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Ecological Studies on some Lakes of the Amazon Valley

by G. MARLIER

Introduction

Amazonian Limnology is still in its infancy. Notwithstanding the numerous studies of several research workers such as H. SIOLI, F. GESSNER, R. BRAUN, E. J. FITTKAU etc. we know only the fundamentals of the condition prevailing in the freshwaters of this huge equatorial region.

What we know already is the great mineral poverty of these waters, even the richer ones, the extreme conditions relating to hydrogen-ion concentration particularly in the black humic waters, and the complex situation created by the absorbing properties of the bottom sediments in the white-water streams.

We know also the relation between geological origin of the drainage area and the chemistry of the waters and, eventually, the distribution of some fauna elements. We have also a picture of the zoological communities which inhabit some rivers. All this information relates to flowing waters which constitute the major part of the Amazon Basin.

The standing waters have been less studied although their interest may be very great. We know the thermal conditions of some small lakes of the basin of the Tapajós river and the region of Santarém, and the faunal succession in them correlated with the thermal and chemical cycles.

Unfortunately, the lakes studied up till now and also the lakes with which this paper deals, are shallow and, being so, do not offer a good comparison with deeper lakes of the temperate zone or with deep African and Indonesian lakes.

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Methods

The methods used in these investigations are standard methods and were chosen as simple as possible.

Temperature was read to the nearest tenth of a degree on a thermometer immersed on the water bottle. This, of 2500.0 ml capacity was a square plexiglas container built on the principle of the Ruttner Wasserschöpfer but with the inferior lid fixed out of the way when lowered in the water. This apparatus was the property of the Max Planck Institut für Limnologie, Plön (Gisewski-bottle).

Dissolved Oxygen was determined by the Winkler method. In order to minimize the effect of reducing matter in humic waters, Beadle's modification of the method was tried. There being no difference in the final result with Rio Negro water, Winkler method was used throughout the work. But much attention was paid to the speed of the analysis, particularly in humic waters; it was indeed observed that a strong loss of iodine took place when more than five minutes elapsed between acidification and titration. In nearly all cases, the titration was made aboard the dug-out canoe right after the dissolution of the precipitate. Thiosulphate n/100 was used for titration.

pH was always studied by colorimetry (by lack of suitable electrodes for such dilute waters). Under pH 4,5 no great attention must be paid to the variations owing to the effect of the indicator itself. Alkalinity was titrated on the spot with HCl n/50.

Oxygen production was determined in 100 ml oxygen bottles disposed horizontally and fixed to a small buoy. The experiments had a duration of twenty-four hours and began on the morning whenever it was possible.

Bottom samples were taken with a Ekman dredge 15 × 15 cm; Fishing was mainly done with nylon twine gillnets of 100 yards length, 4 cm-bar mesh and 22 meshes high; they were hung $^1/_2$, making a 50 yard net when mounted.

General observations and Aim of Mission.

H. Sioli's studies on Amazonian rivers have already made us familiar with the main categories of flowing waters in this huge region. Rivers can be classified according to their colour which is a good indication of chemical conditions and at the same time of several other properties. White rivers are those which originate in the Andes and carry a good load of silt which makes them milky and turbid. Coming from rather soluble soils they are more or less buffered and are relatively rich in minerals. Such are the Amazon proper and several affluents such as the Purus.

Many rivers affluent to the Amazon, principally on the right side carry crystal-clear water. These may be considered as rivers having lost their charge in the sedimentation zone upstreams and now exhibite a very great transparency. Some of these waters are acid and mineral deficient, but not all are so. Several of them have traversed calcareous deposits of the Carboniferous and have thus acquired a certain buffering capacity (for exemple River Tapajós). The third category of amazonian waters are the black waters which arise in forested regiðn and have dissolved humic matter which gives them a characteristic brown coloration and acidic properties. These waters are thus electrolyte-poor and not buffered, with a pH of 3.5 to 5.0 and a layer some centimeters thick hinders light penetration, even of the long wave-lengths.

The flora and fauna of these waters are very scarce both qualitatively and quantitatively. Most of the affluents of the Rio Negro and the Rio Negro itself belong in the category of the black waters. Intermediate stages exist between true white and true black waters, also between these and clear waters. A precise line is sometimes difficult to draw, but this classification is anyway very useful.

Standing waters, in a general way are less easy to classify. White waters loose part of their turbidity and coarse load of silt, black waters may remain unchanged if they stay in the shade but may be progressively bleached by photochemical destruction of their colouring matter. Both extreme types, when standing a long time may be inhabited by planktonic plants and animals and these biotic communities no doubt have profound influences on their environment and on the colour of the water.

Standing waters are better classified according to their relations with the Amazon or its great affluents. These relations indeed determine the frequency and the degree of their mixing with the white mineral-„rich" waters and thus their fertility.

The Amazon and its great affluents are subject to wide fluctuations of level during the year. These may reach as much as 15 meters in the region of Manáus.

The direct affluents of the river, in addition to their own increase in flow, are dammed by the swollen waters of the Amazon and their level may rise very high. In turn they back up their own affluents and, after filling their major valley invade the lowlands of the neighbouring forest.

All transitions exist between invasion of the lateral valleys by the white waters of the Amazon and the simple damming of the affluents flowing in these valleys.

When a lake is located on the sides of the Amazon or of the main affluents, it is invaded every year by their waters. When it is located at a distance from the main streams it may either be invaded by the waters of the later or left without contact with these.

According to their distance from the rivers and from the Amazon proper, to their elevation above the rivers level, to the range of level variation of the Amazon at the point of inflow, and finally, to the comparative flow of the effluent at ists mouth in the river, the Amazonian lakes belong to one of three types.

1. Várzea lakes: in continuous or interrupted liaison with the white waters of the Amazon; they generally lie in the inundation plain of the rivers (lake Maicá, Lake Redondo).

2. Terra firme lakes in direct connection with the affluents or the river proper:
These lakes are never invaded by white waters from the river but their level is in direct relation with that of the river: e.g. Lake Jurucuí, Lake of Rio Preto da Eva, Lake Jarí.

3. Planalto lakes: not in direct connection with the affluents or river. Their rise is autonomous and only depends on the local climate of their drainage basin; no lake of this type has as yet been studied.

Although this classification of amazonian lakes according to their relation with the white waters seems essential, only on the spot observations allow the true nature of a particular lake to be ascertained as no accurate hypsometric map of the region exists.

Few Amazonian lakes have been studied as yet and most of these have been described by R. Braun (1952). Apart from small water bodies on the very shore of the Tapajós, all these lakes may be considered type 2 lakes, being out of reach of the Amazonian waters. Most are very shallow so that their behaviour is more that of big ponds than that of lakes. During the time of Braun's study, the deeper ones behaved as monomictic lakes, the shallower ones as polymictic. The present author has studied two lakes, a várzea lake, Lago Redondo, and a Terra firme lake, Lago do Rio Preto da Eva. During his stay in Amazonia he also paid visits to another várzea lake, Lago Maicá and to some terra firme lakes: Lago Jurucuí, in the Tapajós Valley, Lagos Juçara and Jarí in the Purús drainage.

Lake Redondo

Situation and Shape

Lake Redondo lies in the várzea of the Solimões, 25 km Southwest of Manáus, on the right bank of the Paraná do Careiro, in relation once a year, in principle, with the latter through a channel, called a "furo" and also, on the opposite side, in relation with the upper Solimões, through a complicated net of "furos", lakes and creeks. The shape is a rounded oval with few bays and without island.

Area: the area is 35 hectares during the major part of the year but, during the flood of the Amazon and of the affluents, the lake area may increase enormously and merge in a vast inundation where only the "restingaes" or embankments of the major rivers, with a few farms stay out of the waters.

This was not the case in 1963—64 when the flood was of a very moderate amplitude In 1963, the rains began only to fall regularly in December.

