NOAA Technical Memorandum NMFS-AFSC-488

Size-selectivity and Capture Efficiency of Sablefish (*Anoplopoma fimbria*) in Southeast Alaska Using Pot Gear with Escape Rings

J. Y. Sullivan, A. P. Olson, A. P. Baldwin, B. C. Williams, and S. M. Cleaver

July 2024

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center

This document should be cited as follows:

Sullivan, J. Y., Olson, A. P., Baldwin, A. P., Williams, B. C., and Cleaver, S. M. 2024. Size-selectivity and capture efficiency of sablefish (*Anoplopoma fimbria*) in Southeast Alaska using pot gear with escape rings. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-488, 29 p.

NOAA
FISHERIES

Size-selectivity and Capture Efficiency of Sablefish (*Anoplopoma fimbria*) in Southeast Alaska Using Pot Gear with Escape Rings

J. Y. Sullivan[1], A. P. Olson[2], A. P. Baldwin[3], B. C. Williams[1], and S. M. Cleaver[4]

[1]Auke Bay Laboratories
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
17109 Pt. Lena Loop Road
Juneau, AK 99801

[3]Division of Commercial Fisheries
Alaska Department of Fish and Game
State of Alaska
802 3rd Street
Douglas, AK 99824

[2]Sustainable Fisheries Division
Alaska Regional Office
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
709 West 9th St.
Juneau, AK 99801

[4]North Pacific Fishery Management Council
1007 West Third Avenue
Anchorage, AK 99501

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center

NOAA Technical Memorandum NMFS-TM-AFSC-488

July 2024

ABSTRACT

This study investigates the impact of escape ring size on selectivity and capture efficiency in the Alaska sablefish fishery using pot gear, through an experiment conducted in Chatham Strait, Alaska. Four scenarios were tested: control pots with no escape rings, and three treatment pots with escape rings of varying diameters (8.9, 9.5, and 10.2 cm). Empirical size-selectivity curves were compared with selectivity curves estimated using a Bayesian SELECT (Share Each LEngth's Catch Total) model. Results indicate that small changes in escape ring size significantly alter selectivity, with 8.9 cm rings reducing catch rates of small, immature sablefish while optimizing selectivity and efficiency for larger, mature individuals. However, further research is needed to understand potential discrepancies between empirical and model-derived selectivity curves. This study underscores the complex interplay between gear specifications and target demographics in fisheries management, highlighting practical implications for gear design and regulatory frameworks.

CONTENTS

INTRODUCTION

Fishery selectivity, defined as the relative probability of capture as a function of length or age, is a critical stock assessment quantity for scaling an observed population to total population abundance (Quinn and Deriso 1999, Beverton and Holt 1957). Estimation of selectivity is crucial for determining the age and size composition of harvest and for estimating the distribution of fishing mortality across ages within a stock assessment model. Misspecification of selectivity can produce unreliable estimates of maximum sustainable yield-based biological reference points (Butterworth et al. 2014, Crone and Valero 2014) or lead to biased projections of fish abundance (e.g., Stewart and Martell 2014, Walters and Maguire 1996). Fishery selectivity accounts for the combination of fish availability (i.e., variation in fish density by habitat type, or changes to the demographics of a population over time) and vulnerability to fishing gear (Sampson 2014). The latter, also called contact or gear selectivity, involves the technical interaction between fish and fishing gear and the physical sorting of fish based on their morphology and characteristics of the gear or fish behavior (e.g., Graham and Ferro 2004).

Gear selectivity can be altered through modifications to fishing gear (e.g., changes to mesh sizes, or the inclusion of escape mechanisms), and the effectiveness of gear modifications has made them popular tools for achieving fishery management objectives. For example, gear modifications are often used to reduce bycatch of non-target or protected species, immature individuals of a target species, and to reduce unaccounted mortality of fishery discards (Kennelly and Broadhurst 2002, Broadhurst et al. 2007). Fishery managers often implement gear modifications in conjunction with harvest caps, minimum size limits, or full retention requirements to further these same management objectives. Additionally, shifting markets or processor preferences may influence harvesters to modify their gear to select for higher-valued size classes of the target species. While these gear changes are often implemented to select for larger size classes, there are many cases in live market and plate-sized fisheries where small or medium-sized individuals are the preferred target (e.g., Reddy et al. 2013, Kindsvater et al. 2017).

Specific examples of gear modifications exist for all fishing gear types, including different sizes and styles of net mesh, hooks, or the addition of escape mechanisms in pot and trap gear that allow organisms to exit gear or physical barriers that exclude them from entry (reviewed in Hall and Mainprize 2005). Escape rings, circular metal rings attached to the mesh panels of pot gear that allow small fish or invertebrates to exit the pot prior to hauling the gear (Fig. 1), are one common type of escape mechanism used with pot gear. When sized appropriately, escape rings can efficiently reduce mortality associated with discarding small fish due to regulatory reasons (e.g., size limits) or economic factors, while maintaining catch rates of the larger-bodied target species.

Several recent changes in sablefish (*Anoplopoma fimbria*) fishery dynamics and regulations in Alaska have created the potential for changing fishery selectivity. Sablefish are a long-lived and economically valuable species that inhabit the deep waters of the North Pacific Ocean's continental slope and support valuable commercial fisheries in Russia, Japan, Alaska, and the U.S. West Coast. Sablefish landings in Alaska have averaged 16.5 t annually from 2013 to 2022 with annual ex-vessel value of $124.17 M in 2022 (Shotwell et al., 2023). Recent strong recruitment events of Alaska sablefish have contributed to rapid increases in the overall biomass of the population that are driven by small, immature sablefish. Concerns over lack of diversity in the population's age structure, coupled with high uncertainty in large recruitment events, have prompted precautionary harvest policies for sablefish (Hanselman et al., 2019, 2020; Goethel et al. 2023). Despite these measures, relative economic performance in the Alaskan sablefish fishery is at a historic low, in part due to high catch rates of small fish and suppressed market prices (Shotwell et al. 2023).

Alaska sablefish are managed and regulated under both state and federal governing bodies with many fishery permit holders and processors participating in both fisheries. This can create regulatory complexities and magnify issues should policies diverge as is the case with regulations pertaining to sablefish retention and release requirements and pot gear specifications between fisheries. In the State of Alaska Southeast sablefish fisheries (Chatham and Clarence Straits; Fig. 2), sablefish that are not visibly injured or dead may be released unharmed. Permit holders are required to record their releases in a fishery logbook to account for discards of small fish that can be used as an indicator of incoming recruitment and improve catch per unit effort (CPUE) information in the fishery. In contrast, as of 2024, the federal fishery prohibits discarding of sablefish and requires full retention of all sablefish, regardless of size. There is a considerable economic incentive to target large sablefish; they can be worth more than seven times the price per kg compared to the smallest-sized sablefish caught in the fishery (Sullivan et al. 2019, Cleaver et al. 2024). Consequently, many federal fishery participants have pushed to change federal regulations to allow release of small sablefish in the federal fishery (Armstrong and Cunningham 2018, Armstrong et al. 2021, Cleaver et al. 2024).

Until recently, the majority of the Alaska sablefish fishery was prosecuted using demersal hook-and-line longline gear, for which size selectivity is believed to be well-understood (Joy and Ehresmann 2022, Goethel et al. 2023). In 2017, changes to federal regulations allowed for the use of pot longline gear in the Gulf of Alaska (Hanselman et al., 2018) to mitigate depredation by killer (*Orcinus orca*) and sperm whales (*Physeter macrocephalus*) (Peterson et al. 2014, Peterson and Hanselman 2017) and reduce seabird bycatch on hook-and-line gear (Dietrich et al. 2009, Melvin et al. 2019). While both state and federal sablefish fisheries now allow the use of pot longline gear, regulations on specific gear requirements differ by jurisdiction. In state waters, pot gear is required to have at least two escape rings for each pot located on the vertical or sloping panels of the pot with a minimum inside diameter of 9.5 cm (3.75 in; Joy and Ehresmann 2022), which was reduced from 10.2 cm (4 in) in 2022 (Olson and Sullivan 2019). The federal fishery neither requires nor restricts escape rings in pot gear; therefore, fishermen have flexibility in regards to escape ring presence and size. Pot gear has rapidly been adopted by permit holders, and the introduction of novel collapsible slinky pots has allowed fishery participants to transition their operations to pot gear more efficiently (Goethel et al. 2023). Recent efforts have been made to account for differences in selectivity and capture efficiency between hook-and-line and pot longline gear in Alaska's sablefish fisheries (Sullivan et al. 2022, Cheng et al. 2023, Cheng et al. 2024). However, minimal data exist to inform decision makers on the use of escape rings and potential implications for the sablefish fishery.

An experiment was conducted in 2019 to analyze the effect of escape rings on size-selectivity and capture efficiency in sablefish pot gear, and to inform fishery management regulations in Alaska. An optimal escape ring size provides the best compromise between low catches of immature sablefish while maintaining high CPUE of mature sablefish (Treble et al. 1998). Three alternative escape ring sizes, 8.9 cm (3.5 in), 9.5 cm (3.75 in), and 10.2 cm (4 in), were evaluated during the Alaska Department of Fish and Game (ADFG) sablefish marking survey in May and June 2019 in Chatham Strait (Green et al. 2016). A combination of techniques was employed to evaluate the impact of escape rings on pot size-selectivity. Measurements of girth, the circumference of a fish at its widest point, were collected to define the maximum size of sablefish that can pass through an escape ring. The resultant girth-length relationship was used to develop empirical size-selectivity curves. Additionally, selectivity was estimated directly using the SELECT (Share Each LEngth's Catch Total) model (Millar 1992), which has been applied to a variety of trawl and pot gear experiments (e.g., Millar and Walsh 1992, Xu and Millar 1993). These alternative methods of estimating selectivity are compared and implications for fishery management are discussed.

