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FISH POPULATIONS AND PHYSICAL CONDITIONS IN DITCHED AND IMPOUNDED MARSHES IN EAST-CENTRAL FLORIDA[1]

Salt marsh systems are dominant coastal features that are highly productive and are used by a myriad of fishes as primary nursery habitat (Weinstein 1979) as well as feeding habitat by juvenile and adult marsh resident fishes (Weisberg *et al.* 1981; Weisberg and Lotrich 1982; Kneib 1984, 1987; Rey *et al.* 1990). These systems are increasingly being impacted by development and associated pressures and considerable marsh habitat is being either completely lost (Wilson 1988) or isolated (de-coupled) from the estuary (Gilmore 1987, Rey *et al.* 1990).

In east-central Florida, salt marsh impoundments constitute an important part of the strategy for control of the salt marsh mosquitoes *Aedes taeniorhynchus* and *A. sollicitans*. Impoundments are portions of marsh that have been "diked" to allow holding of water on the marsh floor during the mosquito producing season (about May - October). During the "non-breeding" part of the year some impoundments remain closed while others are open to the estuary, usually through culverts.

An alternative to impounding involves the cutting of ditches to connect isolated depressions and known breeding areas to permanent ponds or tidal channels, thus maintaining water flow to these areas and allowing access to them by larvivorous fishes. An advantage of this method is that the marsh does not have to be closed and flooded during the season.

Below we describe a marsh restoration project that combines both ditching and impounding in an effort to expedite vegetation recovery in a severely impacted marsh, while still maintaining adequate mosquito control. We examined the effects of these alterations upon fish populations and selected physical variables and discuss the impact of the restoration activities on the use of the upper marsh by fishes.

DESCRIPTION OF THE STUDY SITES

The sites are located in the Merritt Island National Wildlife Refuge, Brevard County, Florida (28°39′N, 80°48′W). Impoundment T10-H (Figure 1) was constructed in 1961, and has an area of 136 ha. Prior to impounding, the marsh vegetation consisted of *Batis maritima*-*Salicornia* spp. meadows, with interspersed black (*Avicennia germinans*) and white mangroves (*Laguncularia racemosa*) (Trost 1968). The high water levels initially used to control mosquitoes, and the high salinities that often resulted from evaporation during the non-breeding season, caused serious damage to the marsh vegetation. The elimination of vegetation resulted in a significant decrease in mosquito production at this site. In 1974 the Brevard Mosquito Control District decided to cease flooding the impoundment and to maintain the culvert open throughout the year in an effort to encourage re-vegetation of the area.

The above strategy proved effective in restoring some of the marsh vegetation (Leenhouts 1985), with a concomitant increase in mosquito production, particularly around isolated depressions in the marsh. In 1981 a series of ditches (91.4 cm wide by 61 cm deep) were cut within the impoundment to connect these depressions to larger ponds and to a larger perimeter ditch. An additional 91.4 cm culvert was also installed through the dike at that time.

Boggy Pond is an adjoining 26.3 ha impoundment which remained closed and flooded throughout the study (Figure 1). A 91.4 cm culvert on the north side of the dike permits lagoon waters to flow into the impoundment if water levels in the im-

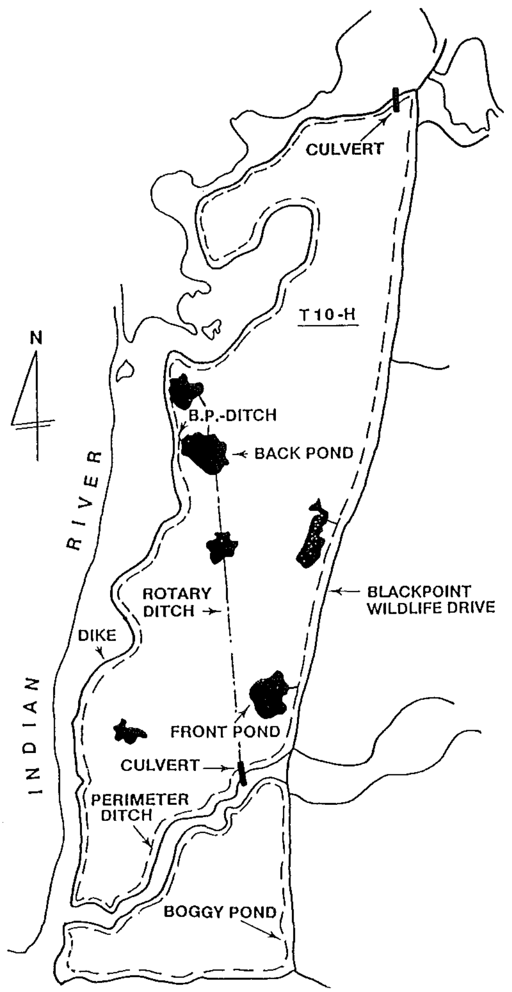

Figure 1. Map of the study area showing T10-H and Boggy Pond. Not all ditches are shown.

