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LIMNOLOGY OF AN ALLIGATOR POND IN SOUTH FLORIDA

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ABSTRACT: *Alligator ponds or gator holes are ecologically important components of the marshes and swamps of southern Florida. Pond limnology was strongly influenced by southern Florida's subtropical environment and its alternating wet and dry seasons. Three morphological types of alligator ponds, peatland, rockland, and cypress ponds, are maintained by the activities of the American alligator. The study pond included emergent and submerged plant zones and was surrounded by swamp and marsh plant communities, particularly cypress swamps. Temperature varied seasonally and was strongly influenced by seasonal plant growth that inhibited mixing and resulted in temperature differentials equivalent to 12 C/m. The water was relatively clear and slightly brown. Physicochemical characteristics varied seasonally being affected by concentration in the dry season, dilution in the wet season, and the effects of fish kills. Oxygen supersaturation was frequent and diurnal fluctuation was great, particularly in the dry season. Low dissolved oxygen, high community respiration, and high fish densities caused fish kills. Reserve pH was consistently 8.2-8.3 and* in situ *pH was usually 7.1-7.8. The water was highly buffered; total alkalinity generally was 130-200 ppm. Nutrient concentrations were generally low. Specific conductance usually ranged 184-290 µmho/cm^2. Most constituents reached extreme levels during a fish kill. Although remote, the pond showed evidence of pesticide contamination.**

ALLIGATOR PONDS or "gator holes" are important features of the wetland ecosystems of southern Florida. These shallow ponds exist in a subtropical environment characterized by seasonal fluctuation of water level and yearly variation in total rainfall. They provide low-water refugia for aquatic organisms and concentrated food sources for mobile predators (Kushlan, 1974a, 1976). Despite their ecological importance, little is known about the limnology of alligator ponds.

In this paper we discuss certain aspects of the descriptive limnology of an alligator pond in the Big Cypress Swamp of southern Florida. The study was

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conducted from 1969 to 1973. The pond was studied intensively from 1969 to 1971 by Kushlan. Some aspects of this study have been presented elsewhere (Kushlan, 1973, 1974a, b, 1976; McPherson, 1969, 1970). Chemical and physical sampling was continued in 1971, 1972, and 1973 under the direction of Hunt.

METHODS—Water levels were measured by standard U.S. Geological Survey staff gauges permanently positioned in the pond but not corrected to mean sea level. Water level data were also collected at U.S. Geological Survey gauging station, Bridge 105, where water level fluctuations closely reflected conditions at the pond 13 km to the southeast. Rainfall and evaporation were measured at the U.S. Weather Service station at 40-mile Bend Ranger Station.

Chemical and physical data were obtained intermittently from April 1969 to April 1973. Two complete chemical samples were taken and processed by Benjamin F. McPherson of the United States Geological Survey in 1969. Samples were taken frequently by Kushlan in 1970, especially from 5 May to 20 August 1970 incident to and following a severe fish kill of 14-24 May. Samples were taken monthly from 30 October 1971 to 8 April 1972 by Paul Evans, and sampling from 23 October 1972 to 19 April 1973 was carried out by Timothy Graham, Kenneth Kirsner and Jimmy Walker, all under Hunt's direction.

Physio-chemical determinations followed standard procedures. Most chemical analyses were performed according to the procedures of the Hach Chemical Company with the Hach Engineering Kit colorimeter except for the following: dissolved oxygen, the Rideal-Stewart modified Winkler method (Welch, 1948); carbon dioxide (Welch, 1948); chloride, Mohr method (A.P.H.A., 1965); pH and reserve pH, Hellige color comparator; conductivity, YSI model 31 conductivity bridge; hardness (Mackereth, 1963); total phosphate, treated by persulfate oxidation (Menzel and Corwin, 1965); and total organic matter (Gonyea and Hunt, 1970). Dissolved inorganic phosphate samples were filtered through a 0.45μ millipore filter.

STUDY SITE—The pond is located in the southeastern part of the Big Cypress Swamp (lat 25°44′50″N., long 80°56′50″W.) (Fig. 1). At the time of the study the pond was owned by the University of Miami and is now part of the Big Cypress National Preserve. In 1970, it had a surface area of 1520 m^2 and a high water volume of 1240 m^3.

The pond included 2 plant zones. As of 1970, the emergent zone occupied 75% of the total surface area. *Panicum hemitomon* amd *P. paludivagum* were the dominant species. From late summer to spring, the central area of the pond was occupied by a dense growth of submerged plants, primarily the naiad, *Najas flexilis*, with some yellow bladderwort (*Utricularia foliosa*).

Four plant communities occur near the pond: hammock forest, cypress swamp, hardwood swamp, and marsh prairie (Fig. 2). The hammock forest grows on an island of limestone outcropping above high water level. Near the pond this community was dominated by plants of West Indian affinity including *Coccoloba diversifolia*, *Nectandra coriacea*, *Bursera simaruba*, *Ficus aurea*, and *Psychotria undata*. Trees of temperate affinity especially *Quercus virginiana* and *Q. lauri-*

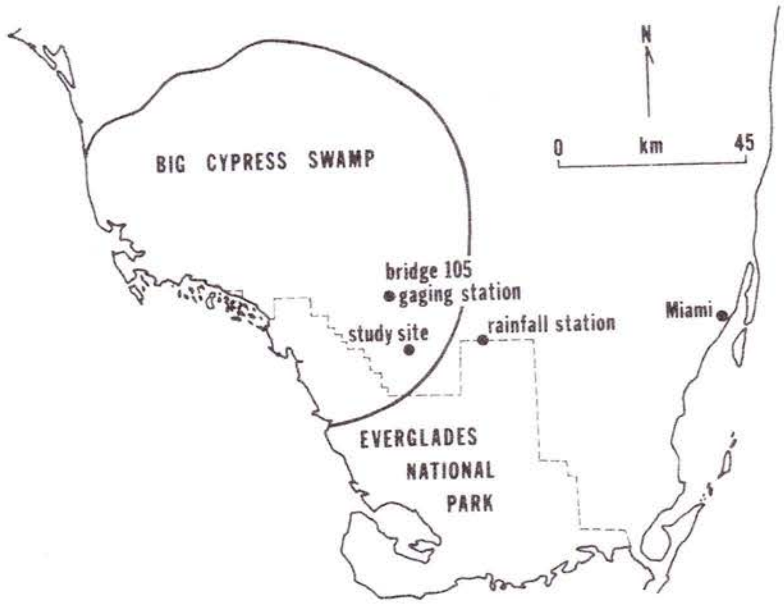

FIG. 1. Map of south Florida.

