**Environmental and Natural Resource Accounting Project (Phase II): Institutionalization of the Philippine Economic-Environmental and Natural Resource Accounting (PEENRA) System**

# Estimation of Fish Biomass in Laguna de Bay Based on Primary Productivity

**Republika ng Pilipinas**
**PAMBANSANG LUPON SA UGNAYANG PANG-ESTADISTIKA**
**(National Statistical Coordination Board)**
**March 1999**

# Estimation of Fish Biomass in Laguna de Bay Based on Primary Productivity[1]

## INTRODUCTION

Phytoplankter have long been used as indicators of water quality and index of the productivity of any given water resource. Their small size and short life cycle enable them to respond quickly to environmental changes, hence, their standing crop and species composition are more likely to indicate the quality of the water mass in which they are found. They influence certain non-biological aspects of water quality (such as: pH, color, taste and odor), hence they are part of water quality.

Phytoplankton productivity is the common and important factor being considered in determining the overall status of a given body of water. This is because they are found at the base of an energy chain or food chain, being the basic source of primary food in a given aquatic system. Hence, information on their contribution is essential in indicating how much biomass energy will be available to all other living resources in the system.

Therefore, this study aims to relate primary production to fishery production in Laguna Lake with the following specific objectives:

1. To prepare a substantial review of related literature on the primary production of the lake;
2. To provide estimates of primary productivity of Laguna Lake over time;
3. to provide estimates on the potential fish yield from the open water of Laguna Lake over time; and,
4. To provide estimates of fish biomass from open water of Laguna Lake over time.

## REVIEW OF LITERATURE

### Brief Description of the Laguna Lake

Laguna Lake (popularly known as Laguna de Bay), the largest lake in the Philippines, lies about 15 km. southeast of Manila on the island of Luzon (Fig. 1). It has a surface area of 911 square kilometers or about 90,000 hectares, a shoreline of 220 km., a total volume of 3.2 x 109 $m^3$ an average depth of 3 m. The lake is generally turbid, most of the year mainly due to its high content of resuspended sediments. In 1994, the annual mean values of lake turbidity ranged from 58 to 84 mg/l $SiO_2$ (LLDA Master Plan, 1995). The shallowness of the lake (no more than 1 meter in secchi disk reading) contributes to its turbidity, too.

Of the 21 rivers which drain into the lake, the Marikina and Pagsanjan rivers contribute about 80% of its water volume (delos Reyes, 1995).

**Topography.** Laguna Lake was formerly a part of Manila Bay and was separated from it during quarternary times by movement along the Marikina fault (LLDA Report, 1978). Vertical displacement along the fault is estimated to be 150 meters in the Pasig area. The fault scarp, comprised of tuff (locally called adobe), constitutes the north/south trending ridge separating the lowland of Laguna Lake and Manila.

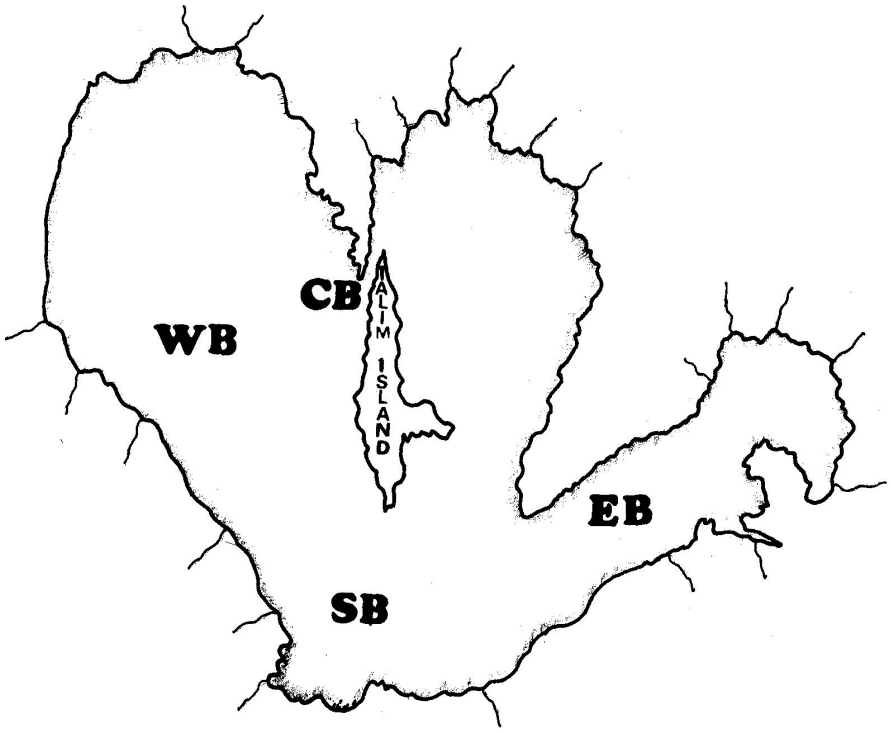
Several minor faults transect the lake area generally along the northeast/southwest

[1] A special study conducted for the Environmental and Natural Resource Accounting (ENRA) Subprogramme of the Integrated Environmental Management for Sustainable Development (IEMSD) Programe of UNDP, a project undertaken by the National Statistical Coordination Board (NSCB) in coordination of the Department of Environment and Natural Resources (DENR) and in support of the United Nations Development Programme (UNDP), which was subcontracted to Dr. Milagrosa R. Martinez-Goss, an Associate Professor from the Institute of Biological Science (IBS), College of Arts and Sciences (CAS), University of the Philippines at Los Baños (UPLB), Laguna.

or northwest/southeast fracture zones. These faults control topographic relief, giving rise to predominantly north/south trending features along the northern half of the lake and separating the lake into four bays, i.e., West, Central, East and South. The first three bays are about 30 to 40 km long and 7 to 20 km wide. The West Bay, the industrial-urban area, is located nearest Metro Manila; the Central Bay is close to the denuded hills with some flat areas where rice is grown; the East Bay rises steeply over a plateau; and the South Bay is generally a flat terrain where duck raising, rice and sugar cane production abound.

**Figure 1. Map of Laguna Lake**

WB - West Bay, CB - Central Bay, EB - East Bay, SB - South Bay



## Some Infrastructures in the Lake that Affected Fishery Production

There are several developments affecting the water resources of the basin, but only three will be considered relevant in this paper, i.e. the fishpen aquaculture, the Napindan Hydraulic Control Structure (NHCS), and the Manggahan Floodway.

**Proliferation of fishpens.** In 1973, when fishpen culture of milkfish (*Chanos chanos*) had just begun, 4,800 hectares of the lake surface area were occupied by fishpens and fish cages. The technology, which was originally intended for the small fisherman, attracted instead several businessmen and entrepreneurs because of promising high yield and profits. The area of fishpens increased rapidly to as high as 35,000 hectares in 1983 or one third of the lake's surface (BAS, 1996; Sogreah, 1991;). At the same time, the stocking of the fishpens was not regulated. This resulted in several problems, such as slow fish growth and lower yield, reduction of open lake for traditional fishermen and fish catches and navigational difficulties.

It was noted that prior to 1973, it was possible to have two croppings of fish per year. In 1973, when the total fishpen area was 5,000 hectares with an average stocking density of 60,000 fingerlings per hectare, the annual harvest averaged 4 tons per hectare or a total yield of 60,000 metric tons per year (Santiago, Handout). Furthermore, the total open water catch was almost the same (LLDA-WHO, 1978).

But in 1982, with 31,000 hectares of fishpens stocked with 60,000 fingerlings per hectare, the food supply area of 12 fingerlings per hectare meant really a total lake area of 372,000 hectares (Sogreah, 1991) to achieve the fast growth and the production that was attained in 1973. Therefore in this case, the number of fish that the natural food resources in the lake could support exceeded its limit or carrying capacity (Delmendo, 1986) hence, creating an imbalance in the lake's food chain.

As a consequence, LLDA recommended the restriction of the fishpen hectarage to 15,000 if they stock at 60,000 fingerlings per hectare or to 10,000 hectares if the stocking density is reduced to 30,000 fingerlings per hectare. This recommendation became effective in 1994 and hopes to achieve a balance yield between the fishpen and the open water.

**Napindan Hydraulic Control Structure.** This consists of a gated dam, lock and navigation facilities across the Napindan Channel. The objectives are: (1) to stop the backflow of saline and polluted water from the Pasig River; (2) to control the lake level for the storage of water needed to ensure an adequate discharges for irrigation and other purposes; and (3) to facilitate the reduction of maximum level during floods. At present, due to the request of lake fishermen, the gates of the structure are left open. The fishermen claim that their catch is adversely affected when the structure is closed. It is their view that the saline water is needed by the fish and the snails, a view which is shared by Neilsen et al. (1981). On the other hand, it was observed that fishkills in a massive scale occurred in the lake in 1972, 1973, 1975, and 1977 due to algal blooms. In all these years, except in 1975, there were backflows. The effect of backflows in 1968 and 1969 on lake fishery were not as severe because aquaculture in the lake developed only after 1970.

**Manggahan Floodway.** The structure consists of a fully gated dam and a 9-kilometer long channel primarily to divert excess floodwater from the Marikina River into the lake. Its main objective is to protect the Metro Manila area against flooding from overflows of the Marikina and Pasig Rivers. The floodway will also serve to hasten the discharge from the lake when its level is higher than the level of the Marikina River.

## Brief Historical Description of the Biology of Laguna Lake

Laguna lake was naturally eutrophic as early as the 1930's with a high biological productivity (delos Reyes, 1995). Later anthropogenic activities added to the lake's natural loading, causing a further increase in eutrophication (Sogreah, 1991). The high levels of

phosphate and nitrogen influenced the occurrence of algal bloom. The bloom-forming algae in the lake are the blue-green algae, which are the Microcystis, Oscillatoria, and Anabaena species.

Rabanal, et al., (1964) recognized four trophic levels in the lake. The primary producers are mainly the phytoplankter and an assortment of macrophytes concentrated along the 220-kilometer shoreline. Due to the turbidity of the water, the submerged macrophytes cannot invade the deeper areas of the lake. The primary consumers are the zooplankter, shrimps and the milkfish together with some herbivorous fish, as tilapia. The secondary consumers include carnivorous fishes (goby). To the fourth level belong the decomposers and benthos (molluscs, midges).

For the 1990's the lake is identified as having three trophic levels as estimated by the Ecopath II model (delos Reyes, 1995). There were 34 pathways leading from the phytoplankter to the apex predator, the catfish. But probably the snakehead (an obligate carnivore) should be considered the apex predator because the catfish is an omnivore aside from the fact that its population has undergone species displacement (Palma, pers. comm.)

**Factors that affect algal production and primary productivity**. There have been some discussions as to the factors, which limit phytoplankton (herewith made synonymous to algae) growth in the lake. This is of vital importance since there seems to be a good correlation between primary production and fish yield in tropical waters (Marten and Polovina, 1982). Earlier studies indicated that nitrogen was the most important limiting factor for algal growth (Sogreah, 1974). However, it now appears that turbidity limits growth at certain times of the year, particularly in the cool, dry season (December to February) and also during windy months and typhoon occurrence (Nielsen, et al, 1981; and Environmental Resources, Ltd., 1977). In periods when turbidity is low, which most of the time occurs after typhoons have passed, algal numbers can increase due to deeper light penetration and by uptake of nutrients in the water. It is at these times that nitrogen can be exhausted by the algae and then nitrogen becomes the limiting factor.

Correlation analyses done on 16 selected parameters in the lake over a period of twelve years indicated a strong evidence that salt concentration affect positively total dissolved solids (delos Reyes, 1995). Nielsen, et al., in 1981 reported also that salt enhanced the aggregation and settling of the sediments. Likewise, WHO-LLDA in 1978 observed from their experiments that turbidity settles out considerably faster during backflows because of higher salinity. It was observed that the positive effect of backflow on algal growth and increase in NPP (net primary productivity) took a lag period of three months. Hence, when backflow of water occurs during the summer months (April to June), thereafter three months or during the rainy season (July to November) there usually occurred a higher NPP than in the dry season (see Charlton, 1993).

The "cleansing" effect of salt intrusion, hence, causing better algal growth can also be attributed to other nutrients that could come in with salt intrusion, as calcium. Calcium showed also a strong positive correlation with total dissolved solids (TDS) and the latter had a strong negative correlation to turbidity (delos Reyes, 1995). Therefore, calcium positively influenced algal growth.

Regression analyses of 16 selected parameters from 1980 to 1992 showed significant decreasing trends for phytoplankton, dissolved oxygen, temperature, pH, total dissolved solids and total solids (delos Reyes, 1995). On the other hand significant increasing trends were noted in net primary productivity, ammonia, turbidity and total suspended solids, and extraordinary trends were recorded in nutrients, such as, nitrate and especially phosphate. A constant trend in calcium hardness was also observed.

**Primary Productivity.** Primary productivity, often referred to as phytoplankton productivity, is the rate of carbon fixed or potential energy (in the form of organic compounds) stored by the algae in the process of oxygenic photosynthesis.

Earlier method of estimating productivity was based on cell enumeration using any calibrated glass slides (like, the haemacytometer) and the compound microscope. Later on, this method was modified converting enumerated algae into biomass. Using this method, one measures the length, width and depth of the organism in micrometer units and the product of the three was recorded as the volume of the organism.

The earlier cell enumeration done by the Laguna Lake Development Authority (LLDA, 1978) for the entire lake for the three algal groups during the warmer months (high algal concentration) of 1973 to 1977 were as follows:

| Year | Cells per milliliter | | | | |
|---|---|---|---|---|---|
| | 1973 | 1974 | 1975 | 1976 | 1977 |
| Blue-green algae | 400,000 | 100,000 | 100,000 [a] | 10,000 | 120,000 [b] |
| Green algae | 70 | 50 | 100 [a] | 800 | 3,000 [b] |
| Diatoms | 8,000 | 10,000 | 20,000 [a] | 20,000 | 3,000 [b] |

Note:
a = data incomplete
b = data taken during fishkills

The corresponding estimates on algal biomass in g/cubic meter were as follows:

| Year | Grams per cubic meter | | | | |
|---|---|---|---|---|---|
| | 1973 | 1974 | 1975 | 1976 | 1977 |
| Blue-green algae | 36 | 26 | -- [a] | 1.30 | -- [a] |
| Green algae | <1 | <1 | <1 | 1.00 | -- [a] |
| Diatoms | 4 | 7.10 | -- [a] | 5.00 | -- [a] |
| ***Average*** | ***14*** | ***12*** | | ***2.43*** | |

Note:
a = data incomplete

Hence, the biomass of the algae during this period was 27.5 g/m$^3$ or 27.5 mg/l or 0.82 mt/ha in wet weight[2]. This was the basis for the biomass of the algae in 1968 by delos Reyes (1995).

