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ARTICLE

Comparison of Gill Nets and Fixed-Frame Trawls for Sampling Threadfin Shad in Tropical Reservoirs

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Abstract

Threadfin shad *Dorosoma petenense* populations were sampled quarterly from 2010 to 2011 to determine appropriate sampling techniques for this species in tropical reservoirs of Puerto Rico. Offshore gill netting and night trawling were compared in terms of catch per unit of effort, size distribution, sampling precision, and bycatch. In total, 90 gill net–trawl pairs of catches were compared, which collected more than 80,000 threadfin shad. Gill-net and trawl catches were not correlated in either number or biomass. Coefficients of variation were greater in gill-net sampling (0.761 for numbers, 0.747 for biomass) than in trawl sampling (0.433 and 0.465, respectively) and were not dependent on reservoir, sampling season, reservoir section, or any combination of these factors for any gear. There was no correspondence in size distributions between gill-net and trawl catches. Gill nets collected threadfin shad in the range of 23–169 mm total length (TL) and displayed strong mesh size selectivity, causing distinct unrealistic peaks in size distribution. Gill nets underestimated threadfin shad smaller than 35 mm TL and overestimated shad bigger than 90 mm TL. The size range of threadfin shad collected via trawl was 10–108 mm TL, and trawls did not appear to be as size selective for fish up to 80 mm TL. Trawling was found to be the superior sampling technique for shad populations in pelagic habitats of Puerto Rican reservoirs, which consisted mainly of fish up to 80 mm TL. Trawling provided a more realistic picture of size distributions, collected far less bycatch, was less affected by the schooling of shad, and was less laborious and more cost-effective than gill nets.

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The historical approach of single-species fisheries management is gradually being replaced by more holistic consideration of prey production as it relates to predator dynamics (Noble 1986). This is because single-species management schemes often fail to consider trophic relationships within the ecosystem (Larkin 1979; May et al. 1979). The development of bioenergetics models in recent decades has further established that effective predator management requires accurate knowledge of prey characteristics (Jenkins and Morais 1978). For example, managers often require precise estimates of prey population variables such as abundance, age and size structure, recruitment, growth, mortality, and production to predict the effects of management actions on predator populations. The precision of these population estimates is determined primarily by the biologist's ability to collect unbiased, representative samples of the prey population under study.

Threadfin shad *Dorosoma petenense* is a primary prey species in many reservoirs located in temperate, subtropical, and tropical environments (Noble 1981; Johnson et al. 1988; DeVries and Stein 1990; Neal et al. 2009). This species is less tolerant of cold temperatures than larger gizzard shad *D. cepedianum* (Strawn 1965), which limits its northern distribution. The southern distribution has been expanded well beyond the native range of threadfin shad in the lower Mississippi River basin to include peninsular Florida and the area down to Guatemala and Belize (Miller 1964; Carlander 1969). Threadfin shad have also been introduced as a forage fish into tropical reservoirs of the Caribbean, where they serve as the primary prey species for important sport fish such as largemouth bass *Micropterus salmoides* and butterfly peacock bass *Cichla ocellaris*.

Although the life history characteristics of threadfin shad in temperate waters are well described, little is known about populations in tropical reservoirs. Stancil et al. (1999) reported that threadfin shad spawning occurs nearly year-round in Lucchetti Reservoir, Puerto Rico, with the exception of a short period from mid-August until mid-September. The same study reported that the maximum length ($n = 2{,}002$) was only 86 mm (TL) and that the maximum age ($n = 124$) was only 141 d. These data suggested that threadfin shad in tropical systems are a prolific and short-lived species. However, Neal et al. (1999) observed threadfin shad in Cidra Reservoir, Puerto Rico, that were up to 175 mm TL, which is about the maximum size reported for this species (Jenkins and Burkhead 1993). Almost nothing is known about the abundance, biomass, or production of this species in tropical waters, largely because targeted threadfin shad sampling has not occurred and effective sampling protocols have not been developed.

Six sampling methods, including hydroacoustics, electrofishing, gill nets, rotenone, seines, and midwater trawls, were used concurrently to obtain data on threadfin shad in Lake Texoma, Oklahoma–Texas (Boxrucker et al. 1995). This study concluded that surface-set gill nets, trawls, and hydroacoustics were the most appropriate gears for sampling threadfin shad in southern reservoirs. Trawls and hydroacoustics were capable of providing biomass estimates, while gill nets were limited to catch per unit of effort (CPUE) trends and size structure. Neal et al. (2001) reported that hydroacoustic data were difficult to interpret for Puerto Rican reservoirs, likely due to the presence of many other species in the open water. Frouzová et al. (2008) also found that the size overlap of multiple species, particularly small invertebrates, complicates the use of hydroacoustics in studies of tropical freshwater ecology. Therefore, hydroacoustics were not considered in this comparison.

