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Management of Tropical Freshwater Fisheries with Stocking: The Past, Present, and Future of Propagated Fishes in Puerto Rico

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Abstract.—The native freshwater fish assemblage in Puerto Rico is limited to a few catadromous species; consequently, many species have been introduced from other regions of the world. In this case study, we examine the use of fish species introduction and propagation in the management of freshwater systems in Puerto Rico. The history of importation, propagation, and introduction is organized into four primary phases: (1) the prehatchery phase, with limited introductions from the United States to rivers and earliest reservoirs; (2) the coldwater phase, with primary emphasis on trout species for high-altitude river introductions; (3) the early warmwater phase, with generous species introductions and supplementation without significant evaluation; and (4) the current modern phase, with primary focus on largemouth bass and prey species with significant assessment, evaluation, and research on stocking efficacy. We describe previous research that has guided the use of fish propagation in Puerto Rico, and we discuss the future of propagated fishes in fisheries management.

Introduction

The native freshwater fish fauna of Puerto Rico is very limited, consisting of only a few catadromous species that rely on the link between rivers and estuaries (Holmquist et al. 1998). These native fishes are typically eliminated from reservoir environments and upstream reaches when rivers are impounded (Erdman 1984), resulting in reservoirs without significant fishery resources. Hence, the creation of sustainable reservoir fisheries depends heavily on introduction of nonnative fish species more adapted to lacustrine environments. Introductory, supplemental, and maintenance stocking programs are a substantial and invaluable part of reservoir fisheries management in Puerto Rico.

In this case history, our intent is to examine the history, magnitude, and effectiveness of stocking as a management tool in Puerto Rico reservoirs. We discuss the influence of biotic and abiotic factors that necessitate stocking activities and influence stocking success, and we review key studies that have defined our current stocking procedures. Finally, we explore the future application of propagated fishes in the management of Puerto Rico freshwater fisheries.

Management Facilities and Environment

Puerto Rico is a Caribbean island in the Greater Antilles located between latitude 17°55' and 18°31'N and longitude 66°37' and 67°17'W. Annual rainfall is quite variable, and ranges from 100 cm in the semiarid rain shadow of the south coast to nearly 500 cm in the eastern rainforest. Mean air temperature and water temperature remain seasonally constant and warm (mean monthly air temperature ranges 23–27°C; water temperature varies but closely follows air tem-

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perature), and photoperiod varies from about 11–13 h per day.

There are 23 reservoirs of management interest on the island, and the 13 largest reservoirs (137–360 ha) are considered priority management systems. The Puerto Rico Department of Natural and Environmental Resources (DNER) is the agency responsible for conducting fisheries management activities in reservoirs. Recreational management stations with full-time biologists are located at several island reservoirs, which provide the public with an access ramp, shoreline fishing access, and picnic and camping facilities. Lucchetti and Guajataca reservoirs currently possess management stations, and additional facilities are under construction or being planned for other reservoirs. The permanent assignment of management biologist at access points greatly facilitates management activities such as angler creel survey, tournament monitoring, and regulations enforcement.

A hatchery facility was constructed in 1937 on the Maricao River. The initial purpose of the Maricao Fish Hatchery was primarily for research, propagation, and introduction of coldwater fish species, including rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta*. In 1946, the hatchery shifted emphasis to warmwater species, which initiated the development of recreational fisheries in Puerto Rico's reservoirs. The hatchery was heavily damaged by flooding and high winds associated with Hurricane Georges in 1998, after which it underwent major reconstruction, renovation, and upgrade. This renovation greatly increased production capacity and eliminated the threat of flooding and limited dry-season water supply, which constrained fingerling production in the previous facility.

History of Stocking Activities

The chronology of stocking as a management tool in Puerto Rico can be divided into four phases: (1) the prehatchery phase, with limited introductions from the United States to rivers and earliest reservoirs; (2) the coldwater phase, with primary emphasis on trout species for high-altitude river introductions; (3) the early warmwater phase, with generous species introductions and supplementation without significant evaluation; and (4) the current modern phase, with primary focus on largemouth bass and prey species along with significant assessment, evaluation, and research on stocking efficacy.

