Aquatic Biology of South Florida Limestone Excavation Lakes[1]

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Abstract: Although mitigation is now required on excavation lakes resulting from limestone mining in South Florida, little baseline information exists on which to base mitigation recommendations. For this study, 8 representative limestone excavation lakes in Dade County, Florida, were sampled during 1981–82 to measure selected limnological parameters. There was little within-lake variation in water quality but substantial differences in means and ranges among lakes. Depths ranged from 3.2 to 15.2 m and surface areas, 8 to 44 ha. Maximum water temperature observed was 33° C and the minimum 19° C. Surface dissolved oxygen was 7.5–8.3 mg/liter and 2.0–7.5 mg/liter at lake bottoms. Other ranges measured included alkalinity 72–170 mg/liter, conductivity 221 to 1,058 μmhos, pH 7.2 to 8.2, and transparency 1.4 to 5.6 m. Mean values for total phosphorus (7.1 to 12.3 mg/m^3) varied greatly by lake. No correlation was found among the mean depth, age, or surface area of each lake and the productivity indicators just cited. The age of each lake was not correlated with density or numbers of macroinvertebrate families. However, the mean depth was negatively correlated with the number of macroinvertebrate/m^2 and the number of families. Mean number of macroinvertebrates ranged from 218 to 2,704/m^2 with dipterans the most abundant. Largemouth bass (*Micropterus salmoides*), redear sunfish (*Lepomis microlophus*), bluegill (*L. macrochirus*), and mosquitofish) (*Gambusia affinis*) were common to all lakes although largemouth bass were generally small, and only 12% of those captured exceeded 300 mm in length. The low productivity and poor biological diversity suggests the potential for fisheries enhancement by such methods as addition of littoral areas, fish shelters, and return of the organic overburden to the lakes following mining.

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The mining of limestone in South Florida has formed hundreds of water-filled excavation lakes over the past 40 years. From 1978 aerial photographs of Dade County, Florida, more than 120 km^2 of limestone excavation lakes were located which ranged in size from <1 ha to <40 ha. These excavations are typically box-shaped, with nearly perpendicular sides, little or no littoral areas, and mean depths as great as 20 m. Organic soils are usually removed during the mining process and a limestone berm surrounding the lake is often left in place after mining (Edgerton 1974). Existing water-filled excavations are thought to have little value as productive fish and wildlife habitats. For this reason, mitigation is now required on future rock-mining operations to offset the loss of wetlands impacted by mining (U.S. Army Corps of Eng. 1981, 1982; Hudy and Gregory 1983). However, state and federal agencies which review rock-mining permits have little information on the aquatic biology of these impoundments on which to base mitigation recommendations. Also, management biologists and aquaculturists lack baseline data to properly evaluate the fisheries potential of these lakes.

Water quality and selected biological parameters were evaluated in this study on 8 representative South Florida limestone excavation lakes to establish a data base for comparison to future excavation lakes which will undergo various mitigation strategies.

Methods

Study Area

Eight limestone excavation lakes were selected through the use of topographical maps, aerial photographs, and site visits. The selected sites are thought to best represent, within the scope of the study, the broad range of age, size, depth, and current use of rock-mining areas in South Florida. The study lakes were 9 to 35 years old, 8 to 44 ha in surface area, and 3.2 to 15.2 m in mean depth (Table 1).

Water Quality

Water samples were taken bimonthly from May 1981 to May 1982. At each lake, water samples were collected 0.5 m below the surface at 3 random mid-lake locations. Water samples were collected in acid-washed polyethylene bottles and stored on ice for later analysis of total phosphorus, total nitrogen, total alkalinity, and total hardness (Am. Public Health Assoc. 1976, Hach Chem Co. 1975). A Yellow Springs Instrument Co. (YSI) Model 57 oxygen-

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Table 1. Location, age, and morphometric features of 8 limestone excavations in Dade County, Florida.

