Incorporating Fishermen’s Knowledge into Standardized Catch-per-Unit-Effort Indices for the Commercial Monkfish Fishery

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Summary - The American monkfish (*Lophius americanus*) fishery is an economically important component of U.S. commercial fisheries, but uncertainty persists in stock assessments due to uncertainty about the species’ biology and fishery-independent surveys. This study develops standardized catch-per-unit-effort indices for the southern gillnet and northern trawl fleets using statistical models of monkfish catch and effort data. Vessel logbook and at-sea observer data were explored, and the analyses were guided by information from a series of workshops with monkfish fishermen. Their feedback clarified typical fishing practices, described fishery monitoring practices, informed data filtering decisions and the identification of possible standardization factors, and helped interpret trends in catch rates. Standardization models incorporated key factors such as year, month, depth, fishing area, and vessel size to account for their relationships with catch rates and changes in fishing behavior to develop potential stock indices. Diagnostic evaluations indicated that the selected models adequately met statistical assumptions, and comparisons among fishery-independent and fishery-dependent indices suggest that models effectively standardized relative abundance trends. Results from southern gillnet and northern trawl catch rates demonstrate long-term declines from peak catch rates in the early 2000s followed by relatively low catch rates in the 2010s, and moderate to high catch rates since the late 2010s for most indices. These standardized indices can be considered as potential stock indices to support monkfish stock assessment and fishery management.

Introduction

The American monkfish (*Lophius americanus*, a.k.a., 'goosefish'), have supported one of the most valuable fisheries in the U.S. (Richards et al., 2008). In the mid-1900s, monkfish were considered undesirable in New England fisheries, often discarded at sea or used in the production of fishmeal (Armstrong et al., 1992). Then, a domestic market developed in the 1980s as monkfish became more popular with American consumers and the availability of other popular groundfish species decreased (Weber, 2001). By the mid-1990s, monkfish surpassed groundfish species such as Atlantic cod, haddock, and flounders in economic revenue to become the highest valued finfish in the Northeast U.S. (Richards et al., 2008). U.S. landings peaked at 62 million pounds (28,000 metric tons) in 1997 with revenues of $35 million then decreased to approximately 13 million pounds (6,000 metric tons) and $9 million in 2024 (NMFS, 2025).

American monkfish inhabit continental shelves from shallow coastal waters to the continental slope (5-500 m), from the Grand Banks to Florida, but are most common from Nova Scotia to Cape Hatteras (Brown et al., 1996; Steimle et al., 1999; Caruso, 2002; Siemann et al., 2018). They are characterized by a broad, flattened head, large mouth, and a modified dorsal spine used as a lure to ambush prey (Fariña et al., 2008). Monkfish typically inhabit soft-bottom substrates and exhibit seasonal inshore-offshore movements, occurring in shallower waters during summer and deeper waters in winter (Steimle et al., 1999; Richards et al., 2008; Siemann et al., 2018). Their diet is broad and opportunistic, consisting primarily of demersal fishes, cephalopods, and crustaceans (Steimle et al., 1999; Fariña et al., 2008).

Monkfish's demersal habitat and behavior make them vulnerable to bottom-contact fisheries. Because of their demersal behavior and large size, monkfish are caught by bottom-tending gears such as sink gillnets, otter trawls, and scallop dredges. Experimental trawl studies in the Scottish North Sea show that European monkfish generally do not attempt to evade oncoming gear, instead relying on camouflage and remaining stationary, which further increases their susceptibility compared to more mobile species (Ferro et al., 2007). This vulnerability confers consistent catchability (q), which describes how effectively a unit of fishing effort captures the portion of the stock that is available (Hilborn & Walters, 1992).

In response to the expansion of the directed monkfish fishery in the 1990s, the fishing industry requested a Fishery Management Plan (Haring & Maguire, 2008). The management plan was developed and jointly implemented in 1999 by the New England and Mid-Atlantic Fishery Management Councils and includes a limited access permit program, a days-at-sea (DAS) management system, trip limits, and minimum size limits (NEFMC, 1998). The plan defines two management areas: the northern management area includes the Gulf of Maine and the northern part of Georges Bank, and the southern management area extends from the southern flank of Georges Bank through the Mid-Atlantic Bight. The management areas are primarily based on different fishing patterns (e.g., mainly gillnets that target monkfish in the south and multispecies trawls in the north; Richards, 2016). In the northern area, 70-75% of total monkfish catch has been from bottom otter trawl trips targeting groundfish species and the remaining 25-30% has been from gillnet trips (Haring & Maguire, 2008; Richards, 2016). In contrast, 60-65% of total monkfish landings in the southern area have been from gillnet trips that target monkfish, 25% is from bottom otter trawl trips, and the remaining landings were from bycatch in the scallop dredge fishery (Haring & Maguire, 2008; Richards, 2016). Age determination from vertebra suggested that monkfish grew faster in the southern management area (Armstrong et al., 1992) than in the northern management area (Hartley, 1995), but the ageing method was found to be unreliable (Bank et al. 2020). The directed monkfish fishery has been managed with annual catch limits for each management area since 2011, a yearly allocation of monkfish days-at-sea and possession limits, and incidental landings are allowed in some fisheries.

Annual landings of monkfish in the U.S. were approximately 100 metric tons in the mid-1960s and increased to a peak of 28,000 metric tons by 1997 (Richards et al., 2008). Landings subsequently declined to only 6,000 metric tons in 2024 resulting from decreased markets and fishery restrictions and management measures such as limited days-at-sea, and trip limits (NMFS, 2025). The New England Fishery Management Council's monkfish advisors consider low monkfish prices and high trip costs to be the main limitations of the current fishery (NEFMC, 2022a).

Despite the value of the monkfish fishery, the biology of monkfish is poorly understood (e.g., Bank et al., 2020; Sutherland and Richards, 2021), survey indices are highly variable (Richards et al., 2008, NEFSC, 2025a, 2025b), and stock assessments have been uncertain. The earliest stock assessments of monkfish were based on descriptive evaluations of fishery catch and NEFSC survey trends by management area (NEFSC, 1992, 1997). Stock assessments in the early 2000s were based on mean-size estimators of mortality that indicated overfishing was occurring in both areas (NEFSC, 2000). The 2002 and 2005 assessments evaluated monkfish catch rates by depth and fleet, included industry-based monkfish surveys that were designed to supplement NEFSC surveys, and concluded that the stock was not overfished but exploitation status could not be evaluated (NEFSC, 2002, 2005). In 2004, the fishery management plan was amended to include a research set-aside program that allocates 500 days-at-sea per year to fund monkfish research and address uncertainties in stock assessment (NEFMC, 2004). Statistical catch-at-length models were developed in 2007 and indicated that the stock was not overfished, and overfishing was not occurring (NEFSC, 2007, 2010, 2013). However, the analytical stock assessment method was rejected in 2016 because of the aging method was found to be unreliable, and an empirical approach was developed based on total catch from the fishery and trends in the NEFSC spring and fall bottom trawl survey indices of exploitable biomass (>43cm) and (Richards, 2016). Since then, Management Track Stock Assessments updated survey indices and catch statistics ('Ismooth') for monkfish to inform annual catch limits (NEFSC, 2020, 2022, 2025a, 2025b).

In 2022, the New England Fishery Management Council voiced concerns about the method used during the last three stock assessments to determine monkfish stock status (NEFMC, 2022c). The empirical stock assessment method applies the recent trend in NEFSC bottom trawl survey indices as a multiplier to the latest three-year average catch from the fishery to develop new catch advice (e.g., if the survey index is increasing, the catch limit increases proportionally, and vice versa). Industry voiced concerns over the empirical approach to catch limits because the trawl survey may not be catching monkfish consistently, and monkfish landings have been low due to COVID-19 pandemic, lack of markets, high trip costs, low fish prices and other factors.

As described in the original Monkfish Fishery Management Plan, "*The only data available to support a definition based on a minimum stock level is from fishery independent surveys. A few state-supported surveys exist, but the most comprehensive are the bottom surveys conducted by NMFS. There are problems because the surveys do not encompass the entire range of the monkfish resource. No samples are taken offshore of the Continental Shelf edge where monkfish are known to occur*" (NEFMC, 1998). Monkfish distribution extends to deeper habitats (e.g., >900 m; ; Siemann et al., 2018) than the maximum depth of survey strata (183 m; Politis et al., 2014), so surveys may not represent the entire stock area (Haring & Maguire, 2008). By comparison, a Scottish survey of European monkfish samples to depths of 1,000 m (Fernandes et al., 2007). A recent spatial comparison of NEFSC surveys and at-sea observer data showed that some monkfish catch is taken from deep waters of the continental slope off southern New England in winter, beyond the depths sampled by surveys (Brown, 2023). NEFSC trawl surveys catch relatively few monkfish (Richards et al., 2008; Siemann et al., 2018) and trawl efficiency studies also indicate that the rock-hopper gear currently used for NEFSC bottom trawl surveys may not catch monkfish as efficiently or consistently as fisheries that target monkfish (Miller et al., 2023).

