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Gillnet selectivity of small coastal sharks off the southeastern United States

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Abstract

Gillnet selectivity parameters for the Atlantic sharpnose, *Rhizoprionodon terraenovae*, blacknose, *Carcharhinus acronotus*, finetooth, *Carcharhinus isodon*, and bonnethead, *Sphyrna tiburo*, sharks were estimated from fishery-independent catches in multi-panel gillnets with stretched mesh sizes ranging from 8.9 to 14.0 cm in steps of 1.3 cm, with an additional size of 20.3 cm. Mesh selectivities were estimated using a maximum-likelihood model, which fits a gamma distribution to length data for each mesh size using the log-likelihood function. The Atlantic sharpnose and finetooth shark exhibited the broadest selection curves. Peak selectivities for the Atlantic sharpnose were reached from 750 mm FL for the 8.9 cm mesh to 1150 mm FL for the 14.0 cm mesh in 50 mm FL increments per mesh. Peak selectivity for the finetooth shark was reached at 550 mm FL for the 8.9 and 10.2 cm meshes, increased to 650 mm FL for the 11.4 mesh, and 750 mm FL for the 12.7 and 14.0 cm meshes. Selectivity was highest at 1150 mm FL for the 20.3 cm mesh. The bonnethead and blacknose shark exhibited narrower selection curves, with peak selectivity occurring at 450 mm FL for the 8.9 cm mesh, 750 mm for the 12.7 cm mesh in 100 mm FL increments per mesh. Maximum selectivity for the 20.3 cm mesh was 950 and 1050 mm FL for bonnethead and blacknose shark, respectively. The θ_1 values for blacknose and finetooth shark were most similar (140.58 and 141.25), whereas the value calculated for Atlantic sharpnose was the highest (211.95) and that for the bonnethead (131.77) was the lowest. Values calculated for θ_2, a parameter that describes the variance of sizes by mesh, ranged from 27,259 for the bonnethead to 189,873 for the finetooth shark. Although gillnets used in this study were not directly constructed for use in estimation of gillnet selectivities, information on mesh selectivities estimated herein has direct applicability to commercial gillnets with meshes of similar sizes.
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Keywords: Shark; Gillnet; Selectivity; Mesh size; Fishery

1. Introduction

Gillnets are widely used for the harvest of fish. Because gillnets are highly selective for fish of certain size, knowledge of the size selection of gillnets is necessary to effectively regulate their use and for population assessment (Regier and Robson, 1966; Hamley, 1975). Using various indirect methods (see review in Millar and Fryer, 1999; Millar, 2000), gillnet selectivity models have been developed and applied to a wide variety of species, such as Spanish mackerel, *Scomberomorus maculatus* (Ehrhardt and Die, 1988); spotted seatrout, *Cynoscion nebulosus* (Helser et al., 1991); lake trout, *Salvelinus namaycush* (Hansen et al., 1997);

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and Greenland halibut, *Reinhardtius hippoglossoides* (Huse et al., 1999).

Despite the importance of gillnet selectivity in fisheries assessment and management, there are few estimates for sharks. Kirkwood and Walker (1986) developed selectivity parameters for the gummy shark, *Mustelus antarcticus*, and McLoughlin and Stevens (1994), for *Carcharhinus tilstoni* and *Carcharhinus sorrah*. Gillnet selectivity models were also estimated for the dusky, *Carcharhinus obscurus*, and whiskery *Furgaleus macki*, sharks (Simpfendorfer and Unsworth, 1998). No selectivity models are available for species harvested with gillnets in US waters.

In the late 1980s, a drift gillnet fishery for sharks developed off the east coast of Florida and Georgia, USA (Trent et al., 1997). Currently, the number of vessels active in this fishery can vary between 4 and 6 depending on the market value of sharks and the level of activity in other fisheries (Carlson and Lee, 2000). Generally, shark driftnet vessels operate in nearshore waters between 4.8 and 14.4 km from shore in areas north of Key West, Florida (∼24°37′–24°58′N) and between West Palm Beach, FL (∼26°46′N) to Altamaha Sound, Georgia (∼31°45′N). Vessels target sharks of the small coastal shark aggregate (i.e. Atlantic sharpnose, *Rhizoprionodon terraenovae*, blacknose, *Carcharhinus acronotus*, finetooth, *Carcharhinus isodon*, and bonnethead, *Sphyrna tiburo*, sharks) and fish gillnets both multi- and monofilament ranging in length from 547.2 to 2,736 m; from 9.1 to 13.7 m in depth, and from 12.7 to 25.4 cm in stretched mesh size (Trent et al., 1997; Carlson and Lee, 2000; Carlson and Baremore, 2001). If this fishery is to be managed efficiently, knowledge of the selectivity of mesh sizes used can aid in recommendations to maximize or minimize the catch of certain shark sizes and species. In addition, an understanding of the selective patterns of the fishing gear is an essential part of any age-structured stock assessment of sharks or other species.

