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ARTICLE

Hook Selectivity in an Artisanal Spotted Rose Snapper *Lutjanus guttatus* Fishery on the Nicoya Peninsula, Costa Rica

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Abstract
Commercial fishing is responsible for declines in both the abundance and biomass of many marine species (Ward and Myers 2005). The Marine Stewardship Council's (MSC) Sustainable Seafood Certification Program focuses on fishery modifications to reduce such impacts on marine species and ecosystems. On the Nicoya Peninsula in northwestern Costa Rica, the Costa Rican nongovernmental organization Programa Restauración de Tortugas Marinas has been working with artisanal fishers since 2007 to promote sustainable fishing practices, with the goal of applying for a sustainable fishery certificate from the MSC. To collect relevant data for the MSC application, we tested the selectivity of the hooks used in the artisanal fishery to determine how the fishery interacts with the target species, the Spotted Rose Snapper *Lutjanus guttatus*, as well as nontarget, bycatch species. We constructed a longline composed of equal numbers of different sized hooks (the Mustad #8 "J" style hooks commonly used in the fishery as well as smaller #10 and larger #6 hooks). Decreasing the hook size led to higher catch rates of both Spotted Rose Snapper and most bycatch species, with no change in mean size of Spotted Rose Snapper. Increasing the hook size led to decreased catch rates of both Spotted Rose Snapper and most bycatch species and an increase in the mean size of Spotted Rose Snapper. The size range of the Spotted Rose Snapper caught on this gear did not exceed that of the artisanal fishery. This study suggests that the artisanal fishery is using an appropriately sized hook to minimize bycatch rates without unduly minimizing the catch rates of the target species, though increasing hook size could exclude the smallest Spotted Rose Snapper from the fishery.

Commercial fishing is responsible for declines in both the abundance and biomass of numerous marine species (Ward and Myers 2005). As a result, global fisheries production has decreased from 86.3 million tons in 1996 to 79.5 million tons in 2008 (FAO 2010). Though small in scale, artisanal fishing can contribute to these declines by altering fish population structure (Campbell and Pardede 2006) and reducing the fish biomass of an area (Hawkins and Roberts 2004) and therefore requires long-term monitoring for the establishment of management measures.

On the southern Nicoya Peninsula in northwestern Costa Rica, the Costa Rican nongovernmental organization Programa Restauración de Tortugas Marinas (PRETOMA) has been working with two artisanal fishers associations—the Asociación de Pescadores de Punta Coyote and the Asociación de Pescadores de Bejuco—since 2007, monitoring fishing effort, catch rates, and the biological parameters of target and bycatch species in an effort to promote sustainable fishing practices. Together, these organizations are assembling data and information relevant to

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applying for sustainable fishery certification from the Marine Stewardship Council (MSC). According to the MSC, the benefits of certification include improved marketability of products, access to new markets, and large reductions in bycatch of fish, birds, and mammals as well as the recovery and stability of stocks (MSC 2009).

The target species of the fishery is the Spotted Rose Snapper *Lutjanus guttatus*, a red- to pink-colored fish with a yellow belly and characteristic black spot just below the posterior dorsal spines (Allen 1985). The Spotted Rose Snapper is an inshore reef-dwelling species found over hard bottoms and ranging from the Gulf of California to Peru (Allen 1985). The maximum size and length at maturity (L50) of Spotted Rose Snapper are approximately 66 cm (Rojas et al. 2009) and 28 cm (Anderson 2005), respectively, the latter of which corresponds to an age of 2–3 years (Rojas et al. 2009). The diet of the Spotted Rose Snapper changes during its development. Juveniles rely largely on crustaceans (especially *Trachypenaeus brevisuturae* and other species of shrimp from the family Penaeidae), with prey fish becoming increasingly important as the fish matures (Saucedo Lozano and Chiapas Carrara 2000; Rojas et al. 2004).

The fishers of the Nicoya Peninsula deploy a demersal longline and retrieve the gear by hand. The longline typically contains 1,000–1,500 #8 Mustad hooks baited with squid or sardines, and the hooks are often checked and rebaited once or twice during a night of fishing. Fishers fish aboard small fiberglass skiffs powered by 25-hp (1 hp = 746 W) engines. PRETOMA's preliminary data (unpublished data, 2008–2012; Mongeon 2012) show that most Spotted Rose Snapper landed are above L50 and below 60 cm (Figure 1). Whether juvenile fish and large adults are present in the area but excluded from the fishery is currently unknown.

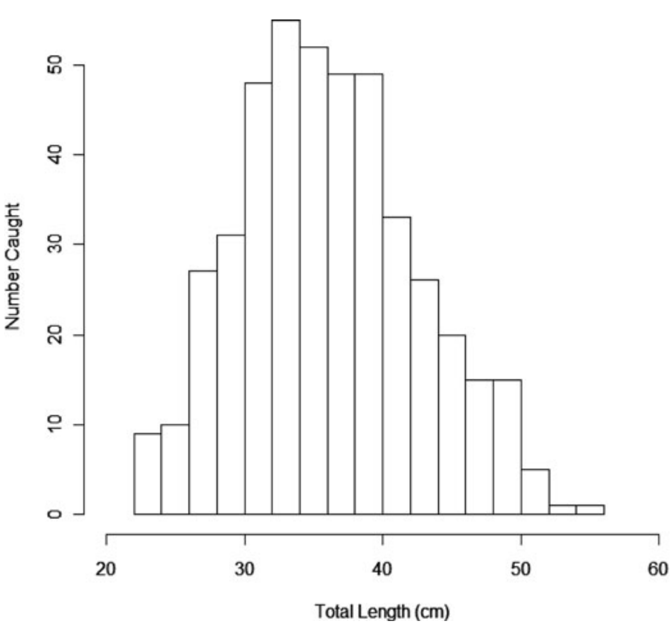

FIGURE 1. Frequency distribution of the total lengths of all Spotted Rose Snapper measured by PRETOMA from 2008 to 2012.

