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Final Project 2001

EFFECTS OF WATER HYACINTH ON WATER QUALITY OF WINAM GULF, LAKE VICTORIA.

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ABSTRACT

Lake Victoria is the second largest freshwater body in the world by surface area. It is important for the livelihood of people living in the area. The lake is currently facing many problems, one of which is macrophyte encroachment mainly the water hyacinth, *Eicchornia crassipes.* Winam Gulf is a large inlet from Lake Victoria that extends into Kenya. In order to study the effects of water hyacinth on water quality in the gulf, measurements of water properties were made in the north-eastern corner of the gulf, when the area was covered with hyacinth in March 2000. The hyacinth was then cut and dumped on the bottom during the period June to beginning of August when all water hyacinth had been removed with measurements being made again in July. Water properties were again measured in November to see the changes made by the cutting of the hyacinth. The oxygen levels in the gulf were found to increase significantly (2-4 mg/l) after the shredding of the hyacinth. The largest changes occurred in the bottom layers. This happened quite soon after the shredding was completed.

Current measurements were also made and they indicate that the wind is the main driving force of currents in the area. They also show that the circulation in the gulf is mainly horizontal rather than vertical.

TABLE OF CONTENTS

FIGURES AND TABLES

1. INTRODUCTION

1.1 Lake Victoria

Lake Victoria with an area of 68,800 km^2 is the second largest freshwater lake in the world. The lake is shared between Kenya, Uganda and Tanzania (Figure 1) in the ratios 6%, 45% and 49% of the surface area respectively. It stretches 412 km from north to south between 0°30'N and 3°12'S and 355 km from west to east between 31°37' and 34°53'E. It lies across the equator at an altitude of 1135 m above sea level. The lake is relatively shallow, with a recorded maximum depth of about 80 m and an average depth of 40 m. It has a water volume of about 2,760 km^3. It has a long (about 3,500 km) indented shoreline, enclosing innumerable small, shallow bays and inlets. It contains numerous islands (Welcomme 1972).

Figure 1: Map showing division of Lake Victoria among the riparian countries.

The lake is an important source of food for the people living in its vicinity. Total fish landings from the lake are estimated to be 500,000 m tons per year, generating over 200 million US$. The lake's fishery is driven by both national and international capital mainly in the processing industry. The lake supports a multi-species fishery. The main commercial species are Nile perch (*Lates niloticus)*, Tilapia (*Tilapia Niloticus)* and a cyprinid (*Rastrineobola argentea).* These are fished by trawling and by artisans using seines and lines from beaches and canoes.

1.2 Winam Gulf

Winam Gulf is a large inlet from Lake Victoria that extends into Kenya (Figure 2). It stretches about 100 km east to west and 50 km north-south and has a shoreline measuring about 550 km. The Gulf is comparatively shallow, having a recorded maximum and average depth of 68 m and 6 m (Figure 3) (Hughes and Hughes 1992). Surface water temperatures range between 23.5^{o}C and 29.0°C. Wind induced currents influence water mixing in the gulf. Secchi transparency ranges between 35 to 155 cm (Hughes and Hughes 1992) and primary productivity is limited to a thin layer at the surface.

The gulf has a narrow opening to the main lake. This was further reduced in 1980 when the causeway between Rusinga Island and the southern mainland was closed. This used to be the deeper opening to the main lake. This considerably reduced water exchange between the gulf and the main lake. As a result there is occasional flooding during the heavy rain season on the mainland south of the opening. Four major rivers, Sondu-Miriu, R. Kibos, Nyando, and Kisat discharge an average of 231 m^3s^{-1} into the gulf (Figure 2). The contribution from the minor streams has not been assessed (Welcomme 1972).

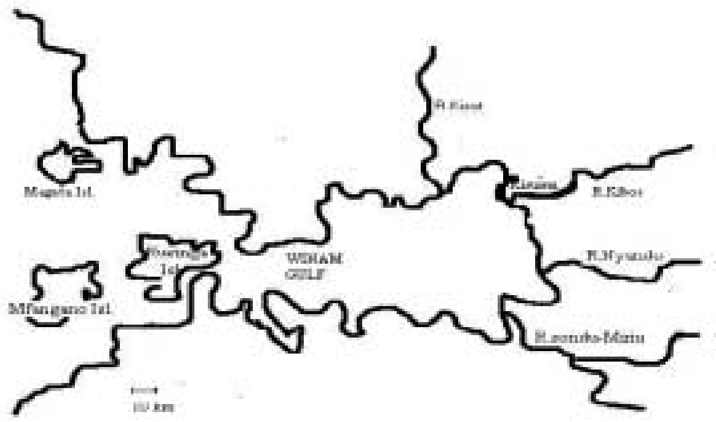

Figure 2: Map showing Winam Gulf, its connection with the main lake, Rusinga Island and major inflowing rivers.

Mean monthly air temperatures range from 21.9-24.3 °C. February and March are the warmest months, while December and January are the coolest ones. The catchment of Winam Gulf lies 1000 to 2000 m above sea level (Kite 1981). It is the main water catchment for the whole lake. The area is characterised by an equatorial hot and humid climate modified by effects of altitude, relief and influence of the lake. Relatively wet agro-ecological zones dominate except near the lake. Yearly rainfall averages 1,000 mm. Westerly winds from the lake prevail. These converge with the northeast passat (or trade) wind causing the air to rise and thus producing heavy showers over the gulf and its catchment. The area has two rainfall seasons, heavy and light rainfall periods. Heavy rainfall period is between March and May while light rainfall period is between September and November. Dry seasons are between December and February and June and September. Because of the cooling influence, which the lake exerts, temperatures are a little lower than a normal equatorial climate. Relative humidity is high. Potential evaporation is 1,800-2,200 mm per year and in most months exceeds monthly rainfall (Kite 1981).

The area is extensively utilised for agriculture with notable increase in fertiliser application. Land for the main food crops is prepared from December-February and July-September. Land degradation, surface run-off and soil erosion have been on the increase. This has resulted in increase of sedimentation and nutrient enrichment (Ochumba and Kibaara 1989). The enrichment of the gulf has resulted in proliferation of macrophytes mainly water hyacinth, *Eicchornia crassipes*.

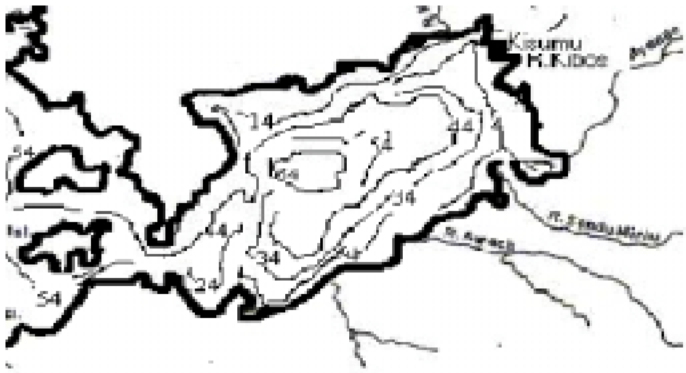

Figure 3: Topography map of Winam Gulf. The map shows the topographic basin of Winam Gulf and its narrow connection with the main lake.

1.3 Water hyacinth

It is widely reported that water hyacinth is indigenous to Brazil having first been described from wild plants collected from Francisco River in 1824. In Africa it was first reported in Egypt between 1879 and 1893. By the early 1990s it had spread to virtually every country in the continent (Makhanu 1997).

It was first reported in the Ugandan portion of Lake Victoria in 1990 (Thompson 1991). It is believed that it entered the lake in 1989 via the Kagera River, which has its mouth in the Ugandan portion of the lake (Muli 1996). It is not exactly known when it entered Winam Gulf.

Water hyacinth (*Eichhornia crassipes)* is a freshwater weed species. It is a free-floating plant and draws all its nutrients directly from water. Currents and wind help in its distribution and dispersal. It comprises 95% water and 5% per cent dry matter of which 50% is silica, 30% potassium, 15% nitrogen and 5% protein (Makhanu 1997). It has been known to thrive well in nutrient-enriched fresh waters in tropical climatic zones. For this purpose it has been used in wastewater treatment facilities.

The weed is mainly found in inshore and shallow areas to which it is swept by currents and some times in patchy offshore areas. It spreads fast in shallow (< 6m) bays and inlets with mud bed surfaces. Lake Victoria's tropical location, shallow depth and nutrient enrichment provide favourable conditions for its proliferation (Mitchell 1976).

Water hyacinth has limited beneficial uses. It cannot be used as a livestock feed because it contains too much silica, calcium oxalate, potassium and too little protein. It cannot be directly used as a fertilizer because its C: N ratio is too high necessitating addition of N-fertilizer (Makhanu 1997).

Its economic significance stems from its potential to produce negative consequences for the habitat quality of water bodies. The 'mats' of aquatic plants reduce dissolved oxygen by restricting the exchange of oxygen across the air/water interface. They also affect wind-driven water movement and impede mixing of oxygen-rich surface water (Smith-Rogers 1999). It also generates large amounts of organic matter. As the organic matter decomposes, biological oxygen demand increases and water quality deteriorates. The oxygen can be reduced to such low levels that it leads to massive fish kills due to oxygen depletion in the water column (Ochumba and Kibaara 1989). This results in loss of aquatic biodiversity (Muli 1996).

In shallow lakes and where plant production is great, complete deoxygenation of the sediments and deeper water can occur. Such conditions are not compatible for the survival of fishes and invertebrates. Moreover, under anoxic conditions, ammonia, iron, manganese and hydrogen sulphide concentrations can rise to levels deleterious to biota. In addition, phosphate and ammonium are released into the water from anoxic sediments, further enriching the ecosystem (International Development Research Centre 2000).

The plant can also block waterways, such as Kisumu harbour and fish landing beaches and piers and prevent boats from docking (Figure 4). The plant can clog irrigation canals and electricity generating turbines and its presence can be a general risk to public health.

Figure 4: Photograph depicting effect of water hyacinth on fish-landing piers in Winam Gulf (Makhanu 1997).

To remove the weed, three basic techniques exist; mechanical, biological and chemical. The mechanical method involves chopping and dumping the plant in the lake (Figure 5). This method is considered both labour intensive and expensive. Biological control involves rearing and releasing *Neochetina eichhorniae* (mottled water hyacinth weevil), a South American native bug that feeds exclusively on water hyacinth into the lake. In 1995 the Kenya Agricultural Research Institute (KARI) released weevils into the gulf on a pilot scale. However this method was found to be ineffective, since water hyacinth grows fast, doubling in biomass every 6 to 18 days. The weevils could also not withstand heavy rainfall that falls over the lake. Chemical methods involve use of herbicides. This method was least favoured owing to the potential damage that herbicides could cause to the lake's fauna. Thus the only last option available was to apply the mechanical shredding.

As an emergency measure, mechanical shredding was started in June 2000. However, it was feared that dumping of huge amounts of organic matter in the lake could result in further deterioration of water quality.

Figure 5: A Picture showing mechanical shredding of water hyacinth in Winam Gulf, Lake Victoria (Aquarius Systems 2001).

1.4 Aims of the study

The purpose of this study was to investigate the effect of water hyacinth and the mechanical shredding of the weed on water quality in Winam Gulf and to:

- provide information on physical water quality parameters – temperature, dissolved oxygen, conductivity, water transparency and acidity
- determine the effect of water hyacinth on the above parameters and
- obtain an initial description of currents and their relation with wind and begin to understand seasonal movement patterns of the weed into and in the gulf.

2. METHODS

2.1 Study area

The sampling area was a small portion of the Gulf in its north-eastern corner. River Kibos has its mouth in the area (Figure 6).

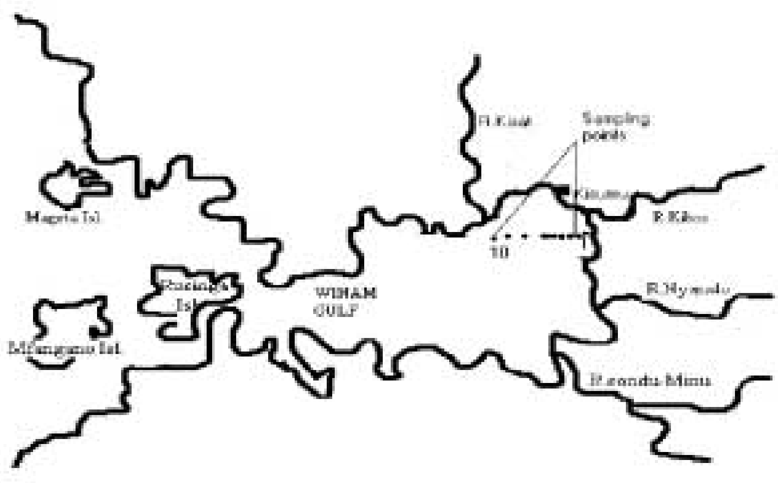

Figure 6: Map showing sampling stations.

The area of study was covered with water hyacinth between January and July 2000. By the beginning of August 2000, the weed had been effectively removed.

The area thus experienced three phases of water hyacinth cover in 2000;

January-May: During this period, the area of study was covered by a water hyacinth 'mat'. Access to fishing grounds by boats and canoes was limited. Fish landing piers were also blocked.
June-August: Water hyacinth harvesting started in mid-June and ended at beginning of August.
September-December: The area was free of water hyacinth. Any remains of the weed had been swept away by current. At this time there was no more water hyacinth in the area.

