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PRIMARY PRODUCTION OF PHYTOPLANKTON IN THE THREE TYPES OF AMAZONIAN WATERS

II. The limnology of a tropical flood-plain lake in central Amazonia (Lago do Castanho)

by

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1. Introduction

Within the framework of these studies of phytoplankton primary productivity in the three types of Amazonian waters Lago do Castanho was chosen as an example of a "decanted" white-water. It best corresponds to the required theoretical and practical prerequisites, i. e. that it as much as possible contains only white-water, has no streams emptying into it, has year-round connection with the main tributary, and is close enough to Manaus to be readily accessible by small boat on a regular basis (see SCHMIDT 1972c). At the time however, nothing was yet known about the limnology of this lake. Not one of the várzea lakes had been studied on a regular basis over a period of at least a year in regard to its general limnological status and its nutrient metabolism.

The accumulated scientific knowledge on the várzea lakes available to us at the onset of the present investigation came primarily from the work of SIOLI (1951, 1957), who had described their common origin and their relationship to the surrounding landscape according to the picture yielded by his work in the lower Amazon region, and from MARLIER (1965, 1967, and 1968), who had already written on the particulars of the chemical-physical and biological conditions in Lago Redondo, a small várzea lake in the vicinity of Manaus. Various data on the electrical conductivity, pH, and oxygen concentrations in the waters of the várzea region were also published by GESSNER (1960a, 1960b, and 1961). A few lakes from the Tertiary shore region of the lower Rio Tapajós were already investigated at a relatively early date by BRAUN (1952) and, so, a comparison of these lakes with the lakes of the várzea was possible. The floodplain area of the great Amazonian white-water rivers, particularly the Amazon River itself, is generally designated as the "várzea" (SIOLI 1957). Considering the great significance which the lakes of the várzea in particular have in so many respects for the entire aquatic ecosystem and even more for the human population of this region because of their abundant fish (see also SIOLI 1968a and FITTKAU 1970), these lakes and the ramifications of their limnology become increasingly more interesting.

Extensive investigations by JUNK (1970a, 1970b) on the ecology and production of floating meadows, which also included consideration of various várzea lakes in the vicinity of Manaus, represented the beginning of a more intensive study of the limnological problems of these waters.

2. Description of locale

Lago do Castanho is located approximately 50 km southwest from Manaus on the right side of the Rio Solimões (Amazon River). Its location is shown in figure 1. It belongs to the group of lakes of Janauacá and is connected year-round, as are all these lakes, to the main river by a ca. 7 km long and very tortuous canal, the Paraná de Janauacá. Only during extreme low water is the connection between the lake and the Paraná broken. The areal dimensions of Lago do Castanho depend on the respective water levels in the lake at different times of the year and, therefore, vary considerably. The maximum values for its surface area, attained at times of average high-water levels, are estimated to be from 1.5 to 2.0 square kilometers. More exact figures are unfortunately not available due to a dearth of suitable maps and due to the lake's very irregular shoreline. The depth of the lake, as indicated previously, also depends on the water level of the river and, thus, on the seasonal conditions. At low water Lago do Castanho is normally almost dry; only a shallow puddle with a maximum depth of 1 m and a diameter of about 200–300 m remains. The maximum depth of the lake reached in the course of a year is around 11–12 m, which corresponds to the mean amplitude of the river's water level.

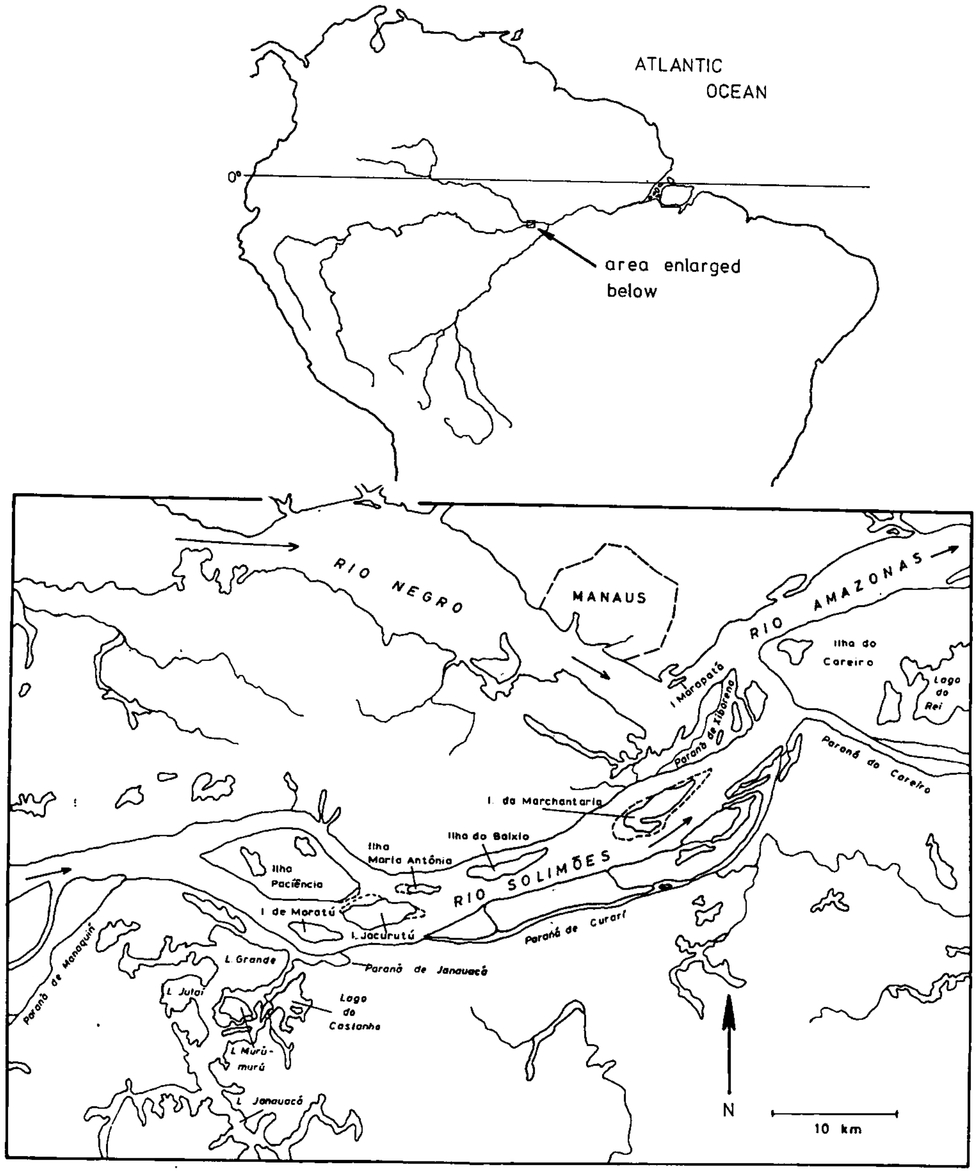


Fig. 1 : Geographical location of Lago do Castanho, ca. 50 km southwest of Manaus.

The southern shore of the lake is formed by the so-called terra firme, which is never flooded and which constitutes the major part of the Amazonian lowlands. In the region of Lago do Castanho the edge of the terra firme is extremely irregular; it has deeply in-cut bays and forms a series of islands and peninsulas. These formations have originated in part from the activities of the Amazon itself, which twists and turns in the valley it has gouged out over the centuries from the original broad plain, composed of the relatively soft material of Tertiary deposits, and in so doing is able to wash against either the northern or southern boundaries of its valley. It is also possible that the edge of the terra firme has also acquired elements of its present form as a result of severe erosion action during the ice ages when the Amazonian waters, due to the lower water level of the world oceans, exhibited a considerably steeper gradient (see SIOLI 1967).

In its northern region Lago do Castanho is separated from the Paraná de Janauacá by a relatively narrow and low dam composed of recent alluvial soil. The shores of the lake on the terra firme side are covered for the most part by a secondary forest. In a few places one can find homes of native settlers, some with agricultural plantings and cleared pastures for cattle. In other places on the terra firme shore one can only find brushwood (Capoeira). The floodplain area in the vicinity of Lago do Castanho has no forest any more, just brushwood and in a few places cattle pastures. Except for the relatively small area around the houses of the inhabitants, the shore proper of the terra firme side of Lago do Castanho is covered by flooded forest (Igapó). To what extent the existing Igapó, however, has also been changed in species composition and in its general structure from its original condition by human incursions can't be discussed here. An appreciable portion of the shore region is taken over additionally during periods of high water level by floating meadows. Through the work of JUNK (1970), we know that there are various types of floating meadows and that their composition depends on where they are located. In Lago do Castanho the floating meadows on the floodplain side consist for the most part of *Paspalum repens.* In the first phase of rising water level *Oryza perennis* also forms great stands on the floodplain side. *Echinochloa polystachia,* often found in várzea lakes together with *P. repens,* was observed very seldom in Lago do Castanho (JUNK 1970). In the deeply in-cut side arms of the lake, *Leersia hexandra* together with *Cyperus* spec. was widely distributed, as has also been described by JUNK for the other várzea lakes. Also frequently encountered in varying abundance in Lago do Castanho's zones of floating grasses were *Eichhornia crassipes, Reussia rotundifolia, Pistia stratioides, Neptunia oleracea, Salvinia auriculata,* and *Azolla* spec. The following species found by JUNK in other lakes were also found here as constituents of the floating meadows, but less frequently than those previously mentioned : *Jussiaea natans, Phyllantus fluitans, Ceratopteris* spec. and *Marsilia* spec.; the latter species were, however, still common, particularly along the edge of the floating meadows in the lake's side arms. *Victoria regia* was absent in Lago do Castanho during the time of this investigation. More detailed information about the floating meadows of this area and data on their faunal populations can be found in JUNK (1970).

The only genuine submerged plant found in Lago do Castanho, *Utricularia* spec., sometimes developed very large stands. This was especially striking in the flooded Igapó region and more specifically in those places where the forest was somewhat less dense, but where no other constituent of the floating meadows could grow any more. In contrast to the *Utricularia* that grew in full sunlight on the edge of the floating meadows, those *Utricularia* individuals which grew in areas of half-shadow remained lighter green and were not so overgrown by epiphytic algae. On the other hand, as shall be simply noted here in passing, flower formation was observed only on those individuals which were growing in full sunlight.

The sampling station and investigation site was located approximately in the center of the main body of the lake over the deepest portion of its basin. All of the data, when not otherwise noted, refer to this station.

3. Chronologue of the study

The investigations began in August 1967 and continued through April 1970. The rhythm of the procedures for collecting individual samples and conducting the various tests and measurements was adjusted so that it conformed to the frequency of the primary production determinations. Briefly outlined, then, the program of investigation was carried out according to the following schedule: from August 1967 to December 1968 samples were collected and measurements made at monthly intervals in order to get a general idea of the magnitude and the pattern of changes over the course of a year for the various factors.

In the succeeding segment of the study, investigations of shorter duration and with shorter intervals of time between them were conducted for those phases of the lake's seasonal changes which had proven to be the most interesting and the most important (the period when the water was just beginning to rise, the period of high water, and the period of low water) in order to reach a better understanding of the dynamics involved in the changes taking place in the lake. Since studies were being conducted simultaneously on other Amazonian waters, this particular program of investigation had to be limited to the periods noted above.

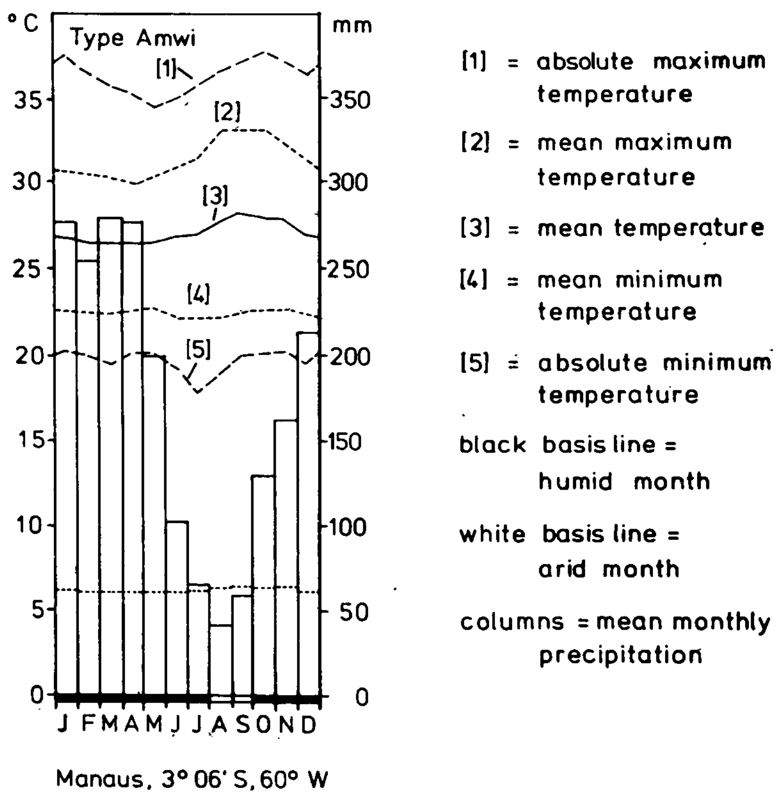


Fig. 2 : Climatological diagram for Manaus, according to REINKE (1962).

4. Climate

According to the description by REINKE (1962), the region around Manaus, a flat land lying only slightly above sea level, has a climate that belongs to the type called "Amwi" in the classification according to KÖPPEN. It is therefore a uniformly warm, damp, tropical climate with a short dry period that normally falls in the months of August and September. As REINKE has already observed, however, and as our own observations confirmed, the duration and intensity of the dry period can vary somewhat, since some rain usually does still fall during this time. In the course of the entire year the temperature fluctuates only slightly around a reading of 28 °C (see fig. 2).

Information on the actual values for a few climatic factors for Manaus during the period of our investigation is provided in table 1. Appreciation is due to Father Bruno Herzberg, Director of the Estação Métereológica de Manaus, who placed this data at our disposal. The data for rainfall included in this table are of particular interest because the amount of rainfall is so closely tied to the water level of the river, as will be shown later. As one can see from the table, fluctuations in the amount of precipitation and the monthly distribution of the precipitation in the three years were at times quite extraordinary. One example of this are the conditions for the second half of 1968, which greatly exceed the normal range of year-to-year fluctuations. In that year, the dry period was for all practical purposes nonexistent. This was not only true of the station at Manaus, but must have also been the case for the vast area of Amazonia, judging from the data for the similarly "abnormal" water levels in this particular year; the latter data will be discussed in more detail in the following section.

The winds in the region of Manaus come mostly from the east and are an offshoot of the trade winds. In general the wind velocities are relatively low, but can on occasion increase suddenly and severely. In such instances solitary squalls or single gusts are usually involved, primarily in association with thunderstorms and rain showers; they generally depart again very quickly.

5. Water level regime

The water level is very dependent on the conditions of precipitation in the catchment region of the Amazon. The irregular distribution of precipitation in that region leads to sharp fluctuations in the water level of the Amazon, which in turn then exerts a decided influence on the seasonal changes that occur in its floodplain, the várzea. In the area around Manaus the average annual amplitude of the water level in the river lies somewhere between 10 and 11 m. In normal years the river rises from about the end of October or beginning of November to about the middle of June and then falls again rather suddenly, in other words, practically precluding any possibility of a long stagnation period. Brief interruptions of this continuous state of flux in the water level occur normally only at the onset of rising water level, usually in December.

During the year, the water level of Lago do Castanho fluctuates pretty much in the same manner as the water level of the Rio Negro at Manaus. In a four-month long study with daily water level readings in the lake, the relationship between the two could be studied in some detail (fig. 3). Both water level curves, that for the Rio Negro at Manaus and that for Lago do Castanho, ran practically parallel for the period studied. This parallelism is, of

Table 1 : Metereological data measured at Manaus during investigation period (acc. to measurements Pe. B. Herzberg).

		Precipitation, mm			Insolation	Winds		
		monthly	max./24 hs.	days	hours	predom. direct.	mean veloc.	max. vel.
June	1967	124.4	20.4	12	206.9	SE – E	3.9 m/sec.	16.7 m/sec.
July		34.2	10.9	5	263.6	E – NE	4.4	16.7
August		2.7	1.8	2	216.4	E – SE	5.5	20.0
September		6.7	6.7	1	229.9	SE – E	6.3	20.0
October		11.2	3.1	9	185.0	NE – E	5.9	20.0
November		131.9	47.5	16	142.5	E – NE	4.8	20.0
December		123.1	16.3	15	195.6	E – N	4.0	14.3
January	1968	280.7	41.9	25	153.8	NE – E	4.4	20.0
February		182.6	31.0	24	119.8	NE – E	4.2	20.0
March		632.8	168.3	21	126.9	NE – N	4.0	20.0
April		302.6	62.4	23	128.7	NE – E	3.2	12.5
May		427.3	59.4	26	118.8	NE – SE	2.7	14.3
June		128.1	42.5	14	181.1	NE – SE	3.7	25.0
July		102.5	41.8	10	177.0	NE – SE	4.1	20.0
August		41.9	11.0	8	194.3	NE – E	4.7	14.3
September		242.8	74.8	12	169.8	NE – E	4.9	14.3
October		37.5	17.8	9	199.7	NE – E	5.0	20.0
November		265.8	69.3	18	135.6	NE – N	6.1	25.0
December		195.1	63.0	21	168.5	NE – E	4.4	14.3

January	1969	257.4	42.0	22	156.7	NE – E	4.4	20.0
February		195.1	34.8	19	122.9	NE – E	5.2	16.7
March		386.8	92.0	25	113.1	NE – E	6.1	33.3
April		572.6	66.4	24	114.9	E – NE	4.4	20.0
May		280.8	87.8	15	201.0	NE – E	4.9	33.3
June		97.0	25.5	16	240.0	NE– E	5.2	20.0
July		86.1	49.3	15	225.3	NE– E	4.7	16.7
August		51.4	14.2	12	250.4	NE – E	3.5	11.1
September		26.3	15.0	5	238.9	E – NE	4.9	16.7
October		81.8	17.3	11	186.5	NE – E	6.3	25.0
November		112.4	40.4	8	210.5	NE – SE	6.6	20.0
December		181.7	49.5	18	129.4	NE – E	5.0	16.7
January	1970	365.2	98.8	20	141.3	NE – E	5.0	16.7
February		326.2	110.3	26	109.1	NE – N	5.4	20.0
March		383.0	64.0	29	113.1	NE – E	5.5	25.0
April		403.6	58.3	25	111.9	NE – SE	3.9	16.7
May		184.6	40.2	20	178.3	NE – SE	4.9	16.7
June		132.1						
July		68.4						

course, independent of the absolute values of the respective water level readings. At times when there are sharp changes in the water level of the river – it can rise or fall as much as 20 cm per day in this region – only small changes in the water level of the lake are discernible due to the length of time required for the water levels in the lakes of Janauacá to be equalized with the water levels in the Solimões through the long and narrow Paraná de Janauacá.

Conversely, other less pronounced differences in the water level curves can originate when the water level of the lakes is changed suddenly for a limited time, perhaps through greater local precipitation, and then equalization of the river's water level with that of the lakes' by means of the Paraná which is here again somewhat slow in taking place. On the whole, the correspondence of the water level curves for the lake and the river is very obvious and, further, indicates as well that the water level of the Rio Negro at Manaus is primarily determined by the water level regime of the Solimões, or Amazon, and only to a lesser extent by the Rio Negro itself. Both the location of Manaus on the lake-like broad lower course of the Rio Negro, very close to the junction of the Rio Negro with the Amazon, and the much greater volume of flow of the Solimões (see also OLTMAN, et. al., 1964) would lead one to suspect this already. However, a final and more detailed clarification of this problem must, of course, remain until another time for special study.

In the next illustration (fig. 4) the water level readings for the Rio Negro at Manaus are given for the entire time of the investigation. The data were furnished by the harbor office of Manaus, and we are most grateful for their cooperation. As the data from over a long period of time (OLTMAN, et. al., 1964) and the monthly means of the last ten years (SCHMIDT 1972a) show, the high-water readings during the investigation period were ve-

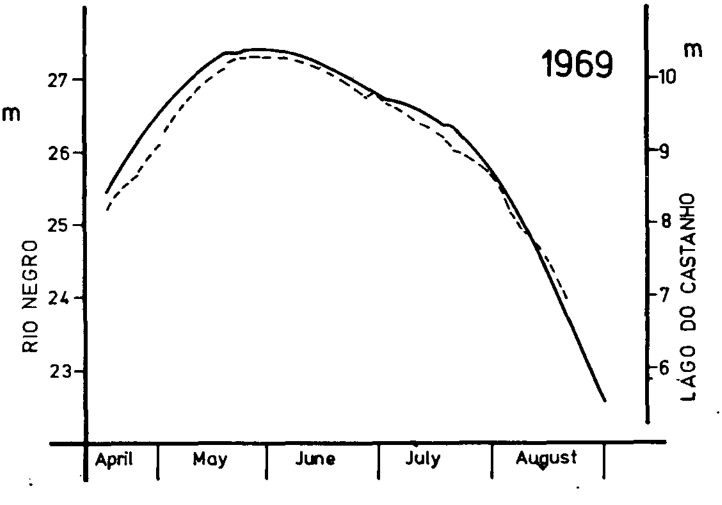


Fig. 3 : Comparison between the Rio Negro's level at Manaus (solid line) and that of Lago do Castanho (broken line) over a period of four months. The absolute heights of the curves for the water levels have been shifted slightly so that both curves would stand out clearly.

ry close to the corresponding averages for the time of occurrence and absolute height of the water and can, therefore, be characterized as "normal". The minimum water level in 1968, however, was about 5 m above the "normal" conditions observed for 1967 and 1969. That means, naturally, that in Lago do Castanho the minimum water level in 1968 also remained about 5 m above "normal". Later discussions will deal with the limnological consequences of this situation.

