SEDAR24-AW05: Selectivity of red snapper in the southeast U.S. Atlantic: dome-shaped or flat topped?

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Selectivity of red snapper in the southeast U.S. Atlantic: dome-shaped or flat-topped?

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The Caribbean Fishery Management Council
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I. Introduction

In the SEDAR 15 stock assessment for red snapper, the selectivity patterns for the commercial handline and recreational sectors were assumed to follow a logistic or flat-topped selectivity pattern with age. This type of selectivity pattern assumes that all fish greater than the age at full selection (in the case of SEDAR 15 this was near age 4) are equally vulnerable to the full fishing mortality. This assumption of a flat-topped selectivity has been common in past SEDAR stock assessments for many of the snapper-grouper fisheries. The primary reason for this assumption is because the most common gear type, hook gear, tends to be non-size selective. Also, for most species the range of depths fished tends to cover or even exceed the range of depths for the species distribution, at least based on anecdotal accounts of fishing activities.

However, depth records of fishing locations for the snapper-grouper species have been largely unavailable until recently. Within the last few years the commercial and headboat logbooks have included a depth field for fishermen to report the depth of fishing. Also, limited depth data, collected by observers, are available for some headboat trips. What has been observed based on these data (and will be shown below) is that the distribution of effort by depth is not constant. This raises the potential for dome-shaped selectivity, provided there is a strong enough gradient for age across depths. It should be noted that both of these properties—variation in age across depth and variation in effort across depth —must be present in order to result in dome-shaped selectivity.

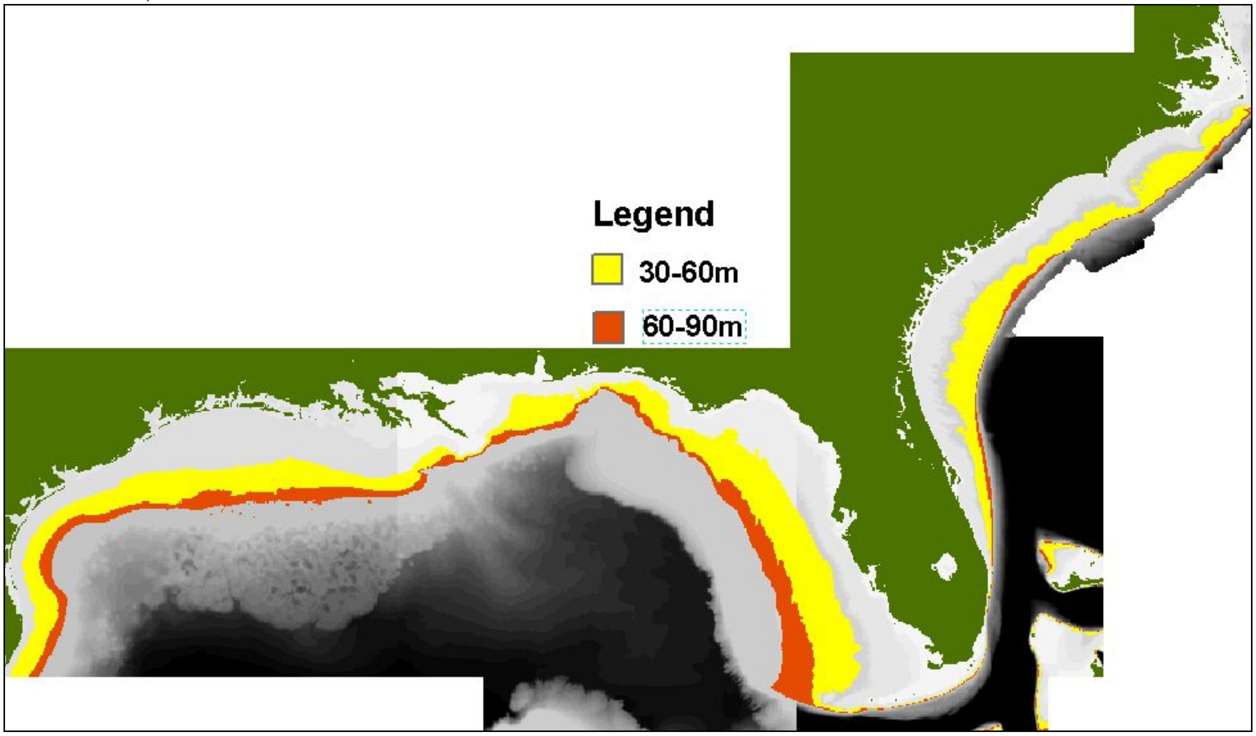
Recently, red snapper fishermen have claimed that a cryptic portion of the red snapper population in the South Atlantic is not being fully exploited or largely missed by the fishery. The fishermen have suggested that the biggest and oldest red snapper exist in the deepest depths and are not accessible by hook and line gear. They note that currents in the deeper depths prevent effective fishing with vertical hook and line gear and that the distance vessels must travel offshore to get to the deeper depths can be cost prohibitive.

The ideal data to analyze for dome-shaped selectivity in the red snapper fisheries would be fishery-independent, spatially explicit samples of red snapper. To accompany the fishery-independent data, we would ideally also have detailed depth of capture information for each red snapper caught in all fishery sectors. Unfortunately such data are not available. Instead we have all fishery-dependent data with self-reported depth records of limited sample size from a period of potentially high exploitation and possible localized over exploitation. No spatial data of sufficient resolution are available. The available data will be described in more detail below.

U.S. South Atlantic Depth Habitat

Most fishing effort in the U.S. South Atlantic occurs within depths of 200 ft (see section III below). Because the bottom slope is steeper outside of 200ft, the depth habitat within 200 ft covers a much broader area (Figure I-1). One of the arguments given for using dome-shaped selectivity in the U.S. South Atlantic is that dome-shaped selectivity was used in the Gulf of Mexico. However, the area spanning the depth range attributed to any cryptic population (197-295 ft; Figure I-1) is substantially smaller in the South Atlantic than in the Gulf of Mexico. This bathymetry also suggests that distances from shore do not vary much among the deepest red snapper depth zones.

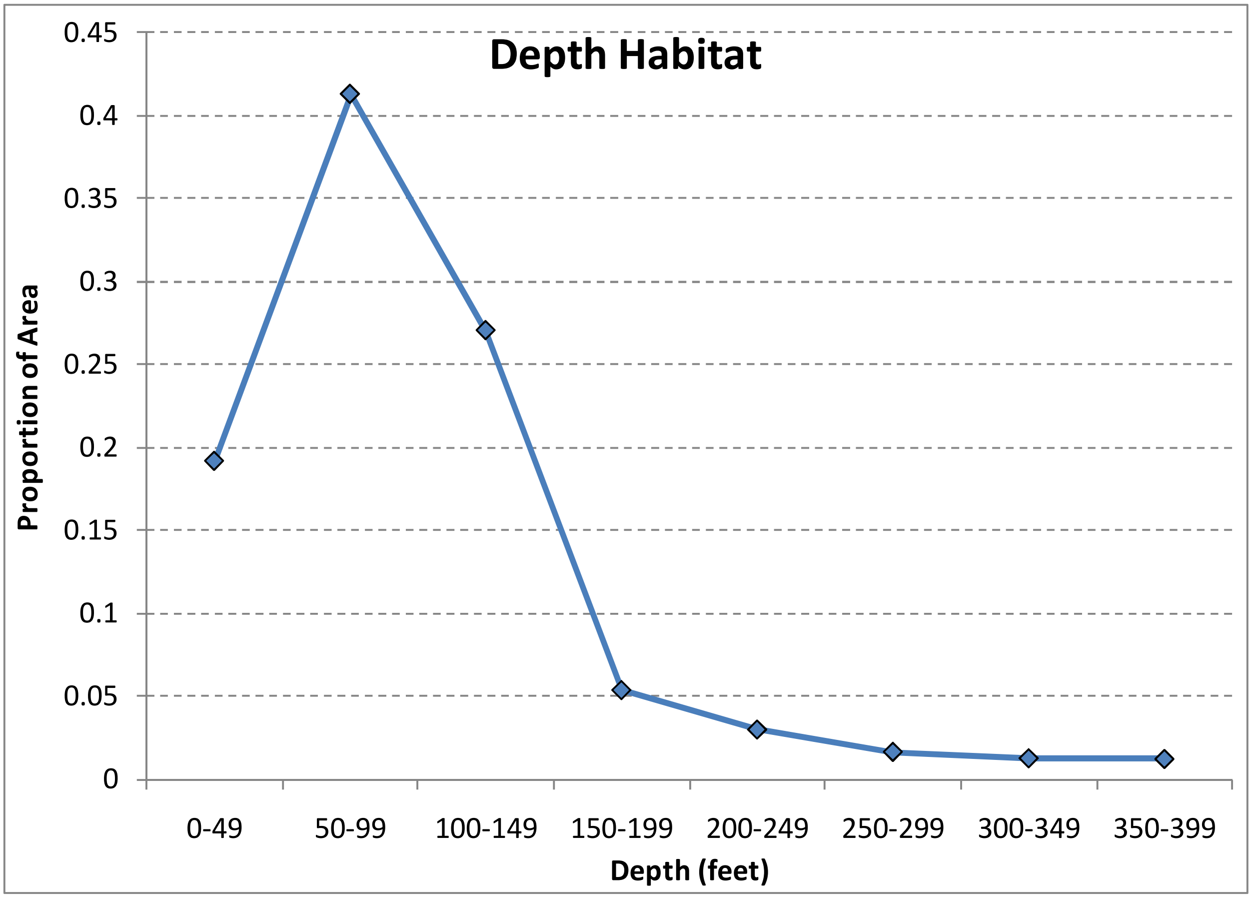
Figure I-1. Bathymetry of U.S. South Atlantic and Gulf of Mexico (30m=98ft, 60m=197ft, 90m=295ft).



Red snapper in the South Atlantic are caught over depths ranging from 50-400 feet. It is important to keep in mind the bathymetry of the South Atlantic compared to this depth range. For instance, fishermen have stated on many occasions that effort in the deepest areas is very limited. Part of the explanation for this may be that the area of the deepest depth zones is itself limited (Figure I-1), which gives the appearance that total effort is reduced in the deepest areas. But, what is critical for inferring selectivity patterns is the density of effort that occurs in some of the deeper depth zones (i.e., effort per area of depths).

To examine the density of effort by depth, we must compute the amount of area by depth in the South Atlantic. To do this we used the depth data available from the GEODAS database (http://www.ngdc.noaa.gov/mgg/geodas/geodas.html). More specifically we used the coastal relief model grids, which provide a depth value over a grid size of 3 seconds of latitude and longitude. This is roughly a grid cell size of 300 feet. Using this grid data we simply added up the number of points within the South Atlantic EEZ that fell within various depth ranges. By normalizing the number of grid points within each depth zone we can compute the relative amount of area by depth. In this case we analyzed the depth over 50 feet intervals out to 400 feet, which is considered the maximum depth for red snapper. The results are shown in Figure I-2.

Figure I-2. The relative amount of area in each depth habitat for the South Atlantic EEZ.



Based on Figure I-2, the amount of habitat in depths from 150-400 feet is clearly a much smaller proportion of the available habitat than the shallower depths.

The basic approach below was to ask the question, is there evidence of dome-shaped selectivity and then, try to provide several different lines of evidence to help get at the question. The lines of evidence are described below in stand-alone sections. The sections are (II) Tagging data, (III) Gradient in commercial effort by depth, (IV) Inference from age composition data, (V) Gradient in age and size by depth, (VI) Theoretical investigations of selectivity, and (VII) Discussion.

II. **Tagging data** (contributed by Chip Collier, North Carolina Division of Marine Fisheries)

Tagging studies have been used to describe selectivity patterns for a variety of fish including chinook salmon (Jones and McPherson 2000), cod (Myers and Hoenig 1997, Pederson and Pope 2003), halibut (Clark and Kaimmer 2006), red drum (Bacheler et al. 2010), sablefish (Assonitis 2008), and yellowtail flounder (Cadrin 2008). Thus tagging data on red snapper were examined for possible indications of selectivity pattern.

Two tagging studies on red snapper have been conducted in the South Atlantic: one by South Carolina Department of Natural Resources (SC DNR) and the other by Mote Marine Lab (MML). SC DNR's tagging of red snapper began in 1990 and is ongoing. Through this study, 1,568 red snapper have been tagged by recreational fishermen with 176 fish returned (11.2% return rate). Few fish tagged have been over the 20 inch size limit (1.6%). Of the fish that have been recaptured, 2.4% of the red snapper were greater than the legal size limit at the time of tagging and 25.6% of the red snapper were greater than the legal size limit at the time of recapture.

Mote Marine Lab has been tagging red snapper off Florida since 1997, and 4,124 have been tagged with 443 fish returned (10.7%). Few fish have been tagged over the 20 inch size limit (1.6%). Of the fish that have been recaptured, 3.6% of the red snapper were greater than the legal size limit at the time of tagging and 32.5% of the red snapper were greater than the legal size at the time of recapture.

Because most of the tagged fish were shorter than the legal size limit, these data sets cannot be used to describe the selectivity of large fish. If sufficient numbers of large red snapper are tagged in the future, other important factors need to be considered before analyzing the data just based on return rates including the size distribution of red snapper related to depth, hook and depth related discard mortality, tag retention, and tag reporting rates. If large red snapper tend to occur in deeper water and have a higher discard mortality rate, then the recapture rates would appear to decrease and falsely assume a decrease in selectivity.

III. Gradient in commercial effort by depth

III-1. Introduction

Details on the snapper-grouper commercial logbook program can be found in SEDAR24-DW01 (with appendices). The Commercial Workgroup concluded that the commercial snapper grouper logbook database provides the best available data for investigating effort and landings of red snapper by depth. This decision was approved by the plenary. During the Data Workshop, discussions raised a number of caveats that should be considered concerning the use of logbook data:

- Logbook data do not include fish size
- These are self reported data, including depth information
- Although depth can be entered separately for each species caught in a given trip, typically only one value has been entered per trip regardless of species.

Landings of red snapper from the longline gear have never been large, certainly not compared to the handline gear (Table 3.13 in SEDAR 24 Data Workshop Report). The South Atlantic Fishery Management Council (SAFMC; Snapper Grouper Amendment 4) prohibited the use of longline gear inside 50 fathoms (300 ft) in 1992. In 1999, the SAFMC prohibited vessels with longline gear aboard to possess of red snapper (Snapper Grouper Amendment 9).

III-2. Data Preparation and Analyses

Before analyzing the Logbook Database, we applied the same filtering program that has been used when analyzing logbook data for estimating discards (SEDAR24-DW01 developed by Kevin McCarthy). This filtering program is less restrictive than that used in developing logbook indices.

Additionally we reduced the data set as follows:

- Region - both Gulf of Mexico and South Atlantic
- Gear – handline and longline
- Depth – less than 1000 ft for years 2005-2009

From this database, two data sets were created:

<u>Red snapper data</u> – consisted of 1 record line per trip which successfully caught and landed red snapper (20,345 records or trips). Sample sizes by gear, region and year are summarized in Table III-1.

<u>Multiple species data</u> – consisted of 1 record line per trip which successfully caught and landed one of the following species: red snapper, red porgy, scamp, snowy grouper, speckled hind, or vermilion snapper (42,168 records or trips). These species were selected based on discussions with local fishermen who have fished for red snapper. It is not meant to be a complete list, but simply for comparison purposes. Sample sizes by gear, region and year are summarized in Table III-2.

III-3. Depth Profiles

Depth profiles were developed from the red snapper data. These calculate the proportion (%) of either trips or catches that fall into a specific depth range. For this analysis, depth was categorized into 25 ft intervals, with the mid-point used for plotting. Cumulative probability plots are presented, based on probability that the trip or catch occurred at less than or equal to the depth interval. Four lines are shown on each plot, two for Gulf of Mexico (handline and longline) and two for South Atlantic (handline and longline). The plot comparing depth profiles for red snapper trips are shown in Figure III-1, and the plot comparing depth profiles for red snapper catches are shown in Figure III-2.

A comparable plot of cumulative depth profiles for trips based on multiple species (Gulf of Mexico versus South Atlantic for handline and longline gear) is shown in Figure III-3. Plots showing the depth profiles of some additional species are shown in Figures III-4 and III-5.

III-4.Discussion points regarding gradient in commercial effort by depth

• The depth profiles for red snapper appear quite similar for handline and longline in the Gulf of Mexico (Figure III-1 and III-2).

• Red snapper South Atlantic handline depth profile suggests trips and landings are caught in shallower water than in Gulf of Mexico with 72% of the trips and 80% of landings were caught between 100-200 ft.

• Red snapper South Atlantic longline depth profile is based on only 9 trips (395 lbs), with 5 of these trips shallower than 50 fathoms. No red snapper discards were reported from longline trips (SEDAR24-DW01, p. 3).

• When considering a suite of species (multiple species: red snapper, red porgy, scamp, snowy grouper, speckled hind, and vermilion snapper), handline gear has the shallower depth profile as expected for both coasts as compared to longline.