The purpose of this paper is to estimate selectivity coefficients for four species of sharks from the small coastal aggregate (i.e. Atlantic sharpnose, blacknose, finetooth, and bonnethead sharks) using multi-panel gillnets with a variety of mesh sizes, some of which are utilized by the commercial shark drift gillnet fishery.

2. Methods

Data necessary for calculation of mesh selectivities were obtained from gillnets used in a fishery-independent survey of coastal shark populations in the northeastern Gulf of Mexico (Carlson and Brusher, 1999). Sharks were collected with a 186 m long gill net consisting of panels of six different mesh sizes (Table 1). Stretched mesh sizes ranged from 8.9 cm (3.5 in.) to 14.0 cm (5.5 in.) in steps of 1.3 cm (0.5 in.), with an additional size of 20.3 cm (8.0 in.). Panel depths when fishing were 3.1 m. Webbing for all panels, except for the 20.3 cm mesh, was clear monofilament, double-knotted and double-selvaged. The 20.3 cm stretched mesh webbing was made of #28 multi-filament nylon, single-knotted, and double-selvaged. When set, the nets were anchored at both ends.

Sampling was conducted from April 1996 through October 2000. The gillnets were randomly set over a 24 h period within an area. Gillnets were checked and cleared of catch, or pulled and reset every 1.0–2.0 h. Sharks captured were measured in fork length (mm) on a straight line. Sharks captured by ‘gilling’ (head caught initially in a single mesh) or ‘entangled and rolled’ were pooled for analysis.

Mesh selectivities were estimated following the method of Kirkwood and Walker (1986). This method has been reviewed and compared with other techniques for estimating gillnet selectivity (Millar, 2000). Millar (2000) advocated this approach because it facilitates a simultaneous fit to the catch data using

Table 1
Specifications of gillnets used for estimation of selectivity coefficients[a]

Stretched mesh size		Twine size no.	Meshes deep	Twine thickness (mm)	Break strength (kg)
cm	in.				
8.9	3.5	208	40	0.52	11.8
10.2	4.0	208	35	0.52	11.8
11.4	4.5	208	35	0.52	11.8
12.7	5.0	277	30	0.62	18.2
14.0	5.5	277	25	0.62	18.2
20.3	8.0	24	20	1.0	115.9

[a] The net was 186 m long and 3.5 m deep. Each panel was 30.1 m long, leadline weight was 4.5 kg, and buoyancy of floats per panel was 2.3 kg.

maximum-likelihood and overcomes problems with parameter estimation. This method fits a gamma distribution to length data for each mesh size using the log-likelihood function defined as

$$L = \sum_{i=1}^{I}\sum_{j=1}^{J}[n_{ij}\ln(\mu_j S_{ij}) - \mu_j S_{ij}]$$

where n_{ij} is the number of sharks of length class j caught in mesh size i,

$$\mu_j = \frac{\sum_{i=1}^{I} n_{ij}}{\sum_{i=1}^{I} S_{ij}}$$

and S_{ij} is the relative selectivity of a shark in length class j caught in mesh size i. Selectivity is modeled as a function of shark length class (l_j) and the parameters α and β which describe the probability density function of the gamma distribution for mesh size i:

$$S_{ij} = \left(\frac{l_j}{\alpha_i \beta_i}\right)^{\alpha_i} \exp\left(\alpha_i - \frac{l_j}{\beta_i}\right)$$

The values of α and β were calculated from the mesh size (m_i), a dimensionless scaling parameter (θ_1) to relate the mode of the gamma distribution (α, β) to mesh size, and the variance (θ_2) as

$$\alpha_i \beta_i = \theta_1 m_i$$

and

$$\beta_i = -0.5(\theta_1 m_i - (\theta_i^2 m_i^2 + 4\theta_2)^{0.5})$$

The assumptions of the model (Kirkwood and Walker, 1986) are (1) the shape of the selectivity curve is represented by a gamma distribution; (2) the length at maximum selectivity is proportional to the mesh size; (3) sampling occurs across the whole population; (4) the variance is constant for each mesh size for a given species; (5) catches within each length class are independent observations from a Poisson distribution; and (6) all mesh sizes have equal fishing power.

