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MORPHOMETRY AND PHYSICO-CHEMICAL PROFILES OF LAKES BALINSASAYAO AND DANAO (PHILIPPINES)

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Morphometry and profiles of temperature, transparency, dissolved oxygen, pH, alkalinity, orthophosphates, iron, chlorides, and specific conductance were examined for two mountain lakes in Negros Oriental.

Profiles suggested the existence of a principal or seasonal storm thermocline near 15 m and possibly a monomolimnion at great depths. Thus, the lakes may be meromictic. Dissolved oxygen profiles were clinograde, with the boundary between trophogenic and tropholytic waters occurring between 5 m and 10 m. Both lakes were poorly buffered and fell within the soft to medium water range. In general, physicochemical conditions indicated a limited productive potential. Comparisons between lake surface waters, inflows, and suspected outflow are discussed.

Lakes Balinsasayao and Danao are located in mountainous, rain-forested, volcanic basins of Sibulan, Negros Oriental, at an approximate altitude of 880m. The lakes are separated by a narrow ridge which, at its minimum, rises 40m above water level and is approximately 70m wide (Fig.1). The lakes have no surface outlets, but apparently are drained through pervious underlying formations.

Though limnological reconnaissance of Balinsasayao and Danao began in the early 1930's (Woltereck, 1941), our knowledge of the lakes remains fragmentary. Recently, information on morphology, surface waters, zooplankton, and fish harvest has been published (Lowrie et al., 1980; Dolar and Perez, 1983; Cadelina et al., 1984), but annual physico-chemical and biological profiles and cycles have not been examined. Thus, we are presently ill-equipped to develop strategies for maximizing protein yields or managing the basins for such commonly suggested purposes as a sanctuary for threatened and endangered species, an agricultural and municipal water supply, hydro-electric and geothermal energy sources, or a national park. This paper provides additional information to that data base requisite for such management strategies. Additional morphological data and initial observations of vertical physico-chemical profiles are presented in this work.

METHODS

Samples were taken weekly during July 1984 in two Balinsasayao embayments and over the deepest portion of the lake. In Danao, samples were collected over maximum depth on one occasion (Fig. 1). Water temperature was measured with a Fisher electronic digital thermometer immediately upon retrieval by a Kemmerer sampler. Light penetration was estimated with a Secchi disk, and specific conductance was measured in situ at 25 C with a Hach conductivity meter. Chemical analyses were performed in situ with Hach field kits (Hach, 1983), all of which follow "Standard Method" (A.P.H.A., 1975) procedures. Depth determination was by sounding line.

MORPHOMETRY

Morphometry of Balinsasayao and Danao is summarized in Table 1. The data were compiled from Lowrie, et al. (1980), Cadelina, et al. (1984), the Philippine Coast and Geodetic Survey (1954) map of the Balinsasayao area, and field observations by the authors.

With respect to length, width, surface area, volume, and shoreline length, Balinsasayao is approximately twice the size of Danao. Mean width, mean depth, and relative depth are similar for both lakes.

Earlier bathymetry indicated a maximum depth of 90 m for Balinsasayao and 55 m for Danao (Lowrie et al., 1980). During the present study, soundings of 97.5 m and 61.3 m, respectively, were recorded. Lake elevations were nearly equal during the earlier and current soundings (Heideman and Erickson, 1987). Close scrutiny of shoreline reference points, lake configurations during July 1984, and the maps of Lowrie, et al., (1980) and the Philippine Coast and Geodetic Survey (1954) suggests this elevation to be approximately 880 m.

The Balinsasayao shoreline development index (2.0) is 40% greater than that for Danao (1.4). This index approaches unity for circular lakes and increases with deviation from the circular (Wetzel, 1975). Shoreline development is of considerable interest because it reflects the potential for development of highly productive littoral communities. The littoral zone is restricted in both lakes, but more so in Danao.

Volume development is an index of form which approaches 0.33 for a conical depression. Most lake basins approximate an elliptic sinusoid and, thus, have a value greater than 0.33 (Neumann, 1959). Lower values occur for lakes with deep holes like Balinsasayao and Danao. Relative depth is a percentage expression derived from the maximum depth/mean diameter ratio. Most lakes have a value less than 2% (Wetzel, 1975). The high values for Balinsasayao and Danao are indicative of a small surface area with respect to depth, a morphometric feature which restricts productivity. There is little superposition of