In a separate study conducted in March to November, 1973 in the four bays of the lake, Sogreah (1974) reported that the blue-green alga (BGA) *Microcystis (Anacystis)* was dominant over the other algal species. Hence, it was thought then to consider the actual fish production to be closely related to the rate of organic matter production by this BGA. It was noted that a concentration of 106 cells per milliliter of the BGA was approximately equal to 2.0 grams per cubic meter. As generally true in water, the inhibition of photosynthesis near the surface by too strong light, the maximum depth below the surface being governed by the decreasing light intensity, coupled by the high turbidity of the water, the thickness of the zone of production is only about one meter. Therefore, carbon fixation rate of 2 grams per cubic meter is about the same as 2 grams per square meter.

During the fishpen period, a biomass of 0.6055 metric tons per hectare was obtained by Nielsen (1983). This estimate was taken from the average values of the Central Bay (0.966 metric tons per hectare) and West Bay (0.245 metric tons per hectare). These relatively high values correspond to the periods of algal blooms in the lake.

[2] (27.5 g/m$^3$) x 3 m ave. depth = 82.5 g/m$^2$ or 0.825 MT/ha

LLDA noted a correlation between nutrient composition, such as, nitrogen and phosphorus, and the algal mass concentration (LLDA, 1978). It was observed that the nutrient concentrations dropped to almost zero every year after the onset of algal bloom. Occasionally a peak for soluble nutrient concentrations in summer months corresponds to the declining algal concentrations.

The overall nutrients available for algal growth as indicated by the nutrient concentrations immediately after the cooler months where there was minimal amount of algae in the lake and the total nutrient inflow to the lake allowed for a potential algal standing crop (biomass) of 49 milligrams per liter (wet weight) based on nitrogen and 83 milligrams per liter based on phosphorus during the periods of 1973 to 1977.

Net primary production has been measured by dissolved oxygen production since 1978 by LLDA (Sogreah, 1991). Two methods were applied, (1) bottle incubation at various depths, and (2) continuous dissolved oxygen (DO) recorder in the open water at 0.5 meter below the lake's surface water (LLDA, 1978). Dissolved oxygen net production is then converted to gram carbon fixation by square meter.

The daily DO production measured from May to September, 1977 ranged from 4.4 to 12 grams per square meter (LLDA, 1978). The compensation depth (the depth where respiration equals photosynthesis) was approximately one meter for the same period. A conversion factor of 7.5 was used to convert DO values to algal biomass that gave approximate biomass values of 33 to 90 grams per square meter per day. At that time there was limited information on biomass growth rates (production per standing crop or biomass), but there was an indication that the range was 0.2 to 6 doublings per day, the lowest occurring at the height of the standing crop in summer.

Between 1978 to 1984, the average primary production was estimated at one gram of carbon per square meter per day (1 g C/$m^2$/day) (Sogreah, 1991). Other measurements of Sogreah (1976) gave an average of only 0.53 g C /$m^2$/day.

Primary production was also measured using carbon-14 method (C14) (Nielsen, et al., 1981). However, this method although very accurate is not affordable locally. Besides, the in situ DO bottle technique has been found to yield good results in Laguna Lake, being a eutrophic lake.

C14 estimates in 1980 yielded an average of 2.1 g C /$m^2$ which gave an annual production of 780 g C/$m^2$. This figure is comparable to the production figures found in Lake Mainit and Lake Lanao in Mindanao which are 1.7 g C/m2/day and 1.75 g C /$m^2$/day, respectively (Lewis, 1974). A production of the same magnitude was also noted in nearby Sampaloc Lake in San Pablo City, Laguna (Nielsen, et al., 1981). The latter three lakes are deep and stratified and regeneration of nutrients from the sediment to the upper layer is incomplete throughout most of the year.

On the other, Laguna Lake is shallow and completely mixed. Therefore, the measured productivity values are lower compared to other tropical lakes.

**Conversion Factor Used.** Earlier calculation of biomass production from dissolved oxygen measurements used a conversion factor of 7.5 (LLDA-WHO, 1978). For example, the DO measurements recorded in May to September, ranged from 4.4 to 12 g/$m^2$ which had a corresponding biomass production of about 33 to 90 g/$m^2$. Later on, after 116 to 139 measurements done simultaneously on productivity and standing crop (biomass) of the algae in seven years, it was found out that the daily biomass production of 1 g C/ $m^2$ gave an equivalent amount of 20 g wet weight/$m^2$/day (LLDA-ADB, 1984). This is based on the following results they obtained from 1978 to 1984. However, not all the carbon fixed by the algae is totally converted to dry matter or biomass because some are used up for extracellular products or “lost” in respiration (up to 100%).

| | n | Average | Max. | Min. |
|---|---|---|---|---|
| Primary Production (g C/$m^2$/day) | 139 | 1.04 (+/- 0.68) | 4.30 | 0.03 |
| Algal biomass ($g/m^{3,}$ wet weight) | 116 | 4.13 (+/- 12) | 90.00 | 0.07 |

Algal growth rate studies (production versus standing crop; P/B) are limited for Laguna Lake. However, earlier studies indicated a range from 0.2 to 6 doublings per day, the lowest occurring at the height of the standing crop in summertime (LLDA-WHO, 1978). Considering that growth is temperature dependent and using maximum specific growth rate of 0.59 doublings per day at zero degrees Centrigrade, the following are the effects of water temperature on algal growth rate of a single species within the observed range of the lake's temperature (LLDA-ADB, 1984):

23°C = 2.6 doublings per day
25°C = 2.9 doublings per day
30°C = 4.0 doublings per day
32°C = 4.6 doublings per day
34°C = 5.2 doublings per day

This means that growth rates increased by a factor of 2 for a temperature interval of 23 to 34 °C. An earlier mathematical model was developed to forecast the algal biomass that took into consideration respiration, turbidity, and lake's depth: as 934 mg/l of algal biomass for turbidity of 0 mg/l, lake's depth of 2.7 meters, growth rate of 2 doublings per day and respiration of 15 percent

There is indeed a great difficulty in measuring algal growth rate (P/B), hence, this value was simply the ratio of the estimated production and biomass at that time as calculated by ECOPATH II (delos Reyes, 1995).

The estimation of the potential fish production from the primary producers could be done by taking the cell volume or algal biomass and multiplying by the growth rate or P/B. The conversion factor of 1/25 was used to convert algal biomass to fish (Sogreah, 1974). This means that it requires 25 grams of algae to produce 1 gram of fish. This conversion factor was noted to be overestimated (Sogreah,1991) besides the fact that the value has not been checked through experimentation for a long time.

Studies on the feeding habits of the main fishes in Laguna Lake have noted that 70 percent of them are considered omnivorous and 30 percent as predators (LLDA-WHO, 1978; Sogreah, 1974).

On the basis of these findings, the fishpens were introduced in 1971 to artificially culture a planktivorous fish, i. e., the milkfish (Chanos chanos) to fully utilize the natural food of the lake (the algae) until their full marketable size. At the height of the success of this fishpen industry, the yield reached up to 4 metric tons per hectare per year. Another planktivore fish is the mullet (Tag. "banak"; Mugil sp.). However, one disadvantage of these species is that they can not reproduce in the lake. Hence, there is a need to continuously restock the lake with their fingerlings.

Various species of Tilapia have been introduced that are both or either planktivores and omnivores. These species are resistant to low levels of oxygen and at the same time they can spawn easily in enclosed waters of the lake.

Dr. Yun-An-Tang, a fishery biologist formerly with FAO, recommended the introduction of silver carps and grass carps which are planktivores and herbivores, respectively either feeding at the bottom of the lake / the water column or on macrophytes

(Sogreah, 1974). Catfish, on the other hand, is omnivorous, using a large range of food items from algae, snails, shrimps, up to fish (de los Reyes,1995).

Based on the food habits of the major species in the lake, Sogreah in 1974 suggested that only 0.7 percent of the algal production is converted into fish flesh. This value is calculated for a population of fish feeding mainly on the planktonic algae. It is not probably possible nor advisable to eliminate completely the predators from the lake. On the average, about 20 percent predators should be maintained in the population to eliminate the weaker fishes. This proportion is maintained in a well-balanced natural waters.

On the other hand, the conversion factor of 1/25 or 4 percent from algae to fish could still be used for strictly planktivorous species, as in the fishpen culture of milkfish.

Another precautionary measure in converting algal production yield to fish production is that not all the algae will be taken up by the various organisms in the various trophic levels, because some of them may "leave" the lake thru outflow when the lake's water is higher than Manila bay, or some of the algae may die and sink and become part of the detritus or sediment. Furthermore, it is not possible for all the algae to be "harvested" by the different organisms - otherwise there won't be any left in the lake.

## MATERIALS AND METHODS

### Sources of Primary Data

Sampling was conducted in the four bays of the lake from July 25 up to September 3, 1997. In situ measurements were done for air and water temperature, water depth, secchi disk transparency, pH and salinity. Salinity was measured using a hand refractometer (ATAGO - S/mill) while the pH was determined using a portable Corning Check-mate 90 pH meter. Water samples were collected at various depths (surface, 0.5 meters and 1.0 meters) using a Van Dorn water sampler. Dissolved oxygen (DO) samples were fixed in the field while the primary production experiments were incubated for three hours using the light and dark bottle technique. A detailed analysis of this method is given in the section for Estimation Methodology.

Within four hours after sampling, the chemical analyses for the primary production experiments and the biological analyses were conducted in the Phycology Laboratory of the Institute of Biological Sciences at UP Los Baños. A 300-milliliter water sample from the three different depths for each bay was filtered through GF/C Whatman filter paper and kept in the freezer until ready for analysis. Likewise, one liter water samples that were collected from the three depths at each bay were concentrated by centrifugation for 10 min at 2,500 rate per miniute using a Kubota KS - 5200C centrifuge and preserved in buffered formalin to make a final concentration of 3 percent, v/v.

The algae were identified and enumerated using the Neubauer improved bright line haemacytometer and an AO Spencer compound microscope following the method of Martinez, et al. (1975). The volume of each cell was computed based on the shapes of the cells. In this case a volume of one cubic centimeter is assumed to be equivalent to one gram. A detailed estimation method using biovolume is discussed in section for Estimation Methodology.

### Sources of Secondary Data

Most of the information was obtained from the Environmental Protection Division of the Laguna Lake Development Authority (LLDA-EPD), the Southeast Asian Fisheries Development Corporation (SEAFDEC), the International Center for Living and Aquatic Resources Management (ICLARM), and the Philippine Council for Aquatic Marine Resources Development (PCMARD).

Some values used for the estimation of the various parameters were obtained from

the Ph. D. dissertation of de los Reyes (1995).

Unpublished data of net primary productivity data (1985 to 1995) and chlorophyll analysis for 1996 were obtained from LLDA-EPD. Other data were obtained from the Freshwater Research Station of the Bureau of Fisheries and Aquatic Resources, Region IV, under the Department of Agriculture (DA-BFAR Region IV, FRS). Production data of finfishes for 1979 to 1996 were obtained from the Bureau of Agricultural Statistics (BAS).

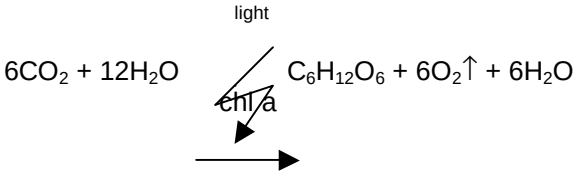
## Estimation Methodologies

The estimation of potential fish production on the basis of primary productivity (NPP and biomass) is summarized in the schematic diagram in Figure 2.

The estimation of the potential fish production of the lake was determined by measuring primary productivity or the oxygenic photosynthetic activity of the algae using the oxygen method or the light and dark bottle technique. Another method used was to measure the standing crop or the biomass of the algae either by getting their biovolume or analyzing their chlorophyll a content.

### 1. Oxygen Method

This method is based on the fact that in photosynthesis, the production of organic matter goes simultaneously with the evolution of oxygen; see chemical equation below:



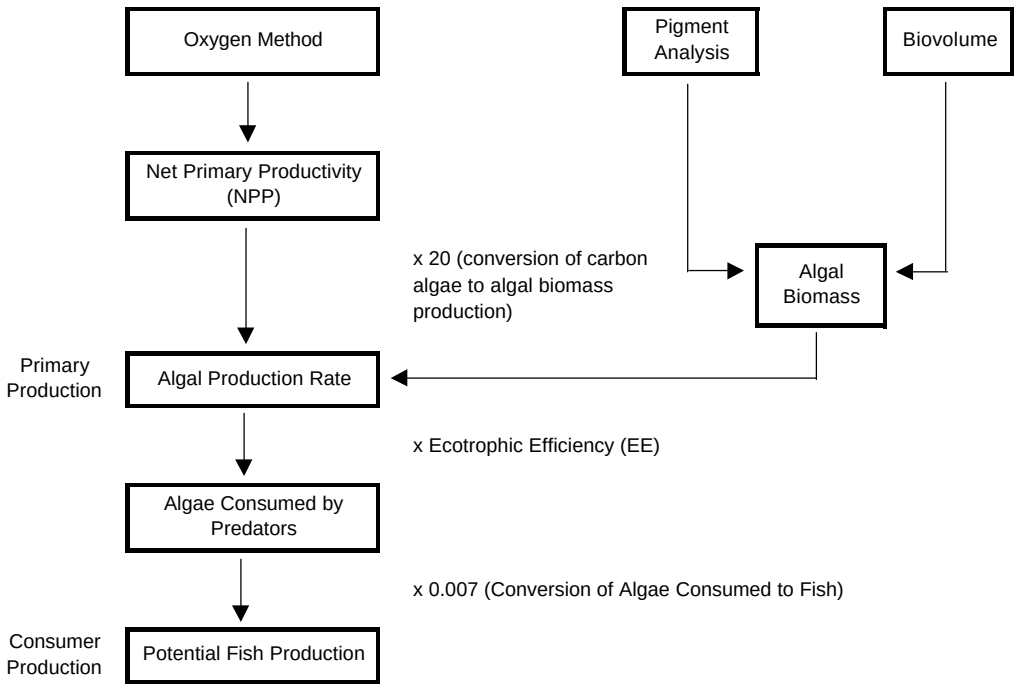

Hence, productivity is calculated on the basis that one atom of carbon is assimilated for each molecule of oxygen released.

### Light and Dark Bottle Technique

The net oxygen evolved was determined using the light-and-dark-bottle technique which was adapted from Strickland and Parsons (1972). In this case 300 ml-BOD (biological oxygen demand) bottles were divided into two lots, i.e., the clear or light bottles (LB) and darkened bottles (DB). The light bottles (LB) presumably measure the amount of oxygen evolved during photosynthesis minus the amount of oxygen consumed by the animals and other microorganisms while at the same time the DB measure the decrease in oxygen due to respiration only. This serves also as a check.

Four stations were selected around Laguna Lake, i.e., Central Bay, West Bay, East Bay, and South Bays and sampling depths were at regular of 0.5 meters from the surface up to 1 meter depth for our study while the LLDA used 0.2 meters regular intervals from the surface up to 1m depth. Earlier studies showed that the compensation depth for the lake was about 1 meter i.e., the depth where respiration equals photosynthesis (LLDA-WHO, 1978), hence, our studies were done only up to this depth.

