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Habitat use by fishes after tidal reconnection of an impounded estuarine wetland in the Indian River Lagoon, Florida (USA)

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Abstract

Most of the wetlands located along the Indian River Lagoon (IRL) in east-central Florida (USA) have been impounded since the 1950's and 1960's to reduce mosquito reproduction. Impounded marsh (i.e., impoundment) dikes physically separate the wetlands from the estuary to allow artificial flooding of the impoundments during the mosquito breeding period (May to October). Presently, Rotational Impoundment Management (RIM) is the preferred impoundment management technique in the IRL. Impoundments maintained under RIM have culverts installed through the dikes which are kept closed during the mosquito breeding season (to control mosquitos) and are allowed to remain open for the remainder of the year (to allow tidal flow). A 24.3 ha impoundment 8 km north of Sebastian Inlet that had been isolated from the IRL for over 39 years was studied for 12 months to determine habitat use by fishes after tidal reconnection and the implementation of RIM. Fish sampling was conducted with a seine in the perimeter ditch and with clover and minnow traps in the upper marsh and tidal creek areas of the impoundment. Water level, impoundment bottom topography, and the seasonal nursery function of the impoundment were factors that contributed to observed patterns of fish habitat use during the study. Within the first 15 weeks of perimeter ditch sampling, an increase from 9 to 40 species was observed. Transient species used the perimeter ditch almost exclusively and entered the impoundment primarily during the spring open period. Juvenile *Pogonias cromis* (Linnaeus), *Elops saurus* Linnaeus, *Centropomus undecimalis* (Bloch), and *Megalops atlanticus* Valenciennes were the most abundant recreationally important species, respectively. Habitat use by the most abundant resident species (*Gambusia holbrooki* Girard, *Poecilia latipinna* (Lesueur), *Cyprinodon variegatus* Lacepède, and *Fundulus confluentus* Goode & Bean) was influenced primarily by water level fluctuations. Resident species used the upper marsh and tidal creek habitats during summer flooded periods and the cyprinodontids left the interior surface of the impoundment last as water levels decreased. This study is the first to document the recovery of fish populations in a reconnected impoundment north of Sebastian Inlet using both active and passive sampling techniques.

Introduction

Wetlands in the Indian River Lagoon (IRL) in east-central Florida can produce large populations of the salt marsh mosquitoes *Aedes taeniorhynchus* (Wiedemann) and *A. sollicitans* (Walker). As a result, growth in this part of the state forced source-reduction mosquito control (O'Bryan et al., 1990). Moist soil on the high marsh becomes exposed seasonally and provides oviposition sites for these mosquitoes (Carlson and O'Bryan, 1988). Because salt marsh mosquitoes do not lay eggs on standing water, 195 impounded marshes (i.e., impoundments) that cover over 16,000 ha of coastal wetlands were created in east-central Florida (Provost, 1977; O'Bryan et al., 1990; Rey et al., 1991). The impounding process involved building earthen dikes around mosquito-breeding marshes and using diesel pumps to flood the marsh surface during the mosquito breeding season (May to October). The dredging of material to build dikes created ditches around the inside perimeter of each impoundment. These perimeter ditches are generally 1–2 m deep and 5–7 m wide. These efforts significantly reduced mosquito populations and minimized insecticide use (Carlson and O'Bryan, 1988).

Although the creation of the impoundments successfully reduced mosquito reproduction, fishes that would normally exploit these wetlands were denied access to them because of the impoundment dikes. Recreationally important fishes that fall into this category include *Pogonias cromis* (Linnaeus), *Elops saurus* Linnaeus, *Centropomus undecimalis* (Bloch), and *Megalops atlanticus* Valenciennes. These species are considered transients because they are temporary occupants of the impoundments, usually while they are juveniles (Harrington and Harrington, 1961; Gilmore, 1987). Resident fishes such as *Gambusia holbrooki* Girard, *Poecilia latipinna* (Lesueur), *Cyprinodon variegatus* Lacepède, and *Fundulus confluentus* Goode & Bean can spend their entire life cycles within the impoundment boundaries and were less affected by the impounding process (Harrington and Harrington, 1961; Gilmore et al., 1982). In general, initial construction and operation of the impoundments greatly reduced fish diversity by eliminating access to nursery areas, altered the natural marsh vegetation because of the artificially high water levels, and caused atypical salinities to occur that ranged from freshwater to over 200 ppt depending on the flood water source and how a given impoundment was managed (Gilmore et al., 1982; Harrington and Harrington, 1982).

Beginning in the early 1980's, efforts have been made to counteract these dramatic changes in the IRL wetland ecosystems. Connections between some impoundments and the IRL were re-established via installation of culverts through the impoundment dikes. The Rotational Impoundment Management (RIM) technique was then implemented for the reconnected impoundments (Carlson and Carroll, 1985; O'Bryan et al., 1990). Impoundments managed by RIM are closed and flooded during the summer mosquito breeding period and reconnected to the IRL by opening water control structures (e.g., flapgates) during the non-breeding months. This management strategy has effectively rehabilitated many impoundments, promotes more natural conditions, and is presently the preferred impoundment management strategy in the IRL system (Brockmeyer et al., 1997).

The use of RIM has restored access to the impoundments for transient fishes (e.g., Gilmore et al., 1982), but the speed of recovery to more natural conditions and how impoundment hydrology, management, and location affects habitat use (i.e., perimeter ditch and interior impoundment) by fishes has not been fully elucidated. The objectives of the present study were to determine: (1) the abundance and composition of fishes (especially recreationally important species) present in the perimeter ditch of the impoundment for the first 12 months after tidal reconnection, and (2) concurrent use of the adjacent interior areas of the impoundment (i.e., higher elevation and intermediate habitat between the perimeter ditch and the upland edge of the marsh) by fishes during flooded periods.

Study location

The IRL is one of the most diverse estuarine systems in the continental United States (Gilmore, 1995). This 250 km long microtidal estuary is 2–4 km wide, averages 1–2 m deep, and spans one third of the east-coast of Florida, with both warm temperate and tropical species contributing to the system's high biodiversity (Smith, 1987; Swain et al., 1995). The IRL spans the transition zone between salt marshes dominated by herbaceous halophytes (e.g., *Batis maritima* L., *Salicornia perennis* Mill., and *S. bigelovii* Torr.; Wunderlin, 1998) to the north, and mangrove forests dominated by large woody mangrove trees (e.g., *Rhizophora mangle* L., *Avicennia germinans* (L.) L., and *Laguncularia racemosa* (L.) C. F. Gaertn.) to the south (Brockmeyer et al., 1997). Wetlands in the central IRL typically support a combination of these vegetation types, and have been referred to as 'mangrove marshes' by Gilmore (1987). The IRL is separated from the Atlantic Ocean by a series of barrier islands and is connected to it by five inlets.

Water level changes in the IRL are related to seasonal scales rather than daily tides (depending on distance to nearest inlet), with short-term fluctuations based on wind direction (Smith, 1987). In the fall

(September-November), a seasonal increase in water level occurs that typically inundates wetlands throughout the system (Provost, 1973). Short-term fluctuations during the rest of the year are aperiodic and are attributed to storm activity or the passage of frontal systems (Brockmeyer et al., 1997).

Methods

Study site

The present study was conducted in 1995 and 1996 in a 24.3 ha privately owned impoundment adjacent to the IRL in Brevard County, Florida (27°56′ N, 80°30′ W; Figure 1). The impoundment is located in the central IRL ca. 8 km north of Sebastian Inlet which is the nearest estuarine connection to the Atlantic Ocean. In 1989, about 65% of the impoundment was covered by a mixed assemblage of mangroves, 10% by upland plant species, and 25% was unvegetated mudflat habitat (Rey and Kain, 1989). The impoundment was constructed in 1956 and had been isolated from the IRL for over 39 years prior to tidal reconnection. The impoundment was historically flooded during the mosquito breeding season with a portable diesel pump and a transfer pipe 46 cm in diameter. The pump station was located in the southwest corner of the impoundment (near culvert C4; Figure 1), where the greatest water depth (ca. 2 m) was found as a result of scouring by the pump.

In early 1995, a permit was granted to a developer for construction within the impoundment with mitigation requirements that four culverts (10 m long, 91 cm diameter) be installed to reconnect the impoundment to the IRL and that the impoundment be subsequently managed by the Brevard Mosquito Control District using RIM. The four culverts were installed in early February 1995 (C1-C4; Figure 1). Culverts C1 and C4 were fitted with solid aluminum flapgates that were opened on 15 March 1995 and remained open during the non-mosquito breeding period thereafter. Culverts C2 and C3 were fitted with 122 cm riserboards that could be added or removed to regulate water level. With the exception of a 24 hour period beginning on 29 September 1995, these culverts were kept closed during the study. Movement of fishes into and out of the impoundment was examined with culvert traps (culverts C1 and C4; described by Rey et al., 1990) as well as riser-fitted plankton nets (culverts C2 and C3; described by Wieher, 1995) during this period, and these data are reported in Poulakis (1996).