• South Atlantic and Gulf of Mexico handline show similar proportions of catch in the depth interval of 200-1000 ft, with about 19% for the South Atlantic and 17% for Gulf of Mexico. However, the depth profile for South Atlantic continues into deeper waters compared to Gulf of Mexico, with 17% caught in waters between 300-1000 ft for South Atlantic and 10% for Gulf of Mexico.

• Other species show similar depth of fishing patterns as red snapper and some species, like snowy grouper suggest there is handline effort out to some of the deepest depths.

Table III-1. Summary of red snapper handline (H) and longline (L) trips reported in the commercial snapper-grouper logbook for which corresponding depth information is available, 2005-2009. Furthermore, trips with depth greater than 1000 ft have been trimmed.

Count of totlbs	Column Labels						
	H		H Total	L		L Total	Grand Total
Row Labels	GoM	SA		GoM	SA		
2005	2996	880	3876	179	3	182	4058
2006	4101	925	5026	292	2	294	5320
2007	2389	1118	3507	121	1	122	3629
2008	2045	1448	3493	125		125	3618
2009	2005	1636	3641	76	3	79	3720
Grand Total	**13536**	**6007**	**19543**	**793**	**9**	**802**	**20345**

Table III-2. Summary of multiple species handline (H) and longline (L) trips reported in the commercial snapper-grouper logbook for which corresponding depth information is available, 2005-2009. Furthermore, trips with depth greater than 1000 ft have been trimmed. Multiple species include red snapper, red porgy, scamp, snowy grouper, speckled hind, and vermilion snapper.

Sum of count	Column Labels						
	H		H Total	L		L Total	Grand Total
Row Labels	GoM	SA		GoM	SA		
2005	4462	2350	6812	808	50	858	7670
2006	5656	2861	8517	1111	87	1198	9715
2007	3601	3832	7433	860	38	898	8331
2008	3462	3933	7395	984	98	1082	8477
2009	3719	3607	7326	548	101	649	7975
Grand Total	**20900**	**16583**	**37483**	**4311**	**374**	**4685**	**42168**

Figure III-1. Depth profiles (in 25 ft intervals, plotted at mid interval) for red snapper trips by region (Gulf of Mexico vs South Atlantic) and gear (handline vs longline).

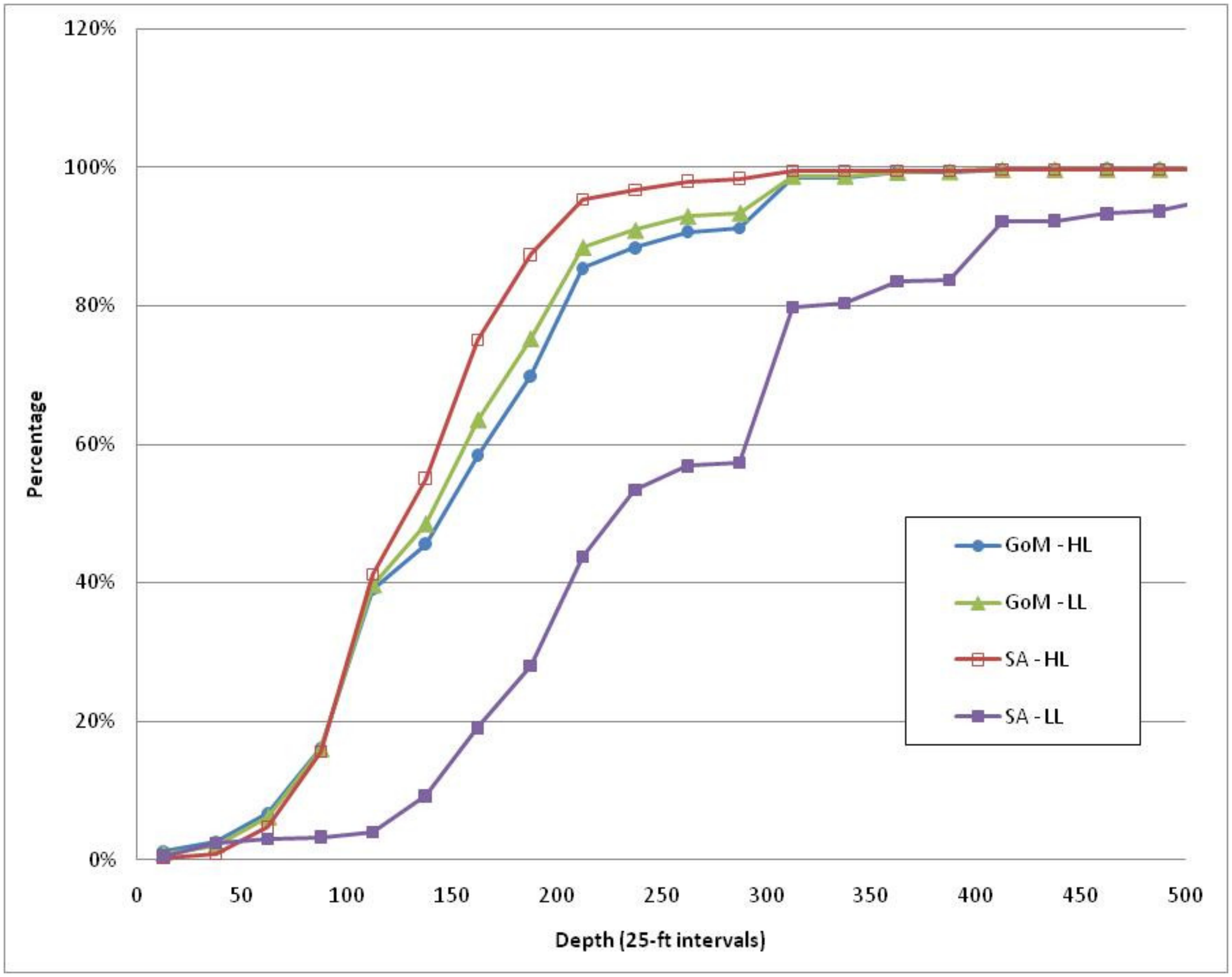


Figure III-2. Depth profiles (in 25 ft intervals, plotted at mid interval) for red snapper landings by region (Gulf of Mexico vs South Atlantic) and gear (handline vs longline).

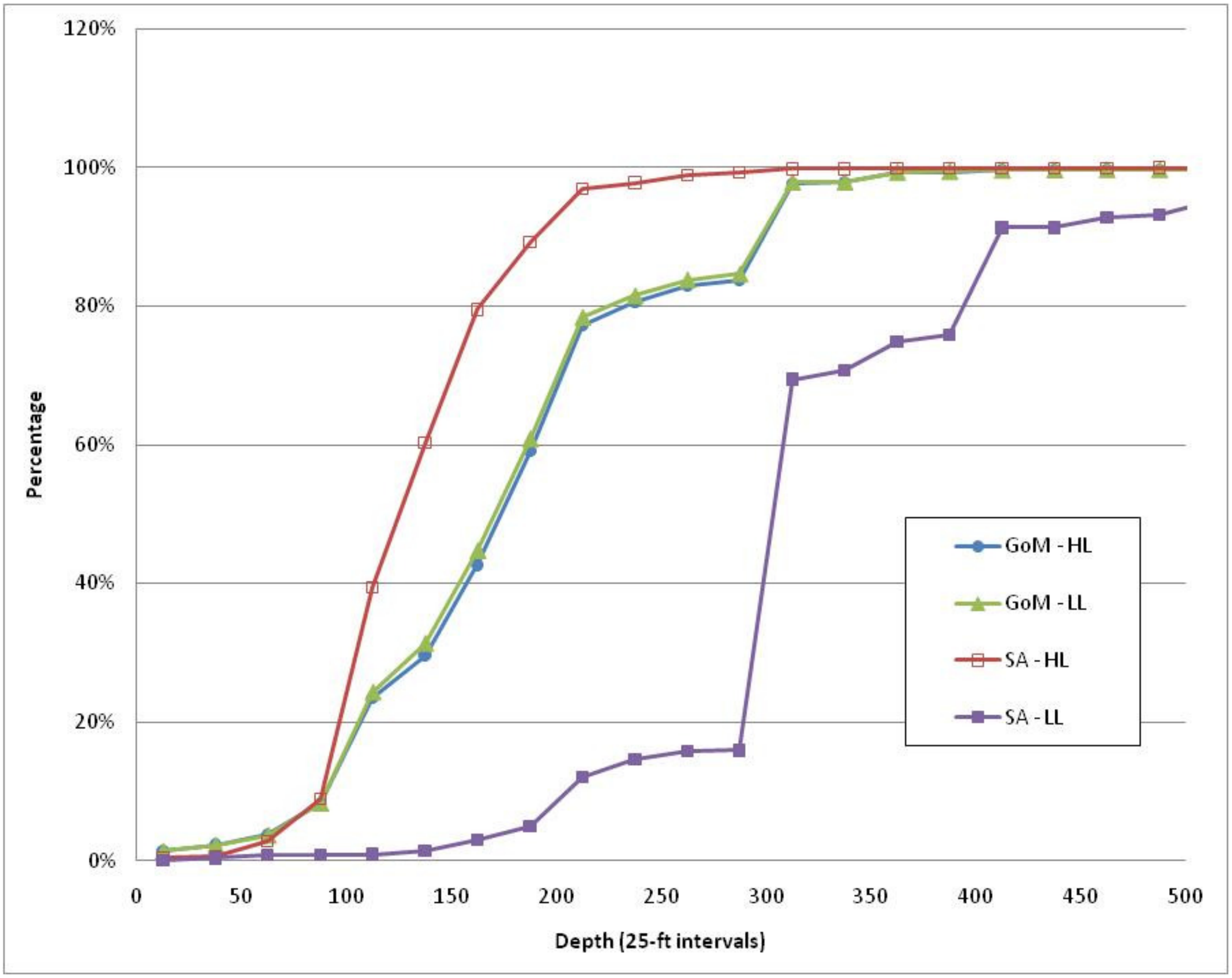


Figure III-3. Depth profiles (in 25 ft intervals, plotted at mid interval) for multiple species trips by region (Gulf of Mexico vs South Atlantic) and gear (handline vs longline). Multiple species include red snapper, red porgy, scamp, snowy grouper, speckled hind, and vermilion snapper.

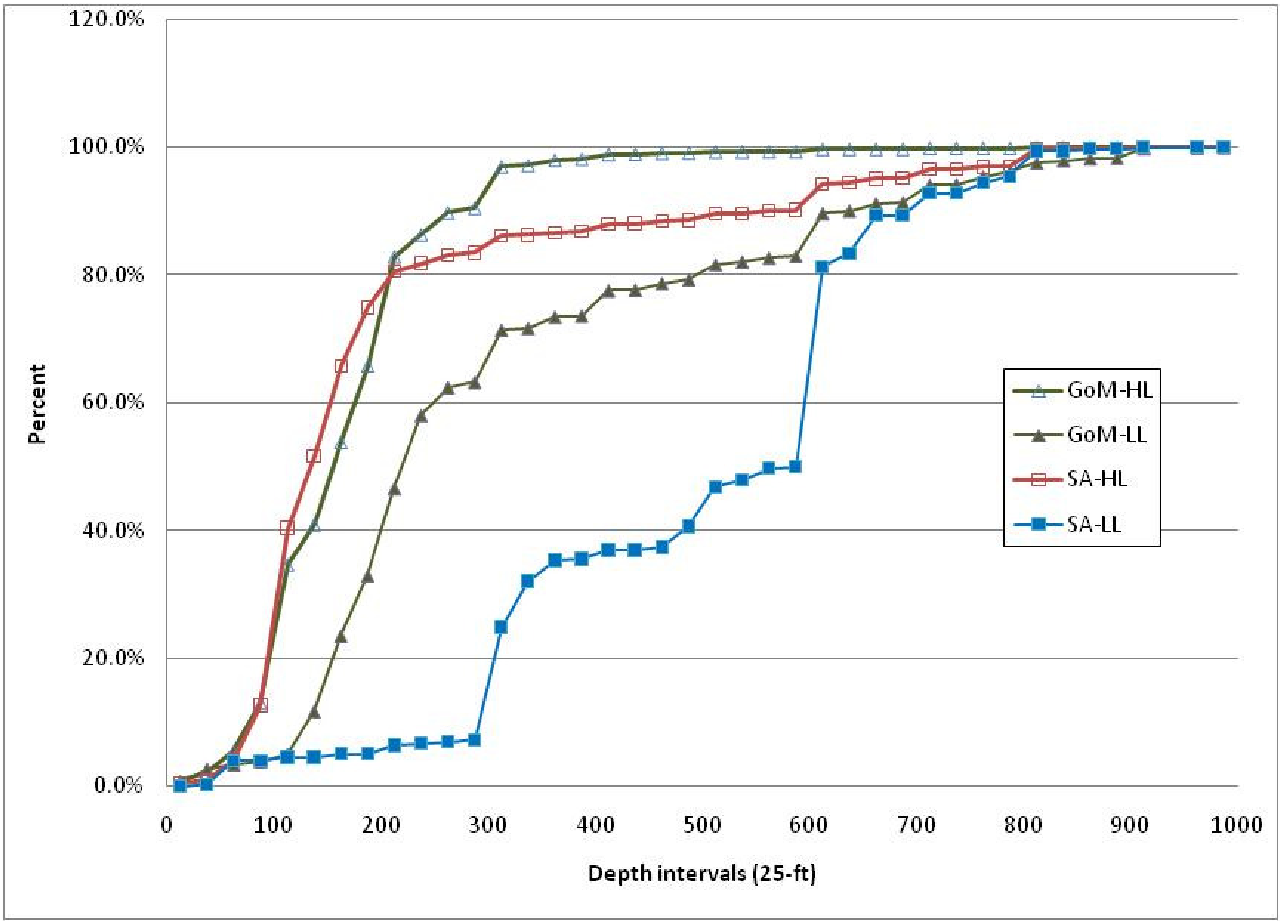


Figure III-4. Depth distributions (in 25 ft intervals, plotted at mid interval) for red snapper and other species trips in the South Atlantic for commercial handline.

