Atlantic Tarpon Distribution in Brackish-water Lagoons, Humacao Natural Reserve, Puerto Rico

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Abstract: Atlantic tarpon *Megalops atlanticus* is an important recreational fisheries resource in the 6 brackish water lagoons located in Puerto Rico's Humacao Natural Reserve. The lagoons, which formed on the reserve after Hurricane David and Tropical Storm Frederick flooded the area in August 1979, are arranged in series and connect to the sea during periods of substantial precipitation. Subsequently, they reflect environmental gradients from essentially marine to low-salinity brackish water conditions. From March 2000 to April 2001, experimental mesh gill nets (*N* = 228) were utilized to conduct stock assessments of tarpon in the lagoons. Relative abundances of tarpon were greater as isolation (i.e., distance) from the system's confluence with the sea increased. Salinity decreased and water clarity increased as the distance from the Caribbean Sea increased. Tarpon relative abundances in the lagoons tended to be related more to water clarity than to salinity.

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Atlantic tarpon *(Megalops atlanticus)* in the brackish water lagoons of Puerto Rico's Humacao Natural Reserve (HNR) are the foundation for an alternative recreational fishery in the region. The reserve is located next to the Caribbean Sea and is within walking distance of a public beach and large public marine fishing pier. Further inland and within an hour's drive are freshwater fisheries in major reservoirs (Alicea et al. 1997). Despite these other attractive fishing opportunities, anglers come to HNR to fish for tarpon that rarely achieve weights >4 kg.

By mainland standards the reserve is a small area, encompassing approximately 1000 ha along the east coast of Puerto Rico. But from the social and cultural perspective of people living on Caribbean islands, it is a large, relatively wild, and natural place. Tarpon anglers on HNR typically fish with light tackle, and when interviewed (Jackson et al. 2001) hold these small tarpon in high esteem. However, several anglers stated that although catching a tarpon is important, the fishery is primarily valued as a means of connecting personally and aesthetically with the natural surroundings afforded by the reserve (*sensu* Hudgins 1984).

Tarpon are migratory, elopomorph fish that frequent coastal and inshore waters of the tropical and subtropical Atlantic Ocean (Crabtree et al. 1997). In Puerto Rico they spawn offshore from March to August (Figuerola-Fernandez et al. 1996). After hatching, tarpon leptocephalus larvae enter estuaries, lagoons, channels, and other small water bodies connected to the sea where they metamorphose through early life history stages (Hildebrand 1934, Wade 1962, Rickards 1968, Smith 1980, Zale and Merrified 1989, Chaverri and McLarney 1992). Within these small backwater systems young tarpon can exploit available resources and attain sizes attractive to anglers. Therefore, understanding the relationship between tarpon and lagoon environments is fundamental to the management of their associated fisheries. The objective of this study was to describe distribution and abundance of tarpon stocks in HNR lagoons and how these may be influenced by selected environmental features.

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Methods

Humacao Natural Reserve is located approximately 56 km southeast of San Juan, Puerto Rico (Fig. 1). It was established as a commonwealth reserve in 1986 and is managed by the Puerto Rico Department of Natural and Environmental Resources. The reserve is in the Subtropical Moist Life Zone (Ewel and Whitmore 1973) with air temperature nearly constant throughout the year (25 ± 3 C), and precipitation patterns that induce a marked yet irregular seasonality (Zerbi 1999) with more variable precipitation during the wet season. The wet season prevails from June through December, while the dry season extends from January to April. Average monthly rainfall may increase fourfold during the wet season (Vilella and Gray 1997). The average annual rainfall is approximately 165 cm (Puerto Rico Dep. Nat. and Environ. Resour. 1981). In addition, hurricanes and tropical storms frequently occur in this region, generally during July–September.

