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Seasonal nutrient cycling of Lake Bosomtwe

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE

BY

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DECLARATION

I hereby declare that this submission is my own work towards the M.Phil and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

Seasonal nutrient cycling of Lake Bosomtwe was investigated from February-December 2008. Bimonthly samples were collected at both inshore and offshore zones of three selected sites namely Abono, Asisriwa and Dompa. Levels of the parameters covered (surface water temperature, transparency, pH, conductivity, phosphorus, nitrogen, organic carbon and primary production) were determined for contrasting seasons. A survey on attitude of fair use and conservation of the catchment area by farmers in the two inhabited sampling sites Abono and Dompa was also conducted. The results showed that lowest surface water temperature of Lake Bosomtwe was in August. Transparency from Secchi disk measurement was low in the dry season and the lowest was recorded at Abono and Dompa. Statistically insignificant correlation existed between transparency and chlorophyll-a at all the three study sites. Mean transparency during the study ranged from 0.64 to 1.49 m. pH of the lake was lowest in the dry season and highest in the main wet season. Organic carbon influenced pH in the inshore zones and mean pH range recorded during the study was 8.77-9.33. Conductivity was highest in October after the main wet season and lowest during the dry season. A correlation analysis between conductivity and all the nutrients (phosphorus, nitrogen and organic carbon) covered in this study revealed non uniform correlation. Mean conductivity recorded ranged from 1047.8 to1268.5 μscm^{-1}. Phosphorus did not follow a marked seasonality and mean phosphorus recorded during the study ranged from 0.025 to 0.48 mg^{-1} with the highest recorded at Dompa in December. Organic carbon levels were high during the heavy rains in June and August at Abono and Dompa. Mean organic carbon levels recorded during the study ranged from 0.667 to 4.339 mg^{-1} with the highest at Abono. Highest mean total nitrogen determined as Total Kjedahl Nitrogen was recorded in June and August in Abono and Dompa. Mean nitrogen levels fluctuated within eutrophic status during the study and levels recorded ranged between 0.89 and 75.37 mg^{-1}. Chlorophyll-a followed a strict seasonality with the highest chlorophyll-a in August. Seasonal nitrogen appeared influential on chlorophyll-a. Mean chlorophyll-a levels recorded during the study ranged from 1.65 to 16.1 mg^{-1}. Primary production determined from the light- dark bottle technique did not follow a marked seasonality, however values from offshore zones were generally higher than inshore zones. The gross primary production (G.P.P) levels recorded during the study ranged from 3.49 to 21.722 $mgCm^{-2}d^{-1}$. Most of the inhabitants engaged in activities within the catchment of Lake Bosomtwe used slash and burn method of land

preparation and were oblivious of the impact of their activities on the water body. Little information on conservational processes to sustain the lake was available to the inhabitants.

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CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND

Lake Bosomtwe is the only natural lake in Ghana and represents an impact crater bounded by a steep slope that rises from the lake edge at 99 m to 460 m (Turner *et al*., 1996a). Studies on Lake Bosomtwe's hydrology describe it as a closed lake which is mostly enervated by water from rainfall and runoffs from its watershed because there are no major inflows or outflows (Turner *et al*., 1996a). The contribution of groundwater penetration to the water balance has not been reported extensively hence lake level fluctuation depends exclusively on precipitation and evaporation (Koeberl and Reimold, 2005). Nonetheless, the lake's hydrology and water balance has undergone some dramatic changes throughout its years evidenced by lacustrine deposits within its basin (Talbot and Delibrias, 1977, 1980). The basin receives an average annual rainfall of 1380 mm throughout a cycle of season characterized by a dry season in December – February, peak rainfall in June through to August and a pre-dry season characterized by reduced rains from September – October (Turner *et al*., 1996a). Turner *et al.* (1996a) used surface elevation, area-volume relationship to determine the volume of the lake as 2.2374 Km^3 on an elevation of 99.8 m (amsl) and at maximum elevation of 213.4 m (amsl), a projected volume of 9.2342 Km^3.

Substantial interest in the Bosomtwe crater has also come from studies of La Cote d'Ivoire tektites, which occur in an area of about 40 km radius in Cote d'Ivoire, West Africa (Koeberl and Reimold 2005). Research has intensified recently with regard to a number of aspects of the Bosomtwe crater and the lakes aquatic system. According to Koeberl and Reimold (2005), the lake has a strong paleo-climate significance and detailed paleo-environmental record making it an ideal geographical location to provide data on climatic variations with time scales ranging from seasonal to very long-term for the West African monsoon and Sahel drought activity.

The accumulation of detailed varved lake sediments record can be used to monitor both past local and Sahel rainfall variation (Street-Perrot and Perrot,1990). By extension, these varved sediments can also be used to study the nutrient dynamics of the lake through the years; especially so when there have been strong indicators of phenomena of the lake having gone through an overflow of the rim and level dropping again (Peck *et al*., 2004; Brooks *et al*., 2005).

The few workers who have worked on the planktonic species composition of Lake Bosomtwe have rated diatoms as being low in abundance and are only found in water samples during the months of July and August yearly (Otu, 2010). The basis of the food web in Lake Bosomtwe, includes deep chlorophyll maximum which consists not only of bacteria, but also includes the cryptophyte *Cryptomonas marssonii*, the chlorophytes *Chlorella* and *Chlamydomonas* and the cyanophyte *Chroococcus.* These are the primary producers that support zooplankton and planktivorous fishes and contribute to the organic matter sedimentation of Lake Bosomtwe (Puchniak *et al.*, 2009). The zooplankton ccommunity structure of Lake Bosomtwe as found by Sanful (2010) revealed that the cyclopoid copepod (*Mesocyclops bosumtwii*), the cladoceran (*Moina*), many rotifers (example *Brachionus, Keratella* and *Hexarthra*) and chaoborids were possibly utilizing phytoplankton as food source, potentially altering the recycling of nutrients and the nature of the sediment composition. The copepods form the largest proportion of community abundance contributing as high as 78 % while the 9 % contribution of *Chaoborus* to community abundance was the least. The majority of the zooplankton species in Lake Bosomtwe selectively feed on phytoplankton (Otu, 2010). The edible phytoplankton are consumed and packaged into fecal pellets, affecting the sedimentation of organic matter to the surface sediments. Overall, how the biological in-lake processes for Lake Bosomtwe affect the formation of sedimentary records is poorly understood.

The fishery composition of the lake according to Amisah and Agbo (2008) currently, holds 12 species of fish, all belonging to the taxonomic family of Cichlidae. *Sarotherodon galilaeus multifasciatus* constitutes the bulk of the cichlids and appears to be the most commercially exploited fish. Their feeding chronology reveals a heavy dependence on phytoplankton, insects and insect larvae, and aquatic macrophytes or angiosperms (Amisah and Agbo, 2008).

Thermal stratification in Lake Bosomtwe, breaks down twice in a year: once in August, during the relatively cool periods between the two major rainfall peaks (when the cool air causes thermal instability and wind strengths are maximum) and January (when hot dry harmattan winds contribute to increased evaporation and stirring). The August mixing is said to be the most vigorous of the mixing events according to Beadle (1981). This renders Lake Bosomtwe meromictic in its overturn regimes. Upwelling events in Lake Bosomtwe is known to cause fish kills as anoxic water and probably H_2S are brought to the surface (Otu, 2010). Thus, physical mechanisms enhancing cross metalimnetic mixing and supply of nutrient-rich water to the epilimnion play decisive roles in determining lake productivity. Certain chemical perturbations that seem to accompany the above physical mechanism have been identified as influencing productivity and nutrient dynamics of lakes (Langenberg, 2008).

Chemical analysis conducted on the lake water include the characterization of mineral distribution in sediment core by Talbot (1984), oxygen and carbon stable isotopes in carbonates (Talbot and Kelts, 1986; 1990), as well as carbon and nitrogen isotopic compositions of sediment organic matter (Talbot and Johannsen, 1992). However, water samples taken at various depths from the center of the lake by (Turner *et al.*,1996b) in 1993 and analyzed for nutrients (NH_4^+, PO_4^3, NO_3) and pH revealed no trend through the depths of the lake suggesting homogeneity. According to Stauffer and Thompson (1978), the lake's significant dominance of the planktonic diatom *Stephanodiscus* from varved sediments at the beginning of the Lake's history suggests a significant source of phosphorus. The lake water has a Na : Cl ratio much higher than that in seawater or rainwater due to additions of sodium from chemical weathering and deposition of harmattan dust (Turner *et al*., 1996a). The dust is known to originate from the sahara and is abundant throughout West Africa during the dry season (Beadle, 1981).

Research on nutrient inputs crucial for increased production levels showed that lake primary productivity is often regulated by availability of growth limiting nutrients, such as phosphorus, nitrogen, carbon and silica (Horne and Goldman, 1994). Puchniak *et al.*, (2009) estimated total phosphorus concentration in the uppermost layer of Lake Bosomtwe to be 2.3 μmol P L^{-1}, whereas below the oxycline, concentrations are more than double this amount (5.8 μmol P L^{-1}). These are concentrations well above the critical threshold of 0.1 μmol P L^{-1}, known to be the condition of phosphorus famine for phytoplankton growth according to the rating by Reynolds (1984). Generally, total nitrogen concentrations range from 20 μmol N L^{-1} at 1 m depth to 2,000 μmol N L^{-1} below the oxycline which is predominantly in the form of ammonium sequestered deep in the anoxic hypolimnion and all concentrations are well above the level of insufficient nitrogen concentrations of 0.2 μmol N L^{-1}.

Since it has been established that water chemistry and physical environment in a freshwater system often dictate the phytoplankton community composition and ultimately the primary production, the nutrient dynamics is of utmost importance for the continuous survival of that water body.

Nutrient cycling in lakes however is an ever evolving phenomenon and that even few of the available nutrients are ever present in the water in such concentrations that can be maintained within the cells of aquatic organism (Reynolds, 1984). Another problem which arises is the monitoring of fluxes of uptake and regeneration of nutrients between external medium and biomass in tropical lakes. This according to Talling and Lemoalle (1998a) have rarely been studied with relatively fine experimental resolution, an exception however is inorganic carbon which is assimilated in photosynthesis by the ^{14}C tracer in primary production studies. Of greater importance is that, the external concentrations of these nutrients are subject to wide variations in space and time and they are present in differing amounts relative to requirements. It is important that in assessing the nutrient levels of a lake, a holistic approach is adopted such that all available input sources are duly covered which will then provide a comprehensive knowledge base as to the nutrient dynamics of the lake. In the wide range of studies published to date on nutrients in lakes, the focus of research has been on nutrient cycling dynamics within the lake ecosystem and the impact of increased nutrient loading on the biotic communities, taking into account only the gross nutrient loading from the catchment sources. Johnes (1999), states that a detailed cause and effect assessment is likely to give a detailed and exhaustive understanding of the lake ecosystem.

To destabilize a well balanced aquatic ecosystem that could eventually affect water quality, various factors add up and their cumulative effect depends on the magnitude on which they occur. To begin with, exponential growth of human populations and its attendant increase in anthropogenic activities within the catchment of the water body are a major source of nutrient load, however other factors depends on where and the magnitude they occur. Non-point source of pollution may also become a source of nutrient load to a water body. The reduction in vegetation of water body’s catchment area contributes to increase in silt and nutrient load of the water body. This leads to the phenomenon of eutrophication which results in decreased O_2 levels as a result of increase in BOD activities, algal blooms and production of H_2S as has been reported in some Ethiopian rift valley lakes (Zinabu, 2007). Nutrients may enter a water body from the atmosphere as a result of excessive burning of forest, crop residue and also from factories and industries cited close to the water body to affect water quality (Whitt, 2007). Although water quality problems may vary from one country to the other, the basic facts would probably be similar given that they share much with respect to their geology, climate and socioeconomic development.

It is well established that even without interferences, lakes change over time due to natural factors such as erosion, sediment loading from overland wash, deposition of animal and plant debris and solution of minerals. These processes run overtime and are phenomena that can be easily monitored; it has however led to the extinction of some lakes. Most importantly is the advantage lakes and rivers have over the oceans; in that restoration is successful through environmentally sound and ecologically reversible regimes. An important aspect is to first identify the most important water quality challenge before appropriate restoration treatments are applied. According to Horne and Goldman (1994), successfully restored lakes such as Lake Washington and Lake Zurich are among the first lakes in which restoration regimes were applied and a general theory of lake management was tested.

Table.1.0. Some lakes and their restoration regimes. (Source: Horne and Goldman,1994)

LAKE	RESTORATION REGIME
Lake Tahoe	Advance waste water treatment and diversion
Lake Washington	Direct waste water diversion
Lake Shagawa	Phosphorus removal
Lake Trummen	Wastewater diversion and dredging

When issues of water quality of a water body arise there is the need to employ laid down process and procedure to assess the levels and workers in this regard have proposed various ways of employment. Sheffer (1998) however has emphasized the difficulty in determining *a priori* whether an alternative stable state is possible to practice, however if a clear system becomes turbid as a result of eutrophication, the nutrient level must have been too high to allow a sufficiently stable clear equilibrium of a lake system.

According to Rees *et al.*, (2008) there is the need to shift towards evaluating the ecological consequence of human activities to employing indicators more widely as explicit as enforcement tools in regulatory process. These indicators in context are just information relayed about the environment in a manner that will determine the necessity for corrective action. Fisher, (2001) defined 'Indicator' as a measure or model used to estimate current and future trends in physical, chemical, biological or socio-economic condition of the environment.

Johnson, (2008) stated the need to employ a multiple approach process which involves either one or more of the following:

(1) Fixed station

(2) Fixed Interval Sampling

(3) Synoptic Survey and

(4) Detailed Cause- Effect Studies

to evaluate the physical, chemical and biological character of the water body. This may be based on assessing the water body in relation to natural quality, human effects and intended uses especially human and aquatic health related issues.

1.1 PROBLEM STATEMENT/ JUSTIFICATION

To a limnologist understanding the ecosystem of inland waters whether fresh or saline is of primary concern. Therefore monitoring water quality in relation to aquatic life, vegetation within the catchment area, watershed of the water body, sediments etc cumulatively may reveal the true status of the water body. In this sense, observations carried out prior to the commencement of this study included;

(1) The Lake is characterized by massive slash and burn farming activities within its catchment areas up to the supra littoral zones.

(2) Livestock rearing activities (mostly pig farming) also occur within the catchment area of the water body.

(3) Average CPUE in Kg/man-h following (Blay and Asabere-Ameyaw, 1993) determined for four local fishermen in April 2007 gave;

(i) 0.495 Kg/man-h, (ii) 0.685 Kg/man–h (iii) 1.3 Kg/man-h (iv) 0.98 Kg/man-h (unpublished data).

With a standard mesh size net, a productive lake barring over – fishing, the CPUE values calculated above are low. These phenomena give cause for water quality assessment.

Data obtained from the research could be used in formulating policies and regulations geared towards sustainable management of the water quality of the lake for the benefit of the local fishery industry for continued support of their economic survival and largely the whole country

1.2 OBJECTIVES

1.2.1 GENERAL OBJECTIVE

This study was to assess the seasonal nutrient cycling of Lake Bosomtwe at 3 selected sites; Abono, Asisiriwa and Dompa.

1.2.2 SPECIFIC OBJECTIVES

The specific objectives of this study were to:

(1) Determine seasonal levels of Nitrogen, Phosphorus and Organic Carbon.

(2) Determine seasonal Primary Productivity

(3) Determine seasonal physico-chemical parameters (pH, Conductivity, Temperature and Transparency)

(4) Assess inhabitants' conservational perception in the exploitation of the catchment areas of the lake.

1.3 SCOPE OF STUDY

(1) The study captured one seasonal nutrient levels at Abono, Dompa and Asisiriwa at the inshore and offshore zones within the Lake. The parameters measured included;

pH, temperature, transparency, conductivity, total nitrogen, total phosphorus, organic carbon and primary productivity.

(2) The study also assessed the level of knowledge of fair use or sustainable use of the lake's catchment area by the inhabitants in the two inhabited sampling stations;- Abono and Dompa through the administration of questionnaires to **ONLY** inhabitants who engage in farming activities within the catchment of the lake.

CHAPTER TWO

LITERATURE REVIEW

2.0 LAKES

Lakes have varied morphology and column characteristics depending on how they were formed. Impact craters and volcanic collapse lakes have similarities in form, structure and internal geometry. They are produced rapidly by catastrophic processes that destroy the biota in the surrounding areas, followed by extended periods of biotic recovery. Many impact craters and volcanic depressions subsequently become filled or partly filled with water to form lakes, such as Lake Bosomtwe (Ghana), and Crater Lake Oregon (USA) in which similar kinds of lacustrine sediments may be deposited. The earliest post-event lake sediments may hold a record of the environmental effects of the impact or eruption and the nature of the initial biologic recovery in the surrounding area (Cockell and Lee, 2002). Several historic explosive and caldera-forming eruptions caused destruction for which there are good records of the stages of biological recovery of plants and animals in the surrounding areas.

Evidence that inland waters are an important component in the processing of carbon on a global scale has increased interest in the metabolism of lakes (Cole *et al*., 2007). Since photosynthetic and respiratory activities are indicated by variations in dissolved oxygen and carbon dioxide, measurements of these gases in lakes provide metrics of metabolism. Although recent technological advances have improved capabilities to determine concentrations of these gases, the theoretical basis for calculations of metabolism and studies in a variety of ecosystems date back over 50 years (Melack, 2009).

Most lakes are comparatively short-lived at least in geological sense, there had been an extensive lake systems extending over much of North America but these are represented now by only a few reduced water surfaces. Most familiar of these is the Great Salt Lake in Utah, the shrunken remnant of the once immense lake Bonneville (Boughey, 1975). Probably they might have been shallow cyclic water bodies that probably silted-up and disappeared as a result of non application of proper management strategies to ensure the continuous survival of the water body. This is especially so because lakes change over time due to natural factors such as erosion, sediment loading from overland wash, deposition of animal and plant debris, solution of minerals etc. The processes run overtime and it is a phenomenon that can be easily monitored; it has however led to the extinction of lakes.

2.1 PHYSICAL INTERACTION IN LAKES

2.1.1 LIGHT

Light is an important factor in the creation and consolidation of the lake structure. Light forms the basis of primary productivity which drives the entire ecosystem of an aquatic body. Specifically, light in lakes drives photosynthesis and lake metabolism, affects the thermal dynamics and regulates biota.

Light creates a vertical zonation in terms of productivity based on the amount and quality of light.

(1) Photic/Euphotic zone which constitutes the well lit upper waters to the depths of 1% of incidented surface light. The littoral zones and the upper parts of the pelagic/open waters fall within the euphotic zone and it is the zone of active production.

(2) Aphotic zone extends from the lower ends of the photic zone to the lake bottom, characterized by little or no productivity. It is basically a zone of respiration. The aphotic zone changes with light intensity and water transparency daily and seasonally. These two zones are not rigid but rather dynamic. The photic zone is also diminished or faces clarity challenges with the presence of algal blooms and increased suspensoids.

2.1.2 LIGHT ATTENUATION IN LAKES

The contribution of light to lake structure depends on the quality of the electromagnetic spectrum. Light plays a dual role in this exercise in that it serves as a source of energy in the form of heat (radiant flux) captured as (Joules/min/ m^2) energy/time/area, then as particles involved in biochemical process as vital as in photosynthesis where they behave as photons (quanta) which are discrete packs of energy needed to excite electrons in phytoplankton. Light intensities and qualities are affected by;

(1) Altitude

(2) Atmospheric transparency (haze smoke particles)

(3) Cloud cover

(4) Latitude

(5) Solar angle (time of day and season).

Conditions that may affect transparency are transient increases in turbidity mainly due to suspended particles associated with floods or strong wave action which is a major phenomenon in tropical lakes (Whyte, 1980). Transparency and turbidity have a telling effect on productivity because the lesser the transparency, the lesser quality of light to initiate photosynthetic activities as more light energy is absorbed, reflected or refracted by obstructing suspended materials (suspensoids).

2.1.3 THERMAL STRUCTURE

The high specific heat capacity of water makes daily temperature changes very slight and seasonal temperature changes slow compared to terrestrial habitats. For most lakes temperature structure is influenced by solar radiation (Brewer, 1978). Solar radiation in a receiving water body causes layering or stratification based on temperature difference which is commonly put into zones: Epilimnion – the upper mixed layer where water is warmer and less dense. The depth of the Epilimnion depends on the amount of solar radiation the lake receives and it varies from region to region.

Metalimnion (Thermocline) – it is the zone where distorted.For instance Lake Tana in Ethiopia whose average depth is 8m is well mixed and does not have any lengthy period with thermal stratification (Wondie *et al.*, 2007). The processes of thermal stratification or layering however follow the same principle.

2.1.3.2 THERMAL STRATIFICATION IN TEMPERATE LAKES

In the temperate regions the pattern of deep lake stratification is in 4 stages:

(1) Summer stratification – Thermal energy from the sun usually causes surface temperature to be raised a few degrees higher than the lower portions of the lake. This warmer water tends to circulate by itself on top of the cooler, heavier water; this then creates a summer stratification of a warmer epilimnion, a thermocline and a larger hypolimnion. The epilimnion cools and more water is drawn from below to the surface to cause mixing which is driven by the interaction between wind and sunshine.

(2) Autumn stratification – As temperatures go down after the summer, the epilimnion cools and more water is drawn from below to the surface. This continues to cause water temperature of the surface to be about the same temperature as the lower waters. This eventually circulate the whole lake as the surface and bottom waters continuously interchange to bring about a phenomenon known as the autumn overturn.

(3) Winter stratification – As the surface water temperature continually drops, its density becomes greater thereby sinking to the bottom of the lake, lighter water from the bottom with less density is sent to the upper part. This cycle continues until the surface water reaches 0^{C} and turn into ice which stays on top to create winter stratification.

(4) Spring stratification – Sunshine after the winter melts the ice on top of the lake to bring temperature at par with the lower waters. As the surface continues to receive heat to melt the ice, wind can then drive the circulation between the surface and lower water to cause spring overturn.

2.1.3.3 THERMAL STRATIFICATION IN TROPICAL LAKES

The dynamics of thermal structure in tropical lakes follows the same principle as that of the temperate lakes and also follows the density/temperature relationship of water. The difference is in temperature range and also the fact that most tropical lakes are polymictic as opposed to temperate lakes being dimictic, monomictic or even amictic especially at the poles (Horne and Goldman, 1994)

2.2 CHEMICAL INTERACTIONS IN LAKES

Lakes have peculiar characteristics of being “close” or “open” and this categorization impacts on the chemical dynamics of lakes; closed basin lakes are known to accumulate solutes over time, their volume at any point as a result of dilution determines chemical structure as has been discovered in Lake Bosomtwe (Turner *et al.*,1996b).

To fully appreciate the chemical composition of a particular water body, an understanding of the nature of the vegetation, weathering of the parent rock and climatic conditions is of importance.

Also, of importance is the topography and vegetation cover at the watershed of a water body in determining its chemical dynamics (Horne and Goldman, 1994).

In water bodies, chemical stratification is influenced by thermal stratification. Exceptions however exist. For instance, Horne and Goldman (1994) reported that chemical stratification in very deep lakes like Lake Superior, Lake Tahoe is independent of temperature but rather microbial processes.

Langenberg (2008) also reported on Lake Tanganyika that chemical stratification is independent of temperature but rather microbial processes thus corroborating the findings of (Horne and Goldman, 1994). Due to upwelling of lake waters, vertical chemical stratification is seasonal and the stability or frailty of the stratification depends on the density stability of the particular water body (Wondie *et al*., 2007). The composition of mineral or nutrient content of lake waters is not constant neither is the water level. The composition of natural lake water is that of dilute solutions of alkali and alkaline earth bicarbonate and carbonate, sulphate and chloride with a variable quantity of largely undissolved silicic acid and also a variety of colloidal materials both organic and inorganic (Hutchinson, 1975).

Hutchinson, in the work compiles a list of various nutrients and levels from rainwater that are deposited in lakes; these include Cl, Br, I, SO_4, B, Na, K, Mg, Ca, $N.NH_3$ and $N.NO_3$; which vary from region to region.

Horne and Goldman (1994) reported that the inorganic nutrients provide chemical constituents which drive the aquatic food web and they are divided into major and minor constituents; those whose effect is ionic and those with toxicating effect; those that can be potentially limiting, especially, CO_2, O_2, NH_4, NO_3, PO_4, SiO_2, SO_4 and Fe.

According to Hutchinson (1975) organic compounds are classified into 7 groups by their function:

(1) Refractory compounds i.e. compounds that do not decompose or do so slowly if they eventually decompose and they are cumulative in nature even in oligotrophic lakes. Humic acids which mostly give the yellow-brownish colouration to water bodies are examples.

(2) Those that provide food for microbes including bacteria, fungi, some protozoan and few dinoflagellates. Examples of such food sources are acetate, glycolate and glucose which are mostly lost from phytoplankton that are stressed by high light source.

(3) Chelating compounds/agents – are compounds that are able to change the ionic state of metals that could have otherwise been lethal. Chelating agents are produced by organisms such as algae in response to protection or a need for the dissolved metal.

(4) Extracellular Enzyme – they are excreted by algae when dissolved phosphate is scarce by splitting of phosphate from a source that was originally bounded to an organic molecule, an example is phosphatases which act on non metallic nutrients.

(5) Compounds for organisms communication – This refers to nutrients that allow aquatic organisms to communicate through chemical means as a protective tool, as mating signals and as an alarm etc.

(6) Chemicals for defense – as found in allelochemistry using antimetabolites.

(7) Odiferous substances secreted by some algae and fungi which cause colour problems in waters.

2.2.1 pH

It is the concentration of Hydrogen ions (H^+) as well as Hydroxyl ions (OH^-) in water. The concentration dynamics is such that the higher the H^+, the more acidic or lower the pH value; and the higher the OH^-, the higher pH value or lower acidity (Agbetsiafa, 2000). Hutchinson (1975) reported that a few elements notably the halogens, a number of non metallic oxides and organic substances when dissolved in water form compounds which when dissociated increases the concentration of hydrogen ions. This chemical phenomenon helps gauge the kinds of reaction proceeding within the water body. It determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituent such as P, N and C, and some heavy metals (http://www.waterontheweb.org/under/streamecology/14_nutrientdynamics-draft.html, 21/4/2009).

In photosynthesis, dissolved CO_2 is removed but it is put back in respiration which dissociates to form HCO_3 (carbonic acid) in lake waters thereby lowering pH to increase acidity. Buffering capacity of natural waters if not manipulated (through pollution) is able to control the overall range of pH under natural conditions. The pH of natural water according to W.H.O (1984) guidelines is 6.5 – 8.5.

2.2.2 CONDUCTIVITY

It is widely used to indicate the total ionized constituents of water; it is directly related to the sum of cations or anions as determined chemically and is closely correlated in general with the total dissolved solids (TDS), (Pescod, 1992). Conditions within a particular water body determines its conductivity values and basically the conditions are just processes that will result in the accumulation of elemental ions; for example the geology of lake sediments can contribute to conductivity range because certain rock types and their composition influences the ionic composition of the lake thereby affecting conductivity; if a lake basin is made of limestone for example it leads to higher conductivity as a result of the dissolution of carbonate minerals in the basin.

The size of watershed can also impart on the conductivity of the water body because the bigger the watershed, the more contact with soil before reaching the lake, therefore more ions are washed into the lake (http://www.waterontheweb.org/under/streamecology/14_nutrientdynamics-draft.html, 21/4/2009).The evaporation of water from the surface leads to the accumulation or a higher concentration of ions and this can lead to high conductivity. Some cases have been reported in some lakes such as the Great Salt Lake, Pyramid Lake and the Mono Lake in the

United States as a result of Lake evaporation raising the conductivity and making the lake salty (http://www.waterontheweb.org/under/streamecology/14_nutrientdynamics-draft.html, 21/4/2009). Accumulation of detritus within the hypolimnion as a result of prolong stratification can also lead to high conductivity. Its determination is rapid and reasonably precise at standard room temperature.

2.2.3 NUTRIENT DYNAMICS

Water bodies depend on a complex nutrient forms. Some are major in the scheme of things of the entire ecosystems dynamics and these major nutrients have been identified as potentially limiting. Several phenomena also allow a worker of lake chemistry to appreciate the nutrient dynamics. The selected phenomena of relevance to this study include:

2.2.3.1 PHOSPHORUS IN LAKE WATERS

Phosphorus is theoretically the most limiting nutrient compared with available nutrient rations.The ratio of phosphorus to other elements that exist ecologically makes phosphorus theoretically the most limiting nutrient. A deficiency of phosphorus is therefore more likely to limit the productivity of any region on the earth's surface. Phosphorus controls the growth of algae and macrophytes and failure to control phosphorus loading can lead to algal blooms (Dakers, 2003).

Phosphorus exists in aquatic systems in the following forms:

(1) Dissolved inorganic phosphorus (polyphosphates $PO^{3-}{}_4$)

(2) Dissolved organic Phosphorus which is most often part of organic colloids and are less quickly available.

According to Schulz (2001) the enzyme phosphatase mediates the release of phosphorus from its colloidal forms to produce much needed phosphorus when it is limiting, therefore the presence of alkaline phosphates can be an indicator of phosphorus limitation.

(3) Particulate phosphorus- often the largest percentage of phosphorus in lakes and present in organisms both living and dead, it is also available in mineral form that is not bioavailable. Barrensheen and Beckh–Widmanstetter (1923) and Rudakov (1927) quoted in their respective publications that bacteria have the ability to reduce phosphate to phosphite, hypophosphite and phosphine ($PH_{3(g)}$) as the phases of phosphorus.

Pathways for phosphorus entry in lakes are in different forms and media.

(1) Through precipitation in the form of dust particles in the air.

(2) Surface runoff most importantly over watershed boundaries.

(3) Groundwater because phosphorus usually adsorbs to soil.

Sources from this mode of entry are:

(1) Weathering of minerals rich in [Ca_5 (PO_4) OH]

(2) Anthropogenic Phosphorus (Lehman, 1980).

The sources of this anthropogenic phosphorus include sewage, urban run-off, and agricultural activities within catchments.