The values of θ_1 and θ_2 were obtained by minimizing the negative log-likelihood function. Confidence intervals for these parameters were estimated through bootstrapping. The original length–frequency distributions for each mesh size were resampled with replacement based on the number of sharks for each length interval for each mesh size. The process was repeated 1000 times and confidence intervals calculated as the 2.5th and 97.5th percentiles. All simulations were run in Microsoft Excel using the Visual Basic for Applications language.[2]

3. Results

Altogether 2,647 sharks from four species in the small coastal aggregate were used for estimation of gillnet selectivity. The Atlantic sharpnose shark was the most abundant species captured ($n = 1,281$). The remaining species captured in decreasing abundance were the bonnethead ($n = 724$), finetooth ($n = 521$), and blacknose sharks ($n = 121$). In general, larger sharks were caught in larger mesh sizes, except for the finetooth shark. The shape of the length–frequency distribution varied by mesh size and species (Fig. 1). Distributions were approximately normal for mesh sizes 8.9 and 10.2 cm for Atlantic sharpnose and blacknose shark, mesh sizes 12.7 and 14.0 for bonnethead, and mesh sizes 11.4–14.0 for finetooth shark. The length–frequency distribution was negatively skewed for the larger mesh panels (12.7–20.3) for Atlantic sharpnose, blacknose, and bonnethead, and positively skewed for smaller meshes for bonnethead. The length–frequency distributions seemed to be bimodally distributed for blacknose shark captured in the 14.0 mesh size.

Depending on species, catch rates (i.e. CPUE: number of sharks/mesh panel/h) varied by mesh (Fig. 2). Analysis of variance on log transformed CPUE data found significant differences in CPUE and mesh size for Atlantic sharpnose and bonnethead sharks ($P < 0.0001$) but not for blacknose and finetooth sharks ($P \geq 0.05$). CPUE was highest for the 8.9 cm mesh for Atlantic sharpnose (CPUE $= 2.14$) and the 11.4 cm mesh for bonnethead (CPUE $= 0.95$). CPUE generally decreased with increasing mesh size, thereafter. Catch rates were highest for mesh size 8.9 cm for blacknose shark (CPUE $= 0.18$) and the 20.3 cm mesh for finetooth (CPUE $= 0.39$). CPUE remained relatively similar for all other meshes.

Relative selectivity varied by species. The Atlantic sharpnose and finetooth sharks exhibited the broadest

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[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