Perimeter ditch sampling procedures

The perimeter ditch adjacent to the pump station was used to sample fishes in the impoundment (Figure 1). It was chosen because the remaining length of the perimeter ditch had been filled in by siltation prior to culvert installation, it was seinable throughout the year, it was located adjacent to one of the new culverts, and it was virtually the only portion of the impoundment that contained water when the surface of the impoundment was dry. The substrate in the perimeter ditch was principally mud.

Collections were made at the perimeter ditch site (ca. 50 m long × 11 m wide) by using a 21.3 m × 1.8 m center bag seine with 3.2 mm mesh. To reduce mortality and enable processing of large samples, the site was divided by a net (3.2 mm mesh) into two sections, one seine haul was made in each section, and the data were combined. This technique was used for the entire study. Samples were processed by measuring the standard length (SL) of transient fishes to the nearest millimeter and returning them to the portion of the site from which they originated. Total lengths were measured for resident species. The volume of large catches of resident fishes during the spring and fall was estimated in 20 liter buckets after transients were removed and an 800 ml subsample was taken. Most collections during these periods were so large that the removal of the subsample was unlikely to impact the overall population. Occasional individuals that could not be readily identified were put on ice and taken to the laboratory with the subsample for processing. Some specimens were not identified to species because they were not distinguishable as small juveniles (*Eucinostomus* spp.; Matheson, 1983), the possibility of hybridization existed (*Brevoortia* spp.; Rogers and Van Den Avyle, 1983), or because of damage. In addition, 23 *Megalops atlanticus* (> 200 mm SL) were marked with numbered Floy® spaghetti tags (see Wydoski and Emery, 1983) during reconnaissance sampling prior to the start of the study. Taxonomic nomenclature for fishes follows that of Robins et al. (1991).

Perimeter ditch sampling occurred at either one or two week intervals during the study (Table 1). The perimeter ditch site was sampled beginning on 15 February 1995 at approximately weekly intervals through the spring culvert-open period and into the beginning of the summer culvert-closure period until 23 June 1995 when any species trapped inside the impoundment from the spring had been documented.

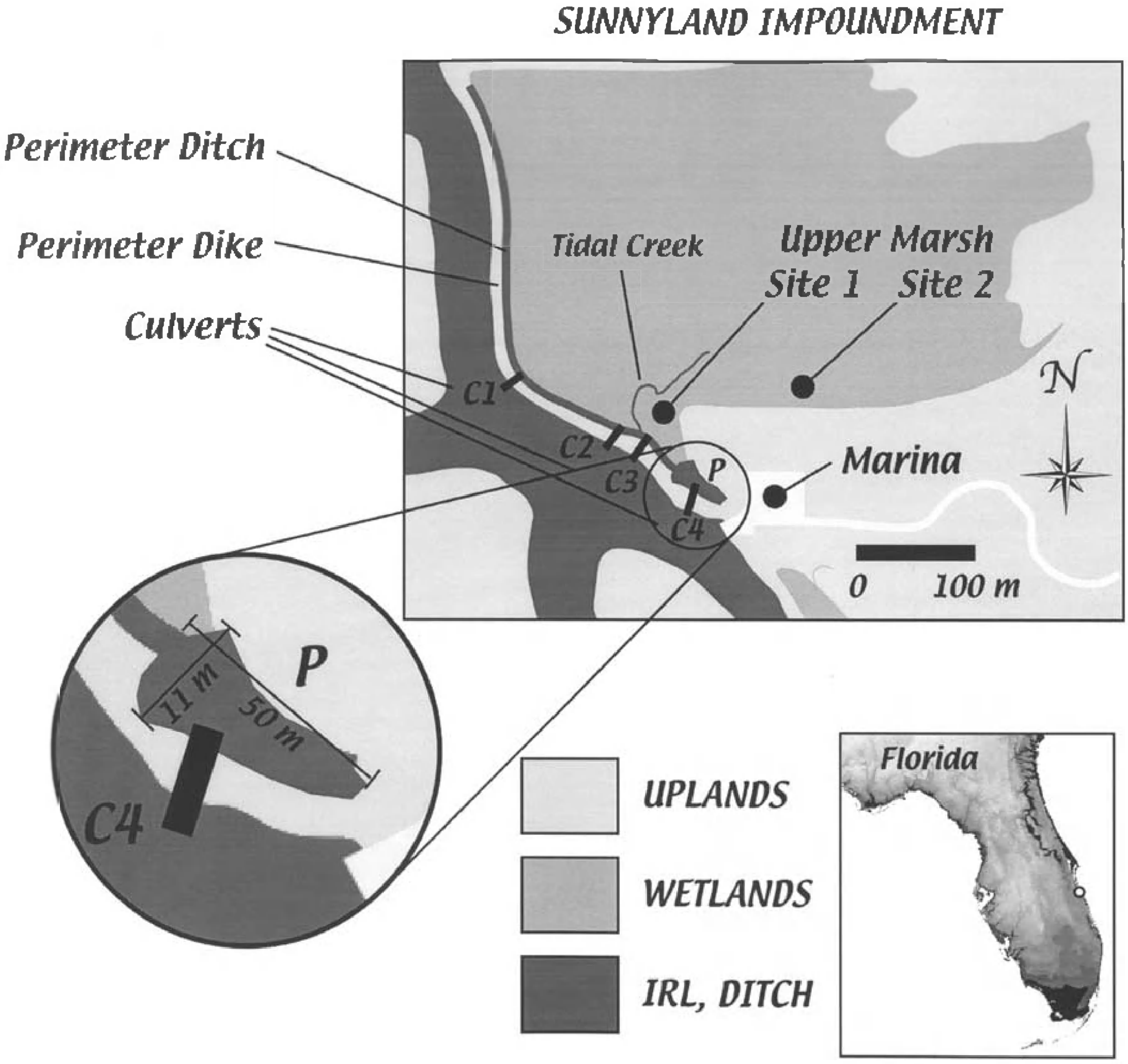

Figure 1. Location of the perimeter ditch site (P), upper marsh sites, tidal creek, and culverts (C1-C4) in the impoundment (27°56′ N, 80°30′ W; adapted from Rey and Kain, 1989). IRL = Indian River Lagoon.

Table 1. Sampling dates, frequencies, and physical parameters for perimeter ditch collections during the four impoundment management periods (i.e., sampling periods). Salinities and temperatures are mean (range) surface water values. Water levels are mean (range) values relative to National Geodetic Vertical Datum (NGVD) at the perimeter ditch site.

Sampling period	Sampling dates	Sampling frequency	No. of collections	Salinity (ppt)	Temperature (°C)	Water level (cm NGVD)
Pre-connection	2/15–3/14/95	~1 wk	3	9 (5–18)	23 (18–25)	19.9 (5.1–33.0)
Spring Open	3/21–5/17/95	1 wk	9	24 (19–30)	30 (24–35)	22.8 (7.9–35.6)
Summer Closure	5/31–9/29/95	1 wk/2 wk	11	23 (11–35)	31 (27–36)	56.5 (51.1–66.0)
Fall/Winter Open	10/13/95–3/8/96	~2 wk	10	18 (10–25)	24 (18.5–30)	28.1 (11.4–55.9)

Table 2. Sampling dates, frequencies, and physical parameters for upper marsh and tidal creek collections during the two impoundment management periods when interior impoundment sampling was conducted. Salinities and temperatures are mean (range) surface water values. Water depths are mean (range) values at each site. UM = Upper Marsh.

Sampling location	Sampling period	Sampling dates	Sampling frequency	No. of collections	Salinity (ppt)	Temperature (°C)	Water depth (cm)
UM-Site 1	Summer Closure	8/1–9/15/95	2 wk	4	17 (11–22)	31.5 (28–36)	21 (14–31)
UM-Site 2	Summer Closure	8/1–9/15/95	2 wk	4	15 (10–22)	31 (29–34)	22 (16–32)
UM-Site 1	Fall/Winter Open	10/5–12/10/95	2 wk	6	16 (10–20)	26 (20.5–35)	13 (0[a]–27)
UM-Site 2	Fall/Winter Open	10/5–12/10/95	2 wk	6	8 (5–12)	24 (16.5–31.5)	16 (8–31)
Tidal Creek	Fall/Winter Open	12/18/95–2/2/96	2 wk	4	15 (10–20)	25 (20–29.5)	9 (6–16)

[a] isolated pools of water were present and water depths were recorded as 0 cm.

Beginning on 7 July, the site was sampled at approximately two week intervals until the completion of the study on 8 March 1996. Data on the initial responses of fishes to the opening of the impoundment have been reported by Taylor et al. (1998), and are included where necessary for the purpose of continuity.