**Figure 2. Schematic Diagram for the Three Alternative Methods of Estimating Potential Fish Production**




Water sample was drawn from each depth and filled the two light bottles and one dark bottle. These filled up bottles were returned to their original depths for incubation of three hours (as in our study) or twelve hours (as in the case of LLDA). A wooden frame with floaters was used to incubate all the bottles at one time (Fig. 3).

**Figure 3a. Biological Oxygen Demand (BOD) Bottles with Incubated Water Sample**

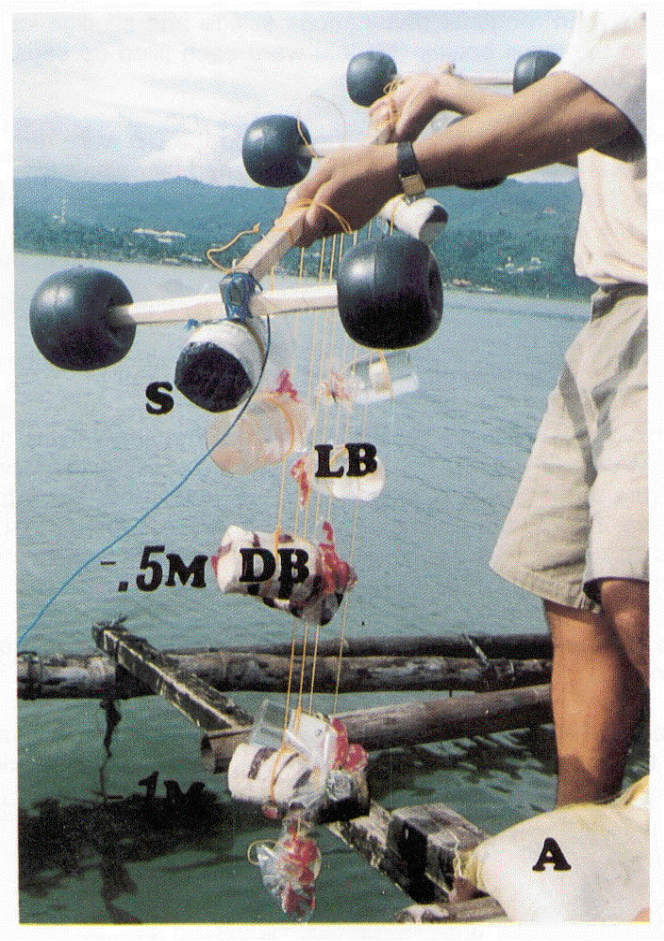
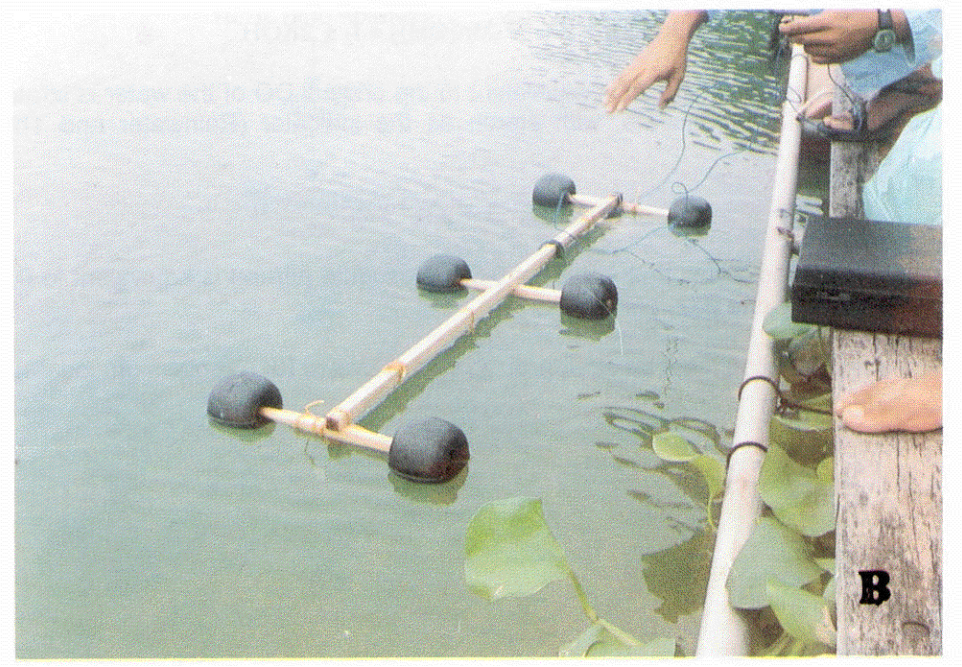



**Figure 3b. BOD Bottles Suspended in Laguna Lake with a Wooden Frame Supported by Floaters (F)**



## Conversion of Dissolved Oxygen from Net Photosynthesis to Carbon-Algae

As soon as the photosynthesis experiment started, the pickling solution of the Winkler's dissolved oxygen reagents (manganous sulfide and alkaline-iodide-azide solution) (Fig. 4) was added to the initial bottles (IB) that were each filled up separately with the lake water for each depth being studied.

Likewise, after the incubation period the LB and the DB were removed without delay and pickled as in IB. Net oxygen evolution was determined by getting the difference between the amount of dissolved oxygen in the light bottle (LB) after the incubation period and the dissolved oxygen in the initial bottle (IB) or at the beginning of the experiment. At the same time, the decrease in oxygen in the darkened bottle determined any respiration that occurred simultaneously with photosynthesis.

## Determination of Dissolved Oxygen

Dissolved oxygen in the bottles was determined chemically using the Modified Azide Winkler's method (MAW; APHA, 1976) or electrometrically using the Corning Check-mate model No. 90 membrane electrode. However, in the course of our study the DO membrane electrode broke down, hence, the chemical method was used throughout the study. In the MAW Method, it is assumed that the DO content of the water was mainly due to the net oxygenic photosynthetic activity.

Figure 4 shows the reagents and the step by step procedure used. The method is based on the following principle:

1. Manganese ions (II) are precipitated to manganous hydroxide in an alkaline solution;
2. The DO in the water is rapidly absorbed by the manganese hydroxide that may be in the following form:

$$MnSO_4 + 2KOH \rightarrow MN(OH)_2 + K_2SO_4$$
$$2Mn(OH)_2 + 0_2 \rightarrow 2MnO(OH)_2$$

2. On acidification with sulfuric acid, the liberated Mn(III) ions then react with previously added iodide ions and oxidized to iodine, which in turn forms a complex with the surplus iodide, thus it is protected from partial evaporation. Therefore, the iodine released is equivalent to DO present.

$$MnO(OH)_2 + 2KI \rightarrow Mn(OH)_2 + I_2 + 2KOH$$

3. The liberated iodine, which is equivalent to the original DO of the water is titrated with 0.025N sodium thiosulfate, with starch as the indicator (Rainwater and Thatcher, 1960).

$$I_2 + 2S_2O_3^{-} \rightarrow S_4O_6^{-2} + 2I^{+}$$

4. This method assumes that 1.0 ml of 0.5N thiosulfate (titrant) is equivalent to 0.25 mg at $O_2$, per L or one g $O_2$ per ml.

   The titrant solution must be standardized with standard $KIO_3$ (potassium iodate).

**Figure 4. The Reagents Used and the Flow Sheet in Determining Dissolved Oxygen in the Open Water of Laguna Lake Based on Modified Azide Winkler's Method (APHA, 1976; Lind, 1979).**

I. Reagents

a. Pickling solution : $MnSO_4 \bullet 2H_2O$ alkali-iodide-azide solution (with NaOH)

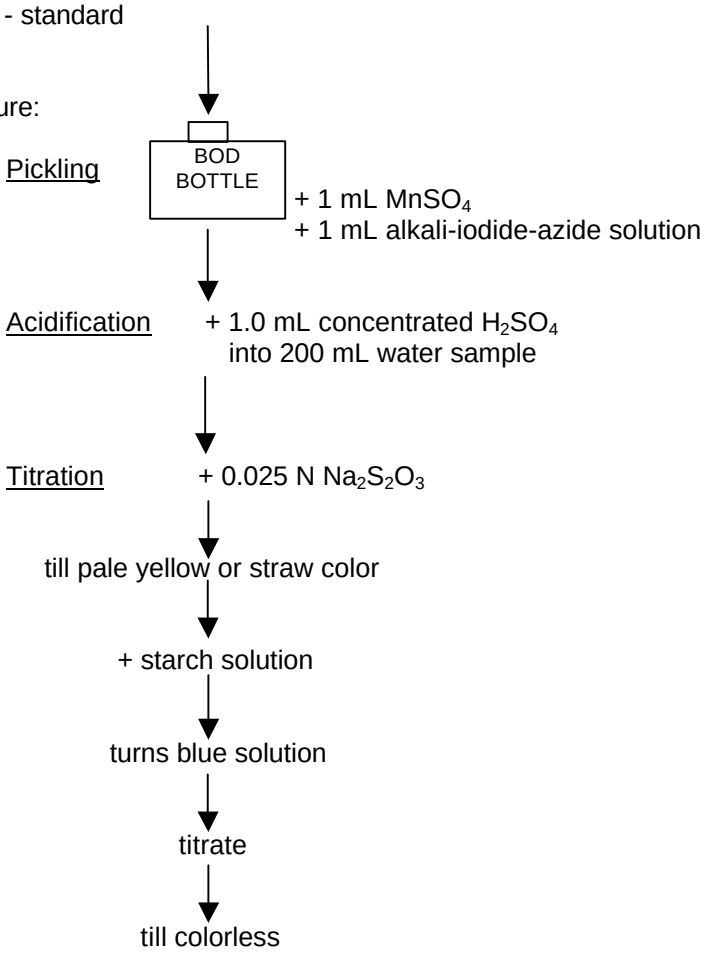
b. concentrated $H_2SO_4$

c. Titrant - 0.0125 N $Na_2S_2O_3 \bullet 5H_2O + Na_2CO_3$

d. soluble starch solution

e. $KIO_3$ - standard

II. Procedure:



## Conversion of Dissolved Oxygen from Net Photosynthesis to Carbon-Algae

Initial study on the dissolved oxygen-versus depth curve for Laguna Lake showed a surface inhibition with optimum value at about 0.2m and gradually decreasing up to about 1m depth (LLDA,1978). Based on this observation, the amount of dissolved oxygen was determined only up to 1-meter depth, hence, expressed beneath the 1 $m^2$ area. The area in the curve was determined by integration.

Net photosynthesis was initially expressed as $O_2$/ml after titration with Winkler's reagents. However, after integration the amount of dissolved oxygen within the $1m^2$ area was converted to g $O_2/m^2$. The oxygen value was converted to C atom by multiplying by a factor of 0.375 or 12/32 on the basis that one mole of $O_2$ (32 g.) is released for each mole of carbon fixed (12) (see chemical equation of photosynthesis). The value that is obtained is expressed as $gC/m^2$/day, which is also designated as net primary productivity.

## Conversion of C-algae to Algal Biomass

A factor of 20 was used to convert tons of C to wet weight of algae based on the assumption that in a given lake, all other elements are present in excess of the physiological needs, then carbon can generate between 10-12.5 times its fresh weight or 2 to 2.5 times its dry weight (Vallentyne, 1974; Lind, 1979).

Figure 5 summarizes the method of estimating algal biomass based on oxygen method. Below is a sample calculation based on the data we obtained in South Bay (SB) of Laguna Lake on July 25, 1997.

1. Initial dissolved oxygen (I. B.), g/mL*
   IB surface(s) --- 7.10
   IB 0.8m --- 7.05
   IB 1.0m --- 6.65
   ave. 6.93 g/mL

2. Dissolved oxygen in the light and dark bottles (LB and DB) after three hours incubation at different depths in the lake.

| Depth (m) | LB (g/mL) | DB (g/mL) |
|---|---|---|
| s (surface) | 10.2 | 7.0 |
| 0.2 | 10.1 | 6.9 |
| 0.4 | 10.1 | 6.9 |
| 0.6 | 9.9 | 6.9 |
| 0.8 | 9.7 | 6.8 |
| 1.0 | 8.9 | 6.8 |

3. Net dissolved oxygen (Net DO) and gross dissolved oxygen (Gross DO) at various depths.

a. LB - IB = Net DO b. LB - DB = Gross DO

| Depth (m) | Net DO (g/mL) | Gross DO (g/mL) |
|---|---|---|
| s (surface) | 3.27 | 3.2 |
| 0.2 | 3.17 | 3.2 |
| 0.4 | 3.17 | 3.2 |
| 0.6 | 2.97 | 3.0 |
| 0.8 | 2.77 | 2.9 |
| 1.0 | 1.97 | 2.3 |

1 mL of 0.025 N $Na_2S_2O_3$ is equivalent to 1 g. of $O_2$ per mL

4. Net primary Productivity

$$NPP = \frac{\text{Net DO at s + Net DO at 0.2m}}{2} \times \text{depth interval, etc.}$$

Then add all NPP — g $O_2$/ml

$\frac{3.27 + 3.17}{2}$ x 0.2 = 0.644

$\frac{3.17 + 3.17}{2}$ x 0.2 = 0.634

$\frac{3.17 + 2.97}{2}$ x 0.2 = 0.614

$\frac{2.97 + 2.77}{2}$ x 0.2 = 0.574

$\frac{2.77 + 1.97}{2}$ x 0.2 = 0.474

summ. = 2.94 g $O_2$/mL

$$NPP = \frac{2.94 \text{ mg } O_2}{m^2 - 3 \text{ hrs}} \times \frac{12 \text{ C}}{32 \text{ } O_2} \times \frac{24 \text{ hr}}{\text{day}}$$

$$NPP = 8.8 \text{ g C/m}^2\text{/day}$$

* For every mole of $O_2$ released there is a corresponding 12 C fixed.

5. Gross Primary Productivity (GPP) at various depths.

$$GPP = \frac{\text{Gross DO at s + Gross DO at 0.2m}}{2} \times \text{depth difference, etc.}$$

Then add all GPP's $g/O_2/mL$

$\frac{3.2 + 3.2}{2} \times 0.2 = 0.64$

$\frac{3.2 + 3.2}{2} \times 0.2 = 0.64$

$\frac{3.2 + 3.0}{2} \times 0.2 = 0.62$

$\frac{3.0 + 2.9}{2} \times 0.2 = 0.59$

$\frac{2.9 + 2.3}{2} \times 0.2 = 0.52$

summ. = 3.01 g $O_2$/mL

$$GPP = \frac{3.01\ mgO_2}{m^2 - 3\ hr} \times \frac{12C}{32O_2} \times \frac{24}{day}$$

6. Respiration = GPP - NPP

= 9.02 - 8.8

= 0.22 g $C/m^2$/day

7. Conversion of NPP to tons C-algae

NPP = 8.8 g $C/m^2$/day x 3.65 = 32.12 tons C/ha/yr.

8. Algal (biomass) production rate

32.12 x 20 = 642.4 tons algae/ha/yr.