2.2 Sampling protocol.

Sampling was done between January and December 2000 on a transect of 10 stations extending from 00°06'09,07"S, 34°44,37',04"E to 00°06'08,00"S, 34°42'00" E. The stations were labelled 1 to 10 with station 1 being closest to shore and station 10 furthest from shore. Stations 1 –7 were shallow (≤4 m). Station 8 was 11 m deep while stations 9 and 10 were 40 m and 30 m deep (Table 1). The last two stations extended into the deep basin of the gulf (Figure 3).

The shallow part of the section (stations 1-7) is relatively flat. After that the bottom slopes down towards station 9.

Table 1: Sampling stations and sampling time.

Site	Position	Distance from shore (m)	Bottom depth (m)	Date (Physical parameters)	Date (Currents)
Station 1	00° 06' 09,07"S 34°44,37', 04"E	100	3	Jan -Dec. 4-12	Mar 7th, Jul 8th Nov. 7th
Station 2	00° 06' 09,07"S 34° 44' 34,12" E	200	2	Mar, Jul Nov. 6-12	
Station 3	00° 06' 09,07"S 34° 44' 29,29" E	300	3	Mar, Jul Nov. 5-13	
Station 4	00° 06' 09,07"S 34° 44' 26,25" E	450	3	Mar, Jul Nov. 3-16	
Station 5	00° 06' 09,07"S; 34°44' 24,28" E	600	4	Mar, Jul Nov. 6-12	
Station 6	00° 06' 09,07"S; 34° 44' 17,20" E	800	3	Mar, Jul Nov. 6-12	
Station 7	00° 06' 09,07"S 34° 44'09, 13" E	1050	4	Jan -Dec 8- 16	Mar 7th, Jul 8th, Nov. 7th
Station 8	00° 06' 09,07"S 34° 44' 00,00"E	1350	11	Mar, Jul Nov. 6-12	Mar 7th, Jul. 8th 12
Station 9	00° 06' 09,07"S 34° 43' 00,00" E	3350	40	Mar, Jul Nov. 6-12	Mar 7th, Jul. 8th
Station 10	00° 06' 08,00"S 34° 42' 00" E	5350	30	Mar, Jul Nov. 6-12	Mar 7th, Jul. 8th

Water temperature, total dissolved oxygen, acidity, conductivity and Secchi disk depth measurements were done at all stations in March, July and November 2000. In addition, monthly measurements were taken at stations 1 and 7 for monitoring purposes from January to December.

Different methods were used for sampling at different stations. At stations 1-7 water samples were taken using a VanDorn water sampler at one metre-depth intervals in the water column. A pH meter, conductance meter and a conventional thermometer respectively were then used to measure the acidity, conductivity and temperature of the water sample. At the deeper stations (8-10) a Hydrolab™ was used. This was considered unsuitable for taking measurements at the surface and at shallow depths. The transparency of the water was measured with a Secchi disk.

On site measurements (stations 1-7)

Temperature: It was determined using a conventional thermometer immediately after surfacing of the water sample bottle.

Dissolved oxygen: Water samples were taken to determine the amount of dissolved oxygen. Analysis for dissolved oxygen in mg/L was determined within 24 hours by Winklers' method (Grasshoff *et al.* 1983) at the Kenya Marine Fisheries Research Institute laboratory.

Secchi disk transparency: The Secchi disk was lowered slowly and the average visual depth at which it disappeared and reappeared recorded.

Conductivity: Water samples were collected in clean glass bottles and stored at $4^{o}C$. Analysis for conductivity was done using a Cole Parmer EC Meter 19101.The meter was calibrated by turning on the automatic temperature compensation mode to display the specific conductance at $25^{o}C$ with a standard solution of 0.0002M KCL (30.29 μS/cm). The conductivity meter probe was thoroughly rinsed with deionised water before and after each use. The conductivity cell was immersed approximately 1.25 inches into a sample and stabilized reading taken in μS/cm.

Acidity: The pH of water was determined directly using a Corning model 440 meter. The meter was setup, standardised and placed into a buffer at pH 7. The water sample was swirled until uniformly mixed and measurement taken on a quiescent sample. The meter was calibrated with a screwdriver and rinsed before successive measurements were taken.

***In situ* Measurements (stations 8-10)**

Water pH, conductivity and temperature were measured using a Hydrolab™ (water quality measurement system). The unit was lowered into water to record data. This was returned to the laboratory and the data downloaded into a computer spreadsheet.

Water samples were taken to determine the amount of dissolved oxygen at the Kenya Marine Fisheries Research Institute laboratory. Analysis of the oxygen content in mg/l was determined within 24 hours by Winklers' method (Grasshoff *et al*. 1983).

Current measurements were taken in March, July and November at stations 1, 7, 8, 9 and 10. This was done using a Geodine current meter. The meter uses a propeller/rotor suspended in the water. Speed was obtained from the number of rotor revolutions for a sampling time of 15 minutes. Two velocity measurements were taken at fixed points at 1m-depth intervals in the water column except at stations 9 and 10 where resolution was lower. A single current direction was obtained.

Wind speed in m/s and direction were obtained from the Kenya Meteorological Station, Kisumu. The station is about 400 m from station 1. Wind speed and direction for the sampling time were obtained.

3. RESULTS

3.1 Current and winds

At the time of sampling in March, a surface current towards the southeast was observed and a north-westerly wind with strength of about 8.5 cm/s and 12.5 m/s respectively. In July, current was towards southwest and a north-easterly wind was observed with strength of about 12 cm/s and 15 m/s respectively. A similar surface current and wind with strength of about 13 cm/s and 17.5 m/s respectively was observed in November.

Figure 7 shows that there was a good correspondence between wind and currents in speed and direction.

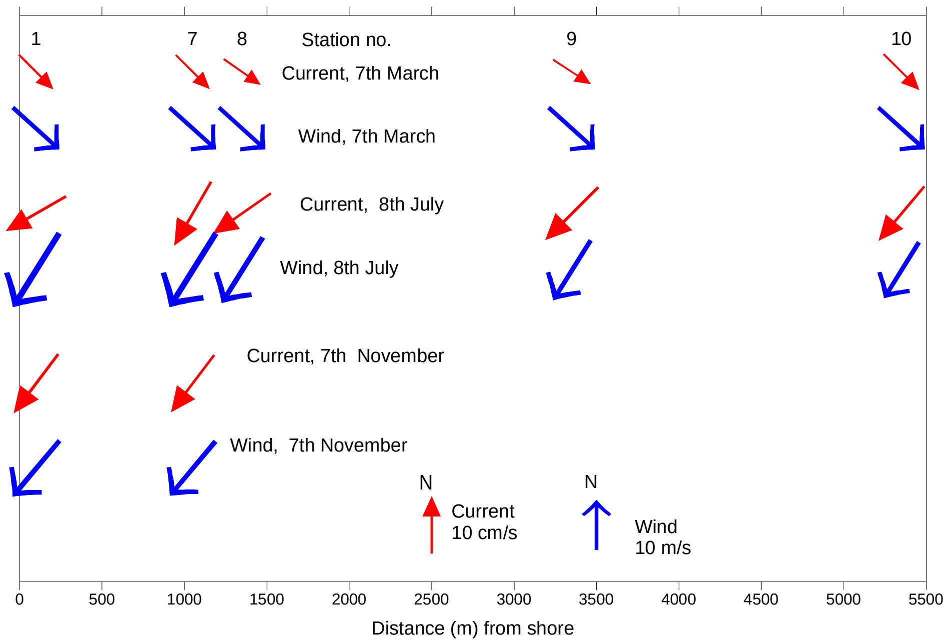

Figure 7: The surface current at the stations where it was measured and wind velocity at Kisumu Airport at the time of the current measurement.

Wind and current relate at different times at each station. Each vector length is proportional to the speed. This can be compared with the fixed size arrows at the bottom pointing to North.

Current and wind direction corresponded with the general westerly and easterly winds characteristic for the climatic (rainy and dry periods) season in the Winam Gulf water catchment.

According to the Ekman theory, the earth's rotation influence current velocity vectors to form a spiral (when projected on a horizontal plane) at increasing depth. The current vectors become progressively smaller with depth. They spiral to the right (looking in the direction of flow) in the Northern Hemisphere and to the left in the Southern with increasing depth. The phenomenon occurs in wind drift currents in which only the Coriolis and frictional forces are significant. The section is roughly 10 km south of the equator and therefore the effect of the earth's rotation (Coriolis force) on current in the gulf should be negligible. This seems to be the case since the current is flowing in the same direction as the wind.

The current has been split into a north-south component (positive towards north) and an east-west component (positive towards east).

Vertical profiles of the components at different stations and time were drawn to show change in current direction and speed with depth. These are shown in Figures 8-15.

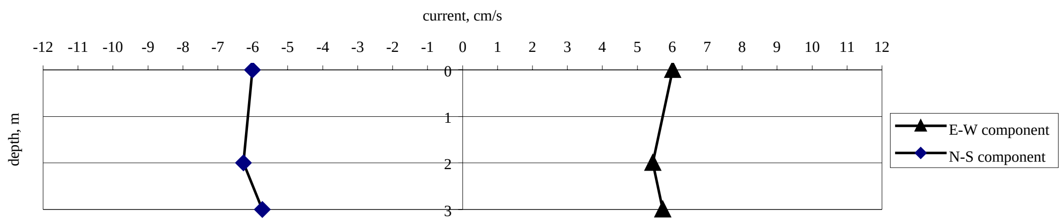

Figure 8: Vertical current profile at station 1 in March.

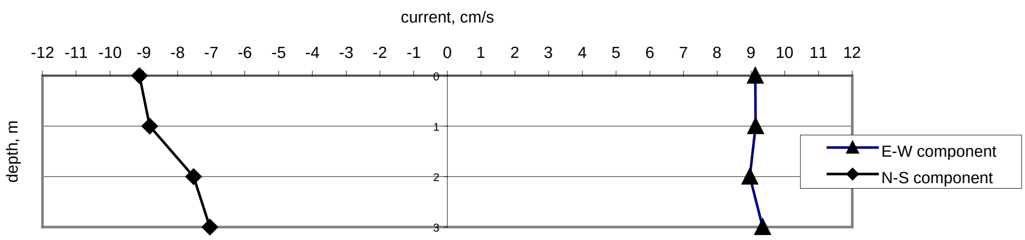

Figure 9: Vertical current profile at station 7 in March.

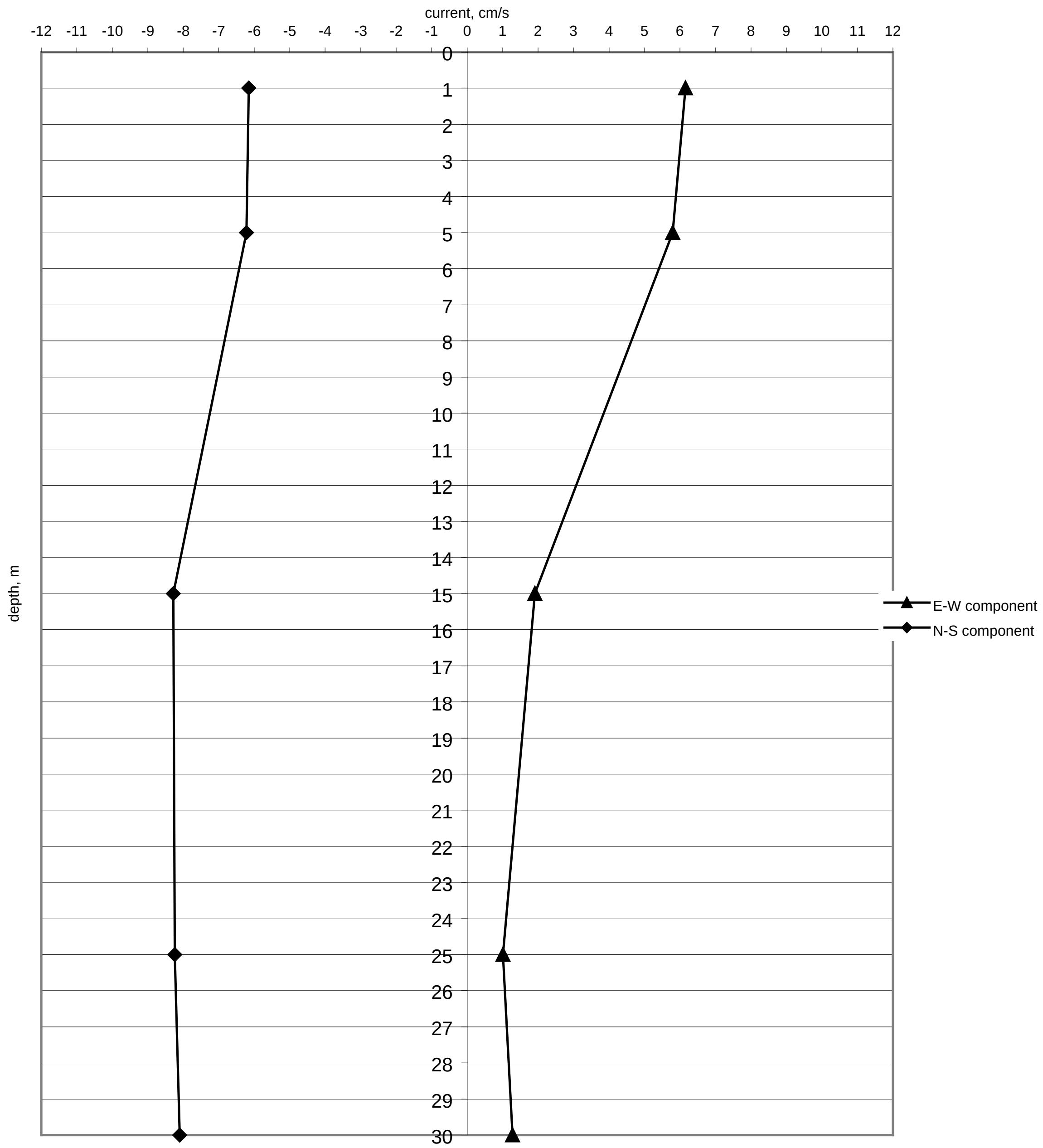

Figure 10: Vertical current profile at station 10 in March.