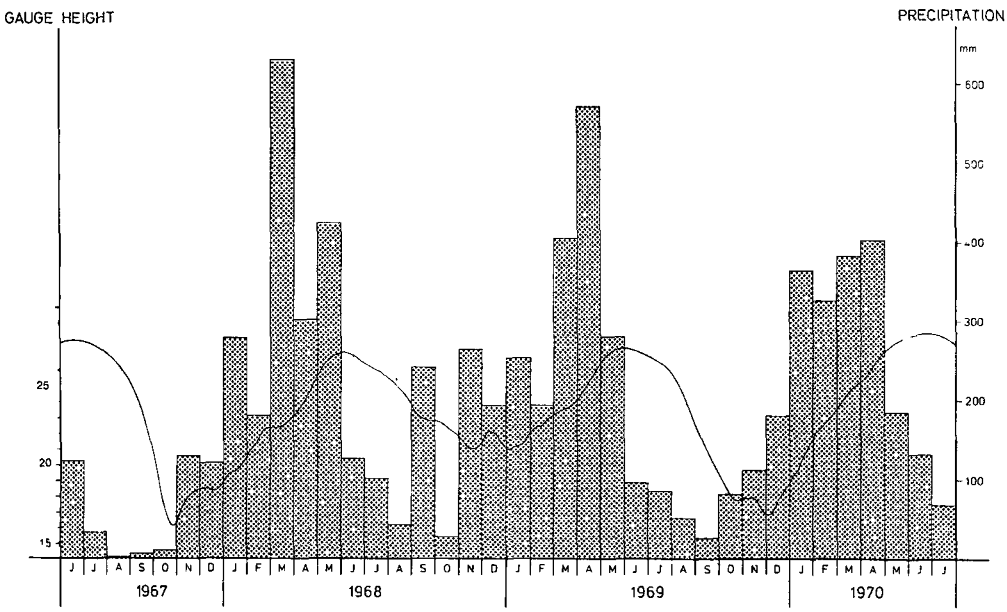


Fig. 4 : Water level values for the Rio Negro (solid line) and the monthly totals of precipitation (columns) for Manaus for the duration of the investigations.

Monthly sums for precipitation for the same time period and the values for Manaus were also noted in the diagram in addition to the water level data. The diagram conveys on the one hand the local precipitation at Manaus and on the other the precipitation conditions in a larger catchment area quite far above the region around the city which are integrated by the river. How vast this catchment area is cannot be estimated here. The size of the Amazon, its low gradient, and its current indicate that wide areas of its total drainage region above the level of Manaus influence the river-gange at Manaus. If one then compares the water level lines and the precipitation columns, a surprising agreement is in many cases immediately noticeable (see also ANON. 1972a) despite the fact that it involves on the one hand daily values and on the other, monthly totals. Both configurations show, however, a phase difference of about four weeks, with the values for precipitation preceding those for water level. This is in good agreement with the findings of REINKE (1962), who estimated that the seasons within Amazonia are shifted by a period of about a few weeks. In the second half of 1968, following the great rainfall in September, which amounted to over 200 mm, the October water level curve became perceptibly smoother. It dropped in November again sharply after a rainfall in October of 37.5 mm, which is in the normal range for this season; however, heavier rains commenced again in November, which led to a small intermediate maximum in the water level readings for December. A temporal time lag of about four weeks could always be observed, as mentioned above. Similar parallels in the particulars can be determined in nearly all instances. From this situation, it seems justifiable to conclude that the pattern of precipitation in Manaus is at least typical for the city's immediate surroundings, hence for example, for the region surrounding Lago do Castanho. At present we have insufficient knowledge to determine the extent to which the extreme values for Manaus may be attributed to possible influences of a "city climate"; further study is necessary to determine this precisely.

6. METHODS

The water samples were obtained with a Van Dorn sampler made of rubber and Plexiglass and were tested either in situ or in the Laboratory of Limnology at the Instituto Nacional de Pesquisas da Amazônia in Manaus, in the latter case the samples being fixed at the time they were taken, if the necessities of the situation demanded it. Specifically, the following methods were utilized:

6.1. Temperature: direct measurement by means of a thermometer built into the water sampler and calibrated to 0.1 °C; in conjunction with the electrometric oxygen measurements, the temperature was measured by a thermistor element and Wheatstone bridge, read with a precision of exactly 0.1 °C.

6.2. Transparency: white Secchi disc with a diameter of about 30 cm.

6.3. Electrical Conductivity and pH: determined directly on the lake with a field instrument from the WTW firm (LF 54 and pH 54); in the laboratory the pH was determined with the WTW instrument pH 390. The electrode for the conductivity was made of glass with a polished platinum surface, i.e. with no platinum black, and the electrode for the pH values was a probe adjusted for electrolyte-poor water.

6.4. Oxygen: titrated by the well-known Winkler method until about the middle of 1969 and thereafter measured electrometrically according to GRASSHOFF (1962). The two methods were shown to be in agreement; however, the electrometric method only achieved a precision of ± ca. 0.25 mg/l, less than that of the conventional titration methods, which achieves a precision of better than ± 0.1 mg O_2/l. Because of the time saved with the electrometric methods, however, it was finally given preference, since the precision it achieved was considered tolerable within the bounds of this general investigation.

6.5 Free Carbon Dioxide: titrated according to HÄSSELBARTH (1965) with 0.05 M $NaHCO_3$ and potentiometric endpoint control (pH 8.35).

6.6 Chemical Oxygen Demand (COD): titrated with $KMnO_4$ (according to the Deutsche Einheitsverfahren 1960).

The determinations for alkalinity, color, turbidity, suspended solids content, calcium, magnesium, sodium, potassium, iron, nitrite, nitrate, Kjeldahl-nitrogen, phosphate, total-phosphorus, dissolved silicate, and chloride were carried out according to the known titration, photometric, and gravimetric methods, which were already referred to elsewhere (SCHMIDT 1972a) and, therefore, will not be discussed again here.

7. RESULTS

7.1. Turbidity and suspended solids content

The suspension load of the Solimões in this region attains its greatest values during the year at the onset of the rainy season. A dry weight of 164.5 mg/l in December of 1969 was determined as the maximum suspended solids content in the one-year-long series of investigations. The lowest concentration of suspended solids, a dry weight of 36.6 mg/l, was observed in August and September of the same year, thus, at a time of year when the river had already long since passed its highest annual level (SCHMIDT 1972a). The turbid white-water of the Rio Solimões which flows into the lake basin of Lago do Castanho at the time of rising water level begins to deposit its suspended material very soon after cessation of the movement caused by the current. This decanting process of the river's suspended material in Lago do Castanho can be followed by means of the changes in depth of visibility in the lake, which exhibit a characteristic annual cycle (see fig. 5). At the time the river water enters the lake's basin, the transparency of the water as measured with the Secchi disc is usually definitely less than 1 m, but higher than the usual values for the river itself, which vary between only 0.5 and 0.3 m. If the velocity of the influxing river water into the lake diminishes now and then for a period of a few days, the depth of visibility in Lago do Castanho can increase appreciably even during this season of the year. As the diagram shows, such a situation was observed in March of 1968.

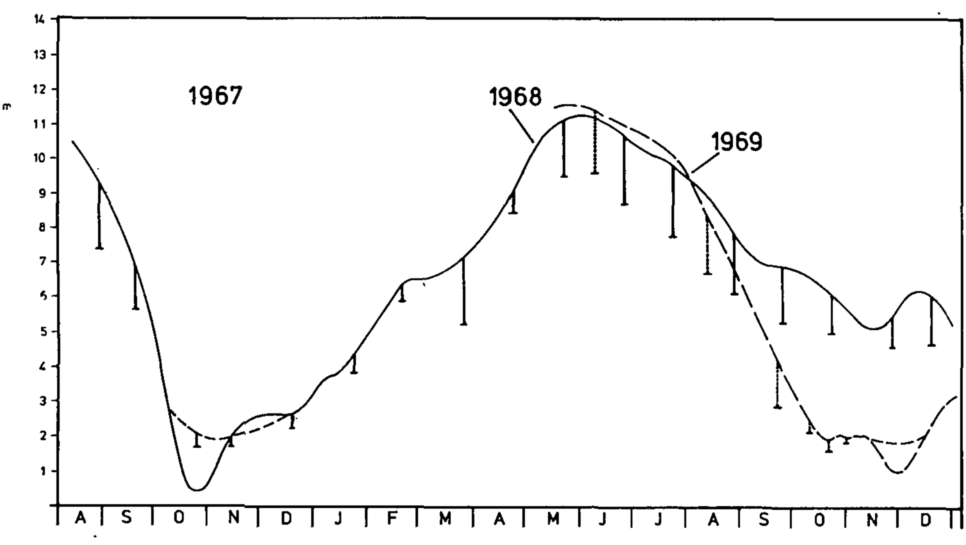


Fig. 5 : Changes in the Secchi transparency in Lago do Castanho in relation to the season of the year; the relationship between these two factors for the second half of 1969 is presented as a broken line. The water level indicated was according to data for the Rio Negro at Manaus; only during the times of minimum water level in 1967 and 1969 was a correction for the lake attempted (see text for explanation).

In general, the greatest depths of visibility in Lago do Castanho are encountered, however, only when the water level has reached its maximum height, most often sometime between June and September. 2 m was the observed maximum value for this season of the year, which nonetheless is still relatively low. Several factors should be mentioned as causing the limitation of the maximum depth of visibility to this range; as the results indicate, all of the factors seemed to be equally significant for this body of water. One of the contributing factors is the phytoplankton, which finds better living conditions after the "decanting" of the suspended material from the invading river water and, hence, always occurs in significantly greater population densities in the lake than in the river (SCHMIDT 1970). A second contributing factor is that the seston of Lago do Castanho always includes relatively large quantities of detritus as can be observed under the microscope. A third contributing factor is the coloration of the water by dissolved organic substances. Numerical data for the latter two factors will be given later in still another connection. The existence of relatively large quantities of dissolved and suspended organic substances in Lago do Castanho is not surprising; on the one hand, one can observe simultaneously an extensive development of floating meadows in the littoral region and a considerable phytoplankton growth (SCHMIDT 1969, 1970), with a corresponding primary production in these waters (SCHMIDT, unpublished), and on the other hand, a not to be ignored addition of allochthonous organic material from the terrestrial surroundings can be expected.

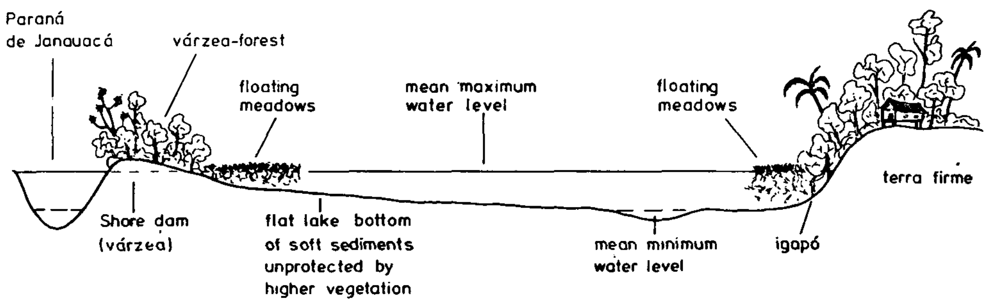


Fig. 6 : A schematic longitudinal section through Lago do Castanho: it shows particularly the broad and shallow morphometry of the lake, a condition by which resuspension of the surface sediments can occur when in conjunction with a very low water level.

When the water level in Lago do Castanho again sinks to a height of less than about 4 m, the transparency of the water decreases very sharply, which means it begins to decrease even before the influx of fresh river water. As the following sketch (fig. 6) illustrates, the waves can't come in contact with the easily stirred-up mud at high water levels, since the shores are protected to certain depths by tall vegetation and floating meadows which lie right up against them. Only if the zone of the Igapó recedes and the floating meadows die out as the water level becomes lower, can the waves reach the now unprotected broad, shallow lake bottom and stir it up. At this time of year the depth of visibility can then drop to values of 10 cm (see fig. 5, October 1969). A similar situation was also observed by JUNK (1970) in the várzea lakes which he investigated. However, as a result of the vigorous phytoplankton growth, which could be detected despite the extremely unfavorable light conditions that exist during this season of the year (SCHMIDT 1969, 1970), the water of the lake looked dirty gray-green in contrast to the yellowish ochre of the Solimões water. With further lowering of the water level, a portion of the original river alluvial material that was recently carried into the lake is again transported out, a process which may essentially retard delta formation and the filling up of the lake basin. At the end of 1968 the critical depth for the resuspension of the sediment in Lago do Castanho was not reached. As the illustration shows, the depth of visibility thus remained more or less in the same range for the months of October to December as in the previous months; it, therefore, was substantially higher than the values for the corresponding periods of the other two years.

In order to get some idea of the rates of sedimentation of suspended solids in the river water and in the lake water, surface samples from the Rio Solimões (about midstream, above Careiro Island) and from Lago do Castanho at high water and at low water were collected and tested. Small quantities of water were carefully pipetted from just below the surface of the samples, which had first been thoroughly shaken to mix, and their light transmission was then expressed as percent turbidity after being photometrically measured against membrane-filtered comparative samples at 420 nm (FREYER 1960). The results are shown in figure 7. One can see first of all that the two bodies of the water exhibit real differences in the level of turbidity, both as compared to each other and in comparing the different yearly seasons. The values nevertheless didn't fluctuate as sharply in the river as in the lake. The decrease in the turbidity, i.e. the rate of sedimentation of suspended solids, was actually greatest in the first few hours. The curves for the Solimões water showed a distinct rectilinear and continuous drop after the first rapid deposition, while the curves for the lake samples revealed a tendency to approach the abscissa asymptotically. The reason for this difference in sedimentation behaviour may be traced to the fact that relatively great quantities of organic seston always exist in the lake which are only slightly different in density from the water. This is the case even during low water, when the extreme turbidity of the water in the lake is caused primarily by the resuspension of the lake sediment.

In table 2 the results of seston weight determinations for a few representative time intervals are stated. Again sharp fluctuations in the space of a year are apparent. The concentrations of the water's suspended material were lowest, as was to be expected, in August, that is, in the phase in which no fresh river water flowed into the lake's basin any more and in which the greatest depths of visibility were encountered. Although the concentration varied, they always remained below 10 mg/l; they revealed at the same time, however, some stratification of the seston. At the end of October, during the phase of extremely low water, the values of around 250–260 mg/l in the lake were far above the maximum concentrations encountered during the course of a year in the Rio Solimões (ca. 165 mg/l on 23.XII.1969). Even the range of fluctuations observed in the concentration of suspended solids was more restricted in the river than in the lake. A more exhaustive investigation concerning the nature of the seston and its relationship to the basin's bottom, to the littoral region, etc., was unfortunately not feasible at this time.

Table 2 : Suspended material in Lago do Castanho in mg of dry weight/l (dried at 110°C).

Depth in meters	13.VIII.69	16.X.69	30.X.69	9.1.70
0	3.5	65	252	25
0.5	3.9	68	261	
1	7.0	73		
2	4.0			
3	2.6			
4	2.5			
5	3.2			
7	6.8			

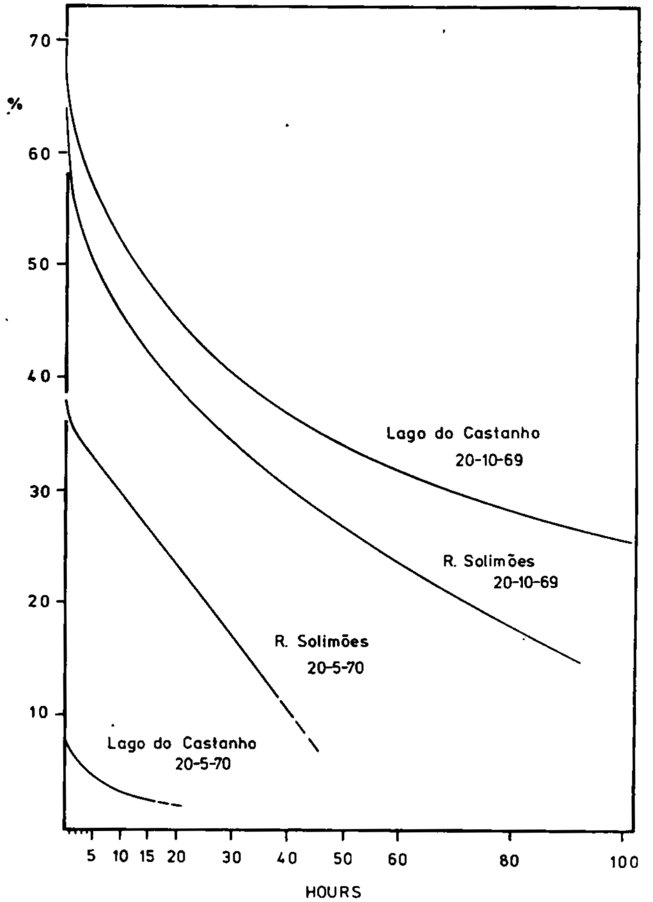


Fig. 7 : Sedimentation of the suspended solids in Rio Solimões (Amazon River) and in Lago do Castanho during the various seasons of the year (shown as a decrease in the percentage of turbidity per unit of time).

7.2. Temperature and stratification

Considering the climatic conditions for this region which were mentioned earlier, no fundamental deviation from isothermy in the water temperature was to be expected during the year. The temperature measurements in Lago do Castanho validated this assumption. Of course, certain differences did appear in terms of the extent of nocturnal cooling and daily warming of the water which were associated with the actual weather conditions at that time. In addition, the entire water mass could once in awhile warm up at low water levels somewhat more than would be possible at high water levels. All of these phenomena nevertheless occurred only on a daily basis and did not signify any basic deviation from the general situation, namely, isothermy throughout the entire year. The following table (table 3) shows several examples of this basic agreement of the water temperatures in the various seasons of the year.

Table 3 : Lago do Castanho – several examples of water temperatures at 06 00 hours (in ^{0}C), indicating that no seasonal gradient exists.

Depth in meters	20.IX. 1967	26.X. 1967	24.I. 1968	24.IV. 1968	24.VII. 1968	25.IX. 1968	23.V. 1969	21.X. 1969	2.III. 1970
0	29.5	28.9	27.8	27.4	29.2	28.2	29.5	29.9	28.7
1	29.5	29.3	27.9	27.4	29.2	28.3	29.6	29.9	28.7
2	29.6	29.2	27.9	27.4	29.2	28.3	29.5	–	28.2

The predominance of a diurnal temperature regime cycle as opposed to a seasonal cycle for Amazonia, which REINKE (1962) stressed and which is generally found in all tropical regions, was also reflected in the water temperatures of Lago do Castanho. But the diurnal changes in water temperature also remained relatively small. A temperature of 28.7 ^{0}C was the average of the 38 temperature measurements made in the mornings at 06 00 hours over a period of three years; the corresponding mean values for the afternoon measurements at 13 00 hours was 30.7 ^{0}C (36 measurements). Both mean values are for 0 m of depth, hence, in practice actually about 10 cm below the water's surface. The lowest temperature recorded in Lago do Castanho during the course of the investigations was 25.6 ^{0}C (on 23.V.68 at 10 m depth, both in the morning at 06 00 hours and in the afternoon at 13 00 hours), and the highest temperature reading recorded was 34.4 ^{0}C (on 16.X.69, at 13 00 hours at the surface). Extreme values such as these appeared to occur rather rarely, however, as they were observed only in isolated instances.