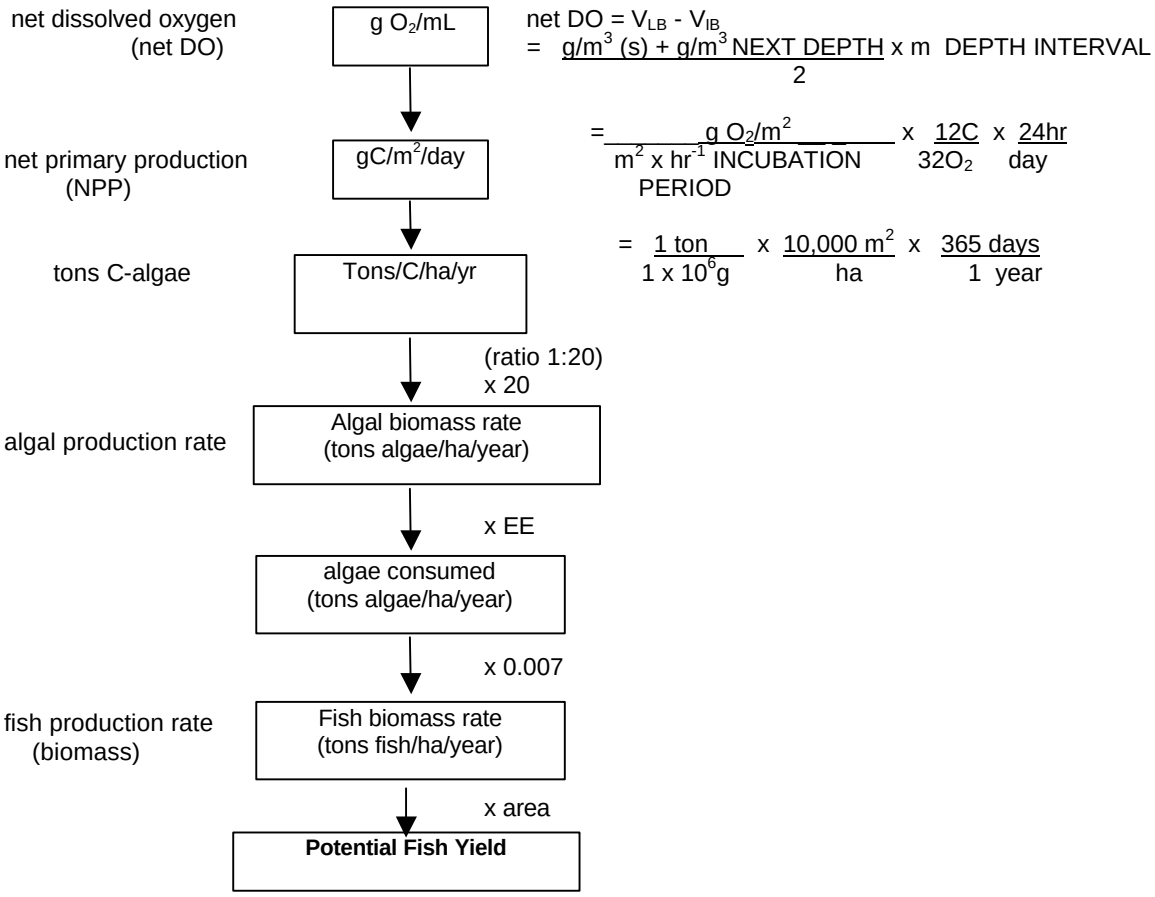
**Advantages of this method**

- This is straightforward method that is applicable in relatively toxic waters, as Laguna Lake.
- Easy to follow method and cheap.
- Samples can be pickled and stored for about 24 hours before titration is done.
- Ensures that live, oxygenic photosynthesizers are measured.

**Disadvantage**

- Laborious.

**Figure 5. Schematic Diagram Showing The Estimation of the Potential Fish Yield Based on Net Primary Productivity in the Open Water of Laguna Lake (Adapted From LLDA's Method)**




**Summary:**

**Potential fish yield** = $\frac{g\ O_2/m^2}{m^2 \times hr^{-1}} \times \frac{12C}{32O_2} \times \frac{24hr}{ton} \times \frac{ton}{1 \times 10^6 g} \times \frac{10{,}000\ m^2}{ha} \times \frac{365\ days}{1\ year} \times 20 \times EE \times .007 \times area$

## 2. Chlorophyll Analysis

Chlorophyll pigments are indeed the basic biological pigments involved in light absorption and photochemistry of photosynthesis in plants and algae. Chlorophyll (chl) content, particularly chl a, is widely accepted as a component in measuring biomass and the physiological condition of the algae. It is also a useful indicator of water quality when the ratio of algal biomass to chl a is taken (autotrophic index).

Chlorophyll a is a universal pigment to the algae because they are oxygenically photosynthesizing organisms. Other chlorophyll pigments are accessory pigments that transfer light energy to chlorophyll a. These accessory chlorophyll pigments include chl b that is common among green pigmented algae; chl c is found among the predominantly brown pigmented types, e. g., the diatoms; and chl d constitutes a minor component of some red pigmented algae.

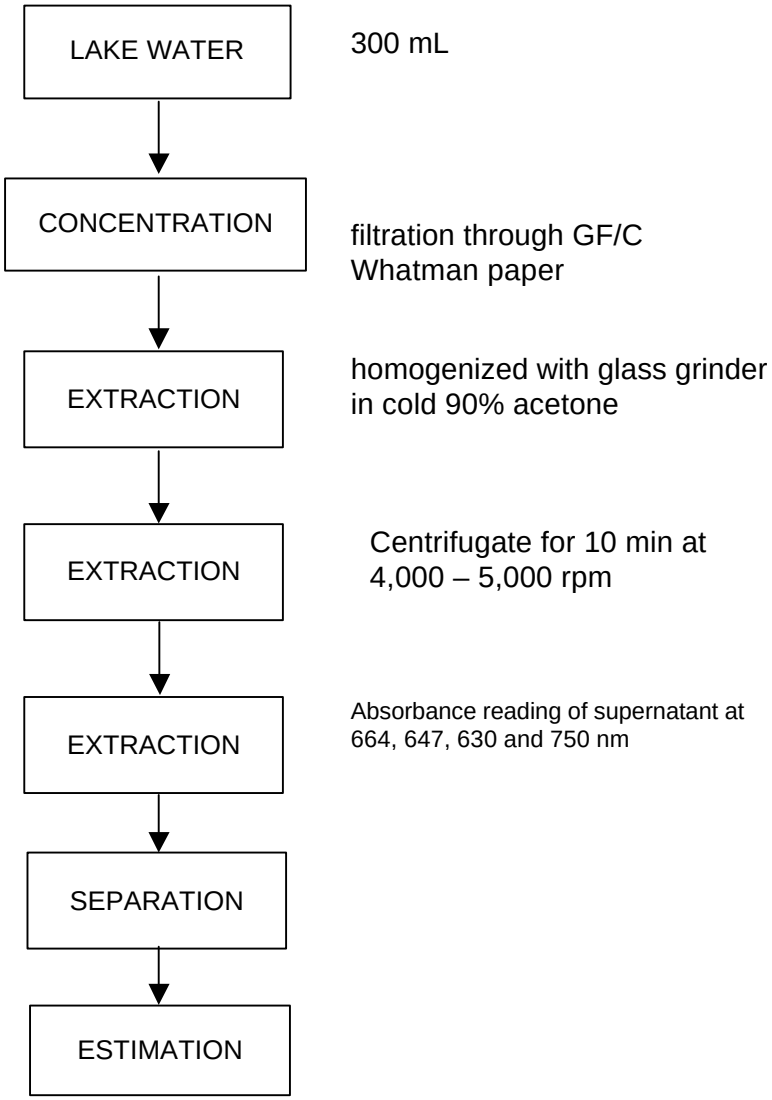
Chlorophyll a constitutes from 0.1 to 2 percent of the dry matter (DM) of algae (Martinez and Dionisio-Sese, 1995), hence, it is a part of their biomass. Although a greater bulk of the finfishes in Laguna Lake prefers feeding on diatoms, which constitute mainly

chlorophyll as its accessory pigments, the conversion of chl c to fish biomass has not yet been reported. However, this may be feasible.

## Methodology

Figure 6 shows the schematic diagram for chemical and colorimetric analyses for chlorophyll content of the algae.

**Figure 6. Schematic Diagram for Chemical and Colorimetric Analyses for Chlorophyll (Adapted From Jeffrey And Humphrey, 1975)**




**Chemical and colorimetric analyses for chlorophyll concentration.** A known volume of the lake water (usually 300 ml) was concentrated by filtration through a 4.7 mm GF/C filter paper (Whatman glass fiber). The filter paper was folded with the algae inside and wrapped in aluminum foil. At this state, the algae was frozen for several days' storage.

## Extraction

The algae together with the glass fiber filter paper was homogenized with a pinch of $MgCO_3$ under dim lights and in ice (Jeffrey and Humphrey, 1975).

## Sedimentation

The extracted mixture was centrifuged for 10 min. at 4,000 - 5,000 rpm and the supernatant was saved in a stoppered cuvette in ice and in the dark.

## Estimation

The concentration of the different chlorophyll pigments was estimated colorimetrically using the Bausch and Lomb, Spectronic 20 spectrophotometer. Chlorophyll absorbance of the supernatant was read at the following wavelengths (nm): 630, 647, 664 and 750 using 90% cold acetone as blank. The absorbance at 750 nm was subtracted from each of the other absorbances to correct for turbidity. The following equations were followed for estimating chlorophyll pigments (microgram chl/mL) of a mixed phytoplankton populations based on Jeffrey and Humphrey (1975).

chl a = $11.85\ A^*_{664} - 1.54\ A_{647} - 0.08\ A_{630}$
chl b = $-5.43\ A_{664} + 21.03\ A_{647} - 2.66\ A_{630}$
chl $c_1 + c_2$ = $-1.67\ A_{664} - 7.60\ A_{647} + 24.52\ A_{630}$

## Calculation

i. chl a concentration

$$mg/m^3 = \frac{\text{chl a (ug/mL) x extract vol. (mL)}}{\text{vol. of lake water filled (L)}}$$

ii. integration

$$\text{chl a, } mg/m^3 = \frac{\text{chl a, } mg/m^3{}_s + \text{mg chl a } m^3{}_{\text{next depth}}}{2} \text{ x depth interval}$$

$$= \text{chl a, } mg/m^2$$

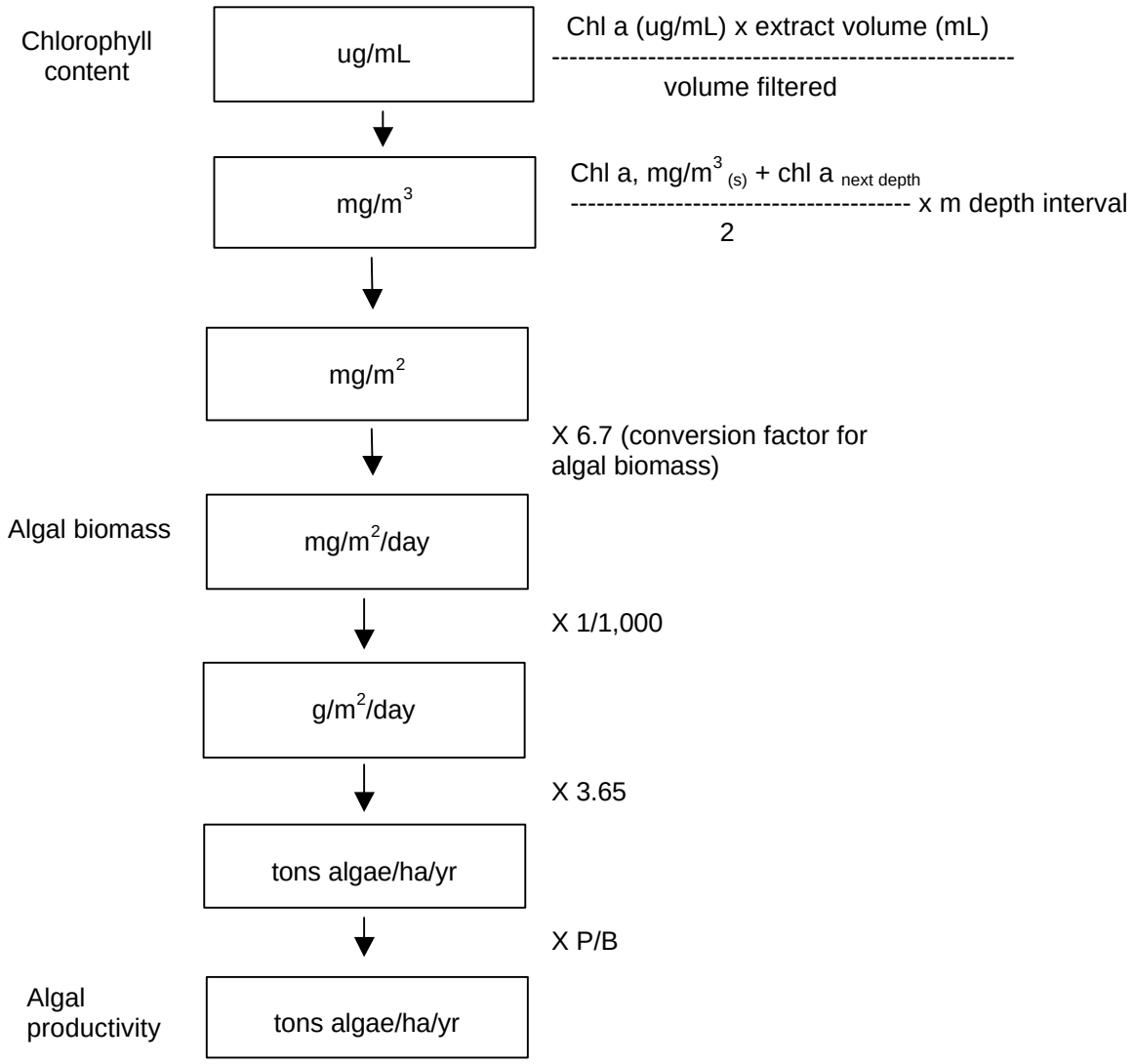
## Conversion of chlorophyll a content to algal biomass

Chlorophyll content ($mg/m^2$) was multiplied by a factor of 67 to convert it to algal biomass (APHA, 1976; Greitz and Richards, 1955). This is based on the assumption that chl a constitutes, on the average, 1.5% of the dry matter (ash-free) of the algae.

## Calculations

Figure 7 shows the estimation of algal biomass based on chlorophyll analysis and below is the sample calculation for estimating biomass based on chlorophyll analysis taken from our data in the south bay (SB) of Laguna lake on July 25, 1991.

