# CHAPTER ONE

# INTRODUCTION

Green mussel is known as the green-lipped mussel; an economically important bivalve species belongs to the family Mytilidae which is widely distributed in the higher latitude regions (Bayne, 1976, Hickman, 1992). It is an intertidal filter feeder and fast growing large warm water marine bivalve (Rajagopal et al., 2006). *P. viridis* mostly distributed in the tropical and sub-tropical areas of the Indo-Pacific region (Sivalingam, 1977; Siddall, 1980). Its distribution extends from Asian region including China, Singapore, Thailand, India and Philippines. *P. viridis* is a significant positive factor of green mussel farming development is the natural availability of seed without need to depend on hatchery production. The green mussel is also a good candidate for cultivation because reproduction can be induced throughout the entire year (Sivalingam, 1977). In many Asian countries and Indo-Pacific region, different species of the green mussel have been cultivated successfully (Chatterji et al., 1984). Nowadays green mussels are considered as a delicious food item in Europe and North America (Boyel, 1981). The rapid growth rate enables wild mussels to compete successfully against other benthic organisms, also ensure a commercial sized product can be reared in a short time period under farming condition. At the same time, the natural ability to live in dense beds in the wild makes it readily adaptable to the population densities necessary for an economically viable farming system.

Bangladesh has vast coastal area which is the most productive zones in the world which is rich in fisheries resources including green mussel (*P. viridis*). Varieties of marine habitats such as sandy, muddy and rocky grounds, mangrove areas and coral reefs are suitable place for bivalves and thus are potentially viable for development of shellfish fishery. The high tide amplitude, sufficient tidal current, absence of pollutants and high phytoplankton abundance offer an ideal environment for the development of mollusk culture around coastal waters of Bangladesh (Ahmad, 1990). Recently, culture of shrimp, crab, mollusk etc. is increasing day by day in coastal area of Bangladesh to ensure blue economy. However, there was little attempt made for mollusk like green mussel culture in Bangladesh due to lack of proper knowledge on distribution and abundance of mollusks populations in our coast and ignorance of mollusk as food value etc.

The export market in the neighboring Southeast countries needs to explore so that excess product can be sold at a reasonable price. The meat party of shrimp and crabs can be exported as a new item by quality processing. The shells of the green mussel can be used for making poultry, fish feed and lime production. This research will help to provide future employment opportunities, alternative protein to tribal people, earn foreign currencies and open a new arena in coastal aquaculture of Bangladesh.

Although Bangladesh has many suitable sites for potential of green mussel culture, now there is no established technological support available in our coastal areas. Naf River is an international river marking the border of southeastern Bangladesh and western Myanmar. It flows into the Bay of Bengal in the Indian Ocean between the Cox's Bazar, Bangladesh and Rakhine State, Burma. Naf River is an important water body which considered as an estuary which rich with bivalve and fisheries resources. These resources are supporting the livelihood of the nearby fisheries communities. Feasibility analysis of Naf River for green mussel culture is important for enhancing the livelihood of the surrounding resources poor peoples. The culture potentiality of green mussel in Naf River could be analyzed by using site suitability rating system, which includes all the biophysical parameters and plankton abundance determination that preset special criteria for the culture sites to rank.

### 1.1 Objectives of the research work:

The main objective of this research is to specify the suitable site and established site suitability rating system in Naf River for establishing green mussel culture system.

Specific objectives are:

- To investigate the monthly variation of plankton abundance and species
- To observe the physico-chemical water quality parameters
- To apply the site suitability rating system for determining the culture potential

## 1.2 Research questions:

The study was conducted to satisfy the following research questions-

- Are the selected sites of Naf River suitable for the green mussel culture?
- Are the physico-chemical parameters of water quality favorable for the green mussel culture?
- Does the qualitative and quantitative abundance of plankton species sufficient for supporting the green mussel culture in these stations?

## 1.2 Limitation of the study:

The major shortcoming of the research work was the unpredictability of the weather. The monsoon flood, tidal surge and storm made the water turbulent and the water quality parameters as well as primary productivity fluctuated at a very high range. In addition, the tidal range also deviated from the mean value which caused variation in the parametrical readings.

# CHAPTER TWO

# REVIEW OF LITERTURE

## 2.1 Biology of green mussel, *Perna viridis* (Linnaeus, 1758):

The green mussel or green lipped mussel, *Perna viridis* belongs to the family Mytilidae (GSFMC, 2005) and the only family in the order Mytiloida. The Mytilidae comprises of 32 genera and the green mussel belongs to the genus *Perna*. The genus Perna consists of only four species, *P. canaliculus, P. picta, P. perna* and *P. viridis.* The species *Perna viridis* is widely distributed in tropical and sub-tropical areas of the Indo-Pacific region. Other members of the *Perna* are found in New Zealand (*Perna canaliculas*) and in coastal South America and Africa (*Perna perna*) (Sallih, 2005).

The green mussel (*P. viridis*) is a large mussel which average size is 80-100mm in length and it has been reported occasionally to achieve a length of 150-165 mm (NIMPIS, 2002; FIGIS, 2005). It has two identical shell valves, a pear-shaped and smooth exterior surface characterized by concentric growth lines and slightly concave ventral margin. The shell surface of *P. viridis* is covered by a smooth and firm periostracum, which bright green in juvenile and brown with green margins in adult (Sallih, 2005).

Figure 1: External view of green mussel (*P. viridis*)

Spawning occurs in response to environmental triggers such as high food levels, temperature fluctuations and physical abundance. The stages after fertilization start with the formation of free swimming larvae or trocophore larvae after 7-8 hours, and growing to last larvae stage, veliger larval with the development of ciliated velum after 16-19 hours and complete metamorphosis in 8-12 days (Tan, 1975). At metamorphosis, an eye spot and extended foot develops, withdraws the vellum and secrets byssal threads as aids to selection of site for settlement. This occurrence is generally referred to as mussel spat fall. Once selected the larvae which are about 2-5 weeks old and of 0.25-0.30 mm in size (Aypa, 1990) attached by anchoring with byssus thread (Spencer, 2002). The young mussels generally referred to as juvenile mussels then grow rapidly and achieve 3-4 mm shell length within 4-8 weeks (Aypa, 1990). The spawning season occurs twice a year between early spring and late autumn (Rajagopal, 1998).

### 2.1.1 Feeding habits:

*P. viridis* is a suspension feeder that feed by actively pumping water through a set of gill filaments which filter out small particles such as phytoplankton, zooplankton and other organic materials from the water body. Phytoplankton cells are the main sources of food of mussel, while other sources of carbon such as macrophytes or re-suspended detritus may also supplement their diet (Sallih, 2005). High biomass of phytoplankton usually results in fast growth and increase the growth rate of *P. viridis* (Ren et al., 2005). The presence of moderate temperature, salinity and availability of phytoplankton throughout the year may contribute to a higher growth rate of green mussel (Kamal and Khan, 1998).

### 2.1.2 Growth:

The growth of bivalves can be distinguished into shell and body growth. The growth rate of green mussels is high compared to other species of mussel (Shafee, 1979). The maximum growth occurs 2 m below to the surface due to increased water productivity and narrow fluctuation of temperature and salinity (Sivalingam, 1977). The other environmental condition such as turbidity, current speed, food availability and competition for space also highly influenced the growth of mussels (Alvarado et al., 1996). First year growth rate vary between locations and range from 49.7 mm/yr in Hong Kong to 120 mm/yr in India (NIMPIS, 2002). According to Spencer (2002) mussels have a number of

attributes that contribute to success in cultivation such as high fecundity and free swimming larvae that ensure a wide distribution of the offspring. In addition, mussels easily settle and attach through the byssal attachment mechanism on rocky shores, intertidal and sub tidal in estuaries and bays, often at high densities and have rapid growth rates.

### 2.1.3 Habitat:

Green mussel (*P. viridis*) is widely distributed in the higher latitudes (Bayne, 1976). It is native to tropical Indo-Pacific region, primarily found in the Indian and the South East Asian coasts. It is also found in the Persian Gulf, Malaysia, Papua New Guinea, South Pacific islands and Japan (Sivalingam, 1977; Siddall, 1980; Vakily, 1989; Cheung, 1993; Rajagopal et al., 2006). *P. viridis* also extends from the Persian Gulf to all of the Philippines plus Sumatra, Borneo, Bali and Sulawesi but excludes the reminder of Indonesia, northeast Vietnam and China (Siddall, 1980; Vakily, 1989). The mussel is also available in the Atlantic basin includes Trinidad and also Venezuela across the Gulf of Persia (Agard et al., 1992; Rylander et al., 1996, Stevely, 2009). *P. viridis* is also distributed in the Musandam Peninsula of Oman (Gindy et al., 2001) but its distribution and abundance at the western edge of its range is poorly documented. Additional localities of *P. viridis* include the Andaman Islands (Appukuttan, 1977; Dorairaj and Soundararajan, 1998), Vietnam (Academy of Natural Sciences of Philadelphia, 2003; Holmyard, 2003), Java (Setyobudiandi, 2001a; 2001b) and southern Sulawesi (Sharifuddin Bin Andy and Gassing Sitepu, 1997). Green mussels are naturally abundant in the Cox's Bazar coast of Bangladesh. It is distributed in the St. Martin Island, Shahporir Dwip and Naf River (Ali, 1975; Ali and Aziz, 1976; Ahmed et al., 1978 and Ahmed, 1990). It is also found in Moheskhali channel (Shahabuddin et al., 2010).

## 2.2 Culture aspects of green mussels:

Aquaculture provides an alternative means of increasing fish production which contribute to the protein food supply and contributing the socio-economic development of nation. Green mussels also have various characteristics which contribute to the potential of mussels in aquaculture (Hickman, 1992). The high fecundity and a mobile free-living phase contribute to the widespread distribution of the relatively few mussel species, and at the same time has greatly influenced the technology and practice of mussel farming. The

natural availability of seed, without the need to resort to hatchery production, has been a significant positive factor in the development of mussel farming. It is a species which have rapid growth rate and reproduce throughout the year (Sivalingam, 1977). For its rapid growth rate, it is enables wild mussels to compete successfully against other benthic organisms. It also has ability to live in dense beds. *P. viridis* is commercially important because of its rapid growth rate and high population densities (Rajagopal et al., 1998). Its larvae and spat are settled through the year round. But the highest peak is found in October and the second highest in March (Hossain et al., 2004; Amin et al., 2005). The green mussel can form dense populations of 35,000 individuals per $m^2$ on a variety of structures (NIMPIS, 2002). And this can contribute to the easy collection of seed for cultivation.

### 2.2.1 Site selection for green mussel culture:

It is important to select a proper site to culture green mussel. The site for green mussel cultivation should be well protected or sheltered coves and bays rather than open unprotected areas (Aypa, 1990). Sites are affected by strong wind and big waves must be avoided because this causes damage to stock and culture materials. The sites must be clear from serving as catchments basins for excessive flood waters. Flood water is instantly change the temperature and salinity of the seawater, which is detrimental to the mussels. Water depth, water movement, turbidity, pH, dissolved oxygen, food availability also are the most important in the selection of a suitable culture site (Lovatelli, 1988).

### 2.2.2 Water depth:

For green mussel culture water depth should be below 1 m mean tide level at least. Water depth varies with culture methods. Bottom culture can be practiced in area where the mean tide level is less than 1.5 m (Lovatelli, 1988). For off bottom culture methods such as raft and long line usually need a minimum water column height during low water spring tide. The hanging ropes with mussel seeds of these culture methods should be at least 1 m above the sea floor during extreme low water spring tides (Lovatelli, 1988) to prevent ground predators, seabed high water turbidity and friction with the bottom. The favorable water depth for both seed collection and mussel cultivation is 2 m or more (Aypa, 1990).

### 2.2.3 Turbidity

Determination of water turbidity is essential for green mussel culture. It determines the presence of suspended, organic and inorganic matters in the culture area. High levels of the suspended materials have a bad effects on mussel culture due to failure of filtering activity. And also these materials reduced penetration of sunlight in the water column, which will result in low primary productivity. As a result, the cultured species may face slow growth rates due to limited food availability. A practical method for determining the turbidity level is the use of the Secchi disc. Culture site having a disc reading of less than 25 cm should be considered unsuitable for mussel culture (Lovatelli, 1988).

### 2.2.4 Salinity

Green mussel can tolerate a high range of salinity. The species has 50% survival salinity tolerance at 24 ppt and 80 ppt for a period of 2 weeks in a laboratory experiment (Sivalingam, 1977). Tropical green mussel occurs typically in estuarine or coastal water that is rich in plankton has high salinity (27 ppt to 33 ppt). The green mussel shows a good growth performance in estuarine habitats with salinities ranging from 18 ppt to 33 ppt as reported in FIGIS, 2005 and this species shows a broad salinity and temperature tolerance in experimental testing. The salinity of 27 ppt to 35 ppt is ideal for mussel farming (Aypa, 1990). According to Rajagopal et al. (1998), the green mussel can grow in salinity ranging from 5.2 ppt to 39.8 ppt.

### 2.2.5 Temperature:

The growth of green mussel culture is also affected by water temperature. Sivalingam (1977) demonstrated that the green mussel has 50% survival temperature tolerance from 10°C to 35°C under experimental testing. It was reported that the optimal temperature for green mussel culture ranges from 26°C to 32°C (Hickman, 1989), 27°C to 30°C (Aypa, 1990), 25.3°C to 34.6°C (Rajagopal et al., 1998). It also tolerates a range of temperature 11°C to 32°C (FIGIS, 2005).

### 2.2.6 Food organisms:

As filter feeders, green mussels mainly feed on a wide range of phytoplankton species, small zooplankton and other suspended fine organic materials. High primary productivity areas lead to high productivity and biomass of mussels. The chlorophyll-a distribution range is from 0.7 $mg/m^3$ to 17 $mg/m^3$ in potential green mussel cultivation (Rajagopal et al., 1998).

### 2.2.7 Plankton composition:

Phytoplankton species are the most favorite food item for green mussel. *Coscinodiscus* is the most favorite phytoplankton species of *P. viridis* (Tan and Ransangan, 2017). High content of *Prorocentrum, Navicula, Rhizosolenia, Ditylum, Thalassionema* spp. also found in the *P. viridis* stomach (Tan and Ransangan, 2017). A little amount of *Proboscia, Protoperidinium, Pleurosigma, Entomoneis,Odentella, Nitzschia* also found in the *P. viridis* stomach (Tan and Ransangan, 2017). Interestingly, *Chaetoceros* spp. and *Bacteriastrum* spp. were selectively rejected by *P. viridis* in both high and low seston conditions (Tan and Ransangan, 2017).

In the diet of *P. viridis* zooplankton has also significant. High numbers of copepod and bivalve larvae were found in the *P. viridis* stomach (Tan and Ransangan, 2017).

## 2.3 Feasibility study for green mussel culture:

*P. viridis* is a self-regulated aquaculture and it required only a little effort to maintain the culture. Proper selection of the farming sites is the most important when considering green lipped mussel aquaculture. Farming trials by suspending the *P. viridis* from off bottom structures in estuaries, semi-enclosed bay and open sea areas have given encouraging results (Kripa et al., 2008).