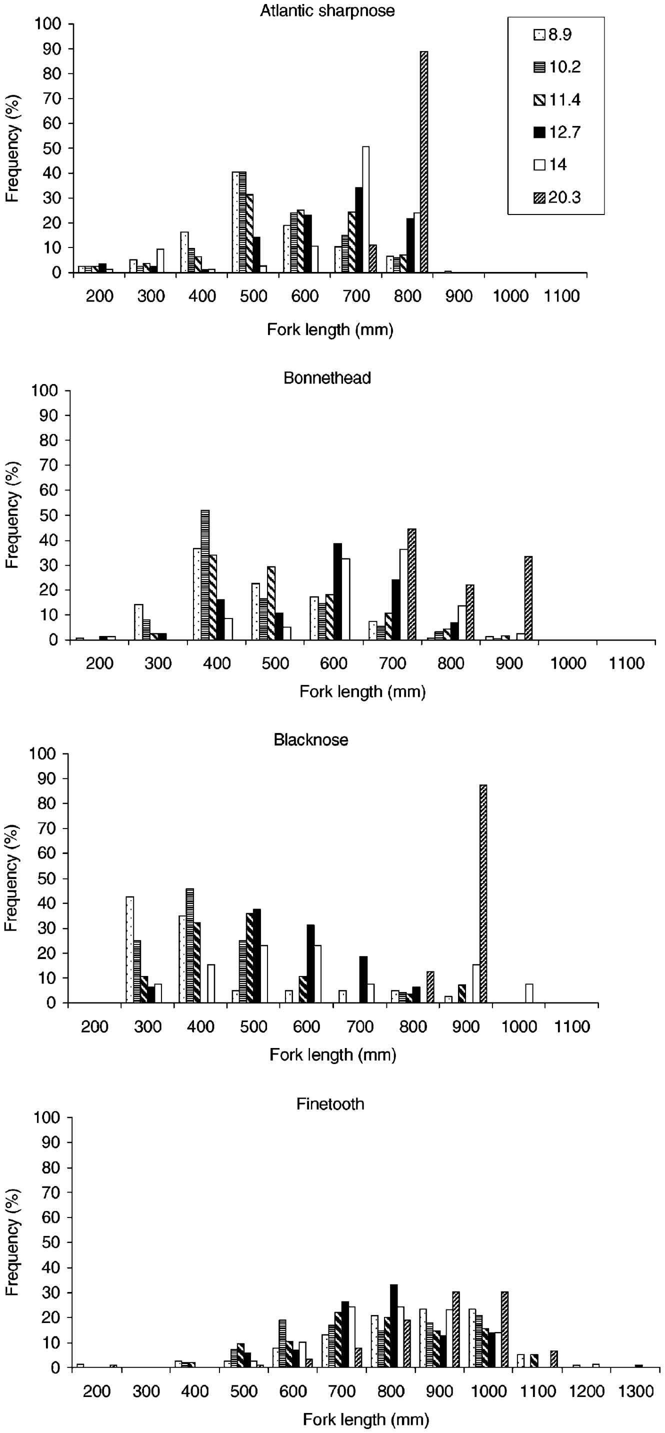

Fig. 1. Length–frequency distributions of 2647 small coastal sharks by species and mesh size panel (cm) used for developing gillnet selectivity models.

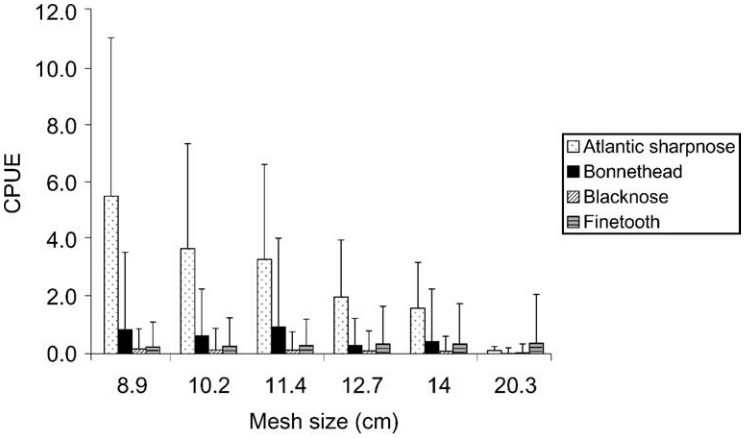

Fig. 2. Observed catch rates by mesh panel for small coastal shark species. CPUE is defined as the number of sharks/mesh panel/h. The vertical error bars represent +1 standard deviation.

selection curves, although the shape of the curve was skewed slightly to the left for the finetooth shark (Fig. 3). The blacknose and bonnethead sharks exhibited narrower selection curves. For Atlantic sharpnose, peak selectivities were reached at 750 mm FL for the 8.9 cm mesh size increasing to 1,150 mm FL for the 14.0 cm mesh size, in 50 mm increments per mesh panel. The bonnethead and blacknose shark exhibited narrower selection curves, with peak selectivity occurring at 450 mm FL for the 8.9 cm mesh, 750 mm for the 12.7 mesh in 100 mm FL increments per mesh. Maximum selectivity for 20.3 cm mesh was 950 and 1,050 mm FL for bonnethead and blacknose shark, respectively. Peak selectivity for finetooth shark was reached at 550 mm FL for the 8.9 and 10.2 cm mesh sizes, increasing to 650 mm FL for the 11.4 cm mesh size, and 750 mm FL for the 12.7 and 14.0 cm mesh size. Selectivity was highest at 1,150 mm FL for the 20.3 cm mesh size.