The prehatchery phase was initially characterized by warmwater species introductions from the United States (Table 1). The earliest record of introductory stocking occurred in 1915 when brown bullhead *Ameiurus nebulosus*, largemouth bass *Micropterus salmoides*, and bluegill *Lepomis machrochirus* were imported from the United States and released in Comerío Reservoir (Hildebrand 1935). Subsequent introductions included these three species along with western mosquitofish *Gambusia affinis* and possibly warmouth *L. gulosus*. Although an official record of warmouth

Table 1. Chronological history of non-native fish importations and stocking activities prior to construction of the Maricao Fish Hatchery. Numbers of fish, size range (mm total length), and source/recipient population data are given where available (n/a is not available).

Year	Species	Number	Size	Source/recipient
1915	*Ameiurus nebulosus*	1,590	n/a	From the U.S. to Comerío Reservoir
	Micropterus salmoides	600	n/a	
	Lepomis macrochirus	1,500	n/a	
1916	*A. nebulosus*	600	n/a	From the U.S. to Comerío Reservoir
	M. salmoides	600	n/a	
	L. macrochirus	600	n/a	
	L. gulosus	1,200	n/a	
1923	*Gambusia affinis*	n/a	n/a	To Patillas Reservoir and Cayey River
1934	*L. macrochirus*	1,000	n/a	From the U.S. to Guayabal Reservoir
	Ictalurus spp.	80	n/a	and Patillas Reservoir
1934–1935	*Oncorhynchus mykiss*	30,000	127–152	From the U.S. to rivers in Luquillo and Toro Negro Forest
1934–1935	*Salmo trutta*	n/a	n/a	From U.S. to Espíritu Santo River at El Yunque Forest
1935	*L. macrochirus*	150	n/a	From the U.S. to Guajataca Reservoir
	Ictalurus spp.	180	n/a	
1935	*O. mykiss*	n/a	n/a	To Maricao River

introduction does not exists, personnel from the Maricao Fish Hatchery collected one in 1971 in Carite Reservoir. Erdman (1984) postulated that this species arrived in the 1916 shipment with largemouth bass, bluegill, and brown bullheads.

In a report to the Puerto Rico Commissioner of Agriculture and Commerce, Hildebrand (1934) recommended the importation and introduction of rainbow trout and brown trout for stocking in the coolwater streams. These actions provided the impetus for construction of the Maricao Fish Hatchery, which began producing fingerlings for release in 1938 (Table 2). Trout production was the primary objective of the hatchery until 1942, when it became apparent that introduced fingerling trout failed to establish sustainable populations because natural reproduction was not occurring (Erdman 1984). During the short-lived coldwater phase of fish propagation, the hatchery also produced some warmwater species, such as bluegill and brown bullhead, which were introduced primarily in new and existing reservoirs. Channel catfish *Ictalurus punctatus* were also imported from the United States and released into Cidra, Dos Bocas, and Loiza reservoirs.

Bluegill and catfishes (most likely channel catfish) were the only species produced and released for 3 years following the cessation of trout propagation, but in 1946, the emphasis of the hatchery shifted in earnest to producing warmwater species. The earliest attempts in 1915 and 1916 to establish largemouth bass populations were unsuccessful (Erdman 1984), so in 1946, a shipment of largemouth bass juveniles and adults from Georgia and Mississippi arrived at the Maricao Fish Hatchery. These fish became the basis of the island's largemouth bass fisheries, and quickly became the most popular freshwater sportfish on the island (Neal and Lopez-Clayton 2001). More than 10,000 largemouth bass fingerlings were produced and stocked during the first year of production. Although it is unclear why the initial introduction failed, it is likely that the stress of shipment combined with low numbers and small size led to their demise when they were immediately released into reservoirs. In 1946, the largemouth bass juveniles were shipped to the Maricao Fish Hatchery, where proper care ensured their survival. The 1946 shipment also purportedly included yellow bullhead *A. natalis*, which were reportedly propagated at the Maricao Fish Hatchery and stocked into Dos Bocas Reservoir. However, yellow bullheads have not been

Table 2. Importation and stocking history of the short-lived coldwater phase of propagated fishes in Puerto Rico. Numbers of fish, size range (mm total length), and source/recipient population data are given where available (n/a is not available). *Salmo* spp. is given for incomplete species information regarding trout stocking.