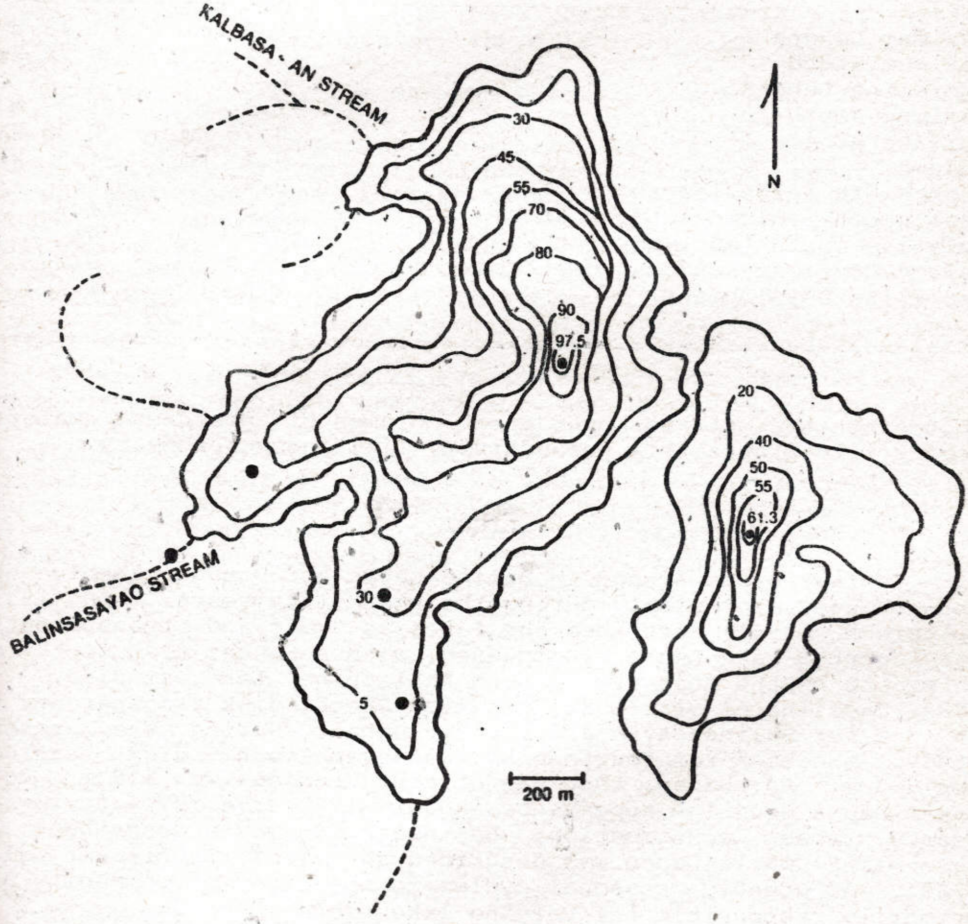


Fig. 1. Map of Lakes Balinsasayao and Danao, showing known contours in meters, sampling stations [ ], and principal tributaries (modified from Cadelina, et al., 1984).

Table 1. Morphometric data for Lakes Balinsasayao and Danao.

	Balinsasayao	Danao
Maximum Length	1.9 km	1.18 km
Maximum Width	1.3 km	0.76 km
Shoreline Length	6	3
Maximum Depth	97.5 m	61.3 m
Surface Area	0.76 km	0.35 km
Volume	9.2 km	4.5 km
Mean Width (area/length)	0.4	0.3
Mean Depth (volume/surface area)	12.1	12.9
Relative Depth (maximum depth/mean dia.)	10%	9%
Volume Development (mean depth/max. depth)	0.12	0.20
Shoreline Development	2.0	1.4

photosynthetic strata over great volumes of profundal waters. Fig. 2 illustrates this productivity-limiting morphometry.

LIGHT

Average transparency in Balinsasayao and Danao probably has not changed appreciably during the past fifty years. In 1933, Woltereck (1941) described the lakes as "soft and transparent," but reported Lake Lanao of Mindanao, with a Secchi disk depth of 6 m, to be the most transparent Philippine Lake studied. In 1982, Cadelina et al, (1984) reported Secchi disk transparency to be 3 m for Balinsasayao and 5 m for Danao. During the present study, the mean for fourteen Balinsasayao Secchi disk readings was 4.3 m. For Danao, the mean of four readings was 5.8 m. Both lakes had a greenish appearance in July 1984. In 1977, following nearby road construction, Balinsasayao was described as "greenish" while Danao was described as "blue" (Lowrie et al., 1980). Apparently, seasonal cycles in the plankton community are primarily responsible for varying lake transparencies.

