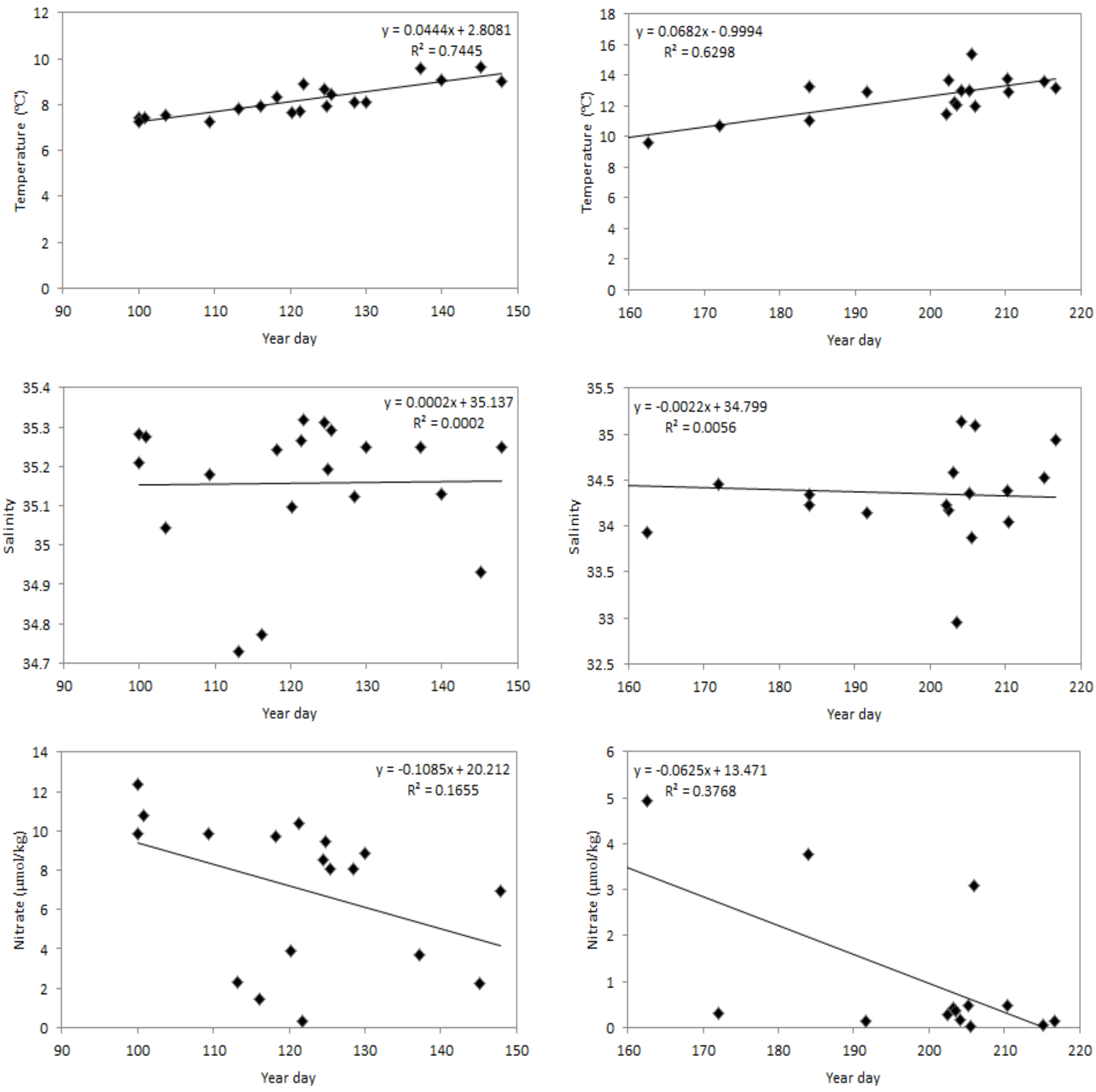
FIGURE 3.23: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the outer part of Svinøy transect transects, at cruises carried out during the bloom (a) and post-bloom (b) periods.

another factor. In the post-bloom period temperature shows good correlation versus nitrate indicates that the bloom inducing by heating (see Figure 3.25b).