Because it is unclear which of these gears is most appropriate for sampling threadfin shad in tropical systems, this paper compares the catch, bycatch, and size selectivity of an active gear (fixed-frame trawl) with those of a passive gear (experimental gill nets) in steep-sided tropical reservoirs.

METHODS

Study sites.—This research was conducted at four reservoirs located on the island of Puerto Rico. Puerto Rico is exclusively tropical habitat and is primarily of volcanic origin. It is 175 km long and approximately 62 km wide and has a central mountain range that runs east to west. Reservoirs in Puerto Rico are generally mesotrophic to eutrophic and are anoxic below about 3 m depth except following infrequent mixing events. Surface water temperatures average around 27°C, though this varies somewhat with altitude and season (Neal et al. 2009). The four study reservoirs were Lucchetti, Guajataca, Cerrillos, and Dos Bocas, which range from 108 to 360 ha in surface area. Turbidity in these reservoirs changes seasonally, being relatively low in winter and spring (up to 50 NTU) and much higher during the rainy season (up to $>$200 NTU). These reservoirs contain a mixture of fish species, with largemouth bass, threadfin shad, tilapia *Oreochromis* spp., sunfishes *Lepomis* spp., ictalurids, and Amazon sailfin catfish *Pterygoplichthys pardalis* being common to all four. Guajataca and Dos Bocas reservoirs also contain the butterfly peacock bass and red devil cichlid *Amphilophus labiatus* (also known as the midas cichlid *Cichlasoma citrinellum*) as additional predators.

Gear specifications.—Experimental gill nets were 1.5 m × 20 m with 8 monofilament panels (2.5 m long) of 19.5-, 6.25-, 10-, 8-, 12.5-, 15.5-, 5-, and 24-mm-bar mesh (mesh size order as in the gill net). Mesh sizes were selected based on those identified as most effective for sampling threadfin shad (6.25–19.5 mm; Van Den Avyle et al. 1995b), with one smaller and one larger mesh added. Fully floating epipelagic gill nets were used to sample the surface water layer (0–1.5 m), and slowly sinking mesopelagic gill nets were suspended to sample the deeper water layer (1.5–3.0 m). To make installation of gill nets easier, epipelagic and mesopelagic gill nets were connected end to end and set together (Figure 1). Along with open-water gill nets (set approximately on the center axes of the reservoirs), inshore, fully floating gill nets were set close to the shore above the depth of 6 m maximum. The inshore catches were included only in portraying the catches of individual mesh sizes; they

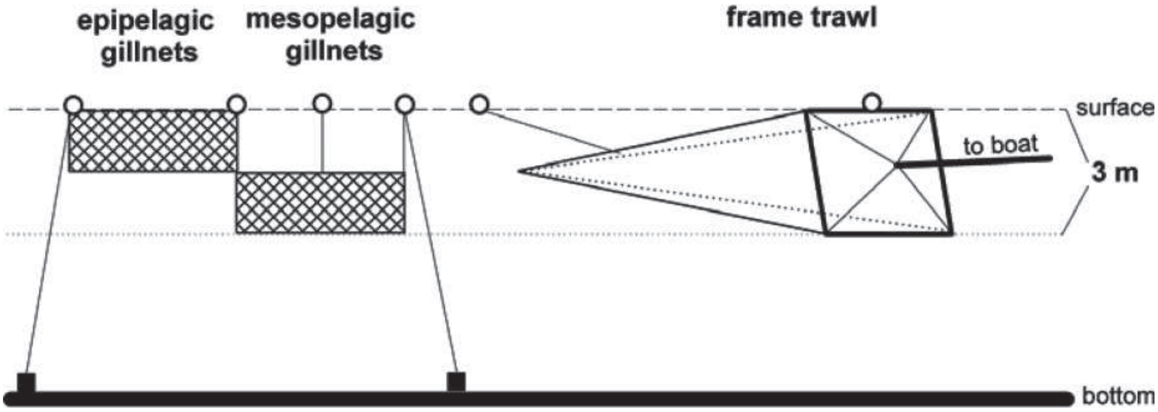

FIGURE 1. Generalized gear rigging for comparison of surface (0–3-m) sampling of threadfin shad using offshore gill nets and a frame trawl.

could not be used in the gear comparison analysis due to their sampling different habitat (Figure 1).

A custom frame fry trawl was designed with frame aperture dimensions of 3 × 3 m, 6-mm mesh in the body of the trawl, 4-mm mesh in the cod end, and a total length of 10.5 m (3.5 m of cod end). Trawls of these dimensions have been reported to be an effective tool for sampling fish up to 90 mm TL (Jůza and Kubečka 2007). The cod end of the trawl was equipped with a funnel, which prevented fish from escaping. The towing rope between the trawler boat and the trawl was 100 m long, and during the tow the boat was kept on a slightly curved trajectory so that the trawl never sampled exactly the area disturbed by the trawler boat. Both gill nets and the trawl were constructed by Pokorny-Site Co., Brloh, Czech Republic (www.pokorny-site.cz/en/).