Lake	Age (yrs)	Surface area (ha)	Depth (m)		Lake bottom (% coverage by vegetation)
			mean	maximum	
1	11	44	15.2	18.3	5
2	11	41	12.3	17.7	5
3	18	37	12.9	14.6	5
4	25	15	6.7	8.3	10–20
5	9	8	8.7	11.3	70–80
6	35	11	3.2	4.6	90–100
7	28	31	3.7	5.5	90–100
8	9	12	6.4	8.2	80–90

temperature meter[4] was used for oxygen and temperature measurements at depth intervals of 1 m. Conductivity was determined 1 m below the surface with a YSI Model 33 conductivity meter. Water transparency was determined with a Secchi disk (20 cm in diameter) and pH was measured with an Orìon model 039410 pH meter. A measured volume of water collected 0.5 below the surface was filtered through a glass fiber 0.3 μm filter for chlorophyll *a* analysis. The filter was blotted dry, stored in desiccant, and frozen until later analysis (Am. Public Health Assoc. 1976).

Biological Parameters

Macroinvertebrates.—Macroinvertebrates were collected using an Ekman dredge (152 × 152 mm) during December 1981 and February and May 1982. Approximately 13 to 15 samples were taken in each lake. Bottom samples were strained through a United States Standard No. 30 sieve and the remaining material preserved in 70% ethyl alcohol. Most macroinvertebrates were identified to family.

Fisheries.—Floating and sinking monofilament experimental gill nets and/or electrofishing (direct current) at night were used to collect fishes from each lake during July 1981 and February 1982. Gill nets were either 91 × 1.8 m with bar mesh sizes of 2.5, 3.8, 5.1, and 6.4 cm or 38 × 2.4 m with bar mesh sizes of 1.9, 2.5, 3.8, 5.1, and 6.4 cm. In addition, underwater transects utilizing scuba were used during July 1981 to index fish populations (Northcote and Wilkie 1963, Werner et al. 1977). Two scuba divers simultaneously swam underwater transects, each 50 m in length, and separately identified and recorded all fish greater than 150 mm in length.

[4] References to trade names do not imply government endorsement of commercial products.

Table 2. Mean and range of selected water quality parameters of 8 limestone excavations in Dade County, Florida. Data collected bimonthly, May 1981–May 1982.

Lake	D.O. (mg/liter) Surface	D.O. (mg/liter) Bottom	Temperature (°C) Surface	Temperature (°C) Bottom	Total phosphorus (mg/m^3)	Total nitrogen (mg/m^3)	Chlorophyll *a*[2] (mg/m^3)	Alkalinity (mg/liter)	Hardness (mg/liter)	pH	Conductivity (µmhos)	Secchi disk (m)
1	7.6 (6.8–8.7)	6.0 (3.5–7.8)	26 (21–30)	24 (20–27)	7.4 (4–12)	260 (200–350)	0.5 (0.3–0.7)	125 (111–141)	230 (206–252)	7.6 (7.3–7.8)	1,058 (970–1,150)	2.7 (1.9–3.8)
2	7.5 (6.5–8.9)	2.0 (0.0–6.2)	27 (21–31)	21 (19–25)	7.1 (4–10)	942 (780–1,070)	2.4 (1.7–3.3)	170 (151–181)	188 (170–203)	7.7 (7.4–8.2)	477 (410–510)	2.2 (1.8–2.4)
3	7.5 (7.0–7.9)	4.1 (0.2–7.0)	26 (20–31)	23 (19–25)	9.1 (5–14)	727 (690–770)	1.2 (0.6–2.4)	129 (113–148)	147 (132–161)	7.6 (7.4–8.2)	412 (400–435)	1.8 (1.4–2.8)
4	7.6 (5.2–8.1)	5.6 (0.1–7.3)	27 (21–31)	26 (20–30)	10.9 (6–23)	586 (540–720)	3.0 (1.4–4.4)	112 (92–130)	161 (194–228)	7.6 (7.2–8.1)	1,004 (850–1,100)	3.4 (1.8–5.6)
5	7.8 (6.5–9.5)	5.5 (0.2–7.0)	27 (21–32)	25 (20–30)	10.5 (7–15)	379 (290–440)	1.8 (0.8–2.7)	117 (106–127)	189 (170–202)	7.5 (7.3–7.8)	824 (710–920)	3.7 (2.3–5.2)
6	8.3 (7.1–9.4)	7.5 (4.2–9.2)	27 (21–33)	27 (20–32)	10.0 (7–15)	761 (690–830)	1.2 (0.8–2.2)	80 (72–89)	87 (77–104)	7.7 (7.5–8.1)	221 (195–260)	4.0 (3.6–b)
7	7.7 (7.0–8.7)	7.1 (6.0–8.5)	27 (21–33)	27 (21–33)	12.3 (6–17)	793 (770–810)	2.7 (1.5–3.9)	72 (58–81)	82 (65–96)	7.8 (7.4–8.1)	260 (250–290)	3.3 (2.1–b)
8	8.0 (6.0–10.3)	5.7 (0.5–8.0)	26 (20–31)	26 (19–30)	11.8 (8–18)	342 (300–450)	4.2 (1.7–5.7)	88 (49–113)	122 (85–157)	7.7 (7.2–8.2)	432 (395–480)	3.3 (1.9–4.8)