Year	Species	Number	Size	Source/recipient
1935–1939	*Salmo* spp.	n/a	n/a	No information
1938	*Oncorhynchus mykiss*	250,000	n/a	From U.S. to Maricao Fish Hatchery
	Ictalurus spp.	437	n/a	
	Lepomis macrochirus	40	n/a	
	O. mykiss	2,668	n/a	From Maricao Fish Hatchery to island's
	Ictalurus spp.	114	n/a	reservoirs
	L. macrochirus	7,150	n/a	
	I. punctatus	n/a	n/a	From U.S. to Cidra, Dos Bocas, and Loiza reservoirs
1939	*O. mykiss*	71,511	n/a	From Maricao Fish Hatchery to island's
	Ameiurus nebulosus	396	n/a	reservoirs
	L. macrochirus	22,830	n/a	
	O. mykiss	15,328	n/a	From Maricao Fish Hatchery to island's
	Ictalurus spp.	1,051	n/a	reservoirs
	L. macrochirus	46,942	n/a	
1941	*Salmo trutta*	40,000	n/a	To Maricao Fish Hatchery
1941	*Salmo* spp.	2,231	n/a	From Maricao Fish Hatchery to island's
	Ictalurus spp.	1,697	n/a	reservoirs
	L. macrochirus	19,896	n/a	
1942	*Salmo* spp.	3,031	n/a	From Maricao Fish Hatchery to island's
	Ictalurus spp.	1,745	n/a	reservoirs
	L. macrochirus	27,994	n/a	

collected from island reservoirs, which suggest that this introduction was unsuccessful or that the species was misidentified.

The early warmwater phase (1942–1973) was characterized by numerous species introductions as well as supplementation of reservoir sportfish populations (Table 3). In 1947 and 1948, guppy *Poecilia reticulata* and *P. vivipara* were introduced for esthet-

Table 3. Importation and stocking history of the early warmwater phase of propagated fishes in Puerto Rico. Numbers of fish, size range (mm total length), and source/recipient population data are given where available (n/a is not available). *Ictalurus* spp. is given for incomplete species information regarding catfish stocking.

Year	Species	Number	Size	Source/recipient
1943	*Ictalurus* spp.	514	n/a	From Maricao Fish Hatchery to island's reservoirs
	Lepomis macrochirus	20,249	n/a	
1944	*Ictalurus* spp.	308	n/a	From Maricao Fish Hatchery to island's reservoirs
	L. macrochirus	11,040	n/a	
1945	*Ictalurus* spp.	261	n/a	From Maricao Fish Hatchery to island's reservoirs
	L. macrochirus	5,010	n/a	
1946	*Micropterus salmoides*	1,067	n/a	From Georgia and Mississippi
	M. salmoides	88	adults	
	Ameiurus natalis	47	adults	
1946	*M. salmoides*	10,536	19–76	From Maricao Fish Hatchery to island's reservoirs
1947	*A. natalis*	1,462	n/a	Produced at the Maricao Fish Hatchery and stocked at Dos Bocas Reservoir
	L. macrochirus	1,420	n/a	From Maricao Fish Hatchery to island's reservoirs
	M. salmoides	22,977	n/a	
1947	*Poecilia reticulata*	20,000	n/a	Stocked at Sabana Llana gulch
1948	*P. vivipara*	50,000	n/a	n/a
	L. macrochirus	1,850	n/a	From Maricao Fish Hatchery to island's reservoirs
	M. salmoides	8,866	n/a	
1949	*L. macrochirus*	650	n/a	From Maricao Fish Hatchery to island's reservoirs
	M. salmoides	298	n/a	
1950	*L. macrochirus*	5,900	n/a	From Maricao Fish Hatchery to island's reservoirs
	M. salmoides	7,455	n/a	
1951	*M. salmoides*	100	n/a	From Maricao Fish Hatchery to island's reservoirs
1953	Redbreast tilapia *Tilapia rendalli*	n/a	n/a	From Auburn, Alabama
	Common carp *Cyprinus carpio*	n/a	n/a	To Maricao Fish Hatchery from Dominican Republic
1957	Fathead minnow *Pimephales promelas*	150	50	From Waleka Hatchery, Florida to Maricao Fish Hatchery
	Redbreast sunfish *L. auritus*	28	n/a	
	Florida largemouth bass *M. s. floridanus*	30	n/a	
	Redear sunfish *L. microlophus*	389	n/a	
1958	Redeye bass *M. coosae*	n/a	n/a	From Georgia
	Mozambique tilapia *T. Mossambica*	n/a	n/a	From Alabama to Aguirre and Mercedita
1963	*Dorosoma petenense*	40	Adults	From Georgia to Guajataca Reservoir
	Wami tilapia *T. hornorum*	n/a	n/a	From the Cooperative Fishery Research Unit in Arizona to Maricao Hatchery
	T. rendalli	19	51	From Alabama
1967	Peacock cichlid *Cichla ocellaris*	50	64–76	From Buga, Colombia to Maricao Hatchery
1971	Blue tilapia *T. aurea*	n/a	n/a	From Alabama to Experimental Station at Lajas