Inner Part

Hydrography and Nutrients Versus Year Day

Straight forward as we can be seen from (Figure 3.26a) temperature shows good correlation versus year day, suggest that heating is the main mechanism causing the stratification of water column in the bloom period. This is followed by the post-bloom period (see Figure 3.26b), where the temperature also shows reasonably good correlation versus year day with same mechanism in the bloom period.

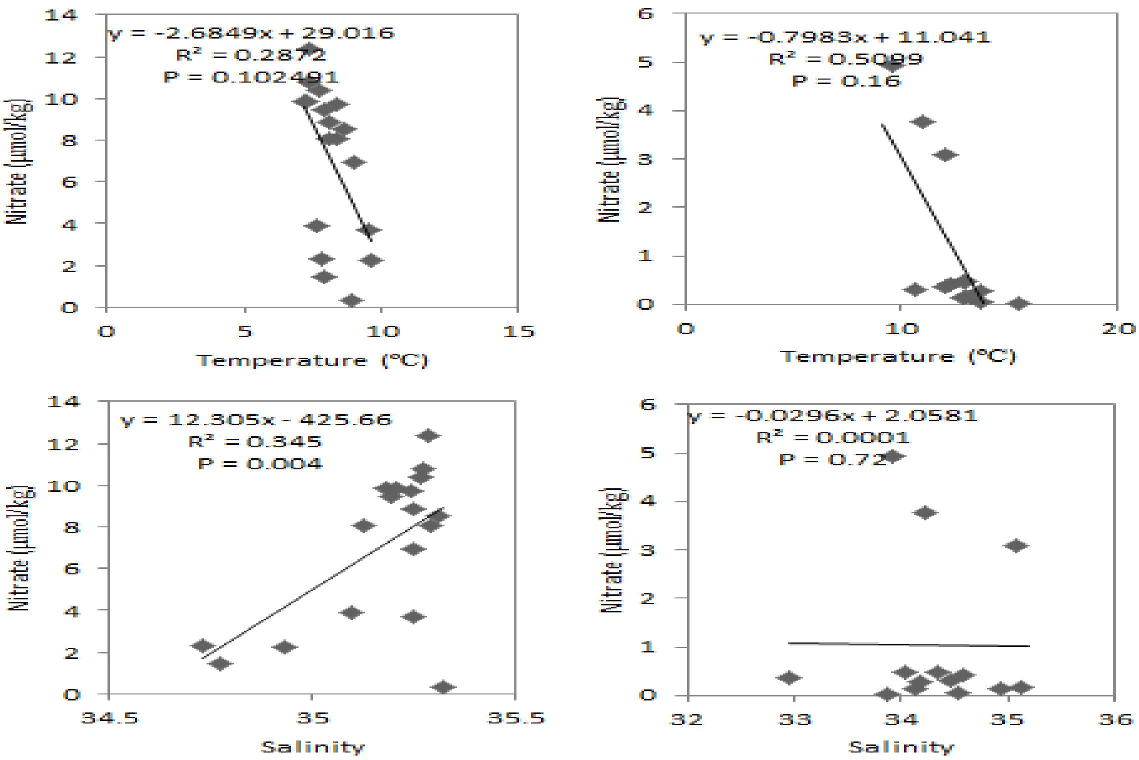


(a) (b)

FIGURE 3.24: The correlations of average temperature, salinity and nitrate respectively in the (a) bloom and (b) post-bloom periods versus year day in the middle part of Svinøy transect.

Temperature and Salinity Versus Nitrate

The nitrate versus temperature do not show correlation almost zero in the bloom , but the nitrate with salinity show weak correlation, 0.25 (see Figure 3.27a). During the post-bloom period the nitrate with temperature show weak correlation 0.4, but significant. The nitrate versus salinity do not show any relation (see Figure 3.27b).



(a) (b)

FIGURE 3.25: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the middle part of Svinøy transect, at cruises carried out during the bloom (a) and post-bloom (b) periods.

