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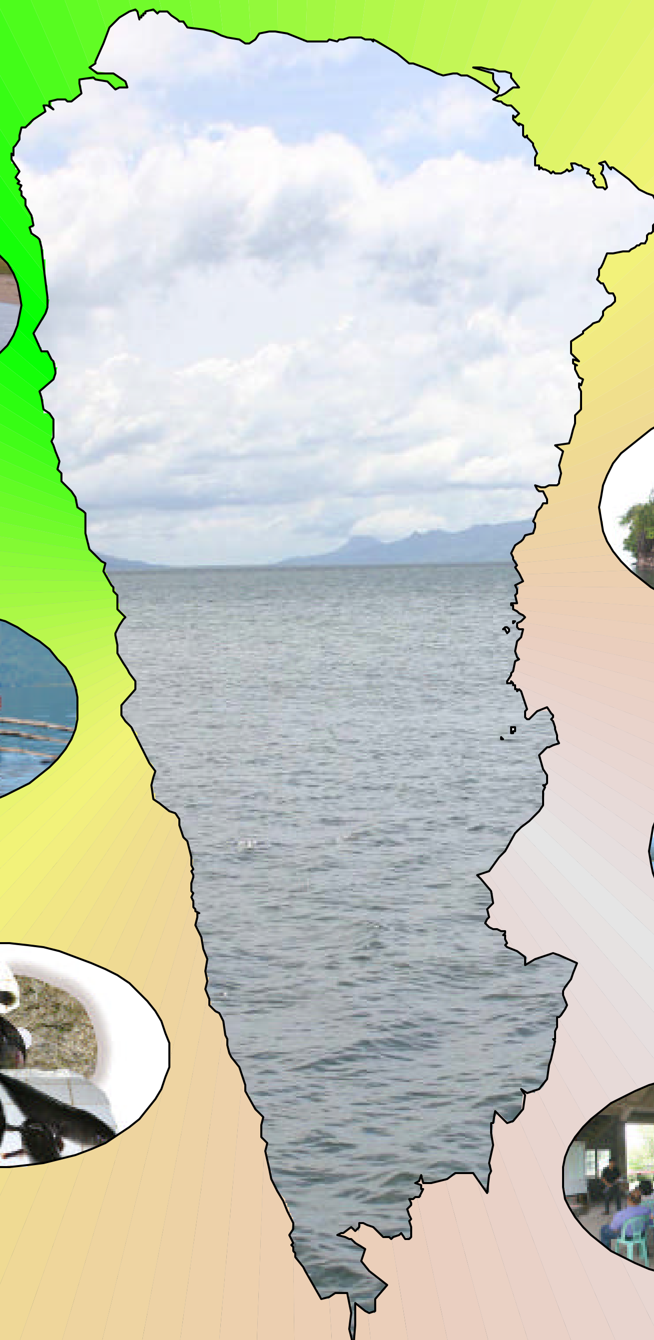

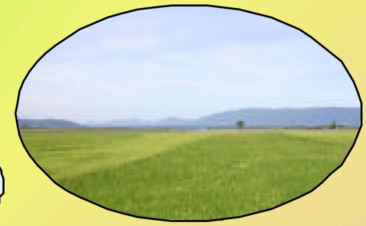

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Abstract

The physical, chemical, and biological characteristics of Lake Mainit were assessed as a step to understand the nature of the lake as an environment. The lake characteristics that were investigated included morphology, bathymetry, visibility, vertical temperature-dissolved oxygen profile, bacterial load profile and the vertical variations of nutrients in the lake basin including those coming from river tributaries. Results from echo soundings and other processed data indicated that Lake Mainit has a surface area of 149.865 km^2 and a water volume of 18.3556 km^3. Maximum depth was estimated at 219.35 m with mean depth of about 122.48 m. Crytodepression of Lake Mainit was estimated at 198 m. Coastline length was estimated at 50 km. Results from vertical and surface temperature measurements indicate that Lake Mainit ranged between 26.60 – 30.60 ^oC. The temperature-depth profile defined the density stratification layers of Lake Mainit. The thermocline layer was observed between 10 – 35 m. Variations in vertical temperature have been observed at 0 m down to a depth of 30 m. Beyond this depth variations are minimal ranging between 0.03°C - 0.15°C. Water visibility of Lake Mainit expressed as Secchi depth ranged between 3.4 – 6.4 m with low visibility waters observed near rice fields and tributaries and highly transparent waters at the southern end of the lake. The dissolved oxygen concentration at the epilimnion ranges between 7.31 – 7.67 $mgOL^{-1}$. Below the thermocline it rapidly decreases to <2 $mgOL^{-1}$ from 50 m down to the 200-m depth. The oxycline has been observed between 10 m - 40 m. The vertical nutrient profile shows a uniform NH_3-N concentration from 0 m - 60 m which significantly increases at 80 m to 200 m. A decreasing trend in the NO_3-N profile has been observed between 0 m to 30 m which then increases at 60 m to 200 m. Phosphate concentrations are relatively low at 0 m - 40 m. Nutrient measurements from 11 river tributaries show high concentration levels with sources coming from predominantly agricultural lands and residential areas. Bacteriological analyses of water samples coming from 12 sampling stations show high total and fecal coliform (350 to 1600 MPN/100mL) in the three populated areas around the lake. Heavy metals and pesticidal residues were also detected in the lake but of no alarming concentrations. Plankton including chlorophyll *a* analyses are also presented.

The study indicates that Lake Mainit is an oligotrophic lake based on its physico-chemical, natural productivity and optical properties and morphometric characteristics.

Keywords: Lake Mainit, bathymetry, nutrient profile, bacterial load, thermocline, oxycline, Caraga Region

I. Introduction

Lake Mainit, the fourth largest lake in the Philippines, is geographically located between the Provinces of Surigao del Norte and Agusan del Norte, in the Island of Mindanao ($9^0$20.32”-$9^0$31.98” N Latitude and $125^0$28.50” E Longitude). It is also the deepest with a maximum depth of about 223 m and a mean depth of about 128 m. It is one of the most productive lakes in the country ranking only third to Laguna de Bay (Balayut, 1983).

The lake is the haven of several commercial species of fish that are a source of livelihood of fishermen around the lakeshore. There are about 12 species of fish identified in the lake (Lewis, 1973), seven of which are commercially exploited by fishermen (Gracia, 1981). Some of them are either migratory or were introduced by the Bureau of Fisheries and Aquatic Resources (BFAR) or by some private individuals to augment the fish stocks in the lake. The most dominant fish in the lake in terms of fish catch are the gobies (*pidianga*) which constitute about 63.3% of the total daily catch (Gracia, 1981). The rest of the catches are distributed among the other groups such as tilapia, mudfish, catfish, common carp, eel and some miscellaneous species. The most dominant species of phytoplankton are the blue green and green algae and some diatoms. The zooplankton species are dominated by copepods and rotifers.

The plan to develop a hydroelectric generating plant that would tap Lake Mainit for its water source would certainly have a far-reaching impact on the biology and ecology of some important aquatic plant and animal species thriving in the lake. In fisheries, for example, the construction of a dam that would regulate the flow of water for the operation of a hydroelectric plant may have drastic effects on the biology and life history cycles of migratory species. Experiences of other countries have shown that where they have lake fish species that migrate over long distances to breed in the sea or vice-versa, the construction of dams along their path of migration has usually wrought havoc to their fish stocks. Moreover, the construction of a dam that would allow an excessive fluctuation of the water level in the lake would also have drastic impacts on the ecology of some lakeshore habitats and may end up seriously damaging important lake fisheries.

The need to obtain some baseline limnological information on Lake Mainit therefore becomes an imperative in the light of the recent developments in the area. Such assessment may be used to recommend remedial measures to preclude adverse ecological disturbances that may happen in the event that the plan to operate a hydroelectric power plant would push through. Moreover, the existence of the Lake Mainit Development Alliance (LMDA), a consortium of local government units (LGUs), non-government organizations (NGOs) and concerned educational institutions whose goals and objectives are for the sustainable development of the lake, may have useful need for this type of baseline information for policy formulation. The study therefore aims to generate baseline information on the bathymetry and water quality of the lake prior to the possible operation of the hydroelectric plant. Monitoring is needed to assess water quality such as the nutrients, levels of coliform bacteria in the water and information on the siltation rates of sediments coming from river tributaries. Determination of primary productivity will be done to assess the natural carrying capacity of the lake. Hydrological parameters will be determined and correlated with other biological and chemical factors obtaining in the area.

II. Objectives

The physical, chemical and biological assessment of Lake Mainit has been aimed to accomplish the following:

1. To determine the bathymetric profile of Lake Mainit.
2. To determine the surface temperature and depth-temperature profile of the lake; and
3. To determine the Secchi disk visibility of the lake.
4. To determine the quality of water in the lake in terms of its nutrients (nitrates, ammonia and phosphates), dissolved oxygen, and pH and
5. To determine the total bacterial counts and the most probable numbers (MPNs) of fecal and non-fecal coliforms in selected areas of the lake;
6. To determine the pollution levels of the lake provided in terms of pesticidal residues and heavy metals;
7. To determine the sediment load of major river tributaries and sedimentation rates of Lake Mainit;
8. To determine the planktonic flora and fauna and the natural productivity of the lake; and
9. To recommend possible management measures aimed at maintaining the ecological sustainability of the lake as a natural resource.

III. Review of Literature

Lake Mainit is a tectonic type of lake of which the basin is formed by movements of the earths crust. The periodic horizontal land displacement along left-stepping left lateral faults produced the pull-apart basin of Lake Mainit that is characterized generally by elongated shape and deep bathymetric contour profile (Punongbayan, 2003). The formation of Lake Mainit was aided by the growth of Kapalaian Volcano that now defines its northern boundary (Punongbayan, 2003).

A limnological survey of Lake Mainit was conducted in 1971 by Lewis (1973) and published the first bathymetric map of Lake Mainit although Woltereck (1941) as cited by Lewis (1973) measured depth at one site and reported a depth of 167 m. Gracia (1981) and Balayut (1983) published limited data on physical properties of the lake. Compiled secondary data on the physical limnology and some revisions on watershed areas of Lake Mainit are reported by PMO-LMDA (2004) in its environmental management plan.

IV. Materials and Methods

Bathymetry

Most limnological phenomena, distribution of biota, and productivity are directly related to the morphological features of the lake basin. The absence of such information would hamper the gathering of other benchmark data aimed at understanding the dynamics of the lake as an aquatic ecosystem. Thus, there is the need to characterize the general topography of the lake basin and come with a profile of its depth and the characteristics of its bottom substrate.

Subsurface physical configuration of Lake Mainit was investigated using echo sounding and line sounding method. The lake was subdivided into horizontal and vertical grid lines whose coordinates were used as guides during the conduct of the echo and line sounding. The echo sounding method employed a Furuno (Model FE 4300) Echo Sounder mounted on a motorized boat. A compass mounted on the boat guided the steady traverse of the boat during echo sounding. All echo sounding activities were conducted when the state of lake surface water is at Beaufort wind scale of 0-1. Line sounding method was employed in areas that are very shallow and where echo-sounding method was rendered impractical. A modified clinometer attached to the sounding line was employed to correct vertical departures and errors. The geographical positions of all sampling stations and transects of echo sounding in the study were determined using a GPS (Global Positioning System). Echosounder paper prints and line sounding records were translated into depths and a bathymetric map was created from the interpreted data sets using a surface mapping software Surfer 7 (Golden Software Inc).

Measurement for surface area of lake was made using a digital polar planimeter Approximation for lake volume was obtained by calculating and summing the volumes of conical segments (frustra) with upper and lower surfaces delimited by the areas of sequential depth contours (Welch, 1948):

$$\text{Lake Volume} = \Sigma \ \text{Frustrum volumes}$$

Where :

$$\text{Frustrum volume} = h / 3 \, (a_1 + a_2 + \sqrt{a_1 a_2})$$

h = Depth of frustrum
a_1 = area of frustrum surface
a_2 = area of frustrum bottom

The shoreline development (SLD) is an index of the regularity of the shoreline. It is determined by the following equation (Lind, 1979):

$$SLD = S / 2\sqrt{a \pi}$$

Where

S = length of shoreline
A = area of Lake

Water Temperature

Horizontal and vertical temperature profile of the lake was investigated with the surface horizontal temperature being measured by a bucket thermometer. The vertical temperature profile was investigated using a reversing thermometer mounted on a Nansen reversing sampling bottle. Water samples collected from the Nansen bottle were also used for pH, dissolved oxygen and nutrient analyses in the water quality studies. Temperature data collected were interpreted and translated into a distribution map for temperature. Vertical profiles identifying layers of temperature were then constructed.

Visibility

Secchi disk visibility is a measure of the water clarity and it is related to the photic depth. Light transparency was investigated in the lake using a standard freshwater Secchi disk. The disappearance and reappearance of the disk as it was lowered and raised up were noted and recorded. Depth corrections were integrated using measurement from a clinometer attached to the line. Data collected were processed in Surfer 7 software and transparency profile of the lake is presented as a distribution map.

Physico-chemical parameters

Water samples were collected using a water sampler and were used for pH, dissolved oxygen (DO) and nutrient analyses. Data collected were interpreted and translated into thematic profile maps for dissolved oxygen. Vertical profiles identifying layers of these parameters were also generated from these data sets.

The collection and analyses of water samples for NO_3-N, NH_3-N, PO_4-P and dissolved oxygen followed the Standard Methods for the Examination of Water and Wastewater (APHA, 1995) while water temperature and pH were determined using a reversing thermometer and pH meter, respectively. The collected water samples were kept in styropore boxes with ice and were brought to MSU-Naawan Chemistry Laboratory for analyses.

Coliform bacteria

Twelve sampling stations were identified in Lake Mainit for the coliform study. The selection of the sampling sites was based on the following criteria: populated areas, beach resorts, fishing villages, drainage coming from poultry and other livestocks and away from populated areas. The middle of the lake which was far from the populated areas served as the control.

The collection of water samples for bacteriological analyses followed the Standard Methods for the Examination of Water and Wastewater (APHA, 1995). The collected water samples were kept in styropore boxes with ice cubes and brought to MSU-Naawan Pathology Laboratory for analyses.

Pesticides

The pollution levels of organochlorines and organophosphates from pesticide residues were determined through gas chromatography. Seven sampling stations were identified for the pesticide study. Included in these sampling stations were the bigger river tributaries of the lake, namely: Baleguian River, San Roque, Mamkas, Magtiaco, Magpayang, Mainit and Mayag River. Samples of bottom sediments from these established sampling stations were collected.

The procedures for the extraction of pesticide residues were those recommended in the Environmental Protection Agency (EPA) Manual for sediment and biological samples.

Heavy metals

Surface and bottom water samples were collected from ten river tributaries and four other stations of Lake Mainit. Composite sediment samples were also taken at the river sites where water samples were taken.

Initial stages of analysis of samples for the determination of the presence and the corresponding concentration levels of trace metals such as lead (Pb), cadmium (Cd) and mercury (Hg) were done following the Standard Methods for the Examination of Water and Wastewater of the American Public Health Association (1997) for water and by the official methods of analyzing waters and sediment samples (AOAC International, 1995).

Final determination was done using the atomic absorption spectrophotometer model SpectrAA-220 Varian Spectra for Pb and Cd and using the vapor generation accessory for Hg analysis.

Sedimentation

Sediment supply of major river tributaries was obtained from the determination of sediment load, cross-sectional area and the outflow rate of rivers. Data on river outflow rates were used to assess the total sediment flux contributed by these tributaries. Sedimentation rates were assessed using sedimentation traps deployed in the selected stations around the lake. A complementary activity on turbidity measurements was also done.

Plankton and Primary Productivity

Twenty sampling stations in the lake were established to assess the plankton population and primary productivity of Lake Mainit and plankton sampling was conducted from October to November, 2003. Phytoplankton samples from the littoral zone (shallow area) were collected from the water column by dipping a one-liter water sampler. A Van Dorn sampler was used to collect samples from the deeper water columns at the middle of the lake. Plankton samples were fixed with 5% buffered formalin and Lugol's solution. Identification and enumeration were done using a compound microscope.

The zooplankton samples were collected using a 20-micron mesh plankton net with a mouth opening measuring 0.5 meter in diameter. Vertical hauls were employed to collect samples from deeper water columns.

Primary productivity measurements were done in selected stations applying the chlorophyll *a* method following the Standard Methods for the Examination of Water and Wastewater (APHA, 1995).