Study design.—All four reservoirs were sampled during the first quarterly sampling in May 2010. After the first quarterly sampling, recreational activities prevented trawling in Cerrillos Reservoir. Hence, Dos Bocas, Lucchetti, and Guajataca reservoirs were sampled for all four quarters and Cerrillos Reservoir was sampled for one quarter, providing 13 reservoir–quarter data sets for comparison. Each reservoir was divided into upper and lower (near dam) sections (Dos Bocas has two upper sections, as it has two primary arms). At each section, three sites suitable for both gill netting and trawling were selected randomly prior to sampling; these sites were generally located in the middle of the reservoir, with water depths of 10–20 m.

Combined gill nets (epipelagic and mesopelagic sets) were installed before sunset by 1700 hours and lifted after sunrise (0800 h) the following day. This time frame was chosen because fish activity shows predictable peaks that are usually around sunset and sunrise (Prchalová et al. 2010). After landing, all fish were removed from the gill nets. Sport fish (largemouth bass, butterfly peacock bass, tilapia) were released alive after being measured and weighed during retrieval. Other species, excluding threadfin shad, were measured, weighed, and released directly if possible, depending on the degree of entanglement. Catches were separated according to mesh size of capture and processed immediately. Each fish was measured for total length (TL, mm) and weighed to the nearest 0.01 g (fish $<$100 mm TL) or the nearest gram (fish $\geq$100 mm TL). When large numbers ($>$50) of threadfin shad were captured per mesh size, subsampling was used.

Trawling was conducted using a two-boat system, with the first boat being used as a trawler and the second boat to retrieve the cod end, empty the catch, and process the samples. Trawling was performed at night starting 2 h after sunset near sites used for open-water gill nets the previous night. The trawl was rigged using buoys to sample the surface layers (0–3 m), thus allowing comparison between gear types. Because of the small size of these reservoirs, the large mouth of the trawl, and excessively high catch rates, the duration of each trawl tow was held at 2 min, which resulted in a trawled distance of about 120 m with average speed of 3.6 km/h and a sampled volume around 1,080 m^3. Further, 2-min tows were justified by the time necessary for a fish to reach the cod end of a trawl, which is 7 and 17 s for slow and fast swimmers, respectively (Winger et al. 2010). At the end of each tow, the cod end of the trawl was lifted and emptied. The catch was stored in a labeled ziplock bag and placed on ice in the cooler for processing in the laboratory. Occasionally, species other than threadfin shad were caught as bycatch; these species were identified, measured, and released alive back to the water. The iced trawl catches were processed the next day using the same procedure as in the gill-net catches. Threadfin shad smaller than 30 mm TL was considered larvae and counted only. Only the smallest individuals were measured to obtain information about the smallest catchable size of threadfin shad.

Data processing and analysis.—Fish records were stored in the database software Pasgear (J. Kolding, University of Bergen, Norway; www.imr.no/forskning/bistandsarbeid/nansis/pasgear_2/en). Results (e.g., relative abundance, biomass, deviation, proportion) were calculated within the Pasgear database. Abundance and biomass are expressed as number per unit effort (NPUE) and biomass per unit effort (BPUE), respectively, reported as the number of individuals or grams per 1,000 m^2 of gill nets or 1,000 m^3 of open water sampled by the trawl. Statistical analyses were performed in the Statistica software. The

TABLE 1. Catches of threadfin shad in four Puerto Rican reservoirs sampled by both gill nets and trawls, in the aggregate and by size-class. The values in parentheses are percentages.

Reservoir	Gear	Total	<35 mm	35–80 mm	>80 mm
Dos Bocas	Gill net	3,486	5 (0.1)	2,948 (84.6)	533 (15.3)
	Trawl	27,883	17,899 (64.2)	9,965 (35.7)	19 (0.1)
Lucchetti	Gill net	1,847	1 (0.1)	1,238 (67.0)	608 (32.9)
	Trawl	34,340	25,003 (72.8)	9,152 (26.7)	185 (0.5)
Guajataca	Gill net	652	4 (0.6)	641 (98.3)	7 (1.1)
	Trawl	7,012	3,968 (56.6)	3,044 (43.4)	0 (0)
Cerrillos	Gill net	646	1 (0.2)	627 (97.0)	18 (2.8)
	Trawl	4,224	3,364 (79.6)	856 (20.3)	4 (0.1)

