Direct Estimation of Bottom Longline Gear Selectivity for Red Snapper, *Lutjanus campechanus*

Estimación Directa de Palangre de Fondo Gear Selectividad para Red Snapper, *Lutjanus campechanus*

Estimation Directe de la Sélectivité des Engins de Fond à la Plangre pour Red Snapper, *Lutjanus campechanus*

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EXTENDED ABSTRACT

Introduction

Fishery-independent abundance surveys provide critical information to stock assessment models regarding size classes for which capture efficiency is too low or biased to generate a reliable signal from the directed fishery (Myers et al. 1997). However, depending on the gear utilized, fishery-independent studies can also generate biased catch size distributions due to differential capture probabilities across size- or age-classes (Millar 1992). It is common practice in stock assessment models to impose asymptotic gear-specific size selectivity upon at least one fishery sector's selectivity to establish a link between catches and the oldest broodstock. Imposing asymptotic selection is based on reasoned judgement but often in the absence of empirical data. Selectivity mis-specification has important implications when estimating fishing mortality rates imposed on older age-classes (Radomski et al. 2005; Ichinokawa et al. 2014; Punt et al. 2014) and may result in a cryptic biomass effect, underestimating stock status or recovery, or even stock collapse (Myers et al. 1997).

Red snapper, *Lutjanus campechanus*, are long-lived (> 50 years), large (> 20 kg) reef fish ubiquitously distributed throughout the northern Gulf of Mexico (nGOM). Red snapper have a strong affinity for structure during juvenile and young-adult life stages but are less reef-associated as they approach maximum size (Patterson 2007). The U.S. National Marine Fisheries Service (NMFS) has been conducting systematic bottom longline (BLL) surveys across the entire nGOM shelf since 1995, and the NMFS BLL survey is thought to provide the only reliable index of older red snapper abundance due to the prevalence of large (> 10 kg), old (≥ 10 years) individuals in the catch. Thus, BLL survey selectivity is fixed to be asymptotic in the red snapper stock assessment model using a logistic equation (SEDAR 2013). A small number of commercial vessels do target red snapper with bottom longline gear in both the eastern and western (primarily the west) GOM subunits. However, commercial fishermen often target and preferentially retain smaller individuals associated with reef structure due to higher marketability (SEDAR 2013). Observer data collected during 2007 - 2011, indicated few red snapper caught by commercial vessels exceeded 700 mm TL (McCarthy 2012), especially in the eastern GOM subunit. Commercial fishery effort directed preferentially towards smaller red snapper emphasizes the importance of the NMFS BLL survey but also suggests the potential for cryptic biomass should survey selection have been misspecified in previous assessments (Hulson and Hanselman 2014, Ichinokawa et al. 2014). Currently, no empirical data exist to inform selectivity parameterization for this important survey. The purpose of this work was to directly estimate selectivity of BLL gear to empirically inform parameterization of NMFS BLL survey selectivity in the red snapper stock assessment model.

Methods and Methods

Bottom longline gear was deployed from the NOAA Ship *Oregon II* at sampling sites in the northern Gulf of Mexico from 11 March through 13 April, 2015. Sampling sites were selected based on 18.5 km grids within predefined geographic (Pascagoula, MS to Cape San Blas, FL) and depth (20 - 140 m) constraints. However, obstructions (e.g., other vessels, petroleum platforms, safety fairways, etc.) caused some stations to be moved from originally planned locations. Following standard protocols, BLLs were set 1 nm in length and contained 100 non-stainless steel circle hooks (Mustad 15/0, model #39965D) attached to the mainline via ~3.7 m gangions spaced approximately evenly every 0.01 nm. Hooks were baited with either cut Atlantic mackerel, *Scomber scombrus*, or squid, *Loligo* spp., in an alternating fashion. Depth and GPS location were recorded at the start of each set. The gear was retrieved after one hour soak time or immediately following the completion of the ROV survey. All red snapper collected with BLL gear were measured to the nearest millimeter total length (TL), weighed to the nearest kilogram (kg), and otoliths were removed for aging following standard protocols (Patterson et al. 2001).

After deploying the BLL gear, a VideoRay Pro4 micro remotely operated vehicle (ROV) equipped with a laser scaler (parallel 5-mW 635-nm class IIIa red lasers with 7.5 cm between lasers) was flown parallel to the gear in the direction of the set at approximately 1 m above the seafloor to estimate the size composition of red snapper encountering the gear. Red snapper crossing the path of the ROV and scaled with both lasers were measured for total length (TL) in the laboratory from digital video by calculating the ratio of the distance between lasers and the TL of the fish measured on the computer screen. The resulting measure was then multiplied by 75 mm and TL estimates were corrected for a 3% (± 0.6% stdev) underestimation bias following Patterson et al. (2009).