Six estuarine lagoons developed in HNR after Hurricane David and Tropical Storm Frederick flooded the area in August 1979. Prior to this time, the area was dedicated to agricultural production (sugar cane) and there were no lagoon environments. Average depth of the lagoons is <1.5 m. The lagoons are named Mandri 1 (67 ha), Mandri 2 (74 ha), and Mandri 3 (52 ha); Santa Teresa 1 (27 ha) and Santa Teresa 2 (24 ha); and Palmas (5 ha). All HNR lagoons are open to free public fishing. Santa Teresa 1, Santa Teresa 2, and Palmas have fishing piers that provide access for bank fishing. Bank access is limited in the Mandri lagoons, thereby forcing most anglers on these lagoons to fish from boats.

Figure 1. Humacao Natural Reserve, Puerto Rico.

Five water courses drain the HNR watershed and shunt surface runoff to the sea: Humacao, Blanco, and Anton Ruiz rivers, and the Boca Prieta and Frontera canals. The lagoons at HNR are connected to the Caribbean Sea through Boca Prieta Canal, Frontera Canal, and the Anton Ruiz River. The Anton Ruiz River connects to the Mandri lagoons, while Frontera Canal connects to the Santa Teresa lagoons. The Mandri lagoons join freely with one another through the Mandri channel and also have a connection (albeit somewhat obstructed) with Santa Teresa 1 through the Mandri channel. Santa Teresa 2 is isolated from the rest of the system for much of the year except for a small culvert that connects it with Santa Teresa 1 and a ditch that connects it with Palmas during and following heavy precipitation. Palmas is connected with Santa Teresa 1 by a culvert that passes underneath Frontera Canal (Vilella and Gray 1997).

The HNR lagoon connections to the Caribbean Sea through the Anton Ruiz River and Frontera Canal can become blocked by natural levees created through the accumulation of sand by longshore currents. Also, lack of runoff can cause the canals to have negligible flow during much of the year. Due to blockage by sand levees, tides minimally influence HNR lagoon hydrology and fishes that are considered transient species (e.g., tarpon) can become isolated within the HNR lagoon system for variable periods of time. Even when the lagoons are connected to the sea, water levels fluctuate approximately 0.25 m/day.

For sampling purposes, each lagoon was considered as a distinct unit. All were sampled with the exception of Palmas Lagoon. Palmas Lagoon was not sampled in order to avoid disturbing waterfowl that were using it for nesting purposes.

For our study purposes, each Mandri and Santa Teresa lagoon was divided into 6 sections. These sections served as experimental units for sampling purposes. The sections were marked with global positioning system (GPS) coordinates and assigned a number from 1 to 6.

Experimental gill nets were set in lagoons on randomly-determined sample dates within the months of March, May, June, July, and October 2000, and January, February, March, and April 2001. Overall, there were 40 sample dates in the study. Gill net was 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. Each net was set in an arbitrary orientation (to avoid movement bias by fishes relative to lagoon shorelines) early to mid-morning in randomly-selected sites (minimum of 1 and maximum of 6 sites/lagoon) within the lagoon(s) addressed on a given sample date. The average net set was 1.02 hours (SE $\pm$ 0.01 hour). This soak time minimized the sample-related fish mortality that might influence future catches in these small lagoons as well as generate negative public reaction to the study. Overall, there were 228 gill net sets during the study.

Total length (TL, mm) was measured and fish were immediately released into the location of capture. Fish were assigned to size groups: small ($<$300mm), intermediate (300–499 mm), and large ($\geq$500 mm). Fish then were placed into 2-cm groups to generate length-frequency distributions. Spatial and temporal relative abundances were expressed in terms of catch per unit of effort (CPUE, number of fish per net-set).

CPUE data were checked for normal distributions (PROC UNIVARIATE, SAS 1999). Log-transformation did not normalize data distributions. Therefore, a non-parametric Kruskal-Wallis one-way ANOVA (Statistix 2000) was used to compare relative abundances of tarpon among lagoons. Separation of means was conducted using Fisher's Least Significant Difference (LSD) test. Significance was established at the 0.05 probability level.