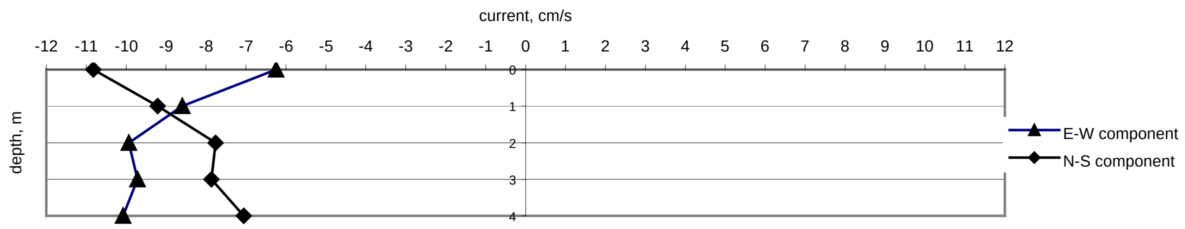

Figure 11: Vertical current profile at station 1 in July.

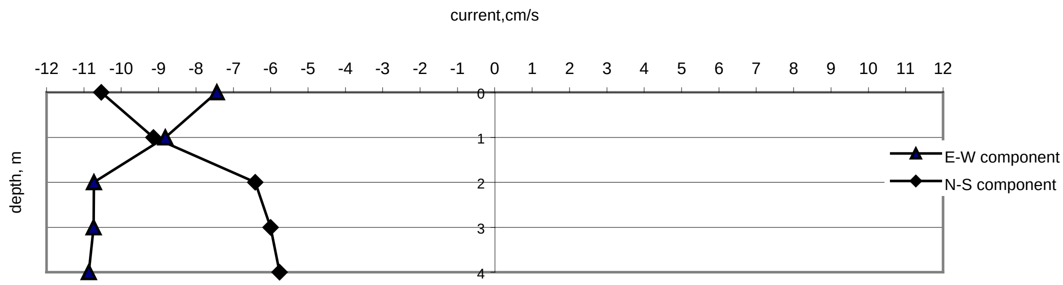

Figure 12: Vertical current profile at station 7 in July.

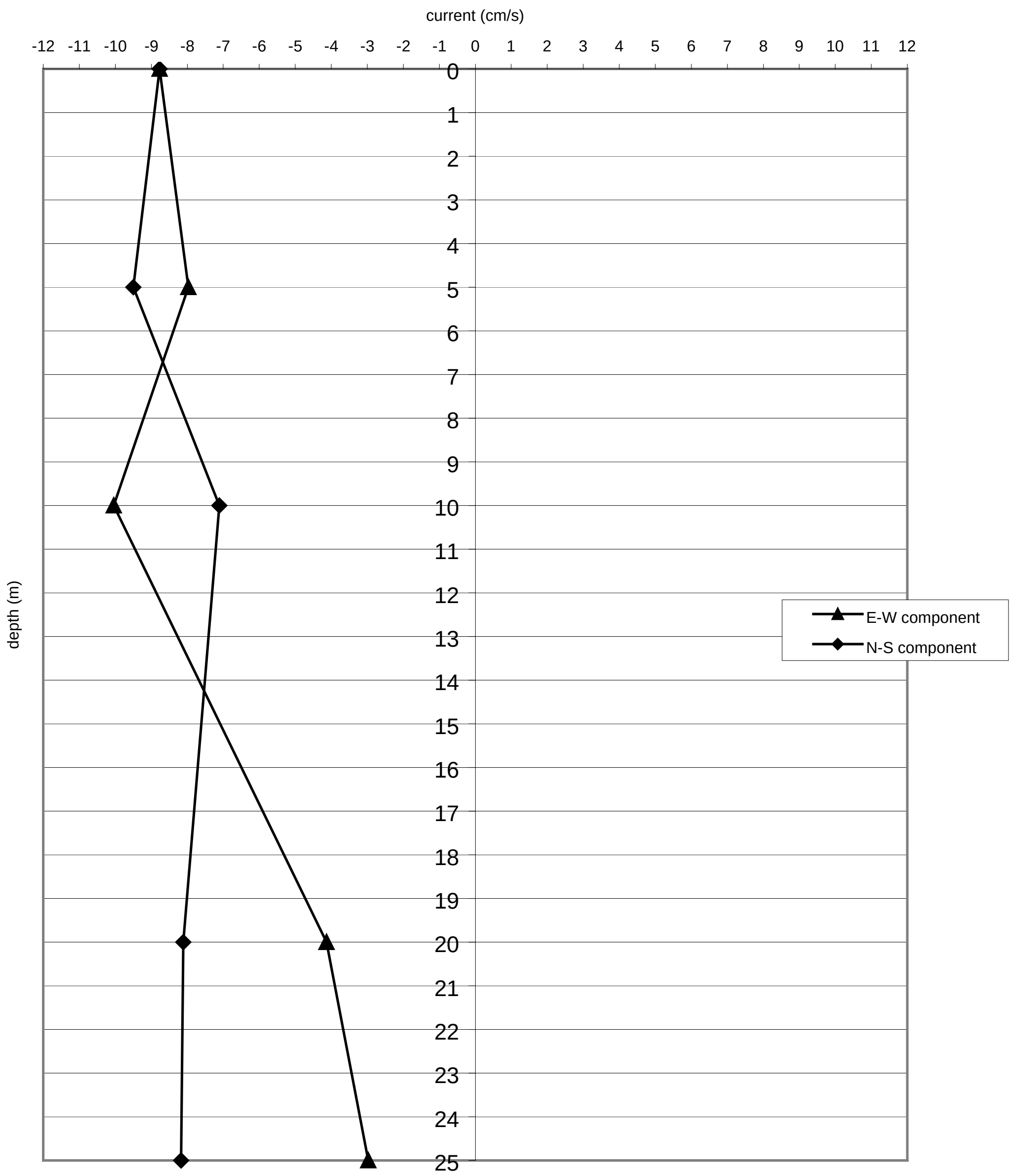

Figure 13: Vertical current profile at station 10 in July.

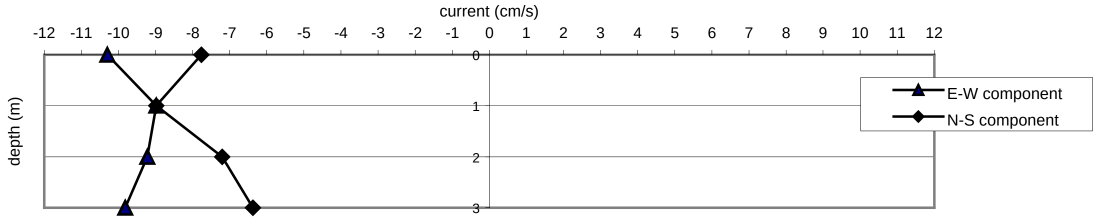

Figure 14: Vertical current profile at station 1 in November.

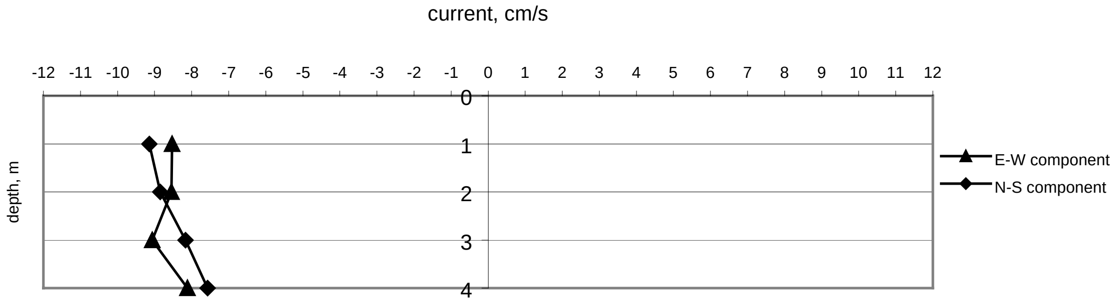

Figure 15: Vertical current profile at station 7 in November.

Over the shallow part of the section, there were only minor variations in current speed and direction with depth.

Also over the deeper part, the speed of the current does not change much with depth. In March the current direction changed with depth. This could be an influence of the gulf topography. The water mass could be directed by topography so as to flow along the isobaths (Figure 3). The water mass in the whole water column was observed to move in a similar direction. In order to satisfy the continuum principle there must be a return flow. This can only occur on the side. Thus the water circulation in the Gulf is likely to be mainly horizontal rather than vertical.

In order to see whether there is a relationship between the wind and current in the Gulf, the surface current speed at station 1 is shown as a function of the wind speed in Figure 16. Since the surface current at all stations was similar, only one station has been considered. There seemed to be a relationship between current speed and wind speed. It was observed that a higher wind speed seemed to produce a stronger current. However from the data available, the exact relationship cannot be conclusively determined. Time series data are required to establish this relation more accurately.

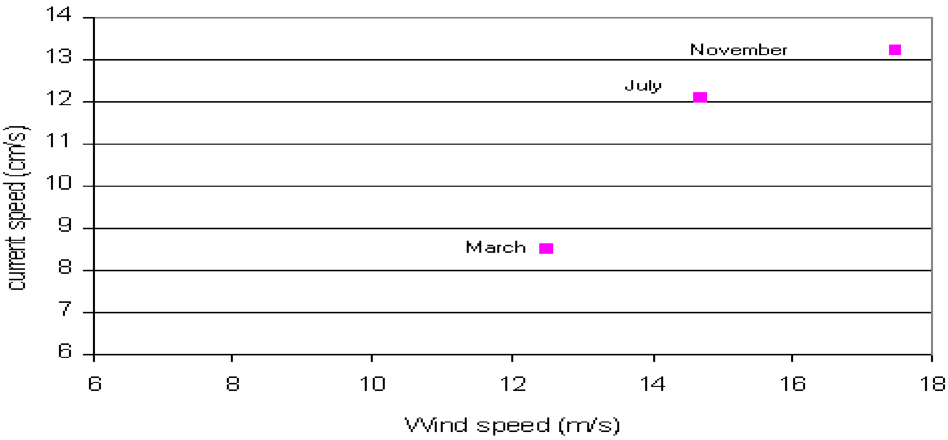

Figure 16: Surface current and wind speed at station 1. The figure shows how surface current and wind speed compare at different times.

Considering the fact that weak strong thermal stratification (as discussed below) was observed, we can ignore effects of temperature differences on current. Thus we can say that winds are probably the most important force driving the currents in the gulf.

3.2 Temperature

Temperature determines the density of water and therefore determines the stratification and thus affects vertical mixing in the water column. This will affect the distribution of many properties such as oxygen.

Figures 17-19 show the distribution of temperature on the section at different times.

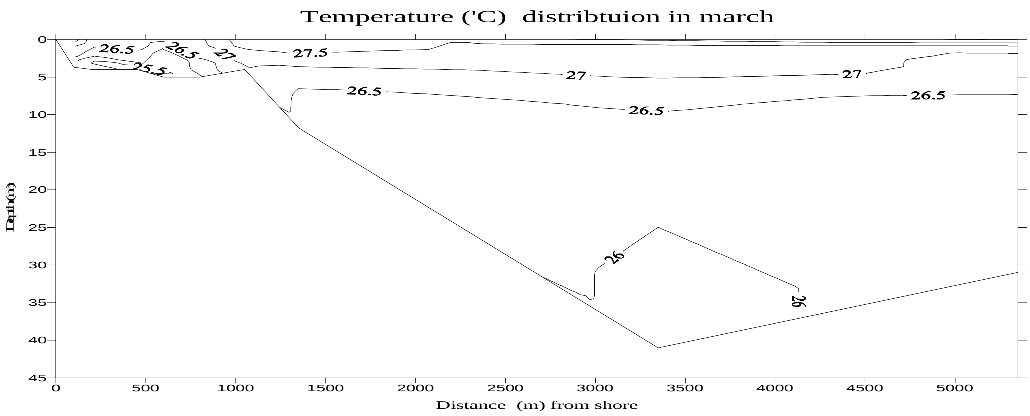

Figure 17: Temperature distribution on the section in March.