In selecting sites for bivalve farming, determination of food abundance, natural availability of seed, lack of major predators and pests, current speed, mixing rates, temperature and salinity variations over an extended period of time would appear essential for *P. viridis* (Hickman, 1992).

For selecting the *P. viridis* farming site is usually done based on the examination of an array of environmental parameters, which represent the environmental condition of the site. The environmental parameters such as water temperature, pH, dissolved oxygen, salinity, transparency, and water depth are given a weighted value, which range from 0.0 to 0.9 based on its effects to the growth or survival of the culture species. The rated value of each parameter in the studied site is multiplied by the weighted value for the parameter in order to determine parameter weighted value of the site. The total parameter's weighted value will then be used to categorize the suitability of the sites for *P. viridis* farming (Tan and Ransangan, 2004).

By using these rating value we can easily estimate whether our coastal areas are suitable or not for green mussel culture. Green mussel is naturally found in the Cox's Bazar region and it can be cultured in this region especially in the Moheskhali channel and other near shore areas (Shahabuddin et al., 2010). The ecological environment of Naf River also suitable for the development of aquaculture of this species. Therefore, the present study is focusing the potentiality of green mussel culture in Naf River by applying site capability rating system.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Study area:

This research work was conducted at Naf River, Teknaf, Cox's Bazar region located in the south-east direction of Bangladesh. Five stations were randomly selected from downstream to upstream areas of this study area (Fig. 1). The approximate geographical location of those stations are Jeti ghat Teknaf (St1, 22°17'02″ N and 91°51′15″E), Chandrakilla (St2, 22°17′49″N and 91°51'30″ E), Jadiapara (St3, 22°18'6″ N and 91°51'53″ E), Chowdhury para (St4, 22°18'31″ N and 91°52′20″ E) and Nhila (St5, 22°18′59″ N and 91°52′43″ E) (Fig. 1)

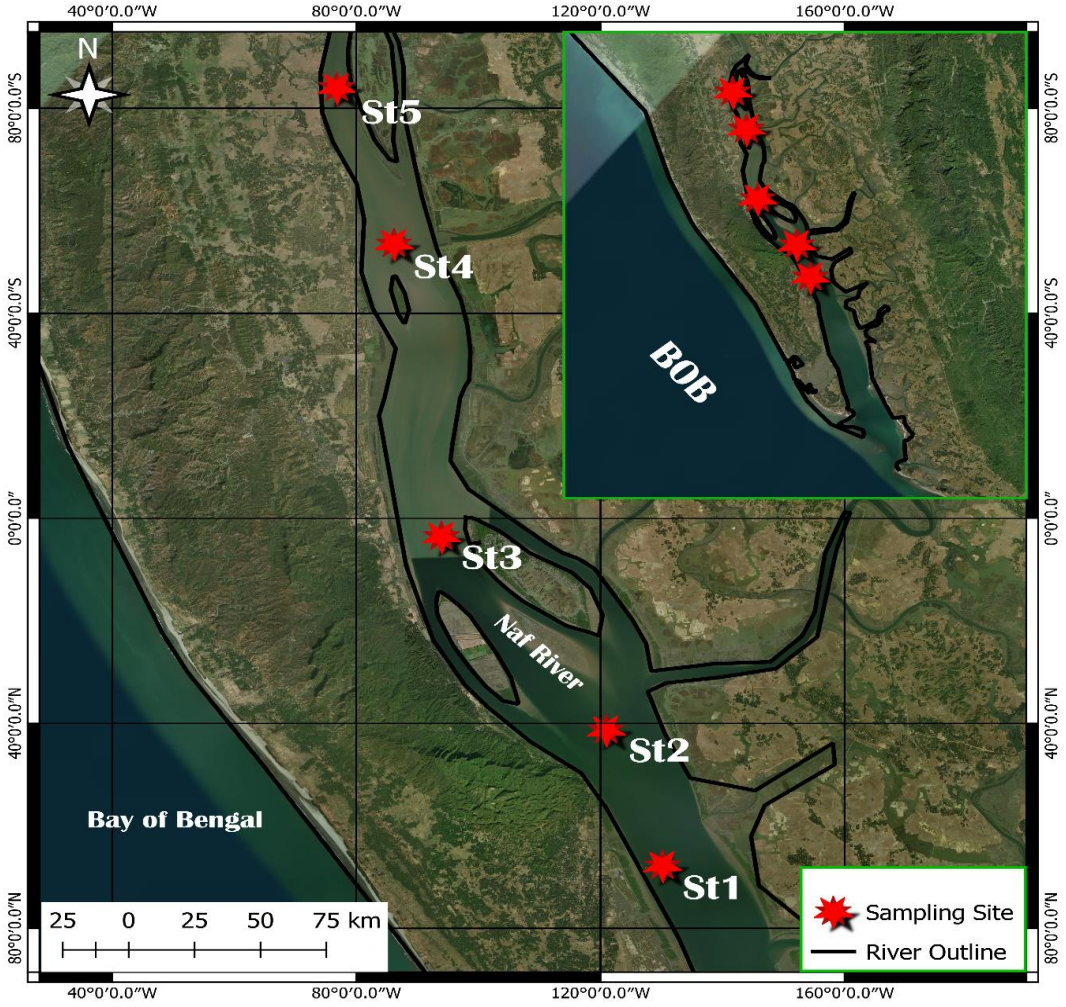


Figure 2: Sampling locations of Naf River

### 3.2 Sampling frequencies and studied parameter

#### 3.2.1 Sample collection

Sampling was collected from the 5 selected on a monthly basis for a period of 7 months from March 2018 to September 2018. Surface water samples collected during high tide condition for measuring water temperature, salinity, pH, water transparency, dissolve oxygen, alkalinity, turbidity, chlorophyll-a, dissolve nutrients as nitrite, nitrate, phosphate and ammonia. Sub-surface water collected from five Stations for measuring plankton composition using plankton net.

#### 3.2.2 Biophysical condition determination

The variation of temperature, salinity, pH, water current, water depth, alkalinity, turbidity, dissolve oxygen, chlorophyll-a, dissolve nutrients such as nitrite, nitrate, phosphate and ammonia was measured at the study area following standard methods (APHA, 2005).

##### 3.2.2.1 Analysis of physico-chemical water quality parameters

Water quality parameters like temperature (Celsius Thermometer), dissolve oxygen (Digital DO Meter), pH (Portable pH meter), salinity (Refractometer), transparency (Secchi Disc) and depth (Weight and Rope) were monitored in-situ during morning on monthly basis. Three replication of water samples were collected from each Station using water sampler and were taken to laboratory as soon as possible for the turbidity (Digital turbidity meter), alkalinity (Titrimetric method), Chlorophyll-a and nutrient ($NO_2$-N, $NO_3$-N, $PO_4$-P, $NH_4^+$) analysis in laboratory. After turbidity determination, water samples were filtered through microfiber filter paper (Whitman GF/C) using a vacuum pressure air pump (Rocker filtration pump). The filtered water was used for alkalinity and nutrient analysis. The filter paper was taken for chlorophyll-a determination.

##### 3.2.2.2 Estimation of nutrient composition

**Nitrite**

The program 305 set before in the photometer (pHoto Flex; WTW, Germany) along with zero adjustment using distilled water. VARIO Nitri 3 F10 Powder pack of chemical content was needed to measure the nitrite concentration in sample. At first 10 ml of sample water

was taken in empty cell using pipette. The contents of the powder pack were added and the cell closed with screw cap. Then the cell was shaken and allowed to react for 15 minutes. Then the cell was inserted in the photometer and the photometric reading was recorded afterwards.

**Nitrate**

The program 314 set before in the photometer (pHoto Flex; WTW, Germany) and zero adjustment was done by using distilled water. VARIO Nitrate Chromotropic Powder pack of chemical content needed to measure the nitrate. At first 10 ml of sample water was taken in vacant cell using pipette. The contents of the powder pack were added and the cell closed with screw cap. Then the cell was shaken and allowed to react for 5 minutes. Then the cell was inserted in the photometer and the photometric reading was recorded afterwards.

**Phosphate**

The program 306 set before in the photometer (pHoto Flex; WTW, Germany) with zero adjustment using distilled water. VARIO Phos3 F10 Powder pack of chemical content required to measure the phosphate in sample water. 10 ml of sample water was taken in empty cell using pipette. The contents of the powder pack were added and the cell closed with screw cap. Then the cell was shaken and allowed to react for 2 minutes. Then the cell was inserted in the photometer and the photometric reading was recorded afterwards.

**Ammonia**

For the determination of Ammonia, the program 324 set in the photometer (pHoto Flex; WTW, Germany) and zero adjustment was done using distilled water. The pH value of the sample was also checked whereas, the desired value; approx. pH 7. VARIO AMMONIA Salicylate F10 Powder pack and VARIO AMMONIA Cyanurate F10 Powder pack needed to measure the ammonia in water sample. At first 10 ml of sample water was taken in empty cell using pipette. The contents of VARIO AMMONIA Salicylate F10 powder packs were added and the cell was closed with screw cap. Then the cell was shaken and allowed to react for 3 minutes. After that the contents of VARIO AMMONIA Cyanurate F10 Powder pack also added and the cell closed with screw cap. Then the cell was shaken and allowed

to react for another 15 minutes. Then the cell was inserted in the photometer and the photometric reading recorded afterwards.

**Ammonium**

The program 71 set before in the photometer (pHoto Flex; WTW, Germany) and zero adjustment was done by using distilled water. The pH value of the sample was checked. Desired value; approx. pH 7. $NH_4^{-1}$ Solution, $NH_4^{-2}$ Powder and $NH_4^{-3}$ Solution was needed to measure the ammonium in sample water. At first 10 ml of sample water was taken in empty cell by using pipette. Then 1.20 ml of $NH_4^{-1}$ Solution was added into the cell by using pipette and mixed it with the sample. Then 2 level blue micro spoons of $NH_4^{-2}$ Powder were added and the cell was closed with screw cap. Then the cell was shaken and allowed to react for 5 minutes. After that 8 drops of $NH_4^{-3}$ Solution was added and the cell was closed with screw cap and mixed it. Then the cell was shaken and allowed to react for 5 minutes. Then the cell was inserted in the photometer and the photometric reading was recorded afterwards.

**Chlorophyll-a measurement**

500 ml water samples were filtered through membrane filter (0.45µm) with the help of a vacuum pump. The filtered membranes were taken into 10 ml of 90% acetone and kept overnight. The filtered papers were mixed thoroughly with acetone using a glass rod. Then centrifugation at 3500 RPM for 2.30 minutes was performed. The supernatant contents (extract) were taken into corvettes and the absorbance of extract was determined at 664, 647 and 630 nm comparing with blank acetone. The chlorophyll-a concentration was calculated by following equation:

$$\text{Chlorophyll-a} = (11.85\ A_{664} - 1.54\ A_{647} - 0.08\ A_{630}) * (V/S) * 1000$$

Where,

- $A_{664}$ = Absorbance at 664 nm
- $A_{647}$ = Absorbance at 647 nm
- $A_{630}$ = Absorbance at 630 nm
- V = Volume of acetone used (ml)

- S = Volume of sampled filter (ml)

### 3.2.3 Qualitative and quantitative estimations of plankton

Plankton samples were collected monthly by pouring 50 liters of water from five different stations and passing them through 45 µm mesh plankton net. The concentrated samples were preserved in small plastic bottles with 5% buffered formalin. Qualitative and quantitative estimations of plankton were done using a Sedgewick-Rafter Cell containing 1000 $1mm^3$ cells. A 1ml sample was taken in the S-R cell and left for 15 minutes undisturbed to allow plankton to settle. The plankton in 10 randomly selected cells were identified up to family level and counted under a binocular microscope with imaging facilities. The planktons were also observed under microscope to study the major plankton classes.

Plankton abundance was calculated by using this formula:

$$N = (P*C*100)/L$$

Where,

- N = Number of Plankton cells or units per liter of original water (Counted by using Sedgewick-Rafter cell)
- P = The number of plankton counted in 10 fields
- C = The volume of final concentration of the sample (ml)
- L = The volume (L) of water sample

### 3.3 Site suitability detection for *P. viridis* farming

Variation of the above biophysical environmental parameters over year round was investigated to evaluate the suitability of each station for *P. viridis* farming. All of these parameters were given a weighted value based on its effects to the growth or survival of bivalves. The rated values of each parameter were multiplied by the weighted value for the parameter to estimate the total weight value of the station.

Table 1: The weighted value and rating point for the range of environmental parameters for mussel farming based on FIGIS (2005), Saxby (2002), Hickman (1992), Aypa (1990), Lovatelli (1990), Sivalingam (1977).

| **Rating Point** | **Salinity (ppt)** | **Dissolved Oxygen (mg/L)** | **pH value** | **Temperature (°C)** | **Chlorophyll-α (µg/L)** | **Water Current (m/s)** | **Water Depth (m)** |
|---|---|---|---|---|---|---|---|
| 10 | 27-32 | >8 | 7.9-8.2 | 26-32 | 2.0-3.0 | 0.1-0.3 | >8 |
| 09 | 25-33 | 6-7 | 7.8-8.3 | 25-33 | 1.8-3.5 | 0.15-0.35 | 8 |
| 08 | 24-34 | 5-6 | 7.7-8.4 | 24-34 | 1.6-4.0 | 0.2-0.4 | 7 |
| 07 | 23-35 | 4-5 | 7.6-8.5 | 23-35 | 1.4-4.5 | 0.25-0.45 | 6 |
| 06 | 18-36 | 3-4 | 7.5-8.6 | 22-36 | 1.2-5.0 | 0.3-0.5 | 5 |
| 05 | 15-40 | - | 7.4-8.7 | 21-37 | 1.0-5.5 | 0.35-0.6 | 4 |
| 04 | 12-45 | - | 7.3-8.8 | 20-38 | 0.8-6.0 | 0.4-0.7 | 3 |
| 03 | 10-50 | 3-2 | 7.0-8.9 | 19-39 | 0.6-6.5 | 0.6-0.9 | - |
| 02 | 5-55 | 2-1 | 6.9-9.0 | 18-40 | 0.4-7.0 | 0.9-15 | - |
| 01 | 0-65 | - | 6.8-9.1 | 17-41 | <0.4->7.0 | >1.5 | 1 |
| Weighted Value | 0.15 | 0.15 | 0.1 | 0.15 | 0.15 | 0.15 | 0.15 |

Table 2: Recommendation for site evaluation.

| **Weighted Category** | **Site Evaluation** | **Recommendation** |
|---|---|---|
| 1.0-2.5 | Not advisable | Not suitable for green mussel farming and cannot support the culture |
| 2.6-5.0 | Poor | May support green mussel but not recommended |
| 5.1-7.5 | Medium | Capable and moderately suitable for green mussel farming |
| 7.6-10.0 | Good | Suitable for green mussel farming and highly recommended |

### 3.4 Data Analysis

The water quality data were investigated for each station monthly and results were demonstrated by using Microsoft Excel 2013. All experimental results of water quality and plankton composition were analyzed by using one-way ANOVA with SPSS version 22.0.