Secchi transparency (m), water temperature (°C), dissolved oxygen (mg/liter), and salinity (ppt) were recorded throughout the period of May 2000–April 2001 ($N =$ 131 samples). Within this period, there were 13 fish sampling days during June, July, and October (representing the wet season) and 27 fish sampling days during January through April (representing the dry season). Physicochemical data collected during fish sampling events were used for comparison of wet and dry season environmental conditions.

Water level (m) was recorded twice each week over the duration of the project from a gauge located on a pier adjacent to the boat ramp in Frontera Canal. Secchi transparency, water temperature, dissolved oxygen, and salinity were measured at mid-water depths with a Yellow Springs Instrument Model 3 or Model 8 meter. Daily rainfall (cm) was obtained from a rain gauge located on HNR. Air temperature (°C), barometric pressure (mm Hg), and wind velocity (knots) data were obtained for each sample day from the Roosevelt Roads U.S. Navy weather station, approximately 10 km northeast of HNR (Natl. Climatic Data Ctr., Ashville, N. C.). Historical storm and precipitation data also were obtained from the National Climatic Data Center.

One-way ANOVA (GLM procedure, SAS 1999) were used for testing differences of selected physiochemical variables among lagoons, and between wet and dry seasons (all lagoons combined). Means separations were conducted using Fisher's LSD test. Significance was established at the 0.05 probability level.

Results

There were 128 tarpon captured during the study. Length-frequency distributions for tarpon for the entire reserve (all data combined) show a range from 290 to 770 mm TL (Fig. 2). There was no significant difference in CPUE (fish/net-set) for small tarpon among lagoons (Fig. 3). However, CPUE values for intermediate and large tarpon were significantly higher in Santa Teresa 2 than in the Mandri lagoons.

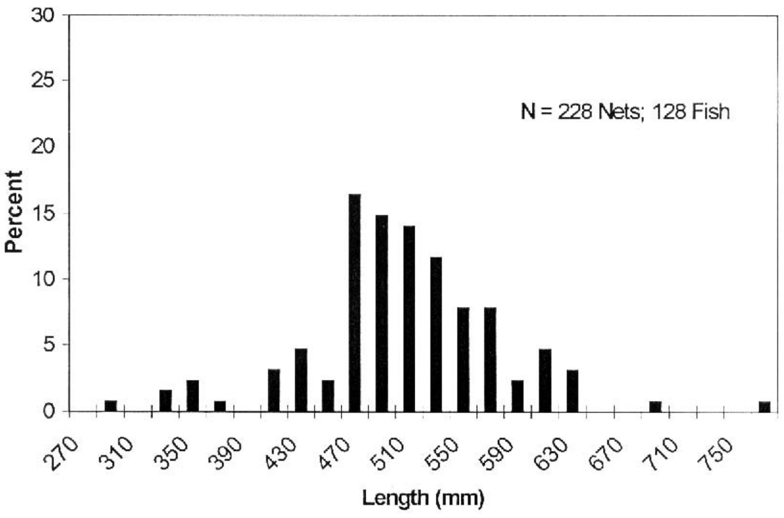

Figure 2. Length frequency of Atlantic tarpon (all lagoons combined) in Humacao Natural Reserve, Puerto Rico. March 2000–April 2001.