Figure 8 shows typical examples of the water temperature profiles at the station where temperature was measured in Lago do Castanho for two days during the period of minimum water level. In the morning at 06 00 hours on 9.X.69 homothermy prevailed; the temperatures were thus the same from the water's surface to the deepest point of the measurement profile, which was approximately 30 cm above the mud-water interface. On this moderately windy day, with an almost cloudless sky in the morning, the condition of homothermy was maintained throughout most of the day. The values for 1000 hours and 1400 hours revealed a maximum difference of only 0.5 ^{0}C between 0 and 1.5 m. Because of the unhindered solar radiation the temperature of the entire water mass had warmed by about 1.5 ^{0}C between 06 00 and 14 00 hours. But after a rain shower in late afternoon the water had already cooled again at 18 00 hours to about the same temperature that had reigned at 06 00 hours that morning. On the following morning a slight inversion of the

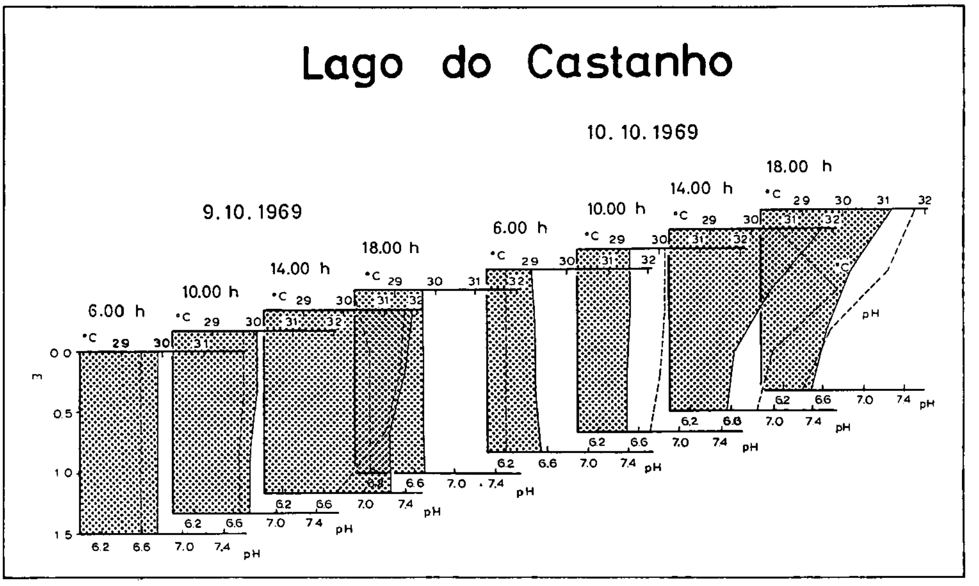


Fig. 8 : Daytime fluctuations of the water temperature and pH values in Lago do Castanho during the low-water phase.

temperature curve could even be observed at about 06 00 hours; the surface values of 29.1 °C were somewhat lower than those of the underlying water layers (29.2–29.3 °C). Owing to the fact that wind movement was very slight, a clear stratification of the water mass could then develop in the course of the day, as the values for 14 00 hours and 18 00 hours show. The difference in temperature between 0 m (31.7 °C) and 1.5 m (29.4 °C) was 2.3 °C at 14 00 hours. The stability of this stratification can readily be understood if one recalls that the density difference in water with a 2.3 °C difference in this temperature region is the same as the density difference that water exhibits between 4 °C and ca. 13.8 °C (see table from KÜSTER, THIEL & FISCHBECK 1958), for, as is known, density differences increase from degree to degree with increasing temperature. The pH values which are also given in the illustration likewise exhibit a diurnal cycle. More about the pH conditions in Lago do Castanho will brought up in a later section.

In the next figure (fig. 9) a few characteristic examples of the temperature readings during the phase of high water level are presented. In each case the data are from readings made at 06 00 hours and 13 00 hours. As can be seen, the temperature curves at both times of day usually intersected between 3 m and 5 m, but they diverged in the upper water layers more or less sharply. Therefore, only the water layers above the region where the curves intersected were normally affected by the daytime warming. Since the temperature curves below the depth where they intersected generally dropped still further, it can be assumed that the circulation processes which occur in association with nocturnal cooling are restricted to the water layers above that point where the curves intersect. As a result of the high density differences of the water in this temperature region, stronger forces counteract a thorough mixing of the water than would be guessed on the basis of the relatively small temperature differences.

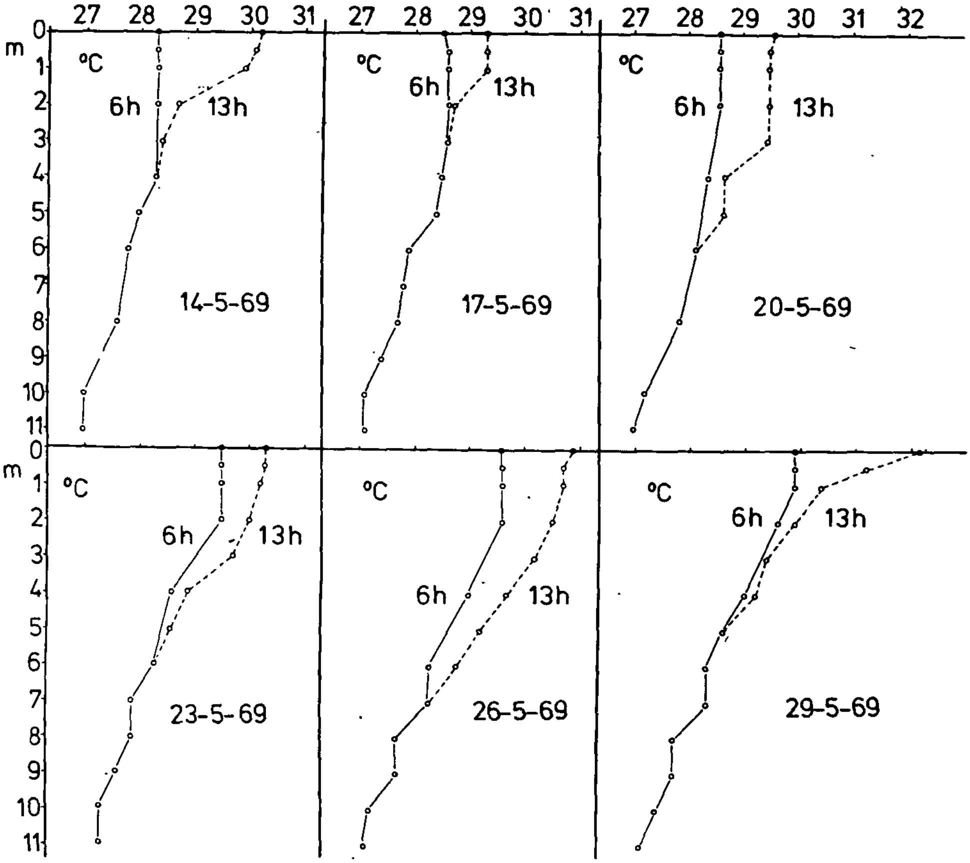


Fig. 9 : Daytime temperature fluctuations and changes in the stratification of Lago do Castanho within short time intervals during May of 1969 (high water phase).

On the whole, it is apparent that a zoning of the water mass into epi-, meta-, and hypolimnion doesn't appear in a sharply defined form over long periods of time (weeks or months) in Lago do Castanho, as is the rule in the lakes of temperate climates during the summer months, but, if it appears at all, lasts only for a few days or even hours. The temperature curves which are presented in figures 9 and 10 don't even always maintain, as one sees, a klinograde form throughout the day, despite the not inconsiderable density differences between the different water layers. Quite often, especially in very calm weather with strong warming of the water directly on its surface, they are more likely to show heterograde or even orthograde character.

The boundaries of the individual zones of the water mass shift for relatively short periods of time upward or downward as a result of partial circulation, which is effective to varying depths according to how it is influenced by the intensity of nocturnal heat loss, wind mixing, and rain showers. The temperature curve can then have the more stair step-like profile, which several of the examples exhibit. The temperature changes which occur in the space of one to three days, which can be seen as well in figures 9 and 10, characterize particularly impressively the instability of the stratification conditions. This is true at high water levels for the shape and size of the epi- and metalimnion. The lower zone, the hypolimnion, on the other hand, exhibits on the whole more stable conditions. This observation was also supported by results of other tests, especially those for the oxygen distribution. Oxygen can never be found deeper than about 6 m in Lago do Castanho, as will be discussed later in further detail. The boundary between aerobic and anaerobic zones moreover shows agreement with the temperature profile, likewise displaying strong fluctuations within short spaces of time. The existence of homothermy and, hence, the possibility of complete circulation at a water level of more than about 5 m, could be clearly established neither from the examples given up to now for the temperature profiles nor from the rest of the test results. The temperature readings, even those for 06 00 hours, always showed a difference between the surface temperature and the temperature at the point of maximum depth. In a few cases this difference was undeniably less than 1 °C or just exactly 1 °C, but it was definitely still present. It is also worth considering that the density difference of the water between 26.5 °C and 27.5 °C is after all just as great as that between 4 °C and ca. 10 °C.

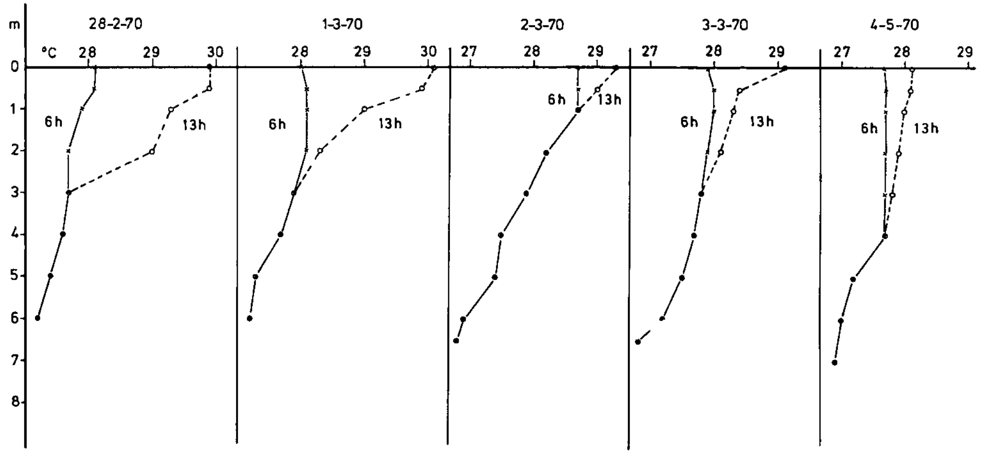


Fig. 10 : Changes in the stratification conditions of Lago do Castanho over a period of five consecutive days as an example of the instability of zonation in this body of water.

Table 4 : Lago do Castanho; the lowest differences (°C) in water temperature encountered at high water level.

24.IV.68 / 06 00 hours		23.V.68 / 06 00 hours	
0 m	27.4	0 m	26.7
7 m	26.8	10 m	25.6

While no complete circulation in Lago do Castanho could be detected at water levels over 5 m, it shouldn't, therefore, be assumed that it is never possible in this lake at high water levels. That full circulation during this period has very seldom actually been achieved, however, appears to be very probable on the basis of the investigation results. In phases where relatively little daily warming occurs due to heavy cloud cover, prolonged heavy rainfall, etc., which can readily happen at the height of the rainy season, approximately from March to May, complete circulation of the lake mass would be conceivable. In addition, full circulation can also be expected in Lago do Castanho when the cold front sets in, which is normally once a year. The so-called "friagem" usually enters this area sometime between May and September, i.e. during the high-water phase, and most of the time lasts four days (see REINKE 1961). The air temperature in this situation can fall to less than 20° C in Manaus, and in the forests near the city down to 15° C (BRINKMANN et al. 1972). That such temperatures, combined with moderate wind velocities, can bring about full circulation of the water mass in Lago do Castanho, may be assumed with great certaintly. Since the periodic arrival of the "friagem" varies within the stated time interval, there was unfortunately no opportunity to set up and carry out suitable investigations concerning this phenomenon on Lago do Castanho.

In summary, on the basis of the investigation it can be determined that Lago do Castanho at low water levels (under about 5 m) can be classified as polymictic, at high water levels (above 5 m), on the other hand, as oligomictic. Just one of these two terms alone would not fully describe the situation.

7.3. Oxygen

The oxygen conditions in a lake are naturally closely connected with its circulation and stratification behaviour. From the investigations on Lago do Castanho it was found that the oxygen distribution exhibited marked differences in the course of a year which were associated with the respective water levels and, thus, with the various seasons of the year (see SCHMIDT 1972d). The conditions at low water, then, differ substantially from the conditions at high water. The foregoing discussion of stratification touched on a few aspects of the oxygen stratification already.

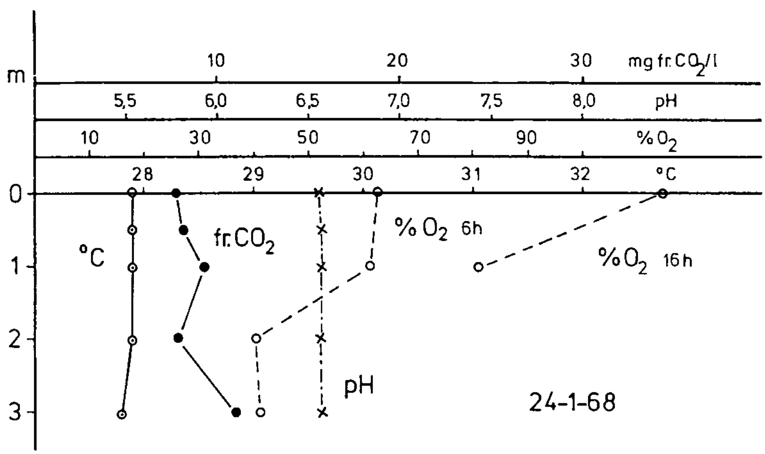


Fig. 11 : Stratification conditions in Lago do Castanho on 24.1.68 at 0600 hours (temperature, free carbon dioxide, pH, oxygen saturation). The oxygen saturations at 0 m and 1 m of depth are also given for 1600 hours; these values show sharp fluctuations during the daytime for this parameter.

At low water, i.e. at water levels lower than about 3 m, oxygen was always observed right down to the lake bottom in Lago do Castanho. Even at this time of year, depending on the stratification pattern of the particular day, a steady decrease in the oxygen concentrations corresponding to increasing depth can also occur throughout, as the example from 24.I.68 (fig. 11) shows. Even in the vicinity of the water's surface the oxygen saturation at 06 00 hours on that day was only about 64 %. In the vicinity of lake bottom it was only 41 %. As a result of the photosynthetic activity of the phytoplankton, the oxygen concentration increased considerably during the day, however, and around 16 00 hours attained about 115 % saturation near the water's surface. The decline in oxygen concentration with increasing depth was even more pronounced at this time of day than during the morning hours.

In the following table (table 5) the distribution of oxygen during minimum water level in 1969 is given. Alongside the oxygen values are additional examples for the stratification conditions at this time of year. In the morning of the first day in this series, 21.X. 69, a temperature reading of 29.9 °C was observed for all depths, indicating a condition of full circulation; 1300 hours the temperature had risen to a reading of 34.2 °C near the surface. The calm weather conditions prevented altogether any mixing of the water during the entire morning, so that at noon at 1 m of depth, which is practically right on the lake bottom the same temperature prevailed that had been observed at 06 00 hours that morning. At 0.5 m depth, however, the temperature was 33.8 °C, indicating that at about 0.5 m above the lake bottom a temperature drop of almost 4 °C existed; this density difference between 0.5 m and 1 m moreover corresponds exactly to the density difference that is found between water temperatures of 4 °C and about 17.5 °C. Only until around 17 00 hours did the temperature at 1 m depth rise to 31.4 °C.

Table 5 : Temperature and oxygen conditions in Lago do Castanho in Oct. 1969
Temperature in °C and % saturation

	21.10.69			22.10.69		23.10.69	
m	6 h	13 h	17 h	6 h	13 h	6 h	13 h
0	29.9	34.2 (149%)	33.9	29.8	33.4 (108%)	30.3	32.8 (96%)
0.5	29.9	33.8 (162%)	33.0	30.0	32.8 (120%)	30.4	32.7 (114%)
1	29.9	29.9 (82%)	31.1	30.8	32.2 (106%)	30.4	32.6 (126%)

On the same day, an oxygen concentration of 149 % indicated a considerable supersaturation at 0 m depth at 13 00 hours. At 0.5 m depth this value was even somewhat higher, 162 %, but in the last half meter then dropped to 82 %. Considering the small size of the euphotic zone – the depth of visibility on this day was 0.25 m – and the almost complete stagnation of the water mass, even this concentration seems relatively high, however when one compares it to the mean values of oxygen saturation for high-water periods. The explanation for this may be found in the existence of full circulation during the preceding night, among other things.

On 22.X.69 a quite drastic inversion of the temperature curve was observed in the morning at 06 00 hours; the reading for 0 m depth lay about 1 °C below the reading for 1 m depth. This would indicate a considerable loss of heat from the surface of the water mass at night. The water temperature didn't rise as sharply between early morning and noon as it had on the previous day, but still reached a reading of 33.4 °C at 13 00 hours. Due to somewhat stronger wind movement, stratification conditions at 13 00 hours were quite a bit less well developed than on the dav before, and, for this reason, the temperature at 1 m depth for that hour was clearly above that for 06 00 hours. Correspondingly, the level of oxygen saturation for the day was definitely less than in the preceding 24 hours.

The highest value was once again found to occur at 0.5 m depth. The concentrations at the other two depths show an even distribution of the oxygen; even above the lake bottom the saturation was close to 100 %. On the following day, 23.X.69, the highest oxygen concentrations of the profile was encountered at 13 00 hours at 1 m depth for the first time. Since the day was decidedly windy (wind: 3–5 on the Beaufort scale), the supersaturation of oxygen at the water's surface caused by intense photosynthetic activity, was reduced to about 100 % (96 % exactly). The decrease in percent of supersaturation to a value close to the 100 % line at the surface indicates a great amount of excess oxygen released into the atmosphere.

When the water level of Lago do Castanho reaches a height of about 3–6 m, the oxygen conditions change dramatically, as has been already noted. The deeper water layers are now so insufficiently supplied with oxygen due to the infrequent occurrence of full circulation that a complete oxygen depletion soon appears there. Table 6 shows the results. Not one of the tests which were carried out during the three-year investigation revealed a presence of oxygen in Lago do Castanho below a depth of 6 m, although, as said, the water level normally climbed to 11–12 m. In fact, oxygen was found to a depth of 6 m only once; on other days no oxygen could be determined at all even at 3 m by the Winkler method (23.V.68), and one time not even at a depth of 2 m (on 28.VIII.68). Looked at generally, the degree of oxygen saturation in Lago do Castanho at high water level, even in the surface water layers, was often astoundingly low. This was of course particularly true for the morning measurements. Thus, for example, on 24.IV.68 at 06 00 hours at 0 m depth an oxygen saturation of only 36.5 % was found. But even the results for 13 00 hours verv seldom reached the vicinity of 100 % saturation. Certainly, however, quite sizeable oxygen saturations are not infrequently reached in the afternoon hours during high-water period as a result of photosynthetic activity by the phytoplankton in the upper water layers.

In several experiments an attempt was made to obtain data on the oxygen consumption. For this purpose samples, which hadn't been shaken and whose initial oxygen content had been ascertained by parallel determinations, were darkened and exposed in the original sampling depth for 24 hours*. The results, computed as the difference, expressed as a percentage, between the initial amount of oxygen present and the final amount of oxygen present in the samples, are shown in the next table (table 7). The numbers reveal important fluctuations in the oxygen consumption, for the vertical dimension as well as for the different seasons of the year. Differences which in principle must exist between the samples that were taken and exposed in the morning and those tested in the afternoon wer not considered to be of much importance here. In some cases more than 80 % of the oxygen originally present in the samples was already consumed after 24 hours, while in others less than 10 % was consumed. For the majority of cases, the actual figures varied within a range of 10 to 30 %. A clear dependence of the oxygen consumption on the water level can't be derived from these still relatively limited data.

* This method was chosen for technical reasons, although it is known that at very low oxygen concentrations a retardation of the oxygen consumption can occur (HÖLL 1968). It offers, however, a first glimpse into the existing natural conditions.