Although Danao was slightly more transparent than Balinsasayao, their light extinction curves below 5 m were nearly identical. Fig. 3 illustrates the mean attenuation for both lakes. If the lower boundary of the trophogenic zone is the depth receiving only 1% of surface light intensity (Frey, 1969), the trophogenic zone is clearly less than 10 m deep in both Balinsasayao and Danao.

TEMPERATURE AND DISSOLVED OXYGEN

The thermal regimes of Balinsasayac and Danao are poorly understood. Historically, the lakes were regarded as oligomictic (Lowrie et al., 1980), but now there is indication of meromixis at extreme depths.

During July 1984, the maximum vertical temperature range was 3.5 C for both lakes: 26.0 - 22.5 C in Balinsasayao and 25.8 - 22.3 C for Danao. Temperature profiles suggest the formation of feeble, high-lying thermoclines and their frequent smearing by breezes and squalls as in Lake Lanao, Mindanao (Lewis, 1973) (Figs. 3, 4, and 5). The principal thermocline was probably in equilibrium with seasonal storms between 10 and 20 m. The maximum relative thermal resistance (RTR) was 36 and occurred in this stratum. Temperate zone lakes typically have RTR values in excess of 60 during summer thermal stratification (Vallentyne, 1957).

Apparently, typhoons or even an infrequent combination of strong winds, cool air temperature, and possibly heavy rains obliterate the more stable, low-lying thermocline, and a major circulation of the water mass occurs. It is not known if this is oligomixis or merely circulation above a deep monimolimnion (meromixis). According to Silliman University investigators, Balinsasayao last appeared turbid or "slightly reddish" in February 1982 (Professor Ruth Utzurrum, Biology Dept., pers. comm.) This is interpreted as the most recent major circulation in the lake. Earlier circulations have apparently reached even greater depths and resulted in major fish kills. The junior author described a "bloody-red" Balinsasayao in August 1980, with its surface rippling with gasping, dying fishes. Local residents report similar incidents for 1970 and 1973, the latter following a strong typhoon.

A temperature inversion occurred over the bottom of Balinsasayao. If Balinsasayao is meromictic, such as inversion in the monomolimnion would be expected (Wetzel, 1975). Possible heat sources include density currents from warmer overlying strata, metabolic activity, and geothermal. The heat is stabilized over the bottom by high densities sufficient to prevent upward convection.

Horizontally, surface temperature declined slightly with distance from shore. The maximum range noted between 5 m off shore and mid-lake was 1.0 C.

Oxygen profiles for Balinsasayao and Danao were clinograde, with anaerobic conditions existing at 65 m in the former and below 40 m in the latter, (Figure 3). The trophogenic zones (upper 10 m) are strongly supersaturated with surface oxygen concentrations ranging form 8.0 mg/l in Danao to 9.0 mg/l in Balinsasayao. However, percent saturation declines sharply below the trophogenic zone. In Balinsasayac, for example, saturation was 92% at 15 m, but only 39% at 17 m.