Maximum length: 860 meters; maximum width: 523 m; perimeter: 2430 m; development of shoreline: 1.04; maximum depth: 3.50 meters, when the lake is independent.

Volume: the accurate computation of the volume of such a shallow lake is very difficult as the errors of manual soundings have great relative importance. Indeed, the softness of the bottom often gives a false impression of depth and thus an error of several centimeters, with the lead-line method of sounding. Thus although having ascertained that depth never exceeded 3.50 m from more than 75 soundings made during the study, the precise bathymetric map of the lake could not be made. The greatest depth is situated near the southern shore and the basin is thus asymetrical. From the total number of soundings, the average depth may be estimated at 2.00 m.

But the depth depends on the relations of the lake with the Amazon. In 1953, when the river reached an exceptionally high level, the lake possibly had a maximum depth of 4.50 meters. This assessment is possible thanks to the presence of some recent Sponge colonies on the stems of littoral Palmtrees. If the mean depth is taken as 2 meters, then the volume is 700000 cubic meters.

During the year 1963—1964, the actual depth fluctuated very little; on August 3d, maximum depth was little more than 3 m; from there on, it decreased slowly and reached, in the same spot, 2.50 in January 1964, increasing very slowly to 2 m 70 in May. The biggest and sudden increase to and above 3 m must take place with the general invasion of amazonian waters in June. Thus, in the following pages, high waters level means the period "May to August" when the water level is rising and when it is really high. Low water time means decreasing water level i.e. September to April.

The shores of the lake have been deforested for many years and are partly cultivated. Much of them bears a crop of Jute; the remainder is marshy and some cattle graze in these swampy meadows.

There is no surf-shore (Brandungsufer). All around the lake, floating plants form "floating meadows", which, as will be shown later on, contribute much organic matter to the lake economy.

Colour of water: Seen from above, the lake appears greenish gray; on the Secchi disc, in the sun light, the water is olive-yellow; it is generally turbid due, at least partly, to wind disturbance.

Evolution of transparency: this was observed with a Secchi disc 0.30 m in diameter. During the whole year 1963 to May 1964, transparency values were low. The maximum was observed at high water time: August 3d: 1.53 m and decreased from then, to reach 0.50 m on October 4th and remained, with fluctuations, around this value, with an increase to 0.80 m at the end of December. These fluctuations are due, not to mixing with white waters of the Amazon, as the lake is, at this time, independent on the river, but to wind action on the bottom sediments which are rich in clay.

Thermal properties. The temperature is variable; surface temperature fluctuating from 29°1C to 32°2; and bottom temperatures from 27° to 30°2. The maximum difference between bottom and surface was 1°8 (August 2d) and there was complete homothermy from the end of August to February 10th. The lake is thus polymictic, as is normal for such a shallow water body.

Depth (m)	2. VIII.	3. VIII.	29. VIII.	4. X. 10 am	4. X. 4 pm	5. X. 9 am	5. X. 10 am
0	30°6	32°0	32°1	32°0	—	32°2	32°1
0.5	—	30°1	—	—	32°5	—	—
1.0	30°2	—	—	—	—	31°8	31°8
1.5	30°1	30°1	—	—	32°5	—	—
2.0	29°8	30°1	—	—	—	—	—
2.5	29°1	—	31°7	31°8	—	—	31°5
Bottom	28°8	—	—	—	—	—	—

Depth (m)	21. XII.	3. I.	6. II.	10. II. 11 am	7. IV.	5. V.
0.	29°1	31°1	30°0	30°0	29°6	29°3
0.5	—	30°8	30°3	30°0	29°4	29°3
1.0	—	30°5	—	—	29°4	—
1.5	—	30°3	30°0	30°0	29°4	29°3
2.0	29°0	30°2	—	30°0	29°0	29°2
2.5	—	—	—	—	—	—
Bottom	29°0	30°2	30°0	30°0	28°8	28°6

Table 1. Temperatures in Lake Redondo

Oxygen: There being no marked stratification at the time of low water and very little during the day at high water, oxygen curves are nearly orthograde during the former period and progressively change to clinograde when water level is rising.

Oxygen saturation never reaches 100% and is fact is never above 82%. It may be noted that the bottom water always holds some oxygen in solution except at the beginning of August.

Date	3. VIII.		29. VIII.		4. X. 10 am		4. X. 4 pm		20. X.	
Depth (m)	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%
0	4.59	60.2	5.53	75.6	5.90	80.6	—	—	5.96	80.6
0.5	—	—	—	—	—	—	6.02	82.8	5.67	76.7
1	3.98	52.9	—	—	—	—	—	—	—	—
1.5	3.74	49.7	—	—	—	—	5.23	71.9	5.66	76.3
2	0.91	12.1	—	—	—	—	—	—	—	—
2.5	0.61	8.6	3.22	43.8	4.20	57.2	—	—	—	—
3	0.0	0.0	—	—	—	—	—	—	—	—

Date	21. XII.		3. I. 1960		10. II.		7. IV.		5. V.	
Depth (m)	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%
0	4.74	60.8	6.03	81.2	6.12	81.2	5.17	68.3	5.05	65.0
0.5	—	—	6.01	80.7	6.12	81.2	4.79	63.1	4.94	63.6
1	4.68	60.0	5.77	77.2	—	—	—	—	—	—
1.5	—	—	5.67	75.6	—	—	4.53	59.6	4.80	61.8
2	—	—	5.19	69.1	6.04	80.2	1.79	23.4	3.68	47.6
2.5	4.17	53.4	4.36	58.0	5.27	70.0	—	—	—	—
3	—	—	—	—	—	—	1.69	22.0	1.45	18.4

Table 2. Dissolved oxygen in lake Redondo, in ppm and in percentage of saturation

Chemistry of water.

From table 3 giving total concentration of salts, as electrical conductivity, pH, alkalinity (in milliequivalents per liter) and dissolved CO2 (in ppm), it is possible to make some general observations.

a. Total concentration in salts is low and generally increases in contact with the bottom.

b. pH is nearly neutral, the lowest value being 6.4, the highest 7.0.

c. Alkalinity is low, but not zero as it is in some black or clear waters; it is never under 0.3 millieq. (S.B.V = 0.3) but never above 0.63 millieq./L.

d. Dissolved CO2 is never very high, as it is to be expected in water bodies without stratification.

m	2. VIII. 1963				29. VIII				4. X.				21. XII.			
	K_{20}	p_H	Alk.	CO_2 ppm	K_{20}	p_H	Alk	CO_2	K_{20}	p_H	Alk	CO_2	K_{20}	p_H	Alk	CO_2
0	55.5	6.6	0.50	0.88	67.8	6.9	0.34	4.27	56.8	6.9	0.57	4.31	44.0	7.0	0.29	n. d.
1.0	—	6.6	—	—	—	—	—	—	—	—	—	—	—	7.0	—	—
1.5	54.6	—	0.48	0.80	—	—	—	—	—	—	—	—	—	—	—	—
2.0	—	—	—	1.30	—	—	—	—	—	—	—	—	—	—	—	—
2.5	56.8	—	—	1.60	—	6.7	—	8.14	—	6.9	—	6.38	—	6.9	—	—
Bottom	77.0	6.5	0.63	2.10	65.5	—	—	—	61.3	—	0.50	—	47.7	—	0.26	n. d.

m	3. I.				10. VI.				7. IV.				5. V. 1964			
	K_{20}	p_H	Alk	CO_2	K_{20}	p_H	Alk	CO_2	K_{20}	p_H	Alk	CO_2	K_{20}	p_H	Alk	CO_2
0	43.5	6.9	0.32	5.50	43.5	6.7	0.22	6.60	39.7	6.6	0.33	7.26	42.3	6.7	0.33	7.48
1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.5	—	—	—	—	—	—	—	7.26	—	—	—	—	—	—	—	—
2.0	—	—	—	—	—	—	—	6.82	—	—	—	10.12	—	—	—	—
2.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bottom	43.5	6.7	0.26	6.16	39.5	6.5	0.22	6.82	40.2	6.5	0.30	12.10	21.4	6.4	0.36	15.18

Table 3. Chemistry of water

A closer examination of the figures shows that

a. Total electrolyte concentration decreases from August to May. This decrease in a general way follows that of alkalinity but not completely as the latter is at a minimum from the end of December when the total concentration remains nearly stable.

b. Dissolved carbon dioxide increases from August to May the pH decreasing during the same period.