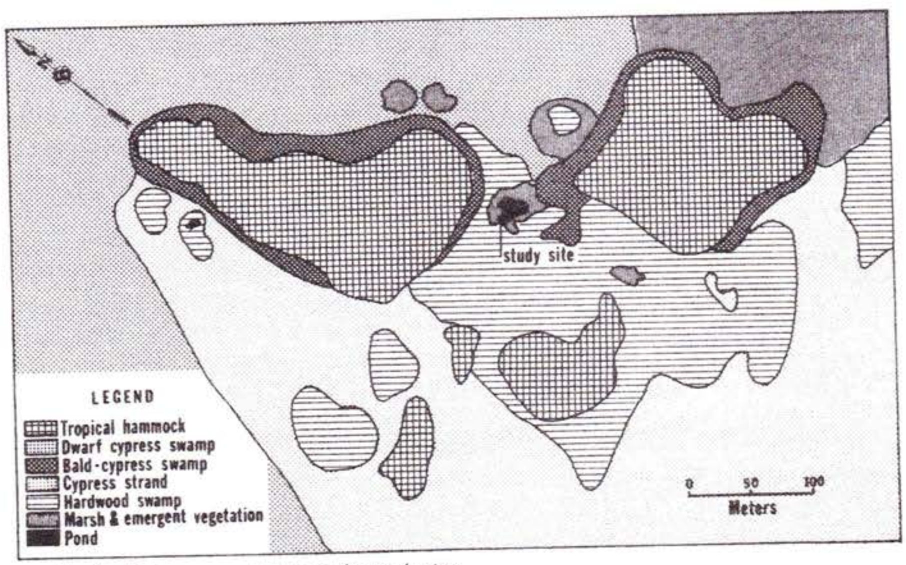

FIG. 2. Plant communities near the study site.

folia occur as well. Epiphytes include *Tillandsia usneoides*, *T. fasciculata*, and *Microgramma heterophylla*.

Three fairly distinct types of cypress swamp are also located near the pond. Dwarf cypress swamp, the most extensive community near the study site, is dominated by thin and widely spaced pond-cypress trees (*Taxodium distichum* var. *nutans*) few of which exceed 5 m in height. Soil is less than 15 cm deep. Epiphytes are common, including *Tillandsia usneoides* and *Encyclia tampensis*. Sawgrass (*Cladium jamaicense*) is the most abundant species of the herbaceous stratum. A mat of periphyton several centimeters thick covers most of the swamp bottom.

The dominant tree of the bald cypress swamp is *Taxodium distichum*, which reached a height of 20 m. These stands occupy a depression in the bedrock along the periphery of the tree islands. Soil is as much as 1 m deep. *Annona glabra*, *Fraxinus caroliniana*, and *Cephalanthus occidentalis* form a second stratum. Epiphytic plants were abundant, including *Psilotum nudum*. Submerged and emergent plants include *Crinum americanum*, *Saururus cernuus*, and *Bacopa caroliniana*. This swamp was severely damaged by intense fires during the spring of 1971. Root burning caused the toppling of many old trees, and thereafter the epiphytic community decreased markedly.

The third type of cypress swamp occurred southwest of the pond. This stand was in many respects intermediate between dwarf cypress and bald-cypress swamps. The trees were larger with more epiphytes. This stand, approximately 1 km wide, formed downstream of the tree island (Fig. 2) and extended to the southwest forming Gum Slough, which drains towards the Gulf of Mexico.

Hardwood swamps included a willow-head located northeast of the study pond. This distinct community of *Salix caroliniana* occupies a depression in the bedrock and may be a former pond. Willows bordered the study pond except on the southern and eastern edges at the time of the study. South of the pond is a hardwood swamp dominated by *Anona glabra* and *Fraxinus caroliniana*. Both *F. caroliniana* and *A. glabra*, primarily the former, make up most of the dense hardwood swamp southwest of the pond.

Several stands of marsh vegetation occur near the pond. These marsh prairies occupy deep basins and are covered during most of the year by up to 1 m of water. They are composed of several distinct stands of marsh vegetation. The dominant plants are *Eleocharis cellulosa*, *Pontederia lanceolata*, *Sagittaria lancifolia*, *Cladium jamaicense*, *Typha* sp., and *Thalia genticulata*.

HYDROLOGY—Annual rainfall at the study site averages 1350 mm/year; 81% of the rain fell from May to October (Fig. 3). Evaporation was highest in the spring and summer (Fig. 3). During the dry season (November to April) evaporation exceeds rainfall, and water levels and surface flow decline. Because water in the study pond is derived from both local rainfall and surface water flow, water levels fluctuated markedly during the alternating periods of rainfall and drought (Fig. 4).

Surface drainage into the pond is from the Big Cypress Swamp to the north. Surface flow in this region of the Big Cypress is constricted by culverts as it passes under U.S. Highway 41 (Fig. 1). At the time of the study the area was considered to have been little altered from natural conditions (Klein et al., 1970; Leach et al., 1972).

MORPHOMETRY—Based upon morphometry, alligator ponds in southern Florida are broadly divisible into 3 types: cypress ponds, rockland ponds, and peatland ponds. Most cypress ponds occur in the Big Cypress Swamp. They are large (up to 200 m in diameter), often bordered by cypress, and relatively deep (up to 4 m). These ponds occupy depressions in the underlying limestone that were probably formed by subaerial solution when sea level was lower. The basin is overlain by a sedimentary deposit of organic mud that is extremely floculent in its top 30 cm. The study site represents this type of pond. The

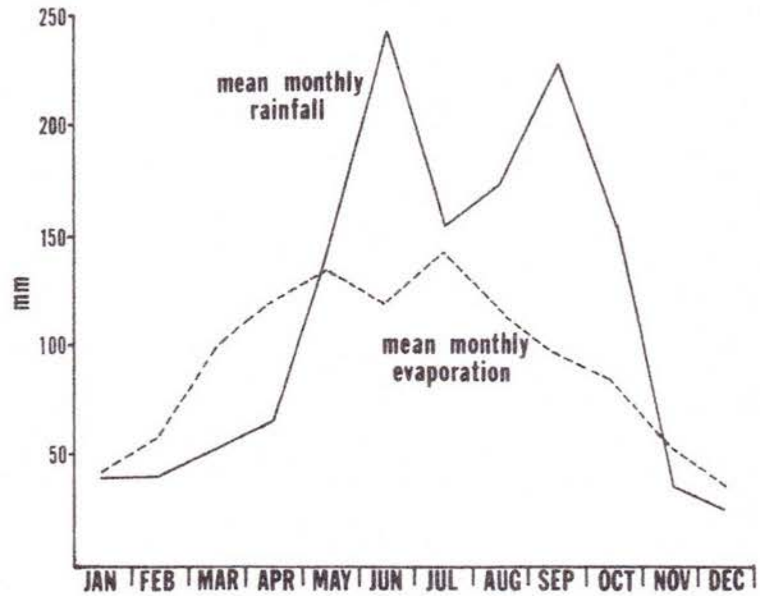

FIG. 3. Mean monthly rainfall (1940-70) and evaporation (1960-69) near the study site.