# CHAPTER FOUR

# RESULTS

## 4.1 Water quality parameters:

The water quality parameters from these selected stations recorded over the 7 months period. These physic-chemical parameters include Temperature, Salinity, pH, Dissolve oxygen, Turbidity, Alkalinity, Water depth and Transparency. The range of nutrient substance as Nitrate, Nitrite, Phosphate, Ammonia, Ammonium and Chlorophyll-a were also recorded. The range of water quality parameters and nutrient substance in Naf River summarized in Table 3 and Table 4.

### 4.1.1 Temperature:

The temperature varied from 27-34º C (Figure 3). No major fluctuation in temperature gradient was observed throughout the study time (Figure 3). No significant difference ($p > 0.05$) was also observed in temperature throughout the stations (Table 3). But highly significant difference ($p < 0.05$) was observed in the monthly variation (Table 4). However, temperature in April was significantly higher ($p < 0.05$) than other months of the study period.

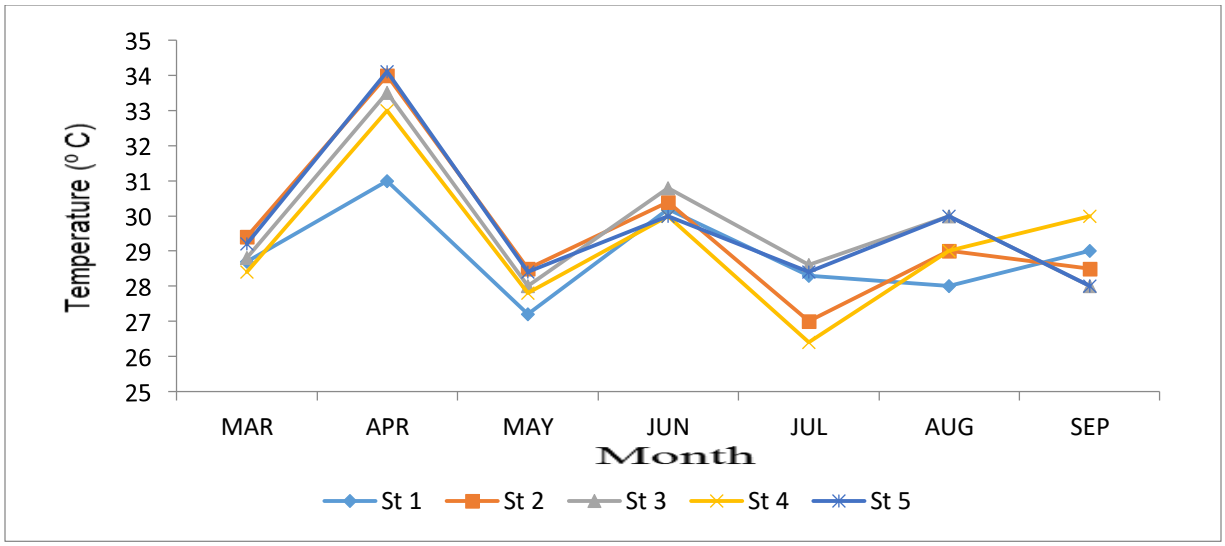


Figure 3: Temperature variation of the Naf River

### 4.1.2 Transparency:

The value of transparency fluctuated from 18-56 cm (Figure 4). No significant difference ($p>0.05$) was also observed in transparency throughout the stations during this research period (Table 3). But highly significant difference ($p <0.05$) of transparency was observed in the monthly variation (Table 4). However, transparency in March was significantly higher ($p<0.05$) and transparency of July was significantly lower than that in other months.

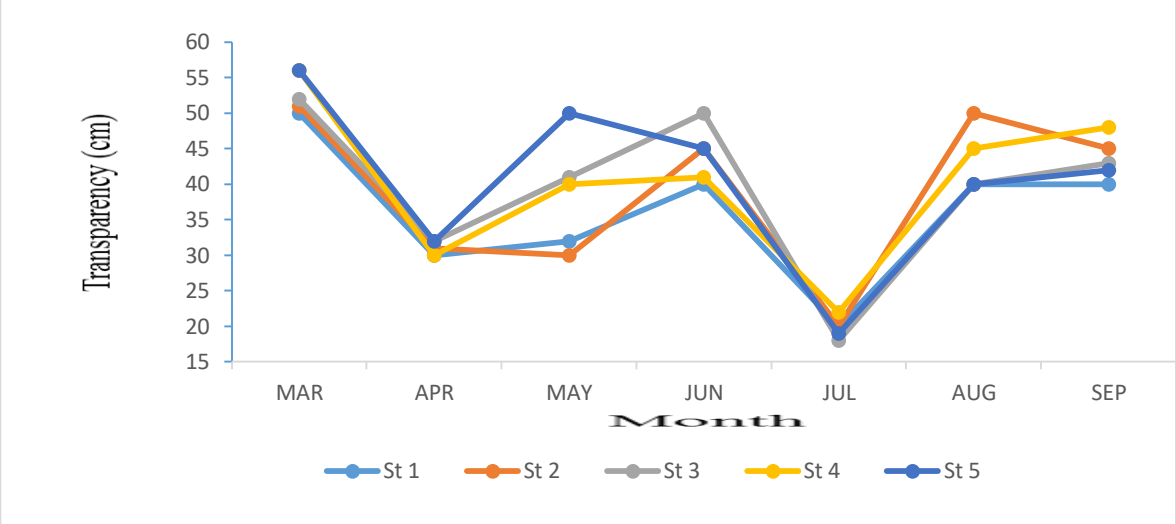


Figure 4: Transparency fluctuation at Naf River Estuary

### 4.1.3 Turbidity:

The range of turbidity varied from 15-150 NTU (Figure 5). No major fluctuation in turbidity was observed throughout the study. No significance difference ($p>0.05$) was observed in turbidity among the different Stations (Table 3). But highly significantly difference ($p< 0.05$) was observed in turbidity in the monthly variation (Table 4). However, turbidity in July was significantly higher ($p<0.05$) than that in other months.

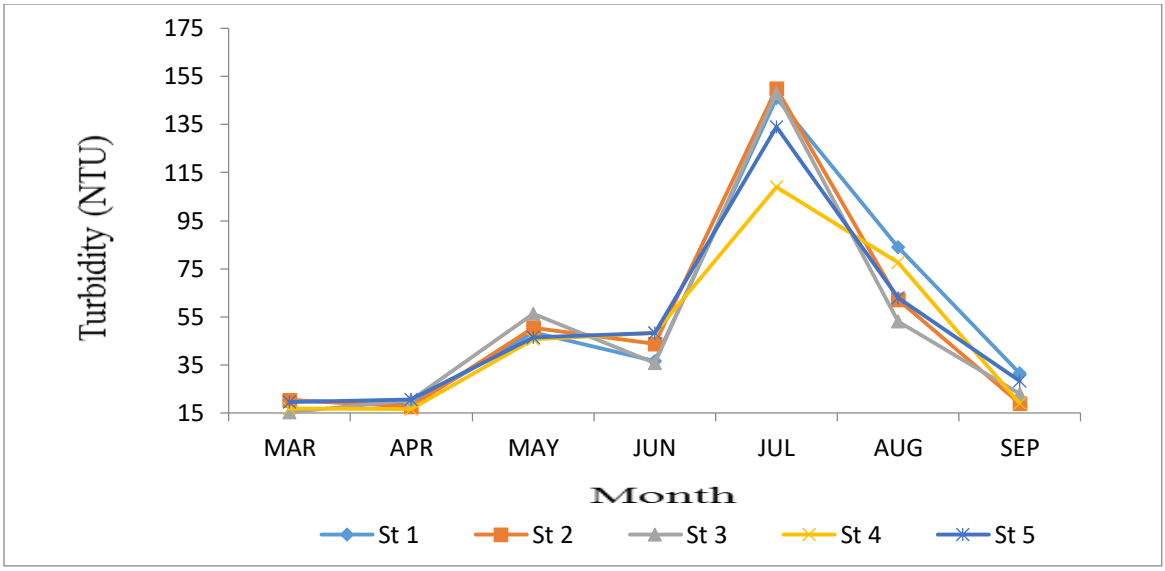


Figure 5: Turbidity fluctuation of the Naf River

### 4.1.4 pH:

The level of pH fluctuated from 7.2-8.7 (Figure 6). No major fluctuation in pH was observed throughout this research. No significance difference ($p>0.05$) was observed in pH among the different Stations (Table 3). But highly significantly difference ($p< 0.05$) was observed in pH in the monthly variation (Table 4). However, pH in July was significantly higher ($p<0.05$) than that in other months.

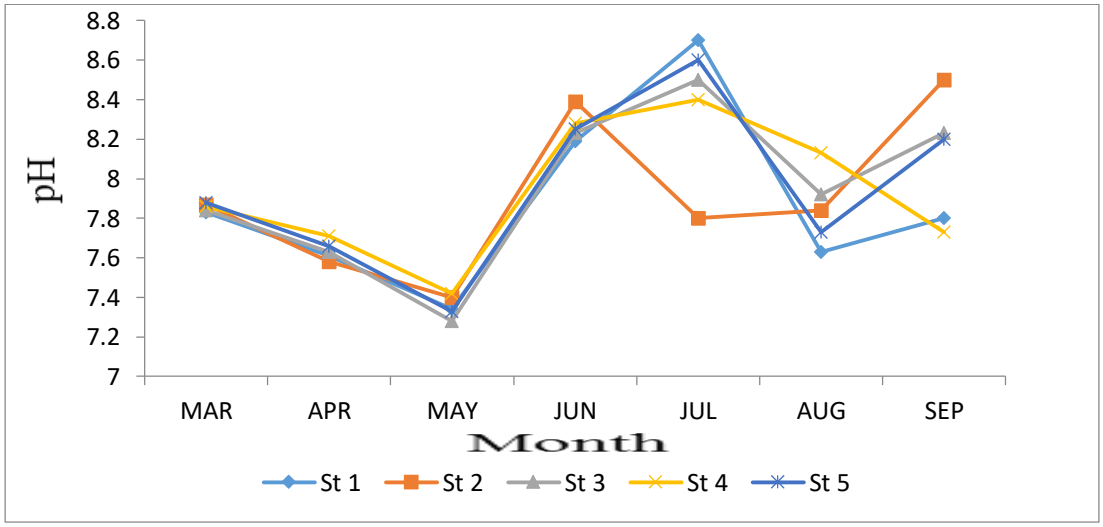


Figure 6: pH fluctuation of the Naf River estuarine region

### 4.1.5 Dissolve oxygen:

The dissolve oxygen reading during the sampling time varied from 6.2-14.6 mg/l (Figure 7). No major fluctuation in DO was observed throughout the study time. No significance difference ($p>0.05$) was observed in DO among the different Stations (Table 3). But highly significantly difference ($p< 0.05$) was observed in DO in the monthly variation (Table 4). However, DO in August was significantly higher ($p<0.05$) than that in other months.

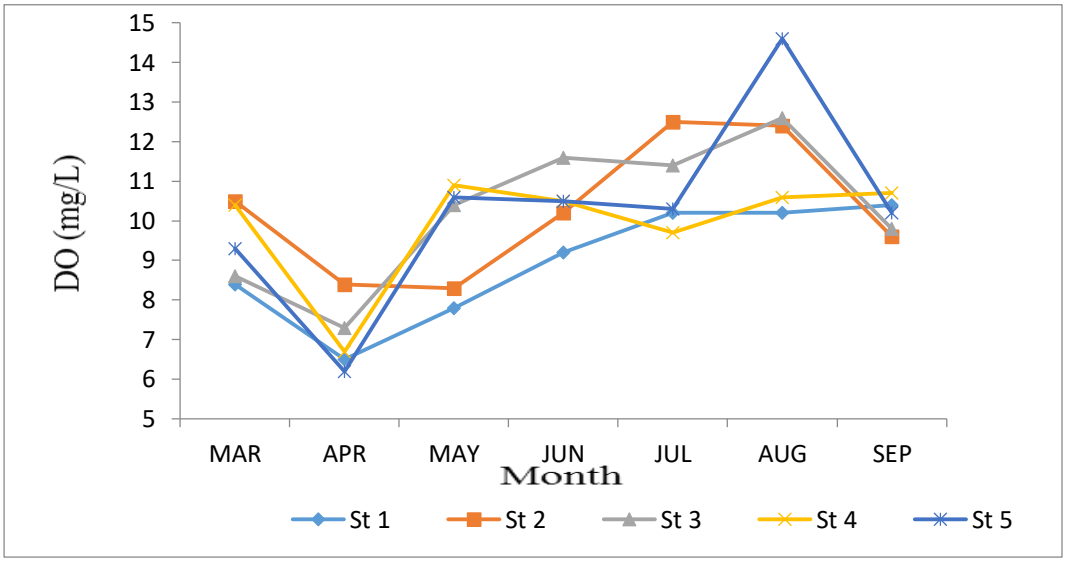


Figure 7: DO fluctuation of the Naf River estuary

### 4.1.6 Salinity:

The concentration of salinity varied from 8-30 ppt (Figure 8). No significance difference ($p>0.05$) was observed in salinity among the different Stations (Table 3). But this fluctuation was observed in monthly variation (Table 4). In July (2018) salinity decreased significantly ($p<0.05$). In this month the range of salinity in all Stations was similar.

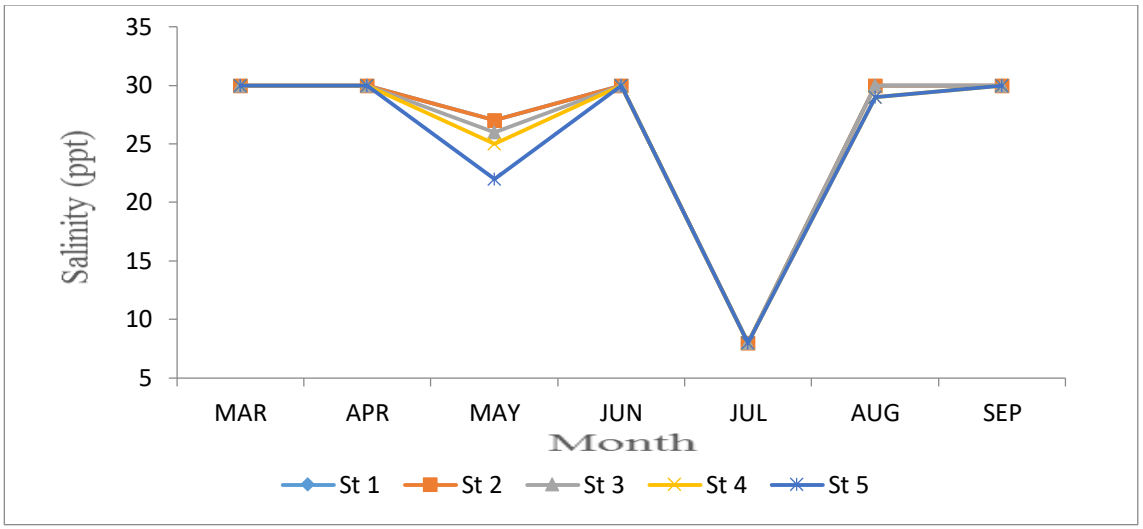


Figure 8: Salinity fluctuation of the Naf River

### 4.1.7 Depth:

The depth reading varied from 1-5 m during the study time during high tide (Figure 9). No significance difference ($p>0.05$) was observed in depth among the different stations (Table 3). But this fluctuation was observed in monthly variation (Table 4). In the month of June and July (2018) depth increased significantly ($p<0.05$).