Interior impoundment sampling procedures

The interior of the impoundment was covered with many small mangrove seedlings and dead, larger mangroves killed by a severe winter freeze in 1989. Two upper marsh sites and one tidal creek site were chosen for sampling the interior of the impoundment when it was flooded (Figure 1). Upper marsh site 1 was located ca. 50 m due north of the perimeter ditch site adjacent to *L. racemosa* seedlings. Upper marsh site 2 was located ca. 100 m northeast of the perimeter ditch site and ca. 3 m from the upland edge of the impoundment in an old section of the perimeter ditch that had silted in. One unbaited metal 'clover' trap (i.e., heart trap containing three 1 cm openings and lobes; each lobe ca. 40 cm diameter × 30 cm high with ca. 3 mm mesh) and four unbaited cylindrical plastic minnow traps (see Hubert, 1983; 42.5 cm long, 20.8 cm maximum diameter, two 2.4 cm openings, 4–7 mm mesh) were placed at each location beginning on 1 August 1995. Traps were placed over mud substrate adjacent to the surrounding vegetation and were the only sampling gears available that could effectively sample live fishes in these areas. After 10 December, water receded to a point where the two upper marsh sites were dry, and all traps (2 clover and 8 minnow) were placed at an adjacent tidal creek site in the same manner (Figure 1). The tidal creek sampling began on 18 December 1995 and ended on 2 February 1996, when only the perimeter ditch contained water. The traps were fished for ca. 24 hour periods, and all fishes collected during the interior sampling (i.e., upper marsh and tidal creek) of the impoundment were placed on ice and returned to the laboratory for processing. Interior impoundment collections were made at about two week intervals (Table 2).

Environmental data

Surface temperature (mercury thermometer), surface salinity (refractometer), and water level were monitored at the perimeter ditch site, both upper marsh sites, and the tidal creek site on each sample date. Water levels were measured in relation to a National Geodetic Vertical Datum (i.e., sea level reference; NGVD) marker at the perimeter ditch site. A meter stick was used for water depths taken within the impoundment during interior impoundment sampling.

Data analysis

The abundances of all fishes collected in the perimeter ditch were examined to identify the numerical dominants in the system as well as habitat use by recreationally important species during the various impoundment management periods. Relationships that existed between population abundances, environmental data, and events such as culvert opening and closing were also examined. Numerical and length frequency data for the four most abundant recreationally important species were plotted from samples collected during the pre-connection (if applicable), spring open, summer closure, and fall/winter open periods (i.e., impoundment management periods; sampling periods). Kolmogorov-Smirnov two-sample tests were used to examine differences in the length distributions between fish collected during the various sampling

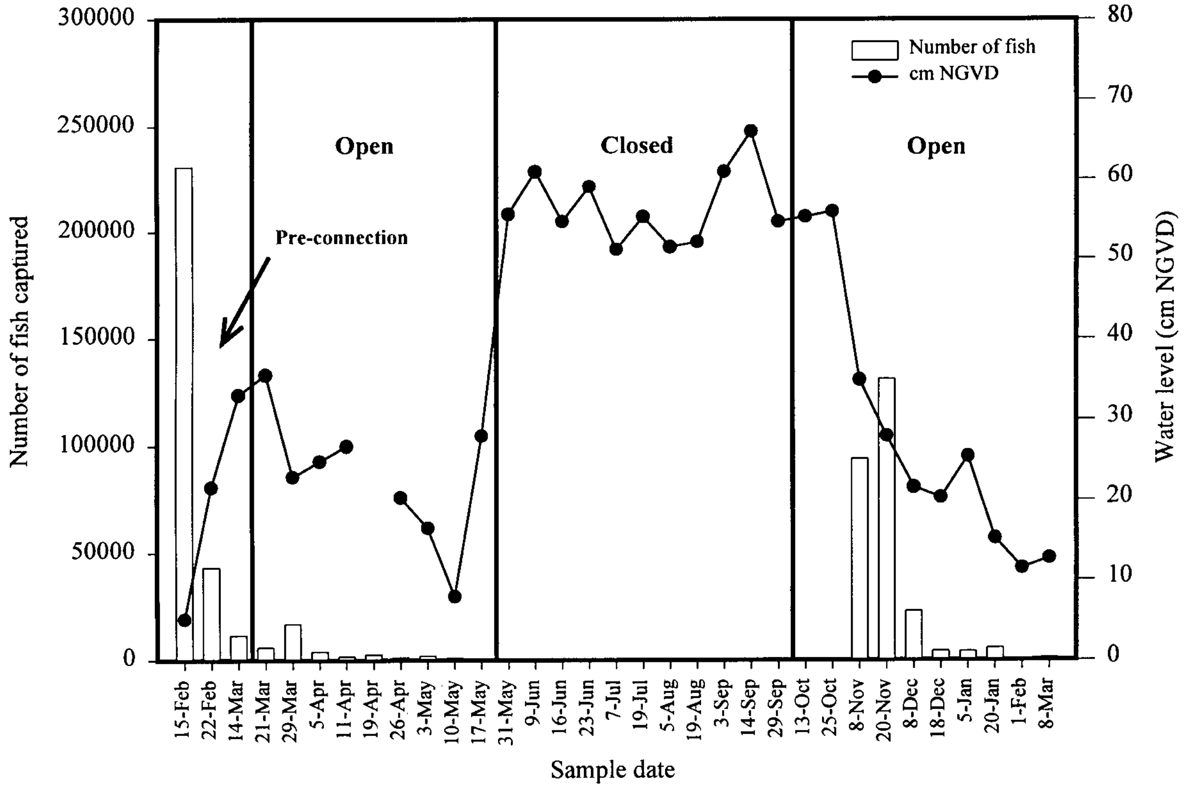

Figure 2. Water levels relative to National Geodetic Vertical Datum (NGVD) and total number of fishes collected at the perimeter ditch site. Vertical lines represent either opening or closing of the culverts and separate the pre-connection, spring open, summer closure, and fall/winter open sampling periods.

periods (Sokal and Rohlf, 1995). Chi-square tests were used to determine if the abundance of fishes captured in the perimeter ditch varied in response to changes in water level (relative to 40 cm NGVD; Sokal and Rohlf, 1995). The 40 cm NGVD mark approximated the level above which fishes could move over the upper marsh. Maximum water depth inside the perimeter ditch at the sample site was ca. 2 m at this water level.

The abundances of all fishes collected during upper marsh and tidal creek collections were also determined. The qualitative data from all traps were combined on individual sample dates for each of the upper marsh and tidal creek sites. Chi-square tests were used to determine if the abundance of fishes captured in the upper marsh (relative to 40 cm NGVD) and tidal creek (relative to mean creek depth) varied in response to changes in water level. Data were summarized for all interior impoundment sampling, and are presented by site (10 clover trap and 40 minnow trap sets for each upper marsh site; 8 clover trap and 32 minnow trap sets for the tidal creek site).

Results

Perimeter ditch environmental data

Water levels in the perimeter ditch fluctuated with rainfall, IRL levels, and mosquito control procedures (i.e., artificial flooding) during the study. Prior to initial reconnection of the impoundment to the estuary, water levels were very low and increased as the time of official culvert opening approached (Figure 2). The water level increase observed on 14 March and 21 March was due to an unusual IRL high water event that occurred as a cold front passed the area on 9 March. During the event, water levels exceeded normal levels for the time of year (Provost, 1973), and were recorded at nearly 60 cm NGVD at an IRL location 1.5 km north of the study site (D. S. Taylor, unpublished data). This high 'tide' forced open the flapgate on the newly-installed culvert C1 and resulted in an abrupt increase in impoundment salinity, entry of the first new transient species, and some dispersal of fishes already

Table 3. Occurrence of fishes collected in the perimeter ditch during the four impoundment management periods (i.e., sampling periods). Resident species and transient species are listed separately in order of abundance. n = number of sampling dates.

Species	Sampling period: Pre-connection (n = 3)	Spring open (n = 9)	Summer closure (n = 11)	Fall/Winter open (n = 10)	Total
Resident species:					
Gambusia holbrooki	140294	19989	172	85776	246231
Poecilia latipinna	94703	3762	6	133388	231859
Cyprinodon variegatus	42781	7601	5	42288	92675
Fundulus confluentus	7724	201		389	8314
Dormitator maculatus		27		44	71
Transient species:					
Pogonias cromis		875	71	2	948
Microgobius gulosus		206	693	49	948
Elops saurus	18	683	119	2	822
Centropomus undecimalis		48	90	607	745
Mugil cephalus		599	77	68	744
Anchoa mitchilli		295	257	3	555
Tilapia melanotheron	9	36	17	449	511
Lucania parva		48		451	499
Megalops atlanticus	79	171	4	235	489
Mugil curema		479	4	2	485
Brevoortia spp.		328	1		329
Diapterus auratus		2	315	10	327
Eucinostomus spp.			215	4	219
Eucinostomus harengulus			140	15	155
Lagodon rhomboides			7	106	113
Gobiosoma bosc		50	42	3	95
Leiostomus xanthurus		48		1	49
Oligoplites saurus			45		45
Strongylura notata			35	1	36
Gobionellus oceanicus		1	25	5	31
Achirus lineatus		3	24	2	29
Other taxa[a] (n = 25)	10	77	79	52	218
Total resident individuals	285502	31580	183	261885	579150
Total transient individuals	116	3949	2260	2067	8392
Total fishes	285618	35529	2443	263952	587542

[a] includes specimens not identified to the species level.

present in the perimeter ditch. This high water event is referred to as the 'unofficial opening' of the culverts.