No explanation is given of the first phenomenon, unless there is some seepage during the dry season and at the beginning of the rains, through the bottom of the lake, rain water diluting the surface water.

Total chemical analyses have been made at different times of the year and the results are now being studied.

Primary Productivity in lake Redondo

1. Planktonic oxygen-production.

No facilities being provided for a more elaborate method, Gran's technique of clear and dark bottles was used.

The values in table 4 are given in ppm produced O2, some values of net production being negative, mainly in the deeper bottles. In the first experiments, i.e. before February 1964, no measurements were made at the water surface, owing to technical difficulties.

The fluctuations of the oxygen produced by the plankton are large, the net production going from 0.11 ppm to 0.95 ppm. The highest figures are the values for August and May, the lowest are those of the low water time.

The average of the values from 0m to 1.50 m for the whole year is 0.32 ppm O2 per 24 hours, which corresponds to the fixation of 0.096 mg C/24h/L.

Date	3.—4. VII. 63			4.—5. X. 63			20.—21. XII. 63			3.—4. I. 64		
Depth (m)	N.P.	R.	G.P.	N.P.	R.	G.P.	N.P.	R.	G.P.	N.P.	R.	G.P.
0	—	—	—	—	—	—	—	—	—	—	—	—
0.5	0.91	0.81	1.72	0.06	0.73	0.79	0.11	0.19	0.29	—0.30	0.45	0.15
1.5	—0.61	1.22	0.61	—0.13	0.13	0	—0.18	0.19	0.01	—0.38	0.44	0.06

Date	6.—7. II. 64			9.—10. II. 64			7.—8. IV. 64			5.—6. V. 64		
Depth (m)	N.P.	R.	G.P.	N.P.	R.	G.P.	N.P.	R.	G.P.	N.P.	R.	G.P.
0	0.24	0.98	1.22	0.95	—	—	0.43	0.91	1.34	0.53	0.50	1.03
0.5	0.00	0.63	0.63	0.74	—	—	0.35	0.56	0.91	0.51	0.43	0.94
1.5	—0.42	0.51	0.09	—0.50	0.53	0.03	—0.49	0.50	0.01	—0.26	0.35	0.09

Table 4. Planktonic Oxygen-production (in p.p.m. per 24 hours)
N.P.: net production; R: respiration; G.P.: gross production

This, in turn is equal to 52 g of carbon per square meter per year in the upper strata of the lake. During this time gross production is 97 g per square meter.

From table, 4, there is no close correlation between any of the chemical factors studied in the field, namely conductivity, pH, alkalinity and dissolved carbon dioxide, with production of planktonic oxygen. Nevertheless the curve expressing the latter follows roughly the same pattern as the curve for electrical conductivity and alkalinity, suggesting thus an indirect correlation, through a common causal environmental factor, such as rainfall which was not determined.

Another important point is the very low figure of carbon fixation per unit area. This is correlated with the poor mineral-content of the waters, the high turbidity and, of course, the low plancton values.

2. Marginal vegetation

An important source of organic matter in Lake Redondo is the marginal floating "meadow".

The bulk of the meadows is formed by *Paspalum repens* Berg and *Panicum*, mixed with *Jussieua affinis* D. C., *J. natans* Humb& Bonp; *Neptunia oleracea* Lour; *Phaseolus trichocarpus* Wright with an external belt of *Scirpus cubensis* Poep& Kunth; the whole of the meadow is interspersed with *Azolla filicoides* and some *Eichhornia azurea* Kunth. These floating meadows were continuous around the lake in a zone about 10 meters wide.

Production in this partly emerged vegetation zone could not be studied by the above methods.

A known area of these grasses was therefore cut, this area being delimited with wooden sticks. The wet and dry weights of the removed plants and animals were determined. After about ten weeks, the same area was cut again and the weights determined in the same way. In principle this method ought to give the organic production of that area of floating meadow. But so many errors creep in, that after all, this technique is not very reliable. Anyway it was applied on one fourth of a square meter and the following data collected.

	In 75 days, per sq. meter (grams)	In 365 days, per sq. meter (grams)	Per ha, per year (tons)	Over whole lake, per year (tons)
fresh weight . . .	9 500.0	47 500.0	475.0	950.0
dry weight	1 000.0	5 000.0	50.0	100.0
carbon*)	462.0	2 300.0	23.1	46.2

Table 5. Floating meadow; new growth

The principal sources of error in this evaluation were.

1. The difficulty of delimiting exactly the same area of meadow at the first and at the final stage of the experiment, even when the experimental portion was indicated by poles driven down into the bottom.
2. Grazing is not taken into consideration: when only the fish and aquatic invertebrates are concerned, this error is likely to be small; it would be important if manatees were present in the area.
3. Cutting of the grass and thus making room for more grass stems and leaves evidently modifies the natural condition and is likely to cause better growth in the surrounding stems. This error seems unavoidable with the present technique unless a much wider area is taken, being naturally delimited by bare channels. This would entail the cutting carrying and weighing of huge quantities of plant material and was of course not feasible in the present case.

Biomass

Determination of total biomass even in a small lake such as lake Redondo is not easy, and probably is not even possible, but an attempt has been made to determine at least partial standing crops.

1. Biomass of marginal vegetation

Three determinations of fresh weight of the plants of the floating meadow have been made: two on the 7th October, one on the 22d December. After this, two determinations of dry weight of the first two samples (of our fourth of a square meter) were performed. The results appear in table 6.

N° sample	per 1/4 sq. m. (grams)	per sq. m. (grams)	per Hectare (tons)	for whole lake (tons)	
one, fresh W. . .	2 050.0	8 200.0	82.0	164.0	Average fresh weight
one, dry W. . .	185.0	740.0	7.4	14.8	per Hectare (three
two, fresh W. . .	2 000.0	8 000.0	80.0	160.0	measurements)
two, dry W. . .	270.0	1 080.0	10.8	21.6	96.0 tons
three, fresh W. .	3 150.0	12 600.0	126.0	252.0	Average dry weight per Hectare (two measurements) 9. 1 tons

Table 6.

*) Computed according to data from Penfound 1956, Limnology and Oceanography 1: 91—101 conversion factor; $\frac{\text{Dry weight}}{\text{carbon W.}} = 2.16$ for *Typha*.

Sample one: 1/4 sq. m. of the floating belt in Paspalum repens stand: 7. X. 1963.
Sample two: 1/4 sq. m. of the floating belt in Scirpus cubensis stand: 7. X. 1963.
Sample three: 1/4 sq. m. of the floating belt in Paspalum repens: 22. XII. 1963.

2. Biomass of invertebrates in the marginal vegetation

Excluding fishes and shrimps, too quick to be caught within the vegetation samples, the small invertebrates living on stems leaves and roots of the floating meadows, were washed off the plants and their weights determined separately; most of them were insects and snails. (Table 7).

N° sample	per 1/4 sq. m. (grams)	per sq. m. (grams)	per hectare (kilograms)	for whole lake (kilograms)
one, fresh weight	9.920	39.680	396.80	793.6
one, dry weight	3.476	13.904	139.04	278.0
two, fresh weight	9.840	39.360	393.60	787.2
two, dry weight	2.636	10.544	105.44	210.8
three, fresh weight	4.748	18.992	189.92	379.8
three, dry weight	0.981	3.924	39.24	78.5

Table 7.

Average wet weight per hectare: 395,2 kg. Average dry weight: 122,2 kg. Sample three was taken in the new growth of grasses cut 75 days ago. The average weight per hectare was computed on the basis of the first two samples. The great differences in the proportions of dry weights to fresh weights are due to the dominance of snails in sample one and to the dominance of shrimps and insects in the fauna of sample two.