METHODS

A longline of 40 conical pots with 5.08 × 5.08 cm mesh spaced 50 m apart was set for approximately 24-hour soaks at 17 stations in Chatham Strait from 14 May to 3 June during the 2019 ADFG sablefish marking survey on the RV *Medeia* (Fig. 2; Green et al. 2016). Each set was comprised of four treatments with ten pots per treatment in a fixed alternating design. The study included four escape ring scenarios: a control with no escape rings, and three treatments with internal ring diameters of 8.9, 9.5, and 10.2 cm, respectively.

The escape ring sizes selected for this study reflect the range of sizes currently in regulation for sablefish in the North Pacific Ocean, including 8.9 cm in British Columbia (Haist et al. 2000) and 10.2 cm in Clarence Sound, Alaska (Olson and Sullivan, 2019). The addition of a third intermediate escape ring size (9.5 cm) allowed us to better characterize capture efficiency of sablefish as a function of escape ring size and was used to develop a generalized size-selectivity equation that can be applied to any escape ring size. Each treatment pot included two escape rings installed on opposing vertical or sloping walls of the pot (Fig. 1). Fork lengths and a random subset of girths were collected from sablefish and assigned to an escape ring treatment. Analysis of these data consisted of three parts: 1) a comparison of capture efficiency or catch rates among escape ring treatments; 2) the development of empirical size-selectivity curves; and 3) an estimation of size-selectivity curves using the SELECT model. Results from the capture efficiency and size-selectivity analyses were evaluated using a reference length of 63 cm, the length at 50% maturity (L_{50}) for sablefish in Southeast Alaska (Dressel 2009).

Capture Efficiency

Numbers of sablefish per pot (CPUE) were not normally distributed; therefore, differences in CPUE between control and treatments pots were analyzed using the non-parametric Kruskal-Wallis test, which evaluates the null hypothesis that the distributions of CPUE between escape ring scenarios are the same (Neter et al. 1974). Statistical comparisons of CPUE between escape ring scenarios were conducted for all sablefish combined, sablefish greater than or equal to 63 cm, and sablefish less than 63 cm. Post hoc multiple comparison Dunn tests were conducted using a Bonferroni adjustment (Zar 1999). Statistical analyses were conducted using the statistical software R (R Core Team 2019) and the R libraries FSA (Ogle et al. 2019) and boot (Canty and Ripley 2019, Davison and Hinkley 1997).

Empirical Size-Selectivity Curves

Sablefish fork length and girth data were collected to develop empirical size-selectivity curves for the escape ring scenarios following an approach developed for Southern rock lobsters (*Jasus edwardsii*) in Australia (Treble et al., 1998). Girth measurements were collected using a length-stratified random design, where five girths per 5-cm fork length bin (≤ 50 cm, 51-55 cm, 56-60, 61-65 cm, 66-70 cm, and < 70) were collected per set to ensure sampling across a broad range of fish sizes. A total of 567 girths were collected during the survey, and an additional 411 girths were collected during the fishery period (September and October 2019) to evaluate seasonal changes in the girth-length relationship. The allometric relationship between girth ($\hat{G}$) and length (L),

$$\hat{G} = aL^b ,$$

was estimated using a linear regression model with log-transformed data. Seasonal changes in the girth-length relationship were evaluated by comparing a single slope and intercept regression model with models that provided for separate intercepts or separate intercepts and slopes between the survey and fishery. Candidate models were compared using the Akaike Information Criterion (AIC; Burnham and Anderson 2002).

Sablefish girths were simulated across a range of lengths for the survey and fishery time periods assuming a lognormal distribution and a standard deviation equal to the residual standard deviation from the best-fitting regression model. All sablefish with an approximate diameter ($\hat{G}/\pi$) greater than the escape ring diameter were assumed to be retained in the pot and those less than or equal to the escape ring diameter were assumed to escape. The proportions of sablefish at length with a $\hat{G}$ greater than the escape ring were plotted as probabilities of retention or empirical size-selectivity curves. Empirical selectivity curves for the control pots were developed in the same way using the pot mesh diameter of 70 mm. Resultant empirical selectivity curves were used to develop priors for the SELECT analyses.

SELECT Modeling of Experimental Escape Ring Data

A SELECT model was developed to compare estimated selectivity curves from the length frequency data collected during the survey to empirical selectivity curves based on the length-girth relationship. The SELECT method estimates selectivity parameters of experimental gear fished in tandem with control gear assumed to retain all length classes of fish encountered by the gear (Millar, 1992). The model was developed using the R library Template Model Builder (Kristensen et al., 2016). Control pots were assumed fully selected at a fork length of 50 cm based on results from the empirical selectivity curves, and length frequencies were binned into 1 cm increments. Length frequencies obtained with each escape ring treatment were compared with those observed in the control pots. Given that a fish in length bin i was caught and retained in a pot in set j, the probability that it was captured in escape ring treatment k (ϕ_{ijk}) was modeled as

$$\phi_{ijk} = \frac{P_{ijk}}{P_{ijk} + \delta r_j},$$

where P_{ijk} is the probability that a fish was retained in an escape ring treatment (i.e., selectivity), δ is the relative probability of entering a control pot (i.e., the probability of entering a control pot / the probability of entering an escape ring pot), and r_j is the ratio of control pots sampled to escape ring pots sampled in set j. The inclusion of r_j permitted unequal sampling of pots across sets (Haist et al. 2000).

Relative gear selectivity (P_{ijk}) was modeled as a logistic function. A random effect was included at the set level (η_j) to account for variability in length frequencies that may be explained within a given set. The probability of retaining a fish of length i in set j and treatment k was defined as

$$P_{ijk} = \frac{1}{1 + \exp(-\mathrm{K}_k(i - S_{50,k}) + \eta_j)},$$

where S_{50} is the length at which 50% of sablefish are selected to the gear, and K is the slope of the logistic curve at s_{50}. The SELECT negative log-likelihood is

$$-\ln(L) = \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} T_{ijk} \cdot \ln(\phi_{ijk}) + C_{ij} \cdot \ln(1 - \phi_{ijk}),$$

where T_{ijk} and C_{ij} are numbers observed in each length bin and set for treatment and control pots, respectively.

Prior distributions on lengths at 0 and 100% retention probabilities were developed using results from the empirical size-selectivity curves for each escape ring. Mean length at 0% retention in the empirical curves was 51, 54, and 57 cm for 8.9, 9.5, and 10.2 cm escape rings, respectively. A weakly informative prior $Beta(1, 2.75)$ was assumed for the length at 0% retention to account for factors that could influence the lower arm of the logistic selectivity curve (e.g., fish availability and soak time). Mean length at 100% retention in the empirical curves was 68, 73, and 77 cm for 8.9, 9.5, and 10.2 cm escape rings, respectively. An informed prior $Beta(10, 1)$ was applied to the length at 100% retention to loosely constrain the upper arm of the logistic curve to asymptote according to the girth-length relationship. Broad uniform priors were used for all other parameters (Table 3).

Uncertainty was estimated using Bayesian inference, and Markov Chain Monte Carlo (MCMC) sampling was implemented in the tmbstan R library using the no-U-turn sampler (NUTS) (Monnahan and Kristensen 2018, Carpenter et al. 2017, Hoffman and Gelman 2014, Stan Development 2018). Three chains were run with 10,000 iterations that were thinned at a 10% rate and had a 2,000 sample burn-in. Convergence diagnostics included a visual examination of trace plots and pairwise correlation plots for fixed effects. The sampling efficiency in the bulk (95%) and tails (outer 5% and 95%) of the posterior distributions was evaluated using the effective sample size (ESS) for each chain and parameter calculated by the tmbstan library. The ESS statistics corrects for autocorrelation within chains, and both the bulk and tail ESS should be greater than 100 per chain (Stan Development 2018). The agreement, or mixing, among chains was evaluated using the $\hat{R}$ convergence diagnostic produced by tmbstan; an $\hat{R}$ less than or equal to 1.05 was considered fully mixed or converged (Vehtari et al. 2021).

The relationship between estimated selectivity parameters for each treatment was used to develop a generalized function to define the size-selectivity P of a pot with any escape ring size (Arana and Ziller 1994, Arana et al. 2011):

$$P = \frac{1}{1 + \exp(-(a_1 + b_1 \cdot E) \cdot (i - (a_2 + b_2 \cdot E)))},$$

where E is the escape ring diameter and a_1, a_2, b_1, and b_2 are coefficients from the following linear relationships: $\mathrm{K} = a_1 + b_1 E_k$ and $S_{50} = a_2 + b_2 E_k$.

RESULTS

Capture Efficiency

A total of 14,234 sablefish were caught in 17 longline sets over a 17-day period in May and June of 2019. Fork lengths were recorded for 11,107 sablefish (Fig. 3, Table 1). All data, code, and output files for this study can be found at https://github.com/JaneSullivan-NOAA/great_escape.