Fishery management has often relied on minimum size limits (MSLs) to preserve populations. Typically, the minimum size is larger than L50, so that fish are allowed to reproduce at least once before being removed from the population. Preservation of larger fish may also be important, since older fish often contain more and higher quality eggs (Love et al. 1990; Berkeley et al. 2004) and have longer spawning periods (Berkeley et al. 2004). While MSLs have proven effective at preserving fish smaller than the limit in some fisheries (Pierce 2010), they may have little impact on larger fish (Arlinghaus et al. 2010). Some researchers believe that slot limits (joint upper and lower limits on the size of fish that may be caught) should be enforced to preserve the older, possibly more fecund members of the population (Arlinghaus et al. 2010).

Increasing the hook size used in a fishery can exclude undersized fish (Alós et al. 2008a, 2008b; Otway and Craig 1993) as well as decrease the catch rate of nontarget species (Otway and Craig 1993; Erzini et al. 1996, 1998; Alós et al. 2008a, 2008b). In a study of the Australasian Snapper *Pagrus auratus*, Otway and Craig (1993) found that increasing hook size from a #12 to a #10 Mustad tuna hook reduced the catch of illegal (<250-mm) fish by 50% without impacting the catch of legal (≥250-mm) fish. While some studies show no difference in selectivity among hook sizes (Ralston 1982; Bertrand 1988; Erzini et al. 1996, 1998), these results may have been due to relatively small size differences among the hooks studied or to a small range of fish sizes in the area (Erzini et al. 1996, 1998).

As a management tool, a change in hook size could be a simple, low-cost means of reducing the catch of undersized fish, larger mature fish, and bycatch. However, a coincident reduction in target fish landings would place an economic burden on the fishers. A change in hook size must therefore take into account the effects on both bycatch and target species. If hook selectivity is occurring, a modified longline could also present a low-cost way to survey the entire snapper population, including juvenile fish (which are currently absent from the fishery) and the largest fish (which are rare).

We report on a study conducted to measure the effect of different hook sizes on target and bycatch species in an artisanal demersal longline fishery. The effects measured include the size selectivity and catch rate of Spotted Rose Snapper and the catch rate and species composition of the bycatch. The objectives of the study were twofold: (1) to inform a management plan for the Spotted Rose Snapper fishery, a key component of the application for sustainable fishery certification through the MSC, and (2) to determine whether the rarity of Spotted Rose Snapper below the reproductive size/age and larger than 60 cm in this fishery is due to hook selectivity.

METHODS

Study site.—We conducted this study on the fishing grounds of the communities of Coyote and Bejuco on the southern

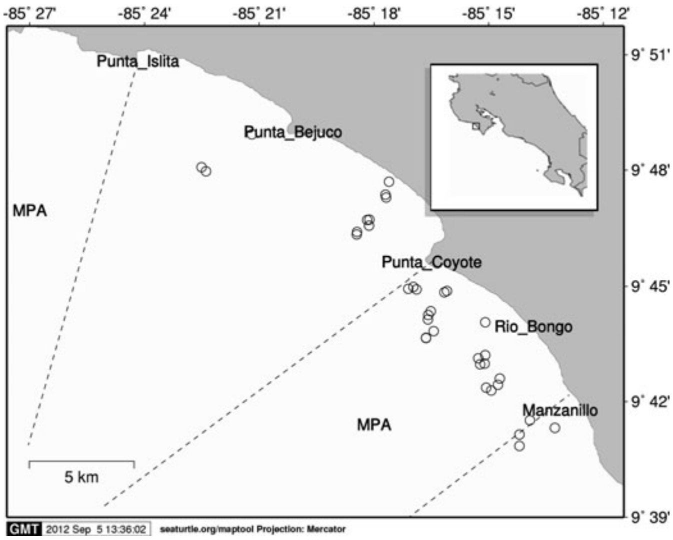

FIGURE 2. Map of the study area along the southwestern coast of the Nicoya Peninsula, Costa Rica, showing marine protected areas (MPAs) and the locations of the experimental fishing trips (circles).

TABLE 1. Hook dimensions and percentage differences among #10, #8, and #6 Mustad "J" style hooks ($n = 10$).

Variable	Hook size (mm)	Mean	SE	% Increase
Absolute size	10	402.5	25.91117	
	8	568.45	26.70669	0.412298
	6	870.35	47.97572	1.16236
Length	10	35	0.666667	
	8	41.5	0.471405	0.185714
	6	51.2	0.483046	0.462857
Width	10	11.5	0.707107	
	8	13.7	0.674949	0.191304
	6	17	0.942809	0.478261
Bill	10	11.9	0.994429	
	8	15.85	0.337474	0.331933
	6	20.3	0.788811	0.705882
Gape	10	9.9	0.875595	
	8	11.5	0.62361	0.161616
	6	14.55	0.437798	0.469697

portion of the Nicoya Peninsula in northwestern Costa Rica (Figure 2). The fishing grounds extend from Punta Islita in the north to Manzanillo in the south, although fishers will occasionally travel outside of these bounds to fish. We conducted all experimental fishing trips within these bounds. There are two marine protected areas (MPAs) in this fishing area. Camaronal National Wildlife Refuge includes an MPA that extends from Islita in the southeast to the northern end of Playa Camaronal (not shown on the map) to the northwest, and Caletas-Ario National Wildlife Refuge includes one that extends from Punta Coyote to Manzanillo. These refuges contain important nesting beaches for olive ridley *Lepidochelys olivacea*, green *Chelonia mydas*, leatherback *Dermochelys coriacea*, and hawksbill *Eretmochelys imbricata* sea turtles. Though shrimp trawling, lobster fishing with compressors, and gill netting are prohibited in these refuges, artisanal demersal longline fishing is allowed. The area between Punta Islita and Punta Coyote (Figure 2), referred to as "the triangle," has no restrictions on fishing activities and is fished regularly by all of the aforementioned fisher groups, including the artisanal demersal longline fishers.

Data collection.—We constructed a demersal longline of polyfilament nylon rope with 50-cm monofilament branch lines attached approximately every 1.5 m. A total of 525 Mustad "J" style hooks (175 each of sizes #6, #8, and #10) were arranged in series. For 10 randomly selected hooks of each size, total length, width, bill, and gape were measured, and its absolute size was calculated as the product of its total length and width as described in Otway and Craig (1993). The #8 and #6 hooks were 41% and 116% larger, respectively, than the #10 hooks (Table 1). We baited each hook with similar-sized pieces of sardine; The #10 hooks were attached with a lighter test monofilament than the #6 and #8 hooks.