V. Results and Discussion

Bathymetry

A total of 183 echosounding tracks were made and 777 coastline points were marked by GPS (Global Positioning System) and used in the construction of a surface map (Fig. 1) and bathymetric map of Lake Mainit. Data sets were then processed in a spreadsheet program and subsequently used in a surface mapping software Surfer V 7.0 (Golden Software Inc.).

The surface area of Lake Mainit was determined using polar planimetry. Surface calculations and cumulative distributions are presented in Table 1. The surface area of Lake Mainit was estimated at 149.86 km^2.

The coastline length of Lake Mainit (Fig. 1) based on GPS readings and interpreted using a surface mapping software was measured using cartometer method. The coastline was estimated at approximately 50 km, which was similar to the reported coastline of Lake Mainit by PMO-LMDA (2004). The coastline of Lake Mainit is irregular as an outcome of its tectonic origin and deltaic buildup of about 28 tributaries that drain water from about 608 km^2 of watershed area. The watershed of Lake Mainit was formerly 313 km^2 (Lewis, 1973) but because of the merger and change of path and divergence of Puyo River to Toliago Creek, the watershed of the lake has widened to its present state as a consequence of these two events. Deltaic build-ups were notable in Mayag River, Magpayang River, Tagbuyawan River, Baleguian River, Alimpatayan River and Puyo River.

Table 1. Distribution of surface area, relative and cumulative surface area at corresponding depths and cumulative depths of Lake Mainit, Philippines.

Depth	Cumulative Depth (%)	Surface Area (km^3)	Surface Area (%)	Cumulative Surface Area (%)
0	0.0	149.87	100.00	100
0.1-5	2.3	9.30	6.20	93.80
5.1-25	11.4	14.86	9.91	83.88
25.1-50	22.8	14.98	10.00	73.88
50.1-75	34.2	11.03	7.36	66.52
75.1-100	45.6	9.54	6.37	60.16
100.1-125	57.0	10.67	7.12	53.04
125.1-150	68.4	11.18	7.46	45.58
150.1-175	79.8	13.73	9.16	36.42
175.1-200	91.2	18.72	12.49	23.93
200.1-210	95.7	12.55	8.37	15.55
210.1-215	98.0	7.51	5.01	10.54
215.1-219.35	100.0	15.80	10.54	0.00

Elevation readings were made at the surface of the lake at different atmospheric pressures. Necessary corrections were made by observing elevation at sea level at different atmospheric pressures. The elevation measurements indicated that Lake Mainit surface elevation was 21.34 m above sea level. The lake surface is subjected to large fluctuations in elevation at different times of the year. The climate type prevailing in Lake Mainit and its watershed area is classified as Type II being characteristic of the southeastern coastal areas of the country that shows a clear trend toward heavy rainfall and low temperature from November through March and a combination of drier weather and higher mean temperature during other months, particularly June through September. During maximum rain period the lake level is raised by as much as 1 m however, during episodic storms the lake level is raised to as high as 2-3 m. During the course of the study, water marks of lake level surface as high as 2.2 m were observed imprinted in the rocks along the coast.

The bathymetric map output (Fig. 1) using the software Surfer 7 (Golden Software Inc.) shows that the lake coastline is irregular and elongated that is characteristic of pull-apart basins of tectonic origin (Punongbayan, 2003). A tectonic activity in Lake Mainit was observed in a report on July 1, 1879 by Fr. Luengo to the Governor General of the Philippines which stated in the account that hills and portions of the coast have slid down to the lake as a result of a very powerful earthquake that rocked Lake Mainit (http://www.philvocs.dost.gov.ph/Earthquakes/1999BayuganEQ/bayugan99.html).

The Lake Mainit boundaries are varied in topography. The western part of the lake is bounded by the Malimono Range which protects it from direct effect of the strong southwest monsoon winds. The Kapalaian Volcano and the floodplains of Mayag River and Magpayang River bound the northern part of the lake. Lowland and mountains of varying elevations bound the eastern part of the lake. The floodplains of Kalinawan River and the shallow Pagusi Lake which are located downriver, bound the southern part of the lake.

The lake basin is relatively deep with steep slopes along the west and partly along the east. However, the eastern part of the basin has a wide shelf region as a consequence of the presence of many tributaries as compared to the west where shelf region is rather wanting. Gentle slopes with moderate shelf region characterize the northern part of the lake basin. The southern part of the lake basin is relatively gentle but has shelf buildup mostly of gravel composition. The lake basin below sea level is termed as cryptodepression. In Lake Mainit, cryptodepression is below a depth of 21.35 m and the basin has a depth of about 198 m which would mean that most of the water lies below sea level.

A comparative bathymetric map published by Lewis (1973) and the map generated by the present study (Fig. 2) indicate changes in the bathymetric profile of the lake basin and coastline. The northwestern part of Lake Mainit basin along the vicinity of the Mayag River delta shows indications of coastline retreat and possible subsidence in some parts as reflected in presence of large tree stumps offshore at 2-m depths in the said area during the survey. The difference in the profile may be actual changes as a result of deposition, siltation and sediment transport in a period of over 30 years or more as Lewis (1973) used maps that were compiled in 1956 or maybe due to differences in mapping techniques or differences in sampling points in this study.

The GPS marked bathymetric data and GPS-marked coastline data were used to create a three-dimensional representation of Lake Mainit (Fig. 3) using surface mapping software Surfer V 7.0 (Golden Software Inc.).

Bathymetric measurements indicate that the deepest portion of the lake was 219.35 m consistent to the same location as observed by Lewis (1973) but differed only in depth approximation of 223 m. The mean depth of Lake Mainit is estimated at 122.48 m. The mean depth is a reliable morphometric indicator of trophic conditions of the lake with mean depth inversely related to production. Shallow lakes are more productive than deep lakes and Lake Mainit is considered a deep tropical lake.

The volume of Lake Mainit was estimated at 18.36 km^3. The distribution of volume by strata is presented in Table 2.

Table 2. Distribution of volume and cumulative volume at corresponding stratum in Lake Mainit.

Stratum	Surface Area (km^2)	Volume (km^3)	Cumulative Volume (km^3)	Cumulative Volume (%)
0	149.87			
0 - 5	140.57	0.73	0.73	3.97
5 - 25	125.71	2.66	3.39	18.05
25 - 50	110.73	2.95	6.34	34.20
50 - 75	99.70	2.63	8.97	48.57
75 - 100	90.16	2.37	11.34	61.54
100 - 125	79.49	2.12	13.46	73.13
125 - 150	68.31	1.85	15.31	83.22
150 - 175	54.57	1.53	16.84	91.60
175 - 200	35.86	1.12	17.96	97.74
200 - 210	23.31	0.29	18.26	99.34
210 - 215	15.80	0.08	18.33	99.88
215 - 219.35		0.02	18.36	100

The maximum length is the longest straight line that may be drawn without intersecting any mainland and the maximum width is the length of a line from shore to shore at right angles to the maximum length. In Lake Mainit the maximum effective length is 22.47 km passing from Jabonga (9.339^o N, 125.5239^{o}E) towards the western part of Mainit municipality (9.53859^{o}N, 125.491^{o}E) while the maximum effective width is 10.79 km in the northern part of the lake. The orientation of a lake is expressed as opposing points on a 16-point compass. The orientation is of great significance because it relates to the prevailing seasonal winds in the region (Lind, 1979) that result to wind generated waves and turbulent mixing. In Lake Mainit the orientation is SSE-NNW thus the eastern and western coasts of Lake Mainit are exposed to the wind-generated effects of the Southwest and Northeast monsoon winds. The Malimono Range protects Lake Mainit during the period of the Southwest monsoon winds thus the fetch distance to spawn wind generated waves is obscured. The coasts of Alegria and Magpayang are highly affected by wind-generated waves during the Southwest monsoons. The Northeast monsoon winds are unrestricted in Lake Mainit thus the Malimono coasts are subjected to the effects of wind-generated waves at varying fetch lengths that begin at the northeast coasts of the lake.

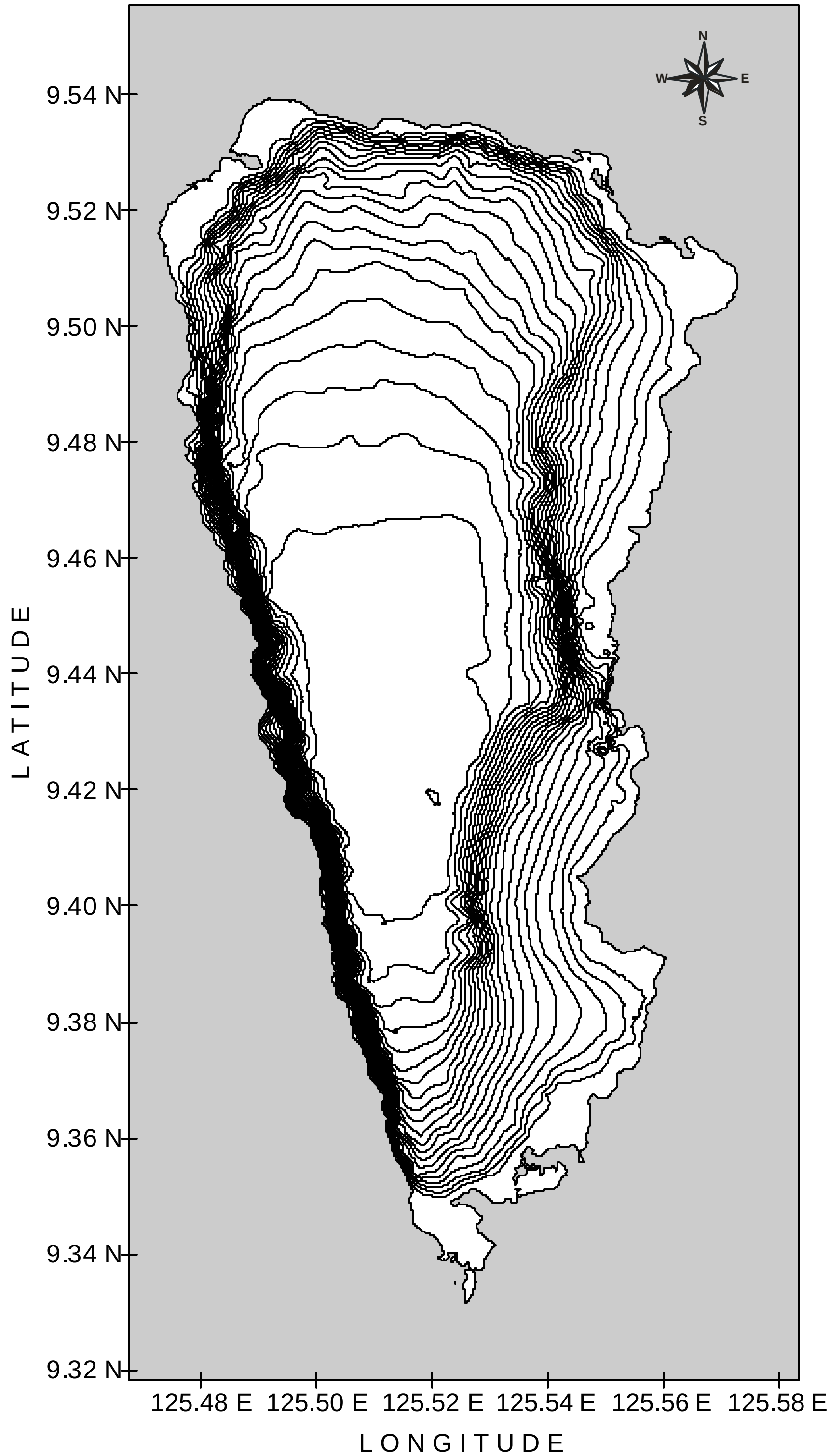

Figure 1. Bathymetric map of Lake Mainit showing 10-m isobath interval. The last isobath polygon found at the middle of the lake has a depth of 219 m.

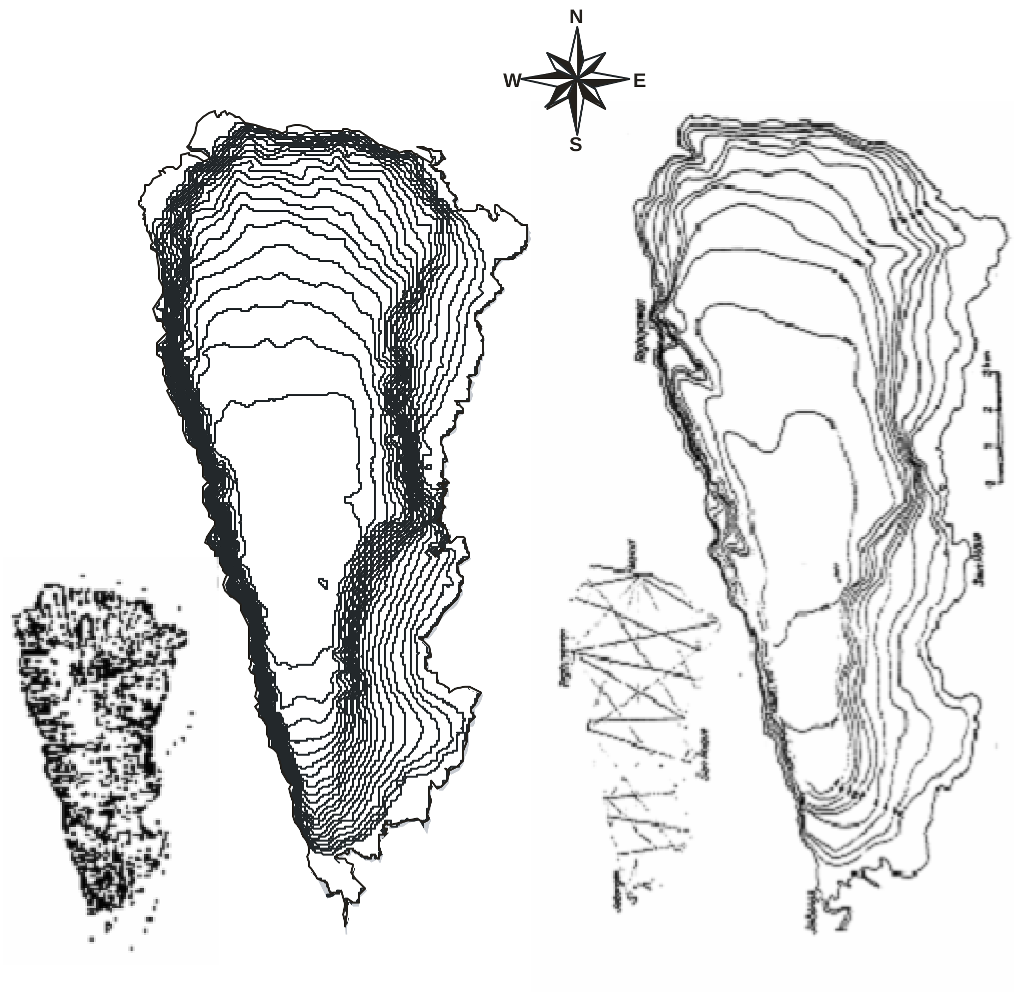

Figure 2. Bathymetric map of Lake Mainit in this study (left) and as presented by Lewis in 1973 (right).