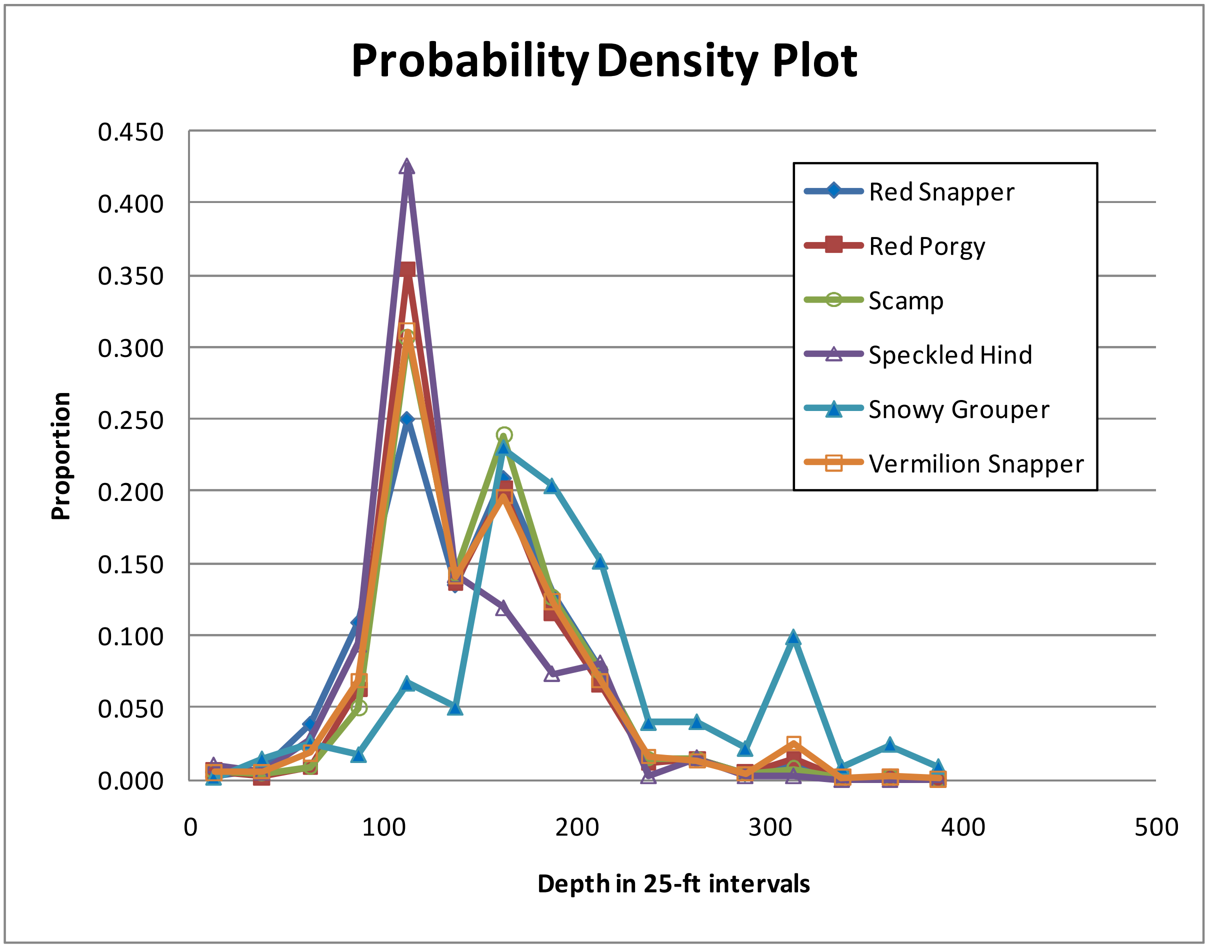
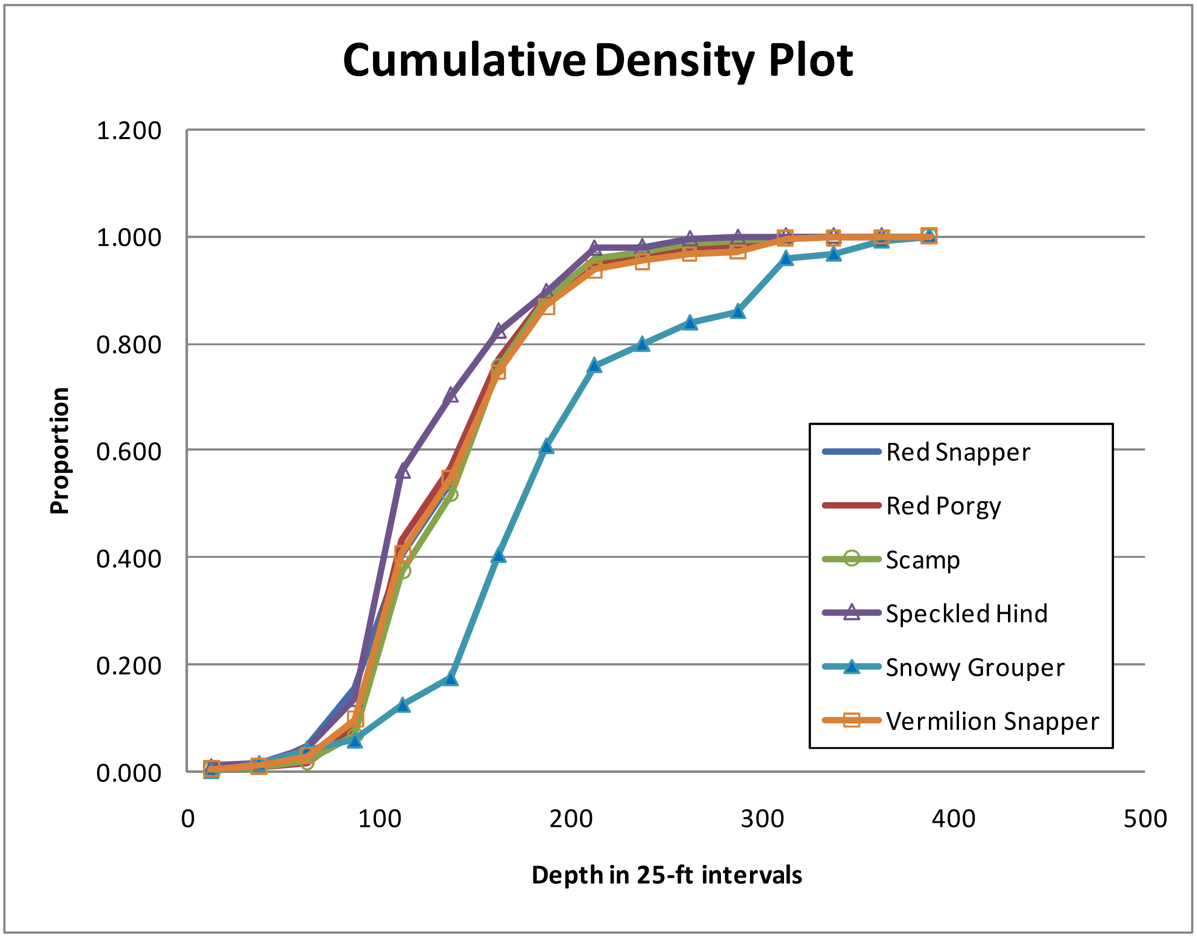


Figure III-5. Depth profiles (in 25 ft intervals, plotted at mid interval) for red snapper and other species trips in the South Atlantic for commercial handline.



IV. Inference from age composition data

Age composition data from the for-hire fleet and the commercial handline fleet were examined for differences in ages caught. These data were pooled over the years 1992−2006, (2007−2009) were excluded because of the expectation that a large year class (or multiple classes) was entering the fishery, which could affect age compositions from the two fleets to different degrees. These pooled age compositions cannot be used to differentiate flat-topped versus dome-shaped selectivity, but they could indicate if selectivity of one fleet is *more* peaked than the other.

The for-hire fleet had a peak at age 3, whereas the commercial fleet peaked at age 3 and 4 (Figure IV-1). When scaled to the density of age-4 fish, it appears that the commercial landings consist of a higher proportion of older fish, particularly ages 5−10 (Figure IV-2). Catch curve analysis of these data (regression estimator, ages 4−12) indicates a slope from the for-hire fleet of −0.75 (SE=0.08) and a slope from the commercial fleet of −0.66 (SE=0.05). Although these estimates of Z are not statistically different, the larger point estimate from the for-hire fleet is consistent with that fleet having a more peaked selectivity.

The difference in the scaled age compositions increases initially with age and then decreases (Figure IV-3). The increase could be due to differences in selectivity, and the decrease could be due to convergence of selectivity patterns or decreased abundance of older fish (these data do not allow us to distinguish between the two possibilities). If the latter is true, and given full selectivity at age-4 from both fleets (which was estimated for red snapper in SEDAR-15), selectivity of the for-hire fleet could be assumed dome-shaped, with full selectivity at age 4, 0.86 at age 5, and 0.79 at ages 6+ (Figure IV-4). This is valid only if the selectivity for the commercial is flat-topped. As can be seen in the next section of this working paper, the selectivity for the commercial sector might be monotonically increasing with age.

Figure IV-1. Densities of pooled age compositions (1992-2006) from for-hire and commercial handline fleets.

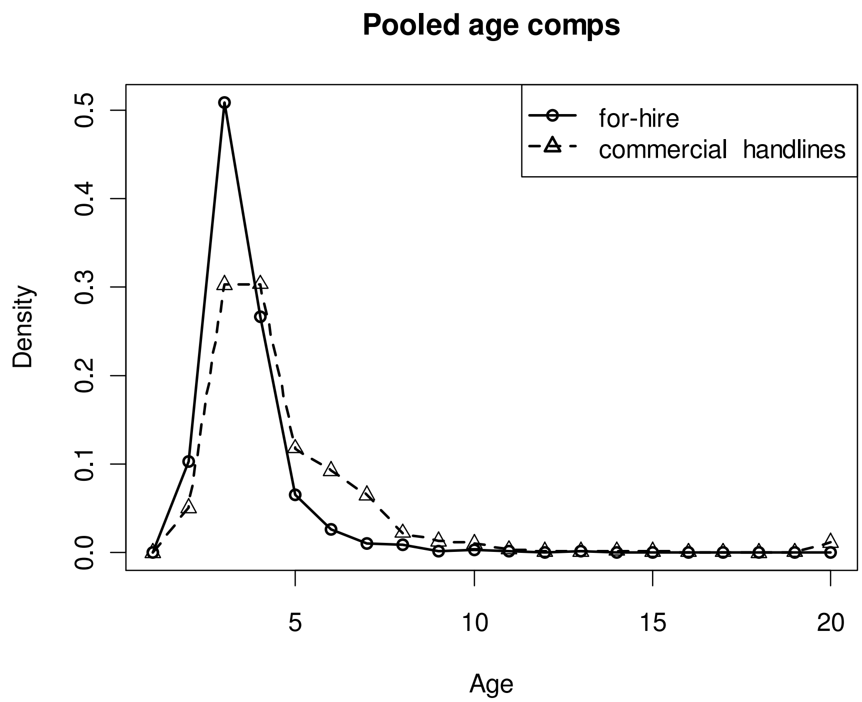


Figure IV-1. Densities of pooled age compositions (1992-2006) from for-hire and commercial handline fleets, scaled to age-4 fish.

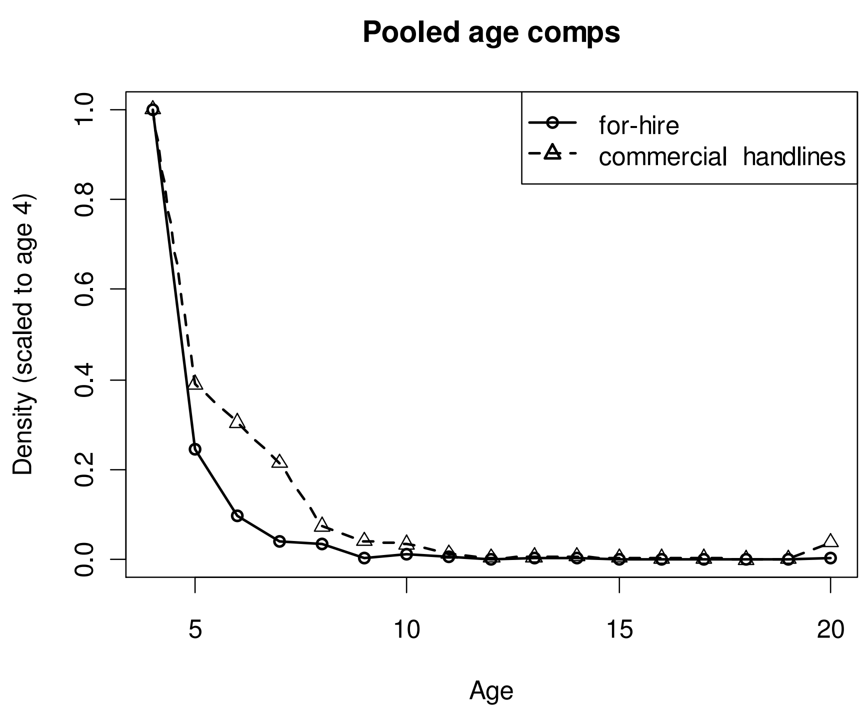


Figure IV-3. Difference in scaled densities of age compositions from Figure IV-2.

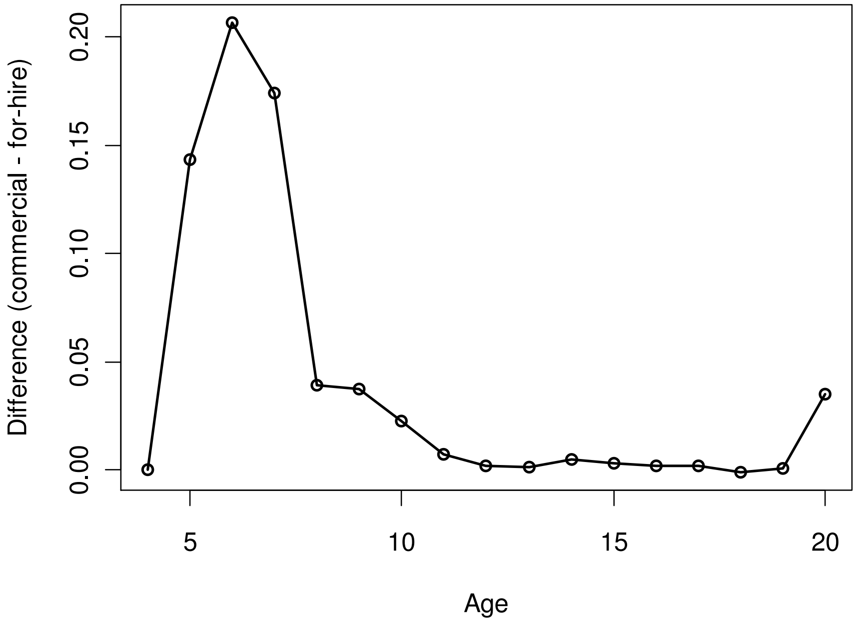
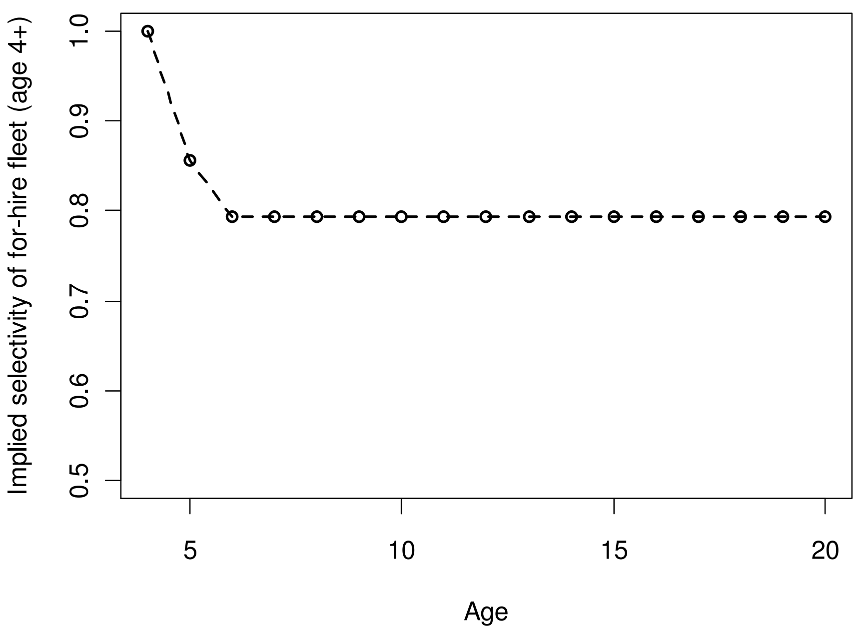


Figure IV-4. Implied selectivity (age 4+) of for-hire fleet, assuming that age-4 is fully selected, that the increase in Figure IV-3 is due to differences in selectivity, and that the decline in Figure IV-3 is due to mortality of fish as they age.



V. Gradient in age and size by depth

V-1 Analysis and results

In this section we examine trends in age and size at depth (50–400 ft) from data supplied by fishermen (3261 records from recreational fishers, and 3929 records from commercial fishers), focusing on age at depth, as the assessment model is age based. Considering all ages, the data show an increasing trend in both age and size (Figure V-1). Pooling ages by quartiles of depths shows a similar trend (Figure V-2), and t-tests of differences in mean ages (H_A: $\mu_{i+1} > \mu_i$) across sequential quartiles (i) were all significant at the α=1% level. Given such a trend, it is impossible to distinguish between two possible explanations with the existing data: one is that the gradient exists because of fish migrations, the other is that the gradient exists because higher exploitation rates in shallower waters crop the age structure. (Of course, the two explanations are not mutually exclusive.)

What drives the observed differences in ages across depths? Are there more young fish at shallower depths, or more old fish at deeper depths, or both? To explore these data further, we first restricted them to fish ages 1–5. In that case, there appears to be few young fish in deeper waters (significantly negative slope), with little or no trend in size (Figure V-3, V-4). However, with respect to selectivity, the susceptibility of the younger fish is modeled by the ascending limb, which increases as those fish enter the fishery. If older fish become less susceptible, this feature would be described by the descending limb of a selectivity curve.

To explore trends in older fish, we next restricted the ages to 5+. In that case, the trend of increasing age with depth is still apparent (Figure V-5), but a t-test of differences in mean ages (H_A: $\mu_4 > \mu_1$) is only marginally significant (P-value=0.054) (Figure V-6). This significance disappears entirely if age 20 is treated as a plus group (Figure V-7), which suggests that the apparent trend is created by the presence of outliers (age 20+ fish in deeper waters). The 99th percentile of ages in the data occurs at age 18. When the data set is restricted to ages 5–20, there are no significant trends in age or size at depth, as measured by significance in slope of trend lines (Figure V-8) or by significance of t-tests in ages pooled by depth (Figure V-9).

V-2 Discussion

As described previously, one of the conditions necessary for dome-shaped selectivity for red snapper is a gradient in age across depth. The data analyzed here suggest that there is a trend in age across depth, but that this trend is driven by the presence of more young fish available at shallower depths. This feature would be modeled by the ascending limb of a selectivity curve. Older fish appear to be equally available across depths (although with more outliers in deeper waters), which is consistent with flat-topped selectivity.

Figure V-1. Age and length at depth with regression lines superimposed.