We fished aboard PRETOMA's research vessel, *Chelonia*, an 18-ft-long (5.5-m) fiberglass boat with a 50-hp outboard engine similar to those used in the artisanal fishery. We deployed the gear from approximately 1730 to 1800 hours and began haulback at approximately 2030 hours. We sorted each fish based on the hook size on which it was caught in order to tie the life history data collected on land to the hook size. We recorded every fish encountered, both target and bycatch species, but did not retain every fish. Some bycatch species were discarded if they were too large, dangerous to handle, or nonmarketable. Marketable bycatch was retained and sampled in order to add to PRETOMA's existing data set.

We collected data over the course of 1 year, which was divided into two sampling periods coinciding with the relatively dry periods, as fishing is often impossible for long periods during the rainy season. All gear and data collection procedures were the same for each sampling period. We completed 17 trips during the relatively dry summer (from June 23 to August 2, 2011) and 18 trips during the much drier winter (from February 14 to March 19, 2012).

During the summer data collection, we attempted to identify sites with high concentrations of large, medium, and small fish using the knowledge of local fishers. We chose nine total sites, with three sites representing each size-class. We had planned to fish each site three times, but poor weather limited fishing effort and we were unable to complete all planned trips. In the winter season, we began to fish these same sites but were catching few if any snappers. The captain informed us that the fishers often fish different sites in different seasons. We decided to alter this aspect of the study and relied on the captain to choose sites based on where others were finding fish. Based on the data collected in

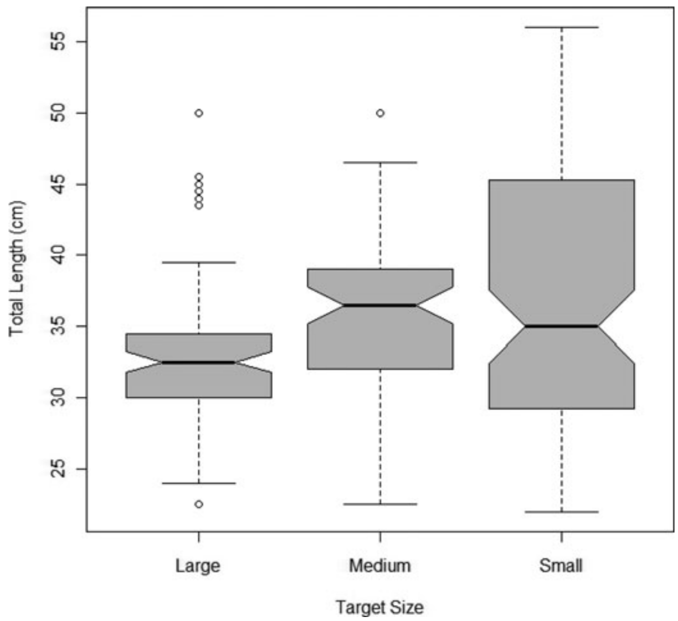

FIGURE 3. Box-and-whisker diagrams of the total length of Spotted Rose Snapper by sites chosen to represent three size classes (see text for details). Boxes indicate the 25th and 75th percentiles, the center line indicates the median, notches indicate 95% CI of the median, whiskers show the maximum and minimum values, and the dots represent outliers.

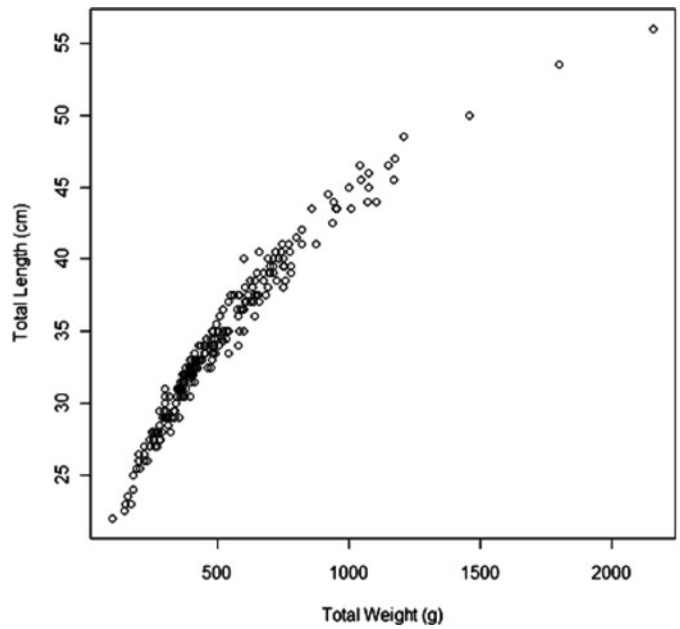

FIGURE 4. Scatterplot of the total lengths and corresponding total weights of Spotted Rose Snapper.

the summer, it does not appear that the sites selected contained the target sizes predicted by the captain (Figure 3).

We recorded the gender, total length (TL), and total weight (TWt) of each retained Spotted Rose Snapper as well as the hook size on which it was caught. We recorded hook size for each individual of bycatch species, and recorded TL and TWt for all retained species. We also recorded the surface temperature and made multiple depth measurements that were averaged for each trip. We attempted to record temperature at depth, but the recorder malfunctioned and we were unable to retrieve these data.

Data analysis.—Since TL correlates strongly with TWt (Figure 4: $r^2 = 0.93$; $P = .0022 \times 10^{-13}$) and TL is easier to collect in the field, we used TL as the measure of size in all analyses. Because mean TL was not evenly distributed in the sample population, we used a Mann–Whitney U-test to compare TL between the two sampling periods, summer and winter. We used a Kruskal–Wallace rank-sum test to compare the TL distribution of snappers caught on each of the three hook sizes. Post hoc multiple comparison analyses were used to determine differences in catch rates across hook sizes. We calculated total biomass by first calculating the mean weight for all fish for which we had measurements and then multiplying this by the total number of fish caught.

