Size Selection of Snappers (*Lutjanidae*) by Hook and Line Gear

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The most commonly used theoretical models of gear selection have been the logistic and normal curves. These are usually applied to trawls and gillnets, respectively. In contrast, little critical work has been completed concerning the selective properties of fish hooks, although both types of selectivity curves have arbitrarily been applied to hook catch data in the literature. No study has clearly demonstrated the actual form of a selection curve for hooks. To determine which type of curve (logistic or normal) best describes the selective sampling characteristics of fish hooks, an experiment was conducted in the Marianas Islands during 1982–84. During all fishing operations two different sizes (#20 and #28) of circle fish hooks were fished simultaneously and in equal number. Under these conditions, the length specific ratios of snapper (*Lutjanidae*) catches taken by the two hook sizes provided a basis for distinguishing which model was most appropriate. Results showed that neither model in its simplest form depicted hook selectivity well. While small hooks caught substantially more small fish, large hooks were somewhat more effective in capturing the larger size classes.

Les modèles théoriques de la sélectivité des engins les plus couramment utilisés sont les courbes logistiques et normales, qui sont généralement appliquées respectivement aux chaluts et aux filets maillants. On a par contre effectué très peu d'études critiques sur les propriétés sélectives des hameçons, bien que les deux types de courbes de sélectivité aient été arbitrairement appliquées dans certaines travaux aux données concernant les prises faites à l'hameçon. Aucune étude n'a clairement démontré la forme réelle d'une courbe de sélectivité des hameçons. Pour déterminer quel type de courbe (logistique ou normale) décrit le mieux les caractéristiques de prélèvement des hameçons, nous avons mené entre 1982 et 1984 une expérience aux îles Mariannes. Pendant toutes les opérations de pêche, on a utilisé des hameçons circulaires de deux tailles différentes (n° 20 et n° 28) simultanément et en nombre égal. Dans ces conditions, le rapport de longueur des captures de vivaneaux (Lutjanidés) effectuées avec les deux hameçons a servi de base pour déterminer quel modèle convenait le mieux. Les résultats ont montré qu'aucun des modèles sous sa forme la plus simiple ne décrivait correctement la sélectivité des hameçons. Tandis que les petits hameçons capturaient nettement plus de poisson de petite taille, les gros hameçons étaient légèrement plus efficaces pour la capture des classes de taille supérieure.

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Many of the world's most important fisheries use hook-and-line gear. Examples include the Japanese, Korean, and Taiwanese distant-water longline fisheries for tuna (Brock 1962), the west coast salmon troll fishery, and the groundline fishery for Pacific halibut (Myhre and Quinn 1984). Likewise, all recreational pole-and-line fisheries, both marine and freshwater, are based on angling with fish hooks. However, despite this widespread use, the sampling characteristics of hook-and-line gear are not well understood. There has been no coherent development of theory concerning the manner in which fish hooks sample a population (Clark 1960; Pope et al. 1975). As a result, it is difficult, if not impossible, to deduce the age or size structure of a population from a single hook-and-line catch sample. One reason for this is that gear selection models developed for trawl and gillnet fisheries have been applied to hook-and-line based fisheries with little or no verification that these models are, under a broad range of conditions, well-suited to the task (e.g. Koike and Kanda 1978; Munro 1983).

One of the earliest works on hook selection showed that length–frequency samples of cod caught with longline gear were shifted to smaller sizes than similar samples that were taken with purse seine gear. The latter gear type was believed to representatively sample the population's size structure (Rollefsen 1953), suggesting that the selectivity curve for hooks must ultimately decrease with increasing size of fish. Such a pattern is in some ways similar to selection curves for gillnets, which show rising and falling limbs. Gillnet selectivity has usually been described with the symmetrical normal curve (Hamley 1975). Other studies have shown similar results from hook-and-line fishing (haddock in McCracken 1963; Koike et al. 1968; Goose Islands halibut in Myhre 1969; Takeuchi and Koike 1969; Kanda et al. 1978; Koike and Kanda 1978; Leclerc and Power 1980). However, in most of these studies the righthand "descending" limb of the selection curve was ill-defined due to sample size limitations.