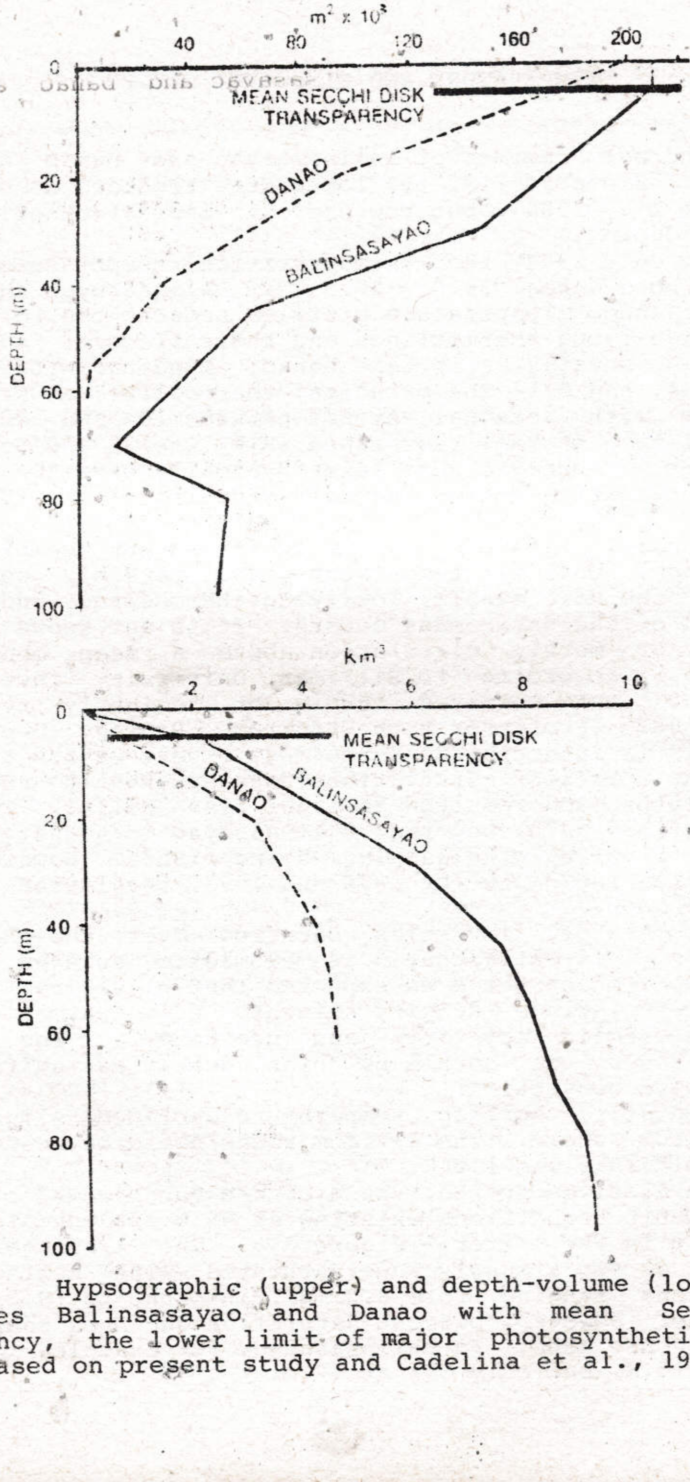


Fig. 2. Hypsographic (upper) and depth-volume (lower) curves for Lakes Balinsasayao and Danao with mean Secchi disk transparency, the lower limit of major photosynthetic activity (based on present study and Cadelina et al., 1984).

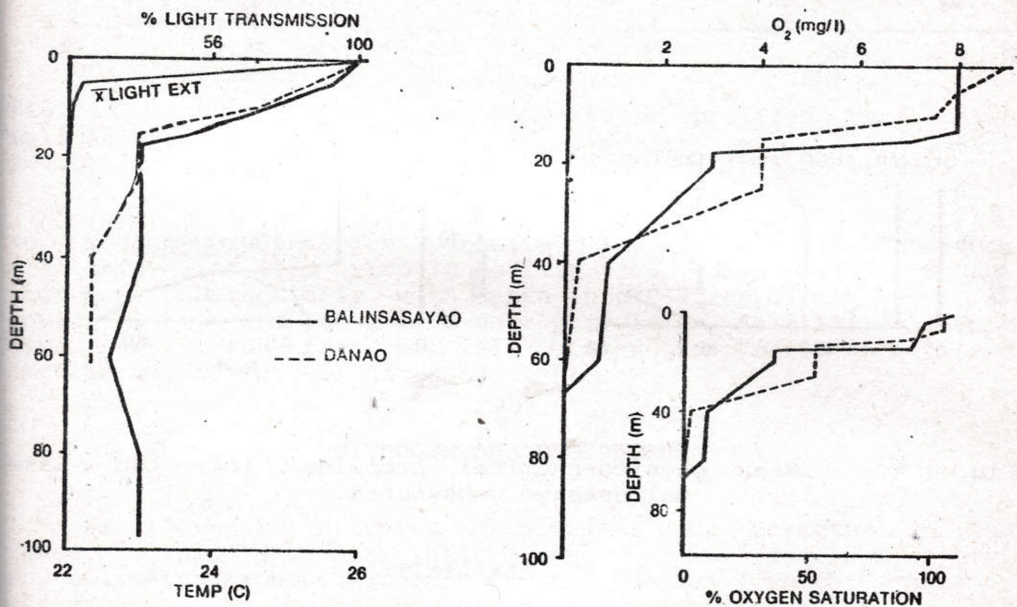


Fig. .3. Mean light extinction curve for Lakes Balinsasayao and Danao and rofiles for mean temperature, dissolved oxygen, and oxygen saturation. (extinction coefficients based on Secchi disk transparency = 5% surface intensity) (Odum, 1971).