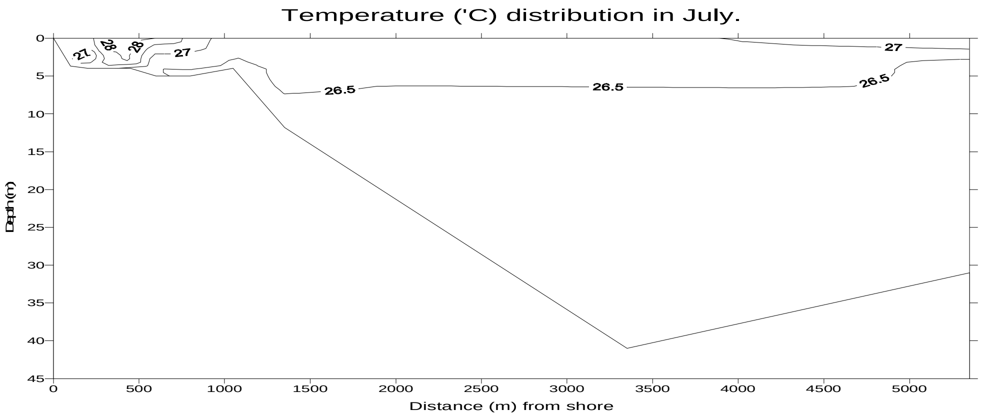

Figure 18: Temperature distribution on the section in July

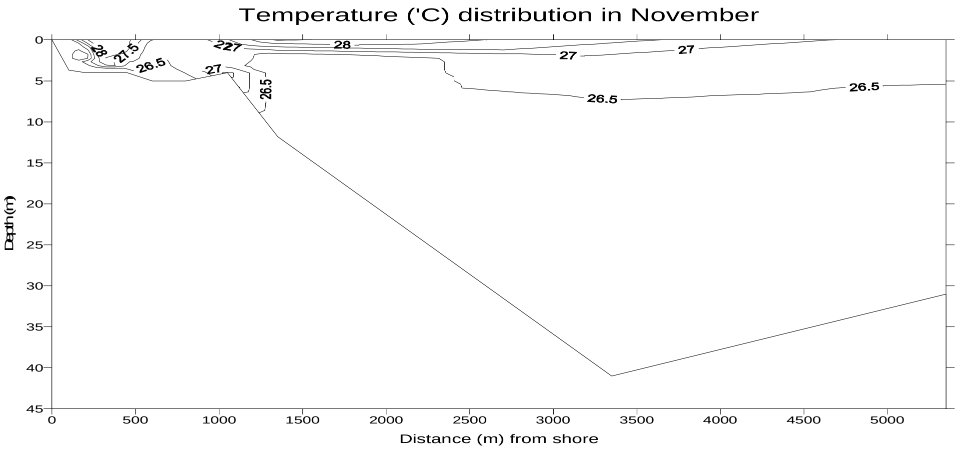

Figure 19: Temperature distribution on the section in November.

Temperature above 25.00°C was recorded throughout the sampling period with generally weak stratification (Figures 17-19).

The deep waters are characterised by temperatures between 26 and 26.5°C. The temperature in the surface waters is generally somewhat higher, up to about 28°C. This indicates that the stratification is not strong but it is probably strong enough to influence other water properties in the Gulf.

Figures 20 and 21 describe the changes in temperature at stations 1 and 7 at various times of sampling during the year.

There was some stratification in February at station 1 (Figure 20). High frequency variations in temperature stratification were observed.

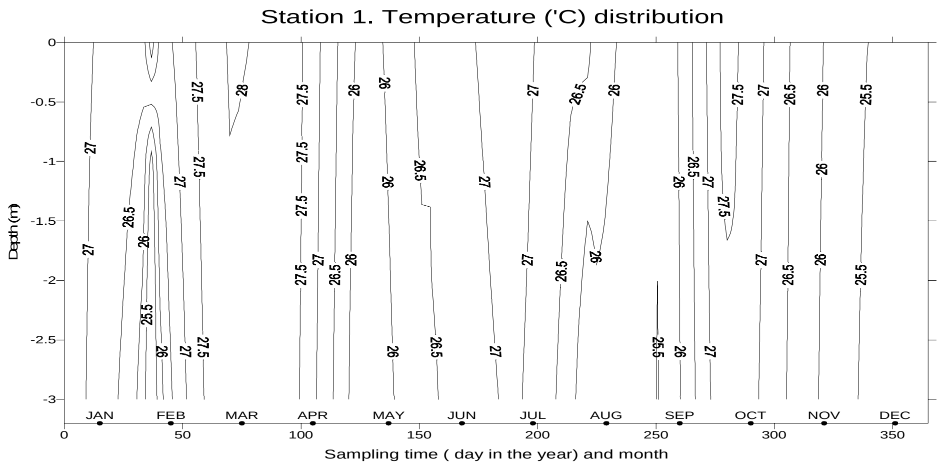

Figure 20: Temperature at station 1.

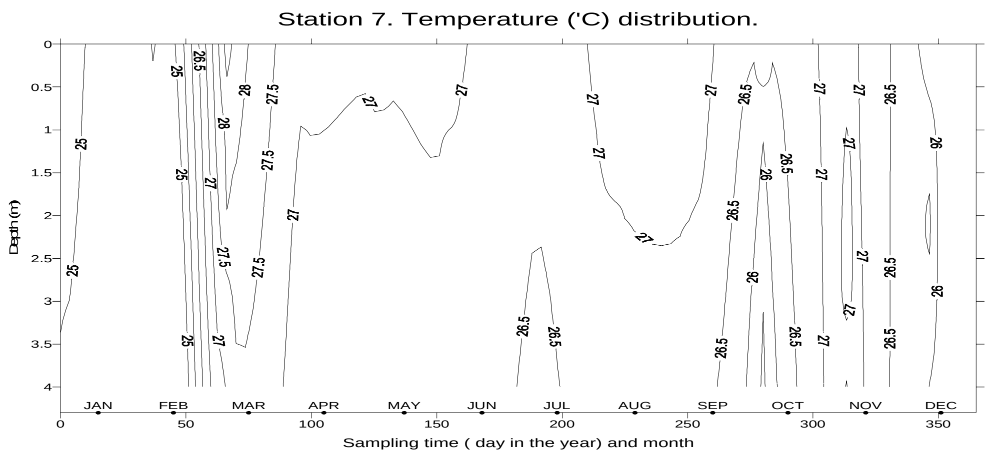

Figure 21: Temperature at station 7.

In order to look more closely at the thermal stratification in the deeper part of the Gulf, temperature profiles at station 10 are shown (Figure 22). Below about 7 m the water was quite homogeneous in temperature and similar during all the three sampling times. Above this depth changes in the temperature distribution were observed, creating a thermocline.

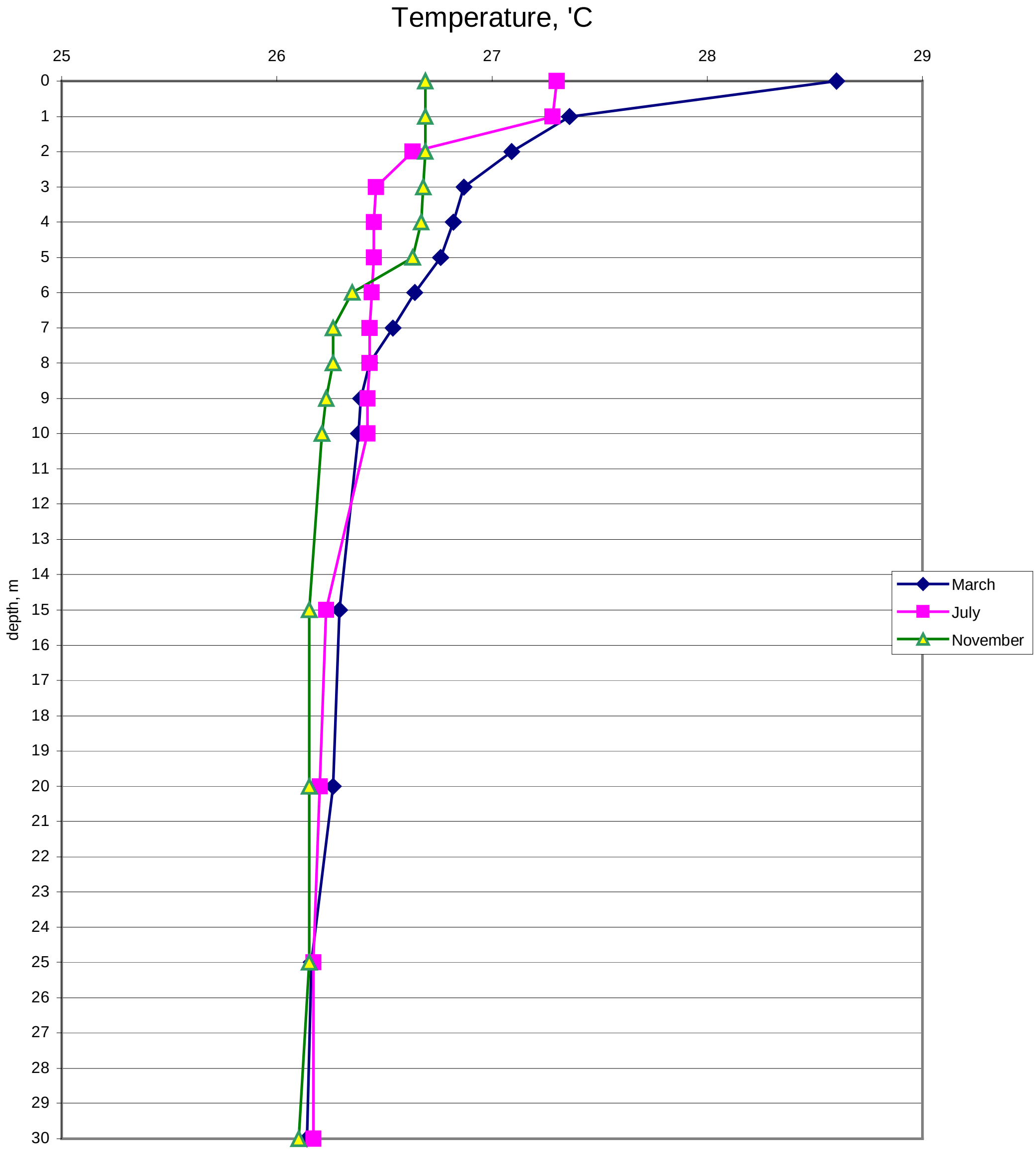

Figure 22: Temperature vertical profile showing a thermocline at station 10.

3.3 Secchi disk depth (transparency)

Highest Secchi disk transparency, 1.5 m was recorded in August and the lowest, 0.2 m in November (Figures 23 and 24). The high Secchi disk transparency between August and September was probably due to the deposit of organic matter on the lake bottom. The huge amount of organic matter deposited on the lake bottom as a result of the hyacinth cutting could form a cover on the lake bottom sediments shielding it from disturbance hence more clarity. The decrease in transparency between October and November was a result of increased in boat traffic that resulted in disturbance of the sediment bottom and/or growth of algae.

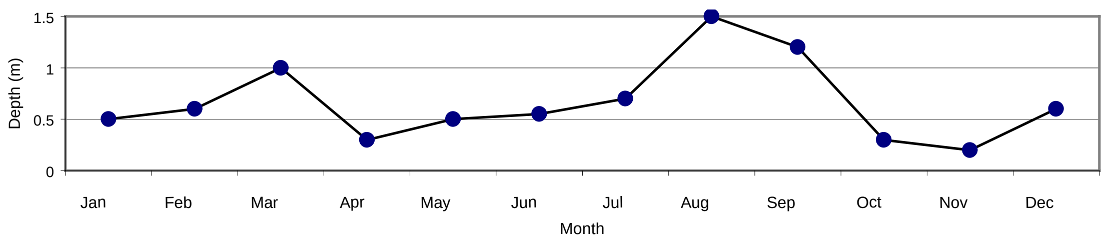

Figure 23: Secchi disk transparency at station 1.

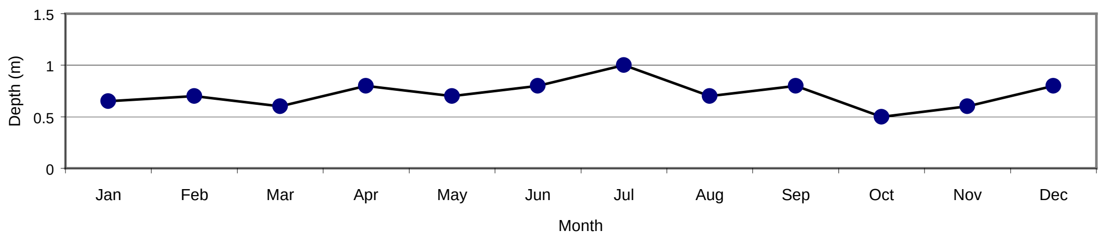

Figure 24: Secchi disk transparency at station 7.

3.4 Dissolved oxygen

Figures 25 - 27 show horizontal dissolved oxygen distribution in the water column at different stations and time.

Dissolved oxygen levels of 1 – 8 mg/l were recorded during the sampling period. These were observed to decrease with depth. The deep water over the deep part of the section was characterised by low dissolved O_2 levels of 3-4 mg/l throughout the sampling period. This was also the case in the shallow part of the section in March (Figure 25) and July (Figure 26). The surface waters were characterised by dissolved oxygen levels of 3- 8 mg/l throughout the sampling period.

The relatively low dissolved O_2 concentration observed in March (Figure 25) and high Secchi depth (Figures 23 and 24) might be because of little algae growth. Water hyacinth cover impedes algae growth and increases water clarity.

Dissolved oxygen was comparatively lower in July (Figure 26) than it was in March (Figure 25). This might be a result of the decomposition of water hyacinth organic matter by bacteria. In July, water hyacinth organic matter was being dumped in the lake by the mechanical shredding of water hyacinth. Due to topography of the area, currents can sweep dead water hyacinth into the deep part of the gulf. This could result in an increase in biological oxygen demand.