We also compared the total number of fish caught on different size hooks for both Spotted Rose Snapper and bycatch species. For all species, a chi-square goodness-of-fit test was applied to determine whether the ratio of the total catches on the three hook sizes was significantly different from 1:1:1, the ratio that would be expected if all hooks caught fish at the same rate. The same test was also applied to the total bycatch. Species richness and evenness of bycatch were tallied for each hook size, and diversity was calculated with Shannon's dissimilarity index.

We used ordinary least squares regression analysis to determine which measured variables were responsible for the differences in the bycatch rate and mean total length (ML) of Spotted Rose Snapper per trip. Bycatch rates were log transformed to meet the assumption of normality, and ML followed a normal distribution. Both bycatch rate and ML met the assumption of equal variance. Because the catch rates for the Spotted Rose Snapper followed a Poisson distribution and could not be normalized through transformation, a generalized linear model was used to determine the variables responsible for differences in catch rates. Catch rates and MLs were compared with respect to hook size, average depth, and day of fishing (with day 0 as the first day of fishing during the study). Season and surface temperature were not used due to strong covariance with day of fishing (0.99 and −0.64, respectively).

RESULTS

Over the course of the study, we caught 454 Spotted Rose Snapper on the modified longline. The fish ranged from a minimum of 22 cm (TWt = 100 g) to a maximum of 56 cm (TWt = 2,240 g), with a mean TL of 36.39 cm (SD = 6.46) and a mean TWt of 601.3 g (SD = 306.19). Of the 437 fish for which gender could be determined, 233 were female and 204 were male, though this disparity was not significant ($\chi^2 = 1.9245$, $P = 0.1654$). Mean total length was greater during the

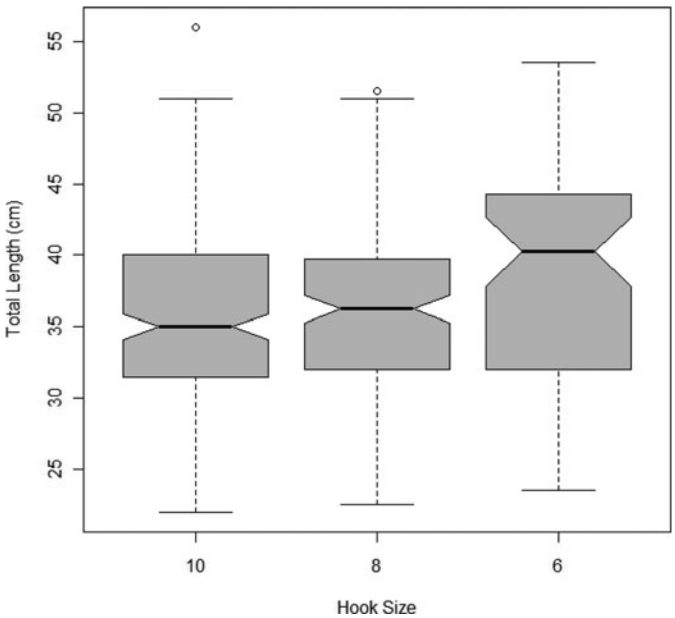

FIGURE 5. Frequency distributions of the mean total lengths of Spotted Rose Snapper caught on hooks of three different sizes, by size-class of fish.

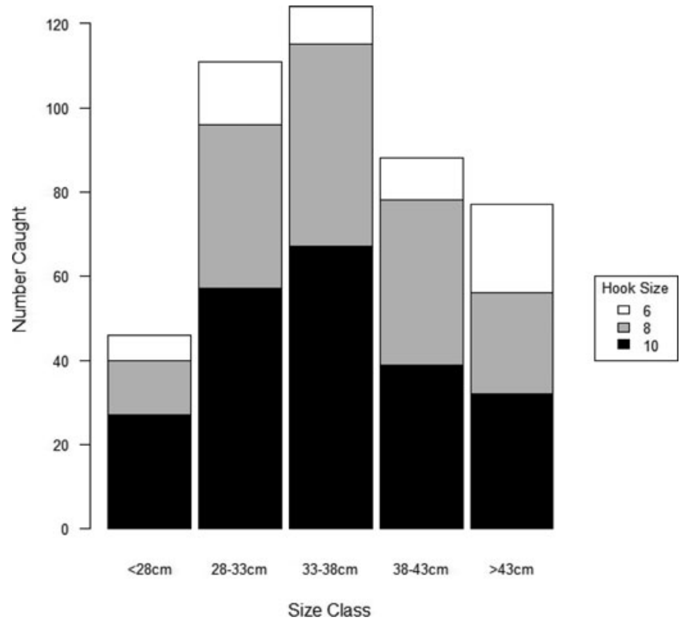

FIGURE 6. Frequency distributions of the mean total lengths of Spotted Rose Snapper, by hook size.

winter sampling period (39.19 cm; SD = 6.03) than during the summer sampling period (33.97 cm; SD = 5.82) ($\chi^2 = 7.9$, $P = 0.019$). We caught 208 Spotted Rose Snapper during the winter and 246 during the summer.

The mean TL (ML) of Spotted Rose Snapper varied across hook sizes (Kruskal–Wallis rank-sum test; $\chi^2 = 7.9$, $P = 0.019$; Table 2). Post hoc multiple comparison analysis determined that the ML of Spotted Rose Snapper caught on #6 hooks was significantly different from that of those caught on #10 hooks but that there was no significant difference between the lengths of fish caught on #8 hooks and those of fish caught on the other hooks (Figure 5). The larger #6 hooks were slightly less able to catch smaller Spotted Rose Snapper, while the smaller #10 hooks were able to catch larger individuals at the same or greater rates than the other two hook sizes (Figure 6). In an ordinary least squares regression analysis, #6 and #10 hooks explained the differences in ML of Spotted Rose Snapper (Table 3), corroborating the findings of our multiple comparison analysis. Depth, day of fishing, and the interaction between the two were also factors explaining the difference in ML.