Values of θ_1 and θ_2 varied by species (Table 2). The θ_1 values for blacknose and finetooth shark were most similar (140.58 and 141.25) whereas the value calculated for Atlantic sharpnose shark was the highest and that for the bonnethead was the lowest. Values calculated for θ_2, a parameter that describes the variance of sizes by mesh, ranged from 27,259 for bonnethead to 189,873 for finetooth.

The estimated size–frequency distributions varied depending on species (Fig. 4). Predicted numbers of Atlantic sharpnose shark were highest at 250 and 550 mm FL, with numbers decreasing beyond the latter. The size–frequency for bonnethead and blacknose shark showed peaks at 450 and 350 mm FL, respectively. Beyond these peaks, the number of sharks decreased with increasing fork length, with the exception of a smaller peak at 950 mm FL for blacknose shark. The size–frequency distribution for finetooth shark indicated the greatest number of sharks was

Table 2
Selectivity parameters for small coastal sharks[a]

Species	θ_1	LCL	UCL	θ_2	LCL	UCL
Atlantic sharpnose	211.95	191.50	242.84	166,598	100,000	288,439
Bonnethead	131.77	128.58	138.25	27,259	15,316	33,553
Blacknose	140.58	135.72	143.94	31,569	22,504	38,099
Finetooth	141.35	138.98	147.04	189,873	122,788	325,023

[a] LCL and UCL indicate lower and upper 95% confidence limits, respectively.

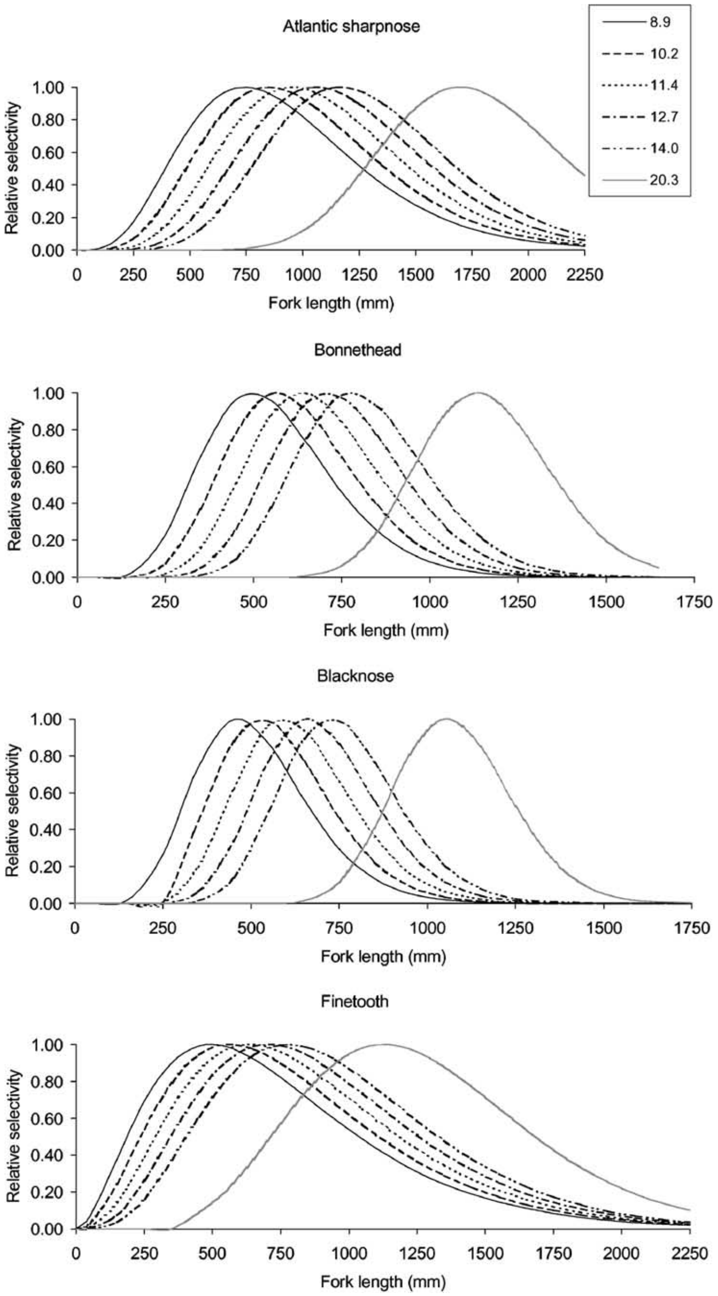

Fig. 3. Estimated relative selectivities by mesh size panel as a function of shark fork length for small coastal shark species.