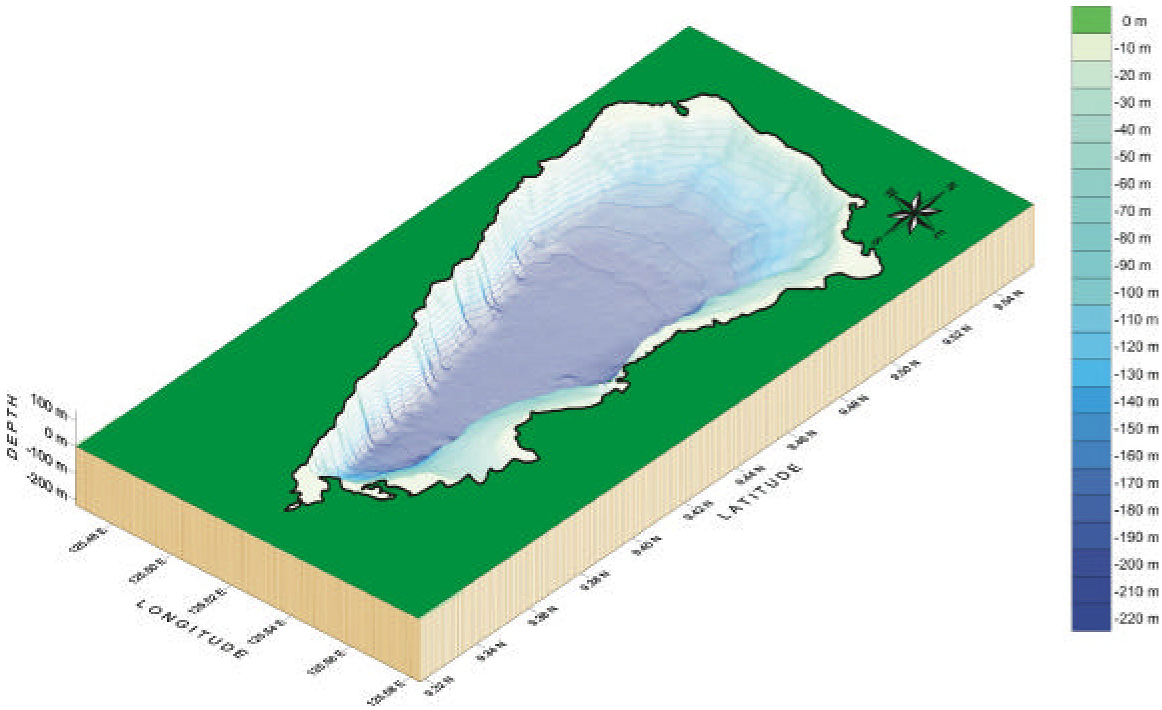

Figure 3. Three-dimensional representation of Lake Mainit basin derived from GPS marked bathymetric and coastline data collected from September 2003 – February 2004 using Surfer V 7.0 (Golden Software Inc.). Data collected during maximum rainfall season were readjusted to October 2003 lake level.

Shoreline development

Shoreline development (SLD) is an index of the regularity of the shoreline. A lake that is a perfect circle has a shoreline development of 1. As the value departs from unity, irregularity is indicated that is lengthening of the shoreline. Shoreline development calculation is of limnological interest because it relates to age and total productivity. Older lakes have had more shoreline erosion and deposition and thus are more regular in outline and have more littoral areas than younger lakes. The shoreline development of Lake Mainit is estimated at 1.152, which reflects the age of Lake Mainit to be young that speciation of fish had never occurred as in Lake Lanao (Lewis, 1973). Most natural lakes have an SLD of 3.0 and most reservoirs have an SLD of 12 or more.

Hypsographic curve

The hypsographic or depth area curve (Fig. 4) of Lake Mainit is a graphic representation between the surface area of the lake and its depth. The hypsographic curve represents the relative proportion of the bottom area and the depth of the lake which is included between the strata under consideration. In lakes with otherwise comparable conditions, biological productivity is generally greater in those with greater superposition of zones of photosynthetic production and of decomposition. The hypsographic curve for Lake Mainit indicates that the water volume available for biological productivity is quite small.

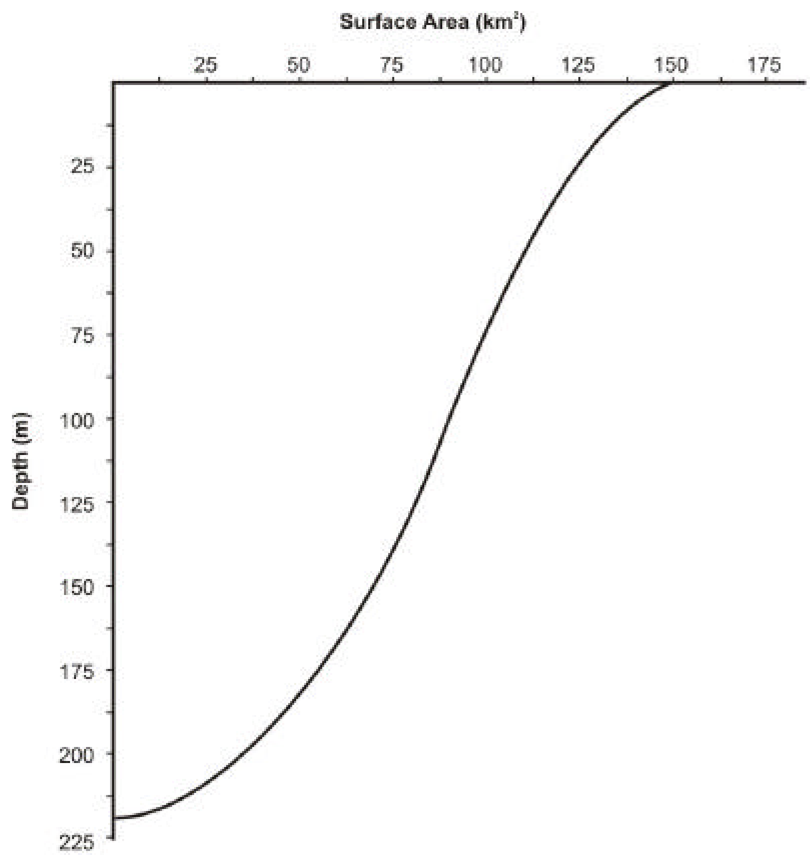

Figure 4. The relationship between absolute surface area and depth in Lake Mainit, Philippines, as indicated by cumulative hypsographic curve derived from measurements by planimetry.

Water temperature

The surface temperature range of Lake Mainit is between 27.00°C - 30.66°C. It is perceived to be complex due to presence of hot springs in the northern and eastern part of the lake and possibly within the lake as shown by temperature anomalies. The vertical profile of temperature distribution expressed as depth-temperature profile is presented in Fig. 5. The vertical water temperature range in Lake Mainit is between 26.60^{o}C - 30.66^{o}C. Depth-temperature data indicated that Lake Mainit is stratified. The epilimnion or the mixed layer is found at the upper 10 m although observations by Lewis (1973) at a different time indicated 12 m. The thermocline layer of Lake Mainit in this study during sampling was observed between 10 - 35 m and the hypolimnion was beyond 35 m. The depth-temperature profile (Fig. 6) was an observation at the height of strong NE monsoon winds thus variation was observed at the surface down to 30 m. This observed variation indicated that turbulent mixing could reach down to 30 m.

Water visibility

Secchi disk visibility is a measure of the water clarity and it is related to the photic depth. Secchi depth measurements ranged between 3.20 - 6.65 m (Fig. 7). It is prominent that Mainit municipality area close to rice fields has very low visibility including municipalities of Kitcharao and Alegria. Areas away from tributaries have higher visibility including Jabonga and areas close to Malimono range. A new Philippine record of 6.65 m Secchi depth for the most transparent lake was observed at the vicinity of Jabonga. Lake Lanao had a maximum Secchi depth reading of 6.0 m in 1932 (Frey, 1974) which made it the most transparent lake in the Philippines until January 2004.

The 1% PAR (photosynthetically active radiation) of Lake Mainit as observed by Lewis (1973) at a Secchi depth of 2.6 m was noted in this study at 13 m. The result would mean that the 1% PAR in Lake Mainit was 5 times the Secchi depth although in natural waters the 1% PAR was generally between 2-5 times the Secchi depths (Lind, 1979). The 1% PAR of Lake Lanao was observed at 11- 25 m (Frey, 1974). The apparent similarity of Lake Lanao and Lake Mainit in terms of Secchi depth readings indicates that the Lake Mainit waters, having a more transparent characteristic, must have more than 25 m as its depth maximum for the 1% PAR.

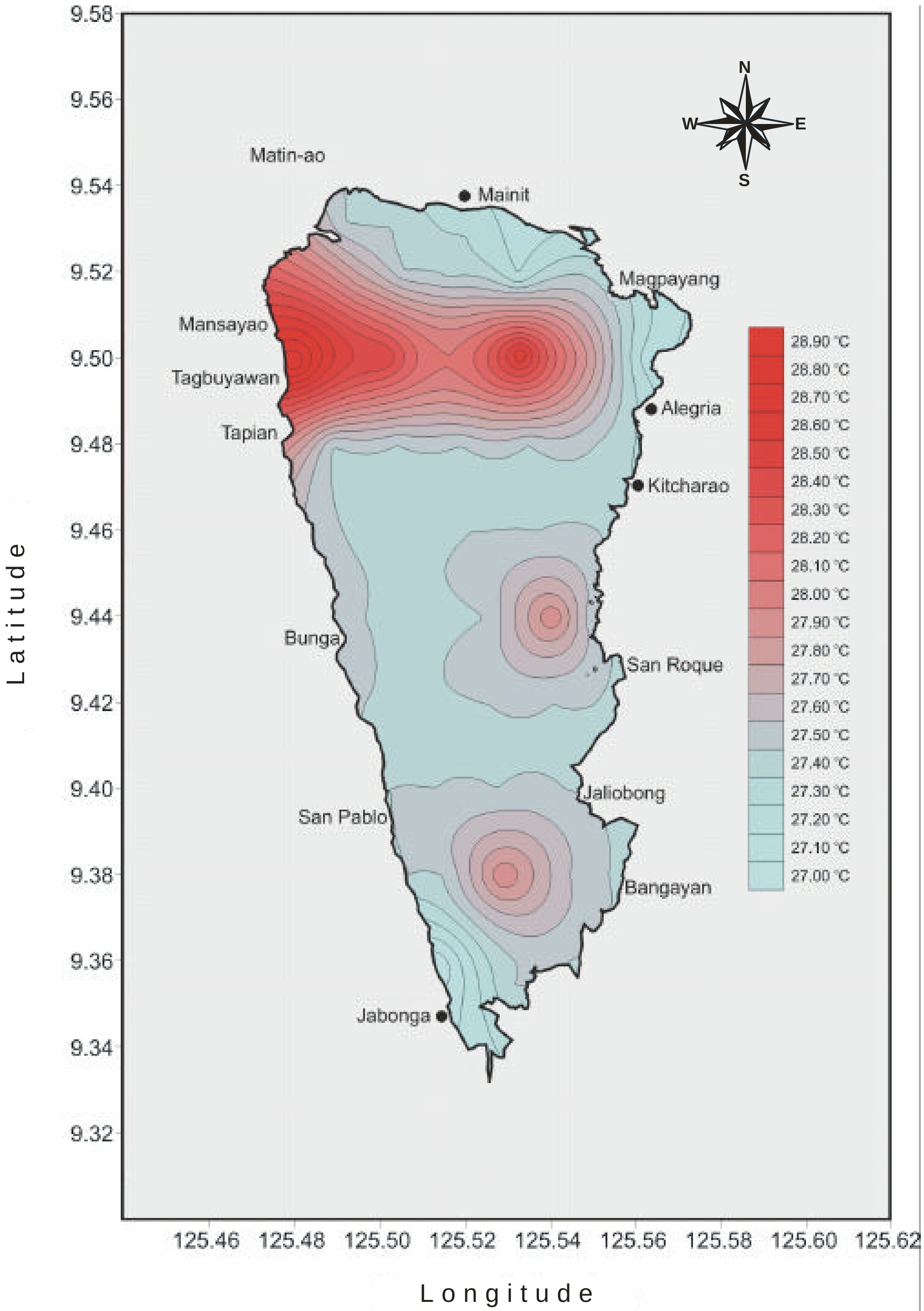

Figure 5. Distribution of surface temperature on January 2004 in Lake Mainit, Philippines.

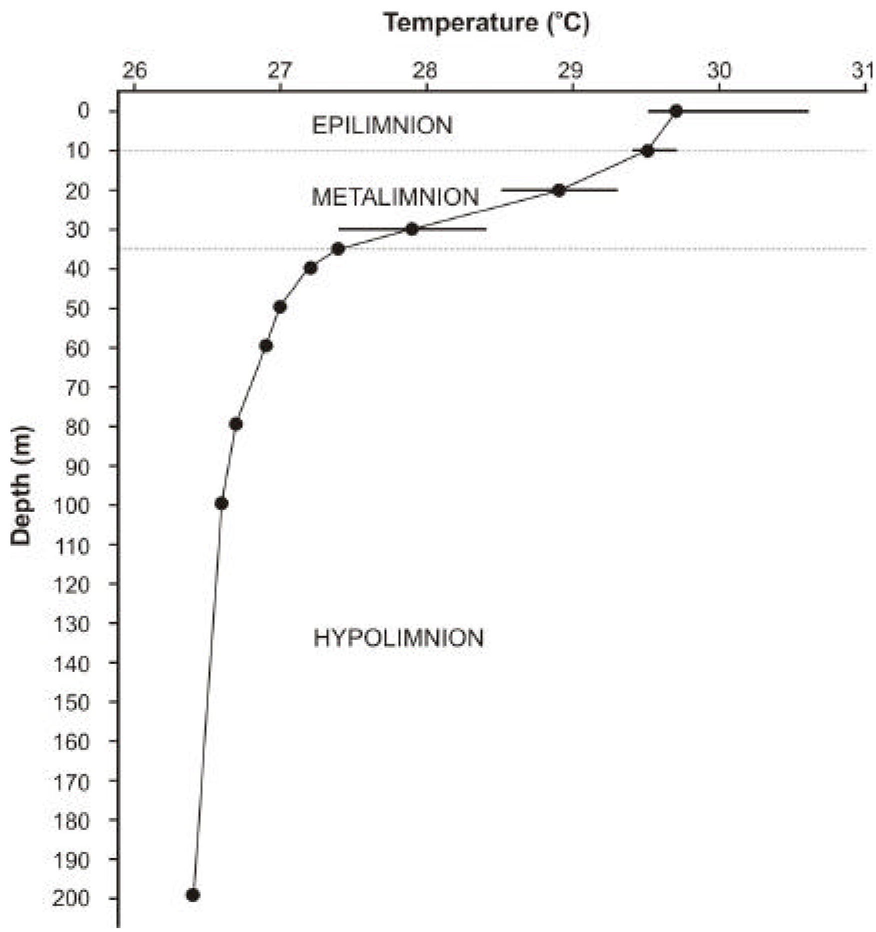

Figure 6. Depth-temperature profile of Lake Mainit showing extent of variation at the upper layer as a result of turbulent mixing. Thermal stratification is pronounced in most parts. The thermocline layer of Lake Mainit is approximately between 10 – 35 m.

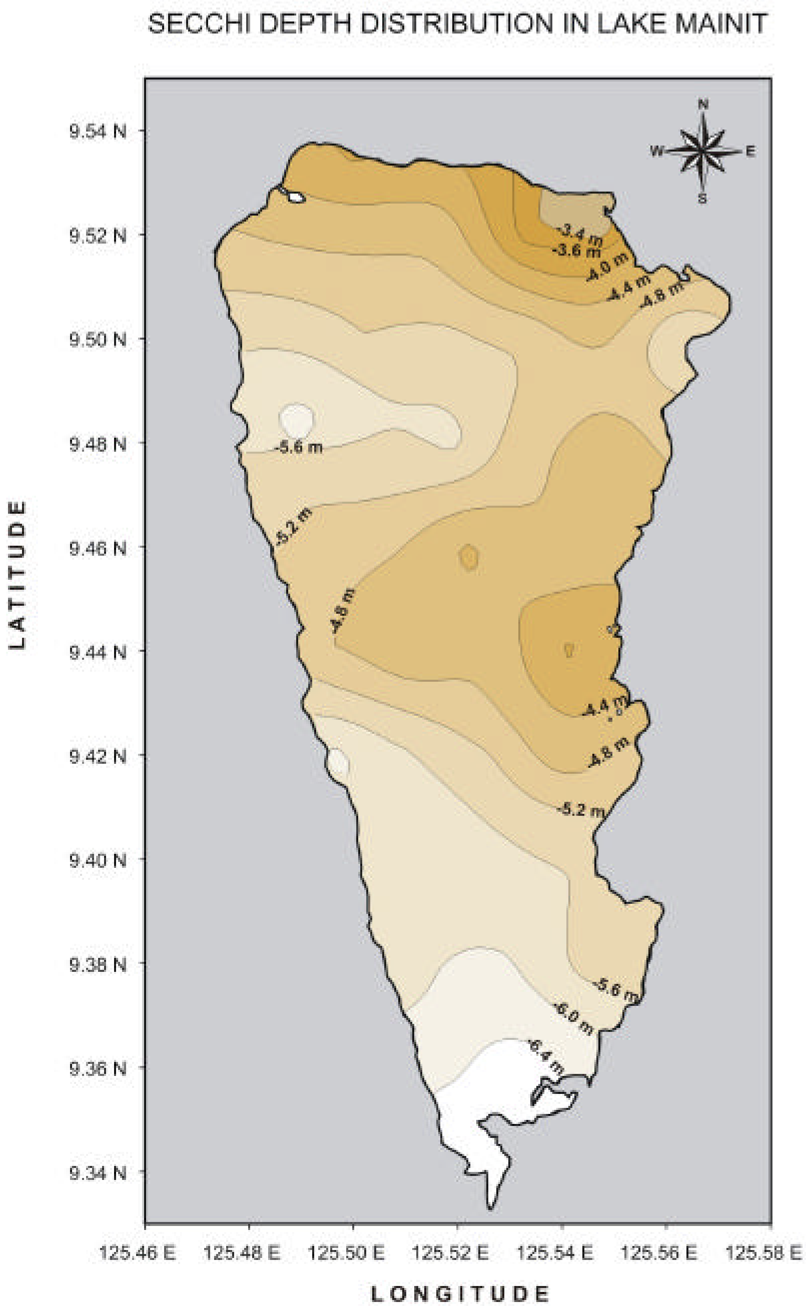

Figure 7. Distribution of water visibility based on Secchi depth measurements (meters) on January 2004 in Lake Mainit, Philippines.