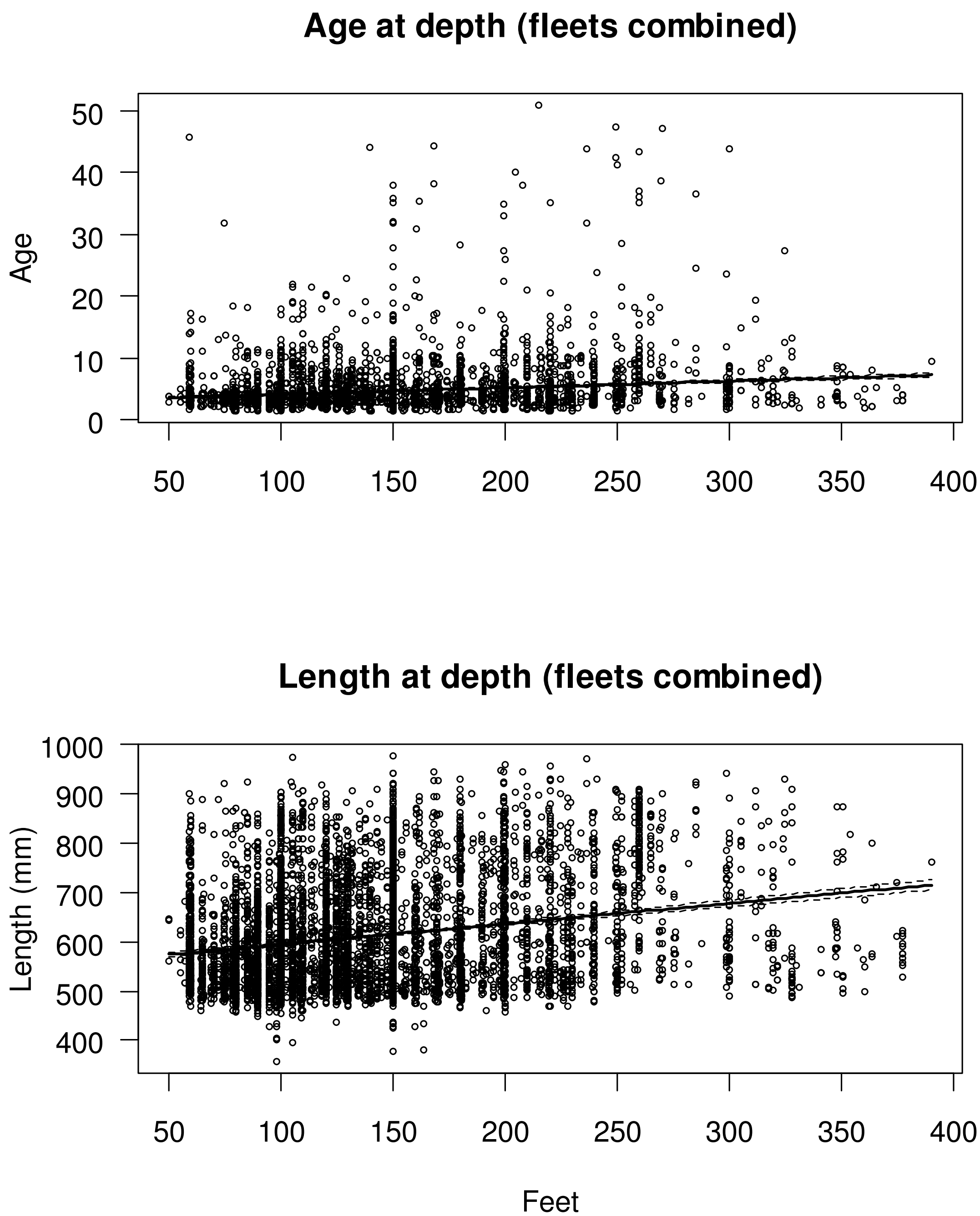


Figure V-2. Box plots of ages summarized over quartiles (Q1−Q4) of depths.

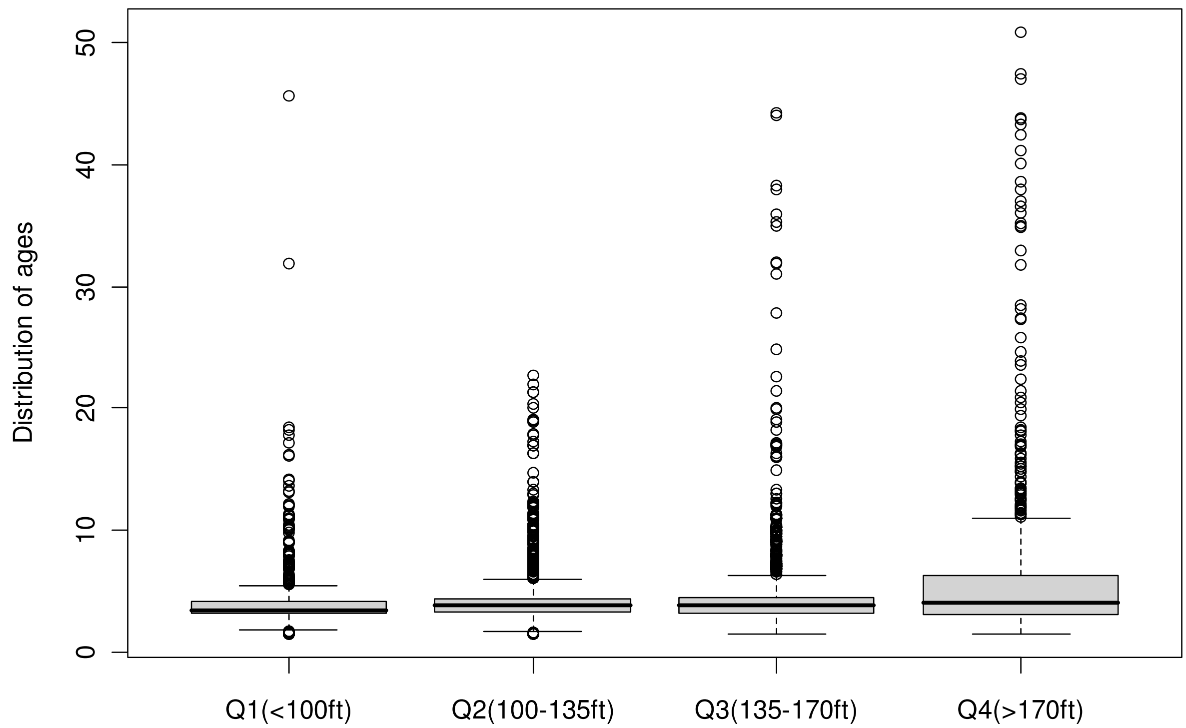


Figure V-3. Age and length at depth with regression lines superimposed, using ages 1–5.

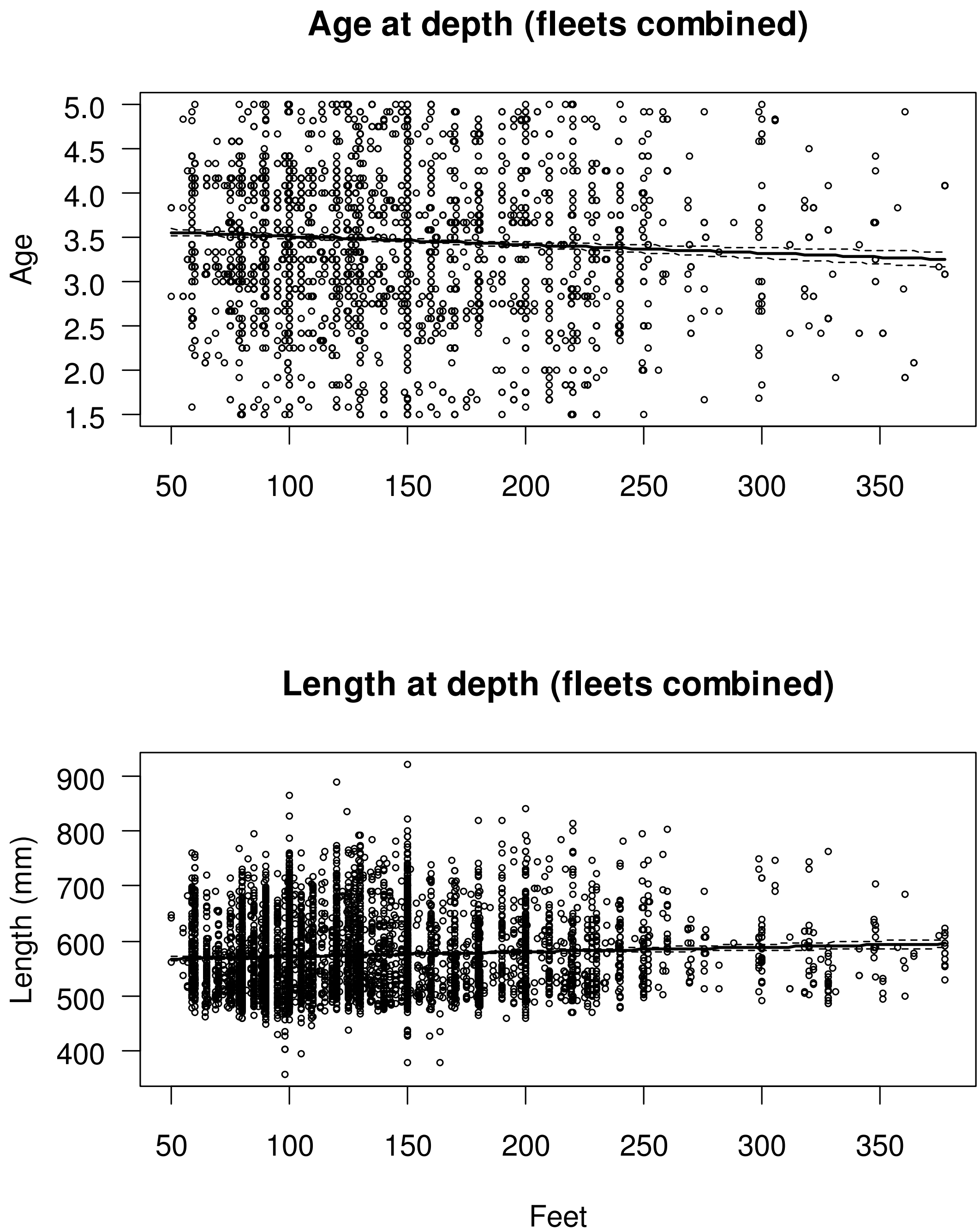


Figure V-4. Box plots of ages summarized over quartiles (Q1−Q4) of depths, using ages 1−5.

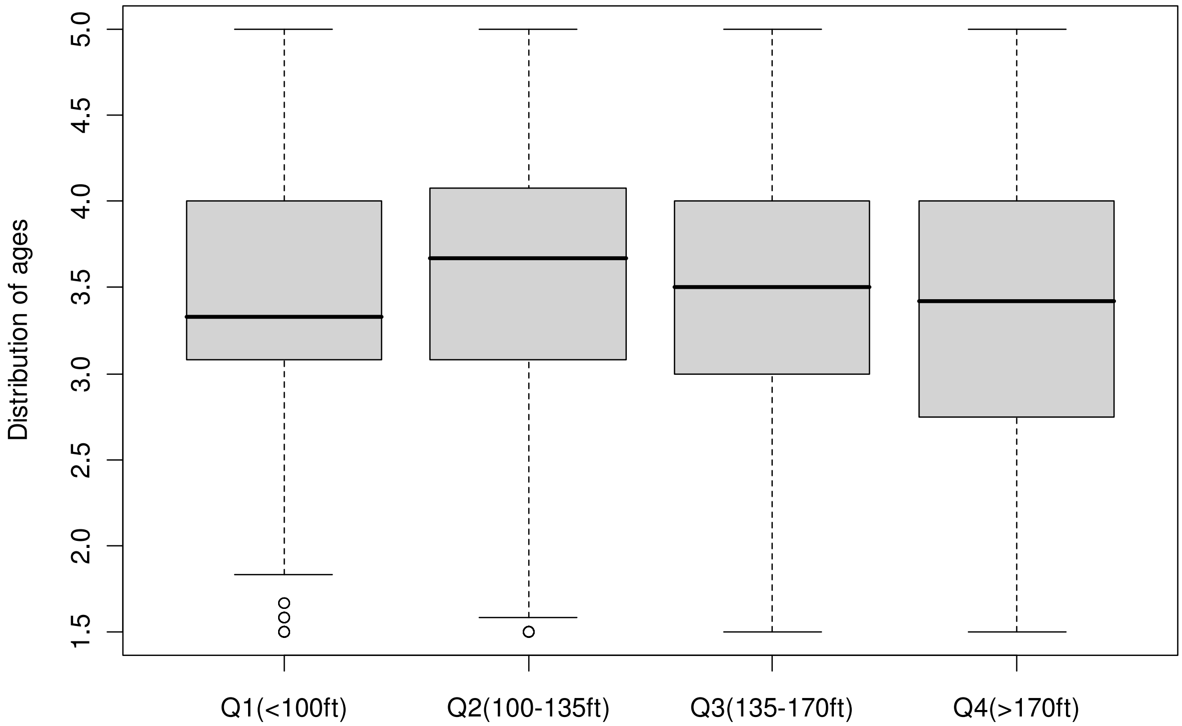


Figure V-5. Age and length at depth with regression lines superimposed, using ages 5+.

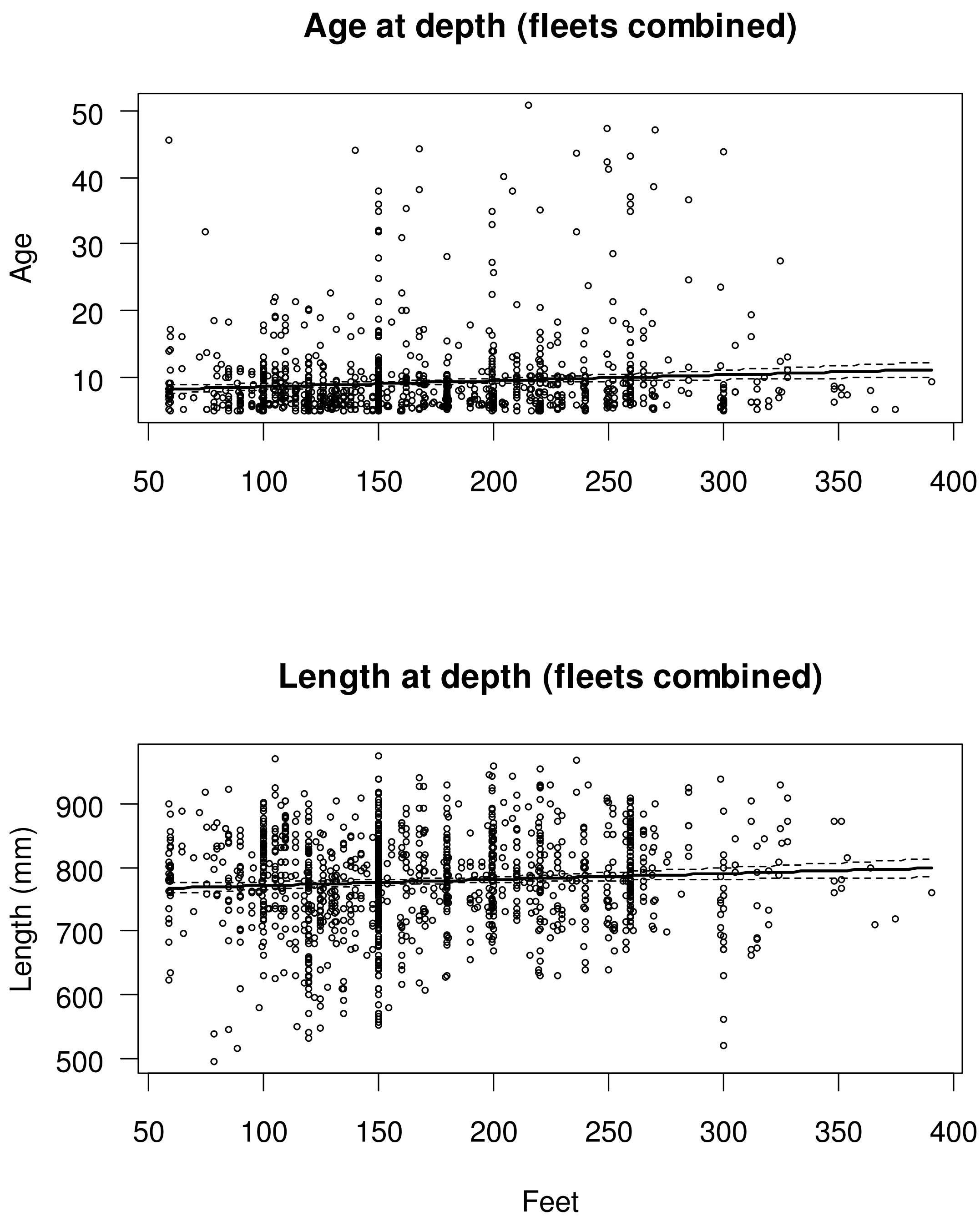


Figure V-6. Box plots of ages summarized over quartiles (Q1−Q4) of depths, using ages 5+.