From 17 May until 29 September, the culverts were closed and the impoundment was flooded for mosquito control. Water levels in the impoundment fluctuated between about 50 and 70 cm NGVD during this period (Figure 2). Between 29 August and 15 September, water levels in the IRL occasionally exceeded that of the perimeter ditch, allowing water to enter the perimeter ditch through the flapgates (G. R. Poulakis, personal observation). These unusually high IRL water levels were associated with precipitation and wind-driven water flow associated with tropical weather systems that affected the area in August and September. Water levels in the perimeter ditch as well as the IRL remained above 50 cm NGVD for about one month after the culverts were reopened in the fall, and gradually receded until the end of the study.

Water temperature and salinity exhibited short-term variability as well as predictable seasonal pat-

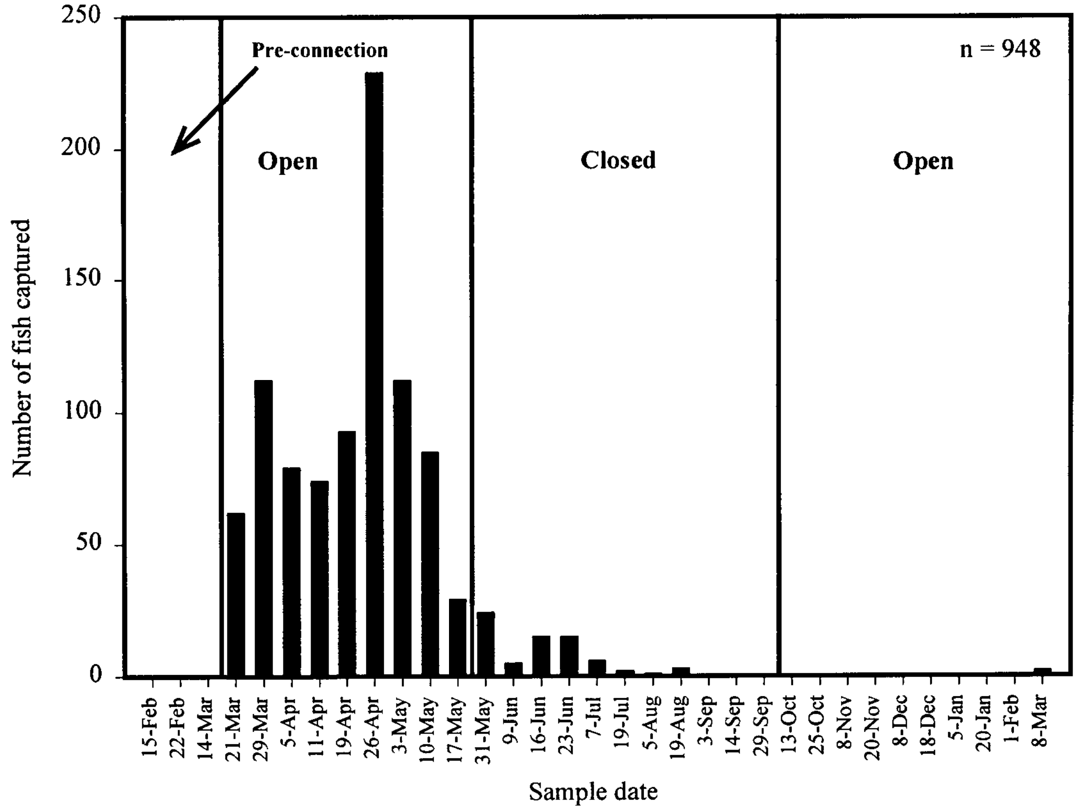

Figure 3. The number of *Pogonias cromis* collected on each sample date at the perimeter ditch site. Vertical lines represent either opening or closing of the culverts and separate the pre-connection, spring open, summer closure, and fall/winter open sampling periods.

terns in the perimeter ditch during the study (Table 1). Temperatures ranged from 18 °C on 22 February 1995 to 36 °C on 9 June 1995. Salinity was highly variable during the study, with values ranging from 5 ppt during the pre-connection period to 35 ppt during the summer closure period.

Perimeter ditch fish abundance

A total of 587,542 fishes and 51 taxa were collected at the perimeter ditch site (Table 3). The resident fishes *G. holbrooki*, *P. latipinna*, *C. variegatus*, and *F. confluentus* numerically dominated the catch. *Pogonias cromis*, *E. saurus*, *C. undecimalis*, and *M. atlanticus* were the most abundant recreationally important transient species, respectively. Because fishes were released alive at the site of capture, an unknown proportion of the catches summarized in Table 3 may represent recaptures of the same individuals. However, the opening of the culverts in the spring and fall, as well as high water levels in the summer provided these fishes with access to other habitats. The abundances of resident fishes ($p < 0.001$, $\chi^2 = 375{,}741$, 1 df) and transient fishes ($p < 0.001$, $\chi^2 = 430$, 1 df) within the perimeter ditch were significantly associated with water levels below 40 cm NGVD, reflecting the restriction of suitable interior impoundment habitats to periods of high water.

Resident species. Peak use of the perimeter ditch site by resident fishes occurred during two periods: (1) prior to impoundment reconnection in the spring, and (2) during the fall/winter open period when water levels were ca. 20–40 cm NGVD (i.e., at the onset of the dry season; Figure 2). The fishes in the perimeter ditch during these periods were primarily *G. holbrooki*, *P. latipinna*, *C. variegatus*, and *F. confluentus* (Table 3). These peaks in abundance at the perimeter ditch site lasted for about one month in both seasons. These four species also used the interior areas of the impoundment when it was accessible (see *Interior impoundment fish abundance* section).

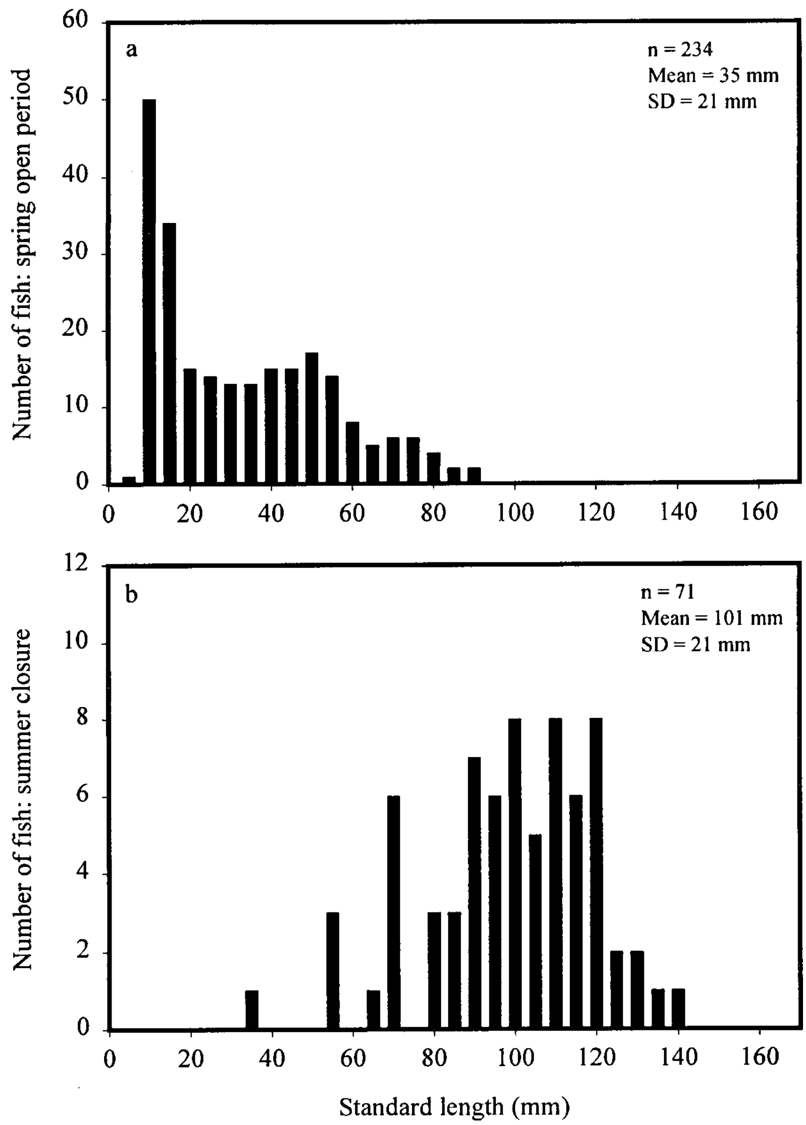

Figure 4. Length frequencies of *Pogonias cromis* collected at the perimeter ditch site during the spring open (a) and summer closure (b) periods. SD = standard deviation.