Temperature, dissolved oxygen and pH

The observed temperature profile of Lake Mainit ranges between 26.55^{o}C - 30.60^{o}C. The surface temperature ranges between 29.20^{o}C - 30.60^{o}C while the vertical temperature profile indicates a mixed layer at a depth of 10 m during calm weather conditions and extending to 30 m during intense weather conditions (Fig. 8). The thermocline layer ranges between 10 m to 35 m.

Dissolved oxygen is an important regulator of chemical processes and biological activity. It is the most fundamental parameter essential to all aerobic organisms. However, the levels often differ greatly because mixing is seldom complete. In addition, biological reactions in the lake consume or release oxygen. The vertical distribution of dissolved oxygen (Fig. 8) shows that the oxycline of the lake has been observed to be between 10 m to 35 m at about 27.50^{o}C to 30.00^{o}C. The DO concentration is more or less uniform in the epilimnion or upper water layer (7.31 - 7.67 mgOL^{-1}) where there is mixing of water due to wind action. The DO level rapidly decreases below the thermocline (~10 - 35 m) to less than 2 mgOL^{-1} at 50 m and down to the bottom at about 200 m depth.

The lowering of DO with depth may be due to the existence of a thermal stratification of the lake where the hypolimnion becomes isolated from the sources of oxygen at the upper layer. Dissolved oxygen is widely observed to decrease progressively in the hypolimnion over a period of stratification because the demand for oxygen associated with respiration and decay exceeds the sources. Moreover, oxygen consumption is greatest near the bottom of the lake where settled organic matter is continually being decomposed (Frick *et al.*, 1990). Its concentration also decreases progressively with depth at the hypolimnion and towards the sediments because of localized biological and chemical oxygen demand at the bottom and the limited vertical mixing at these depths.

The lowest DO level (4.04 mgO.L^{-1}) was observed in the vicinity of Magpayang to Alegria and parts of Puyo (Fig. 9). Most areas of the lake have DO levels between 6.0 - 8.05 mgOL^{-1}.

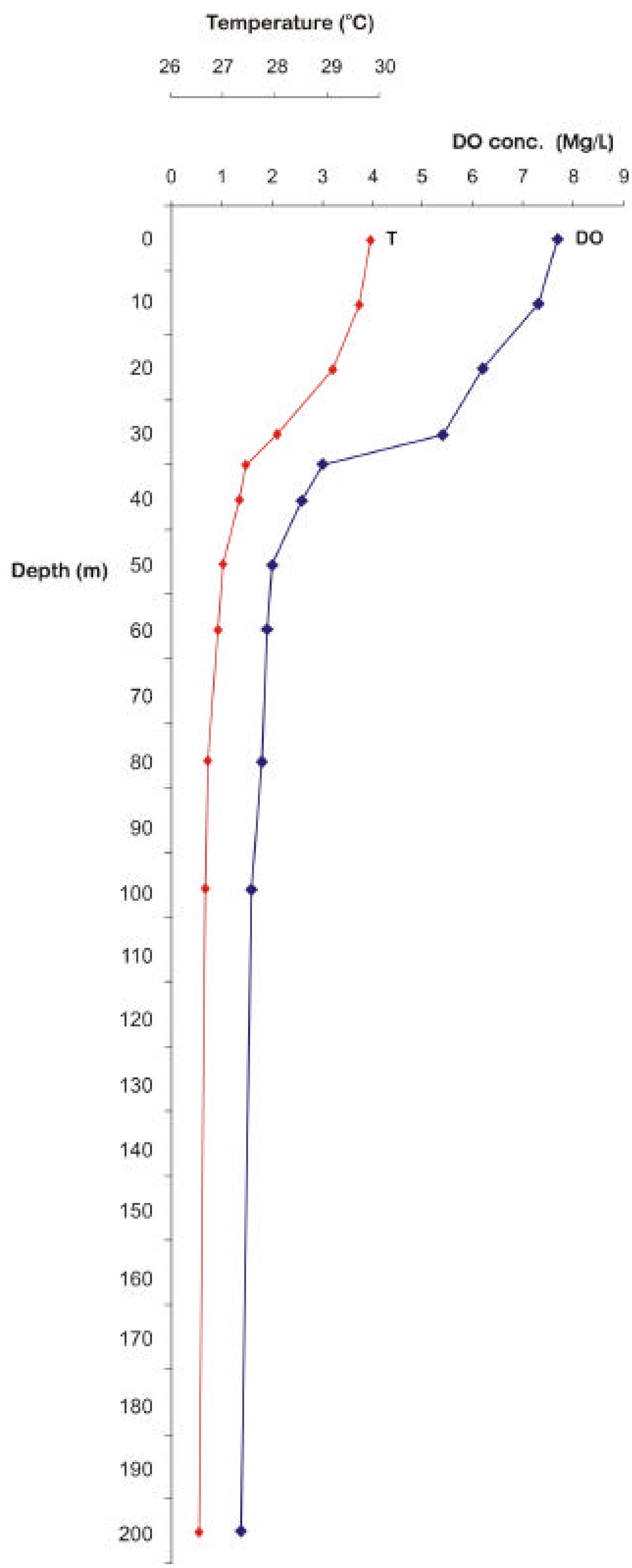

Figure 8. Depth-temperature and dissolved oxygen profiles of Lake Mainit.

DO levels <3 ppm are stressful to most aquatic organisms while DO concentration of <2 ppm could no longer support fish life. DO levels of 5-6 ppm are required for growth and activity of most aquatic organisms. The mean DO concentrations observed from the river tributaries (Table 3 & Fig. 9) range from 5.90 - 7.67 $mgOL^{-1}$. This range is above the minimum 5 $mgOL^{-1}$ DO concentration for fishery water that is fit for growth and propagation of fish and other aquatic resources (DENR, 1990).

Table 3. DO and heavy metal concentrations in some river tributaries of Lake Mainit collected last October, 2003.

Stations	**DO $mgOL^{-1}$**	**Water Sample**		**Sediment Samples**	
		Pb (ppm)	**Cd (ppm)**	**Pb (ppm)**	**Cd (ppm)**
Magpayang	5.90	bdc	0.008	0.93	0.17
Magtiaco	7.67	0.01	0.005	1.20	0.22
Jaliobong	7.09	0.02	0.008	0.98	0.17
Mayag	6.84	0.04	0.008	0.50	0.11
Anahaw	nd	0.03	0.008	1.45	0.24
Tagbuyawan	6.92	0.03	0.013	0.85	0.26
Mainit	6.84	0.03	0.004	bdc	0.06
Kalinawan	7.50	0.02	0.008	nd	nd
Roxas	7.00	bdc	0.013	0.90	0.16
Tapian	nd	0.02	0.016	0.68	0.24
San Isidro	nd	bdc	0.012	0.15	0.07

Legend: bdc – below detectable concentration
nd – no data/ no sample analyzed

The pH of most natural waters falls more often in the range of 6.0 to 8.0. It decreases from the epilimnion to the hypolimnion because of the diffusion of CO_2 from the atmosphere, respiration and decomposition processes. Organic matter that settles onto the bottom of the lake is subjected to decomposition processes and contributes to the differences in pH readings with depth in the lake (Frick *et al.*, 1990). The lowering of pH values may also be due to the presence of acids other than HCO_3^{-1} and most likely H_2SO_4. In Lake Mainit the mean pH values observed at the surface water was 7.9 down to a depth of 5 m and continuously decreased to 7.2 at 45 m depth. It is highest at the surface and has been observed to decrease with depth. A pH of 6.5 to 8.2 is optimal for most organisms.

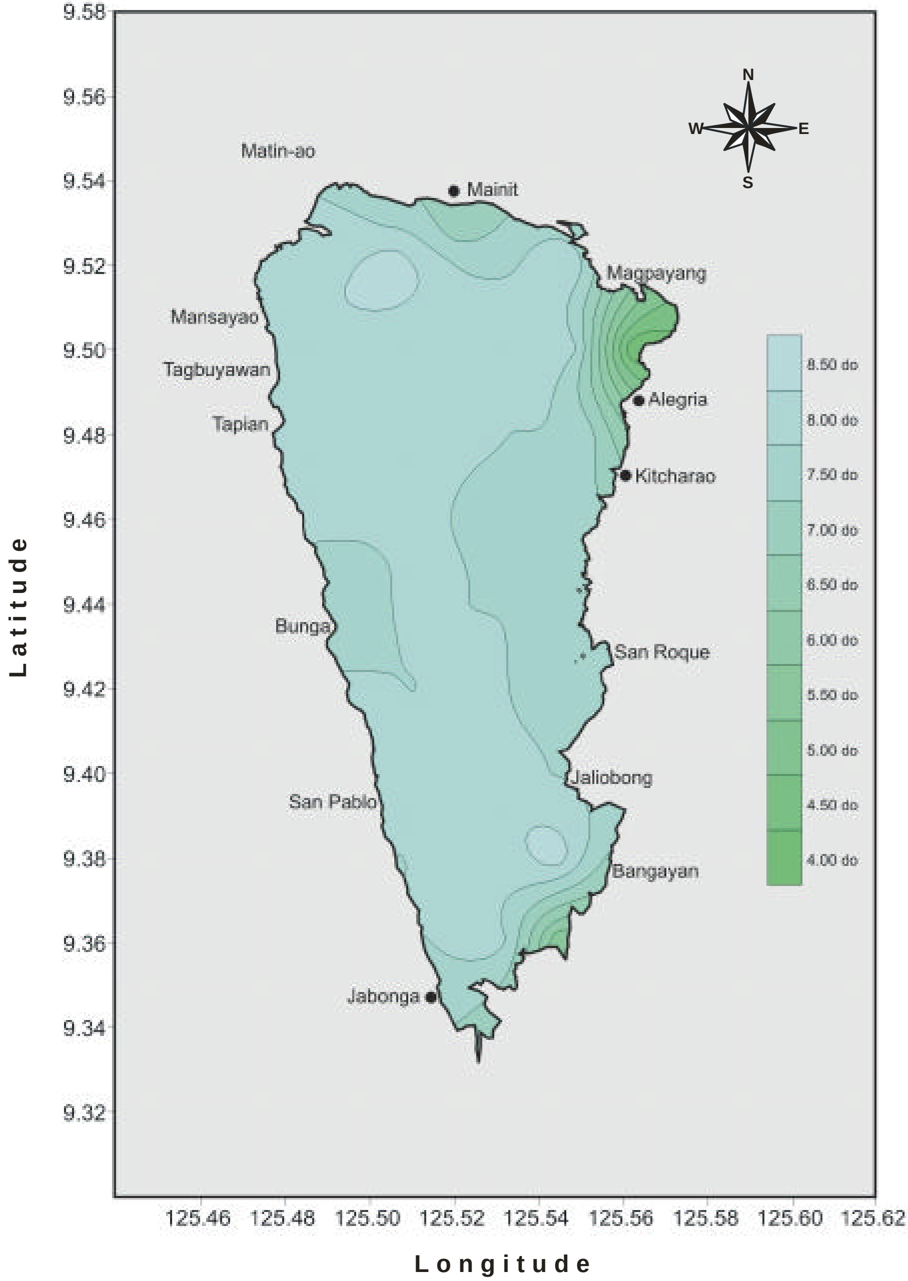

Figure 9. Dissolved oxygen profile of Lake Mainit.

Nutrients

Aquatic organisms influence and are influenced by the chemistry of the surrounding environment. Essential nutrients such as the bioavailable forms of phosphorous and nitrogen (dissolved phosphate, nitrate and ammonium) typically decrease at the epilimnion during stratification as nutrients are taken up by the algae and eventually transported to the hypolimnion when the algae die and settle down. Stratification affects dissolved oxygen and other nutrient concentrations in the water column (Lebo *et al.*, 2002). Nutrient concentrations in Lake Mainit show a strong vertical gradient (Fig. 10) with mean NO_3-N varying from 0.099 $mgNL^{-1}$ at 35 m to 0.507 $mgNL^{-1}$ at the surface water. The mean NH_3-N concentration is uniform from the surface water to 60 m and gradually increases with depth. It ranges from 0.004 to 0.037 $mgNL^{-1}$ (Fig. 10). The mean PO_4-P concentrations ranges from a below detectable concentration at the surface water to 0.20 $mgPL^{-1}$ at 200 m (Fig. 10). Relatively lower nutrient values have been observed at 20 - 50 m which are within or at the vicinity of the oxycline. The oxycline is around 10 - 35 m, thus inhibiting many macroorganisms from living at the bottom of the lake. With lower number of organisms fewer nutrients are used. Thus, deep waters tend to be nutrient rich. Higher nutrient values below the thermocline may probably be caused by the regeneration of particulate matter sedimenting from the epilimnion.

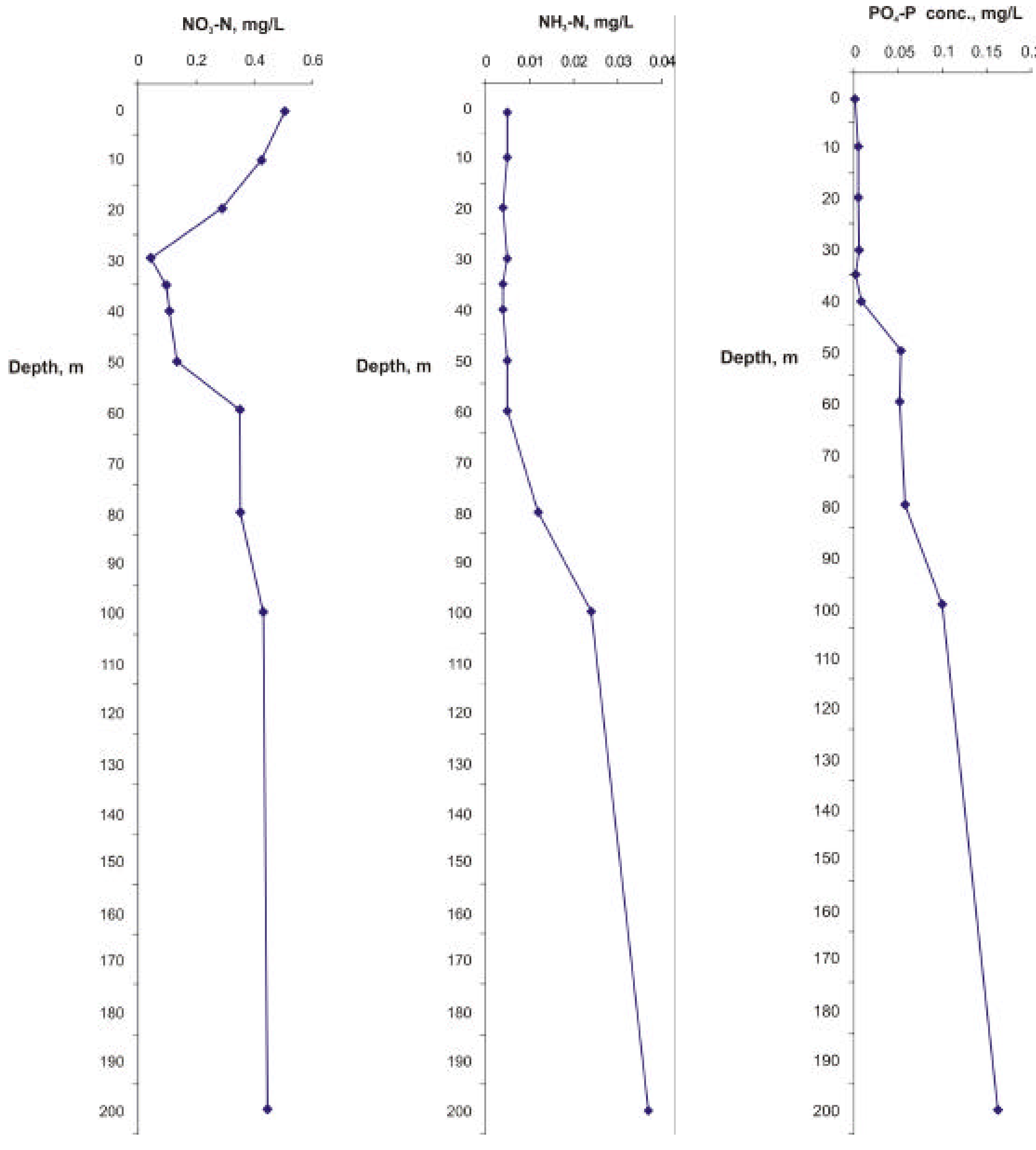

Figure 10. Vertical profiles of nutrient (NO_3-N, NH_3-N and PO_4-P) in Lake Mainit. Date of sampling: October 2003.