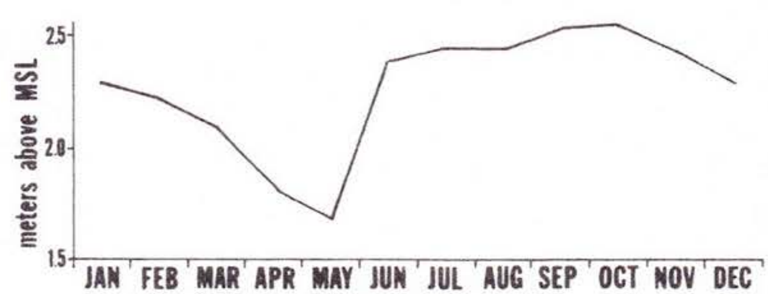

FIG. 4. Average monthly water level (1962-1972) at gauging station Bridge 105 near the study site.

morphometry of the study pond basin is irregular and shows two sub-basins, one deeper than the other (Fig. 5). There is little correlation between basin morphometry and the location of plant zones. The sedimentary deposit varies 30-225 cm in depth, being thickest over the deepest parts of the basin (Fig. 6). The pond is generally deeper in the central plant zone and shallower in the peripheral emergent zone (Fig. 5). This is especially evident in certain locations where there was a 60 cm dropoff at the interface of the submerged and emergent plant zones. In other areas the difference in depth between zones is less.

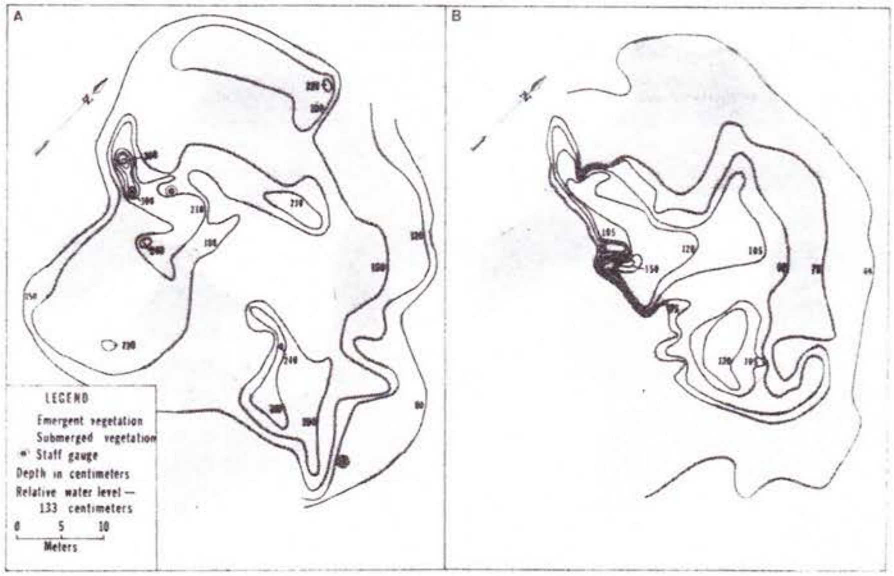

FIG. 5. Bathymetry (A) and morphometry (B) of the study pond in 1970. Depth contours are in cm. Dark shading represents emergent plant zone. Light shading represents submerged plant zone.

It is useful to compare cypress ponds such as the one studied, with other types of ponds. Rockland ponds are found throughout the southern Everglades. They differ from cypress ponds by being smaller, shallower, and lacking cypress trees. They are common throughout the Everglades marsh. Like cypress ponds, these ponds occupy basins in the underlying limestone, and the sedimentary deposit is an organic mud. These ponds usually have a sloping bottom with the deepest part of the basin and the deepest part of the pond coinciding near the center (Fig. 6). In some cases sediment may be lacking in the center, and the rock bottom may be visible.

Peatland ponds are holes in thick peat. Morphometry of the pond shows no relation to the underlying bedrock, as it occupies a pocket within the thick peat sediment (Fig. 6). The sedimentary deposit is highly organic and compact. Such ponds may form when fire causes a localized burnout of the peat to considerable depths, an origin similar to ponds in the Okeefenokee Swamp (Cypert,

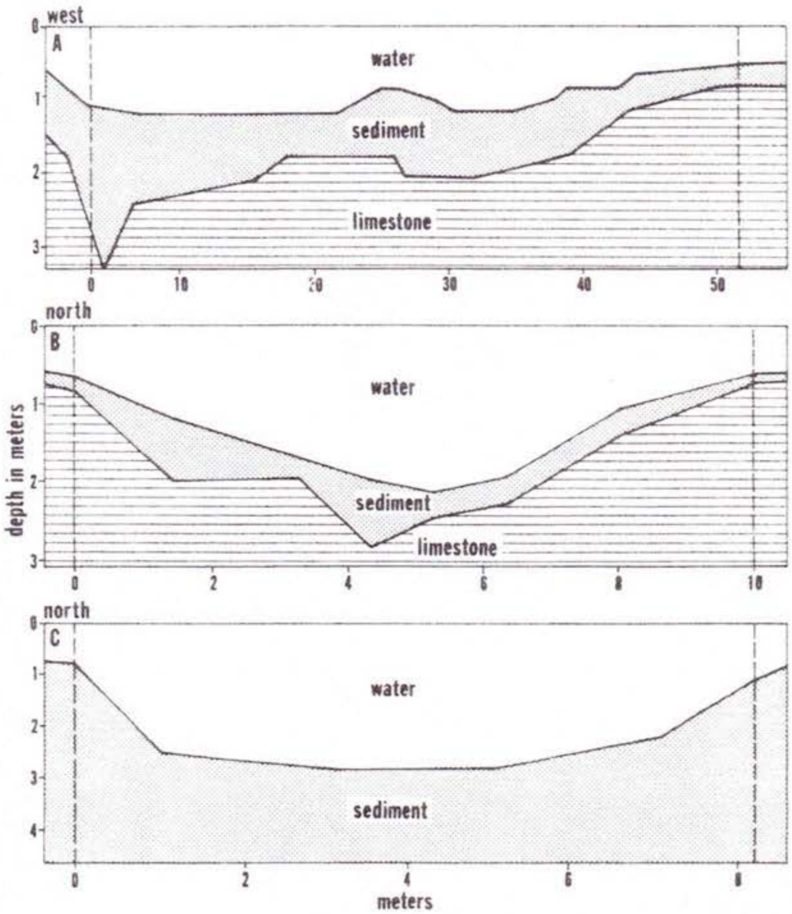

FIG. 6. Representative morphometric transects of 3 types of alligator ponds. Top: cypress pond (study pond). Center: rockland pond. Bottom: peatland pond. Vertical scales exaggerated; vertical dotted lines indicate edge of the pond as determined by plant zonation.