CPUE of sablefish (all sizes combined) declined significantly with increasing escape ring size, with control pots catching 30.7 fish on average, two times the mean CPUE of the 10.2 cm treatment (Fig. 4, Table 2; $\chi^2 = 77.2$, $p < 0.001$). However, when sablefish were grouped by L_{50} (< 63 cm and ≥ 63 cm), the difference in CPUE among treatments was best explained by catch rates of small (< 63 cm) sablefish (Fig. 4, Table 2). Control pots caught on average 13 more small sablefish per pot than the 10.2 cm treatment (130% difference; Table 2). In contrast, control pots caught 1.6 more large (≥ 63 cm) sablefish per pot than the 10.2 cm treatment (37% difference). In post hoc Dunn tests, the Control - 10.2 cm combination was the only significantly different pairwise comparison for the ≥ 63 cm sablefish group (Table 2). The reduced CPUE of small sablefish was fully realized in the medium-sized 9.5 cm treatment; there was no statistical difference between the CPUE of 9.5 and 10.2 cm escape rings (11.6 and 10.1 sablefish per pot, respectively) in post hoc Dunn tests (Table 2). Escape rings greatly reduced CPUE of small sablefish, while reductions in the CPUE of large fish were present but not statistically significant.

Empirical Size-Selectivity Curves

The girth-length relationship for sablefish was best characterized by a linear model with a single intercept and separate slopes for data collected in May/June and Sept./Oct. (Fig. 5A). Empirical selectivity curves showed that as girth-at-length increases throughout the growing season, the proportion retained at length by the pot gear increases for a given escape ring size (Fig. 5B). In other words, as fish condition factor increases over the growing season, they are retained at a higher rate for a given length. Results suggest substantial selectivity changes with relatively small increases in escape ring size (Fig. 5B). For the 8.9 cm escape ring, sablefish were fully selected by 65 cm in the fishery (Sept./Oct.), meaning that by the time 50% of sablefish are mature at 63 cm, they are 99% selected to the gear. In contrast, results from the 9.5 cm and 10.2 cm escape rings showed that 87% and 50% of 63 cm fish are selected during Sept./Oct., respectively. Empirical selectivity curves for Sept./Oct. showed that sablefish are not fully selected to the gear until 69 cm and 73 cm for 9.5 and 10.2 cm rings, respectively. If the management goal is to protect immature sablefish while maximizing the proportion retained above L_{50}, empirical size-selectivity curves suggest that an escape ring as small as 8.9 cm may be appropriate.

SELECT Modeling of Experimental Escape Ring Data

Selectivity estimates from the Bayesian SELECT model for the three escape ring treatments are presented in Table 3. Residual plots suggested the model fit the data well, with the exception of residual patterns in the larger length bins for the 8.9 cm escape ring (Fig. 6). The relative probability of entering a control pot (δ) was estimated to be 0.98, which suggests there is a roughly equal probability of a fish entering a pot with or without escape rings (Table 3). Random effects at the set level (η_j) accounted for variability in length frequencies within a given set were approximately normally distributed (Table 3).

Posterior distributions and correlation plots for the model's fixed effects showed a positive linear correlation between the S_{50} parameters and escape ring size (Fig. 7). This result is not surprising; pot gear with larger escape rings should obtain 50% selectivity at a larger size than pots with smaller escape rings. Otherwise, there was minimal correlation among model parameters, which suggests that credible intervals for parameters were well-estimated (Fig. 7, Table 3). Trace plots for the three chains indicated the model was well mixed. This interpretation was corroborated by an $\widehat{R}$ statistic of 1.00, below the maximum convergence threshold of 1.05, and a minimum bulk and tail ESS well above the recommended minimum of 100.

A visual comparison of empirical and SELECT curves show that empirical curves are far steeper than the SELECT curves, resulting in a much narrower selection range (Fig. 8). At L_{50} = 63 cm, sablefish were 89% (95% credible interval: 85-94%), 74% (68-79%), and 62% (56-69%) selected for the 8.9, 9.5, and 10.2 cm escape rings, respectively. These retention probabilities were lower at L_{50} than they were for the empirical curves, resulting in different management implications. However, based on seasonal changes in the empirical selectivity curves, one may expect the SELECT curves to be shifted to the left later in the year when the fishery occurs, resulting in an increased retention probability at L_{50} for all escape rings. The SELECT curves retained a much higher proportion of smaller-sized sablefish than would be suggested by the empirical size-selectivity curves. The SELECT curves indicated that sablefish are not fully selected until they are at least 82 cm for the 8.9 cm escape ring and even greater for the 9.5 cm and 10.2 cm escape rings. Linear regressions of SELECT model parameter estimates K and S_{50} yielded the following results: $\mathrm{K} = 0.70 - 0.057 \cdot E$ $(R^2 = 0.95)$ and $S_{50} = 1.32 + 5.71 \cdot E$ $(R^2 = 0.99)$, where E was the internal escape ring diameter. These regression coefficients were used to develop a generalized equation that can be used to calculate the size-selectivity for any escape ring size:

$$P = \frac{1}{1 + \exp(-(0.70 - 0.057 \cdot E) \cdot \left(i - (1.32 + 5.71 \cdot E)\right))}.$$

DISCUSSION

We analyzed size-selectivity and capture efficiency of sablefish in pot gear outfitted with different sized escape rings. We found that all of the escape ring sizes investigated in this study significantly reduced catch rates of small, immature sablefish (L_{50} = 63 cm), with minimal reductions in catch rates of larger, mature individuals (Table 2, Fig. 4). Empirical and SELECT-estimated size-selectivity curves suggest that the 8.9 cm escape ring will maximize catch rates of sablefish greater than or equal to 63 cm, with the tradeoff that it will also result in the highest catch rates of sablefish less than 63 cm. This tradeoff was realized in the capture efficiency analysis; the 8.9 cm escape ring had intermediate CPUE for small fish, but its distribution of CPUE of large sablefish was most similar to the control pot CPUE that had no escape rings (Fig. 4). While we found a significant decrease in CPUE of small sablefish between the 8.9 cm and 9.5 cm escape rings, there was no additional decrease between 9.5 and 10.2 cm. If the desired management outcome is to provide the best compromise between minimizing catches of small fish to reduce discard mortality, while maximizing catches of large fish, results from this study suggest that that an escape ring size less than 9.5 cm may be preferred.

We found the empirical selectivity curves were much steeper than the SELECT curves, resulting in a much narrower selection range (Fig. 8). One hypothesis that may explain these apparent differences is the current study's soak time of 24 hours. The empirical curves assume all fish smaller than the escape ring will escape, which may be unrealistic given search time, attraction to bait, and crowding in the pots. Further experimentation is warranted to assess the effects of soak time on escape ring size-selectivity and capture efficiency. Another factor to consider is the availability of small sablefish in the population during the time of the study. Large recruitment events of sablefish from 2014 and 2016 were observed as peaks in the length frequencies around 48 cm and 53 cm (Fig. 3). The high abundance of small fish may have caused crowding in the pots, making it difficult for fish to escape, and thus biasing selectivity estimates. Finally, residual patterns in the model fits to the data (Fig. 6) could potentially be remedied with alternative selectivity curves. Other studies have suggested that sablefish pot gear selectivity may follow a dome-shaped (Assonitis 2008) or asymmetric logistic selectivity curve (Haist and Hilborn 2000, Haist et al. 2000). However, residual patterns were not consistent across escape ring treatments. Further research would be needed to develop methods to generalize these alternative selectivity parameterizations as a function of escape ring size as was done for logistic selectivity in this study. Finally, the SELECT model relies on the assumption that all size classes included in the analysis are fully selected to the control gear (Millar 1992). If this assumption is violated, selectivity estimates from this method may be unreliable.

Size-selectivity estimates from our study differed from previous escape ring studies conducted in British Columbia for sablefish. For example, Haist et al. (2000) found that sablefish S_{50} was 60-64 cm for a 9.8 cm escape ring, while S_{50} was 52-59 cm in this study for the escape ring sizes examined. This difference may be attributed to the parameterizations of the logistic curve, which varied between the two studies. However, it is likely due to the differences in the data collected in the two studies. For example, the proportion of sablefish in treatment pots (ϕ) showed significantly more contrast in Haist et al. (2000), with observations of ϕ ranging between 0 and 1, while the ϕ in this study ranged between 0.2 and 0.6. These differences are likely explained by variation in fish availability between areas and years. Recent large recruitment events would increase the availability of small fish, thus shifting the s_{50} towards smaller sizes.

A natural consequence of narrowing size-selectivity in order to meet management objectives is a reduction in overall gear efficiency (Broadhurst et al. 2007). This became apparent in our study with a significant reduction in CPUE between the 8.9-10.2 cm escape rings (Table 2, Fig. 4). Managers and stakeholders must ultimately decide what constitutes a tolerable reduction in efficiency when choosing the optimal strategy for changing selectivity. In waters where release of small sablefish is legal, there is a large incentive to discard small fish because large sablefish can be worth more than seven times per kilogram than smaller fish (Sullivan et al. 2019, Cleaver et al. 2024). In such a scenario, fishery managers may opt for a medium-sized escape ring (9.5 cm) to reduce CPUE of small sablefish (Fig. 4) and mortality from fishery discards. In contrast, the smaller escape ring (8.9 cm) may be more suitable in full retention fisheries in order to promote balanced harvest of sablefish across a wider spectrum of size and age classes. Currently, the use of escape rings is not required in federal waters, despite a large increase in the use of pot gear in the directed federal sablefish fishery since 2017 (Goethel et al. 2023). Anecdotal evidence suggests many federal fishery participants voluntarily use escape rings ranging in size from 8.9 to 10.2 cm (primarily 8.9 cm) to mitigate catch rates of small sablefish; however, at-sea observer data to link this information to fishery-dependent CPUE and age/length data has only been collected since January 2024 (AFSC 2024). Given the large differences in apparent selectivity among escape ring treatments, an adoption of a consistent escape ring size in all Alaska waters would improve fishery-dependent data quality for this gear type.