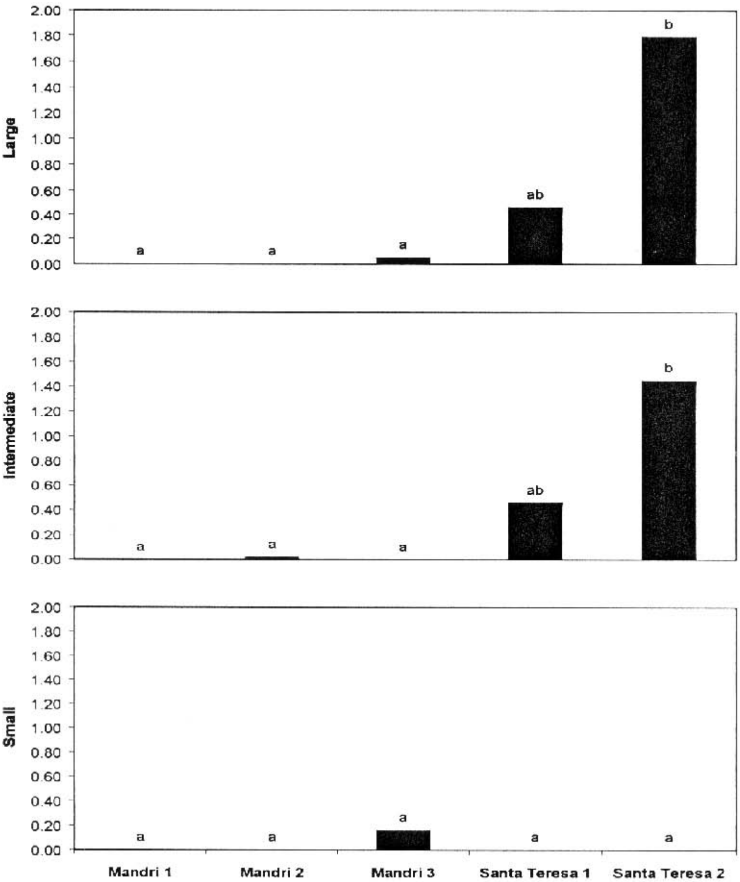

Figure 3. Experimental gill net mean catch per unit of effort (fish per net) for small (<300 mm), intermediate (≥300–499 mm), and large (≥500 mm Atlantic tarpon) in brackish water lagoons, Humacao Natural Reserve, Puerto Rico, March 2000–April 2001. Means with the same letter are not significantly different. (Kruskal-Wallis 1-way ANOVA; Fisher's Least Significant Difference test; $\alpha = 0.05$).

The CPUE values for intermediate and large tarpon in Santa Teresa 1 were between those of Santa Teresa 2 and the Mandri lagoons. Considering all lagoons combined, there was no significant difference in CPUE between the wet and dry season for any of the tarpon size groups.

With the exception of dissolved oxygen, physicochemical variables differed significantly among lagoons (Table 1). There was a gradient for salinity among lagoons, with salinity decreasing as one proceeded from Mandri 1 through the reserve system

Table 1. Mean (±SE) of physicochemical variables, compared across lagoons, measured during morning ($N = 131$ samples) in Humacao Natural Reserve, Puerto Rico, May 2000–April 2001.

Variable	Mandri-1	Mandri-2	Mandri-3	Santa Teresa-1	Santa Teresa-2
Secchi disk depth(m)	0.27 (0.02)C[a]	0.22(0.00)C	0.28 (0.01)C	0.44 (0.02)B	0.65 (0.05)A
Water temperature (°C)	29.59 (0.39)A	28.69 (0.20)AB	26.98 (0.24)C	28.23 (0.33)B	27.78 (0.47)BC
Dissolved oxygen (mg/liter)	3.05 (0.63)A	2.78 (0.29)A	2.91 (0.20)A	2.87 (0.23)A	3.06 (0.33)A
Salinity (ppt)	9.48 (0.39)A	8.05 (0.72)B	6.01 (0.34)B	3.52 (0.29)C	2.83 (0.33)C

a. Means followed by the same letter are not significantly different ($P > 0.05$).

Table 2. Mean (±SE) of physicochemical variables measured in the morning compared between the wet season (June, July, and October 2000), and dry season (January–April 2001), all lagoons combined, at the Humacao Natural Reserve, Puerto Rico. N = number of sample days per season.