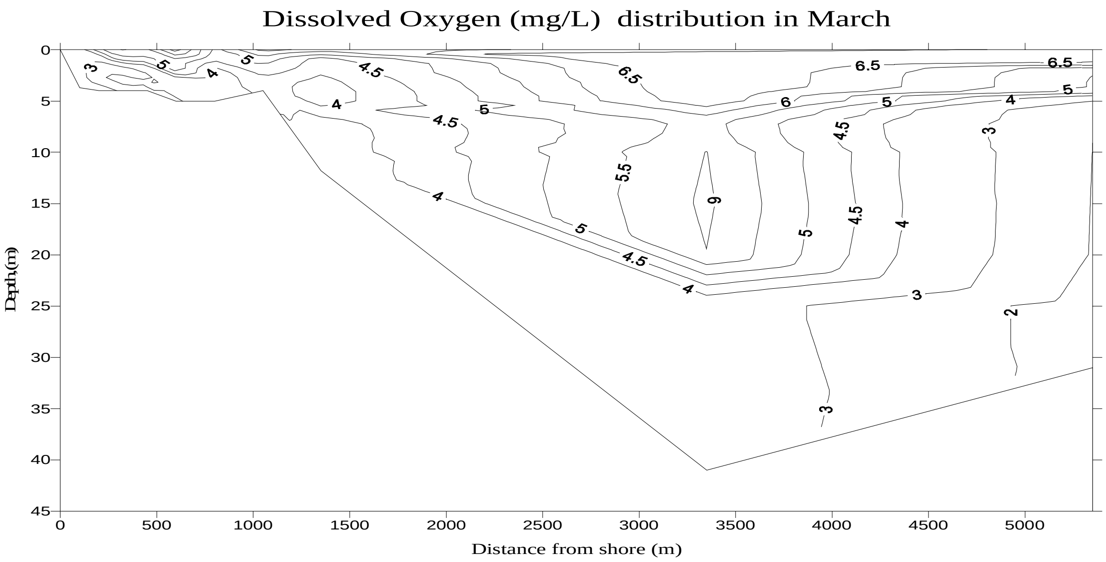

Figure 25: Dissolved oxygen in March

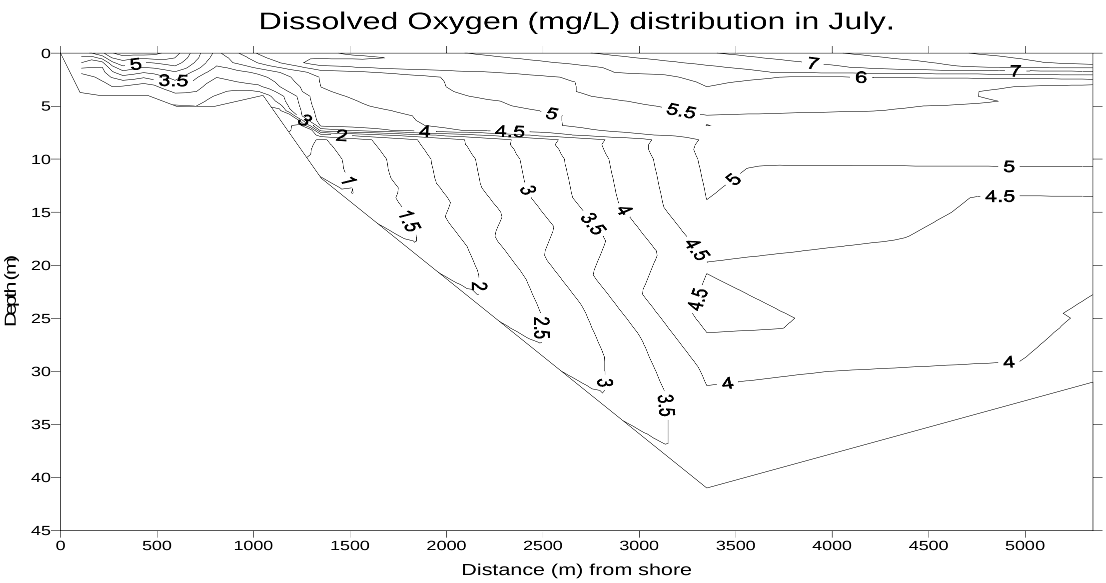

Figure 26: Dissolved oxygen in July.

Dissolved oxygen concentration levels were markedly higher in November (Figure 27) than March (Figure 25) and July (Figure 26). This was especially the case at the shallow part of the section and in the surface waters.

The relatively high dissolved oxygen concentration observed in November but low Secchi depth (Figures 23 and 24) might be because of algae growth. This could result in higher photosynthetic activity in the water resulting in higher oxygen levels.

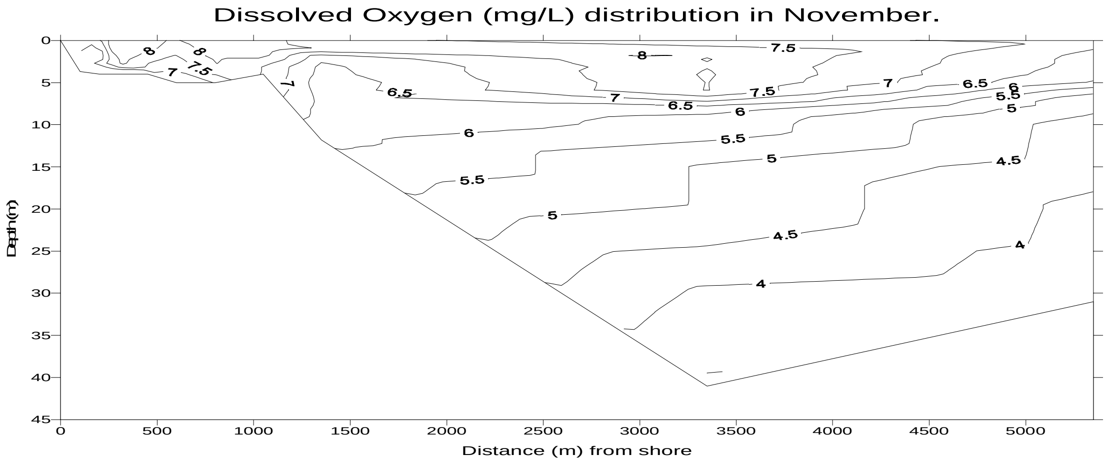

Figure 27: Dissolved oxygen in November.

In Figures 28 and 29 is shown a distribution of oxygen throughout the year, using the monthly values. From these figures, a time development of the O_2 is seen and one can get a better idea of when the O_2 levels started to increase as a result of the shredding of the water hyacinth. During the water hyacinth cover period, the O_2 concentration was generally low at both stations. The shredding of water hyacinth was finished by the beginning of August. Already when measurements were done on August 8th oxygen levels had increased markedly at both stations throughout the water column. The effect of dumping the water hyacinth on the bottom and its decomposition on the effect of the O_2 levels does not seem to take much time, maybe a few weeks.

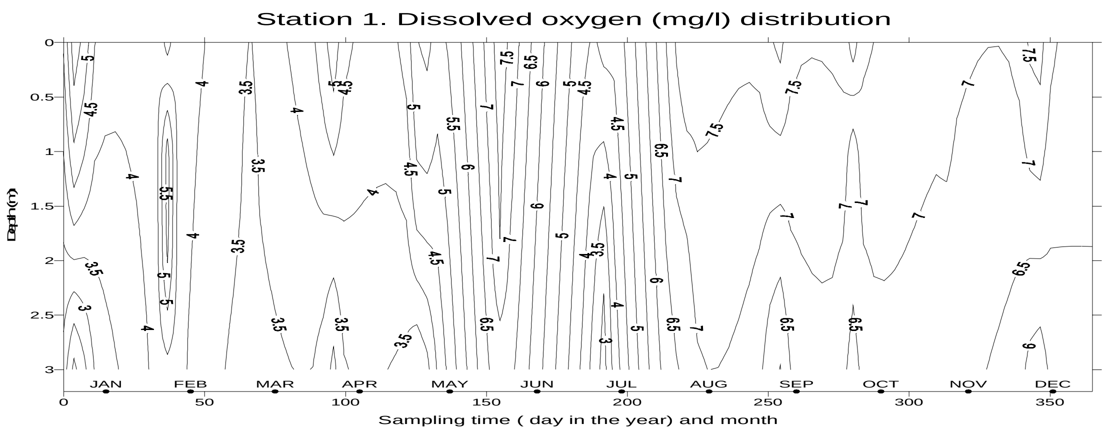

Figure 28: Dissolved oxygen concentration at station 1.

The second half of the year showed high and fairly stable oxygen concentrations. In this period there was no water hyacinth in the area. This can result in increased mixing of surface oxygen-rich water with the sub-surface water. This seems to show the effect of water hyacinth on dissolved oxygen.

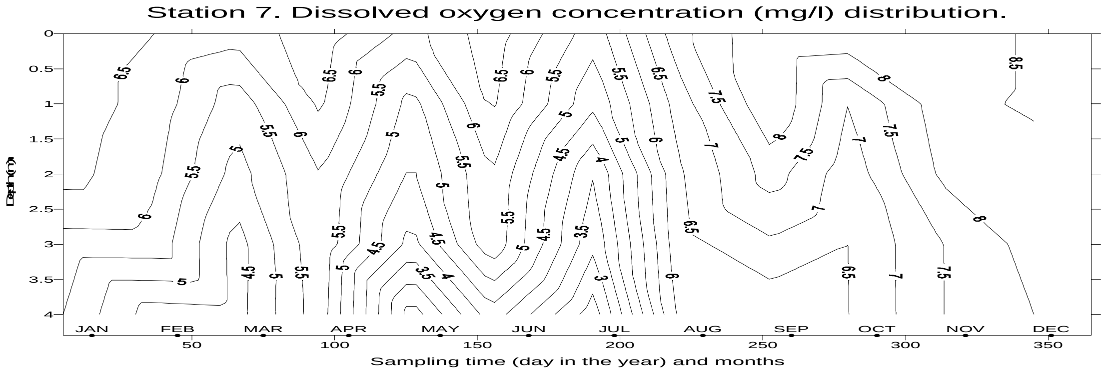

Figure 29: Dissolved oxygen at station 7.

Figures 30 – 32 show changes in dissolved oxygen with depth, at stations 1, 7 and 10 in March. The surface water O_2 was about 5 - 6 mg/l in March. Bottom water O_2 was about 3 - 4 mg/l at the shallow part of the section. At the deeper part of the section there was an oxycline between 3-7 m. This might be a result of the thermocline observed.

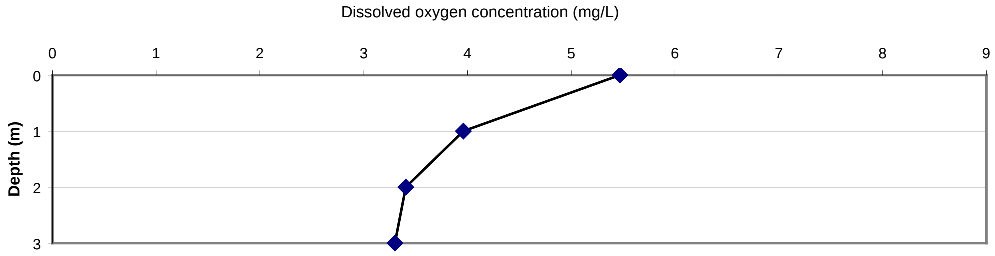

Figure 30: Dissolved oxygen concentration vertical profile at station 1 in March.

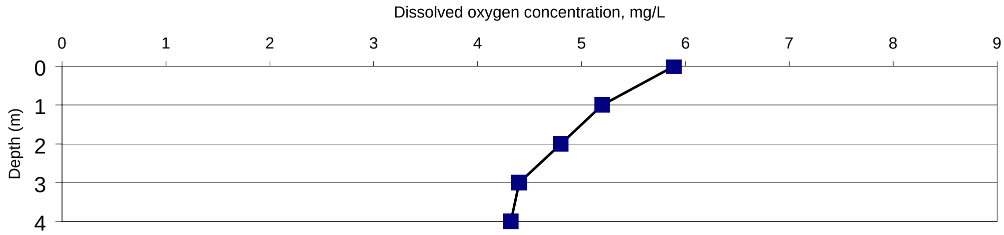

Figure 31: Dissolved oxygen concentration vertical profile at station 7 in March.

