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Assessing the Habitat Structure for Common Snook (*Centropomus undecimalis* Bloch, 1792) and Tarpon (*Megalops atlanticus* Valenciennes, 1847) in Santa Teresa Lagoons, Puerto Rico

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Abstract

This paper assessed whether the habitat structure of the Santa Teresa lagoons, Humacao Natural Reserve (HNR), Puerto Rico was able to support long-term fisheries of tarpon (*Megalops atlanticus*) and common snook (*Centropomus undecimalis*). Relations between fish and invertebrate communities and the physicochemical and habitat structure of the lagoon system were identified. Santa Teresa 2 (ST2) was physicochemically and structurally different than Santa Teresa 1 (ST1). Reduced turbidity and increased habitat complexity created by submersed vegetation in ST2 were reflected in the composition of the fisheries resources. Tarpon predominated in ST2 and common snook predominated in ST1. Catch-per-unit-effort (CPUE) of tilapia (Mozambique tilapia *Oreochromis mossambicus* and redbreast tilapia *Tilapia rendalli*) was the highest in ST2, and CPUE of grass shrimp (*Palaemonetes* sp.) was the highest in ST1. Tilapia represented 96% of the tarpon diet, whereas grass shrimp represented 23% of the snook diet. Links between fish habitat use and habitat structure indicated that the Santa Teresa lagoons have the habitat structure necessary to support tarpon and snook long-term fisheries.

Keywords: Caribbean Sea, coastal lagoon, fisheries, habitat.

Introduction

Fish abundance, species diversity and use (e.g., spawning, nursery, duration of residency) have been used to determine whether particular wetland habitats provide adequate functional value for fish (Levin *et al*., 1996). Fish rapidly colonize new sites, often leading to the perception that such sites provide fully functional value (Callaway *et al*., 2001). However, accumulating evidence suggests that species occurrence or abundance may not accurately indicate habitat value (Minello and Web, 1997). The spatial distribution of food and habitat differences may be important in determining fish habitat use (Lima and Dill, 1990).

Coastal lagoons are important habitats for fish reproduction, feeding and shelter (Kuo *et al*., 2001). The lagoon system at Humacao Natural Reserve (HNR), Puerto Rico represents an important source of fish for the surrounding municipalities. It has developed with no anthropogenic attempts; e.g., engineering the topography or hydrology, amending the soil, and/or manipulating vegetation or fauna to accelerate or modify ecological processes (Vilella and Gray, 1997; Zedler, 2001). However, the connection to the sea and the interconnectivity of the lagoons are dependent on a remnant artificial channel that likely allows the entire lagoon system to maintain its ecological integrity. These facts confer the lagoon system a unique ecological status; it is not an artificial system, because it was not conceived as such and because it's historical development followed with little direct human intervention, but it cannot be considered as a natural system either, because an artificial channel supports its ecological functionality. Because of historical evidence indicating a coastal lagoon existed in the area [United States Department of Commerce (USDC) and Department of Natural and Environmental Resources of Puerto Rico (DNER), 1986], the lagoon system is defined here as a semi-natural environment. Thus, the interest was to determine whether the HNR lagoon system had a habitat structure equivalent to that of a natural system to support common snook (*Centropomus undecimalis* Bloch, 1792; from now on just snook) and tarpon (*Megalops atlanticus* Valenciennes, 1847) long-term fisheries.

Materials and Methods

Study Site

The HNR lagoon system, located in eastern Puerto Rico (18°10' N, 65°46' W) (Figure 1), was created in 1979 when Hurricane David and Tropical Storm Frederick overtopped and breached extensive levees and ditches that diverted Anton Ruiz River to maintain a sugar cane industry that was established in the 1920s when extensive wetland areas were deforested and drained (USDC-DNER, 1986). Two major channels (Mandri and Frontera) were dredged, and a pumping station was constructed at their confluence to drain the entire area. Agreements between the sugar cane industry owners and the