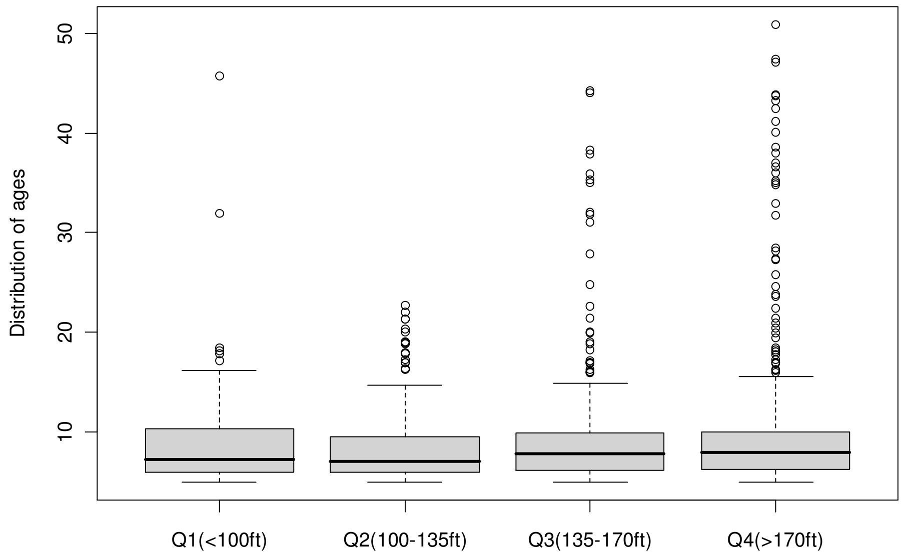


Figure V-7. Box plots of ages summarized over quartiles (Q1−Q4) of depths, using ages 5+ and age 20 as a plus group.

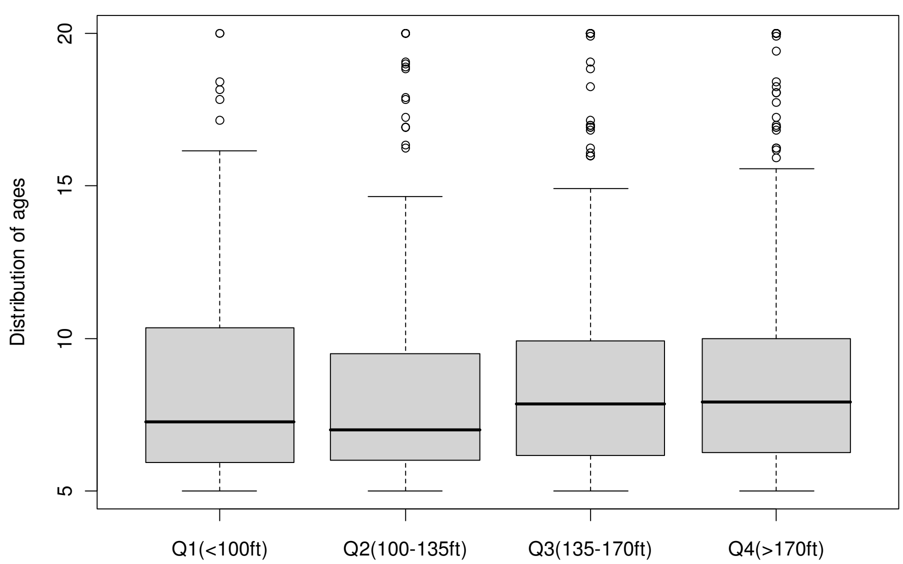
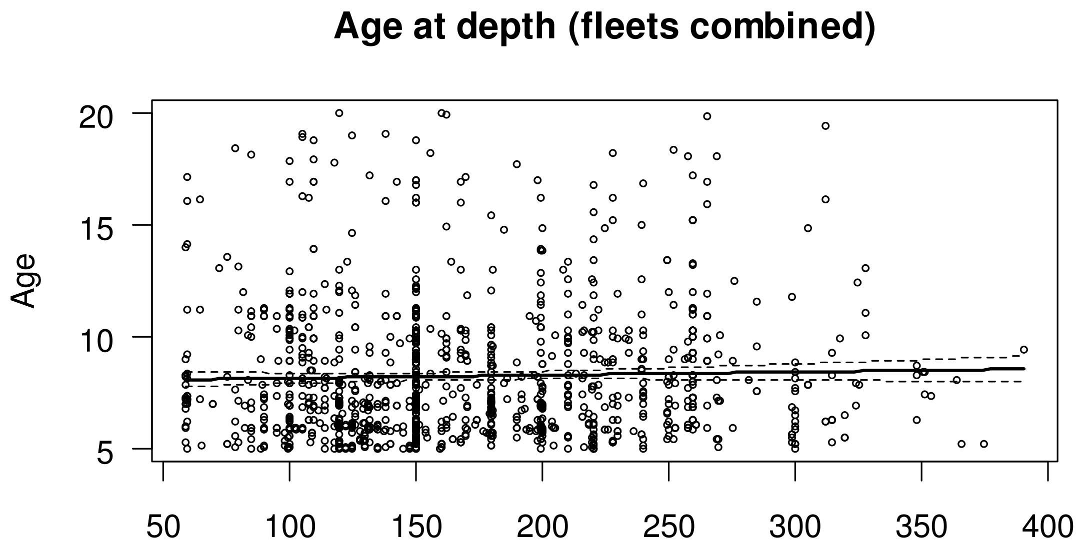


Figure V-8. Age and length at depth with regression lines superimposed, using ages 5–20.



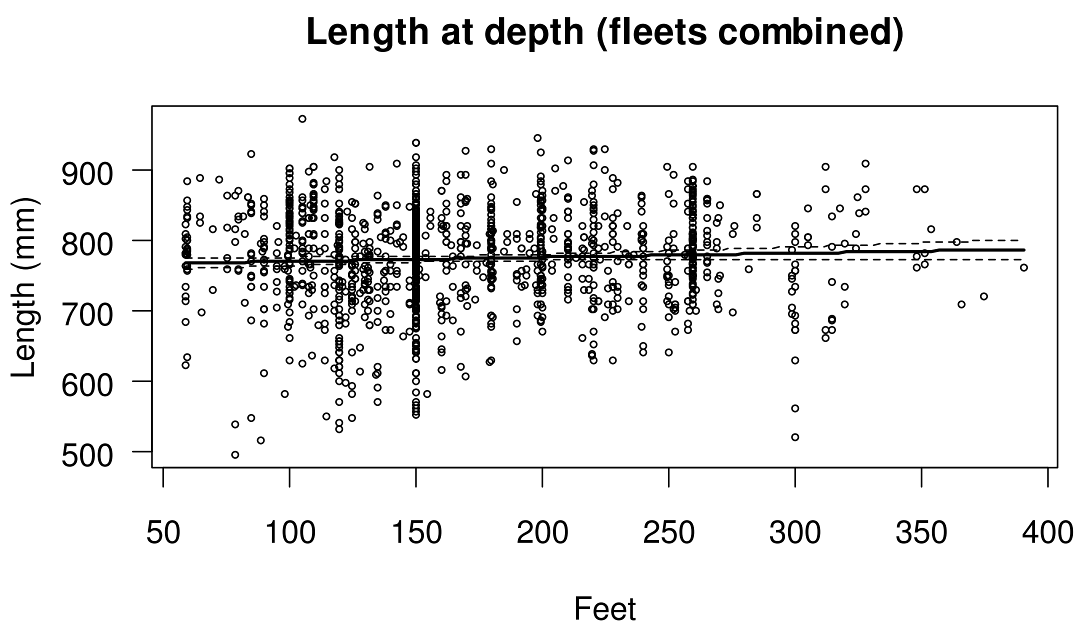
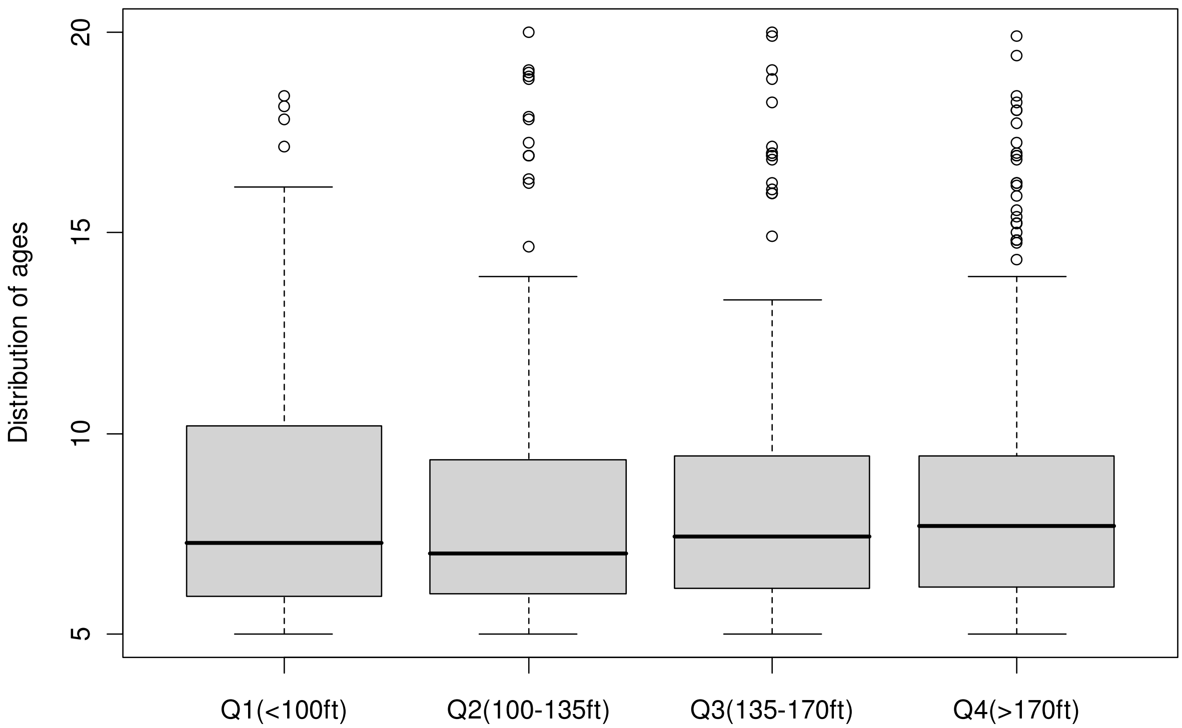


Figure V-9. Box plots of ages summarized over quartiles (Q1–Q4) of depths, using ages 1–20.



VI. Theoretical investigations of selectivity

Extensions on Selectivity

Total mortality (*Z*) is often broken down into two major components, natural mortality (*M*) and fishing mortality (*F*). These quantities are also often specified as a function of age (*a*) and by year (*y*), as follows:

Eq. 1 $$Z_{a,y} = F_{a,y} + M_{a,y}$$

The Z mortality above is an instantaneous rate, representing the rate of exponential decline of the population with time/age. Often *M* is assumed constant across years and ages. Recent stock assessment models have incorporated a power function to model *M* at age, with nonlinearly decreasing mortality rates at older ages.

The fishing mortality term in the equations above is often separated into an age-specific 'selectivity' (*s*) component and an annual full *F*, as follows:

Eq. 2 $$Z_{a,y} = s_a F_y + M_{a,y}$$

The term 'selectivity' used above is really composed of several factors, including fishing gear selectivity and fish availability to name a couple. Some of these factors can include several sub-components. In general, all the factors and sub-components can be summarized as the (1) physical interactions between the fish, the fishermen, and the gear, given an encounter, and (2) the spatial and environmental conditions leading to a potential encounter. When used in an assessment model, the selectivity term is used to reflect the proportion of fish susceptible to fishing mortality.

In the case of red snapper it has been hypothesized that the fishery is typically operating in depths where the oldest red snapper are either absent or in low numbers (disproportionately low relative to the population at large). Depth could be treated as an additional subscript for Eq. 2 above, as follows:

Eq. 3 $$Z_{a,d,y} = s_{a,d} F_y + M_{a,d,y}$$

Ideally, population and fishery dynamics associated with depth could be incorporated into the stock assessment model, but this additional complexity is not possible given the data available for red snapper. What is really important here is the partial fishing mortality at age. Selectivity is really just the proportion of fishing mortality relative to the maximum fishing mortality at age [i.e. F_a / max(F_a)]. We could break down fishing mortality into further components and use this to infer the general shape of the age-specific selectivity function. In other words, with an examination of some of the depth data we could inform the shape of the fishery selectivity. To add the depth dimension to the problem we need to consider the susceptibility of the fish for both the age and depth dimensions.

Some important factors that need to be considered that could result in differential selection at age include: (1) gear selectivity, (2) regulations (e.g. minimum size limit), (3) distribution of depths for each age, (4) distribution of fishing mortality by depth, and (5) relative abundance by depth and age.

This last factor is probably the most important in the case of red snapper. The relative abundance of each age by depth is going to be a function of the distribution of ages by depth and the amount of depth habitat. This could be expressed as follows:

Eq. 4 $$Q_{a,d} = \frac{p_{a,d} A_d}{\sum_d p_{a,d} A_d}$$

where $Q_{a,d}$ is the relative abundance of each age (a) by depth (d), $p_{a,d}$ is the relative proportion of depths for each age (factor (3) above), and A_d is the area of habitat for each depth. The Q handles the abundance of age each age at depth, but there are other factors important to selectivity mentioned above. Factors (1) and (2) above can be expressed as functions of age, by allowing g_a to represent gear selectivity and r_a to represent the partial recruitment to the fishery due to regulations, in this case the 20" minimum size limit.

In many fisheries it is common to focus on g and r only, as these tend to be the dominant factors governing selectivity at age. In the case of red snapper, the dominant gear type is hook gear, which in general tends to be non-selective with respect to age, except for the very youngest fish. When considering the minimum size limit of 20", then the gear selectivity of hook gear becomes more likely to be non-selective over the range of ages corresponding to fish greater than 20". So, the r factor is an important factor for age-specific selectivity and is only going to affect the youngest ages and those around the 20" size limit.

The next factor, (4) above, to discuss is the fishing mortality, F, at depth. Fishing mortality can be expressed in terms of effort (E), as $F = qE$, where q is the catchability. If we assume q is constant with depth, then we could get F_d by computing E_d. We can compute E_d from the density of trips which caught red snapper at various depths of fishing.

Essentially we need to get an estimate of the fishing mortality at age, F_a, which can then be used to compute the selectivity of the fishery by dividing by the maximum F_a. By assuming $M = 0$ and rearranging the Baranov catch equation we can solve for F_a as follows:

Eq. 5 $$F_a = g_a r_a \left[-\ln\left(1 - \left[\sum_d Q_{a,d} \left(1 - \exp[-F_d]\right)\right]\right)\right]$$

By rescaling the F_a values to the maximum we obtain an estimate of the selectivity.

Hypothetical Case

Let's examine a hypothetical case using equation 5 above. In this example we will structure the hypothetical case to match red snapper in some ways. For instance, the hypothetical case will model ages 1-20+, we'll assume that g_a is 1.0 for all ages (the likely case for hook gear), and that

r_a is driven primarily by the 20" minimum size limit. To get r_a we used the fishery weighted selectivity pattern from SEDAR 15 (Figure VI-1). This suggests age 4 fish are nearly fully selected. An age 4 fish roughly corresponds to 20" red snapper. In this hypothetical case we will use the density of red snapper trips from the commercial logbooks for F_d (Figure VI-2).

Figure VI-1. The catch weighted average selectivity from the SEDAR 15 stock assessment.