1961). Peatland ponds are characteristic of the northern Everglades, but are also found in wet prairies in the Big Cypress Swamp.

Ponds of all types are maintained by the American alligator (*Alligator mississippiensis*) (Kushlan, 1974a). The alligator's activity arrests hydrarch succession by maintaining pond depth and inhibiting encroachment by both peripheral emergent plants and open water submerged plants. It does this by digging, especially in the dry season, and by day-to-day movements that uproot plants. Droughts encourage the encroachment of rooted plants in drying ponds by permitting seedling establishment and rhizome sprouting; the alligator's activity at this time is especially important. Thus, the existence of ponds and their morphometry depend on the presence of alligators and on maintenance of water levels (Kushlan, 1974a).

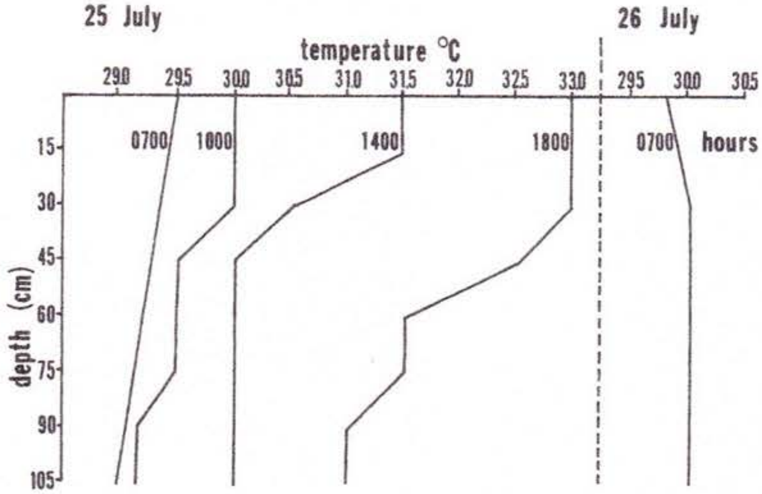

FIG. 7. Variation in the vertical temperature profile of the pond on 25-26 July 1970.

TEMPERATURE—Although the alligator pond is relatively shallow, water temperature was seldom uniform from surface to bottom (Fig. 7). Heating was primarily from the surface and apparently lacked any contribution by bottom absorption or convection. A decided lag in heating existed in the deeper water even though the depth at the sampling site was only 1 m. As expected, surface temperature fluctuated more than that of the bottom (3.5 C as compared to 2.0 C in Fig. 7). Characteristically, the total diurnal variation was not great. Even during periods of relatively low temperature, the alligator pond showed significant resistance to cooling over a diurnal period.

Seasonally, water temperature was lowest in November through January (winter) and highest in June through August (summer). Weather and atmospheric conditions are also of considerable importance in determining the thermal character of alligator ponds because the amount of energy impinging on the pond's surface is directly related to the amount of sunlight and therefore to time of day and the amount of overcast. Fig. 8 is a 54-hr series of temperature measurements that demonstrate the effect of atmospheric conditions. The first day of measurement was continuously overcast with heavy precipitation totaling 9.5 cm. Water temperature remained unchanged at 21 C during this time. The second day was rainless but heavily overcast. The temperature reached a maximum of 26 C at an unusually late hour of 2100. The third day was clear and the diurnal temperature variation showed a typical pattern. The densely shaded cypress swamp adjacent to the pond had lower temperatures than did the open pond (Fig. 8).

Vegetation also affected water temperature in the alligator pond (Fig. 9). On 25 July 1970 when little submerged vegetation was present, the temperature profile in the central area had a vertical range of only 2°C. For much of the

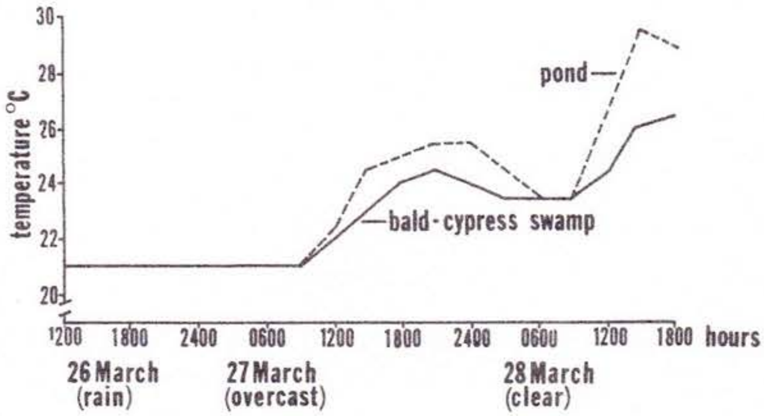

FIG. 8. Variation in water temperature in the pond and in adjacent cypress swamp on successive rainy, overcast, and clear days, 26-28 March 1970.

year, however, the dense growth of naiad occurring in the central area of the pond had a dampening effect on mixing of the water. On 22 March 1969, when all but about 10 m^2 of the central area was covered with naiad, there was a vertical temperature differential of 5 C in only 50 cm of water in the submerged zone. The emergent vegetation also had a significant effect (Fig. 9). Surface temperature was highest at the interface of the emergent and submerged zones. At that point the vertical temperature differential was 7C in 60 cm of water, equivalent to a thermal gradient of 12 C/m. This temperature differential resulted from the dampening effect of both emergent and submerged vegetation, which decreased the transfer of radiant energy to the bottom waters. In addition, the effect of wind was considerably lessened by the pond vegetation and surrounding trees. Lack of mixing had important effects on the distribution of dissolved gases and other chemical constituents.