Variable	Dry season ($N = 27$)	Wet season ($N = 13$)
Secchi disk depth (m)	0.57 ± 0.05 A[a]	0.33 ± 0.05 B
Water temperature (°C)	27.01 ± 0.31 A	28.38 ± 0.22 B
Dissolved oxygen (mg/liter)	5.41 ± 0.40 A	3.35 ± 0.27 B
Salinity (ppt)	7.00 ± 0.69 A	5.16 ± 0.74 A
Wind speed (kn)	9.00 ± 0.36 A	7.77 ± 0.89 A
Rain (cm)	0.30 ± 0.09 A	0.52 ± 0.21 A
Air temperature (°C)	25.24 ± 0.14 A	27.43 ± 0.21 A
Barometric pressure (mm Hg)	763.31 ± 0.24 A	761.82 ± 0.32 A

a. Means followed by the same letter are not significantly different according to LSD ($P > 0.05$).

and into Santa Teresa 2. Secchi disk depth was greatest for the Santa Teresa lagoons and lowest for the Mandri lagoons. Temperature tended to be higher in lagoons closer to the sea (Mandri 1, Mandri 2) and lower in lagoons more remote from the sea (Mandri 3, Santa Teresa 1, Santa Teresa 2).

Considering the entire lagoon complex on the reserve as one integrated system, Secchi disk depth, water temperature, and dissolved oxygen concentration were significantly different between the wet and dry seasons (Table 2). Dissolved oxygen concentration and Secchi disk depth were lower and water temperature was higher during the wet season. Although average water temperature was significantly higher during the wet season, the difference between seasons was rather small (<1.4 C). There was no significant difference in salinity between the 2 seasons.

There was no significant difference in the average amount of rainfall recorded for sampling days during the dry season (0.30 ± 0.09 cm) as compared to the wet season (0.52 ± 0.21), but the wet season had higher variation in rainfall. Also, there was no significant difference in the average water gauge readings in Frontera Canal (the index of water level within the reserve) between the dry season ($N = 39$) and the wet season ($N = 56$), with values of 0.30 ± 0.01 m and 0.30 ± 0.02 m for the 2 seasons, respectively. Additionally, there were no significant differences in air temperature, wind speed and barometric pressure between the wet and dry seasons.

Discussion

Environmental gradients are present among the brackish water lagoons in HNR that may influence distribution of the reserve's tarpon stocks. As one moves from the system's connection to the sea along the linear series of lagoons from the Mandri through the Santa Teresa systems, salinity decreases and water clarity increases.

Tarpon recruitment in HNR is dependent on early life history stages entering the system from the sea and their diffusion through the Mandri system and connecting canals into the Santa Teresa system. This recruitment typically occurs in Puerto Rico during May–November (Zerbi 1999) which coincides with the hurricane and tropical storm season.

Once within lagoons and estuaries, juvenile tarpon are generally found in shallow, isolated pools of dark-colored (not turbid) water (Rickards, 1968, Wade 1962). These environmental characteristics for juvenile tarpon improve in HNR as one moves further from the sea toward and into the Santa Teresa lagoons.

Recruitment also is influenced by the availability (or apparent availability, *sensu* O'Brien 1979) of prey. In this regard, and even though the potential prey base for tarpon is substantial in the Mandri lagoons (Jackson et al. 2001), persistent wind-induced turbidity in the Mandri lagoons likely reduces foraging efficiency by these visually oriented predators. Subsequently, tarpon were relatively more abundant in the less turbid environments of the Santa Teresa lagoons.

To improve the tarpon fishery in the reserve, Jackson et al. (2001) recommended that a system of protective levees be constructed within the Mandri lagoon system to reduce wave-induced turbidity. These levees would be oriented to block the prevailing winds along the general fetch of the Mandri lagoon basins. This should increase the contributions made by the Mandri lagoons to the HNR fishery.

Additionally, the historical challenge of an intermittent connection between the lagoons and the sea has apparently been overcome. Near the end of this study, the U.S. Army Corps of Engineers completed excavation of a channel to provide a more permanent opening between the Caribbean Sea and the HNR lagoons. The creation of this access route should enhance angling on the reserve as young tarpon from the Caribbean Sea are recruited into and grow within the lagoons.

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