Spring recruiting transient species. Pogonias cromis moved into the impoundment immediately after official opening of the culverts and peaked in abundance in late April (Figure 3). Numbers began decreasing in late spring, and only a few were trapped when the impoundment was closed. The juveniles captured throughout the spring open period were small new recruits (mean = 35 mm SL; Figure 4). The length distribution of *Pogonias cromis* captured in the perimeter ditch during the summer (mean = 101 mm SL) was significantly different than the distribution observed in the spring (K-S test, $p < 0.01$), and most likely included numerous recaptures of growing fish.

Leptocephalus larvae of *E. saurus* first appeared on 14 March 1995, just after the unofficial opening of the culverts (Figure 5). Most *E. saurus* were captured during the ensuing spring open period and were small post-metamorphic recruits (mean = 36 mm SL; Figure 6). Fewer individuals were captured during the summer closure period, but these fish had a significantly different length distribution (K-S test, $p < 0.01$; mean = 155 mm SL), and most likely included numerous recaptures of growing fish as well as a few

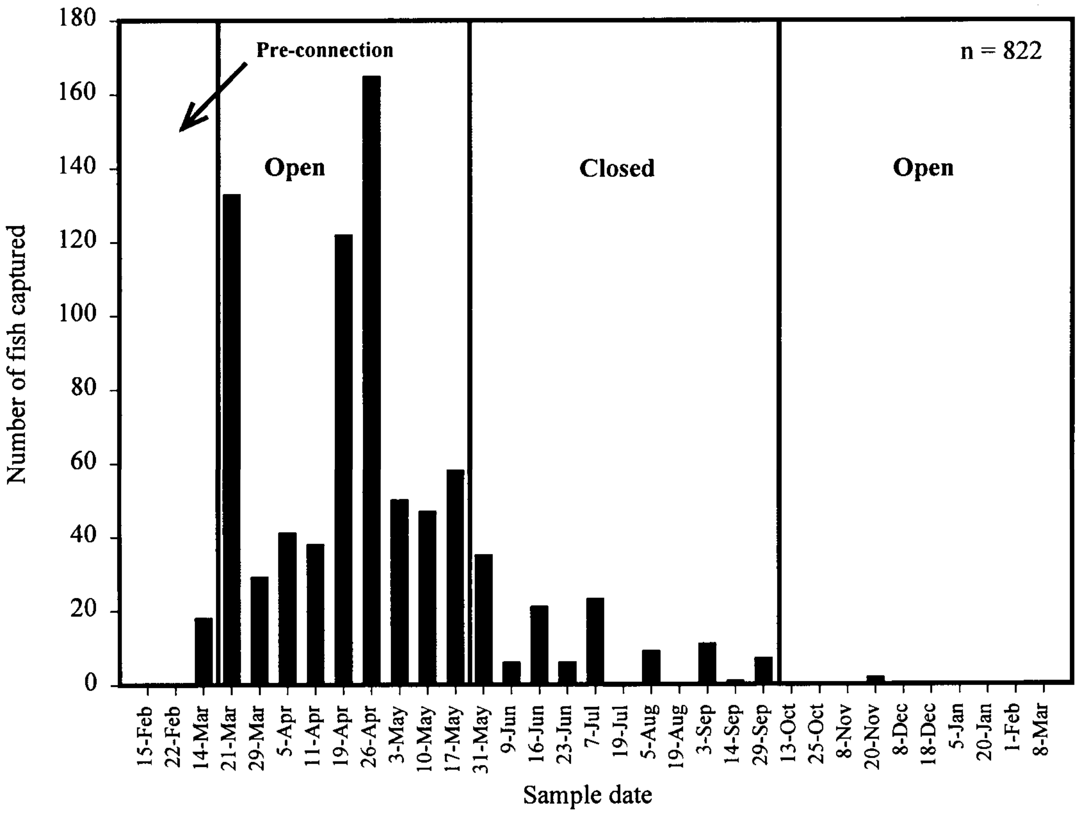

Figure 5. The number of *Elops saurus* collected on each sample date at the perimeter ditch site. Vertical lines represent either opening or closing of the culverts and separate the pre-connection, spring open, summer closure, and fall/winter open sampling periods.

small new recruits that were probably introduced via the pump used to flood the impoundment. Only two *E. saurus* were captured in the impoundment during the fall/winter open period.

Fall recruiting transient species. Centropomus undecimalis first appeared at the perimeter ditch site after the official opening of the culverts, but were most abundant during the fall/winter open period (Figure 7). Small numbers of new recruits were collected during the spring open period (Figure 8), and a gap of approximately three months existed before *C. undecimalis* were again captured at the study site. The presence of *C. undecimalis* at the end of the summer closure period is thought to be related to increased IRL water levels which occasionally forced the flapgates open. Six, 24, and 49 *C. undecimalis* were captured on sequential samples beginning on 3 September when flapgates on culverts C1 and C4 were known to have opened (G.R. Poulakis, personal observation). Observed length distributions were significantly different in each of the sampling periods in which *C. undecimalis* were collected (K-S test, $p < 0.01$). The largest number of small recruits (mean = 39 mm SL) was collected at the perimeter ditch site on 20 November 1995, with numbers declining throughout the rest of the study. In addition, there were only two *C. undecimalis* over 250 mm SL collected in the perimeter ditch during the study, one during the spring open period and one during the fall/winter open period (not shown in Figure 8).

Megalops atlanticus was the only recreationally important transient species captured in the perimeter ditch prior to the unofficial opening of the culverts, with 28 individuals present in the first collection. Tagged individuals were repeatedly recaptured throughout the spring open period, although total numbers declined as the spring progressed (Figure 9). Recapture rates from collections of tagged fish decreased from 76% to 33% during the spring. Based on the high recapture rates of tagged individuals, many of these fish remained at the site for one to two months even though they had easy access to the adjacent IRL through culvert C4. Thus, no difference was found in the length distributions of fish collected between the pre-connection period and the spring open period (K-S

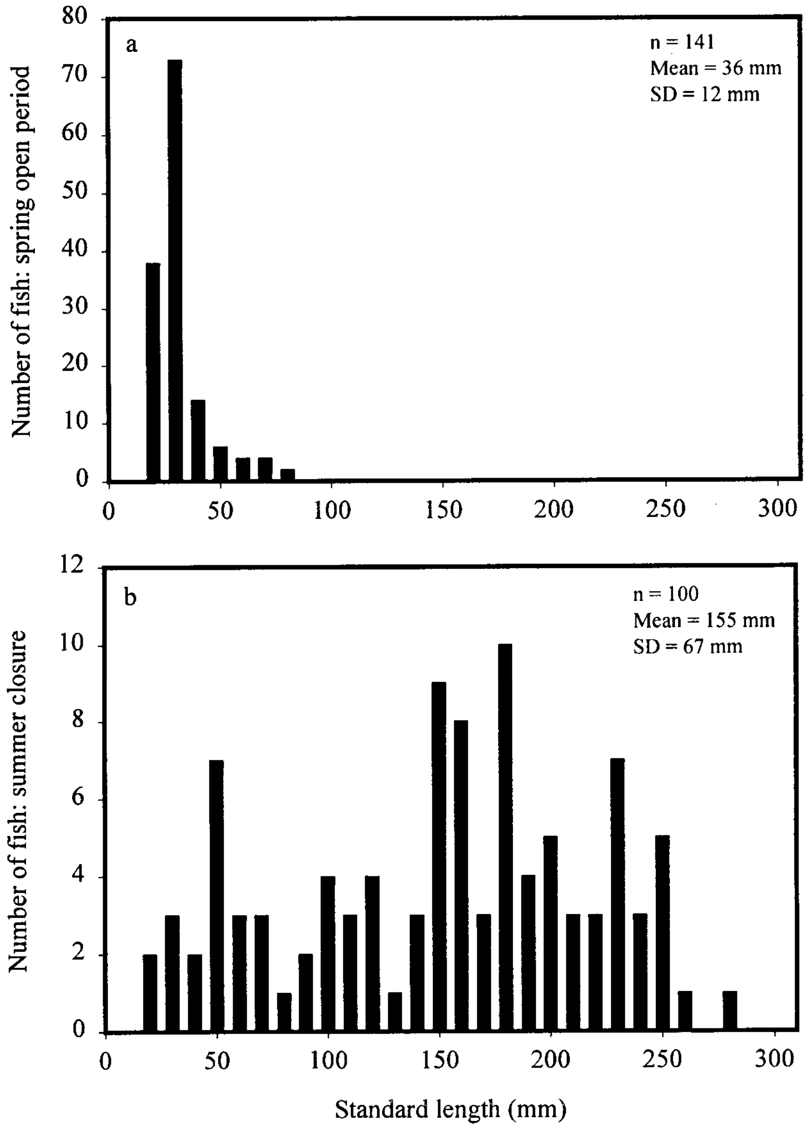

Figure 6. Length frequencies of *Elops saurus* collected at the perimeter ditch site during the spring open (a) and summer closure (b) periods. SD = standard deviation.

test, $p > 0.05$). However, the fall/winter open period was characterized by the entrance of numerous new recruits into the impoundment (mean = 144 mm SL; Figure 10), and the length distribution of these fish was significantly different than the distribution observed during the spring open period (K-S test, $p < 0.01$). In addition, there was only one *M. atlanticus* over 300 mm SL collected in the perimeter ditch during the study (485 mm SL). This fish was captured during the pre-connection period (not shown in Figure 10), and exited the impoundment when the culverts were officially opened (Poulakis, 1996).