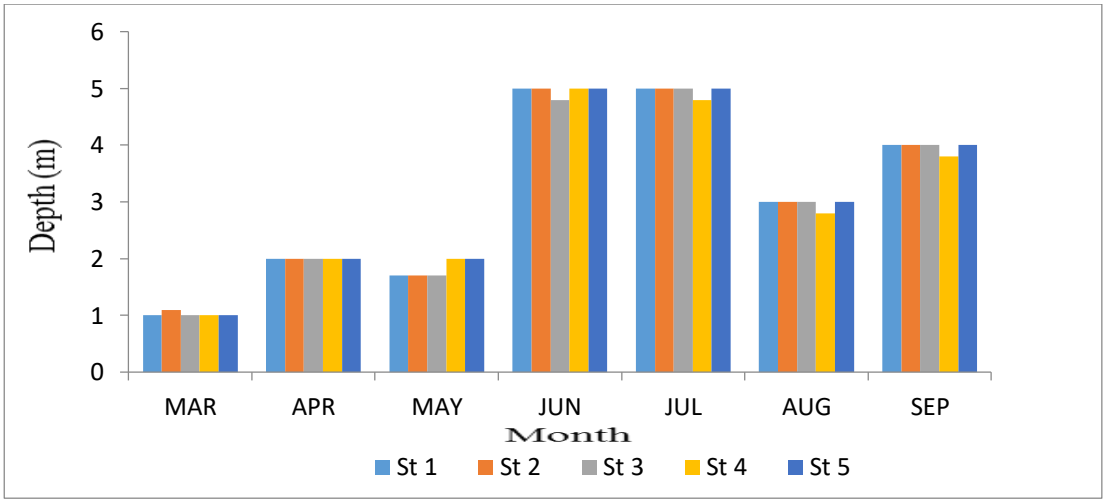


Figure 9: Depth fluctuation of the Naf River

### 4.1.8 Alkalinity:

The range of alkalinity fluctuated from 74-356 ppm (Figure 10). No significance difference ($p>0.05$) was observed in alkalinity among the different stations (Table 3). But this fluctuation was observed in monthly variation (Table 4). In July (2018) alkalinity decreased significantly ($p<0.05$).

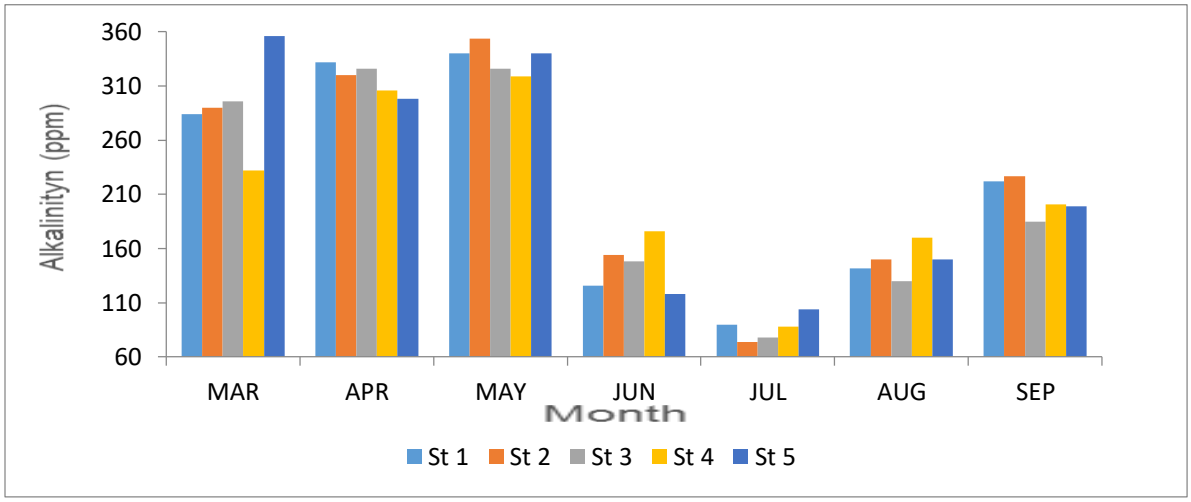


Figure 10: Alkalinity fluctuation of the Naf River

### 4.1.9 Nitrate:

The value of nitrate fluctuated from 0.15-0.2 ppm (Figure 11). No major fluctuation was observed during the study time. No significance difference ($p>0.05$) was observed in nitrate among the different stations and monthly variation (Table 3 and Table 4).

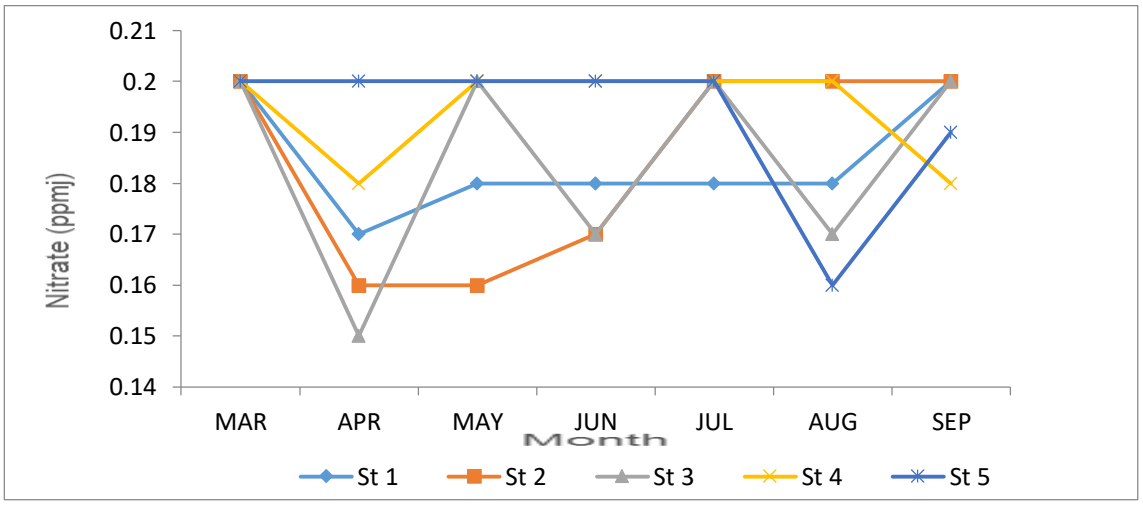


Figure 11: Nitrate fluctuation of the Naf River

### 4.1.10 Nitrite:

The value of nitrite fluctuated from 0.002-0.227 ppm (Figure 12). No major significance was observed throughout the study time. Also no significant difference ($p>0.05$) was observed in nitrate among the different stations (Table 3) but highly significantly difference ($p<0.05$) was observed in monthly variation (Table 4). Nitrite in June was significantly higher and March and July was significantly lower than the other months.

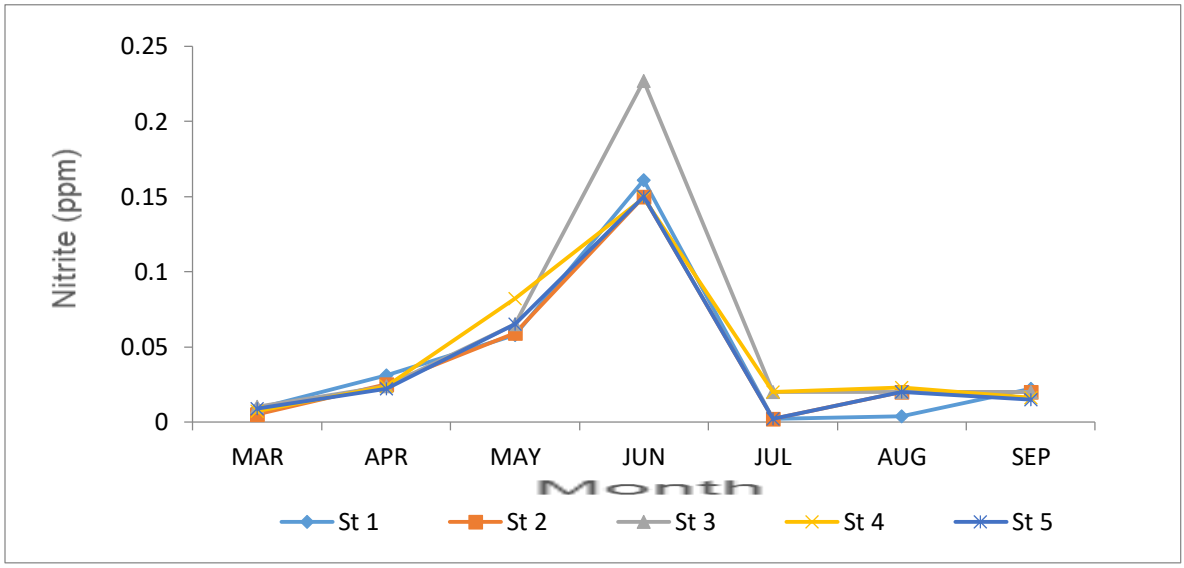


Figure 12: Nitrite fluctuation of the Naf River

### 4.1.11 Phosphate:

During the study time, the concentration of phosphate fluctuated from 0.005-1.6 ppm (Figure 13). No major significant was observed throughout the study time. Also no significant difference ($p>0.05$) was observed in phosphate among the different stations (Table 3) but highly significant difference ($p<0.05$) was observed in monthly variation (Table 4).

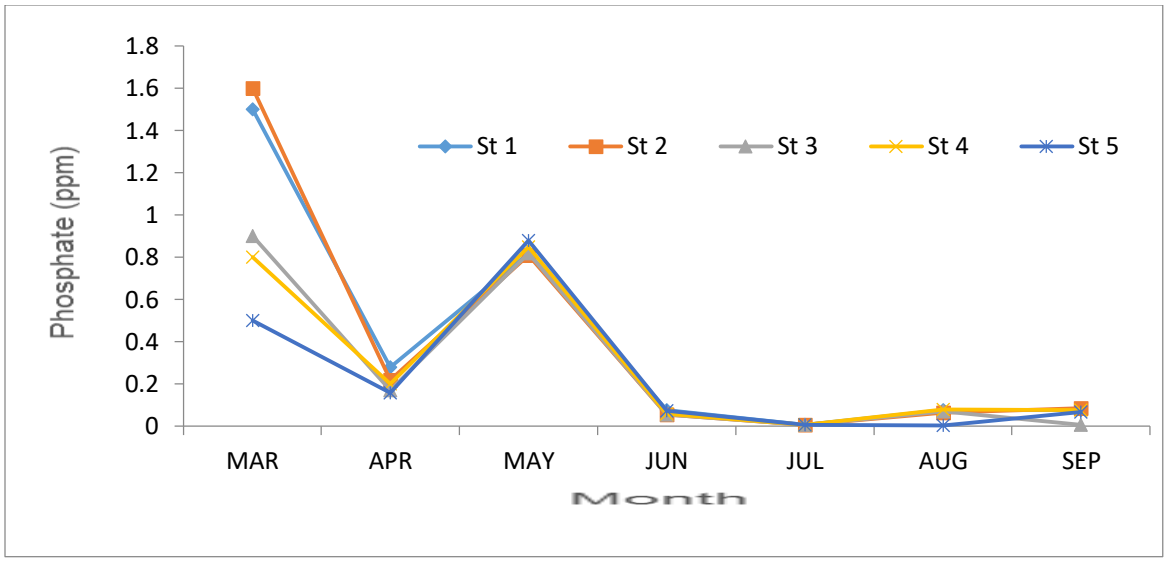


Figure 13: Phosphate fluctuation of the Naf River

### 4.1.12 Ammonia:

The value of ammonia varied from 0.013-0.442 ppm (Figure 14). No significance difference ($p>0.05$) was observed in ammonia among the different stations (Table 3). But this fluctuation was observed in monthly variation (Table 4). In the month of July (2018) ammonia increased significantly ($p<0.05$).

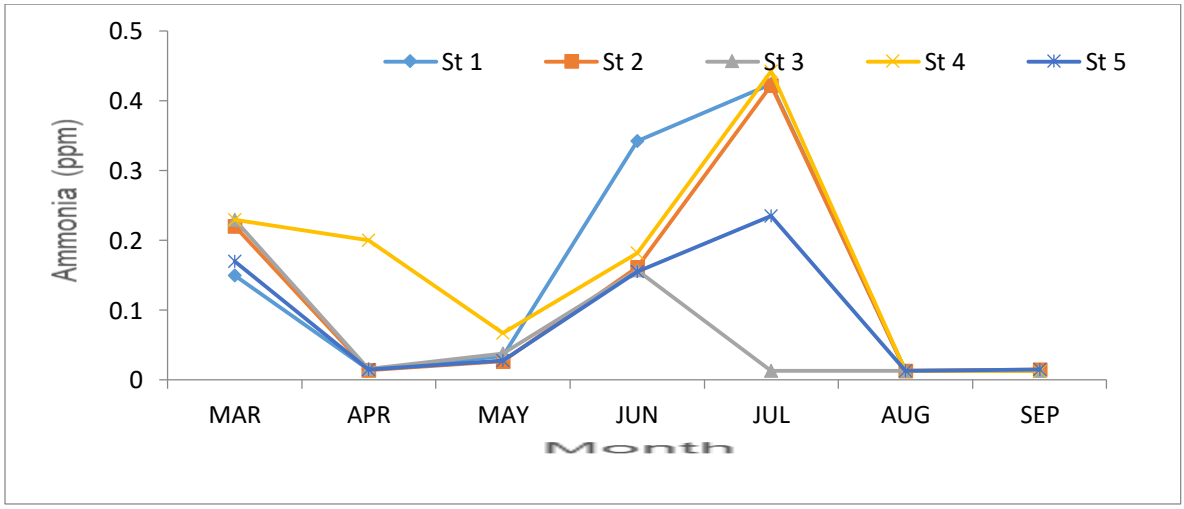


Figure 14: Ammonia fluctuation of the Naf River

### 4.1.13 Ammonium:

The value of ammonia varied from 1.4-1.8 ppm (Figure 15). No significance difference ($p>0.05$) was observed in ammonium among the different stations (Table 3). But this fluctuation was observed in monthly variation (Table 4).