PHYSICO-CHEMICAL CHARACTERISTICS—Seasonal differences in many of the chemical features were associated with the low water period that normally occurs in winter and early spring and the high water period of summer and fall. Typically many salts and metals were present in greater amounts, because of concentration, during the lower water period and decreased during the wet season because of dilution. Substances such as dissolved oxygen and free carbon dioxide, as well as pH, that were subject to diurnal change fluctuated widely depending on the density of aquatic plants and on the rates of decomposition and community metabolism. In a 3 wk period during and following the complete fish kill, lasting 14-24 May 1970, the conductivity, turbidity, color, concentrations of metals and inorganic salts, total hardness, total alkalinity, total organic matter and free carbon dioxide increased greatly. The amounts of these substances tended to return to usual levels about a month after the fish kill.

Because of such fluctuations, it is not always easy to establish a base or usual level for some of the chemical properties of the pond. Certainly samples taken

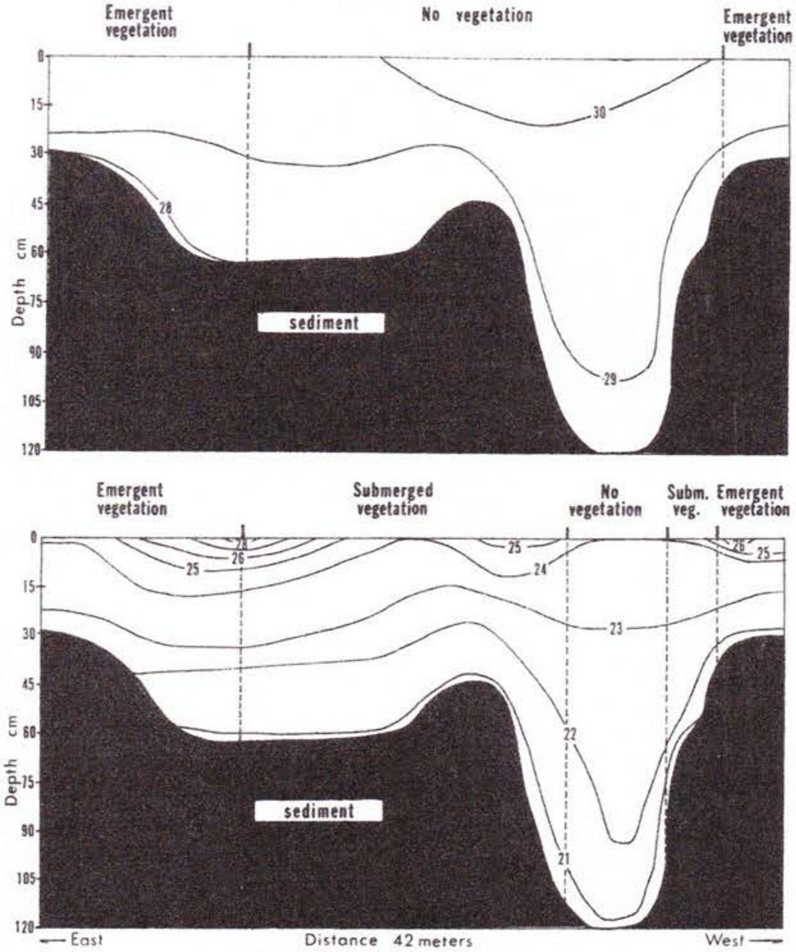

FIG. 9. Thermal contours (C) of the pond on 25 July 1970 when no submerged vegetation was present and 22 March 1969 when submerged vegetation was present.

during the fish kill were unrepresentative of the year round limnological characteristics of the pond. Table 1 shows extensive analyses of pond water that may be taken as representative of the seasonal variation of chemical characteristics of the pond during high and low water.

Dissolved Oxygen: Except for the period of the fish kill, the amount of oxygen measured in surface waters during daytime hours over the 4-yr period ranged 0.39 ppm (5% saturation)-18.6 ppm (214% saturation). Afternoon dissolved oxygen data for 3 widely spaced samples taken at low water levels are in Table 2. The not atypical supersaturation of water is notable. These data show an apparent correlation between high fish densities and low oxygen levels during the dry season. The dissolved oxygen encountered generally ranged from 2-5 ppm, although both higher and lower values were not uncommon.

TABLE 1. Levels of physico-chemical parameters in the pond during low and high water levels. Dashes indicate measurements that were not made.

Item	Low water 22 April 1969	High water 16 July 1969	Low water 11 May 1970
Relative water stage (cm)	89.1	122.1	90.0
Time (hrs)	1530	1300	1500
Water temperature (C)	30	32	30
Turbidity (JTU)	15.0	8.8	5
Color (Pl-Co units)	40	20	20
Oxygen (ppm)	11.60	7.20	3.7
Oxygen (% saturation)	150	97	49
pH	7.8	7.8	7.4
Conductivity (μmho/cm^2 @ 25 C)	400	208	355
Chloride (ppm)	29	11	25
Alkalinity (ppm as H_2CO_3)	180	110	162
Hardness (ppm as $CaCO_3$)	152	92	174
Calcium (ppm)	56	34	62
Magnesium (ppm)	2.9	1.6	4.4
Total dissolved solids (residue @ 180 C)	240	138	–
Total organic matter (ppm)	54	–	16.2
Floride (ppm)	0.2	0.2	–
Iron (ppm)	0.22	0.05	0.0
Potassium (ppm)	1.9	0.6	–
Silica (ppm SiO_2)	2.2	3.2	0.76
Sodium (ppm)	20.0	7.6	–
Strontium (ppm)	–	0.35	–
Sulfate (ppm)	0.8	0.0	–
Tannin, lignin (ppm)	1.0	0.0	–
Nitrate (ppm)	0.1	0.1	0.022
Nitrite (ppm)	0.01	0.01	0.017
Ammonia (ppm)	0.02	0.02	–
Organic nitrogen (ppm)	0.87	0.87	–
Phosphorous (ppm PO_4)	0.08	0.00	0.08
Aluminum (ppm)	0.19	0.07	–
Arsenic (ppm)	0.00	0.01	–
Boron (ppm)	0.05	0.02	–
Bromide (ppm)	0.00	0.00	–
Chromium (ppm)	0.00	0.00	–
Copper (ppm)	0.00	0.01	–
Iodide (ppm)	0.00	0.00	–
Lead (ppm)	0.00	0.00	–
Lithium (ppm)	0.00	0.00	–
Manganese (ppm)	0.00	0.00	–
Zinc (ppm)	0.02	0.01	–
Phenolic material (ppm)	0.003	–	–

TABLE 2. Dissolved oxygen in alligator pond on dates when relative water level was approximately 90 cm.