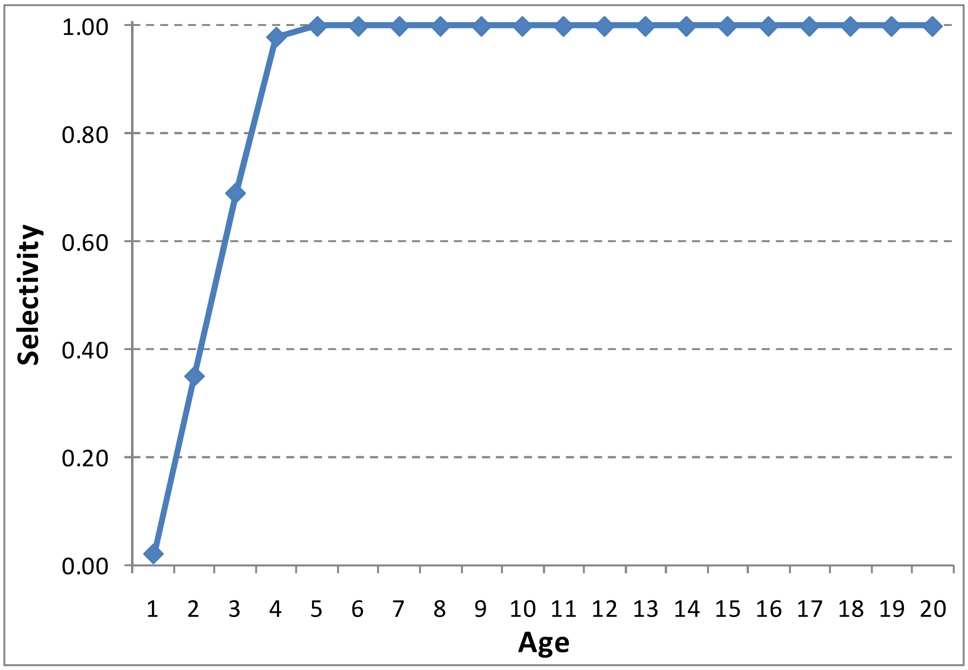
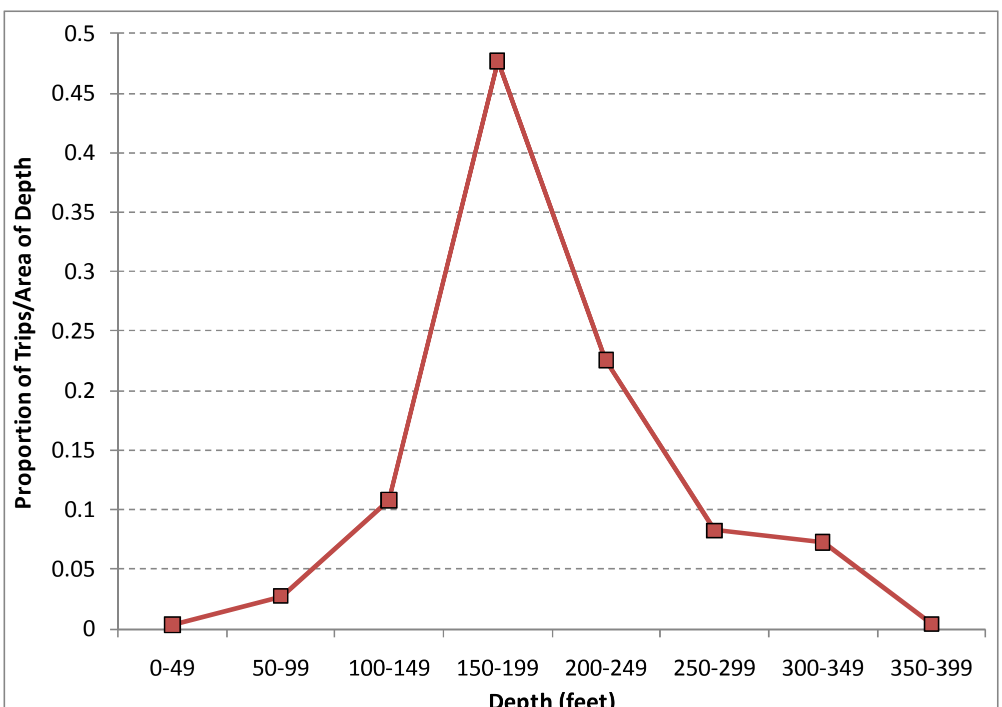


Figure VI-2. The relative density of effort (trips/area of depth) for trips that caught red snapper from commercial logbooks.



In this hypothetical population we will assume that there is an ontogenetic shift in red snapper, with older fish moving to deeper waters. This pattern can be expressed in the $p_{a,d}$ matrix as follows:

Table VI-1. A hypothetical $p_{a,d}$ matrix, designed to represent an ontogenetic shift in which older fish move out of shallow water and into deeper water.

	Depth (ft)							
Age	**0-49**	**50-99**	**100-149**	**150-199**	**200-249**	**250-299**	**300-349**	**350-399**
1	1.00	1.00	0.50	0.00	0.00	0.00	0.00	0.00
2	1.00	1.00	1.00	0.50	0.00	0.00	0.00	0.00
3	0.75	1.00	1.00	1.00	0.50	0.00	0.00	0.00
4	0.50	0.75	1.00	1.00	1.00	0.50	0.00	0.00
5	0.25	0.50	0.75	1.00	1.00	1.00	0.50	0.00
6	0.00	0.25	0.50	0.80	1.00	1.00	1.00	0.50
7	0.00	0.00	0.25	0.60	0.80	1.00	1.00	1.00
8	0.00	0.00	0.00	0.40	0.70	1.00	1.00	1.00
9	0.00	0.00	0.00	0.20	0.60	1.00	1.00	1.00
10	0.00	0.00	0.00	0.10	0.50	1.00	1.00	1.00
11	0.00	0.00	0.00	0.00	0.40	1.00	1.00	1.00
12	0.00	0.00	0.00	0.00	0.30	0.90	1.00	1.00
13	0.00	0.00	0.00	0.00	0.20	0.80	1.00	1.00
14	0.00	0.00	0.00	0.00	0.10	0.70	1.00	1.00
15	0.00	0.00	0.00	0.00	0.00	0.60	1.00	1.00
16	0.00	0.00	0.00	0.00	0.00	0.50	1.00	1.00
17	0.00	0.00	0.00	0.00	0.00	0.50	1.00	1.00
18	0.00	0.00	0.00	0.00	0.00	0.50	1.00	1.00
19	0.00	0.00	0.00	0.00	0.00	0.50	1.00	1.00
20	0.00	0.00	0.00	0.00	0.00	0.50	1.00	1.00

Visually this can be seen in Figure VI-3.

Figure VI-3. Hypothetical red snapper age-depth probability matrix, α, for selectivity calculations.

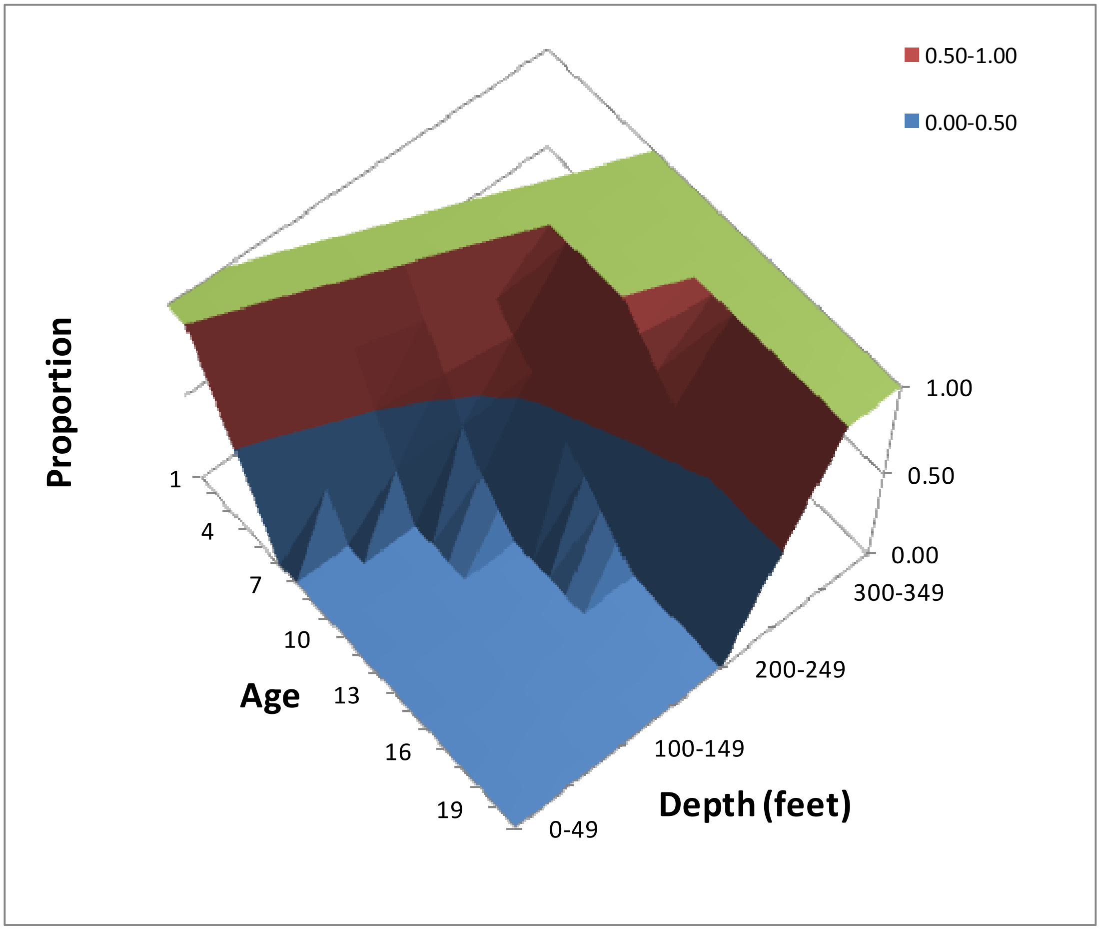
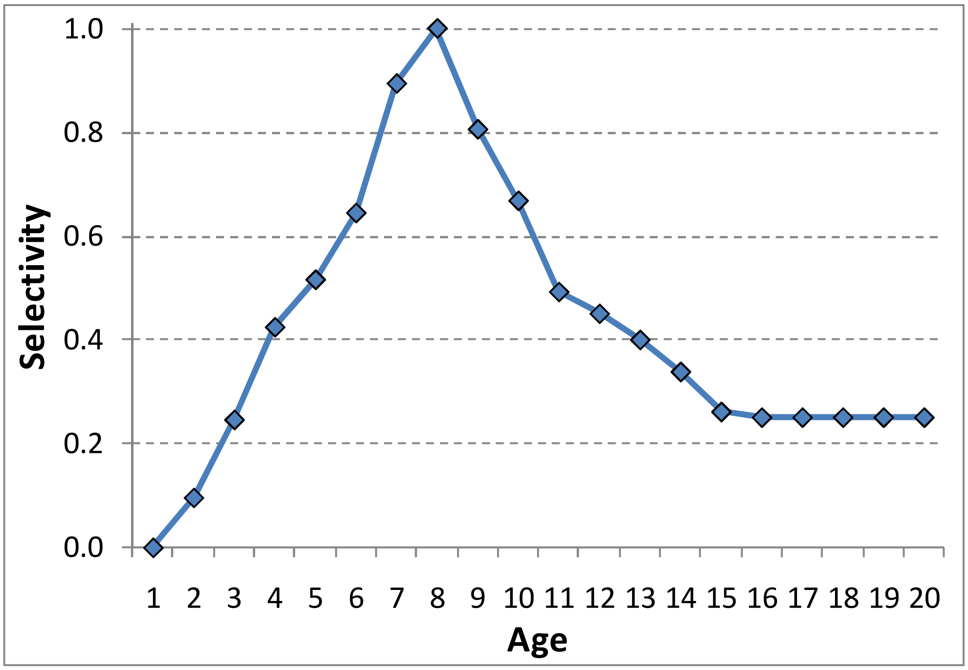


Figure VI-3 indicates that the youngest fish only occur in the shallow waters and do not occur in the deeper waters. Also, this matrix indicates there are very fish over age 7 in the shallower waters and the oldest fish only occur in the deepest waters. Using this matrix along with the other settings mentioned above yields a relative selectivity shown in Figure VI-4.

Figure VI-4. Selectivity results for a hypothetical red snapper example with a $p_{a,d}$ matrix suggesting an ontogenetic shift to deeper waters with increasing age.



With this hypothetical example it can be seen that with some of the data available for red snapper, it is possible to infer potential selectivity patterns. In the hypothetical case it clearly demonstrates that when red snapper effort is concentrated in a middle depth zone and there is an ontogenetic shift toward deeper waters for older red snapper, the result is a dome-shaped selectivity (Figure VI-4).

<u>South Atlantic Red Snapper</u>

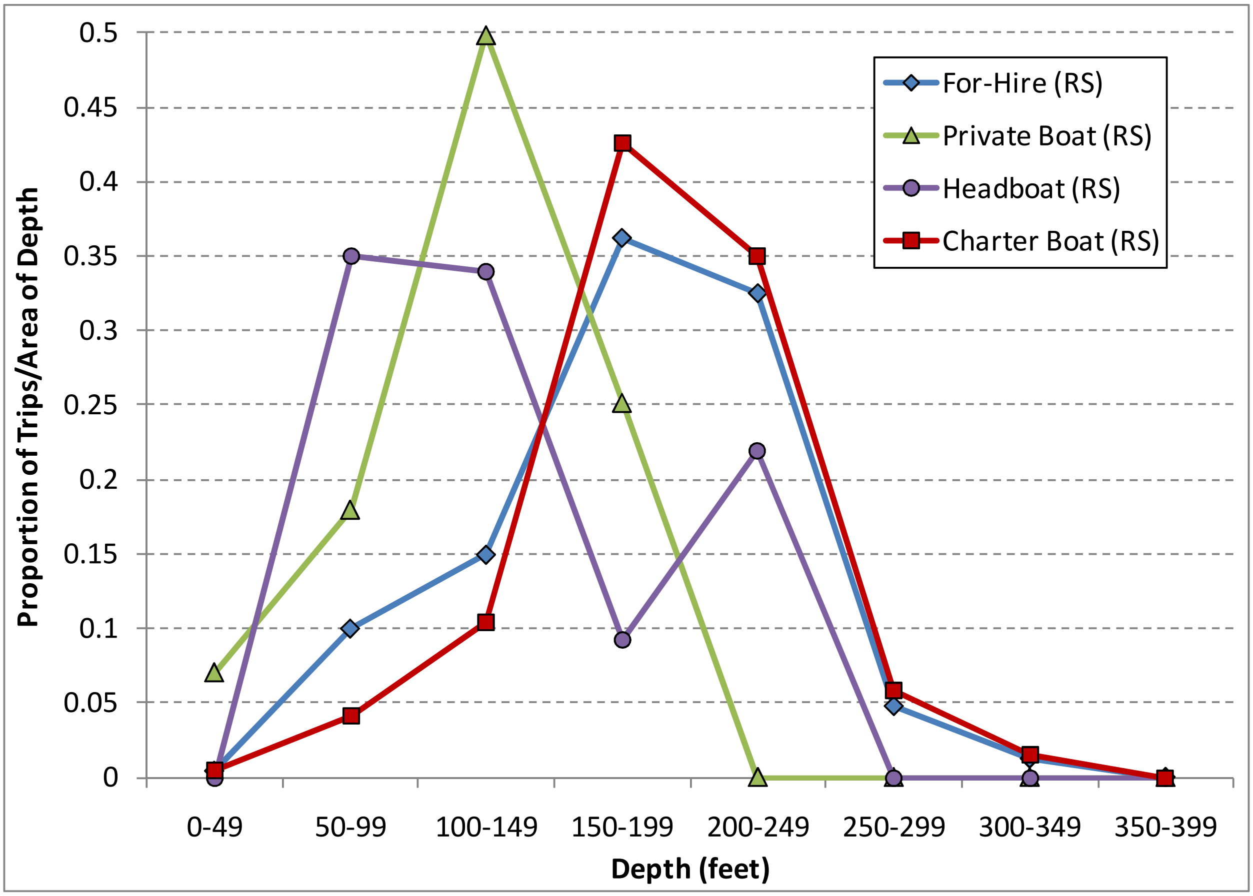
For the case of South Atlantic red snapper we will assume that g_a, the gear selectivity, is constant at full selection across all ages. This is not an unreasonable assumption since hook gear tends to be non-selective, except in the few cases when hook gape approaches or exceeds fish mouth size, which does not appear to be the case for red snapper. Gear selectivity could decline at older ages if the hook gear is fragile enough to allow the biggest fish to break the line and escape. In general, the hook gear used to capture red snapper utilizes hook sizes that are more than sufficient for capturing 20" inch fish and larger. The gear is often rigged with 100+ pound test monofilament line so that the biggest fish are unlikely to escape the gear. With red snapper there is the potential for preferential selection of the older fish as some fishermen have indicated that bigger red snapper tend to be more aggressive when biting a hook. The term "hook happy" has been used to describe red snapper, owing to their overall aggressive nature when biting a hook, potentially outcompeting other reef fish species.

The selectivity due to regulations (r_a), in this case a 20" minimum size limit will be handled by using the catch weighted average selectivity from the SEDAR 15 assessment. This selectivity suggests that age 4 fish are nearly fully selected (Figure VI-1). An age 4 fish corresponds to about a 20" red snapper.

The density of effort per unit depth was computed using the depth area values from the depth habitat analysis and data from the fisheries on the number of trips that caught red snapper that also recorded depth. The commercial logbook contains a field for recording depth. For this analysis, the trips which caught red snapper and recorded depth were combined to produce a depth profile of red snapper trips. These data were then divided by the amount of area in each 50 foot depth zone. The results were used in the hypothetical example above and are shown in Figure VI-2.