In contrast, some investigators have been unable to show a decline in the righthand limb of hook selection curves, suggesting something akin to the asymptotic logistic selectivity of trawl gear (Pope et al. 1975). In particular, length–frequency samples of cod studied by McCracken (1963) and Saetersdal (1963) showed: (1) no difference from trawl catch size structure

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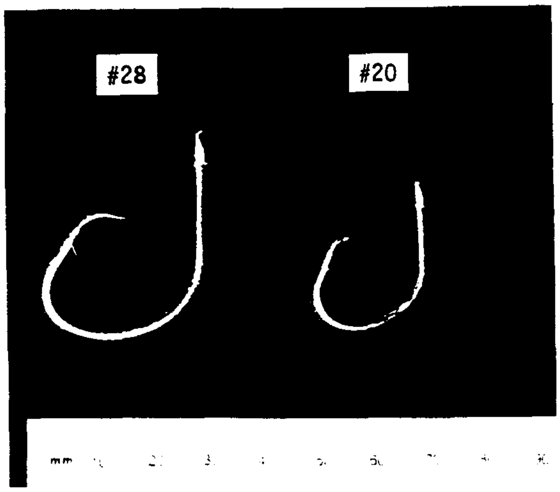

FIG. 1. The two sizes of Izuo circle fish hooks used during comparative fishing trials in the Marianas archipelago from 1982–84.

and (2) no effect of changing hook size on the catch of medium-large sized fish. Comparable findings were also reported for halibut by Myhre (1969); Ralston (1982); and Bertrand (1988).

The purpose of this study was, therefore, to perform a comparative fishing experiment (sensu Margetts 1969) with the goal of evaluating the efficacy of the logistic and normal selection models in describing patterns of hook selectivity.

Methods

As part of a multispecies resource assessment (Polovina and Ralston 1986), deepwater (100–300 m) fishing with hook-and-line gear was conducted throughout the Mariana Islands (lat. 13–20°N, long. 143–146°E) from April 1982 to May 1984. During this time six 40-d cruises were completed, with the waters surrounding all the islands of the archipelago sampled at least once, and some as many as six times (Polovina 1986). Fishing activity was directed toward the assemblage of eteline snappers (Lutjanidae), groupers (Epinephelinae), and jacks (Carangidae) that characteristically occupy deep reef habitats throughout the tropical Indo-Pacific (Forster 1984; Ralston et al. 1986).

Sampling was done from the R/V *Townsend Cromwell* while drift fishing with four hand-operated hydraulic fishing gurdies, each outfitted with ~365 m of braided prestretched Dacron line. The terminal rig was equipped with four Izuo[2] circle fish hooks (Forster 1973) attached by 60-cm gangions to the main line, which was weighted with a 2-kg iron bar. The two forward fishing lines on the vessel were equipped exclusively with #20 hooks, while the two aft lines only used #28 hooks (Fig. 1). Baits were pieces of uniformly cut stripped squid that were randomly allocated to each rig. Overall, the type and configuration of the fishing gear was similar to that employed commercially.

During fishing operations all four lines were fished concurrently so that at any point in time equal numbers (eight) of the two sizes of hooks were in use. All fish that were landed were classified by hook size of capture, identified to species, measured to the nearest millimetre fork length (FL), and weighed to the nearest 0.01 kg. Data were summarized for each species and hook size combination by rounding FL to the nearest 20 mm and aggregating the data into length–frequency distributions.

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

Evaluating Competing Models of Gear Selection

It is useful to draw a distinction between the intrinsic selective properties of a fishing gear and other aspects of "selectivity" extrinsic to the gear (Clark 1960). For example, year-to-year changes in the availability of a stock contribute to the latter. Likewise, selection curves obtained from cohort, virtual population, or catch-at-age analysis represent the combined effects of intrinsic and extrinsic selection factors. However, in this paper I refer to selectivity in the narrower, intrinsic sense, i.e., the size-specific likelihood of capture once a fish has encountered the gear. Selection coefficients are scaled to the fish size caught most readily and, therefore, range from 0.00–1.00. Thus, selection curves can be characterized for specific gear types, irrespective of changes in the distribution or behavior of the fish.

A more explicit quantitative definition of selectivity is provided by the relationship:

$$(1)\quad C_{i,j} = s_{i,j}\, q_i f_i N_j$$

where $C_{i,j}$ is the catch in numbers of fish in size class j on some fishing gear of size i; $s_{i,j}$ is the selection coefficient of gear size i to fish size j; q_i is the full selection ($s_{i,j} = 1.00$) catchability coefficient of gear size i; f_i is the amount of fishing effort with gear size i; and N_j is the number of fish in the population of size j (based on Hamley 1975).