Table 6a: Lago do Castanho
Oxygen concentrations as percent of saturation.
Sampling hour: 06 00

Depth m	24.1.68	21.2.68	27.3.68	24.4.68	23.5.68	26.6.68
0	63.7	68.1	71.5	36.5	45.1	59.8
0.5	–	63.9	60.6	40.4	30.6	56.2
1	61.8	58.0	59.2	36.8	31.5	52.7
2	40.2	27.7	23.9	32.9	27.0	49.2
3	42.2	13.3	1.3	30.5	0	48.7
4	bottom	2.9	0	–		48.4
5		2.2		5.1		0
6		bottom		0		

Table 6b: Lago do Castanho
Oxygen concentrations as percent of saturation.
Sampling hour: 13 00

Depth m	26.7.68	28.8.68	25.9.68	23.10.68	27.11.68	19.12.68	19.3.69	28.3.69	2.4.69	9.4.69
0	100.1	77.2	42.7	86.9	76.5	67.2	74.8	75.6	67.5	60.7
0.5	100.4	71.0	42.6	89.9	69.9	65.8	71.6	65.5	69.2	58.3
1	100.3	77.8	35.2	88.0	69.3	66.3	64.0	57.0	64.3	52.3
2	69.1		19.9	54.3	67.5	39.7	47.7	33.9	42.2	50.9
3	37.6	0	16.9	3.3	48.8	10.0	41.9	18.1	23.7	47.3
4	1.4		4.2	0	6.8	0	17.0	7.2	18.3	42.5
5	0		0		0.1		0	0	1.4	14.8
6					bottom				< 1	–
									0	0

Table 7: Oxygen consumption of samples from the upper water layers. Results indicate % difference to initial O_2-concentration after a 24-hour exposition in dark bottles at the original depths.

a) Sampling hour: 06 00

m	24.1.68	21.2.68	27.3.68	24.4.68	23.5.68
0	18	29	27	27	45
0.5	–	23	18	17	24
1	21	19	41	21	16
2		18	83	18	37
3		37	83		

b) Sampling hour: 13 00

m	24,7.68	28.8.68	25.9.68	23.10.68	27.11.68	19.12.68	28.3.69	2.4.69	9.4.69
0	22	18	22	52	14	16	8	14	8
0.5	21	27	30	53	11	16	14	12	6
1	21	40	34	53	17	21	10	12	1
2	32	+	39	57	14	26	5	17	5
3	24		46	36	12	86	8	14	1
4			64		71		15	19	9
5					50				17

+ (1.5 m = 29 %)

As the oxygen data shows, stagnation of the lower water layers during the high-water phase must persist for at least a few days in order to bring about the complete disappearance of oxygen. Nevertheless, occasional instances of full circulation occurring at this time of year between the monthly sampling days can't be precluded either on the basis of these results. Definite statements could be made only after measurements of longer duration, and these made preferably with the aid of a continuous recorder. Nonetheless, even the oxygen measurements made at three-day intervals from the 14th to the 29th of May 1969 afford the same picture, i.e. no indication of full circulation having occurred, which is further evidence to support the theory that in Lago do Castanho at high water levels full circulation probably very seldom ever occurs in actuality.

Not only was oxygen never encountered all the way to the lake bottom at high water levels in Lago do Castanho, but quite the opposite; hydrogen sulfide (H_2S) was always found in the lower water layers. The proof was a qualitative "nose" test for the smell of this compound. Complete quantitative tests for this gas were not possible, so no data for its concentrations can be made available here. Figure 12 illustrates when and to what extent H_2S was found in Lago do Castanho during the year. Simultaneously, figure 12 indicates those depths – expressed in meters – in which oxygen was present. August and September of 1967 are the only months for which nothing can be said about the oxygen distribution. The illustration reveals the characteristic distribution of both substances and clarifies once more the previous statements. An oxygen-containing zone of relatively uniform thickness can be detected throughout the year, but a zone of varying thickness containing hydrogen sulfide can only be detected at times of high water levels. In a few instances hydrogen sulfide was found at depths which still contained small concentrations of oxygen. Since hydrogen sulfide is readily oxidized, its presence concurrently with that of oxygen leads one to the conclusion that the rate of hydrogen sulfide formation is faster than the rate of hydrogen sulfide oxidation, and, thus, that considerable decomposition activity exists in the water layers in question.

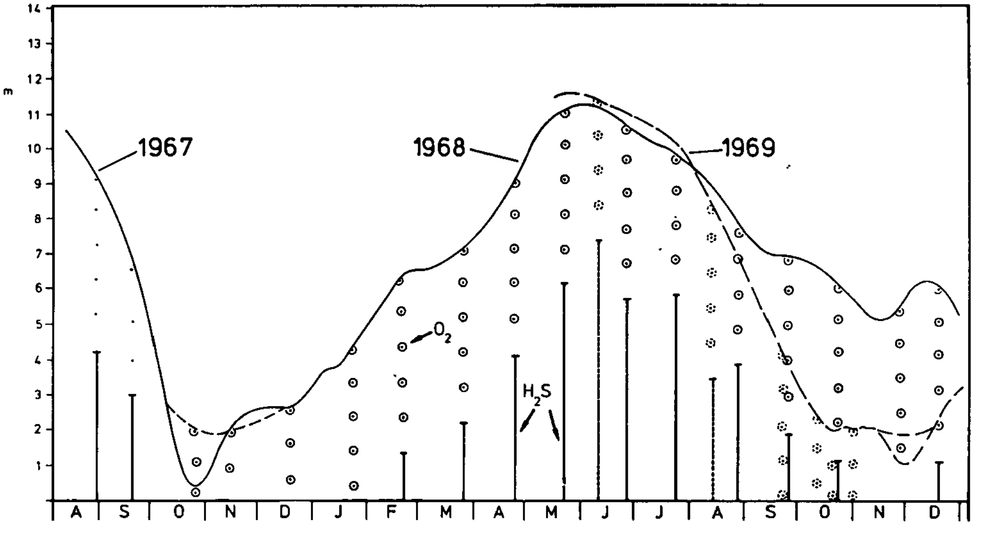


Fig. 12 : The distribution of H_2S (columns) in Lago do Castanho during various seasons of the year. The depths in which oxygen is encountered are marked by circles (there are no O_2 data for August and September of 1967). The distribution of these two factors for the second half of 1969 is indicated by a broken line.

As the diagram once again shows, the "abnormally" high water levels during the second half of 1968 also affected the oxygen distribution. Except for November, an oxygen depletion and the presence of hydrogen sulfide above the lake bottom could be observed that year for every measurement. The second half of 1969, which was also projected in the diagram, again establishes the "normal" picture of conditions in the lake.

In addition to the formation of hydrogen sulfide, other accompanying phenomena typical for the anaerobic zone of a standing water were also identified. The decrease in the pH and the increases in the concentrations of free carbon dioxide and phosphate ions and the sudden changes in NO_2^- and NO_3^- conditions can be mentioned here in particular. Further discussion of these factors will follow in later sections.

One can with great probability expect to find much less favorable oxygen conditions in the protected inlets of Lago do Castanho or under certain parts of the floating meadows than in the free water. JUNK (1970) found that a similar situation existed in other várzea lakes. Besides the differences in oxygen conditions, other differences in those biotopes in terms of numerous chemical and physical characteristics that can be attributed to the special conditions should also be expected. Within the scope of the present study, however, these other problems could unfortunately not be considered.

During the "friagem", which was mentioned above, a catastrophic dying off of fish takes place in many lakes of this region, due to the complete mixing of the water mass and the correspondingly low oxygen concentrations associated with it (see GEISLER 1969; GEISLER, KNÖPPEL and SIOLI 1971). As a result of the investigations on Lago do Castanho, we now have for the first time more detailed information about the unfavorable oxygen situation which exists for fish in the middle Amazonian várzea lakes at high-water periods. The results prove that with complete circulation at this time of year the concentration of oxygen in the water can be severely reduced just through dilution action alone. It is, therefore, not difficult to understand how its concentrations can then easily fall below a limit, which for fish is critical, although, as studies by GEISLER (1969) have shown, many Amazonian species are entirely capable of tolerating very low oxygen concentrations. An additional reduction of the oxygen concentrations by more or less intensive oxidation processes can also be expected in the water.

7.4. Total salt content and its principal characteristics

The salt content of Lago do Castanho is determined largely by the Solimões water which flows into it. The river water itself has a relatively low electrolyte concentration, which in addition varies to some extent according to the season of the year and the volume of flow of the water. During the previously mentioned one-year investigation of the Solimões, the electrical conductivity of the river at a sampling station directly above its junction with the Rio Negro fluctuated between approximately 45 μS_{20}/cm (high-water, July 1970) and 84 μS_{20}/cm (low-water, but after rainy season had already begun, December 1969). While in the lake basin the river water undergoes certain changes, of which its continuing dilution is perhaps the chief one. The causes for this dilution effect seems to be the precipitation which falls directly on the lake's surface and drainage water coming from the vicinity of Lago do Castanho. According to the data from the meteorological station at Manaus, the average level of precipitation in the last 10 years came to about 2300 mm per year; during the time of the investigation the mean values exceeded this figure somewhat (see table 1). The dilution of the salt content of the inflowing Solimões water is naturally the greatest when the rainy season is at its peak. This about coincides with the phase of especially rapidly rising water. For this reason, it is understandable that in Lago do Castanho even the maximum values for conductivity always lie somewhat below those values which are observed at exactly the same time in the river. The maximum value for the total salt content in Lago do Castanho will generally be reached during the first phase of influx of river water, sometime during the months of January and February, which is still before the peak of the rainy season. The dilution process continues all year long until the water level begins to rise again, since, as has been mentioned, a certain amount of rain falls even during the dry season in this area in normal years. The order of magnitude and the trends of the changes in total salt content in Lago do Castanho during the period of the investigation are presented in the following illustration (figure 13), which has been borrowed from another publication (SCHMIDT 1972d), where the main features of the seasonal variations in the water chemistry of Lago do Castanho were treated. As can be recognized, the results vary between values of over 50 μS_{20}/cm (maximum 58.8 μS_{20}/cm on 28.II.70) and less than 20 μS_{20}/cm (the lowest reading obtained was 16.1 μS_{20}/cm on 30.X.69).

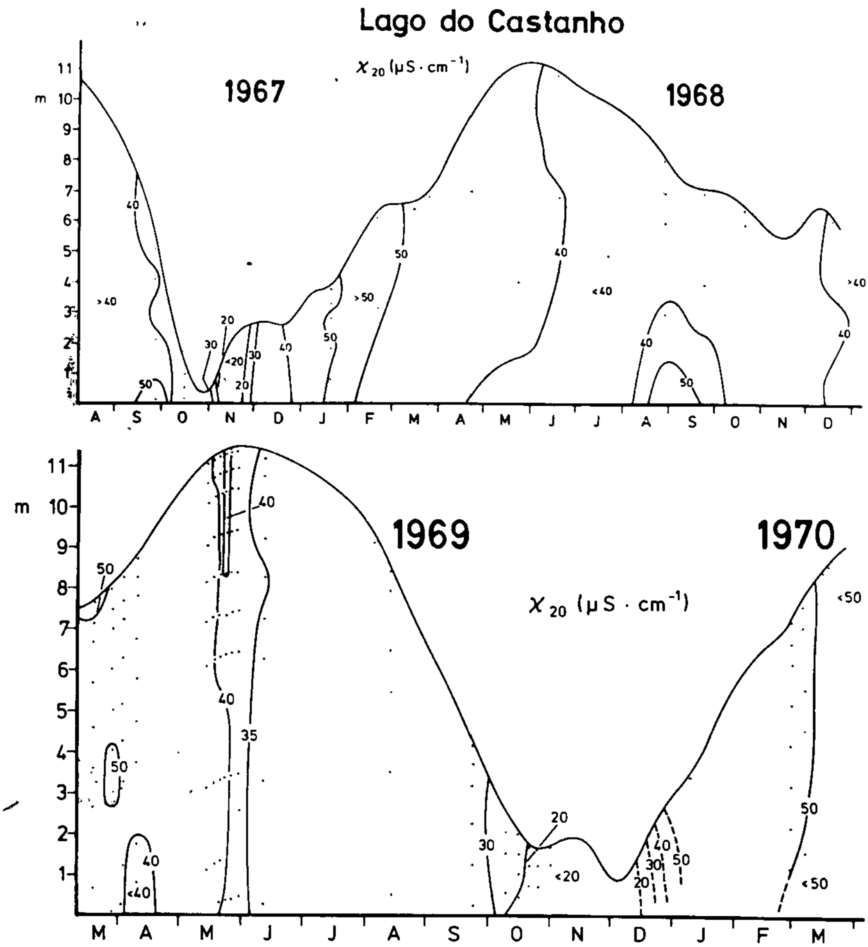


Fig. 13 : The order of magnitude of the electrical conductivity X_{20} (as μS/cm) and the seasonal variations of its values in Lago do Castanho during the time of investigation (from SCHMIDT 1972a).

If one uses the same conversion factor for calculating the weight of dissolved salts in the water that GIBBS (1967) used for the Amazonian waters, namely 0.7, the extreme values in Lago do Castanho fluctuated between 11 and 41 mg/l. But this factor, which was originally ascertained for North American rivers (U.S. Geological Survey, 1958), is probably too low for Lago do Castanho. To what extent it is generally applicable for Amazonian waters must of course remain open here. Conversion factors between 0.94 and 0.78 were computed by using the values for Lago do Castanho given in table 8. The mean value turned out to be 0.83 and, so, clearly lies above the number used by GIBBS, although by no means all the important ions could be included in table 8 (e.g. $SO_4^{=}$). Using the mean value of 0.83, which certainly reflected the conditions in Lago do Castanho more accurately, the range for fluctuations in the salt content of this lake rose to between 13 and 49 mg/l.

The vertical differences in the conductivity were generally slight, as can be seen from the pattern of the isopleths in fig. 13. This holds true even for periods of high-water, although during this time a slight decline in the conductivity with an increase in depth could almost always be observed; it usually didn't go beyond the isopleth, however. The stagnation of the lower water layers at high-water has, therefore, little influence as a whole on the distribution of the principal ions. This suggests that occasionally circulation does reach the lower water layers or at least that sufficiently intense convection currents occur in the body of water to make possible a slow equalization of the salt content between the different water layers. This doesn't contradict the preceding statements about the stability of stratification in Lago do Castanho at high-water, since the convection currents could be so slow that they had no real influence on the oxygen distribution.

Table 8 : Lago do Castanho 1969
Om Fractions of the main ions as mval/l

	19.3	14.5.	11.6.	13.8.	23.9.	16.10.	30.10.
Ca^{++}	0.284	0.191	0.178	0.187	0.142	0.035	0.029
Mg^{++}	0.098	0.085	0.102	0.040	0.076	0.075	0.059
Na^{+}	0.106	0.086	0.062	0.057	0.077	0.068	0.094
K^{+}	0.023	0.025	0.020	0.017	0.020	0.013	0.024
Fe^{+++}	0.027	0.010	0.011	0.005	0.016	0.029	0.034
total	0.538	0.397	0.373	0.306	0.331	0.219	0.240
HCO_3^{-}	0.440	0.380	0.350	0.320	0.280	0.130	0.065
Cl^{-}	0.051	0.045	0.042	0.051	0.042	0.040	0.042
total	0.491	0.425	0.392	0.371	0.322	0.170	0.107

Calcium bicarbonate constitutes the major portion of the total salt content in Lago do Castanho at high-water, just as it does in the middle Amazon (compare SCHMIDT 1972a). By a sunken water level, though, magnesium and sodium rather than calcium could predominate in the lake (see table 8). As can be seen from the comparison of the equivalent – ratios between the cations and anions which are given in table 8, bicarbonate is then somewhat more poorly represented among the anions. On the whole, though, this seems to occur only during phase of intense resuspension of the sediment, hence, only for a limited period of time. For this reason the changes in the concentrations of both principal ions, namely Ca^{++} and HCO_3^-, during the course of the year reflect quite clearly the changes in the electrical conductivity. The following illustration (fig. 14) should make this even more clear.

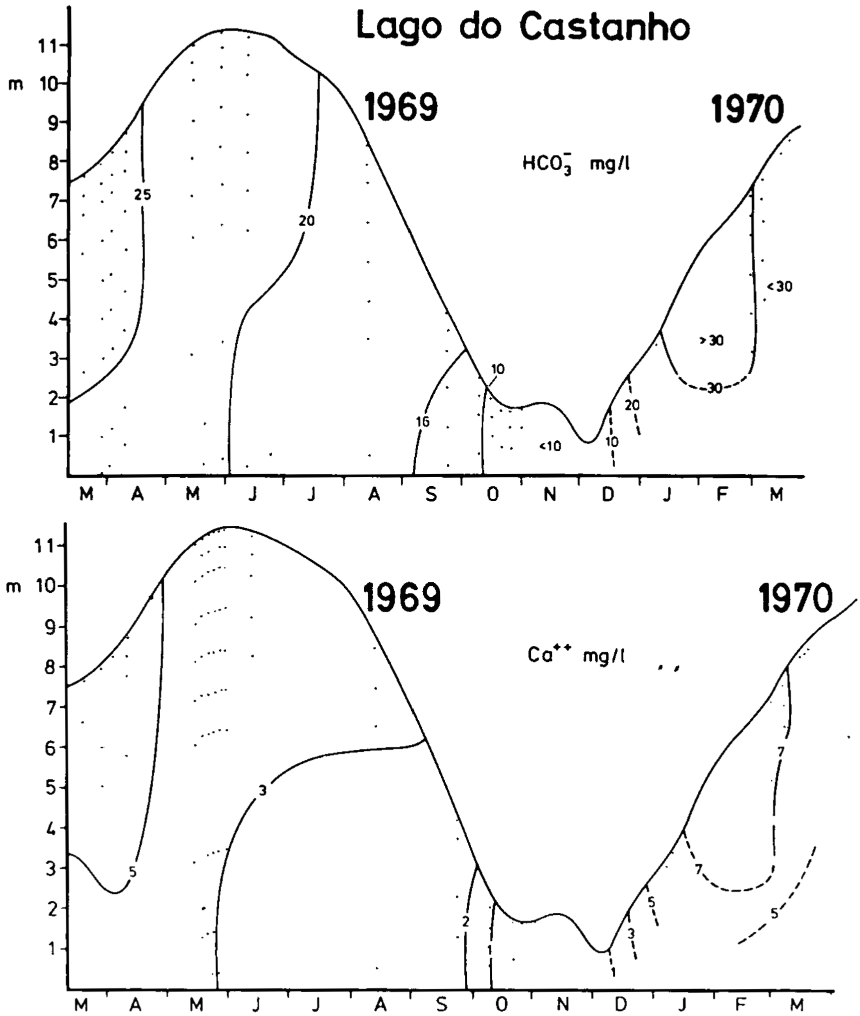


Fig. 14 : Variations in the HCO_3^- and Ca^{++} concentrations in Lago do Castanho from March 1969 to March 1970 (from SCHMIDT 1972a).

Table 9a: Lago do Castanho 1968
mg Mg^{++}/l

m	25.1.	21.2.	27.3.	24.4.	23.5.	26.6.	24.7.	28.8.	25.9.	23.10.	27.11.	19.12.
0	1.5	1.7	0.7	1.0	–	–	0.8	–	0.9	0.7	0.9	1.1
1	1.5	2.2	0.7	1.0	0.9	1.0	–	0.5	0.9	0.7	1.3	1.1
2	–	–	–	–	–		0.8	–	1.2	0.8	–	–
3	1.6	2.0	0.8	1.0	1.0	1.0	–	0.7	–	–	1.3	1.1
4	–	–	–	–	–	–	–	–	–	–	–	–
5		1.8	1.5	1.1	1.1	–	1.4	1.0	1.7	1.0	1.1	1.2
6					–	1.0	–	–				
7					–	–	–	1. 2				
8						–	1.5					
9					–	0.9						
10					1.6							

Table 9b: Lago do Castanho 1969/70
mg Mg^{++}/l

m	19.3.69	9.4.	14.5.	29.5.	11.6.	13.8.	23.9.	9.10.	16.10.	23.10.	30.10.	9.1.70	28.2.	3.3.	19.3.
0	1.2	0.9	1.0	0.9	1.2	0.5	0.9	0.9	0.9	0.9	0.7	1.8	1.1	1.2	0.9
0.5	1.2	1.1	1.0	0.9	1.2	1.0	0.9	0.9	0.9	0.9	0.7		1.2	1.3	–
1	1.3	1.1	1.0	0.9	1.2	1.0	1.2	0.9	1.0	0.9			1.2	1.3	–
1.5	–	–					1.2	0.9					–	–	–
2	1.5	1.1	1.0	0.9	1.2	1.0	1.2						1.3	1.5	–
3	1.6	1.1	1.5	1.0	1.4	1.3	1.2						1.4	1.6	–
4	1.7	1.2	1.4	0.8	1.5	1.4							1.5	1.5	–
5	1.5	1.0	1 5	1.0	1.5	1.4							–	–	–
6		–	–	–									1.6	1.4	–
7	1.4	1.5	–	–	–	1.5									
8		1.5	1.5	0.9	1.6										
9			–	–	–										
10			1.1	–	–										
11				0.7	1.6										

The equivalent-ratios between anions and cations for 1969 samples which were given in table 8 were relatively balanced at high water. The somewhat stronger preponderance of cation fractions in the samples for the period of low water (October dates) may be undoubtedly attributed to the fact that the sulfate ion is not included in the computations, but, at least during this phase of the year, it does play a definite role in the lake.

In addition, definite seasonal fluctuations were also identified for dissolved silicate, total-iron, and total-phosphorus (SCHMIDT 1972d). A dependence of the changes in magnesium concentrations on the changes in season was not so clearly recognizable, as table 9 shows, but was nonetheless indicated to some extent. While the annual cycles of cloride, sodium, potassium and magnesium ran parallel to that of the principal ions, that is, with a maximum during the phase of influxing fresh water and a minimum at the end of the phase of falling water level, total-iron and total-phosphorus attained their annual maxima during the time of lowest water level, and their concentrations then fell again relatively quickly with rising water level. The annual maximum concentration range for dissolved silicate was likewise already reached before the influx of the fresh river water, that is, during the time of minimum water level; it lasted generally longer, however, than the maxima of total-iron and total-phosphorus. This variable behavior in the concentrations of dissolved silicate, total-iron and total-phosphorus was attributed to the resuspension of the lake sediments (see SCHMIDT 1972d).