Interior impoundment environmental data

Water depth in the interior of the impoundment (i.e., habitat availability) fluctuated in response to rainfall, IRL levels, mosquito control procedures, and evaporation during the study. Depths at the two upper marsh sites varied together over time, and were greatest during the artificially flooded summer closure period (Table 2). Depths were about 15 cm at the beginning of the sampling period in early August, and reached their maximum in mid-September at 32 cm (ca. 67 cm NGVD). A general decrease during the remainder of

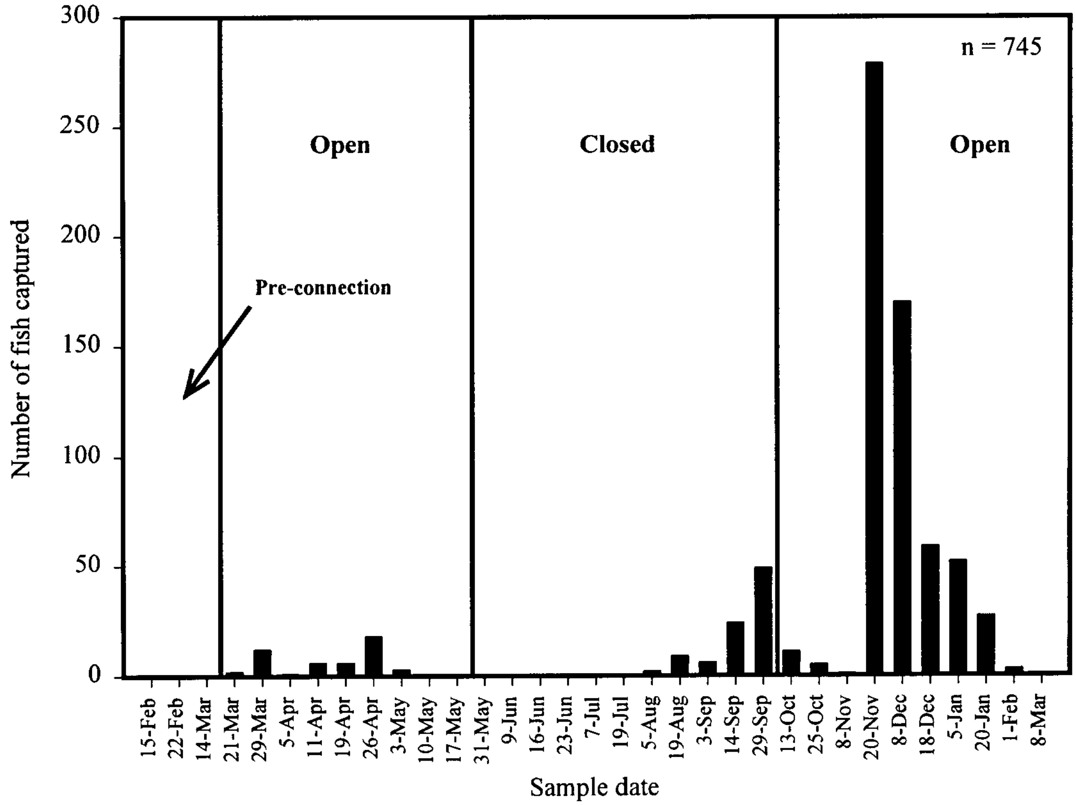

Figure 7. The number of *Centropomus undecimalis* collected on each sample date at the perimeter ditch site. Vertical lines represent either opening or closing of the culverts and separate the pre-connection, spring open, summer closure, and fall/winter open sampling periods.

the summer closure period was observed until the culverts were reopened on 29 September. After the seasonal peak in late October, water levels gradually decreased. Upper marsh site 1 contained only isolated pools by 20 November. Upper marsh site 2 was located at a slightly lower elevation than site 1 and was fishable until 10 December. The traps from both upper marsh sites were then relocated to the nearby tidal creek where water depths ranged from 6 to 16 cm while water was present during the four tidal creek samples (Table 2).

Water temperature and salinity values were similar at the interior impoundment sites during the study (Table 2). The mean temperature at the two upper marsh sites was ca. 31 °C during the summer closure period, and decreased to a minimum of 16.5 °C at site 2 on 10 December. The mean temperature was 25 °C during the four tidal creek samples. Larger diel fluctuations most likely occurred however. Salinity values at the two upper marsh sites ranged from 10 ppt to 22 ppt during the summer closure period, and from 5 ppt to 20 ppt during the fall/winter open period. Beginning in early November, salinities were 7–10 ppt higher at site 1 than at site 2 for the remainder of the upper marsh portion of the study. The mean salinity was 15 ppt during the tidal creek samples.

Interior impoundment fish abundance

A total of 7,251 fishes and seven species were collected at the two upper marsh sites (Table 4). The resident fishes *G. holbrooki*, *P. latipinna*, *C. variegatus*, and *F. confluentus* collectively made up over 99% of the total catch at the two upper marsh sites. *Dormitator maculatus* (Bloch) (n = 3; resident), *Lucania parva* (Baird & Girard) (n = 1; transient), and *Tilapia melanotheron* (Rüppell) (n = 1; transient) were also collected. The abundance of fishes at the two upper marsh sites was significantly associated with water level ($p < 0.001$, $\chi^2 = 957$, 1 df). Peaks of abundance were observed during periods that approached about 40 cm NGVD as the impoundment surface dried and fishes became concentrated at the trap sites. In addition, 67% of all

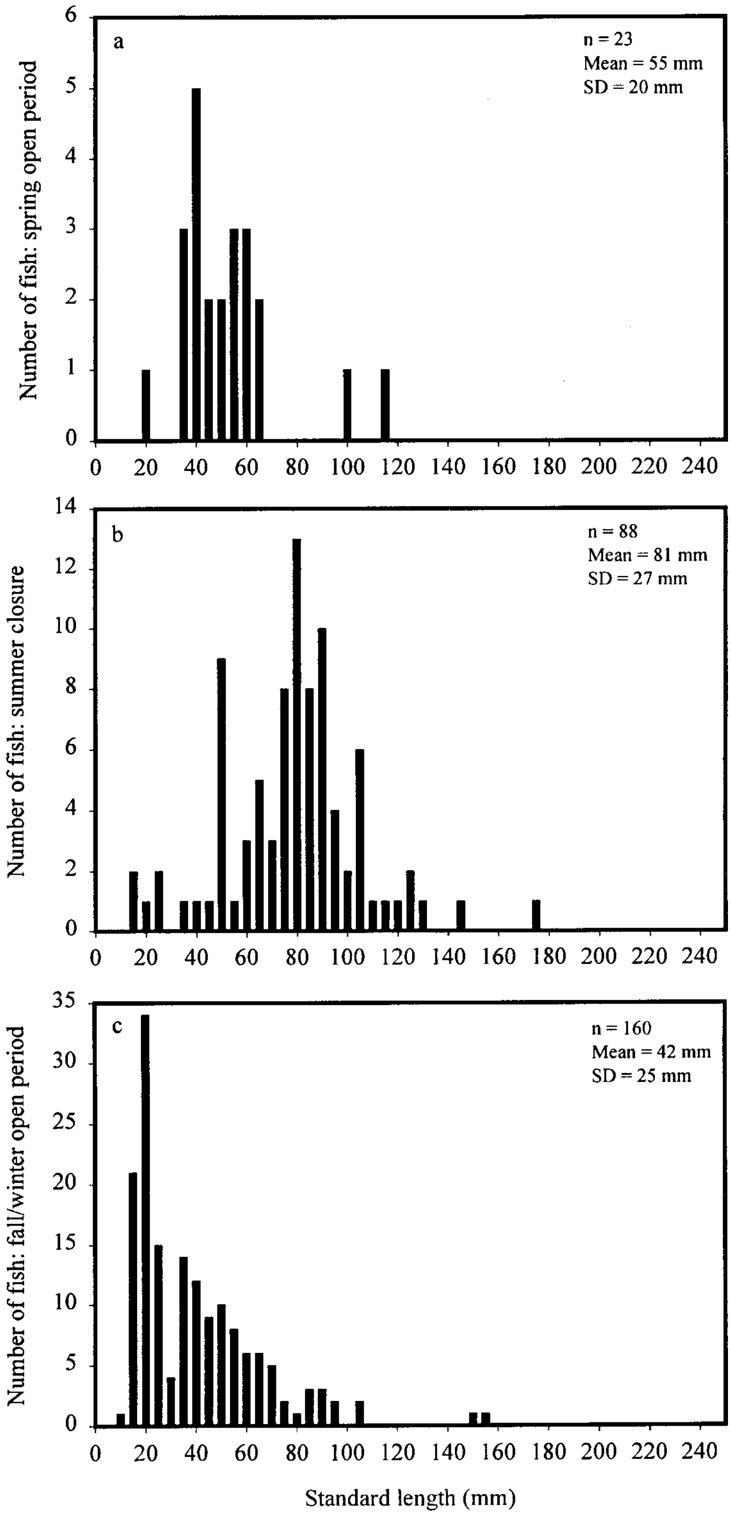

Figure 8. Length frequencies of *Centropomus undecimalis* collected at the perimeter ditch site during the spring open (a), summer closure (b), and fall/winter open (c) periods. SD = standard deviation.