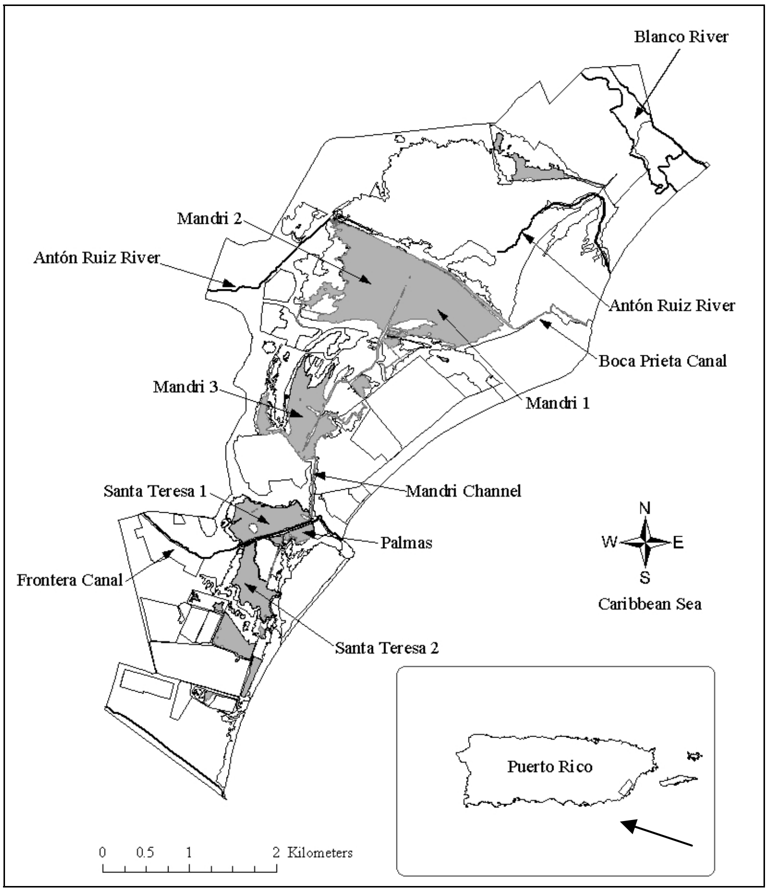

Figure 1. Map of Humacao Natural Reserve, Puerto Rico showing major hydrographic features.

Puerto Rico Government, and legal actions filed by local environmental organizations led to the designation of the area as a natural reserve in 1986 (DNER, 1995).

Six lagoons compose the system: Mandri 1, 67 ha; Mandri 2, 74 ha; Mandri 3, 52 ha (Mandri System; MS); Santa Teresa 1 (ST1), 27 ha; Santa Teresa 2 (ST2), 24 ha (Santa Teresa System; STS); and Palmas, 5 ha. The entire lagoon system only connects to the sea through the MS during periods of substantial precipitation; this semi-closed nature likely influences fish and invertebrate abundance and species composition, and determine habitat structure of the lagoon system (Jackson *et al*., 2001).

This study was limited to the STS because most of the fisheries developed in the HNR lagoon system concentrate on it (Jackson *et al*., 2001). The immersed wetland of the STS is mainly characterized by erect, rooted, herbaceous hydrophytes, typically cordgrass (*Spartina* sp.) and cattail (*Typha dominguensis* Pers.); ST2 also contains submersed vegetation (najas, *Najas* sp. and chara, *Chara* sp.) that potentially provides microhabitat structure important to fish. The STS is shallow (~1 m), and water levels mostly vary in response to precipitation.

Determination of Prey Availability

For assessing invertebrates and early life stages of fish, microhabitats were sampled using light traps and pop nets. Sixty-seven light traps (Floyd *et al*., 1984) were set for one night/month from approximately 3-h before sunset to 1-h after sunrise from May 2000 through April 2001. A 12-h Cyalume chemical stick illuminated each trap.

Ninety-four pop nets (Larson *et al*., 1986; Killgore *et al*., 1989) were set for 10 minutes each from June 2000 through May 2001. Samples were retrieved by carefully inserting a 0.5-mm mesh net mounted in an aluminium frame below the pop net and then lifting it slowly to the surface with trapped prey items. Fish and invertebrates collected were preserved in 5% formalin, counted and identified in the laboratory.