study design resulted in 90 gill net–trawl pairs of NPUEs and BPUEs to be compared using the linear regression. Two pairs were removed from the set as obvious outliers (the uppermost sample in Lucchetti Reservoir in January 2011; and the middle-dam sample in Dos Bocas Reservoir in January 2011, which had an extremely high [4 times] trawl catch and a subnormal [one-tenth] gill-net catch in comparison with the other catches in the section). Coefficients of variation (CVs [SD/mean]) were compared using the *t*-test for independent samples between gears. Factorial analysis of variance (ANOVA) was used to assess the effects of reservoir, sampling season, reservoir section, and their interactions on the CVs. As the size ranges of gill-net and trawl catches did not correspond to each other, a size range 35–80 mm was selected in order to compare NPUEs, BPUEs, CVs, and size distributions between the two gears (Table 1; Figure 2). The range was set as the most frequent minimum and maximum sizes (5-mm intervals) that contained reasonable amounts of shad in both gears across all campaigns. In setting the thresholds, we took into account the size limitations of the gill nets used (minimum, 40 mm TL; Prchalová et al. 2009) and trawl (maximum, 90 mm TL; Jůza and Kubečka 2007). On average, 87% and 32% of shad were within the comparable size range in gill-net and trawl catches, respectively (Table 1). Size distributions were compared using the two-sample Kolmogorov–Smirnov test.

RESULTS

A total of 6,631 and 73,459 threadfin shad were captured in offshore gill-net and trawl sampling, respectively, over the duration of the study. Trawl and gill-net NPUEs were not significantly correlated ($t = 1.124$, df = 78, $P = 0.265$), with the coefficient of determination being only 0.016 (Figure 3). However, the intercept of the NPUE regression was significant ($t = 4.515$, df = 78, $P < 0.001$), so that the curve did not go through zero. The comparison of biomasses provided similar, nonsignificant correlation ($t = 0.980$, df = 78, $P = 0.330$, $r^2 = 0.012$; intercept: $t = 3.824$, df = 78, $P < 0.001$).

The trawl and gill-net catches significantly differed in sampling precision in both the NPUE and BPUE comparisons within comparable size ranges (NPUE: $t = –3.645$, df = 56, $P < 0.001$; BPUE: $t = –3.307$, df = 56, $P = 0.002$). The trawl catches had coefficients of variation of 0.433 and 0.465 for NPUE and BPUE, respectively, whereas those for the gill-net catches were 0.761 and 0.747. The CVs did

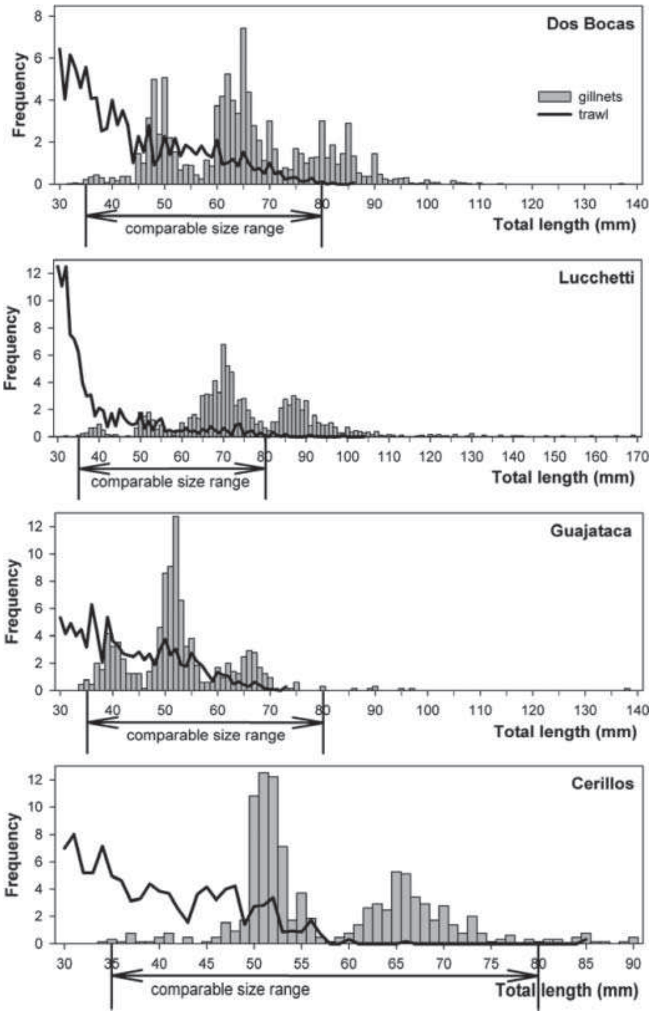

FIGURE 2. Size distributions of gill-net and trawl catches of threadfin shad above 30 mm TL in four Puerto Rican reservoirs and the size ranges used in comparisons of NPUE, BPUE, CV, and size distributions.