Table 3. Continued

Year	Species	Number	Size	Source/recipient
1972	White bass *Morone chrysops*	12	203–304	From Georgia to Loiza Reseroir
	Grass carp *Ctenopharyngodon idella*	200	n/a	From Arkansas to Dorodo Beach Hotel
1973	Nile tilapia *T. nilotica*	n/a	n/a	From Brazil

ics, prey supplementation, and mosquito control. Occurrence of other livebearers, including green swordtail *Xiphophorus helleri* and southern platyfish *X. maculates*, in island aquatic systems are not related to hatchery and management activities and are likely a result of the aquarium and bait trade. Largemouth bass and bluegill were produced at Maricao and stocked into island reservoirs annually between 1948 and 1951. In 1953, the first cichlids arrived to the island. An unknown quantity of redbreast tilapia were imported from Auburn, Alabama, although there is no record of these fish leaving the confines of the hatchery. That same year, common carp (mirror carp variety) were imported from the Dominican Republic, but these fish were also not introduced outside of the hatchery.

In 1957, a shipment containing fathead minnow, redbreast sunfish, redear sunfish, and Florida largemouth bass arrived from the Waleka Hatchery in Florida to the Maricao Fish Hatchery. The fathead minnow was cultured as forage for largemouth bass at the hatchery, but introductions into natural systems failed to establish. Both redbreast and redear sunfish have thrived in island aquatic systems, and the redear sunfish has become a valuable addition to the reservoir sport fisheries. The Florida largemouth bass was cultured and introduced into island reservoirs, but no attempts at management specifically for the Florida subspecies were made during the early warmwater period.

Redeye bass were imported in 1958 from Georgia with the intention of improving river fisheries. This species was cultivated at the Maricao Fish Hatchery and introduced into several rivers where it still persists today. That same year, Mozambique tilapia was brought to the island from Auburn, Alabama, on the recommendation of the Puerto Rico Secretary of Agriculture (Erdman 1984). This species is now in most of the island's aquatic systems.

In 1963, an important addition to the reservoir fish community was made when threadfin shad were introduced as a forage species. This species is now a primary prey for all piscivorous sport fish (Neal et al. 2001), and largemouth bass condition factor reportedly increased following the introduction of threadfin shad (Erdman 1984). That same year, the Maricao Fish Hatchery received a second shipment of redbreast tilapia, and these fish were propagated and introduced widely as a sportfish and for control of rooted macrophytes. Wami tilapia were also imported, and males of this species were crossed with female Mozambique tilapia. Hybrid males were introduced into small ponds in Puerto Rico and have likely disappeared from the island. However, in an attempt to keep a pure strain of Wami tilapia, Erdman (1984) stocked 100 fingerlings in a small pond on Mona Island, west of Puerto Rico. Descendents of this introduction are believed to still occur there.

In 1967, the government of Colombia shipped 200 peacock cichlid fingerlings from the fish culture station at Buga to Puerto Rico, and 50 arrived alive to San Juan. Of these fish, 30 survived the trip to Maricao and became the founder population of the island's peacock cichlid sport fishery. This species was propagated at the hatchery and introduced into several island reservoirs, but records of these introductions have not been found. Intentional movements between reservoirs of peacock cichlids by anglers further complicate the stocking history of this species.

Blue tilapia, imported in 1971 from Auburn, Alabama to the Agriculture Experiment Station in Lajas, Puerto Rico, were imported initially for experimental aquaculture as a food fish. However, this species now occurs in several reservoirs in Puerto Rico. White bass, the only temperate bass species imported to the island, arrived from Atlanta, Georgia in 1972. Most did not survive the trip, and the 12 that survived were introduced into Loiza Reservoir, although none have since been recovered. That same year, grass carp were first imported for control of aquatic macrophytes such as southern naiad *Najas guadaloupensis*. Grass carp has been successfully used for biocontrol by private organizations in small systems on the island, but does not occur in the larger systems. The

last recorded introduction was the Nile tilapia, which was brought from Brazil in 1973 by the University of Puerto Rico for experimental purposes and does not occur at the Maricao Hatchery or in the island sport fisheries.