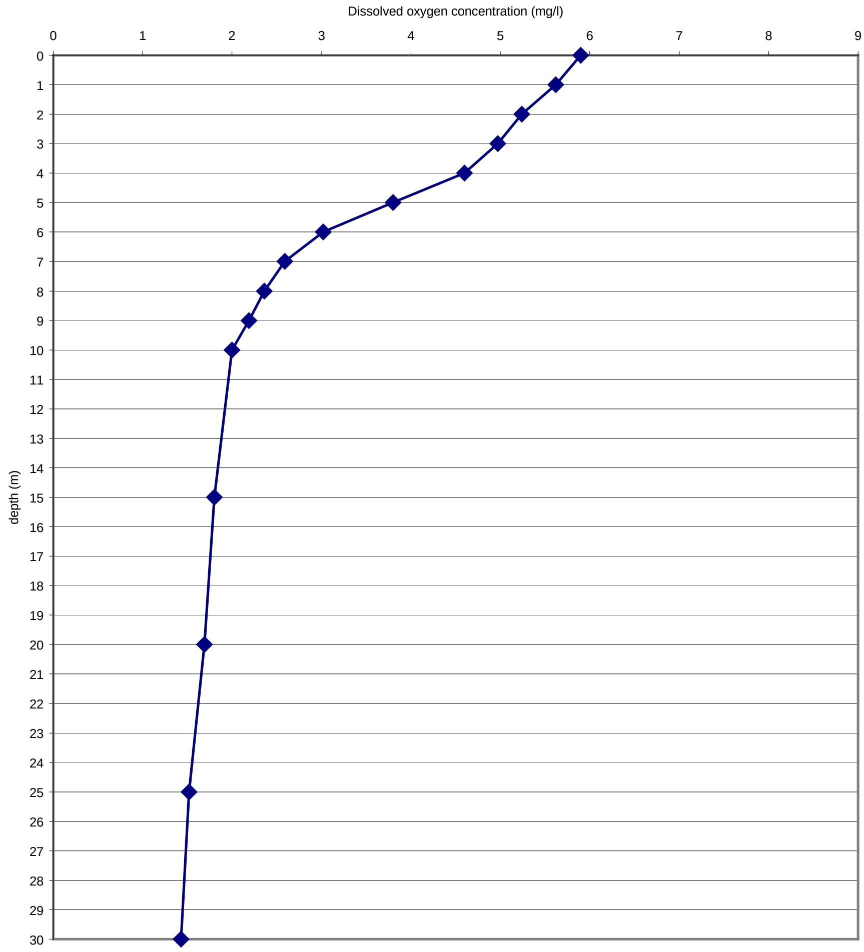

Figure 32: Dissolved oxygen concentration vertical profile at station 10 in March. Note the low dissolved oxygen concentration at the bottom depth.

A hypoxic condition (1.5 mg/L dissolved oxygen concentration) was observed at station 10 at the bottom depth (Figure 32). This might be a result of deep depth and water hyacinth cover on the surface.

Vertical distribution of dissolved oxygen in July is shown in Figures 33, 34 and 35. The figures show dissolved oxygen concentration levels of about 4.8 mg/l at all stations at the surface waters. This was about 2.5 mg/l at the bottom depth in the shallow part (Figures 33 and 34) and 1 mg/l in the deeper part of the section (Figure 35).

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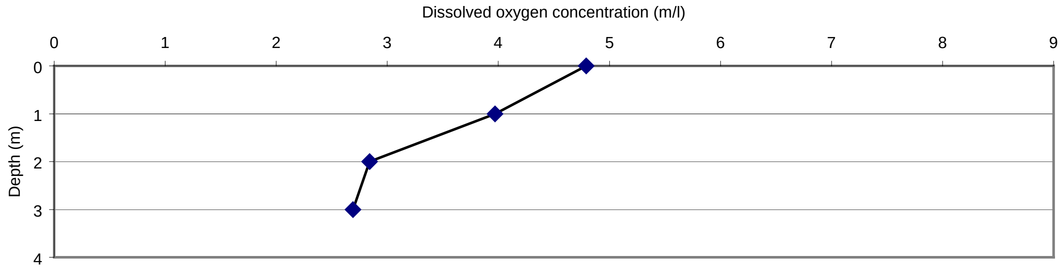

Figure 33: Dissolved oxygen concentration vertical profile at station 1 in July.

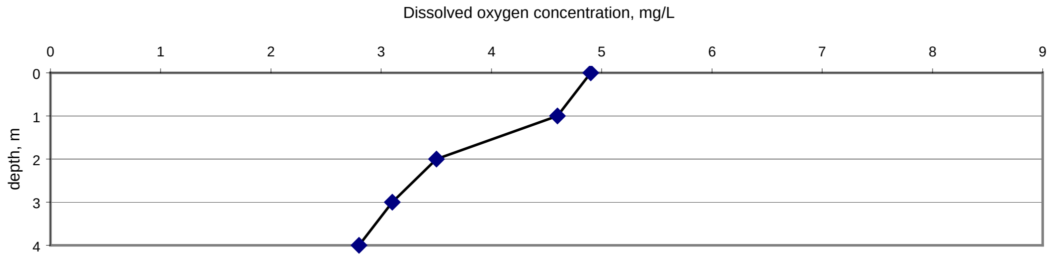

Figure 34: Dissolved oxygen concentration vertical profile at station 7 in July.

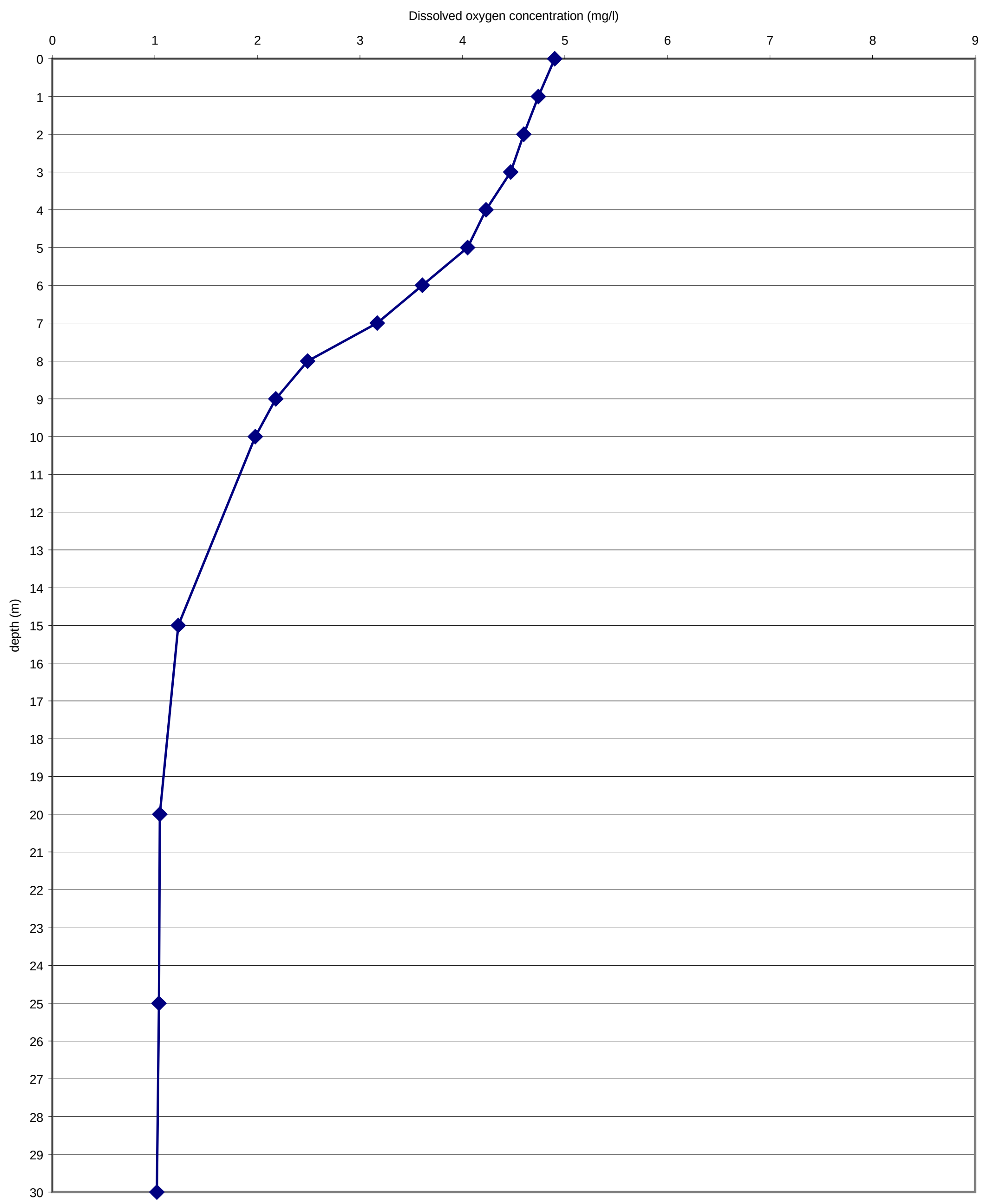

Figure 35: Dissolved oxygen concentration vertical profile at station 10 in July.

During the year, lowest dissolved O_2 levels were measured in July. This might be due to the use of oxygen by water hyacinth organic matter in decay. July was the water hyacinth cutting period.

Figures 36, 37 and 38 show the vertical distribution of dissolved oxygen at stations 1, 7 and 10 in November. The figures show dissolved O_2 concentration levels of between 7.3 mg/l and 8.3 mg/l in the surface waters and between 4.3 mg/l and 7.5 mg/l in the bottom waters.

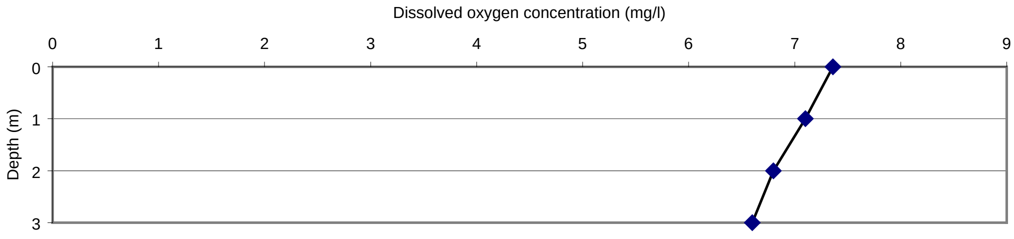

Figure 36: Dissolved oxygen concentration vertical profile at station 1 in November.

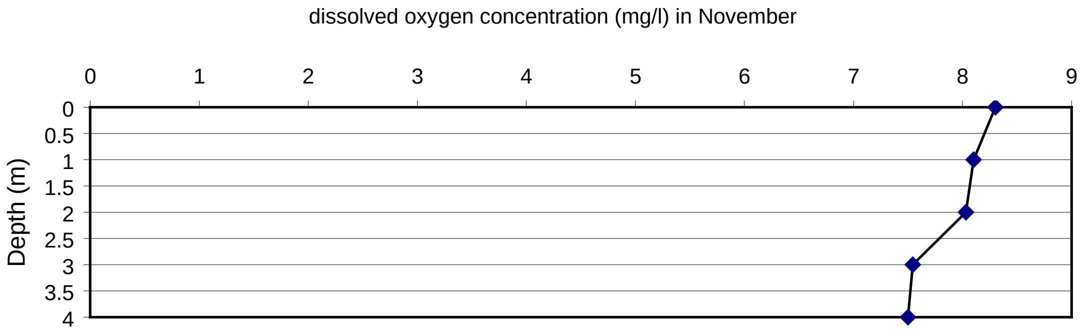

Figure 37: Dissolved oxygen concentration vertical profile at station 7 in November.

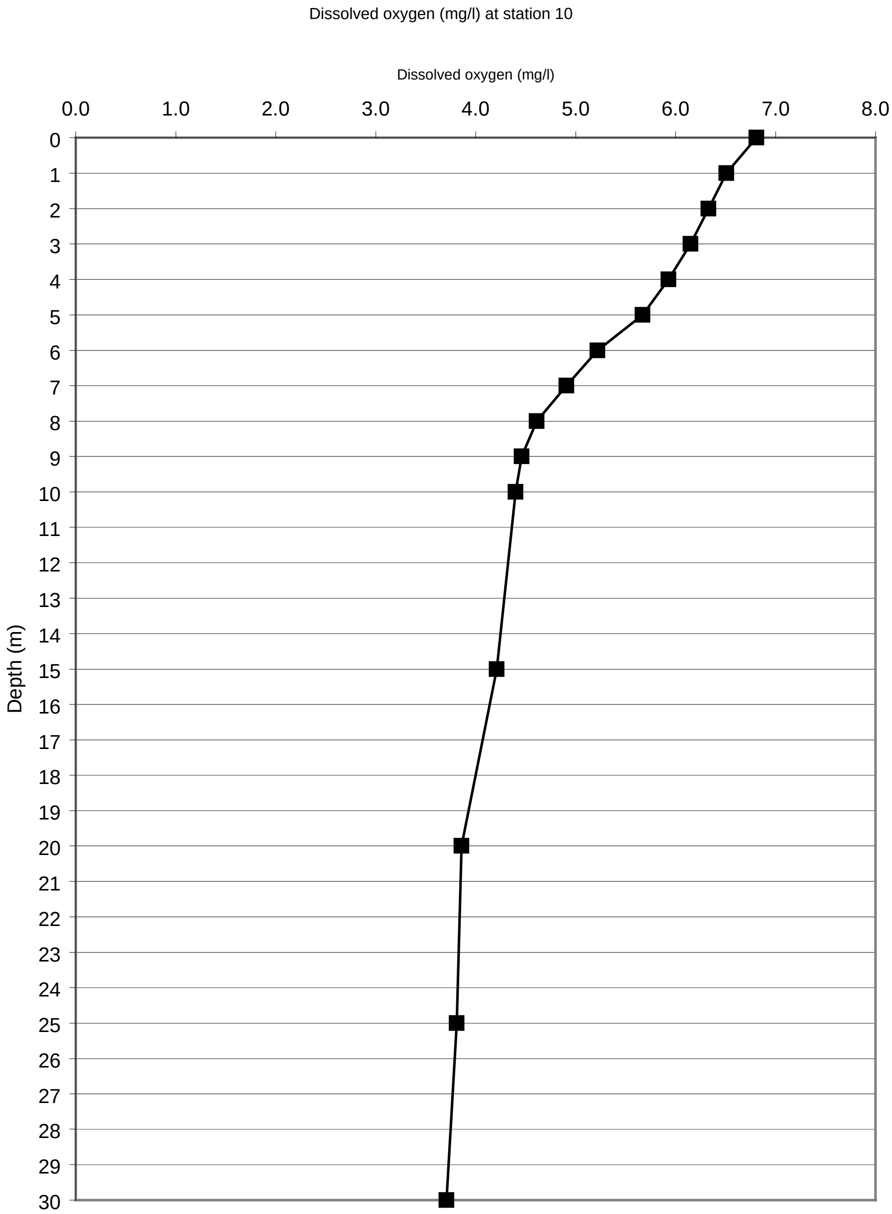

Figure 38: Vertical distribution of dissolved oxygen concentration at station 10 in November.