A standard gear selection curve shows the relationship between the selection coefficient on the ordinate and fish size on the abscissa (Type A curve sensu Regier and Robson 1966). While there are a number of ways in which to estimate the shape of a selection curve, direct determination (Pope et al. 1975) is best. Unfortunately, there are few such studies in the literature, especially for hooks, because the size structure of the sampled population must be accurately known, a difficult requirement to meet. A more common practice is to compare the size structure of the catch made on different sizes of fishing gear to estimate the parameters of an assumed theoretical selection curve (e.g. Holt 1963), or to develop Type B selection curves (selection coefficient plotted against size of gear for a particular size class of fish).

In situations where the underlying form of the theoretical selection model is known or assumed (e.g. the logistic curve for trawl gear or the normal curve for gillnets), Type B curves have been used to estimate model parameters (see Hamley 1975 for a review of methods). In a more general context, however, comparative fishing studies provide little direct information about the shape or general form of an unknown selection curve (Pope et al. 1975). Still, comparative fishing can provide a basis for testing the validity of competing selection models.

If two different sizes of the same type of gear (e.g. hooks) are fished simultaneously on the same stock of fish with the same amount of fishing effort (i.e., $f_1 = f_2$ where the subscripts 1 and 2 refer to the smaller and larger gears, respectively), then as long as full vulnerability catchability is independent of gear size (i.e., $q_1 = q_2$), the ratio of catch in any common length class j ($C_{2,j}/C_{1,j}$) is equal to the ratio of selection coefficients

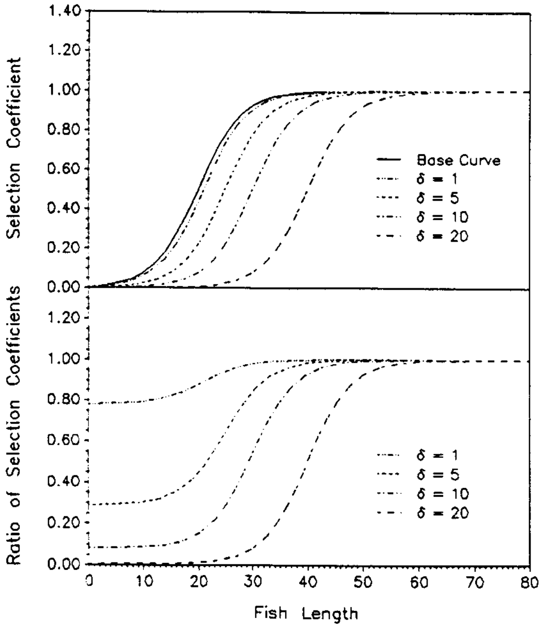

FIG. 2. Predicted ratios of catch taken on different sizes of a hypothetical fishing gear governed by logistic selection. See text for further explanation.

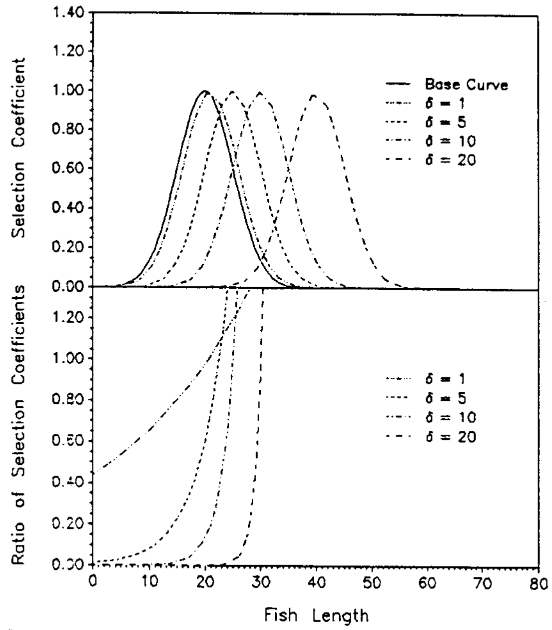

FIG. 3. Predicted ratios of catch taken on different sizes of a hypothetical fishing gear governed by normal selection. See text for further explanation.

$(s_{2,j}/s_{1,j})$. This property can be used to test the hypothesis that hook selectivity is best described by either the logistic or normal curves.

Specifically, if selection by fish hooks, like trawls, is governed by the logistic curve (Pope et al. 1975), then the ratio of catches taken on different hook sizes when plotted against length interval should, like the ratio of two logistic curves with common asymptote, increase asymptotically to a value of 1.00 (Fig. 2). Note that in the upper panel of the figure the standard base curve (solid line) depicts the selection curve for the smallest gear size. The other four curves represent selection curves for larger sizes of the same type of gear. Increasing gear size is presumed to simply shift selection curves to the right, without altering the asymptote or rate (i.e., steepness) parameters. The degree of shift is measured by δ, i.e., the difference between the scaling/position parameters of the selection curve for the larger gear and the base curve. The lower panel depicts the ratio of selection coefficients as a function of length, for each of the shifted curves relative to the base curve. This ratio consistently approaches a value of one.