**Figure 7. Schematic Diagram Showing the Estimation of the Algal Biomass Based on Chlorophyll A Analysis**




$$\text{Summary: tons algae/ha/yr} = \frac{\dfrac{\text{Chl a ug/mL x extr. mL}}{\text{volume filtered (L)}} \times 6.7 \times 3.65}{\dfrac{1{,}000}{}} \times \text{P/B}$$

a. Surface water chl analysis: chl mg/mL

i. chl a
= 11.85 (0.18) - 1.54 (0.12) - 2.66 (0.06)
= 2.133 - 0.1848 - 0.0048
= 1.9434 ug/mL

ii. chl b
= -5.43 (0.18) + 21.03 (0.12) - 2.66 (0.06)
= -0.9774 + 2.5236 - 0.1596
= 1.3866 ug/mL

iii. chl c
= -1.671 (0.18) - 7.60 (0.12) + 24.52 (0.06)
= -0.30078 - 0.912 + 1.4712
= 0.25042 ug/mL

b. chl a in $mg/m^3$

$$= \frac{\text{chl a (ug/mL) x extract volume (mL)}}{\text{volume of lake water filtered (L)}}$$

$$\text{Ex.} = \frac{1.96855 \text{ ug/mL} \times 3 \text{ mL}}{0.3 \text{ L}}$$

$= 52.494 \text{ mg/m}^3$

c. integration to convert chl a $mg/m^3$ to chl a $mg/m^2$

$$= \frac{\text{chl } a_s \text{ (mg/m}^3\text{)} + \text{chl } a_{\text{next depth}} \text{ (mg/m}_3\text{)}}{2} \times \text{depth interval (m)}$$

= chl a $(mg/m^2)$

Ex. i. $= \frac{52.494 + 29.793}{2} \times .5 \text{ m}$

$= 20.442 \text{ mg/m}^2$

ii. $= \frac{29.273 + 49.063}{2} \times .5 \text{ m}$

$= 19.584 \text{ mg/m}^2$

Sum = 40.026

d. chl a conversion to algal biomass $(g/m^2/day)$

$$= \text{chl a (mg/m}^2\text{)} \times 67 \times \frac{1 \text{ g}}{1{,}000 \text{ mg}}$$

$$\text{Ex.} = 40.026 \text{ (mg/m}^2\text{)} \times 67 \times \frac{1 \text{ g}}{1{,}000 \text{ mg}}$$

$= 2.682 \text{ g/m}^2\text{/day}$

e. conversion from algal biomass to tons algae/ha/yr

= chl a mg/$m^2$/day x 3.65

Ex. = 2.682 g/$m^2$/day x 3.65
= 9.7893 tons algae/ha/yr

**Advantages**

- A rapid method of estimating algal biomass;
- Can differentiate between groups of algae by the absorption peak of their accessory chlorophyll pigments.

**Disadvantage**

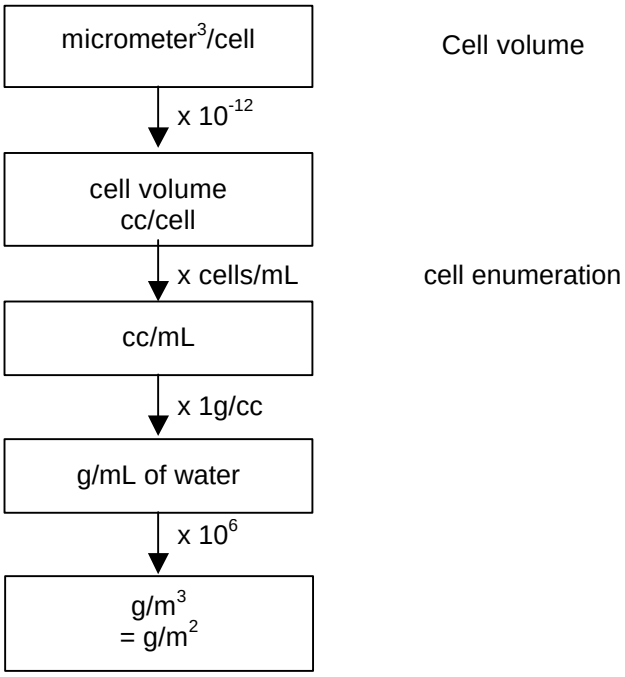
- Chlorophyll a concentration varies with groups of algae and state of nutrition of the algae.

### 3. Cell volume

One liter water sample was collected from three depths (surface, 0.5 m and 1.0 m depth) at every station around Laguna lake. These were preserved in buffered formalin to make a final concentration of 4 percent v/v. The samples were concentrated by centrifugation for 10 min at 2,500 rpm using a Kubota KS-5200C centrifuge.

The algae were identified and enumerated using the Neubauer improved bright line haematocytometer and an AO Spencer compound microscope following the method of Martinez, et al., (1975). The volume of each cell was computed based on the shapes of the cells. In this case, a volume of one cubic centimeter is assumed to be equivalent to one gram (Figure 8).

**Figure 8. Schematic Diagram Showing the Calculation of Algal Biomass Based on Cell Enumeration**



**Advantages**

- Inexpensive and readily available equipments;
- Allows identification of algae;
- Provides information on the viability and structural features of the algae.

**Disadvantages**

- Time consuming;
- Difficulty in obtaining the dimensions of some species.

### 4. Estimation of Potential Fish Production from Algal Production

Conversion of algal production rate was multiplied by the ecotrophic efficiency for that period (EE) to get the amount of algae consumed by the predators. Then the product obtained was multiplied by 0.007 to convert the algal biomass to fish biomass (Figure 5).

## Parameters Used

### 1. Biomass

Biomass (B) or the standing crop is the living weight present of the algae at any given time. Historically, the biomass of the algae in the lake was based on cell enumeration and conversion of the cell number to cell volume. No biomass data were gathered earlier than 1968. Therefore, the values for 1968 were based on the averages of the 1973, 1974, 1976 as recorded by LLDA-WHO (1978). The biomass during this period was reported as 27.5 mg/L or 0.825 MT/ha in wet weight (delos Reyes, 1995). During the fishpen period, a value of 0.6055 MT/ha was obtained from Nielsen (1983). This was the average value taken from the Central bay (0.966 MT/ha) and West bay (0.245 MT/ha). For years prior to 1973, biomass was calculated by ECOPATH II model (delos Reyes, 1995). Some data on algal biomass were based on chlorophyll content.

On the other hand, fish biomass for the different years was based mainly from the production data from BAS (Bureau of Agricultural Statistics). Production value for each fish species was divided by the P/B (Production / biomass ratio) of that species to get its corresponding biomass.

### 2. Production/Biomass Ratio (P/B)

Under steady-state conditions, P/B is equal to the instantaneous rate of total mortality (Z), if the growth of individual organisms is describable through the von Bertalanffy Growth Function (VBGF) (Allen, 1971). The P/B of the phytoplankton was more difficult to estimate in the lake, hence, this was assumed simply as the ratio of the estimated production and biomass (delos Reyes, 1995). Although, earlier studies indicated that the growth rates of algal biomass could range from 0.2 to 6 doublings per day (LLDA-WHO, 1978).

### 3. Ecotrophic Efficiency

Ecotrophic efficiency (EE) is that part of the total production which is consumed by predators or caught by a fishery. This parameter was difficult to determine and it was assumed to be between 0.1 to 1.0 (delos Reyes, 1995). All values were estimated by the ECOPATH II using the biomass values inputted (delos Reyes, 1995). The EE used for given year was very subjective based on the author's perception of the prevailing condition in the lake at that time. The higher the EE the greater was the amount of the algal production utilized, hence, assuming also more consumers, and vice-versa.

## 4. Production

Production includes all matter elaborated by the algae (whether it is ultimately eaten, washed out or dies of other causes) over the period considered. Total mortality, when constant, is equal to production over biomass. Therefore, in steady-state models, it is safe to treat estimates of total mortality (Z) as equivalent to production/biomass ratio (P/B), (Allen, 1971). Hence, the budget equation is in the form below (delos Reyes, 1993).

$$P_i = Mp_i - M_{ni} - C_i = 0$$

Where: $P_i$ is the production of species i,
$M_{pi}$. its predator mortality,
$M_{ni}$ other mortality, and
$C_i$: the fisheries catch of species i.

The production data obtained from various sources, including that from the Bureau of Agricultural Statistics (BAS) were taken to mean as is.

## 5. Conversion Factors Used

Calculations of algal production from net primary productivity (NPP) was based on the conversion factor of 20 or it means that there is 20-fold times algal biomass production from algal-carbon assimilated. While the ratio of algae to fish production used was 0.007 in the open water and 1/25 was used in fishpens where planktivorous species of fish are cultivated in captivity. The conversion factor of chlorophyll content to algal biomass was 6.7 instead of 67 (APHA, 1976) based on 1.5 percent chlorophyll content in algae (DM) and 100 percent moisture content of the algae.

### Reliability of Data

The primary and secondary data gathered were compared in a tabular form to examine whether there were some data that showed big discrepancies, hence, the latter were analyzed and/or discarded.

# RESULTS AND DISCUSSION

### Water Quality of the Lake

The variation of the water temperature over the entire lake was small, within a magnitude of three degrees (28-31°C) (Table 1). Time series analysis done for this parameter in the lake showed a decreasing trend over a period of twelve years, that is, from 1980 to 1992 (delos Reyes, 1995).

The depth of the lake had an average value of 3.34 meters (Table 1), although the usual average depth reported for the lake was 2.8 meters (Sogreah, 1974; Santiago, 1988).

**Table 1. Some Physico-Chemical Data in the Four Bays of Laguna Lake, July 25 to September 3, 1997***

| BAYS | South | Central | West | East |
|---|---|---|---|---|
| Temperature | | | | |
| Air | 24.00 | 27.00 | 30.00 | 30.00 |
| Water | 30.60 | 28.70 | 28.70 | 28.00 |
| Depth (m) | 3.00 | 3.00 | 3.25 | 4.13 |
| Secchi disk depth (cm) | 75.00 | 55.00 | 15.00 | 35.00 |
| pH | 8.55 | 8.64 | 8.69 | 8.44 |
| Salinity (ppt) | 1.00 | 2.00 | 2.00 | 2.00 |
| Dissolved oxygen-surface (g.mL) | 7.20 | 3.30 | 0.40 | 8.00 |

NOTE: Primary data

**Table 2. Net Primary Productivity (NPP) in the Three Depths of the Four Bays of Laguna Lake, July 25 to September 3, 1997***

| STATION | NPP (g-C/$m^2$/day) |
|---|---|
| I. South Bay | 8.80 |
| II. Central Bay | 2.08 |
| III. West Bay | 10.14 |
| IV. East Bay | 6.45 |
| **AVERAGE** | **6.87** |

NOTE: Primary data

**Table 3. Mean Chlorophyll Content of the Algae in the Four Bays at Different Depths in Laguna Lake, July 25 to September 3, 1997[1/]**

| BAYS/DEPTH | Mean Chlorophyll Values (ug/L) | | |
|---|---|---|---|
| | chl a[2/] | chl b | chl c |
| **I. South Bay** | | | |
| Surface | 52.49467 | 35.10187 | 5.31293 |
| -0.5 m | 29.27730 | 19.77333 | 4.01333 |
| -1.0 m | 49.06267 | 33.52400 | 18.72693 |
| ***Average*** | ***43.61150*** | ***29.46640*** | ***9.35106*** |
| **II. Central Bay** | | | |
| Surface | 119.94400 | 62.48000 | (12.57260) |
| -0.5 m | 147.36267 | 15.56900 | (49.31587) |
| -1.0 m | 52.41333 | 28.56400 | 9.93120 |
| ***Average*** | ***106.57333*** | ***35.53767*** | ***(51.96100)*** |
| **III. West Bay** | | | |
| Surface | 27.93800 | 45.24000 | 15.17547 |
| -0.5 m | 44.86933 | 59.49267 | (2.69147) |
| -1.0 m | 39.97133 | 23.34133 | 4.94235 |
| ***Average*** | ***39.59222*** | ***42.69133*** | ***17.42640*** |
| **IV. East Bay** | | | |
| Surface | 22.94667 | 16.77733 | 8.17600 |
| -0.5 m | 22.47600 | 13.28800 | 6.53712 |
| -1.0 m | 3.16400 | 27.53200 | 1.27333 |
| ***Average*** | ***16.19556*** | ***19.19911*** | ***5.32882*** |

**Table 3b. Mean Values by Depth for Every Chlorophyll Type, Regardless of the Bay**

| DEPTH | mg/L | | |
|---|---|---|---|
| | chl a | chl b | chl c |
| Surface | 55.83200 | 39.89867 | 3.35733 |
| -0.5 m | 60.99467 | 27.03200 | (10.36533) |
| -1.0 m | 36.15200 | 28.24000 | 8.08267 |
| ***Average*** | ***50.99289*** | ***31.72356*** | ***0.35882*** |

1/ Primary data
2/ chl a, b, c = chlorophyll a, b, c

**Table 4. Mean Cell Density of the Algae in the Four Bays at Different Depths in Laguna Lake, July 25 to September 3, 1997**

| BAYS/DEPTH | Biovolume ($g/m^2$) | | | |
|---|---|---|---|---|
| | Blue-green algae | Diatoms | Green algae | Total |
| **I. South Bay** | | | | |
| Surface | 0.38590 | 0.23730 | - | 0.62320 |
| -0.5 m | 0.01645 | 0.00292 | - | 0.01937 |
| -1.0 m | 0.33659 | 1.51560 | 0.00736 | 1.85955 |
| **II. Central Bay** | | | | |
| Surface | 0.17839 | 0.02737 | - | 0.20576 |
| -0.5 m | 0.14662 | 0.00997 | - | 0.15659 |
| -1.0 m | 0.05480 | 0.03687 | 0.01140 | 0.10307 |
| **III. West Bay** | | | | |
| Surface | 0.00139 | 0.73014 | 0.00210 | 0.73273 |
| -0.5 m | 0.00935 | 1.09135 | 0.00058 | 1.10128 |
| -1.0 m | - | - | - | - |
| **IV. East Bay** | | | | |
| Surface | 0.00995 | 0.42876 | 0.00010 | 0.43881 |
| -0.5 m | 0.01826 | 0.45101 | 0.00323 | 0.47250 |
| -1.0 m | 0.00608 | 0.30377 | 0.00087 | 0.31072 |

**Table 4b. Mean Values by Depth for Every Group of Algae, Regardless of the Bay**

| DEPTH | $g/m^2$ | | | |
|---|---|---|---|---|
| | Blue-green algae | Diatoms | Green algae | Total |
| Surface | 1.14390 | 0.35590 | 0.00030 | 0.50010 |
| -0.5 m | 0.04770 | 0.38880 | 0.00100 | 0.43740 |
| -1.0 m | 0.09940 | 0.46410 | 0.00490 | 0.56830 |

The transparency of the water never went deeper than 1 meter, the deepest recorded value was 75 cm in the South Bay and the shallowest was 15 cm in the West Bay. Transparency of the water is inversely related to turbidity. Turbidity values for the lake ranged from 30 to 200 mg/L of $SiO_2$ (1967-88) (LLDA-WHO, 1978; Sogreah, 1991). This is rather a high turbidity value due to the lake's shallowness, unprotected nature of the lake from wind action, ease in resuspension of the bottom sediments, or it may also be due to high concentration of the algae at certain period.