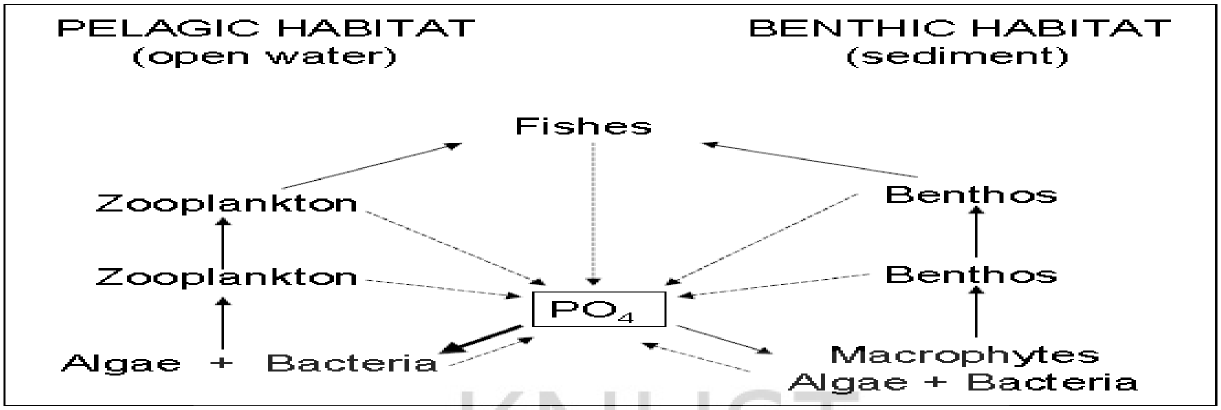


Fig.2.0 Biotic component of phosphorus cycle. Source (Lehman, 1980).

Plants and bacteria can take up phosphorus directly from the water. All other organisms accumulate phosphorus through their food. All organisms excrete phosphorus and therefore recycle it back to the pool (within the water column) available to plants and bacteria. Most consumers are homeostatic with respect to their elemental composition. This means that an organism must excrete a lot of the elements it consumes, unless it is growing rapidly. In the case of phosphorus, consumers can excrete substantial amounts of this element to avoid accumulating it. Many plants and bacteria have flexible concentrations of phosphorus, and therefore take up as much as they can and often save it for later growth.

Benthos is important at moving phosphorus out of sediments and into the water column. Analysis on the quantity of phosphorus in the epilimnetic zones of inland waters indicates small quantities, but these are old and can probably be unreliable; later studies however revealed that more phosphorus are usually present in inland waters than could be determined as phosphate ions (Hutchinson, 1975).

Total phosphorus in lake waters is known to vary from undetectable amounts to immense quantities and then again a good deal of regional variation occurs in total phosphorus content that arises from differences in geochemical causes.

2.2.3.2 NITROGEN

Nitrogen is often in short supply generally for plant growth within both aquatic and terrestrial ecosystems hence its character as a growth limiting factor in the aquatic environment. Beyond this, it is an important indicator of eutrophic waters especially for those contaminated by animal wastes, fertilizer run off and domestic sewage (www.ausetute.com.au/waterana.html, 21/4/2009) but theoretically there are three possible sources of nitrogen compounds input to lake water bodies including the following:

(1) Influents to the lake which also include addition of dissolved minerals through groundwater.

(2) Precipitation on lake surfaces from rain water, particles containing nitrogenous compounds etc.

(3) Fixation within the lake through the nitrogen cycle.

Aquatic nitrogen is essential for growth of aquatic organisms and is produced in natural processes including decay of proteins, the action of lightening and the action of N-fixing bacteria on NH_3. In natural waters, the forms of nitrogen of greatest interest in order of decreasing oxidation are nitrate, nitrite, ammonia and organic N (Greenberg *et al*, 1992). The most abundant form of nitrogen is NO_3 and it is the most highly oxidized. The concentration of the forms of nitrogen varies regularly with seasonal patterns and its availability influences abundance and nutritional value of aquatic plants.

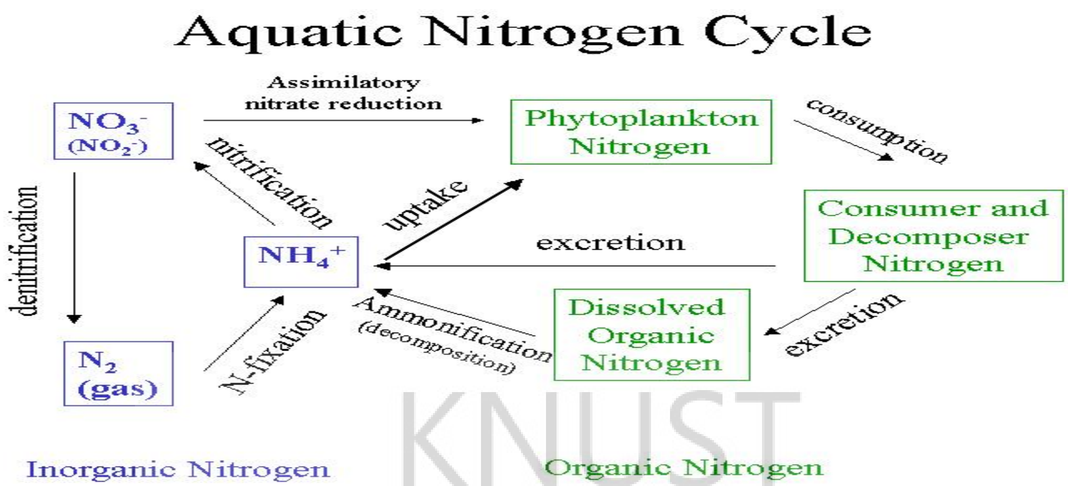


Fig.2.1 The aquatic nitrogen cycle. Source (Schulz, 2001).

2.2.3.2.1 REACTIONS WITHIN THE AQUATIC NITROGEN CYCLE

A. NH_4^+ uptake by algae: $NH_4^+ \rightarrow organic - N(NH_3)$

B. Ammonificaton - ammonium production through decomposition of organic matter this includes all organisms that make use of algae within the system as well as others for example fallen leaves, twigs etc: organic – $N(NH_3) \rightarrow NH^+$ NH_4OH (toxic).

C. Nitrification -- NH_4^+ conversion to NO_3^- (oxidation; bacterial gain of energy)

$$NH_4^+ + \frac{3}{2}O_2 \Leftrightarrow NO_2^- + 2H^+ + H_2O \quad NO_2^- + \frac{1}{2}O_2 \Leftrightarrow NO_3^-$$

D. NO_3^- eventual uptake by algae mostly as nutrition (assimilatory nitrate reduction): NO_3^- to organic - $N(NH_3)$ $NO_3^- + H^+ \rightarrow NH_3 - organic$

E. Denitrification- dissimilatory NO_3^- to N_2 (reduction) $CH_2O + NO_3^- + 2H^+ \Leftrightarrow CO_2 + \frac{1}{2}N_2 + 2H_2O$

F. Nitrogen fixation -- N_2 to organic-N (NH_3); cyanobacteria

In the scheme of things of a lake researcher, more emphasis will be laid on inputs of nitrogen and its level in the face of challenges posed by anthropogenic activities in order to be able to gauge the lake on the basis of eutrophication.

2.2.2.3 ORGANIC CARBON

Organic matter found within lakes or its sediment may be either material that has been formed within the lake basin either by photosynthetic activity of the green plants, activity or demise of non- chlorophyll containing organisms or it may be material formed outside and brought into the lake body through any means.

Table 2.0 Sources of Carbon in the aquatic environment. Source (Shulz, 2001)

	PARTICULATE	**DISSOLVED**
ORGANIC	Living organisms Dead organic material	Soluble organics: DOC (dissolved organic carbon) Amino acids Sugars
INORGANIC	$CaCO_3$ Carbonates of Mg, K, Na, etc. (minerals)	DIC (dissolved inorganic carbon) CO_2 H_2CO_3 HCO_3^- CO_3^{2-}

This diversity in the sources of allochthonous organic matter input in lakes is wider because inputs continue even without human influence and in some cases both human and natural sources come into play. Also autochthonous organic matter varies from lake to lake according to whether it was produced by macrophytes or phytoplankton. On this basis there is every reason to expect considerable differences in the composition as well as the colloidal and dissolved organic wastes of lake waters. Analysis of this parameter in totality is more appropriate as Hutchinson (1975) admits the difficulty in accurately assessing the quantity of total organic matter especially as total organic carbon.

2.2.4 PRIMARY PRODUCTION

Most workers have discovered that Primary production in warm tropical lakes is higher than in temperate lakes (Melack, 1979a). Two workers on primary production have assigned two reasons to this phenomenon. According to Harris, (1978) the maximum rate of photosynthesis per biomass and time (photosynthetic capacity) is a function of temperature. Lewis (1987) stated that higher incident irradiance often experienced in the tropics and enhanced vertical mixing are additional factors promoting primary production in tropical lakes. Lewis (1987) also indicated that at comparable phytoplankton biomass within the photic zone, primary production in tropical lakes is in general two to three times higher than in temperate lakes. The same conclusions were drawn by these workers using global data on incident irradiance and water temperature, and assumptions of quantum yield and chlorophyll-*a* in the photic zone.

Details on primary production enable workers to improve their understanding of food web relationships in an aquatic ecosystem, for instance Lovell and Konopka (1985) discovered the development of a bacterial production peak in the water column to following a period of intense primary production activity at that depth; which makes primary production appears to have the most direct influence on bacterial production. Lovell and Konopka (1985) also noticed a lag of about 2 to 3 weeks between a burst of photosynthetic activity and an increase in bacterial production in the two lakes they worked on. They interpreted this to be the time required for the naturally occurring bacteria at the depth of peak primary production to respond to the increase in carbon availability from primary production. Most importantly primary production’s diel pattern has led to methods fashioned along the diel pattern for its study under well lit conditions primarily because of changing light conditions since the photosynthetic active radiation (PAR) of light which is the energy source necessary for the transformation of inorganic matter into organic matter by the planktonic algae needed to drive production is constrained by time.

Primary production is the direct product of photosynthesis, and primary productivity is the sum of all photosynthetic rates in an ecosystem. According to Verduin (1956) three quantities, related to primary production in lakes are measured by aquatic biologists:

(1) the volume of autotrophic organisms,

(2) the ash-free dry weight of suspended particles (organic seston), and

(3) the concentration of chlorophylls.

Each of these is expressed per unit volume of water. Some biological workers who study studied photosynthesis or a relation under approximately natural conditions have related the observed O_2-production or CO_2-consumption to one or more of the three quantities stated above.

Methods of estimation may vary, for instance as a result of changing light conditions, most workers estimate the values of daily primary production by an integration of results from *in situ* incubations of light and dark bottles at different depths over the photic zone. A caveat however, for this method of estimation is that it is done only in clear waters for reliable results to be achieved since in highly productive waters (turbid waters) incubation cannot be performed over a long period (from onset of day light to evening) as a result of partial consumption of ^{14}C-label (used in highly turbid waters as PAR penetration in turbid waters is restricted) by the algal cells during long-term incubation due to respiration of photosynthetic products as found by Lancelot & Mathot (1986).

In order to acquire integrated results over longer time periods, many consecutive measurements of instantaneous photosynthetic rate should be carried out and integrated. Many workers have used one or more of the following methods; Cell Counts, Chlorophyll -a levels, ATP, Total Organic or Inorganic Carbon, and Dissolved Oxygen to measure changes in primary productivity.

Assessing primary productivity of a lake body is essential in assessing its food chain dynamics. Sustainable fishery yield can be estimated from measurements of primary production (Steele, 1974). Again changes in photosynthetic rates show the most instantaneous effect of disruptions in nutrient availability or physical changes in the lake environment. According to Horne and Goldman, (1994) primary production can vary widely over the surface of very large lakes. (Hecky and Kling, 1981; Edmond *et al.*, 1993, Kurki *et al.*, 1999) reported a high variability of nutrients and planktonic organisms which may be caused by physical processes in Lake Tanganyika.

2.2.4.1 OXYGEN AND LAKE STRUCTURE

Oxygen concentration in lakes has been extensively studied by most workers, and it is usually the source of information on a lake body as per its trophic status than any other chemical determination. If dissolved oxygen determinations are accompanied by other parameters such as Secchi disk transparency, lake colour and morphometric data, a great deal of information of a lake body is given out.

Oxygen concentration in a lake is affected by:

(1) Solubility and this is directly proportional to the partial pressure in the gas phase.

(2) Temperature- increases in temperature decreases solubility of dissolved oxygen

Concentration of dissolved oxygen follows Henry's law which states that 'at constant temperature the amount of gas absorbed by a given volume of liquid is proportional to the pressure in atmospheres that the gas exerts'. Source (Shulz, 2001).

Dissolved oxygen is easily depleted in the aquatic environment as compared to the terrestrial through respiration and decomposition of aquatic organisms. The short and long term variations in dissolved oxygen of lakes are a good measure of their trophic status. For example, in an oligotrophic lake, there is little variation from saturation. However, in eutrophic lakes there is a range from anoxia within the hypolimnion to supersaturation in the epilimnion.

2.3 TEMPERATURE AND LAKE NUTRIENT DYNAMICS

In lakes, a stable thermal stratification is required to determine the distribution of the biota, important nutrients, distribution of gases etc. What this means is that thermal stratification determines chemical stratification. There are instances where winds and higher temperatures have resulted in dislocation of nutrients through upwelling. Langenberg (2008) reported a higher phytoplankton biomass resulting from upwelling in Lake Tanganyika. This phenomenon can impact on primary productivity profile of any water body. Coulter (1968) reported a higher phytoplankton biomass in the epilimnion of Lake Tanganyika as a result of upwelling. Temperature and wind dynamics also cause patchiness in the distribution of organisms. Vuorinen and Kurki (1994) observed patchiness in the distribution of autotrophic (Algal blooms) as well as heterotrophic blooms (zooplankton blooms) in Lake Tanganyika. There has been a considerable advancement in the determination of water temperature from the ordinary mercury in class thermometers method to remote sensing where contact with the water body is not necessary and signals and recordings are picked by satellites and computer processed with images. Remote sensing is able to detect heat radiation (5000 – 14000 mm) emitted by water.

2.4 PROTECTION OF WATER BODIES AND FAIR USE

Long before the advent of colonialism, the various communities that currently constitute the modern Ghanaian society had evolved various rules governing the use of water notable among them was the scare tactic employed by mostly fetish priests and village elders. Climatic and ecological changes coupled with population increases and their attendant requirements for water have sharply reduced the resource. To ensure the continuous survival and sustainable use of water as a natural resource various laws and guidelines for sustainable use have been promulgated.

In Ghana the establishment of the Environmental Action Plan in 1991 and the passage of Environmental protection Agency Act by Ghana's parliament which conferred regulatory and enforcement powers on the EPA initiated stronger reforms aimed at protection of water and the general environment (Freshwater country profile 2004 www.un.org/esa/agenda21/natlinfo/**ghana**/water**ghana**04f.pdf, 27/4/2009*)*. These establishments have been sustained by both government and non – governmental agencies. There is also the issue of shared responsibility of water resources in terms of sustainability in usage and accessibility purposes, the reason being that some water resources run across borders and sovereign states. It will therefore be necessary for the states involved to equally take responsibility and also allow access in the case of research collaborations between nationals and non nationals. In this sense laws such as the declarations and resolutions of the United Nations Water Conference - Mar del Plata, March 1977 where it was recognized as necessary for co-operation between states on interboundary water resources by the declaration that;

It is necessary for States to co-operate in the case of shared water resources in recognition of the growing economic, environmental and physical interdependencies across international frontiers. Such co-operation, in accordance with the Charter of the United Nations and principles of international law, must be exercised on the basis of the equality, sovereignty and territorial integrity of all States, and taking due account of the principle expressed, *inter alia,* in principle 21 of the Declaration of the United Nations Conference on the Human Environment (www.fao.org/DORCREP/005/w9549E/9549e05.htm#fn91, 27/4/2009).

Sustainable use of water resources has evolved over the years to capture holistically all aspects of water body. This has resulted in a change of research parameters to embrace a wider spectrum of a water body such that fields of water research are being extended to include research in social and financial issues, integrated catchment management, policy analysis and development, decision support systems, capacity building (including education and training), ecosystem structure and function and development of new technologies and management practices. This new research format has enabled forecast to be made on the future state of a water body proceeding on current available data.

The research institutions are also focusing on interdisciplinary and participatory research that recognizes the need for a link between technology and communities as well as reviewing and updating data and information on land-water resources and related socio-economic issues.

Water resources assessment in Ghana is undertaken by the Water Resources Commission (WRC), Hydrological Services and some donors particularly DANIDA.

CHAPTER THREE

MATERIALS AND METHODS

3.0 STUDY SITE

Lake Bosomtwe is a crater lake and the only natural lake in Ghana. It is located 30km south east (6^{0} 30'N; 1^{0}24.5 W) of Kumasi the Ashanti regional capital of Ghana.

Fig. 3.0 Map of Ghana showing the location of Lake Bosomtwe. Source (Google maps).

It is formed on Precambrian metasedimentary and metavolcanic rocks. It is 10.5 km (rim to rim) average diameter and it is up to 78 m deep in its central part. The prominent rim is elevated by 210 m -350 m from the lake water level. It is one of only 19 confirmed African impact craters and the youngest in the world of all impact crater lakes (Koeberl and Reimold, 2005). The lake has a maximum depth of 81 m and average depth 45 m. It has maximum length of 8.6 km. It is a closed basin lake with no known major outflows or inflows; though there are a couple of permanent inflowing streams namely"Abrewa and Abono" and a few seasonal streams that contribute considerable discharges during the rainy seasons.

Plate 3.0 A photograph of River "Abrewa" showing point of entry into Lake Bosomtwe.

The "Abrewa" river opens into the lake at Dompa village but there is not much literature to the evidence pointing to whether its inflow to the lake is significant to the lake's water balance. Turner *et al.* (1996a) have noted the lack of data on hydraulic conductivity measurements on the lake basin making it impossible to quantify the contribution of groundwater seepage to water balance.

The primary source of water supply to the lake is rainfall and run–offs from watershed. Rainfall at Lake Bosomtwe is lowest in January averaging 17.0 mm and highest in June averaging 233.9 mm. These recordings are however highly variable from year to year; although interannual variations in the rainfall pattern of Lake Bosomtwe area are not highly correlated with that of the Sahel zone located several hundred km to the north of Bosomtwe (Opoku-Ankomah and Cordery, 1994). The sediment records of the lake have been used to monitor both local and Sahel rainfall variations (Street-Perrot and Perrot,1990).

About 30 villages occupy the lake's catchment. The occupation of the inhabitants is predominantly peasant farming and artisanal fishing. The catchment area is characterized largely by farming activities almost up to the supralitoral zone.

Plate 3.1 Land use activities at Lake Bosomtwe (Photograph depicts the extent of "slash and burn" farming activities occurring in close proximity to the lake).

Plate 3.2 Land use activities at Lake Bosomtwe (Photograph depicts the extent of "slash and burn" farming activities occurring close to the lake. Note the topography of cleared space).

The vegetation has both dense (perhaps an indicator of the original lake catchment cover) to sparse tropical rainforest, although the dense forest is in patches within the catchment. The lake and its catchment area serve as a tourist and recreational center.

3.1 SITE SELECTION

The 3 sampling stations administratively fall under 2 different district assemblies. Dompa was formerly administrated by the Amansie East District Assembly local authority (AEDA) but the newly created Bosome Freho District Assembly (BFDA) now has the oversight responsibility.

Abono and Asisiriwa are under the jurisdiction of Bosomtwe Atwima Kwanwoma District Assembly (BAKDA). The topography of the 2 districts is characterized by undulating forest covered-ridges (both dense and sparse).

The site selection was done on the basis of population density and the overall volume of activity within the lake's catchment which have potential impact on water quality. On this basis, the following villages were selected.

3.1.1 ABONO

Comparatively, Abono (6^0 32′01.50′N; 1^0 25′44.53′W) is the most populated of the all the 30 villages around the lake with a population estimated at 1154 based on the projections of the year 2000 population census. The locals engage in livestock rearing and massive slash and burn farming activities all within the catchment area of the lake. Abono is largely the point of call for most tourists and visitors to the lake. Holiday revelers use this part of the water for recreational purposes. Taxi drivers wash their vehicles at the shores (Plate 3.3). The locals also wash and bathe in the lake.

Plate 3.3 Photograph showing a car washing activity at Abono village of Lake Bosomtwe with local tourists at the background.

3.1.2 DOMPA

Dompa (6^{0} 28’43. 42’N; 1^{o}26’34.05’W) is the next most populous town after Abono. The catchment area of this site is very much exposed. The locals engage in livestock rearing, slash and burn farming activities, as well as washing and bathing in the water body. However washing of cars was not observed because there is no visible motorable road that leads to the shore of the water body and it is again not used as point for holiday revelers. Nevertheless the activities mentioned above, have the potential to affect the lake.

3.1.3 ASISIRIWA

Asisiriwa (6^{o}30’43.50”N; 1^{o}22’30.73”W) by observation is different from the other 2 sites. It is known that the original inhabitants of this village once lived very close to the lake just like most villages but moved away to their current location at some point. There are signs of considerable forest cover having been removed for farming activities; it is however not on a massive scale as compared to the other two sites. Dotted huts do exist within the lake’s catchment area. Four huts and later two additional huts were encountered in the course of field work at this study site. Apart from these observations, there were no activities occurring at this side of the lake. Judging from the nature of the catchment area of this part of the lake, some of the pristine qualities of the lake could be maintained. On this basis samples from this site were used as the standard (control) for the other 2 sites.

Fig. 3.1 Google earth satellite view of study area showing sampling locations.

3.2 CLIMATIC CONDITIONS

Climatic conditions of the lake have been characterized by the Ghana Meteorological Agency, Ashanti Regional office, into the following:

(i) Pre- rainy season between March - May.

(ii) Main rainy season with heavy rains between June- September

(iii) Post rainy/Pre-dry season between October - December

(iv) Dry season between December and February. (Robert Ghanney, personal communication)

This seasonal pattern is however dynamic and does not follow any strict regime and most importantly subject to changes depending on seasonal behaviour of the Intertropical

Convergence Zone (ITCZ) which influences the weather pattern over Lake Bosomtwe and Ashanti region as a whole.

3.3 SAMPLING PARAMETERS

Each of the three sites was divided into 2 stations:

(I) Inshore zone (100 m)

(II) Offshore zone (open water, 2km from shore)

Physico-chemical parameters of the lake analyzed in this study included pH, conductivity, water temperature, transparency, phosphorus, organic carbon, and total nitrogen: Primary production from oxygen (Winkler method) and Chlorophyll- a, over a one seasonal cycle spanning February 2008 to December 2008 and designed to include different climatic conditions and their effect on the Lake. This assessment was conducted using fixed interval sampling (Bi-monthly). Water samples were collected within the euphotic zone with a discrete sampler (6L Van Dorn water sampler) stored and transported to the laboratory for subsequent analysis. The euphotic depth was estimated through Secchi disk measurements prior to commencement of the study. All physical parameters covered by this study were measured on site.

Rainfall data recorded during the study period were obtained from Ghana Meteorological Agency, Ashanti Regional office. Mean temperatures were deployed from Hobo Weather Station mounted at study site by Theoretical And Applied Biology Department (KNUST).

All sample collectors were cleaned with 1M HCl (Suess, 1998) and thoroughly rinsed before sample collection to minimize contamination.

3.3.1 TEMPERATURE

Mercury in-glass thermometer was used to determine the temperature of the water sampled. The water sample was collected within the euphotic zone (1 m) with a Van Dorn water sampler. The water was quickly transferred into the 250 ml polypropylene collector and the thermometer was quickly dipped in the water and the reading taken (Wondie *et al.*, 2007). The reliability of this method is due to the high heat- capacity property of water (Schwoerbel, 1970).

3.3.2 TRANSPARENCY

This parameter was measured with a standard (25cm diameter) Secchi disc with calibrated line holder. With the eyes shielded from the sun's glare, the disk was slowly lowered along the calibrated line in the water to the point where it completely disappeared, this depth was recorded, the disk was slowly raised and the point where it became visible such that the boundaries between the black and white quadrants could be distinguished again was noted and the depth read. The average between the depths of disappearance and reappearance of the disk was taken as transparency reading. For accuracy, several readings were taken and averaged.

3.3.3 EUPHOTIC ZONE

This was determined from the transparency depth (Secchi disc measurements). It was determined as from the water surface to the depth where 1% of surface light reaches. This estimation was achieved by multiplying the Secchi disc reading by a factor 3 i.e. ($Z_{eu} = Z_{sd}$ x3). This procedure has been employed for estimating productivity in African lakes (Talling and Lemoalle 1998; Wetzel, 2001) and the Mediterranean region (Huq *et al.*, 1976; Yayla *et al.*, 2001).

All other samples for analysis were collected and kept in a dark cool box and transported to the laboratory for analysis.

3.3.4 PH

Previously cooled water sample's temperature was raised to room temperature (25 ^{o}C) and 100 ml

was poured in a glass beaker and a Cyberscan PC 300 series probe was dipped into the sample and

stirred gently until a stable pH reading was achieved.

3.3.5 CONDUCTIVITY

Previously cooled water sample's temperature was raised to room temperature (25 ^{o}C) and 100 ml of sample water was poured in a glass beaker and a Cyberscan PC 300 series probe was dipped into the sample and stirred gently until a stable conductivity reading was achieved.

3.3.6 TOTAL PHOSPHORUS

Before the procedure, all glassware were rinsed with 1:1 hydrochloric acid and washed off with distilled water. Previously cooled sample's temperature was raised to room temperature and 25 ml of the sample was measured into a 50 ml Erlenmeyer flask using a graduated cylinder. One potassium persulphate powder pillow was added to the sample and mixed by swirling. 2.0 ml of 5.25N sulfuric acid solution was added using 1- ml calibrated dropper. The sample was placed on a hot plate and boiled for 30 mins. The boiling sample's volume was maintained at 20 ml by adding small amounts of distilled water as the boiling drops the volume of the sample. The sample was cooled to room temperature after the boiling for 30 mins. and 2.0 ml of 5.0N NaOH solution was added using the 1-ml calibrated dropper and the sample mixed by swirling. The sample was then poured into a graduated cylinder, the flask was then washed with small amounts of demineralised water and also poured into the graduated cylinder to return the volume to 25 ml.

The HaCH Dr 2010 was calibrated to set the wavelength of 890 nm by entering the stored program number for reactive phosphorus ascorbic acid method to display zero sample; 10 ml of the 25 ml sample prepared was poured into a10 ml HaCH Dr 2010 spectrophotometric cell and the contents of one PhosVer 3 phosphate pillow was added and swirled immediately to mix. A 10 min. reaction time was allowed by timing the spectrophotometer also at 10 mins, after which the there was a beep to indicate completion of reaction. A blank (the prepared sample without the PhosVer 3 pillow) was used to zero the HaCH Dr 2010 spectrophotometer. The sample was then read for the expected total phosphorus concentration.

3.3.7 TOTAL NITROGEN (TN)

Total Nitrogen in the sample was determined using the Total Kjedahl Nitrogen (TKN) procedure (Greenberg *et al.*, 1992) involving Initial distillation and digestion steps described below:

A sample (250 ml) was placed in a distillation flask. Previously prepared 25 ml borate buffer and 10ml 6N NaOH were added to the sample. It was then placed on the kjedahl distillation apparatus.

About 200 ml of sample was distilled into a conical flask containing 50 ml boric acid indicator, the tip of the delivery tube vertical condenser was submerged below the surface of the receiving boric acid indicator solution. The distillate which turned green upon being distilled into the boric acid indicator was then carried through the titrimetric step by titrating the distillate against 0.02N H_2SO_4 as the titrant to pale lavender endpoint.

A 10ml conc. H_2SO_4 was added to the rest of the sample in the kjedahl flask, one digestion tablet was added to the sample and digested. The digested sample was diluted to 250 ml with distilled water after cooling it. 50 ml NaOH- Sodium thiosulphate and 10 ml 6 N NaOH were added and distilled into conical flask containing 50 ml boric acid indicator.

Blank:

A blank was carried out with distilled water through all the steps of the procedure and the necessary correction was applied.

Expected total N was computed as mg/l from

$$= \frac{(A-B) \times 280}{\text{ml sample}}$$

Where

A= vol. of 0.02 H_2SO_4 titrated for sample in ml.

B= vol. 0.02 H_2SO_4 titrated for blank in ml.

280 = constant incorporated in the indicator boric acid solution to produce the actual conditions of sample titration i.e. 1.00 ml = 280 ml

3.3.8 ORGANIC CARBON

Sucrose was used as the primary standard C source. Different quantities of sucrose (1 – 20 mg) were measured into a 100 ml flask. 5 ml of 0.1667 M standard $K_2Cr_2\ 0_7$ and 10 ml conc. H_2SO_4 containing 1.25% $AgSO_4$ was added to each of the quantities of sucrose. The flask was swirled and 30mins reaction time was allowed.

A blank was prepared in similar manner without adding sucrose.

A green colour developed and was read and zeroed at 660 nm on the spectrophotometer (cecil CE 2041 2000 SERIES). Each quantity of sucrose so prepared was also read on the spectrophotometer at 660 nm after zeroing the spectrophotometer at 660 nm with the blank. The spectrophotometric readings so recorded were plotted directly against each milligram of sucrose as the C source.

3.3.8.1 SAMPLE PREPARATION

200ml of the sample was evaporated to dryness in a crucible. 5 ml of 0.1667 M standard $K_2Cr_2 0_7$ and 10 ml of conc. H_2SO_4 containing 1.25% $AgSO_4$ was added. This was stirred with a previously cleaned and dried glass rod to mix thoroughly and 30 mins reaction time was allowed to complete reaction, a green colour of chromium sulphate developed which was read on the (cecil CE 2041 2000 SERIES) spectrophotometer at 660 nm after zeroing the spectrophotometer with a blank prepared in a similar manner without a sample. The C content of the sample was read and recorded from the standard curve which show the C content (milligrams of C versus spectrophotometer readings as absorbance) Motsara and Roy (2008).

3.3.9 PRIMARY PRODUCTIVITY

The underlying assumption in the following methods is that the change in O_2 concentration in an illuminated volume of water containing plants and animals is a result of O_2 production in photosynthesis by chlorophyll-containing plants and of O_2 consumption in respiration by both plants and animals.

Primary production was measured *in situ* using the oxygen light and dark bottle technique. The Light- dark bottles technique was used to measure oxygen (Winkler method) production at different predetermined depths (1m, 2m, 3m). Winkler bottles (300 ml) were filled with water from each of the depth using a Van Dorn water sampler in subdued light. The water filled in the winkler bottles was allowed to overflow and the tube was slowly withdrawn whiles the Lake water was still flowing into the bottles to avoid entrapment of air bubbles and stoppered. The bottles were then suspended at the same predetermined depths where the water was captured within the euphotic zone. For each depth sampled at each of the two stations stated above, 2 replicate bottles (both light and dark bottles) were also filled with the same sampled water and incubated at the same depth as the original bottles. Incubations were done after day break i.e. after 10:00hrs GMT. A bamboo frame was constructed as a buoy to keep the bottles suspended and in vertical position in the water column. The bottles were kept 25cm apart to avoid self-shading. The bottles were hauled up after 4hrs and the contents fixed immediately with Winkler's regents to arrest D.O level and all biological activities that would affect D.O levels in the bottle and transported to the laboratory in a cool dark box. The sample was acidified to dissolve all flocculation and thoroughly mixed before titration with drops of starch as indicator to a just clear solution endpoint. The results from the Winkler determination were averages from samples at each discrete depth including replicate bottles.