Catch rates in the monkfish fishery could provide a stock index to improve monkfish stock assessments for informing management of monkfish fisheries. More specifically, standardized catch-per-unit-effort (*CPUE*) indices from the southern gillnet fishery or the northern trawl fishery may be valuable supplements to NEFSC bottom trawl survey indices. The New England Fishery Management Council's Fishery Data for Stock Assessment Working Group recommended the development of a catch rate index for monkfish as a priority (Cadrin et al., 2020). "*Research to develop a standardized catch per unit effort (CPUE) index for the commercial directed monkfish gillnet fishery to be used for stock assessment purposes*" was identified as a top priority for the monkfish research set-aside program (NMFS, 2023). The Research Track Steering Committee encouraged the Monkfish Research Track Working Group to engage with the research set-aside programs for developing fishery catch rates (Simpkins et al., 2024). The 2025 Scientific and Statistical Committee recommended alternative assessment methods and consideration of additional survey indices (NEFMC, 2025).

Stock assessment models assume that abundance indices (survey trends, CPUE, or landings-per unit-effort, LPUE) are proportional to stock biomass (*B*) at time *t*:

1) $CPUE_t = qB_t$

assuming that catchability (*q*) is constant over time (Cadrin et al., 2016). Catchability (*q*) is the product of capture efficiency (*e*) and area fished or sampled (*a*) relative to the total stock area (*A*)

2) $q = e\frac{a}{A}$

Constant *q* is implicitly assumed in the management of fishing effort (e.g., days-at-sea limits) to achieve a fishing mortality (*F*) target, because *q* is assumed to be the constant effect of a unit of fishing effort (*E*) on the fished population over time:

3) $F_t = qE_t$

For a catch rate series to reflect changes in stock size, *q* must remain relatively stable over time. However, capture efficiency varies among fishing gears, vessel characteristics, fisher behavior, habitat, and seasonal fishing patterns (Gulland 1964; Hilborn & Walters, 1992; Harley et al., 2001; Maunder & Punt, 2004). These sources of variability can increase or decrease catch rates for reasons that are not related to stock size, so catch rates must be standardized to be considered as a stock index. Unlike fishery independent surveys, which standardize sampling gear, seasonal timing, and sampling design, catch and effort from commercial fisheries result from individual fishing decisions that are influenced by markets and regulations. Therefore, analytical standardization is needed to isolate relative abundance signals from fishery catch rates.

Statistical methods such as generalized linear models (GLMs), generalized additive models (GAMs), and spatiotemporal models have been developed to account for common factors affecting catch rates, including fishing area, season, vessel characteristics, and fishing gear (Gavaris, 1980; Maunder & Punt, 2004; Grüss et al., 2019; Hoyle et al., 2024). By estimating how these predictor variables influence catch rates, standardization models adjust for differences in fishing power among vessels, variation in fishing gear and practices, spatial and temporal fishing patterns, and environmental conditions that interfere with the index–stock relationship (Maunder et al., 2006). For example, standardized catch rates for a fleet can be derived from relative fishing power by adjusting CPUE upward for low-power vessels and adjusting CPUE downward for high-powered vessels (Beverton & Holt, 1957) so that standardized CPUE is not affected by changes in fleet composition (e.g., from low-powered vessels to high-powered vessels; Maunder & Punt, 2004).

Effective catch rate standardization relies on rigorous data exploration, assessment of influential observations, understanding of fishing behavior, and interpretation in the context of fleet dynamics and species distribution (Hoyle et al., 2024). Implementing these practices helps to support the assumption that standardized catch rates reflect trends in stock size rather than changes in the fleet or fishing behavior, while also improving understanding of factors that influence CPUE trends for scientists, managers, and fishermen (Bentley et al., 2012). Understanding each fishery and associated fishery monitoring programs is needed to develop a standardized catch rate series that is a reliable index of abundance (Hoyle et al., 2024). For example, information on target species is helpful for developing a standardized CPUE series based on selected fishing effort that is targeted at the species of interest and to exclude avoidance behavior for non-target stocks. Catch estimates need to be accurate for an informative catch rate index, either for an entire fleet, or for a smaller reference fleet. An understanding of fishing effort is needed to develop a standardized catch rate index, including information on fishing gear, fishing power, and an appropriate unit of fishing effort for each type of fishery. Temporal and spatial information is helpful for measuring and standardizing fishing effort. Fine-scale temporal and spatial information is ideal for standardizing fishing effort (e.g., Grüss et al., 2019; Hoyle et al., 2024).

Fishermen’s ecological knowledge is valuable for data exploration to guide catch rate standardization (O’Donnell et al., 2010) and to determine factors that may be influencing catch rates (e.g., Johannes et al., 2000; Lapp et al., 2015; Wright et al., 2017; Hansell et al., 2018a, 2018b). Incorporating this knowledge is essential for data interpretation. Collaborating with fishermen also increases the quantity and quality of data and can reduce the cost of science (Karp et al., 2001; NRC, 2004; Read & Hartley, 2006; Johnson & van Densen, 2007; Mackinson et al., 2015), and incorporating fishermen’s ecological knowledge into a scientific process can increase fishermen’s confidence in the scientific results and promotes trust between fishermen and scientists (NRC 1998). Therefore, collaborative catch rate standardization can contribute fishermen’s ecological knowledge to conventional stock assessments and potentially improve assessments by filling knowledge gaps.

Stock assessments of most northeast U.S. fisheries do not use fishery catch rates as indices of abundance within stock assessment models (NEFSC, 2019; O’Keefe et al., 2015; Cadrin et al., 2020), but fishery catch rate indices are valuable for assessments of species that are not well sampled by trawl surveys (e.g., black sea bass, NEFSC 2023a; Jones et al., 2025; golden tilefish, NEFSC, 2024; bluefish, NEFSC 2025c). Several recent groundfish assessments considered CPUE or LPUE as indices of abundance during the assessment review process but did not include them as indices of abundance in the final assessment models. For example, a workshop on the use of fishery catch rates for Gulf of Maine and Georges Bank cod concluded that LPUE indices should be formally considered in stock assessments (NEFSC, 2012). Subsequently, the cod research track stock assessment working group used a recreational CPUE index in the stock assessment of southern New England cod, because the NEFSC trawl surveys do not sample cod well in that region (NEFSC, 2023b).

The use of standardized catch rates as a relative index of abundance has the potential to enhance monkfish stock assessments, especially during periods when survey data are limited or interrupted (e.g., Link et al., 2021). However, the ability of fishery catch rates to improve assessment performance quantitatively depends on whether the index can be sufficiently standardized and validated against independent abundance indicators, which remains an open question. Regardless of whether fishery CPUE is ultimately incorporated into the assessment model, fishery-dependent indices can still improve stakeholder confidence and understanding of fishery dynamics as well as management actions to limit fishing effort. As noted in a review of Northeast stock assessments, "*fishers have a greater trust in the data that they themselves provide, and therefore, an effort should be made to validate and use CPUE data*" (NRC, 1998). Additionally, CPUE can provide greater spatial and temporal resolution than fishery-independent surveys, contributing valuable context for management discussions (NEFSC, 2012; Cadrin et al., 2020).

The objectives of this project were to:

1. Elicit fishermen's ecological knowledge to understand the monkfish fishery and fishery monitoring data;
2. Develop standardized catch rate indices for the directed monkish gillnet fishery and possibly the multispecies trawl fishery; and
3. Compare alternative standardized indices with NEFSC survey trends to evaluate consistency in interannual trends.

Methods

Data

Logbook (Vessel Trip Reports, VTR; NMFS, 2020) and at-sea observer data from the Northeast Fisheries Observer Program (NEFSC, 2016) and At-Sea Monitoring Program (NEFSC, 2011) were provided by NOAA in the spring of 2024 through a data sharing agreement. The logbook data contained records for all commercial fishing trips that caught monkfish from 1999 to 2023, while the observer data ranges from 1989 to 2023. The observer data contains information on retained and discarded catch from each haul from sampled trips that caught monkfish and was used to quantify total catch and CPUE. Data exploration and modeling was conducted in R (version 4.4.0) to understand the data, visualize patterns and estimate standardization parameters, and the analytical code is available (github.com/scadrin/monkfishCPUE). NEFSC trawl survey indices were reported in the 2025 monkfish stock assessments (NEFSC, 2025a, 2025b). An alternative high-resolution series of monkfish catch rates from the NEFSC Study Fleet and observer data (Jones & Legault, 2026) were provided for comparison.