3.4 Comparison of the Three Transects

The bloom over the Svinøy transect started before the bloom in the Gimsøy transect. While the bloom in the Gimsøy transect started before the Fugløya-Bjørnøya transect. This is because the cooling increases northward. And this is corresponded with changes of the temperature over the three transects during the bloom period. Along the Fugløya-Bjørnøya transect the bloom begins first in the outer part early and from there to the middle part to the inner part as depicted in (Table 3.4). The early beginning of the bloom in the outer part is due to the shallow mixed layer formed by the Polar Water. This is confirmed by the low temperature value over the outer part during the bloom period. In winter the high value of the sea surface temperature observes at the Svinøy transect and from there decreases to the Gimsøy transect to the Fugløya-Bjørnøya transect as illustrated in (Table 3.4). The nitrate over the three transects show low nitrate concentration in the inner part compared with the outer and middle parts during the winter. This because the inner part is dominated by the coastal water

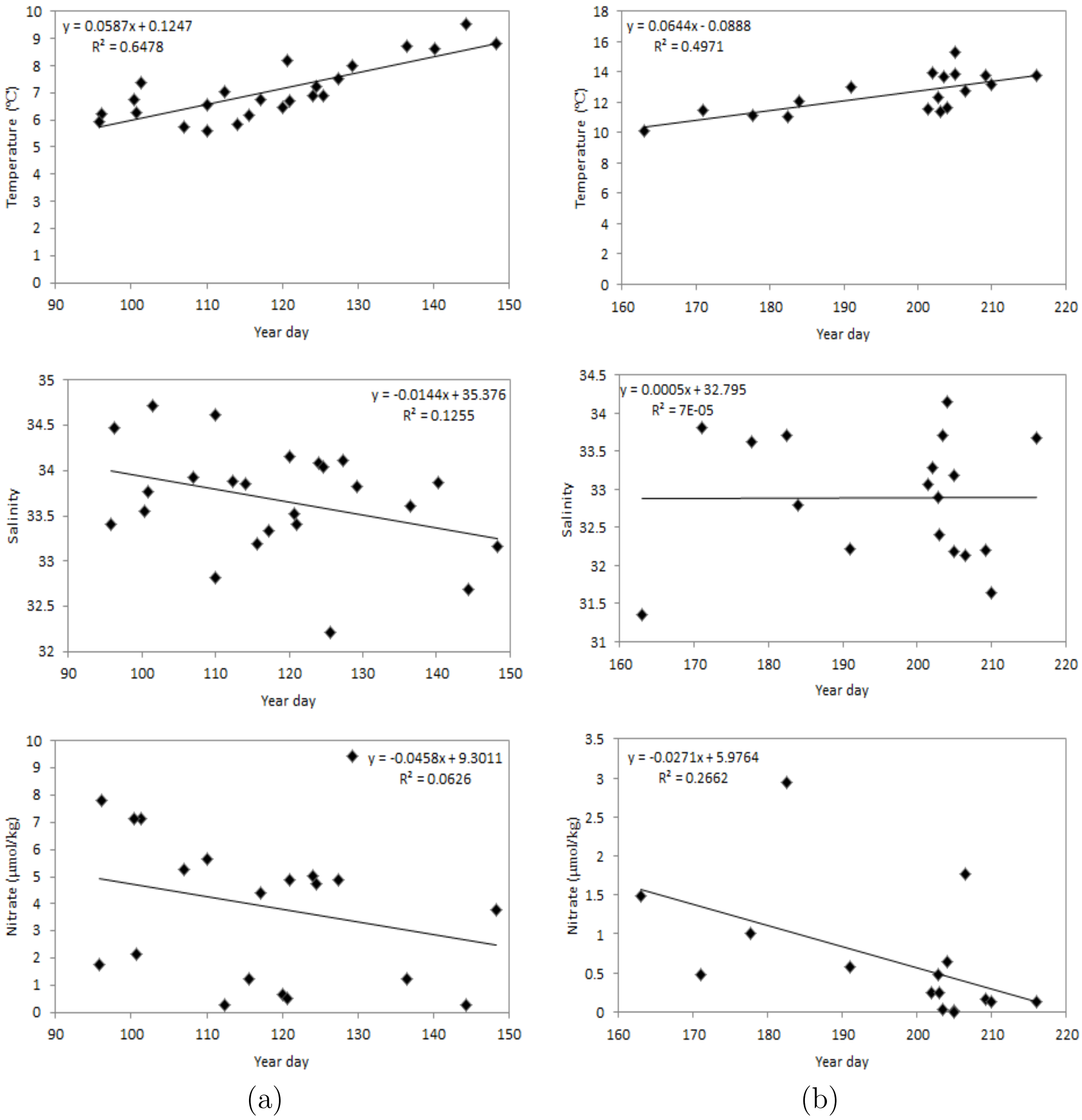


FIGURE 3.26: The correlations of average temperature, salinity and nitrate respectively in the (a) bloom and (b) post-bloom periods versus year day in the inner part of Svinøy transect.