Gross primary productivity was calculated from

$$O/mg/m^{-3} = \frac{LB - DB}{t} \times 1000$$

Where

LB = DO concentration in light bottle after incubation

DB = DO concentration in dark bottle after incubation

t = incubation period in hours (Vollenweider, 1974; Greeson *et al.*, 1977).

1000 = converts ml to m^3

Oxygen production was converted to carbon fixation and this was performed using the relationship 1mg C = 0.375 mg 0_2 based on a photosynthetic quotient of 1 (Greeson *et al.*, 1977). P^B_{max} ; µg C(µgChl-a)$^{-1}$h^{-1} ; the maximum rate of light-saturated chlorophyll-a specific photosynthesis (= assimilation number) was determined from the ratio of the maximum rate of production P_{max}; in mg Cm^{3}h^{-1} in the depth profile and the average chlorophyll-a concentration at that station (Harding, 1997). Gross photosynthetic production rates were determined from linear rate diagrams and the mathematical integral. The depth-integral of gross production per day (ΣGPP) was determined over the euphotic zone depth (Z_{eu}) and the day length assumed for period of photosynthetic activity was taken at 10 hours.

3.3.10 CHLOROPHYLL -a

Water samples for chlorophyll –a estimates were collected at all 3 sites and 6 stations. Samples were taken at same depth as all other parameters and kept in a cool box with ice in a double coated black polyethylene bag to avoid light injury to the algal cells to prevent chlorophyll pigment degradation. The samples were then transported to the laboratory. A sample (250 ml) was filtered through a Whatman GF/F (0.7 µm pore size) filter and frozen at below 0^{o}C under reduced light intensity. The filtrate was transferred into a tube and 25 ml 80% Ethanol was added and stoppered. The tube was placed in a water bath at 75^{o}C for approximately 5 min (A thermometer was also placed in the water bath to monitor the temperature from going above 75^{0}C). A rod was used to promote destruction of the algal cells and Whatman GF filter placed in the tube after removing tube from the water bath. The tube and its content was then cooled in ice and divided into 2 centrifuging tubes and centrifuged for 10 mins at 3000 rpm. One pair of the supernatant was then read on a (cecil CE 2041 2000 SERIES) spectrophotometer at 750 mm (

10 ml of the extract (supernatant) and left for 5- 30 mins. It was then read at 750 nm

and elders) were also used. Interviewees were strictly inhabitants from the two study sites who have been resident in the village for some years.

3.4.1 SURVEY ETHICS

Crop and livestock farmers which the survey covered were visited by this writer and were served with prior notices as to the impending interview and permission sought in that regard. Contact telephone numbers and other forms of communication were used to fix convenient dates for the interview. An 'Akwaesidae" (resting Sunday) was used as the day of questionnaire administration, this was a day when chiefs and elders gather to deliberate on issues concerning the village and also hear family and other disputes. It was therefore a useful and appropriate time to approach them to introduce the work.

3.4.2 ENUMERATORS

Three (3) other enumerators who could translate questionnaire into local language were employed to undertake the work. These were M.Sc. students some of whom were also undertaking survey works on their own. Two local inhabitants were also employed as protocol officers

3.4.3 SCOPE OF WORK

Each village was divided into 2 sections and 2 workers accompanied by a local protocol officer were responsible for each section. Interviews were done strictly on individual basis i.e. one farmer at a time. All workers then converged at one designated spot after covering the required number of interviewees.

Results of the survey were analyzed with SPSS 16.0 version statistical software.

CHAPTER FOUR

RESULTS

4.0 SEASONAL DYNAMICS OF PHYSICO-CHEMICAL PARAMETERS IN LAKE BOSOMTWE

4.1 CLIMATIC CONDITIONS.

The pattern of rainfall during the period of sampling at Lake Bosomtwe is presented in figure **4.0** below.

Rainfall pattern

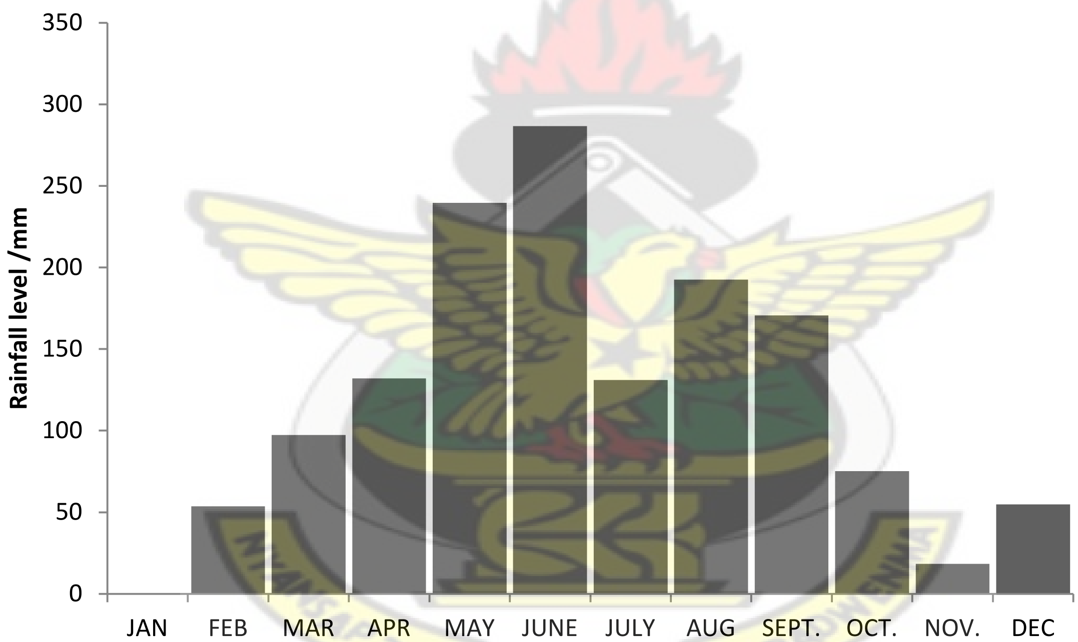


Fig. 4.0 Mean monthly rainfall (mm) recorded in 2008. Source (Ghana Meteorological Agency, Ashanti Regional office).

Rainfall level during the study period recorded two peaks, a higher peak in June (286.7 mm) and a lower peak in August (192.6 mm). Lowest rainfall was recorded in November while none was recorded in January.

Atmospheric temperature

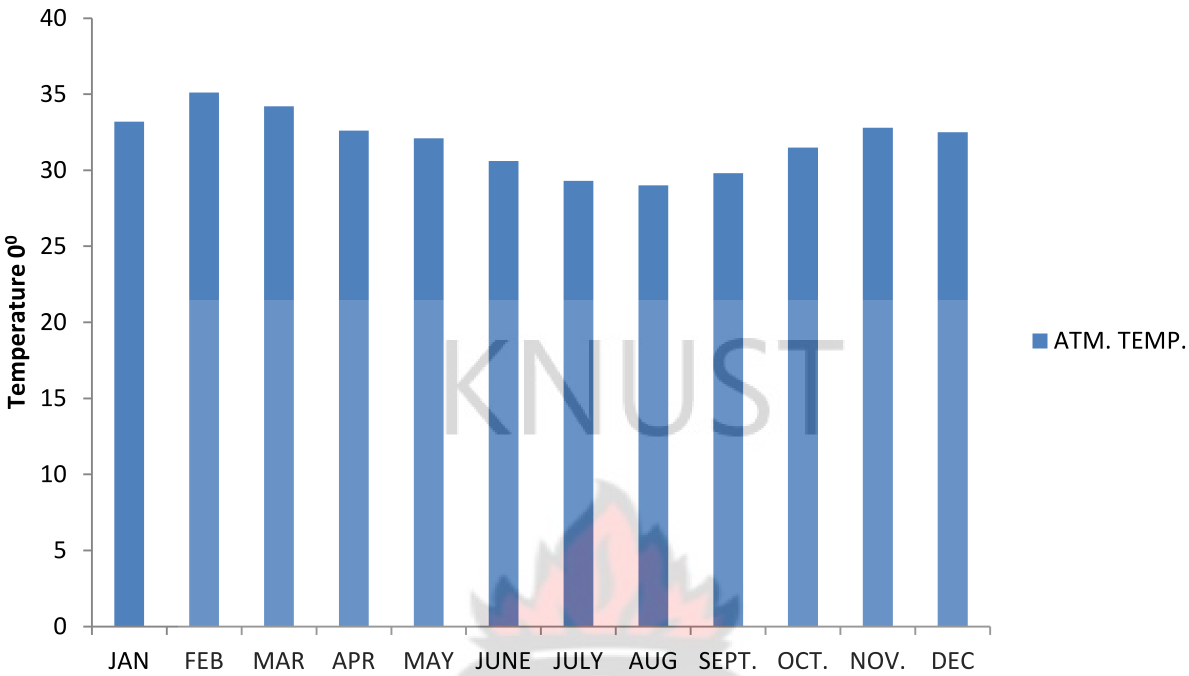


Fig. 4.1 Mean monthly Temperatures (°C) during the year 2008

Two peaks in atmospheric temperature were recorded in February (35.1 °C) and November (32.8 °C). Lowest atmospheric temperature during the period of sampling was in August (29 °C). Generally, temperature decreased from February to August and rose from September to November.

4.2 RESULTS OF PHYSICAL PARAMETERS

4.2.1 Water temperature

4.2.1.1 Abono

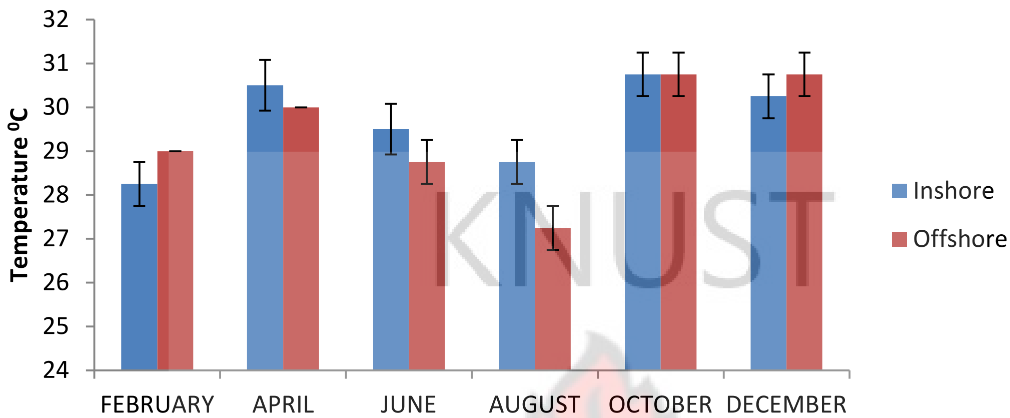


Fig 4.2 Mean bimonthly surface water Temperature (^{o}C) levels at Abono. Bars represent standard deviation (SD).

Water temperature at Abono generally, decreased from April to August and rose in October and December with the lowest mean temperature of 27.25^{0}C recorded in August in the offshore. Water temperatures showed a similar trend to atmospheric temperatures from April to August (see Fig.4.1). The highest mean temperature recorded at this site was 30.75^{o}C ± 0.5 in October in both inshore and offshore zones. The dynamics of temperature differences between all sampling months at Abono during the study period is represented in figure **4.2**

4.2.1.2 Asisiriwa

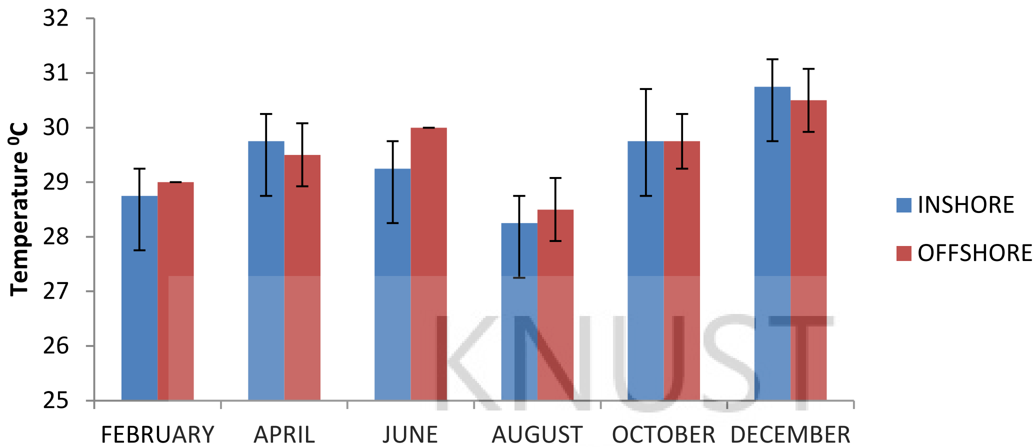


Fig. 4.3 Mean bimonthly surface water Temperature (^oC) levels at Asisiriwa. Bars represent standard deviation (SD).

The highest mean temperature recorded was in December in the inshore (30.75^{0}C). Mean water temperature at Asisiriwa was lowest in August where mean inshore water temperature recorded was 28.25^{0}C, while the offshore also recorded 28.50^{0}C. The water temperature at this site rose in October and December as was in Abono. The temperature for all sampling months at Asisiriwa during the study period is represented in figure **4.3** above.

4.2.1.3 Dompa

Dompa site recorded temperature drop from April (30^{0}C inshore and 29.5^{0}C offshore) to August (inshore 28.75^{0}C and offshore 28^{0}C) (and the trend followed as has been recorded in the atmospheric temperature) and rose in October. There was however a drop in the mean temperature in December. Between the inshore and offshore, temperature variations did not follow a specific trend. The changes in temperature at Dompa during the study period is represented in figure **4.4**

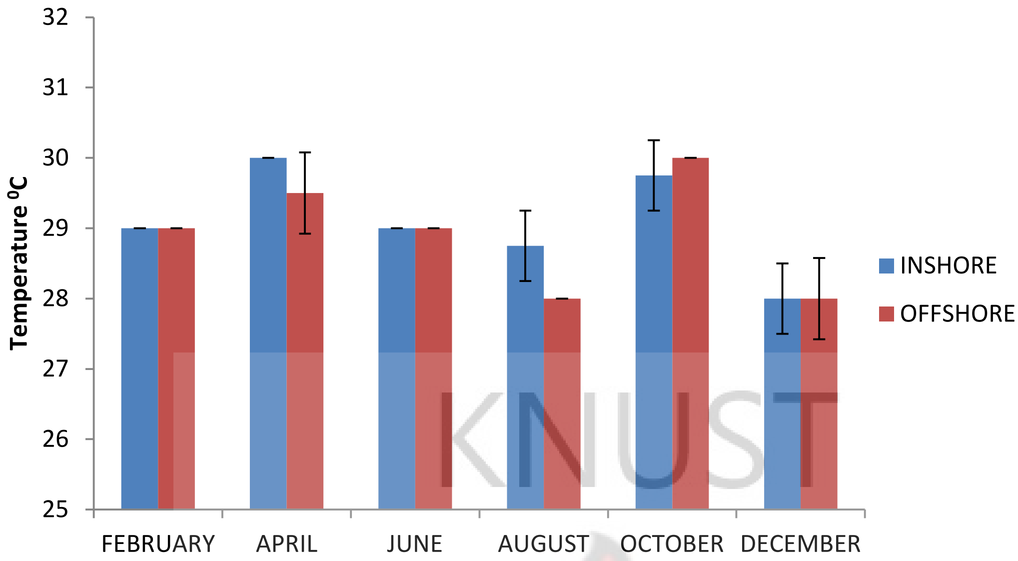


Fig.4.4 Mean bimonthly water surface Temperature (^{o}C) levels at Dompa. Bars represent standard deviation (SD).

4.2.2 Water transparency (Secchi disk depth)

4.2.2.1 Abono

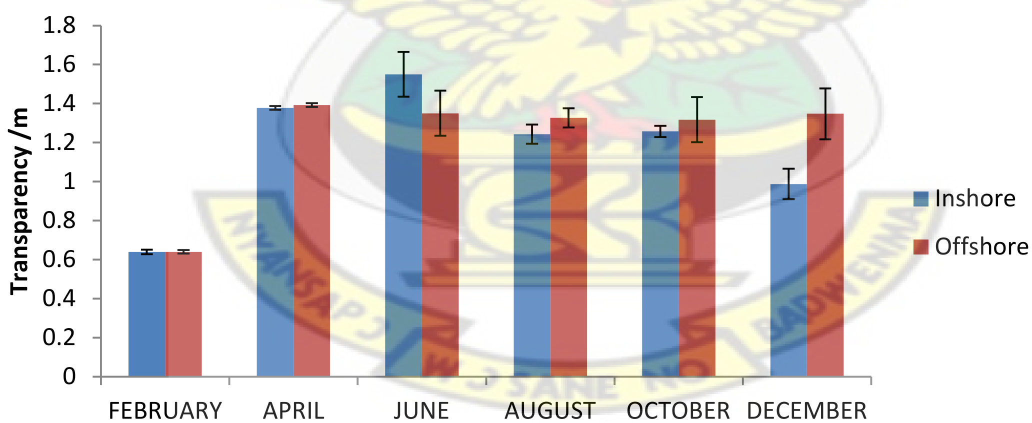


Fig. 4.5 Mean bimonthly Transparency (m) levels recorded at Abono during the study period. Bars represent standard deviation (SD).

The lowest mean transparency value was recorded in February (0.63 m ± 0.01) in both inshore and offshore zones. The sampling months thereafter showed increased transparency except August (1.24 m) and December (0.98 m) where transparency reduced especially in the inshore zones. The highest mean transparency recorded was in June (1.55 m) in the inshore. The transparency recorded at Abono during the study period is represented in figure **4.5** above.

4.2.2.2 Asisiriwa

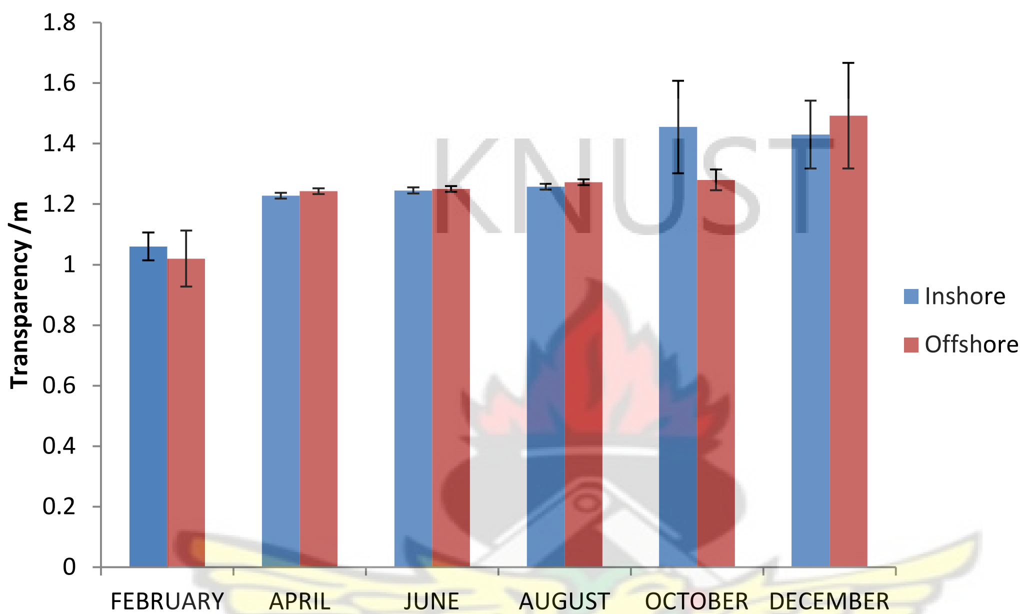


Fig. 4.6 Mean bimonthly Transparency (m) levels recorded at Asisiriwa. Bars represent standard deviation (SD).

The highest mean transparency during the sampling period was recorded in December (1.49 m) in the offshore zone. The lowest transparency was recorded in February where mean transparency recorded was (1.06 m ± 0.04 and 1.02 m ± 0.09) in the inshore and offshore zones respectively. Transparency then showed increments throughout the rest of the study period. The mean offshore transparency was generally higher than the inshore. The transparency recorded at Asisiriwa during the study period is represented in figure **4.6** above.

4.2.2.3 Dompa

The lowest mean transparency at Dompa was recorded in February (0.99 m ± 0.02 and 1.02 m ± 0.02) in the inshore and offshore respectively. Transparency increased in the subsequent months. The highest transparency was however recorded in April (1.31 m and 1.37 m) in the inshore and offshore respectively. Generally transparency was lower in the inshore than the offshore with an exception in August and October. The transparency values recorded during the study period at Dompa study site are represented in figure **4.7**

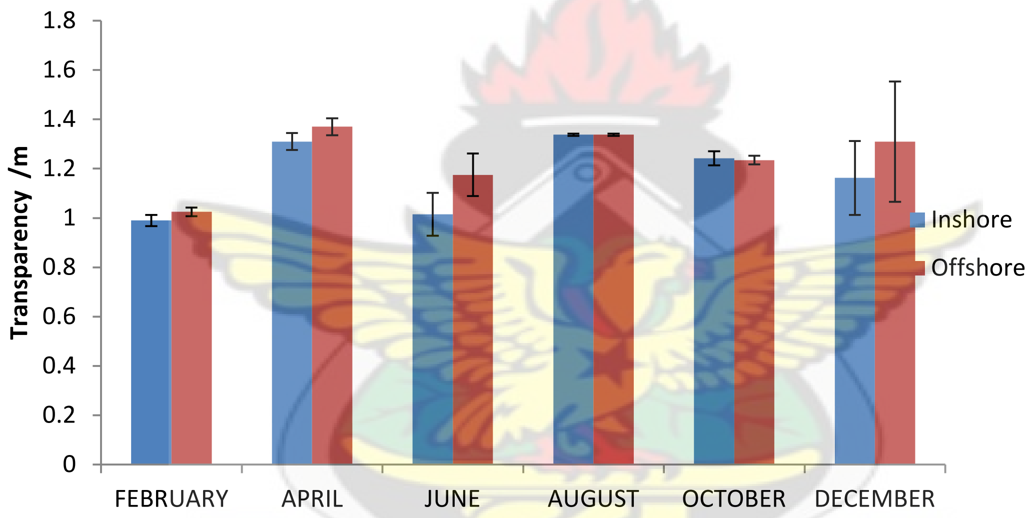


Fig. 4.7 Mean bimonthly Transparency (m) levels recorded at Dompa. Bars represent standard deviation (SD).

The depth of the Euphotic zone determined from transparency values gave a corresponding low euphotic zone depth (Z_{eu}) in February compared to the other sampling months. See appendix (1) for Euphotic zone depth.

Table 4.0 Correlation analysis between Transparency (SD depth) and Chlorophyll-a at all 3 study sites of lake Bosomtwe. r = Pearson's correlation coefficient, α = alpha (0.05) level, n = 4

		ABONO		ASISIRIWA		DOMPA	
MONTH	ZONE	r	α	r	α	r	α
February	Inshore	-0.574	0.426	0.010	0.990	-0.002	0.999
	Offshore	0.165	0.835	0.402	0.507	0.781	0.219
April	Inshore	-0.309	0.691	-0.302	0.698	0.488	0.512
	Offshore	-0.302	0.691	-0.302	0.698	-0.577	0.423
June	Inshore	0.392	0.624	0.577	0.423	0.318	0.680
	Offshore	0.354	0.702	0.522	0.478	-0.016	0.984
August	Inshore	-0.866	0.134	-0.905	0.095	-0.816	0.184
	Offshore	0.059	0.941	0.302	0.698	-0.522	0.478
October	Inshore	0.682	0.318	-0.758	0.242	0.414	0.586
	Offshore	-0.383	0.617	-0.313	0.687	-0.643	0.357
December	Inshore	0.781	0.219	0.433	0.567	-0.107	0.893

Correlation analysis between transparency and chlorophyll-a revealed strong negative correlation at Abono (-0.866), Dompa (-0.816) in August in the inshore, Asisiriwa in August (-0.905) and October (-0.758) in the inshore. Strong positive correlation between the two parameters existed at Abono (0.781) in December and Dompa (0.781) in February in the inshore and offshore respectively. Weak positive correlations were recorded at Abono (0.682) in October in the inshore zone; Asisiriwa (0.577 and 0.522) in June in both zones while weak negative correlations were recorded at Dompa in April in the offshore, August in the offshore and October in the offshore. Correlations that lacked statistical significance were also recorded at all the sites.

4.3 RESULTS OF CHEMICAL PARAMETERS

4.3.1 pH

4.3.1.1 Abono

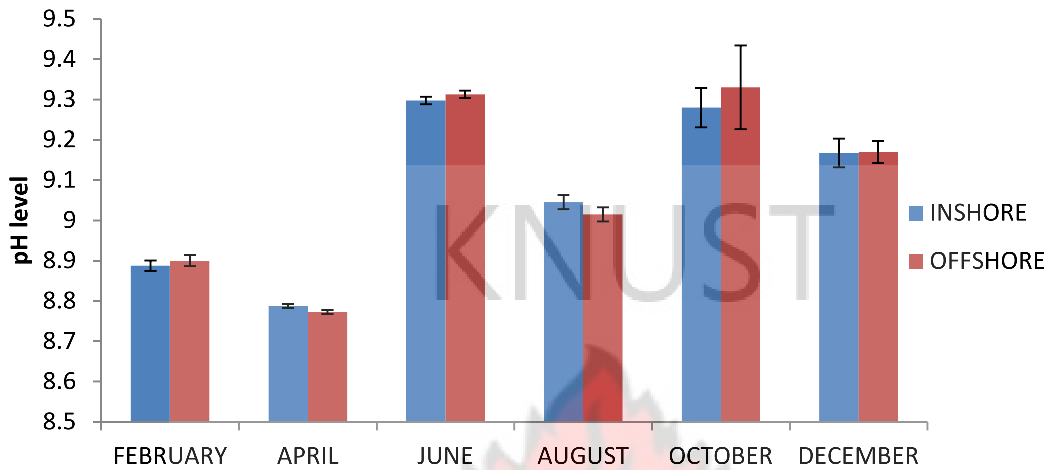


Fig.4.8 Mean bimonthly pH levels recorded at Abono during the study period. Bars represent standard deviation (SD).

Lowest mean pH level was recorded in April (8.77 $\pm$ 0.00) in the offshore compared with the other months. pH increased in June and October. Changes in level of pH at the 2 zones were slight except in October where the highest change was recorded (9.28 inshore - 9.33 offshore). The pH values during the study period at Abono are represented in figure **4.8** above.

4.3.1.2 Asisiriwa

The lowest mean pH levels were recorded in February (8.85 and 8.88) and April (8.8 and 8.82) in both the inshore and offshore zones respectively. Levels increased in the subsequent months and the highest pH level was recorded in June in both the inshore (9.27) and offshore (9.28). The pH values during the study period at Abono are represented in figure **4.9**

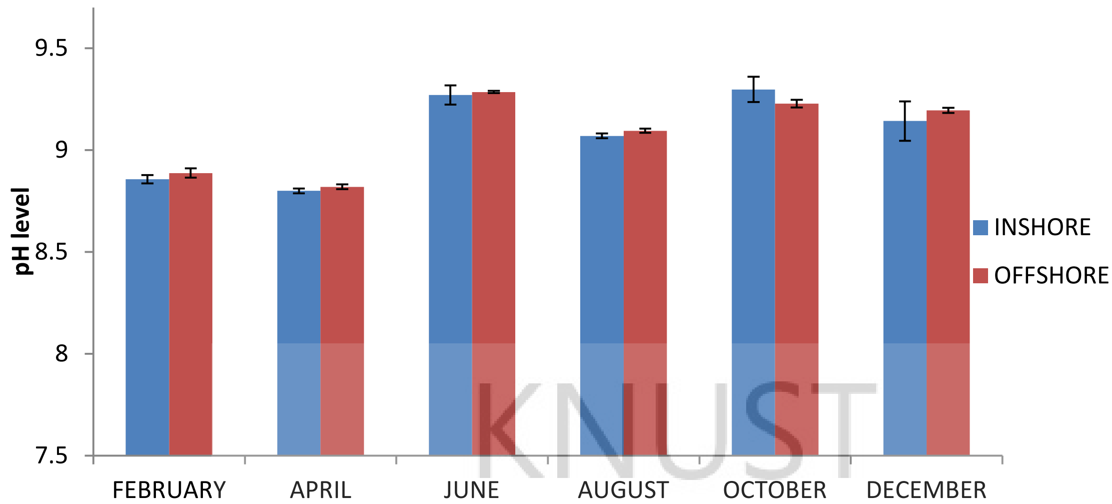


Fig. 4.9 Mean bimonthly pH levels recorded at Asisiriwa during the study period. Bars represent standard deviation (SD).

4.3.1.2 Dompa

The lowest mean pH values were recorded in April (8.78) in both the inshore and offshore. Increased levels were recorded for the other months. Generally, no pronounced peak(s) were recorded. The pH values during the study period at Dompa study site is represented in figure **4.10** below.

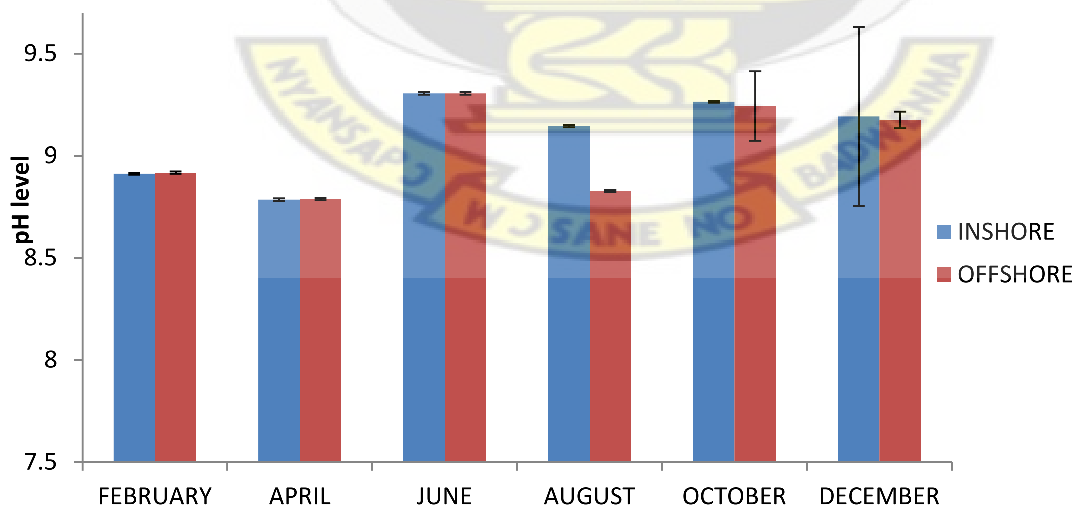


Fig.4.10 Mean bimonthly pH levels recorded at Dompa during the study period. Bars represent standard deviation (SD).