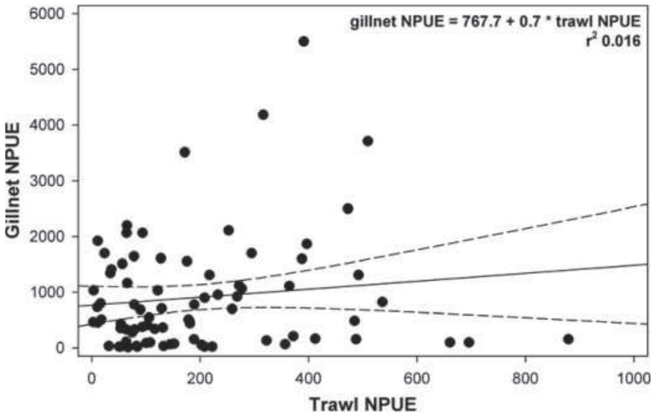

FIGURE 3. Relationship between trawl and gill-net NPUEs within the comparable size range 35–80 mm, with the regression line (solid) and its 95% confidence band (dashed). The units are individuals/1,000 m^3 for trawls and individuals/1,000 m^2 for gill nets.

not differ between reservoirs, sampling seasons, sections, or any combination of these three factors ($P > 0.050$ in every comparison).

Ten of the 13 comparisons of size distributions within the comparable size ranges of gill-net and trawl catches showed significant differences (Table 2). Only in 3 cases did the size distributions correspond between gill-net and trawl samples. In 12 cases, the mean total length of the threadfin shad caught in gill nets was greater than that of fish caught by trawl; the range for the gill nets was 23–169 mm, that for trawls 10–108 mm. Contrary to the gill-net samples, a majority of the trawl catch was represented by larvae (<30 mm TL), with little evidence of length-cohorts (Table 1, Figure 2).

In contrast, the gill-net size distributions showed distinct peaks of size-groups corresponding to the catches of individual mesh sizes. The relative proportions of these peaks did not correspond to continuous the size distribution obtained by trawling. All mesh sizes but 24 mm caught threadfin shad, and most shad were captured by 8-mm mesh and adjacent mesh sizes (6.25 and 10 mm). Other mesh sizes represented small (<5%) or negligible proportions of the total catch. The mean total lengths of the threadfin shad collected displayed a positive relationship with mesh size, as did the standard deviations and ranges (Figure 4). Mesh sizes 5–12.5 mm displayed unimodal distributions of catch. The distribution for the 15.5-mm mesh showed two distinct peaks, with that for the smaller fish being generated by shad with higher body height (probably females) than those of similar sizes caught in the 12.5-mm mesh.

Gill-nets and trawl catches differed markedly in their bycatches ($t = 3.558$, df $= 24$, $P = 0.002$). Bycatch comprised 15.4% (1,208 fish) of the gill-net catch, whereas it accounted for only 0.7% (537) of the trawl catch (Table 3). Thirteen species were recorded in the gill-net bycatch. Trawl bycatch consisted of 8 species, all of which also were collected by gill nets. The principal bycaught species in the gill-net catches were red devil cichlids, channel catfish *Ictalurus punctatus*, white catfish *Ameiurus catus*, and tilapias. The most important bycaught species in the trawl sampling were tilapias and Amazon sailfin catfish (both mainly as larvae up to 20 mm TL) and red devil cichlids (Table 3).

Gill netting and trawling further differed in the labor needed per standardized unit of catch, including sampling and catch processing. Gill nets required 3.5 h of labor per 100 processed shad, excluding exposure and repairing time. Trawling was

TABLE 2. Results of two-sample Kolmogorov–Smirnov tests of the size distributions of threadfin shad caught in gill nets and trawls in each reservoir–quarter comparison. Mean total lengths (mm) and SDs are presented for each gear. *P*-values for the size distributions that corresponded to each other are given in bold italics.

		Gill net		Trawl	
Campaign	*P*-value	Mean	SD	Mean	SD
Cerrillos, Apr	<0.001	56.632	9.832	44.090	6.592
Dos Bocas, Apr	<0.001	55.861	9.949	44.588	9.257
Dos Bocas, Jun	<0.001	63.881	10.037	58.226	11.298
Dos Bocas, Oct	***>0.100***	66.445	9.309	65.750	9.014
Dos Bocas, Jan	<0.010	49.673	8.564	48.362	10.764
Guajataca, Apr	<0.001	51.648	7.246	42.165	6.648
Guajataca, Jun	***<0.100***	50.981	8.006	49.192	6.661
Guajataca, Oct	<0.001	47.427	7.734	41.788	6.792
Guajataca, Jan	<0.001	61.437	9.165	55.137	6.875
Lucchetti, Apr	<0.001	59.184	10.183	45.558	7.892
Lucchetti, Jun	***>0.100***	53.104	11.368	53.327	11.104
Lucchetti, Oct	<0.001	66.505	4.816	62.286	10.514
Lucchetti, Jan	<0.001	67.170	9.936	46.570	13.277

TABLE 3. Species caught by offshore gill nets (G) and trawls (T) in each reservoir. The absolute numbers (*N*) and percentages of the total catch (%) are presented.