[1] See Table 1 for lake descriptions.
[2] No phaeothytin correction made.
[b] Lake bottom.

Results

Water Quality

Annual variation in most water quality characteristics within a particular lake was minimal; however, substantial differences occurred in the means and ranges among lakes (Table 2). Water quality values for lakes in this study were similar to those reported for other south Florida limestone excavation lakes (Table 3).

In this study, differences in water temperature and dissolved oxygen varied by lake, depth, and month. Differences between surface and bottom water temperature were never greater than 3° C in lakes with mean depths less than 8 m, where lakes greater than 8 m in mean depth exhibited differences of 8°–10° C in May through September (Figs. 1, 2). The maximum observed water temperature was 33° C and the minimum, 19° C (Table 2). Mean dissolved oxygen values ranged from 7.5 to 8.3 mg/liter at the lake surfaces and 2.0 to 7.5 mg/liter at the lake bottoms. Dissolved oxygen concentrations were seldom below 5 mg/liter except during July through September and then only at water depths greater than 7 m (Figs. 3, 4).

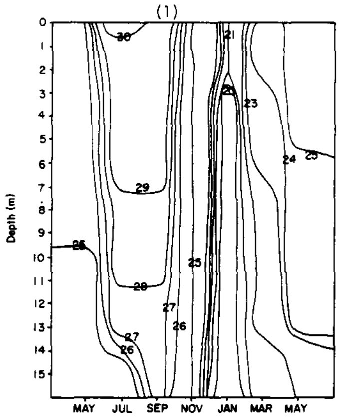
There were annual within-lake variations in total alkalinity and total hardness but variability was lake specific with no common pattern. The range of means was 72-170 mg/liter for alkalinity and 28-230 mg/liter for hardness (Table 2). The mean pH ranged from 7.5 to 7.8 with the highest bimonthly reading 8.2 and the lowest, 7.2. The range of means for conductivity was 221 to 1,058 mhos with a high bimonthly reading of 1,150 μmhos and a low of 195 μmhos. Maximum transparency was 5.6 m and the minimum 1.4 m; means were 1.8 to 4.0 m.

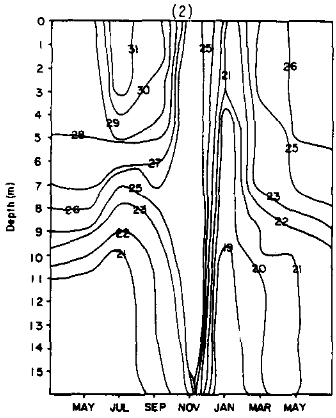
Annual variations within a lake for total phosphorous, total nitrogen, and chlorophyll *a* were lake specific. Mean values for total phosphorus (7.1–12.3 mg/m^3), total nitrogen (260–942 mg/m^3), and chlorophyll *a* (0.5–4.2 mg/m^3) varied greatly by lake; however, all values were within the general trophic classification of oligotrophic or oligotrophic-mesotrophic lakes (Carlson 1977).