Table 4.1 Differences in pH levels between study sites and season. Sampling months are defined in seasonal terms as February (Dry Season) June (Wet Season) and October (Pre Dry Season) (Mann-Whitney U-test; test significant at $\alpha<0.05$)

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	Dry season	Offshore	Dompa	Wet season	Offshore	0.030
Abono	Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.470
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.772
Dompa	P- Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.030
Abono	P-Dry season	Inshore	Dompa	Dry season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.248
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.312
Abono	P-Dry season	Offshore	Dompa	Dry season	Offshore	0.885
Abono	P-Dry season	Offshore	Asisiriwa	Dry season	Offshore	0.312
Dompa	P-Dry season	Offshore	Asisiriwa	Dry season	Offshore	1.000

Table 4.2 Differences in pH levels between study sites and season. Sampling months are defined in seasonal terms as April (Pre-Wet Season) August (Wet Season) and December (Pre Dry Season) (Mann-Whitney U-test; test significant at $\alpha<0.05$)

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	P-Dry season	Offshore	Dompa	Wet season	Offshore	0.030
Abono	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.312
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P- Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.030
Abono	P-Wet season	Inshore	Dompa	P-Dry season	Inshore	0.030
Abono	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.030
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.030
Abono	P-Wet season	Offshore	Dompa	P-Dry season	Offshore	0.030
Abono	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.030
Dompa	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.030

Mean pH differed amongst sites and seasons while no statistical differences were also recorded (0.470, 0.772, 0.312, 0.248, 0.312, 0.885, 0.312, 1.000) in **Table 4.1.** However, in the second months of sampling, there were differences in mean pH at all sites and seasons except Abono in the inshore of the Pre Dry Season and Dompa in the inshore of the Wet season α = 0.312 (**Table 4.2)**

Relationship between pH and organic carbon (OC) in February and April at all three sites are summarized graphically in figures **Fig. 4.11, Fig. 4.12**and **Fig. 4.13**.

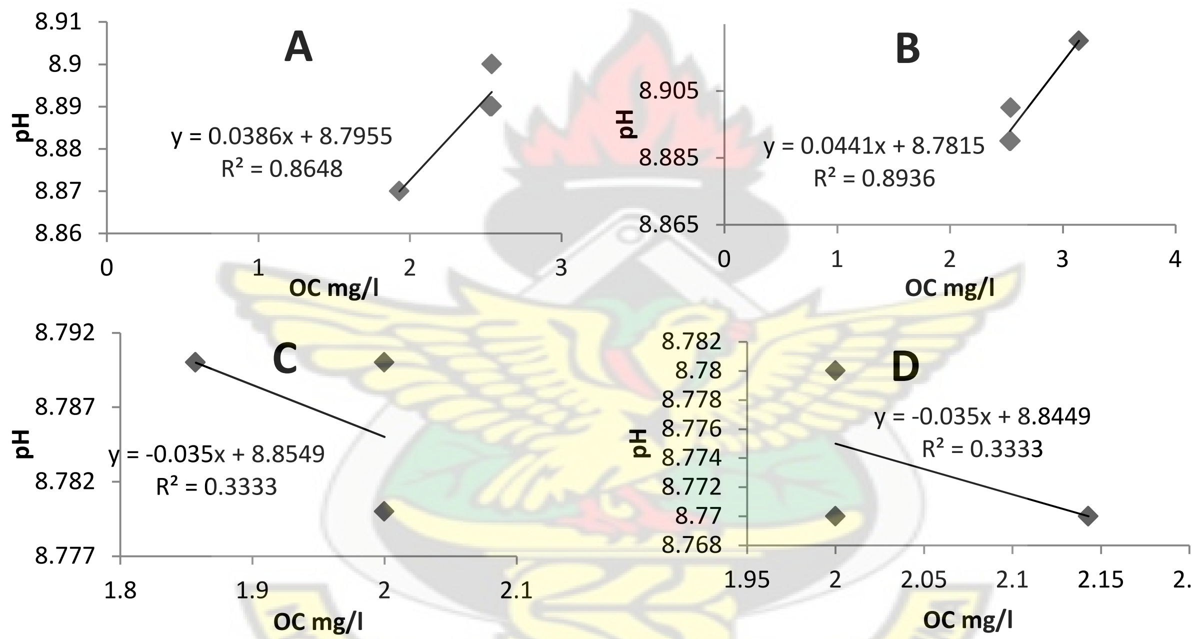
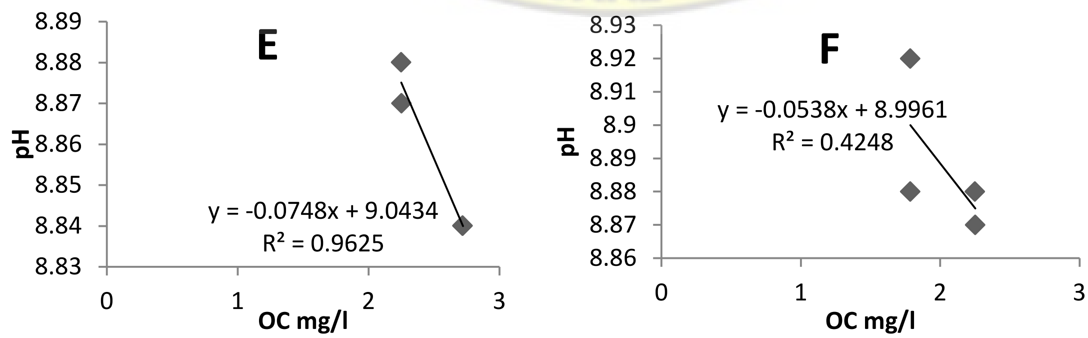


Fig. 4.11 Relationship between pH and OC at Abono in February (A= inshore; B= offshore) and April (C= inshore; D= offshore) during the study period.



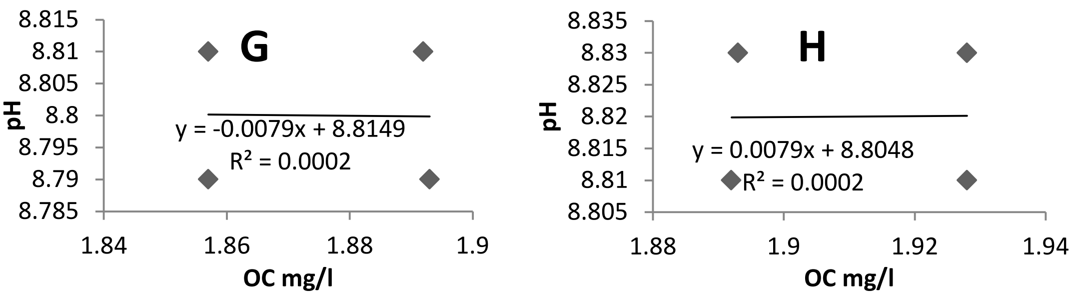


Fig. 4.12 Relationship between pH and OC at Asisiriwa in February (E= inshore; F= offshore) and April (G= inshore; H= offshore) during the study period.

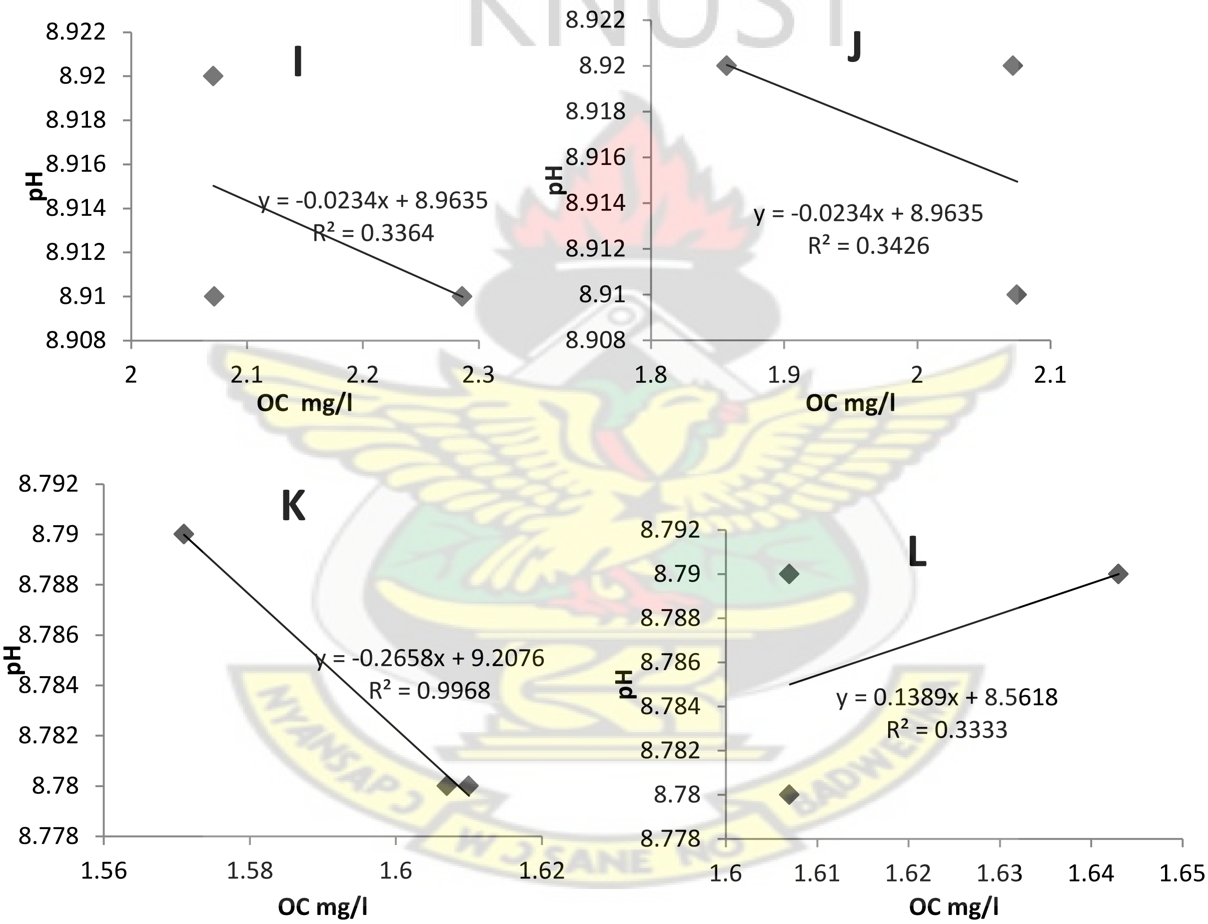


Fig. 4.13 Relationship between pH and OC at Dompa in February (I= inshore; J= offshore) and April (K= inshore; L= offshore) during the study period.

From the above graphical summary, pH dynamics showed a strong relation with OC levels at Abono in the inshore A (R^2 = 0.864) and offshore B (R^2 = 0.893) zones in February. Asisiriwa in

February in the inshore E (R^2 = 0.962) as well as Dompa in the inshore K (R^2 = 0.966) zone in April, were seasons during which pH values recorded were comparatively low.

4.3.2 CONDUCTIVITY

4.3.2.1 Abono

Conductivity values recorded during the study period at the Abono revealed a low mean conductivity for February and April with the latter recording the lowest values. Conductivity increased in the subsequent sampling months with the highest recorded in October. The dynamics of conductivity values during the study period at Abono are represented in figure **4.14**

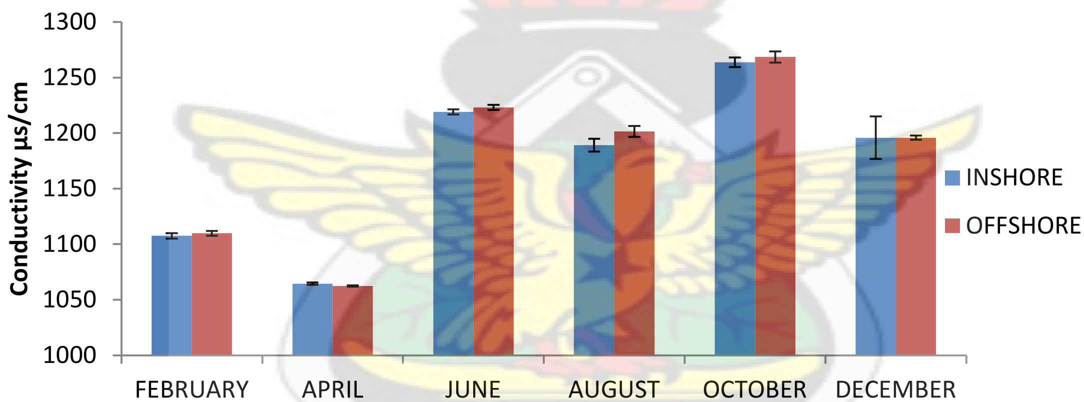


Fig.4.14 Mean bimonthly Conductivity (µs/cm) levels recorded at Abono during the study period. Bars represent standard deviation (SD).

4.3.2.2 Asisiriwa

Slight variability in conductivity at the inshore and offshore zones was observed in Asisiriwa study site except in February and October. Mean conductivity for this site was low in February and April but increased in the subsequent months. The highest conductivity was recorded in October. The mean conductivity values during the study period at Asisiriwa are represented in figure **4.15** below.

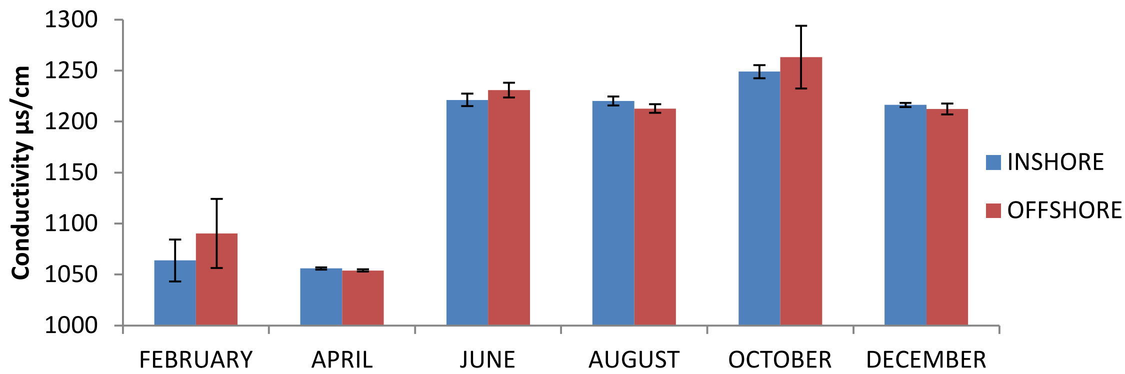


Fig.4.15 Mean bimonthly Conductivity (µs/cm) levels recorded at Asisiriwa during the study period. Bars represent standard deviation (SD).

4.3.2.3Dompa

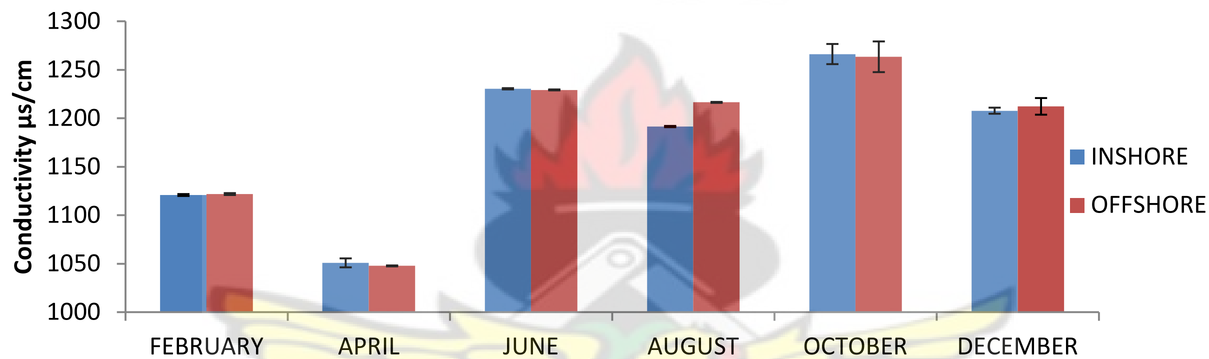


Fig. 4.16 Mean bimonthly Conductivity (µs/cm) levels recorded at Dompa during the study period. Bars represent standard deviation (SD).

The highest mean conductivity was recorded in October in both the inshore (1266.3 µs/cm) and offshore (1263.5 µs/cm) while the lowest was in April also in the inshore and offshore (1051 and 1047.8 µs/cm) zones respectively. Conductivity values between the zones did not follow a specific trend. The mean conductivity values during the study period at Dompa are represented in figure **4.16**

The relationship between Conductivity and T.N at all study sites are summarized in table **4.3** below.

Table 4.3 Correlation analysis between Conductivity and Total Nitrogen at all 3 study sites of Lake Bosomtwe. r = Pearson's correlation coefficient, α = alpha (0.05) level, n = 4

		ABONO		ASISIRIWA		DOMPA	
MONTH	ZONE	r	α	r	α	r	α
February	Inshore	-0.420	0.580	0.318	0.680	-0.870	0.130
	Offshore	0.651	0.349	0.908	0.092	0.522	0.478
April	Inshore	0.577	0.423	-0.905	0.095	-0.560	0.440
	Offshore	0.577	0.423	-0.905	0.095	0.577	0.423
June	Inshore	-0.309	0.691	-0.513	0.487	0.682	0.318
	Offshore	-0.577	0.423	0.023	0.977	-0.577	0.423
August	Inshore	0.577	0.423	0.059	0.941	0.433	0.567
	Offshore	0.577	0.423	-0.018	0.982	0.530	0.470
October	Inshore	-0.081	0.919	0.548	0.452	0.609	0.391
	Offshore	0.584	0.416	-0.152	0.848	0.322	0.678
December	Inshore	0.488	0.512	0.616	0.384	-0.406	0.594
	Offshore	0.365	0.635	-0.300	0.700	0.595	0.405

Correlation analysis between conductivity and total nitrogen at the sampling sites revealed weak positive correlation between the two parameters at Abono in February (0.651) in the offshore, April (0.577 and 0.577) in the inshore and offshore respectively, August (0.577 and 0.577) in the inshore and offshore respectively and October (0.584) in the offshore. A weak negative correlation (-0.577) also existed in the offshore in June. At Asisiriwa a strong positive correlation (0.908) existed at the offshore in February, while weak positive correlations were also recorded, in April a strong negative correlation (-0.905) was recorded in the two zones. Dompa recorded a strong negative correlation (-0.870) in February.

The relationship between Conductivity and OC at all study sites are summarized in table **4.4**

Table 4.4 Correlation analysis between Conductivity and Organic Carbon at all 3 study sites of Lake Bosomtwe. r = Pearson's correlation coefficient, α = alpha (0.05) level, n = 4

		ABONO		ASISIRIWA		DOMPA	
MONTH	ZONE	r	α	r	α	r	α
February	Inshore	0.983	0.017	0.781	0.219	-0.304	0.696
	Offshore	0.975	0.025	0.299	0.701	-0.297	0.703
April	Inshore	-0.577	0.423	-0.040	0.960	-0.040	0.960
	Offshore	0.322	0.678	-0.577	0.423	-0.577	0.423
June	Inshore	0.577	0.423	0.404	0.596	-0.577	0.423
	Offshore	0.577	0.423	0.040	0.960	0.333	0.667
August	Inshore	0.002	0.998	-0.001	0.999	-0.00	0.999
	Offshore	-0.577	0.423	-0.001	0.999	-0.001	0.999
October	Inshore	-0.744	0.256	0.609	0.391	0.933	0.067
	Offshore	-0.638	0.362	0.203	0.797	-0.156	0.844
December	Inshore	0.084	0.916	-0.021	0.979	-0.021	0.979
	Offshore	-0.545	0.455	-0.594	0.406	-0.594	0.406

Correlation analysis revealed that OC correlated strongly with conductivity in both the inshore (0.983) and offshore (0.975) zones of Abono in February while a strong negative correlation (-0.744) existed in the inshore in October. At Asisiriwa, a strong positive correlation (0.781) existed between the parameters in February in the inshore. At Dompa, a strong positive correlation (0.933) existed between the parameters in the inshore in October. Weak correlation and statistically insignificant correlations between the two parameters were also recorded.

The relationship between conductivity and total phosphorus at all three study sites are summarized in table **4.5** below.

Table 4.5 Correlation analysis between conductivity and total phosphorus at all 3 study sites of Lake Bosomtwe. r = Pearson's correlation coefficient, α = alpha (0.05) level, n = 4

		ABONO		ASISIRIWA		DOMPA	
MONTH	ZONE	r	α	r	α	r	α
February	Inshore	0.140	0.860	0.140	0.860	-0.870	0.139
	Offshore	0.392	0.609	-0.988	0.609	0.302	0.698
April	Inshore	0.577	0.423	0.318	0.613	0.577	0.423
	Offshore	0.000	1.000	0.000	1.000	0.333	0.667
June	Inshore	0.577	0.423	-0.315	0.680	-0.904	0.095
	Offshore	-0.577	0.423	-0.040	0.960	-0.870	0.130
August	Inshore	0.577	0.423	-0.575	0.425	-0.577	0.423
	Offshore	-0.333	0.667	-0.575	0.425	-0.577	0.423
October	Inshore	0.809	0.191	0.156	0.844	0.273	0.727
	Offshore	-0.566	0.434	0.603	0.397	0.851	0.149
December	Inshore	0.821	0.179	0.328	0.672	-0.648	0.352
	Offshore	0.701	0.299	-0.443	0.557	-0.155	0.545

A strong positive correlation (0.809) and (0.821) existed between the parameters in the inshore zones in October and December at Abono. At Asisiriwa, a strong negative correlation (-0.988) existed in the offshore zone in February. At Dompa, strong negative correlations existed during February inshore (-0.870), June (-0.904 and -0.870) in the inshore and offshore respectively, a strong positive correlation (0.851) existed in the offshore in October. Weak and statistically insignificant correlations were also recorded between the two parameters at all the three sites during the sampling period.

4.3.3 TOTAL PHOSPHOROUS

4.3.3.1 Abono

Mean total phosphorous recorded in April, June and December were comparatively higher at Abono. There were no wide variations between the two zones throughout the sampling months, except in June where the difference between the inshore and the offshore zones was wide. Of the 2 zones, the offshore zone had comparatively higher values. The total phosphorous values during the study period at Abono study site is represented in figure **4.17**

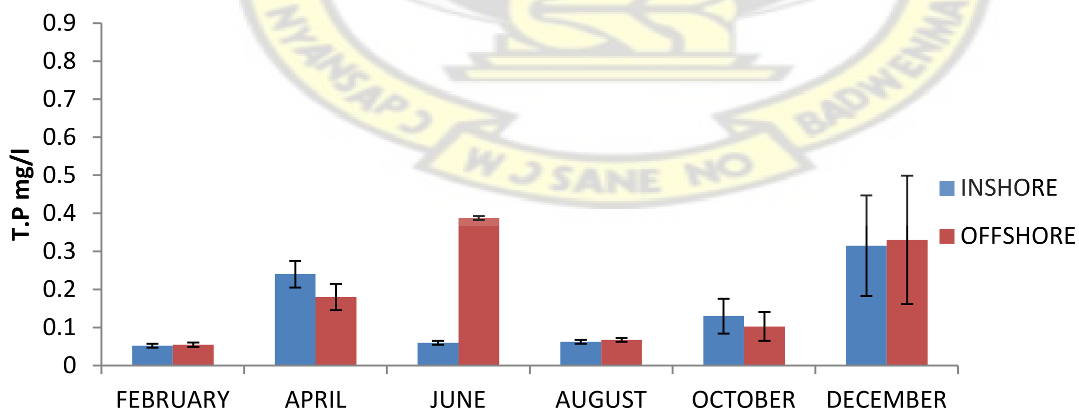


Fig. 4.17 Mean bimonthly Total Phosphorus (mg/l) levels recorded at Abono during the study period. Bars represent standard deviation (SD).

4.3.3.2 Asisiriwa

Mean total phosphorous levels recorded at Asisiriwa did not reveal marked seasonality. Generally the inshore TP was higher than the offshore apart from April and August. The highest TP was recorded in December in the inshore (0.23 mg/l) and offshore (0.22 mg/l). The total phosphorous values during the study period at Asisiriwa study site are represented in figure **4.18** below**.**

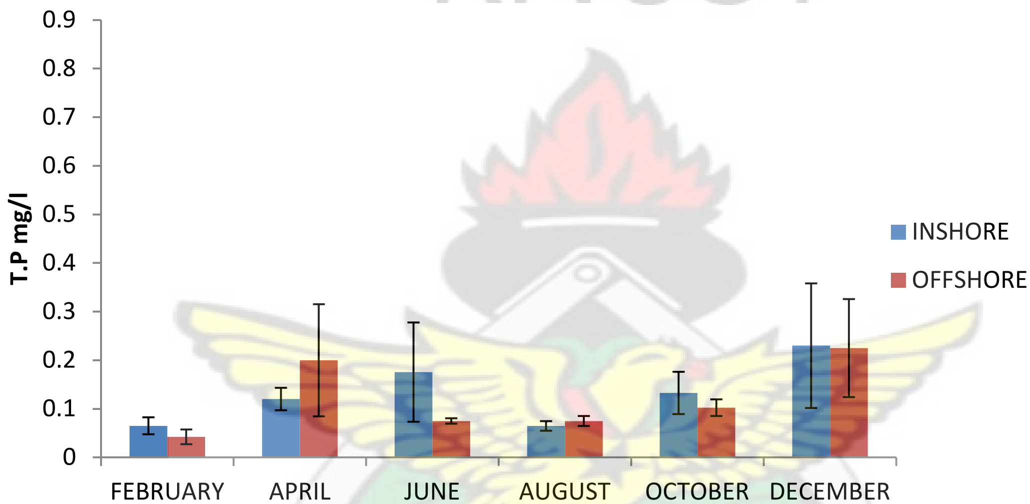


Fig. 4.18 Mean bimonthly Total Phosphorus (mg/l) levels recorded at Asisiriwa during the study period. Bars represent standard deviation (SD).

4.3.3.3 Dompa

Total phosphorous levels recorded at this site increased gradually from February to December where a high peak was recorded in the offshore (0.48 mg/l) zone. The total phosphorous values recorded during the study period at Dompa are represented in figure **4.19** below.

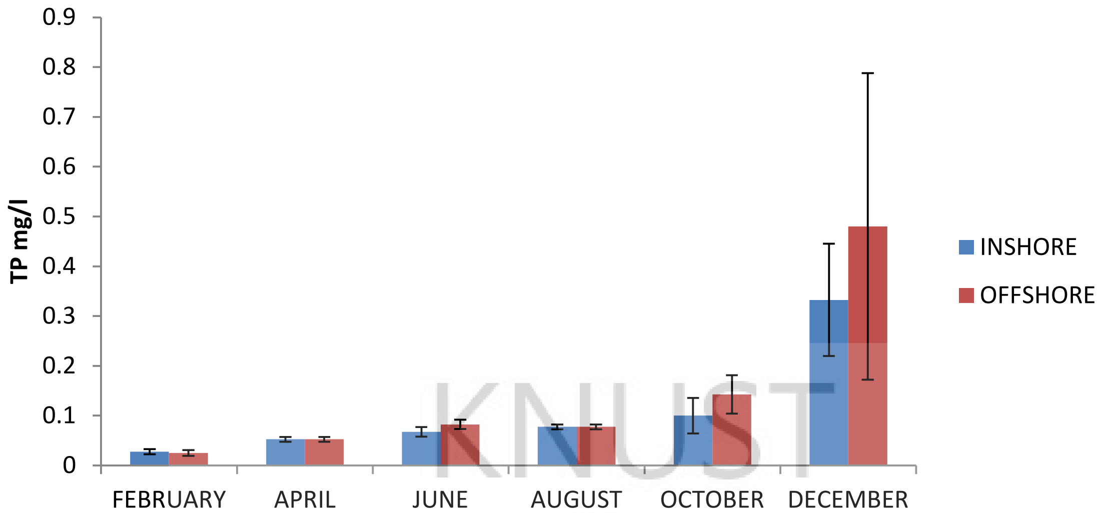


Fig. 4.19 Mean bimonthly Total Phosphorus (mg/l) levels recorded at Dompa during the study period. Bars represent standard deviation (SD).

Table 4.6 Differences in T.P levels between study sites and season. Sampling months are defined in seasonal terms as February (Dry Season) June (Wet Season) and October (Pre Dry Season) (Mann-Whitney U-test; test significant at α<0.05).

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	Dry season	Offshore	Dompa	Wet season	Offshore	0.030
Abono	Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	Dry season	Inshore	Dompa	Wet season	Inshore	0.060
Abono	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Dompa	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.193
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.043
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Dompa	P- Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.060
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.312
Abono	P-Dry season	Inshore	Dompa	Dry season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.083
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.030
Abono	P-Dry season	Offshore	Dompa	Dry season	Offshore	0.312
Abono	P-Dry Season	Offshore	Asisiriwa	Dry season	Offshore	0.312
Dompa	P-Dry Season	Offshore	Asisiriwa	Dry season	Offshore	0.030

Table 4.7 Differences in T.P levels between study sites and season. Sampling months are defined in seasonal terms as April (P-Wet Season) August (Wet Season) and December (Pre Dry Season) (Mann-Whitney U-test; test significant at α<0.05).

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	P-Dry season	Offshore	Dompa	Wet season	Offshore	0.030
Abono	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.148
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.112
Dompa	P- Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.112
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.030
Abono	P-Wet season	Inshore	Dompa	P-Dry season	Inshore	0.030
Abono	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.312
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.193
Abono	P-Wet season	Offshore	Dompa	P-Dry season	Offshore	0.030
Abono	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.030
Dompa	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.030

Compared mean T.P between sites and seasons differed significantly (α<0.05) while no differences were also recorded, weak differences were also recorded between Abono in the dry and Dompa wet season in the inshore as well as Abono in the Pre dry and Asisiriwa in the wet season inshore (α<0.060) in **Table 4.6.** In **Table 4.7**, no weak differences were recorded however, there were no differences in mean T.P between sites and seasons with alpha values 0.148, 0.112, 0.112, 0.312 and 0.193

4.3.4 TOTAL NITROGEN (TN)

4.3.4.1 Abono

Mean total nitrogen (TN) recorded very high levels in June and August at Abono and showed decreased levels in April and October. Mean TN levels recorded in February was also comparatively high. A pronounced peak (75.37mgl^{-1}) was recorded in the offshore in August. Wide variability between the inshore and the offshore zones was recorded in June and August.