In an ordinary least squares regression analysis, hook size, site depth, day of fishing, and the interaction between depth and day of fishing explained the differences in catch rate. The #10 hooks caught substantially more Spotted Rose Snapper than the #6 hooks, and the #8 hooks caught an intermediate number (Figures 6, 7). Only the largest of the Spotted Rose Snapper (>43 cm) were caught at similar rates on all three hook sizes (Table 4).

We observed a difference in the total catch rates of bycatch on different size hooks (Figure 8), with an inverse relationship between hook size and catch rate, and confirmed this trend for many individual species (Table 2; Figure 9). Scalloped Hammerheads, Pacific Spoon-Nose Eels, Amarillo Snapper, and Barred Pargoes appear to show the opposite pattern, with the highest catch rates on #6 hooks and the lowest on #10 hooks (Table 2; Figure 9); a chi-square goodness-of-fit test did not show significant differences from a 1:1:1 ratio for these species, however. While the #10 hooks had slightly more species than the #8 or #6 hooks, the diversity of bycatch species was similar (Table 5).

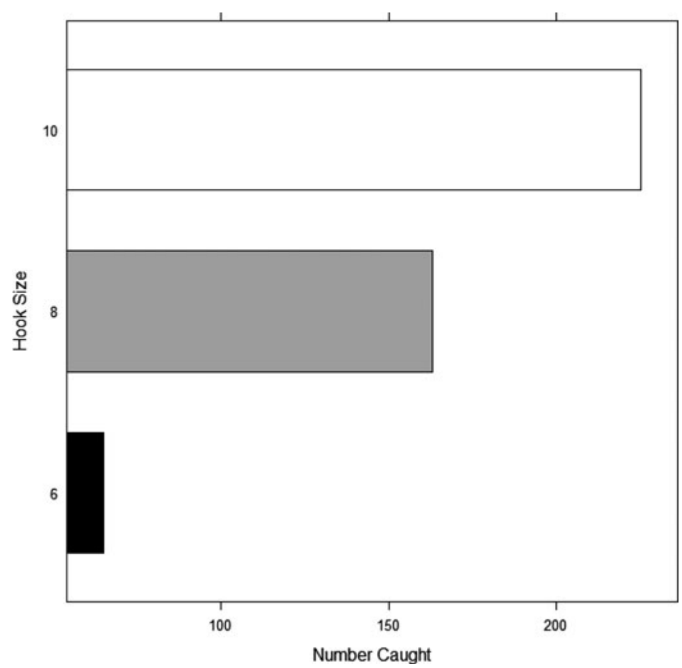

FIGURE 7. Number of Spotted Rose Snapper caught on three sizes of hooks.

TABLE 2. Mean TL (ML [cm]), catch rates (CRs), and total biomass (Bio [g]) of all species hooked, by hook size. Asterisks denote ratios of catch rates that are significantly differ from 1:1:1.

	Hook #6						Hook #8						Hook #10					
Species	*n*	ML	SD	CR	SD	Bio	*n*	ML	SD	CR	SD	Bio	*n*	ML	SD	CR	SD	Bio
Lutjanids																		
Spotted Rose Snapper *Lutjanus guttatus**[a]	65	38.48	7.29	1.86	1.90	45,829.1	163	36.44	6.14	4.66	4.84	97,813.2	225	35.76	6.33	6.43	5.73	128,742.3
Amarillo Snapper *Lutjanus argentiventris*				0.00	0.00	0.0	3	35.17	1.61	0.09	0.37	1,954.0	3	45.17	10.75	0.09	0.28	4,856.0
Colorado Snapper *Lutjanus colorado*				0.00	0.00	0.0				0.00	0.00	0.0	2	45.25	0.35	0.06	0.24	2,354.4
Pacific Red Snapper *Lutjanus peru**	1	33.00		0.03	0.17	429.3	10	32.50	4.40	0.29	1.07	4,352.6	14	31.64	6.89	0.40	1.65	6,738.9
Barred Pargo *Hoplopagrus guentherii*	4	48.13	12.87	0.11	0.32	6,702.0				0.00	0.00	0.0	1	53.00		0.03	0.17	1,960.0
Sharks and rays																		
Spotted Eagle Ray *Aetobatus narinari*	2						2						1					
Blacktip Shark *Carcharhinus limbatus*				0.00	0.00	0.0	3			0.09	0.51	0.0	1			0.03	0.17	0.0
Nurse Shark *Ginglymostoma cirratum*	1			0.03	0.17	0.0	1			0.03	0.17	0.0	1			0.03	0.17	0.0
Golden Cownose Ray *Rhinoptera steindachneri*	2			0.06	0.24	0.0	1			0.03	0.17	0.0	3			0.09	0.37	0.0
Scalloped Hammerhead *Sphyrna lewini*	8	53.93	5.13	0.23	0.65	5,636.6	5	52.25	0.35	0.14	0.36	3,450.0	4	53.00	4.24	0.11	0.32	2,336.0
Thorny Stingray *Urotrygon rogersi*	3			0.09	0.28	0.0	2			0.06	0.34	0.0	2			0.06	0.34	0.0
Guitarfishes Rhinobatidae*				0.00	0.00	0.0	1			0.03	0.17	0.0	8			0.23	1.03	0.0
Unidentified ray "Mahagua"*	11			0.31	0.72	0.0	17			0.49	1.36	0.0	40			1.14	1.94	0.0
Eels																		
Conehead Eel *Cynoponticus coniceps**	18			0.51	1.40	0.0	23			0.66	1.61	0.0	35			1.00	2.65	0.0
Fangjaw Eel *Echiophis brunneus*	3			0.00	0.00	0.0	2			0.03	0.17	0.0	1			0.11	0.32	0.0
Spottail Moray *Gymnothorax equatorialis**	5			0.14	0.55	0.0	19			0.54	1.09	0.0	25			0.71	1.49	0.0
Pacific Snake Eel *Ophichthus triserialis*	3			0.09	0.28	0.0	4			0.11	0.40	0.0	3			0.09	0.37	0.0
Yellow Snake Eel *Ophichthus zophochir**	70			2.00	2.74	0.0	100			2.86	2.55	0.0	169			4.83	4.13	0.0
Other Osteicthyes																		
Bonefish *Albula vulpes*	1			0.03	0.17		4			0.11	0.47		7	39.00		0.20	0.76	3,360.0
Sea catfishes Ariidae*	11			0.31	1.13		35			1.00	2.75		57			1.63	4.75	0.0
Toadfishes *Batrachoides* spp.	1			0.03	0.17					0.00	0.00					0.00	0.00	0.0
Pacific Porgy *Calamus brachysomus**	1	44.00		0.03	0.17	1707.2	4	42.00	2.00	0.11	0.32	5,082.3	10	39.88	2.12	0.29	0.46	9,315.8

(Continued on next page)

TABLE 2. Continued.