3. Biomass of benthic animals

The numbers of various invertebrates living in the mud were found to vary widely during the year, according to their own cycle of development and to their mortality rate. Some are permanent dwellers in the sediments and have either an annual cycle as in Campsurid Ephemeroptera nymphs, or a longer cycle as in snails and clams.

Others have much shorter cycles as do chironomoid larvae, water-mites (probably), others still are short-lived and intermittent dwellers in the mud (*Chaoborus* sp).

Egg laying, larval growth, emigration from the sediments, emerging as adults or natural mortality are intricate factors which continuously affect the numbers and biomass in the sediments.

Numbers were determined in mud-samples collected with a dredge on three occasions during the year. Each determination was made on several samples, the arithmetic means of which are given here, multiplied by 44.4 (Ekman dredge 15 cm × 15 cm) to obtain the value per square meter.

Date / Items	28. VIII. 63 per sample	28. VIII. 63 per sq. m.	6. X. 63 per sample	6. X. 63 per sq. m.	4. IV. 64 per sample 8 samples	4. IV. 64 per sq. m.	
Campsurid Nymphs .	1.3	57.7	15.4	684.0	3.6	159.0	Biomass on
Chironom. larv. . .	0.71	31.5	2.0	88.8	14.8	657.0	october 6.
Hydracari	—	—	2.8	124.0	6.1	271.0	Dry weight 0.245 g per
Chaoborus larv. . .	—	—	0.8	35.5	1.75	78.0	sq. m.
Clams (Pisidium sp) and Snails (Hydrobiids) . . .	—	—	0.6	17.7	2.7	108.0	2450.0 g per hectare. 80.85 kg for the whole lake.
Nematods	—	—	—	—	1.1	49.0	
Copepods	—	—	—	—	3.7	164.0	

Table 8. Numbers of biota in the sediments of lake Redondo

4. Biomass of the plankton. Total plankton

Plankton samples were taken with a 2.5 litre Gizewski bottle and filtered in a nylon nr 25 bolting silk plankton net, thus mixing phyto- and zooplankton; two hauls, thus giving a total filtered volume of 5 litres, were taken at each station. Zooplankton was separated under the microscope, counted and identified.

The total quantity of plankton in each sample was so small that it was not possible to weight it.

Depth (m)	30. VIII. 1963	6. X. 1963	22. XII. 1963	7. IV. 1964	5. V. 1964
0	0.04	0.06	0.04	0.10	0.06
1.0	—	0.02	0.02	—	0.06
2.5	0.09	0.03	0.05	0.08	0.03
Average for whole water column . . .	0.065	0.031	0.033	0.09	0.051

Table 9. Total plankton volume collected in each station in ml per litre, sedimented (not centrifuged)

Average for whole year and whole water column 0,054 ml. per litre = 54 ml/cu. m

Approximate area of lake (without floating meadow) = 330.000 sq metres

Approximate mean depth 2 metres.

Approximate volume 660.000 cubic metres.

Total volume of plankton: 35.640,0 litres. (not centrifuged).

Zooplankton formed the bulk of this total plankton zooplankton.

Zooplankton was sorted under the microscope according to classes and orders and the following categories were recognized.

Cladocera: *Diaphanosoma*, *Moina*, *Ceriodaphnia*, *Bosmina*, *Daphnia*.

Copepoda: Calanoidea, Cyclopoidea, Harpacticoidea, larvae of Copepoda.

Rotifera

Hydracari

Chaoborus larvae

Detailed composition of the individual samples have been published elsewhere (Marlier 1966). To obtain the biomass of zooplankton, the following assumptions were made (some of which are not proved).

One thousand *Diaphanosoma* sp were weighed fresh: it gave 17 mg. i. e. one *Diaphanosoma* weighed 17 γ.

According to their size, fresh weights of the different kinds of the zooplanktonts were estimated in multiples or fractions of 17 γ.

Diaphanosoma: 17 γ; Calanoidea: $2 \times 17 \gamma = 34 \gamma$; Cyclopoidea*): 8,5 γ

Moina: 8,5 γ

Ceriodaphnia: $0{,}4 \times 17 \gamma = 7{,}2 \gamma$; *Bosmina*: 7,2 γ; larv al Copepoda: 3,6 γ; Rotifera: 3,6 γ

Then the fresh weights of zooplankton were

5. X. 1963: 1.88 mg per litre.	Average of four periods: 1.61 mg per litre.
22. XII. 1963: 1.29 mg per litre.	Or 1.61 g. per cubic metre.
7. IV. 1964: 1.58 mg per litre.	Total volume of the lake**): 700 000 cubic metres.
2. V. 1964: 1.69 mg per litre.	Biomass: 3,22 g per square metre.

It must be noticed that these fresh weights have been computed and not obtained by actual weighing. It would seem desirable to compute also to which dry weights these quantities of zooplankton correspond. For this, a factor must be chosen. In the preceding biomasses estimations the transformation of fresh weights into dry weights rests on actual weighing after drying to constant weights. Comparison of the fresh and dry weights shows very great differences between the relative values of dry to fresh weights.

1st floating meadows (*Paspalum*):	factor 2.85
2d floating meadows (*Scirpus*):	factor 3.75
3d floating meadows (regeneration):	factor 4.84
Bottom fauna:	factor 5.87

This is understandable as the fauna of the littoral vegetation includes a variable but always large proportion of Snails, the latter beeing nearly absent in the bottom fauna where "soft" arthropods predominate. The last factor (5.87) seems thus better adapted to the zooplankton estimations. It has been used here.

Average biomass of zooplankton: fresh weight: 3.22 g per square metre (see above)
dry weight 0,54 g per Square metre; 189 kg for the whole lake.

Fluctuations of this total zooplankton are not very important and the higher and the lower are never distant from the mean by more than 1,5 times the standard deviation. This value may thus be considered constant over the whole year, when the lake is independent.

Shrimps and fish. No attempt has been made to estimate the biomass of Decapods and fish. Four species of prawns and forty nine species of fish have been collected. The first have been identified by Dr. J. Holthuis, of Leiden, while the fishes have been identified by Dr. J. P. Gosse, of Brussels.

*) According to Naber 1933, 1 individual of *Cyclops strenuus* weighs 9,8 γ.

**) As zooplankton is also abundant in the littoral zone the total area and volume of the lake have been taken and not only free water area and volume.

Decapods

Macrobrachium amazonicum (HELLER); *M. jelskii* (HELLER); *Palaemonetes carteri* GORDON and *Euryrhynchus burchelli* CALMAN. The second was the most common of the prawns, followed by the fourth and the first.

The two first species have been examined for their feeding habits. Both were found to feed on grass leaves and roots. Only plant debris were identified in their guts.

Fishes

The feeding habits of the fishes of Lake Redondo have been studied. The following categories have been recognized.

A. Stenophagous

I. Carnivorous

a. not specialized: Serrasalmus nattereri Kner; Serrasalmus elongatus (Kner); Eigenmannia virescens (Valenciennes); Pimelodella cristata (Müller & Troschel); Plagioscion squamosissimus (Heckel); ? Geophagus surinamensis (Bloch); Apistogramma taeniatum Günther; Colomesus psittacus (Schneider).

b. specialized

1. fish-eaters: Arapaima gigas (Cuvier); Boulengeriella cuvieri (Spix); Ageneiosus ucayalensis Castelnau; ? Symbranchus marmoratus (Bloch); Cichla ocellaris (Schneider).
2. insect-eaters: Triportheus elongatus (Günther); Oxydoras niger (Valenciennes).
3. zooplankton-eaters: Metynnis hypsauchen (Müller & Troschel); Astyanax fasciatus (Cuvier); Hypophthalmus edentatus Spix.