poundment are lower than in the lagoon. This, however, is not common since in this region there is no lunar tidal cycle, and wind-driven tides reach a sufficient magnitude only infrequently (Provost 1973).

METHODS

Sampling Stations. Sampling stations were established at the following locations: 1) the perimeter ditch on the southeast side of T10-H (Perimeter Ditch); 2) a small, shallow pond on the east side of the impoundment (Front Pond); 3) a similar pond on the west side (Back Pond); 4) rotary ditches leading to each of the ponds (Front Pond Ditch and Back Pond Ditch); 5) the perimeter ditch at Boggy Pond (Boggy Pond); and 6) the east perimeter ditch in T10-H and the west perimeter ditch of Boggy Pond (T10-H Trammel and Boggy Trammel, respectively).

Fish Sampling. Our ability to sample fish in this area was limited by two facts: 1) no permanent sampling structures could be constructed adjacent to the Blackpoint Wildlife Drive (Figure 1) and 2) the extremely soft substratum and shallow waters made it impossible to employ active sampling techniques (*e.g.*, seines, etc.) in this area. Thus, we used passive techniques (traps and trammel nets) for fish sampling.

The fish traps consisted of heart-shaped aluminum frames with 74 × 79 × 61 cm sides covered with 0.318 cm #24 ace weave nylon netting. A vertical opening was located between the two lobes of the heart-shaped trap. Three traps were set monthly at each sampling station from October 1981 to February 1984 and fished for two days. "Heart traps" have been shown to be effective in capturing small resident species in this type of habitat (Harrington & Harrington 1961, 1982; Gilmore *et al.* 1982). Additionally, one plastic minnow trap (0.476 cm square mesh) was used with the heart traps at each station.

Additional fish collections were taken from January 1983 to February 1984 at the trammel net stations. Each net was 15.25 m long, 1.22 m deep, with 1.91 cm inside netting and 6.35 cm square walls with standard floats and weights. The nets were set across each perimeter ditch and fished for 24 hours.

Physical Variables. The following variables were measured monthly at each station: existing and maximum and minimum water levels, salinity, temperature, pH, and air temperature. Rainfall data

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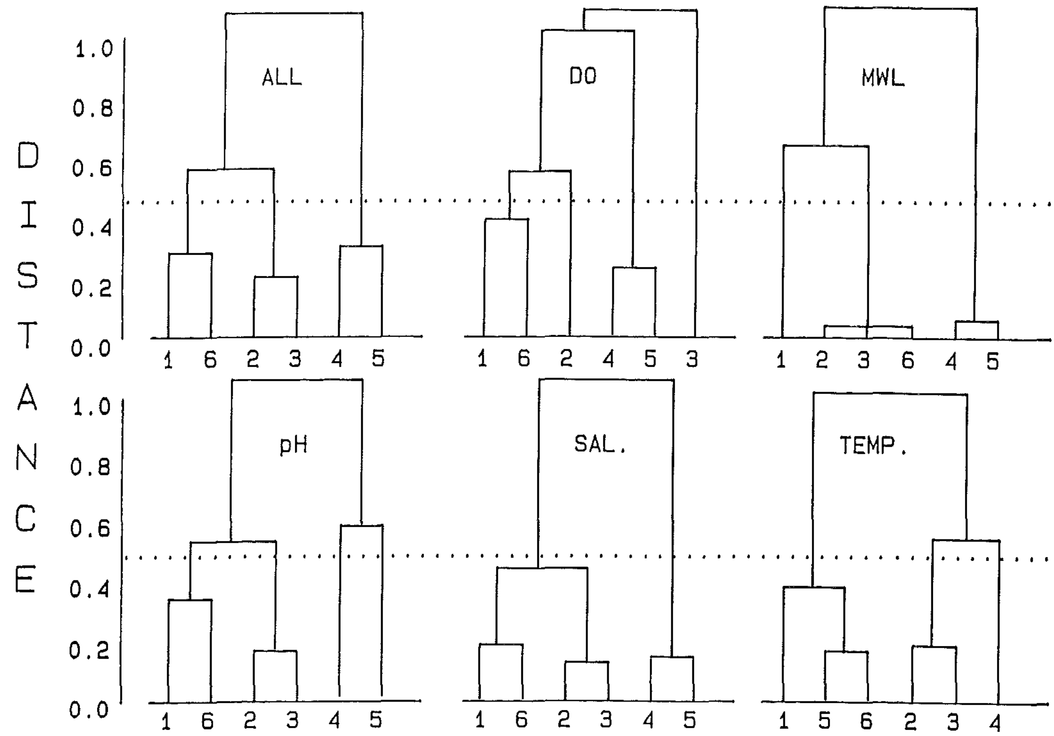