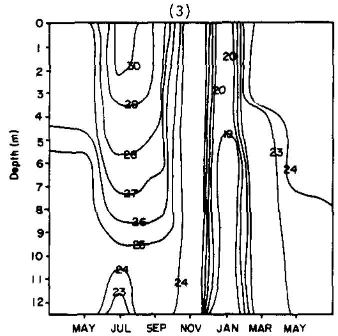
No correlation was found among the mean depth, age, or surface area of each lake and total phosphorus, total nitrogen, or chlorophyll *a* (Spearman's rank correlation, $P \geq 0.05$, Ostle and Mensing 1975). Mean depth was positively correlated, ($P \leq 0.05$) with total alkalinity and total hardness.

Macroinvertebrates

There were significant differences among lakes in the number of macroinvertebrates per square meter (Duncan's multiple range test, $N = 103$, $P \leq 0.05$). The mean number ranged from 218 to 2,704/m^2. Dipterans (Chironomidae, Chaoboridae, and Ceratopogonidae) were the most abundant macroinvertebrates (Table 4). The amphipod, *Hyalella axteca* was the next most







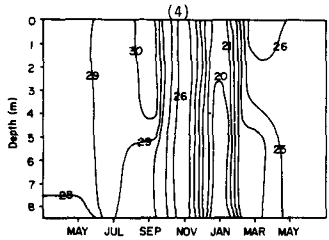
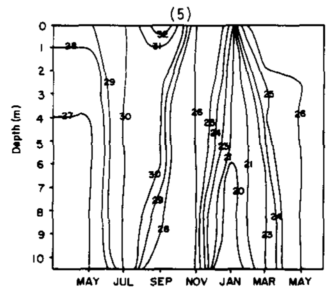
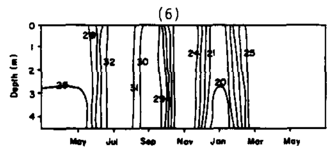
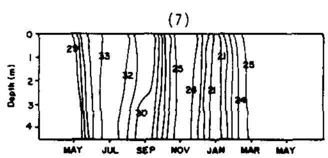


Figure 1. Seasonal variations in water temperature isotherms in limestone excavation Lakes 1–4, Dade County, Florida. Data collected bimonthly May 1981–May 1982.







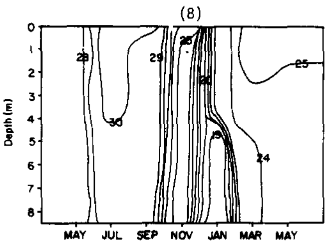


Figure 2. Seasonal variations in water temperature isotherms in limestone excavation Lakes 5–8, Dade County, Florida. Data collected bimonthly May 1981–May 1982.

Table 3. Summary of selected data from water quality studies on limestone excavations in South Florida.

Study	Number of lakes	Sampling frequency (per year)	pH	Conductivity (μmphos)	Alkalinity (mg/liter)	Total nitrogen (mg/m³)	Total phosphorus (mg/m³)	Chlorophyll *a* (mg/m³)
Pope (1967)	2	26	7.8–8.8	NA	32–205	NA	NA	NA
Pope (unpublished, 1976)	124	1	7.0–8.9	105–10,000	54–265	NA	NA	0–65
Rhoads (1969)	1	26	NA	NA	45–109	NA	NA	NA
Beaven and McPherson (1978)	3	1	7.8	535	125	530	30	NA
Environmental Science and Engineering (1979)	4	4–40	6.1–8.4	41–1,700	NA	490–4,010	50–7,980	1.3–44.4
Weinberg et al (1980)	1	10	7.0–8.2	282–457	138–220	610–650	NA	NA
Canfield (1981)	1	3	8.6–9.3	160–173	50–88	566–608	10–28	0.8–9.5
U.S. Army Corps of Engineers (1982)	21	1	NA	270–>8,000	NA	140–4,400	<5–2,180	NA
This study	8	7	7.2–8.2	195–1,150	49–181	200–1,070	4–23	0.3–5.7
Overall	165	1–40	6.1–8.9	41–10,000	32–265	140–4,400	4–7,980	0–65

NA = not applicable.