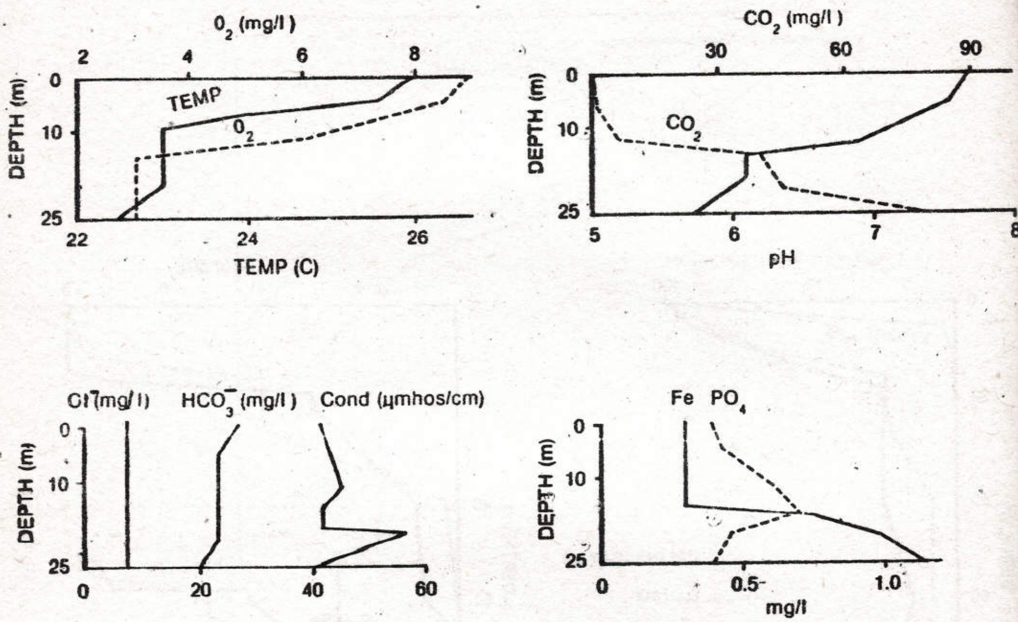


Fig. 4. Mean physico-chemical profiles for two Lake Balinsasayo embayments.

pH AND ALKALINITY

Profiles of pH and bicarbonate alkalinity were negative-heterograde for both lakes (Fig. 6). Balinsasayao was less acidic than Danao, with a mean pH range from 7.8 at the surface to 5.9 at the bottom. In Danao, the surface pH was 7.1, and the bottom pH was 6.2; however, a minimum pH of 5.5 occurred at 25 m. The negative heterograde notches occurred just below the trophogenic zones and were associated with a incresing carbon dioxide level (Fig. 6), presumably from bacterial plates or aggregations of zooplankton, or both (Nagasawa, 1959).

Biologically mediated reactions strongly influence the vertical distribution of pH, carbon dioxide, and bicarbonate alkalinity. These curves, along with the oxygen data, give some indication of the intensity of photosynthesis and decompostion throughout the water column. Although photosynthetic activity, pH, and carbon dioxide levels ascribe an "almost eutrophicd" quality to the epilimnia of Balinsasayao and Danao, the alkalinity profiles suggest a poorly buffered condition and low

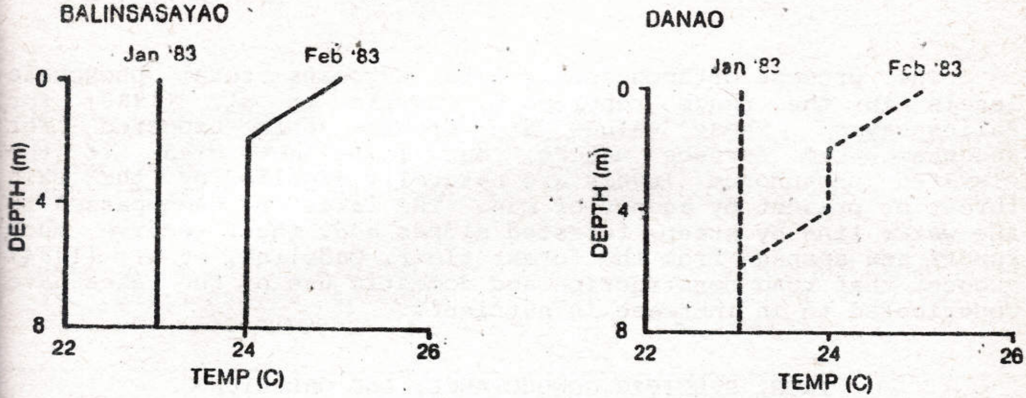


Fig. 5. Upper epilimnial temperature profiles for Lakes Balinsasayao and Danao from Cadelina et. al. (1984), indicating occurence of ephemeral, high lying thermoclines.

to medium productivity potential (Moyle, 1949). Surface alkalinity is less than 30 mg/l in both lakes and does not increase substantially with depth in the tropholytic zone as would be expected for a true eutrophic lake. Alkalinity and pH data sugest that the lakes fall between the "soft water" and "medium water" categories (Reid, 1961).