The Total Nitrogen values recorded during the study period at Abono are represented in figure **4.20** below

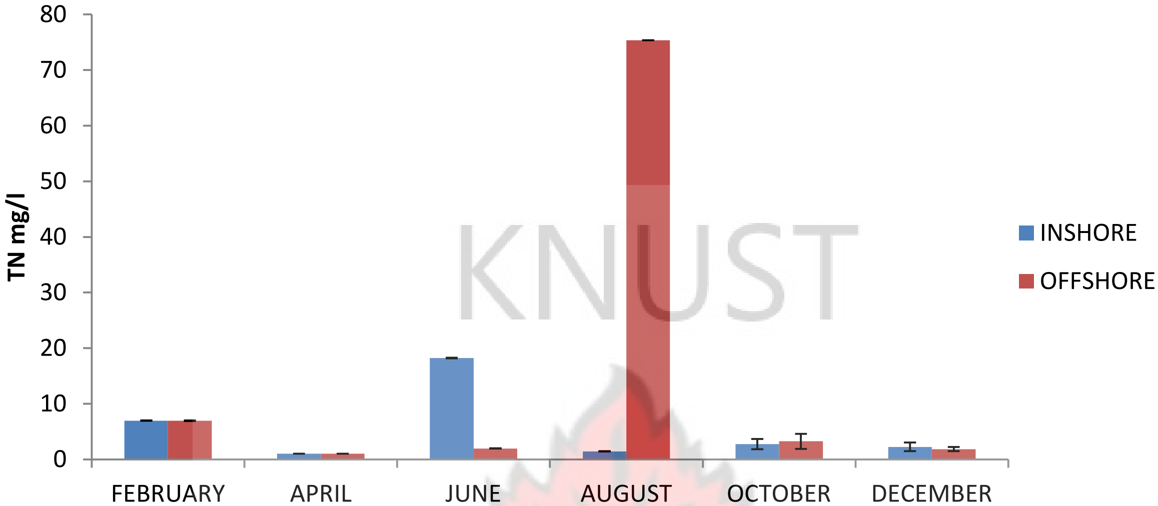


Fig.4.20 Mean bimonthly Total Nitrogen (mg/l) levels recorded at Abono. Bars represent standard deviation (SD).

4.3.4.2 Asisiriwa

Seasonality in TN levels recorded at Asisiriwa was not as pronounced as was recorded at Abono and Dompa. However, the TN values recorded for February was comparatively high in both zones (6.82 and 6.93 mg/l) and again in December where a high value (3.87 mg/l) was recorded in the offshore zone. The TN values recorded during the study period at Asisiriwa are represented in figure **4.21** below.

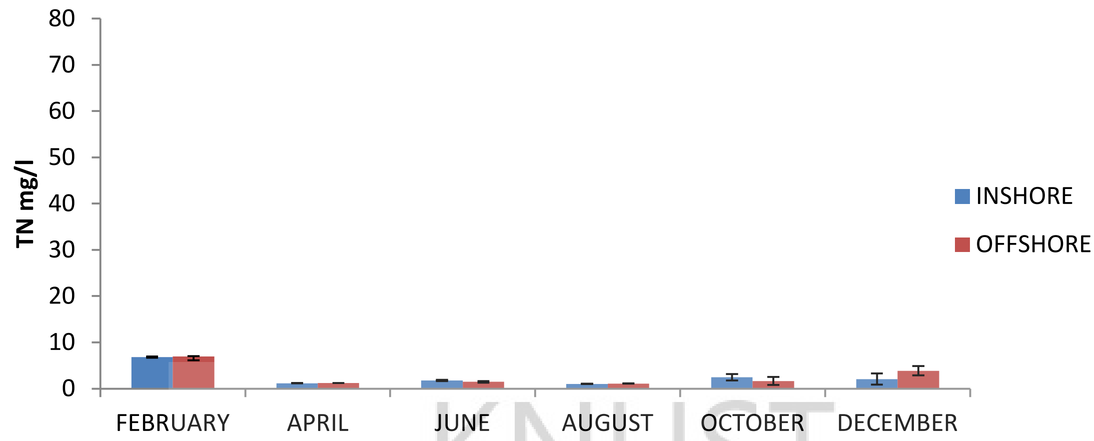


Fig.4.21 Mean bimonthly Total Nitrogen (mg/l) levels recorded at Asisiriwa. Bars represent standard deviation (SD).

4.3.4.3 Dompa

Mean Nitrogen levels recorded were high in August in both zones at the Dompa study site and showed decreased levels in April, June and December. The offshore value recorded in October was significantly higher than the inshore. The Total Nitrogen values during the study period at Dompa are represented in figure **4.22** below.

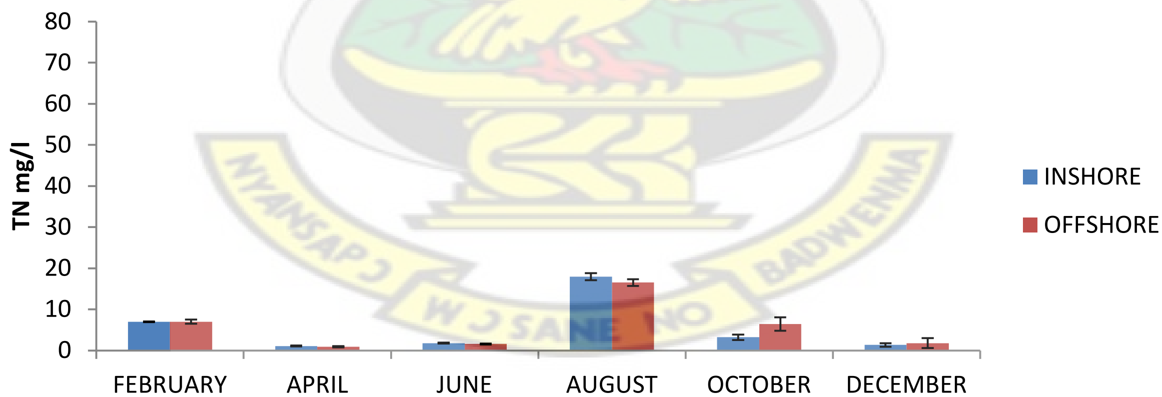


Fig.4.22 Mean bimonthly Total Nitrogen (mg/l) levels recorded at Dompa. Bars represent standard deviation (SD).

Table 4.8 Differences in T.N levels between study sites and season. Sampling months are defined in seasonal terms as February (Dry Season) June (Wet Season) and October (Pre Dry Season) (Mann-Whitney U-test; test significant at α<0.05)

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	Dry season	Offshore	Dompa	Wet season	Offshore	0.030
Abono	Dry Season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.060
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.112
Dompa	P- Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.030
Abono	P-Dry season	Inshore	Dompa	Dry season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	1.000
Abono	P-Dry season	Offshore	Dompa	Dry season	Offshore	0.030
Abono	P-Dry season	Offshore	Asisiriwa	Dry season	Offshore	0.030
Dompa	P-Dry season	Offshore	Asisiriwa	Dry season	Offshore	0.030

Table 4.9 Differences in T.N levels between study sites and season. Sampling months are defined in seasonal terms as April (Pre-Wet Season) August (Wet Season) and December (Pre Dry Season) (Mann-Whitney U-test; test significant at α<0.05).

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	P-Dry season	Offshore	Dompa	Wet season	Offshore	0.030
Abono	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.665
Dompa	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.450
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.312
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P- Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	1.000
Abono	P-Wet season	Inshore	Dompa	P-Dry season	Inshore	0.030
Abono	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.030
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	1.000
Abono	P-Wet season	Offshore	Dompa	P-Dry season	Offshore	0.030
Abono	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.030
Dompa	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.112

Differences in TN levels between sites and seasons were either significant or non-significant in some of the months of sampling. In **Table 4.8** weak differences existed in TN between Abono P-

Dry Season inshore and Dompa wet season inshore (α = 0.060); while no differences existed between Abono P-Dry season inshore and Asisiriwa wet season inshore (α = 0.112); Dompa P-Dry season inshore and Asisiriwa Dry season inshore (α = 1.000). In **Table 4.9**, no differences existed in the alpha values (0.665, 0.450, 0.312, 1.000 and 0.112) during the same period.

4.3.5 ORGANIC CARBON

4.3.5.1 Abono

Peak organic carbon (OC) was recorded in August while values of the other sampling months revealed reduced levels. However, offshore values were comparatively higher than the inshore values. The (OC) values during the study period at Abono study site are represented in figure **4.23** below.

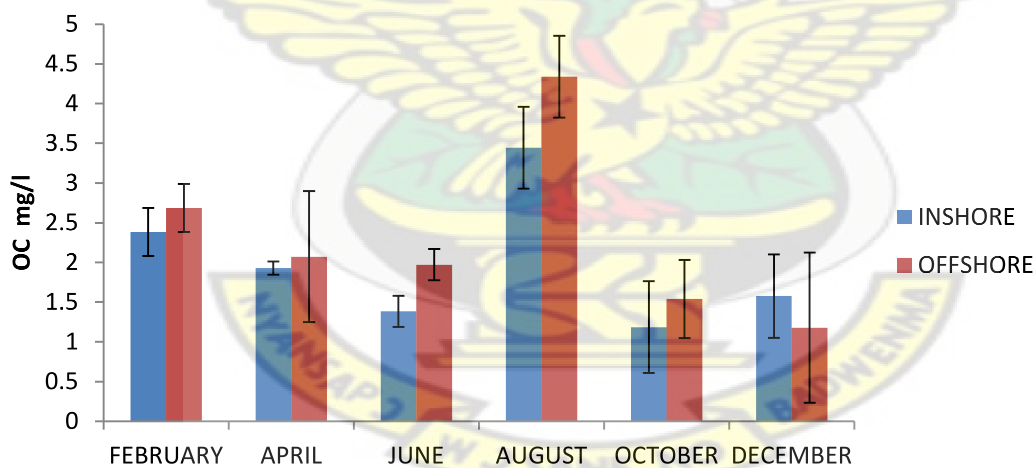


Fig.4.23 Mean bimonthly organic carbon (mg/l) levels recorded at Abono. Bars represent standard deviation (SD).

4.3.5.2 Asisiriwa

OC values recorded at Asisiriwa revealed comparatively higher values in the offshore zone than the inshore except in February. OC levels relatively did not show pronounced variability between the 2 zones except in August and December where OC levels in the inshore dropped. The OC values during the study period at Asisiriwa are represented in figure **4.24**

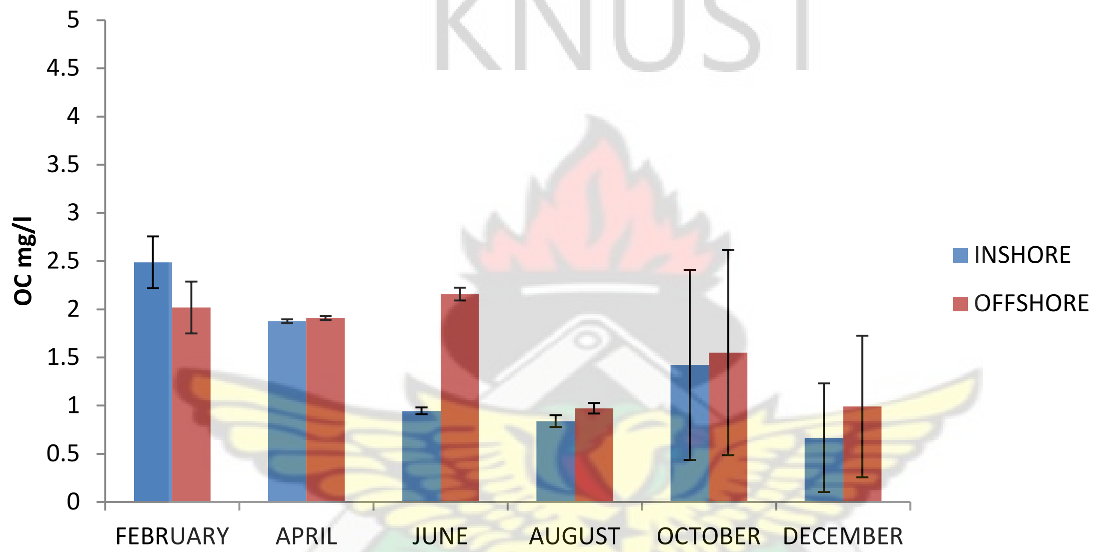


Fig. 4.24 Mean bimonthly organic carbon (mg/l) levels recorded at Asisiriwa. Bars represent standard deviation (SD).

4.3.5.3 Dompa

OC levels revealed a pronounced peak in June and then dropped in the following month. OC in October also revealed a minimal rise. The OC values during the study period at Dompa are represented in figure **4.25** below.

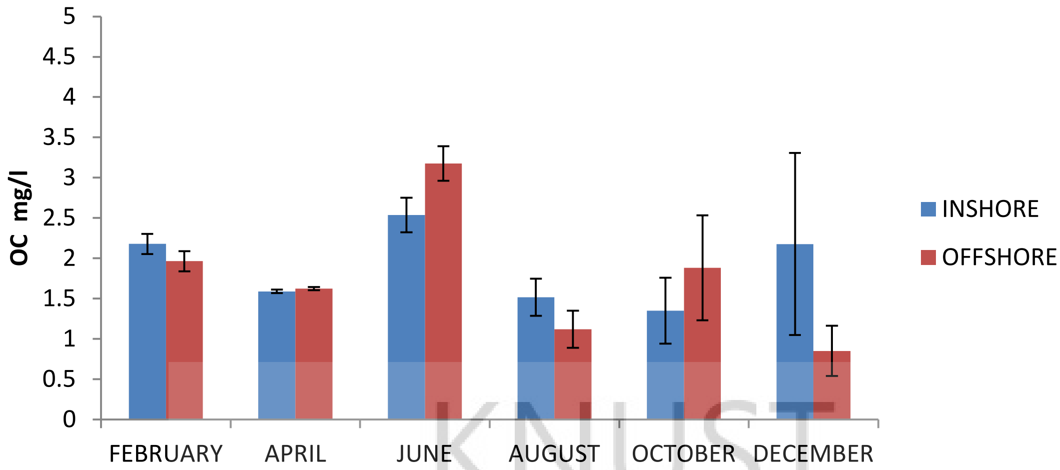


Fig.4.25 Mean bimonthly organic carbon (mg/l) levels recorded at Dompa. Bars represent standard deviation (SD).

Table 4.10 Differences in OC levels between study sites and season. Sampling months are defined in seasonal terms as February (Dry Season) June (Wet Season) and October (Pre Dry Season) (Mann-Whitney U-test; test significant at α<0.05).

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	Dry season	Offshore	Dompa	Wet season	Offshore	0.060
Abono	Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	Dry season	Inshore	Dompa	Wet season	Inshore	0.885
Abono	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.470
Dompa	P- Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.312
Abono	P-Dry season	Inshore	Dompa	Dry season	Inshore	0.312
Abono	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.665
Abono	P-Dry season	Offshore	Dompa	Dry season	Offshore	0.030
Abono	P-Dry season	Offshore	Asisiriwa	Dry season	Offshore	0.312
Dompa	P-Dry season	Offshore	Asisiriwa	Dry season	Offshore	0.312

Table 4.11 Differences in OC levels between study sites and season. Sampling months are defined in seasonal terms as April (P-Wet Season) August (Wet Season) and December (Pre Dry Season) (Mann-Whitney U-test; test significant at α<0.05).

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	P-Dry season	Offshore	Dompa	Wet season	Offshore	0.030
Abono	P-Dry Season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.312
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.112
Dompa	P- Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.312
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.312
Abono	P-Wet season	Inshore	Dompa	P-Dry season	Inshore	0.030
Abono	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.312
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.030
Abono	P-Wet season	Offshore	Dompa	P-Dry season	Offshore	0.665
Abono	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.312
Dompa	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	1.000

Compared differences in measured OC between sites and seasons revealed both significant and non significant differences in **Table 4.10** however, a weak difference existed between Abono in the dry season offshore and Dompa wet season offshore. In **Table 4.11** differences were either significant or non- significant between sites and seasons.

4.4 PRIMARY PRODUCTION

4.4.1 CHLOROPHYLL-a

4.4.1.1 Abono

Chlorophyll-a levels recorded at this study site decreased slightly from February (10.76 and 10.25 mg/l) to June (8.77 and 9.76 mg/l) inshore and offshore respectively. A peak was recorded in August (14.12 mg/l) in the inshore and a decrease in October (4.69 and 2.83 mg/l). Comparatively inshore levels were higher than the offshore levels with the highest disparity between the two zones recorded in August. The dynamics of monthly mean chlorophyll-a values during the study period at Abono study site are represented in figure **4.26** below.

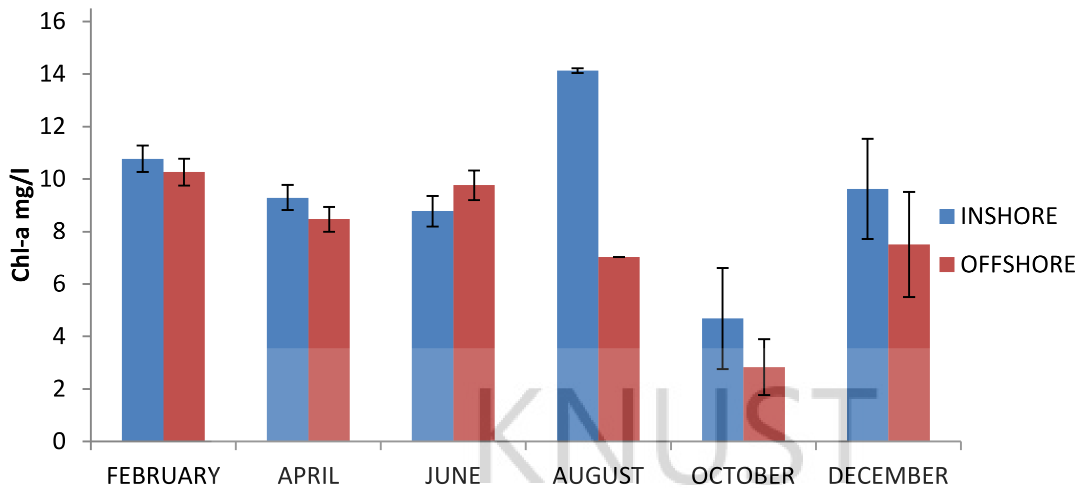


Fig.4.26 Mean bimonthly Chlorophyll-a (mg/l) recorded at Abono. Bars represent standard deviation (SD).

4.4.1.2 Asisiriwa

Chlorophyll-a levels peaked in August, and decreased in October. Generally, variability between the two zones was not pronounced during the study period at this site. However concentrations in October showed wide differences between the inshore (4.81 mg/l) and offshore (8.14 mg/l) zones and again in December inshore (5.95 mg/l) and offshore (1.65 mg/l). The mean chlorophyll-a values during the study period at Asisiriwa are represented in figure **4.27** below.

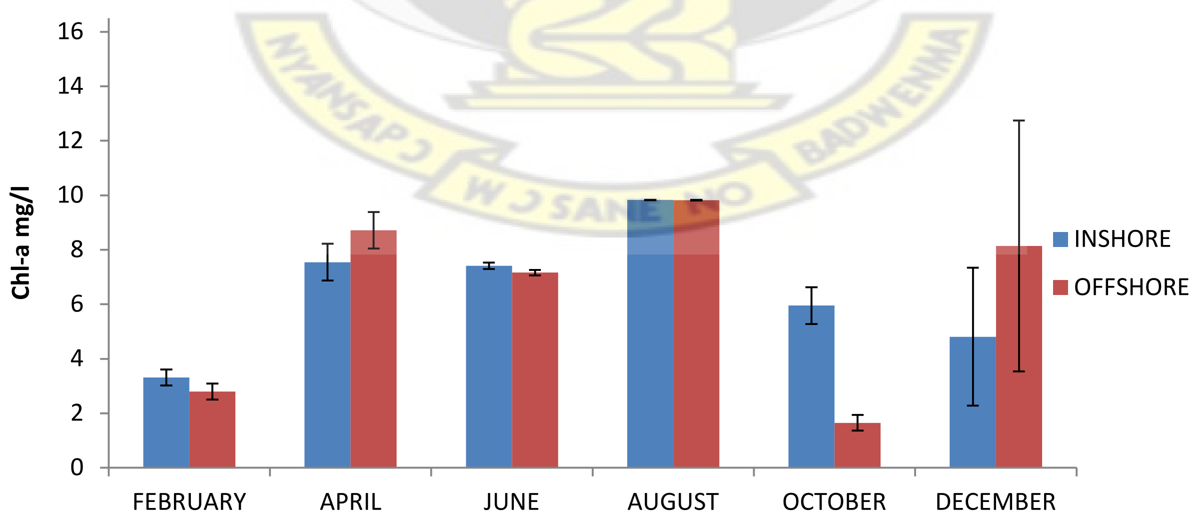


Fig.4.27 Mean bimonthly Chlorophyll-a (mg/l) recorded at Asisiriwa. Bars represent standard deviation (SD).

4.4.1.3 Dompa

The lowest mean chlorophyll-a level for this site was recorded in October (1.793 mg/l and 4.04 mg/l) in the inshore and offshore respectively and the highest in August (16.1 mg/l and 11.325 mg/l) in the inshore and offshore respectively. The offshore zone comparatively recorded higher levels except in August. The mean chlorophyll-a concentration recorded during the study period at Dompa are represented in figure **4.28** below.

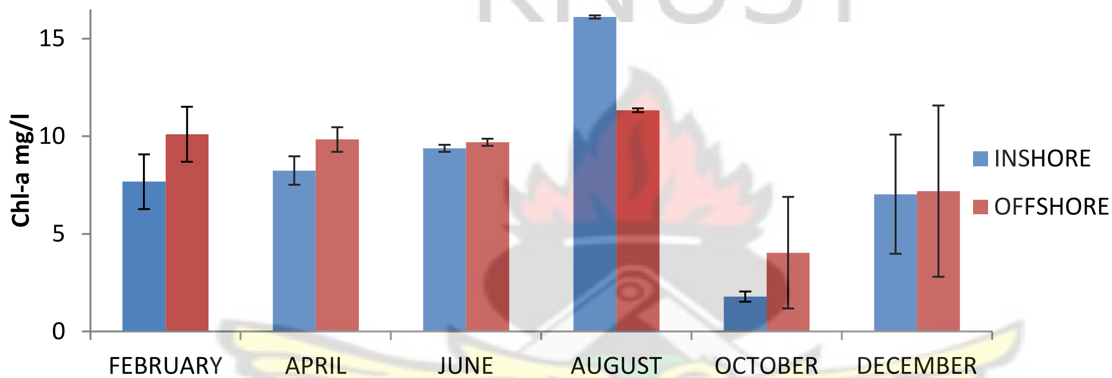


Fig.4.28 Mean bimonthly Chlorophyll-a (mg/l) recorded at Dompa. Bars represent standard deviation (SD).

Table 4.12 Differences in Chl-a concentration between study sites and season. Sampling months are defined in seasonal terms as February (Dry Season) June (Wet Season) and October (Pre Dry Season) (Mann-Whitney U-test; significant at α<0.05).

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	Dry season	Offshore	Dompa	Wet season	Offshore	0.312
Abono	Dry season	Offshore	Asisiriw	Wet season	Offshore	0.030
Dompa	Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Abono	Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	Dry season	Inshore	Asisiriwa	Wet season	Inshore	1.000
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.112
Dompa	P- Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.112
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.030
Abono	P-Dry season	Inshore	Dompa	Dry season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.312
Dompa	P-Dry season	Inshore	Asisiriwa	Dry season	Inshore	0.665
Abono	P-Dry season	Offshore	Dompa	Dry season	Offshore	0.030
Abono	P-Dry season	Offshore	Asisiriwa	Dry season	Offshore	0.030
Dompa	P-Dry season	Offshore	Asisiriwa	Dry season	Offshore	0.312

Table 4.13 Differences in measured Chl-a between study sites and season. Sampling months are defined in seasonal terms as April (Pre-Wet Season) August (Wet Season) and Dec. (Pre-Dry Season) (Mann-Whitney U-test; significant at α<0.05).

SITE	SEASON	ZONE	SITE	SEASON	ZONE	α-LEVEL
Abono	P-Dry season	Offshore	Dompa	Wet season	Offshore	0.030
Abono	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.030
Dompa	P-Dry season	Offshore	Asisiriwa	Wet season	Offshore	0.312
Abono	P-Dry season	Inshore	Dompa	Wet season	Inshore	0.030
Abono	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Dompa	P-Dry season	Inshore	Asisiriwa	Wet season	Inshore	0.030
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	1.000
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.312
Dompa	P- Wet season	Inshore	Asisiriwa	Wet season	Inshore	0.470
Abono	P-Wet season	Inshore	Dompa	Wet season	Inshore	0.112
Abono	P-Wet season	Inshore	Asisiriwa	Wet season	Inshore	1.000
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.312
Abono	P-Wet season	Inshore	Dompa	P-Dry season	Inshore	0.312
Abono	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.312
Dompa	P-Wet season	Inshore	Asisiriwa	P-Dry season	Inshore	0.665
Abono	P-Wet season	Offshore	Dompa	P-Dry season	Offshore	0.030
Abono	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.312
Dompa	P-Wet season	Offshore	Asisiriwa	P-Dry season	Offshore	0.312

Compared differences in mean Chl-a levels between seasons and sites as summarized in **Tables 4.12** and **4.13** reveal either significant or non-significant difference between some sites and seasons. There were no weak differences recorded in both tables.

4.4.2 GROSS PRIMARY PRODUCTION

4.4.2.1Abono

Depth integrated gross primary production (GPP) per day generally declined from February to December in both inshore and offshore. There was a slight rise in June in the offshore and August in the inshore in August. Generally, offshore zone production was higher than the inshore zone throughout sampling period. The GPP per day values recorded during the study period at Abono are represented in figure **4.29**

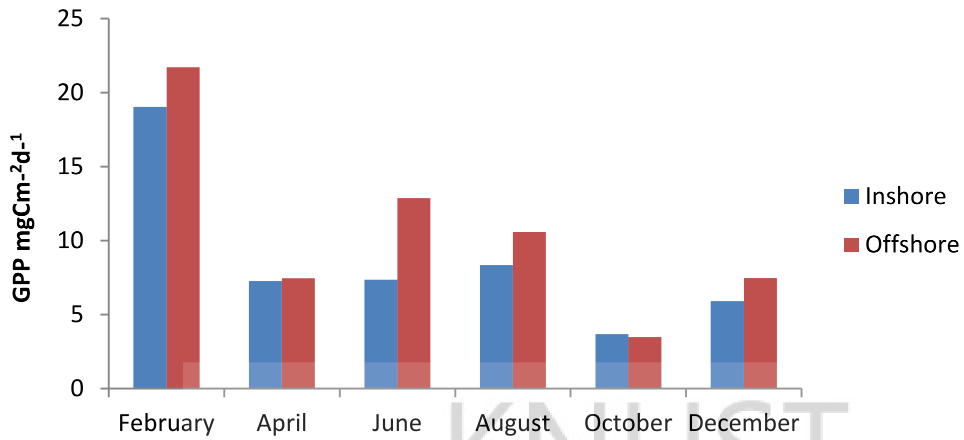


Fig.4.29 Bimonthly depth integrated Gross primary production per day (mg C m^{-2} d^{-1}) recorded at Abono.

4.4.2.2 Asisiriwa

GPP at this site was fairly constant offshore but quite variable in the inshore area. At the inshore GPP levels rose sharply from February to June and dropped significantly in August. Offshore zone levels were higher than the inshore zone except in June where the inshore zone level rose higher than the offshore. The GPP per day values recorded during the study period at Asisiriwa are represented in figure **4.30**

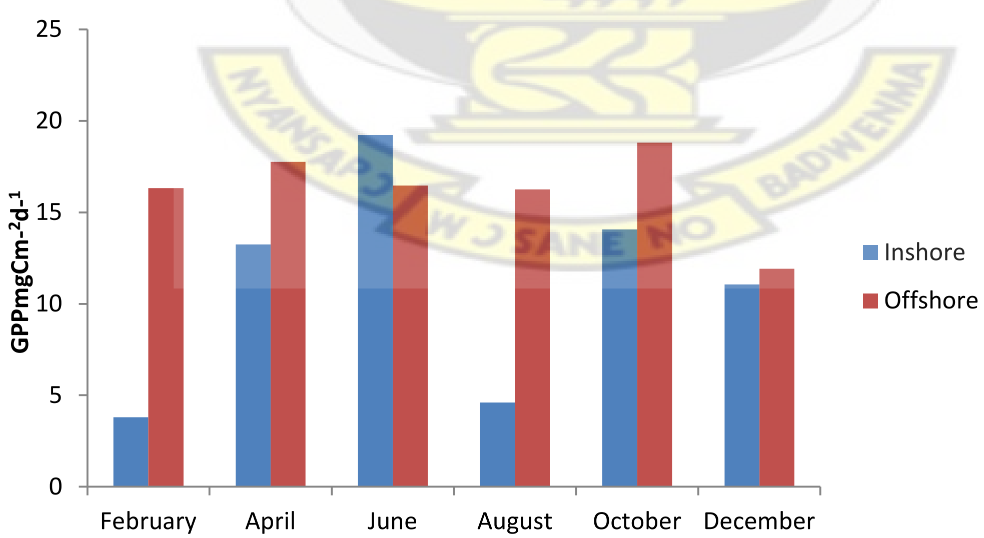


Fig.4.30 Bimonthly depth integrated Gross primary production per day (mg C m^{-2} d^{-1}) recorded at Asisiriwa.

4.4.2.3 Dompa

Similar trend in GPP as above at both inshore and offshore zones was observed at this site although there were deviations in April, June and August. Levels of GPP were consistent during the sampling period but increased from August to December. The depth integrated G.P.P per day recorded during the study period at Dompa is represented in figure **4.31** below.

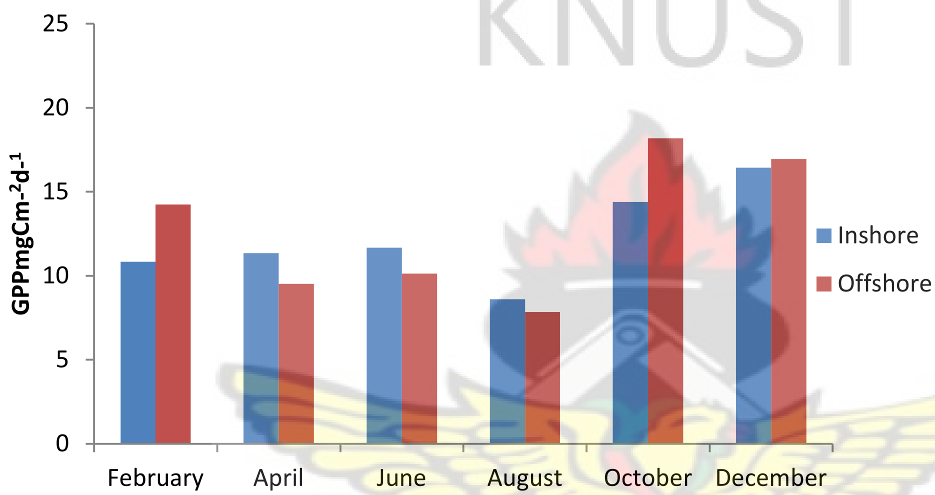


Fig.4.31 Bimonthly integrated Gross primary production per day (mg C m^{-2} d^{-1}) recorded at Dompa.