In order to make possible a general overall view of the concentration ranges of the most important salts which show an annual cycle, the extreme values determined for each of them are presented in the following table (table 10).

Table 10 : Maximum and minimum results for some chemical factors with seasonal fluctuations in Lago do Castanho.

		date	Depth, m	max.	date	Depth, m	min.
HCO_3^-	mg/l	3. 3.70	3	31.7	15.11.67	0	3.7
Cl^-	mg/l	21. 2.68	0 and 1	3.2	23.10.68	2	1.0
$Si_{dissolv.}$	mg/l	19.12.68	5	4.97	9.10.69	0	2.05
P_{total}	μg/l	30.10.69	0.5	210.	23. 5.69	0	5
Ca^{++}	mg/l	28. 2.70	0	7.57	23.10.69	0	0.53
Mg^{++}	mg/l	21. 2.68	1	2.16	13. 8.69	0	0.49
Na^+	mg/l	9. 1.70	0	2.98	11. 6.69	11	1.2
K^+	mg/l	14. 5.69	1	1.27	16.10.69	0	0.51
Fe_{total}	mg/l	30.10.69	0.5	4.05	13. 8.69	3	0.17

7.5. Buffering conditions, pH, and free carbon dioxide

Within the scope of an investigation of the limnology and most especially of the phytoplankton primary production in Lago do Castanho, the free carbon dioxide-bicarbonate system was naturally of particular importance. As is well known, it forms, together with the rest of the dissociation steps of carbon dioxide, the basis for the buffering capacity of a bodv of water and, through the regulation of the pH conditions, it affects the general living conditions in an aquatic biotope.

Table 11a : Lago do Castanho 1967/68
mg HCO_3^-/l

m	30.8.	20.9.	26.10.	15.11.	20.12.	24.1.	21.2.	27.3.	24.4.	23.5.	26.6.	24.7.	28.8.	29.9.	23.10.	27.11.	19.12.
	1967					1968											
0	20.8	20.8	15.3	3.7	6.7	22.0	23.2	23.8	26.2	26.8	20.8	19.5	25.6	17.1	17.1	17.7	15.3
0.5	–	–	14.6	3.7	6.7	21.4	23.2	23.8	26.2	25.0	20.8	19.5	25.6	17.1	17.7	17.7	15.3
1	20.2	20.2	14.6		6.7	22.0	23.8	23.2	26.2	25.0	20.8	19.5	25.6	17.1	17.7	17.7	15.3
2	19.5	20.2	15.3			21.4	23.8	23.8	25.6	25.0	20.8	19.5	25.0	17.1	17.7	17.7	15.3
3	20.2	20.2				22.0	23.8	23.8	25.6	24.4	20.2	18.9	23.2	17.1	17.7	17.7	15.3
4	19.0	21.4					20.2	24.4		24.4	20.2	18.9	23.2			18.3	15.3
5	19.5	28.6					19.5	24.4		25.0		20.8				18.3	17.1
6	–	29.9								–							
7	20.2									–							
10										20.2							

(at higher water levels deeper layers mostly not included)

Table 11b : Lago do Castanho 1969/70
mg HCO_3^-/l

m	19.3.69	9.4.	14.5.	29.5.	11.6.	13.8.	23.9.	9.10.	16.10.	23.10.	30.10.	9.1.70	28.2.	3.3.	19.3.
0	26.8	25.0	23.2	20.8	21.4	19.5	17.1	11.6	7.9	6.7	4.0	29.9	30.5	29.9	26.8
0.5	26.8	24.4	23.2	20.8	21.4	19.5	17.1	11.6	7.9	6.7	4.0		30.5	29.9	–
1	26.8	24.4	23.2	20.8	21.4	19.5	17.1	11.6	7.9	6.7			30.5	29.9	–
1.5	–	–	–	–	–	–	16.5	11.6					–	–	–
2	26.8	25.6	22.0	20.8	21.4	19.5	15.2						30.5	29.9	–
3	26.8	26.8	–	–	21.4	19.5	15.2						30.5	31.7	–
4	26.8	26.8	22.0	20.8	21.4	18.1							30.5	–	–
5	25.6	26.8	–	–	21.4								–	–	–
6	–	–	–	20.8	–								–	–	–
7	19.5	22.0	22.0	–	–										
8		21.4	–	–	18.9										
9				–	–										
10					–										
11					18.3										

(deeper layers not included in April and May 1969)

As was discussed in the previous section, the total salt content in Lago do Castanho is relatively low, but is composed for the most part of calcium and bicarbonate. The alkalinity tests yielded a maximum value of 0.52 mval l on 3.III.70, which was a time of inflowing river water. This value corresponds to a bicarbonate concentration of 31.7 mg HCO_3^-/l. The observed minima for alkalinity, on the other hand, were only 0.06 mval/l on 15.XI.67 and 0.065 mval/l on 30.X.69. The corresponding bicarbonate values were 3.66 mg/l and 3.97 mg/l respectively. The effect of these low bicarbonate concentrations and the associated correspondingly low buffering conditions on the pH shall be demonstrated below by an example.

A stratification of the bicarbonate concentrations was relatively seldom pronounced (table 11). Only at high-water levels could a certain decrease in the values be ascertained in the lower water layers. Because of the low earth alkali concentrations, a stratification of the bicarbonate content due to the biogenic calcium precipitation in the euphotic zone and the solution of calcium carbonate by means of free carbon dioxide in the deep zone (see OHLE 1934, 1952) in Lago do Castanho certainly would not be expected. The definitely measurable, though small decrease in the bicarbonate concentrations at high-water, together with the afore mentioned decrease in total salt content in the lower hypolimnion, indicated rather that the deeper water may be eventually mixed with cooler rün-off water from the terra firme after heavy rainfalls, which possibly lays itself under the warmer water of the lake. BEAUCHAMP's (1964) conclusion about the stratification conditions in Lake Victoria at the beginning of the rainy season, "this stratification seems to be brought about by cooling the lower layers, and not as in temperate lakes, by warming the surface water", is probably true also for the Amazonian várzea lakes of the type represented by Lago do Castanho.

The pH values for Lago do Castanho generally lie between pH 6 and pH 7, i.e. in the weak-acid range. Like the temperature, a definite diurnal cycle could also as a rule be observed for the pH conditions in the upper illuminated, oxygen-containing water layers, while seasonal differences didn't seem to appear. Almost always distinctly lower pH values were measured in the euphotic zone in the mornings at 06 00 hours than in the afternoons. The photosynthetic activity of the phytoplankton, through which the CO_2-concentration of the water is reduced should be omitted thus affects relatively quickly the lake's pH values due to the limited buffering capacity of the water. At the same time a more or less strong decrease in the pH was always noted in the anaerobic zone at high-water levels. In this region the lowest value pH 5.45 on 19.III.69 at a depth of 4 m – was also determined.

During the period of low water level no stratification of the pH was usually evident in the morning due to full circulation having occurred during the preceding night. During the course of the day, however, stratification could set in even at this time of year, depending on the weather conditions. Reference should be made once more to figure 8, which presents two patterns for daytime variation in pH at low-water level that are regarded as typical.

The range of the daily pH fluctuations was generally more restricted at high-water levels than at low-water levels. The critical depth is again, moreover, that water level height which is also significant for the general stratification and circulation conditions, i.e. around 3–5 m. The reason for the more limited range of fluctuations may be, on the one hand, the fact that at high-water the buffering capacity is considerably more favorable, and, on the other hand, the fact that the phytoplankton population densities, insofar as computations have shown up to now, are not as great at this time as during the water level minimum. A few examples of daytime pH fluctuations during the period of high-water are given in table 12.

In the following table (table 13) a few examples of really extreme pH fluctuations measured for the period of low-water are cited for purposes of comparison. They again illustrate the foregoing statements.

Table 12 : Diurnal pH-variations in Lago do Castanho at high-water level

	24.7.68		28.8.68		23.5.69		29.5.69		4.3.70	
m	6 h	13 h	6 h	13 h	6 h	13 h	6 h	13 h	6 h	13 h
0	6.5	6.8	6.3	6.4	6.6	6.8	6.7	7.4	6.4	6.7
0.5	6.5	6.8	6.3	6.4	6.6	6.8	6.7	7.4	6.5	6.7
1	6.6	6.8	6.3	6.4	6.6	6.8	6.7	6.6	6.5	6.7
2	6.6	6.5	6.1	6.1	6.6	6.8	6.7	6.5	6.5	6.7
3	6.5	6.1	6.0	6.0	–	6.5	–	6.3	6.6	6.6
4	6.1	5.8	6.0	6.0	6.3	6.2	6.3	6.3		6.4
5	5.9	5.7		5.8	–	6.2	–	6.3		
6		–		–	6.2	–	6.2	–		6.3
7		–		5.8		–		–		6.2
8		5.5				6.1		6.0		
9						–		–		
10						–		–		
11						6.1		6.1		

Table 13 : pH values in Lago do Castanho on three days during the period of minimum water level.

Depth in meters	21.X.1969 06 00 hours	21.X.1969 13 00 hours	21.X.1969 17 00 hours	22.X.1969 06 00 hours	22.X.1969 13 00 hours	23.X.1969 06 00 hours	23.X.1969 13 00 hours
0	6.30	8.65	8.70	6.10	8.40	6.20	7.00
0.5	6.30	8.65	8.80	6.10	8.45	6.20	7.13
1	6.30	6.30	6.85	6.13	8.05	6.20	7.13

On 21.X.69 the values at 0 m and 0.5 m climbed from a morning pH reading of 6.30 to an afternoon reading at 13 00 hours of 8.65. Until about noon the pH at 1 m of depth remained, as the temperature also had (see table 5), at the same level it had occupied in the morning. Then by 17 00 hours, the values near the water's surface, 0.0–0.5 m depth, had once more risen slightly from their midday reading to reach the highest level, 8.70–8.80, that was ever reported for Lago do Castanho. From about 06 00 hours in the morning the pH value in this layer had thus risen more than two units ! Although no further measurements were made in the afternoon, it is presumed that this sort of pH increase during the course of a day for this season of the year is not unusual. The very stable temperature stratification already described for 21.X.69 is also reflected in the pH conditions. Even into late afternoon, thepH at 1 m depth had risen only insignificantly. During the following night the values again fell sharply, so that the next morning (22.X.69) practically the

same reading was measured as 24 hours before. The values, including even that for 1 m depth, i.e. above the lake bottom, rose past pH 8 by afternoon. On the following day, 23. X.69, the pH just barely crept past the neutral point by 13 00 hours. The heavy cloud cover obviously affected the daily cycle of pH conditions as well as affecting the temperature conditions.

The inordinately sharp rise in the pH observed on the 21st and 22nd of October must be attributed to the photosynthetic activity of the phytoplankton, which on some days with suitable weather conditions can be very intense, as is evident from the productivity data (SCHMIDT, unpublished). The phytoplankton has the ability, therefore, to continue removing carbon dioxide from the system even at times of extremely low bicarbonate concentrations. Because of the low concentrations of earth alkalies, a direct precipitation of carbonates in association with biogenic decalcification is of course out of the question (see p. 172). The sharp pH fluctuations within a period of a single day are readily understandable, however, in view of the extremely low buffering capacity of the water caused by the existing earth alkali and bicarbonate concentrations. In order to portray the buffering capacity yet again, the concentrations of calcium, magnesium, and bicarbonate have been compiled in table 14 for the three days in question. The equivalent concentrations, as can be inferred from the numbers, for both earth alkalies and bicarbonate ions, were about 0.1 mval/l.

Table 14.: Concentrations of Ca^{++}, Mg^{++}, and HCO_3^- in mg/l in Lago do Castanho on three days during the period of minimum water level at 13 00 hours.

Depth in	21.X.1969			22.X.1969			23.X.1969		
meters	Ca^{++}	Mg^{++}	HCO_3^-	Ca^{++}	Mg^{++}	HCO_3^-	Ca^{++}	Mg^{++}	HCO_3^-
0	0.71	0.86	6.7	0.59	0.83	6.7	0.53	0.86	6.7
0.5	0.71	0.86	6.7	0.53	0.86	6.7	0.53	0.86	6.7
1	0.71	0.92	6.7	0.53	0.90	6.7	0.53	0.90	6.7

Like the lakes investigated by BRAUN (1952) in the Tertiary of the lower Amazon region, Lago do Castanho also generally contained a relatively high concentration of free carbon dioxide (see table 15). The cause for this may be the very rapid decomposition of organic material at high temperatures. The markedly low oxygen concentrations usually observed, and, as shall be further described, the high values for $KMnO_4$ consumption (COD) provide further support for this explanation. In contrast to BRAUN, who during his investigations never found a lake in which free carbon dioxide was lacking near the water's surface, an occasional absence of free carbon dioxide was determined in Lago do Castanho, as was already seen to some extent from pH conditions already discussed. Moreover, in contrast again to the findings of BRAUN, a clear relationship between the pH stratification and the carbon dioxide distribution in Lago do Castanho could often be determined, as the examples given in figure 15 will show. At the same time, however, it must be borne in mind that on the basis of the low buffering conditions, even for a body of water like Lago do Castanho, a mathematical determination of these interrelationships encounters certain difficulties. The lower the bicarbonate concentrations become, the more strongly relatively small measurement errors, in pH and alkalinity determinations, for example, affect the computation of free carbon dioxide according to the known equilibrium formula (compare SCHMIDT 1968). For this reason, within the framework of the present study the free carbon dioxide was always determined by titrating directly on the lake.

Clear correlations between the content of free carbon dioxide in the surface water measured at 06 00 hours and the seasonal data, that for the water level conditions in particular, were not found in this study. The values remained more or less in the same order of magnitude throughout the year, and their variations reveal no seasonal trends (table 15).

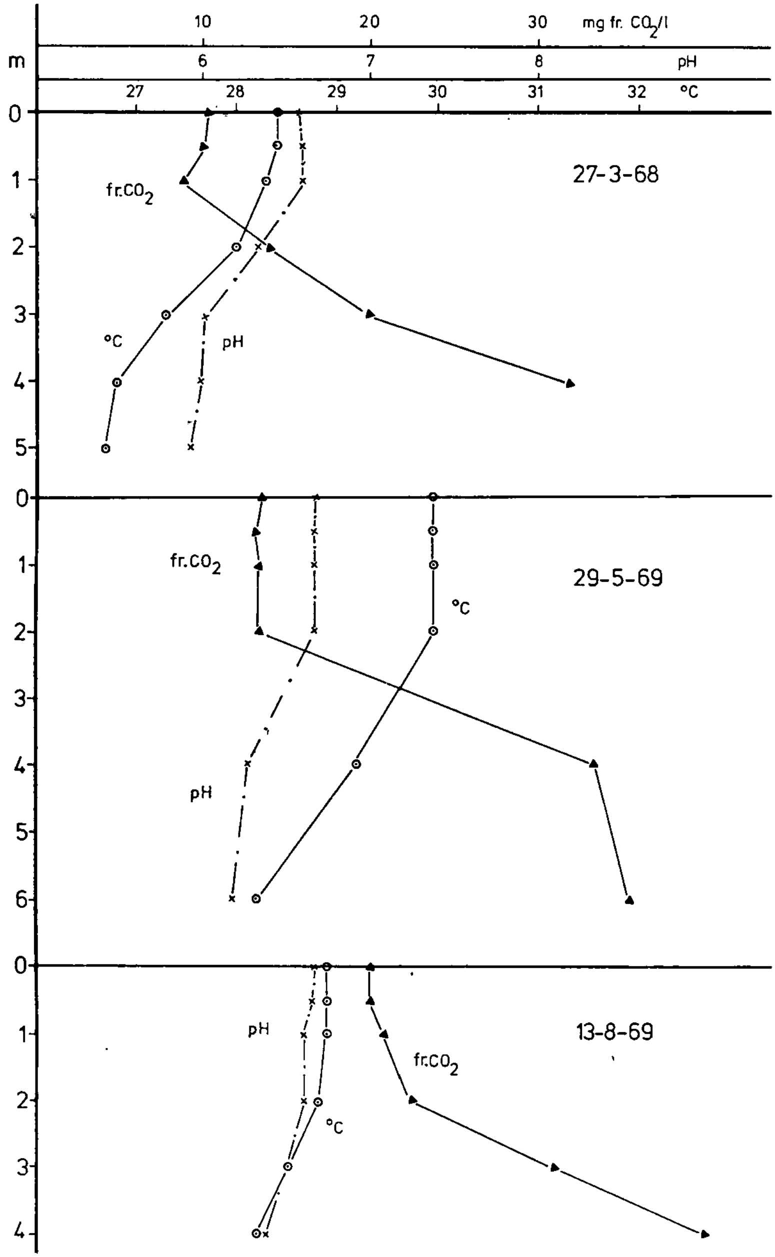


Fig. 15 : Concentrations of free carbon dioxide and pH, measured at 0600 hours in Lago do Castanho on several days.

Table 15: Lago do Castanho 1967/68, 06 00 hours
mg free carbon dioxide

m	1967 30.8.	20.9.	26.10.	15.11.	20.12.	1968 24.1.	21.2.	27.3.	24.4.	23.5.	26.6.	24.7.	28.8.	25.9.	23.10.
0	5.1	6.9	7.3	6.8	6.1	7.8	8.0	10.3	13.6	13.4	9.0	6.1	9.3	13.5	12.2
0.5	–	–	7.1	7.4	6.7	8.2	8.9	10.1	13.6	13.3	9.2	6.5	9.3	14.1	12.6
1	4.6	6.9	7.1		6.9	9.3	9.8	8.9	13.6	12.9	9.7	6.5	9.3	14.0	12.6
1.5	–	–	–			–	–	–	13.6	–	–	–	–	13.9	12.6
2	4.6	7.3	7.3			8.9	12.8	14.0	13.6	12.9	11.3	6.4	13.8	13.2	12.6
3	12.1	13.3				11.1	15.3	20.6	13.7	16.3	14.4	6.6	17.3	13.2	22.1
4	19.0	19.0					29.1	30.0		16.3	16.7	20.2	20.8		
5	25.8	29.9					27.1					32.1			
6	–	31.3													
7	32.8														

Table 16: Concentrations of free carbon dioxide in mg/l in Lago do Castanho at various times of day during the period of low-water level.

Depth in meters	9.X.1969 06 00 hours	10 00 hours	14 00 hours	18 00+) hours	10.X.1969 06 00 hours	10 00 hours	14 00 hours	18 00 hours	21.X.1969 06 00 hours	17 00 hours
0	5.3	3.8	0.11	4.6	8.6	3.0	2.0	0.9	3.9	0
0.5	5.1	3.8	0.12	5.0	7.1	3.0	0.8	1.5	3.8	0
1	5.2	4.3	0.17	6.3	6.1	3.2	2.2	4.4	3.9	0.45
1.5	4.9	4.3	4.5	7.3	5.3	4.0	2.8	6.4		

+) after a rain shower.

Although only the euphotic zone could usually be examined by means of the direct determination of free carbon dioxide, the results nonetheless showed in most cases a definite increase in the concentrations with increasing depth (see fig. 15), especially in the anaerobic zone.

The results for free carbon dioxide reproduced in the next table (table 16) show us that this substance disappears almost entirely in Lago do Castanho under certain conditions, primarily during periods of low-water and during the afternoon hours, and, so, can also be effective as a productivity limiting factor.

7.6. Phosphorus

The concentrations for total-phosphorus were in general relatively high, as is indicated in table 17; however, during the course of the year they fluctuated considerably (see SCHMIDT 1972d). In contrast, concentrations for free phosphate were very much lower; they fluctuated, however, just as drastically, but without any clear correspondence to the changing seasons. The maximum concentration determined for free phosphate was, to be sure, relatively high with a value of 46 μP-PO_4/l, but on the other hand now and then absolutely no free phosphate at all could be determined to exist in the water sample (see table 18). The ratio of free phosphate to the total amount of phosphorus was greatest during that time of the investigation when the total-phosphorus concentrations were the lowest. As table 18 shows, this was especially true at times of high-water. Unfortunately, it wasn't possible to determine the organically and inorganically bound phosphorus separately, so that ratios of these fractions to the total-phosphorus content could not be calculated. The sharp increase in total-phosphorus during times of low-water (see October dates for 1969, table 17), however, may be traceable primarily to the resuspension of the surface sediments and, thus, to the probable resuspension of inorganic phosphorus compounds which were transported into the lake basin at the time of rising water as components of the river water's suspension load and then deposited along with the rest of the suspended material. Since clear parallels could be found in the water of the Solimões between the annual cycles visible for the concentrations of suspended phosphorus compounds (whose portion of the total-phosphorus incidently always lie above 50 %), the suspended iron compounds, and the total suspension load of the river water, the hypothesis was advanced that the suspended phosphorus and iron compounds would correspond to the general character of the river's suspension load and be inorganic in nature (SCHMIDT 1972a). Special studies concerning the nature of the suspended phosphorus compounds, not only in the Solimões and Amazon waters, but also in the water of Lago do Castanho, would be of special interest because of their not insignificant concentrations. They could at the same time also provide information about the availability of this material for phytoplankton. Similarly, it should be pointed out here and now that iron, as the following discussion will show, also occurs in Lago do Castanho in relatively great abundance in an undissolved form.