NITROGEN AND PHOSPHORUS

No inorganic nitrates or nitrites were detected in the lakes. This suggests that during maximum development of phytoplankton populations, the processes which balance assimilation in the trophogenic zone and dentrification in the tropholytic zone may exhaust nitrates completely.

Only tests for soluble inorganic phosphorus (orthophosphates) were conducted during the present study. Such phosphates are a small proportion, perhaps 10% or less, of the total available phosphorus (Pomeroy, 1960). Much or virtually all of the phosphate in a lake may be in protoplasm, bound in organic molecules, or adsorbed to other materials.

Overall, orthophosphate concentration was greater in Balinsasayao (Fig. 7). The range in trophogenic waters of Balinsasayao and Danao was 0.15 mg/l to 0.7 mg/l. Maximum values for both lakes occurred deep in the tropholytic zone.

Elevated hypolimnial phosphate levels are common and are related to an increase in the solubility under hypolimnial conditions. In Balinsasayao, the decline in phosphates just above bottom sediments may be related to phosphorus exchange processes between sediments and overlying water. Much of the phosphorus could, therefore, be in fractions not detectable by the procedures employed (Stumn and Morgan, 1970; Wetzel, 1975).

The present orthophosphate data suggests total phosphate levels in the range reported by Lowrie et al. (1980) for Balinsasayao. These values are greater than expected for uncontaminated surface waters, but it is not clear if the elevated phosphorus levels are naturally supplied by the rain forest or present by agency of man. The lakes are encompassed to the water line by steep, forested slopes and, thus, receive much runoff and seepage from the forest floor. Cadelina, et al. (1984) suggest that road construction and domestic use of the lakes have contributed to an increase in nutrients.

IRON, SPECIFIC CONDUCTANCE, AND CHLORIDES

The iron profiles for both lakes followed the typical lacustrine pattern, ranging from low values in the epilimnion (0.1 mg/l to 0.38 mg/l) to over 6 mg/l deep in the tropholytic zone where anaerobic conditions promote the formation of soluble ferrous iron (Fig. 7).

Specific conductance (conductivity) is a function of the electrolytes present and proportional to the concentration of dissolved solids. Total dissolved solids are approximately 70% of conductivity (Kimmel and Moon, 1982). Both lakes have similar conductance profiles with peaks approximately 20 m over the bottom (Fig. 7). The decline in conductivity with proximity to the water-sediment interface reflects the poor conductive property of suspensions (Ellis et al., 1948).

There is indication from temperture, phosphate, iron, and conductivity data, including Balinsasayao embayment profiles, that meromixix or density currents occur in the lakes (Figs. 3, 4, 6, and 7). High densities in the deepest strata would, thus, prevent complete homogenization even when all thermoclines are obliterated. The monomolimnion would occur below 40 m in Danao and below 30 m in Balinsasayao. The eventual reclassificaiton of Balinsasayao and Danao as meromictic lakes would not be surprising since meromixis is common in deep tropical lakes (Wetzel, 1975).

Little variation occurred in the vertical distribution of chlorides (Fig. 6). In Danao, the concentration was 7.6 mg/l throughout the water column. In Balinsasayao, the range was from 7.6 mg/l in the upper 60 m to 11.4 mg/l in the deepest strata. Based upon inflow data (Table 2), these concentrations reflect the natural occurring levels derived from soils and formations in the basins.

INFLOW AND OUTFLOW

The four mountains which surround lakes Balinsasayao and

Danao rise abruptly from the water's edge. Thus, the lakes receive much seepage and direct run-off from the steep-sloping forest floor. There are, additionally, six small tributaries confluent with Balinsasayao, two of which are permanent; there

Table 2. Mean surface data for Lakes Balinsasayao and Danao, two Lake Balinsasayao tributaries, and a suspected outflow at resurgence in valley below lake basins.