Generally, the epilimnion shows lower nutrient concentration due to the uptake by photosynthetic organisms. However, the results of nitrate analyses show that NO_3-N values are higher at the surface waters. It has been noted that heavy rains occurred the night before water sampling was done. The water coming from the agricultural lands and residential areas brought by river tributaries may have contributed to the increase in NO_3-N levels.

Nutrients like phosphorous and nitrogen can enter a lake from surface runoff, ground water, streams and by atmospheric deposition as well as recycled from bottom lake sediments. Eleven river tributaries and one river outlet (Kalinawan River) were considered for nutrient analyses.

Sewage is the main source of nitrate added by humans into rivers and lakes. Nitrate is also used widely in inorganic fertilizers, in explosives and as raw chemical in industrial processes. The nitrate concentration in groundwater and surface water is normally low, but can reach high levels from agricultural runoff or from contamination by human and livestock wastes and farm manure.

The NO_3-N concentration observed in the river tributaries ranged between 0.26 mgL^{-1} and 1.21 mgL^{-1} in Agong-ongan and Jaliobong River, respectively, during the first sampling period in October 2003, while it was below detectable concentration in Mainit, Tagbuyawan and Magtiaco River during the second sampling period in April 2004 (Fig. 11). During the same sampling period Baleguian River had a concentration of 0.76 mgL^{-1}. Due to sampling difficulties, water samples were not collected from Baleguian and Puyo Rivers during the first sampling period.

The excreta of aquatic organisms are very high in ammonia. Through the decomposition of dead plants, animals and excreta, nitrogen that has been previously 'locked up' is released in the water (Weaver, 1997). Water samples collected from Agong-ongan River were observed to have the highest ammonia concentration (0.052 mgL^{-1}) during the first sampling period and Baleguian River of 0.04 $mgNL^{-1}$ during the next sampling (Fig. 12). It was noted that several carabaos were wallowing in both rivers during sampling and the catchment area of these rivers are agricultural lands. These may have contributed to the elevated nitrate-N and ammonia-N concentrations.

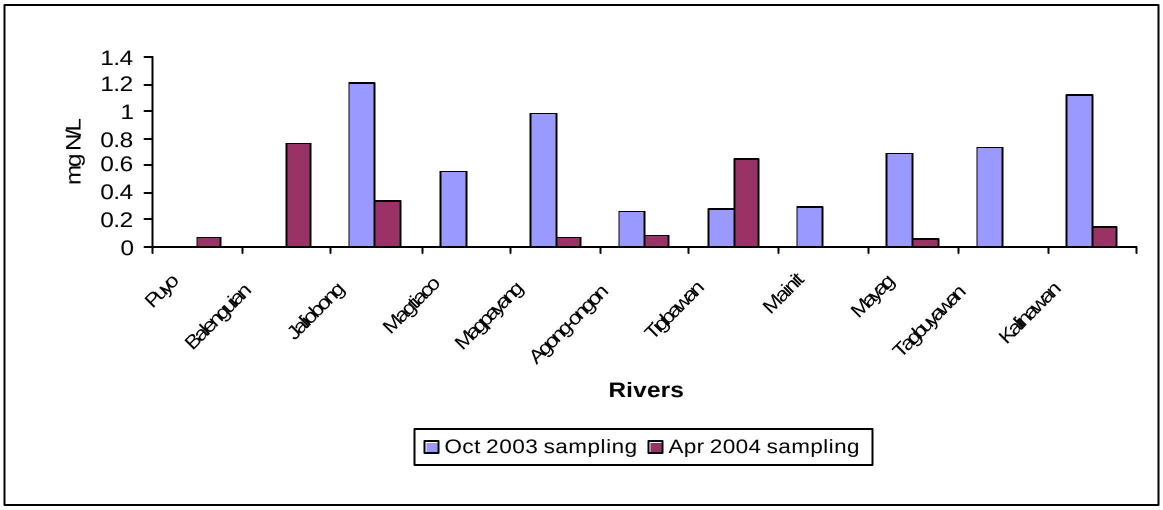

Figure. 11. NO_3-N concentrations from the river tributaries of Lake Mainit and Kalinawan River during the October, 2003 and April, 2004, sampling.

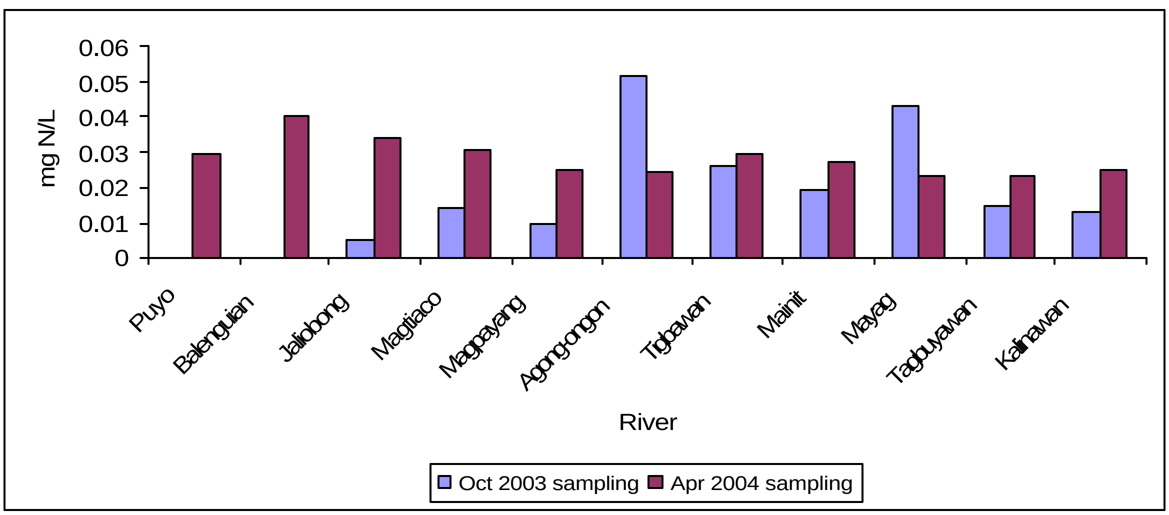

Figure. 12. NH_3-N concentrations from the river tributaries of Lake Mainit and Kalinawan River during the October, 2003 and April, 2004, sampling.

Phosphorous in phosphate form has the largest commercial applications. It is present in most types of fertilizers, synthetic detergents and tooth pastes. It is also present in almost all volcanic and sedimentary rocks. The highest PO_4-P concentration was observed in Jaliobong (0.089 $mgPL^{-1}$) followed by Mainit (0.088 $mgPL^{-1}$) and Tigbawan River (0.087 $mgPL^{-1}$) during the first sampling period while Tigbawan (0.069 mgL^{-1}) followed by Magpayang River (0.067 mgL^{-1}) were observed to have the highest PO_4-P concentration levels during the second sampling (Fig. 13). The river tributaries that were observed to have high PO_4-P concentration are either surrounded by agricultural lands or those coming from Lake Mahukdam that drains from Mt. Kapayahan and Malimono Range or both. Thus, no specific pattern was observed in nutrient concentrations in these river tributaries.

Natural concentrations of NO_3-N rarely exceed 10 $mgNL^{-1}$ and are frequently less than 1 $mgNL^{-1}$. Oligotrophic lakes have NO_3-N of up to 0.3 mgL^{-1} while eutrophic lakes range from 0.5 $mgNL^{-1}$ to 1.5 mgL^{-1} (Wetzel, 1983). The nitrate concentration levels (0.099 - 0.507 $mgNL^{-1}$) observed in this study were lower than the nitrate levels (1.00 - 2.6 $mgNL^{-1}$) observed in Lake Duminagat of Mt. Malindang (Hansel, 2002). The PO4-P values in the oligotrophic Mirror Lake is less than 5 gPO4-P per liter while the eutrophic Lake Erie has 30-50 gPO4-P per liter (Likens, 1985). The nitrate-N and PO4-P concentrations in the lake and river tributaries do not exceed the 1.00 mgNL-1 and 0.1 mgPL-1 maximum permissible NO3-N and PO4-P concentrations for waters fit for fish growth and propagation set by the US-EPA and DENR-DAO, 1990.

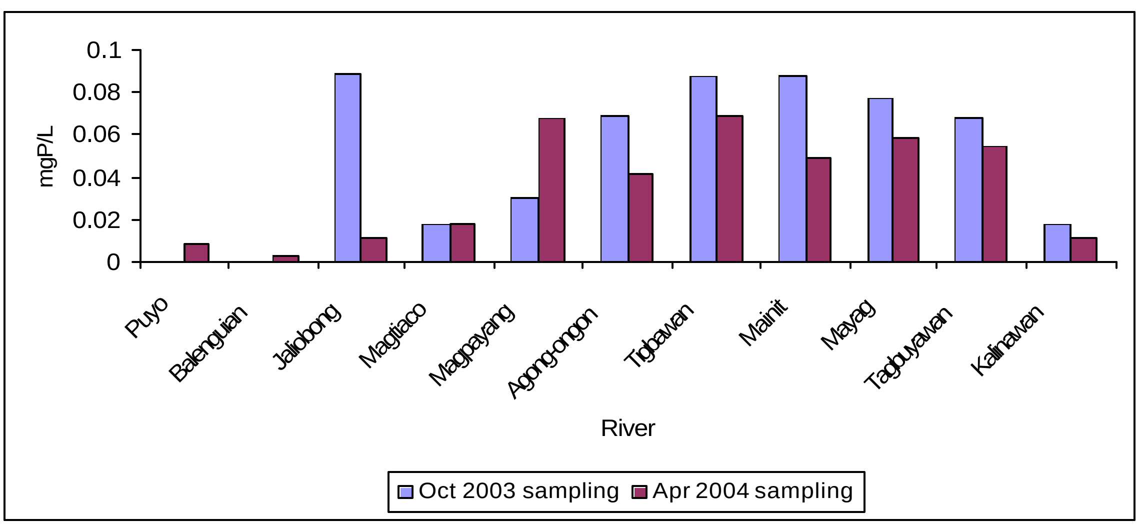

Figure 13. PO_4-P concentrations from the river tributaries of Lake Mainit and Kalinawan River during the October, 2003 and April, 2004, sampling.

Heavy Metals

The considerable interest and apprehension about the role and fate of toxic metals in aquatic environments are the result of several catastrophic events that have happened in the country and elsewhere (e.g., Marinduque mines in the country; mercury poisoning in Japan). The heavy metals considered in the study included lead (Pb), and cadmium (Cd).

Lead appears to be uniquitous in aquatic ecosystems and generally does not bioaccumulate in aquatic organisms. Lead as a pollutant has assumed particular importance due to its relatively high toxicity to humans, especially on the retardation of brain development in children (Sadiq, 1992).

Lead was not detected in most parts of the lake, but a concentration of 0.04 ppm was observed in the lake area near the municipality of Mainit (Table 3). The presence of Pb in the area may be due to the active navigational activities in the municipality. Several boats were observed to dock in this area, some are owned by the local fishermen of Mainit while others are commercial boats that ferry passengers from the municipality of Mainit to Jabonga.

The amount of Pb detected from selected river tributaries of Lake Mainit ranged between below detectable concentration to 0.04 mgL^{-1}. Mayag River was observed to have the highest Pb concentration.

Table 4. Heavy metal concentration in the water at different parts of Lake Mainit.

Geographical Location	9.4959 N 125 E (Mainit)	9.4691 N 125 E (Magpayang)	9.4406 N 125 E (Alegria)	9.4136 N 125 E (Jaliobong)	9.3843 N 125 E (Puyo)	EMB Caraga data
Cd,mgL^{-1}	0.002	0.004	0.001	0.001	0.001	nd-.023
Pb,mgL^{-1}	0.04	bdc	bdc	0.01	0.03	nd-0.097
Hg, mgL^{-1}	bdc	bdc	bdc	bdc	bdc	bdc

Legend : bdc - below detection concentration nd-not detected

The highest observed Pb concentration in water from the various river tributaries (Table 3) is lower than the reported 0.2 mgL^{-1} Pb that can cause adverse effects in aquatic biota (Wong *et al.*, 1978) and also lower than the maximum permissible Pb concentration of 0.05 mgL^{-1} for water that is fit for fish growth and propagation (DENR-DAO, 1990). Similarly, the concentration of Pb in the lake is far below the maximum permissible concentration.

Anthropogenic or man-induced activities are responsible for most of the Pb pollution (Sadiq, 1992). Several numbers of motorized boats were observed either navigating or docking in the lake area. Thus, its presence in Lake Mainit is probably attributed by continuous use of leaded gasoline in combustion engines. Also, the elevated lead concentration levels in the atmosphere may consequently find its way into the lake.

Cadmium is reportedly present in pesticides and fertilizers, e.g., common super-phosphate fertilizers contain 50-170 ppm Cd (Sadiq, 1992). Fertilizers and pesticides may be important sources of Cd pollution since they are intentionally introduced in the natural environment in fairly high amounts.

Cadmium was also detected in the water samples collected from several points in the lake (Table 4). It ranges from 0.001 to 0.004 ppm. Cd must have been brought to the lake via river tributaries.

Lake Mainit is surrounded by rice fields with intensive farming activities. Among the twelve river tributaries, Tapian River (0.016 ppm) was observed to have the highest Cd concentration followed by Roxas River (0.013 mgL^{-1}), and Tagbuyawan River (0.013 mgL^{-1}). The stations observed to contain high cadmium concentration levels were also reported to have high nutrient concentrations, which may suggest that agriculture related activities might have contributed to high Cd concentration. Ocular observations also suggest that majority of the total land use surrounding the lake is agricultural in nature.

Mercury (Hg) was purposely analyzed from the water and sediment samples because gold mining activities were previously reported to be happening in the upstream areas of river tributaries emptying into the lake. However, Hg was not detected in the water samples and a minute level of 208 ppb was detected in the sediment samples collected in Magpayang River and 139 ppb from Agong-ongan River. These Hg concentration values are very much lower than the 1000-ppb total Hg load for polluted sediments (Sadiq, 1992).

The heavy metal concentrations (Cd, Pb and Hg) obtained in the monthly monitoring of the Environment Management Bureau-DENR, Caraga Region, were approximately similar to the values obtained in this study. However, they cannot be compared from site to site since the exact locations of their sampling sites were not available (Tables 4 and 5).

Table 5. Comparison of the concentrations of some physico-chemical parameters obtained by the EMB-DENR Cagara Region.

Parameters	EMB-DENR Caraga Region[a]	Present Study[b]	DENR Standard
NO_3-N, mgN L^{-1}	no data available	0.099-0.507	1.0
PO_4-P, mgP L^{-1}	no data available	nd-0.2	0.10
Pb, ppm	nd-0.097	nd-0.04	0.05
Cd, ppm	nd-0.023	0.001-0.016	0.01
Hg, ppb	No data	nd	2.0ppb
TDS,mgL^{-1}	96-99	63.3-138.5	96-100
Fecal coliformMPN/100ml	2.0-240	<2 - ≥1600	nil

[a] EMB monitoring as of March 2003 to Oct 2003 nd – not detected/below detectable concentration
[b] Samples collected last October 2003

Sediment is the ultimate sink of all foreign substances in the aquatic environment (Sadiq, 1992). A higher frequency of detection and generally higher concentrations of trace metals were observed in sediments than those in the water of the 11 river tributaries. Sediment samples from Anahaw River and Tagbuyawan River were observed to have the highest Pb and Cd concentrations, respectively (Table 3). The ranges of Pb (below detectable concentration (bdc) to 1.45 ppm and Cd (0.06 to 0.26 ppm) concentrations were both lower than the 5-ppm Pb and 1 ppm Cd for sediments categorized as polluted areas (Sadiq, 1992). However, permanent deposition and accumulation of these substances may lead to long term problems affecting benthic organisms.