II. Herbivorous

a. not specialized: Anodus laticeps (Valenciennes): phytoplankton, epiphytic diatoms
Cichlasoma bimaculatum Linné: filamentous algae; higher plants debris.
Cichlasoma festivum Heckel: Epiphytic diatoms; grass leaves and roots.

b. specialized.

Ctenobrycon hauxvellianus (Cope): grass seeds.
Metynnis maculatus Kner: water grasses.
Leporinus maculatus (Müller & Troschel): water grasses.
Colossoma bidens (Spix): fruits.
Poecilobrycon trifasciatus (+ unifasciatus) (Steindachner): filamentous algae and "Aufwuchs".

III. Pelophagous

Curimatus sp; Potamorhina pristigaster (Steindachner); Prochilodus sp.; Pterygoplichthys multiradiatus (Hancock).

B. Euryphagous

a. predominantly carnivorous.
Osteoglossum bicirrhosum vandelli; Serrasalmus rhombeus (Linné)

b. predominantly herbivorous.

Anchoviella brevirostris (GÜNTHER): phytoplankton, zooplankton; *Pyrrhulina brevis* STEINDACHNER; *Hyphessobrycon rosaceus* DURBIN; *Hyphessobrycon callistus* (BOULENGER): grass leaves, grass seeds, insects.; *Hyphessobrycon* sp (?); *Cheirodon piaba* LUETKEN: benthic and epiphytic diatoms, Cladocera; *Metynnis lippincottianus* (COPE): algae, grass, Cladocera; *Corydoras* sp: Aufwuchs.

Acarichthys heckeli (COPE): seeds, snails; *Plataxoides scalare* (VALENCIENNES): littoral zooplankton, higher plants.

The preceding summary is admittedly very rough and ought to be refined. As such it suffices to show how complicated can be the food-web even in small water-body. The parts of the food-web which relate to other groups than decapod prawns and fishes cannot be reconstructed as yet. Indeed the principal invertebrate groups are not yet studied and will be known taxonomically much later. But as is well known, insects are much more likely to have a standardized diet according to their systematic position, even if some particular preference may be masked when alluding to the usual regime of the family. But this part of the description of the food relations of the community would only be complete if we could identify (or even distinguish) all species on the spot and study their food requirements.

It is obviously impossible and we have to rely on our knowledge of some northern relatives of the amazonian species to fill in the gaps.

The food-web in lake Redondo.

Producers I Shore plants: contributing leaves, fruits etc.
II Littoral floating meadow: area 2 hectares.
III Aufwuchs.
IV Phytoplankton.

The share of I is difficult to ascertain, for obvious reasons.

II contributes the bulk of organic matter to the lake. It is not clear whether its supply in nutrients is drawn from the lake, from the littoral soil or from both: total biomass 192,0 tons fresh; 18,2 tons dry weight.

III Owing to the great surface of the substrate (grass leaves, halms and roots) their Aufwuchs must have an enormous extension; this is confirmed by the examination of fish stomach contents where Aufwuchs is very often present as food but is not very striking on direct observation. The nutrients used by these organisms come from the water.

IV Phytoplankton: Although no direct counts have been made, it has been shown above that this does not constitute a very big source of organic matter; this is confirmed by the oxygen-production observations. The total biomass is unknown; one third of total plankton (animal and plants), i.e. 12000 litres uncentrifuged plankton would correspond at the utmost to 6.000 litres of true volume of organisms. This would give a maximum figure of 6,0 tons for the whole lake.

Surplus of production: organic remains in sediments of allochtonous and autochtonous origin; bottom bacteria.

Plant-eating animals: Primary consumers on living plants.

Oligochaeta, Decapod prawns, Phyllopods; planctonic Copepods and Cladocera, Corixidae, Ephemeroptera, Trichoptera, Diptera Chironomidae (at least 9 spp), Coleoptera Helodidae, Snails (Ancylidae, Planorbidae, Hydrobiidae); Fishes (9 spp.).

Scavengers: Oligochaeta, Tubificidae; Snails; Sphaeriidae (1 sp); Ephemeroptera Campsuridae (1 or 2 spp); Chironomidae (at least 2 spp); Fishes (4 spp.).

Carnivorous animals: secondary and tertiary consumers.
Hemiptera Nepidae, Belostomatidae, Pleidae, Naucoridae.
Coleoptera Dytiscidae, Odonata.
Chaoborus: preying on zooplankton.
Ostracods; Hydracari (preying on chironomids)
Insect-eating fish (eg. *Triportheus*); snail-eating fish (eg. *Acarichthys*); prawn-eating fish (eg. *Plagioscion, Serrasalmus, Colomesus*).
Zooplankton-eating fish: (e.g., ? *Anchoviella, Astyanax, Hypophthalmus*).
Fish preying on mud-eating larvae (eg. *Oxydoras*).
Fish-eaters (e.g. *Arapaima, Serrasalmus, Ageneiosus, Cichla* etc.).

Discussion

The study of lake Redondo seems to provide an ideal example of a small equatorial lake in a electrolyte-poor area.

Great cyclical changes are absent, the only apparent feature being a progressive decrease of production during the low-water time. The environment may be considered as reasonably constant over one year.

The maximum biomass is, of course, made by the plants and, as is to be expected, by the littoral rooted plants, which probably derive most of their nutrients from the soil, not from water.

Phytoplankton is scarce, probably owing to the general nutrient-deficiency of the waters. It must not be forgotten however that according to GESSNER (1960), the varzea sediments may act as phosphate-storage for plankton and it is thus possible that phosphorus is not the limiting factor for plankton produktion unless the particular plankton community is unable to use this element to its lowest limit. In fact the clear- and dark-bottle experiments, which in this use are an index of the free available nutrients to this particular plankton community show how poor this supply is during the year. The community is thus made of a great amount of plants, littoral and to a minor extent, pelagic, and a smaller biomass of animals, with a very low amount of available (circulating) nutrients and this situation seems relatively stable. The ecological niches of this community are numerous (number of species).

Even if these populations of animals are abundant, it seems that they "crop" very little from the plants and that the supply of these is in much bigger excess over the demand. This state of affairs is comparable with the tropical rain-forest, with a large quantity of producers, a much smaller quantity of animal biomass, although absolutely large, organized in quite a number of diversified niches, and with very little "circulating" nutrients in the soil.

The true fertility is a matter of supposition, but is more accessible to measurement in the case of a water-body. The latter is indeed free from the risk of erosion, compared with the terrestrial forest.

Production without cropping is only measurable by the metabolism of biota and energy circulation in the lake. Secondary production with cropping is probably high owing to the stock of producers (floating meadow) and the diversity of the consumers.

Primary production (with cropping) of the floating meadow is high, as showed by the preliminary experiments on regeneration where 5,000 g dry weight (per year, per sq.m) were observed to be replaced, and this may be explained by the fact that these floating grasses are rooted in the shore and thus derive their nutrients from outside the water.

A small varzea lake of this type seems a nearly ideal natural laboratory for such problems of tropical freshwater production.

Moreover as only very little subsistence fishing is practised in it, it would be easy to try various experiments and measurements of its productivity under different conditions.

Lake Rio Preto da Eva

The Rio Prêto da Eva is a left bank affluent of the Amazon, downstream of the mouth of the Rio Negro. Its middle course forms a lake, of the shape of a dammed valley, belonging to the "lateral lakes" type of HUTCHINSON and to the type II of the present classification (see above). It is never invaded by the "white" Amazon waters but its extension and level is largely under the influence of the Amazon water level. Its tributaries are, apart from the Upper Rio Preto, negligible, owing to their minute size. The effluent, the lower Rio Preto has a length of about 30 km, being nearly parallel with the Amazon of which the lake is very little distant "as the crow flies". Level fluctuations are important and probably around 9 meters, the maximum being in June and the minimum in December.