while the middle and outer parts are dominated by Atlantic Water. The temperature, salinity, and nitrate over all transects show reasonably good seasonal cycle as showed in (Table 3.4). The mean value of the nitrate depletion over the Svinøy transect is higher than the Fugløya-Bjørnøya transect, and the Gimsøy transect during the post-bloom period (see Table 3.4). The data revealed weakness in the spatial and temporal covering of the three transects, because reflect of the clear seasonal cycle of the nutrients and temperature depend on the timing of the cruise when was carried out.

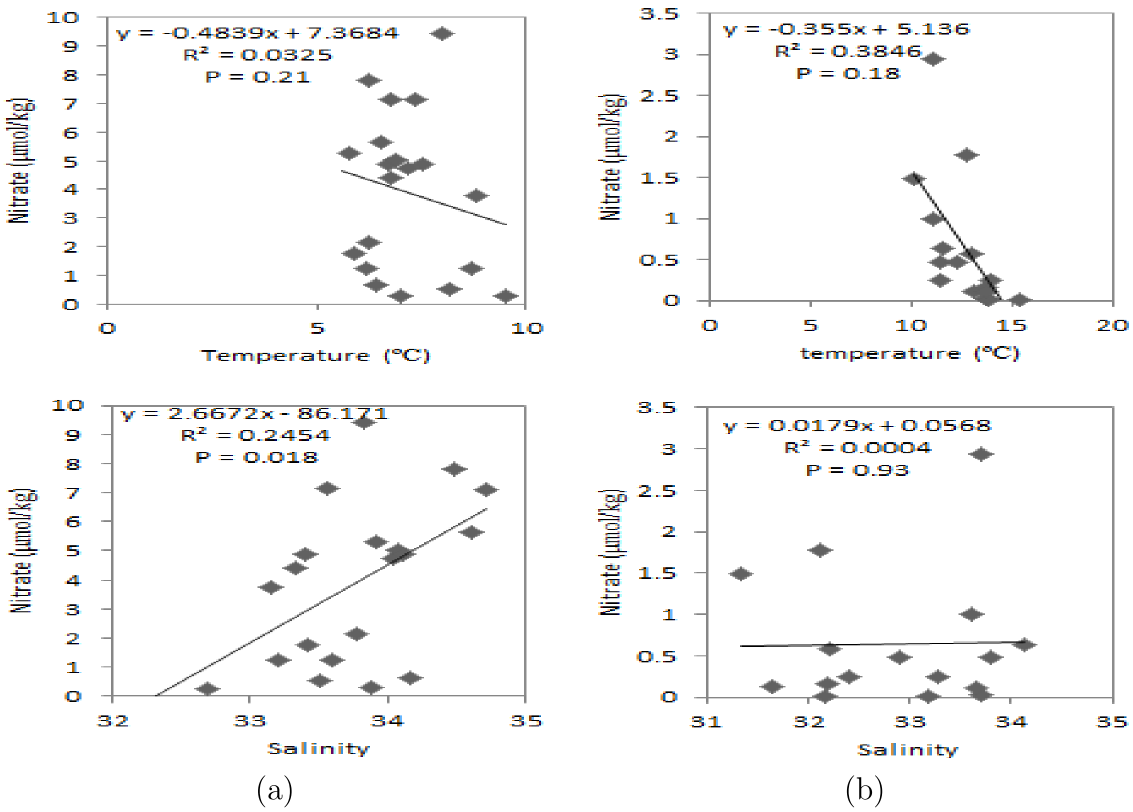


FIGURE 3.27: Correlations of the concentration of nitrate versus the sea surface temperature, and the concentration of nitrate versus the sea surface salinity in the upper 10 meter as observed in the inner part of Svinøy transect, at cruises carried out during the bloom (a) and post-bloom (b) periods.