Pesticides

Sediment samples that were collected from some river tributaries of Lake Mainit for pesticide determination were brought to the MSU-IIT Chemistry Laboratory in Iligan City for analyses. Standards for these types of pesticides are required in the analyses. Since organochlorine standards were the only ones available in the chemistry laboratory, the analyses were thus limited to organochlorine pesticides. If there were organophosphate pesticides present in the samples, these were not detected due to this limitation.

The analyses of the sediment samples showed that among the 17 types of pesticides only β-BHC, heptachlor and heptachlor epoxidenone were present (Table 6). It is surprising why these types of pesticides were detected in the analyses since these are already banned in the market. The detection of β-BHC, heptachlor and heptachlor epoxidenone in the sediments may indicate the continuous use of these pesticides despite the ban. It is also possible that the farmers may not be using these pesticides at present but have used them in the previous years and their residues have settled in the sediments without being degraded.

Table 6. Pesticides levels µgL^{-1} in selected river tributaries of Lake Mainit.

OCP	Kitcharao	Magpayang	Mayag	Mamkas	Jaliobong	Mainit	Magtiaco
α- BHC	bdc	bdc	bdc	bdc	bdc	bdc	bdc
β- BHC	2.93	3.61	bdc	bdc	2.55	2.54	3.46
γ- BHC	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Heptachlor	8.09	7.07	6.30	7.58	6.33	7.91	9.27
δ- BHC	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Aldrin	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Heptachlor epoxide	3.98	bdc	bdc	bdc	bdc	bdc	bdc
Endosulfan I	bdc	bdc	bdc	bdc	bdc	bdc	bdc
4,4'- DDE	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Dieldrin	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Endrin	bdc	bdc	bdc	bdc	bdc	bdc	bdc
4,4'- DDD	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Endosulfan II	bdc	bdc	bdc	bdc	bdc	bdc	bdc
4,4'- DDT	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Endrin aldehyde	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Endosulfan sulfate	bdc	bdc	bdc	bdc	bdc	bdc	bdc
Methoxychlor	bdc	bdc	bdc	bdc	bdc	bdc	bdc

Date of sampling: October 2003
bdc – below detectable concentration

The negligible pesticide levels in other river stations may be due to the limited frequency of sampling. Whether or not there were discharges from other possible sources during the sampling were not noted but their detection could have been influenced by the occasional drainage from agricultural lands. It is also possible that certain pesticides present in these rivers were not among those included in the analysis.

The absence of pesticides from the sediment samples may also be attributed to the people's awareness of the effects of pesticides to the aquatic environment. Observing better management practices such as using alternative pesticides that could easily be degraded into harmless substances could be possible reason for the absence of these pesticides.

In the absence of the data on the types of pesticides used by the farmers and the limited pesticide standards as well as the limited frequency of sampling, a conclusion on whether the detected pesticides are the only pesticides present in area can not be drawn. β-

BHC, heptachlor and heptachlor epoxidenone were detected in some areas, however, their concentrations are low to cause adverse effects to the aquatic biota.

Total dissolved solids

Total dissolved solids (TDS) are the total amount of ions present in the water. Both the concentration of TDS and the relative amounts or ratios of different ions influence the species of organisms that can best survive in the lake. The total dissolved solids in the various rivers surrounding the lake range between 67.33 mg L^{-1} to 138.5 mg L^{-1} in Kalinawan and Tagbuyawan River, respectively (Fig. 14). The highest and lowest TDS values obtained in this study are relatively higher and lower, respectively, than the TDS concentrations reported by DENR-EMB Caraga Region (96-100 mgL^{-1}). The sites where the samples were collected may not be the same which may explain the differences in readings that were obtained.

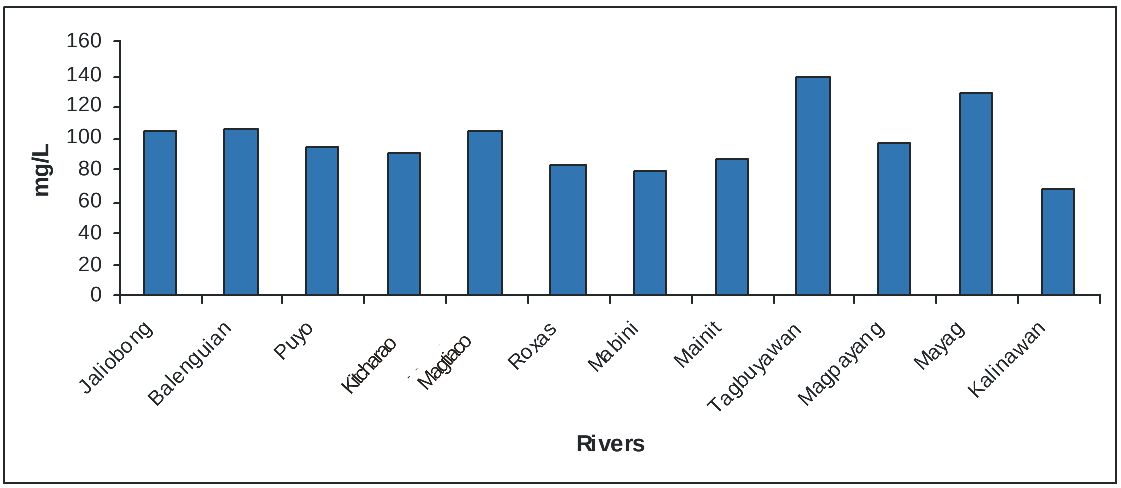

Figure 14. Total dissolved solids from the river tributaries of Lake Mainit and Kalinawan River during the April, 2004, sampling.

Sedimentation

Sedimentation study in Lake Mainit was conducted in October and November, 2003 in order to obtain a rapid overview of deposition occurring in the lake and sediment supply of tributaries. This was implemented by determining the sedimentation rates *in situ* and measuring the suspended solids and the discharge rates of rivers. Water turbidity was also included as a parameter related to sedimentation.

The lake is supplied by streams and run-offs of 28 rivers and creeks from the eight municipalities of Surigao del Norte and Agusan del Norte (Environmental Management Plan, April, 1999). Out of these 28 tributaries, only fourteen have streams of water flowing during the observation and sampling period as shown in Fig. 14 and Table 7. Those with higher water discharge rates are Mayag, Puyo, Baleguian and Magpayang River. Others with smaller drainages have intermediate stream flow while a few can be classified as brooks. Volume estimates based on one time sampling showed that the total water input from the 14 tributaries is approximately 1.8 million $m^3.d^{-1}$ while the water output through Kalinawan River is almost 2 million $m^3.d^{-1}$. The disparity in volume between input and output can be attributed to other sources which were not accounted such as precipitation, coastal runoffs and probably domestic wastewater.

Sediment supply

Rivers are responsible for most of the terrestrial inputs of materials entering the lakes including silt and clay. They affect the clarity of the water and interfere with the natural processes of a lake ecosystem. These particles are commonly referred to as total suspended solids (TSS) and include colloidal and fine dispersions which are always present in natural waters. They also include particles of coarse sizes which are common during flood conditions. In Lake Mainit wastes coming from domestic activities of populated areas and other similar operations may contribute to and augment the quantity of suspended solids. However, no investigation has been done to support it. Despite this, most rivers in Lake Mainit generally discharge clear water having suspended solid levels ranging from 1 to 38 mgL^{-1} (Table 7). DENR classifies them as Class AA (1 - 25 mgL^{-1}) and A (not more than 50 mgL^{-1}). Only Mayag River showed high solid content (74 mgL^{-1}) because of the influence of flood which has brought in large amount of silt materials.

Table 7. Discharge rates and levels suspended solids of river tributaries in Lake Mainit including Kalinawan River

Name of River	Volume ($m^3.day^{-1}$)	Suspended solids (mgL^{-1})
New Camalig River	4,268	5
Alimpatayan River	7,677	10
Tugbongan River	7,925	27
Tigbawan River	7,983	2
Mainit River	13,608	7
Mamkas River	17,280	1
Agong-ongan River	17,574	25
San Isidro River	18,386	3
Jaliobong River	38,561	4
Magtiaco River	58,294	4
Magpayang River	138,931	7
Baleguian River	175,694	38
Puyo River	221,184	9
Mayag River	1,052,352	74
Total	**1,779,717**	
Kalinawan River	1,969,229	2

The sediment contribution of river tributaries based on the discharge rates and concentration of suspended sediments is shown in Fig. 16. Mayag River which was heavily flooded supplied a substantial quantity of silt (77.874 $tons.d^{-1}$) or 87.66 % of the total load. This is indicative of the high erosion rate occurring within the drainage areas and the deterioration of land cover. Observation near the sampling site showed that the Mayag River bank near the mouth of the lake is without cover and is vulnerable to more erosion during flood thus contributing to siltation. This could be also true to other river banks. Baleguian River only provided 6.676 $tons.d^{-1}$ while Puyo River with higher discharge rate but low suspended solids only contributed lower amount of silt at 1.992 $tons.d^{-1}$. Minor rivers and brooks accounted for the remaining load of 2.294 tons d^{-1}. The total sediment supply of the 14 tributaries is 88.835 $tons.d^{-1}$ out of which only 3.938 $tons.d^{-1}$ are flushed out through Kalinawan River, the only outlet of the lake. Although discharging large volume of water, Kalinawan River is low in suspended solids (2 $mg.L^{-1}$) that characterizes its quiet and often clear water thus leaving behind about 95.6% of the sediment supply being deposited in the lake floor. Continuous supply of silt results to shallowing causing backflows often experienced by coastal residents during heavy rains.

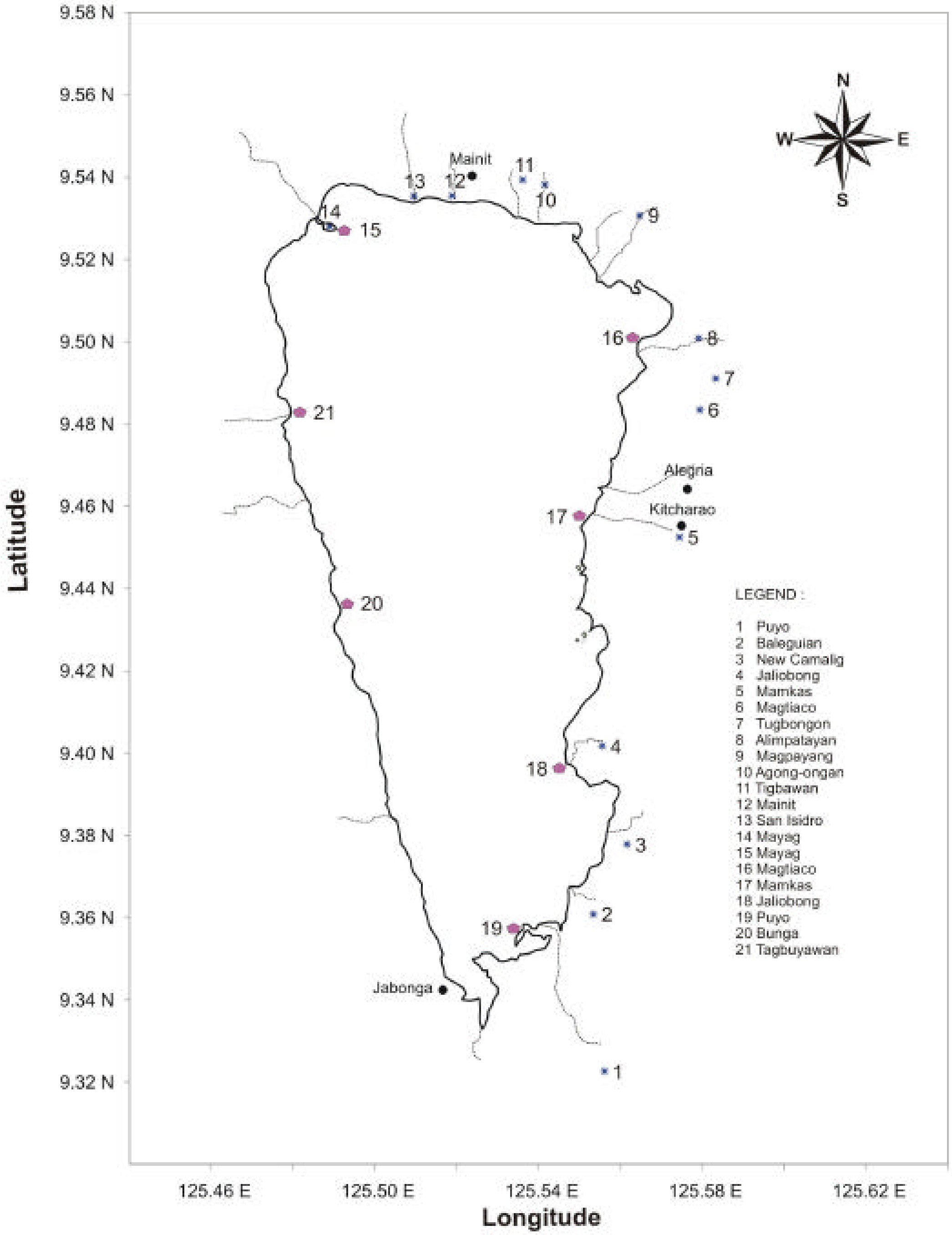

Figure. 15. Map of Lake Mainit showing the sampling sites for Sediment supply (* 1-14) and Sedimentation rate (⬟ 15-21)

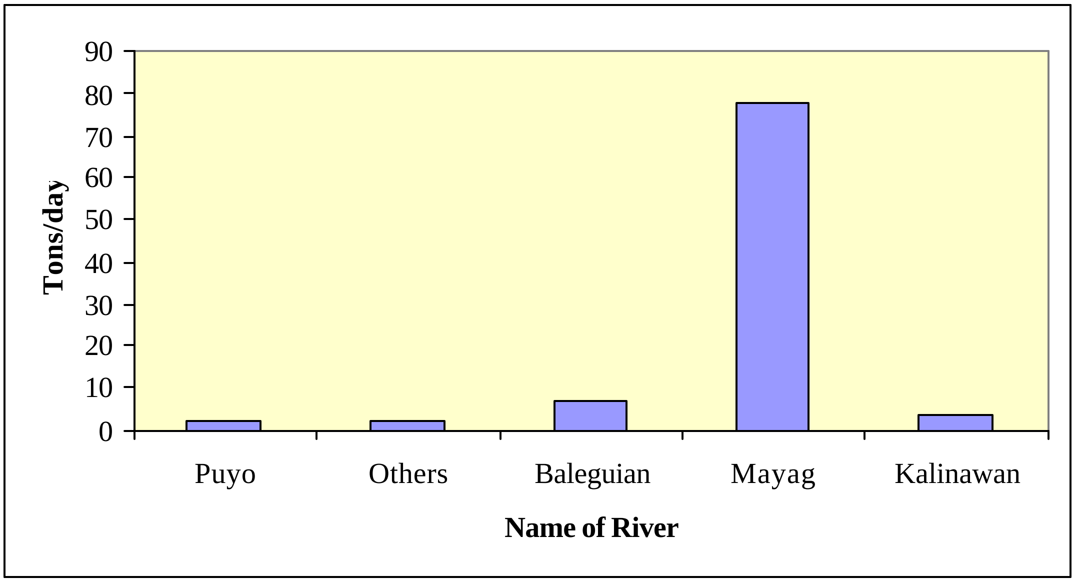

Figure 16. Sediment supply of rivers in Lake Mainit including Kalinawan River.

Sedimentation rate

Sedimentation rate refers to the settling down of suspended materials brought by run-offs from rivers and coastline for a certain period of time. Measurements in seven lakeshore areas (Fig. 17) showed high deposition particularly in the eastern portion such as those in Kitcharao (134.5 $mg.cm^{-2}.d^{-1}$), Magtiaco (86.96 $mg.cm^{-2}.d^{-1}$), Jaliobong (73.82 $mg.cm^{-2}.d^{-1}$) and significantly lower in Puyo (26.82 $mg.cm^{-2}.d^{-1}$). Consequently, a large part of this side of the lake has a sandy muddy substrate which shows murky water when turbulent waves resuspend its benthic deposits. Likewise, the heavy deposition observed in Mayag River (909.46 $mg.cm^{-2}.d^{-1}$) during flood condition has an apparent influence on the sandy-muddy substrate in its vicinity at the northern portion. On the other hand, very low deposition was observed in Tagbuyawan (4.01 $mg.cm^{-2}.d^{-1}$) and Bunga (1.38 $mg. Cm^{-2}.d^{-1}$), two sites of the lake that seldom receive heavy amount of suspended solids having a narrow watershed area along the Malimono Ridge. The deeper bottom profile, low deposition and the characteristic rocky substrate make this western portion of the lake provide a generally clear water. Lake Mainit has higher sedimentation rates than the marine environment because the latter has higher water density and allows more movement to transport suspended materials elsewhere by tides and currents. Such processes are lacking in lakes allowing particles to settle faster.