The area of the lake is very variable, being hardly more than a middle size river at low water, and extending far into the forest at high water. At this time the area must be around 52 square kilometres. It was possible to visit it in July at the beginning of the level decrease but it was not possible to see it at the minimum level, as parts of the effluent were no longer navigable. It was studied on four occasions by the author in July, 1963, January, February and April 1964 and by Antonio dos Santos in August 1964.

The depth of the lake fluctuates from 6,50 m to 15,60 m in the central channel of the stream, most of the lake being much shallower. The length of the shore must be close to 146 km (map at 1 cm for 10 km, enlarged ten times) and the shore development coefficient is thus around 5,6. The waters are humic, dark yellow in the river, bleaching in the lake but still distinctly pale yellow. By reflection, they appear black, hence the name of the lake (black river).

The shores of the lake are almost completely covered with forest, with some clearings for a sparse cultivation of cassava.

Table 10 shows the variation of transparency, colour and temperature, at the times of the visits.

Electrical conductibility: This value is always very low, and very little different in the various layers. January: $K_{20} = 6{,}0\ \mu$ S; February: 6.2 μ S; April: 3,9 μ S at 0m and 10,2 μ S on the bottom.

pH: Colorimetric determinations of pH with Bromcresol green: January 5.8° at 0 m, 4,9 at 9 m. February: pH 4,9 at all depths; April: 0 m: 4,7 bottom: pH = 4,5. August: 0 m : 4,9; 14 m: 4.8.

Alkalinity: always lower than the experimental error.

Depth (m)	14. VII. 63	25. I. 1964	27. II. 1964	22. IV. 1964	23. IV. 1964	28. VIII. 1964
0	29°4	31°4	30°0	29°0	28°6	31°4
1	29°6	31°3	—	29°0	28°6	30°6
2	29°6	31°3	—	—	28°6	30°3
3	29°0	31°1	30°0	29°0	28°5	30°0
4	28°2	—	—	—	—	29°4
5	27°3	29°8	—	28°7	—	28°3
6	26°8	—	—	—	27°3	28°0
7	26°3	28°9	—	27°4	—	27°7
8	26°2	—	—	—	27°2	26°8
9	—	28°9	29°7	—	—	—
10	26°0	28°8	bottom	—	—	26°6
12	26°0	bottom		26°8	26°8	26°6
12.40	26°0			bottom	bottom	—
14	bottom					26°5
Transparency	2.75 m	2.80 m	3.16 m	3.50 m		2.70 m
Colour 0 m .					15.20 Pt.un.	40 Pt.un.
12 m .					70 Pt.un.	

Table 10

Calcium and Magnesium: always in concentrations inferior to the sensibility limit of the complexometric methods.

Acidity (titration up to pH: 8,4 with sodium carbonate): due to CO 2 and "humic" acids.

Depth (m)	15. VII. 1963	25. I. 1964	27. II. 1964	23. IV. 1964	28. VIII. 1964
0	—	0.154	0.244	0.384	0.085
2	—	0.170	—	—	—
3	—	—	—	—	0.085
5	—	0.474	—	—	0.345
9	—	0.584	—	—	0.425
10	1.010	0.656	0.244	1.000	0.450
14	—	bottom	—	—	0.500

Table 11. Acidity in milliequivalents per litre

Dissolved oxygen: Temperature stratification corresponds to an oxygen stratification and shows a period of stability at high water level and a long period of circulation corresponding to decrease in depth and low water period. Lake Rio Preto da Eva is thus a monomictic lake in the true meaning of this term. But it is not to be forgotten that the circulation period is not brought by a low temperature season but by the increasing action of the affluent river on a lowering lake.

This destruction of the stratification is progressive till the complete overturn period in February and the reformation of a stable situation is also progressive. At the circulation period, the oxygen is plentiful to the bottom Owing probably to the nature of the sediments, the exhaustion of the hypolimnic oxygen is slow and even when the thermocline is well established, as in January there is still 50 percent of the saturation value in the bottom waters.

Dates Depth in m	15. VII. 1963 ppm	 %	25. I. 1964 ppm	 %	26. II. ppm	 %	27. II. ppm	 %	29. II. ppm	 %
0	7.00	90.8	8.06	107.4	6.10	79.1	6.48	84.0	6.75	88.4
0.5	—	—	—	—	6.01	78.3	—	—	6.80	89.1
1.0	6.95	90.0	8.04	106.9	—	—	—	—	—	—
1.5	—	—	—	—	6.09	79.5	—	—	6.69	87.6
2.0	6.95	90.0	8.04	106.9	ND	—	—	—	ND	—
3.0	3.46	44.3	—	—	—	—	—	—	—	—
4.0	1.03	13.0	—	—	ND	—	—	—	ND	—
5.0	0	0	4.07	52.8	—	—	—	—	—	—
6.0	—	—	—	—	ND	—	—	—	ND	—
7.0	—	—	3.96	50.7	—	—	—	—	—	—
8.0	—	—	—	—	ND	—	6.33	82.0	ND	—
9.0	—	—	4.06	51.8	—	—	6.21	80.5	—	—
10.0	—	—	bottom		bottom		bottom			
12.0	0	0							—	—

Dates Depth in m	2. III. ppm	 %	22. IV. ppm	 %	23. IV. ppm	 %	28. VIII. ppm	 %
0	—	—	6.36	81.5	—	—	7.75	105.0
0.5	6.57	85.6	6.45	82.7	6.17	78.4	—	—
1.0	—	—	—	—	—	—	7.81	104.6
1.5	6.53	85.1	6.32	81.0	6.16	78.3	—	—
2.0	—	—	—	—	—	—	7.70	102.6
3.0	6.44	83.9	—	—	6.19	78.6	—	—
4.0	—	—	—	—	—	—	4.73	62.3
5.0	—	—	5.12	66.3	—	—	0.96	12.4
6.0	—	—	—	—	2.65	32.9	0	0
7.0	—	—	3.06	38.1	—	—	0	—
8.0	—	—	—	—	3.03	37.6	—	—
9.0	—	—	—	—	—	—	—	—
10.0	—	—	—	—	—	—	—	—
12.0	—	—	0.54	6.6	0.79	9.7	—	—

Table 12. Dissolved oxygen in ppm and percent of the saturation
(N.D. means not determined)

Plankton. The plankton of lake Rio Preto da Eva is sparse and composed in its major part of very small organisms.

As for lake Redondo, it was not possible to have a quantitative estimation of phytoplankton; total plankton was measured in the same way as for the preceding lake.

Zooplankton was counted under the microscope and sorted by groups. In table 14, the numbers of individuals per litre are indicated. Owing to the variations of area, and the indecise limits of the lake, no attempt has been made to compute the numbers per unit area. The zooplankton is composed of Cladocera (*Holopedium amazonicum*, *Bosmina* sp, *Moina* sp, and very few *Diaphanosoma*) generally of a small size, of Copepods and their larvae, Rotifers, Gasterotrichs, Hydracari, and few *Chaoborus* larvae. The details of their repartition has been published in another note. Here, only the numbers will be indicated.

Date	Depth: 0 m	1	2	3	4	6	8	9
2. VII.	0.02	0.02	—	under 0.01	0	0	—	—
2. III.	0.02	—	—	0.01	—	0.01	—	0.02
23. IV.	0.01	—	0.01	—	0.01	0.02	0.01	—

Table 13. Total plankton volume (not centrifuged) in one litre of water

m	13. VII.	2. III.	23. IV.
0	250	413	201
1	196	—	—
2	—	—	275
3	181	153	—
4	0	—	162
5	—	—	—
6	—	156	52
8	—	—	34
9	—	122	—
10	—	—	21

Table 14. Repartition of zooplankton organisms with depth during the year: number of individuals per litre

The biomass per litre is still less important than in lake Redondo owing to the smaller size of the individual organisms, but the space occupied in a square meter of the surface by the planktonts is of course much bigger, the inhabited depth being much greater. Accurate estimation of this biomass has not been made.