Table 4.14 Relative efficiencies (maximum rate of light-saturated Chlorophyll-a photosynthesis) determined for all 3 study sites during the study period.

MONTH	ZONE	PHOTOSYNTHETIC EFFICIENCY P^{B}_{max} mg C (mg Chl-a)$^{-1}$h^{-1} ABONO	ASISIRIWA	DOMPA
February	Inshore	14.97	29.65	15.54
	Offshore	25.56	67.28	15.58
April	Inshore	18.96	28.08	19.10
	Offshore	13.28	26.25	16.02
June	Inshore	17.79	33.90	12.16
	Offshore	26.89	32.52	14.32
August	Inshore	9.72	7.67	7.75
	Offshore	35.23	23.33	9.60
October	Inshore	18.63	44.67	110.84
	Offshore	30.82	154.54	65.99
December	Inshore	9.08	36.56	29.33
	Offshore	16.63	28.33	35.20

Photosynthetic efficiency recorded during the study period from **Table 4.14** above revealed that the most productive period of Lake Bosomtwe was in October at Asisiriwa and Dompa study sites (in the offshore zone and inshore zone respectively). Abono was generally the most unproductive part of the lake and Asisiriwa the most productive. The lowest period of production efficiency was recorded in August in the inshore zone across all three study sites.

4.5 INHABITANTS CONSERVATIONAL ATTITUDE

The survey covered farmers (both livestock and crop) within the catchment of Lake Bosomtwe. A sealing was however put on the distance of location of farms. According to (Turner, 1996) the basin of lake from the lowest elevation to the highest elevation of 460 m above (msl) stretches 1.5 km; however the sealing on distance of farm from the lake was put at within 100m from the lake shores.

4.5.1 RESULTS OF SURVEY FOR CROP FARMERS

4.5.1.1 Abono

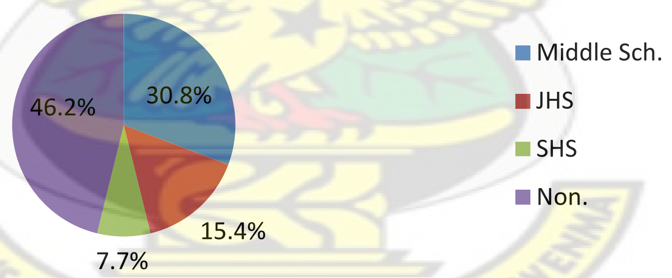


Fig.4.32 Percentage educational background distribution of respondents (Crop farmers from Abono).

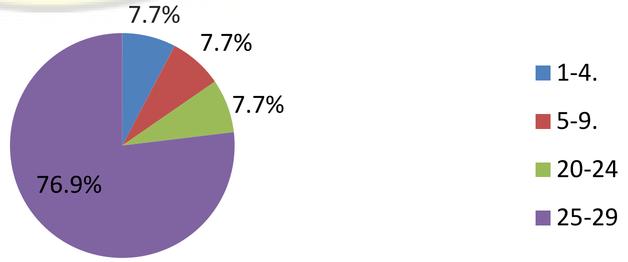


Fig. 4.33 Percentage distribution of distance (meters) of farm from lake of respondents (Crop farmers from Abono).

Table 4.15 Percentage response to questions administered on crop farmers of Abono study site.

QUESTION STATEMENT	PERCENTAGE (%) RESPONSE		FREQUENCY
What type of farmer are you	Full time	76.9	10
	Part time	23.1	3
Do you think that your mode of land preparation can affect the lake in any way	Yes	30.8	4
	No	69.2	9
Do you use fertilizer to help you in farming	Yes	7.7	1
	No	92.3	12
Do you get any advice on how to use lake water for your farming activities.	Yes	15.4	2
	No	84.6	11
Do you attend any form of meeting on farming around the lake.	Yes	15.4	2
	No	84.6	11
Do you think your farming activities can have any effect on the lake.	Yes	7.7	1
	No	92.3	12

Majority of the respondents were illiterates (46.2%) and majority of them (76.9%) had their farms between 25-30 m from the lake shores. The predominant (100%; See appendix 4) mode of land preparation was through the "slash and burn" method and majority (69.2%) did not fault their mode of land preparation (Table 4.15). Fertilizer usage in farming activities around the lake was low and 7.7% of respondents used fertilizers in their faming activities. 92.3% of respondents did not fault their farming activities within the catchment of the lake as shown in table 4.15.

4.5.2 RESULTS OF SURVEY FOR LIVESTOCK FARMERS

4.5.2.1 Abono

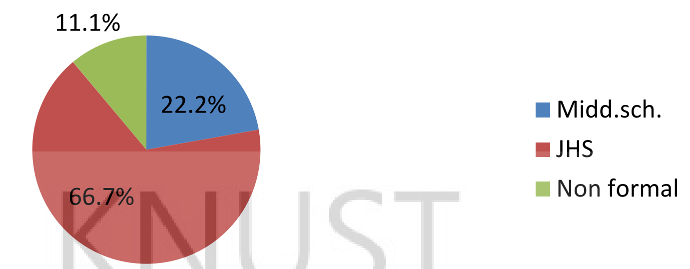


Fig. 4.34 Percentage educational background distribution of respondents (Livestock farmers from Abono)

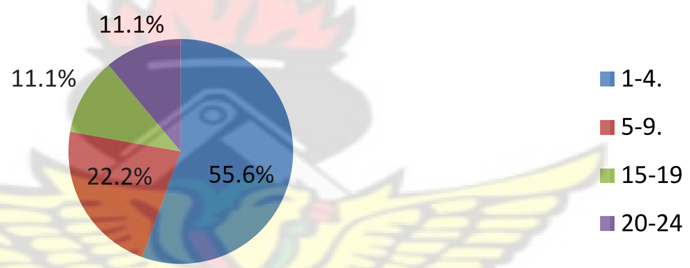


Fig.4.35 Percentage distribution of distance (meters) of farm from lake of respondents (Livestock farmers from Abono)

Table 4.16 Percentage response to questions administered on Livestock farmers of Abono study site.

QUESTION STATEMENT	PERCENTAGE (%)	RESPONSE	FREQUENCY
What type of farmer are you	Full time	22.2	2
	Part time	77.8	7
Do you think that your mode of land preparation can affect the lake in any way	Yes	0.0	0
	No	100	9
Do your animals drink from lake	Yes	66.7	6
	No	33.3	3
Do your animals play in lake to cool down	Yes	44.4	5
	No	55.6	4
How do you dispose animal waste	Near sty	100	9
	Far from sty	0.0	0
Do you get any advice on how to use lake water for your farming activities.	Yes	11.1	1
	No	88.9	8
Do you attend any form of meeting on farming around the lake.	Yes	11.1	1
	No	88.9	8
Do you think your farming activities can have any effect on the lake.	Yes	0.0	0
	No	100	9

All respondents were pig farmers (see appendix 3). Majority (66.7%) of livestock farmers were junior high school graduates and most (55.6%) of them had their farms within between 20-25 m from the lake shores. The major (100%; See appendix 3) mode of land preparation was through the "slash and burn" method and majority (100%) did not think their mode of land preparation can affect the lake (Table 4.16). In their livestock activities, 66.7% of respondents allowed their animals to drink direct from the lake and 44.4% of respondents thought their animals should play in the lake to cool down. All respondents dumped their waste from the livestock activities near the sty. All respondents (100%) did not think their farming had effect on the lake.

4.5.3 RESULTS OF SURVEY FOR CROP FARMERS

4.5.3.1 Dompa

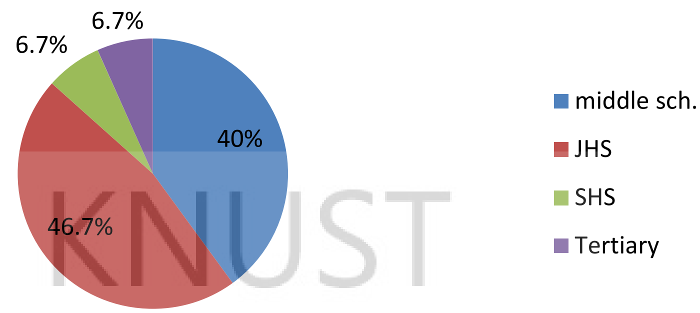


Fig.4.36 Percentage educational background distribution of respondents (Crop farmers from Dompa).

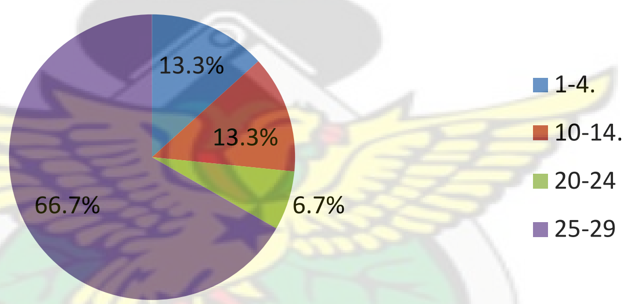


Fig.4.37 Percentage distribution of distance (meters) of farm from lake of respondents (Crop farmers from Dompa).

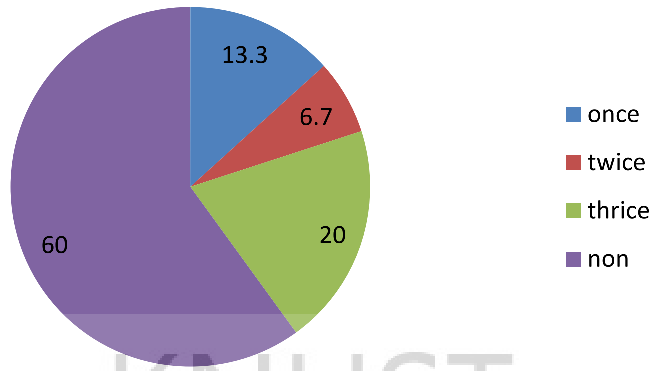


Fig.4.38 Percentage frequency of application of fertilizer on farm by respondents (Crop farmers from Dompa).

Table 4.17 Percentage responses to questions administered on Crop farmers of Dompa study

QUESTION STATEMENT		PERCENTAGE (%) RESPONSE	FREQUENCY
What type of farmer are you	Full time	53.3	8
	Part time	46.7	7
Do you think that your mode of land preparation can affect the lake in any way	Yes	20.0	3
	No	80.0	12
Do you use fertilizer to help you in farming	Yes	40.0	6
	No	60.0	9
Do you get any advice on how to use lake water for your farming activities.	Yes	93.3	14
	No	6.7	1
Do you attend any form of meeting on farming around the lake.	Yes	93.3	14
	No	6.7	1
Do you think your of farming activities can have any effect on the lake.	Yes	0.0	0
	No	100	15

Educational level of respondents in this site was spread between middle school leavers(40%) and junior high school graduates (46.7). Most of them (66.7%) had their farms between 25-30 m from the lake shores. The predominant (100%; See appendix 6) mode of land preparation was through the "slash and burn" method and majority (80%) did not think their mode of land preparation can affect the lake (Table 4.17). 40% of respondents used fertilizer in their farming activities and the frequency of the usage was fairly significant. All respondents (100%) did not fault their farming activities within the catchment of the lake.

4.5.4 RESULTS OF SURVEY FOR LIVESTOCK FARMERS

4.5.4.1 Dompa

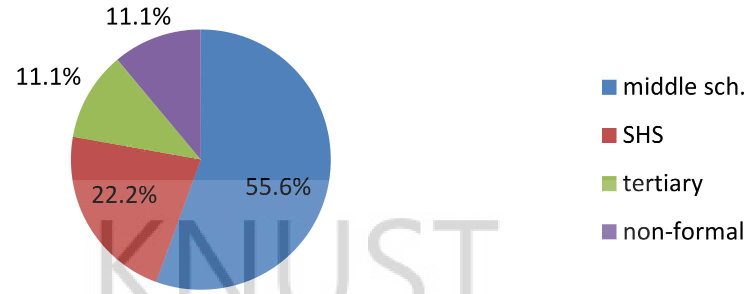


Fig.4.39 Percentage educational background distribution of respondents (Livestock farmers from Dompa)

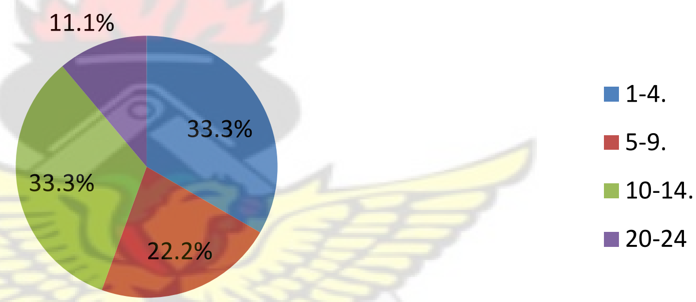


Fig.4.40 Percentage distribution of distance (meters) of farm from lake of respondents (Livestock farmers from Dompa).

Table 4.18 Percentage responses to questions administered on Livestock farmers of Dompa.

QUESTION STATEMENT		PERCENTAGE (%) RESPONSE	FREQUENCY
What type of farmer are you	Full time	33.3	3
	Part time	66.7	6
Do you think that your mode of land preparation can affect the lake in any way	Yes	0.0	0
	No	100	9
Do your animals drink from lake	Yes	11.1	1
	No	88.9	8
Do your animals play in lake to cool down	Yes	22.2	2
	No	77.8	7
How do you dispose animals waste	Near sty	100	9
	Far from sty	0.0	0
Does the lake have an effect on your work	Yes	22.2	2
	No	77.8	7
Do you get any advice on how to use lake water for your farming activities.	Yes	44.4	4
	No	55.6	5

Do you attend any form of meeting on farming around the lake.	Yes	11.1	1
	No	88.9	8
Do you think your farming activities can have any effect on the lake.	Yes	0.0	0
	No	100	9

All respondents were pig farmers (see appendix 5). Majority (55.6%) of livestock farmers were middle school leaving certificate holders. Distances from the lake to the various sty was scattered between 1- 25 m from the lake shores. The major (100%; See appendix 5) mode of land preparation was through the "slash and burn" method and majority (100%) did not think their mode of land preparation can affect the lake (Table 4.18). In their livestock activities, 11.1% of respondents allowed their animals to drink direct from the lake and 22.2% of respondents allowed their animals to play in the lake to cool down. All respondents dumped their waste from the livestock activities near the sty. All respondents (100%) did not think their farming had effect on the lake. Generally, majority of respondents from the survey had not had any form awareness on the impact of their activities on Lake Bosomtwe.

CHAPTER FIVE

DISCUSSION

5.0 SEASONAL DYNAMICS OF PHYSICAL PARAMETERS

5.0.1 Temperature

From the studies, lower surface water temperatures were recorded in August at all three study sites in the main wet season. These lower temperatures coincided with lower atmospheric temperatures (Fig.4.1). The surface water temperature fluctuations were similar to atmospheric temperature patterns as was also found by (Otu, 2010), who discovered that lower air temperatures recorded in August produced a cooling event in the surface waters of Lake Bosomtwe. This close relationship between air temperatures and lake surface temperatures is a well known phenomenon in aquatic systems and is important for many rate processes (Beadle, 1981). The small variability in temperature between the inshore and offshore zones of the lake as also found by (Otu, 2010) is characteristic of tropical water bodies as tropical systems are known to have high and uninterrupted solar irradiation resulting in high air temperatures and corresponding surface water temperatures (Beadle, 1981 and Talling and Lemoalle, 1998b).

The fluctuation of the surface water temperature of Lake Bosomtwe in tandem with atmospheric temperature probably makes climatic temperature the most influential parameter on the temperature dynamics of the lake, since from Turner *et al*. (1996a) and Talbot and Delibrias (1977, 1980) the established water input sources of the lake is mostly rain water and the contribution of 'input channels" such as River 'Abrewa' (Fig.3.0) to cause disturbances in the lake's temperature regime has been mostly ignored. The most established temperature disturbance in Lake Bosomtwe is the breaking of stratification which is believed to occur only in the months of January in the main dry season and August in the wet season where the lake experiences overturn events (Beadle, 1981; Turner *et al*., 1996a; Puchniak *et al*., 2009).

5.0.2 Transparency

This study recorded lower transparency (Secchi Disk depth; "S_d") values in the main dry season (February, 2008) at all three sampling sites. The other seasons recorded higher transparency values notably June and August at all three study sites. Abono and Asisiriwa however showed pronounced increases. The increases in transparency in the wet season corroborated the findings of Otu (2010) who established that the long rainy season was characterized by a deepening of the thermocline and increased Secchi disk depth, as water transparency increased. The maximum transparency level 3 m recorded by Otu (2010) however, exceeded results from this present study which may suggest the lake's transparency exhibits annual variations. This is emphasised by the fact that other researchers (Wondie *et al*., 2007; Kling, 1988) have recorded lower transparency values in the wet season in contrast to this study, and others on Lake Bosomtwe.

Anthropogenic activities have been implicated as a major cause of reduction in transparency (Knud-Hansen, 1997). These activities are sources of ash and burnt leaves which by their proximity to the lake water are deposited with ease into the inshore zones. Knud-Hansen (1997), discovered that these anthropogenic activities which include frequent burning activities close to water bodies dry up soils as a result of the frequent burning activities making the soil relatively light and can be easily dislodged into the inshore of the lake from the banks to reduce transparency. The slight early rains in February which run over exposed land in the catchment of the lake is also implicated in reduction of transparencies as found in some African lakes (Britton *et al*., 1993). These phenomena could be aided by the steep slope nature of the banks of Lake

Bosomtwe. Another assumption for this phenomenon of reduced water clarity in February could be the creation of internal seiches from the early rains (February and April). These seiches so created have been known to carry along with it organisms as well as suspended particles oscillating in the internal waves direction (Langenberg, 2008). Most of the time since the dissipation of the wave energy is at the water surface, the cloud of suspended materials and organisms could rise and reduce water surface clarity leading to reduction in transparency values. Comparatively, transparency was lower in the inshore than the offshore in the two inhabited stations (Abono and Dompa) than the uninhabited station giving further evidence of catchment activities on transparency.

From other lakes where limited farming activities occur within the catchment, transparency rates are lower in the main rainy season than the main dry season as a result of overland wash from watershed and also thunderstorm induced re-suspension of bottom sediments (Zinabu, 2007). These higher transparencies in the main rainy season reduce light limitation in primary production rates and also extend euphotic zone depths as was found along the course of Lake Tanganyika at Kigoma (8.1–23.5 m) and Mpulungu (7.0–20.5 m) by Langenberg (2008). The phenomenon of clearer water has also been recorded in the main wet season in lakes with basin-like morphology and the phenomenon is due to dilution from precipitation during the main wet season (Wondie *et al*., 2007).

The depth of Euphotic zone (Z_{eu}) values obtained from this study determined from transparency depths notwithstanding, it has been established that attenuation of downwelling irradiance can go beyond the conventional Z_{eu} of 1% light when light scattering is due to suspensoids (Grobbelaar, 1989). Since the Z_{eu} was only estimated from transparency values and not in-depth studies of irradiance, the findings of Grobbelar could hold true for Lake Bosomtwe to hypothetically deduce that production can go beyond Z_{eu}.

Correlation analysis between Transparency and Chl-a revealed a non uniform correlation as there were instances of both strong positive and negative, weak positive and negative as well as no correlations (Table 4.1) showing transparency was not necessarily related to algal (Chl-a) growth but other factors which this study did not cover. This is however not peculiar to Lake Bosomtwe as Langenberg *et al*., (2002) found Secchi disk depth correlated negatively with chlorophyll-a in Lake Tanganyika.

Transparency of lakes potentially can be altered within short periods leading to variations in transparency on daily or hourly basis especially within the 0m-5m depths (Langenberg, 2008).

5.1 SEASONAL DYNAMICS OF CHEMICAL PARAMETERS

5.1.1 pH

pH values recorded were lower in the main dry season (February and April) at all sampling sites in both the inshore and offshore zones. Naturally when CO_2 dissolves to produce H_2CO_3 it dissociate to build up H^+ coupled with a reduction in water levels during the main dry season will lead to natural waters approaching acidity, hence the relatively lower pH recordings of Lake Bosomtwe in the dry season. This is a phenomenon mostly associated with African lakes (Talling, 2001). Lower pH has also been recorded in the dry season in Lake Tanganyika although much of the results were from deep water, the other months of the sampling also from deep waters did not record low pH (Langenberg, 2008). Previous work on pH of Lake Bosomtwe in which water samples taken at various depths from the middle of the lake by Turner *et al*. (1996b) in 1993 and analyzed gave a mean pH of 8.73 with the highest being 9.00. Puchniak *et al*. (2009)

recorded a pH level of 8.9 from Lake Bosomtwe in the pelagic zone. These recordings however were not designed to cover spatio-temporal studies. Since the lake has been established to undergo fluctuating depths through times, such spatio-temporal studies is most likely to reveal the true pH values since contrasting environments and activities have a significant impact on the ionic composition of the lake. The values of the present study revealed elevated pH above the level 9 recorded by (Otu, 2010) from the onset of the wet season. Differences in pH levels between the study sites and seasons conducted revealed that either significant or non-significant differences existed at different study sites and the seasons (Table 4.1) suggesting a possibility of pH dynamics within the lake exhibiting in spatial terms heterogeneity as against homogeneity.

pH levels recorded in June and October across all three study sites as well as other sampling months, although were not uniform across all sampling sites, were above the maximum permissible level of Ghana's Environmental protection Agency (EPA) standards which ranges from 6 to 9. There was strong relationship between pH and OC at Abono in the inshore (Fig. 4.11), Abono offshore (Fig. 4.12), Asisiriwa inshore (Fig. 4.15), Dompa inshore (Fig. 4.13) probably alluding to the fact that OC loading activities do occur and it is higher at inshore zone than the offshore zone.

5.1.2 Conductivity

From the study, the highest conductivity was recorded in October throughout all the three sampling sites while the lowest conductivity was recorded in the month of April across all three sampling sites. Generally, conductivity increased during and immediately after the main rains across all three sites. Seasonality in conductivity has been observed elsewhere in tropical lakes. Langenberg (2008) noted important differences at the end of the dry and wet seasons.

Langenberg's measurements of conductivity corroborated this study as the highest conductivity was recorded in October in Lake Tanganyika, attributing it to nutrients entrainment and increase in ionic activities. There were strong, weak and negative correlations between conductivity and nutrients (phosphorus, nitrogen, organic carbon) covered by this research at some zones and months. The highest mean conductivity of 1268.5μscm^{-1} in the offshore and 1263.8μscm^{-1} in the inshore were recorded in the month of October at Abono. Generally however, the conductivity of the pelagic water was higher than the inshore across all three sampling sites. Puchniak *et al*. (2009) recorded a mean conductivity of 1150μScm^{-1} from deep waters of the pelagic zone but this research did not cover spatio-temporal investigations.

Lake Bosomtwe has been identified as acquiring ionic elements dissolved in rain drops as a source of nutrient input (Turner *et al*. 1996b and Stallard and Edmond, 1981) and this also might have perhaps contributed to the general trend of increase in conductivity during the main rains. Conductivity of Lake Bosomtwe recorded during this study throughout the seasons were higher than conductivities of some tropical lakes by other researchers (Marshall, 1997; Adeniji *et al*., 2001; Wondie *et al*., 2007; Kibichi *et al*., 2008).

The conductivities recorded in this study however were well within the permissible level of 1500μScm^{-1} by the standards of Ghana's EPA for natural water bodies. Generally, conductivity levels of Lake Bosomtwe were high compared with some conductivity measurements by some workers on tropical lakes. Generally, the pattern of seasonal fluctuation of temperature and transparency in this study were consistent with the measurements from 2004-2006 by (Otu, 2010); pH and conductivity measurements of Lake Bosomtwe as found in this study appears to have been elevated from 2004-2006 (Otu, 2010) although much of Otu's measurements did not elucidate spatiality.

5.1.3 Nutrients

From the results, the highest total phosphorus (TP) level was recorded at the two inhabited study sites (Abono and Dompa) during June and December after the main rains. Phosphorus loading trend was visible at Dompa where there was a gradual incremental trend and mean TP of (0.48 mg/l ± 0.30) recorded in December in the offshore zone. Seasonality in TP from the results appears to be less pronounced in the surface of the lake; nonetheless researchers like Otu (2010) suggest that the phosphorus dynamics of the lake is restricted by the themocline depth. Levels of phosphorus recorded during most part of this study were slightly lower compared to some published phosphorus levels in some tropical lakes such as Nakuru and Tana (Kibichi et al., 2008; Wondie et al., 2007). Turner *et al,* (1996b) in 1993 recorded a mean phosphate level of PO_4^{3}= 0.093, with the highest being 0.167 µg/l at various depths from the middle of the lake. There was however no spatial determinations to elucidate variations in phosphorus at different locations as seasonal variability in phosphorus has been found to run in tandem with catchment processes (Britton *et al*., 1993). The anthropogenic activities as found in the survey conducted in this study and the observed volume of activity occurring within the catchment coupled with overland wash can positively contribute to phosphorus loading as has already been established by other workers in the field of lake nutrients (Britton *et al*., 1993). Categorization of phosphorus levels by some researchers however seem to depend on particular goals targeted for the level stated in the program of that research (Thorton, 1979; Dakers, 2003; Lampert and Sommer, 2007). Levels of TP recorded in this study were generally not critically above the permissible level of 2 mgl^{-1} (which is the standard total phosphorus for natural water systems recommended by EPA of Ghana) across all study sites and all sampling months. From the results of the study, high TN levels were recorded in Abono and Dompa during the wet season and fairly elevated levels in February across all study sites. TN levels recorded over the study period in Lake Bosomtwe shows that it has very pronounced seasonal TN variations compared to other tropical lakes such as Lake Nakuru (0.21 mgL^{-1}) by Kibichi *et al*., (2008), Lake Kariba ranging between 96 μgL^{-1} and 2448 μgL^{-1} by (Magadza, 2000; Mhlanga, 2001). This seasonal catchment induced variability in TN as well as other nutrient levels is well documented in African lakes and has been attributed to catchment size and land use activities Magadza (2000) as well as rain and storm events (Britton *et al*., 1993).

The seasonal elevation in TN recorded during this study could possibly implicate the early February rains (Fig. 4.0) run over exposed land resulting in the input of debris/sediment from catchment areas from the erodible catchment area. This seasonal anthropogenic activity is potentially enhanced by the current farming practices in the catchment, where raffled soils from the farming activities during overland flow events are conveniently deposited in the lake shores. This was also found by Otu, (2010) and has also been hypothesized by (Shanahan et al., 2008). Secondly, Lake Bosomtwe is known to go through its overturn regimes in the months of January (where fish kills was actually witnessed by this writer during site inspection) and August. The elevated levels recorded in February could actually be receding TN levels resulting from potential overturn event in January since levels reduced from February until the main rains started in June. Otu (2010) also recorded high TN levels in February attributing it to deep-water nutrient upwelling during the Harmattan. The month of June also recorded high TN at the Abono station in the inshore and it is a month when the rains had actually intensified. These seasonal TN levels were recorded in the two inhabited study sites where anthropogenic activities have been sited to be going on in the catchment. Current levels of T.N recorded in this study reveal Lake Bosomtwe has a challenge with nitrogen enrichment from catchment activities in line with the findings of Perez- Ruzafa *et al*. (2002) and Salas *et al*. (2008). Anthropogenic nitrogen has been theorized by Ryan *et al*. (2008) as a major problem in catchment induced aquatic systems. Turner *et al*. (1996b) in 1993, analyzed nutrients of water samples taken at various depths from the middle of the lake for NH_3-N which averaged 2.20 µg/l with the highest being 5.21µg/l. Such previous levels in Lake Bosomtwe and that of other workers on tropical lakes recorded put that levels recorded in the inhabited villages of the study site in eutrophic status.

The maximum permissible level of NH_3-N as standard for natural waters as recommended EPA (Ghana) is 1 mgl^{-1}. Organic Carbon level recorded was higher in the wet season (June and August) at the 2 inhabited study sites while at the Asisiriwa site, OC also increased in June although the value recorded in February (2.486 mg/l) did not differ greatly from the June value (2.157mg/l). As has been stated already, there was strong relationship between pH and OC especially at the inshore zone pages (55 and 56) showing OC loading activities are higher at the inshore zone than the offshore zone.

Researchers on water nutrients have established a link between the concentration and supply of nutrients (N,P,OC) as intimately connected with land use practices on the watershed. Lake Bosomtwe has been duly identified as having the potential to increase its nutrient load per activities proceeding within the watershed (Otu, 2010).

This study found either significant or non-significant differences in levels of nutrient obtained between sites and seasons **(Tables 4.3, 4.4, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23)**, although some earlier workers suggest homogeneity in nutrient regime of the lake (Turner et al.,1996b).

Ideally to gauge the effects of such activities on the Lake, seasonal measurements of nutrients as has been shown in this study is likely to reveal impacts on the water body over time. This study and probably others to come could underestimate input of nutrients if it is gauged from only within the lake's catchments; the reason being the admission of Langenberg (2008) that the relatively high dissolved inorganic nitrogen concentrations found in rainwater during the study on Lake Tanganyika are most likely caused by biomass burning within the lakes catchment because biomass burning is widespread in the riparian countries of Tanzania, D. R. Congo, Burundi, and Zambia.

5.2 Primary production

Generally the nutrient loading of lake Bosomtwe during the study showed increased levels in the wet season (June and August), and again slight increases in February. It follows that growth of algae might have thrived during these periods. This study found peak levels in chlorophyll – a during August at all three study sites. These findings were consistent with (Otu, 2010) on Lake Bosomtwe who recorded a peak in surface water chlorophyll-*a* concentrations annually in August in association with disruption in the water column stability causing a threefold increase in chlorophyll-a level. Some researchers on algae have found (and some proposed could be found) elevated concentrations of chlorophyll-*a* during, or directly following periods characterized by a rise or breakdown of the thermocline (Falconer, 1973).

In the present study, the pattern of chlorophyll-a fluctuation followed that of the nutrient nitrogen, making it probably the most influential nutrient in the dynamics of chlorophyll-a abundance considering also the response of chlorophyll-a to the slight increase in level of nitrogen in the month of February across all three study sites. Although chlorophyll-a level recorded at the Asisiriwa study site showed a slowed response in the fluctuation of nitrogen however, the December rise in nitrogen level was accompanied by a corresponding rise in chlorophyll-a. Sheffer (1998) has reported the importance of nitrogen in the growth of phytoplankton. Langenberg (2008) also discovered seasonal variations in abundance of phytoplankton and a spring peak in phytoplankton from a wind induced turbulence as nitrogen and other nutrients increased.

Diehl (2002) found that effects of nutrient enrichment can be explained with a shift in the relative importance of nutrient and light limitation of algal production. At equilibrium, an increase in nutrient enrichment reduces nutrient limitation of algal production and algal biomass concentration increases because any increase in biomass inevitably increases the degree of algal light limitation.