Reservoir (gear)	Measure	Threadfin shad	Red devil cichlid	Channel catfish	Tilapia	White catfish	Largemouth bass	Amazon sailfin catfish
Cerrillos (G)	*N*	646				7	1	
	%	98.0				1.1	0.2	
Cerrillos (T)	*N*	4,224					1	
	%	99.06					0.02	
Dos Bocas (G)	*N*	3,486	559	279	115	56		
	%	77.5	12.4	6.2	2.6	1.2		
Dos Bocas (T)	*N*	27,883	42	7	268	7		136
	%	98.4	0.1	0.02	0.9	0.02		0.5
Guajataca (G)	*N*	652	3		6	6	1	23
	%	91.7	0.4		0.8	0.8	0.1	3.2
Guajataca (T)	*N*	7,012						2
	%	99.07						0.03
Lucchetti (G)	*N*	1,847		54	33		26	1
	%	93.7		2.7	1.7		1.3	0.1
Lucchetti (T)	*N*	34,340		3	48		2	20
	%	99.8		0.01	0.1		0.01	0.1
Total G	*N*	6,631	562	333	154	69	28	24
	%	84.6	7.2	4.2	2.0	0.9	0.4	0.3
Total T	*N*	73,459	42	10	316	7	3	158
	%	99.3	0.1	0.01	0.4	0.01	0.004	0.2

almost ninefold more effective, with 0.4 h of labor per 100 processed shad.

DISCUSSION

Comparison of gill-net and trawl sampling in this study suggests that trawling is better for sampling threadfin shad in the tropical reservoirs of Puerto Rico. The majority of shad populations consisted of fish up to 80 mm TL, and in this size range trawling provided a more realistic picture of the size distribution than gill nets. Further, as an active sampling, trawling was less affected by schooling, thus providing less variable results. Trawling also produced negligible bycatch and was less laborious and more cost-effective than gill nets. These factors support the recommendation of trawling as the method of choice for threadfin shad management and research in Puerto Rico and other tropical reservoirs with similar characteristics. In some reservoirs, shad larger than 80 mm TL were also present in the population (Figure 2). To obtain representative samples of this part of the size spectrum by trawling, larger trawl openings, higher towing speeds, and/or longer tows have to be used.

Comparison of the results from active and passive gears is difficult. Passive gill nets provide a picture of the fish community that is active during the exposure time of the nets (Prchalová et al. 2010). It is generally accepted that the gill-net catch is dependent on a given fish density (e.g., Mehner and Schulz 2002; Bonar et al. 2009; Olin et al. 2009); however, some authors pointed out that elevated gill-net catches were related to increased fish activity rather than to the density recorded by trawling (Olin and Malinen 2003). Furthermore, gill-net catchability does not necessarily vary linearly with fish density, as factors such as net saturation, fish escapement, and avoidance of/attraction to a gill net with already enmeshed fish play a significant role during every gill-net sample (Borgström 1992; Olin et al. 2004; Prchalová et al. 2011). Thus, the passive nature of gill nets results in sensitivity to several types of serious selectivities. This is further support for the selection of active trawl sampling over passive gill-net sampling.

Active trawling offer an immediate picture of a fish community, biased only by selectivity dependent on gear characteristics and sampling design and not on fish community characteristics (Kubečka et al. 2012). In general, it is important to select sampling protocols like the diel period of trawling, towing speed, mesh sizes, and mouth opening area based on the community to be sampled. Usually, night is the most efficient period for trawling due to the lower visibility of the net (Glass and Wardle 1989), lower activity of most fish species (Prchalová et al. 2010; Rakowitz et al. 2012), and more homogeneous spatial distribution of fish species that tend to school or shoal during

TABLE 3. Extended.

Reservoir (gear)	Butterfly peacock bass	Redear sunfish *Lepomis microlophus*	Bluegill *Lepomis macrochirus*	Green swordtail *Xiphophorus helleri*	Redhead cichlid *Cichlasoma synspilum*	Brown bullhead *Ameiurus nebulosus*	Marbled bullhead *Ameiurus nebulosus marmoratus*	Total bycatch
Cerrillos (G)		5						13
		0.8						2.0
Cerrillos (T)		1						2
		0.02						0.04
Dos Bocas (G)				3				1,012
				0.1				22.5
Dos Bocas (T)								460
								1.6
Guajataca (G)	19				1			59
	2.7				0.1			8.3
Guajataca (T)								2
								0.03
Lucchetti (G)		3	5			1	1	124
		0.2	0.3			0.1	0.1	6.3
Lucchetti (T)								73
								0.2
Total G	19	8	5	3	1	1	1	1,208
	0.2	0.1	0.1	0.04	0.01	0.01	0.01	15.4
Total T		1						537
		0.001						0.7

the day (Vondracek et al. 1989). The 3- × 3-m fixed-frame trawl used in this study was found to be a quantitative tool for fry abundance and size estimates in artificial temperate reservoirs, showing that fish up to 90 mm TL are mostly passive without important avoidance behavior at night (Jůza and Kubečka 2007). Larger individuals or species are less vulnerable to capture as they detect the trawl sooner (Zhang and Arimoto 1993), and they are more able to avoid trawls at slower towing speeds, with finer mesh sizes in the trawl netting, and/or with smaller mouth openings (Wardle 1993; Jůza and Kubečka 2007).