Bottom animals

The lake sediments are mainly sandy on the shore and down to 7 meters depth (January), gradually passing to a brown mud in the deepest places, sometimes mixed with a dark mud. In the period of stagnation the hypolimnion mud is black. The shore sediments are mixed with terrestrial debris, forest leaves and twigs, the more finely divided the greater the distance from the shore. In the littoral zone, many pieces of terrestrial insects, sponge gemmulae, polyzoa statoblasts and empty cases of Trichoptera (*Oecetis* sp) are mixed with the sand and give an impression of great faunal diversity. In fact, few living individuals are found, sponge and polyzoan colonies on twigs, and trichopterous larvae among the dead leaves.

In the big pieces of decaying trees, one finds campsurid ephemeroptera nymphs, some caenids and several species of chironomid larvae. Also decapod crustacea, *Macrobrachium jelskii* (Miers), *Euryrhynchus burchelli* Calman, already found in lake Redondo, and *Macrobrachium nattereri* (Heller), more common, are found in these littoral debris as well as ostracods and some hydracari. Between wood and bark of the decaying trees it is not rare to find young individuals of *Symbranchus marmoratus* (Bloch).

The off-shore sediments are more uniform and give shelter to a much more reduced fauna. The total numbers found in a 225 sq cm Ekman dredge were so low that a quantitative study was not possible with such a small gear. (table 15).

Ol	: Oligochaeta	Ch.	: Chaoborus
T	: Tanypid	Ar.	: Argulid
Os	: Ostracod	C	: Copepod
H	: Hydracari	N	: Nematod
Ce	: Ceratopogonid	Co	: Corixa

	Date: VII.	27. I.
Sample 1	no fauna collected	9 m: 1 Ol, 1 T
Sample 2	—	9 m: 7 Ol
Sample 3	—	9 m: 2 Ol, 1 T
Sample 4	—	9 m: 5 Ol, 3 T
Sample 5	—	7 m: 1 T, 9 Ch, 12 Os
Sample 6	—	7 m: 2 H, 3 Ol, 1 C, 1 Ar

24. IV.

Nr. of Sample	Nature sediment	Depth	Animals
Sample 1	sand	11 m	28 Ol, 1 Ch
Sample 2	sand	11 m	11 Ol, 5 T, 2 Ch, 1 N, 7 Os
Sample 3	brown mud	11 m	1 Ol, 3 T
Sample 4	,, ,,	12 m	3 Ol, 4 T
Sample 5	,, ,,	13 m	4 Ol, 4 T, 2 Ch, 2 Co
Sample 6	,, ,,	12 m	1 T, 1 H
Sample 7	,, ,,	9 m	2 Ol, 3 T, 4 Ch, 1 H, 1 Co, 4 Os
Sample 8	,, ,,	9 m	1 Ol, 10 T, 4 H, 2 Os, 1 Ce
Sample 9	,, ,,	9 m 50	2 Ol, 3 T, 1 Co, 3 H
Sample 10	hard clay	7 m 50	3 larvae Thienemanniella

Table 15. Standing crop of lake Rio Preto da Eva: in numbers

The bottom fauna of the deep parts of the lake is thus sparse and less uniform than that of eutrophic lakes. It becomes more and more diversified when one collects closer to the shore. At high water time, no fauna at all is found under the thermocline.

Production of oxygen by the plankton. Table 16 gives the result of experiments made by the clear-and-dark-bottles method to measures oxygen production by the plankton. P N is the quantity of oxygen (in ppm) produced in the clear bottles, R the quantity of oxygen consumed in the dark bottles, P B is the gross production, obtained by the algebraic sum of P N and R.; R. being always preceded of the positive sign; P.N. being positive when there is more oxygen in the bottles after 24 hours than at the beginning of the experiment.

As can be seen in table 16, net production is often negative at the surface, which means that, even in the light, oxygen is consumed and not produced or is produced in smaller quantities than is consumed by some process. It is to be supposed that a photochemical oxidation of the dissolved organic matter is taking place. Of course it cannot be such a thing as a gross production at the surface of the water even when, as on the 26th February and on the 22d April, some oxygen has been produced in the clear bottles. As this photooxidation must be working even at some depth (as shown in January and August), the significance of the whole experiment may well be questioned; we observe indeed two opposite processes at work in these humic waters: photochemical oxygen

Depth (m)	Date: 25. I. PN	R	PB	26. I. PN	R	PB
0.0	— 2.22	+ 0.19	—	— 2.04	+ 0.74	—
0.5	— 0.99	+ 0.60	— 0.39	— 0.92	+ 0.54	— 0.38
1.5	—	—	—	—	—	—
2,0	— 0.75	+ 1.27	+ 0.52	—	+ 0.27	—

Depth (m)	26. II. PN	R	PB	29. II. PN	R	PB
0.0	+ 0.09	+ 0.07	+ 0.16	+ 0.07	0	+ 0.07
0.5	+ 0.64	—	—	+ 0.18	+ 0.77	+ 0.95
1.5	+ 0.15	+ 0.13	+ 0.28	+ 0.14	+ 0.42	+ 0.56
2.0	—	—	—	—	—	—

Depth (m)	Date: 2. III. PN	R	PB	22. IV. PN	R	PB
0.0	—	—	—	+ 0.32	+ 0.20	+ 0.52
0.5	+ 0.16	+ 0.20	+ 0.36	+ 0.28	+ 0.31	+ 0.59
1.5	+ 0.16	+ 0.06	+ 0.24	+ 0.09	+ 0.26	+ 0.29
3.0	+ 0.14	+ 0.04	+ 0.18	—	—	—

Depth (m)	23. IV. PN	R	PB	26. VIII. 64 PN	R	PB
0.0	—	—	—	—	—	—
0.5	+ 0.42	+ 0.42	+ 0.84	— 0.55	+ 1.48	+ 0.93
1.5	+ 0.11	+ 0.37	+ 0.48	+ 0.30	+ 0.45	+ 0.75
3.0	— 0.48	+ 0.48	0	+ 0.31	0	+ 0.31

Table 16.

production by chlorophyll-bearing organisms and photochemical oxidation of organic matter. In addition to this, even chlorophyllic synthesis often is reduced in the strong light of the upper strata of the water. New experiments must be made under varied conditions to ascertain the part of all factors in such forest waters.

Plant Biomass: excepted the scarse phytoplankton, there are no rooted plants or floating plants in the lake. This is not to say that plants play no role in the trophic chains of the lake. The forested shore and the inundated forest (igapos) in the ramifications of the lake are rich sources of plant material.

Fish. In the igapos and the small forest affluents, the fish fauna is rather diversified but in the main lake very few fishes can be seen. It must be noted however, that at rising water time, fishes enter the lake from its effluent and the Amazon, probably for spawning. Among these, the Pescada *Plagioscion squamosissimus* may be cited.

The sedentary fishes include the Tucunaré, *Cichla temensis*, the Mandubé *Ageneiosus ucayalensis* CASTELNAU; the Piracatinga, the black Piranha: *Serrasalmus* sp and some small characids.

In addition to fish, at some seasons, at high water, two species of fresh water dolphins *Sotalia* and *Inia* appear. These must exploit the shoals of migratory fish at the spawning season.

Other lakes

Three other lakes have been visited in addition to the Redondo and the lago Rio Preto da Eva. These lakes are lago Jurucuí, in the State of Pará, lago Maicá in the same State and lago Jarí in Amazonas.

Lake Jurucuí

Lago Jurucuí has been studied in 1952 by R. BRAUN. It is situated in a small affluent of the river Tapajós. It is not more than 20 hectares in area.

Three visits have been made to the Jurucuí, one in August, at lowering level and two in December, at low waters. It is a crystal clear water lake fed by two small creeks, Igarapé do Tento and Igarapé Grande. Its characteristics have changed very much during the ten years since BRAUN's study. Transparency was complete down to the bottom. Maximum depth was 2,35 m on the 13 th December.