Snook and Tarpon Stock Assessment

For assessing snook and tarpon, 84 gill nets and 42 trap nets were used during March, June, July, October 2000 and January-April 2001. Gill nets were 30 m long by 2 m deep and consisted of four 7.5 m panels of 1.3, 2.5, 3.8 and 5.1 cm bar-mesh monofilament nylon netting. 2 to 15 gill nets per month in each lagoon were set early to mid-morning. Trap nets were 1.3 cm bar-mesh nylon with two 1.8 m by 0.9 m frames, four 0.8-m diameter hoops and a 14 m by 0.8 m lead. One to nine trap nets were set per month in each lagoon; all trap nets were set in mid-morning and retrieved soon after sunrise the following morning. Fish collected were measured to the nearest millimeter (total length), weighed to the nearest gram, and returned to the water.

14 snook and 12 tarpon were retained to determine stomach contents. Although this sample can be considered as too low, the amount of fish retained was limited to minimize the sample-related fish mortality that might influence future catches in these small lagoons as well as generate negative public reaction to the study. Guts were removed and preserved in 5% formalin; and in the laboratory whole guts and gut contents were individually weighed (wet weight) and contents examined with a dissecting microscope. Gut contents were sorted by prey item and each individual item weighed to the nearest 0.001 g. All items were identified to the lowest possible taxon. Fish identifications were based on Erdman *et al*. (1986). Primary reference for identification of invertebrates was Pennak (1989).

Physicochemical Variables

Depth (m), Secchi transparency (m), water temperature (°C), dissolved oxygen (mg/L), dissolved oxygen percent saturation (%), specific conductance (µS/cm), salinity (ppt), total dissolved solids (g/L), turbidity (NTU) and pH were determined at each sampling site. Depth was measured with a stadia rod and the remaining variables with a Datasonde 4A Hydrolab Multi-Parameter Water Quality Instrument with a Surveyor 4 display (Hach Corporation, Loveland, Colorado). All readings were taken at the time of light traps and pop net setting at mid-water depth. Records of lagoon system water levels were taken from a depth gauge at the canal in front of HNR headquarters. Daily precipitation data from 1988 to 2001 were obtained from records at HNR headquarters. These values were used to calculate monthly average precipitation for 12 years preceding the study, as well as for the study period.

Data Analyses

Fish and invertebrate catch-per-unit-effort (CPUE) were independently determined for sampling gear and specific habitat type. A paired-samples Student's t-test (PROC MEANS; SAS, 2003) was used for testing differences of fish and invertebrate CPUEs between lagoons. A one-way analysis of variance (ANOVA, PROC GLM; SAS, 2003) was used to test for differences in fish and invertebrate CPUEs among microhabitats within lagoons. Data of all sampling dates were pooled for these analyses. Levels of statistical significance for all analyses were set at P<0.05. All ANOVA assumptions were tested following directions by Milliken and Johnson (1992) and Underwood (1997).

Results

Physicochemical Variables

Over 54% (93 out of 170 cm) of all precipitation during the study occurred between May and September 2000 (Figure 2). The wettest months were May, August and September 2000, when total precipitation was 53% higher than the 12 yr average (24.3 vs. 15.9 cm). The driest month was March 2000, when total precipitation was 66% lower than the 12-yr average (2.08 vs. 6.09 cm). Overall, 2000 was a dry year with a 26 cm (16%) precipitation deficit relative to 1988-1999. Water level was the lowest during April-July 2000 and the highest during September-October 2000 (Figure 2). The substantial increase in the water level observed in August 2000 was the result of Hurricane Debby, which produced 11 cm of