The Modern Era of Sport Fish Propagation and Management

There is a 21-year gap in the stocking history following the last record of 1973 because of poor record keeping and limited management-oriented activities. The Maricao Fish Hatchery was not heavily involved in sportfish propagation and supplementation, and most introductory stocking during this period consisted of unauthorized angler movements and undocumented transfers. However, in 1994 the directive of the Maricao Fish Hatchery was re-established as primarily freshwater sportfish production, and production and supplemental stocking of largemouth bass and other species began in earnest. The reinitiation of hatchery objectives coincided with an increased interest in science-based management objectives, and DNER teamed up with North Carolina State University and the Federal Aid in Sport Fish Restoration program to evaluate management regimes and the use of stocking as a management tool.

The rejuvenated hatchery initiative was marked by a sizeable increase in largemouth bass fingerling production (Table 4). However, the need for assessing which largemouth bass population could benefit most from supplementation using hatchery fingerlings soon became evident. Semiannual (spring and fall) boat-mounted boom electrofishing was initiated to determine largemouth bass population structure and relative abundance for development of management recommendations. Although these efforts greatly enhanced knowledge of general community structure in the reservoirs sampled, they did not specifically measure year-class strength of juvenile largemouth bass, which are not accurately sampled using boat-mounted boom electrofishing (Jackson and Noble 1995). Ozen (2002) found that a hand-held electrofisher used along shoreline areas at night between April and September provided a more reliable estimate of largemouth bass year-class strength in Puerto Rico. This technique has been used effectively in several island reservoirs to evaluate supplementation needs, but it has not yet been fully adopted as a prestocking assessment technique.

Supplementation of wild populations with hatchery-produced fingerlings is critical to maintaining stable largemouth bass populations in Puerto Rico reservoirs because stock size can vary threefold annually (Ashe et al. 1998). This variation is created by natural fluctuations in year-class strength that are magnified by population age structure, which is characterized by two primary age-classes with high mortality of older fish (Neal et al. 1997). Prey fish are available year-round (Alicea et al. 1997), and water temperatures in these tropical systems are continuously appropriate for rapid juvenile growth (Gran 1995). Hence, supplemental stocking can yield high survival and growth during any month of the year, and overwinter mortality is not a concern as it is in many temperate systems (e.g., Garvey et al. 2002). However, competition with wild year classes is a concern if hatchery fish are stocked into large wild year-classes of similar size. Neal et al. (2002) determined that supplemental stocking should be performed from October to November, which maximizes the time between previous and future wild spawning events. In addition, delaying stocking until autumn allows evaluation of wild year-class strength during summer months to determine if stocking is needed.

The Maricao Hatchery has the capacity to produce fingerling largemouth bass for any month of the year (Figure 1). However, there is a distinct peak in fingerling output during the summer months, and these fish are typically similar in size to wild-spawned juveniles. This increases the likelihood of intraspecific competition with wild year-classes during spring and summer stocking, and fingerling availability limits the capacity for supplemental stocking during autumn months. Under the current production regime, spring and summer supplementation should focus on systems with poor year-class strength, and off-season (autumn) stocking may be used to supplement important fisheries where recruitment is often strong but fishing pressure is high. It appears that autumn stockings reduce intraspecific competition, thereby having an additive impact on year-class strength and potentially maximizing growth rates of hatchery fish (Neal et al. 2002). Hence, improvement in off-season fingerling production by the Maricao Fish Hatchery is needed to maximize supplementation capacity for Puerto Rico reservoirs.

There are two genetically distinct stocks of largemouth bass in Puerto Rico (Neal et al. 1999). Most reservoirs contain intergraded populations with both northern *M. s. salmoides* and Florida *M. s. floridanus* largemouth bass alleles, while two reservoirs contain largemouth bass with only Florida alleles. Although the genetic composition of intergrade largemouth bass is strongly skewed toward the Florida subspecies, this

Table 4. Stocking records of the Puerto Rico Maricao Fish Hatchery from 1994 to 2002. Numbers of fish, size range (mm total length), and source/recipient population data are given where available (n/a is not available).