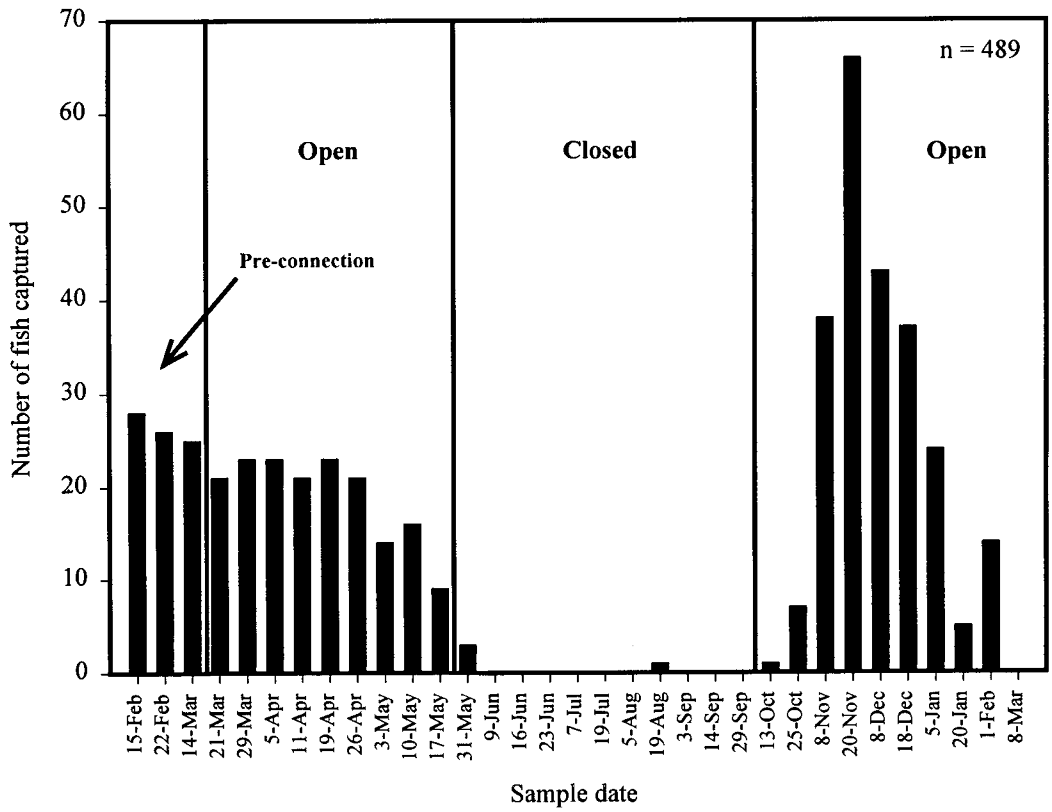

Figure 9. The number of *Megalops atlanticus* collected on each sample date at the perimeter ditch site. Vertical lines represent either opening or closing of the culverts and separate the pre-connection, spring open, summer closure, and fall/winter open sampling periods.

Table 4. Occurrence of fishes collected during interior impoundment sampling at the two upper marsh sites and the tidal creek site. Species are listed in order of abundance. n = number of sampling dates.

Species	Upper marsh Site 1 (n = 10)	Upper marsh Site 2 (n = 10)	Tidal creek (n = 4)	Total
Cyprinodon variegatus	1237	2268	221	3726
Fundulus confluentus	629	581	640	1850
Gambusia holbrooki	1210	446	85	1741
Poecilia latipinna	307	568	125	1000
Dormitator maculatus	3	0	3	6
Lucania parva	0	1	0	1
Tilapia melanotheron	0	1	0	1
Mugil cephalus	0	0	1	1
Total	3386	3865	1075	8326

fishes captured at the two upper marsh sites were taken in the clover traps.

A total of 1,075 fishes and six species were collected during tidal creek sampling (Table 4). *Fundulus confluentus*, *C. variegatus*, *P. latipinna* and *G. holbrooki* numerically dominated the catch at the tidal creek site, respectively. *Dormitator maculatus* (n = 3) and *Mugil cephalus* Linnaeus (n = 1; transient) were also collected. The abundance of fishes collected at the tidal creek site was greatest during the last two samples when average water depths were about 6 cm (i.e., the shallowest depth at which the traps could effectively fish; $p < 0.001$, $\chi^2 = 382$, 1 df), and lower at depths above 10 cm when fish could disperse more. The cyprinodontids were largely responsible for the increased catches as the tidal creek dried. These observations suggested that *F. confluentus* and *C. variegatus* were the last species to leave the interior areas of this impoundment as they dried.

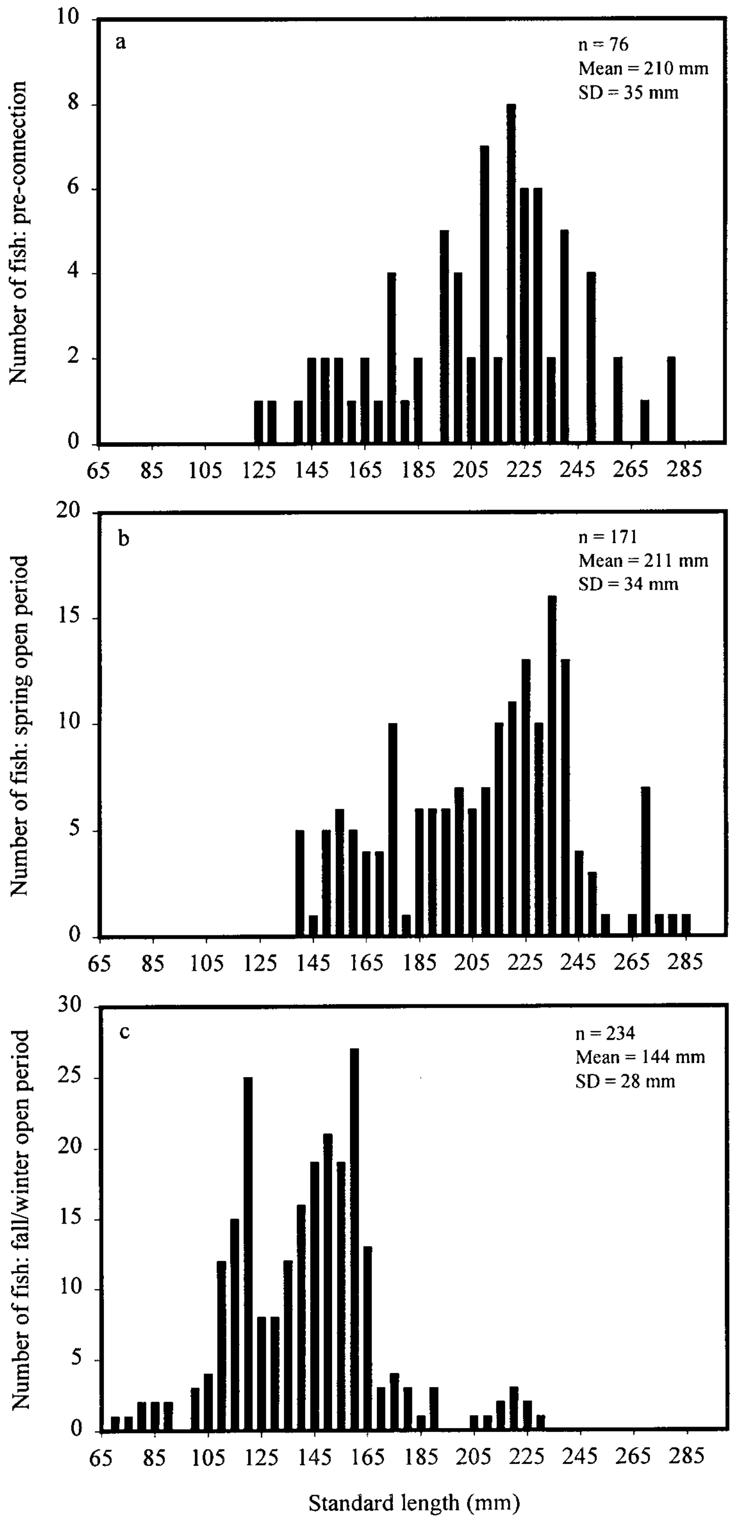

Figure 10. Length frequencies of *Megalops atlanticus* collected at the perimeter ditch site during the pre-connection (a), spring open (b), and fall/winter open (c) periods. SD = standard deviation.