In the initial data exploration, catch and effort records were separated by anchored sink gillnets (NEGEAR.x = 100 for observer data and GEARCODE = GNS for logbook data) and bottom otter trawls that target fish (NEGEAR.x = 50 for observer data and GEARCODE = OTF for logbook data). Statistical area codes for reporting fishing catch and effort were used to identify management area. Management areas were defined as the Northern Fishery Management Area (US jurisdictional portions of statistical areas 464, 465, 511, 512, 513, 514, 515, 521, 522, 561, and 563), and the Southern Fishery Management Area (statistical areas 525, 526, 537, 538, 539, 552, 562, 611, 612, 613, 614, 615, 616, 621, 622, 623, 625, 626, 627, 631, 632, 635, and 636; Figure 1). Prior to the industry workshops, relationships among key variables were explored to understand the underlying structure of the fishery and monitoring data to present them at workshops.

Alternative measures of fishing effort were examined for their suitability in the catch-per-unit effort calculations. For gillnet trips, several alternative metrics of fishing effort were evaluated: soak duration, days-at-sea, soak duration x number of nets, or soak duration x number of nets x panel length. For trawl trips, fishing effort was explored using tow duration or days-at-sea. The fishing effort statistics selected to derive catch rates were gillnet soak duration and trawl duration because of data quality problems with more precise metrics of effort. Plots comparing unstandardized catch rates with variables such as depth, month, and year were generated to visualize preliminary patterns and present them to fishermen. Logbook data were used to calculate and plot total annual monkfish landings and several metrics of fishing effort, including days-at-sea, number of trips, total trawl duration, and total soak hours, to characterize long-term trends in fishing activity. These annual summaries were stratified by management area, providing a clearer depiction of how landings and effort differed between the northern and southern fishery management areas and how these dynamics have shifted through time.

Fishery Expertise

The project team met with an Industry Working Group and other scientists in the summer of 2024 to review the project objectives, the general approach for deriving standardized indices, the plan for eliciting input from the monkfish fleet, and to coordinate this project with other monkfish CPUE projects and the monkfish stock assessment. Workshops with monkfish fishermen were conducted in fall 2024 to provide qualitative context for interpreting standardized catch rate indices and to inform data treatment and model development (Figure 2). Workshops were organized by the Cape Cod Commercial Fishermen's Alliance and held at multiple ports along the U.S. East Coast, with participation from commercial gillnet and trawl fishermen, industry representatives, scientists, and fisheries managers. In-person industry workshops were held in Point Judith, Rhode Island (October 21, 2024); New Bedford, Massachusetts (October 24, 2024); Portland, Maine (November 4, 2024); Chatham, Massachusetts (November 6, 2024); and Gloucester, Massachusetts (November 12, 2024). A virtual workshop with fishermen from New Jersey and New York was held on October 22, 2024.

Workshops followed a semi-structured format. Preliminary summaries of monkfish catch, effort, and unstandardized CPUE were presented, and participants were invited to discuss fishing practices, gear configurations, targeting behavior, seasonal patterns, and data-reporting considerations. Notes were recorded during each workshop and compiled to identify recurring themes across regions and fleets. Industry input from these workshops was used to identify realistic data ranges for fishing depth, soak duration, vessel characteristics, and gear configurations; diagnose inconsistencies and ambiguities in logbook and observer data fields; and guide data filtering decisions, covariate selection, and interpretation of standardized CPUE trends.

Following the industry workshops, several meetings were conducted to present preliminary analyses and obtain feedback from industry representatives, scientific collaborators, and management bodies. Preliminary results were presented to the New England Fishery Management Council's Monkfish Advisory Panel and Committee on September 9, 2024 and March 20, 2025 and to the Council's Monkfish CPUE Workign Group in July 22, 2025. Follow-up meetings with monkfish fishermen were held on May 13, 2025, July 28, 2025, and October 20, 2025. These meetings focused on reviewing preliminary standardized CPUE results, discussing exploratory analyses, and clarifying interpretation of model outputs. Feedback from these sessions was used to refine presentation of results and ensure that standardized catch rate indices were developed in a manner consistent with operational understanding of the fishery. In the interpretation of model results, fishing gear experts and members of the Industry Working Group were contacted for their perspectives on technological advancements. They were asked: "*What have been the major changes in fishing gear (like monofilament gillnets, synthetic trawl mesh) or other technologies (like hydraulic haulers, winches or net reels; fish finders; plotters; net or door sensors) that have increased fishing power in your fishery, and when did that happen*?" and "*Have here been any advances in fishing technology over the last 25 years that have increased your fishing power*?"

Standardization Models

Generalized Additive Models (GAMs) were applied to standardize catch rates for monkfish. GAMs are widely used in ecological and fisheries analyses because they can flexibly model nonlinear relationships between the response variable (e.g., CPUE) and predictor variables (e.g., area, season, vessel size) using smooth functions in which the number of knots (k) determines the degree of curvilinearity (Wood, 2017). This flexibility was particularly valuable for standardizing monkfish catch rates, because preliminary data exploration showed that depth had a nonlinear relationship with monkfish CPUE for gillnet and trawl fleets. Incorporating smoothing terms in standardization models allowed them to better capture these complex, spatially structured patterns in the data and produce standardized indices that more accurately reflected variation in monkfish availability. Significance was indicated by a low probability of no effect for each predictor variable ($p<0.05$). Significance of smooth functions was determined from effective degrees of freedom (edf) and F-tests (Wood, 2017).

A series of data decisions and model variations were explored to evaluate model sensitivity and robustness (Appendix A). Alternative statistical distributions were tested using both logbook and observer datasets for each fleet, including the Tweedie, Gamma, and Gaussian families. The Tweedie distribution was selected because of its flexibility and demonstrated suitability for fisheries catch rate data (Shono, 2008; Campbell, 2015; Grüss et al., 2023). A key feature of the Tweedie family is the ρ (rho) parameter, which governs the shape of the statistical distribution and allows it approximate Poisson, Gamma, or mixture distributions. In this study, ρ was estimated directly from the data, enabling the model to accommodate heavy-tailed catch rate distributions (e.g., more extremely low or high CPUE values than expected from theoretical distributions), which improved overall model fit and residual diagnostics. In addition to testing alternative statistical distributions, alternative models were explored to investigate patterns identified in the industry workshops. For example, a southern gillnet model was fit using observer data that included skate catch rate as a covariate to explore the magnitude of skate interference on monkfish catch rates (Appendix B).

Multiple definitions of the response variable (catch rate) were explored, representing alternative combinations of catch and effort metrics. Guided by input from fishermen, a wide range of potential predictor variables were tested, including year, statistical area, month, depth, latitude, longitude, mesh size, tow speed, use of gillnet tiedowns, vessel length, vessel tonnage, and horsepower, as well as depth x area and area x month interactions. For predictor variables that were correlated (e.g., vessel size metrics), only the variable that had the strongest effect on catch-per-unit-effort was retained. This iterative process helped identify the set of predictors that were most strongly associated with catch rates and ensured that the final model was statistically valid and accounted for the major features of the monkfish fishery. Collinearity, variable selection, and residual structure were evaluated following best-practice guidance for ecological GAM modeling (Zuur et al., 2010).

Model Selection

Four candidate models were selected to represent each combination of data source (logbook or observer) and fleet (southern gillnet or northern trawl). All models were fit without an intercept to estimate standardized annual effects across the full time series. For the northern trawl models, catch rate was defined as live weight per tow duration for observer data and kept weight per tow duration for logbook data. Models included year, month, statistical area, depth (smoother with 5 knots, *k*=5), and vessel length as predictor variables to account for temporal, spatial, vessel, and environmental influences on catch rates:

4) $\widehat{CPUE}_{i,t} = f(year, month, area, depth, vessel\ length) + \varepsilon_i$

where CPUE for fleet *i* in year *t* was predicted as a function of year, month, statistical area, depth and vessel length, with an observation error residual (ε). Predictor variables included year, month, depth (*k* = 5), and statistical area, with the observer model also incorporating a tiedown presence variable.

Among the alternative model specifications developed for each fleet and dataset, the optimal models were selected through a combination of statistical diagnostics and practical considerations informed by fishery workshops. Candidate models were compared using standard validation tools. Model convergence, residual analyses, percent deviance in CPUE explained by each model, Akaike Information Criterion (AIC), and adjusted R^2 (variance explained, adjusted for the number of predictor variables) were used as supporting metrics to evaluate overall model performance. Model selection emphasized whether diagnostic plots indicated nonrandom patterns of variance, independence of residuals, and adequate representation of nonlinear relationships in depth and spatial variables. Alternative formulations of the response variable, the choice of statistical distribution, and combinations of predictor variables were iteratively tested and assessed. Consistency with known fishing practices and patterns described by workshop participants was also considered when choosing between models with similar statistical performance. This process ensured that the final selected models represented a balance between robust statistical fit and ecological and operational realism for both fleets.