Bottom longline gear selectivity was estimated in AD Model Builder (Fournier et al. 2012) with the approach described in Patterson et al. (2012) and Garner et al. (2015) by directly conditioning the catch on the size distribution of red snapper observed *in situ* during ROV surveys. Bottom longline selectivity was estimated by fitting the exponential-logistic function:

$$S = \frac{e^{\beta\alpha(\theta - l)}}{1 - \beta(1 - e^{\alpha(\theta - l)}} \quad (1)$$

where α is the rate of increase in the ascending limb, θ is the size at peak selection, β is the rate of decrease in the descending limb, and l is the midpoint of each size bin. The β parameter is estimated such that a value near zero indicates an asymptotic functional form and a value significantly different from zero indicates a decrease in selection probability with increasing size (i.e., dome-shaped selection).

The total catch of red snapper was assumed to be normally distributed with mean μ and variance σ^2 and the proportion of the catch in each length bin was assumed to be approximately multinomially distributed with mean np_i and variance $np_i(1\text{-}p_i)$ such that maximum likelihood parameters could be estimated for the parameters q and S in the equations:

$$\begin{cases} C_{lk} = \dfrac{f_k q S_l V_{lk}(1 - e^{-F_{lk}})}{edF_{lk}} \\ F_{lk} = \Sigma f_k q S_l \end{cases} \quad (2)$$

by minimizing the log-likelihood equation:

$$L = 0.5 \sum_k \left[\left(\frac{c_k^{obs} - c_k}{\sigma} \right)^2 - \log_e \sigma^2 \right] + \sum_k n_k \sum_l p_{lk}^{obs} \log_e p_{lk} \quad (3)$$

where n is the effective sample size. Variables in equation 2 are defined as: N_k is the number of red snapper of length l at site k, C_{lk} is the number of red snapper caught, V_{lk} is the number of red snapper scaled by lasers during ROV surveys, f is the fishing effort (i.e., the number of longline sets), and e is the visual effort (i.e., the number of longline sets surveyed by the ROV). The detectability parameter (d = the proportion of red snapper scaled by lasers) was assumed to be low and set at d = 0.1. The parameter q refers to the relative fishing power and estimated in the model. Data were pooled across all sample sites and the parameters were estimated with a stepwise approach.

Results

A total of 77 BLL sets were completed in March and April 2015 aboard the NOAA ship Oregon II at depths between 20 and 140 m. A total of 17 red snapper were scaled with lasers during 22 of the 77 ROV surveys. Seventy-two red snapper were caught during the 77 bottom longline sets (catch rate = 0.935 red snapper per BLL set or per 10^3 hooks). Mean TL (SE) of captured red snapper was 782.3 (11.1) mm TL; mean (SE) and modal age of captured red snapper were 9.6 (0.4) and 9 years, respectively (Figure 1).

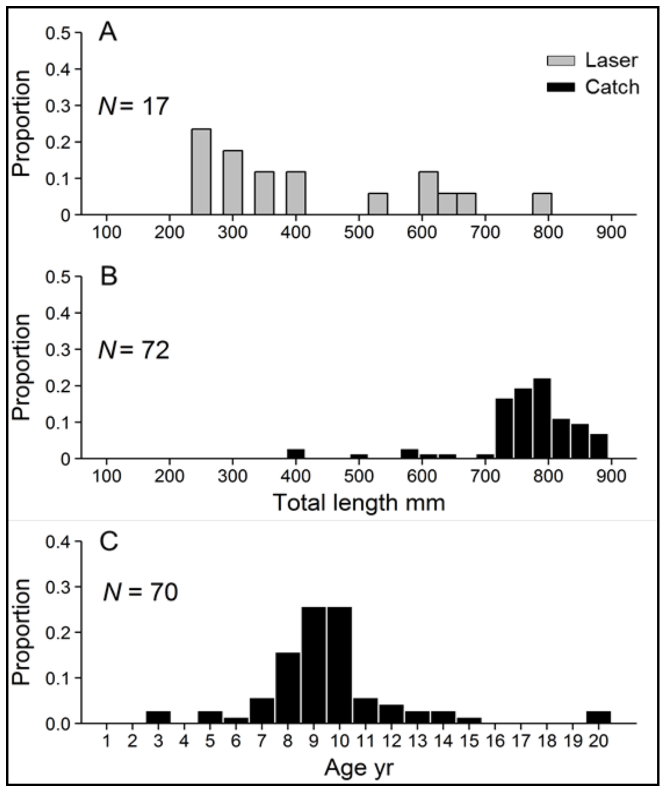

Figure 1. Size frequency histograms of red snapper (A) laser scaled during ROV video surveys and (B) caught with bottom longline gear. Panel C indicates the age-frequency of red snapper caught with bottom longline gear. The number of observations is shown on each panel.

Mean (SE) TL of red snapper estimated from ROV video was 399.7 (42.9) mm. Despite a low frequency of observations during ROV surveys, two distinct groups of red snapper were identified:

i) Smaller (< 500 mm TL), and presumably younger, individuals forming relatively large aggregations (20 - 50 individuals) tightly aggregated with other reef fishes located around small (< 5 m^3) natural reef structures, and

ii) Larger, and presumably older, individuals in relatively small aggregations (< 5 individuals) not associated with reef structure or other fish species.