Date	Sample time (hours)	Water level (cm)	Oxygen (ppm)	Temperature C	% Saturation oxygen	Fish density
22 April 1969	1600	89.1	11.6	30	150	Low
9 May 1970	1400	95.2	4.5	30	59	High
16 December 1970	1500	93.3	14.0	24	169	Low

Most of the oxygen in this pond is produced by photosynthetic activity of phytoplankton, periphyton, and especially submerged aquatic plants. Because of this, as is generally true elsewhere in south Florida, the diurnal fluctuation of dissolved oxygen in this pond was often very great. The maximum amounts present in the afternoon were usually relatively high and the amounts present at daybreak were usually relatively low. On a sunny day in early spring when submerged vegetation was abundant, it was not unusual to find dissolved oxygen increasing from a trace at 0600 hr to 150% saturation or more by 1500 hr. Particularly when naiad was abundant in the alligator pond, high oxygen levels were attained, but great diurnal fluctuations also occurred. At such times the daily minimum was often 1 ppm or less. The 5 highest recorded values of dissolved oxygen in the pond were 18.6 ppm (214% sat.) on 26 February 1972, 15.0 ppm (186% sat.) on 25 January 1971, 14.0 ppm (169% sat.) on 16 December 1970, 13.5 ppm (153% sat.) on 13 February 1972, and 11.6 ppm (150% sat.) on 22 April 1969.

The effects of sunny weather, rain, and very cloudy weather, and concomitant changes in rates of community metabolism and decomposition, on diurnal dissolved oxygen fluctuation were often striking. This is shown in Fig. 10. During heavy rains the diurnal fluctuation was small, reaching only 54% of saturation (3.4 ppm). Overcast days without rainfall and clear days reached progressively higher levels with greater range of fluctuation. Under these conditions the pond became supersaturated for several hours during the day.

When submerged plants were sparse, the diurnal fluctuation often was appreciable even though the maximum and minimum amounts were fairly low. Typical diurnal variation of oxygen with water depth is in Fig. 11. At 0700 hr on 25 July 1970 the dissolved oxygen at the surface in the open water of the pond was 1.55 ppm, and it was only .50 ppm less near the bottom at a depth of 120 cm. Additional measurements during the day revealed that by 1800 hr the oxygen increased to 4.20 ppm at the surface compared to 2.20 ppm at the bottom. At 0700 hr the following day the difference in oxygen at the surface and bottom was again very small. However, the bottom water then had increased to 1.70 ppm from 1.05 ppm 24 hr earlier. At this time, the surface water contained 2.00 ppm of oxygen compared to 1.55 ppm 24 hr earlier, but it had lost 2.20 ppm of dissolved oxygen from the maximum amount present at 1800 hr the day before.

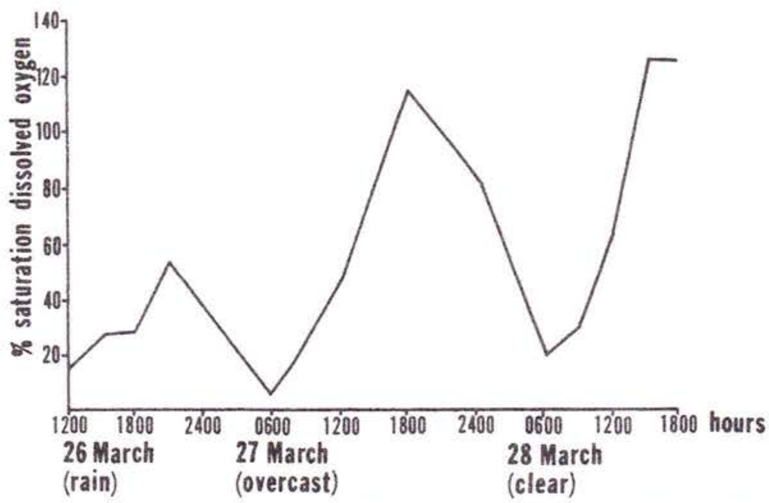

FIG. 10. Variation of dissolved oxygen in the pond on successive rainy, overcast, and clear days, 26-28 March 1970.

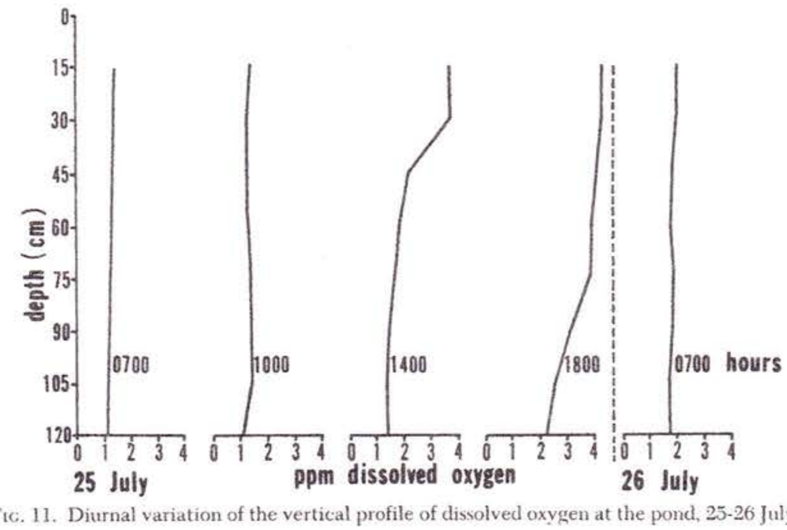

FIG. 11. Diurnal variation of the vertical profile of dissolved oxygen at the pond, 25-26 July 1970.

The fish kill of 14-24 May 1970 was caused by anoxia resulting from a combination of lowering water level, breakdown of the formerly luxurious naiad growth, high densities of fish, high rates of respiration and decomposition, and high water temperature (29-20°C). It was apparent several days before fish began to die that oxygen production was lagging behind oxygen demand and that free carbon dioxide was increasing. Caged fish, including largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and spotted sunfish (*L. punctatus*), were placed in the emergent plant zone the night of 5-6 May 1970 and all died, evidence that prolonged anoxic conditions occurred during the night. On 9 May at 1400 hr the oxygen was 2.14 ppm in the emergent plant zone and 4.50 ppm (59% sat.) in the central open water area (Table 3). Three days before the fish kill began the oxygen at 1500 hr was 3.70 ppm at a water temperature of 30 C.

Although the low maximum and minimum oxygen levels during the period preceeding the beginning of fish mortality were within the usual range encountered in the pond, the cumulative stressful effect was such that fish began to die at about 0800 hr on 14 May 1970 and deaths continued until 1100 hr. At 1000 hr on that day dissolved oxygen was 1.3 ppm and the free carbon dioxide was 11.2 ppm. By the end of the day the water mass deeper than about 1 cm of depth was devoid of oxygen, a condition that persisted until 27 May. The distribution of dissolved oxygen between 5 and 21 May is in Table 3. The maximum amounts of oxygen in the open water of the pond before and after the fish kill of 1970 are in Fig. 12.