In summary, this study provides an analysis of size-selectivity and capture efficiency of sablefish across a range of escape ring sizes, and interpretation of these results as they relate to fishery management decisions. As pot gear becomes more prevalent in sablefish fisheries in Alaska, the selectivity differences between hook-and-line and pot gear may warrant further investigation within stock assessments (Cheng et al. 2024). This study provides direct estimates of pot gear selectivity for multiple escape ring sizes, although a comparison of SELECT and empirical selectivity curves suggest that selectivity may vary as a function of fishery timing, fish availability, and soak time. We found that escape rings can have both biological and economic benefits by successfully minimizing catch rates of sexually immature, low-value sablefish, with minimal reductions to catch rates of sexually mature, high-value sablefish. Finally, we have shown that the size of the escape rings can be tailored to complement existing regulations in fisheries with different management goals and harvest strategies.

ACKNOWLEDGMENTS

The data collection and analysis for this research was completed while Jane Sullivan, Andrew Olson, and Benjamin Williams were employed at the Alaska Department of Fish and Game. We are grateful to the crew of the RV *Medeia* and Alaska Department of Fish and Game biologists for assisting in data collection and review. We would like to thank Kellii Wood for providing the map of the study area (Fig. 2) and Chris Siddon, Cara Rodgveller, Daniel Goethel, and Pat Malecha, whose feedback improved the quality of this manuscript.

CITATIONS

Alaska Fisheries Science Center. 2024. Observer Sampling Manual. Fisheries Monitoring and Analysis Division, North Pacific Groundfish Observer Program. AFSC, 7600 Sand Point Way N.E., Seattle, Washington, 98115.

Arana, P., and Ziller, S. 1994. Modelación de la selectividad de trampas para la captura de langosta (*Jasus frontalis*) en el archipiélago de Juan Fernández (Chile). Investigación Pesquera 38: 1-21.

Arana, P. M., Orellana, J. C., and De Caso, Á. 2011. Escape vents and trap selectivity in the fishery for the Juan Fernández rock lobster (*Jasus frontalis*), Chile. Fisheries Research 110: 1–9.

Armstrong, J., and Cunningham, S. 2018. Sablefish discard allowance. North Pacific Fishery Management Council. Discussion Paper. 1–32. URL: https://meetings.npfmc.org/CommentReview/DownloadFile?p=b6b509dd-a14c-442b-867b-3f88fa9f8d98.pdf&fileName=D2%20Sablefish%20Discard%20Allowance.pdf.

Armstrong, J., Krieger, J., Sullivan, J., Cahalan, J., Ganz, P., Gasper, J., and Cates, K. 2021. IFQ Sablefish Release Allowance. North Pacific Fishery Management Council, Initial Review Environmental Assessment/Regulatory Impact Review. 1–166. URL: https://meetings.npfmc.org/CommentReview/DownloadFile?p=0a70f8a0-25c2-4d5e-9044-f289c7f4e40d.pdf&fileName=C3%20IFQ%20Sablefish%20Release%20Allowance%20Analysis.pdf

Assonitis, K. 2008. Size-selectivity of British Columbia's sablefish (*Anoplopoma fimbria*) fisheries and implications for the economic losses associated with discarding. Ph.D. thesis, School of Resource and Environmental Management-Simon Fraser University.

Beverton, R. J., and Holt, S. J. 1957. On the Dynamics of Exploited Fish Populations. Chapman and Hall, London.

Broadhurst, M. K., Kennelly, S. J., and Gray, C. 2007. Strategies for improving the selectivity of fishing gears. *In* By-catch Reduction in the World's Fisheries, New York, NY: Springer New York. 1–21.

Burnham, K. P., and Anderson, D. R. (eds.) 2002. Model selection and multimodel inference: a practical information-theoretic approach. New York, NY: Springer New York.

Butterworth, D. S., Rademeyer, R. A., Brandão, A., Geromont, H. F., and Johnston, S. J. 2014. Does selectivity matter? A fisheries management perspective. Fisheries Research 158: 194–204.

Canty, A., and Ripley, B. D. 2019. boot: Bootstrap R (S-Plus) Functions. R package version (1): 3-24.

Carpenter, B., Gelman, A., Hoffman, M. D., Lee, D., Goodrich, B., Betancourt, M., Brubaker, M., Guo, J., Li, P., and Riddell, A. 2017. Stan: A probabilistic programming language. Journal of Statistical Software 76(1): 1-32.

Cheng, M. L. H., Rodgveller, C. J., Langan, J. A., and Cunningham, C. J. 2023. Standardizing fishery-dependent catch-rate information across gears and data collection programs for Alaska sablefish (*Anoplopoma fimbria*). ICES Journal of Marine Science 80(4): 1028-1042.

Cheng, M. L., Goethel, D. R., and Cunningham, C. J. 2024. Addressing complex fleet structure in fishery stock assessment models: Accounting for a rapidly developing pot fishery for Alaska sablefish (*Anoplopoma fimbria*). Fisheries Research (271): 1-15.

Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. Canadian Journal of Fisheries and Aquatic Sciences 48: 734–750.

Cleaver, S.M., McCracken, J., Olson, A.P., Goethel, D.R., and Fey, M. 2024. Small Sablefish Release. North Pacific Fishery Management Council, Initial Review Environmental Assessment/Regulatory Impact Review. 1–198. URL: https://meetings.npfmc.org/CommentReview/DownloadFile?p=03fd2da2-8a1e-495b-97ff-2ca6c50e66e8.pdf&fileName=C4%20Small%20Sablefish%20Release%20Analysis.pdf

Crone, P. R., and Valero, J. L. 2014. Evaluation of length-vs. age-composition data and associated selectivity assumptions used in stock assessments based on robustness of derived management quantities. Fisheries Research 158: 165–171.

Davison, A. C., and Hinkley, D. V. 1997. Bootstrap Methods and Their Applications. Cambridge: Cambridge University Press. URL: http://statwww.epfl.ch/davison/BMA/. ISBN 0-521-57391-2.

Dressel, S. C. 2009. 2006 Northern Southeast Inside sablefish stock assessment and 2007 forecast and quota. Alaska Department of Fish and Game Fishery Data Series. No. 09-50: 1–78.

Goethel, D. R., Cheng, M. L. H., Echave, K. B., Marsh, C., Rodgveller, C. J., Shotwell, K., and Siwicke, K. 2023. Assessment of the sablefish stock in Alaska. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the GOA and BS/AI. North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, L92 Building, 4th floor, Anchorage, AK 99501.

N. Graham, and Ferro R. S. T. 2004. The *Nephrops* Fisheries of the Northeast Atlantic and Mediterranean: A Review and Assessment of Fishing Gear Design, ICES, Copenhagen. 1-40.

Green, K., Baldwin, A., and Stahl, J. 2016. Northern Southeast Inside (Chatham Strait) sablefish marking survey. Alaska Department of Fish and Game Regional Operation Plan. CF.1J.2015.06: 1–24.

Haist, V., and Hilborn, R. 2000. Sablefish stock assessment for 2000 and recommended yield options for 2001. Fisheries and Oceans Canada, Research Document. 2000/157: 1–74.

Haist, V., Kronlund, A., and Wyeth, M. 2000. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: Stock assessment for 2003 and advice to managers for 2004. Fisheries and Oceans Canada, Research Document 2004/055: 1–74.

Hall, S.J., and Mainprize, B.M. 2005. Managing by-catch and discards: how much progress are we making and how can we do better? Fish and Fisheries 6(2): 134–155.

Hanselman, D. H., Rodgveller, C. J., Fenske, K. H., Shotwell, S. K., Echave, K. B., Malecha, P. W., and Lunsford, C. R. 2018. Assessment of the sablefish stock in Alaska. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the GOA and BS/AI. North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, L92 Building, 4th floor, Anchorage, AK 99501.

Hanselman, D. H., Rodgveller, C. J., Fenske, K. H., Shotwell, S. K., Echave, K. B., Malecha, P. W., and Lunsford, C. R. 2019. Assessment of the sablefish stock in Alaska. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the GOA and BS/AI. North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, L92 Building, 4th floor, Anchorage, AK 99501.

Hanselman, D. H., Rodgveller, C. J., Fenske, K. H., Shotwell, S. K., Echave, K. B., Malecha, P. W., and Lunsford, C. R. 2020. Assessment of the sablefish stock in Alaska. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the GOA and BS/AI. North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, L92 Building, 4th floor, Anchorage, AK 99501.

Hoffman, M. D., and Gelman, A. 2014. The No-U-Turn sampler: adaptively setting path lengths in Hamiltonian Monte Carlo. Journal of Machine Learning Research 15: 1593–1623.

Joy, P., and Ehresmann, R. 2022. Northern Southeast Inside Subdistrict sablefish management plan and stock assessment for 2022. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J22-19, Douglas. URL: https://www.adfg.alaska.gov/FedAidPDFs/RIR.1J.2022.19.pdf

Kennelly, S. J., and Broadhurst, M. K. 2002. By-catch begone: changes in the philosophy of fishing technology. Fish and Fisheries 3: 340–355.

Kindsvater, H. K., Reynolds, J. D., Sadovy de Mitcheson, Y., and Mangel, M. 2017. Selectivity matters: rules of thumb for management of plate-sized, sex-changing fish in the live reef food fish trade. Fish and Fisheries 18: 821–836.

Kristensen, K., Nielsen, A., Berg, C. W., Skaug, H., and Bell, B. M. 2016. TMB: Automatic differentiation and Laplace approximation. Journal of Statistical Software 70: 1–21.

Millar, R., and Walsh, S. 1992. Analysis of trawl selectivity studies with an application to trouser trawls. Fisheries Research 13: 205–220.