	Hook #6						Hook #8						Hook #10					
Species	*n*	ML	SD	CR	SD	Bio	*n*	ML	SD	CR	SD	Bio	*n*	ML	SD	CR	SD	Bio
Pacific Crevalle Jack *Caranx caninus*	5	61.63	2.95	0.14	0.43	12,800.0	10	56.28	10.40	0.29	0.71	21,371.4	9	55.14	11.24	0.26	0.44	15,015.6
Dolphinfish *Coryphaena hippurus*	1	94.00		0.03	0.17	4,020.0				0.00	0.00	0.0				0.00	0.00	0.0
Toothed Flounder *Cyclopsetta querna*	1	26.00		0.03	0.17	161.0				0.00	0.00	0.0	1	25.00		0.03	0.17	147.0
Scalyfin Corvina *Cynoscion squamipinnis*	3	56.00	7.37	0.09	0.37	5,509.0	3	39.00	10.61	0.09	0.28	2,043.0	4	43.38	13.78	0.11	0.32	2,132.0
Yellowtail Corvina *Cynoscion stolzmanni*				0.00	0.00	0.0				0.00	0.00	0.0	2	59.50	9.19	0.06	0.24	4,120.0
Pacific Sand Perch *Diplectrum pacificum**	4	27.00	0.00	0.11	0.32	1,011.6	7	26.93	2.03	0.20	0.87	1,582.5	14	26.33	1.75	0.40	0.91	3,333.6
Spotted Cabrilla *Epinephelus analogus*				0.11	0.32	0.0	1	43.00		0.51	0.98	1,100.0	4	26.50	13.44	0.57	1.52	1,295.6
Mojarra Grunt *Haemulon scudderii**	5	26.50	5.85	0.14	0.43	1,419.8	9	26.44	6.38	0.26	0.61	2,815.7	18	27.03	4.27	0.51	1.04	4,694.3
Highfin Kingfish *Menticirrhus nasus*				0.00	0.00	0.0	1			0.03	0.17	0.0	1	29.00		0.03	0.17	246.0
Golden Croaker *Micropogonias altipinnis*	1	55.00		0.03	0.17	0.0	8	48.56	13.48	0.23	0.60	9,016.0	4	44.00	5.90	0.11	0.32	2,844.5
Longspine Grunt *Pomadasys macracanthus**	1	29.50		0.03	0.17	423.7	7	30.79	2.86	0.20	0.63	3,500.8	16	28.64	2.88	0.46	1.56	6,005.4
Pacific Moonfish *Selene peruviana*	1	56.00		0.03	0.17	2,240.0				0.00	0.00	0.0				0.00	0.00	0.0
Barracudas *Sphyraena* spp.	1	50.00		0.03	0.17	540.0				0.00	0.00	0.0				0.00	0.00	0.0
Spotted Lizardfish *Synodus evermanni*				0.00	0.00	0.0				0.00	0.00	0.0	2			0.06	0.24	0.0
Blackblotch Pompano *Trachinotus kennedyi*				0.00	0.00	0.0				0.00	0.00	0.0	1	49.00		0.03	0.17	1,400.0
Longspine Croaker *Umbrina analis**	2	34.00	2.12	0.06	0.34	991.0	7	34.21	2.06	0.20	0.72	3,452.6	23	35.22	2.36	0.66	2.70	11,939.3
Invertebrates																		
Seastars Echinodermata*	4			0.09	0.28	0.0	18			0.06	0.24	0.0	20			0.03	0.17	0.0
Green spiny lobster *Panulirus gracilis*	1			0.03	0.17	0.0				0.00	0.00	0.0	1			0.03	0.17	423.0
Sea Turtle																		
Olive ridley turtle *Lepidochelys olivacea*	2			0.06	0.24	0.0				0.00	0.00	0.0				0.00	0.00	0.0

[a]The hook size for one Spotted Rose Snapper was not recorded.

DISCUSSION

Hook size had a large effect on the total catch rates of both Spotted Rose Snapper and bycatch species and a small but significant impact on the size of Spotted Rose Snapper caught (though all hooks caught a similar range of fish sizes). The larger hooks had lower catch rates of both Spotted Rose Snapper and bycatch, with a larger reduction in the catch rate of the smallest Spotted Rose Snapper being found on #6 hooks, though small individuals were not excluded entirely. We found a slight increase in the mean TL of Spotted Rose Snapper caught on #6 hooks over those caught on #10 hooks; however, the mean TL of those caught on #8 hooks did not differ significantly from

TABLE 3. Results of ordinary least squares regression (mean total length of Spotted Rose Snapper and mean total catch rate of all species) and generalized linear model (mean catch rate of Spotted Rose Snapper). Nonsignificant results are denoted by bold italics.