Only a few studies have correlated gill-net and trawl catches, usually with a positive correlation in numbers or biomass assessments. For example, Van Den Avyle et al. (1995a) compared six gears for sampling threadfin shad in Lake Texoma and reported correlations between trawl and gill-net catches with relatively strong correlation coefficients. Significant positive correlations of trawl and gill-net estimates were found for four species in the study of Olin et al. (2009) when they removed the smallest fish from the comparison. The same approach was used by Olin and Malinen (2003), who reported a positive relationship but were not able to detect a significant correlation.

The size distributions of the threadfin shad captured in gill nets did not correspond to those of the fish captured by trawls and showed distinct size groupings. Multimodal size distributions are common in temperate waters, where populations consist of several cohorts that are different in size due to fixed-period annual spawning, and peaks in the size distributions in these cases can be detected with both active and passive gears (Prchalová et al. 2008, 2009; Vašek et al. 2009). In Puerto Rican reservoirs, threadfin shad tend to spawn nearly year-round (Stancil et al. 1999), creating almost continuous size distributions, as was evidenced by the trawl samples in this study. Similar differences between gill-net and trawl size distributions have also been reported by Van Den Avyle et al. (1995a) in Lake Texoma. These discrepancies between gill-net and trawl size distributions indicate the strong mesh size selectivity of gill nets, with biased proportions of adjacent-size peaks. Gill-net size selectivity could be responsible for the lack of correlations between gill-net and trawl NPUEs and BPUEs.

There are several potential reasons for the observed mesh size selectivity of threadfin shad in Puerto Rican reservoirs. First, it is possible that the mesh sizes, which were selected according to a geometric series with a factor 1.25 between adjacent meshes, were not appropriate for the continuous size distributions. The factor 1.25 was found to be the best one for covering the whole size spectrum of coarse species in temperate European waters and, as such, it has been accepted as a norm for standardized gill