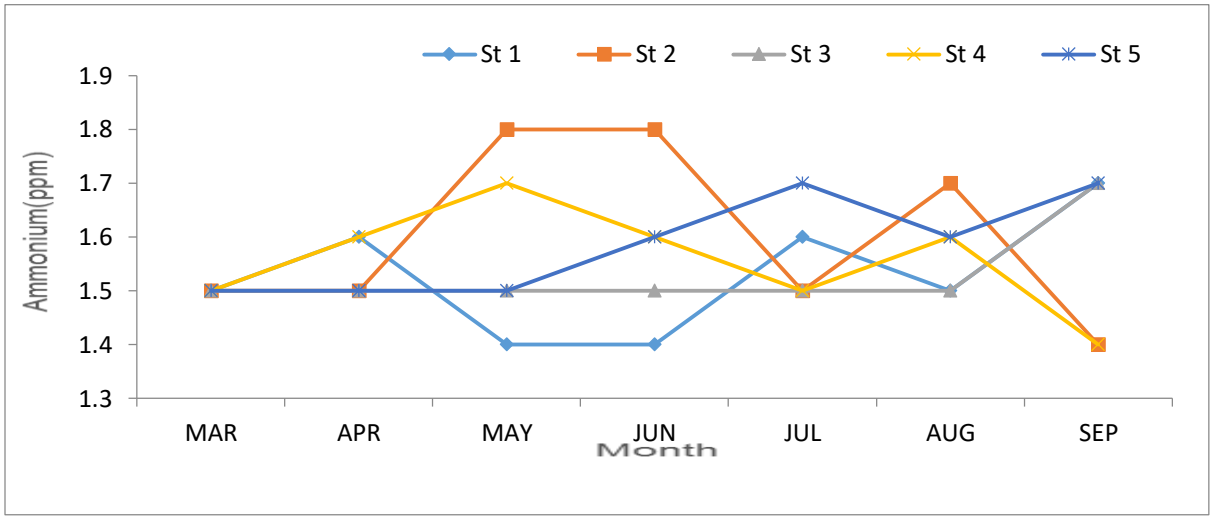


Figure 15: Ammonium fluctuation of the Naf River estuary

### 4.1.14 Chlorophyll-a:

The value of chlorophyll-a fluctuated from 1.8-6.3 (Figure 16). Wide range of fluctuation was observed throughout the study time. Highly significant difference ($p<0.05$) was also observed in chlorophyll-a. Highly significant difference ($p<0.05$) was observed in chlorophyll-a among the different stations (Table 3) as well as monthly variation (Table 4). In the month of August and September chlorophyll-a are higher and July are lower than other month.

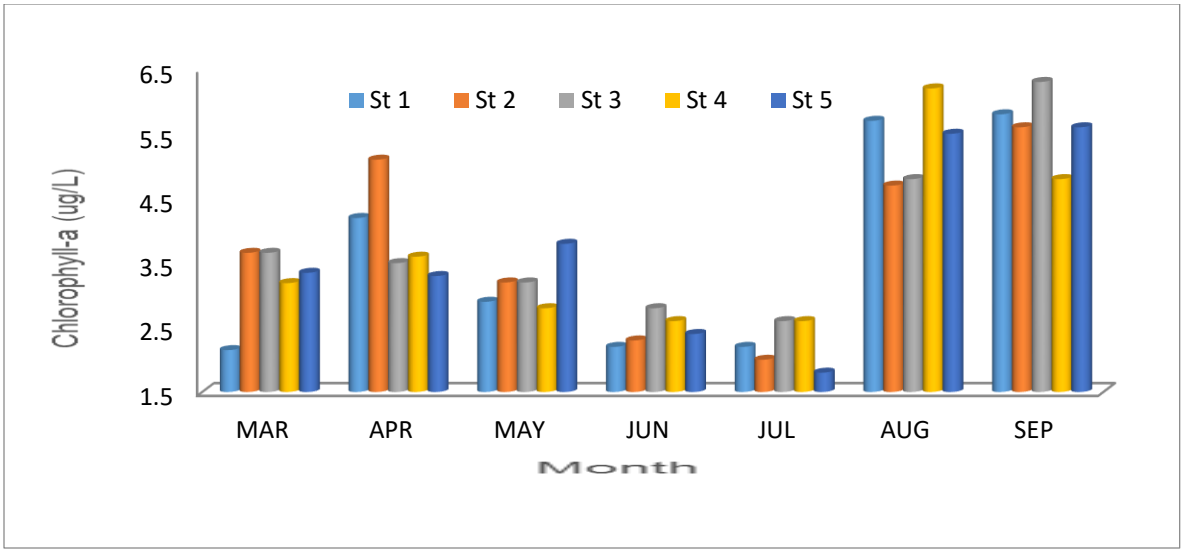


Figure 16: Chlorophyll-a fluctuation of the Naf River

Table 3: Water quality parameters (mean ± SD; min-max value is presented within the parenthesis) of five stations in Naf River recorded from March 2018 to September 2018

| **Parameters** | **Station 1** | **Station 2** | **Station 3** | **Station 4** | **Station 5** | **Sig. level** |
|---|---|---|---|---|---|---|
| Depth (m) | 3.1±1.56[a] (.9-5.5) | 3.08±1.51[a] (.9-5.2) | 3.1±1.58[a] (.8-5.5) | 3.04±1.44[a] (0.8-5.1) | 3.14±1.51[a] (.8-5.3) | NS |
| Temperature (˚C) | 28.96±1.2[a] (27-31.2) | 29.54±2.13[a] (26.5-34.1) | 29.67±1.91[a] (27.5-33.7) | 29.23±2.00[a] (26-33.2) | 29.73±2.00[a] (27.5-34.3) | NS |
| Transparency (cm) | 36±9.22[a] (18-51) | 38.9±11.46[a] (19-54) | 39.48±11.06[a] (17-53) | 40.29±10.94 [a] (21-57) | 40.57±11.78 [a] (18-58) | NS |
| Turbidity (NTU) | 55.01±43.5 [a] (18.3-147) | 51.9±44.21[a] (17.6-152) | 50.27±43.60[a] (15.2-150) | 47.59±33.32[a] (16.4-111) | 51.4±37.76[a] (19.3-136) | NS |
| pH | 7.83±.46[a] (7.2-8.8) | 7.9±.42[a] (7.3-8.6) | 7.9±.41[a] (7.2-8.6) | 7.9±.36[a] (7.3-8.5) | 7.9±.44[a] (7.2-8.8) | NS |
| DO(mg/l) | 8.95±1.4[a] (6.3-10.6) | 10.27±1.62[b] (8.2-12.7) | 10.24±1.76[b] (7.2-12.8) | 9.9±1.4[ab] (6.6-11.2) | 10.11±2.35[b] (6.1-14.8) | NS |
| Salinity(ppt) | 26.43±7.82[a] (7.5-31.5) | 26.43±7.84[a] (7-31) | 26.29±7.86 [a] (7.8-32) | 26.00±7.78 [a] (7.4-32) | 25.57±7.94[a] (7.9-32) | NS |
| Alkalinity (mg/l) | 219.4±97.1[a] (89-341) | 224.1±97.5[a] (73-356) | 212.5±97.03[a] (76-328) | 213.1±76.73[a] (86-320) | 223.6±101.1[a] (102-357) | NS |
| Nitrite(ppm) | .041±.054[a] (.001-.162) | .039±.05[a] (.001-.160) | .082±.10[a] (.009-.35) | .046±.049 [a] (.006-.150) | .048±.054[a] (.001-.16) | NS |

| | | | | | | |
|---|---|---|---|---|---|---|
| Nitrate(ppm) | .18±.016[a] (.16-.22) | .18±.02[a] (.15-.21) | .19±.026[a] (.14-.24) | .19±.012[a] (.17-.21) | .19±.022[a] (.15-.23) | NS |
| Phosphate (ppm) | .41±.53[a] (.005-1.6) | .41±.57[a] (.006-1.7) | .3±.39[a] (.005-1.1) | .3±.35[a] (.004-.9) | .24±.32[a] (.004-.9) | NS |
| Ammonia (ppm) | .14±.16[ab] (.012-.43) | .12±.15[ab] (.01-.42) | .07±.08[a] (.011-.24) | .16±.14[b] (.011-.44) | .09±.09[ab] (.011-.24) | NS |
| Ammonium (ppm) | 1.5±.16[a] (1.3-1.8) | 1.6±.2[a] (1.3-1.9) | 1.5±.2[a] (1.1-1.9) | 1.56±.19[a] (1.3-1.9) | 1.6±.13[a] (1.3-1.8) | NS |
| Chlorophyll a | 3.59±1.56 [a] (2.10-5.9) | 3.8±1.33 [a] (1.9-5.7) | 3.84±1.24 [a] (2.5-6.4) | 3.68±1.28 [a] (2.5-6.3) | 3.7±1.37 [a] (1.7-5.7) | NS |

Table 4: Water quality parameters (mean ± SD) in Naf River recorded from March 2018 to September 2018

| **Parameter** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Sig. level** |
|---|---|---|---|---|---|---|---|---|
| Depth (m) | 1.02±.16 | 2±.2 | 1.8±.5 | 4.96±.25 | 4.96±.26 | 2.96±.26 | 3.94±.28 | *** |
| Temperature(ºC) | 28.8±.38 | 33.05±1.34 | 27.98±.51 | 30.28±.44 | 27.76±.96 | 29.2±.97 | 28.8±.98 | *** |
| Transparency(cm) | 53.07±2.99 | 30.93±1.67 | 38.67±7.79 | 44.27±4.03 | 19.80±1.74 | 43.0±4.9 | 43.6±3.29 | *** |
| Turbidity(NTU) | 18.46±2.12 | 18.74±1.55 | 49.44±3.98 | 42.56±5.69 | 137.4±15.86 | 67.92±11.61 | 24.14±5.1 | *** |
| pH | 7.8±.14 | 7.6±.14 | 7.34±.099 | 8.28±.13 | 8.4±.34 | 7.82±.25 | 8.08±.35 | *** |
| DO(mg/l) | 9.44±.91 | 7.01±.82 | 9.6±1.3 | 10.2±.88 | 10.8±1.04 | 12.08±1.6 | 10.14±.45 | *** |
| Salinity (ppt) | 30±.96 | 30±1.18 | 25.4±2.15 | 30±1.1 | 8±.49 | 29.6±1.17 | 30±.096 | *** |
| Alkalinity | 291.6±40.84 | 316.4±13.08 | 335.8±12.71 | 144.13±21.55 | 86.8±10.94 | 148.4±13.66 | 206.8±16.14 | *** |
| Nitrite(ppm) | .008±.002 | .025±.005 | .066±.009 | .167±.032 | .009±.009 | .027±.035 | .056±.1 | *** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Nitrate(ppm) | .20±.016 | .17±.02 | .19±.022 | .185±.0196 | .189±.0155 | .182±.186 | .194±.018 | ** |
| Phosphate | 1.07±.45 | .21±.06 | .84±.031 | .064±.01 | .007±.001 | .06±.03 | .063±.03 | *** |
| Ammonia | .2±.036 | .052±.077 | .039±.015 | .2±.074 | .307±.171 | .013±.002 | .014±.002 | *** |
| Ammonium | 1.5±.16 | 1.56±.23 | 1.58±.174 | 1.58±.174 | 1.58±.15 | 1.58±.17 | 1.58±.19 | NS |
| Chlorophyll a | 3.20±.58 | 3.95±.69 | 3.18±.38 | 2.46±.24 | 2.24±.34 | 5.38±.6 | 5.62±.51 | *** |

Here, " * " indicates the level of significant,

* ⟶ <0.05; ** ⟶ <0.01; *** ⟶ <0.001

**4.2 Plankton composition:**

Plankton is the main food item for green mussel. Water sample collected for plankton observation. From the collected water sample of the Naf River both phytoplankton and Zooplankton were observed. A total number of phytoplankton genera, representatives of four classes were identified (Table 5). In Naf River 11 genera of zooplankton were identified (Table 6).

**4.2.1 Phytoplankton composition:**

The contribution of phytoplankton was 91.38% of the total count of plankton. The observed four class of phytoplankton was Bacillariophyceae, Chlorophyceae, Dinophyceae and Pyrrophyceae.

**4.2.1.1Bacillariophyceae:**

The class Bacillariophyceae dominated the plankton community in the Naf River with 62.06% total count consisting of 23 genera (Table 7). The most dominated genus of Bacillariophyceae was *Coscinodiscus, Ditylum* and *Skeletonema.* The contribution of *Coscinodiscus was 5.17%, Ditylum 2.12% and Skeletonema 1.47%* of the total count. No significance difference ($p>0.05$) was observed in Bacillariophyceae among the different stations and monthly variation but highly significant difference ($p<0.05$) was observed

among different stations in the month March (2018).The highest abundance was observed in March and lowest in April to August and again a peak started from September (Figure 17).

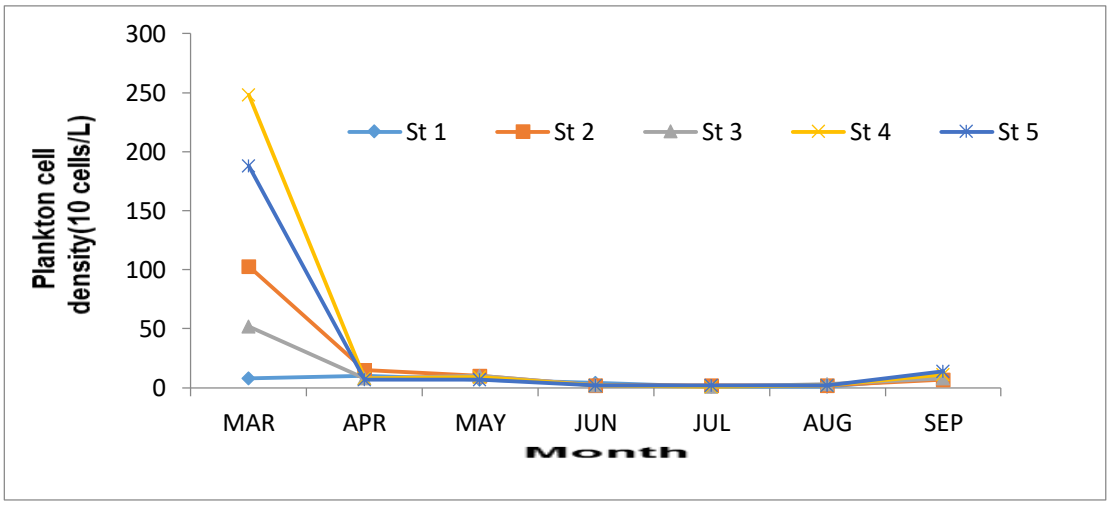


Figure 17: Graphical representation of monthly variation of Bacillariophyceae at Naf River estuary

#### 4.2.1.2 Chlorophyceae:

The class Chlorophyceae contributed 28.59% of the total count consisting 3 genera (*Spirogyra, Ulothrix and Oscillatoria*). Highly significant difference ($p<0.05$) was observed in Chlorophyceae in the monthly variation. However, Chlorophyceae in the month of July was significantly higher ($p<0.05$) than other months. In the month of July, highest abundance was observed (Figure 18).