Millar, R. B. 1992. Estimating the size-selectivity of fishing gear by conditioning on the total catch. Journal of the American Statistical Association 87: 962–968.

Monnahan, C. C., and Kristensen, K. 2018. No-U-turn sampling for fast Bayesian inference in ADMB and TMB: Introducing the adnuts and tmbstan R packages. PloS One 13: e0197954.

Neter, J., Wasserman, W., and Kutner, M. H. 1974. Applied Linear Statistical Models. 4th Edition. McGraw-Hill/Irwin.

Ogle, D. H., Wheeler, P., and Dinno, A. 2019. FSA: Fisheries Stock Analysis. URL: https://github.com/droglenc/FSA. R package version 0.8.25.

Olson, A., and Sullivan, J. 2019. 2019 Southern Southeast Inside subdistrict sablefish Fishery Management Plan. Alaska Department of Fish and Game Regional Information Report. No. 1J19-06: 1–17.

Özbilgin, H., Tosunoğlu, Z., Tokaç, A., and Metin, G. 2007. Seasonal variation in the trawl codend selectivity of picarel (*Spicare smaris*). ICES Journal of Marine Science 64: 1569–1572.

Peterson, M. J., and Hanselman, D. 2017. Sablefish mortality associated with whale depredation in Alaska. ICES Journal of Marine Science 74(5): 1382–1394.

Peterson, M. J., Mueter, F., Criddle, K., and Haynie, A. C. 2014. Killer whale depredation and associated costs to Alaskan sablefish, Pacific halibut and Greenland turbot longliners. PLoS One 9: e88906.

Peterson, M. J., Mueter, F., Hanselman, D., Lunsford, C., Matkin, C., and Fearnbach, H. 2013. Killer whale (Orcinus orca) depredation effects on catch rates of six groundfish species: implications for commercial longline fisheries in Alaska. ICES Journal of Marine Science 70: 1220–1232.

Quinn, T. J., and Deriso, R. B. 1999. Quantitative Fish Dynamics. Oxford University Press.

Reddy, S. M., Wentz, A., Aburto-Oropeza, O., Maxey, M., Nagavarapu, S., and Leslie, H. M. 2013. Evidence of market-driven size-selective fishing and the mediating effects of biological and institutional factors. Ecological Applications 23: 726–741.

Sampson, D. B. 2014. Fishery selection and its relevance to stock assessment and fishery management. Fisheries Research 158: 5–14.

Shotwell, S.K., Echave, K., Ferriss, B., Goethel, D., Lunsford, C., Oke, K., Siddon, E., Siwicke, K., Sullivan, J., Szymkowiak, M., and Williams, B. 2023. Appendix 3C. Ecosystem and socioeconomic profile of the sablefish stock in Alaska - Report Card. *In* Goethel, D.R., Cheng, M.L.H., Echave, K.B., Marsh, C., Rodgveller, C.J., Shotwell, K., and Siwicke, K. Assessment of the Sablefish stock in Alaska, Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, L92 Building, 4th floor, Anchorage, AK 99501.

Stan Development Team. 2018. Stan modeling language users guide and reference manual, version 2.18.0.

Stewart, I. J., and Martell, S. J. 2014. A historical review of selectivity approaches and retrospective patterns in the Pacific halibut stock assessment. Fisheries Research 158: 40–49.

Sullivan, J., Olson, A., and Williams, B. 2019. 2018 Northern Southeast Inside subdistrict sablefish fishery stock assessment and 2019 management plan. Alaska Department of Fish and Game Regional Information Report. No. 5J19-03: 1–81.

Sullivan, J., Dimond, J. A., and Malecha, P. 2022. Slinky pot and hook-and-line comparison project during the experimental leg of the 2021 AFSC sablefish longline survey. AFSC Processed Rep. 2022-02, 18 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., Auke Bay Laboratories, 17109 Pt. Lena Loop Road, Juneau, AK, 99801.

Tallack, S. M. L. 2007. Escape ring selectivity, bycatch, and discard survivability in the New England fishery for deep-water red crab, *Chaceon quinquedens*. ICES Journal of Marine Science 64(8): 1579–1586.

Treble, R. J., Millar, R. B., and Walker, T. I. 1998. Size-selectivity of lobster pots with escape-gaps: application of the SELECT method to the southern rock lobster (*Jasus edwardsii*) fishery in Victoria, Australia. Fisheries Research 34: 289–305.

Vehtari, A., Gelman, A., Simpson, D., Carpenter, B., and Bürkner, P.C. 2021. Rank-normalization, folding, and localization: An improved $\widehat{R}$ for assessing convergence of MCMC (with discussion). Bayesian Analysis 16(2): 667–718.

Walters, C., and Maguire, J. J. 1996. Lessons for stock assessment from the northern cod collapse. Reviews in Fish Biology and Fisheries 6: 125–137.

Xu, X., and Millar, R. B. 1993. Estimation of trap selectivity for male snow crab (*Chionoecetes opilio*) using the SELECT modeling approach with unequal sampling effort. Canadian Journal of Fisheries and Aquatic Sciences 50: 2485–2490.

Zar, J. H. 1999. Biostatistical Analysis. Pearson Education India.

Table 1. -- Number of sablefish caught, fork lengths sampled, and mean fork length with standard error (SE) by escape ring treatment during the 2019 pot survey in May and June. Control = no escape ring.

Treatment	Total catch (N)	Fork lengths (N)	Mean fork length (cm)(SE)
Control	5,216	4,059	56.7 (0.13)
8.9 cm	3,604	2,827	58.0 (0.15)
9.5 cm	2,918	2,244	58.2 (0.18)
10.2 cm	2,495	1,977	58.2 (0.21)
Total	14,233	11,107	57.6 (0.08)

Table 2. --Summary of the number of sablefish per pot (catch per unit effort; CPUE; number of sablefish per pot) for all sizes of sablefish combined, sablefish < 63 cm, and sablefish ≥ 63 cm, including non-parametric Kruskal-Wallis test results, number of pots sampled (N), and mean and median CPUE with 95% bootstrap confidence intervals (CI) calculated using the percentile method. Treatments with statistically significant (α = 0.05) pairwise comparisons in post hoc Dunn tests with the Bonferroni adjustment are listed in italics in parentheses. If no pairwise comparisons are listed, there were no significantly different results for that treatment.

Treatment	N	Mean CPUE (95% CI)	Median CPUE (95% CI)
All sizes combined: χ^2-statistic = 77.2, p < 0.001			
Control *(8.9 cm, 9.5 cm, 10.2 cm)*	170	30.7 (27.7, 34.0)	27.5 (22.0, 32.0)
8.9 cm (*Control, 9.5 cm, 10.2 cm)*	170	21.2 (19.1, 23.5)	21.0 (17.0, 22.5)
9.5 cm *(Control, 8.9 cm)*	170	17.2 (15.4, 19.2)	13.5 (12.0, 15.0)
10.2 cm *(Control, 8.9 cm)*	170	14.7 (13.2, 16.4)	13.0 (11.0, 14.0)
Sablefish < 63 cm: χ^2-statistic = 48.1, p < 0.001			
Control *(9.5 cm, 10.2 cm)*	139	23.3 (20.1, 26.8)	18.0 (13.0, 24.0)
8.9 cm *(9.5 cm, 10.2 cm)*	136	15.3 (13.4, 17.6)	12.0 (9.0, 13.0)
9.5 cm *(Control, 8.9 cm)*	139	11.6 (10.1, 13.8)	9.0 (6.0, 11.0)
10.2 cm *(Control, 8.9 cm)*	138	10.1 (8.6, 11.9)	7.5 (6.0, 9.0)
Sablefish ≥ 63 cm: χ^2-statistic = 11.4, p = 0.010			
Control *(10.2 cm)*	139	5.9 (5.1, 6.9)	4.0 (3.0, 4.0)
8.9 cm	136	5.5 (4.6, 6.6)	3.0 (2.0, 3.0)
9.5 cm	139	4.6 (3.8, 5.4)	3.0 (2.0, 3.0)
10.2 cm *(Control)*	138	4.3 (3.6, 5.1)	3.0 (2.0, 3.5)

Table 3. -- SELECT model parameters estimates (medians with 95% credible intervals, CI) for fixed and random effects with priors used for Bayesian analysis. Parameters are indexed by escape ring treatment, such that 1 = 8.9 cm, 2 = 9.5 cm, and 3 = 10.2 cm and set numbers for random effects correspond to labeled stations in Figure 2. The relative probability of entering a control pot was estimated on the log-scale.