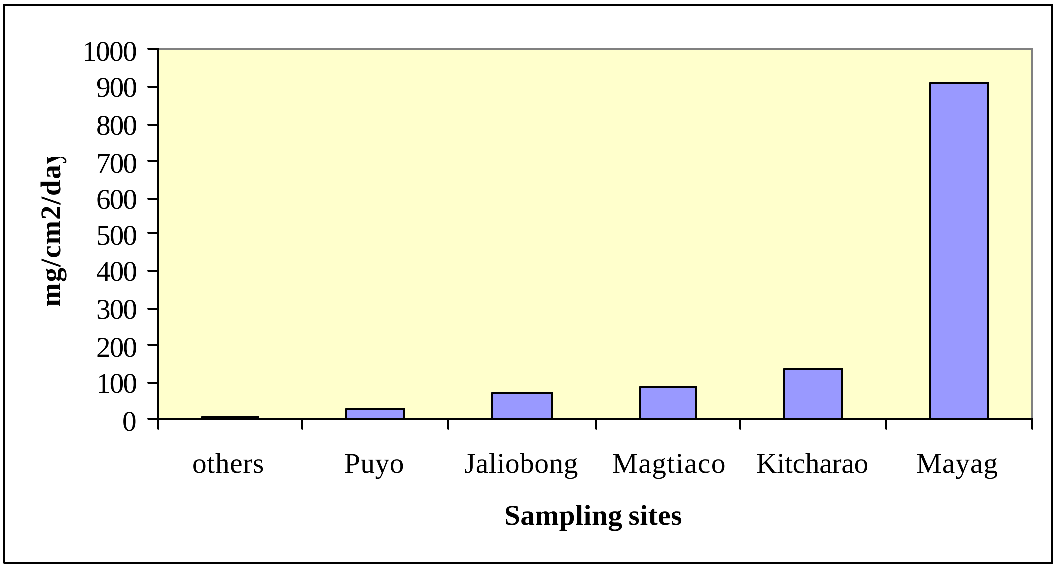

Figure 17. Sedimentation rates from various lakeshore areas of Lake Mainit.

Turbidity

Turbidity measurements were made as an estimate of total suspended solids (TSS) to describe the entire lake body including the open water zone. Analytical method for TSS is not sensitive to low concentration particularly in the middle area of the lake. As a parameter it does not only measure particulates due to silt and clay but also organic materials due to wastewater discharges and phytoplankton. When present in high concentrations, these suspended particulates interfere with light penetration in the water column. Aquatic organisms, particularly fish, are generally affected by high levels of turbidity caused by sediments and manifesting a wide range of responses such as stress to more deleterious ones depending upon the time of exposure.

Turbidity readings obtained in a clear day ranged from 0.35 to 1.45 nephelometric turbidity units (NTU) indicating that water in Lake Mainit is very clear meeting turbidity standards that would qualify it as source of water supply for drinking and domestic use. The general turbidity profile of the lake in Figure 18 shows the effect of suspended particulate matter from each river tributary as it forms a decreasing concentration gradient towards the middle portion of the lake. The more prominent one is the TSS discharge from Jaliobong River which contained higher concentration of suspended solids at the river mouth and dispersing toward the Tapian portion of the lake. This observation coincides with the mass transport caused by the prevailing Northeast monsoon winds during time of sampling.

Because of time limitation no measurements were made during the time when there was water disturbance due to strong winds.

Impacts of sedimentation

Sediments are a major pollutant of lakes and have always had adverse effects on aquatic organisms and the lake environment. Continuous heavy flow of silts from rivers and lakeshores eventually form deposits on the lake floor. On a large scale basis, the build up of sediments may result in the formation of delta that will gradually change the bottom feature of the lake basin. Slackening of the outflow of water from the lake during heavy precipitation is one of the disastrous consequences of sedimentation and as it may cause flooding of the lakeshore villages.

The effect of sedimentation on water quality is exhibited in the reduction of the level of dissolved oxygen, the most fundamental life-sustaining parameter of lake waters. Murky water reduces light penetration in the water column curtailing photosynthetic process and making it difficult for light to reach organisms at the deeper layers. It also interferes in the interaction between air and water at the interface, a natural process involved in the formation of dissolved oxygen. Mud accumulation always leads to anoxic and unstable conditions unfit for many aquatic organisms.

Silt materials are also harmful to aquatic plants and animal dwellers. Fine particulate materials easily suffocate newly-hatched larvae and clog or damage the gill structures of fishes, decrease their resistance to diseases, prevent proper egg and larval development and interfere with particle feeding activities. In plants silt particles prevent natural processes to take place by filling and covering their pores and preventing the uptake of nutrients and necessary gases. The effect of reduced light penetration would in turn impact on organisms dependent upon them for food and cover. Loss of standing vegetative structure generally makes lake less productive of invertebrates.

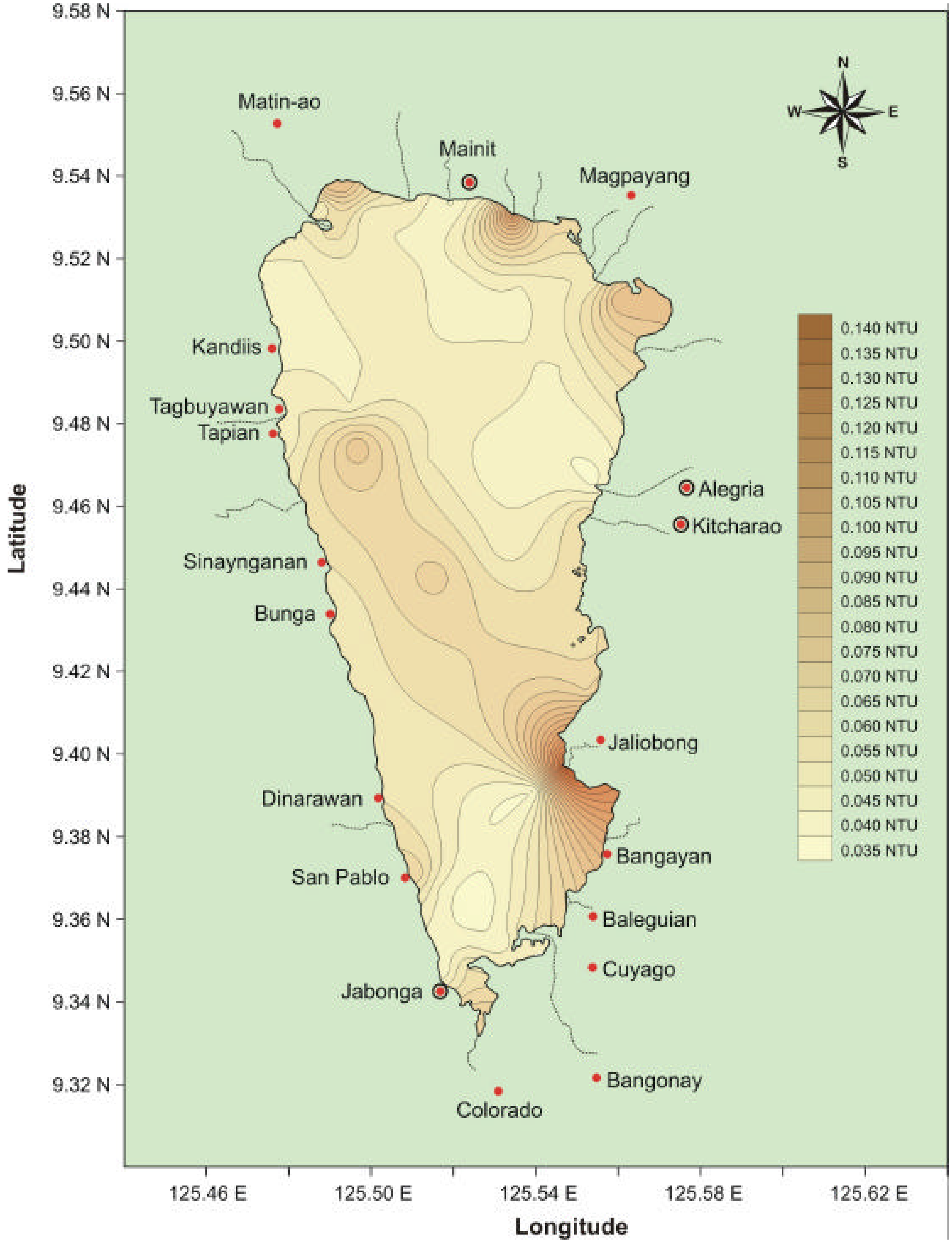

Figure 18. Turbidity profile of Lake Mainit (Nov. 13, 2004).

Bacteriological Analyses

Bacteriological analyses of water samples from twelve sampling sites in Lake Mainit vary with sites, particularly for heterotrophic plate counts (bacterial density), total coliforms, and fecal coliforms (Table 8 & Fig. 19). The values for bacterial density range from <30 up to 41,333 cfu.mL^{-1}. For total and fecal coliforms the differences in values from the highest to the lowest are not as wide and range from <2- =1600MPN.mL^{-100}.

The sites with highest total bacterial densities of 41,333 cfu.mL^{-1} and 14,329 cfu.mL^{-1} have been observed in Mainit and Jaliobong, respectively. Bacterial densities are values representing the entire bacterial flora of the aquatic environment and consisting of various groups and species coming from different sources.

Total coliform count is also highest in the town of Mainit (=1600MPN.mL^{-100}). A very close value for total coliforms has been noted in San Roque (1600MPN.mL^{-100}). For fecal coliforms, the same pattern has been observed in Mainit and San Roque ranking them highly (=1600 MPN.mL^{-100}, 1600 MPN.mL^{-100}, respectively) among the sampling areas. Mainit and San Roque are coastal places that are visibly populated. Runoff waters from these places could have contributed as sources of bacterial contamination of the lake.

The remaining areas have far lesser densities for total bacteria, total coliforms and fecal coliforms. The lowest bacterial densities (<30 cfu.mL^{-1}), total coliforms (2 & <2 MPN.mL^{-100}), and fecal coliforms (<2 MPN.mL^{-100}) have been observed in samples collected from the surface and in mid-water at the central part of the lake. These findings are not surprising considering that the sampling site is located offshore and quite far from potential sources of recontamination.

By DENR standards the quality of water in the middle of the lake and the coastal water of Magpayang are relatively good. As such, the water requires only approved disinfection protocols to meet the national standards for drinking water. In contrast, the coastal waters in Mainit, San Roque, and Bunga are comparably of lower quality. This means that its beneficial use would be limited for bathing, swimming and skin diving. In Jaliobong, San Pablo, Bangayan, Jabonga, the lake water requires complete treatment (coagulation, sedimentation, filtration and disinfection) in order to meet the national standards for drinking water.

Table 8. Total bacterial density, total coliforms, fecal coliforms (*Escherichia coli*) and water classification of some areas of Lake Mainit, Surigao del Norte.

Sampling site	Bacterial density ($cfu.mL^{-1}$)	Total Coliforms ($MPN.mL^{-100}$)	Fecal Coliforms ($MPN.mL^{-100}$)	Tentative Classification of water based on Fecal Coliforms
Mainit	41,333	=1600	=1600	Class B
Jaliobong	14,329	130	79	Class A
San Pablo	5,833	24	24	Class A
San Roque	503	1600	1600	Class B
Bangayan	498	79	79	Class A
Magpayang	388	27	17	Class AA
Bunga	106	350	350	Class B
San Pablo (near poultry)	52	49	49	Class A
Jabonga (fishing Village)	50	49	22	Class A
Jabonga beach	32	33	33	Class A
Middle portion of lake (surface)	<30	2	<2	Class AA
(middle)	<30	<2	<2	Class AA

Legend:

	Class AA	Class A	Class B	Class C	Class D
Total Coliforms($MPN.\ mL^{-100}$)	$50^{(m)}$	$1,000^{(m)}$	$1,000^{(m)}$	$5,000^{(m)}$	-
Fecal Coliforms($MPN.mL^{-100}$)	$20^{(m)}$	$100^{(m)}$	$200^{(m)}$	-	-

Coliform bacteria - are rod-shaped bacteria found in soil and the intestinal tract of warm blooded animals including humans

Fecal Coliforms(Escherichia coli) – are bacteria entirely of fecal origin and are used as indicator organisms of fecal pollution.

MPN – Most Probable Number (a statistical estimate of the concentration of the total and fecal coliforms that are present in the water sample.

M - refers to the geometric mean of the MPN of coliform organisms during a 3-month period and that the limit indicated shall not be exceeded in 20 percent of the samples taken during the same period.

- means the standards of these are not considered necessary for the present time, considering the stage of the country's development and DENR capabilities, equipment and resources

Classification	Beneficial Use
Class AA	Public Water Supply Class I. This class is intended primarily for waters having watersheds which are uninhabited and otherwise protected and which require only approved disinfection in order to meet the National Standards for Drinking Water (NSDW) of the Philippines.
Class A	Public Water Supply Class II. For sources of water supply that will require complete treatment (coagulation, sedimentation, filtration and disinfection) in order to meet the NSDW.
Class B	Recreational Water Class I. For primary contact recreation such as bathing, swimming, skin diving, etc. (particularly those designated for tourism purposes).
Class C	1) Fishery Water for the propagation and growth of fish and other aquatic resources; 2) Recreational Water Class II (Boatings, etc). 3) Industrial Water Supply Class I (For manufacturing processes after Treatment).
Class D	1) For agriculture, irrigation, livestock watering, etc. 2) Industrial Water Supply Class II (e.g. cooling, etc.); 3) Other inland waters, by their quality, belong to this classification.

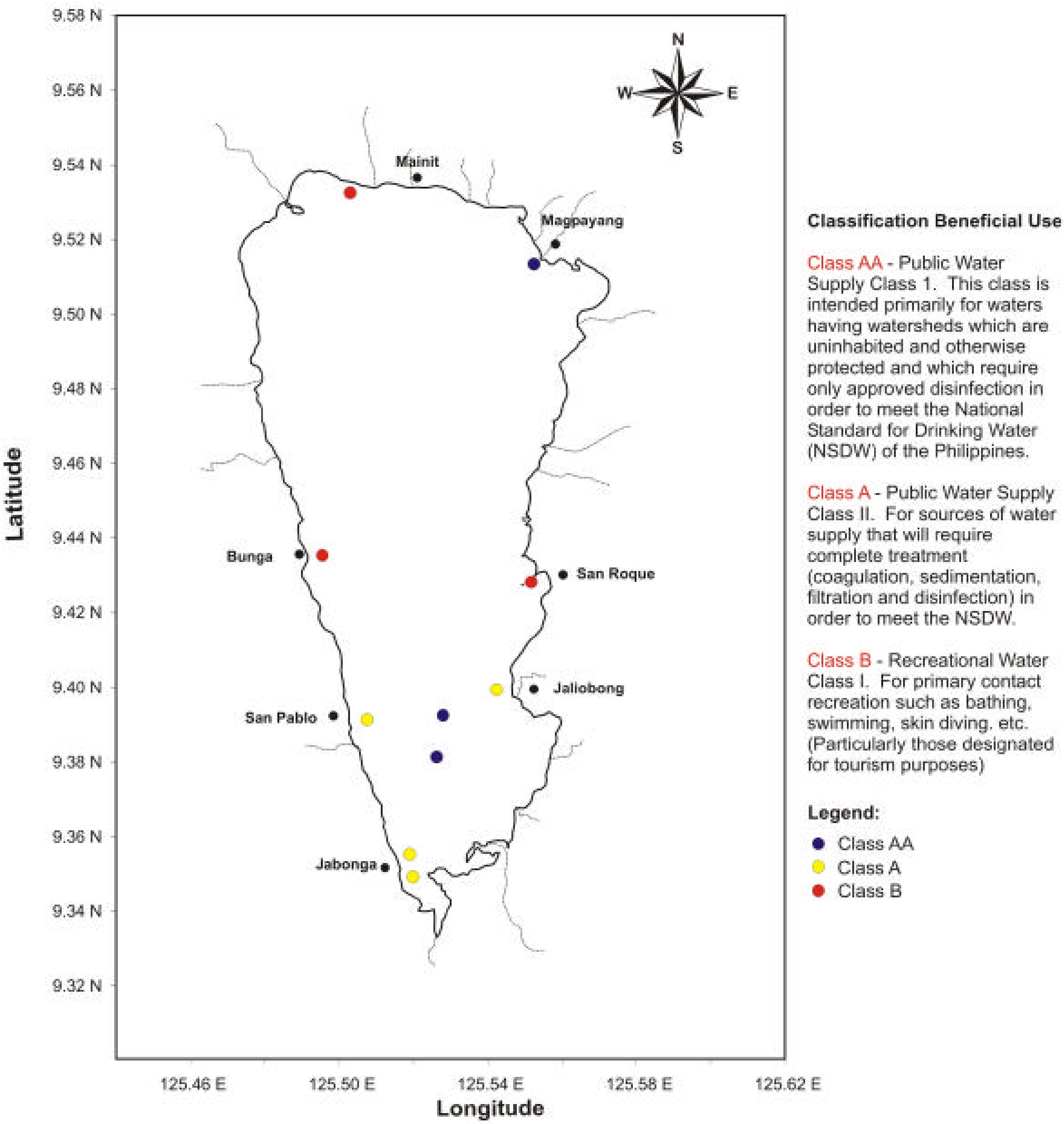

Figure 19. Bacterial load profile of various sampling stations in Lake Mainit with their comparative beneficial uses.