All the observations at station 10 show an oxycline to about 7 m (Figure 38) below which the oxygen levels do not change much. This might be caused by the stratification of the water caused by different temperature (Figure 22). The layer below about 7 m is usually homogeneous in temperature, with a thermocline above that prevents mixing further down.

The dissolved oxygen concentration levels were observed to be markedly higher in November than both July and March. March was within the water hyacinth cover period while July was within the cutting of the water hyacinth period. Thus the water hyacinth cover in March and its shredding in July might have resulted in the low O_2 levels observed.

3.5 Conductivity

Conductivity, µS/cm can be treated as an indicator of pollution (by incoming ionic salts) and a tracer of flow of polluting effluents. This is based on the near unreactive behaviour of ionic constituents.

Figures 39 – 41 show conductivity at various time of the sampling period. They generally show higher conductivity over the shallow part of the section than over the deeper part. This might be a result of incoming salts from land-based activities and R. Kibos (whose mouth is close to the section, Figure 2) that carries with it pollutants to the gulf. Conductivity was observed to increase with depth. The water hyacinth and other organic matter can sink, decompose and in the process result in carbonate and bicarbonate ions resulting in an increase in electrical conductivity with depth.

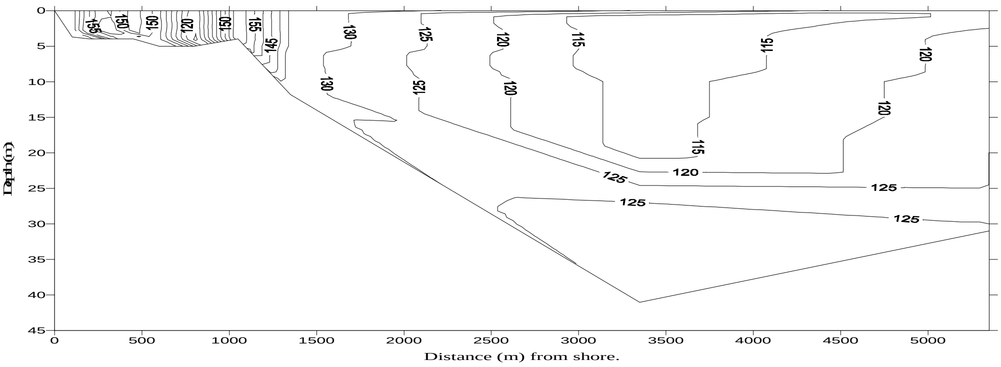

Figure 39: Conductivity in March.

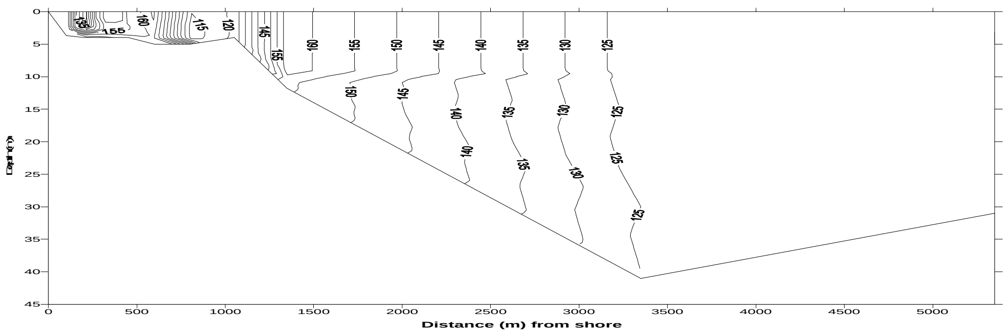

Figure 40: Conductivity in July.

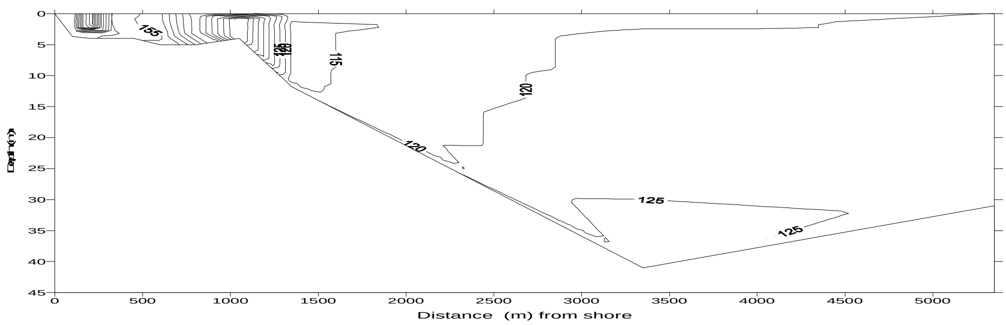

Figure 41: Conductivity in November.

Figures 42 and 43 show a monthly time variation in conductivity at stations 1 and 7 during the sampling period. They show a high variability in conductivity during the year. The changes in conductivity could be a result of HCO_3^- and CO_3^- resulting from the release of CO_2 by bacteria during decomposition of organic matter and or as a result of incoming salts with effluents. Thus, without accurate estimates of incoming salts the effects of water hyacinth on conductivity cannot conclusively be determined.

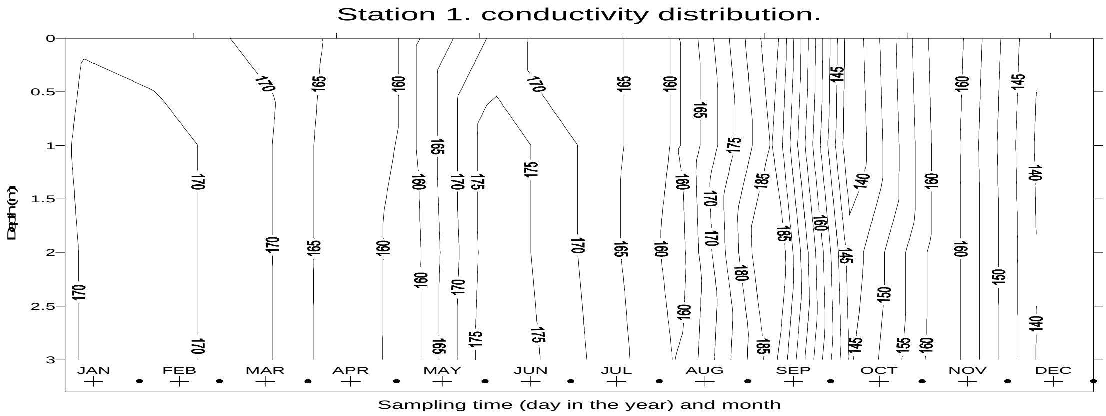

Figure 42: Conductivity at station 1.

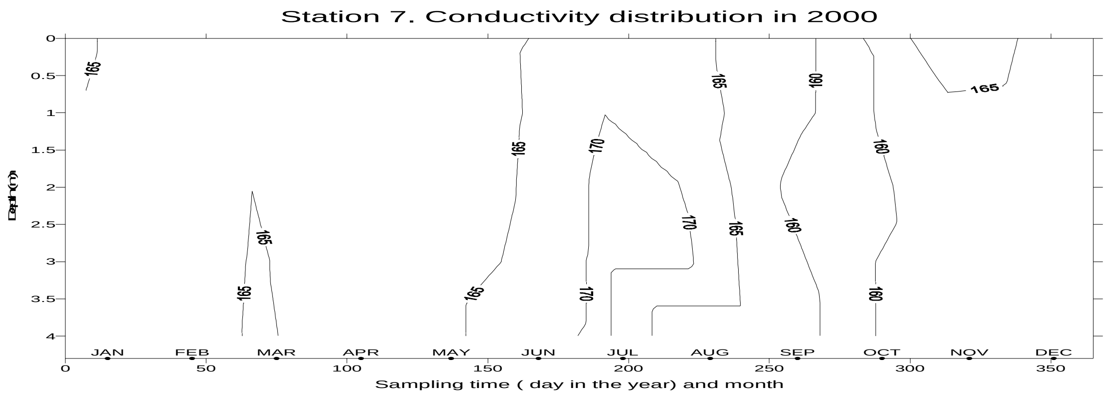

Figure 43: Conductivity at station 7.

3.6 Acidity

Acidity at various times during the sampling period is shown in Figures 44, 45 and 46. At the shallow part of the section, pH values of 7.6 – 8.4 were observed. In the deeper part of the section, lower pH values of between 7.2 and 8 in the surface waters were observed. In the bottom waters pH values of 7 –7.2 were observed.

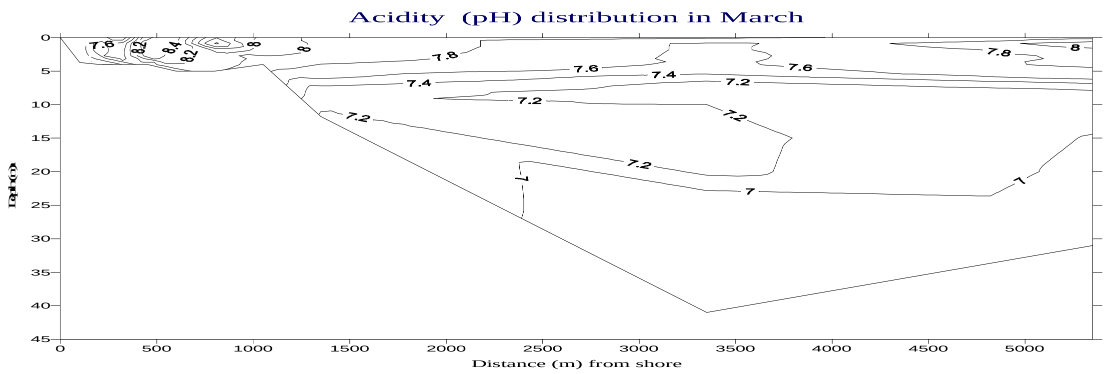

Figure 44: Acidity in March

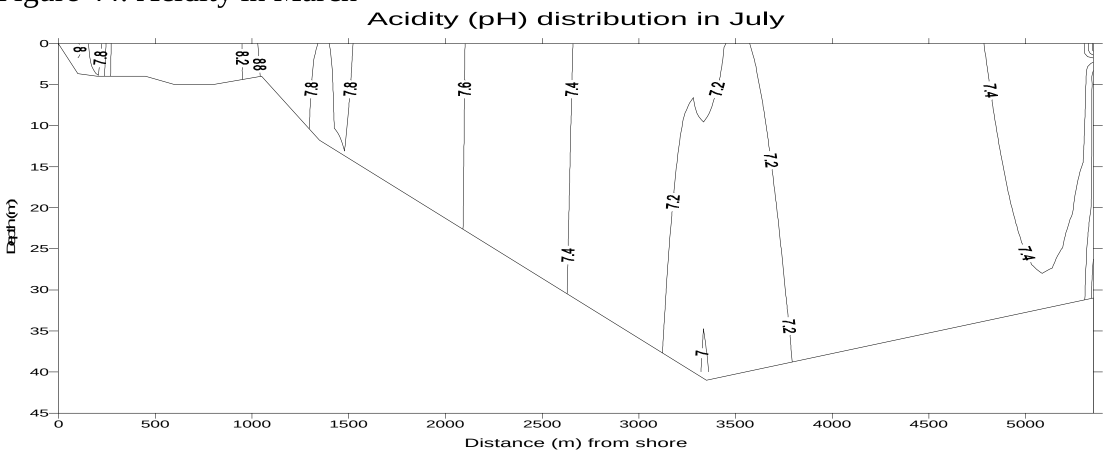

Figure 45: Acidity in July.

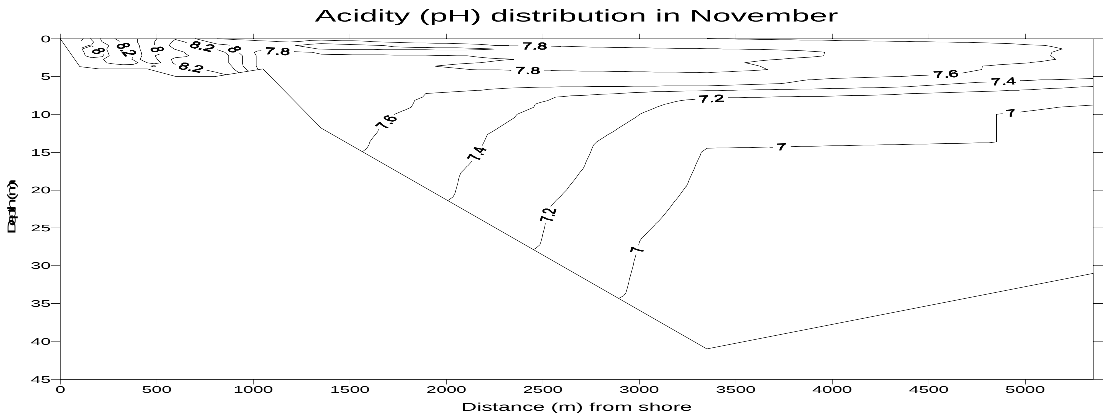

Figure 46: Acidity in November.