Year	Species	Number	Size	Source/recipient
1994	*Micropterus salmoides*	3,966	38.1	Loiza Reservoir
1995	*M. salmoides*	64,653	25–63.5	Carraizo, Dos Bocas, Toa Vaca, Patillas, Ponce I, Ponce II, Ponce III, Carite, Cidra, Prieto, Guayo, Guayabal reservoirs; and Tortuguero Lagoon
	Dorosoma petenense	200	25–50	Cerrillos Reservoir
1996	*M. salmoides*	49,467	38–76	Carite, Dos Bocas, Toa Vaca, La Plata,
	M. s. floridanus	1,412	n/a	Lucchetti Reservoir
	L. microlophus	11,569	38–50	Cerrillos, Toa Vaca, Guayabal reservoirs
1997	*M. salmoides*	38,026	38–76	Toa Vaca, Dos Bocas, Lucchetti, Garzas, Las Curias, Carite, Carraizo, Cidra reservoirs; Tortuguero Lagoon; private pond
	M. s. floridanus	48,520	25–76	Guajataca, Lucchetti, Cerrillos reservoirs
	L. microlophus	59,515	12–38	Toa Vaca, Cerrillos, Guayo, Guayabal, La Plata, Garzas, Las Curias reservoirs
	Tilapia spp.	450	88.9–105	Private ponds
1998	*M. salmoides*	41,114	25–76	Las Curias, Dos Bocas, Patillas, La Plata, Toa Vaca, Guayabal reservoirs; private ponds
	L. microlophus	16,000	25–63	Toa Vaca, Cerrillos reservoirs
	T. rendallli	100	n/a	Private ponds
2000	*M. s. floridanus*	193,024	38–69	Guajataca, Cidra, Dos Bocas, Guayabal, Guayo, Toa Vaca, Patillas, Carraizo, La Plata, Matrullas, Garzas reservoirs; and Tortuguero Lagoon
	L. microlophus	9,440	n/a	La Plata Reservoir
	Tilapia spp.	1,100	n/a	Private ponds
2001	*M. s. floridanus*	133,421	25–171	Guayabal, Guajataca, Cidra, La Plata, Dos Bocas, Carraizo, Las Curias, Toa Vaca, Lucchetti reservoirs; and private ponds
	L. microlophus	69,762	12.7–50.8	Guajataca, Cerrillos, Cidra, Guayabal, Lucchetti, Matrullas reservoirs; and private ponds
	Tilapia spp.	2,120	n/a	Private ponds
2002	*M. s. floridanus*	84,419	44.4–63.5	Loco, Dos Bocas, La Plata, Guayo, Garzas, Caonillas, Guajataca, Cidra reservoirs; and private ponds
	L. microlophus	63,076	12.7–63.5	Lucchetti, Cidra, La Plata, Loco, Garzas, Guajataca reservoirs
	L. macrochirus	38,880	12.7–50.8	Lucchetti, Caonillas reservoirs
	Tilapia spp.	825	n/a	Private ponds

stock does exhibit differences from Florida fish in population characteristics. Both genetic stocks have similar growth as juveniles and adults, but Florida largemouth bass have greater survival beyond age 2 (Neal and Noble 2002). Whereas intergrade populations are typically comprised of primarily age-1 and age-2 fish, the greater survival of Florida fish can be exploited to improve population age structure and reduce variability in abundance from year to year. Beginning in 2000, only Florida largemouth bass have been propagated and stocked by the Maricao Fish Hatchery. This action ensures that the integrity of the two pure Florida populations will be maintained and promises to improve overall age structure of intergrade populations.

In 1998, following severe damage to the facilities during Hurricane Georges, the Maricao Fish Hatch-

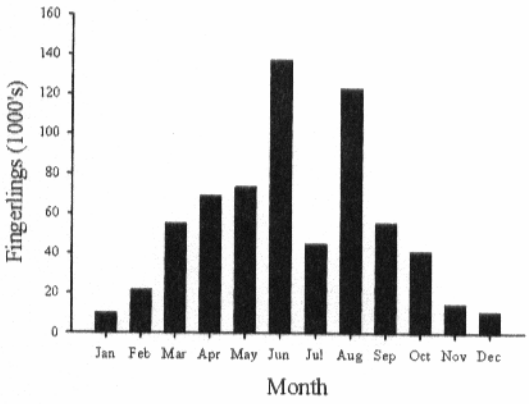

Figure 1. Monthly largemouth bass fingerling production by the Maricao Fish Hatchery from 1994 to 2002. The number of fingerlings plotted is in thousands.

ery underwent major renovations that more than doubled production capabilities for largemouth bass and other species. These improvements included a 62% increase in pond surface area for the hatchery and the construction of a new dam, which supplies the surface water to the entire hatchery facility during the dry season. Because of reconstruction, fingerling production did not occur during 1999.