According to Ferris and Christian (1991) and Reynolds (1994) it has been established that phytoplankton are sensitive not only to the absolute average light level but also to the pattern of light supply. The pattern of light supply did not appear to be the most influential on the abundance of phytoplankton (or had less influence) in this study since relatively high temperatures were recorded in the month of February (Fig. 4.1) and the period where peak Chl-a concentration was observed was also characterized by low atmospheric temperature (Light intensity). Higher inshore Chl-a concentrations were found in Abono and Asisiriwa while Dompa recorded slight offshore elevations.

Spatial heterogeneity in nitrogen levels possibly could have limited the access to nitrogen by phytoplankton at some stations or sites. Vera *et al*. (2006) reported a poor relationship between total phosphorus and chlorophyll abundance in a collation of tropical, subtropical and temperate data, perhaps emphasizing the importance of nitrogen as a limiting nutrient in chlorophyll-a abundance.

The depth integrated gross primary production (GPP) dropped from February to April and rose in June where levels dropped in October and then rose in December for both the inshore and offshore zones at the Abono sampling site. These dynamics followed the trend of chlorophyll-a although it was not a strict adherence. Generally, the study revealed that GPP in the offshore was higher than the inshore zone and did not follow a specific trend with fluctuations of Chl-a across all three study sites. These inconsistent trends between Chl-a and GPP corroborates the findings of (Yayla *et al.*, 2001). The initial elevation in GPP recorded in February could probably be due to the initial February elevation in nutrients (TN) availability due to the peculiar conditions of the catchment at that time which also resulted in elevated Chl-a from the early scanty rains. These rain induced increases in primary production rates have been observed in other lakes (Lemoalle, 1975; Mellack, 1979b; Thomas *et al.*, 2000; Wondie *et al.*, 2007). During the main rains however, mixed GPP rates with no major peaks were recorded across all three study sites. This observation is not a deviation from other tropical lakes where in the main rainy season primary production has been found to be probably limited by reduced duration and intensity of sunlight (Wondie *et al.*, 2007). Levels of GPP rates recorded in this study at some periods exceeded 11 $mgCm^{-2}d^{-1}$($30mg\ O_2m^{-2}d^{-1}$). Such levels according to Melack and Kilham (1974) are evidence of human induced primary production. High levels of GPP rates in lakes with human induced enrichment have been reported in some African lakes such as Aranguadi (Talling *et al.*, 1973), Hartbeespoort (Allanson *et al.*, 1990); reservoirs such as Sri Lanka (Silva and Gavies, 1987 and Costa and de Silva, 1995).

Elevations in GPP were observed in October (although there were no general increase in nutrients) with the exception of Abono after the main rains and this is in agreement with Grobbelaar (1992) who concluded that an increased availability of nutrients is primarily responsible for the high primary production in the pre-dry season (post rainy season) cannot be wholly admissible but rather the ratio of euphotic to mixing depth was the most important factor affecting overall productivity and that nutrients are of secondary importance.

In this study the incubation of DO bottles was conducted within the surface waters (1 m-3 m). Therefore substantial part of depth production profile might have been missed which can lead to an underestimation of primary production and finding relationships of GPP with other factors could be impaired. Therefore, relationships with other parameters could be clearer if a substantial depth production profile within the column was captured which would then have allowed a comprehensive cause-effect assessment between Chloropyll-a and GPP rates and perhaps other contributory nutrients (Grobbelaar, 1985) clearly shows the problem of such measurements.

From (**Table 4.14**), the highest production levels in the lake during the study period was at Asisiriwa in the offshore in October where a photosynthetic efficiency of 154.54 mg C (mg Chl-a)$^{-1}$h^{-1} was recorded. Generally the most unproductive part of Lake Bosomtwe was the waters of Abono while the overall most productive part was the waters of Asisiriwa village.

5.3 INHABITANTS' CONSERVATIONAL ATTITUDE

From the data gathered, all livestock farmers interviewed practised their trade within one to twenty five meters from the lake shore although some were even closer (as close as two meters as observed at Dompa) while crop farmers practised from zero to thirty meters (Fig.3.1). The established mode of land preparation was slash and burn for both crop and livestock farmers covered in the survey. This mode of farm land preparation has been identified as very destructive to forests and detrimental if it occurs within the forested catchments of an aquatic system and the closeness to that aquatic body hastens the destructive process. The topography of the catchment area of Lake Bosomtwe is one of steep rising slopes (as a result of the nature of formation) which give an added advantage of siltation in the case of reduced forest cover thus placing the lake in a rather disadvantaged position. The threat on the survival of Lake Bosomtwe is quite real in view of the volume of farming activity and the established mode of land preparation for both crop and livestock farming.

Hillman (1988) reported that the clearing of forests, animal grazing and other reductions in the vegetation of the catchment areas of Ethiopian lakes which have expanded considerably during recent years have resulted in increased silt and nutrient load of water bodies concerned. Sheffer (1998) has reported that nutrient loading is probably a major reason why the stability properties of lakes have changed and inversely if no major disturbances occur, the system will stay in its current state responding only weakly to enrichment events. It was however identified in that same work that nitrogen loading was more important than phosphorus in destabilizing lakes although less work is available in that regard (This study recorded evidences of nitrogen loading).

From the study, an overwhelming number of respondents of the livestock farmers have not evolved an ingenious way to dump their waste but rather dump it where it is most convenient to them. Almost all of respondents dump beside the sty which is certain to eventually wash into the water body. Upon inspection, some were found to dig the ground and dump which raises issues of percolation through aquifers depending on proximity to the lake. Ironically respondents who dumped their waste in this fashion were very sure that it was the safest way to dump their waste since it did not have any direct contact with the water. Some livestock respondents allowed their livestock to roam and wander into the lake. This practice, apart from raising water quality issues may also affect the aesthetic value of the lake as some tourists who visit the lake do so to appreciate nature.

Data gathered from respondents exposed a very weak educational background and a negligible percentage had no dependant(s) (see appendix on survey results). The inference is that in order to survive together with their dependant(s), a farmer may engage in unbridled exploitation of the catchment area in the face of weak by-laws and haphazard enforcement. Beyond this, since it has been established that respondents have low educational background, they genuinely may be oblivious of the implications of their activities within the catchments.

From the data, only a small percentage of crop farmers used chemicals (fertilizer) in their farming activities and therefore there is the likelihood to ignore the add up potential of fertilizer within the catchment to the nutrient load of the lake water. However the volume of farming activity and the established mode of land preparation (from data) within the watershed boundary of the lake is likely to trigger mass fertilizer usage in the case of crop failure. Eventually, if it happens that population of farmers within the catchment increases (since for now no form of prohibition is being exercised), the major source of chemical inputs into the water body will then come in two folds.

Johnes (1999) reported the various activities within the catchment of aquatic systems showing exponential growth and corresponding nutrient loading cycles thereby requiring monitoring and much adaptation as the evidence of catchment induced water quality issues arise. From this established observation, the basis for more stringent adherence to management processes and sustainable use of lake resources becomes more apparent in threatened aquatic systems.

The incorporation of level of education in the questionnaire was to access the depth of education of the inhabitants and to use it to measure formal conservational knowledge which is incorporated in the national educational curriculum and through it the level of appreciation of the conservational processes could be gauged. However, from the data, only a few respondents from Dompa admit their farming activities may negatively affect the lake and even went on to explain the expected negativity and possible impact, while majority of respondents claimed they had never received any form of awareness on the effect of such activities on lake water body. Such lack of education is likely to cause a feeling of deprivation of livelihood by the indigenes if suddenly they are prevented from exploiting the lake's catchment for a living.

In a personal communication with key informants of the villages (Assemblyman, Unit committee leaders, Chiefs and Sub chiefs) it came to light that there are bye-laws that bar bathing, washing, washing of cars, using mosquito netting to fish for fingerlings at the littoral zones etc but these laws are blatantly flouted in broad daylight.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.0 Research Overview and General Comments

This research enabled assessment of seasonal variations in nutrient levels, primary production, Chlorophyll-a levels as well as physico-chemical parameters representing contrasting climatic conditions (dry season, rainy season, pre-dry season) from February to December (2008) in both pelagic and inshore waters of Lake Bosomtwe (impact crater) and an assessment of the conservational attitude and fair use of the lake's catchment by inhabitants. The nutrient cycles of Lake Bosomtwe follows most tropical lakes with similar activities within its catchment. Pronounced variation in N throughout the seasonal cycle revealed classic N loading and total phosphorus showing incremental tendencies during the early rains and continuous heavy rains in the wet season washing into the lake debris from the exposed catchment. The nutrients cycling in Lake Bosomtwe did not follow a similar seasonal pattern as some nutrients fairly maintained their levels throughout the different seasons captured. Chlorophyll-a abundance followed a seasonal trend and it appeared the most influential nutrient on the abundance of chlorophyll-a was nitrogen. The physico-chemical parameters of Lake Bosomtwe such as temperature and transparency were also influenced by seasonality and other factors such as atmospheric temperature and catchment activity dynamics. Integral gross primary production followed the trend of most African tropical lakes with a few deviations that could be peculiar to Lake Bosomtwe. Farmers who exploit the lake's catchment for their farming activities were generally not aware of how detrimental it can be on the water body and consequences thereafter for future use.

6.1 MAJOR FINDINGS AND CONCLUSIONS

6.1.1 Seasonal dynamics of physical parameters

1. The water surface temperature fluctuations pattern of Lake Bosomtwe followed atmospheric temperature patterns and the lowest surface temperature throughout the season was in August (wet season).

2. Transparency of Lake Bosomtwe was heavily dependent on the catchment dynamics such that the amount of activity that proceeds in the catchment for a particular season or year greatly influenced the lake's transparency. In view of this phenomenon, the inshore zones became comparatively more turbid than the offshore zones since the sediment loading events occurred within the inshore.

3. Strong positive and negative as well as weak positive and negative correlations between transparency and chlorophyll-a existed in the surface waters of Lake Bosomtwe during the study.

4. Transparency of Lake Bosomtwe in this study (February and April, 2008) was lower in the dry season particularly in the inshore of the two inhabited stations due to the catchment activities.

5. Dilution events of the lake resulted in higher transparencies during the main rainy season.

6.1.2 Seasonal dynamics of chemical parameters

1. pH of Lake Bosomtwe was at its lowest during the main dry season.

2. Organic carbon dynamics influenced pH and the influence was pronounced in the inshore zones of the lake.

3. pH dynamics of the surface waters of Lake Bosomtwe did not show strict homogeneity as pH levels differed at different stations.

4. pH level of Lake Bosomtwe fluctuated within as well as above the accepted pH level for natural waters in Ghana.

5. Conductivity regime of Lake Bosomtwe was highest during and immediately after the peak rains and followed a strict seasonal trend.

6. Conductivity levels of Lake Bosomtwe throughout the study period fell within the accepted levels for natural water systems in Ghana.

7. The correlations of major nutrients (N, P and OC) and conductivity of the lake were either strong, weak or negative during the study period.

6.1.3 Seasonal nutrient dynamics

6.1.3.1 Nitrogen

1. The volume of activity within the watershed of Lake Bosomtwe was found to be apparently contributing to the Nitrogen loading. The measured levels compared to other measured levels of productive Lakes showed a rather higher N levels in Lake Bosomtwe.

2. Nitrogen levels of Lake Bosomtwe was high in the main wet season (June and August) and February.

3. Nitrogen levels recorded were high at Dompa and Abono where comparatively greater volume of activity goes on within the catchment.

4. Nitrogen was perhaps the single most important nutrient that influenced the production of Chlorophyll-a, the trend of abundance of this pigment followed the trend of seasonal pattern of fluctuation of the nutrient nitrogen.

6. Nitrogen levels of Lake Bosomtwe followed a marked seasonal regime.

7. Nitrogen levels recorded during the study were above the accepted level for natural water systems in Ghana for almost all year round and at certain seasons fell within eutrophic status.

6.1.3.2 Phosphorus

1. Phosphorus levels in Lake Bosomtwe did not follow a specific regime or showed a marked fluctuation with seasonality but evidence of P-loading was visible.

3. Total phosphorus differed between zones showing that homogeneity in phosphorus throughout Lake Bosomtwe could be doubtful against the backdrop of the differences in the volume of catchment activities.

4. Total phosphorus levels recorded during this study fell within the accepted total phosphorus levels for natural water systems in Ghana almost throughout all the seasons.

6.1.3.3 Organic carbon

1. Organic carbon dynamics did not follow a classic seasonality in Lake Bosomtwe, however at the two inhabited study sites, OC level during the main rainy season was high.

3. Organic carbon showed a strong relationship with pH at the inshore zones.

6.1.4 PRIMARY PRODUCTIVITY

6.1.4.1 Chlorophyll-a

1. The trend of chlorophyll-a fluctuation of Lake Bosomtwe followed a marked seasonality.

2. Growth of chlorophyll-a algae was very high during the main rainy season and was at its lowest after the cessation of the rains.

3. Fluctuations in seasonal abundance of chlorophyll-a in Lake Bosomtwe followed the level of fluctuation of nitrogen showing the influence of such nutrients on growth of chlorophyll-a algae such that the slight or early rains that tended to wash in nutrients triggered the abundance of

chlorophyll-a.

4. Rain indirectly influenced the abundance of chlorophyll-a in Lake Bosomtwe as it aided the loading of nutrients that influenced the dynamics of chlorophyll-a.

5. The abundance of chlorophyll-a in Lake Bosomtwe was generally higher in the pelagic zones than the inshore zones.

6.1.4.2 Gross primary production

1. Primary production of Lake Bosomtwe did not follow particular spatial and Seasonal trend.

2. Primary production in the pelagic zone of Lake Bosomtwe was slightly higher than the inshore zone probably in response to the increase in the abundance of chlorophyll-a.

3. Primary production rate of Lake Bosomtwe depicted influences of catchment enrichment as GPP levels fluctuated within levels that showed such influences.

6.1.5 INHABITANTS CONSERVATIONAL ATITTUDE

1. Lake Bosomtwe is currently facing some impacts of catchment activities.

2. Land preparation towards any form of farming activity whether crop cultivation or livestock production is by the slash and burn method.

3. The proximity of exploitatory activities including both crop and livestock farming of the catchment areas by inhabitants is dangerously close to the water body such that products from the exploitation can easily be dislodged into the lake.

4. Local inhabitants who exploit the catchment areas of Lake Bosomtwe have educational backgrounds not strong enough and may be oblivious of the impact of their activities on the water body.

5. Information on awareness creation by way of communal discussions on sustainable use of the catchment area of lake Bosomtwe is less available therefore adherence to already weak bye-laws is close to non-existence which has resulted in practices that is likely to impact negatively on the water body.

6.2 RECOMMENDATIONS AND FUTURE STUDIES

It has well been established that nutrient load into water bodies is well linked with activities within watershed boundaries and the extent of the activity can cumulatively determine the nutrient levels within the spatio-temporal realms. Nutrients within a water body is the basis for the survival or otherwise of that water body as it drives the food web and also ensures trophic level transfer efficiencies. In the nutrient dynamics of Lake Bosomtwe, this study has revealed the potential of nutrient level elevation in the months of February, June and August. It has been established that overturn events in Lake Bosomtwe occur in the months of January and August and whilst August is a period of heavy rains it is likely to correlate with nutrient elevation, however February is known for slight or no rains therefore elevated nutrient levels could be a spilled over effect of turn over phenomenon from the month of January, again some lakes experience a rise in nutrients during turbulent periods and nutrient loss during calm periods due to settling events. These arguments are however hypothetical therefore extensive spatio-temporal studies of lake column nutrient dynamics can form the basis of another study as it could possibly reveal the true nutrient budget of Lake Bosomtwe.

Further studies on nutrient availability and its effect on total algal and zooplankton biomass and on general secondary production could reveal shortfalls in trophic transfers and allow the assessment of the overall production of the lake.

Since the ultimate goal of this research is to ensure maintenance of water quality and generally sustainability of the fish resources as the most immediate concern of the indigenes whose livelihoods depend on the continuous survival of the lake, a holistic fishery assessment of Lake Bosomtwe which embraces all aspects of fishery research will reveal which aspect(s) of the fishery pose as a gap resulting in low fishery yield.

A compensation package for the local inhabitants whose livelihoods depend on their activities within the catchment areas of the lake should be worked out for them as a matter of urgency and barred from using the catchment of the lake as a source of livelihood by the district authorities in conjunction with the government of Ghana as this will curtail further illegal exploitation of the catchment as the population of the inhabitants increases. Existing bye-laws should be reinforced and strict penalties instituted to deter would be offenders.

The constitution of task force members who ensure the compliance of existing bye-laws should not be solely indigenes as enforcement could be compromised based on familiarity. Regular awareness on the importance of the water body to the communities around it should be instituted and this can be in the form of regular visits by information vans and the involvement of key community leaders.

6.3 CHALLENGES AND LIMITATIONS OF STUDY

1) Consistency in spot sampling could not be achieved because no transect was constructed.

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APPPENDIX 1

BASIC DESCRIPTIVE STATISTICS OF CHEMICAL AND PHYSICO-CHEMICAL PARAMETERS OF LAKE BOSOMTWE. (FEB-DEC 2008)

ABONO

Month	Zone	Parameter	Mean	StDev	Min	Max	Range
February	Inshore	Temp.	28.250	0.500	28.000	29.000	1.000
February	Offshore	Temp.	29.000	0.000	29.000	29.000	0.000
April	Inshore	Temp.	30.500	0.577	30.000	31.000	1.000
April	Offshore	Temp.	30.000	0.000	30.000	30.000	0.000
June	Inshore	Temp.	29.500	0.577	29.000	30.000	1.000
June	Offshore	Temp.	28.750	0.500	28.000	29.000	1.000
August	Inshore	Temp.	28.750	0.500	28.000	29.000	1.000
August	Offshore	Temp.	27.250	0.500	27.000	28.000	1.000
October	Inshore	Temp.	30.750	0.500	30.000	31.000	1.000
October	Offshore	Temp.	30.750	0.500	30.000	31.000	1.000
December	Inshore	Temp.	30.250	0.500	30.000	31.000	1.000
December	Offshore	Temp.	30.750	0.500	30.000	31.000	1.000
February	Inshore	pH	8.8875	0.0126	8.8700	8.9000	0.030
February	Offshore	pH	8.9000	0.0141	8.8900	8.9200	0.0300
April	Inshore	pH	8.7875	0.0050	8.7800	8.7900	0.0100
April	Offshore	pH	8.7725	0.0050	8.7700	8.7800	0.0100
June	Inshore	pH	9.2975	0.00957	9.2900	9.3100	0.0200
June	Offsore	pH	9.3125	0.00957	9.3000	9.3200	0.0200
August	Inshore	pH	9.0450	0.0173	9.0300	9.0600	0.0300
August	Offshore	pH	9.0150	0.0173	9.0000	9.0300	0.0300
October	Inshore	pH	9.2800	0.0490	9.2400	9.3400	0.1000
October	Offshore	pH	9.3300	0.1039	9.2000	9.4400	0.2400

December	Inshore	pH	9.1675	0.0359	9.1200	9.2000	0.0800
December	Offshore	pH	9.1700	0.0271	9.1500	9.2100	0.0600
February	Inshore	Conductivity	1107.5	2.38	1104.0	1109.0	5.00
February	Offshore	Conductivity	1109.8	2.22	1108.0	1113.0	5.00
April	Inshore	Conductivity	1064.5	1.00	1063.0	1065.0	2.00
April	Offshore	Conductivity	1062.5	0.577	1062.0	1063.0	1.00
June	Inshore	Conductivity	1219.0	2.31	1217.0	1221.0	4.00
June	Offshore	Conductivity	1223.0	2.31	1221.0	1225.0	4.00
August	Inshore	Conductivity	1189.0	5.77	1184.0	1194.0	10.0
August	Offshore	Conductivity	1201.5	5.00	1194.0	1204.0	10.0
October	Inshore	Conductivity	1263.8	4.35	1260.0	1268.0	8.00
October	Offshore	Conductivity	1268.5	5.07	1261.0	1272.0	11.0
December	Inshore	Conductivity	1195.8	19.2	1168.0	1210.0	42.0
December	Offshore	Conductivity	1210.5	1.91	1209.0	1213.0	4.00
February	Inshore	E. Zone	1.9500	0.0577	1.9000	2.0000	0.1000
February	Offshore	E. Zone	1.9500	0.0577	1.9000	2.0000	0.1000
April	Inshore	E. Zone	4.1250	0.0500	4.1000	4.2000	0.1000
April	Offshore	E. Zone	4.1750	0.0500	4.1000	4.2000	0.1000
June	Inshore	E. Zone	4.488	0.275	4.350	4.900	0.550
June	Offshore	E. Zone	4.075	0.318	3.800	4.350	0.550
August	Inshore	E. Zone	3.7375	0.1601	3.6000	3.9000	0.3000
August	Offshore	E. Zone	3.9875	0.1315	3.8500	4.1000	0.2500
October	Inshore	E. Zone	3.7250	0.0957	3.6000	3.8000	0.2000
October	Offshore	E. Zone	3.925	0.386	3.700	4.500	0.800
December	Inshore	E. Zone	2.950	0.265	2.700	3.300	0.600
December	Offshore	E. Zone	4.075	0.377	3.700	4.400	0.700
February	Inshore	Secchi D.	0.63000	0.01155	0.62000	0.64000	0.020

February	Offshore	Secchi D.	0.63250	0.00957	0.62000	0.64000	0.020
April	Inshore	Secchi D.	1.3775	0.00957	1.3700	1.3900	0.0200
April	Offshore	Secchi D.	1.3925	0.00957	1.3800	1.4000	0.0200
June	Inshore	Secchi D.	1.5500	0.1155	1.4500	1.6500	0.2000
June	Offshore	Secchi D.	1.3500	0.1155	1.2500	1.4500	0.2000
August	Inshore	Secchi D.	1.2425	0.0492	1.2000	1.2900	0.0900
August	Offshore	Secchi D.	1.3275	0.0492	1.2800	1.3700	0.0900
October	Inshore	Secchi D.	1.2575	0.0287	1.2200	1.2800	0.0600
October	Offshore	Secchi D.	1.3175	0.1159	1.2500	1.4900	0.2400
December	Inshore	Secchi D.	0.9875	0.0776	0.9100	1.0900	0.1800
December	Offshore	Secchi D.	1.3475	0.1305	1.2200	1.4600	0.240
February	Inshore	T.P	0.05250	0.00500	0.05000	0.06000	0.01000
February	Offshore	T.P	0.05500	0.00577	0.05000	0.06000	0.01000
April	Inshore	T.P	0.2400	0.0346	0.2100	0.2700	0.0600
April	Offshore	T.P	0.1800	0.0346	0.1500	0.2100	0.0600
June	Inshore	T.P	0.05750	0.00500	0.05000	0.06000	0.01000
June	Offshore	T.P	0.38750	0.00500	0.38000	0.39000	0.01000
Aug.	Inshore	T.P	0.06250	0.00500	0.06000	0.07000	0.01000
Aug.	Offshore	T.P	0.06750	0.00500	0.06000	0.07000	0.01000
Oct.	Inshore	T.P	0.1300	0.0455	0.0800	0.1900	0.1100
Oct.	Offshore	T.P	0.1025	0.0377	0.0500	0.1300	0.0800
Dec.	Inshore	T.P	0.3150	0.1323	0.1300	0.4200	0.2900
Dec.	Offshore	T.P	0.3300	0.1689	0.1700	0.5500	0.3800
Feb.	Inshore	T.N	6.9750	0.0500	6.9000	7.0000	0.1000
Feb.	Offshore	T.N	6.9500	0.0577	6.9000	7.0000	0.1000
April	Inshore	T.N	1.0150	0.00577	1.0100	1.0200	0.0100
April	Offshore	T.N	1.0125	0.00500	1.0100	1.0200	0.0100

June	Inshore	T.N	18.235	0.0404	18.200	18.270	0.0700
June	Offshore	T.N	1.9750	0.0500	1.9000	2.0000	0.1000
Aug.	Inshore	T.N	1.4575	0.00500	1.4500	1.4600	0.0100
Aug.	Offshore	T.N	75.370	0.0141	75.350	75.380	0.0300
Oct.	Inshore	T.N	2.750	0.904	1.900	3.800	1.900
Oct.	Offshore	T.N	3.255	1.353	2.080	5.200	3.120
Dec.	Inshore	T.N	2.253	0.785	1.79	3.420	1.630
Dec.	Offshore	T.N	1.848	0.369	1.460	2.350	0.890
Feb.	Inshore	Chl-a	10.768	0.508	10.510	11.530	1.020
Feb.	Offshore	Chl-a	10.258	0.512	9.490	10.520	1.030
April	Inshore	Chl-a	9.293	0.482	8.870	9.710	0.840
April	Offshore	Chl-a	8.468	0.471	8.040	8.880	0.840
June	Inshore	Chl-a	8.770	0.577	8.270	9.270	1.000
June	Offshore	Chl-a	9.760	0.566	9.270	10.250	0.980
Aug.	Inshore	Chl-a	14.125	0.0957	14.000	14.200	0.200
Aug.	Offshore	Chl-a	7.0250	0.00577	7.0200	7.0300	0.0100
Oct.	Inshore	Chl-a	4.690	1.926	3.010	7.460	4.450
Oct.	Offshore	Chl-a	2.835	1.060	2.010	4.390	2.380
Dec.	Inshore	Chl-a	9.620	1.911	7.400	11.840	4.440
Dec.	Offshore	Chl-a	7.51	2.00	5.92	10.36	4.44
Feb.	Inshore	OC	2.385	0.303	1.930	2.540	0.610
Feb.	Offshore	OC	2.688	0.303	2.530	3.143	0.613
April	Inshore	OC	1.9285	0.0826	1.8570	2.0000	0.1430
April	Offshore	OC	2.0715	0.0826	2.0000	2.1430	0.1430
June	Inshore	OC	1.3840	0.1960	1.2860	1.6780	0.3920
June	Offshore	OC	1.9728	0.1965	1.6780	2.0710	0.3930
Aug.	Inshore	OC	3.446	0.515	3.000	3.893	0.893

Aug.	Offshore	OC	4.339	0.516	3.890	4.786	0.896
Oct.	Inshore	OC	1.185	0.576	0.650	2.001	1.351
Oct.	Offshore	OC	1.540	0.492	1.034	2.001	0.967
Dec.	Inshore	OC	1.576	0.526	0.811	2.012	1.201
Dec.	Offshore	OC	1.178	0.945	0.0127	2.300	2.287
Feb.	Inshore	DO	0.330	0.173	0.130	0.430	0.300
Feb.	Offshore	DO	0.377	0.293	0.130	0.700	0.570
April	Inshore	DO	0.267	0.180	0.130	0.470	0.340
April	Offshore	DO	0.2767	0.0404	0.2300	0.3000	0.0700
June	Inshore	DO	0.2940	0.1070	0.2160	0.4160	0.2000
June	Offshore	DO	0.466	0.296	0.133	0.700	0.567
Aug.	Inshore	DO	0.2773	0.0768	0.2330	0.3660	0.1330
Aug.	Offshore	DO	0.377	0.269	0.133	0.666	0.533
Oct.	Inshore	DO	0.1220	0.1018	0.0330	0.2330	0.2000
Oct.	Offshore	DO	0.1220	0.1018	0.0330	0.2330	0.2000
Dec.	Inshore	DO	0.1553	0.0693	0.1000	0.2330	0.1330
Dec.	Offshore	DO	0.2660	0.0580	0.2320	0.3330	0.1010

ASISIRIWA

Month	Zone	Parameter	Mean	StDev	Min	Max	Range
Feb.	Inshore	Temp.	28.750	0.500	28.000	29.000	1.000
Feb.	Offshore	Temp.	29.000	0.000	29.000	29.000	0.000
April	Inshore	Temp.	29.750	0.500	29.000	30.000	1.000
April	Offshore	Temp.	29.500	0.577	29.000	30.000	1.000
June	Inshore	Temp.	29.250	0.500	29.000	30.000	1.000
June	Offshore	Temp.	30.000	0.000	30.000	30.000	0.000
Aug.	Inshore	Temp.	28.250	0.500	28.000	29.000	1.000
Aug.	Offshore	Temp.	28.500	0.577	28.000	29.000	1.000

Oct.	Inshore	Temp.	29.750	0.957	29.000	31.000	2.000
Oct.	Offshore	Temp.	29.750	0.500	29.000	30.000	1.000
Dec.	Inshore	Temp.	30.750	0.500	30.000	31.000	1.000
Dec.	Offshore	Temp.	30.500	0.577	30.000	31.000	1.000
Feb.	Inshore	Secchi D	1.0600	0.0462	1.0200	1.1000	0.0800
Feb.	Offshore	Secchi D	1.0200	0.0924	0.9400	1.1000	0.1600
April.	Inshore	Secchi D	1.2275	0.00957	1.2200	1.2400	0.0200
April	Offshore	Secchi D	1.2425	0.00957	1.2300	1.2500	0.0200
June	Inshore	Secchi D	1.2450	0.0100	1.2300	1.2500	0.0200
June	Offshore	Secchi D	1.2425	0.00957	1.2300	1.2500	0.0200
Aug.	Inshore	Secchi D	1.2575	0.00957	1.2500	1.2700	0.0200
Aug.	Offshore	Secchi D.	1.2725	0.00957	1.2600	1.2800	0.0200
Oct.	Inshore	Secchi D.	1.4550	0.1526	1.2500	1.5900	0.3400
Oct.	Offshore	Secchi D.	1.2800	0.0346	1.2500	1.3100	0.0600
Dec.	Inshore	Secchi D.	1.4300	0.1122	1.3100	1.5800	0.2700
Dec.	Offshore	Secchi D.	1.4925	0.1744	1.2500	1.6500	0.4000
Feb.	Inshore	E. Zone	3.1750	0.1443	3.0500	3.3000	0.2500
Feb.	Offshore	E. Zone	2.9250	0.1443	2.8000	3.0500	0.2500
April	Inshore	E. Zone	3.7500	0.0577	3.7000	3.8000	0.1000
April	Offshore	E. Zone	3.7750	0.0500	3.7000	3.8000	0.1000
June	Inshore	E. Zone	3.6500	0.0577	3.6000	3.7000	0.1000
June	Offshore	E. Zone	3.6500	0.0577	3.6000	3.7000	0.1000
Aug.	Inshore	E. Zone	3.7675	0.0126	3.7500	3.7800	0.0300
Aug.	Offshore	E. Zone	3.7950	0.0100	3.7800	3.8000	0.0200
Oct.	Inshore	E. Zone	4.400	0.455	3.800	4.800	1.000
Oct.	Offshore	E. Zone	3.8000	0.1155	3.7000	3.9000	0.2000
Dec.	Inshore	E. Zone	4.275	0.330	3.900	4.700	0.800