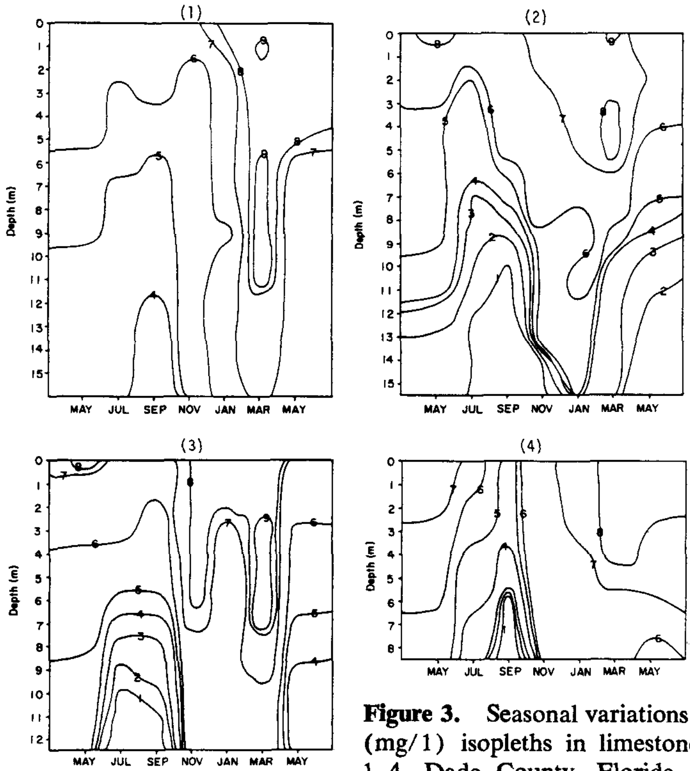


Figure 3. Seasonal variations in dissolved oxygen (mg/1) isopleths in limestone excavation Lakes 1–4, Dade County, Florida. Data collected bi-monthly May 1981–May 1982.

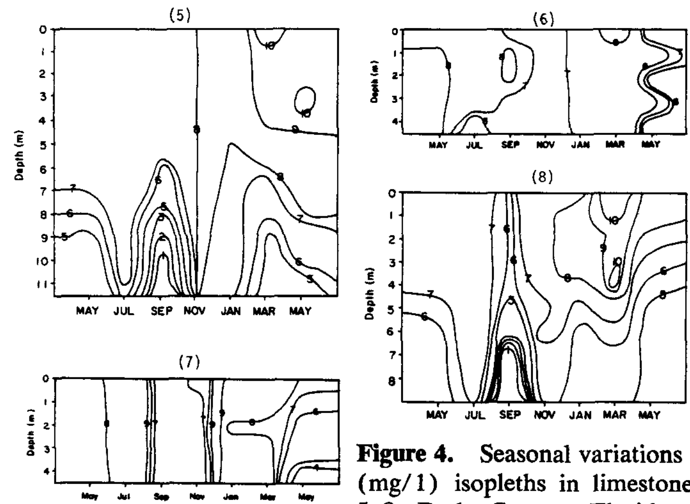


Figure 4. Seasonal variations in dissolved oxygen (mg/1) isopleths in limestone excavation Lakes 5–8, Dade County, Florida. Data collected bi-monthly May 1981–May 1982.

Table 4. Percent composition of each taxon of macroinvertebrates collected from 8 limestone excavations in Dade County, Florida. Samples collected by Ekman dredge in December 1981 and February and May 1982. Numbers of macroinvertebrates per square meter (in parenthesis, in box heading) followed by a common letter in the same row are not significantly different according to Duncan's multiple range test ($P \leq 0.05, N = 103$).