Date	Depth m	Temperature	pH	CO_2 (milleq. per l)	Alkal. (millieq.)	K_{20} µS	Oxygen ppm	Oxygen Sat.
15. VIII. .	0	31° (15h)	5.4	0.17	0.012	—	—	—
6. XII. . .	0	29°6 (11h)	—	—	—	—	—	—
	0	31°5 (17h)	—	—	—	—	—	—
	1.5	29°2 (id)	—	—	—	—	—	—
13. XII. . .	0	29°5	5.5	1.2	—	11.4	8.64	109.9
	1.5	30°0	4.8	1.2	—	8.6	8.05	104.9

The bottom fauna of the lake was very poor, limited to sparse chironomid larvae and oligochaeta. On the other hand the fauna of the two affluents was rich and dense. The fish fauna of the lake was equally rare and only *Prochilodus* sp, *Leporinus* sp and a small species of *Cheirodon* were caught.

The nature of the bottom sediments was also very different from when BRAUN studied the lake: it was a fluid mud, of a greenish-gray colour, without any smell of hydrogen sulfide.

Oxygen production in the clear and dark bottles method was always negative in the present experiments. No explanation of this can be given unless that productivity is very low at low water time, which is the period of complete mixing.

Lake Maicá

Lake Maicá is a várzea lake in permanent continuity with the Amazon, a little downstreams from Santarém (Parà). Its waters are "white". Very little time was spent on it; no fishing and no productivity measurements were made. The visits were made on the 14th and the 18th August when the waters were falling.

Transparency: 1.37 m; Depth: 3.60 m.

Depth (m)	Temperature 14. VIII.	Temperature 18. VIII.	CO_2	Alkalinity	pH
0	30°3	29°6	0.338	0.032	5.2
2	31°2	—	—	—	—
3	29°8	29°4	—	0.033	5.2

Superficial examination suggested that fish were plentiful, and the dolphins were rather numerous, which confirmed the general impression. Lake Majcá has extensive floating meadows. Moreover the waters are manured by the numerous cattle grazing on the shore and going far in the shallow littoral zone to drink, and even to graze in the floating meadow.

Lake Jarí

Lake Jarí is a lateral lake situated on an affluent of the Rio Purús, itself an affluent of the Amazon. It is never invaded by the white waters of the Purús but its level fluctuations depend on those of the Purús. It is traversed along its whole length by the river Jarí, the upper reaches of which are as yet not well explored. The lake itself, at the time of the visit had an approximate length of 45 km and a width of 3 to 6 km. A bathymetrical survey was not made, due to lack of time. On the 26th March, the level was starting its annual rise. The colour of the water is light brown, (25—30 degrees Hazen). Several soundings were made on 26th March. The middle of the lake was 9 m deep, and, at the lakeside limit of the inundated forest, the depth was 7.5 m. Transparency varied from 1.98 m to 1.75 m.

Temperature and dissolved oxygen: a tendency towards a stratification was observed at this time of the year.

Chemistry: No true stratification was present, and the waters were certainly still circulating at times.

Depth (m)	Temperature	Diss. Oxygen ppm	saturation	K_{20} µS	pH	Acidity millieq
0	29°8	5.94	75.8	2.7	4.8	0.19
2	29°9	5.87	76.4	—	—	—
3	29°5	5.89	76.2	—	—	0.25
4	29°3	5.53	71.3	—	—	0.25
5	28°4	3.03	38.4	2.7	4.8	0.49
6.60	28°2	2.42	30.5	—	4.7	—

Benthic fauna.

The bottom fauna was as scarse as in lake Preto da Eva. In the brown odourless mud at 9 metres, 10 samples of 1/44 square meter gave an average of 2.9 Tanypid larvae, 0.6 Ostracods, 9.7 Oligochaeta, 0.3 Hydracari, 1.5 Chaoborus larvae, 0.1 beetle larvae. The corresponding figures for the Lake Preto in April (eight brown-mud samples) were:

3.5 Tanypids, 0.8 Ostracods, 1.6 Oligochaeta, 1.0 Hydracari, 0.8 Chaoborus and 0.5 Corixidae. This comparison shows how similar these two lakes are.

Planktonic Oxygen production.

Owing to a strong gale, the only experiment with clear-and-dark-bottles was only partly successful.

Only at 1.5 m depth could primary production be studied. Net production was negative (—0.38 ppm Oxygen), "respiration": + 0,50 ppm and gross production could thus not be ascertained as the photochemical effect, noticed in the lago Preto, was at work in the Jarí also.

Zooplankton and Phytoplankton of this lake were also very poor, and as no floating grass grew on the shores, the total biomass in the lago Jari was very low. The principal source of food and organic matter of this lake is the littoral forest, as in the lago Preto da Eva.

Summary

Of the three types of lakes studied, clear water, white water, and brown water, the white water lakes are the only ones to have a reasonable autochtonous production of organic matter. Owing probably to the lack of mineral salts, the primary production is very low in the two other types and not very high even in the white waters.

The total biomass is high in the white water lakes and the production increases only with rising water level. This may be due to different processes. One is the rains which bring in some quantities of nitrogen, as is well known. The other is the seeping of ground water through the bottom when the general level of the waters around the lake is rising. Of course, when the lake receives water directly from a white water affluent or from the rising Amazon, it also gets a new supply of mineral matter.

In the clear and black waters of the forest lakes, the organic production is allochtonous and probably the stock of organic material in the lake is increasing progressively with the ecological evolution of the water and with the action of the organisms which store nutrients in their own substance. The autochtonous productivity shows also a small increase when the water level rises but the total biomass always remains small.

One of the productivity factors which thus appears important is the number of animals. Firstly these store nutrients which would otherwise be lost to the effluents of the lakes; secondly, they increase the speed of mineralisation of the littoral plant material, which drops into the water, and make it available to the lake cycle. The first process is thus density-dependent, the second density-and-diversity-dependent.

The favourable action of the Amazon and white waters on the productivity shows the importance of an accurate hypsometric survey of the region for the delimitation of productivity zones in the Amazon basin.

Resumo

Dos três tipos de lagos estudados: de água clara, água branca e água "preta", são somente os lagos de água branca que possuem uma produção autóctona razoavel de matéria orgânica. Devido, provavelmente, à falta de sais minerais, a produção primária é muito baixa nos dois outros tipos, sendo mesmo não muito alta tambêm nas águas brancas.

A biomassa é alta nos lagos de água branca, e a produção aumenta somente com a enchente, quer dizer, com o nivel d'água subindo. Este fenómeno pode ter a sua razão em processos diferentes. Um deles são as chuvas que trazem alguma quantidade de nitrogênio, como bem se sabe. O outro é a penetração de água freática atravês do fundo do lago quando sóbe o nivel geral das águas ao redor do lago. E óbvio que o lago quando receber água diretamente dum afluente de água branca ou do enchendo Amazonas mesmo, também ganha um novo suplemento de matéria mineral.

Nas águas claras e pretas de lagos florestais, a produção orgânica é allóctona. Parece provavel que o estoque de matéria orgânica, no lago, aumenta progressivamente com a evolução ecológica da água e com a ação dos órganismos os quais acumulam nutrimentos dentro da própria substância. A produtividade autóctona mostra também um pequeno aumento quando sóbe o nivel da àgua, porém a biomassa total sempre permanece pequena.

Um dos fatores da produtividade o qual, desta maneira, parece importante, é o número de animais. Primeiro, eles armazenam nutrimentos os quais, em outro caso, seriam perdidos aos cursos d'água, efluentes dos lagos; segundo, eles aumentam a velocidade da mineralização do material, fornecido pelas plantas do litoral, o que cai para dentro da água, e tornam-no acessivel ao ciclo do lago. O primeiro processo é, desta forma, dependente da densidade da população animal, o segundo é dependente da densidade e da diversidade da mesma.

A ação favoravel do Amazonas e das águas brancas sôbre a produtividade demonstra a impórtância de um levantamento hipsométrico acurado da região para o fim duma delimitação de zonas de produtividade na bacia amazônica.

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