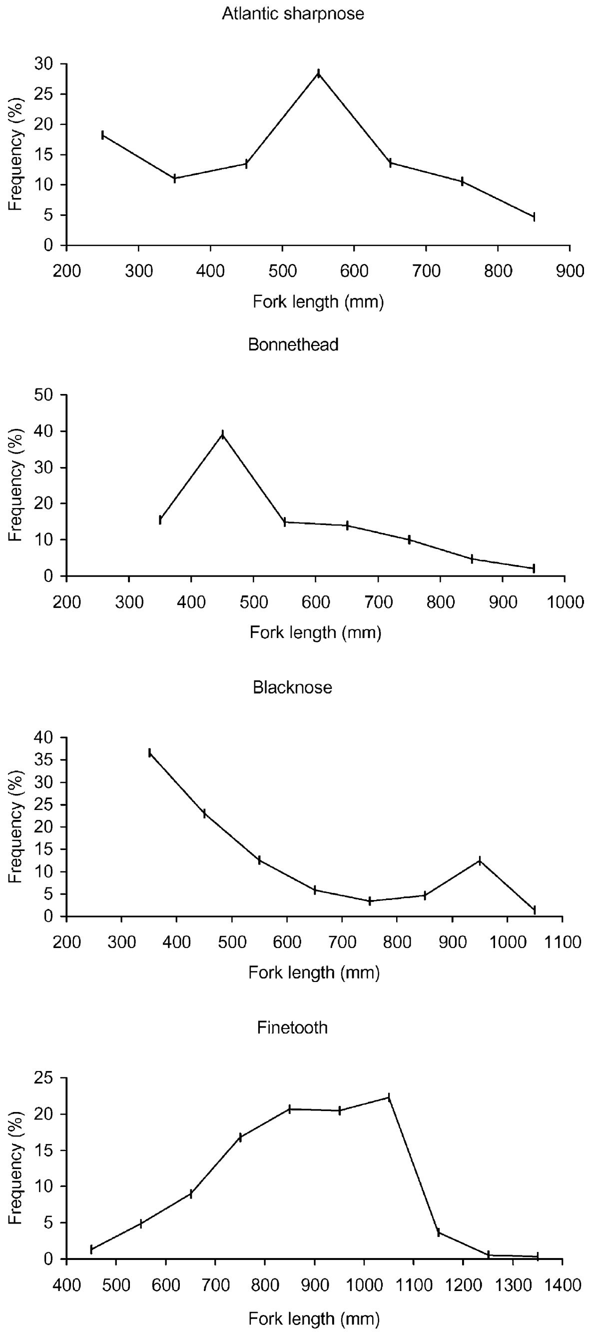

Fig. 4. Estimated relative population length–frequency distributions for small coastal shark species estimated by fitting the gillnet selectivity model.

between 750 and 1050 mm FL, with numbers declining beyond both limits of this interval.

4. Discussion

If the values of selectivity parameters derived for this study are to be considered valid, it is important to examine the assumptions of the model. The assumption that length at maximum selectivity is proportional to mesh size seems to have been met. A significant fit was found between length and girth for Atlantic sharpnose (girth $= 0.40(\text{FL}) - 28.27$, $P < 0.00001$, $r^2 = 0.78$, $n = 66$), bonnethead (girth $= 0.42(\text{FL}) - 51.37$, $P < 0.00001$, $r^2 = 0.83$, $n = 63$), blacknose (girth $= 0.43(\text{FL}) - 16.50$, $P < 0.00001$, $r^2 = 0.84$, $n = 19$) and finetooth (girth $= 0.39(\text{FL}) + 49.73$, $P < 0.0001$, $r^2 = 0.53$, $n = 25$) sharks. As girth is expected to be the primary variable in determining net retention, it follows that length at maximum selectivity is proportional to mesh size. Moreover, in plots of observed vs. predicted catches of each size class in each mesh panel (Fig. 5), a high correlation ($r^2 = 0.87$–0.95) was observed, indicating low residuals. This indicates that individual catches are independent of mesh size and that sharks were randomly distributed throughout meshes.