Alternatively, if selection by hooks is, like gillnets, governed by the normal curve (Hamley 1975), then the ratio of catches by length interval should, like the ratio of two normal curves with similar height and dispersion parameters, increase geometrically without bound (Fig. 3). As in the preceding example, the upper panel depicts a base selection curve for the smallest gear size (solid line), with four selection curves from larger gears shifted progressively to the right. With increasing size of gear there is no alteration in the height or dispersion parameters of the selection curves. The degree of shift is again measured by δ, the difference in scaling parameters between each curve and the base. The ratio of selection coefficients, for each of the

TABLE 1. Catch of four deepwater snappers by fork length category and hook size.

Fork length (mm)	*Pristipomoides* *zonatus* #20	#28	*auricilla* #20	#28	*flavipinnis* #20	#28	*Etelis carbunculus* #20	#28
200	2	1	0	0	0	0	0	0
220	3	2	1	0	0	0	2	0
240	9	5	2	0	0	0	1	2
260	27	23	21	5	0	0	5	4
280	46	48	36	11	0	0	16	13
300	92	84	97	30	2	2	30	41
320	138	169	142	44	7	4	35	41
340	181	226	157	50	15	11	69	95
360	236	334	169	62	25	19	80	76
380	280	405	115	41	51	51	63	83
400	228	379	50	24	54	44	25	56
420	175	255	3	2	20	34	12	19
440	61	88	0	0	15	24	7	17
460	2	9	0	0	7	6	2	7
480	0	1	1	0	0	3	2	2
500	0	1	0	0	1	1	0	1
520	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	1	0
Total	1480	2030	794	269	197	199	350	457
Species total	3510		1063		396		807	

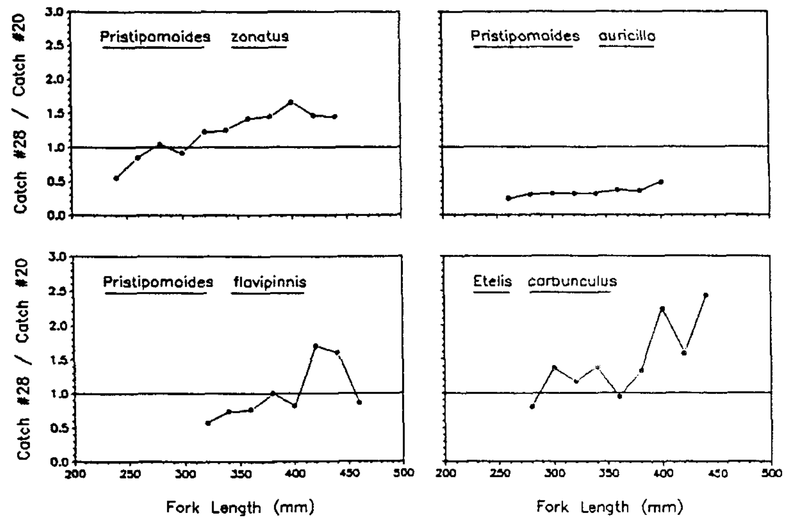

FIG. 4. Ratios of catches taken on #28 and #20 hooks, summarized by 20-mm FL categories, for the four species examined. A ratio of one corresponds to equal numbers of fish on the two hook sizes.

shifted curves relative to the base curve, is shown in the lower panel. In all cases the ratio of selection coefficients displays a precipitous monotonic increase.

Results

Over 7000 fish, comprising in excess of 30 species, were caught during handline fishing operations (see also Polovina 1986; Ralston and Williams 1988; Ralston 1988). However, 86% of the catch was composed of four snapper species: *Pristipomoides zonatus*, *P. auricilla*, *P. flavipinnis*, and *Etelis carbunculus*. Due to the relatively good catches of these four species, hook size catch ratios by length interval were calculated for each. Catch totals show (Table 1) that *P. zonatus* was particularly abundant, accounting for over half of all fish caught.

An examination of the size-specific ratio of catches taken on size #28 hooks, divided by the catches taken on size #20 hooks, shows a consistent increasing trend with FL for each species (Fig. 4). To reduce instability due to small sample size, catch ratios were calculated only if the combined sample size in a 20-mm interval of FL was ≥10.