	Lake (see Table 1 for description)							
	1	2	3	4	5	6	7	8
Mean/m^2	(218) w	(869) w,x	(460) w	(1,785) x,y	(4,382) z	(1,591) x	(2,704) y	(1,858) x,y
Taxon								
Insecta								
Diptera								
Chironomidae	93	27	54	70	30	73	50	63
Chaoboridae		71	35	18	69		16	28
Ceratopogonidae	5	T	10	5		20		2
Ephemeroptera								
Caenidae				T		2		T
Odonata								
Libellulidae						T	T	T
Coenagrionidae						T	T	T
Trichoptera								
Polycentropodae	T			T		3	8	T
Crustacea								
Amphipoda								
Talitridae				5		T	21	5
Gastropoda								
Basommatophora								
Planorbidae	T					T	3	
Mesogastropoda								
Pleuroceridae				T				
Arachnida								
Acarina						T		T
Hirudinea		T	T		T	T		T

T = Trace amounts, less than 1%.

abundant, followed by Trichoptera (Polycentropodae), Ephemeroptera (Caenidae) and Odonata (Libellulidae, Coenagrionidae). Leeches (Hirudinea), gastropods (Planorbidae, Pleuroceridae), and water mites (Acarina) were only collected occasionally. The age of each lake was not correlated with the density of macroinvertebrates or the number of families present. However, mean depth of the study lakes was negatively correlated with the number of macroinvertebrates/m^2 and the number of families of macroinvertebrates found in each lake (Spearman's rank correlation, $P \leq 0.05$).

The prawn, *Palaemonetes paludosus,* and crayfish, *Procambarus alleni* were found in several largemouth bass stomachs collected from Lakes 6 and 7 although none appeared in Ekman dredge samples.

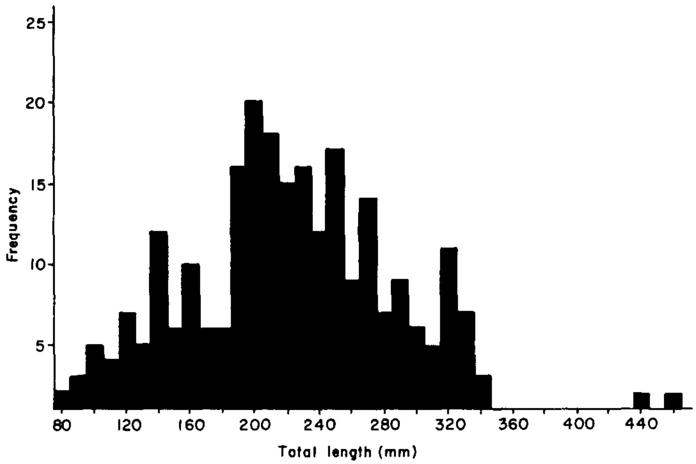


Figure 5. Length frequency of largemouth bass collected in 8 limestone excavation Lakes, Dade County, Florida. Fish collected by electrofishing, gill netting and angling July 1981–February 1982, $N = 224$.

Table 5. Occurrence of fish species collected by experimental gill nets and electrofishing in 8 limestone excavations in Dade County, Florida.

Species	Lake (see Table 1 for description)							
	1	2	3	4	5	6	7	8
Largemouth bass	√	√	√	√	√	√	√	√
Redear sunfish	√	√	√	√	√	√	√	√
Bluegill	√	√	√	√	√	√	√	√
Warmouth		√	√	√		√	√	
Spotted sunfish				√		√	√	
Mosquitofish	√	√	√	√	√	√	√	√
Sailfin molly		√	√	√				
Variable platyfish				√				
Brook silverside		√	√	√				
Black acara								√
Spotted tilapia						√		√
Florida gar		√	√	√			√	
American eel			√					
Walking catfish				√	√		√	√
Threadfin shad				√				
Striped mullet				√				
Brown bullhead			√					
Golden shiner				√				

Fisheries

None of the collection techniques employed captured enough fish to obtain a population estimate by mark-recapture methodology or provide an unbiased index of relative abundance. Catch per unit effort was generally low regardless of sampling method (Hudy and Gregory 1983).