Kirkwood and Walker (1986) and McLoughlin and Stevens (1994) stated that the assumption of equal fishing power at maximum selectivity is difficult to assess directly. Attempts were made to sample over a broad geographic range to sample the entire population, yet the plots of estimated size–frequency distributions for these species indicate that larger sharks were less abundant in the areas sampled, rather than larger mesh sizes having lower fishing power. Small coastal sharks of all life stages are generally found in nearshore waters where sampling for this study took place. Data from a longline survey for Atlantic sharpnose, blacknose, and finetooth sharks (Carlson and Brusher, 1999) in these same areas in the northeastern Gulf of Mexico show a similar size distribution to the size–frequency estimated in the present study.

As suggested by Simpfendorfer and Unsworth (1998), there appears to be a similarity between values of θ_1 and body form within and among similar genera. The θ_1 values calculated for sharks in this study ranged from 131.7 to 211.9, which is similar to

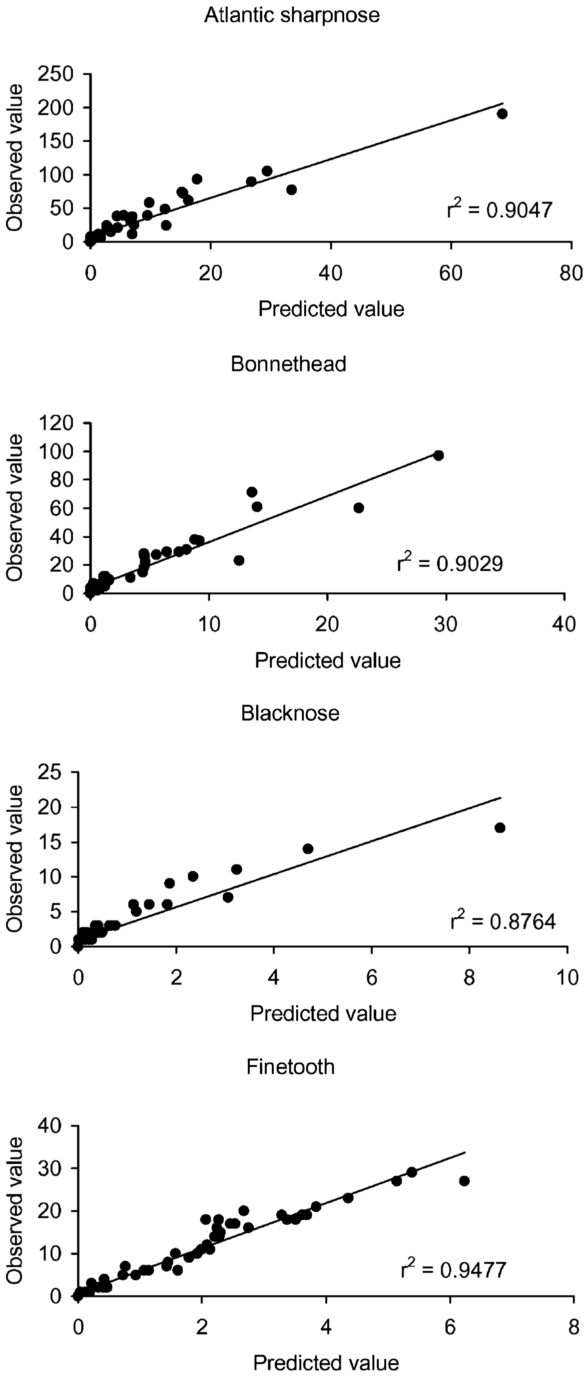

Fig. 5. Observed values as a function of predicted values of the number of sharks caught by mesh size panel for small coastal species.

values calculated for *C. sorrah* (131.6) and *C. tilstoni* (124.3) by McLoughlin and Stevens (1994) and to values calculated for dusky shark (130.1) and whiskery shark (173.7) by Simpfendorfer and Unsworth (1998). Fitzhugh et al. (2002) calculated values for gulf flounder (*Paralichthys albigutta*) and for southern flounder (*Paralichthys lethostigma*) of 76.2 and 79.2, respectively, using the method of Kirkwood and Walker (1986). All flounder are generally morphologically similar and closely related phylogenically. Interestingly, θ_1 values of 105.7 were found for guitarfish, *Rhinobatus productus*, a species that morphologically is intermediate between a Carcharhinid shark and a Paralichthid flounder (J.F. Márquez-Farias, Instituto Nacional de la Pesca, CRIP Guaymas, Sonora, Mexico, personal communication, 2001). Thus, a predictable relationship between values of θ_1 and the morphology and taxonomy of a species may exist. More analyses using this method of selectivity determination are required to test this hypothesis.