Parameter	Symbol	Median (95% CI)	Prior
Fixed effects			
Length at 50% selectivity, 8.9 cm	$S_{50,1}$	51.9 (50.0, 53.5)	U ~ (0, 100)
Length at 50% selectivity, 9.5 cm	$S_{50,2}$	56.0 (54.1, 57.9)	U ~ (0, 100)
Length at 50% selectivity, 10.2 cm	$S_{50,3}$	59.1 (56.9, 61.2)	U ~ (0, 100)
Slope at 50% selectivity, 8.9 cm	k_1	0.20 (0.15, 0.26)	U ~ (0, 0.9)
Slope at 50% selectivity, 9.5 cm	k_2	0.15 (0.12, 0.18)	U ~ (0, 0.9)
Slope at 50% selectivity,10.2 cm	k_3	0.13 (0.11, 0.15)	U ~ (0, 0.9)
Relative probability of entering a control pot	$\ln(\delta)$	-0.02 (-0.09, 0.05)	U ~ (-2.3, 0.7)
Random effects			
Set 1	η_1	0.10 (-0.30, 0.49)	U ~ (-5,5)
Set 2	η_2	0.12 (-0.34, 0.57)	U ~ (-5,5)
Set 3	η_3	0.21 (-0.19, 0.61)	U ~ (-5,5)
Set 4	η_4	-1.20 (-1.94, -0.63)	U ~ (-5,5)
Set 5	η_5	0.82 (0.44, 1.18)	U ~ (-5,5)
Set 6	η_6	0.11 (-0.29, 0.50)	U ~ (-5,5)
Set 7	η_7	0.04 (-0.40, 0.47)	U ~ (-5,5)
Set 8	η_8	-0.67 (-1.24, -0.20)	U ~ (-5,5)
Set 9	η_9	1.85 (1.46, 2.23)	U ~ (-5,5)
Set 10	η_{10}	-0.74 (-1.61, -0.10)	U ~ (-5,5)
Set 11	η_{11}	-0.42 (-0.94, 0.05)	U ~ (-5,5)
Set 12	η_{12}	-1.50 (-2.47, -0.84)	U ~ (-5,5)
Set 13	η_{13}	-0.47 (-1.38, 0.17)	U ~ (-5,5)
Set 14	η_{14}	-0.22 (-0.74, 0.26)	U ~ (-5,5)
Set 15	η_{15}	-2.06 (-3.25, -1.23)	U ~ (-5,5)
Set 16	η_{16}	0.21 (-0.30, 0.66)	U ~ (-5,5)
Set 17	η_{17}	-2.40 (-3.66, -1.46)	U ~ (-5,5)

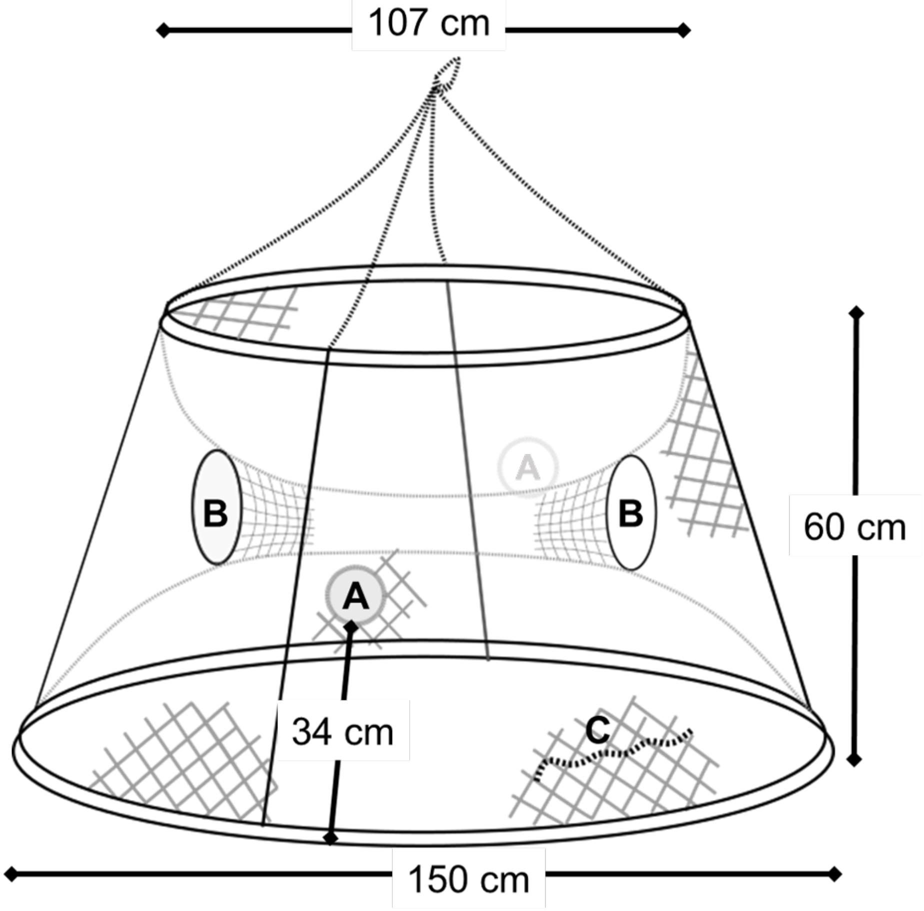

Figure 1. -- Diagram of the conical pot used during the survey, including the placement of the escape rings (A), the soft-sided entrance tunnels (B), the biodegradable cotton twine (C), the top diameter (107 cm), bottom diameter (150 cm), pot height (60 cm), and distance from the pot bottom of the pot to the bottom of the escape ring (34 cm).

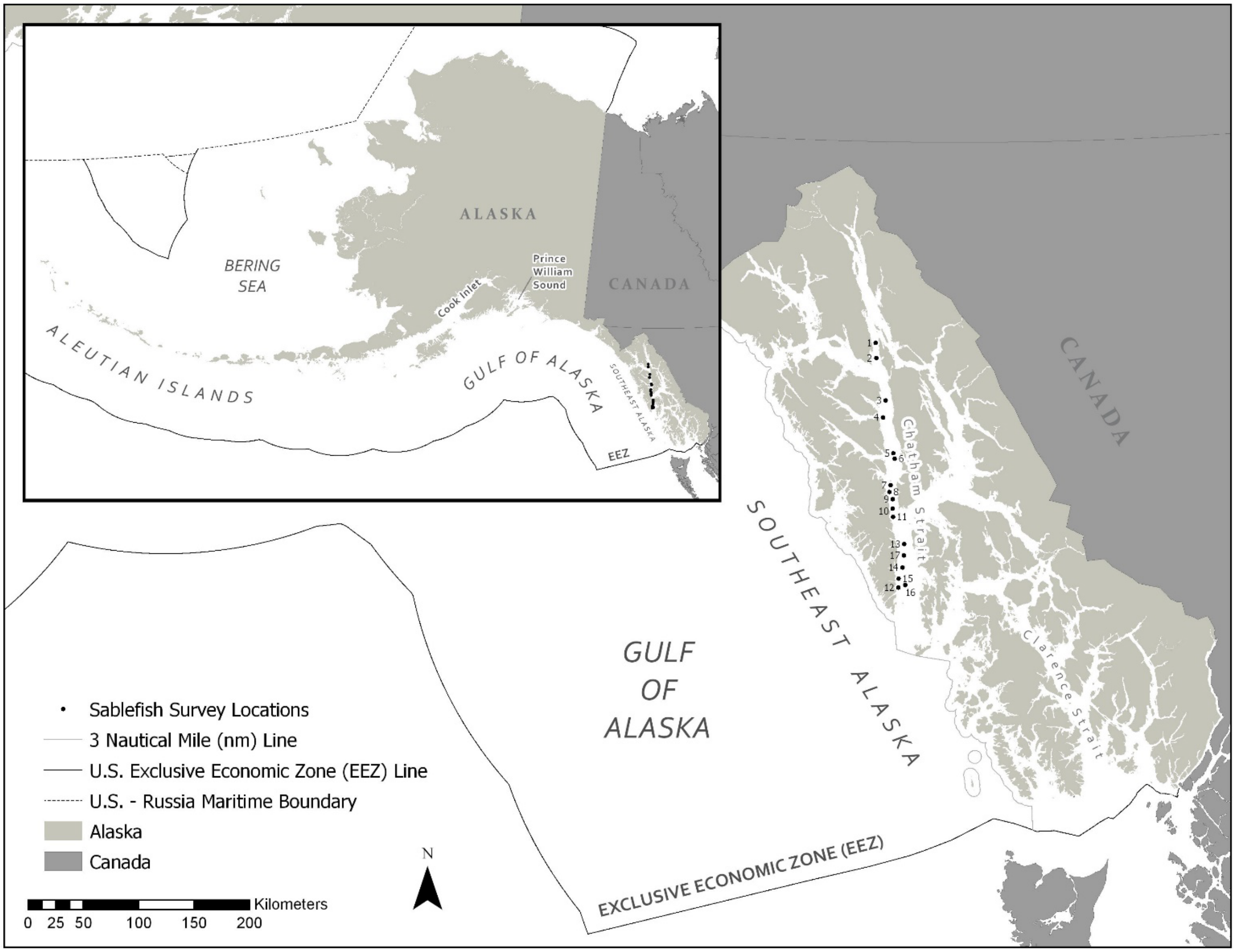

Figure 2. -- Map of the study area in Chatham Strait, Alaska, with numbered survey set locations.