Results for *P. zonatus* show that the smaller hooks caught more small fish than did the larger hooks (ratio <1.00). At a size of about 280 mm FL an equivalent number of fish were caught on each size of hook and at the larger sizes the largest hooks performed better. A Spearman rank correlation analysis of the *P. zonatus* data in Fig. 4 resulted in $r = 0.927$ ($P = 0.0001$), confirming the strong dependence between the size structure of the catch and the size of hook used.

Regardless of the size of fish, the smaller #20 hooks always caught more *P. auricilla* than did the larger #28 hooks, although to a lesser extent as fish size increased. Still, there was a strong Spearman rank correlation between fish size and the ratio of catch taken on the two hook sizes ($r = 0.976$, $P = 0.0001$). The low catch rate of *P. auricilla* on large hooks, in comparison to the other three snapper species, is likely due to its relatively small gape (Allen 1985) and planktivorous food habits (Seki and Callahan 1988).

For most sizes the catch of *P. flavipinnis* was generally greater on the small hooks than on the larger hooks, except in the largest length categories (FL >400 mm). Though not as strong as that of the preceding two species, a significant Spearman correlation existed between the size of *P. flavipinnis* and the ratio of catches taken on the size #28 and #20 hooks ($r = 0.786$, $P = 0.021$).

In contrast to the preceding two species, more *E. carbunculus* were caught on the #28 hooks than on the #20 hooks, especially in the largest size classes. As with all species examined, there was a significant Spearman rank correlation between fish size and catch ratio ($r = 0.767$, $P = 0.016$).

Discussion

The results presented here do not directly support either of the selectivity models presented earlier. The simple logistic model (Fig. 2) is not supported because the ratio of catches taken on the different hook sizes consistently rises to values in excess of 1.00. Likewise, the simple normal model (Fig. 3) is not supported because hook catch ratios do not seem to increase geometrically without bound.

Both these models are simple because full selection catchability is assumed to be unaffected by alterations in gear size (i.e., $q_1 = q_2$). There is evidence to show, however, that the catchability of optimally sized walleye to gillnets increases with increasing mesh size (Hamley and Regier 1973; Hamley 1975). Similarly, Beverton and Holt (1957) present data from alternating haul experiments showing that large mesh trawls catch more plaice in shared fully vulnerable size categories than do small mesh trawls, suggesting an increased efficiency of large mesh gear.

These findings demonstrate that increasing gear size can lead not only to a righthand shift of the selection curve, but also to an increase in catchability. Thus, the assumption that catchability in the fully vulnerable size range is independent of gear size is too simplistic.

If catchability varies the catch ratio is no longer equal to the simple ratio of selection coefficients, but includes the ratio of catchability coefficients as an additional term; that is:

$$C_{2,j}/C_{1,j} = (s_{2,j}/s_{1,j})(q_2/q_1)$$

Extending this result to a hypothetical model of logistic hook selection would suggest that catch ratios can exceed a value of one if $q_1 < q_2$. Catch ratios would then asymptotically approach a value equal to the ratio of catchability coefficients, rather than approaching a value of 1.00. The results presented in Fig. 4 (especially *P. zonatus*) are consistant with this interpretation, but they are not conclusive.

Conversely, a hypothetical model of hook selection based on righthand shifted normal curves in conjunction with progressively increasing full selection catchability coefficients, would simply accentuate the geometric unbounded increase evident in Fig. 3. Although none of the results presented in Fig. 4 seem to conform to such a pattern, it could be that the size range of fish sampled was too small to detect the strong curvature predicted by the model. Such an explanation, however, seems unlikely.

Our present understanding of the intrinsic nature of hook selectivity is rudimentary at best. There is no generally accepted theoretical model of selection by fish hooks, as there are for trawls, gillnets, and other meshed gears. It is likely that in reality neither of the models examined is particularly well-suited to the quantitative description of hook selectivity, although of the two, the logistic model is most consistent with the comparative fishing results presented here (see also Ralston 1982). What is needed is a direct determination (Pope et al. 1975) of selection coefficients through an experimental program, in which a population of known size structure is fished with hooks of various sizes. The sampled population could either be experimentally fished in captivity or it could be a known marked population in the field. The latter approach has been used effectively with gillnets (Hamley and Regier 1973) and was employed with limited success by Leclerc and Power (1980) in their work on angling and gillnet selectivities. In their study, however, small sample sizes prevented precise resolution of the selection pattern. Likewise, in two separate studies, Myhre (1969) compared the size structure of Pacific halibut captures with hooks against a known marked population, but he obtained conflicting results. Regardless, until a more definitive study is completed, it will be difficult to make inferences about the size structure of fish populations from single catch samples acquired with hook-and-line gear.

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