Table 3.5 represents the correlation coefficients of the temperature, nitrate, salinity, and year day of the Fugløya-Bjørnøya transect during the bloom period. During the bloom period at the Fugløya-Bjørnøya, Gimsøy, and Svinøy the nitrate and temperature are not entirely independent of year day but show slight signature of the seasonal cycle (see Tables 3.5, 3.7 and 3.9) and not much information on the interannual variations. Also the differences between the correlation coefficients of the three transects are mostly a result of changes in the timing of the cruise. From (Table 3.5) as expected nitrate is closely correlated with sea surface temperature during the bloom period at Fugløya-Bjørnøya transect, as shown during the outer part in (Section 3.1.1), the evolution of the bloom depend on the heating. And these data reflect the evolution of the bloom. In contrast the nitrate is not closely correlated with salinity and temperature at the Gimsøy transect during the bloom period (see Table 3.7), because the data in this transect is not sufficient to reflect fact relationship. In the Svinøy transect the nitrate is not showed closely correlated with temperature at the inner part and weak correlation with salinity at the outer part (see Table 3.9). During the post-bloom period over the three transects when the temperature is high, there is no any response nitrate because it has been finished during bloom, this is explain the weak correlation (see Tables 3.6, 3.8, and 3.10). And also not much information on the interannual variations. The nitrate versus sea surface temperature and salinity during the bloom period over the three transects do not show high correlation coefficients, except of the middle and the outer parts of Svinøy transect, and the middle part of Fugløya-Bjørnøya transect (see Tables 3.6 and 3.10).

TABLE 3.4: Represents the average of temperature, salinity, and nitrate during the winter, bloom and post-bloom periods over the three transects,in addition start and end of bloom. SB is start of bloom, EB is the end of bloom, SF is the start fall, WSST is the winter sea surface temperature, WN is the winter nitrate, BSST is the bloom sea surface temperature, BSSS is the bloom sea surface salinity, PB is the post-bloom.

Transect	Part	SB	EB	SF	WSST	WSSS	WN	BSST	BSSS	PBSST	PBSSS	PBN
	Outer	100	200	250	3.3±0.9	34.90±0.4	10.9±0.7	4.9±1.3	34.96±0.09	6.5±1.1	34.71±0.2	0.6±0.5
Fugløya	Middle	127	200	250	5.7±0.5	35.08±0.03	10.8±0.6	6.9±1.5	35.00±0.1	9.4±1.0	34.80±0.1	0.7±0.6
	Inner	140	200	250	5.5±0.5	34.6±0.2	9.4±1.1	7.7±1.2	34.46±0.3	10.5±1.1	34.40±0.2	0.4±0.5
	Outer	120	185	250	5.8±0.8	35.16±0.04	11.5±0.6	7.4±1.3	35.13±0.05	10.4±0.8	35.03±0.1	0.3±0.3
Gimsøy	Middle	120	180	250	6.5±0.5	35.09±0.1	10.0±2.0	7.4±0.8	35.08±0.1	11.1±1.1	34.76±0.4	0.4±0.6
	Inner	120	190	250	5.4±1.0	34.08±0.4	7.6±1.5	7.3±1.3	34.21±0.2	11.6±1.2	33.84±0.3	0.4±0.9
	Outer	100	200	240	6.2±0.6	35.09±0.08	11.8±0.6	8.1±1.6	35.09±0.1	12.1±1.1	35.04±0.1	1.3±1.3
Svinøy	Middle	100	150	240	7.7±0.5	35.17±0.2	10.7±1.6	8.2±0.7	35.16±0.2	12.4±1.6	34.36±0.5	0.8±1.6
	Inner	90	150	240	7.3±0.9	34.27±0.4	7.9±1.4	7.1±1.1	33.68±0.6	12.6±1.3	32.89±0.8	0.6±0.8

Table 3.5: Correlation coefficients of the nutrients at the Fugløya-Bjørnøya transect during the bloom. SSS is the sea surface salinity and SST is the sea surface temperature.

	Part	SSS	SST	NITRATE
YEAR DAY	Outer	0.63	0.10	0.72
	Middle	0.70	0.20	0.74
	Inner	0.63	0.00	0.80
SST	Outer	–	–	0.41
	Middle	–	–	0.60
	Inner	–	–	0.60
SSS	Outer	–	–	0.00
	Middle	–	–	0.30
	Inner	–	–	0.22

Table 3.6: Correlation coefficients of the nutrients at the Fugløya–Bjørnøya transect during the post-bloom. SSS is the sea surface salinity and SST is the sea surface temperature.