Selectivity curves fit with the exponential-logistic function estimated asymptotic selection for 15/0 circle hooks fished on BLL gear (Figure 2). Standard deviations around parameter estimates were high α = 0.2531(± 7.1), θ = 517.7 (± 1194.4), and β = 0.0001 (± 0.0012), and there was high negative covariance between α and θ parameters (-0.9). A plot of the predicted and observed proportions at size versus total length (Figure 2) indicated the model performed poorly at estimating catches given the low sample sizes and lack of observations for many of the available length bins.

Discussion

The NMFS bottom longline survey is assumed to select for the oldest, largest red snapper, and the data and selection estimates presented here are consistent with logistic selection. Although a small sample size in this experiment reduces the power to detect a significant β parameter, the data suggest an asymptotic curve is realistic given 94.1% of the laser scaled individuals were < 700 mm TL while 90.3% of the catch was > 700 mm TL. Large variances around parameter estimates indicate the model was unable to precisely estimate the ascending limb and selection peak. Assuming ROV video and BLL catch samples from a much larger sample size follow similar patterns observed in this experiment, additional samples would be beneficial for estimating the ascending limb of the curve and the age at full selection. Millar (1992) suggested that bottom longline gear generally has a broad, asymptotic selection curve given it typically:

i) Targets larger individuals,
ii) Employs relatively large hooks,
iii) Consists of many miles of gear, and
iv) Is deployed across wide spatial scales.

Specifying a link to the abundance of older spawners via the NMFS BLL survey is especially important considering the tendency for older individuals to occupy unstructured habitat, while all other fishery-dependent and independent sectors employ gears that select for smaller, younger fish (SEDAR 2013, 2015).

In contrast to the selectivity estimates reported in this study, previous empirical studies estimated strong dome-shaped selection when red snapper were targeted with 15/0 circle hooks fished vertically at artificial reefs in the nGOM (Patterson et al. 2012, Garner et al. 2014). We suggest availability as being the regulating factor explaining the discrepancy between selection curves for the same hooks fished on different gear types. Reef structures predominantly aggregate smaller, younger red snapper (Dance et al. 2011) which are effectively targeted by fishermen repeatedly deploying vertical line gear across a relatively small area. Unlike vertical line gear, BLL gear samples relatively large expanses of habitat with only a few hooks in close proximity to reef structure. Large red snapper do occur around reef structures and are captured with vertical line gear at reef sites, but are not strongly selected likely due to the disproportionate abundance of smaller individuals and their aggressiveness toward fished baits. The NMFS survey deploys BLL gear primarily across unstructured bottom throughout the coastal shelf where larger, older red snapper occur due to a reduced affinity for reef structure with ontogeny. Commercial red snapper fishery sectors were estimated to have moderately dome-shaped selection patterns (SEDAR 2013), which can be explained by commercial vessels targeting smaller individuals associated with reef structure and the opportunistic retention of larger individuals as bycatch by vessels with low quota allocation. Strong reef affinity exhibited by smaller red snapper greatly limits their availability to expansive BLL gear and quickly saturates hooks in close proximity to reef structure, whereas small, roaming shoals of larger, older red snapper are available to BLL gear without saturation.

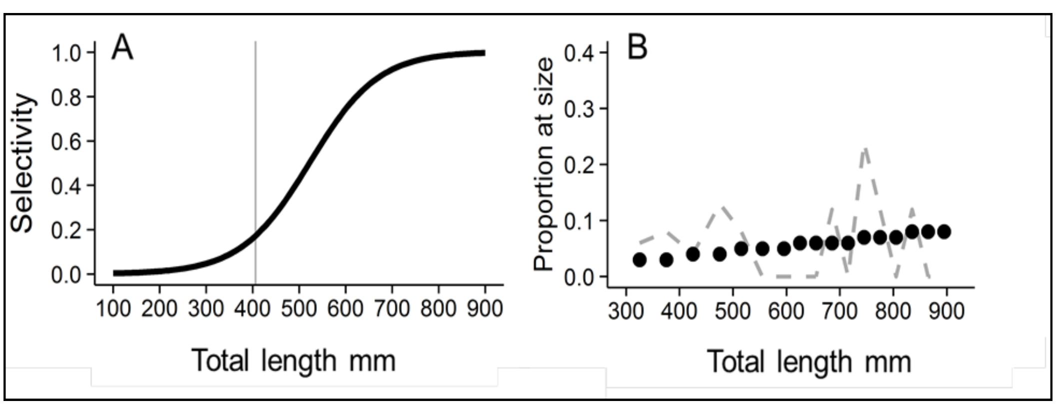

Figure 2. Plots of (A) size selectivity of bottom longline gear estimated using an exponential-logistic equation, and (B) observed (filled black circles) versus predicted (dashed gray line) estimates of red snapper proportions at size by total length (mm). The vertical gray line in panel A indicates the current red snapper minimum length limit.

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