	Mean total length[a]			Total catch rate[b]			Spotted Rose Snapper catch rate		
Factor	Estimate	SE	*P*	Estimate	SE	*P*	Estimate	SE	*P*
Intercept	45.80	5.40	$.01 \times 10^{-10}$	4.39	0.46	0.02×10^{-13}	2.07	0.42	0.006×10^{-4}
Hook #8	1.24	1.29	.03	−0.43	0.12	0.0007	−0.32	0.14	0.02×10^{-14}
Hook #6	***2.92***	***1.32***	***.33***	−1.12	0.12	0.04×10^{-13}	−1.24	0.10	0.002
Depth	−0.40	0.16	0.01	−0.044	0.002	0.003	***0.002***	***0.002***	***0.21***
Day	−0.08	0.03	0.003	−0.0066	0.014	0.002	***−0.003***	***0.01***	***0.81***
Depth:Day	0.003	0.0008	0.00009	0.0002	0.00007	0.004	***−0.0001***	***0.00007***	***0.07***

[a]Adj. $R^2 = 0.35$, $F = 9.9$, $P = 0.02 \times 10^{-5}$.
[b]Adj. $R^2 = 0.47$, $F = 19.66$, $P = 0.01 \times 10^{-11}$.

those caught on #10 or #6 hooks. Hook selectivity is affected by both the degree of difference in hook size and the size of the fish species (Erzini et al. 1996). We found evidence of hook selectivity with a 116% increase in hook size (over the smallest hook), but no selectivity associated with a 41% increase. Ralston (1982) found no evidence of hook selectivity with a maximum increase in hook size of 71%. Erzini et al. (1996, 1998) had mixed results with hooks of a similar size distribution (increases of 1.49 and 2.09 times), reporting evidence of selectivity among some of the larger species in the studies. While increases of over 200% are often required to determine hook selectivity in small species (Erzini et al. 1996), Otway and Craig (1993) found that the catch of undersized Australasian Snapper could be reduced with only a 65% increase in hook size.

Many studies have found an inverse relationship between catch rates and hook size (Otway and Craig 1993; Erzini et al. 1996, 1998; Alós et al. 2008a), as was the case with our findings. Erzini et al. (1996) suggest that higher catch rates are the result of the smaller hooks' ability to catch more small-mouthed invertebrate feeders. The difference in the catch rates of Spotted Rose Snapper between #10 and #8 hooks cannot be explained simply as an increase in the catch of smaller fish, though, since size selectivity between these hooks was not observed. One explanation may be that smaller hooks are more likely to be swallowed and therefore hooked more deeply in the body (Alós et al. 2008b), reducing the likelihood of a fish escaping.

TABLE 4. Significance of the differences between the actual ratios of the catch rates of Spotted Rose Snapper and the 1:1:1 ratio that would be expected if no hook selectivity exists (asterisks denote significant differences with respect to the Bonferroni-adjusted *P*-value of 0.005).

Size-class (cm)	*n*	*P*-value
22–28	46	0.00058*
28–33	111	0.00064×10^{-2}*
33–38	124	0.00065×10^{-6}*
38–43	88	0.000071*
>43	77	0.28

Our analysis revealed that the catch rates of 11 additional fish species, one fish genus, and various species of echinoderms (seastars) were also inversely proportional to hook size (Table 2). Most other bycatch species were caught in very low numbers (Table 2), making the discernment of any patterns difficult. Higher catch rates of these species would be necessary to determine whether catch rates differ with hook size.

Depth, day of fishing, and the interaction between the two were also factors in the observed ML of Spotted Rose Snapper and the catch rates of bycatch, though they did not appear to affect the catch rate of Spotted Rose Snapper. The importance of day of fishing may be due to both the daily movement of Spotted Rose Snapper and the observed difference between the two seasons. Whether this is a typical seasonal trend will require longer-term data collection. Temperature at depth, which we

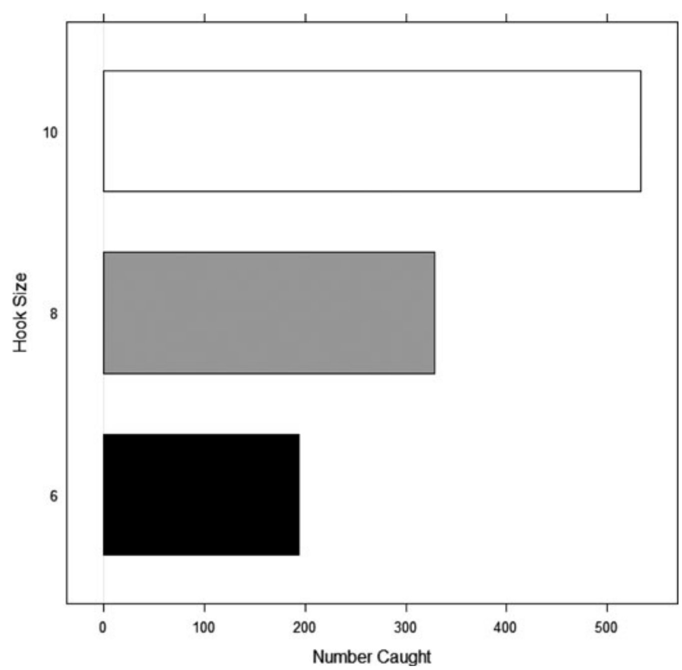

FIGURE 8. Number of bycatch species caught on three sizes of hooks.