All study lakes contained fish and species composition was similar to that found in canals and wetlands of the region (Table 5) (Kushlan and Lodge 1974). Largemouth bass, redear sunfish, bluegill and mosquitofish were common to all lakes. Largemouth bass were generally small, only 12% exceeded 300 mm in length and less than 1% exceeded 350 mm (Fig. 5).

Discussion

The wide range of water quality characteristics found in this study were not detrimental to fish but in part may be limiting lake productivity. The levels of phosphorus, nitrogen, and chlorophyll *a* found are lower than reported in other Florida waters (Miller 1975, U.S. Environ. Protection Agency 1978, Canfield 1981), and indicate relatively unproductive or oligotrophic to oligotrophic-mesotrophic systems (Carlson 1977).

The number of macroinvertebrates was low, but within the densities reported for freshwater Florida habitats (Wegener et al. 1974, Waller 1976). However, diversity was low in this study and dominated by the Chironomidae and Chaoboridae. Important fish food invertebrates of other Florida waters (McLane 1948, Huish 1949, Wegener et al. 1974) such as scuds, freshwater shrimp, crayfish, dragonflies, damselflies, mayflies, and other littoral species were absent or rarely found in dredge samples or in largemouth bass stomachs. The lack of littoral areas, small amounts of submergent and emergent aquatic vegetation, and great mean depths of some limestone excavation lakes undoubtedly limit abundance and diversity of macroinvertebrates (Moyer and Williams 1982). Removal of organic matter prior to mining may also limit densities of certain functional groups of aquatic insects such as collecters and shredders which feed on fine and coarse organic matter (Merrit and Cummins 1978). Mining practices that increase littoral areas, aquatic vegetation, and organic matter in excavation lakes should increase the diversity and density of important fish and wildlife food items.

Traditional fisheries techniques used for standing crop and population estimates in Florida were not successful in the large, deep, sparsely vegetated excavation lakes because: (1) block nets, drop traps (Kushlan 1974) and Wegener rings (Wegener et al. 1973) are best suited for sampling relatively shallow water, (2) too few fish were captured for mark-recapture population estimates, and (3) total eradication with rotenone was considered too expensive. However, the low catch per unit effort, regardless of capture method, suggests low densities and standing crops of fishes. Lakes with nutrient levels similar to those found in this study generally have low standing crops of fishes, even when excellent fish habitat is present (Oglesby 1977, Kautz 1980, Hanson and Leggett 1982). Marsh, littoral, and other vegetated areas are important fish rearing and feeding areas. In the Everglades, canals with adjacent marsh had more fish and pounds of fish than canals with a berm and no marsh (Dineen 1965). In Lake Tohopekaliga, Florida, shallow vegetated habitats had considerable more value per acre than limnetic areas of the lake (Wegener and Holcomb 1972, Wegener et al. 1973).

We believe the initial composition of fish in most limestone excavations is primarily the result of: (1) fish randomly stocked by individuals, and (2) movements of fishes from adjacent canals and wetlands during periods of high water. Most of the fish collected, with the exception of *Anguilla rostrata* and *Mugil cephalus*, are probably capable of limited reproduction in limestone excavations. Mitigation measures that create additional shallow, vegetated habitat would likely enhance the reproductive success of most fish species by providing additional fish spawning and rearing habitat. In addition, appropriate fish strategies together with artificial fish shelters may help improve fish production.

It is hard to predict the specific effects of mitigation because no studies have been done to evaluate specific mitigation or management strategies. However, it seems reasonable to assume that mitigation measures such as: (1) removal of berms, (2) sloping to create littoral areas, and (3) return of some portion of the organic overburden would increase the amounts of allochthonous matter and nutrients entering excavation lakes. The increase in allochthonous matter and nutrients should help increase the productivity of most lakes. Lake fertilization also may prove practical on some of the smaller excavations.

General impressions of low productivity in limestone excavations were substantiated by this study and clearly document the potential to enhance the fisheries in rock-mined areas through mitigation and management.

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