There are remarkable correlations of lake turbidity with water temperature and wind velocity. It appears that a prolong period of strong wind during the cooler months supported by a high water viscosity and low water temperature is one of the factors for high turbidity. It is also possible that the bottom sediments of clayey particles have a great cooling effect on the water and the strong wind current cools off the water column faster when it is shallow. Hence, the lake water seemed to be getting cooler with shallowing of the water depth.

Previous data showed no apparent relationship existed between turbidity and the algal density (LLDA-WHO, 1978). However, the constancy of the pH values towards the alkaline side strongly indicates that the greater bulk of the microorganisms in the lake are photosynthetic phytoplankter that take up $CO_2$ and bicarbonates and cause shifting of pH towards higher values (Round, 1973).

## Primary Productivity of the Lake

Primary productivity in Laguna lake is really synonymous to phytoplankton productivity because phytoplankter are numerous and very minute that they form the bulk of the lake's biomass. They are responsible in converting radiant energy into biochemical form of energy in their body. They use water as the hydrogen donor for the reduction of carbon dioxide ($CO_2$), the latter forming the carbon skeletal framework for the different organic compounds synthesized. Concomitant to carbohydrate production is the release of oxygen (see chemical equation of photosynthesis). This is the oxygen being measured in the incubation of the light and dark bottles at various depths in the lake, wherein it is assumed that for every mole of $O_2$ (32 grams) released there is an equal and corresponding 12 C atoms being "fixed" in the system.

Hence, primary productivity can also mean the rate of photosynthesis, the basis of the food chain. This is expressed as some measure of biomass (C) per unit of time (day and year), per surface area ($m^2$, ha). Net primary productivity in the lake is expressed as g C/ $m^{-2}$ /day $^{-1}$.

### 1. Primary data

The net primary productivity data (NPP) that was obtained from the three depths of each of the four bays of Laguna Lake from July 25 to September 3, 1997 showed that the West Bay (by the Binangonan side) had the highest value (10.14 g C/$m^2$/day) while the lowest value was noted in Central Bay (2.08 g C/$m^2$/day) with a mean value of 6.87 g C/$m^2$/day. This is a mean value from 12 samplings. When these values are compared to the data obtained by LLDA our data are about 10 x higher than their monthly and annual values. For example, the monthly mean values for the West Bay in July to September for 1986, 1987 and 1988 ranged from 0.4 to 1.45 g C/$m^2$/day (Charlton, 1993) while the annual mean values for the same year were 0.70, 0.74 and 1.0 g C/$m^2$/day, respectively (Table 6). This means that the mean values from 32 samplings per month and 384 samplings per year would result in a 1/10 decrease in the NPP values as compared to 12 samplings only. It is also possible that analysis of our samples within four hours after sampling yielded values that are close to the time of sampling. Moreover, our samplings and analysis were done by the same person that eliminated the error due to greater variations. We also used the three hour incubation period instead of 12 hours (LLDA's method) that facilitated our work yielding the same result by extrapolation to the whole day. Moreover, our samplings were done always in the morning that usually yields higher values than measurements taken towards the end of the day, as in the case of LLDA. In fact, one of the recommendations of Charlton (1993) to LLDA was also to measure the lowest oxygen each day at daybreak as well as the ambient oxygen at the end of the day when NPP work is done. According to him, the difference should give the true open water net daytime areal community production (NDACP).

Chlorophyll a (chl a) values in the lake during our study showed a broad range from 3.164 to 147.363 ug/L (Table 3). Values as high as 150 ug/L were also earlier noted in the West Bay in 1987 (Charlton, 1993). Based on the Chlorophyll values recorded for the lake, it indicates that the lake is highly eutrophic (Vollenweider, 1971). Our study shows that Central Bay had the highest chl a followed by the following sites in decreasing order: South Bay, West bay and East bay. The trend was similar to that observed in 1987 and 1988 (Charlton, 1993). A comparison of the chl a values in different depths shows that generally, the 0.5 meter depth had relatively higher values than the surface with the 1.0 meter depth having the least value. This is also the trend observed in the NPP parameter.

Of the accessory chl pigments analyzed, chl c was observed to be the least in composition which is logical because this is of minor component in the algae (Martinez and Dionisio-Sese). Relatively, chl c was observed to be highest in West Bay, followed by the South, then East, and the least amount was noted in Central Bay. This type of chlorophyll was noted to be always high at the surface of the lake than in the other depths. This means the algae that contain an abundant chl c, like the diatoms, were predominantly found on the surface of the water and in the West Bay than, in Central Bay. Analysis of chl c in algae is not difficult, but because of its relatively lower composition in the cells it is usually not used for estimating algal biomass.

Analysis for chlorophyll b (chl b) showed that the highest value was noted in the West Bay, followed by the following sites in decreasing order: Central Bay, South Bay and East Bay. It is noted that when a site had a chl a:b ratio of 1.5 or higher , then the place had relatively fewer diatoms compared to the green and blue-green algae.

The mean cell density of the algae in the four bays showed that blue-green and diatoms equally predominate the waters in the lake with the green algae of the least in composition.

Of the three methods used in estimating primary productivity, it is apparent that the Biovolume and the chlorophyll analysis are more closely related to each other (Table 8).

## 2. Secondary Data

The net primary productivity data (NPP) that was obtained from 1985 to 1996 from LLDA had annual mean values ranging from 0.66 to 1.75 g C/$m^2$/day which are equivalent to 48 up to 127.75 metric ton of algae/ha/yr (Table 6). A relatively high mean value of 6.87 for 1997 may be due to one sampling done for each bay (Table 2). As you would have noted the mean annual NPP values presented by LLDA are relatively low because these are average monthly values from the four bays and the value from each bay was the mean value for the various depths up to 1 meter.

Time series analysis done on NPP over a period of twelve years, shows that there is a decreasing tendency for NPP values (delos Reyes, 1995). This is also the trend that was observed in the data gathered from 1980, 1985 to 1996.

When the available algal production values from 1986 to 1988 were examined for correlation with some other variables, such as, secchi disk depth, turbidity and biomass, it was noted that there was a strong negative correlation between NPP and turbidity (Charlton, 1993). Monthly NPP values for the West, East and Central bays showed minimal differences in the order of a factor of two or three. Hence, when the monthly NPP values for the West bay were studied, it was noted that there was a rise in NPP in May that coincided with the usual increase in rainfall at the end of the dry spell. Furthermore, decreasing wind speeds and the low lake levels at this time of the year which lessen the prevalence of deep mixing could have been more conducive to algal growth.

NPP values in the cooler months did not show an increasing trend, instead, there was a peak in July followed by a low value in September and a rising trend in November. Hence, it can be surmised that primary productivity did not follow a seasonal cycle for the three years studied. The pattern is also true on an annual scale, and this needs further investigation. But there seems to be a seasonal turbidity cycle regardless of the salt intrusion or “backflow” from Manila Bay through Pasig River. Laguna Lake is indeed prone to wind driven re-suspension of bottom sediments, especially since it is shallow (mean depth of 2.8 - 3.0 m). Wind speeds follow a seasonal cycle with a minimum in August rising to a maximum in April. The decline in water level between October and May seems to coincide with the higher wind speeds that tend to stimulate the re-suspension of the lakes bottom’s particles.

Although, the hypothesis that “backflow” tends to cause “cleansing” of the lake water and concominantly cause good algal growth may not hold true all the time. For example in 1987 there was no backflow and yet the succeeding months did not show relatively low NPP values (Charlton, 1993). Hence, there may be several factors acting at one time to give the impression that “Backflow” or salt intrusion is responsible for the productivity cycle of the lake.

On the other hand, NPP did not show any correlation with algal biomass because when NPP is observed to be high, then the production per unit biomass in the lake was also high (Charlton, 1993). NPP is usually three times higher than the algal biomass values (Tables 2 to 4).

The chlorophyll content of the algae found in the lake compared well with what is usually found in the field (Martinez-Goss and Dionisio Sese, 1995) (Table 3). The chlorophyll a:b ratio ranged from 6 to 1 which means that there is a diverse group of algae in the lake ranging from the blue-green algae to green and diatoms (Table 4 and 5). The diatoms were found to be relatively numerous in the lake, except at the time of algal bloom wherein the blue-green algae *Microcystis, Oscillatoria, Anabaena* and *Calothrix* are in abundance.

Algal bloom due to *Microcystis* had its peak in 1972 to 1974 and its occurrence decreased since 1981. Hence, algal bloom may not always mean that this is favorable for growth of the fish because generally the fishes show preferential food for some groups of algae. Stomach content analysis of the perch showed that the feed was mostly composed of diatoms (Delmendo, 1968). Other algae were not observed probably because they got degraded easily while the cell wall of the diatoms remained intact but the protoplast got digested by the fish. It seems that when there is algal bloom, especially due to *Microcystis* the effect was a massive fish kill as in 1972, 1973, and 1974 (Delmendo, 1974).

## Fishery Production

A total of 20 species of finfishes are included in the study of which 30 percent are phytoplankton feeders (Table 9). A greater percentage of the fishes are omnivores (40 percent) while the rest are carnivores (15 percent), herbivores (10 percent), and detrivores (5 percent).

**Table 5. List of Algae Observed in Laguna Lake, July 25 to September 3, 1997**

| Blue-Green Algae | Diatoms | Green Algae | Euglenoid |
|---|---|---|---|
| Aphanothece | Coscinodiscus | Ankistrodesmus | Trachelomonas |
| Calothrix | Cyclotella | Coelstrum | |
| Lyngbya | Melosira | Pediastrum | |
| Microcystis (Anacystis) | Melosira spiralis | Planktosphaeria | |
| Nostoc | Navicula | Tetraedron | |
| Oscillatoria | Nitzschia | | |
| Phormidium | | | |
| Plectonema | | | |

Table 6 shows the estimation of fish production based on algal productivity (NPP or $C_{14}$). The estimated fish yields based on the given NPP value of 1.49 g C/$m^2$/day for 1990 were different using two different formulas, i. e., A (where ecotrophic efficiency (EE) was considered and the conversion factor from algae to fish was 0.007) and B (did not consider EE and used .04 as the conversion factor).

Using formula A, the fish yield was 17,912 mt per year of 10% higher than harvest data of BAS. Formula B, on the other hand, predicted a fish yield equivalent to 367,565 mt per year, which was 2,163% higher than catch data of BAS. Formula A was used in Table 6.

Table 7 shows the estimation of potential fish production based on estimated algal biomass thru either chlorophyll analysis or biovolume. The trend of the calculated potential fish yield based on algal biomass (biovolume method) shows a peak value in 1976 (51,595 MT) which may be due to the high biomass obtained by Nielsen, et al., (1983) and the high ecotrophic efficiency. The patchy regional algal agglomerations with biomasses that were far beyond normal values reported in the fishkill study in 1977 in Central Bay supports the high algal biomass figure obtained by Nielsen in 1976.

Table 8 shows all the fish production figures, i. e., actual fish production (BAS), as well as the three potential fish production estimates.

**Table 6. Estimated Potential Fish Production Based on Algal Productivity (NPP of C14) in Laguna Lake, 1978-1997**

| YEAR | BAYS | A Net Primary Productivity (NPP) (g C/m$^2$/day) | B Carbon Production B=Ax3.65 (C/ha/yr) | C Algal Biomass Production Rate C=Bx20 (mt/ha/yr) | D Ecotrophic Efficiency (EE)[2] | E Algae Consumed (E=CxD) (mt/ha/yr) | F Potential Fish Production F=Ex0.007[3] (mt/ha/yr) | G Area of Open Water (ha) | H Potential Fish Production H=FxG (mt/yr) |
|---|---|---|---|---|---|---|---|---|---|
| 1978-1984 * | | 1.000 | 3.650 | 73.00 | 0.715 | 52.195 | 0.365 | 79,600 | 29,054 |
| 1978-1984 ** | | 1.040 | 3.796 | 75.92 | 0.715 | 54.280 | 0.380 | 73,600 | 27,968 |
| 1980 | | 2.100 | 7.665 | 153.30 | 0.715 | 109.610 | 0.767 | 79,600 | 61,053 |
| 1985 | WB[4] | 0.576 | | | | | | | |
| | CB | 0.626 | | | | | | | |
| | EB | 0.925 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 0.662 | | | | | | | |
| | AVE. | 0.700 | 2.555 | 51.40 | 0.715 | 36.540 | 0.256 | 62,000 | 15,872 |
| 1986 | WB | 0.770 | | | | | | | |
| | CB | 0.640 | | | | | | | |
| | EB | 0.670 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 0.860 | | | | | | | |
| | AVE. | 0.740 | 2.701 | 54.02 | 0.715 | 38.620 | 0.270 | 70,400 | 19,008 |
| 1987 | WB | 0.900 | | | | | | | |
| | CB | 0.980 | | | | | | | |
| | EB | 0.880 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 1.230 | | | | | | | |
| | AVE. | 1.000 | 3.650 | 73.00 | 0.715 | 52.200 | 0.365 | 76,100 | 2,776 |
| 1988 | WB | 0.600 | | | | | | | |
| | CB | 0.690 | | | | | | | |
| | EB | 0.670 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 0.660 | | | | | | | |
| | AVE. | 0.660 | 2.409 | 48.18 | 0.715 | 34.450 | 0.241 | 79,200 | 19,087 |
| 1989 | WB | 0.440 | | | | | | | |
| | CB | 0.760 | | | | | | | |
| | EB | 0.720 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 0.630 | | | | | | | |
| | AVE. | 0.640 | 2.336 | 46.72 | 0.715 | 33.400 | 0.234 | 84,200 | 19,703 |
| 1990 | WB | 1.260 | | | | | | | |
| | CB | 1.830 | | | | | | | |
| | EB | 0.970 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 1.900 | | | | | | | |
| | AVE. | 1.490 | 5.438 | 108.76 | 0.279 | 30.340 | 0.212 | 84,490 | 19,703 |
| 1991 | WB | 1.710 | | | | | | | |
| | CB | 1.740 | | | | | | | |
| | EB | 1.500 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 2.050 | | | | | | | |
| | AVE. | 1.750 | 6.387 | 127.74 | 0.279 | 35.640 | 0.249 | 83,750 | 20,854 |