Not only in Amazonian waters, but also elsewhere the availability of phosphorus compounds is of particular significance. As works of GOLTERMAN and his colleagues (GOLTERMAN 1967; GOLTERMAN, BAKELS & JACOBS-MÖGELIN 1969; FITZGERALD 1970; and others) showed, phosphorus in the form of almost insoluble phosphorus compounds from the mud of European and North American lakes turned out to be particularly unfavorable for utilization by certain algae. GESSNER (1960b) demonstrated in several very interesting experiments that the suspended solids of white-water have the capability of adsorbing or releasing certain quantities of phosphate, depending on the conditions. In view of the significance of these processes, therefore, he characterized the várzea as a phosphate buffer system.

Table 17: Lago do Castanho 1969
μg total phosphorus (P_{total})/l

m	19.3.	28.3.	2.4.	9.4.	14.5.	17.5.	20.5.	23.5.	26.5.	29.5.	11.6.	13.8.	23.9.	9.10.	10.10.	16.10.	21.10.	22.10.	23.10.	30.10.
0	42	58	42	19	23	20	20	5	20	20	13	16	30	48	48	81	120	127	134	154
0.5	43	46	41	41	22	20	28	5	28	18	43	18	35	49	51	152	175	147	152	210
1	46	44	41	45	22	18	29	19	25	46	43	24	43	56	59	129	133	169	169	
2	48	38	39	37	26	19	19	16	35	24	45	16	36	49*	50*					
3	44	43	39	32	24	19	25	17	23	27	53	18	39							
4	45	40	38	40	25	22	26	19	23	21	34	17								
5	48	38	37	46	33	20	25	20	21	11	24	19								
7	56	41	26	42	–	–	–	–	–	–	–	27								
8		33	27	43	33	40	28	25	30	14	35	–								
10					41	37	37	–	–	–	–									
11							39	27	31	42	51									

* 1.5 m

Table 18: Lago do Castanho 1969
μg phosphate $P(PO_4^{3-})$/l

m	14.5.	17.5.	20.5.	23.5.	26.5.	29.5.	11.6.	13.8.	23.9.	9.10.	10.10.	21.10.	22.10.	23.10.	30.10.
0	7	2	9	3	13	4	5	2	0	22	15	2	0	0	10
0.5	7	2	8	5	13	4	5	3	2	27	30	3	3	16	12
1	11	2	13	5	12	4	6	2	7	19	23	27	46	39	
2	10	2	13	5	15	4	6	3	4	21*	24*				
3	10	2	9	7	17	4	23	3	2						
4	19	5	20	7	14	4	15	0							
5	20	7	5	7	12	2	6	0							
7	–	–	–	–	–	–	–	11							
8	32	18	24	8	17	14	15								
10		21	28	–	–	–	–								
11			29	16	27	33	24								

* 1.5 m

During the high-water phase, an accumulation of free phosphate could almost always be definitely detected in the anaerobic zone. A few examples of this condition are presented in the following figure (fig. 16). The examples show on the one hand a relatively uniform distribution of free phosphate in the vicinity of the water's surface, though with certain differences in the absolute values of the concentrations, and on the other hand an increase in the concentration beneath the oxygen boundary to around 30 μP-PO_4/l. As figure 17 shows, a relationship between free phosphate and undissolved iron in the anaerobic zone can also be demonstrated to exist. The following section will deal with this in detail.

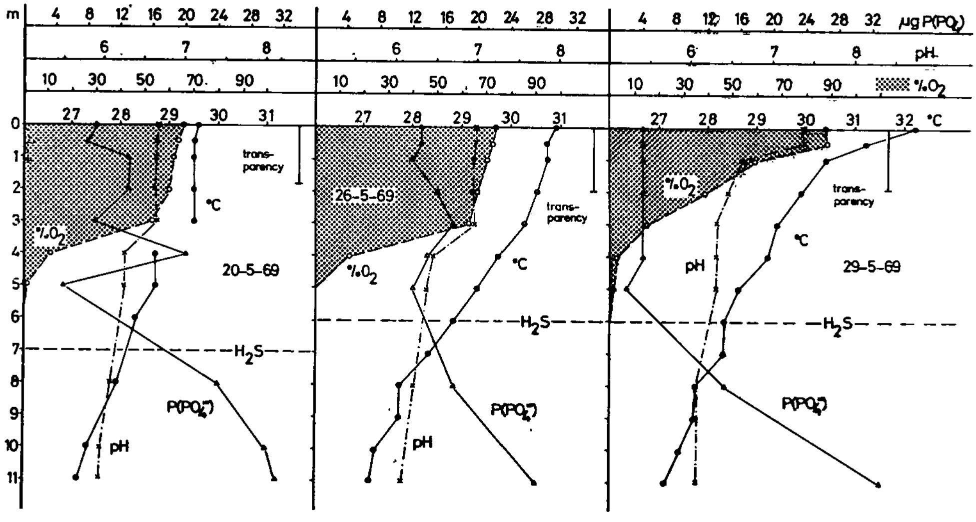


Fig. 16 : The accumulation of free phosphate in the hypolimnion of Lago do Castanho on several days during the high-water phase (samples taken at 1300 hours).

7.7. Iron

Iron has already been mentioned in connection with seasonal changes in the water chemistry of Lago do Castanho. This element was present in the water of the Solimões (see SCHMIDT 1972a) and thereby was also always present in the water of Lago do Castanho in relatively high concentrations. A similar situation was also encountered, by the way, in streams in the terra firme region north of Manaus (SCHMIDT 1972b), while BRAUN (1952) found only a very low iron content in the waters which he studied.

The results of the total iron determinations for Lago do Castanho revealed fluctuations between 0.17 mg/l during the phase of high-water on 13.VIII.69 and 4.05 mg/l during the phase of extreme low-water on 30.X.69. The latter being at a time when the superficial lake sediments were being rapidly resuspended (see table 19). In contrast to the river water, where the portion of suspended iron in the total iron load was almost always clearly greater than that of the dissolved iron, the fraction of dissolved iron in the lake often exceeded considerably that of the undissolved iron. The latter condition is especially true for the anaerobic zone during the high-water period. During the time when sediment was being re-

Table 19a: Lago do Castanho 1968
mg total iron (Fe_{total})/l

m	25.1.	21.2.	27.3.	24.4.	23.5.	26.6.	24.7.	28.8.	25.9.	23.10.	27.11.	19.12.
0	1.35	1.16	0.37	0.78	–	–	0.28	–	0.66	0.60	0.74	0.73
1	1.53	1.16	0.40	0.80	0.80	0.30	–	0.42	0.70	0.66	0.64	0.82
2	–	–	–	–	–	–	0.32	–	1.00	0.94	–	–
3	1.13	1.15	0.75	1.26	0.93	0.33	–	0.54	–	–	0.70	0.93
4	–	–	–	–	–	–	–	–	–	–	–	–
5		1.92	3.18	1.08	1.10	–	1.10	2.26	3.30	3.46	1.38	3.19
6					–	1.02	–	–				
7					–	–	–	2.73				
8					–	–	2.72					
9					–	2.55						
10					1.63							

Table 19b: Lago do Castanho 1969
mg total iron (Fe_{total})/l

m	19.3.	28.3.	2.4.	9.4.	14.5.	11.6.	13.8.	23.9.	16.10	30.10
0	0.80	0.99	0.89	0.78	0.36	0.71	0.25	0.98	1.49	2.89
0.5	0.85	0.99	0.89	0.92	0.36	0.87	0.33	0.87	1.49	4.05
1	1.02	1.05	0.89	0.88	0.35	0.69	0.38	0.72	1.75	
2	1.06	1.08	1.07	0.89	0.41	1.34	0.21	0.87		
3	1.26	1.26	1.21	0.89	0.39	0.78	0.17	1.62		
4	1.30	1.22	1.88	0.93	0.48	1.67	0.20			
5	1.41	2.07	2.24	1.19	0.91	0.81	0.34			
6	–	–	–	–	–	–	–			
7	2.41	2.53	2.90	1.17	–	–	1.97			
8		2.43	3.50	1.37	0.95	2.75				
9					–	–				
10					1.46	–				

Table 20: Lago do Castanho 1969
mg suspended iron ($Fe_{susp.}$)/l

m	19.3.	28.3.	2.4.	9.4.	14.5.	11.6.	13.8.	23.9.	16.10.	30.10.
0	0.30	0.28	0.20	0.13	0.17	0.50	0.15	0.68	0.95	2.26
0.5	0.34	0.25	0.19	0.19	0.20	0.41	0.23	0.60	0.95	2.99
1	0.50	0.28	0.19	0.13	0.18	0.49	0.27	0.52	1.36	–
1.5	–	–	–	–	–	–	–	0.54	–	–
2	0.52	0.16	0.22	0.11	0.25	0.90	0.13	0.60	–	–
3	0.68	0.45	0.16	0.11	0.23	0.57	0.10	1.20	–	–
4	0.72	0.18	0.62	0.08	0.28	0.46	0.13	–	–	–
5	0.79	1.01	0.44	0.36	0.61	0.40	0.23	–	–	–
7	1.65	0.79	1.18	0.23	–	–	1.65	–	–	–
8	–	0.59	0.29	0.07	0.63	1.53	–	–	–	–
10	–	–	–	–	1.06	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–

Table 21: Lago do Castanho 1969
mg dissolved iron ($Fe_{dissolv.}$)/l

m	19.3.	28.3.	2.4.	9.4.	14.5.	11.6.	13.8.	23.9.	16.10.	30.10.
0	0.50	0.71	0.69	0.65	0.19	0.21	0.10	0.30	0.54	0.63
0.5	0.51	0.74	0.70	0.73	0.16	0.46	0.10	0.27	0.54	1.06
1	0.52	0.77	0.70	0.75	0.17	0.20	0.11	0.20	0.39	
2	0.54	0.92	0.85	0.78	0.16	0.44	0.08	0.27		
3	0.58	0.81	1.05	0.78	0.16	0.21	0.07	0.42		
4	0.58	1.04	1.26	0.85	0.20	1.21	0.07			
5	0.62	1.06	1.80	0.83	0.30	0.41	0.11			
7	0.76	1.74	1.72	0.94	–	–	0.32			
8		1.84	3.21	1.30	0.32	1.22				
10					0.40	–				
11						2.00				

suspended, however, the portion of suspended iron clearly exceeded that of the dissolved iron (see tables 20 and 21). On the whole, fluctuations between 0.07 mg/l (13.VIII.69) and 3.21 mg/l (2.IV.69) were observed for dissolved iron. So, even here strong differences were to be noted.

Since separation of the bivalent and trivalent forms was not feasible in the determination of dissolved iron, definite statements as to the proportional relationships of the respective oxidation states of iron are not possible. However, a few conclusions may be drawn with certainty concerning the oxidative conditions in the water. Above all, the sometimes very conspicuous increases in the concentrations of dissolved iron in the anaerobic zone suggest an accumulation of bivalent iron. The simultaneous increase in free phosphate in this zone points, moreover, to the existence of dissolved iron (II)-phosphate. In figure 17 an example for this is given. Another portion of the dissolved iron may probably occur at these depths as iron (II)-bicarbonate. In the diagram the curve for the dissolved iron in the hydrogen sulfide zone has a distinct bend downward, which allows us to conclude that part of the iron has precipitated as FeS. The question of whether black iron sulfide occurs in the sediments of Lago do Castanho at this time of year could not be tested, however. When this question is tested out, it must, of course, be taken into consideration that the redox potential above and in the mud itself is related to the water level conditions and, thus, to the oxygen conditions in the region of the lake bottom. FeS is formed, therefore, during the high-water layers and as a result of the disappearance of oxygen at a simultaneous and corresponding low redox potential (< 0.1 V). One must reckon with the fact, however, that the FeS disappears again when oxygen re-enters this zone and the redox potential rises. In the sediment itself, of course, the reducing conditions can persist in certain cases even at low-water, depending on the feasibility of oxygen's entering the sediment. JUNK (1970) discovered strong sapropel activated sludge formation with black FeS in the small várzea lake Lago Xiborena, which lies in the immediate vicinity of Manaus. He was able to detect, furthermore, that the suspended iron in the white-water occurred at least partially as Fe $(OH)_3$ under oxidizing conditions.

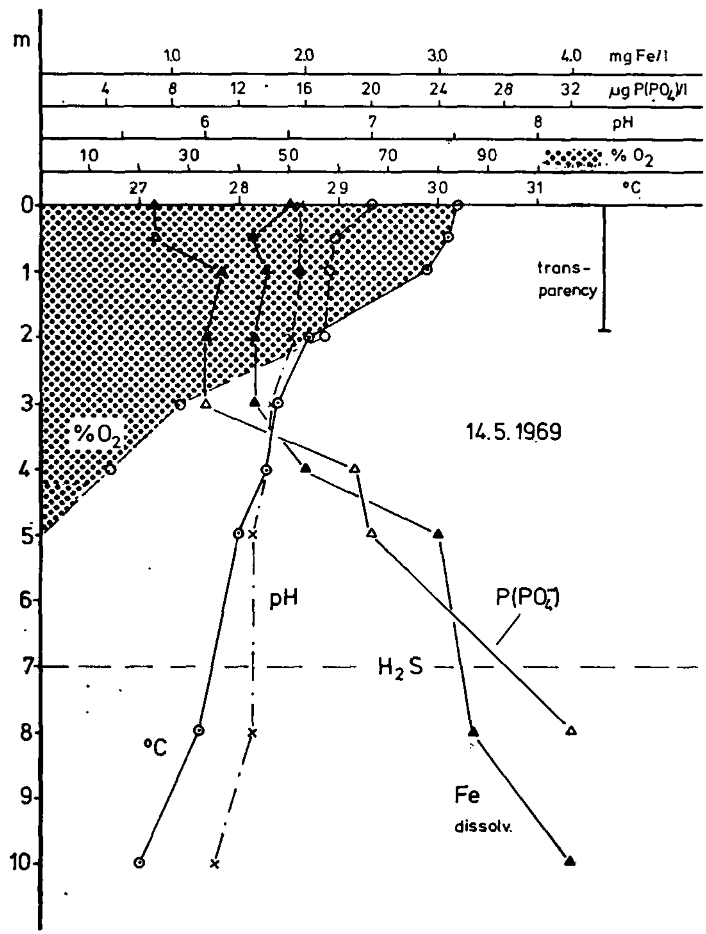


Fig. 17 : The vertical distribution of free phosphate and dissolved iron in Lago do Castanho on 14.5.69 (samples taken at 1300 hours).

7.8. Nitrogen compounds

Within the scope of the investigation were included the following nitrogen fractions: nitrite, nitrate, Kjeldahl-nitrogen, and total-nitrogen. The results showed that the nitrite and nitrate in Lago do Castanho always constituted a negligibly small fraction of the measurable total-nitrogen in the water. Nitrate was present in the lake most of the time in concentrations of less than 20μg N-NO_3^-/l or even less than 10μg N-NO_3^-/l, respectively. That means that these substances were often present in even smaller quantities than free phosphate. In several instances no nitrite or nitrate at all could be detected. No clear connection between seasonal conditions and the concentrations determined for either nitrite or nitrate could be found. The only definite seasonal pattern that could be said to exist was observed in nitrite; it was detected very much less often during periods of extreme low water than during the remainder of the year (see table 22).

Interesting differences in the vertical distribution of nitrite and nitrate within relatively short time intervals were noted. A few examples of this can be seen in the next diagram (fig. 18). As will also be apparent from the examples given, nitrite showed generally a tendency toward a slight increase in concentration corresponding to an increase in depth, with minimum concentrations near the water's surface. Nitrate, on the other hand, had slightly increased concentrations quite often in the uppermost water layers. This could possibly indicate a certain input of nitrogen by means of rain water, which, considering the low concentrations in which nitrate occurs in the lake, would be quite perceptible. Recently published investigations by UNGEMACH (ANON. 1972b) show that the N-NO_3^- concentrations in the rain water at Manaus and at a forest reserve located approximately 25 km east of the city are much higher than the concentrations of N-NO_3^- in the water of Lago do Castanho. Possible restriction of the biological activity near the water's surface by ultra-violet rays, which in this region could cause, for example, a restriction of NO_3^- assimilation by algae as well as a hindering of the denitrification process, should perhaps also be considered.

In several vertical profiles a conspicuous concentration of nitrate in the border region between the aerobic and anaerobic zones and then an immediate and sudden subsequent reduction of nitrate right down to almost zero was ascertained. This distribution pattern, which suggests intensive nitrification and denitrification processes in spatially more or less sharply limited zones, corresponds exactly to the same picture which is known for eutrophic lakes in the temperate latitudes during summer stagnation (see, for example, RUTTNER 1962). The low concentrations of nitrite and nitrate in the euphotic zones are of course attributable to their being utilized by phytoplankton. Associated with the decrease in nitrate concentrations, an increase in the concentrations of nitrite and ammonia in the deeper zones is to be expected. This phenomenon was observed directly in the case of nitrite, but unfortunately no determinations for ammonia could be carried out. Additionally nitrate ions in association with strong decomposition processes become a factor in the development of the nitrate maximum just above the anaerobic zone.

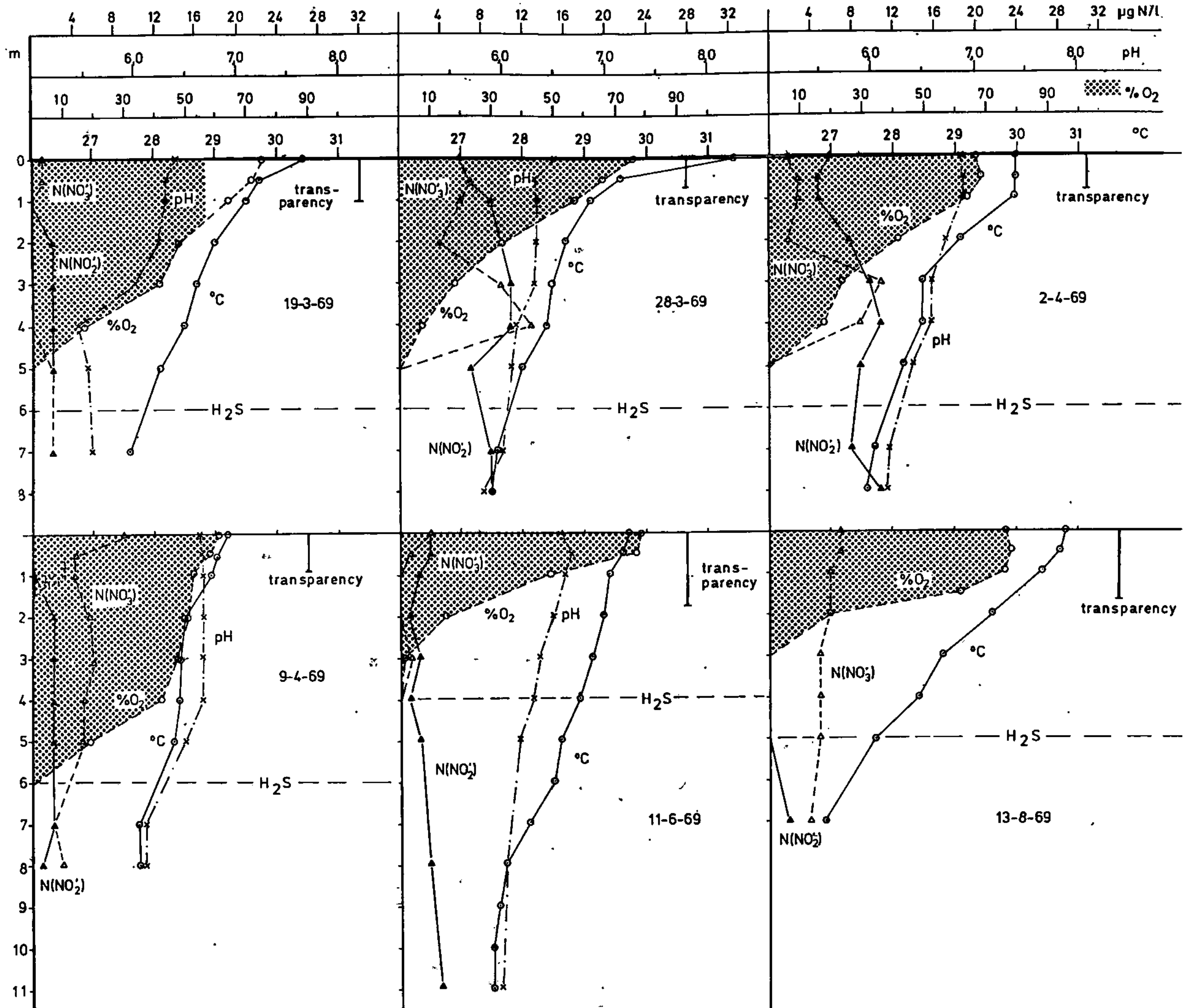
The relatively close proximity of the various activity centers can be accounted for by the high reaction rate of the individual processes, which, according to the rule of van t' Hoff, are approximately 4–8 times faster in this temperature regime than in the waters of northern middle Europe. The sort of sharply developed nitrate and nitrite maxima which are encountered directly in lakes of that region and in others of the temperate latitudes (for example, OHLE 1964, OVERBECK 1967) could not be observed, however, in Lago do Castanho.