For the recreational sectors, charter boat, headboat, for-hire (charter boat and headboat) and private boat, the data were much more limiting. When computing the combined for-hire sector depth profile, we used the same catch weighted method (assumes 58% charter boat) as used in the SEDAR 24 DW report. In the recreational fishing surveys, depth is not a routine data field being collected. We relied on estimates provided during the SEDAR 24 DW. This included dockside interviews, observer data, and tagging data. This data does not include any samples from North Carolina, with most of the samples coming from Florida. Because this sampling is not in direct proportion to the fishery, there are potentially some unknown biases. Much like the commercial data, a profile of the frequency of trips catching red snapper was divided by the area of depth estimates to produce a vector of relative effort density by depth (Figure VI-5).

Figure VI-5. The relative density of effort (trips/area of depth) for trips that caught red snapper from recreational sectors.



It is not surprising that the estimates from the charter boat sector are quite similar to the commercial sector estimates in Figure VI-2. These data indicate that the private sector expends more effort in the shallower waters and that the headboat fishery seems to direct effort in both the shallowest waters and out to 250 feet of water.

It should be noted that the relative effort profiles in Figures VI-2 and 5 rely primarily on very recent collected data and therefore could be biased by localized depletion and possible over exploitation. If localized depletion is occurring or the population is over-exploited, this leads to lower catches overall and can be more pronounced for the oldest ages. This could lead to a biased estimate of effort, when using only trips that caught red snapper as the measure of effort.

The depth profiles shown above give us an indication of the F_d for each sector. The difficult part is determining the $p_{a,d}$ matrix for red snapper. In order to encompass the uncertainty in computing this matrix, we applied the following methods; (1) use the collected age-depth data and normalize the data across depth for each age so that the proportions sum to one (Table VI-2, Figure VI-6), and (2) use the age-depth data to compute a normal parametric model of depth distributions at age (Table VI-3, Figure VI-7). This last method was computed by fitting a linear trend to the mean depth and standard deviations of depth across ages. These linear trends in the mean and standard deviation were then plugged into a normal distribution to get the final proportions of ages by depth.

Table VI-2. The $p_{a,d}$ matrix computed from the SEDAR 24 DW age samples using proportions of depth at age.

Age	Depth 0-49	(feet) 50-99	100-149	150-199	200-249	250-299	300-349	349-399
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.02	0.10	0.30	0.29	0.24	0.01	0.01	0.03
3	0.01	0.18	0.32	0.27	0.13	0.02	0.03	0.03
4	0.02	0.28	0.33	0.26	0.07	0.02	0.02	0.02
5	0.01	0.25	0.31	0.30	0.08	0.02	0.01	0.02
6	0.00	0.09	0.29	0.29	0.18	0.07	0.03	0.04
7	0.00	0.04	0.34	0.26	0.17	0.08	0.05	0.05
8	0.02	0.11	0.25	0.30	0.13	0.09	0.03	0.07
9	0.01	0.06	0.19	0.26	0.09	0.27	0.04	0.08
10	0.03	0.02	0.17	0.36	0.16	0.18	0.01	0.06
11	0.02	0.10	0.26	0.28	0.19	0.12	0.01	0.02
12	0.00	0.11	0.26	0.25	0.18	0.18	0.02	0.02
13	0.00	0.04	0.32	0.24	0.24	0.12	0.04	0.00
14	0.00	0.14	0.18	0.18	0.27	0.18	0.05	0.00
15	0.00	0.18	0.09	0.18	0.27	0.00	0.09	0.18
16	0.00	0.00	0.00	0.10	0.30	0.40	0.00	0.20
17	0.00	0.10	0.33	0.29	0.19	0.05	0.05	0.00
18	0.00	0.09	0.36	0.45	0.00	0.09	0.00	0.00
19	0.00	0.18	0.18	0.18	0.09	0.27	0.00	0.09
20	0.00	0.04	0.13	0.27	0.25	0.25	0.04	0.02

Figure VI-6. The $p_{a,d}$ matrix computed from the SEDAR 24 DW age samples using proportions of depth at age.

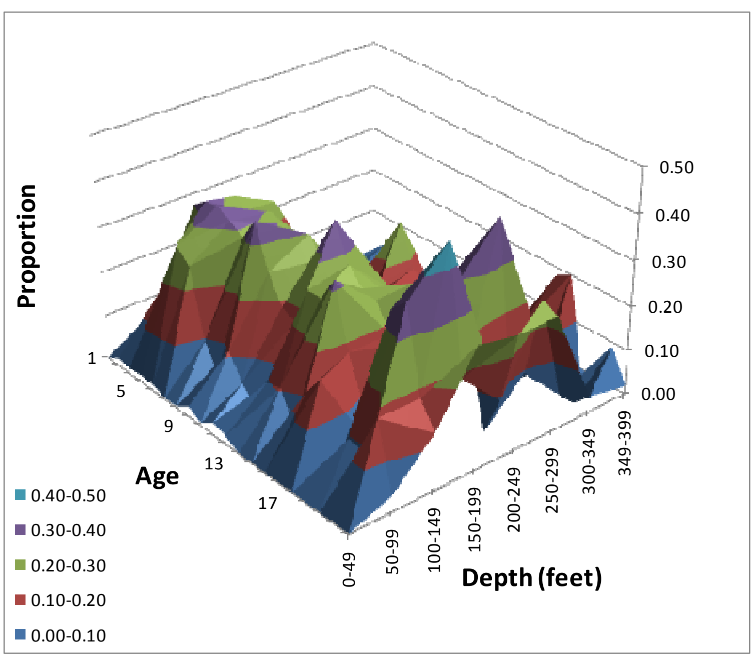
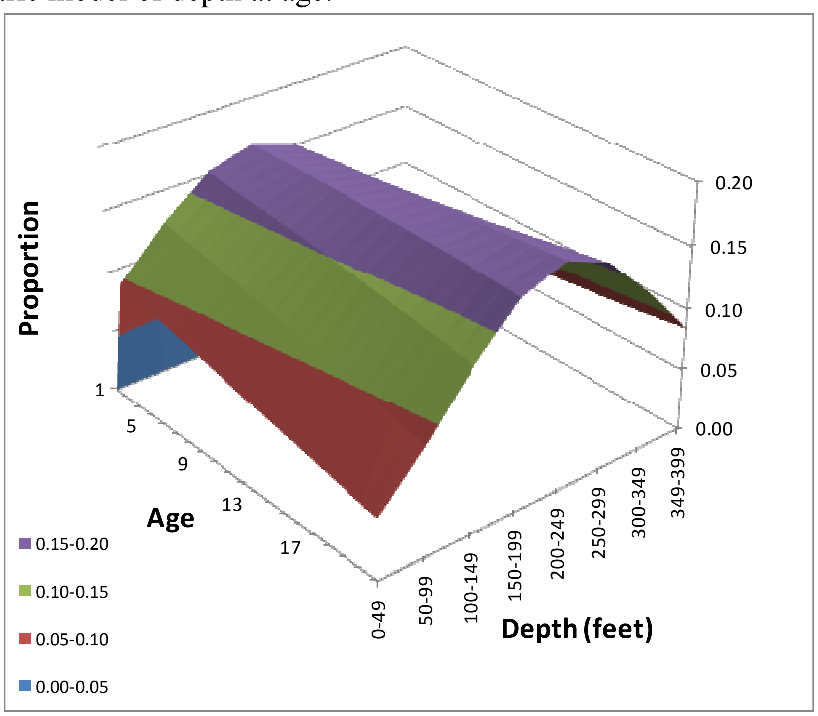


Table VI-3. The $p_{a,d}$ matrix computed from the SEDAR 24 DW age samples using a smoothed normal parametric model of depth at age.

	Depth	(feet)						
Age	0-49	50-99	100-149	150-199	200-249	250-299	300-349	349-399
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.10	0.13	0.16	0.17	0.16	0.13	0.09	0.06
3	0.09	0.13	0.16	0.17	0.16	0.13	0.09	0.06
4	0.09	0.13	0.16	0.17	0.16	0.13	0.09	0.06
5	0.09	0.13	0.16	0.17	0.16	0.13	0.10	0.06
6	0.09	0.12	0.16	0.17	0.16	0.14	0.10	0.06
7	0.08	0.12	0.16	0.17	0.17	0.14	0.10	0.06
8	0.08	0.12	0.15	0.17	0.17	0.14	0.10	0.06
9	0.08	0.12	0.15	0.17	0.17	0.14	0.10	0.07
10	0.08	0.12	0.15	0.17	0.17	0.14	0.11	0.07
11	0.07	0.11	0.15	0.17	0.17	0.15	0.11	0.07
12	0.07	0.11	0.15	0.17	0.17	0.15	0.11	0.07
13	0.07	0.11	0.15	0.17	0.17	0.15	0.11	0.07
14	0.07	0.10	0.14	0.17	0.17	0.15	0.11	0.07
15	0.06	0.10	0.14	0.17	0.18	0.15	0.12	0.08
16	0.06	0.10	0.14	0.17	0.18	0.16	0.12	0.08
17	0.06	0.10	0.14	0.17	0.18	0.16	0.12	0.08
18	0.06	0.09	0.14	0.17	0.18	0.16	0.12	0.08
19	0.05	0.09	0.13	0.17	0.18	0.16	0.13	0.08
20	0.05	0.09	0.13	0.17	0.18	0.17	0.13	0.08

Figure VI-7. The $p_{a,d}$ matrix computed from the SEDAR 24 DW age samples using a smoothed normal parametric model of depth at age.



The results of applying the two types of $p_{a,d}$ matrices along with the relative effort density vectors are shown in Figures VI-10– VI-14. These results suggest a dome-shaped selectivity may not be appropriate for any of the sectors, and suggest a selectivity pattern that is quite the opposite of dome-shaped for the commercial and charter boat sectors. This analysis suggests the commercial handline selectivity may actually be a monotonic increase to the oldest ages and that full selection is not until the oldest ages. If fishermen's claims about older fish moving inshore to form spawning aggregations during the summer months are true, than this increased vulnerability for the older fish may explain the selectivity patterns estimated in this analysis.

Figure VI-10. Relative selectivity estimates for the commercial handline fishery based on various methods (Prop = proportions of depth at age from age data, Smooth Prop = the smoothed normal parametric model of depth at age) for computing the $p_{a,d}$ matrix.

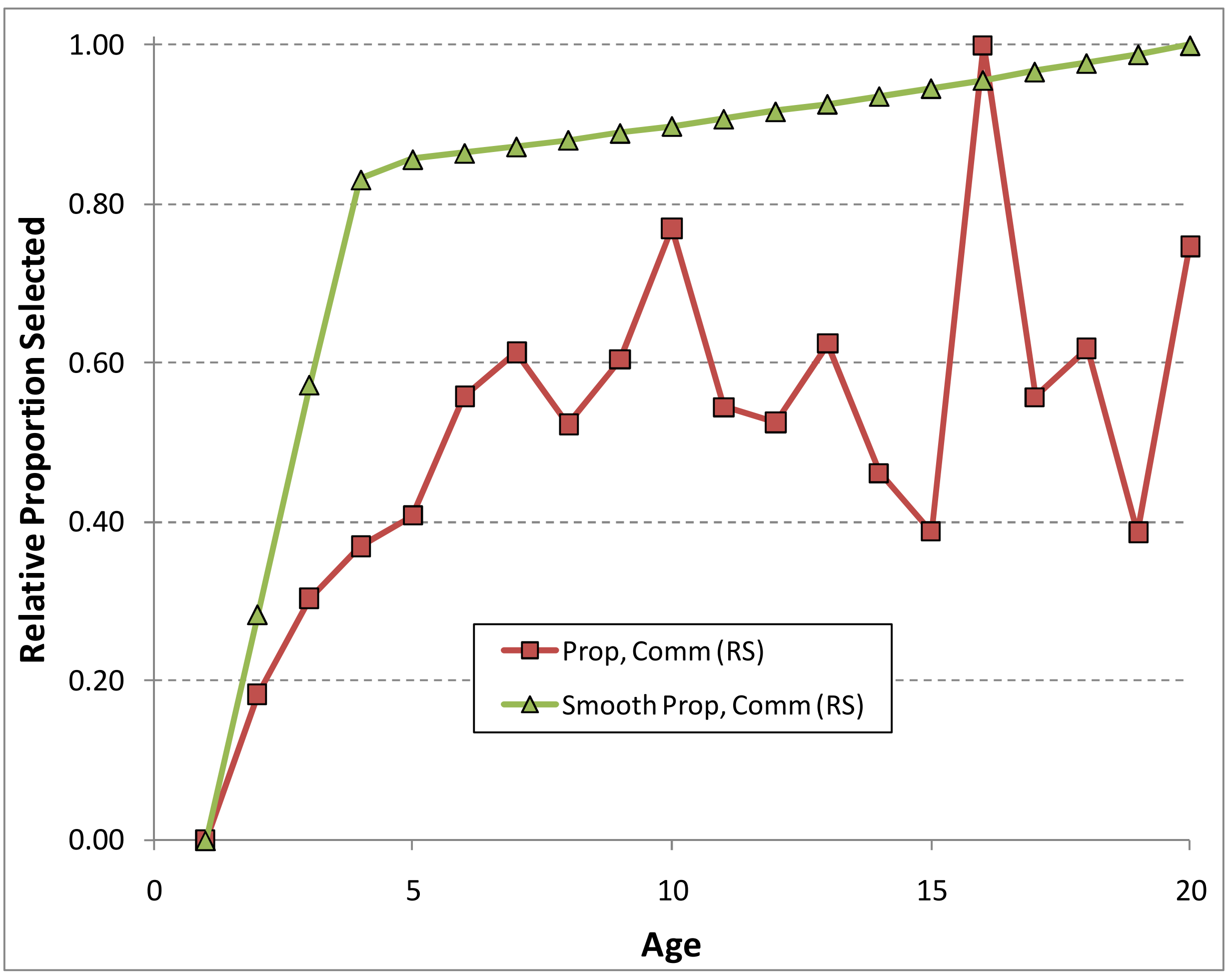


Figure VI-11. Relative selectivity estimates for the recreational charter boat fishery based on various methods (Prop = proportions of depth at age from age data, Smooth Prop = the smoothed normal parametric model of depth at age) for computing the $p_{a,d}$ matrix.

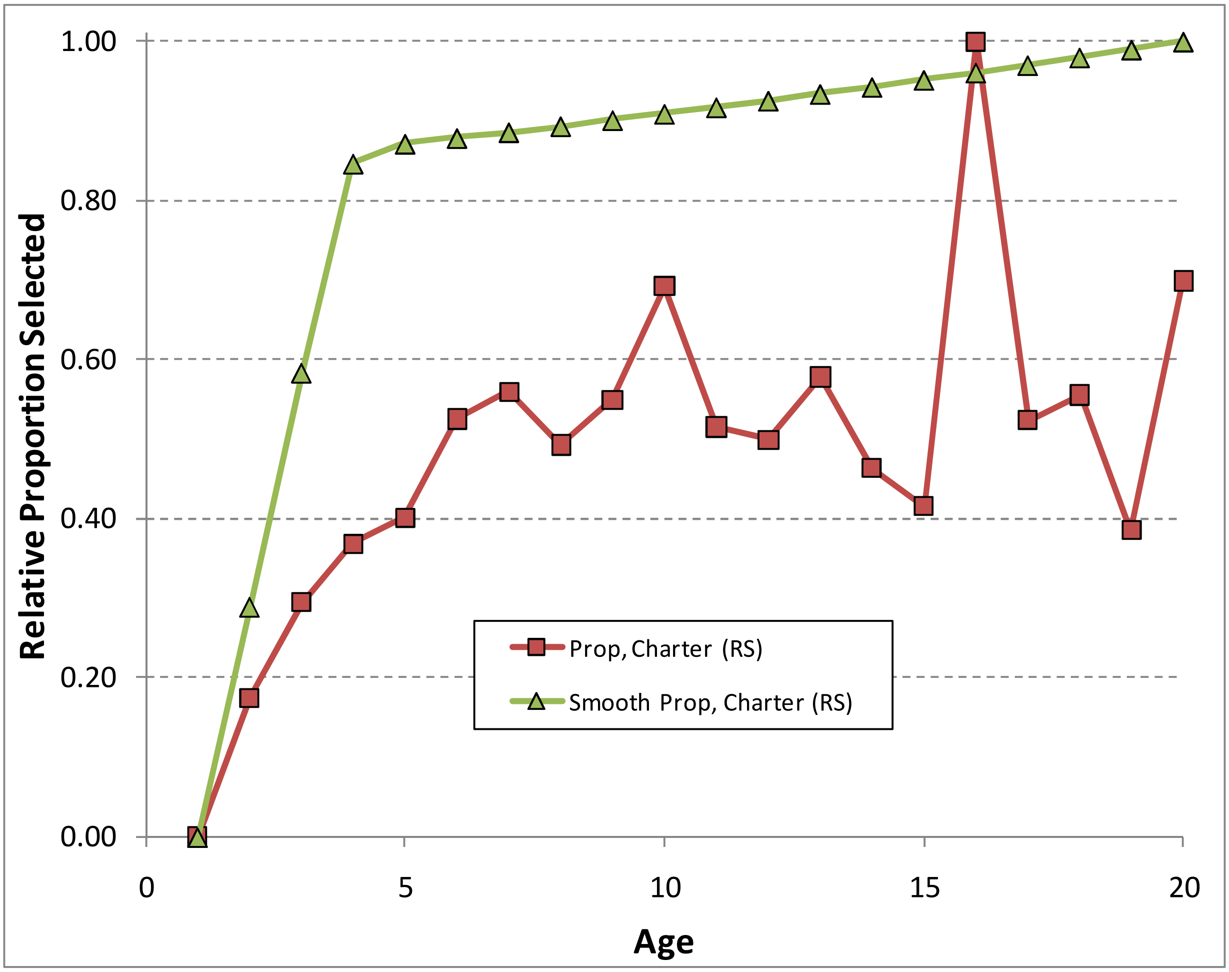


Figure VI-12. Relative selectivity estimates for the recreational headboat fishery based on various methods (Prop = proportions of depth at age from age data, Smooth Prop = the smoothed normal parametric model of depth at age) for computing the $p_{a,d}$ matrix.