***continued,***

**Table 6. Estimated Potential Fish Production.... *continuation.***

| YEAR | BAYS | A<br>Net Primary Productivity (NPP)<br>(g C/m$^2$/day) | B<br>Carbon Production<br>B=Ax3.65<br>(C/ha/yr) | C<br>Algal Biomass Production Rate<br>C=Bx20<br>(mt/ha/yr) | D<br>Ecotrophic Efficiency (EE)[2] | E<br>Algae Consumed<br>(E=CxD)<br>(mt/ha/yr) | F<br>Potential Fish Production<br>F=Ex0.007[3]<br>(mt/ha/yr) | G<br>Area of Open Water<br>(ha) | H<br>Potential Fish Production<br>H=FxG<br>(mt/yr) |
|---|---|---|---|---|---|---|---|---|---|
| 1992 | WB | 1.810 | | | | | | | |
| | CB | 1.410 | | | | | | | |
| | EB | 1.040 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 1.390 | | | | | | | |
| | AVE. | 1.410 | 5.146 | 102.92 | 0.279 | 28.710 | 0.201 | 83,520 | 16,788 |
| 1993 | WB | 1.920 | | | | | | | |
| | CB | 1.060 | | | | | | | |
| | EB | 0.360 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 2.410 | | | | | | | |
| | AVE. | 1.440 | 5.256 | 105.12 | 0.279 | 29.330 | 0.205 | 79,660 | 16,330 |
| 1994 | WB | 0.930 | | | | | | | |
| | CB | 0.420 | | | | | | | |
| | EB | 0.260 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 1.020 | | | | | | | |
| | AVE. | 0.660 | 2.409 | 48.18 | 0.279 | 13.440 | 0.094 | 77,870 | 7,320 |
| 1995 | WB | 1.350 | | | | | | | |
| | CB | 0.660 | | | | | | | |
| | EB | 0.580 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 0.820 | | | | | | | |
| | AVE. | 0.780 | 2.847 | 56.94 | 0.279 | 15.890 | 0.111 | 83,800 | 9,302 |
| 1996 | WB | 0.820 | | | | | | | |
| | CB | 0.580 | | | | | | | |
| | EB | 0.530 | | | | | | | |
| | SB | | | | | | | | |
| | LOOC | 1.190 | | | | | | | |
| | AVE. | 0.780 | 2.847 | 56.94 | 0.279 | 15.890 | 0.111 | 80,000 | 8,880 |

[1] NPP data from Laguna Lake Development Authority except 1978-1984; 1997; 1978-1984* derived from BCEOM, 1984; 1978-1984** data derived from LLDA-WHO, 1984; 1980 derived from C14 study of Nielsen (1981);

[2] EE derived from delos Reyes, 1995

[3] Conversion factor of 0.007 derived from SOGREAH, 1974

[4] WB=West Bay; CB=Central Bay; EB=East Bay; SB=South Bay; Loo, Cardona Rizal

## Table 7. Estimated Potential Fish Production Based on Algal Biomass, P/B and Ecotrophic Efficiency (EE) in Laguna Lake, 1820-1997[1]

| YEAR | A<br>Algal Biomass<br>(mt/ha) | B<br>P/B Production/Biomass | C<br>Algal Productivity<br>C=AxB (mt/ha) | D<br>(EE) Ecotrophic Efficiency | E<br>Algae Consumed<br>(E=CxD) (mt/ha/yr) | F<br>Potential Fish Production Rate<br>F=Ex0.007[2] (mt/ha/yr) | G<br>Area of Open Water<br>(ha) | H<br>Potential Fish Production<br>H=FxG (mt/yr) |
|---|---|---|---|---|---|---|---|---|
| 1820 | 0.9075 | 268.36 | 243.54 | 0.163 | 39.70 | 0.278 | 90,000 | 25,020 |
| 1920 | 0.8250 | 268.36 | 243.54 | 0.162 | 39.45 | 0.243 | 90,000 | 24,840 |
| 1950 | 0.8250 | 268.36 | 221.40 | 0.157 | 34.76 | 0.242 | 90,000 | 21,870 |
| 1968 | 0.8250 | 268.36 | 221.40 | 0.156 | 34.54 | 0.242 | 90,000 | 21,780 |
| 1973 | 0.8250 | 268.36 | 221.40 | 0.156 | 34.54 | 0.242 | 85,000 | 20,570 |
| 1974 | 0.8250 | 268.36 | 221.40 | 0.156 | 34.54 | 0.242 | 85,000 | 20,570 |
| 1974 * | 1.5122 | 146.90 | 405.81 | 0.156 | 63.31 | 0.443 | 85,000 | 37,655 |
| 1975 * | 0.3996 | 146.90 | 58.10 | 0.715 | 41.54 | 0.291 | 85,000 | 24,735 |
| 1976 | 0.8250 | 146.90 | 121.19 | 0.715 | 86.65 | 0.607 | 85,000 | 51,595 |
| 1980 | 0.6055 | 146.90 | 88.95 | 0.715 | 63.60 | 0.445 | 79,600 | 35,422 |
| 1982 * | 0.4577 | 146.90 | 67.24 | 0.715 | 48.08 | 0.337 | 64,900 | 21,871 |
| 1983 * | 0.4255 | 146.90 | 62.83 | 0.715 | 44.92 | 0.314 | 54,900 | 17,239 |
| 1990 | 0.6688 | 146.90 | 98.25 | 0.279 | 27.41 | 0.192 | 84,490 | 16,222 |
| 1996 [3] | 1.1650 | 146.90 | 171.14 | 0.279 | 47.75 | 0.334 | 80,000 | 26,720 |
| 1997 [4] | 1.3490 | 146.90 | 198.17 | 0.279 | 55.29 | 0.387 | 80,000 | 30,960 |

[1] Algal biomass for all years except 1973-1976; 1982-1983based from delos Reyes, 1995; algal biomass for 1973, 1974, 1976 based from Nielsen, et.al 1983; algal biomass for 1974*, 1975*, 1983* based from LLDA-WHO, 1984; P/B and EE based from delos reyes, 1995

[2] Conversion factor of 0.007 based on SOGREAH, 1974

[3] Based on chlorophyll analysis of LLDA

[4] Based on chlorophyll analysis from one sampling per bay

**Table 8. A Comparison of the Potential Fish Production (Metric Tons/Year) from Different Sources in the Open Water of Laguna Lake, 1820 to 1997[1/]**

| YEAR | Production[2] | Indirect Means | | |
|---|---|---|---|---|
| | | Net Primary Productivity[3] | Biomass | |
| | | | Biovolume[4] | Chlorophyll[5] |
| 1820 | | | 25,020 | |
| 1920 | | | 24,840 | |
| 1950 | | | 21,870 | |
| 1968 | | | 21,780 | |
| 1973 | | | 20,570 | |
| 1974 | | | 37,668 | |
| | | | 20,570[10] | |
| 1975 | | | 24,735 | |
| 1976 | | | 51,595 | |
| 1978-1984 | | 29,083[7] | | |
| 1979 | 9,887 | | | |
| | 30,940.17[6] | | | |
| 1980 | 14,761 | 61,074[8] | 35,422 | |
| | 20,403.98[6] | | | |
| 1981 | 20,424 | | | |
| 1982 | 19,218 | | 21,871[10] | |
| 1983 | 13,360 | | 17,238[10] | |
| 1984 | 29,637 | | | |
| 1985 | 25,544 | 15,778 | | |
| 1986 | 34,797 | 18,905 | | |
| 1987 | 19,158 | 27,804 | | |
| 1988 | 16,867 | 18,954 | | |
| 1989 | 15,881 | 19,612 | | |
| 1990 | 16,245 | 17,948 | 16,222 | |
| 1991 | 16,618 | 20,895 | | |
| 1992 | 16,999 | 16,789 | | |
| 1993 | 21,745 | 16,326 | | |
| 1994 | 18,020 | 7,299 | | |
| 1995 | 24,431 | 9,289 | | |
| | 6,350.4[9] | | | |
| 1996 | 13,061 | 8,896 | | 26,720 |
| | 1,104.9[9] | | | |
| 1997[11] | | 78,327 | 34,960 | 30,960 |

[1] EE and P/B based on the calculated values by ECOPATH II (delos Reyes, 1995)

[2] From: Bureau of Agricultural Statistics (1996)

[3] Calculated from NNPP data mostly taken from LLDA-EPD

[4] Based from the biomass data taken mostly from delos Reyes (1995).

[5] 1996 data from: LLDA-EPD; 1997 - primary data

[6] From: Mercene, 1977

[7] From: Sogreah, 1991

[8] From C14 data, Nielsen, 1981

[9] From: FRS, BFAR Region IV

[10] Based from the biomass data taken from LLDA-WHO, 1984

[11] Based on single sampling per bay of three depths per sample

The three different methods of estimating potential fish yield can not be completely compared statistically because there is not single year where all the three estimated values are given together with the BAS value.

At most we can compare the production values based on NPP with the BAS production data for 13 years (1980, 1985 - 1996); and production values based on biovolume with the BAS production data for three years (1980, 1983, 1990). A close relationship is observed between the estimated production data based on NPP and the BAS production data but only from 1988 to 1993. This means that only 50 percent of the pairs of values are close to each other.

The estimated fish yields based on biovolume and BAS production are close only for 1983 and 1990. The estimates based on NPP and biovolume figures are close to each other in 1990. The NPP figure for 1997 involved only one sampling, therefore, we can not safely make a conclusion. The same can be said of the estimated values from biovolume and chlorophyll content in 1997.

## Estimated Fish Biomass

The fish biomass was computed from actual fish production as reported by BAS using the formula:

$$B = \frac{P}{(P/B)},$$

where: B = biomass
P = production data from BAS
(P/B) = obtained from delos Reyes, 1995

There are 20 species of finfishes calculated for their biomass (Tables 9 and 10). The highest biomass recorded was for mudfish (Ophicephalus striatus) at 4,930.76 metric tons in 1986.

Table 11 compares the fish biomass values estimated as above (A) with those derived from delos Reyes (1995) as estimated by ECOPATH II model (B). For all the estimates, the values obtained by the ECOPATH II was much larger than those estimated from the actual fish production data. This is understandable because ECOPATH II estimated biomass from catch data that are even larger than the catch data of BAS. For example, the catch for *therapon* in 1990 reported by delos Reyes (1995) was 10.498 MT/km$^2$ or 8,398 metric tons for the whole lake (800 square kilometers). On the other hand, BAS reported a catch figure of 1,407 metric tons for the whole lake. However, the catch supposedly should not exceed the potential production.

## Table 9. List of Fish Species Included in this Study*

| Phytoplankton Feeders | Others |
|---|---|
| 1. Milkfish<br>*Chanos chanos Forskal (Tag. Bangus)*<br>2. Mullet<br>*Mugil Valenciennes (Tag. Banak)*<br>3. Tilapia<br>*Oreochormis niloticus Linn. (tag. Tilapia)*<br>*= Tilapia niloticus*<br>*Oreochormis mossambicus Peters* | 1. Carp<br>*Cyprinus carpio Linn. (Tag. Karpa)*<br>2. Catfish<br>*Arius manilensis Valenciennes (Tag. Kanduli)*<br>*Arius batrachus Linn. (Tag. Hito)*<br>3. Climbing Perch<br>*Anabas testudineus Bloch (Tag. Martiniko)*<br>4. Clupeids<br>*Anodontosoma chacunda (Tag. Tawilis; herring)*<br>observed only in 1820-1920<br>5. Eel<br>*Anguilla marmorata (Tag. Igat) = A. mauritiana*<br>6. Goby<br>*Glossogobius giurus Buchanan-Hamilton (Tag. Biya)*<br>7. Gourami<br>*Trichogaster (Tag. Guraming maliit; Eng. Pla-salit)*<br>*Osphronemus (Tag. "giant gurami")*<br>8. Mudfish/Murrel/Snakehead<br>*Ophicephalus striatus Bloch (Tag. Dalag)*<br>*= Channa striata*<br>9. Ornate sleeper<br>*Ophiocara aporos Bleeker (Tag. Papalo)*<br>10. Spade fish<br>*Scatophagus argus (Tag. Kitang)*<br>11. Tarpon<br>*Megaplops cyprinoides Broussonet*<br>*(Tag. Buan-buan, bidbid)*<br>12. Tawes<br>*Puntius javanicus (Tag. Tawes)*<br>13. Therapon<br>*Therapon plumbeus Kner (Tag. Ayungin)* |

* Silver side fish (Tag. gono) is not included here

**Table 10. Estimated Fish Biomass (mt/year) Based on BAS Fish Production Data in Laguna Lake, 1979-1996**

| SPECIES | P/B1 | 1979 | | 1980 | | 1981 | | 1982 | | 1983 | | 1984 | | 1985 | | 1986 | | 1987 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) |
| **A. Phytoplankton Feeders** | | | | | | | | | | | | | | | | | | | |
| 1. Milkfish | 4.80 | | 15.83 | | | | | | | | | | | | | | | | |
| *Chanos chanos* | | 76 | 15.83 | 190 | 39.58 | 10,888 | 2,268.33 | 12,025 | 2,505.21 | 6,032 | 1,256.67 | 3,025 | 630.21 | 1,526 | 317.92 | 4,640 | 966.67 | 1,184 | 246.67 |
| 2. Mullet | 0.70 | | | | | | | | | | | | | | | | | | |
| *Mugil (Banak)* | | | | | | | | 1 | 1.43 | 4 | 5.71 | 5 | 7.14 | 6 | 8.57 | 10 | 14.29 | 14 | 20.00 |
| 3. Tilapia | | | | | | | | | | | | | | | | | | | |
| *Oreochormis aureus* | 5.34 | 511 | 96.69 | 2,585 | 484.08 | 2,222 | 416.10 | 1,685 | 315.54 | 1,789 | 335.02 | 6,541 | 1,224.91 | 6,631 | 1,241.76 | 8,767 | 1,641.76 | 4,379 | 820.04 |
| *Oreochormis mossambicus* | | | | | | | | | | | | | | | | | | | |
| **B. Others** | | | | | | | | | | | | | | | | | | | |
| 1. Carp | 1.25 | | | | | | | | | | | | | | | | | | |
| *Cyprinus carpio* | | 434 | 347.20 | 731 | 584.80 | 426 | 340.80 | 334 | 267.20 | 249 | 199.20 | 733 | 586.40 | 3,235 | 2,588.00 | 5,652 | 4,521.60 | 3,399 | 2,719.20 |
| 2. Catfish | | | | | | | | | | | | | | | | | | | |
| *Arius manilensis (Kanduli)* | 1.55 | 497 | 320.65 | 1,410 | 909.68 | 467 | 301.29 | 532 | 343.23 | 745 | 480.65 | 3,530 | 2,277.42 | 2,607 | 1,681.94 | 3,500 | 2,258.06 | 2,335 | 1,506.45 |
| *Arius batrachus (Hito)* | 1.55 | 324 | 209.03 | 1,369 | 883.23 | 1,235 | 796.77 | 909 | 586.45 | 827 | 533.55 | 1,968 | 1,269.68 | 1,907 | 1,230.32 | 3,954 | 2,550.97 | 2,175 | 1,403.23 |
| 3. Climbing Perch | | | | | | | | | | | | | | | | | | | |
| *Anabas testudineus (Martiniko)* | 0.75 | | | | | 5 | 6.67 | | | | | | | | | | | 9 | 12.00 |
| 4. Clupeids | 5.50 | | | | | | | | | | | | | | | | | | |
| *Anodontosoma chacunda* | | | | | | | | | | | | | | | | | | | |
| 5. Eel | | | | | | | | | | | | | | | | | | | |
| *Anguilla sp* | 0.80 ** | 4 | 5.00 | 5 | 6.25 | | | 1 | 1.25 | 4 | 5.00 | 11 | 13.75 | 10 | 12.50 | 9 | 11.25 | 6 | 7.50 |
| 6. Goby | | | | | | | | | | | | | | | | | | | |
| *Glossogobius giurus* sp *(Biya)* | 2.72 | 2,474 | 909.56 | 2,111 | 776.10 | 765 | 281.25 | 243 | 89.34 | 895 | 329.04 | 4,436 | 1,630.88 | 2,844 | 1,045.59 | 866 | 318.38 | 1,041 | 382.72 |
| *Microgobius sp (Dulong)* | 2.72 | | | 144 | 52.94 | 132 | 48.53 | 745 | 273.90 | 384 | 141.18 | 276 | 101.47 | 49 | 18.01 | 94 | 34.56 | 6 | 2.21 |
| 7. Gourami | 0.75 * | 18 | 24.00 | 7 | 9.33 | 57 | 76.00 | 45 | 60.00 | 51 | 68.00 | 76 | 101.33 | 30 | 40.00 | 78 | 104.00 | 60 | 80.00 |
| *Trichogaster* | | | | | | | | | | | | | | | | | | | |
| *Osphronemus* | | | | | | | | | | | | | | | | | | | |
| 8. Mudfish/Murrel/Snakehead | | | | | | | | | | | | | | | | | | | |
| *Ophicephalus striatus (Dalag)* | 0.75 | 750 | 1,000.00 | 2,250 | 3,000.00 | 1,618 | 2,157.33 | 1,102 | 1,469.33 | 997 | 1,329.33 | 2,789 | 3,718.67 | 1,951 | 2,601.33 | 3,698 | 4,930.67 | 2,227 | 2,969.33 |
| 9. Ornate sleeper | | | | | | | | | | | | | | | | | | | |
| *Ophiocara aporos* | | | | | | | | | | | | | | | | | | | |
| 10. Silver side | | | | | | | | | | | | | | | | | | | |
| 11. Tarpon | 0.60 | | | | | | | | | | | | | | | | | | |
| *Megaplops cyprinoides* | | | | | | | | | | | | | | | | | | | |
| 12. Tawes | | | | | | | | | | | | | | | | | | | |
| *Puntius javanicus* | | | | | | | | | | | | | | | | | | | |
| 13. Therapon | | | | | | | | | | | | | | | | | | | |
| *Therapon plumbeus (Ayungin)* | 2.64 | 4,799 | 1,817.80 | 3,959 | 1,499.62 | 2,609 | 988.26 | 1,596 | 604.55 | 1,383 | 523.86 | 6,247 | 2,366.29 | 4,748 | 1,798.48 | 3,529 | 1,336.74 | 2,323 | 879.92 |