Standardized catch rate series were compared to fishery-independent survey indices and alternative fishery-dependent indices derived from NEFSC Study Fleet data. Annual indices of standardized catch rates were plotted with the corresponding NEFSC spring and fall bottom-trawl survey indices (NEFSC, 2025a, 2025b), as well as alternative high-resolution CPUE indices for the commercial monkfish fishery that integrate study fleet and observer data (Jones & Legault, 2026). Overlaying standardized *z*-scores, from the alternative indices enabled qualitative comparison of temporal patterns across datasets.

$$5)\quad z_{i,t} = \frac{\widehat{CPUE}_{i,t} - mean\left(\widehat{CPUE_{i,2000-2022}}\right)}{standard\ deviation\left(\widehat{CPUE_{i,2000-2022}}\right)}$$

where the *z*-score for fleet (or survey) *i* in year *t* is derived from the predicted catch rate index for fleet *i* and year *t* and the mean and standard deviation of predicted catch rates for fleet *i* for 2000-2022, the common period for all indices in the comparisons.

These comparisons were used to evaluate similarities and differences in temporal dynamics among fishery-independent and fishery-dependent indices, considering differences in sampling design, spatial coverage, and timing. To complement the visual comparisons, a Pearson correlation (*r*) matrix was calculated to quantify the degree of temporal coherence among fishery-dependent indices and between CPUE series and NEFSC survey indices, using pairwise complete observations to account for differences in temporal coverage. Together, these analyses provided a diagnostic assessment of whether fishery catch rate indices exhibited patterns consistent with, divergent from, or complementary to fishery-independent indices, and helped identify how differences in sampling and fleet behavior may influence observed trends across fleets, regions, and data-collection programs.

Results

Stakeholder Input

Industry workshops included 25 fishermen and others from the fishing industry who described consistent themes that helped interpret CPUE trends and fishery dynamics (Table 1, Appendix C). Fishermen reported that recent declines in monkfish landings were driven primarily by increased skate catch in the gillnet fishery, market weakness, and regulatory constraints rather than reduced monkfish availability. Large catches of skates (primarily winter skate, *Leucoraja ocellata*) appear to saturate and clog gillnets and reduce capture efficiency of monkfish, while low monkfish prices reduced economic incentives to target the species, leading many vessels to shift effort to other fisheries or exit the fishery entirely. Participants in each workshop emphasized differences in fishing behavior and gear use, including shifts toward larger mesh sizes to catch more monkfish and less skates, variation in soak duration by season and depth, and the influence of seasonal migrations on depth distribution of monkfish.

Industry feedback also highlighted problems in the quality of logbook and observer data (e.g., inconsistent gear fields and effort metrics) and suggested improvements for future analysis, such as standardizing effort calculations, accounting for changes in days-at-sea allocations and trip limits for each management area over time, and a reference fleet of monkfish 'highliners' (i.e., vessels that consistently targeted monkfish throughout the time series). Reasonable data ranges were considered to identify monkfish-directed fishing effort, including standard gear used and typical fishing practices. Workshops provided crucial operational context for interpreting catch rate indices and guided model refinement and data filtering decisions.

Data 'Cleaning'

Following initial data compilation, a series of data selection steps were applied to remove erroneous or non-representative observations and to incorporate feedback from industry workshops. These steps resulted in selected datasets to reflect realistic operational ranges of fishing gear configurations, soak duration, tow speed, and fishing depth in the monkfish fishery. All data filtering steps were validated using visual assessments (e.g., histograms) to confirm that excluded values represented a small proportion of observations and did not bias results (Appendix A). The final datasets were constructed separately for each combination of gear type (southern gillnet, northern trawl) and data source (logbook, observer) and formed the basis for all subsequent CPUE standardization and model results presented below.

For the northern trawl fishery, tow speeds exceeding 6 knots were removed from both logbook and observer datasets. Such fast tow speeds were considered implausible by fishermen. Although tow speed data were frequently missing, removing only values greater than 6 knots excluded 0.8% of observations in the northern trawl observer dataset.

For the southern gillnet fishery, soak durations exceeding 168 hours (7 days) were removed, because workshop participants explained that longer durations are rare and typically associated with data entry errors or exceptional circumstances (e.g., weather-related delays). Catch records with soak durations less than or equal to zero were also removed. These exclusions accounted for less than 5% of observations in each dataset. Gillnet mesh sizes smaller than 10 inches were removed from logbook data because values below this threshold were inconsistent with standard gillnet practices. Mesh sizes larger than 15 inches were also removed to avoid retaining erroneous entries. In total, 5.3% of southern gillnet observations were removed based on mesh size. Gillnet panel lengths were restricted to 200–400 feet, consistent with ranges described by fishermen. Values outside this range were interpreted as data entry errors, possibly total gear length rather than panel length. This data decision excluded 4.9% of southern gillnet observations.

Depth values exceeding 200 fathoms were removed for both gillnet and trawl datasets to retain targeted monkfish fishing effort and exclude questionable depth records. This data decision excluded less than 1% of observations in both the southern gillnet and northern trawl datasets. All retained fishing events occurred at depths shallower than 200 fathoms. Extreme catch rate values above the 99th percentile were removed from both gillnet and trawl datasets to reduce the influence of outliers on subsequent analyses. This exclusion affected only a small fraction of records and did not alter the overall distributional structure of catch rates.

In response to workshop discussions that highlighted the effect of skates on monkfish catch rates in the southern gillnet fishery, additional exploratory dataset configurations were developed. These included excluding trips in which skates comprised more than 50% of total catch and defining monkfish-targeted trips as those in which monkfish represented more than 50%, 60%, or 70% of total catch. These configurations were used to evaluate sensitivity of standardized catch rate estimates to target behavior and bycatch interference rather than to define the final dataset.

Southern Gillnet Model – Logbook Data

The southern gillnet logbook model was developed using a Tweedie distribution (ρ=1.69) with a log link to accommodate continuous, right-skewed catch rate data. The response variable was defined as monkfish catch rate (lbs per hour), and the model included year, month, statistical area, and a smooth term for depth as predictor variables. The model was fit using restricted maximum likelihood estimation, achieving full convergence after eight iterations with a positive definite Hessian and stable parameter estimates.

Nearly all year effects were significant ($p<0.001$), reflecting substantial interannual variability in monkfish catch rates across the 1999–2023 time series, with generally decreasing catch rates in the 2000s and an increasing trend since 2015 (Figure 3). Seasonal effects were also evident (Figure 4), with significantly elevated catch rates during late spring and early summer (May-June; $p<0.001$) and lower rates during midsummer to early fall (July-September). This pattern likely reflects both seasonal shifts in monkfish distribution and differences in fishing behavior across months.

The smooth function for depth was significant (edf=3.87, $F=570$, $p<0.001$), indicating a strong nonlinear effect on catch rate (Figure 5). Catch rates generally increased with depth up to an intermediate range but decreased in deeper waters, consistent with the known mid-shelf distribution of monkfish within the southern area. Several statistical areas exhibited significant differences in catch rate ($p<0.05$). Higher catch rates occurred in Areas 621, 625, 626, 627, 635, 613, and 615 (Mid Atlantic Bight), and lower catch rates were observed in Areas 538 and 562 (southern New England; Table C3). These spatial contrasts suggest localized concentrations of monkfish biomass and varying habitat suitability across the southern region.

Model diagnostics (Appendix D) indicated reasonable performance given the variability inherent in logbook data. The model explained 9.1% of the deviance, with an adjusted R^2 of 0.088, values typical for commercial fisheries datasets characterized by high natural and operational variability. The fitted smooth captured the major environmental gradient associated with depth, and residual patterns showed no serious violations of model assumptions.

Southern Gillnet Model - Observer

The southern gillnet observer model was developed using a Tweedie distribution ($\rho=1.738$) with a log link to accommodate continuous, right-skewed catch rate data. The response variable was defined as live weight (lbs) per soak duration (hours), and the model included year, month, statistical area, tiedown presence, and a smooth term for depth as predictor variables.

Among categorical predictors, several year effects were significant ($p<0.001$), suggesting substantial interannual variability in monkfish catch rates across the 1998-2023 time series, with generally decreasing catch rates in the 2000s and increasing trend since 2017 (Figure 6). Seasonal effects were also evident (Figure 7), with elevated catch rates during late spring and early summer months (May-June) and reduced catch rates in late summer (July-September). The smooth function for depth was significant (edf=4.89, $F=74$, $p<0.001$), indicating a strong nonlinear effect on catch rate (Figure 8). Spatially, significant differences occurred among several statistical areas, with higher catch rates in Areas 625, 635, and 615 (Mid Atlantic Bight), and lower catch rates in Area 538 (Southern New England; Table C4). The presence of tiedowns had a significantly positive effect (p<0.001), indicating that tiedown gear configurations were associated with higher catch efficiency (Table C4).

Model diagnostics (Appendix D) indicated reasonable performance given the variability inherent in commercial fisheries data. The model explained 7.8 % of the deviance, with an adjusted R^2=0.094. Although modest, this level of explanatory power is typical for complex CPUE datasets with high natural variability. Residual patterns showed no major violations of model assumptions, and the fitted smooths captured the primary environmental and operational gradients influencing catch rate.