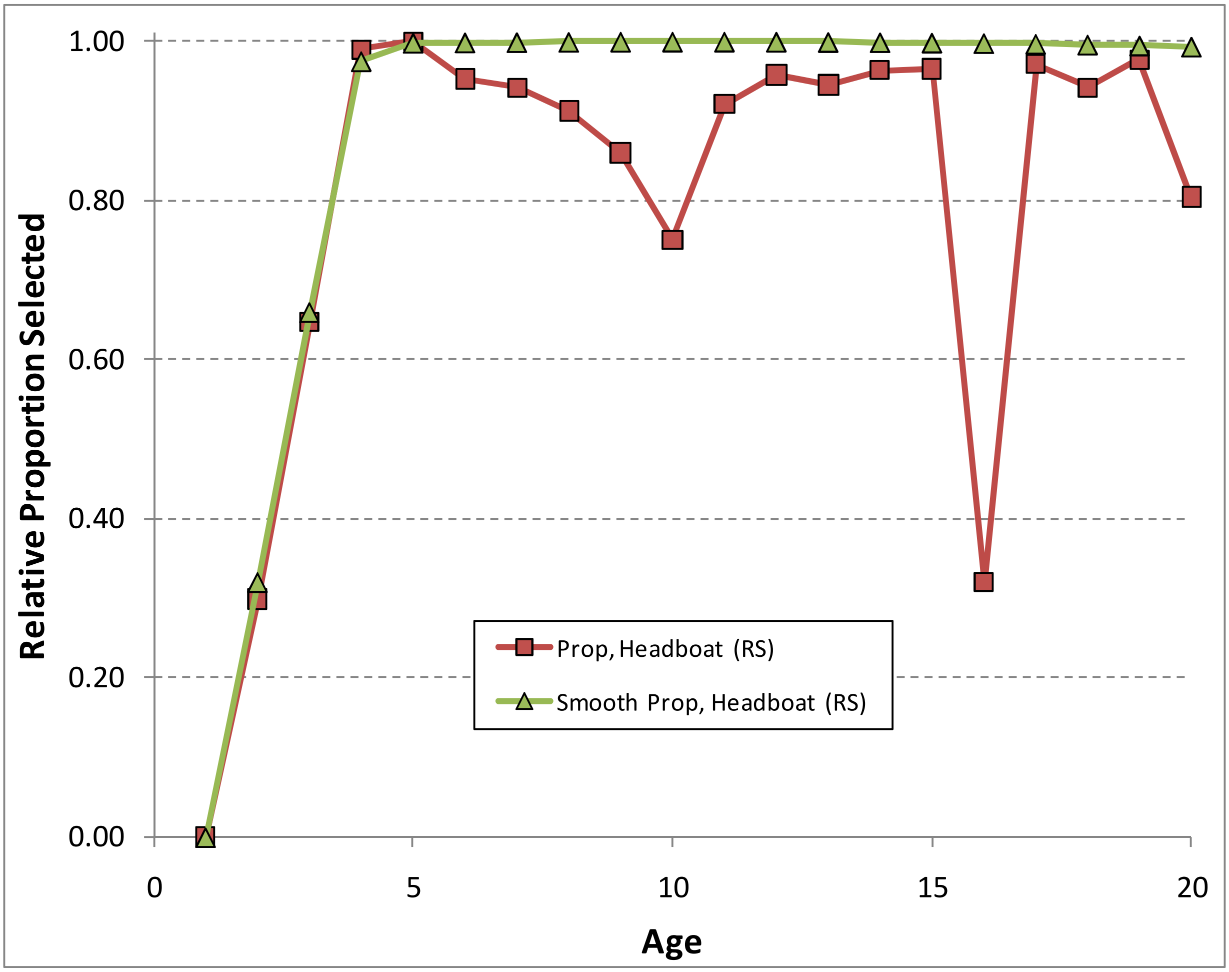


Figure VI-13. Relative selectivity estimates for the recreational for-hire (charter boat + headboat) fishery based on various methods (Prop = proportions of depth at age from age data, Smooth Prop = the smoothed normal parametric model of depth at age) for computing the $p_{a,d}$ matrix.

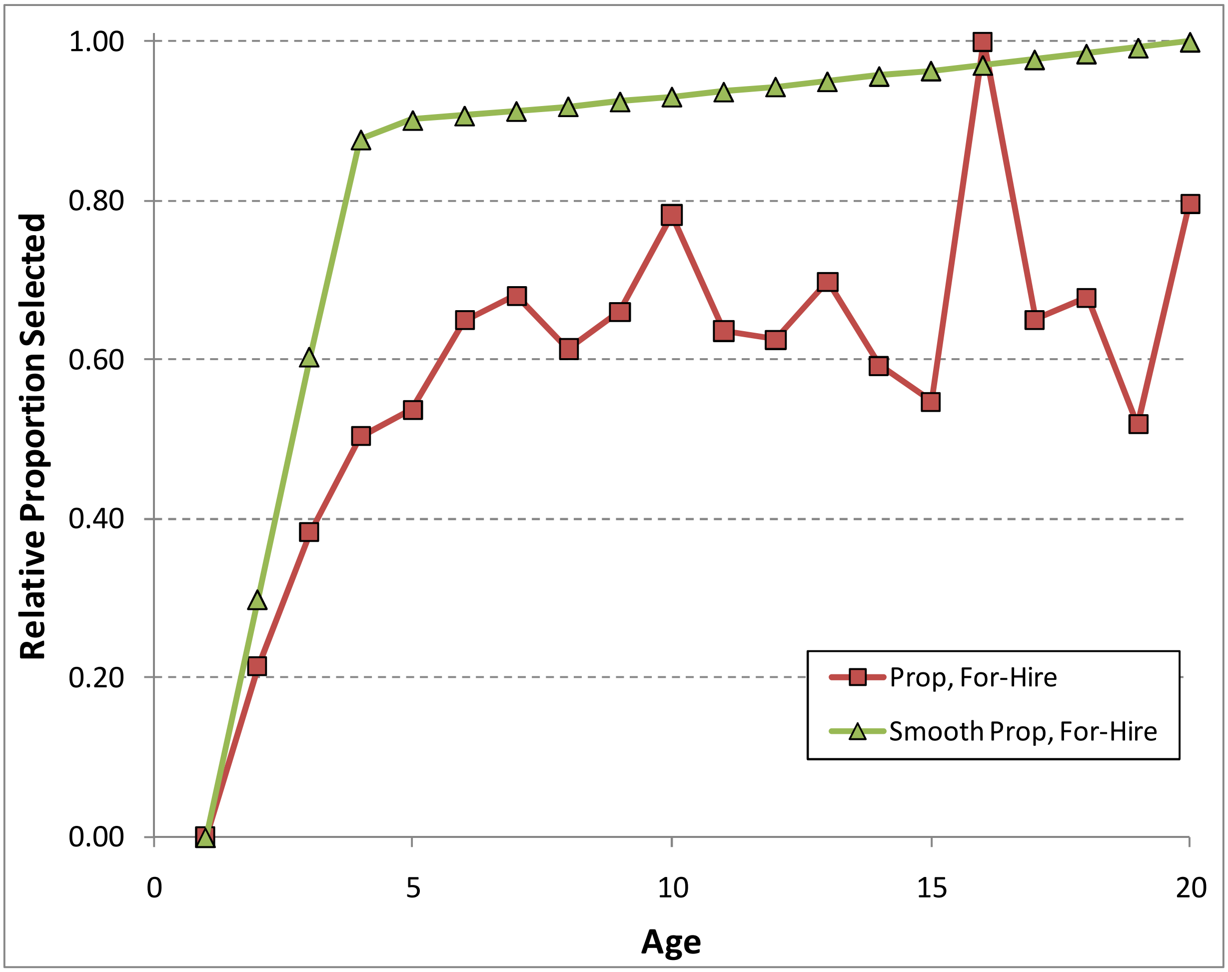
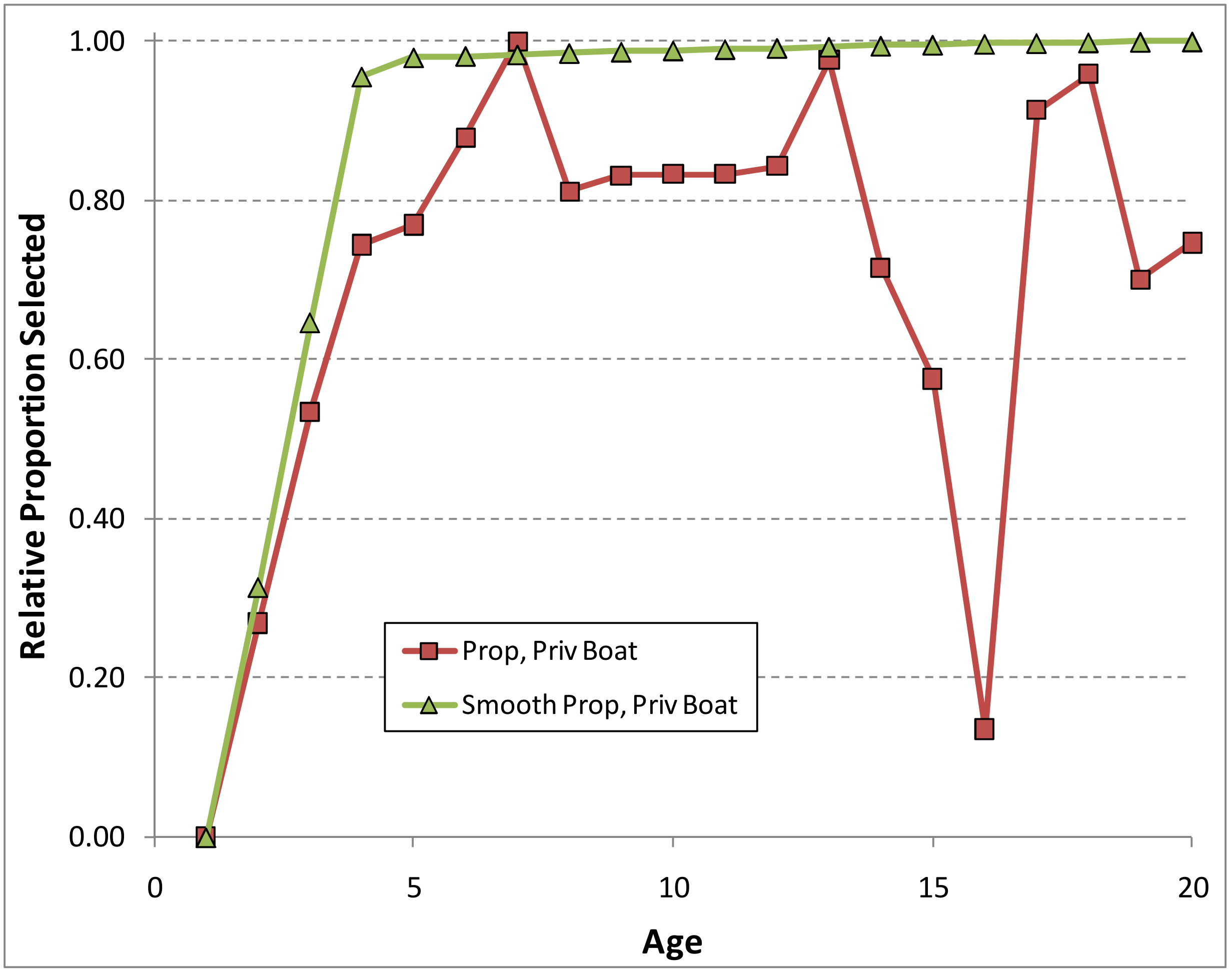


Figure VI-14. Relative selectivity estimates for the recreational private boat fishery based on various methods (Prop = proportions of depth at age from age data, Smooth Prop = the smoothed normal parametric model of depth at age) for computing the $p_{a,d}$ matrix.



VII. Discussion

Much of the analysis in this report is contingent on the collected age and depth information being unbiased. Certainly the data accurately represent the catch of the fishery in the most recent years, as this is when they were collected. However, the degree to which they reflect catches from years prior to the data collection and the degree to which they may reflect relative abundance of ages at depth is unknown. Along similar lines, some of the analyses presented in this report are dependent on the accuracy of the depth reporting in the logbooks. Just like the age data, what is reported is only data from the most recent years and therefore may not accurately reflect the past distribution of effort by depth. There is some evidence to suggest that handline effort in the deepest waters has decreased in the most recent years. The history of the snowy grouper and tilefish fisheries suggest more handline and longline effort (effort which is likely to have intercepted red snapper) was prosecuted in earlier years compared to the most recent time period.

The most uncertain data in this report come from the recreational sectors. Both the age and depth data are very limiting for the recreational sectors, with the notable exception of age data from the headboat sector.

The general conclusion that can be drawn from this analysis suggests that dome-shaped selectivity is likely not appropriate for the commercial handline sector and may not be appropriate for the recreational sectors. This result is largely driven by the age at depth data, which suggests no significant trend in age 5+ fish with depth. Fishermen accounts of larger fish in deeper water may be explained by the age 2–4 fish, which do appear to be most common in shallow waters. Since the age of a fish cannot be determined by external examination or inferred very accurately from length, then it makes sense that what fishermen are likely describing is the change in relative abundance of the youngest fish. It should be noted that an age 4 red snapper can range from 300 to almost 800 mm in length. Red snapper from about 700 mm and larger can be almost any age older than 4. Based on this, it becomes clear that on-the-water observations are not reliable for determining if age 5 or older red snapper are more abundant inshore or offshore.

Other accounts by fishermen have suggested that red snapper appear to exhibit an inshore-offshore seasonal migration. This is not uncommon for members of the snapper-grouper complex. The suggestion by fishermen has been that during the summer months the biggest fish move inshore to form spawning aggregations. These aggregations have been termed “snapper bonanzas,” owing to the large daily catches produced during these events. Like other snapper-groupers that form spawning aggregations, they are likely more vulnerable during this time. This has been well documented for other snapper-grouper species, most notably some of the grouper species, including snowy grouper (Epperly and Dodrill, 1995). If the largest (and oldest) red snapper are moving inshore to form spawning aggregations and their vulnerability is increased during that time period, than the results suggesting a constantly increasing selectivity, peaking at the oldest ages, may be more accurate.

Finally, it should be noted the assumption of dome-shaped selectivity should not be taken lightly in stock assessment models. The overall model estimates when estimating a dome-shaped selectivity have the potential to be very misleading. If the selectivity is assumed to be dome-shaped for all the sectors or the dominant sectors of the fisheries, its estimation within a stock assessment model may not be possible. It is likely the degree of the dome-shape would be confounded with the estimates of mortality, particularly if the age data are only collected during a period of high exploitation and no age data are present during lightly exploited periods. The more common stock assessment practice is to assume flat-topped selectivity unless there is conclusive evidence that certain sizes or ages are being excluded from the fishery. Examples of such evidence include gear limitations that prevent bigger/older fish from being retained (e.g. gillnet fisheries), fisheries where the species exhibits a clear shift to inaccessible habitat at older ages (e.g. red drum), or fisheries where the regulations have limited or eliminated fishing effort for the older fish (e.g. slot limits).

In a document titled "Recommendations for SEDAR assessments," Dr. Carl Walters provided during SEDAR 10 some advice on selectivity, as follows: "Beware of complex size-age and temporally changing vulnerability schedules. Dome-shaped and temporally variable vulnerability schedules "use up" information about mortality and recruitment that would otherwise be present in size-age composition data. When a large number of nuisance parameters need be included in the model to describe such changes, the data then essentially contribute nothing to assessments of overall abundance and rates, except for modest information about relative sizes of adjacent year-classes. The overall assessments then end up being dominated in their basic results by patterns in relative abundance data, which can also be misleading for a variety of obvious reasons."

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