Figure 2. Results of cluster analysis of the various stations based upon physical variables. Station codes are as follows: (1) Back Pond, (2) Front Pond, (3) Perimeter Ditch, (4) Boggy Pond, (5) Trammel Boggy, (6) Trammel T10-H.

were obtained from the NOAA weather station at Titusville, 5 km west of the study sites.

Statistical Analyses. All analyses of variance were carried out using the GLM procedure of SAS (Freund *et al.* 1986). Only the data for 1982 and 1983 were used in the yearly comparisons since we only had data for October - December 1981, and for January - February 1984. Cluster analyses of the physical data were carried out with the SAS clustering procedure using the UPGMA method (Boesch 1977); input consisted of a distance matrix based on Morisita's similarity index.

RESULTS

Physical Variables. Several months of low precipitation preceded and extended into the start of this study. As a consequence, salinity at all sites was higher during the first 7 months of the study than during the remaining months (Table 1), and water levels dropped considerably below their yearly means.

Most physical variables were significantly correlated between sites, especially among sites within the same impoundment (Table 2). One-way ANOVAs for the physical data from 1982 through 1984 reveal a significant effect of site only for dissolved oxygen ($F = 2.60$, $p \leq 0.05$, 5 df). Duncan's Multiple Range Test (DMR) for the D.O. data indicates that the Perimeter Ditch site had significantly lower D.O. than the other sites. If the data for the first seven months, when salinities were high everywhere because of the abnormally low rainfall, are excluded from the analysis, then a significant effect of site upon salinity is revealed ($F = 6.19$, $p < 0.001$). DMR results show that the sites at Boggy Pond had significantly lower salini-

Table 1. Summary statistics for the physical data collected at the individual stations. Two maxima are reported for the salinity data: Max. indicates the maximum salinity reached at each site during the study, Max* excludes the high salinity period at the start of the study.

	BACK POND	FRONT POND	PERIM. DITCH	BOGGY POND	TRAMMEL BOGGY	TRAMMEL T-10H
SALINITY						
Mean	23.0	23.8	23.9	18.4	15.0	18.6
S.D.	11.8	11.5	10.4	10.2	6.5	5.3
Max.	52.0	50.0	47.1	34.9	29.4	31.0
Max*	37.0	35.1	32.2	16.0	—	—
Min.	10.0	12.2	11.4	8.1	11.2	10.6
TEMPERATURE						
Mean	24.0	22.9	22.0	21.4	22.4	22.5
S.D.	6.2	6.5	6.0	5.7	5.5	5.2
Max.	35.1	34.3	31.5	30.0	32.1	31.5
Min.	14.8	13.2	12.0	12.0	13.8	15.2
pH						
Mean	7.9	7.8	7.8	7.8	7.8	7.8
S.D.	0.4	0.4	0.4	0.5	0.4	0.4
Max.	8.7	8.6	8.7	8.9	8.8	8.4
Min.	7.1	7.0	7.1	6.3	7.0	7.1
D.O.						
Mean	6.7	6.5	5.1	6.7	6.7	6.3
S.D.	2.2	1.9	2.1	2.7	2.7	1.6
Max.	12.0	11.4	9.2	12.6	12.5	9.5
Min.	2.3	2.7	1.1	1.4	3.1	3.8

Table 2. Significance of Pearson correlations for salinity, dissolved oxygen, and pH among the various sites.
(A) Upper triangular matrix = D.O., lower matrix = pH.
(B) Salinity. * = $p<0.05$, NS = $p>0.05$.