	Balinsasayao Stream	Kalbasa-an Stream	Valley Resurgence	Lake Balinsasayao	Lake Danao
pH	7.2	7.3	7.4	7.8	7.1
Dissolved Oxygen (mg/l)	7.0	-	-	9.0	8.0
Bicarbonate Alkalinity* (mg/l)	27.4	27.4	37.6	27.4	27.4
Carbon Dioxide (mg/l)	3.5	2.8	3.1	0	4.5
Orthophosphate (mg/l)	0.5	0.3	trace†	0.4	0.15
Iron (mg/l)	0.3	0.2	0.1	0.38	0.1
Chloride (mg/l)	7.6	15.0	7.6	7.6	7.6
Conductance (umhos/cm)	46	53	-	43	42
Water Temperature (C)	20.0	20.3	23.1	26	25.8

†trace in solution but appreciably more adsorbed on particulates

are no known permanent Danao tributaries (Paul Heideman, University of Michigan, pers. comm.).

The largest Balinsasayao tributary, Balinsasayao Stream, and one of the smallest, Kalbasa-an Stream, were sampled above points of use by man (Fig. 1). Thus, the data should reflect pristine conditions. Stream data and surface data for the lakes are summarized in Table 2.

In general, the stream data is quite similar to surface data for the lakes. Lacustrine photosythesis was responsible for the major differences. Both streams were very clear and flowed under luxuriant vegetation, thus light intensity was low. The flow rate in Balinsasayao Stream at aproximately 150 m above lake confluence was estimated (by the method of Robins and Crawford, 1954) to be 24.1 dm /sec. Average gradient at the sampling point was 242 m/km. In like fashion, the flow rate of Kalbasa-an Stream was estimated to be 0.3 dm /sec at some 70 m above the lake. No rainfall occurred over the lakes during the 48 hours preceding the measurements.

Subsurface drainage from Balinsasayao during the 1983 dry season resulted in an approximate 2 cm/day fall in water level or an estimated outflow rate of 14,600 m /day (Heideman and