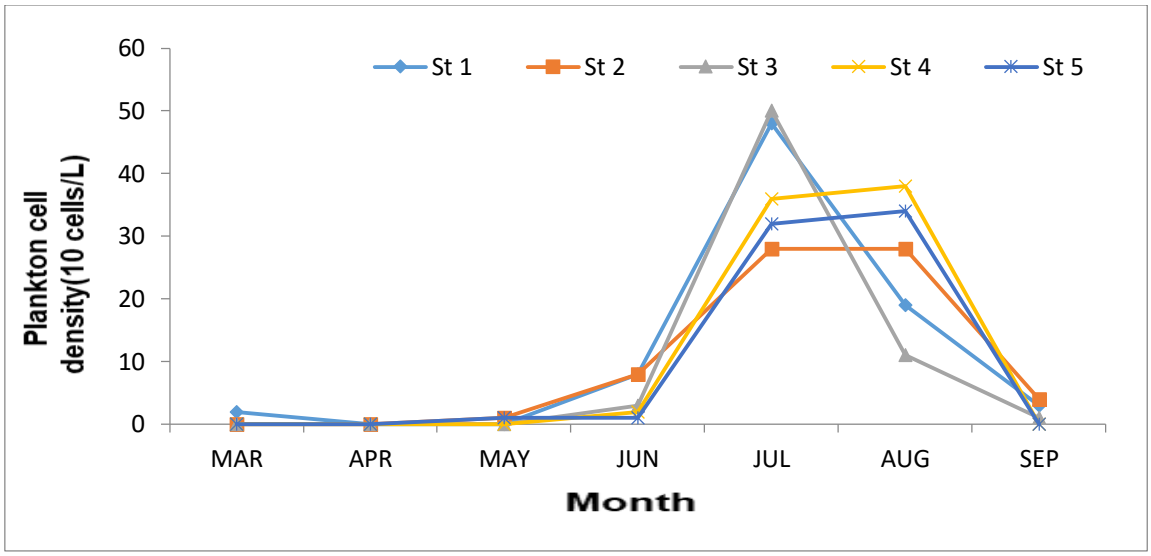


Figure 18: Graphical representation of monthly variation of Chlorophyceae at Naf River estuarine region

#### 4.2.1.3 Dinophyceae:

The class Dinophyceae contributed 0.14% of the total count consisting of only *Cerataulina* genera. No significance difference ($p>0.05$) was observed in Dinophyceae among the different stations and the monthly variation. Zigzag pattern were observed in the abundance of Dinophyceace during study period (Figure 19).

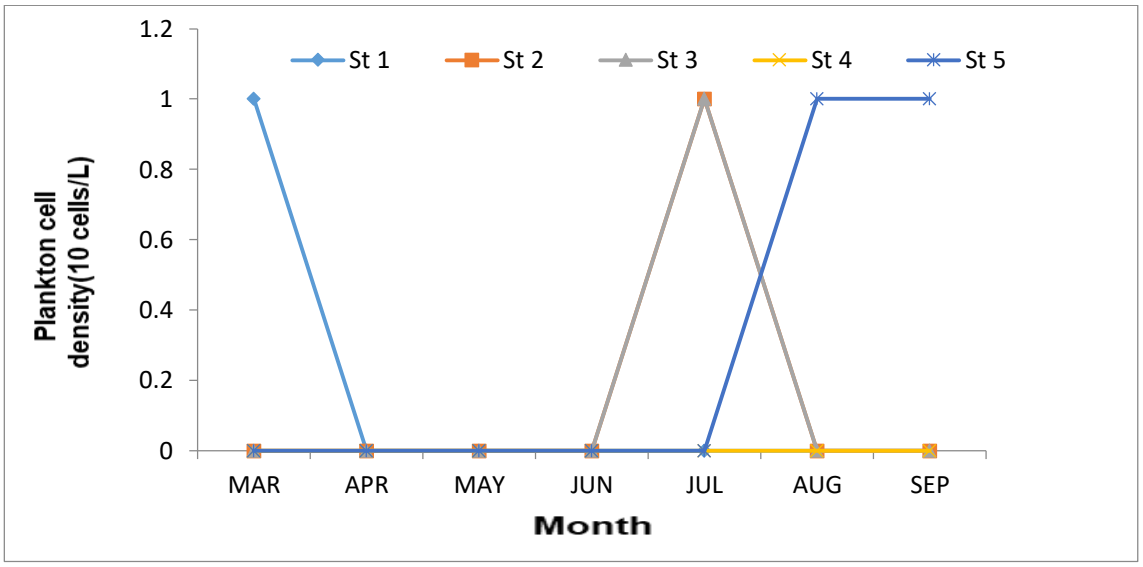


Figure 19: Graphical representation of monthly variation of Dinophyceae at Naf River estuarine region

#### 4.2.1.4 Pyrrophyceae:

The class Pyrrophyceae contributed 0.45% of the total count consisting of 2 genera (*Ceratium* and *Prorocentrum*). No significance difference ($p>0.05$) was observed in Pyrrophyceae among the different stations and the monthly variation. Irregular abundance were shown in this class during study time (Figure 20).

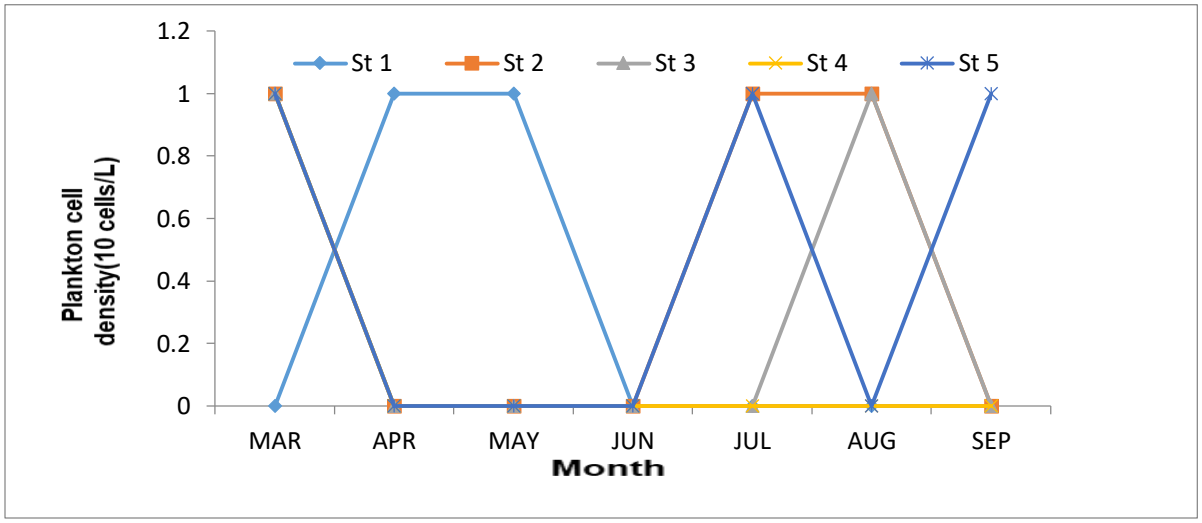


Figure 20: Graphical representation of monthly variation of Pyrrophyceae at Naf River

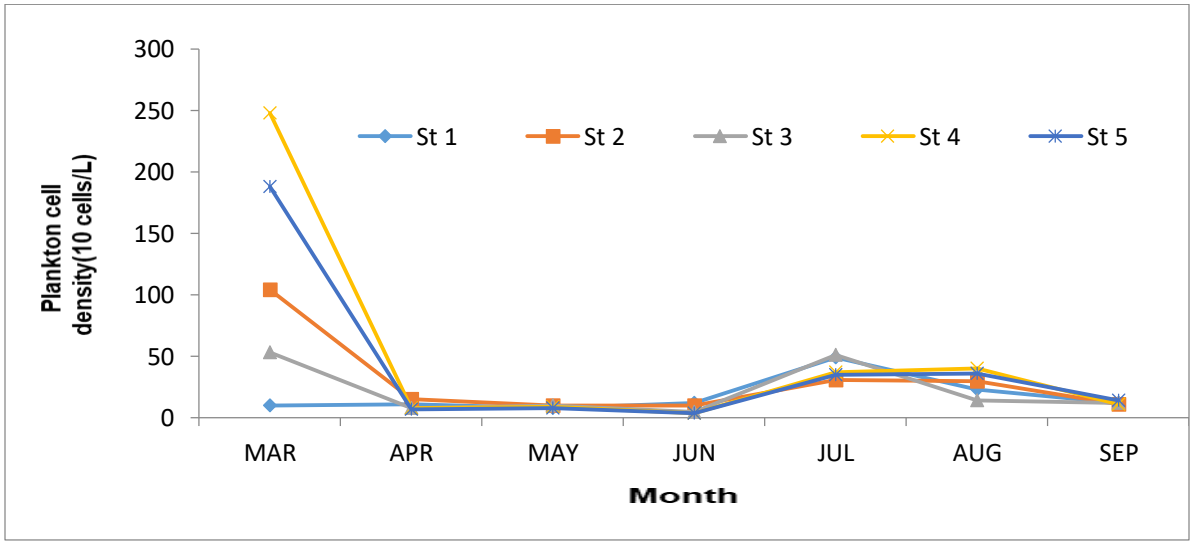


Figure 21: Graphical representation of monthly variation of total phytoplankton at Naf River region

Table 5: Phytoplankton composition in Naf River, recorded from March 2018 to September 2018

| Phytoplankton | Mean count ($\times 10^3$ cells/ L) | % | S1 | S1 (%) | S2 | S2 (%) | S3 | S3 (%) | S4 | S4 (%) | S5 | S5 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Asterionella* | 0.05 | 0.03 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0.05 | 0.11.2 |
| *Biddulphia* | 0.22 | 0.62 | 0.24 | 1.2 | 0.38 | 1.1 | 0.09 | 0.4 | 0.19 | 0.3 | 0.19 | 0.4 |
| *Chaetoceros* | .33 | 0.94 | 0.2 | 0.96 | 0.81 | 2.44 | 0.28 | 1.13 | 0.19 | 0.35 | 0.19 | 0.43 |
| *Coscinodiscus* | 1.84 | 5.17 | 2.1 | 10.6 | 2.09 | 6.32 | 1.86 | 7.34 | 1.67 | 3.04 | 1.48 | 3.29 |
| *Cyclotella* | 0.15 | 0.43 | 0.14 | 0.72 | 0.05 | 0.14 | 0.28 | 1.13 | 0.19 | 0.35 | 0.09 | 0.21 |
| *Diploneis* | .01 | 0.03 | 0 | 0.0 | 0 | 0.0 | 0.05 | 0.19 | 0 | 0.0 | 0 | 0.00 |
| *Ditylum* | 0.75 | 2.12 | 0.95 | 4.82 | 1.05 | 3.16 | 0.33 | 1.32 | 0.62 | 1.13 | 0.81 | 1.81 |
| *Eucampia* | .01 | 0.32 | 0.05 | 0.24 | 0.19 | 0.57 | 0.09 | 0.38 | 0.14 | 0.26 | 0.09 | 0.21 |
| *Golenkinia* | 0.03 | 0.08 | 0 | 0.0 | 0.14 | 0.43 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| *Hemiaulus* | 0.37 | 1.04 | 0.38 | 1.93 | 0.33 | 1 | 0.33 | 1.32 | 0.19 | 0.35 | 0.62 | 1.38 |
| *Leptocylindricus* | 0.01 | 0.03 | 0.05 | 0.24 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.00 |
| *Melosira* | 0.09 | 0.27 | 0.14 | 0.72 | 0 | 0.0 | 0.09 | 0.38 | 0.19 | 0.35 | 0.05 | 0.12 |
| *Nitzschia* | 0.03 | 0.08 | 0.05 | 0.24 | 0.05 | 0.14 | 0.05 | 0.19 | 0 | 0.0 | 0 | 0.0 |
| *Odontella* | 0.02 | 0.05 | 0 | 0.0 | 0 | 0.00 | 0.09 | 0.38 | 0 | 0.0 | 0 | 0.0 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pleurosigma* | 0.41 | 1.18 | 0.62 | 3.13 | 0.48 | 1.44 | 0.38 | 1.51 | 0.28 | 0.52 | 0.33 | 0.74 |
| *Pseudo-nitzschia* | 16.34 | 45.94 | 0 | 0.0 | 13.57 | 40.95 | 7.48 | 29.57 | 34.14 | 62.24 | 26.52 | 59.19 |
| *Rhizosolenia* | 0.42 | 1.18 | 0.19 | 0.96 | 0.43 | 1.29 | 0.28 | 1.13 | 0.95 | 1.74 | 0.24 | 0.53 |
| *Skeletonema* | 0.52 | 1.47 | 0.33 | 1.67 | 0.33 | 1 | 0.33 | 1.31 | 0.86 | 1.56 | 0.76 | 1.7 |
| *Tetradron* | 0.11 | 0.31 | 0.09 | 0.48 | 0.09 | 0.29 | 0.19 | 0.75 | 0.09 | 0.17 | 0.09 | 0.21 |
| *Triceratium* | 0.12 | 0.35 | 0.24 | 1.2 | 0.09 | 0.29 | 0.09 | 0.38 | 0.14 | 0.26 | 0.05 | 0.11 |
| *Thalassiosira* | 0.02 | 0.05 | 0.05 | 0.24 | 0.05 | 0.14 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| *Thalassionema* | 0.02 | 0.05 | 0 | 0.0 | 0.05 | 0.14 | 0 | 0.0 | 0 | 0.0 | 0.05 | 0.1 |
| *Thalassiothrix* | 0.11 | 0.32 | 0.09 | 0.48 | 0.09 | 0.29 | 0.24 | 0.94 | 0.05 | 0.09 | 0.09 | 0.21 |
| Total Bacillariophyceae | 22.08 | 62.06 | 5.86 | 29.64 | 20.19 | 60.92 | 12.57 | 49.72 | 40.05 | 73.0 | 31.71 | 70.78 |
| *Spirogyra* | 0.02 | 0.05 | 0.09 | 0.48 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| *Ulothrix* | 10.2 | 28.67 | 11.71 | 59.28 | 9.62 | 29.02 | 9.05 | 35.78 | 10.90 | 19.88 | 9.71 | 21.68 |
| *Oscillatoria* | 0.05 | 0.14 | 0 | 0.0 | 0 | 0.00 | 0.19 | 0.75 | 0 | 0.0 | 0.05 | 0.1 |
| Total Chlorophyceae | 10.27 | 28.59 | 11.81 | 59.76 | 9.62 | 29.02 | 9.24 | 36.53 | 10.90 | 19.88 | 9.76 | 21.78 |
| *Cerataulina* | 0.05 | 0.14 | 0.05 | 0.24 | 0.05 | 0.14 | 0.05 | 0.19 | 0 | 0.0 | 0.09 | 0.21 |
| Total Dinophyceae | 0.05 | 0.14 | 0.05 | 0.24 | 0.05 | 0.14 | 0.05 | 0.19 | 0 | 0.0 | 0.09 | 0.21 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ceratium* | 0.14 | 0.4 | 0.09 | 0.48 | 0.24 | 0.72 | 0.19 | 0.75 | 0.05 | 0.1 | 0.14 | 0.32 |
| *Prorocentrum* | 0.02 | 0.05 | 0 | 0.0 | 0.05 | 0.14 | 0 | 0.0 | 0 | 0.0 | 0.05 | 0.1 |
| Total Pyrrophyceae | 0.16 | 0.45 | 0.09 | 0.48 | 0.28 | 0.86 | 0.19 | 0.75 | 0.05 | 0.1 | 0.19 | 0.42 |
| Total Phytoplankton | 32.56 | 91.38 | 17.86 | 90.36 | 30.09 | 90.8 | 21.86 | 86.44 | 50.95 | 92.88 | 41.76 | 93.2 |

### 4.2.2 Zooplankton composition:

The contribution of zooplankton was 8.62% of the total count of collected plankton samples (Table 6). The dominated species of the zooplankton community in Naf River was Copepod (5.17% of the total plankton count), Rotifer (1.15% of the total plankton count). It was the main contributors to the bulk of the biomass. Highly significance difference ($p<0.05$) was observed in zooplankton among the different stations and the monthly variation in Naf River.