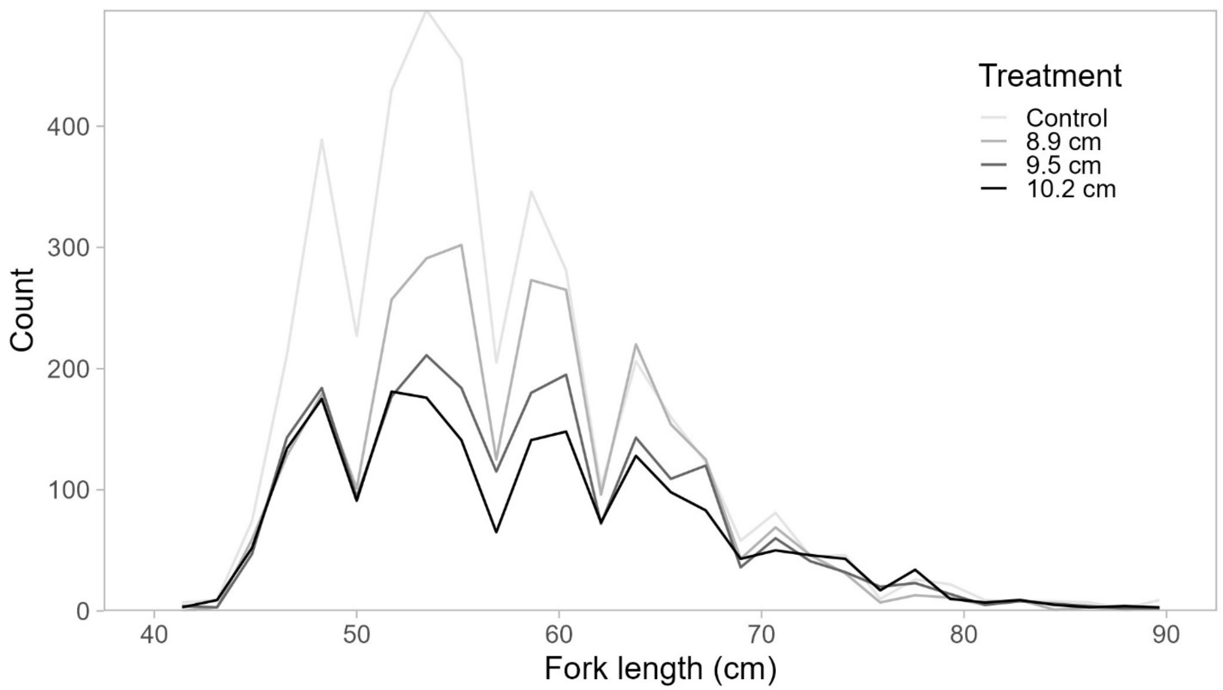

Figure 3. -- Length frequency distributions obtained using different sizes of escape rings (Control = no escape ring).

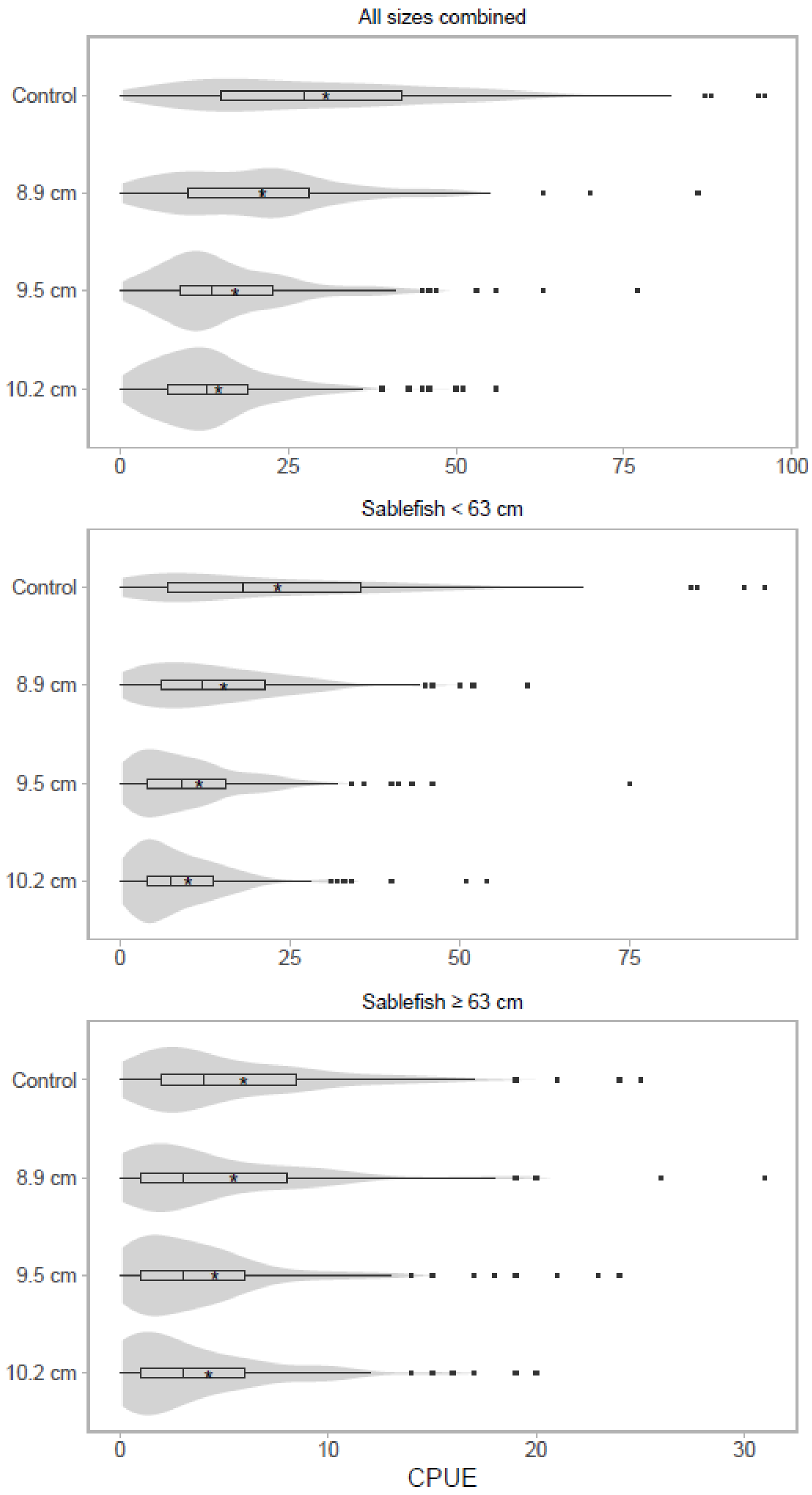

Figure 4. -- The distribution of sablefish per pot (CPUE) by escape ring treatment for all sized fish combined, sablefish < 63 cm and sablefish ≥ 63 cm. Each internal box plot shows the median (vertical line), mean (asterisk), interquartile range (IQR, the box), 1.5 × IQR (the whiskers), and outlying data (small points). Note that the horizontal axes vary by panel.

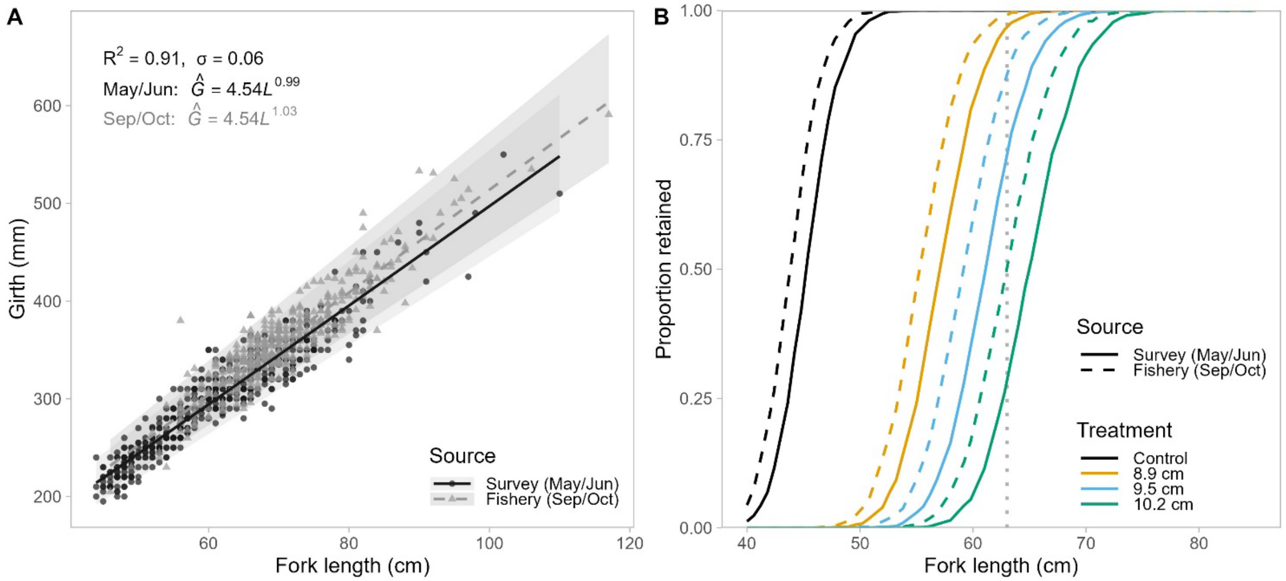

Figure 5. -- A) Fitted values and prediction intervals for the regression of girth on length for data collected during the survey in May and June (black circles, solid line) and fishery in September and October (grey triangles, dashed line). The coefficient of variation (R^2), residual standard deviation (σ), and model equations are shown in the upper left. B) Empirical selectivity curves developed using the girth-length regression and σ for each escape ring treatment and source/season. The length at 50% maturity (L_{50}) for sablefish is shown as a grey dotted vertical line for reference.