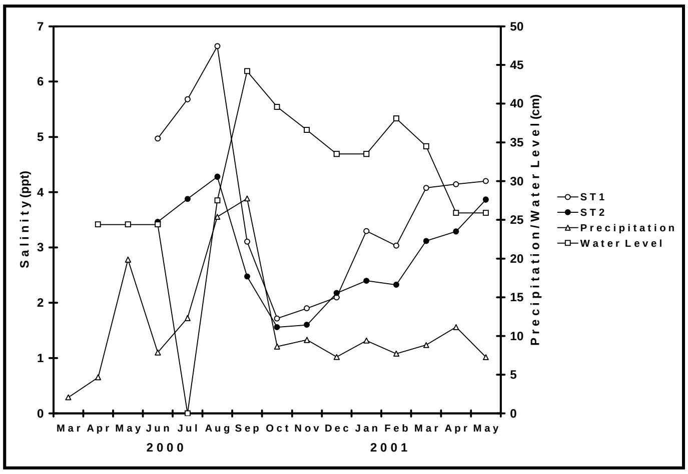

Figure 2. Mean monthly lagoon water level (cm), monthly precipitation values (cm) and mean monthly salinity (ppt) for Santa Teresa 1 (ST1) and Santa Teresa 2 (ST2), Humacao Natural Reserve, Puerto Rico, March 2000-May 2001.

precipitation. Relative to ST1, ST2 had greater depth and Secchi disk depth, and lower salinity, total dissolved solids, turbidity, pH, and specific conductance. In general, average salinity in the lagoons increased and decreased following patterns of precipitation in the reserve (Figure 2).

Total Abundance of Fish and Invertebrates

A total of 11 families and 14 species of fish were collected with all sampling gear: 2,637 in ST1 (71.3%), and 1,059 (28.7%) in ST2. The the highest abundances of tarpon and tilapia (Mozambique tilapia *Oreochromis mossambicus* and redbreast tilapia *Tilapia rendalli*) were from ST2, whereas the the highest abundance of snook was from ST1. A total of 18,642 grass shrimp (*Palaemonetes* sp.) was collected (15,311 in ST1; 3,331 in ST2).

Relative Abundance of Prey Items

Santa Teresa 2 yielded the greatest mean CPUE of tilapia collected with pop nets and ST1 yielded the greatest mean CPUE of tilapia collected with light traps. However, difference between lagoons was significant (t = 3.68, df = 11, P<0.05) for pop nets but not for light traps (t = 0.16, df = 11, P>0.05). Santa Teresa 2 yielded significantly greater mean CPUE of tilapia collected with gill nets (t = 7.09, df = 7, P<0.05) and trap nets (t = 3.11, df = 7, P<0.05) than ST1. Santa Teresa 1 yielded the greatest mean CPUE of grass shrimp collected with pop nets and light traps however, difference between lagoons was significant for light traps (t = 3.60, df = 11, P<0.05), but not for pop nets (t = 0.67, df = 11, P>0.05).

Overall, relative abundance of tilapia was greater in submersed vegetation (i.e., najas, chara) than in the other plant communities in ST2, whereas in ST1 no difference between plant communities was observed (Figure 3). On the other hand, relative abundances of grass shrimp were homogeneous among plant communities in ST2, whereas in ST1 CPUE of grass shrimp was greater in cordgrass for pop nets and no differences were detected between plant communities for light traps (Figure 4).

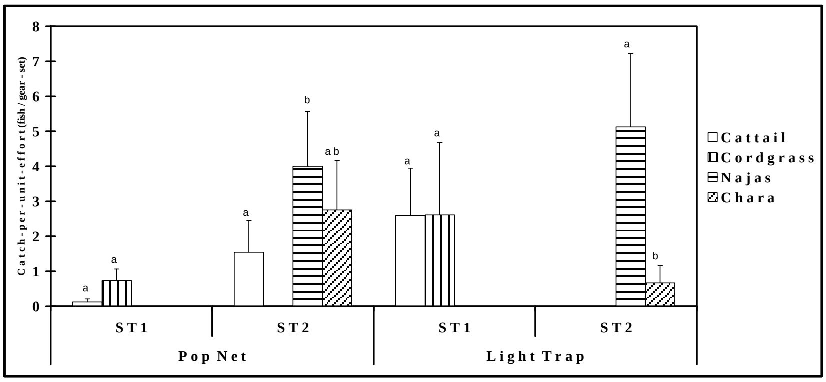

Figure 3. Mean catch-per-unit-effort ± SE (fish/gear-set) of Mozambique tilapia (*Oreochromis mossambicus*) and redbreast tilapia (*Tilapia rendalli*) collected with pop nets or light traps among microhabitats at Humacao Natural Reserve, Puerto Rico, May 2000-May 2001. Microhabitats: Cattail= *Typha dominguensis* Pers., Cordgrass= *Spartina* sp., Najas= *Najas* sp., Chara= *Chara* sp. Means with the same letter are not significantly different among microhabitats.