Northern Trawl Model – Logbook Data

The northern trawl logbook model was fit using a Tweedie distribution (ρ=1.604) with a log link to accommodate the right-skewed, continuous nature of catch rate data. The response variable was defined as kept weight (lbs) per tow duration (hours). Predictor variables included year, month, depth, statistical area, and vessel length. The model explained 33% of the deviance in catch rates, with an adjusted R^2 of 0.247, indicating a moderate level of explanatory power given the variability typical of fishery-dependent data.

Among the categorical predictors, year effects were significant throughout the time series (p<0.001), with higher catch rates estimated during the early 2000s and a gradual decline in later years (Figure 9). Seasonal patterns were also evident, with peak catch rates occurring from June through October (Figure 10). Monthly effects were lowest in late winter and early spring (March–April), then increased steadily through summer, reaching the highest predicted values in September and October. This pattern suggests higher monkfish availability, or catchability, during warmer months in areas fished by the trawl fleet. Both GAM smooth terms were significant, with depth (edf=3.98, F=1694, p<0.001) exhibiting a strong nonlinear relationship with catch rate (Figure 11), and vessel length (edf=8.81, F=453, p<0.001) indicating size-related differences in catch efficiency (Figure 12).

Spatial patterns were evident among statistical areas: catch rates were significantly higher in Areas 512 (off coastal Maine and New Hampshire), 515 (central Gulf of Maine), 521 (Great South Channel), 522 (western Georges Bank), and 561 (northern edge of Georges Bank; p<0.001), and lower in Area 514 (Cape Cod and Massachusetts Bay; Table C3). These spatial differences likely reflect variations in monkfish distribution and habitat across the northern region.

The northern trawl logbook model estimated significant temporal, spatial, and operational effects on monkfish catch rates in the northern trawl fishery. The strong correspondence between depth and vessel length effects suggests that both environmental conditions and vessel capacity influence catch efficiency. Model diagnostics (Appendix D) indicated some heteroscedasticity in the distribution of model residuals (e.g., greater variability of residuals for high CPUE), but diagnostics suggest that there were no major violations of assumptions, with residual distributions generally consistent with the Tweedie error distribution and no strong patterns in residual plots that would indicate remaining nonrandom patterns in the data that were not accounted for by predictor variables, with some deviations from the expected distribution for the highest values of CPUE.

Northern Trawl Model – Observer Data

The northern trawl observer model was fit using a Tweedie distribution (p=1.766) with a log link to model continuous, right-skewed catch rate data typical of commercial trawl fisheries. The response variable was defined as live weight (lbs) per tow duration (hours). Predictor variables included year, month, statistical area, and a smooth term for depth to account for temporal, spatial, and environmental variation in catch rates across the Northern Fishery Management Area.

Nearly all annual effects were significant (p<0.001), reflecting substantial interannual variability in monkfish abundance or catchability throughout the 1989-2023 time series, with peak catch rates in 2003 and 2017 (Figure 13). Monthly effects were highest in winter and early spring (January–March), then declined during April–May, followed by moderate values in summer and early fall, and the lowest relative effects in October–November (Figure 14). The smooth function for depth was significant (edf=4.84, F= 99, p<0.001), confirming a strong nonlinear relationship between depth and catch rate (Figure 15), with higher catches generally occurring at intermediate depths. Thus, the observer data suggest greater winter monkfish availability or catchability, contrasting with the summer–fall peak seen in the logbook model. Several spatial differences were detected among statistical areas, with lower catch rates in Areas 465, 511, 514 (Gulf of Maine), and 561 (northern edge of Georges Bank), and relatively higher rates in Area 522 (western Georges Bank), suggesting regional differences in monkfish distribution or trawl efficiency (Table D2).

The model explained 6.4% of the deviance in catch rates, with an adjusted R^2 of 0.065. Although the proportion of variance explained was modest, it is consistent with the variable catch rates of monkfish in the multispecies trawl fishery. Model diagnostics (Appendix D) indicated a good overall fit, with no major violations of assumptions and smooth functions appropriately capturing key environmental gradients.

Comparisons of Survey and CPUE Series

All fishery-dependent indices were positively correlated with the NEFSC survey indices, though correlations ranged from weak (r=0.11) to strong (r=0.86; Figure 16), indicating that commercial CPUE and surveys capture similar general trends despite differences in sampling design. The southern gillnet logbook, observer, and study fleet indices displayed consistently strong correlations, demonstrating internal coherence among fishery-dependent data sources in that region (Figure 17). Correlations within the northern trawl fleet were also positive, except for the logbook and observer indices. There were also generally consistent trends and positive correlations among northern surveys and fishery CPUE indices, except for the different historical trend in northern trawl observed data and the recent trend from northern trawl logbooks (Figure 18).

Discussion

The standardized indices of monkfish catch rates derived from observer and logbook datasets for the southern gillnet and northern trawl fleets showed broadly similar temporal patterns (Figures 17-18), but each fleet and data source presented distinct strengths and limitations that shape its usefulness for CPUE standardization. Most fishery-dependent and fishery-independent indices showed high relative abundance in the early 2000s, lower values in the late 2000s, and increases in the late 2010s, consistent with the strong 2015 monkfish year class identified in recent assessments (Richards, 2016; Sutherland & Richards, 2021). The common trends in surveys and fishery CPUE for the northern and southern management areas suggest common stock trends in both areas and support the conclusions of a single population of American monkfish in U.S. waters (Richards, 2016). Information from genetics, spatial distribution, a strong 2015 recruitment event in both areas, and observations of cross-boundary movement indicate a single biological population of American monkfish in US waters (Cadrin & Richardson, 2025). The northern and southern management areas appear to represent discrete fleets rather than discrete stocks of monkfish (Richards, 2016), so the monkfish stock can be assessed by standardized catch rates in the northern trawl fishery and the southern gillnet fishery.

Trends in survey and fishery catch rate indices were consistent among all five indices for the southern management area (Figure 18) and most of the indices for the northern area (Figure 17). The exceptions to these general trends were low catch rates in the early 1990s from northern trawl observer data and a declining trend in northern trawl logbook CPUE since 2019. The inconsistent trend from the northern trawl indices may result from several aspects of the northern trawl fishery, changes in fishery management strategies, and relative merits of observer and logbook data. For example, observer coverage in the northern trawl fishery was low and focused on high-bycatch portions of the fleet in the 1990s (Brooke, 2012; NEFMC, 2022b), so CPUE from observer data in those years may not represent monkfish catch rates for the entire fleet. The northern trawl fleet is also less directed toward monkfish than the southern gillnet fleet. Many northern trawl vessels participate in multiple fisheries, targeting several groundfish species (Haring & Maguire, 2008). The transition from days-at-sea to catch-share management of the New England multispecies fishery produced major changes in fishing behavior (Labree, 2012; Feeney, 2015; Swasey et al. 2021). Such heterogeneity in targeting behavior introduced variability in trip-based logbook data that apparently was not fully standardized through modeling, because some tows in a trip may have targeted monkfish but other tows in the same trip targeting other species. Seasonal patterns also differed by data source and fleet. Catch rates in the northern trawl fishery were higher in summer and early fall for logbook data but peaked in winter and early spring in observer data. These different seasonal patterns suggest that catch rates of monkfish vary widely between targeted monkfish tows and other tows in the same trip targeted toward other species. The northern trawl logbook model explained more deviance than other models, apparently because of the greater heterogeneity of the northern trawl fleet (i.e., targeting multiple species with various trawl configurations) and mixed targeting of tows within logbook trips. Hoyle et al. (2024) describe the general loss of information from aggregated catch rate data (e.g., logbook trips) and the advantages of fine-scale data (e.g., haul-based observer data) for understanding fishing behavior and standardizing catch rates.

Observer data are often regarded as more reliable because they are collected by scientists who sample both kept and discarded catch and follow standardized sampling protocols. These data provide detailed haul-level information on fishing behavior and catch composition. However, important information on depth, latitude, longitude, and other key variables were frequently missing in the observer dataset, particularly for the early portion of the time series. Observer coverage also varied considerably across years, resulting in periods of low sampling intensity and greater uncertainty in standardized estimates, reflected in the wider confidence intervals of the observer-based indices. Observer coverage generally increased for both gillnet and trawl fleets following the transition to management by annual catch limits in 2011 (Brooke, 2012) and has been near 100% for the New England multispecies fishery (e.g., the northern trawl fleet) since 2022 (NEFMC, 2022a, 2022b).

Vessel logbook records were often viewed more favorably by industry participants, who expressed confidence in their self-reported landings that are validated through dealer records. Logbooks provide a large dataset encompassing the full spatial and temporal extent of commercial fishing activity. Despite this broad coverage, logbook data have considerable limitations. Only retained catch was used from logbooks, because discard information is considered to be unreliable. However, differences in discarding practices, size selectivity, and the prevalence of mixed-target tows can therefore influence the magnitude and variability of standardized catch rates. Some gear configuration variables were inconsistently recorded in logbooks. For example, values intended to represent the length of a single gillnet panel were occasionally entered as total string length (number of panels x panel size). Although these inconsistencies restrict the use of certain covariates, the overall temporal patterns observed in both logbook and observer indices from both fleets indicate that each dataset captures meaningful variation in monkfish availability. When considered together, the two data sources may provide a stronger and more comprehensive foundation for interpreting relative abundance than either can provide alone.