The Future of Propagated Fishes in Puerto Rico

Recent advancements at the Maricao Fish Hatchery and science-based improvements in fisheries management in Puerto Rico reservoirs has greatly improved DNER's capacity for community manipulation and sport fish supplementation. The future of fisheries management in Puerto Rico will continue to rely on sport fish propagation and stocking, and new advancements will be necessary to meet the increasing demand for quality freshwater fishing opportunities.

One area of particular importance to DNER management objectives is increasing growth potential of largemouth bass. Although the shift from intergrade to Florida largemouth bass increases persistence of older fish in the population, it does not provide improved size structure (Neal and Noble 2002). Growth rates of both largemouth bass genetic stocks decline sharply when maturity is reached and growth is negligible by age 2. This results in a truncated size structure with few fish reaching larger sizes desired by many anglers, despite the year-round availability of prey (Alicea et al. 1997).

Neal (2003) theorized that the slow growth of adult fish results from excessive energy allocation to reproduction. Unlike largemouth bass in temperate regions, spawning in Puerto Rico occurs during a 6-month period beginning in midwinter, and individual bass spawn multiple times each season (Gran 1995; Waters 1999). Reproduction is generally an energetically expensive undertaking, and energy must be diverted from other processes such as growth and maintenance (Wootton 1985). Bioenergetics modeling of largemouth bass reproduction in Puerto Rico suggested that the extended reproductive effort reduces growth of a first-year spawning adult by more than 60% during the 6-month spawning season (Neal 2003), and the occurrence of natural mortality directly coincides with spawning season (Waters 1999).

Sterilization of hatchery-produced largemouth bass may be a solution to the slow growth and high mortality that appears to result from extended multiple reproductive efforts. Triploidy, which can be readily induced in many fish species by shocking eggs early in development with sharp temperature changes (up or down), increases in hydrostatic pressure, or chemical treatments (see review by Thorgaard and Allen 1987; Ihssen et al. 1990), can be used to provide sterile fish for research and management purposes. Neal (2003) refined triploidy production techniques for largemouth bass in Puerto Rico and found that triploids of this species expend significantly less energy for gamete production than normal diploid largemouth bass. Hence, there is a physiological mechanism for improved growth using triploids, and triploids may play an important role in future management activities in Puerto Rico if this energetic advantage can be translated into improved growth.

There is a renewed interest in the introduction of new species in Puerto Rico reservoirs. The butterfly peacock cichlid found in several reservoirs has developed into a sizable fishery, but the average size of this species is generally below angler expectations. There is an increasing desire to import the larger speckled peacock cichlid *Cichla temensis*, which would diversify angling opportunities and may exert predatory pressure on abundant tilapia populations. Any future introductions will be conducted with greater care than previous introductions, and imported fish will be quarantined and studied for possible negative effects before distribution to island reservoirs.

Native species management is a growing issue for fisheries management in Puerto Rico. Although there are only a handful of native freshwater fish species on the island, several are of particular interest for possible propagation. For instance, the bigmouth sleeper

Gobiomorus dormitor occurs regularly in several island reservoirs and has an abundant population in Carite Reservoir where it contributes significantly to the sport fishery (Neal et al. 2001). Bacheler (2002) determined that this species was reproducing in the reservoir, indicating that native species can thrive in impounded rivers under certain conditions. It is important to determine why this species can only complete its lifecycle in Carite Reservoir. If factors that allow successful reproduction (such as water level or habitat availability) can be identified, management for this species in other reservoirs can be improved. The Maricao Fish Hatchery can play a role in the re-establishment and maintenance of native species above dams, providing more diverse angling opportunities while maintaining species diversity.

References

Alicea, A. R., R. L. Noble, and T. N. Churchill. 1997. Tropic dynamics of juvenile largemouth bass in Lucchetti Reservoir, Puerto Rico. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 51:149–158.

Ashe, D. E., T. N. Churchill, R. L. Noble, and C. G. Lilyestrom. 1998. Temporal variability in the littoral fish community of a Puerto Rico reservoir. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 52:39–48.