Dec.	Offshore	E. Zone	4.450	0.526	3.700	4.900	1.200
Feb.	Inshore	Cond.	1063.8	20.5	1046.0	1082.0	36.0
Feb.	Offshore	Cond.	1090.3	34.0	1046.0	1117.0	71.0
April	Inshore	Cond.	1056.0	1.15	1055.0	1057.0	2.00
April	Offshore	Cond.	1054.0	1.15	1053.0	1055.0	2.00
June	Inshore	Cond.	1221.3	6.18	1212.0	1225.0	13.0
June	Offshore	Cond.	1230.8	7.23	1224.0	1237.0	13.0
Aug.	Inshore	Cond.	1220.3	4.35	1216.0	1224.0	8.00
Aug.	Offshore	Cond.	1212.8	4.35	1209.0	1217.0	8.00
Oct.	Inshore	Cond.	1249.0	6.38	1244.0	1258.0	14.0
Oct.	Offshore	Cond.	1263.3	30.7	1224.0	1297.0	73.0
Dec.	Inshore	Cond.	1216.3	2.06	1214.0	1218.0	4.00
Dec.	Offshore	Cond.	1212.3	5.32	1208.0	1220.0	12.0
Feb.	Inshore	pH	8.8575	0.0206	8.8400	8.8800	0.0400
Feb.	Offshore	pH	8.8875	0.0222	8.8700	8.9200	0.0500
April	Inshore	pH	8.8000	0.0115	8.7900	8.8100	0.0200
April	Offshore	pH	8.8200	0.0115	8.8100	8.8300	0.0200
June	Inshore	pH	9.2700	0.0469	9.2000	9.3000	0.1000
June	Offshore	pH	9.2850	0.00577	9.2800	9.2900	0.0100
Aug.	Inshore	pH	9.0700	0.0115	9.0600	9.0800	0.0200
Aug.	Offshore	pH	9.0950	0.0100	9.0800	9.1000	0.0200
Oct.	Inshore	pH	9.2975	0.0624	9.2300	9.3800	0.1500
Oct.	Offshore	pH	9.2275	0.0189	9.2000	9.2400	0.0400
Dec.	Inshore	pH	9.1425	0.0964	9.0000	9.2100	0.2100
Dec.	Offshore	pH	9.1950	0.0129	9.1800	9.2100	0.0300
Feb.	Inshore	TP	0.06500	0.01732	0.05000	0.08000	0.03000
Feb.	Offshore	TP	0.04250	0.01500	0.03000	0.06000	0.03000

April	Inshore	TP	0.1200	0.0231	0.1000	0.1400	0.0400
April	Offshore	TP	0.2000	0.1155	0.1000	0.3000	0.2000
June	Inshore	TP	0.1755	0.1024	0.0220	0.2300	0.2080
June	Offshore	TP	0.07500	0.00577	0.07000	0.08000	0.01000
Aug.	Inshore	TP	0.06500	0.01000	0.05000	0.07000	0.02000
Aug.	Offshore	TP	0.07500	0.01000	0.07000	0.09000	0.02000
Oct.	Inshore	TP	0.1325	0.0435	0.0700	0.1700	0.1000
Oct.	Offshore	TP	0.10250	0.01708	0.08000	0.12000	0.04000
Dec.	Inshore	TP	0.2300	0.1283	0.0500	0.3400	0.2900
Dec.	Offshore	TP	0.2250	0.1012	0.1100	0.3500	0.2400
Feb.	Inshore	T.N	6.8250	0.1340	6.7200	7.0000	0.2800
Feb.	Offshore	T.N	6.9300	0.0808	6.8600	7.0000	0.1400
April	Inshore	T.N	1.1775	0.00957	1.1700	1.1900	0.0200
April	Offshore	T.N	1.1925	0.00957	1.1800	1.2000	0.0200
June	Inshore	T.N	1.7675	0.1646	1.6200	1.9100	0.2900
June	Offshore	T.N	1.4825	0.1646	1.3400	1.6300	0.2900
Aug	Inshore	T.N	1.0375	0.0320	1.0100	1.0700	0.0600
Aug.	Offshore	T.N	1.0925	0.0320	1.0600	1.1200	0.0600
Oct.	Inshore	T.N	2.455	0.707	1.720	3.200	1.480
Oct.	Offshore	T.N	1.643	0.869	0.940	2.800	1.860
Dec.	Inshore	T.N	2.71	2.52	1.34	6.49	5.15
Dec.	Offshore	T.N	3.875	0.987	0.890	3.140	2.250
Feb.	Inshore	Chl-a	3.313	0.297	3.050	3.570	0.520
Feb.	Offshore	Chl-a	2.798	0.297	2.540	3.060	0.520
April	Inshore	Chl-a	7.545	0.675	6.960	8.130	1.170
April	Offshore	Chl-a	8.715	0.675	8.130	9.300	1.170
June	Inshore	Chl-a	7.4100	0.1155	7.3100	7.5100	0.2000

June	Offshore	Chl-a	7.1600	0.1000	7.1100	7.3100	0.2000
Aug.	Inshore	Chl-a	9.8250	0.00577	9.8200	9.8300	0.0100
Aug	Offshore	Chl-a	9.8200	0.0115	9.8100	9.8300	0.0200
Oct.	Inshore	Chl-a	5.950	0.670	5.070	6.700	1.630
Oct.	Offshore	Chl-a	1.650	0.292	1.340	1.980	0.640
Dec.	Inshore	Chl-a	4.81	2.53	1.48	7.40	5.92
Dec.	Offshore	Chl-a	8.14	4.60	4.44	14.80	0.36
Feb.	Inshore	OC	2.486	0.270	2.250	2.720	0.470
Feb.	Offshore	OC	2.019	0.269	1.786	2.253	0.467
April	Inshore	OC	1.8748	0.0205	1.8570	1.8930	0.0360
April	Offshore	OC	1.9103	0.0205	1.8920	1.9280	0.0360
June	Inshore	OC	0.9468	0.0355	0.9290	1.0000	0.0710
June	Offshore	OC	2.1570	0.0658	2.1000	2.2140	0.1140
Aug.	Inshore	OC	0.8395	0.0618	0.7860	0.8930	0.1070
Aug.	Offshore	OC	0.9733	0.0535	0.8930	1.0000	0.1070
Oct.	Inshore	OC	1.423	0.985	0.0210	2.127	2.106
Oct.	Offshore	OC	1.550	1.063	0.459	2.810	2.351
Dec.	Inshore	OC	0.667	0.563	0.112	1.452	1.340
Dec.	Offshore	OC	0.992	0.733	0.195	2.471	2.276
Feb.	Inshore	DO	0.1073	0.1339	0.0300	0.2620	0.2320
Feb	Offshore	DO	0.4243	0.0872	0.3300	0.5020	0.1720
April	Inshore	DO	0.4417	0.1141	0.3400	0.5650	0.2250
April	Offshore	DO	0.5950	0.0260	0.5650	0.6100	0.0450
June	Inshore	DO	0.6237	0.0412	0.5910	0.6700	0.0790
June	Offshore	DO	0.5340	0.0960	0.4310	0.6210	0.1900
Aug.	Inshore	DO	0.1540	0.0805	0.0610	0.2010	0.1400
Aug.	Offshore	DO	0.5483	0.1000	0.4330	0.6110	0.1780

Month	Zone	Parameter	Mean	StDev	Min	Max	Range
Oct.	Inshore	DO	0.5500	0.1435	0.4300	0.7090	0.2790
Oct	Offshore	DO	0.6350	0.0754	0.5480	0.6800	0.1320
Dec.	Inshore	DO	0.4200	0.0840	0.3230	0.4690	0.1460
Dec.	Offshore	DO	0.4710	0.1425	0.3300	0.6150	0.2850

DOMPA

Month	Zone	Parameter	Mean	StDev	Min	Max	Range
Feb.	Inshore	Temp.	29.000	0.000	29.000	29.000	0.000
Feb.	Offshore	Temp.	29.000	0.000	29.000	29.000	0.000
April	Inshore	Temp.	30.000	0.000	30.000	30.000	0.000
April	Offshore	Temp.	29.500	0.577	29.000	30.000	1.000
June	Inshore	Temp.	29.000	0.000	29.000	29.000	0.000
June	Offshore	Temp.	29.000	0.000	29.000	29.000	0.000
Aug	Inshore	Temp.	28.750	0.500	28.000	29.000	1.000
Aug.	Offshore	Temp.	28.000	0.000	28.000	28.000	0.000
Oct.	Inshore	Temp.	29.750	0.500	29.000	30.000	1.000
Oct.	Offshore	Temp.	30.000	0.000	30.000	30.000	0.000
Dec.	Inshore	Temp.	30.250	0.500	30.000	31.000	1.000
Dec.	Offshore	Temp.	30.500	0.577	30.000	31.000	1.000
Feb.	Inshore	Secchi D	0.9900	0.0231	0.9700	1.0100	0.0400
Feb.	Offshore	Secchi D	1.0250	0.0173	1.0100	1.0400	0.0300
April	Inshore	Secchi D	1.3100	0.0346	1.2800	1.3400	0.0600
April	Offshore	Secchi D	1.3700	0.0346	1.3400	1.4000	0.0600
June	Inshore	Secchi D	1.0150	0.0866	0.9400	1.0900	0.1500
June	Offshore	Secchi D	1.1750	0.0866	1.1000	1.2500	0.1500
Aug.	Inshore	Secchi D	1.3375	0.00500	1.3300	1.3400	0.0100
Aug.	Offshore	Secchi D	1.3375	0.00500	1.3300	1.3400	0.0100
Oct.	Inshore	Secchi D	1.2425	0.0287	1.2200	1.2800	0.0600

Oct.	Offshore	Secchi D	1.2350	0.0173	1.2200	1.2500	0.0300
Dec.	Inshore	Secchi D	1.1625	0.1502	1.0000	1.3000	0.3000
Dec.	Offshore	Secchi D	1.310	0.244	0.950	1.490	0.540
Feb.	Inshore	E.Zone	2.9500	0.0577	2.9000	3.0000	0.1000
Feb.	Offshore	E.Zone	3.0500	0.0577	3.0000	3.1000	0.1000
April	Inshore	E.Zone	3.7750	0.0500	3.7000	3.8000	0.1000
April	Offshore	E.Zone	4.0500	0.1000	4.0000	4.2000	0.2000
June	Inshore	E.Zone	2.6950	0.1723	2.5000	2.8400	0.3400
June	Offshore	E.Zone	3.600	0.400	3.000	3.800	0.800
Aug.	Inshore	E.Zone	3.9750	0.0500	3.9000	4.0000	0.100
Aug.	Offshore	E.Zone	3.9750	0.0500	3.9000	4.0000	0.100
Oct.	Inshore	E.Zone	3.6750	0.0957	3.6000	3.8000	0.200
Oct.	Offshore	E.Zone	3.6500	0.0577	3.6000	3.7000	0.100
Dec.	Inshore	E.Zone	3.475	0.443	3.000	3.900	0.900
Dec.	Offshore	E.Zone	3.925	0.763	2.800	4.500	1.700
Feb.	Inshore	Cond.	1120.8	0.957	1120.0	1122.0	2.00
Feb.	Offshore	Cond.	1121.8	0.957	1121.0	1123.0	2.00
April	Inshore	Cond.	1051.0	4.62	1047.0	1055.0	8.00
April	Offshore	Cond.	1047.8	0.500	1047.0	1048.0	1.00
June	Inshore	Cond.	1230.5	0.577	1230.0	1231.0	1.00
June	Offshore	Cond.	1229.3	0.500	1229.0	1230.0	1.00
Aug.	Inshore	Cond.	1191.5	0.577	1191.0	1192.0	1.00
Aug.	Offshore	Cond.	1216.5	0.577	1216.0	1217.0	1.00
Oct.	Inshore	Cond.	1266.3	10.3	1255.0	1275.0	20.0
Oct.	Offshore	Cond.	1263.5	15.9	1240.0	1274.0	34.0
Dec.	Inshore	Cond.	1207.8	3.10	1205.0	1212.0	7.00
Dec.	Offshore	Cond.	1212.3	8.66	1201.0	1220.0	19.0

Feb.	Inshore	pH	8.9125	0.00500	8.9100	8.9200	0.0100
Feb.	Offshore	pH	8.9175	0.00500	8.9100	8.9200	0.0100
April	Inshore	pH	8.7850	0.00577	8.7800	8.7900	0.0100
April	Offshore	pH	8.7875	0.00500	8.7800	8.7900	0.0100
June	Inshore	pH	9.3050	0.00577	9.3000	9.3100	0.0100
June	Offshore	pH	9.3050	0.00577	9.3000	9.3100	0.0100
Aug.	Inshore	pH	9.1450	0.00577	9.1400	9.1500	0.0100
Aug.	Offshore	pH	8.8275	0.00500	8.8200	8.8300	0.0100
Oct.	Inshore	pH	9.2650	0.1702	9.0100	9.3600	0.3500
Oct.	Offshore	pH	9.243	0.439	8.780	9.800	1.020
Dec.	Inshore	pH	9.1925	0.0411	9.1400	9.2400	0.1000
Dec.	Offshore	pH	9.1750	0.0129	9.1600	9.1900	0.0300
Feb.	Inshore	T.P	0.0275	0.005	0.020	0.030	0.010
Feb.	Offshore	T.P	0.02500	0.00577	0.020	0.030	0.010
April	Inshore	T.P	0.05250	0.0050	0.050	0.060	0.010
April	Offshore	T.P	0.05250	0.0050	0.050	0.060	0.010
June	Inshore	T.P	0.06750	0.00957	0.060	0.080	0.020
June	Offshore	T.P	0.08250	0.00957	0.070	0.090	0.020
Aug.	Inshore	T.P	0.07750	0.0050	0.070	0.080	0.010
Aug.	Offshore	T.P	0.07750	0.0050	0.070	0.080	0.010
Oct.	Inshore	T.P	0.1000	0.0356	0.070	0.1400	0.0700
Oct.	Offshore	T.P	0.1425	0.0386	0.090	0.1800	0.0900
Dec.	Inshore	T.P	0.3325	0.1127	0.2300	0.4900	0.2600
Dec.	Offshore	T.P	0.480	0.308	0.220	0.910	1.880
Feb.	Inshore	T.N	6.9650	0.0700	6.8600	7.0000	0.1400
Feb.	Offshore	T.N	6.750	0.500	6.000	7.000	1.000
April	Inshore	T.N	1.0600	0.1134	1.0000	1.2300	0.2300

April	Offshore	T.N	0.8925	0.1300	0.7800	1.0100	0.2300
June	Inshore	T.N	1.7900	0.1270	1.6800	1.9000	0.2200
June	Offshore	T.N	1.5700	0.1270	1.4600	1.6800	0.2200
Aug.	Inshore	T.N	17.970	0.843	17.240	18.700	1.460
Aug.	Offshore	T.N	16.510	0.843	15.780	17.240	1.460
Oct.	Inshore	T.N	3.215	0.665	2.430	3.820	1.390
Oct.	Offshore	T.N	6.425	1.626	4.900	8.200	3.300
Dec.	Inshore	T.N	1.343	0.439	0.890	1.900	1.010
Dec.	Offshore	T.N	1.760	1.208	1.12	3.570	2.450
Feb.	Inshore	Chl-a	7.673	1.400	6.460	8.890	2.430
Feb.	Offshore	Chl-a	10.105	1.403	8.890	11.320	2.430
April	Inshore	Chl-a	8.245	0.733	7.610	8.880	1.270
April	Offshore	Chl-a	9.833	0.635	8.880	10.150	1.270
June	Inshore	Chl-a	9.3775	0.1819	9.2200	9.5400	0.3200
June	Offshore	Chl-a	9.6925	0.1819	9.5300	9.8500	0.3200
Aug	Inshore	Chl-a	16.100	0.0816	16.000	16.200	0.200
Aug.	Offshore	Chl-a	11.325	0.0957	11.200	11.400	0.200
Oct.	Inshore	Chl-a	1.793	0.263	1.480	2.010	0.530
Oct.	Offshore	Chl-a	4.04	2.85	1.48	8.03	6.55
Dec.	Inshore	Chl-a	7.03	3.05	2.96	10.36	7.40
Dec.	Offshore	Chl-a	7.19	4.38	1.48	11.84	10.36
Feb.	Inshore	OC	2.1788	0.1238	2.0710	2.2860	0.2150
Feb.	Offshore	OC	1.9653	0.1250	1.8570	2.0750	0.2180
April	Inshore	OC	1.5898	0.0217	1.5710	1.6100	0.0390
April	Offshore	OC	1.6250	0.0208	1.6070	1.6430	0.0360
June	inshore	OC	2.536	0.214	2.429	2.857	0.428
June	offshore	OC	3.178	0.214	2.857	3.285	0.428

Aug.	inshore	OC	1.517	0.229	1.318	1.715	0.397
Aug .	offshore	OC	1.120	0.229	0.922	1.319	0.397
Oct.	inshore	OC	1.349	0.409	0.783	1.674	0.891
Oct.	offshore	OC	1.884	0.651	1.098	2.675	1.577
Dec.	inshore	OC	2.177	1.130	0.632	3.100	2.468
Dec.	offshore	OC	0.852	0.312	0.401	1.092	0.691
Feb.	inshore	DO	0.2837	0.0586	0.2160	0.3180	0.1020
Feb.	offshore	DO	0.3860	0.0589	0.3180	0.4200	0.1020
April	inshore	DO	0.3810	0.0667	0.3040	0.4200	0.1160
April	offshore	DO	0.3760	0.0745	0.2900	0.4200	0.1300
June	inshore	DO	0.2787	0.0396	0.2330	0.3020	0.0690
June	offshore	DO	0.3243	0.0396	0.3010	0.3700	0.0690
Aug.	inshore	DO	0.3053	0.0240	0.2910	0.3330	0.0420
Aug.	offshore	DO	0.2780	0.0234	0.2510	0.2920	0.0410
Oct.	inshore	DO	0.4707	0.1036	0.3510	0.5310	0.1800
Oct.	offshore	DO	0.5910	0.1039	0.5310	0.7110	0.1800
Dec.	inshore	DO	0.5077	0.0725	0.4240	0.5500	0.1260
Dec.	offshore	DO	0.5913	0.0725	0.5490	0.6750	0.1260

APPPENDIX 2

SURVEY QUESTIONAIRE

CROP FARMERS WITHIN CATCHMENT OF LAKE BOSOMTWE

ENUMERATORS NAME…………………………………………………………………………………………….DATE……………………..

SECTION 1: **PERSONAL RECORD**

NAME…….

AGE……………………………………………..

SEX…………………………….

EDUCATIONAL BACKGROUND: TICK/WRITE

MIDDLE SCH.	J.H.S.	S.H.S	OTHER

FAMILY BACKGROUND

MARITAL STATUS…………………………………………………………………………………………

DEPENDANTS:

CHILDREN……………………

WIFE……………………………

HUSBAND……………………..

NATIVE OR MIGRANT…………………………………..

NUMBER OF YRS. IN VILLAGE………………………..

FARMING DETAILS

WHAT TYPE OF CROP DO YOU CULTIVATE……………………………………………………………………………….

WHAT IS THE SIZE OF YOUR FARM……………………………………………………………………………………………….

WOULD YOU SAY YOU ARE A COMMERCIAL OR SUBSISTENCE FARMER…………………………………………………….

ARE YOU FULL OR PART TIME FARMER……………………………………………………………………………………………

HOW MANY PEOPLE HAVE YOU EMPLOYED TO WORK ON YOUR FARM…………………………………………………

HOW MUCH DO YOU PAY THEM………………………………………………………………………………………………

HOW DO YOU PREPARE THE LAND-(1) BY TRACTORS……………………………….

(2) WEED AND BURN……………………………

DOES YOUR LAND PREPARATION AFFECT THE LAKE……………………………………………

IF YES HOW DOES IT AFFECT IT…………………………………………………………………

WHEN DO YOU PLANT………

WHEN DO YOU HARVEST……..

DOES GOV'T HELP YOU IN YOUR FARM………………………………………………………………………

IF YES IN WHAT FORM………

WHAT TYPE OF FERTILIZER DO YOU USE………………………………………………………………………………………..

HOW MANY TIMES DO YOU APPLY FERTILIZER…………………………………………………………………..

WHAT IS THE DISTANCE FROM THE LAKE TO YOUR FARM…………………………………………………………

DOES THE LAKE WATER HELP YOU IN YOUR WORK………………………………………………………………………….

IF YES IN WHAT WAY………

DO YOU GET ANY ADVICE ON HOW TO USE THE WATER IN FARMING………………………………………………….

IF YES WHO GIVES IT………

DO YOU ATTEND ANY MEETING ON HOW YOU CAN USE THE LAKE WATER FOR FARMING……………………..

IF YES WHO ORGANISES IT……………………………………………………………………………………………………

DOES THE LAKE HAVE AN EFFECT ON YOUR WORK………………………………………………………………………

CAN YOUR FARMING ACTIVITIES AFFECT THE LAKE……………………………………………………………………..

IF YES IN WHAT WAY……….

LIVESTOCK FARMERS WITHIN CATCHMENT OF LAKE BOSOMTWE

ENUMERATORS NAME…………………………………………………………………………………….DATE……………………..

SECTION 1: **<u>PERSONAL RECORD</u>**

NAME……………………………………………………………………………………………….

AGE………………………………………………..

SEX…………………………….

EDUCATIONAL BACKGROUND: TICK/WRITE

MIDDLE SCH.	J.H.S.	S.H.S	OTHER

FAMILY BACKGROUND

MARITAL STATUS………………………………………………………………………………………

DEPENDANTS:

CHILDREN……………………

WIFE……………………………

HUSBAND……………………..

NATIVE OR MIGRANT…………………………………..

NUMBER OF YRS. IN VILLAGE………………………..

FARMING DETAILS

WHAT TYPE OF LIVESTOCK DO YOU REAR…………………………………………………………………………………….

HOW MANY ANIMALS DO YOU KEEP………..………………………………………………………………………………………

WOULD YOU SAY YOU ARE A COMMERCIAL OR SUBSISTENCE FARMER…………………………………………………….

ARE YOU FULL OR PART TIME FARMER……………………………………………………………………………………………………

HOW MANY PEOPLE HAVE YOU EMPLOYED TO WORK ON YOUR FARM……………………………………………………

HOW MUCH DO YOU PAY THEM……

HOW DO YOU PREPARE THE LAND-(1) BY TRACTORS……………………………….

(2) WEED AND BURN……………………………

DOES YOUR LAND PREPARATION AFFECT THE LAKE……………………………………………

IF YES HOW DOES IT AFFECT IT……………………………………………………………………………………………………

HOW LONG DOES IT TAKE FOR YOUR ANIMALS TO MATURE……………………………………………………………

DOES GOV'T HELP YOU IN YOUR FARM………………………………………………………………………

IF YES IN WHAT FORM………

WHAT TYPE OF FEED DO GIVE YOUR ANIMALS………………………………………………………………………………………..

DOES THE ANIMALS DRINK DIRECT FROM THE LAKE……………………………………………………………………………….

DO THE ANIMALS GET THE CHANCE TO GO TO THE LAKE………………………………………………………………………..

WHAT IS THE DISTANCE FROM THE LAKE TO YOUR FARM………………………………………………………………………..

DOES THE LAKE WATER HELP YOU IN YOUR WORK……………………………………………………………………………….

IF YES IN WHAT WAY……

DO YOU GET ANY ADVICE ON HOW TO USE THE WATER IN FARMING…………………………………………………….

IF YES WHO GIVES IT……

DO YOU ATTEND ANY MEETING ON HOW YOU CAN USE THE LAKE WATER FOR FARMING……………………..

IF YES WHO ORGANISES IT………

DOES THE LAKE HAVE AN EFFECT ON YOUR WORK……………………………………………………………………………………

CAN YOUR FARMING ACTIVITIES AFFECT THE LAKE……………………………………………………………………………….

IF YES IN WHAT WAY…….

DO YOU WASH YOUR CAGE………

WHAT IS THE FREQUENCY OF THE WASHING (DAILY, WEEKLY, ETC)………………………………………………………….

WHERE DO YOU FETCH WATER FOR THE WASHING……………………………………………………………………………………

DO YOU USE THE WASTE WATER FOR ANY PURPOSE……………………………………………………………………………………

IF YES WHAT IS THE PURPOSE……….

HOW DO YOU DISPOSE OFF IT IF NO…….

HAVE YOU CREATED ANY CHANNEL FROM YOUR CAGE TO THE LAKE……………………………………………………….

IF YES WHAT IS THE BENEFIT………..

APPPENDIX 3

RESPONSES OF REPONDENTS

LIVESTOCK FARMERS-ABONO

Frequency Table

Gender of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	male	7	77.8	77.8	77.8
	female	2	22.2	22.2	100.0
	Total	9	100.0	100.0	

Age of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	24-34	5	55.6	55.6	55.6
	35-44	2	22.2	22.2	77.8
	45-54	1	11.1	11.1	88.9
	55-64	1	11.1	11.1	100.0
	Total	9	100.0	100.0	

Dependents on respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	9	100.0	100.0	100.0

Is respondent native or migrant

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Mi	1	11.1	11.1	11.1
	Na	8	88.9	88.9	100.0
	Total	9	100.0	100.0	

No of years respondent has spent in village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10-19	2	22.2	22.2	22.2
	20-29	5	55.6	55.6	77.8
	40-49	2	22.2	22.2	100.0

No of years respondent has spent in village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10-19	2	22.2	22.2	22.2
	20-29	5	55.6	55.6	77.8
	40-49	2	22.2	22.2	100.0
	Total	9	100.0	100.0	

Occupation of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Pig	9	100.0	100.0	100.0

If farmer then subsistence or commercial

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Commercial farmer	1	11.1	11.1	11.1
	subsistence	8	88.9	88.9	100.0
	Total	9	100.0	100.0	

Do you have employees working for you

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	9	100.0	100.0	100.0

How do you prepare you farm land

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Slash and burn	9	100.0	100.0	100.0

Do you receive any help from the government

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	9	100.0	100.0	100.0

APPPENDIX 4

RESPONSES OF REPONDENTS
CROP FARMERS-ABONO

Frequency Table

age of respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	15-24	1	7.7	7.7	7.7
	25-34	2	15.4	15.4	23.1
	35-44	2	15.4	15.4	38.5
	45-54	3	23.1	23.1	61.5
	55-64	3	23.1	23.1	84.6
	65-74	2	15.4	15.4	100.0
	Total	13	100.0	100.0	

gender of respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	male	5	38.5	38.5	38.5
	female	8	61.5	61.5	100.0
	Total	13	100.0	100.0	

does respondents have dependants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	13	100.0	100.0	100.0

is respondents a native

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Mi	3	23.1	23.1	23.1
	Na	10	76.9	76.9	100.0
	Total	13	100.0	100.0	

years respondents has spent in village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1-9	2	15.4	15.4	15.4
	20-29	3	23.1	23.1	38.5
	40-49	2	15.4	15.4	53.8
	50-59	5	38.5	38.5	92.3
	60-69	1	7.7	7.7	100.0

years respondents has spent in village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1-9	2	15.4	15.4	15.4
	20-29	3	23.1	23.1	38.5
	40-49	2	15.4	15.4	53.8
	50-59	5	38.5	38.5	92.3
	60-69	1	7.7	7.7	100.0
	Total	13	100.0	100.0	

type of crop grown by respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	local crop	8	61.5	61.5	61.5
	both	5	38.5	38.5	100.0
	Total	13	100.0	100.0	

is respondents commercial or subsistent farmer

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	commercial	7	53.8	53.8	53.8
	subsistence	6	46.2	46.2	100.0
	Total	13	100.0	100.0	

does respondents have employees on farm

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	6	46.2	46.2	46.2
	yes	7	53.8	53.8	100.0
	Total	13	100.0	100.0	

mode of land preparation by respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	slash and burn	13	100.0	100.0	100.0

do you get help from government

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	12	92.3	92.3	92.3
	yes	1	7.7	7.7	100.0
	Total	13	100.0	100.0	

how often do you use fertilizer

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	10	76.9	76.9	76.9
	once	1	7.7	7.7	84.6
	none	2	15.4	15.4	100.0
	Total	13	100.0	100.0	

APPPENDIX 5

RESPONSES OF REPONDENTS

LIVESTOCK FARMERS-DOMPA

Frequency Table

Age of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	15-24 years	3	33.3	33.3	33.3
	25-34 years	1	11.1	11.1	44.4
	35-44 years	4	44.4	44.4	88.9
	45-54 years	1	11.1	11.1	100.0
	Total	9	100.0	100.0	

Gender of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	male	9	100.0	100.0	100.0

Dependents on respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	3	33.3	33.3	33.3
	yes	6	66.7	66.7	100.0
	Total	9	100.0	100.0	

Is respondent native or migrant

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	native	9	100.0	100.0	100.0

No of years respondent has spent in village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10-19	1	11.1	11.1	11.1
	20-29	3	33.3	33.3	44.4
	30-39	4	44.4	44.4	88.9
	50-59	1	11.1	11.1	100.0
	Total	9	100.0	100.0	

Occupation of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	pig	8	88.9	88.9	88.9
	2	1	11.1	11.1	100.0
	Total	9	100.0	100.0	

If farmer then subsistence or commercial

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	commercial	3	33.3	33.3	33.3
	subsistence	6	66.7	66.7	100.0
	Total	9	100.0	100.0	

Do you have employees working for you

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	9	100.0	100.0	100.0

How do you prepare you farm land

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	9	100.0	100.0	100.0

Do you receive any help from the government

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	9	100.0	100.0	100.0

APPPENDIX 6

RESPONSES OF REPONDENTS
CROP FARMERS-DOMPA

Frequency Table

age of respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	15-24	1	6.7	6.7	6.7
	25-34	6	40.0	40.0	46.7
	35-44	4	26.7	26.7	73.3
	45-54	3	20.0	20.0	93.3
	55-64	1	6.7	6.7	100.0
	Total	15	100.0	100.0	

gender of respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	male	15	100.0	100.0	100.0

does respondents have dependants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	15	100.0	100.0	100.0

is respondents a native

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Na	15	100.0	100.0	100.0

years respondents has spent in village

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-29	4	26.7	26.7	26.7
	30-39	6	40.0	40.0	66.7
	40-49	1	6.7	6.7	73.3
	50-69	3	20.0	20.0	93.3
	7	1	6.7	6.7	100.0
	Total	15	100.0	100.0	

type of crop grown by respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	cash	1	6.7	6.7	6.7
	local	10	66.7	66.7	73.3
	both	4	26.7	26.7	100.0
	Total	15	100.0	100.0	

is respondent commercial or subsistent farmer

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	commercial	14	93.3	93.3	93.3
	subsistence	1	6.7	6.7	100.0
	Total	15	100.0	100.0	

does respondents have employees on farm

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	6	40.0	40.0	40.0
	yes	9	60.0	60.0	100.0
	Total	15	100.0	100.0	

mode of land preparation by respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	slash and burn	15	100.0	100.0	100.0

do you get help from government

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	15	100.0	100.0	100.0