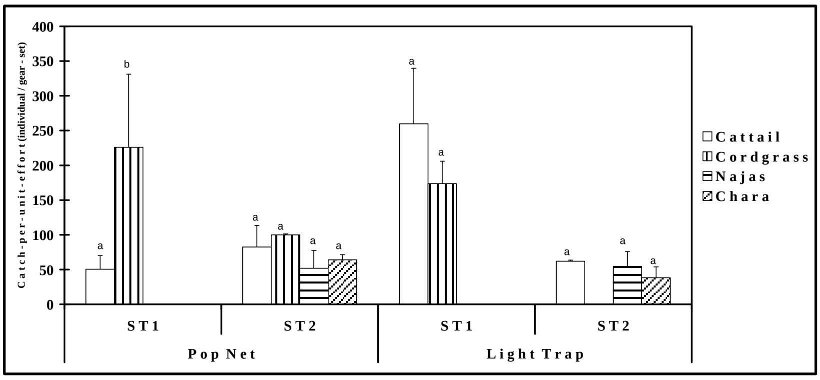

Figure 4. Mean catch-per-unit-effort ± SE (individual/gear-set) of grass shrimp (*Palaemonetes* sp.) collected with pop nets or light traps among microhabitats at Humacao Natural Reserve, Puerto Rico, May 2000-May 2001. Microhabitats: Cattail= *Typha dominguensis* Pers., Cordgrass= *Spartina* sp., Najas= *Najas* sp., Chara= *Chara* sp. Means with the same letter are not significantly different among microhabitats.

Food Habits

Total length ranges of fish used for stomach content analyses were 192 to 562 mm for snook, and 380 to 552 mm for tarpon. Eleven (79%; 8 from ST1, 3 from ST2) stomachs of snook and six of tarpon (50%; 2 from ST1, 4 from ST2) contained prey items. Stomach contents of snook were dominated by vegetal matter, followed by grass shrimp, tilapia, crabs, and snails, whereas tarpon stomachs were dominated by tilapia and grass shrimp.

Snook and Tarpon Assessment

Mean CPUEs for snook and tarpon collected with trap nets and gill nets are shown in Table 1. Mean CPUE of snook collected with gill nets was not significantly different between lagoons (t = 1.50, df = 7, P>0.05). Only three snook (one in ST1, two in ST2) were collected with trap nets. Therefore, no statistical analyses were done. Mean CPUE of tarpon collected with gill nets was significantly greater in ST2 than in ST1 (t = 2.37, df = 7, P<0.05). Santa Teresa 2 yielded a greater mean CPUE than ST1 of tarpon collected with trap nets, although difference between lagoons was not significant (t = 0.83, df = 7, P>0.05).

Discussion

Fish and invertebrates are primary attributes reflecting habitat value for wetlands (Minello and Zimmerman, 1992; Williams and Desmond, 2001); benthic invertebrates provide food-web support for consumers such as birds and fish (Quammen, 1984), and fish function as vehicles for nutrient cycling and energy transfer across habitats at a number of trophic levels in the estuarine food web (Kwak and Zedler, 1997). In return, wetlands provide these animals with areas for refuge, reproduction, feeding, and other essential functions (Williams and Desmond, 2001). This study suggests that current environmental conditions of the lagoons provide important habitats that could support fisheries of tarpon and snook. These findings are not just based on the paradigm that fish presence reflects habitat value, but a confirmation that the STS provides spawning habitat and refuge to fish and invertebrates that serve as food to tarpon and snook.