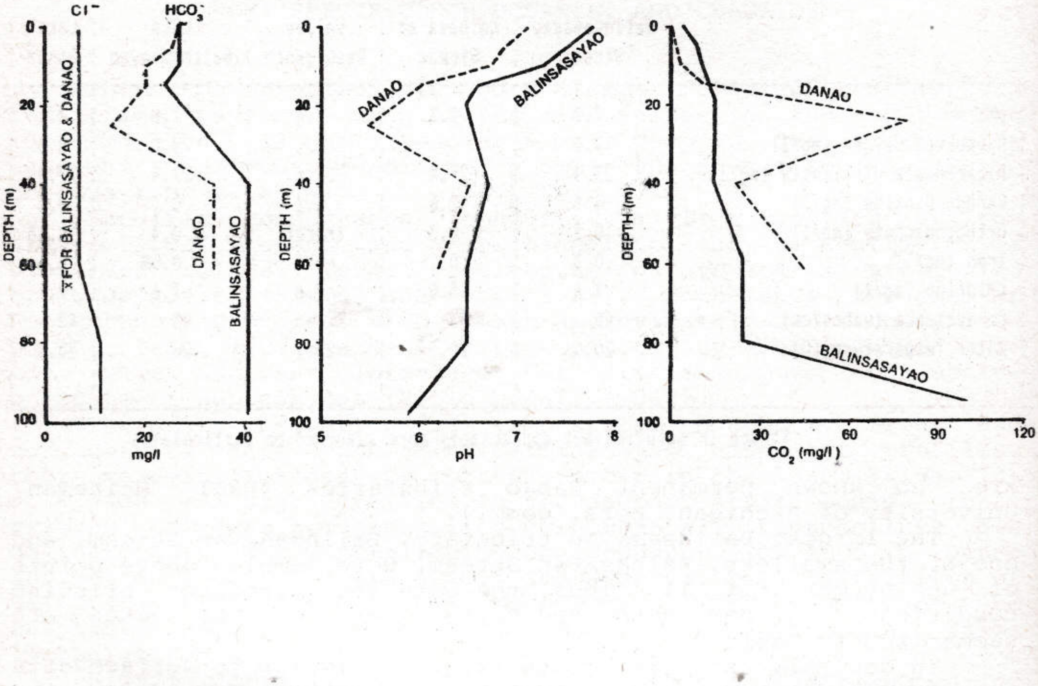
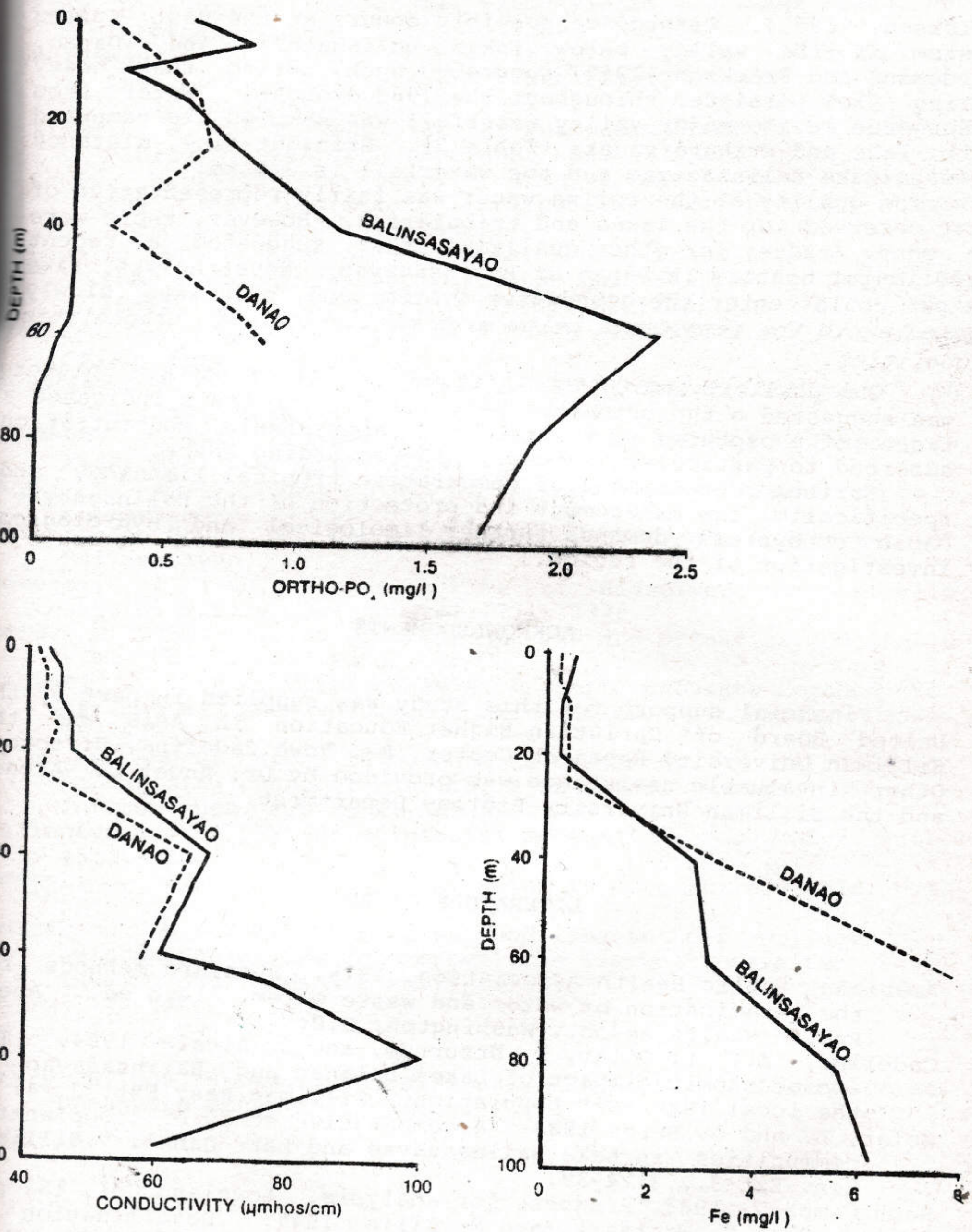


Fig. 6. Profiles for mean bicarbonate alkalinity, chlorides, pH, and free carbon dioxide in Lakes Balinsasayao and Danao.



ig. 7. Profiles for mean orthophosphates, conductivity, and iron in Lakes Balinsasayao and Danao.

Erickson, 1987). Resurgence possibly occurs at the vast spring system in the valley below lakes Balinsasayao and Danao. Heideman and Erickson (1987) suggested such, noting that heavy spring flow persisted throughout the 1983 drought. Water from resurgence at the major valley waterfall was sampled and compared with lake and tributary data (Table 2). Straight-line distance between Lake Balinsasayao and the waterfall is 3.5 km.

The quality of the spring water was fairly representative of that observed for the lakes and tributaries. However, there were no odor, taste, or other qualities that suggested a recent hypolimnial history in Danao or Balinsasayao. Nevertheless, lake water could enter the goundwater system and percolate slowly enroute to the resurgence below with mitigation of tropholytic qualities.

One possible indication of recent lentic or surface history was suggested b the orthophosphate tests. The tests indicated a trace of phosphates in solution and appreciable concentrations adsorbed to particulate matter in the resurging water.

Further development of comparative tropical limnology and, specifically, the management and protection of the Balinsasayao - Danao ecosystems demands further limological and hydrological investigation of the region.

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