Bacheler, N. M. 2002. Ecology of bigmouth sleepers *Gobiomorus dormitor* (Eleotridae) in a Puerto Rico Reservoir. Master's thesis. North Carolina State University, Raleigh.

Erdman, D. S. 1984. Exotic fishes in Puerto Rico. Pages 162–176 *in* W. R. Courtenay, Jr., and J. R. Stauffer, Jr., editors. Distribution, biology, and management of exotic fishes. John Hopkins University Press, Baltimore, Maryland.

Garvey, J. E., R. A. Stein, R. A. Wright, and M. T. Bremigan. 2002. Exploring ecological mechanisms underlying largemouth bass recruitment along environmental gradients. Pages 7–23 *in* D. P. Philipp and M. S. Ridgway, editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Gran, J. E. 1995. Gonad development and spawning of largemouth bass in a tropical reservoir. Master's thesis. North Carolina State University, Raleigh.

Hildebrand, S. F. 1934. An investigation of the fishes and fish cultural possibilities of the freshwaters of Puerto Rico, with recommendations. Typewritten report to Commissioner of Agriculture and Commerce, Puerto Rico.

Hildebrand, S. F. 1935. An annotated list of fishes of the freshwaters of Puerto Rico. Copeia 49–56.

Holmquist, J. G., J. M. Schmidt-Gengenbach, and B. Buchanan Yoshioka. 1998. High dams and marine-freshwater linkages: effects on native and introduced fauna in the Caribbean. Conservation Biology 12:621–630.

Ihssen, P. E., L. R. McKay, I. McMillan, and R. B. Phillips. 1990. Ploidy manipulation and gynogenesis in fishes: cytogenetic and fisheries applications. Transactions of the American Fisheries Society 119:698–717.

Jackson, J. R., and R. L. Noble. 1995. Selectivity of sampling methods for juvenile largemouth bass in assessments of recruitment processes. North American Journal of Fisheries Management 15:408–418.

Neal, J. W. 2003. Live fast and die young: on the growth and mortality of largemouth bass in Puerto Rico. Doctoral dissertation. North Carolina State University, Raleigh.

Neal, J. W., and D. Lopez-Clayton. 2001. Mortality of largemouth bass during catch-and-release tournaments in a Puerto Rico reservoir. North American Journal of Fisheries Management 21(4):834–842.

Neal, J. W., and R. L. Noble. 2002. Growth, survival, and movement of Florida and intergrade largemouth bass in a tropical reservoir. North American Journal of Fisheries Management 22:528–536.

Neal, J. W., R. L. Noble, A. R. Alicea, T. N. Churchill. 1997. Invalidation of otolith ageing techniques for tropical largemouth bass. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 51:159–165.

Neal, J. W., R. L. Noble, and T. N. Churchill. 2002. Timing of largemouth bass supplemental stocking in a tropical reservoir: impacts on growth and survival. Pages 691–701 *in* D. P. Philipp and M. S. Ridgeway, editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Neal, J. W., R. L. Noble, C. G. Lilyestrom, N. M. Bacheler, and J. C. Taylor. 2001. Freshwater sportfish community investigations and management. Puerto Rico Department of Natural and Environmental Resources, Federal Aid in Sport Fish Restoration, Final Report, Project F-41, Study 2, San Juan.

Neal, J. W., R. L. Noble, C. G. Lilyestrom, T. N. Churchill, A. R. Alicea, D. E. Ashe, F. M. Holliman, and D. S. Waters. 1999. Freshwater sportfish community investigations and management. Puerto Rico Department of Natural and Environmental Resources, Federal Aid in Sport Fish Restoration, Final Report, Project F-41, Study 2, San Juan.

Ozen, O. 2002. Population dynamics of largemouth

bass in Lucchetti Reservoir, Puerto Rico. Doctoral dissertation. North Carolina State University, Raleigh.

Thorgaard, G. H., and S. K. Allen. 1987. Chromosome manipulation and markers in fisheries management. Pages 319–331 *in* N. Ryman and F. Utter, editors. Population genetics and fisheries management. University of Washington Press, Seattle.

Waters, D. S. 1999. Spawning season and mortality of adult largemouth bass (*Micropterus salmoides*) in a tropical reservoir. Master's thesis. North Carolina State University, Raleigh.

Wootton, R. J. 1985. Energetics of reproduction. Pages 231–256 *in* P. Tytler and P. Calow, editors. Fish energetics: new perspectives. The John Hopkins University Press, Baltimore, Maryland.