As has become clear both from the preceding discussion and from investigations of the vertical distribution of bacteria and algae in Lago do Castanho (SCHMIDT 1969), production and decomposition layers in this body of water lie in much closer proximity and are generally also much less thick than in lakes of the temperate zones. It would thus be pos-

Table 22: Lago do Castanho 1969
$\mu g\ N\ (NO_2^-)/l$

m	19.3.	28.3.	2.4.	9.4.	14.5.	17.5.	20.5.	23.5.	26.5.	29.5.	11.6.	13.8.	23.9.	9.10.	10.10.	16.10.	21.10.	22.10.	23.10.	30.10.
0	0	6	6	0	2	2	1	7	4	2	3	0	1	0	0	0	0	0	0	1
0.5	0	7	5	0	2	2	2	7	4	3	3	0	0	0	0	0	0	0	0	1
1	0	8	5	0	2	2	2	6	4	3	2	0	0	0	0	0	0	0	0	
2	2	10	8	2	2	2	2	6	3	3	1	0	0							
3	2	11	9	2	1	2	2	6	2	3	2	0	1							
4	2	11	11	2	2	2	2	4	2	2	1	0								
5	2	7	9	2	3	2	2	5	2	2	2	0								
6	–	–	–	–	–	–	–	–	–	–	–	–								
7	2	9	8	2	–	–	–	–	–	–	–	2								
8		9	11	1	3	4	3	7	5	4	3									
9					–	–		–	–	–	–									
10					5	4	4	–	–	–	–									
11							4	8	7	6	4									

Fig. 18 : Different modifications of the vertical distribution of nitrate and nitrite in Lago do Castanho (samples taken at 1300 hours). Nitrate is represented by light and nitrite by dark triangles.



sible on days with calm weather that in Lago do Castanho certain processes, such as, for example, stronger nitrification and denitrification action, concentrate in such thin layers that they could not be clearly demarcated by the usual methods of meterwise sampling using water samplers which operate on too large a scale. For this reason, there is an unequivocal need, particularly for work in shallow tropical waters with their more intensive but relatively thinner layering, as was often observed in Lago do Castanho, for a refined sampling procedure and for improved methods of conducting analyses in situ. In particular, the use of continuous monitoring and sampling devices which can draw samples from layers as thin and undisturbed as possible should be considered.

Considering the differing vertical distribution pattern of nitrite and nitrate in Lago do Castanho, there remains the question whether always the indispensable accumulation of organisms responsible for the conversion of the nitrogen compounds can develop at all, despite the fact that this lake can attain a definite stratification in a matter of hours. Frequent partial circulation of the water to varying depths could perhaps hinder more subtile stratification patterns of this type temporarily, so that for this reason it wouldn't always be possible for a distinct stratification of nitrite and nitrate to develop.

The concentrations of total nitrogen hardly ever differ from the results for Kjeldahl-nitrogen because of the previously mentioned low content of nitrite and nitrate. They varied between 0.27 mg N total/l on 2.IV.69 and 3.00 mg N total/l on 30.X.69. These extreme values, however, were somewhat isolated; the concentrations varied mostly between 0.4 and 1.0 mg N total/l (see table 23). The lowest concentrations were generally found at times of rising water level and the highest at times of extremely low water level. In 1968, on the other hand, an annual cycle was scarely discernible in the total-nitrogen results, which was also attributable to the abnormal water level conditions during the second half of that year. This, as previously mentioned, had prevented the resuspension of the sediments and the dying off of the floating meadows with the subsequent remineralization of their organic substances, which in normal years, at least, contributed to the simultaneous increase in the population density of phytoplankton.

Total-nitrogen exhibited, to be sure, different values for the various depths, but still no clear tendencies in its vertical distribution could be derived from them.

7.9. Potassium permanganate consumption (COD) and color

The consumption of potassium permanganate and, thus, the chemical oxygen demand (COD), in Lago do Castanho was usually remarkably constant within a range of 40 to 60 mg $KMnO_4$/l. It, therefore, indicated the presence of not inconsiderable quantities of organic oxidizable material (compare HÖLL 1968). Very seldom did the values lie under 40 mg/l. On 3.III.70, a $KMnO_4$-consumption of only 32.6 mg/l was determined as minimum for the entire investigation time. The maximum was found to be 72.9 mg/l. On the whole, then, the values fluctuated much less than those for total-nitrogen. At the same time, however, an annual cycle of $KMnO_4$-consumption was likewise only comparatively weakly indicated. Like total-nitrogen, potassium permanganate shows, to be sure, vertical differences. They don't present a very uniform picture, however, so that even in this no clear tendencies from the results came to light. To what extent connections exist between the $KMnO_4$-consumption and the phytoplankton distribution will be examined in a later report.

If the values for $KMnO_4$-consumption are calculated as direct chemical oxygen demand, the mean values fluctuate between approximately 10 and 15 mg/O_2/l. As HUTCHINSON (1957) points out, however, based on the investigations of JUDAY & BIRGE (1932), only about 40 % of the available organic carbon in the water will be oxidized by $KMnO_4$. If one

Table 23a: Lago do Castanho 1968
mg N_{total}/l

m	25.1.	21.2.	27.3.	24.4.	23.5.	25.6.	24.7.	18.8.	25.9.	23.10.	27.11.	19.12.
0	0.31	0.40	0.49	0.40	–	–	0.64	–	0.62	–	0.60	0.57
1	0.49	0.42	0.47	0.45	0.37	0.46	–	0.69	0.66	0.84	0.74	0.57
2	–	–	–	–	–	–	0.56	–	0.55	0.85	–	–
3	0.33	0.45	0.63	0.37	0.33	0.38	–	0.50	–	–	0.56	0.60
4	–	–	–	–	–	–	–	–	–	–	–	–
5		0.63	0.46	0.39	0.36	–	0.54	0.54	0.63	0.64	0.59	0.70
6					–	0.34	–	–				
7					–	–	–	0.62				
8					–	–	0.59					
9					–	0.45						
10					0.51							

Table 23b: Lago do Castanho 1969
mg N_{total}/l

m	19.3.	28.3.	2.4.	9.4.	14.5.	17.5.	20.5.	23.5.	26.5.	29.5.	11.6.	13.8.	23.9.	9.10.	10.10.	16.10.	21.10.	22.10.	23.10.	30.10.
0	0.59	–	0.27	0.47	0.50	0.50	0.53	0.59	0.52	0.66	0.70	0.58	0.69	0.87	0.87	0.99	1.44	1.53	1.70	3.00
0.5	0.58	0.60	0.28	0.48	0.53	0.49	0.64	0.48	0.55	0.59	0.68	0.59	0.78	0.87	0.87	1.13	1.26	1.42	1.75	2.86
1	0.58	0.52	0.33	0.54	0.52	0.40	0.64	0.48	0.52	0.96	0.68	0.60	0.92	0.85	0.87	1.05	1.13	1.17	1.41	
2	0.43	0.43	0.30	0.49	0.46	0.41	0.69	0.67	0.58	0.72	0.71	0.59	0.78	0.93*	0.93*					
3	0.48	0.48	0.39	0.45	0.46	0.46	0.64	0.47	0.50	0.73	0.71	0.60	0.70							
4	0.51	0.49	0.42	0.43	0.46	0.47	0.60	0.40	0.59	0.63	0.57	0.70								
5	0.52	0.55	0.45	0.47	0.45	0.59	0.56	0.37	0.54	0.56	0.49	0.53								
6	–	–	–	–	–	–	–	–	–	–	–	–	–							
7	0.61	0.56	0.49	0.48	–	–	–	–	–	–	–	0.60								
8		0.46	0.61	0.50	0.45	0.51	0.52	0.34	0.49	0.69	0.53	–								
9						–	–	–	–	–	–									
10						0.62	0.63													
11							0.63	0.47	0.51	0.59	0.58									

*) 1.5 m

applies this conversion factor to the data for Lago do Castanho and considers the aliquot amounts of oxygen and carbon, they, thus, yield concentrations of between 10 and 15 mg organically bound carbon per liter. Since the oxidation by $KMnO_4$ is exclusively an approximation method and because of its to some extent varying effectiveness, it affords us no absolute picture of the quantities of organic substances (see HUTCHINSON 1957, RUTTNER 1962, HÖLL 1968, and others). The above-mentioned figures can, therefore, serve only as rough estimates.

In a series of measurements an attempt was made to gain some insight as to the significance of the humic substances in Lago do Castanho and their contribution to the relatively high $KMnO_4$-consumption of this water by using the Platinum-color test. The results obtained for Lago do Castanho are compared with those of several other Amazonian waters in table 24. Of these, Lago Moratú and Lago do Calado are várzea lakes with "decanted" white-water, just as Lago do Castanho. Rio Branco and Rio Solimões are, as is well known, white-water rivers; the Rio Negro is the classic black-water river, and the Rio Tapajós is a typical representative of the Amazonian clear-water rivers (see SIOLI 1967b).

The latter also exhibits the lowest values for the Platinum-color test. The data for Lago do Castanho likewise are very low and indicate that in this lake humic material has only slight significance with respect to the occurrence of relatively high $KMnO_4$-consumption, at least on those days on which both factors are determined simultaneously. In this way the white-water of the várzea lakes of the type represented by Lago do Castanho differ clearly from black-water, in which a very high humic content is linked to their very high $KMnO_4$-consumption (see SIOLI 1955, BRAUN 1952).

Table 24: Color of some Amazonian waters in mg Pt/l

Depth	Lago do Castanho				L. Calado	L.Moratu	R.Tapajóz
m	13.8.69	16.10.69	30.10.69	9.1.70	18.8.69	15.8.69	15.12.69
0	29	35	22	35	41	26	11
1	31	36	22		40	25	11
2	28	35			42	47	–
3	28				40		–
4	28				69		–
5	27				78		11
7	33				65		–

Rio Solimões (near Manaus)

m	19.8.69	16.10.69	23.1.70	24.4.70
0	40	40	33	44

Rio Negro

	Tapuruquara	Cantagalo	Manaus	Manaus
m	16.7.69	23.7.69	24.7.69	20.5.70
0	114	134	109	145

Primary production by phytoplankton and by the floating meadows in the littoral region must be considered as principal sources for organic material in Lago do Castanho. As has been already mentioned and has been studied by JUNK (1970) in detail, the floating meadows die out extensively at times of subsiding water. The great quantities of organic detritus which result from this are certainly of special significance for the body of water. Even during the growing phase, however, the floating meadows probably always supply more or less great quantities of dissolved organic material and detritus to the water, which is supplementary to that being added as a result of phytoplankton production. Another portion of the organic material in the lake is with certainty of allochthonous origin and derives from the terrestrial surroundings and/or from the Igapó region. In order to clarify the significance of the individual sources of organic substances, however, extensive research would be necessary, which would doubtless be of general interest.

The relationships between the dissolved and colloidal organic substances and the mineral suspended solids of the inflowing white-water present yet another important problem. Since the mineral suspended solids of the Amazon water consist to a large extent of tiny clay particles which contain relatively large quantities of iron as well (GIBBS 1967), numerous adsorption possibilities are conceivable, which in certain cases are significant for the material cycles of these waters. This is also held true, moreover, for inorganic material dissolved in the water of the lake. A decrease in the general nutritive content of a lake through adsorption of inorganic particles and subsequent precipitation is already known for waters of other regions (for example, OHLE 1962). If such processes should also occur in Lago do Castanho, one would on the other hand then have to of course take into account a regeneration of inorganic material into the open water body – at least in particulate form – during the resuspension of the uppermost sediment layers. Insofar as this applies to organic material, however, the very modest increase in $KMnO_4$-consumption at this time of the year points to at best little quantitative significance for these sorts of processes.

8. DISCUSSION

On the basis of all the results of the investigation two important phenomena can be mentioned as primary limnological characteristics of Lago do Castanho. On the one hand pronounced fluctuations controlled by seasonal conditions can be observed and on the other, various factors operating dynamically within brief time intervals, usually in the space of a day, without any direct seasonally-conditioned tendencies.

The seasonal variations are those which perhaps are most striking, because to this group belongs, of course, the particularly conspicuous rhythm of the fluctuations in water level with all of its associated complex phenomena. In this connection, the measure of the annual minimum water level is especially important, for it determines to what extent the water level in the lake drops, i.e. to what extent the lake is emptied of its present water supply and, thus, later filled again with fresh river water. The extreme annual drop in the water level of the lake has, as could be perceived from the preceding discussions, a decisive effect on the physical-chemical conditions in the lake and also has numerous biological consequences. The unusual chemical conditions in the water during the second half of 1968, compared to the conditions during "normal" low-water levels, pointed up especially the significance of the water level regime. The most important biological consequences of the extensive drying up of the lake in normal years include above all the dying off of the floating meadows and the migrations of numerous fish species.

Distinct seasonal variations are exhibited, as mentioned, primarily by the total salt content, with its most important constituents, and by the general stratification and oxygen conditions. The fundamental aspects of the order of magnitude and pattern of these fluctuations could be grasped by means of the monthly investigations.

The dynamic changes over short time intervals to depths of about 5 m were especially notable in certain of the investigated parameters, primarily the temperature and pH conditions, the distribution of carbon dioxide, nitrite, nitrate, phosphate, and the subtiler aspects of the stratification and oxygen conditions. Several investigation series of consecutive measurements made at close intervals of time produced the first information as to the nature of these phenomena. As a result of the high temperatures it is to be expected that many biogenic processes in the metabolism of the lake point to a very dynamic situation.

If one wants to explore the question of to what extent the limnological conditions in Lago do Castanho are typical for the várzea lakes, one must bear in mind that comparisons of the specifics are only possible then when analogous water-level and watershed conditions exist. Lakes which are connected year-round with the main tributary, as Lago do Castanho is, and whose basins are annually freshly filled and then practically completely emptied again, should be expected to be quite dissimilar, for example in their chemical action, to other várzea lakes, whose water masses are from time to time isolated and, therefore, never empty and which can thus accumulate various materials in them. Differences in the chemical action of the water are also a result of the location and the environs. Várzea lakes which are encircled by recent alluvial várzea soil receive drainage waters of somewhat differing composition than those which border on the considerably older terra firme. In case of larger areas in the catchment region of a water body are already cleared of forests, the differences in the supply of allochthonous organic material have to be considered in addition. The size of the várzea lakes also plays a role, of course, since the relative influence of the environs and other factors are tied closely to it.

In the várzea lake Lago Calado which lies about 80 km southwest of Manaus on the left side of the Rio Solimões (Amazon River) and which connected directly to the river all year around, JUNK (1970) also observed distinctly greater electrical conductivity values at rising water than at preceding low-water levels. In contrast, the same author found a pronounced maximum in the salt content during the low-water phase in the very small and to some extent isolated Lago Xiborena. It supported at that time an electrical conductivity of over 300 μS_{20}/cm. Values of that magnitude are far above those which were known even for the main river itself up to then (see SCHMIDT 1972a). JUNK attributed this extreme increase in the salt content to remineralization of organic materials. Lago Xiborena has a heavy growth of floating meadows and receives in addition very large quantities of allochthonous organic material from its environs in proportion to its own volume. In that the lake is not connected to the river any more at falling water levels, the remineralization products from these organic materials can then concentrate in the remaining water mass and, so, the increase in electrical conductivity.

In Lago dos Passarinhos, one of the other várzea lakes in the vicinity of Manaus, which although similar to Lago Xiborena in that it is from time to time without connection to the river, is considerably bigger than the latter and produced fluctuations in the conductivity of only 25.3–42.7 μS_{20}/cm from November 1967 to September 1968, according to the investigation by JUNK. At low-water (November) the values were in the vicinity of 35 μS_{20}/cm. It is to be assumed, however, that in Lago dos Passarinhos the considerably smaller addition of allochthonous organic material is certainly due not only to the relatively smaller amount of shore area in comparison to Lago Xiborena, but also to the fact that broad sections of its shore region are grassy plains. A definite annual cycle of the electrical conductivity in Lago dos Passarinhos could moreover not be discerned in JUNK's data.

The data from MARLIER (1967), who investigated the small várzea lake Lago Redondo, which also lies in the vicinity of Manaus and which is also periodically isolated from the river, likewise does not indicate any sort of definite annual conductivity cycle. To be sure, the values given show a decrease in the readings from August 1963 to May 1964, but these variations were in no way connected to any other factors that did show seasonal fluctuations. Just as JUNK's data for Lago dos Passarinhos, MARLIER's experimental data for Lago Redondo are still too limited to allow one to draw any general conclusions from it.

This is true also for MARLIER's data for the oxygen, pH, and alkalinity values of Lago Redondo. The values lie in the same range of magnitude as those which were encountered in Lago do Castanho, but otherwise reveal no further possibilities for comparison. Since this lake evidently had a maximum depth of only 3 m, stratification was very seldom observed in it. Nevertheless, MARLIER did ascertain on one occasion a complete absence of oxygen at 3 m, i.e. right above the lake bottom. The oxygen saturations measured in Lago Redondo by MARLIER were always relatively low and never reached 100 %. Unfortunately, he never indicated the time of day the measurements were made.

In 1960 GESSNER reported on several investigations conducted on Lago Janauacá. From his description of the locale, however, it can't be learned exactly where his sampling stations were located. It is surmised that he meant by Lago Janauacá the entire group of lakes. Since Lago do Castanho also belongs to this group of lakes, more detailed comparisons would have been very interesting. The supposition by GESSNER that the mixing of black- and white-water was the cause of the differences observed in electrical conductivity between the Solimões water and the water of Lago Janauacá can't, of course, be ignored when considering the black-water tributaries from the terra firme. GESSNER attributed the lower conductivity in such várzea lakes, however, exclusively to the mixing of river water and black-water. Quite apart from the fact that not all drainage water from the terra firme, even in central Amazonia, can be designated as black-water (see SIOLI 1967, 1968; FITTKAU 1971; SCHMIDT 1972b), the investigations on Lago do Castanho demonstrated that the decline of electrical conductivity during the time the river water remained in the lake basin can also be caused exclusively by rain falling directly on the lake's surface and on the immediately adjacent shore region, without the influence of regular streams flowing into it.

In order to determine to what extent the area of a lake's surface independent of its depth affects the oxygen and stratification conditions, i.e. how these conditions vary in lakes of approximately equal depth, but of varying surface area, and to what extent Lago do Castanho generally compares to other lakes of the area in this respect, several measurements were made in other lakes in April of 1970. In so doing, precautions were taken to ensure that the investigations were proximate as possible in time and also that otherwise reasonably comparable conditions prevailed, especially in regard to the general weather conditions and the time of day the measurements were made. In table 25 some data have been compiled to characterize the individual lakes. The size of the lakes is related to the time of year the samples were taken, which here was during a high-water phase; the size of the lakes could only be roughly estimated, since no suitable maps existed. These data should, therefore, merely facilitate a general idea of the size of the individual lakes. The data for the depths are those for the respective sampling stations. It was attempted as far as possible to sample at the point of greatest depth in each lake. As one can further see from the table, all lakes except Lago Manacapurú are várzea lakes, and all are connected with the river year-round. In addition, the amount of exposure to the wind the lakes had due to their locations naturally strongly affected the structural layering of their water masses. Even in this respect the six lakes show no fundamental differences, though Lago do Castanho and Lago Calado were somewhat more protected from the wind than the others.

The results for oxygen, pH, and temperature measurements are given in the following figure (figure 19). As one can perceive, at the time of the investigation all three parameters in each lake were clearly stratified. However, differences in the stratification profiles were present, which can be attributed to the specific conditions in each lake. In the hours prior to the measurements on Lago Manacapurú and Lago do Castanho, very calm weather prevailed with an estimated wind velocity of about 1 on the Beaufort scale. These conditions produced most notably a sharp temperature increase near the water's surface. In contrast, a heavy rain shower of about 30 minutes duration accompanied by gusts of wind preceded the measurements on Lago Jutai. Prior to the investigations on the remaining lakes, the weather was calm with wind velocities of 1–2 on the Beaufort scale and partially clouded skies. Unusual weather conditions did not appear in the days before the measurements on any of the six lakes, according to information provided by the neighbouring settlers. The weather picture was normal, as the general conditions were appropriate for this season of the year, which happened to be the rainy season. These statements seem important in order to be able to clarify the stratification patterns encountered.

Table 25: Some general features of six lakes of Central Amazonia.