Juveniles and sub-adult fish dominated the catches of both snook and tarpon, indicating the lagoons act as early life stage habitats. Although female snook mature at 500-522 mm fork length (FL) and males at 330-348 mm FL (Peters *et al*., 1998), and some of them in the lagoon exceeded this length, snook require salinities >27 ppt for spawning (Peters *et al*., 1998), indicating these fish were not reproductively active. Tarpon do not mature until 880 mm FL (Crabtree *et al*., 1997), far exceeding the maximum size captured in this study. Thus, it was concluded that tarpon and snook did not use the lagoon system as a spawning ground, and that early life stages and juveniles of these species likely enter the lagoons from the sea in pursuit of food and refuge.

It was evident from this study that the actual importance of the lagoon system for tarpon and snook has to do with the connection to the ocean being opened. The time of year and duration of open connection to the sea may control abundance and species composition within intermittently open estuaries (Griffiths, 2001), suggesting that the longer a system is open to the sea, the greater the chance of marine fish entering. In Puerto Rico spawning of tarpon and snook occurs during March-October, and recruitment during May-November (Crabtree *et al*., 1992). However, the lagoon system rarely remains connected to the sea for more than two weeks and mostly during the peak hurricane season (September) (Jackson *et al*., 2001). Consequently, despite snook and tarpon spawn in the vicinity (Crabtree *et al*., 1992), recruitment of these species to the lagoon system would be limited.

However, the limited connection of the lagoons with the sea creates conditions favouring tarpon and snook establishment in the lagoons. Low salinity in ST2 favours submersed vegetation, which plays an

Table 1. Mean catch-per-unit-effort ± SE (fish/gear-set) of common snook (*Centropomus undecimalis* Bloch) and tarpon (*Megalops atlanticus* Valenciennes) collected from Santa Teresa 1 and Santa Teresa 2 with gill nets and trap nets, Humacao Natural Reserve, Puerto Rico, March 2000-April 2001. NS= no sample

Month	Snook				Tarpon			
	Gill Net		Trap Net		Gill Net		Trap Net	
	Santa Teresa 1	Santa Teresa 2	Santa Teresa 1	Santa Teresa 2	Santa Teresa 1	Santa Teresa 2	Santa Teresa 1	Santa Teresa 2
March	NS	0.0	NS	0.0	NS	5.5 ± 0.5	NS	0.0
June	0.9 ± 0.3	0.0	0.0	0.0	2.8 ± 1.4	2.0 ± 2.0	0.3 ± 0.3	0.0
July	2.3 ± 1.6	0.3 ± 0.3	0.0	0.0	1.3 ± 0.7	3.7 ± 2.3	0.0	0.0
October	0.3 ± 0.3	NS	0.0	0.0	1.0 ± 1.0	NS	0.0	0.0
January	0.5 ± 0.5	0.0	0.0	0.0	1.7 ± 1.7	9.0 ± 2.0	0.0	3.0 ± 3.0
February	0.0	0.3 ± 0.2	0.3 ± 0.1	0.5 ± 0.3	0.5 ± 0.2	2.6 ± 0.9	0.0	0.2 ± 0.2
March	0.0	0.3 ± 0.3	0.0	0.0	0.0	0.8 ± 0.4	0.0	0.0
April	0.0	0.0	0.0	0.0	0.0	0.7 ± 0.7	0.0	0.0
Average	0.5 ± 0.2	0.2 ± 0.1	0.04 ± 0.01	0.1 ± 0.1	0.9 ± 0.3	2.2 ± 0.5	0.04 ± 0.04	0.3 ± 0.2

important role in structuring the physicochemical and biological characteristics of this lagoon. Submersed macrophytes in ST2 dampen wave action so that fine-grained mud, characteristic of the whole lagoon system bottom, accumulates in shallow water among the vegetation, rendering it a clearer water system (Jackson *et al*., 2001). Clearer water systems with submersed vegetation represent a better habitat for large fish predators (e.g., tarpon and snook) that rely heavily on vision for prey encounters (Helfman *et al*., 1997).