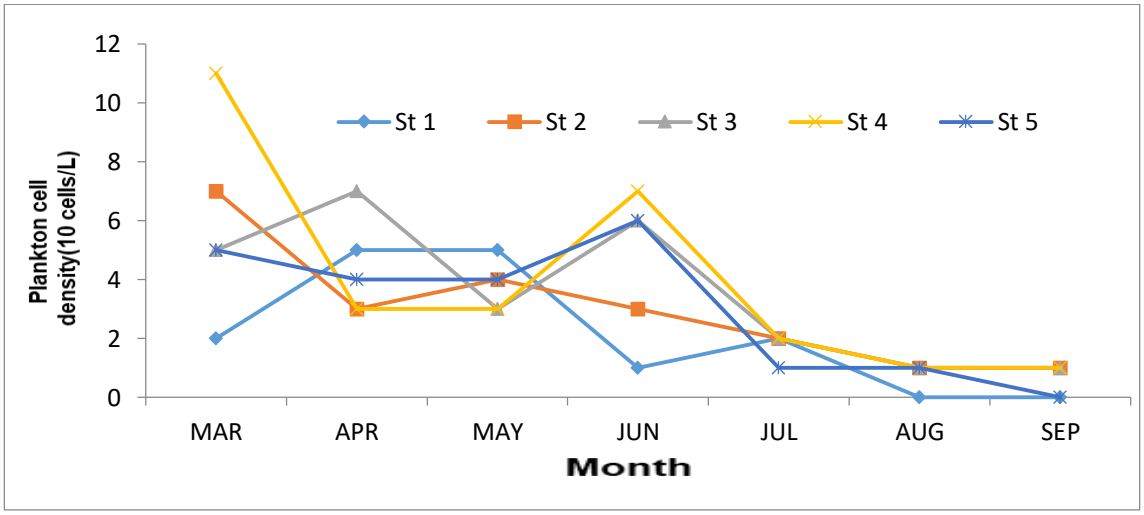


Figure 22: Graphical representation of monthly variation of zooplankton at Naf Riverine area

Table 6: Zooplankton composition in Naf River, recorded from March 2018 to September 2018

| Zooplankton | Mean count ($\times 10^3$cells/L) | % | S1 | S1 (%) | S2 | S2 (%) | S3 | S3 (%) | S4 | S4 (%) | S5 | S5 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Acetes* | 0.01 | 0.03 | 0.05 | 0.24 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Amphipoda | 0.03 | 0.08 | 0.05 | 0.24 | 0 | 0.0 | 0.05 | 0.19 | 0 | 0.0 | 0.05 | 0.1 |
| Copepoda | 1.84 | 5.17 | 0.95 | 4.82 | 1.52 | 4.6 | 2.09 | 8.29 | 2.29 | 4.17 | 2.33 | 5.2 |
| Crab zoea | 0.25 | 0.69 | 0.14 | 0.72 | 0.43 | 1.29 | 0.09 | 0.38 | 0.38 | 0.69 | 0.19 | 0.4 |
| Daphnia | 0.01 | 0.03 | 0 | 0.0 | 0.05 | 0.14 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Fish egg | 0.29 | 0.8 | 0.29 | 1.45 | 0.29 | 0.86 | 0.29 | 1.13 | 0.52 | 0.95 | 0.05 | 0.1 |
| Isopoda | 0.02 | 0.05 | 0 | 0.0 | 0 | 0.0 | 0.09 | 0.38 | 0 | 0.0 | 0 | 0.0 |
| Lucifer | 0.01 | 0.03 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0.05 | 0.1 |
| Mollusc larvae | 0.02 | 0.05 | 0 | 0.0 | 0 | 0.0 | 0.05 | 0.19 | 0.05 | 0.09 | 0 | 0.0 |
| Rotifer | 0.41 | 1.15 | 0.38 | 1.93 | 0.48 | 1.44 | 0.52 | 2.07 | 0.38 | 0.69 | 0.29 | 0.64 |
| Shrimp larvae | 0.2 | 0.56 | 0.05 | 0.24 | 0.29 | 0.86 | 0.24 | 0.94 | 0.33 | 0.61 | 0.09 | 0.21 |
| Total zooplankton | 3.09 | 8.62 | 1.90 | 9.64 | 3.05 | 9.2 | 3.43 | 13.56 | 3.90 | 7.12 | 3.05 | 6.8 |

### 4.3 Site suitability for *P. viridis* farming:

The variations of environmental parameters over study period were used in site suitability rating system. The environmental variables were given a weighted value based on its effects to the growth or survival of the bivalves. The total weighted values were used to evaluate the suitability of the stations. The evaluation of biophysical variation was considered to be most appropriate for aquaculture purpose.

Table 7: Site suitability rating system for Naf River, Teknaf, Cox's Bazar

| **Parameter** | **Station 1** | | **Station 2** | | **Station 3** | | **Station 4** | | **Station 5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Rating** | **Score** | **Rating** | **Score** | **Rating** | **Score** | **Rating** | **Score** | **Rating** | **Score** |
| Salinity | 3 | .45 | 3 | .45 | 3 | .45 | 3 | .45 | 3 | .45 |
| DO | 10 | 1.5 | 10 | 1.5 | 10 | 1.5 | 10 | 1.5 | 10 | 1.5 |
| pH | 5 | .5 | 4 | .4 | 5 | .5 | 4 | .4 | 5 | .5 |
| Temperature | 8 | 1.2 | 8 | 1.2 | 8 | 1.2 | 8 | 1.2 | 7 | 1.2 |
| Chlorophyll-a | 6 | .9 | 7 | 1.05 | 6 | .9 | 6 | .9 | 6 | .9 |
| Water depth | 5 | 0.75 | 6 | 0.90 | 5 | 0.75 | 5 | 0.75 | 6 | 0.90 |
| Weighted | 5.3 | | 5.5 | | 5.3 | | 5.2 | | 5.45 | |
| Category | Medium | | Medium | | Medium | | Medium | | Medium | |

The result of the site evaluation was summarized in table 7. The environmental variables in all stations were categorized as **medium** in terms of suitability for green mussel culture.

# CHAPTER FIVE

# DISCUSSION

The purpose of this study was to identify whether it is possible to grow green mussels in the Naf River based on the evaluation of biophysical parameters or not. To assess the environmental parameters of potential sites, a site suitability rating system was developed. Identifying the most suitable sites for this aquaculture activity is critical for farmers and investors. The biophysical evaluation system was an important tool to get fast and effective results of potential sites for green mussel farming. Furthermore, the gathered information will provide the best information to determine the feasibility of green mussel farming.

## 5.1 Environmental variables:

Generally the range of environmental variables (Temperature, Salinity, pH and Dissolve oxygen) in all five stations recorded over this research period. Temperature, DO and pH in all stations were recorded within tolerance range of *P. viridis* (Sallih, 2005; Tan and Ransangan, 2015).

However, all stations experienced relatively higher temporal salinity fluctuation in July during high rainfall and hill run off. *P. viridis* is a marine water mussel species that requires high salinity of 27-35 ppt for optimal growth (Aypa, 1990; Rajagopal et al., 2006; Tan and Ransangan, 2014). Low salinity caused by fresh water dilution during heavy rainfall and it might negatively affects the growth and survival of the bivalve (Saxby, 2002).

Though, Lovatelli (1988) showed that the bottom culture can be practiced in areas where the mean tide level is less than 1.5 m. But the weighted value and rating point for the range of environmental parameters for mussel farming based on Sivalingam (1977), Aypa (1990), Lovatelli (1990), Hickman (1992), Saxby (2002) and FIGIS (2005) were investigated that the rating point for 3 m depth was 4 and less than 3 m the point was very poor 2-1. Aypa (1990) also showed that the favorable water depth for both seed collection and mussel cultivation is 2 m or more. The water depth of the study area varied from 1-5 m. From this consultation the water depth in Naf River be considered as suitable for green mussel culture but not well.

Because of hill landslides and runoff high turbidity was observed during July which affect in primary production. For this reason, the cultured species face slow growth rates due to limited food availability during this turbid conditions. Aypa (1990) reported that the high turbidity might not prevent the predator.

The level of transparency is important in mussel culture, because it can determine the presence of suspended, organic and inorganic matters and also level of primary production in culture area. Culture site having a disc reading of less than 25 cm should be considered unsuitable for mussel culture (Lovatelli, 1988). The value of transparency measured from 18-56 cm during this study. Because of high hill runoff low transparency was observed highest during the month of July.

Organic effluents from land are known to be the main factor reducing the pH value in marine environments (Sany et al., 2004). The pH value fluctuated from 7.2-8.7 during study time. The level of DO in the study might not be the direct factor that induced culture potentiality in *P. viridis* but it could be the consequences from the energy demanding selective feeding activities in *P. viridis* which requires high level of oxygen (Bayne, 1998). The level of DO varied from 6.2-14.6 mg/l.

### 5.2 Plankton composition

#### 5.2.1 Phytoplankton composition

Most of the aquatic organisms directly or indirectly depend on phytoplankton for the basic sources of food and so phytoplankton population indicates the productive status of a water body. In natural water phytoplankton abundance depends upon the supply of nutrients. Small diatoms Bacillariophyceae were found dominant in Naf River. *Coscinodiscus* and *Skeletonema* was the dominant genus of Bacillariophyceae. *Coscinodiscus* was also found all around the study period. *P. viridis* like to feed mostly *Coscinodiscus*. Enrichment of stomach content with *Coscinodiscus* spp. was recorded *P. viridis* (Tan and Ransangan, 2017). So, it is a positive result which indicates that in Naf River *P. viridis* culture can be possible.

Among phytoplankton, 0.05% *Prorocentrum,* 2.12% *Ditylum,* 0.05% *Thalassionema,* 1.18% *Rhizosolenia* were found in Naf River. *Prorocentrum, Ditylum, Thalassionema, Rhizosolenia* are also favorite species of *P. viridis* (Tan and Ransangan, 2017).

*Cheatoceros* spp. was also found in Naf River. But *P. viridis* never consume this species while *Coscinodiscus* was low to detect in water (Tan and Ransangan, 2017).

Larger phytoplankton species particularly *Coscinodiscus* spp. dominating in the nutrient enriched coastal waters of Northern Bay of Bengal (Sarkar et al., 2006) and Sepanggar Bay (Sidik et al., 2008). Therefore, small phytoplankton species have an advantage, it can absorb the available nutrients over the large phytoplankton species (Tan and Ransangan, 2015; Cemeno et al., 2006).

### 5.2.2 Zooplankton composition:

Zooplankton is an important alternative food source for *P. viridis* which comprised about 2.5-20.2% of the total diet of this green mussel (Tan and Ransangan, 2006). About 8.62% of the total count of plankton was investigated as zooplankton from Naf River. The dominated species of the zooplankton community in Naf River was Copepod (5.17% of the total plankton count) used by *P. viridis* mostly. High numbers of copepod and bivalve larvae were found in the *P. viridis* stomach (Tan and Ransangan, 2017). Zooplankton concentration could be the result of phytoplankton density in the study area. The parameters as temperature, pH, DO, phytoplankton population density and gross primary productivity exhibited a positive correlation with the zooplankton population density (Prabhahar et al., 2011).

### 5.3 Site suitability for *P. viridis* farming:

Site capability rating system is an important tool to achieve a fast and effective evaluation for potential farming sites of green mussel (Sallih, 2005). The consecutive rating system of a specific area is the first and foremost consideration before aquaculture. All station can be considered as a moderate site based on biophysical evaluation. In term of food availability, the chlorophyll-a consideration in all stations were higher than the minimum recommended consideration of 1µg/L (Saxby, 2002). This indicated that the food availability of Naf River is adequate to sustain the bivalve farming (Tan and Ransangan,

2014). Because of unfavorable condition, the environmental parameter fluctuated in some months, which is not favorable for green mussel culture.

# CHAPTER SIX

# CONCLUSION

Green mussel (*P. viridis*) is one of the high demand species used as the main food to the tribal people of Bangladesh as well as neighboring countries like Japan, Thailand, Malaysia, Cambodia and China. Fish processing industries, exporter and other associated stakeholders can export green mussel flesh to those neighboring countries. Green Mussels are rich source of selenium, iron, Vitamin B12 and iodine, magnesium, calcium protein and omega-3 from EPA and DHA in one serving. Naf River bears significance as an important water body supporting the livelihood of the nearby people. This potential industry will offer employment opportunities for the unemployed coastal people in the adjacent areas of Naf River. About two million tribal people who regularly take mollusks meat in their daily diet will be benefited through this research and would be able to get cheap sources of alternative protein by increased supply and consumption of green mussel. Properly processed green mussel flesh can be exported to foreign countries as a new item along with shrimp and crabs. Developing of *P. viridis* culture techniques can be a great source of livelihood for many people and can be a means for developing the socio-economic conditions. But it is critical for farmers and investors for introducing a new species for commercial aquaculture farming. The site selection is generally the most critical step especially as it needs some biological background in assessing the site suitability. In the Naf River, the total plankton count varies $12.27\times10^3$ to $126.67\times10^3$ cells/L. The water quality parameters such as temperature, pH, DO, in all stations were within the tolerance range of *P. viridis*. Higher temporal fluctuation of salinity was observed due to high rainfall and hill runways. After analyzing all biophysical parameters, all the stations are moderately suitable for green mussel culture. In all stations, the chlorophyll-a consideration were higher than the minimum recommendation consideration of 1 µg/L. The site suitability rating system could become an important planning and management tool to achieve a fast and effective evaluation for potential farming sites of green mussel culture in the future.