*continued,*

**Table 10. Estimated Fish Biomass..., *continuation.***

| SPECIES | P/B1 | 1988 | | 1989 | | 1990 | | 1991 | | 1992 | | 1993 | | 1994 | | 1995 | | 1996 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) | Production (mt) | Biomass (mt/yr) |
| **A. Phytoplankton Feeders** | | | | | | | | | | | | | | | | | | | |
| 1. Milkfish | 4.80 | | | | | | | | | | | | | | | | | | |
| *Chanos chanos* | | 3,377 | 703.54 | 3,140 | 654.17 | 3,212 | 669.17 | 3,286 | 684.58 | 3,361 | 700.21 | 1,286 | 267.92 | 4,620 | 926.50 | 3,857 | 803.54 | 226 | 47.08 |
| 2. Mullet | 0.70 | | | | | | | | | | | | | | | | | | |
| *Mugil (Banak)* | | | | | | | | | | | | | | | | | | | |
| 3. Tilapia | | | | | | | | | | | | | | | | | | | |
| *Oreochormis aureus* | 5.34 | 4,186 | 783.90 | 3,892 | 728.84 | 3,981 | 745.51 | 4,073 | 762.73 | 4,166 | 780.15 | 7,046 | 1,319.48 | 6,768 | 1,267.42 | 10,025 | 1,877.34 | 5,302 | 992.88 |
| *Oreochormis mossambicus* | | | | | | | | | | | | | | | | | | | |
| **B. Others** | | | | | | | | | | | | | | | | | | | |
| 1. Carp | 1.25 | | | | | | | | | | | | | | | | | | |
| *Cyprinus carpio* | | 2,782 | 225.60 | 2,586 | 2,068.80 | 2,645 | 2,116.00 | 2,706 | 2,164.80 | 2,768 | 2,214.40 | 747 | 597.60 | 750 | 600.00 | 3,591 | 2,872.80 | 453 | 362.40 |
| 2. Catfish | | | | | | | | | | | | | | | | | | | |
| *Arius manilensis (Kanduli)* | 1.55 | 1,888 | 1,218.06 | 1,755 | 1,132.26 | 1,795 | 1,158.06 | 1,836 | 1,184.52 | 1,879 | 1,212.26 | 2,863 | 1,847.10 | 2,357 | 1,520.65 | 1,865 | 1,203.23 | 2,667 | 1,720.65 |
| *Arius batrachus (Hito)* | 1.55 | 1,302 | 840.00 | 1,210 | 780.65 | 1,238 | 798.71 | 1,266 | 816.77 | 1,295 | 835.48 | 57 | 36.77 | 8 | 5.16 | 45 | 29.03 | 30 | 19.35 |
| 3. Climbing Perch | | | | | | | | | | | | | | | | | | | |
| *Anabas testudineus (Martiniko)* | 0.75 | 1 | 1.33 | 1 | 1.33 | 1 | 1.33 | 1 | 1.33 | 1 | 1.33 | | | | | | | | |
| 4. Clupeids | 5.50 | | | | | | | | | | | | | | | | | | |
| *Anodontosoma chacunda* | | | | | | | | | | | | | | | | | | | |
| 5. Eel | | | | | | | | | | | | | | | | | | | |
| *Anguilla sp* | 0.80 ** | | | | | | | | | | | | | | | | | | |
| 6. Goby | | | | | | | | | | | | | | | | | | | |
| *Glossogobius giurus* sp *(Biya)* | 2.72 | 737 | 270.96 | 885 | 325.37 | 905 | 332.72 | 926 | 340.44 | 947 | 348.16 | 3,218 | 1,183.09 | 1,075 | 395.22 | 824 | 302.94 | 1,026 | 377.21 |
| *Microgobius sp (Dulong)* | 2.72 | | | | | | | | | | | | | | | 5 | 1.84 | | |
| 7. Gourami | 0.75 * | | | | | | | | | | | 17 | 22.67 | | | 6 | 8.00 | 5 | 6.67 |
| *Trichogaster* | | | | | | | | | | | | | | | | | | | |
| *Osphronemus* | | | | | | | | | | | | | | | | | | | |
| 8. Mudfish/Murrel/Snakehead | | | | | | | | | | | | | | | | | | | |
| *Ophicephalus striatus (Dalag)* | 0.75 | 1,110 | 1,480.00 | 1,032 | 1,376.00 | 1,056 | 1,408.00 | 1,080 | 1,440.00 | 1,105 | 1,473.33 | 263 | 350.67 | 148 | 197.33 | 392 | 522.67 | 204 | 272.00 |
| 9. Ornate sleeper | | | | | | | | | | | | | | | | | | | |
| *Ophiocara aporos* | | | | | | | | | | | | | | | | | | | |
| 10. Silver side | | | | | | | | | | | | | | | | | | | |
| 11. Tarpon | 0.60 | | | | | | | | | | | | | | | | | | |
| *Megaplops cyprinoides* | | | | | | | | | | | | | | | | | | | |
| 12. Tawes | | | | | | | | | | | | | | | | | | | |
| *Puntius javanicus* | | | | | | | | | | | | | | | | | | | |
| 13. Therapon | | | | | | | | | | | | | | | | | | | |
| *Therapon plumbeus (Ayungin)* | 2.64 | 1,479 | 560.23 | 1,375 | 520.83 | 1,407 | 532.95 | 1,439 | 545.08 | 1,472 | 557.58 | 6,248 | 2,366.67 | 2,294 | 868.94 | 3,821 | 1,447.35 | 3,148 | 1,192.42 |

**Table 11. A Comparison Of The Calculated Fish Biomass For Selected Species MT/Ha) in the Open Water of Laguna Lake Based on Production Data of BAS (A) and the Biomass Calculated by ECOPATH II Model (B)[1]**

| Year | Grams per cubic meter | | | | |
|---|---|---|---|---|---|
| | 1973 | 1974 | 1975 | 1976 | 1977 |
| Blue-green algae | 36 | 26 | -- [a] | 1.30 | -- [a] |
| Green algae | <1 | <1 | <1 | 1.00 | -- [a] |
| Diatoms | 4 | 7.10 | -- [a] | 5.00 | -- [a] |
| ***Average*** | ***14*** | ***12*** | | ***2.43*** | |

Note:
a = data incomplete

## CONCLUSIONS

The fish production calculated from the net primary productivity data is a good estimate of the actual fish production (BAS). Likewise, fish production can be calculated from algal biovolume. Fish biomass values computed from the fish catch by the ECOPATH II model do not tally with those computed from the Bureau of Agricultural Statistics (BAS) production data.

## RECOMMENDATIONS

In order to validate the results of this study more primary data should be gathered using the three methods of estimating primary productivity, which are net primary productivity (NPP), biovolume, and chlorophyll a analyses for about 5 to 10 years. This kind of extensive study can be undertaken in collaboration with all the research and academic institutions around Laguna Lake.

Moreover, since the diatoms usually predominate the phytoplankter of Laguna Lake both in quantity and types, and since they are the preferred natural food of the phytoplankter fish feeders, probably a means of estimating primary productivity based on chl c can be studied.

## LITERATURE CITED


Allen, K.R. 1971. Relation between production and biomass. J. Fish. Res. Board can. 28: 1573-1581.

APHA-AWWA-WPCF. 1976. Standard Methods for the Examination of Water and Waste Water. Am. Pub. Health Assoc. Pub. Co., Washington, D.C. 1193p.

Bureau of Agricultural Statistics. 1996. Data of the fish catch in Laguna lake by species.

Charlton, M. N. 1993. Laguna lake (Philippines) water quality trend analysis study. In. P. G. Sly (ed.) Laguna Lake Basin, Philippines: Problems and Opportunities. EMRP Report no. 7. pp. 168 - 211.

Delmendo, M. N. 1974. The plankton of Laguna de Bay. Primary basis of milkfish farming in enclosures in the area. Philippine Agriculturist 57: 335 - 342.

Delmendo, M. N. 1968. Studies on the food and feeding of economic species of fish in Laguna de Bay. Proc. IPFC. 13 (II): 143 - 161.

Delos Reyes, Mario R. 1995. Geoecology of Laguna de Bay, Philippines: Long-term Alternatives of a Tropical-Aquatic Ecosystem. 1820-1992, Ph. D. dissertation. Hamburg, Univ. 138p.

Environmental Resources, Ltd. 1985. Laguna Lake Development Project: Post-Evaluation Report, Environmental Issues, Report to Asian Development Bank, Manila.

Greitz, G.I. and F.A. Richards. 1955. The estimation and characterization of plankton population by pigment analysis. J. Mar. Res. 14:211.

Jeffrey, S.W. and G.F. Humphrey. 1975. New spectrophotometric equations for determining cholorphylls a, b, c, and $c_2$ in higher plants, algae, and natural populations. Biochem. Physiol. Pflanzen. 167: 191-194.

Lewis, L. 1974. As cited in B. H. Nielsen. 1981. Cited here.

Lind, O.T. 1979. Handbook of Common Methods in Limnology. London, C.V. Mosby Co., 199 p.

LLDA. 1978. Comprehensive Water Quality Management, Program Laguna de Bay. Summary Report Vol. I. Laguna Lake Development Authority, Pasig, MM. 123.

LLDA. 1984-1988. Water Quality Data on the Laguna de Bay and Tributary Rivers. Annual Reports, Laguna Lake Development Authority, Pasig, MM.

LLDA, 1995. Master Plan Final Report Main Report.

Marten, G. G. and J. J. Polovina, 1982. A comparative study of fish yields from various tropical ecosystems. In. D. Pauly and G. I. Murphy (eds.) Theory and Management of Tropical Fisheries. ICLARM. Conf. Proc. 9, ICLARM, Makati, Philippines.

Martinez, M.R., R.P. Chakroff and J.B. Pantastico, 1975. Note: Direct phytoplankton counting techniques using the haemaecytometer. Phil. Agr. 59: 43-50.

Martinez-Goss, M.R. and M.L. Dionisio-Sese, 1995. Chlorophyll analysis of algae. In. DOST-UPLB Training Course in Phycological Methods Chemical Analyses for Food, UPLB, pp. 19-35.

Nielsen, B. H. 1981. The hydraulic control structure - a threat to the fishpen industries of

Laguna de Bay. Likas Yaman 3 (5): 9-28.

Nielsen, B.H. 1983. Limnological studies in Laguna de Bay, 1980-1983. Terminal Report to SEAFDEC, Aquaculture Department, April 1983. Danish International Development Agency, Copenhagen, 58 p.

Rabanal, H. R., P. Acosta and M. N. Delmendo, 1964. Limnological survey of Laguna de Bay - a pilot study of aquatic productivity, Phil. J. Fish. 8(1): 101 - 109.

Round, F.E. 1973. The Biology of Algae. New York, St. Martin's Press, 278 p.

Santiago, A. E. 1988. Limnological notes on the finfish production problem of Laguna de Bay. Nat. and Appl. Sci. Bul. 46 (2): 119 - 121.

SOGREAH, 1974. Laguna de Bay water resources development. Vol. 3 Water Quality Study Annexes. LLDA.

SOGREAH, 1991. Environmental Assessment of Laguna de Bay.

Strickland, J. D. H. and T. R. Parsons. 1972. A Practical Handbook of Seawater Analysis. Journal of Science. Res. Board of Canada. 167:1-311.

Vallentyne, J.R. 1974. The Algal Bowl, Lakes and Man. Miscellaneous Publication no. 22. Ottawa, Canada, Department of the Environment Fisheries and Marine Services, 186 p.

Vollenweider, R. A. 1971. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. United Nations Organization for Economic and Cultural Development. Technical Report DAS/CSI/ 68.2. Paris, France.

World Health Organization (WHO), United Nations Development Program, (UNDP), Asian Development Bank (ADB) and Laguna Lake Development Authority (LLDA), 1978. Comprehensive Water Quality Management Program of Laguna de Bay. Vol. 3, 7, 11, 15- Limnology of Laguna de Bay, WHO, UNDP, ADB, LLDA, May 1978.

***Laguna de Bay, Philippines***


*For further information, please call/write*

**National Statistical Coordination Board**
2nd Floor Midland Buendia Building
#403 Sen. Gil J. Puyat Avenue, Makati City 1200
Tel. Nos. 896-7981, 899-3444, 896-5388,
895-2425, 896-5372
Fax No. 890-9397, 895-5002
E-mail address: nscb@psdn.org.ph