	Part	SSS	SST	NITRATE
YEAR DAY	Outer	0.06	0.40	0.02
	Middle	0.03	0.10	0.01
	Inner	0.10	0.00	0.08
SST	Outer	–	–	0.20
	Middle	–	–	0.50
	Inner	–	–	0.20
SSS	Outer	–	–	0.06
	Middle	–	–	0.00
	Inner	–	–	0.07

TABLE 3.7: Correlation coefficients of the nutrients at the Gimsøy transect during the bloom. SSS is the sea surface salinity and SST is the sea surface temperature.

	Part	SSS	SST	NITRATE
YEAR DAY	Outer	0.40	0.02	0.40
	Middle	0.52	0.08	0.30
	Inner	0.40	0.08	0.20
SST	Outer	–	–	0.05
	Middle	–	–	0.00
	Inner	–	–	0.00
SSS	Outer	–	–	0.50
	Middle	–	–	0.44
	Inner	–	–	0.30

TABLE 3.8: Correlation coefficients of the nutrients at the Gimsøy transect during the post-bloom. SSS is the sea surface salinity and SST is the sea surface temperature.

	Part	SSS	SST	NITRATE
YEAR DAY	Outer	0.07	0.05	0.06
	Middle	0.25	0.09	0.03
	Inner	0.24	0.03	0.00
SST	Outer	–	–	0.99
	Middle	–	–	0.00
	Inner	–	–	0.25
SSS	Outer	–	–	0.50
	Middle	–	–	0.10
	Inner	–	–	0.00

TABLE 3.9: Correlation coefficients of the nutrients at the Svinøy transect during the bloom. SSS is the sea surface salinity and SST is the sea surface temperature.

	Part	SSS	SST	NITRATE
YEAR DAY	Outer	0.63	0.17	0.70
	Middle	0.74	0.00	0.03
	Inner	0.65	0.13	0.00
SST	Outer	–	–	0.60
	Middle	–	–	0.30
	Inner	–	–	0.007
SSS	Outer	–	–	0.01
	Middle	–	–	0.32
	Inner	–	–	0.25

TABLE 3.10: Correlation coefficients of the nutrients at the Svinøy transect during the post-bloom. SSS is the sea surface salinity and SST is the sea surface temperature.

	Part	SSS	SST	NITRATE
	Outer	0.20	0.21	0.32
YEAR DAY	Middle	0.63	0.00	0.40
	Inner	0.24	0.03	0.30
	Outer	–	–	0.6
SST	Middle	–	–	0.51
	Inner	–	–	0.40
	Outer	–	–	0.10
SSS	Middle	–	–	0.00
	Inner	–	–	0.00

Chapter 4

Conclusion and Recommendations

4.1 Conclusion and Recommendations

The results over the three transects indicate that the data covering and the time of the cruise have significant effect on the seasonal and interannual variation, and there is not much information on the interannual variations. The Fugløya-Bjørnøya transect showed good signature of the seasonal cycle over the three parts during the bloom and post-bloom periods. The operational definition of the bloom and post-bloom done in this work depends on when nitrate drop down during the bloom period until almost depleted during the post-bloom. The bloom evolution of the outer, middle, and inner parts of the Fugløya-Bjørnøya transect are triggered by the heating mainly. Also at the outer part the evolution is affected by the shallow mixed layer created by the Polar Water corresponded with the values of temperature and salinity in Table 3.4. The Gimsøy transect showed good seasonal cycle over the middle and inner parts during the bloom and post-bloom periods, but the outer part did not show seasonal cycle during the two periods. The evolution of the bloom at the outer, middle, and inner parts of the Gimsøy transect is caused mainly by the heating. The Svinøy transect showed good seasonal cycle over the three parts during the bloom and post-bloom periods. The bloom evolution over the three parts of the Svinøy transect is triggered by the heating. The bloom was started from the south to the north as illustrated in Table 3.4. This is because the cooling increases northward (Blindheim and Osterhus, 2005; Hansen and Østerhus, 2000). In order to obtain good results we recommend imporving the data coverage and the timing of the cruises over the three transects. Also we recommend to make study of all factors that effect on the phytoplankton primary productivity in the Norwegian Sea.

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