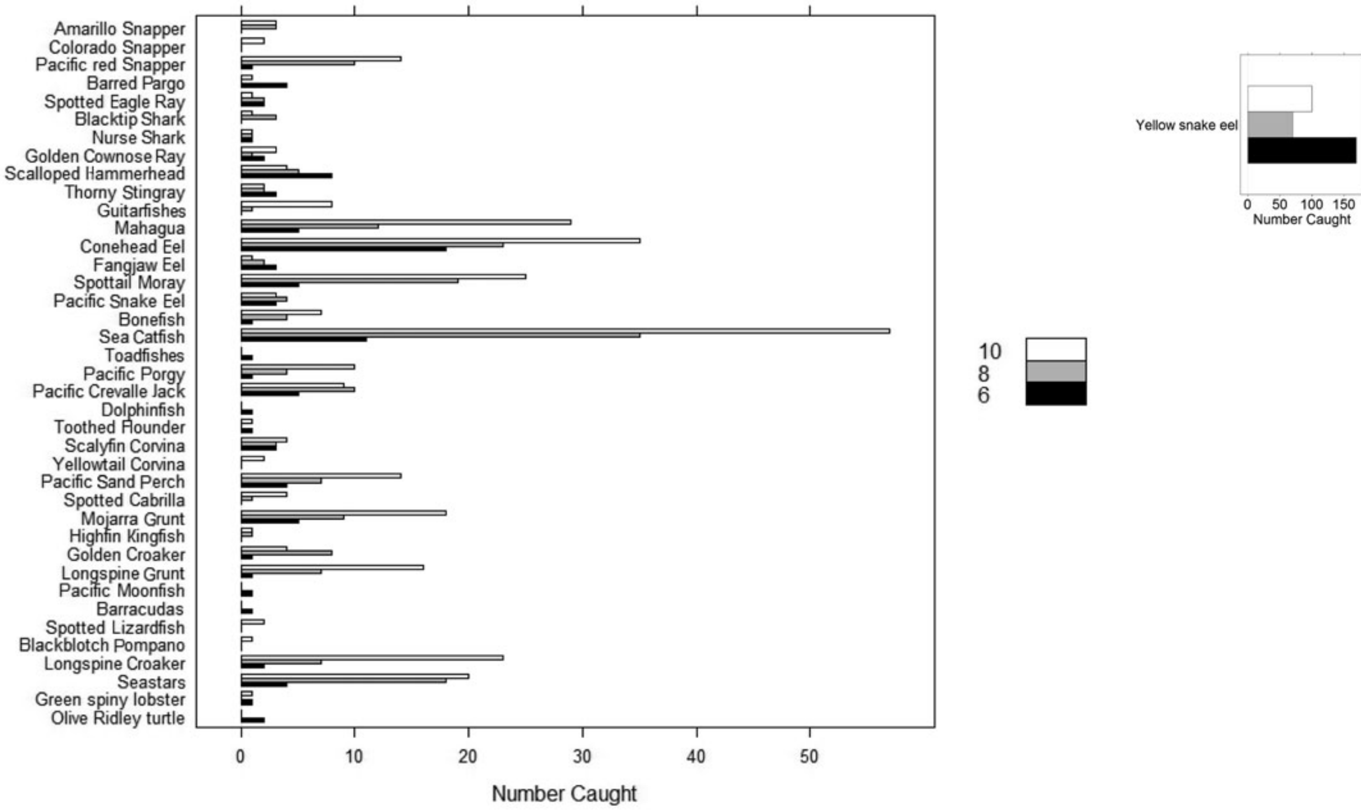

FIGURE 9. Numbers of the most common bycatch species caught on three sizes of hooks, by species. The inset shows the results for the Yellow Snake Eel, which are presented separately due to the high catch volume for this species.

were unable to measure due to equipment failure, may have proven to be an important factor in determining catch rates and TL and may have shed light on the interaction between depth and day of fishing.

We believe that the lighter-strength monofilament used on #10 hooks does not alter our results regarding the catch rates or TL of Spotted Rose Snapper. Had larger Spotted Rose Snapper been breaking these lighter lines more frequently, we would have concluded that the catch rates on #10 hooks were even higher than those we reported. We found no evidence of exclusion of larger Spotted Rose Snapper on #10 hooks, so additional observations of large Spotted Rose Snapper on #10 hooks would not alter this conclusion. However, the lighter-strength monofilament may explain the observed patterns for Scalloped Hammerheads, Pacific Spoon-Nose Eels, Amarillo Snapper, and Barred Pargoes, which are larger species and may have been hooked more frequently than was observed on #10 hooks.

TABLE 5. Diversity of bycatch as measured by Shannon's diversity index (H) and species richness, by hook size.

Hook size	H	Species richness
#10	2.80	51
#8	2.85	43
#6	2.78	45

Based on the results of this study, the current hook size is the most appropriate of the three studied for maximizing the catch of target size individuals and minimizing the catch of small ones and overall bycatch. Therefore, a change in hook size would not be an effective management strategy for this fishery. Future studies should focus on other gear changes that may reduce bycatch and undersized Spotted Rose Snapper without a corresponding reduction in the catch rate of larger Spotted Rose Snapper and the economic hardship this would cause fishers. Decreases in the bycatch of some fish species could be attained through changes in bait type (Alós et al. 2009) or the use of circle hooks (which have been recommended to reduce the bycatch mortality, particularly for sea turtles; Lewison et al. 2004). Circle hooks could maintain or even increase the catch rates of the target species (Løkkeborg and Bjordal 1992; Woll et al. 2001), especially for those species that tend to be hooked in the mouth (Løkkeborg and Bjordal 1992). In addition, circle hooks could reduce the mortality of released fish (Alós et al. 2008b). If fishers were to adopt a slot limit, circle hooks could allow large and small fish to be released with less injury.

A modified longline as described in this study would not be an effective way to better sample the population, as the size range did not differ from that of the fishery. The rarity of juvenile fish observed in the fishery could be a result of the competitive exclusion of juveniles by adults (Jones 1987) or the use of sardines as bait. The smallest Spotted Rose Snapper observed in this study was 22 cm TL, which is approximately the size at which Spotted Rose Snapper begin to shift their diet from shrimp and other crustaceans to small fish (Saucedo-Lozano and Chiappa-Carrara 2000; Rojas-Herrera and Chiappa-Carrara 2002).

This study provides insight into the effects of the artisanal longline fishery on Spotted Rose Snapper stocks and bycatch species and will inform the management plan that is a critical part of the MSC sustainable fishery certification. A management plan that includes a change in hook size could have unintended negative consequences for the fishery. An increase in hook size could lead to reduced catch rates of Spotted Rose Snapper, which would create an economic hardship for fishers and would not voluntarily be adopted. An increase in hook size may also increase the catch rate of Scalloped Hammerheads, a species listed in Appendix III of the Convention on International Trade in Endangered Species of Wild Fauna and Flora for Costa Rica in 2012 (www.cites.org/eng/app/index.php).

The data presented here indicate that the hook size currently in use by the fishery is the most appropriate one for maintaining a sustainable fishery. However, given the pressure on the fishery from other catch methods, including shrimp trawls and gill nets, there is a need for ongoing and regular monitoring to assure the sustainability of the fishery. Future research on bait preference, alternative hook styles, seasonal population patterns, the effects of temperature and depth on fish distribution, and habitat mapping for both Spotted Rose Snapper and bycatch species would further inform sustainable management of the Spotted Rose Snapper fishery off the Nicoya Peninsula.

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