Name	L. Cabaliana	L. Manacapurú	L. Calado	L. Grande	L. Jutai	L. do Castanho
approx. location	100 km west of Manaus	100 km west of Manaus	80 km west of Manaus	50 km south-west of Manaus	50 km south-west of Manaus	50 km south-west of Manaus
date of investigation	12.4.1970	13.4.1970	14.4.1970	23.4.1970	23.4.1970	24.4.1970
hour of investigation	13	13	12	15	16	13
estimated area (km^2)	100	40	1–2	15	1–2	1–2
depth at sampling station (m)	10	12	10	9	8	10
electr. conductivity (μ_{20}/cm) at surface	45.9	8.3	31.4	52.5	51.9	46.9
at maximum depth	48.3	8.7	26.3	53.0	51.5	40.1
type of water	"decanted" white-water	black-water	"decanted" white-water	"decanted" white-water	"decanted" white-water	"decanted" white-water

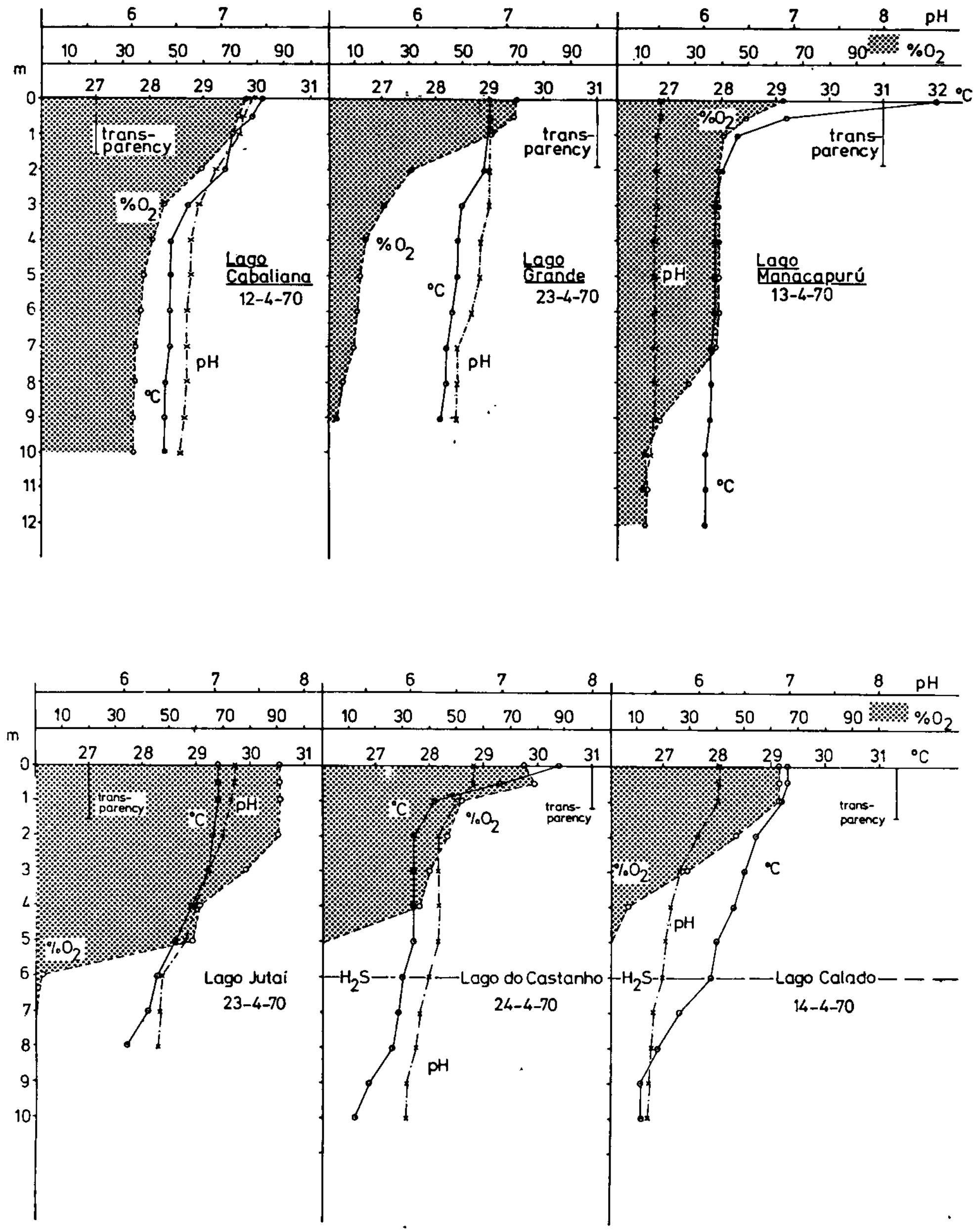


Fig. 19 : Temperature-, pH-, and oxygen-stratification in six different lakes of Central-Amazonia in April of 1970, that is, during the early part of the high-water phase.

As the diagram further illustrates, there is a definite relationship between the oxygen distribution and the surface area of the individual lakes. While oxygen could be found all the way to the lake bottom in the three larger lakes, independent of their other properties, none could be found at the bottom in the three smaller lakes. The oxygen situation in Lago Calado was particularly unfavorable, but also in Lago do Castanho hydrogen sulfide was already present in the deep zones. Although no oxygen was present above the lake bottom in Lago Jutai either, no hydrogen sulfide could be definitely determined to be present at the time of sampling.

These comparative measurements showed that in the larger lakes, at least at the time of sampling, full circulation must have occurred just often enough, so that in deeper regions the rate of oxygen supply was greater than the consumption of oxygen. On the whole, Lago Manacapurú is rather unsuited for further comparison, however, since it is not a várzea lake, as has been said, but contains black-water. In the five remaining várzea lakes it can be concluded with some certainty that the orders of magnitude of primary production of the phytoplankton were comparable. Because of the relatively modest shore growth in the two bigger várzea lakes, Lago Cabaliana and Lago Grande, the portion of allochthonous organic material from the environs and, thus, also the oxygen consumption were probably less than in the three smaller várzea lakes. This, as well as the amount of surface area exposure to wind action could also contribute to a certain extent to a more favorable oxygen situation in these two lakes.

It seems clear that in the larger várzea lakes of central Amazonia the oxygen distribution may be generally more favorable than in the smaller lakes and that it seems to be heavily dependent on the size of the lake. This may be explained, as mentioned, by a greater potential for exposure to and mixing action by wind and the relatively smaller quantity of allochthonous organic material and, hence, the somewhat lower oxygen consumption.

Altogether, the results of these comparative measurements showed that Lago do Castanho is apparently a completely typical representative of the várzea lakes in this region, but that in comparing the lakes, the specific feature of each lake, e.g. surface area, wind exposure, etc., must be taken into consideration.

Even though the lakes in the entire várzea region of the Amazon may be similar in many of their properties, one should not overlook the fact that certain regional differences attributable to the properties and behavior of the river itself are to be expected. The salt content of the Amazon River, for example, shows a definite decrease, insofar as studies have revealed to this time, between its upper course and its estuary from about 120 μS_{20}/cm to about 30 μS_{20}/cm (see GIBBS 1967, SCHMIDT 1972a). That means, naturally, that the water flowing into the lakes at a time of rising water level in the river exhibits certain regional differences in its composition. Furthermore, one must reckon with the fact that several chemical components, which are present in such small concentrations that an addition of them by rain may be very important (as for example NO_2^- and NO_3^- in Lago do Castanho), show regional differences which correspond to the local precipitation conditions.

Another factor which should be considered as contributing to the differences in limnological conditions in the várzea lakes of the various reaches of the river are the regional differences in the mean amplitudes of the river's water level. At Manaus the mean amplitude is, as mentioned, normally about 11 m. At Santarém on the lower Amazon the mean difference is only about 6 m and near the area of the delta, only 1.0–1.5 m (LE COINTE 1945).

During the time of low-water in the river, however, the várzea lakes of the lower Amazon region also dry up almost completely, hence, even in them a water level of at most only 1 –2 m remains (SIOLI 1968b). On the other hand, their maximum water levels are, corresponding to the changes in water level of the river, considerably less than in those várzea lakes of central Amazonia which are directly connected with the river. In view of these water level conditions, one can, therefore, assume that in the várzea lakes of the lower Amazon region, as long as the ratio between the surface area and the lake's depth doesn't reach the critical value, a longer stagnation of the deeper water layers will not take place, as is the case in Lago do Castanho, for example. Hence, the more shallow the várzea lakes become, the more unstable are the general stratification conditions, and the better is the supply of oxygen up to the surface of the lake bottom. Since the trade winds also blow more strongly and more regularly as one approaches the Atlantic, they can expedite more readily a complete mixing of the water in várzea lakes of the low Amazon regions. For this reason, therefore, the oxygen conditions of the várzea lakes on the lower course of the Amazon River must be definitely more favorable than in those lakes of central Amazonia. Longer lasting periods of stagnation, with which are associated an absence of oxygen and a formation of hydrogen sulfide, can thus be expected to occur there at most in very small lakes or in small, isolated sections of the larger lakes or in sections of those lakes which are protected from the wind.

These statements also describe to some extent those standing waters of lower Amazonia that do not belong to the group of lakes known as the várzea lakes, such as, for example, the lakes investigated by BRAUN (1952) which are located mainly in the Tertiary zone. In general they exhibit fluctuations in water level similar to those of várzea lakes of that region, since they usually are also directly connected to the rivers. BRAUN was in fact able to ascertain generally clear oxygen decreases with increasing depths, but only in one instance could he find a complete absence of oxygen above the lake bottom.

Apart from the shallowness of the lakes investigated by BRAUN, as compared to the depths of the central Amazonian várzea lakes, the more favorable oxygen conditions can also be explained, according to BRAUN's data, by the low rate of oxygen consumption that results from a meager production of indigenous organic material. In addition, better light conditions in these lakes enable the relatively small numbers of phytoplankton to produce oxygen right down into the lower depths, so that even with temporary stagnation an oxygen supply is available throughout a relatively large portion of the total water mass.

Conditions such as these which clearly differentiate BRAUN's lakes from the lakes of the várzea could be observed, however, even in the region of Manaus, although standing waters containing clear-water very seldom exist there. Near the bank of the Rio Negro opposite from Manaus, about 20 km distant from the city, there is a small forest lake with unusually clear water for this area. Unfortunately, the name of this lake could not be learned despite all efforts to this effect, as its shores are uninhabited, so it will here be called simply Lago Cristalino. Lago Cristalino is located in a valley flanking the Rio Negro and is separated from the river by means of a wide barrier of sand and loam; it is flooded by the river only for short durations at times of very high water level in the river. Except for the side adjacent to the Rio Negro, the banks are formed of relatively steeply-rising terra firme and are overgrown by a high tropical forest; on the whole, the lake is protected from the wind extremely well. The depth of visibility on the day of the investigation was 3.9 m, and the color of the water was pale green without any noticeable turbidity. As table 26 shows, the water in this lake was in fact definitely stratified, but still contained an ample supply of oxygen throughout the water mass. Above the lake bottom in Lago Cristalino at a depth of 6 m, a depth at which in Lago do Castanho small traces, or more usually, no oxygen at all could be found, over 60 % oxygen saturation, was still ascertained.

Table 26: Lago Cristalino near Manaus, 26.3.1970, 11.00 h.

Depth in meters	°C	pH	µS20/cm	oxygen saturation %
0	30.7	5.2	4.75	86.0
1	29.8	5.2	4.73	82.5
2	29.3	5.2	4.74	82.0
3	29.3	5.1	4.74	82.5
4	29.2	5.1	4.91	77.0
5	29.1	5.0	5.29	65.7
6	28.9	5.0	5.55	61.3

Even in this lake the very favorable oxygen conditions, as compared to conditions existing in a similar várzea lake, can only be explained, as was the case for the lakes investigated by BRAUN, by the very low production of indigenous organic material and by the relatively small addition of allochthonous organic substances. This was all the more astounding for Lago Cristalino, since its banks are surrounded by a dense belt of the Araceae *Montrichardia arborescens*. It may be, that this belt functions as a filter for the organic material rinsed into the lake from its surroundings. The small indigenous production of organic material will, hence, be more easily understood, if one considers the low electrical conductivity values. They corresponded almost exactly to the conductivity values for rain water in this region (e.g. rain water over Lago do Castanho, measured on 20.XII.67: electrical conductivity = 4.55 S_{20}/cm; pH = 4.45; temperature = 23.4 °C; and compare ANON. 1972b).

The comparison of the data for Lago Cristalino with that gained for Lago do Castanho or with that reported by MARLIER (1969) for Lago Redondo and by JUNK (1970) for Lago Calado and Lago Xiborena, points once more very clearly to the very dynamic situation in the várzea-lakes which is accelerated by the water of the Amazon, or Solimões, respectively.

As in the other tropical waters investigated up to this time, seasonal differences in the várzea lakes of the Amazon region are also occasioned primarily not by temperature changes, but by seasonal fluctuations in the precipitation and in part by the wind conditions (see RUTTNER 1931, HUTCHINSON 1957, BEAUCHAMP 1964, TALLING 1966, MORGAN & KALK 1970, and others). The precipitation conditions affect the várzea lakes directly through rain falling on the water and indirectly through the fluctuations in water level, and, thereby, by the precipitation regime that prevails throughout the upper catchment area of the Amazon. Also in the lakes investigated by BRAUN (1952) in the lower Amazon Tertiary region, the seasonal differences are occasioned by the direct and indirect influx of precipitation. In contrast to the várzea lakes, the most significant additions of nutrients to these lakes during the course of the year came not from the invading water of the Rio Tapajós, which is extremely low in salt content, but from remineralization products washed from the immediately surrounding terrestrial catchment area at the beginning of the rainy season. This effect, which BRAUN called the "shore factor" ("Uferfaktor") is superceded in significance for the várzea lakes by the influx of the relative salt-rich Amazon water.

A further characteristic common to many tropical lakes, especially those deeper ones, seems to be their clearly more unfavorable oxygen conditions, as opposed to lakes in the temperate latitudes. This is above all attributable to the low solubility of oxygen at higher temperatures, accelerated oxygen consumption processes, and, in association with the rapidity of oxygen consumption, the infrequency with which full circulation occurs (see RUTTNER 1931, GANAPATI 1960, BEADLE 1966, TALLING 1957, 1969; et al.). Somewhat surprisingly, however, it was found that this led to an absence of oxygen for longer periods of time in the deeper layers of these still relatively shallow lakes in central Amazonia.

The data acquired for Lago do Castanho with regard to the vertical distribution of algae and bacteria (SCHMIDT 1969), the stratification and oxygen conditions, the changes in concentrations of free carbon dioxide, nitrite, nitrate, and other factors, point to a close proximity of the production and decomposition layers. In comparison to standing waters of somewhat similar size and type in the temperate zones, these processes seem on the whole to be shifted closer toward the water's surface in the várzea lakes. The relative thinness of the euphotic zone, even at the time when it had attained its maximum volume in Lago do Castanho, and the high water temperatures are primarily responsible for this phenomenon. Phytoplankton itself and its primary production in Lago do Castanho shall be discussed in detail elsewhere.

As our example, Lago do Castanho, showed, the oxygen conditions in particular must be considered in any future intensive use of the várzea lakes, such as by a possible fish management program. A damming up to conserve the maximum water level of several lakes in central Amazonia, for instance, could have very disastrous consequences, while it is quite probable that in the várzea of the lower Amazon region conditions would lend themselves much more to this sort of action, without the dire results. On the other hand, a partial damming up to maintain a minimum water level of about 5 m – as the critical height in regard to the mixing and oxygen conditions – would have some positive effects in appropriate várzea lakes of central Amazonia:

1. Prevention of fish emigrations from the lake during the low-water season.
2. Maintaining of larger lake areas for primary production and production of food organisms of fishes during low-water season.
3. Influx of fertilizing river water into the lake basin at water levels higher than the dam would be possible furtheron.

9. SUMMARY

The limnological conditions in Lago do Castanho, a middle-sized várzea lake of central Amazonia, are determined largely by the Rio Solimões (Amazon River). The lake is connected to the river by means of a canal throughout the entire year, so that the river's fluctuations in water level always affect the lake directly. These changes in the water level, which amount to an amplitude of about 10 m annually on the average in that region, indicate that the lake basin is filled each year with river water and then almost entirely emptied again. This, thus, causes sharp seasonal variations in the chemical-physical and biological conditions of the water.

Other factors which exhibit clear seasonal fluctuations in the lake are first and foremost the general stratification and oxygen conditions and the total salt content, including all of its most important constituents, but also the turbidity of the water and its seston content.

The height of the water level proved to be especially important for the stratification and circulation conditions in the lake in view of the considerable density differences of the water from temperature unit to temperature unit at the high temperatures which prevailed. It was determined that circulation brought about by normal nightly cooling – seasonal temperature differences practically don't occur at all – can penetrate only up to certain depths in the water mass. The critical depth, or boundary, is usually about 5 m in Lago do Castanho.

As a consequence of this situation, the lower water layers stagnate extensively as soon as the water level has risen commensurately, so that in this region a persisting absence of oxygen and formation of hydrogen sulfide occur. At the same time, increasing concentrations of free carbon dioxide, phosphate, and dissolved iron were found in the anaerobic deeper zone, which exists from about March to September. Within the scope of this investigation it could not be established whether in normal years full circulation is not actually achieved occasionally during the high-water phase. The problem is being debated, in the process of which it has been pointed out that all investigation results suggest that such an event supposing it occurs at all during this season of the year, at least does so very seldom.

The salt content of the river water decreases gradually during the entire time the river water remains in the lake basin. Rain falling on the lake's surface and drainage water from the immediately surrounding landscape are cited as the cause for this, since no true streams flow into Lago do Castanho.

Other factors are subject to greater fluctuations of a daily than a seasonal nature. However, only the water to a depth of about 5 m will be affected by these fluctuations. Included among these factors are primarily the water temperature and the stratification conditions in the upper depths of the water, which are products of the existing circulation conditions. The oxygen-free deeper zone which is observable at high-water is not always separated clearly from the often completely mixed upper zone by strong density discontinuities. A distinct arrangement of the water mass into epi-, meta-, and hypolimnion isn't found over longer periods of time, but is usually observed only during the day. At high-water during the night, and often during the day as well, the temperature curve is not klinograde, but usually of a heterograde stair-step nature. In contrast, at times of corresponding low water, full circulation with homothermy occurs almost every night and also many times during the day.

Factors which are related to the process of photosynthesis likewise show greater diurnal than seasonal variation. To these belong pH, free carbon dioxide, and oxygen saturation.

Fluctuations of relatively short duration and lacking any seasonal tendencies were observed as well in the vertical distribution of nitrite and nitrate.

The suspended solids contained in the white-water which flows into the lake basin at times of rising water level are sedimented out relatively quickly. As a consequence of this, the transparency of the water is increased in the lake, but never reaches values which are much greater than about 2 m. The causes of this are assumed to be phytoplankton development and also organic detritus of autochthonous and allochthonous origin.

If the maximum water depths reached in the lake during the course of the year fall below about 4 m, resuspension of the upper region of the sediment begins due to wave action. Simultaneously, the transparency is decreased very sharply, during the phase in which lake sediment is being resuspended, a considerable increase in the concentrations of total-iron and total-phosphorus can be observed as well. The causes and consequences of this process are being debated.

Further into the study, the limnological conditions found in Lago do Castanho were compared with those of other standing Amazonian waters. So far as the information available to us at this time shows, Lago do Castanho is a typical representative of those middle -sized várzea lakes in central Amazonia that are connected year-round with the main river. In conclusion some similarities to be found in tropical lakes of different regions were pointed out. Finally, the practical use of várzea lakes – particularly the possibility of damming up such lakes – is discussed in some aspects basing on the presented limnological conditions.

10. RESUMO

As condições limnológicas no Lago do Castanho, um lago de várzea de tamanho medio na Amazônia Central, são determinadas preponderamente pelo Rio Solimões. Durante todo o ano o lago está em ligação com o rio através de um canal, de modo que as variações do nível dêste podem influenciá-lo plenamente. Estas modificações do nível d'água, que naquela região perfazem anualmente em média 11 metros, significam que o leito do lago é preenchido cada ano com água branca e de novo totalmente esvaziado. Elas causam portanto grandes diferenças sazonais nas condições físico-químicas e biológicas do corpo d'água.

Fatôres que mostram oscilações sazonais nítidas no lago são principalmente as condições gerais de estratificação e oxigenação, e o teor salino total com os seus principais componentes, além da turvação d'água e seu conteúdo em seston.

Com níveis superiores a ca. 5 m as camadas inferiores estagnam durante longo tempo. Isto leva a condições anaeróbicas duradouras nestas zonas. Com níveis baixos porém as circulações plenas são muito frequentes.

Outros fatôres mostram oscilações diárias maiores do que anuais. Isto se refere principalmente as camadas superficiais da água. A êstes fatôres pertencem principalmente a temperatura e a estratificação de densidade a ela relacionada nesta zona, assim como fatôres correlacionados à bioatividade, como pH e concentrações de CO_2 e de O_2.

Com nível d'água muito baixo verifica-se uma resuspensão das camadas superiores do sedimento, o que se manifesta sob multiplos aspectos.

O Lago do Castanho é comparado com outros corpos d'água amazônicos na medida em que isto é possível.

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