The standardized catch rate indices developed in this study are intended to reflect changes in relative abundance of monkfish by controlling for major sources of variability such as year, month, area, depth, and vessel characteristics that reflect patterns in fishing behavior. These standardized CPUE indices can provide a cost-effective, repeatable, and complementary perspective, because fishery-independent survey indices for monkfish have historically exhibited high variability, limited coverage of deeper habitats, and occasionally missing surveys (e.g., COVID-19, vessel availability; Link et al., 2021; Hare et al., 2022). These data and methods can be replicated and updated for monkfish stock assessments or data updates. This approach is consistent with recommendations from the New England Fishery Management Council and NOAA's Fishery Data for Stock Assessment Working Group, which encourage the development of fishery-dependent indices to strengthen the information base for stock assessments (Cadrin et al., 2020). Spatial, depth, and seasonal effects estimated by the GAMs are generally consistent with monkfish habitats and ecology. Depth effects were strongly nonlinear, with high catch rates in deeper habitats. Spatial patterns were also ecologically consistent, with higher CPUE observed in established fishing grounds such as Georges Bank and the Mid-Atlantic Bight, and lower CPUE in inshore and shallower areas.

Feedback from fishermen provided essential context for interpreting CPUE data and patterns as well as and the broader operational factors that influence catch rates. Across workshops, participants consistently emphasized that recent declines in monkfish landings are not driven by reduced monkfish availability but by increasing skate abundance and poor market conditions. Large skate catches physically interfere with gillnet performance, forcing vessels to shorten soak times, deploy fewer nets, or abandon productive areas altogether. In parallel, low monkfish prices reduced economic incentives to target monkfish, leading many vessels to decrease monkfish-directed effort, shift effort to other fisheries, or exit the fishery entirely. Together, skate-dominated catches and weak market conditions have substantially reduced effective fishing effort. These operational and economic constraints directly affect catchability and therefore have important implications for how standardized CPUE indices should be interpreted, motivating further exploration of skate-related effects on catch rates. The metrics of fishing effort (soak or tow duration) as well as month, area, and depth effects were intended to account for these changes in fishing patterns to derive standardized catch rates that are more comparable over time for candidate stock indices. Although skate catch was not included in the final standardized models, exploratory analyses provided useful diagnostic insight into the role of skate interactions (Appendix B). When trips with high skate catch were filtered or skate catch rate was included as a covariate, the resulting standardized monkfish indices were notably more stable in recent years compared to models without skate effects. While these exploratory models did not meet statistical assumptions for formal inference, their results align closely with fishermen's observations, reinforcing the conclusion that declining CPUE reflects reduced fishing efficiency driven by skate-dominated gear saturation rather than a true decrease in monkfish biomass.

Workshop participants also suggested several methodological refinements for future analysis. These included developing an index-fleet approach focused on vessels that consistently targeted monkfish throughout the time series (i.e., a 'core fleet'; Hoyle et al., 2024). Participants also emphasized the value of continued joint examination of monkfish and skate catch patterns by area, depth, and season. Advanced models with interaction terms could be used in the future to explore these more detailed behaviors, and there is potential for additional CPUE analyses that include environmental variables. The New England Fishery Management Council's Monkfish Advisory Panel and Committee discussed the potential to improve days-at-sea management by accounting for significant factors of catchability (e.g., Wright et al. 2017, 2018).

Despite the generally consistent trends in fishery catch rates and fishery-independent surveys (Figures 17-18), and the standardization of fishing gear (e.g., mesh size, gillnet tie downs) or vessel size (length, horsepower, tonnage), some variation in catchability may not have been standardized. A common concern for using fishery CPUE as a stock index is 'technology creep', or continual advances in fishing technology that may be difficult to standardize (Eigaard et al., 2014; Scherrer & Galbraith, 2000; Jones & Legault, 2026). However, the major technical developments that increased commercial gillnet and bottom trawl fisheries occurred before the time period of these monkfish indices (e.g., diesel engines in the 1930s; sonar, freezing technology, and hydraulic haulers, net reels or winches in the 1950s, synthetic nets in the 1960s, global positioning systems, GPS, in the 1970s; trawl door and net sensors in the 1980s; Eigaard et al., 2014; Finley, 2017; Kumar, 2002). For example, the transition to monofilament mesh increased catchability of gillnets, but that occurred in the early 1970s (Collins, 1979). Similarly, Palomares & Pauly (2019) estimated increased efficiency of the English demersal trawl fishery because of technology creep, but the increases in efficiency were in the 1970s and 1980s. Robins et al. (1998) found increased efficiencies from vessels that had GPS and plotters, but the increases were primarily in the early 1990s. A broader concern for 'effort creep' includes gradual learning in a fishing community on how to target a species more efficiently over time (Hoyle et al., 2024). However, New England fleets have been targeting monkfish since the 1980s (Weber, 2001; Richards et al., 2008), and the fishing community is ageing with little recruitment of new fishermen (NOAA, 2022). Monkfish fishermen explained that gillnet gear and configuration has not changed much in the last 25 years. There has been some experimentation with alternative tri-ply and thicker monofilaments, but they were not as effective. Although standardized monkfish catch rates may not account for all technological advances, the similar rates of decrease in the 2000s and early 2010s (Figures 17-18) suggest that there were no substantial increases in catchability that were not accounted for by standardization.

Conclusions and Recommendations

The general agreement among fishery-independent and standardized fishery-dependent indices as well as the alignment between industry observations, data trends, and model results suggest that there are strong signals of relative stock size in the available fishery data, and some of these indices can be considered as relative abundance indices for stock assessment or fishery management advice. Our approach also demonstrates the expertise of fishermen for understanding the monkfish resource, their fishery and the available fishery monitoring data. Integrating industry knowledge with quantitative modeling clarified sources of variability, improved interpretation of CPUE trends, and strengthened trust between fishermen, scientists, and managers. Considered together, the logbook, observer, study fleet, and survey indices provide a comprehensive and reliable understanding of monkfish population dynamics and offer a stronger foundation for future assessment and management than any single data source alone.

Based on acceptable model diagnostics, consistency with fishery input, general agreement in trends over time, and practical repeatability (e.g., updating through a management track assessment process), we recommend several alternative series of standardized catch rates that can be considered as monkfish stock indices:

- the southern gillnet observer index,
- the southern gillnet Study Fleet-observer index (Jones & Legault, 2026),
- the southern gillnet logbook index,
- the northern trawl observer index (truncated to remove early years with low observer coverage), and
- the northern trawl Study Fleet-observer index (Jones & Legault, 2026).

The alternative indices within each management area are estimated with data from the same fishing trips, so a single index should be selected for each fleet in a stock assessment model. After considering the strengths and weaknesses of each index, we did not identify preferred alternatives. Therefore, the selection of an index for each management area could be based on goodness-of-fit with other sources of information (e.g., total annual catch, size composition, fishery-independent indices) in an integrated stock assessment model.

For demographic stock assessment models (e.g., size-based or age-based), these standardized catch rate series could index the exploitable monkfish stock (i.e., the portion of the stock that is vulnerable to the fishery). The southern gillnet logbook LPUE index would be associated with the landed size composition and size selectivity for the gillnet fleet. The northern trawl and southern gillnet observer or Study Fleet CPUE indices would be associated with the size composition and size selectivity of total catch (kept and discarded) for each fleet. For aggregate production models, these CPUE series could index exploitable biomass, similar to indices of exploitable biomass of monkfish (>43cm) from NEFSC surveys (Richards, 2016; Figures 17-18). Time of year was standardized by month effects, but most analytical models assume that CPUE indexes stock size at mid-year.