Discussion

The increase in the diversity of species within the impoundment following tidal reconnection was more rapid than has been reported in other studies. Rey et al. (1990) demonstrated an increase from 14 to 22 species and from 12 to 16 species two years after tidal reconnection of two impoundments in Indian River County, Florida (16.19 ha and 12.14 ha, respectively). O'Bryan et al. (1990) collected seven species before and 23 species approximately two years after tidal reconnection of a 129.5 ha Indian River County impoundment. However, Taylor et al. (1998) demonstrated an increase from 9 to 21 species after only a 27 day period within this impoundment. Additional data presented here showed that 19 more species were found during the next 11 weeks. Thus, this impoundment experienced an increase from 9 to 40 species within only a 15 week period after tidal reconnection. Throughout the remainder of the study (37 weeks), only 5 new species were collected within the perimeter ditch. This rapid recolonization indicates that fishes living in the IRL adjacent to impoundments will use the habitat expansion provided via the culverts virtually as soon as the opportunity arises, seemingly regardless of season. The diversity of species observed here may have been enhanced as a result of the bottom topography of the impoundment (i.e., less net avoidance because fishes were forced to inhabit the study site at water levels below 40 cm NGVD), its close proximity to Sebastian Inlet, and the exceptionally high water levels that existed when tidal reconnection (culvert opening) initially took place. In addition, although the rapid increase in the number of species found within the impoundment was due to the collection of more low abundance species than in other studies, the presence of some of these species (e.g., *Cynoscion nebulosus* (Cuvier), *Archosargus probatocephalus* (Walbaum), *Sciaenops ocellatus* (Linnaeus), and *Trachinotus falcatus* (Linnaeus)) suggests that the benefits of restoring marsh access for transient fishes are even greater than previous studies have suggested. The increase was also somewhat unexpected since the majority of transient species have historically entered impoundments in east-central Florida during the fall and winter (Gilmore, 1987).

Water level is an influential environmental parameter that affects the abundance and distribution of fishes in wetland habitats (Subrahmanyam and Drake, 1975; Gilmore, 1987; Rey et al., 1990; Faunce and Paperno, 1999), and had the greatest effect on resident fish habitat use during this study. Large numbers of resident fishes were trapped in the perimeter ditch before initial impoundment reconnection in the spring, and again as the water level receded in late fall (see Figure 2, Table 3). When the culverts were first opened in the spring, many of these trapped residents emigrated out of the impoundment (Taylor et al., 1998). When water levels inside the impoundment rose above 40 cm NGVD, these fishes moved to the otherwise inaccessible interior areas of the impoundment. Upper marsh and tidal creek collections produced only three transient individuals out of 8,326 fishes captured, suggesting that during the first year of tidal reconnection, primarily residents used the interior areas of the impoundment during high water periods. Although the traps we used to sample the interior of the impoundment would have been effective at capturing only small transients, this type of habitat use has been observed in other studies (Talbot and Able, 1984; Gilmore, 1987; Rey et al., 1990), and may be related to perimeter ditch overcrowding, the ability of resident species to handle extreme environmental conditions (Gilmore et al., 1982; Nordlie, 1985), predation risk (Rey et al., 1990), their willingness to go into shallow water associated with marsh vegetation, or a combination of these factors.

The seasonal patterns of impoundment use by transient species were primarily associated with spawning seasonality and water level. Most transient species used the impoundment during a single impoundment management period, but some were captured throughout the year (e.g., *M. cephalus*) or were abundant in multiple periods (e.g., *M. atlanticus*). In addition, the fact that transients almost exclusively resided in the perimeter ditch during the study may be due to increased predatory efficiency, better access to the IRL, or to pump effects on the site (i.e., rheotaxis or enhanced dissolved oxygen) during the artificially flooded summer closure period. Harrington and Harrington (1961) found transients in their pre-impoundment upper marsh collections; however, not surprisingly most were collected in seines used to sample more open pond-like habitats. Few seinable areas existed in the interior of this impoundment even at the highest water levels due to extensive mangrove growth, and no larger transients were visually observed during either exploration of the interior areas of the impoundment or while conducting interior impoundment sampling.

Although temperature and salinity followed predictable seasonal patterns, they did not appear to be major limiting factors that affected habitat use for most species. This observation has been made by other investigators and may be explained by the subtropical climate and euryhaline nature of most fish species that inhabit marshes at these latitudes (Blaber and Blaber, 1980; Gilmore, 1987; Rey et al., 1990). The one exception to this generalization was *T. melanotheron*, a nonindigenous species that has become very abundant since its introduction into the IRL system. This species is even considered a resident of other impounded marshes in the IRL (Faunce, 1995). *Tilapia melanotheron* initially present in the impoundment died as a result of a cold weather period in February 1995 (Taylor et al., 1998), and although collected periodically throughout the year, had not permanently recolonized the impoundment by the conclusion of this study. Temperature and impoundment bottom topography are likely to be important factors that determine the success of this species in this impoundment as well as other impounded wetlands throughout the IRL system.

Compared with other studies conducted in the IRL, a large number of *P. cromis* were collected in this study. Although an unknown percentage of the 948 *P. cromis* collected in this study were recaptures, up to 229 were captured in a single sample. This observation, combined with the fact that fish appeared to grow (see Figure 4) at rates comparable to other Florida populations of this species (Peters and McMichael, 1990), suggests that the perimeter ditch site was favorable habitat for juveniles during the spring and summer (similar observations were made for *E. saurus* as well). The absence of *P. cromis* in summer closure period collections after 19 August may have been the result of mortality, but more likely indirectly indicated movement of this species out of the impoundment during flapgate opening events that were observed in late summer.

Seasonal use of the impoundment by *C. undecimalis* was observed during the study. While some *C. undecimalis* were captured during the spring, these were mostly less than 70 mm SL and were probably from late spring spawning activity (Tucker and Campbell, 1988). Most spawning typically occurs in the summer however (Gilmore et al., 1983), and indirect evidence suggested that new juveniles recruited into the impoundment during the periods of high water that caused flapgates to open in late summer. The largest numbers of newly recruited *C. undecimalis* were captured after the culverts were reopened in the fall and many individuals moved through the culverts during the first 24 hours that the culverts were open following the mosquito breeding season (101 in two culvert traps and 44 in two plankton nets; Poulakis, 1996).

Megalops atlanticus is a euryoecious transient species that was collected in all four impoundment management periods. It was the only recreationally important species collected before initial reconnection of the impoundment, and its presence was most likely due to pump transport of leptocephalus larvae into the impoundment. Because water quality is poorest during periods when impoundments are isolated from estuarine connection (Gilmore et al., 1982; Rey et al., 1992), their survival before tidal reconnection was likely related to the ability of these fish to breathe air (Wade, 1962).

Megalops atlanticus were most abundant during the spring and the fall. During the spring open period, many tagged fish present before culvert opening remained within the impoundment well after tidal reconnection took place. The principle food source for *M. atlanticus* (and other transients) are the resident fish species (Gilmore, 1987) which were present in high numbers during the spring and fall. The tagged fish probably remained in the impoundment well into the spring open period because there were abundant food resources and there was low predation pressure. The large numbers of *M. atlanticus* collected in the fall were small new recruits from summer spawning activity (Crabtree et al., 1992) and these fish used the study site as a nursery ground in the fall when prey were abundant.

Extensive sampling in various habitats within the impoundment revealed patterns of habitat use by fishes associated mainly with water level, impoundment bottom topography, and the seasonal nursery function of the impoundment for transient species. These observations support the contention that reconnecting isolated wetlands (or enhancing existing connections) to estuaries (especially those near ocean inlets), restores valuable habitat for estuarine-dependent fishes. The RIM technique employed in the IRL is effective in balancing insect control considerations as well as habitat access for organisms and its success should motivate restoration efforts in other estuarine systems that have extensively impacted wetlands. Multi-agency cooperation is often necessary to enhance project development and maximize the balance between diverse management goals and the restoration and preservation of valuable wetlands.

Future investigations in the IRL should address potential differences in the recruitment of fishes into different impoundments based on distance from the nearest ocean inlet, and in the case of an elongated, narrow estuary with multiple inlets like the IRL, whether differences in recruitment might depend upon impoundment location north or south of mid-estuary inlets. Future research should also examine the potential attractive properties of the mosquito control pump in these impoundments as well as the fate of transients trapped within the impoundments during the summer closure period. A better understanding of the dynamics associated with habitat use by fishes in a variety of impounded marshes on both short- and long-term time scales may help impoundment managers maximize the fisheries enhancement properties of these systems.

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