The higher pH values observed at the shallow part of the section might be a result of incoming salts. The decrease in pH with distance from shore might be a result of mixing of pollutant-rich water with fresh water.

A general decrease in pH values with depth is shown in Figures 44 - 46. This might be a result of decomposition of organic matter by bacteria in the water column as it sinks. During decomposition of organic matter by bacteria, CO_2 is released. This dissolves in water to form H_2CO_3 which results in the water becoming more acidic.

Figures 47 and 48 show a monthly time variation in acidity at stations 1 and 7 during the sampling period. pH values between 6.8 and 8.5 with a high variability was observed. Higher variability was observed at station 1 which is closer to the shore.

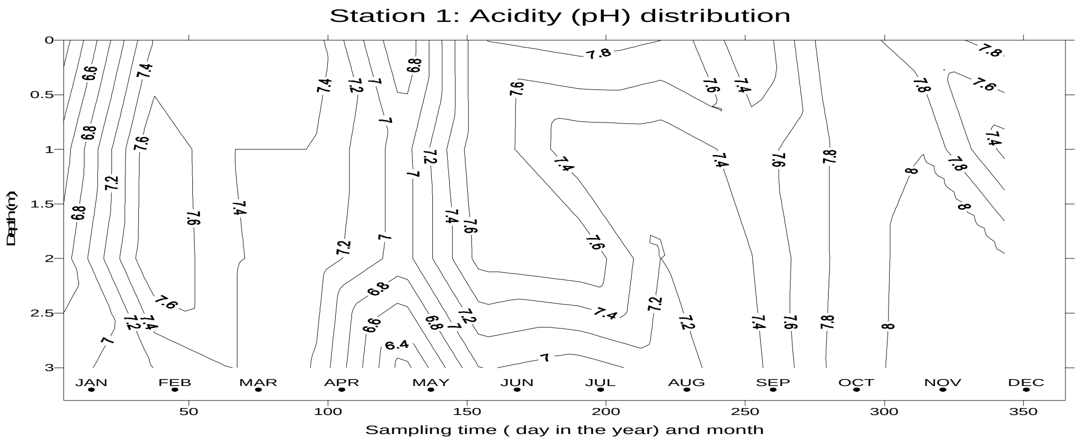

Figure 47: Acidity at station 1.

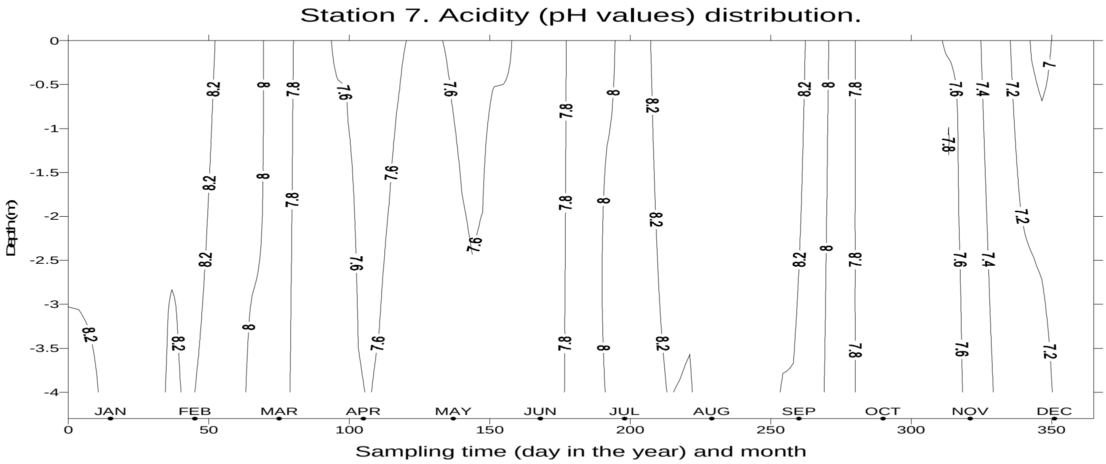

Figure 48: Acidity at station 7.

Generally, alkaline conditions were observed during the sampling period. Being on the equator, evaporation potential is usually high. This could increase salt concentration and raise pH values.

4. DISCUSSION

Lake Victoria is located on the equator. This is especially true for the Winam Gulf and the section used here since it is located about 10 km south of the equator. Therefore the effect of the earth's rotation on water motion in the lake is small. Being a shallow freshwater lake, the main force driving the current in the gulf is wind. The thermal stratification measured during this study seems not to have been strong enough to influence the vertical structure of the current significantly in the gulf.

Humid westerly winds from the lake, typical for the rainy season (March –May), combines with easterly trade wind. The air rises, cools, and releases part of its water vapour as rain in the catchment area. A water hyacinth 'mat' could impede direct evaporation. As a result during water hyacinth cover periods there is likely to be drier weather conditions in the water catchment area. This is likely to result in less surface run-off and river discharge and hence less enrichment of the Gulf. During this period there is also likely to be good quality water (water hyacinth draws mineral ions from water) for domestic and industrial use but poor quality for the lake's biota.

In March the wind was from the northwest as it usually is during the rainy season and the currents observed were also in the same direction. When the westerly wind reaches the mountains further east the air rises and releases part of its water vapour as rain. Also the easterly wind further inland could increase the precipitation. Wind and current as was observed in the sampling period could push and compact the water hyacinth close to shore in the south-east corner of the gulf. This could reduce the surface area that has to be covered to remove the plant, thus reducing costs. This would also lead to removing it near shore and thus making it easier to dump it on land rather than dumping it into the lake where it decomposes using up the oxygen in the deeper parts of the gulf as discussed below. Periods with dominating westerly winds could be ideal for the removal of the plant.

In July and November at the time of sampling there was a north-easterly wind and the surface current was towards southwest roughly corresponding to the wind direction. This is characteristic of the easterly trade wind that dominates during the dry seasons in the area. In November there is usually a rainy season, but it is not as strong as the other rainy season (March-May) and the westerly wind is not as persistent, so it is not surprising to observe a north-easterly wind during that period.

The Coriolis force, resulting from the earth's rotation tends to deflect moving objects in the northern hemisphere to the right and objects moving in the southern hemisphere to the left. This force is minimal around the equator. Considering the fact that the sampled section is almost on the equator, effects of the Coriolis force on current is insignificant. The water column at all stations was observed to move in one general direction. However to satisfy the continuum principle there must be a return flow to replace the moving water mass. This can only occur on the sides and therefore the water circulation in the gulf is likely to be horizontal as opposed to vertical circulation.

Water hyacinth grows up to three feet in height above water with leaves 4 to 8 inches in diameter. It grows erect, thick stalks (up to 20 inches long), which link together to form dense rafts that can affect wind-driven currents. The hyacinth can increase the drag of the wind and thereby increase the current. If the wind blows over a long period of time and is blowing towards the shore, it can push the plant into a dense mass. When the water hyacinth cannot move anymore, the wind blows over the hyacinth with very little drag on the water and the current reduces. On the other hand if wind is blowing towards the main lake, it can increase the current speed. The plant could also reduce the response time of current to wind.

During the period of this study, temperatures above 25^{o}C were observed. The deep waters were characterised by temperatures between 26^{o}C and 26.5^{o}C. The temperature in the surface waters was somewhat higher, up to 28^{o}C. The stratification observed in the section was not strong enough to significantly affect the vertical structure of the current. It was however strong enough to influence some other water properties e.g. dissolved oxygen. The stratification also showed high frequency variations over the shallow part of the section.

Over the deeper part, the water below 5 – 7 m was more or less isothermal. Above this the temperature increased towards the surface. This thermocline seems to have affected the mixing of oxygen to deeper levels.

Though very low Secchi depth (<1.5 m) was recorded, the surface waters in the section seemed to be well oxygenated. This could indicate a high rate of primary productivity and good circulation in the Gulf. This was shown by a relation between high Secchi and higher dissolved oxygen concentration levels for instance in November. However a comprehensive study, particularly on primary productivity is required so as to be able to decisively determine this.

The deep water in the deep part of the section was characterised by dissolved oxygen levels of 1 – 4 mg/l throughout the sampling period. The surface waters were characterised by dissolved oxygen levels of 4- 8 mg/l.

Markedly higher dissolved oxygen concentration levels were recorded in November than in March and July. The lowest dissolved oxygen concentration levels were recorded in July. This was especially the case in the shallow part of the section and in the surface waters.

The water hyacinth cover and its shredding and dumping in the lake seemed to have had an effect on dissolved oxygen. This was shown by the low O_2 concentration recorded in July.

Though relatively low oxygen levels were recorded during the water hyacinth shredding period, this did not last long, maybe a few weeks. This seems to show that the effect of dumping the water hyacinth on the bottom and its decomposition does not seem to have a long-term effect on dissolved oxygen levels. However it might have been long enough to affect the benthic biota. After the shredding period the oxygen levels rose relatively quickly, at least over the shallow part of the gulf, and in November the oxygen had increased significantly at all depths. This was probably caused by increased algae growth.

Higher conductivity in the shallow part of the section was observed. The conductivity was also observed to increase with depth in the deeper part of the section. Alkaline pH values were recorded throughout the sampling period. These were observed to decrease with depth. Both conductivity and pH values of the water showed high variability so it is difficult to conclusively determine effects of water hyacinth. A longer time-series and accurate estimates of incoming salts is required to decisively determine this.

5. CONCLUSION

In this study both water hyacinth and its mechanical shredding were both shown to affect dissolved oxygen concentration levels. Temperature stratification also seemed to influence the vertical distribution of the oxygen.

The Gulf seemed to be generally well oxygenated throughout the water column. This was observed throughout the sampling period.

The mechanical shredding of the water hyacinth seemed to lower dissolved oxygen levels over a short period of time, maybe a few weeks due to its decomposition after dumping it on the bottom. Thus, a better option could be to mechanically shred the water hyacinth and dump it on land. After this short period the O_2 levels in the whole water column rose and remained higher for the rest of the period. The increase was probably caused by increased algae growth.

Westerly and easterly winds corresponding to surface current directions were recorded during this study. Thus, winds seem to be the main force driving current in the gulf.

The Coriolis force deflects moving objects to the right in the Northern hemisphere and to the left in the Southern hemisphere when viewed along the line of motion. This force is least felt on the equator. The sampled section is about 10 km south of the equator and the Coriolis force is insignificant here. The water mass was observed to move in one general direction in the whole water column. Thus the circulation in the gulf is more likely to be horizontal rather than vertical.

6. RECOMMENDATIONS AND FUTURE RESEARCH

It seems that the problem of macrophyte encroachment in Lake Victoria is greatly enhanced by nutrient enrichment (Muli 1996). In controlling the problem, there is a need for a study in nutrient fluxes into Winam Gulf and the lake as a whole.

There is also a need to study the effects of dumping huge amounts of organic matter on the lake's benthic biota, even though this study indicates that the breakdown of the organic matter does not take a very long time.

More distributed current meter deployment in the whole gulf could be necessary to get longer time-series measurements. This could give better-established relations between wind and current such as the response time of the lake to the wind and dynamics of circulation in the Gulf. A better understanding of water exchange between the gulf and the main lake could be an interesting aspect that could be incorporated into the study. This could have a practical aspect in understanding the occasional flooding in the gulf.

There is also a need to map the gulf's topography and an in-depth understanding of the movement of currents and the influence these have on sedimentation on a longer time scale.

The fact that most of the effluent to the lake takes place in the gulf (231 m^3s^{-1}) and the only outlet being in the extreme opposite of the gulf, this would create a pressure gradient along the channel through which the outflow occurs and there should be a near permanent flow from the gulf to the main lake. Determination of water budgets into and out of the gulf should be incorporated into some future study. This could help generate information on the occasional flooding in the Gulf.

ACKNOWLEDGEMENTS

I am indebted to the United Nations University for sponsorship, the board of directors of the Fisheries Training Programme and all those who work behind the scenes to make this course a success. I sincerely thank the Programme Director, Dr. Tumi Tomasson for selecting me for this programme and the Deputy Programme Director, Mr. Thor Asgeirsson, for guiding me during the course. The two deserve special recognition for the hours they spent in making my stay here in Iceland the best experience of my life.

My heartfelt thanks to my supervisor Steingrímur Jónsson, Professor of Oceanography, University of Akureyri for his precious time. His instructions are invaluable and his patience commendable.

I appreciate my lecturers, too many to list here.

I thankfully acknowledge my colleagues' supervisors in Akureyri. I am indebted to the director and staff of the Marine Research Institute and staff of the Fisheries Department, Akureyri University. I am thankful to my director, Dr. Johnson Kazungu, KMFRI, Kenya for nominating me for this course. I also appreciate the help of the assistant and deputy directors, KMFRI, Kisumu.

Last but not least, I acknowledge Mr Friðrik Karlsson, Storholt 1, who ensured that my stay in Akureyri was as comfortable as possible.

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