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Figures

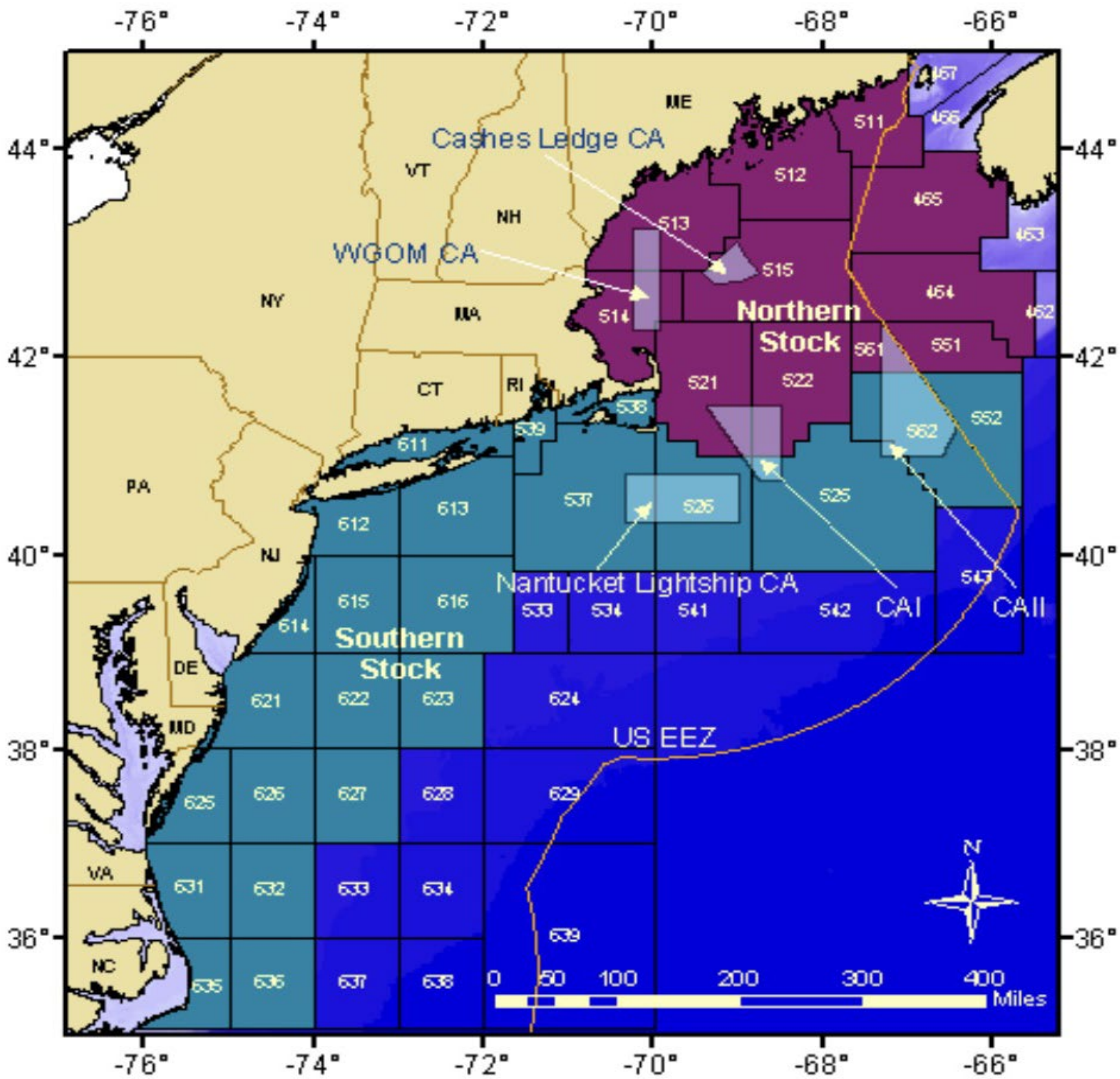

Figure 1. Spatial delineation of the northern and southern monkfish management areas based on NEFSC statistical areas (from Richards, 2016).

Figure 2. Flyer for industry workshops held.

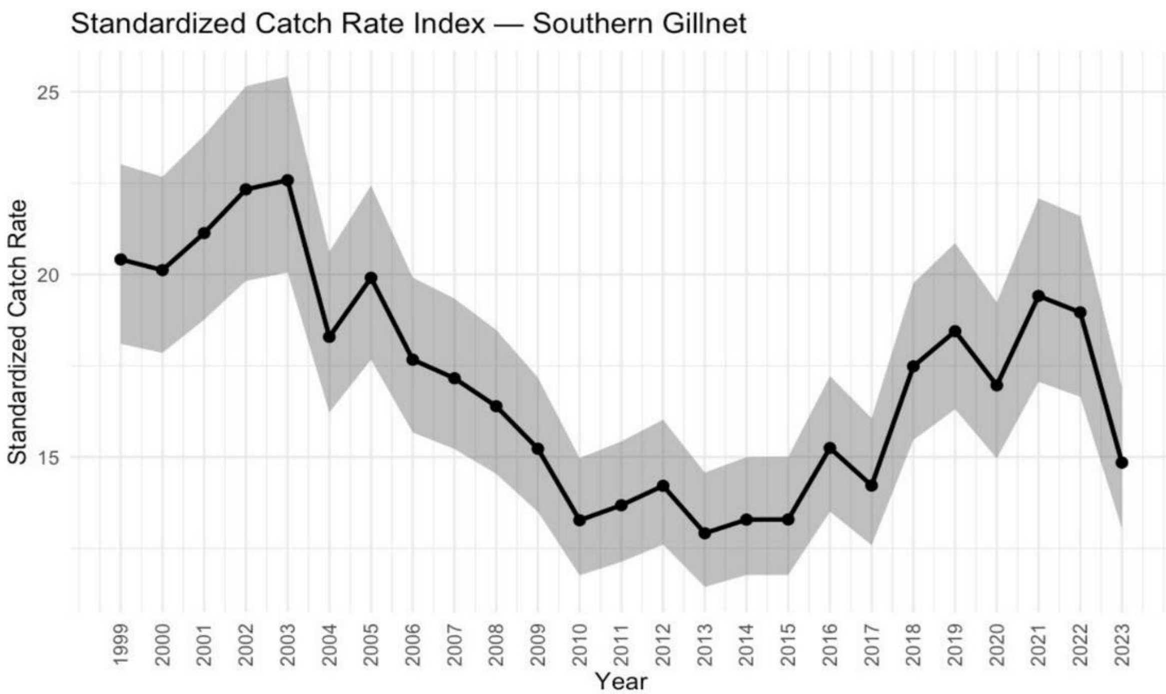

Figure 3. Southern gillnet standardized catch rate index using logbook data.

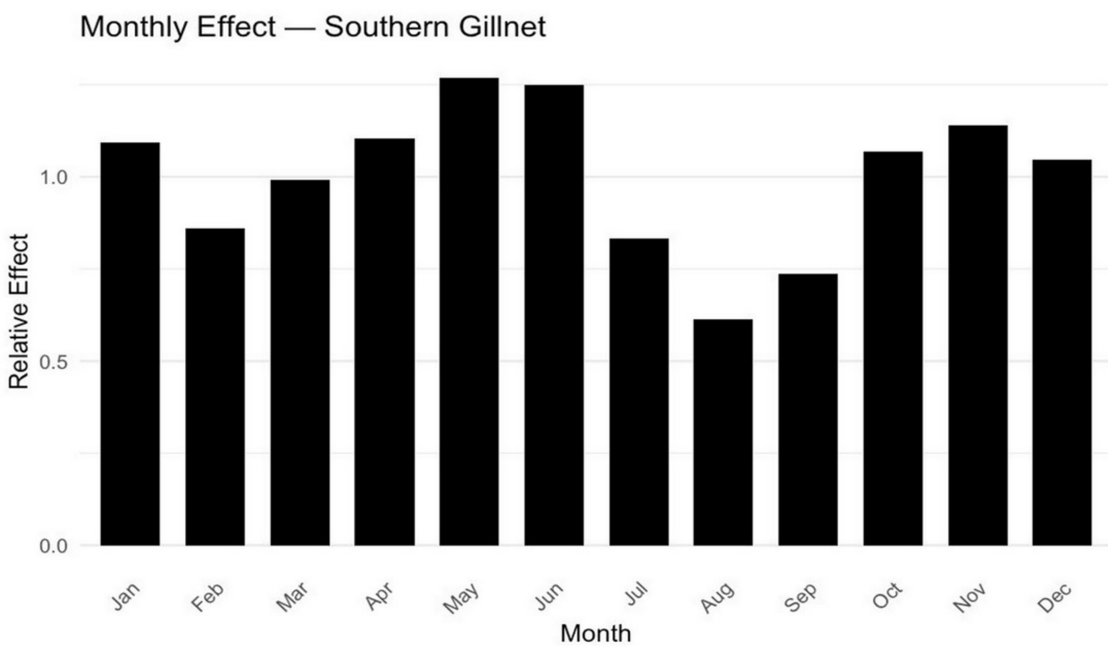

Figure 4. Southern gillnet logbook model month effects.