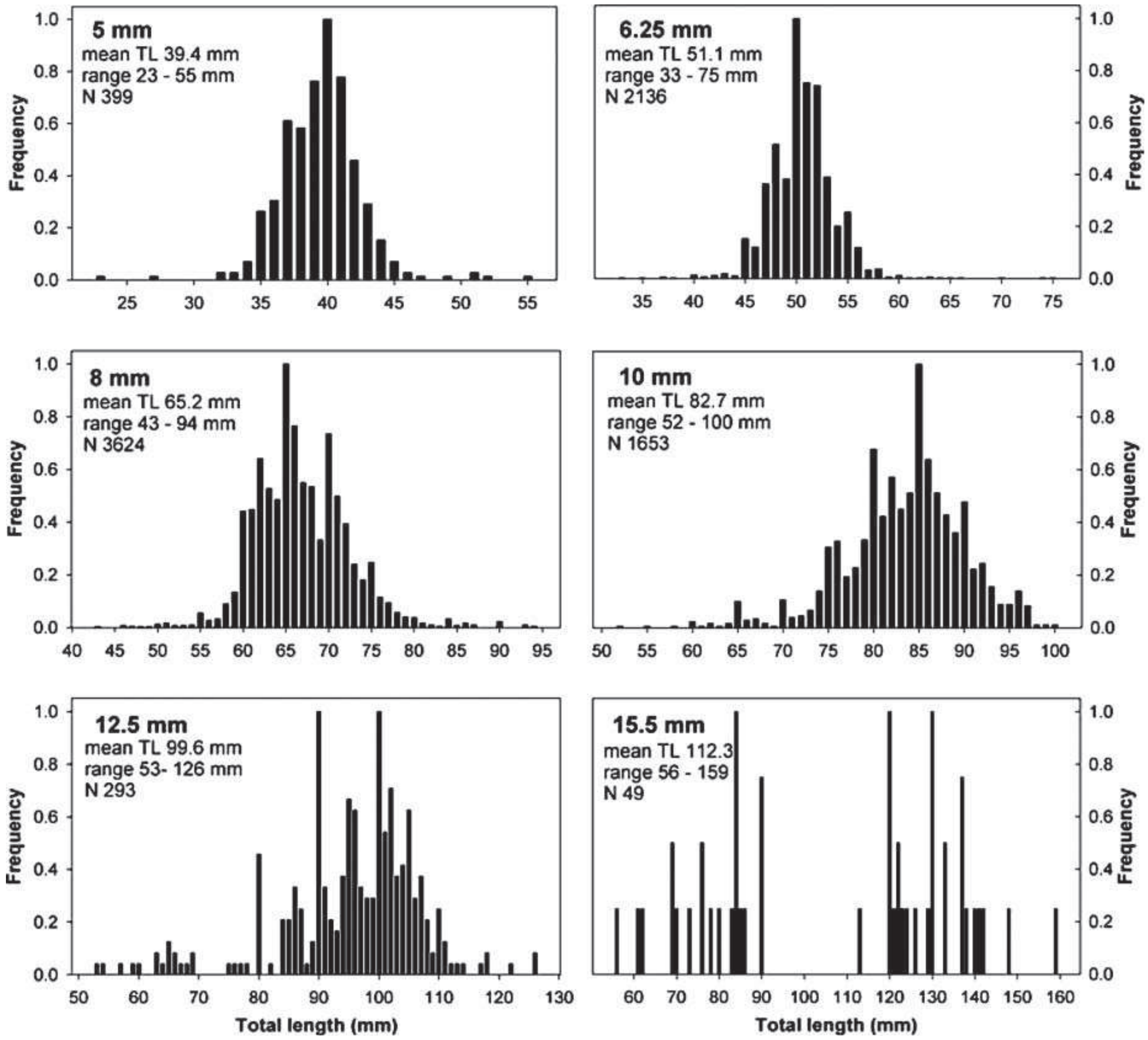

FIGURE 4. Size distributions of threadfin shad caught in gill nets with different mesh sizes. The mean sizes of captured shad (mean TL), the size range, and the total number of shad caught (*N*) are listed as well.

netting (CEN 2005). In the case of threadfin shad in Puerto Rico, this factor may need to be reduced to better sample the range of fish sizes. This topic would require specialized research involving calibration with representative active gear or experiments with known populations.

The mesh size selectivity could also be caused by different behavior or activity of threadfin shad of different sizes. It is generally known that fish of bigger sizes swim with higher speeds, thus crossing larger distances, which may increase their probability of encountering the gill net (Rudstam et al. 1984; Anderson 1998; Čech and Kubečka 2002). This is well documented by overestimation of catches of larger fish in larger meshes (Mattson 1994; Jensen 1995; Kurkilahti et al. 1998; Huse et al. 2000; Irwin et al. 2008). However, Borgström (1989) proposed that higher catches of larger fish cannot be explained solely by the higher probability of encounter due to swimming speed, as it would require swimming speeds around 100 m/s to account for some observed differences. Thus, underestimation of smaller fish due to the mechanical parameters of gill nets as well as the biological characteristics of smaller fish should be considered too (for an overview, see Prchalová et al. 2009). In the case of Puerto Rican threadfin shad, the smallest mesh size (5 mm) was still too big to cover the high proportion of shad smaller than 40 mm TL in the population. It is not feasible to construct gill nets with smaller mesh and finer thread, so it is not possible to reduce the underestimation of small fish in this way. Another feature that may differ during shad ontogeny is the use of space during the 24-h cycle. Larger fish sometimes migrate inshore from open water at dusk and back to open water at dawn (Kubečka 1993; Říha et al. 2011), which may result in offshore gill-net catches but no catches in solely night offshore trawl samples.

The lack of correlation between gill-net and trawl catches could be also explained by catch variability, which was much greater with gill nets. The coefficients of variation for gill-net samples were greater than 0.5, which has been proposed as the target maximum CV for comparative studies (Cyr et al. 1992). The variability of gill-net catches within a single section was substantial, and we assumed this variability was caused by the schooling of threadfin shad and by predators attacking shad enmeshed in gill nets. Threadfin shad have been reported to aggregate intensively, with dense, smaller schools during the day and larger, looser schools during the night (Vondracek and Degan 1995). Therefore, the distribution of threadfin shad is decidedly uneven, which introduces variability into any passive sampling. In contrast, active sampling with a frame trawl covers representative volumes of water and has the potential to reduce the natural variability caused by uneven distribution, which was evident in the small values of CV obtained. Considerable gill-net damage occurred during each deployment, and the finer mesh sizes displayed multiple holes that significantly reduced the effective netting area. Thus, gill nets had to be repaired or replaced by new ones very frequently (after each quarterly sampling of approximately three exposures). It appeared that threadfin shad enmeshed in gill nets represented an irresistible bait for predators, and many shad showed signs of being attacked. On the other hand, we did not observe any damage to or significant wear of the single trawl net used throughout the study, and due to this fact it kept the same efficiency. This also favors using trawling rather than gill netting for monitoring shad in tropical reservoirs.

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