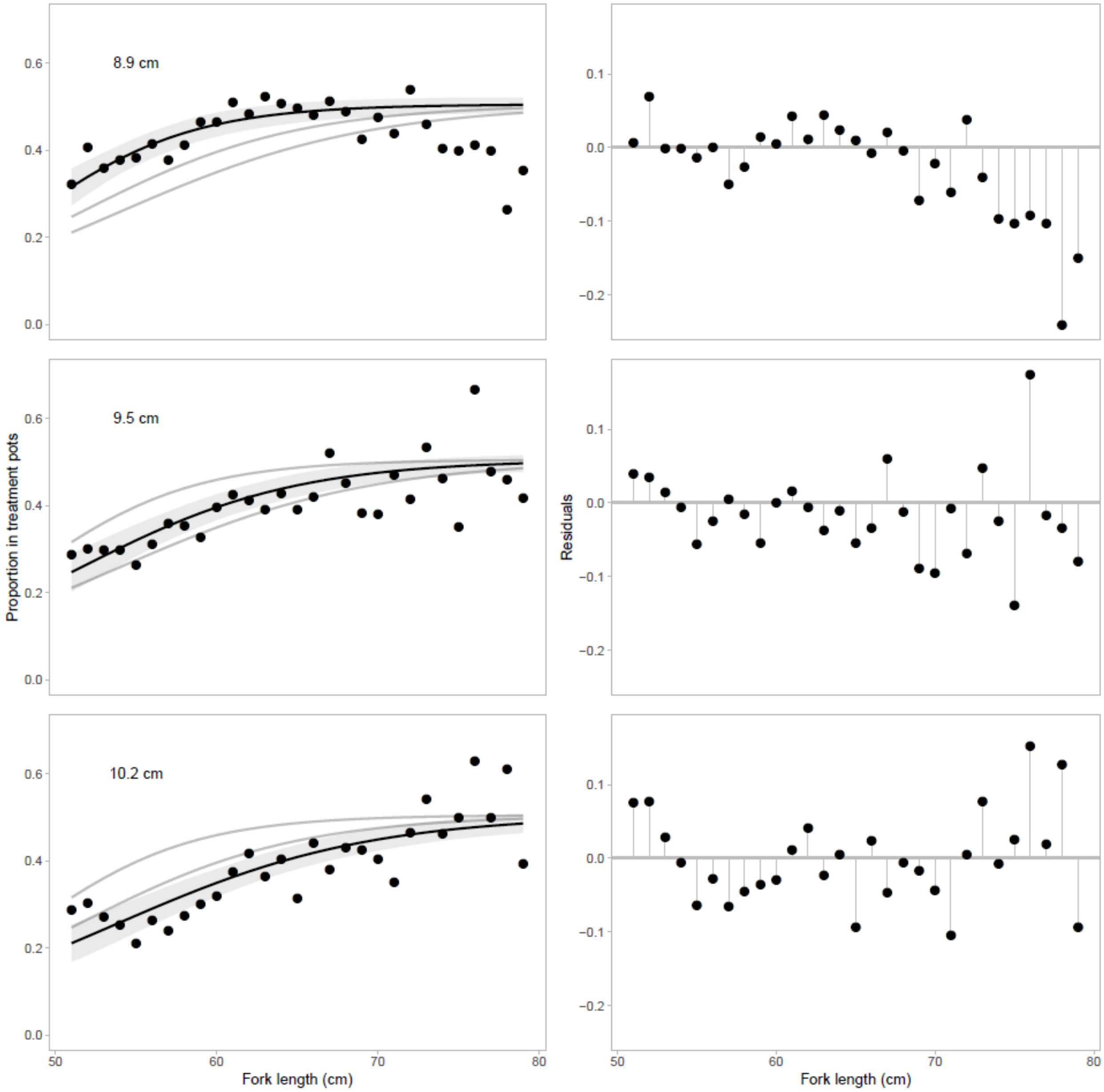

Figure 6. -- SELECT model fits to proportion of fish in each treatment with 95% credible intervals (left) with associated residuals by length bin (right). Fits for the other treatments are shown in grey for comparison.

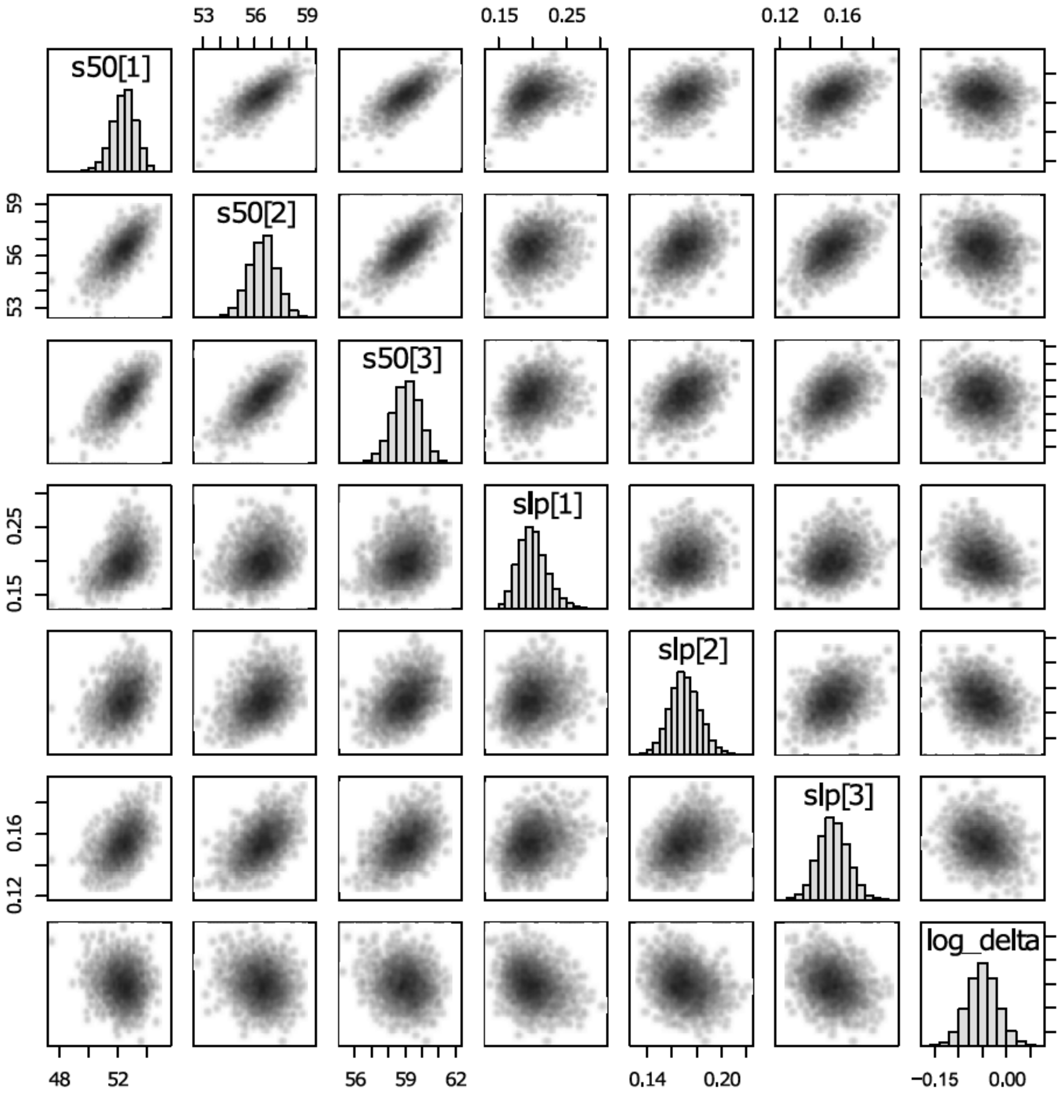

Figure 7. -- Marginal posterior distributions for the fixed effects in the SELECT model (diagonal) with pairwise correlation plots. Parameters include the length at 50% selectivity (S_{50}, “s50”) and the slope at 50% selectivity (k ,“slp”), which were indexed as 1 = 8.9 cm, 2 = 9.5 cm, and 3 = 10.2 cm for each escape ring treatment. The relative probability of entering a control pot ($\ln(\delta)$, “log_delta”) was estimated on the log-scale.

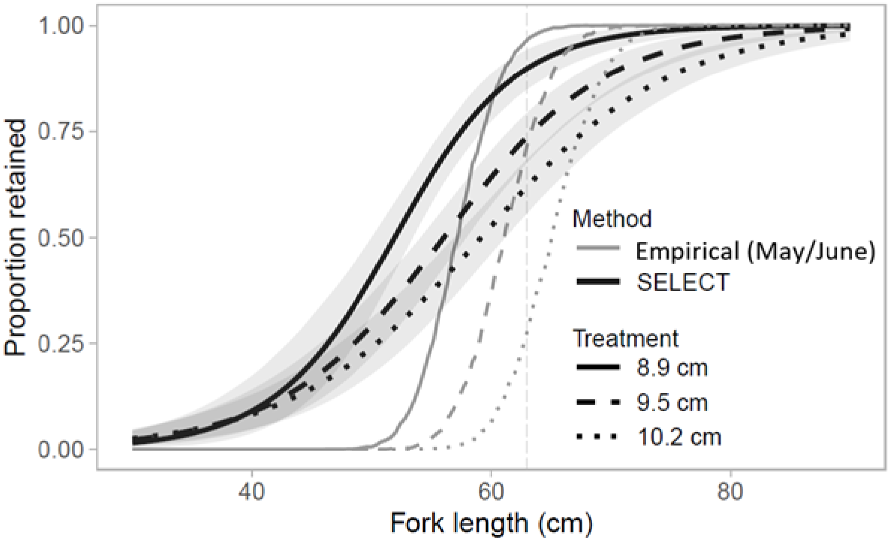

Figure 8. -- Empirical selectivity curves calculated using girth data collected during the survey in May and June (grey) are compared with SELECT model estimated curves with 95% credible intervals for each treatment. The length at 50% maturity (L_{50}) for sablefish is shown as a grey vertical line for reference.

U.S. Secretary of Commerce
Gina M. Raimondo

Under Secretary of Commerce
for Oceans and Atmosphere
Dr. Richard W. Spinrad

Assistant Administrator, National
Marine Fisheries Service.
Janet Coit

July 2024

www.nmfs.noaa.gov

OFFICIAL BUSINESS

National Marine
Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way N.E.
Seattle, WA 98115-6349