Plankton

Plankton are minute components of aquatic plants and animals whose movement is dependent on the strength and direction of the water current. Phytoplanktonic organisms contribute largely to the primary productivity of the aquatic environment. As primary producers in lake ecosystems, they play an important role of supporting the myriad of zooplankton population and a host of fauna belonging to other trophic levels. The production in terms of fish yield would depend on the rates of primary and secondary production carried out by these planktonic organisms.

Phytoplankton

About 53 species of phytoplankton have been identified in Lake Mainit. They are represented by the four groups, namely, the Bacillarophytes (diatoms), Chlorophytes (green algae), Cyanophytes (cyanobacteria or blue-green alga) and the Pyrrophytes (dinoflagellates). Lewis (1973) has identified 33 species belonging to the four phytoplankton groups although some species were different from what were identified in the present study. Although the four groups were represented in the samples only the chlorophytes and the diatoms dominated the phytoplankton population of the lake. The two groups were represented by *Oedogonium* and *Staurastrum* with relative abundance values of 68.89% and 20.65%, respectively. The mean population count was 2,483 cells.L^{-1} with the lowest (1,399 cells.L^{-1}) being observed in Bunga and the highest in Mainit (4,751 cells.L^{-1}) (Table 9).

The members of the Bacillarophytes are commonly referred to as the diatoms with a large number of unicellular and colonial genera. The cell wall is highly silicified and composed of two overlapping halves or frustules which fit together.

The important species of diatoms existing in the lake are the *Nitzchia, Diatoma, Fragillaria* and *Melosira*. All of the genera belong to pinnate groups except Melosira, which belongs to the centric group. This important diatom constitutes about 82% of the phytoplankton population.

Chlorophytes were also observed in the samples. They obtained the highest percentage of abundance (94.05%) of the phytoplankton population. They comprise the major group of green algae that exhibit tolerance for a wide range of environmental conditions. They include the unicellular, colonial, filamentous, membranous and tubular forms which were very common in the collected samples. Among them were *Apiocystis, Bactrachospernum, Chlamidomonads, Chlorosarcina,* and *Golenkenia*.

The cyanophytes were also commonly observed in the samples. These are called the blue-green algae and are distinct from the other algae because they do not have true nucleus and their chromatin material is not enclosed by a distinct nuclear envelope. The pigments are not localized in definite chromatophores or in definite plastids. Species belonging to *Gomphosphaera*, *Anabaena*, *Anacystis* and *Lyngbia* comprise the cyanophyte group and constituted 4.28% of the total phytoplankton population.

The dinoflagellates were also observed in minimal numbers in the lake. They were composed of the *Gonyaulax*, *Glenodinium*, *Ceratium* and *Peridinium*. These are flagellated phytoplankters which have pigments localized in chromatophores and usually greenish tan to golden brown in color. This group constituted 0.84% of the total phytoplankton population.

Chlorophyll *a*

Chlorophyll *a* readings range from 0.14 – 2.56 mg Chl *a*.m^{-3} with the lowest reading being obtained from Magtiaco and the highest from Puyo (Table 10). The average chlorophyll *a* reading is 1.20 mg Chl *a*.m^{-3} from the littoral zone and 0.29 mg Chl *a*.m^{-3} from the middle portion of the lake.

The chlorophyll *a* increasing readings were observed as the water column goes deeper up to a depth of 15 m. These could be explained by the light penetrating to the water column (Fig. 20).

Table 9. Phytoplankton densities and relative abundance.

Phytoplankton		**Cells/ sample**	**Cells.L^{-1}**	**Relative Abundance**
Bacillarophyta				
	Asterionella	4	21.00	
	Coscinodiscus	1	0.03	
	Denticula elegans	166	8.29	
	Diatoma	11	0.54	
	Meridion	37	1.83	
	Navicula	2	0.10	
	Nitzschia	143	7.14	
	Surirella spp	16	0.79	
				0.82
Chlorophyta				
	Apiocystis	1	0.03	
	Bactraspermum	1	0.06	
	Chlamydomonas	1	0.06	
	Chlorococcus lemniticus	26	1.30	
	Chlorosarcina consociata	1	0.03	
	Golenkenia radiata	971	48.50	
	Kirchneriella lunaris	133	6.63	
	Oocystis borgei	3	0.14	
	Oedogonium	41374	2069	
	Sphaerocystis	1172	58.60	
	Spirogyra	6	0.32	
	Volvox auseaus	11	0.539	
				94.05
Chryptophyceae				
	Rhodomonas	3	0.14	
				0.65
Cyanophyceae				
	Anabaena spp	315	15.78	
	Anabaenopsis	402	20.10	
	Anacystis	1	0.03	
	Aphanothece stagnina	4	0.19	
	Aphanocapsa gravilleli	491	24.50	
	Coelospherium kuitzingianu	1	0.06	
	Gomphosphaera	61	3.01	
	Lyngbia	3	0.16	
	Marssaniella elegans	17	0.86	
	Oocystis	112	5.29	
	Phormidium	5	0.26	
	Planktosphaera	574	28.50	
	Spirulina	4	0.22	
				4.28
Dinophyceae				
	Ceratium sp	84	4.18	
	Gonyaulax	300	15.00	
	Glenodinium	5	0.27	
	Gymnodinium	1	0.056	
				0.84

Table 10. Chlorophyll *a* readings and plankton densities in Lake Mainit.

	Station	Chlorophyll *a* (mgChl a m^{-3})	Phytoplankton (cells L^{-1})	Zooplankton (indiv.L^{-1})	Ichthyoplankton (indiv.$haul^{-1}$)
1	Center	0.29	1610	23	0
2	Mabini	1.53	2325	127	13
3	Puyo	2.56	4019	578	3
4	Magpayang	0.55	1416	54	3
5	Mainit	1.71	3751	768	5
6	Jabonga	1.66	3527	110	4
7	Bangunay	1.54	1937	67	8
8	Roxas	1.31	3566	122	2
9	Mansayao	1.56	1648	232	5
10	San Isidro	0.61	1659	162	2
11	Bunga	0.50	1399	75	4
12	Tapian	0.60	1539	219	15
13	San Pablo	1.53	2683	226	17
14	Anahao	1.29	2202	111	10
15	Tagbuyawan	1.64	1788	92	1
16	Mayag	1.55	2125	198	1
17	Magtiaco	1.4	4230	92	1
18	Jaliobong	1.13	1692	186	1
19	San Roque	1.16	3983	221	6
20	Pakuyab	1.55	1542	22	1

Zooplankton

Four groups of zooplankton dominated Lake Mainit, namely: copepods, rotifers, cladocerans, tintinnids, ostracods and insect (Table 12). The average population density is 184 indiv.L^{-1} with the highest population (578 indiv.L^{-1}) being observed in Puyo and the lowest was observed in Pakuyab (22 indiv.L^{-1}). The mean population density was 184 indiv. L^{-1} which categorized the la ke as oligotrophic. Up to 500 individuals per liter may be found in eutrophic lakes (Goldman and Horne, 1983 as cited by Hansel *et al.*, 2002)

The eggs, nauplii and the adult stages comprised the population of the copepod group while *Brachionus* spp, *Keratella* and *Proales* comprise the rotifers. The cladocerans were represented by the *Diaphanosoma* sp.

The abundance of zooplankton in the lake does not mean that they are grazing solely on phytoplankton. Bacteria apparently represent a large portion of the diet of some zooplankton species (Hwang *et al.*, 2003). Bacterivory in rotifers is the significant channel through which these species become abundant. It was observed that copepods outnumbered the cladoceran population which may be an index of an unproductive community.

Almost all of the identified plankton groups and species were also found in the 1975 survey of Lewis but since the method used were not the same with what Lewis had used in the assessment, the number expressed in the population density cannot be differentiated.

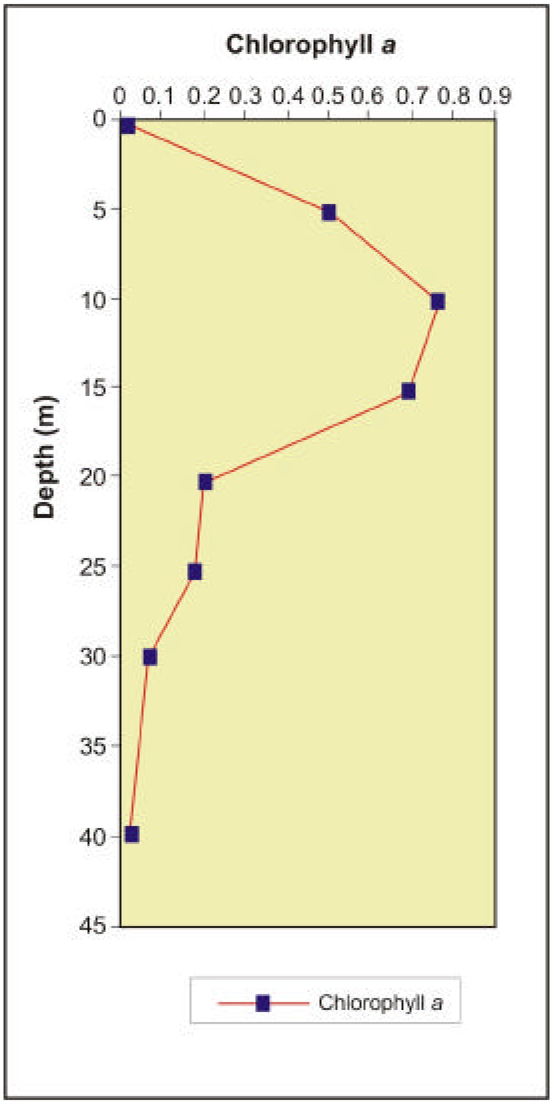

Figure 20. Chlorophyll *a* readings at different depths in Lake Mainit.

Ichthyoplankton

Ichthyoplankton is the term given to the larval stages of finfishes. They are distributed throughout the littoral zone of the lake. The collected samples ranged from 1 to 17 individuals per haul. The high number of collections were taken from San Pablo (15 indiv.haul^{-1}), Tapian (15 indiv.haul^{-1}) and Mabini (13 indiv.haul^{-1}). The rest of the stations obtained low counts ranging from 1 to 10 indiv.haul^{-1} (Table 10).

No ichthyoplankton was observed at the center part of the lake. The absence of ichthyoplankton in the area could be attributed to the scarcity of food and the physical condition of the water.

Table 12. Zooplankton densities and relative abundance.

Organism		**Population density (indiv.m^{-3})**	**Total**	**Relative abundance (%)**
Copepod				
	Adult	26738		
	Eggs	1672		
	Nauplii	33760		
			62170	41.95
Rotifers				
	Brachionus eggs	22740		
	Brachionus spp	2961		
	B. forficula	27922		
	B. dimidiatus	7		
	B. vaviabilis	634		
	Chydorus barroisi	123		
	Conochiloides dossaurius	666		
	Filinia brachiata	14		
	Keratella cochloris	26624		
	K. serrulata	465		
	Monostyla bulla	3128		
	Trichocera	382		
			85284	57.55
Cladocera				
	Alona sp	184		
	Camptocercus oklahoman	20		
	Daphnia sp	7		
	Kurzia sp	109		
	Moinodaphnia	27		
	Monophilis sp	68		
	Simocephalus	14		
			429	0.29
Ostracod				
	Cyclocypris sp	14	14	0.00
Insect				
	Mosquito larvae	170	170	0.11
Tintinnids				
	Tintinnopsis spp	126	126	0.09

VI. Summary, Conclusion and Recommendations

The ecological integrity of the Lake Mainit ecosystem, as a productive reservoir, is influenced by both its physical environment and water quality conditions. Lake Mainit is the receptacle of heavy siltation coming from its catchment areas, from agricultural lands and domestic activities which are carried down through its river tributaries. One of the main concerns of lake management is the continuous and fast deposition of silt. This study may not provide complete picture of sedimentation in the lake because it has not identified other potential sediment sources due to the limited observation period. Many residents around the lake are however aware that rivers in the lake watershed have high sediment loads that indicate a disturbed ecosystem. Some management strategies that would reduce sediment inputs are presented.

The uncontrolled introduction and accumulation of fine materials into the lake which cannot drain outside is already a threat to the integrity of the lake. This should be an immediate concern for policy makers as it can result to a situation where it would be very difficult to manage. The prevention of floods that reach higher grounds and inundating the lakeshore areas can be accomplished by dredging the areas where silt has accumulated. This scheme would allow faster flow of water to its outlet. Avoiding further entry of silt into the lake would require the cooperation of land users in the highlands and should include soil conservation to minimize soil erosion. Appropriate slope farming technologies are now available that can be adopted by farmers to mitigate rapid soil erosion. Other measures which can be employed to reduce siltation in Lake Mainit are the reduction of quarrying, mining, illegal logging activities. Improvement of vegetative cover through reforestation in the watershed areas and along the river banks, proper disposal of domestic wastes including its treatment should be part of the lake management plan.

Future management effort should also include information drive to farmers regarding the use of pesticides and fertilizers. The right amount and the timing of application and draining must be stressed so that Cd and pesticide pollution in the lake will be prevented.

The study also indicated that biological pollution in Lake Mainit is not serious and confined only within a small part of the water body. It should be emphasized, however, that the bacteriological analysis of water conducted in the Lake is very limited in terms of temporal and spatial coverage.

The results obtained by the DENR-EMB, Caraga Region, have already shown exceedance of the maximum allowable Cd concentrations in some parts of the lake. This is consistent to the results obtained in this study. It is therefore recommended that monitoring should be done not only in water but also in the sediments, plants and aquatic organisms.

Lake Mainit has rich aquatic resource potentials that can be developed and bring about economic benefits for the lakeshore residents. It has been the source of income for many fishermen and food for many residents in the area but its utilization can be enhanced by creating projects such as tourism and recreation activities and tapping it as a source of water supply. The improvement of the lake productivity would include establishment of sanctuaries where sedimentation should be an important consideration. Identification of appropriate suitable places for such activities would require careful planning.

Information on the fishery resources are also necessary in coming up of a management strategy to prevent depletion and exploitation of aquatic resources. In the absence of these data fish stock assessment is also recommended.

The ecological condition of Lake Mainit needs to be monitored in the context of maintaining its diverse fishery resources while exploiting their commercial uses. The limited monitoring of the nutrient conditions of the lake during the two sampling periods indicates that nutrient loading into Lake Mainit is sufficient to maintain its oligotrophic condition while the corresponding chlorophyll *a* data indicate an optimum level of productivity. Further, lake transparency, as measured by Secchi depth, is high and consistent with chlorophyll *a* data. The positive correlation between Secchi depth and chlorophyll *a* would likely reflect the low turbidity in most parts of the lake basin. An examination of the algal population would however also indicate that the oligotrophic level of lake productivity is supported by the amount of nutrient inflow into the lake.

Finally, a thorough water quality monitoring should be done to understand fully the effects of sediment loading, possible pollutant and nutrient delivery through the tributaries to the lake. This should include in depth studies on water clarity, water retention time, nutrients, macro-invertebrates and other biological parameters, all of which may affect the biological productivity and ecological health of Lake Mainit.

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