A

	BACK POND	FRONT POND	PERIM. DITCH	BOGGY POND	T10-H TRAMMEL	BOGGY TRAMMEL
BACK		*	NS	NS	*	NS
FRONT	*		*	NS	*	*
PERIM	*	*		*	*	*
BOGGY	NS	NS	NS		NS	*
T-TRAM	*	*	*	*		NS
T-BOG	*	NS	*	*	NS	

B

	BACK POND	FRONT POND	PERIM. DITCH	BOGGY POND	T10-H TRAMMEL	BOGGY TRAMMEL
BACK	—					
FRONT	*	—				
PERIM	*	*	—			
BOGGY	*	*	*	—		
T-TRAM	*	*	*	*	—	
T-BOG	*	*	NS	*	*	—

ties that those at T10-H.

Cluster analysis of the physical data split stations at Boggy Pond from those at T10-H, and tended to combine Perimeter Ditch with Front Pond (Figure 2). The latter pairing breaks down only for D.O., where the Perimeter Ditch site splits off by itself as a result of the lower D.O. levels recorded there (Table 1).

Fish Populations. A total of 22 species and 42,573 individuals were captured in

Table 3. Comparison of fish species collected from marsh habitats along the Indian River Lagoon. Only heart trap data are used. O = open impoundment; C = closed impoundment; H & H = Harrington & Harrington; T = transient.

SPECIES	H & H 1961	H & H 1982	Gilmore Pers.	Gilmore Com.	T10-H	Boggy
	O	C	O	C	O	C
Elops saurus T	+				+	
Megalops atlantica T	+					
Cyprinodon variegatus	+	+	+	+	+	+
Floridichthyes carpio T			+			
Fundulus confluentus	+	+	+	+	+	
F. grandis	+		+	+	+	+
F. similis T	+		+			+
Lucania parva	+	+			+	+
Rivulus marmoratus	+		+			
Gambusia affinis	+	+	+	+	+	+
Poecilia latipinna	+	+	+	+	+	+
Menidia peninsulae	+				+	+
M. beryllina					+	+
Sygnathus scovelli T						+
Centropomus undecimalis T	+				+	
Eugerres plumeri T	+					
Leiostomus xanthurus T					+	
Mugil cephalus T	+				+	
M. curema T					+	
Evorthodus lyricus	+		+			
Gobiosoma robustum			+		+	+
G. bosci			+		+	+
Gobiosoma sp.					+	+
Microgobius gulosus			+		+	+
Dormitator maculatus	+				+	
Total:	16	5	12	5	18	13

the impoundments during this study (Table 3); of these, 20 species and 41,779 individuals were collected in the T10-H traps, 8 species and 794 individuals in the trammel nets. The Perimeter Ditch and Front Pond sites were the most diverse overall, with 16 species captured in each, followed by West Pond (15 species), Boggy Pond (14), West Pond Ditch (13), Front Pond Ditch (9), T10-H Trammel (7) and Boggy Trammel (5). Five marsh resident species dominated the T10-H and Boggy Pond collections accounting for 57% of the individuals captured. These species are: *Gambusia affinis* (7900 individuals, 18.6%), *Lucania parva* (7371, 17.3%), *Cyprinodon variegatus* (5002, 11.7%), *Poecilia latipinna* (2803, 6.6%), and *Menidia peninsulae* (1216, 2.9%). Peaks in numbers of individuals generally occurred between July and October, with numbers of species following the same general pattern.

Analysis of variance of the fish data indicate significant effects of site upon mean number of species and individuals captured at each site, and a significant effect of year on numbers of species (Table 4). DMR for these data indicates that the average number of species collected at Boggy Pond and Perimeter Ditch was significantly higher than that collected at Front Pond and at the rotary ditch stations (Table 5). Mean number of individuals was greater at Perimeter Ditch, followed by Boggy Pond, Back Pond and Front Pond, and then by the Rotary Ditch stations but the differences between Boggy, Front, and Back Ponds and between the last two and the ditch stations are not statistically significant (Table 5). Mean number of species col-

Table 4. Results of two-way ANOVAs for numbers of species and numbers of individuals captured during 1982 – 1983 at the various stations.