The patterns of distribution among the microhabitats show large similarities in catches of grass shrimp within the lagoons. In ST2, grass shrimp distributed evenly among the microhabitats, indicating an extensive use of all available habitats in this lagoon. Conversely, in the absence of submersed vegetation in ST1, grass shrimp select cordgrass as the preferred microhabitat. Why grass shrimp were significantly more abundant in ST1 than in ST2 despite that ST2 had more habitat complexity is not clear. It can be explained by fish predation rate. Although overall fish abundance was higher in ST1 than in ST2, most of this abundance was numerically represented by crested goby, a small demersal species (10 cm maximum TL; Martin and Patus, 1984) that is not reported as an important predator and thus it is not expected to significantly predate on grass shrimp or fish within the lagoons. Small tilapia, on the other hand, were significantly more abundant in ST2 than in ST1. Although adult tilapia are herbivorous or detritivorous (Erdman, 1967; Pauly, 1976), early life stages and juveniles are carnivorous (Froese and Pauly, 2000). Thus, tilapia potentially predate on small palaemonids and could have accounted for the difference in grass shrimp abundance between the lagoons.

It was evident from the stomach content analyses that tilapia were an important food source for snook and tarpon. Tilapia were found more in tarpon stomachs than in snook; 96% of the tarpon diet was composed of tilapia and 4% grass shrimp. Tilapia were ubiquitous in the lagoon system and spawned successfully in all the lagoons several times a year (Jackson *et al.*, 2001). Thus, tarpon, which were more abundant in this lagoon, seem to take advantage of the most abundant food resource in ST2.

In conclusion, collection of fish and invertebrates with several sampling gears and strategies and examination of the habitat structure of the STS indicated that it is able to support long-term fisheries of snook and tarpon.

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References

Callaway, J.C., Sullivan, G., Desmond, J.S., Williams, G.D. and Zedler, J.B. 2001. Assessment and monitoring. In: J.B. Zedler (Ed.), Handbook for restoring tidal wetlands. CRC Press, Boca Raton, FL, USA: 271-335.

Crabtree, R.E., Cyr, E.C., Bishop, R.E., Falkenstein, L.M. and Dean, J.M. 1992. Age and growth of tarpon, *Megalops atlanticus*, larvae in the eastern Gulf of Mexico, with notes on relative abundance and probable spawning areas. Environmental Biology of Fishes, 35: 361-370.

Crabtree, R.E., Cyr, E.C., Chacón-Cheverri, D., McLarney, W.O. and Dean, J.M. 1997. Reproduction of tarpon, *Megalops atlanticus*, from Florida and Costa Rican waters and notes on their age and growth. Bulletin of Marine Science, 61: 271-285.

Department of Natural and Environmental Resources of Puerto Rico. 1995. Operation of the Humacao Wildlife Refuge, Grant Agreement FW-10. Estado Libre Asociado de Puerto Rico. San Juan, Puerto Rico, 27 pp.

Erdman, D.S. 1967. Inland game fishes of Puerto Rico. Department of Agriculture, San Juan, Puerto Rico, 85 pp.

Erdman, D.S., Berríos-Díaz, J.M., Corujo-Flores, I.N. and González-Azar, J. 1986. Los peces marinos de Puerto Rico. Compendio Enciclopédico de los Recursos Naturales de Puerto Rico, Estado Libre Asociado de Puerto Rico, San Juan, Puerto Rico, 487 pp.

Floyd, K.B., Hoyt, R.D. and Timbrook, S. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. Transactions of the American Fisheries Society, 113: 217-223.

Froese, R. and Pauly, D. 2000. FishBase 2000: concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines.

Griffiths, S.P. 2001. Factors influencing fish composition in an Australian intermittently open estuary. Is stability salinity-dependent? Estuarine, Coastal and Shelf Science, 52: 739-751.

Helfman, G.S., Collette, B.C. and Facey, D.E. 1997. The diversity of fishes. Blackwell Science, Boston, Massachusetts, 528 pp.

Jackson, D.C., Dibble, E.D., Rundle, K. and Ferrer-Montaño, O.J. 2001. Fisheries dynamics and management orientations for Humacao Natural Reserve, Puerto Rico. Completion Report, Federal Aid Project F-44.1, Department of Wildlife and Fisheries, Mississippi State University, 133 pp.