Previous studies on shark gillnet selectivity have generally analyzed data separately for sharks that are gilled and those that are gilled and rolled within the mesh. Although the use of data from combined sets may result in poorer estimates of population size frequency (Simpfendorfer and Unsworth, 1998), we initially pooled all sharks for analysis because our objective was to provide information that could represent the catch in fisheries that use gillnets for harvesting sharks. For example, although certain specifications of gillnets used in the shark drift gillnet fishery are designed to keep the net and sharks from rolling (Trent et al., 1997), the majority of sharks caught exhibit rolling and many are brought aboard completely wrapped within the mesh (personal communication to J. Carlson by drift gillnet observers, 2001).

Length at maximum selectivity increased with mesh size. However, for the finetooth shark there was generally more overlap among lengths at maximum selectivity for the smaller meshes and the selection curves were broader than those found for other species. Overall, mesh size and shark morphology are major factors affecting selectivity, but elasticity, hanging ratio, strength of the twine, and fish behavior can also be related to selectivity (Hamley, 1975). As all the smaller mesh panels were constructed similarly and the sharks are related in general morphology (Thompson and Simanek, 1977), the behavior of the finetooth shark may be the cause of the overlap in selectivity among the smaller meshes. Finetooth sharks roll in the net much more than other sharks even when a small portion of their body becomes wrapped or gilled within the net (Carlson, personal observation).

It is worthwhile to provide a comparison of the sizes of sharks captured in the drift gillnet fishery and the mesh sizes they are caught in. It is difficult to correctly assign catch and the exact size of the shark to a particular mesh size because generally observers have other data collection priorities while onboard and cannot easily discern one mesh size from another during haulback. However, based on observer information obtained prior to each set, catch for each set of the net can be divided into mesh size categories. For Atlantic sharpnose sharks estimated to be between 600 and 900 mm FL, approximately 78% of the total catch occurred in mesh sizes 12.7, 14.0, 15.2, and 20.3 cm stretch mesh. Peak selectivities in the present study for the Atlantic sharpnose were reached from 750 mm FL for the 8.9 cm mesh size to 1150 mm FL for the 14.0 cm mesh size. In the drift gillnet fishery, approximately 64% of the total catch of blacknose sharks 900 mm FL and larger were captured in mesh sizes 20.3 cm and larger (Carlson, unpublished data). Maximum selectivity found in the present study for blacknose shark occurred at 1,150 mm FL for the 20.3 cm mesh panels.

Despite the fact that there are currently no minimum size regulations for small coastal sharks in the commercial fishery, recent demographic evidence suggests that population growth rates are much more sensitive to survival of certain sizes or life stages of sharks (Cortés, 2002). For example, when considering small coastal species, Cortés (2002) suggests that management actions should focus preferentially on protection of juveniles and adults rather than age-0 individuals. Recommendations on minimum or maximum mesh sizes could thus be an effective tool to enhance juvenile and adult survival should stocks of these species become overfished.

Although gillnets used in this study were not directly constructed for use in estimation of gillnet selectivities, we feel that the mesh selectivities estimated herein have direct applicability to commercial gillnets with meshes of similar sizes. It should be noted that construction (i.e. net diameter and hanging coefficient) of gillnets used in this study was done after consultation with fishers who use gillnets when targeting sharks. Twine sizes for monofilament gillnets used in this study (#208 and #277) were also identical to those used by shark drift gillnet fishers (Trent et al., 1997). In addition, there are many coastal gillnet fisheries (e.g., Spanish mackerel fishery, Ehrhardt and Die, 1988; North Carolina sink net fishery, Ross, 1989; Chris Jensen, North Carolina Sea Grant, personal communication, 2001) that likely capture small coastal sharks as bycatch. Despite differences in methodologies among the fisheries that preclude a direct comparison, results from this study will aid in future recommendations to minimize bycatch of small coastal sharks.

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