# CHAPTER SEVEN

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# APPENDIX I

Table no 8: Monthly abundance of phytoplankton in Naf River, recorded from March 2018 to September 2018

| **Phytoplankton** | **Mean count ($\times 10^3$cells/L)** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** |
|---|---|---|---|---|---|---|---|---|
| *Asterionella* | 0.01 | 0 | 0 | 0 | 0 | 0.07 | 0 | 0 |
| *Biddulphia* | 0.22 | 0.07 | 0 | 0.2 | 0.2 | 0 | 0.07 | 1 |
| *Chaetoceros* | 0.33 | 0 | 1.27 | 0.47 | 0 | 0.2 | 0.07 | 0.33 |
| *Coscinodiscus* | 1.84 | 2.8 | 3.93 | 2.6 | 0.67 | 0.4 | 0.73 | 1.73 |
| *Cyclotella* | 0.15 | 0.27 | 0.27 | 0.2 | 0 | 0 | 0.07 | 0.27 |
| *Diploneis* | 0.01 | 0 | 0 | 0 | 0.07 | 0 | 0 | 0 |
| *Ditylum* | 0.75 | 0.13 | 1.13 | 0.67 | 0 | 0 | 0.07 | 3.27 |
| *Eucampia* | 0.11 | 0.53 | 0.13 | 0.13 | 0 | 0 | 0 | 0 |
| *Golenkinia* | 0.03 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0 |
| *Hemiaulus* | 0.37 | 0.13 | 0.8 | 0.73 | 0.33 | 0.27 | 0.27 | 0.07 |
| *Leptocylindricus* | 0.01 | 0 | 0.07 | 0 | 0 | 0 | 0 | 0 |
| *Melosira* | 0.09 | 0.13 | 0 | 0 | 0 | 0.2 | 0.27 | 0.07 |
| *Nitzschia* | 0.03 | 0.07 | 0 | 0.07 | 0.07 | 0 | 0 | 0 |
| *Odontella* | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 | 0.13 |
| *Pleurosigma* | 0.42 | 0.27 | 0.47 | 0.6 | 1.13 | 0.2 | 0.07 | 0.2 |
| *Pseudo-nitzschia* | 16.34 | 112.53 | 0.07 | 1.8 | 0 | 0 | 0 | 0 |
| *Rhizosolenia* | 0.42 | 1.73 | 0.53 | 0.47 | 0 | 0.07 | 0.07 | 0.07 |
| *Skeletonema* | 0.52 | 0.87 | 0 | 0.07 | 0.13 | 0.07 | 0.07 | 2.47 |
| *Tetradron* | 0.11 | 0.07 | 0.13 | 0.27 | 0 | 0 | 0.13 | 0.2 |
| *Triceratium* | 0.12 | 0 | 0.33 | 0.13 | 0 | 0.07 | 0 | 0.33 |
| *Thalassiosira* | 0.02 | 0.13 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Thalassionema* | 0.02 | 0.07 | 0.07 | 0 | 0 | 0 | 0 | 0 |
| *Thalassiothrix* | 0.11 | 0.2 | 0.47 | 0.07 | 0 | 0 | 0 | 0.07 |
| Total Bacillariophyceae | 22.08 | 119.73 | 9.67 | 8.8 | 2.67 | 1.53 | 1.87 | 10.27 |
| *Spirogyra* | 0.02 | 0.07 | 0 | 0 | 0 | 0.07 | 0 | 0 |
| *Ulothrix* | 10.2 | 0.27 | 0 | 0.13 | 4.27 | 38.6 | 26.67 | 1.47 |
| *Oscillatoria* | 0.05 | 0 | 0 | 0 | 0.13 | 0.07 | 0 | 0.13 |
| Total Chlorophyceae | 10.27 | 0.34 | 0 | 0.13 | 4.4 | 38.73 | 26 | 1.6 |
| *Cerataulina* | 0.05 | 0.07 | 0 | 0 | 0 | 0.13 | 0.07 | 0.07 |
| Total Dinophyceae | 0.05 | 0.07 | 0 | 0 | 0 | 0.13 | 0.07 | 0.07 |
| *Ceratium* | 0.14 | 0.4 | 0.07 | 0.07 | 0 | 0.2 | 0.2 | 0.07 |
| *Prorocentrum* | 0.02 | 0.07 | 0 | 0 | 0 | 0.07 | 0 | 0 |
| Total Pyrrophyceae | 0.16 | 0.47 | 0.07 | 0.07 | 0 | 0.27 | 0.2 | 0.07 |
| Total Phytoplankton | 32.56 | 120.61 | 9.73 | 8.67 | 7 | 40.67 | 28.8 | 12.07 |

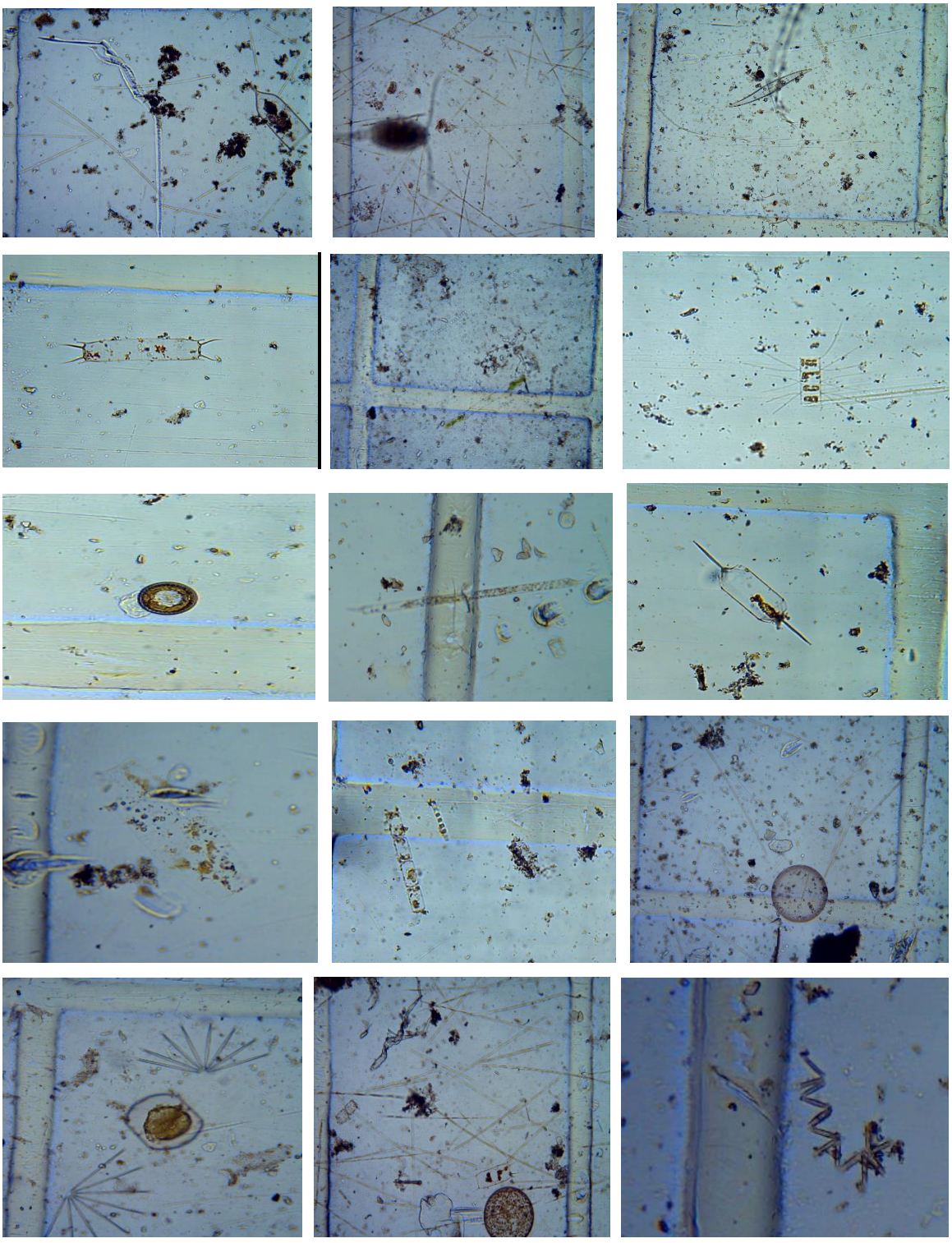
# APPENDIX II

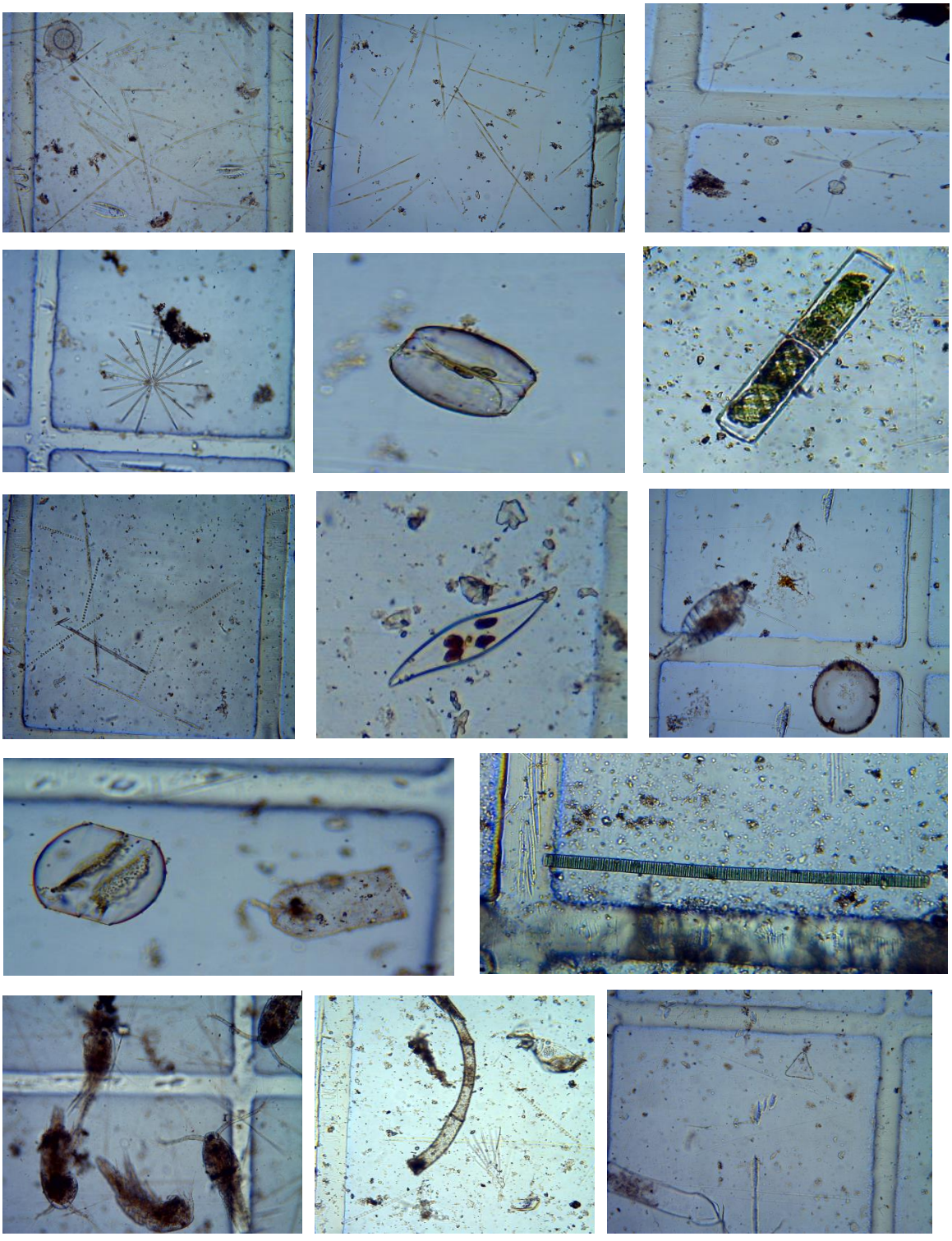
Table no 9: Monthly abundance of zooplankton in Naf River, recorded from March 2018 to September 2018

| **Zooplankton** | **Mean count ($\times 10^3$cells/L)** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** |
|---|---|---|---|---|---|---|---|---|
| *Acetes* | 0.01 | 0 | 0.07 | 0 | 0 | 0 | 0 | 0 |
| Amphipoda | 0.03 | 0 | 0.07 | 0 | 0.13 | 0 | 0 | 0 |
| Copepoda | 1.84 | 3.07 | 2.47 | 1.8 | 3.53 | 1.6 | 0.4 | 0 |
| Crab zoea | 0.25 | 0.6 | 0.13 | 0.53 | 0.33 | 0.07 | 0 | 0.07 |
| Daphnia | 0.01 | 0.07 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fish egg | 0.29 | 0.53 | 0.4 | 0.73 | 0.13 | 0.07 | 0.07 | 0.07 |
| Isopoda | 0.02 | 0.07 | 0 | 0 | 0 | 0 | 0.07 | 0 |
| Lucifer | 0.01 | 0 | 0 | 0.07 | 0 | 0 | 0 | 0 |
| Mollusc larvae | 0.02 | 0 | 0 | 0.07 | 0.07 | 0 | 0 | 0 |
| Rotifer | 0.41 | 0.67 | 1.27 | 0.53 | 0.27 | 0.13 | 0 | 0 |
| Shrimp larvae | 0.2 | 1.07 | 0.07 | 0 | 0.2 | 0 | 0 | 0.07 |
| Total zooplankton | 3.09 | 6.08 | 4.4 | 3.73 | 4.67 | 1.87 | 0.53 | 0.2 |

# APPENDIX III

## Some observed plankton under microscope





# APPENDIX IV

**Materials and Methodology's picture in laboratory:**

Fig no 23: Nitrite test of sample


Fig no 24: Nitrate test of sample

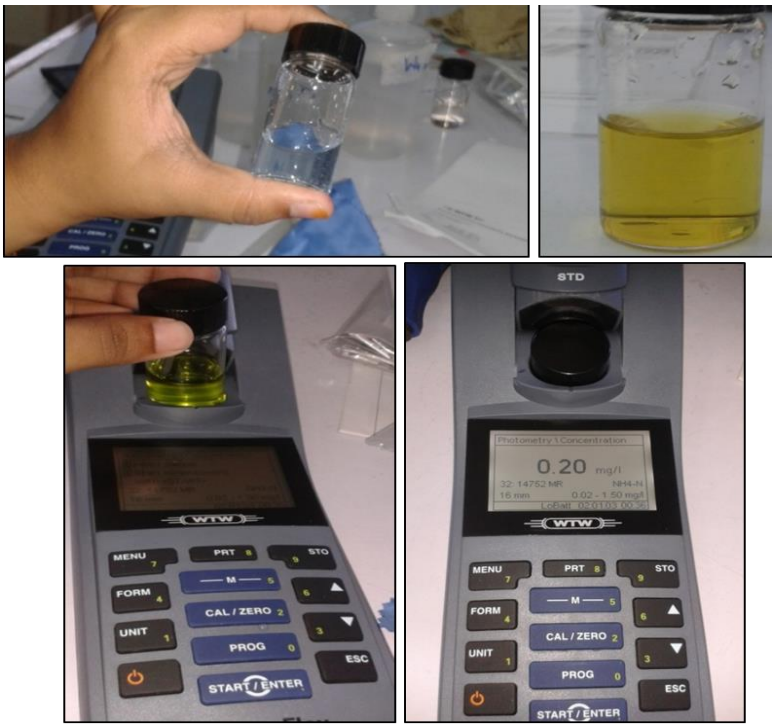



Fig no 25: Ammonia test of sample


Fig no 26: Ammonium test of sample


Fig no 27: Phosphate test of sample


Fig no 28: Chlorophyll-a test

Fig no 29: Alkalinity test of sample

Fig no 30: Filtration of sample water

# APPENDIX V

**Some picture of field work:**








## Brief Biography of the author

This is Md. Abdullah Al Mahmud; son of Md. Harun and Jabunnasa Begum from Rangunia Upazila under Chattogram district of Bangladesh. He passed the Secondary School Certificate Examination in 2011 and Higher Secondary Certificate Examination in 2013 from Chittagong Engineering University School and College, Chattogram. He obtained his B. Sc. in Fisheries (Hons.) Degree in 2017 from Faculty of Fisheries, Chittagong Veterinary and Animal Sciences University (CVASU), Chattogram, Bangladesh. Now, he is a candidate for the degree of MS in Marine Bioresource Science under the Department of Marine Bioresource Science, Faculty of Fisheries, CVASU. He has great interest on scientific research on Marine Science.