Free Carbon Dioxide, pH and Total Alkalinity: Free carbon dioxide was usually present in surface waters in amounts ranging from a trace to 19 ppm although quantities most commonly encountered ranged 3-10 ppm. This is a condition similar to many other freshwater environments of south Florida. Considerable variation existed seasonally and diurnally and the quantities of this gas tended to reflect the rates of decomposition and community respiration. Free carbon dioxide was absent only on those few occasions when photosynthetic activity was great enough to utilize all of the free gas present. During the fish kill the very large quantities present in surface water ranged 10.2-37.6 ppm (Table 3) and one sample of water taken from the bottom on 17 May 1970 contained 98 ppm of CO_2.

Measurements of pH were made throughout the study period and thoroughly aerated water samples always gave readings of 8.2-8.3 (reserve pH). The *in situ* pH of the pond waters, largely determined by the considerable amounts of free CO_2 present, was usually 7.1-7.8, although on a few occasions when photosynthetic activity was very great, the scale reading was 8 or above and reached 8.4. Because the water was highly buffered and ordinarily contained appreciable amounts of free CO_2, diurnal changes were usually not great, although on one occasion when a luxuriant growth of naiad was present, the pH changed 7.6 to 8.2 in a period of 4 hr between mid-morning and mid-afternoon. This magnitude of change was not unusual under such conditions and even greater rates of change of pH have been measured for other heavily vegetated waters

TABLE 3. Temperature and concentrations of oxygen and carbon dioxide in pond during May, 1970.

Date:	5 May	9 May		11 May	14 May			15 May		17 May			21 May
Hours:	1400	1000	1400	1400	1000	1500	2000	0500	1100	1100	1400	1900	1400
Emergent zone													
Temperature (°C)													
-3 cm			29		29	29	28	28	29	30	32	29	
O_2 (ppm)-1 cm								0.24	0.35	0.00	0.20	0.00	
O_2 (ppm)-6 cm			2.14		0.76	0.56	0.00	0.00	0.00	0.00	0.00	0.00	
CO_2 (ppm)-1 cm								17.8		34.6	18.2		
CO_2 (ppm)-6 cm							15.9	23.8		34.6			
Central area													
Temperature (°C)													
-3 cm	31	28	30	30	29	30	28	28	30	30	32	28	31
O_2 (ppm)-1 cm						3.00	2.20	0.22	0.41	0.05	0.38	0.17	0.50
O_2 (ppm)-6 cm	5.24	2.32	4.50	3.70	1.30	2.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2 (ppm)-1 cm								24.7		16.8	10.2	37.6	
CO_2 (ppm)-6 cm					11.2		20.8	32.2		30.0			

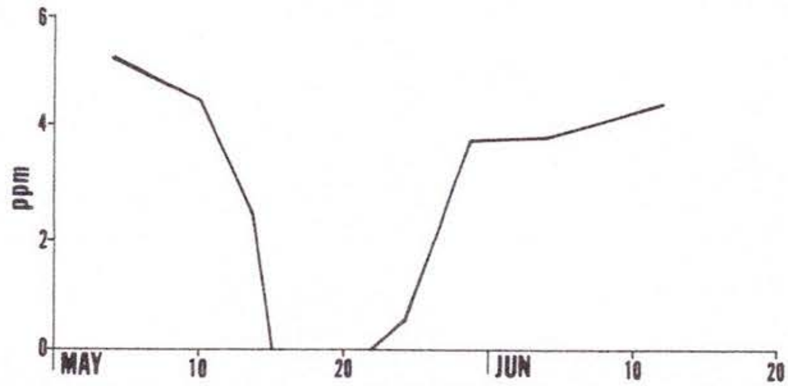

FIG. 12. Fluctuation of dissolved oxygen May-June 1970. All samples were taken at 1400-1500 hr at 6 cm depth.

in south Florida. During the fish kill, when the free carbon dioxide quantities exceeded 30 ppm, the *in situ* pH was as low as 6.6 in surface waters.

Total alkalinity, related as it is to free CO_2 and pH, generally ranged between 130-230 ppm. During most of the sampling period of 1971-72 the values were close to 200 ppm (169-228 ppm). In 1972-73 the values were less (137-214 ppm). In general the total alkalinity was lowest during the high water period of the summer when readings varied from 100-180 ppm and higher during the low water period of late winter and spring when it varied from 180-242 ppm. Changes from one sampling period to another were usually less than 15 ppm but sometimes were as great as 20 to 40 units in one month. During and immediately after the fish kill total alkalinity rose drastically to a maximum of 441 ppm on 21 May 1970. During late May it rapidly declined to 262 ppm. By early June the total alkalinity had dropped to 147 ppm and a slow decline continued into July when a measurement of 89 ppm, the lowest on record, was obtained. Subsequently, the alkalinity began to increase and soon rose to more usual levels above 100 ppm.

Hardness, Calcium and Magnesium: Thirty-eight measurements of EDTA hardness made during the 4 yr ranged 94-235 ppm. The highest value was measured during the latter part of the fish kill period and the lowest of 16 July 1970, 52 days after the fish kill ended. During 1971-73 hardness ranged 142-234 ppm with the highest value occurring on 19 December 1971 and the lowest on 13 January 1973. The amounts usually encountered ranged 150-200 ppm. No obvious seasonal pattern was evident, both high and low amounts were found in winter and spring. However, in general the amounts present during summer when water levels were high were lower than at other times of year. Fluctuations in hardness followed those of total alkalinity rather closely.

Calcium ion concentration ranged 34-86 ppm. Again the highest measurements were during the latter part of the fish kill and the lowest about 2 mo afterwards. From 1971 to 1973, calcium varied 53-83 ppm, with a mean of 71. The fluctuations of calcium were directly correlated with EDTA hardness.

Magnesium was measured in 1969 and from 1970 to early 1971, the amounts ranging 1.60-5.12 ppm, with a mean of 3.40. The greatest amounts were found during the latter part of the fish kill period and the lowest about 2 mo afterwards.

Calcium-magnesium ratios ranged 14.1-26.3 ppm with an average of 18.1. The highest values occurred in May 1970 immediately following the fish kill and the lowest just before and in July following that event. No distinct seasonal pattern in the relative amounts of these ions was discernible.

Chloride and Sulfate: Chloride varied from a high of 60 ppm on 21 May 1970 to a low of 5 ppm during high water levels in 1972. The amounts usually encountered ranged 11-29 ppm. The greatest quantity was present when dead fish were decomposing in the pond and lesser quantities were present during periods of high water. The amounts occurring in this pond are typical of those usually found in inland fresh waters in south Florida.