Killgore, K.J., Morgan II, R.P. and Rybicki, N.B. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. North American Journal of Fisheries Management, 9: 101-111.

Kuo, S.R., Lin, H.J. and Shan, K.T. 2001. Seasonal changes in abundance and composition of the fish assemblage in Chiku Lagoon, southwestern Taiwan. Bulletin of Marine Science, 68: 85-99.

Kwak, T.J. and Zedler, J.B. 1997. Food web analysis of southern California coastal wetlands using multiple stable isotopes. Oecologia, 110: 262-277.

Larson, E.W., Johnson, D.L. and Lynch Jr., W.E. 1986. A buoyant pop net for accurately sampling fish at artificial habitat structures. Transactions of the American Fisheries Society, 115: 351-355.

Levin, L.A., Talley, D. and Thayer, G. 1996. Succession of macrobenthos in a created salt marsh. Marine Ecology Progress Series, 141: 67-82.

Lima, S.L. and Dill, L.M. 1990. Behavioral decisions made under the risk of predation: a review and prospectus. Canadian Journal of Zoology, 68: 619-640.

Martin, F.D. and Patus, J.W. 1984. An annotated key to the teleost fishes of Puerto Rico. In: F.D. Martin and J.W. Patus (Eds.) Compendio Enciclopédico de los Recursos Naturales de Puerto Rico, Estado Libre Asociado de Puerto Rico, San Juan, Puerto Rico: 1-191.

Milliken, G.A. and Johnson, D.E. 1992. Analysis of messy data. Designed experiments. Chapman and Hall/CRC, Boca Raton, FL, USA, 480 pp.

Minello, T.J. and Webb Jr., J.W. 1997. Use of natural and created *Spartina alterniflora* salt marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Marine Ecology Progress Series, 151: 165-179.

Minello, T.J. and Zimmerman, R.J. 1992. Utilization of natural and transplanted Texas salt marshes by fish and decapod crustaceans. Marine Ecology Progress Series, 90: 273-285.

Pauly, D. 1976. The biology, fishery and potential for aquaculture of *Tilapia melanotheron* in a small West African lagoon. Aquaculture, 7: 33-49.

Pennak, R.W. 1989. Fresh-Water Invertebrates of the United States. Protozoa to Mollusca. 3rd Edition. John Wiley and Sons, New York, NY, USA, 628 pp.

Peters, K.M., Matheson Jr., R.E. and Taylor, R.G. 1998. Reproduction and early life history of common snook, *Centropomus undecimalis* (Bloch), in Florida. Bulletin of Marine Science, 62: 509-529.

Quammen, M.L. 1984. Predation by shorebirds, fish and crabs on invertebrates in intertidal mudflats: an experimental test. Ecology, 65: 529-537.

SAS. (2003) SAS/STAT Version 9.1.3. SAS Institute, Inc., Cary, North Carolina.

Underwood, A.J. 1997. Experiments in ecology. Their logical design and interpretation using analysis of variance. Cambridge University Press, Cambridge, U.K, 522 pp.

United States Department of Commerce and Department of Natural and Environmental Resources of Puerto Rico. 1986. Declaración de impacto ambiental preliminar y plan de manejo para el propuesto segmento de Humacao del sistema nacional para investigaciones estuarinas de Puerto Rico. Washington D.C. and San Juan, Puerto Rico, USA, 97 pp.

Vilella, F. and Gray, M. 1997. Ecological assessment and management plan for the Humacao Wildlife Refuge. Final Report. Federal Aid Project FW-10. Puerto Rico Department of Natural and Environmental Resources, San Juan, Puerto Rico, USA, 315 pp.

Williams, G.D. and Desmond, J.S. 2001. Restoring assemblages of invertebrates and fishes. In: J.B. Zedler (Ed.) Handbook for restoring tidal wetlands. CRC Press, Boca Raton, FL, USA: 235-269.

Zedler, J.B. 2001. Introduction. J.B. Zedler (Ed.) Handbook for restoring tidal wetlands. CRC Press, Boca Raton, FL, USA: 1-37.