EFFECT	F	DF	p
	Species		
STATION	25.12	6	0.0001
YEAR	11.92	1	0.0007
ST × YR	1.04	6	0.4132
	Individuals		
STATION	4.02	6	0.0009
YEAR	2.56	1	0.1120
ST × YR	1.02	6	0.4000

lected during 1983 was significantly higher than during 1982 (Table 4, DMR $p<0.05$).

DISCUSSION

The observed relationships between salinity, water levels and precipitation illustrate the fact that these are isolated or semi-isolated systems existing in an area devoid of regular tidal influence. The lower salinity observed at Boggy Pond sites is due to its isolation from lagoon waters so that it receives much of its water from precipitation; at T10-H there is more frequent mixing of impoundment and lagoon waters during periods of high water levels, and when wind-driven tides invade and then retreat from the impoundment through the culverts.

The lower D.O. values at Perimeter Ditch are probably a result of several factors: 1) this site is deeper than the other sites, and is adjacent to the impoundment dike — both factors reducing wind-promoted mixing and oxygenation of the water column; 2) when waters are receding from other parts of the marsh, they drain into this site and possibly deposit part of their organic load into it, thus increasing BOD; 3) during low water periods, most of the fish and macroinvertebrates inhabiting the marsh must retreat to this site, again increasing biological activity and decreasing dissolved oxygen.

The cluster analysis segregation of Boggy from T10-H sites reveals the overall differences in physical conditions existing in closed vs open impoundments, and is weakest for water temperature, the variable that should be least affected by the different management of the two sites. The Front Pond-Perimeter Ditch pairings reflect the close physical connection between these two sites and demonstrate the effectiveness of the ditches in balancing physical conditions between connected areas.

In spite of the fact that Boggy Pond contains much more submerged habitat than T10-H, abundance and diverstiy of fishes at T10-H compare favorably with those at Boggy Pond, as well as with those of other open and closed marshes in Florida (Gilmore *et al.* 1982 and *pers. comm.*; Harrington and Harrington 1961, 1982). The fish fauna of Boggy Pond is particularly lacking in transient species, reflecting the more isolated (closed) nature of that site. In natural marsh systems, transients are more abundant in the upper marsh because they use this habitat during a portion of their life

Table 5. Results of Duncan Multiple Range Tests for number of species and numbers of individuals captured at the different stations. Sites in the same "group" do not differ significantly at the 0.05 level.

STATION	SPECIES MEAN	GROUP	STATION	INDIVIDUALS MEAN	GROUP
Boggy Pond	6.29	A	Per. Ditch	388.29	A
Per. Ditch	5.82	A	Boggy Pond	224.88	B
Back Pond	5.42	AB	Back Pond	176.50	BC
Front Pond	4.51	B	Front Pond	87.26	BC
Back Pond RD	2.78	C	Back Pond RD	31.89	C
Front Pond RD	1.12	D	Front Pond RD	29.71	C

history and have access during high tide for feeding and refuge from predation (Weinstein 1979, Kneib 1987). As in some northeast marshes (Able *et al.* 1979, Balling *et al.* 1979, Talbot *et al.* 1986), the ditch system has resulted in increased pathways for organism exchange between marsh and estuary, moderated physical conditions, and expanded internal access by fish to formerly isolated areas of the marsh.

As mentioned above, during 1982 salinity was higher and water levels lower than during 1983, and both were more variable (higher coefficient of variation) during the former. It is possible that these differences were partially responsible for the lower mean numbers of species collected during 1982. For example, Nordlie and Walsh (1989) indicated that there are distinct differences in salinity tolerance and osmoregulatory ability among closely related cyprinodonts that use marsh habitats. Also, experimental data on the effects of salinity and low oxygen concentrations on several marsh resident species suggest that marsh fishes can be affected by variations in salinity and oxygen levels (Peterson 1990). Additional experimental data are needed to confirm this assertion, but similar effects of salinity and water level variations upon fish species diversity and abundance were reported by Morton *et al.* (1988) from large pools and small isolated depressions in Australian salt marshes.

It is evident from our results that the ditch system is being used by fish to gain access to what would have otherwise been isolated depressions in the marsh, and that the same ditches provide an efficient connection between temporary upper marsh ponds and the more permanent perimeter ditch. The ditch system has also allowed the marsh to remain open to the lagoon throughout the year, granting marsh access to transient species that are generally excluded from closed impoundments such as Boggy Pond.

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