Sulfate usually ranged 0.0-8 ppm. During the fish kill it rose to 14, 19, and 34 ppm on 19, 21 and 24 May 1970, respectively. This was a result of the decay of dead fish. By 27 May the sulfate concentration dropped to 6 ppm and declined further during June and July of that year.

Phosphate, Nitrate and Nitrite: During the fish kill, total phosphate was present in unusually large quantities, reaching a high of 36 ppm on 21 May 1970. During this time it was always higher than 10 ppm due to the decay of fish and the breakdown of the plankton bloom that followed. The quantities present preceeding and during the 2 mo following the fish kill, ranging 0.15-0.90 ppm, are more representative of usual conditions in the pond.

Dissolved inorganic phosphate was also present in large quantities during the fish kill, reaching a high of 13 ppm on 19 May 1970. The amounts present before and in the June-August period following the fish kill, ranged from 0.10-0.99 ppm.

Between 3 June and 20 August 1970, 11 measurements of nitrate were made; the amounts ranged 0.005-0.10 ppm with an average of 0.046. These very small amounts are in sharp contrast to conditions during the fish kill when nitrate was elevated to almost 2 ppm by the decomposition of organic matter.

Nitrite also reached a high value (0.12 ppm) at the end of the fish kill. During that event both nitrate and nitrite peaked on 17 May, subsided, then peaked again on 27 May. On the first of these dates the decay of fish was at a maximum and on the second date the intense plankton bloom was deteriorating. Before and after the fish kill the amounts varied 0.005-0.02 ppm.

Other Chemicals: Silica, measured periodically from 1969-1972, showed considerable fluctuation; the highest value (4.2 ppm) occurred on 27 June 1970. Amounts ranging 1.3-2.6 ppm during the fish kill may have been caused in part by release of silcate from the sediment by reducing conditions. Quantities before and after the fish kill ranged 0.08-3.2 ppm.

The 17 measurements of manganese, taken in 1969 and 1970, ranged 0.0-1.1 ppm, with the highest value obtained in May 1970. Decomposition of fish and plankton and resultant anaerobic conditions may have caused release of manganese from the sediment.

Iron was present in measurable amounts only on a few dates. On 22 April 1969 the amount was 0.22 ppm and on 16 July 1969, 0.05 ppm. During the fish kill, the presence of iron on 19 May (0.01 ppm) and 21 May 1970 (0.18 ppm) may have been the result of release of ferrous ions into the water from the sediment because of oxygen depletion.

Other inorganic and organic substances were measured only a few times, and the results in Table 1 are representative.

Specific Conductance: Specific conductance fluctuated seasonally, being highest during low water conditions and lowest during periods of high water. In late summer and fall measurements usually ranged 184-290 μmho/cm^2 at 25 C. During the low water period of late winter and spring, conductivity ranged from 300-540. On 13 occasions, measurements were taken at the surface and at the bottom; in all cases the amounts were similar. Although fluctuations as great as 90 units occurred from one sampling interval to the next, there were periods when little change occurred. In 1972, from late February to May, conductance remained virtually constant, ranging 396-440. During the fish kill, conductivity was 495 at the beginning, 615 at the end, and reached a peak of 998 on 21 May 1970. After June it dropped markedly and ranged 184-337 during June, July and August 1970.

Turbidity and Color: The pond was relatively clear for most of the summer. Turbidity, during ordinary conditions, ranged from 5 JTU in high water to 15 JTU during low water. During the fish kill and plankton bloom, the turbidity increased drastically to a high of 165 JTU. Following the fish kill and subsidence of the plankton bloom, the turbidity fell to usual levels.

Color usually ranged from 10 color units during high water to 40 units during low water. The hue of the water under usual conditions was slightly brown. During the fish kill and plankton bloom, total color increased to levels of 85-380 units, a condition which lasted until 2 wk after the fish kill when the color measured only 20 units. During the fish kill, centrifuged water still had color ranging 30-210 units. Under such conditions the hue of the pond water was bright green.

Organic Matter: Amounts of dissolved organic matter in the pond were usually very high even compared to the elevated characteristic of most south Florida waters (Gonyea and Hunt, 1970). At the height of decomposition during the fish kill, 147 ppm of organic matter was measured. The smallest quantity, (12.3 ppm), was measured on 27 June 1970 about 1 mo after the fish kill. From 5 June to 16 December 1970 the quantities of organic matter in 12 samples ranged 12.3-61.5 with an average of 32.6 ppm. During 1971-1973, 27 measurements ranged 23.9-56.8 ppm with a mean of 36.5. During this interval the variation from one sampling period to the next was usually less than 10 ppm but was sometimes as great as 18 ppm. The amounts were generally greater during January to March than at other times of the year.

Pesticides: Samples of water, sediment and fish were collected in April and July, 1969 and analyzed for chlorinated hydrocarbon insecticides (Table 4). The concentrations found in sediments obtained in April were higher than those found in samples collected that month in other parts of the Everglades and Big

TABLE 4. Chlorinated hydrocarbon insecticides in water, sediment, and fish from alligator pond.

	DDD	DDE	DDT	Dieldren
April 1969				
Water (μg/1)	0.00	0.00	0.01	0.00
Sediment (μg/kg)	3.69	4.74	7.96	0.00
July 1969				
Water (μg/1)	0.00	0.00	0.00	0.00
Sediment (μg/kg)	0.00	0.00	8.30	0.00
Fish (μg/kg)				
Lepisosteus platyrhincus	21.45	35.68	101.10	3.27
Lepomis microlophus	0.00	46.77	6.00	0.00
Ictalurus natalis	0.00	22.04	0.00	0.00
Poecilia latipinna	0.00	18.94	0.00	0.00

Cypress Swamp by McPherson (1969). In general, however, the levels of these compounds fell within the usual range found in southern Florida (A. Higer, pers. comm.).

The pond was remote from the nearest road, habitations, or areas where pesticides were being used. Contamination presumably was the result of transport of these substances by wind and rainfall. Movement of surface waters and of fish and other animals into the pond from distant areas where pesticides were present may also have had an effect.

The amounts of pesticides in the sediment indicate that some accumulation has taken place. The rather high levels of 4 compounds found in spotted gar (*Lepisosteus platyrhincus*) and the incidence of DDE in 3 other fish species suggested that these substances were cycled through food chains resulting in accumulations in carnivorous fish. There is a distinct possibility that alligator ponds may serve as ecosystem sinks for pesticides as well as other persistent exotic substances.

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