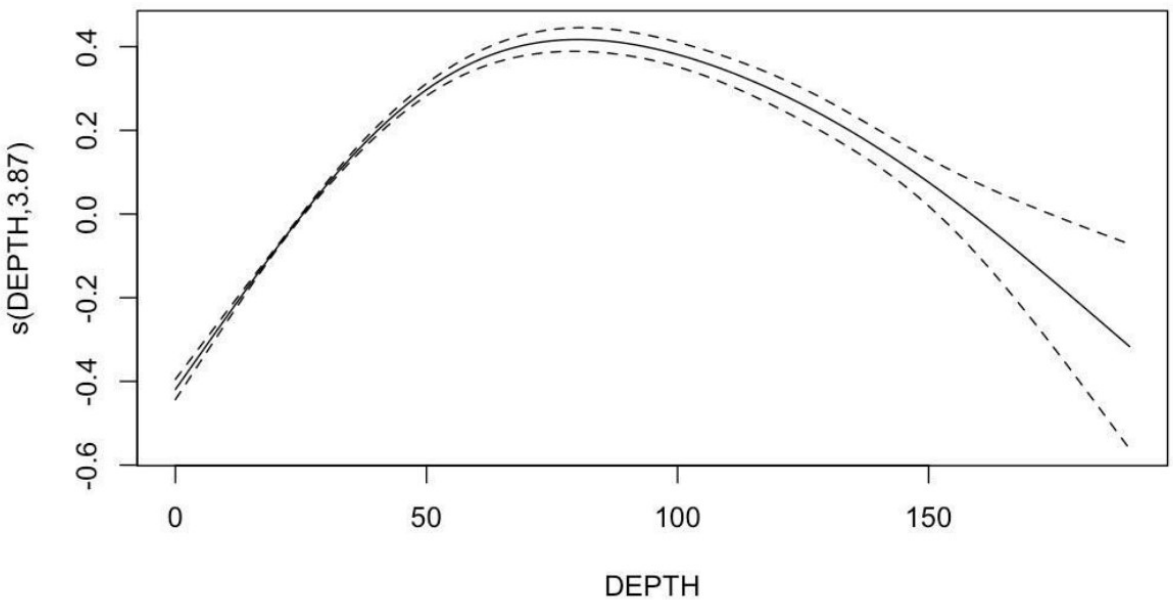

Figure 5. Southern gillnet logbook model depth effect plot, s(DEPTH,3.87)).

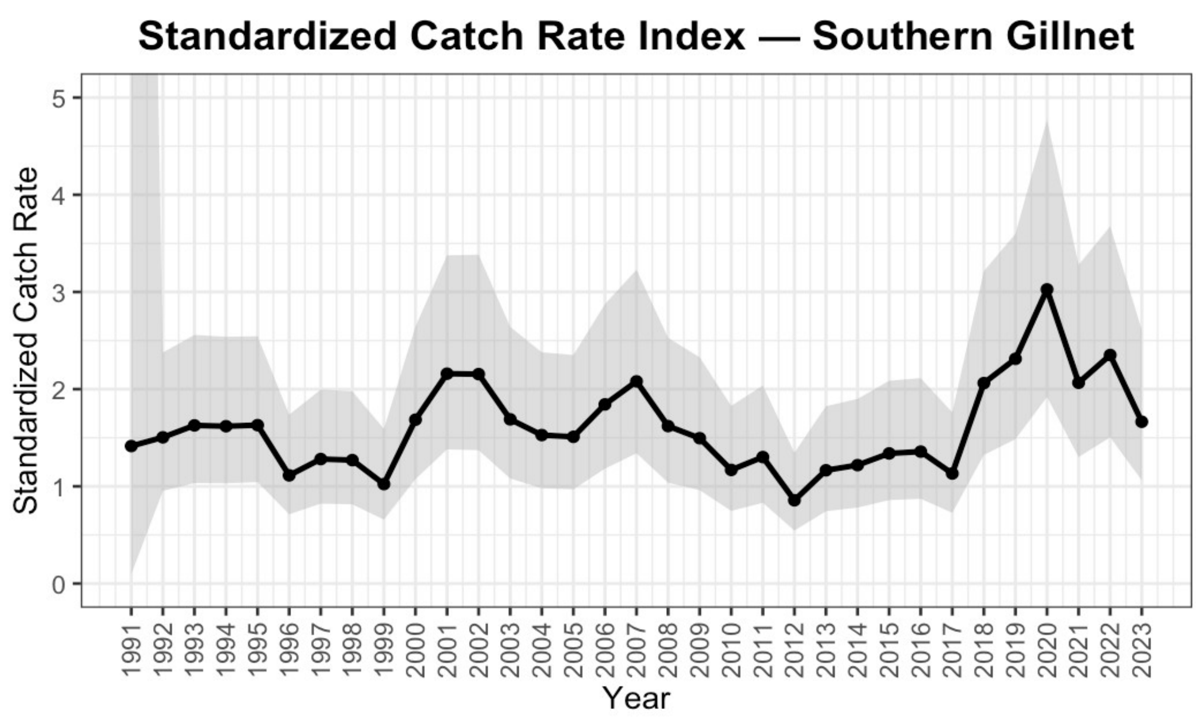

Figure 6. Southern gillnet standardized catch rate index from observer data.

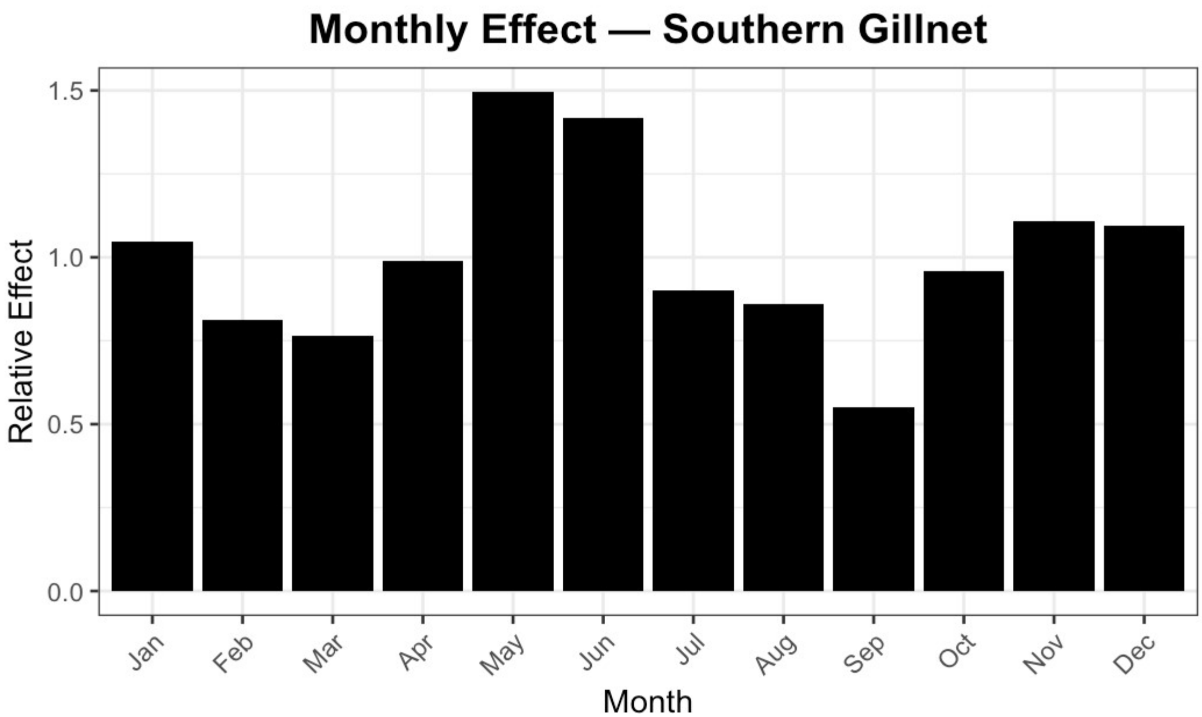

Figure 7. Southern gillnet observer model month effects.

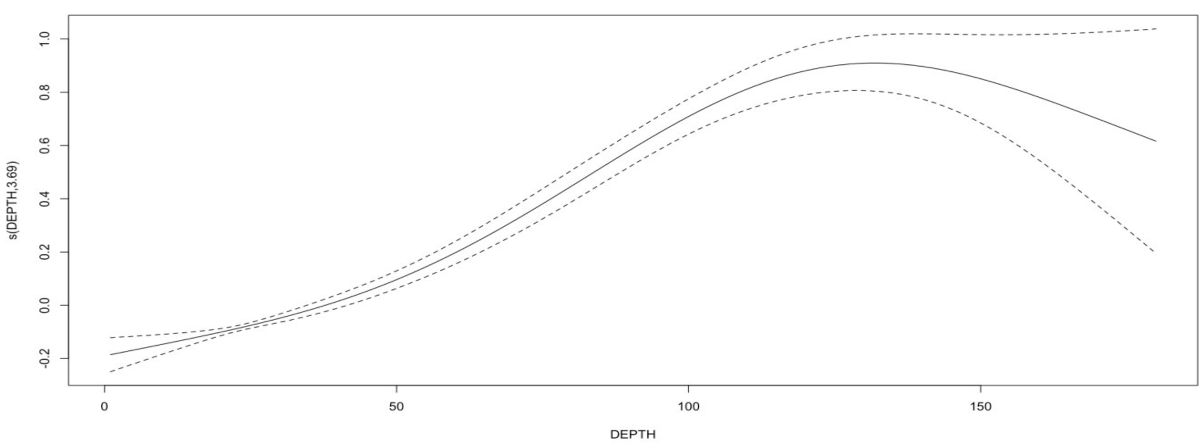

Figure 8. Southern gillnet observer model depth effect plot, (s(DEPTH_num,3.69).

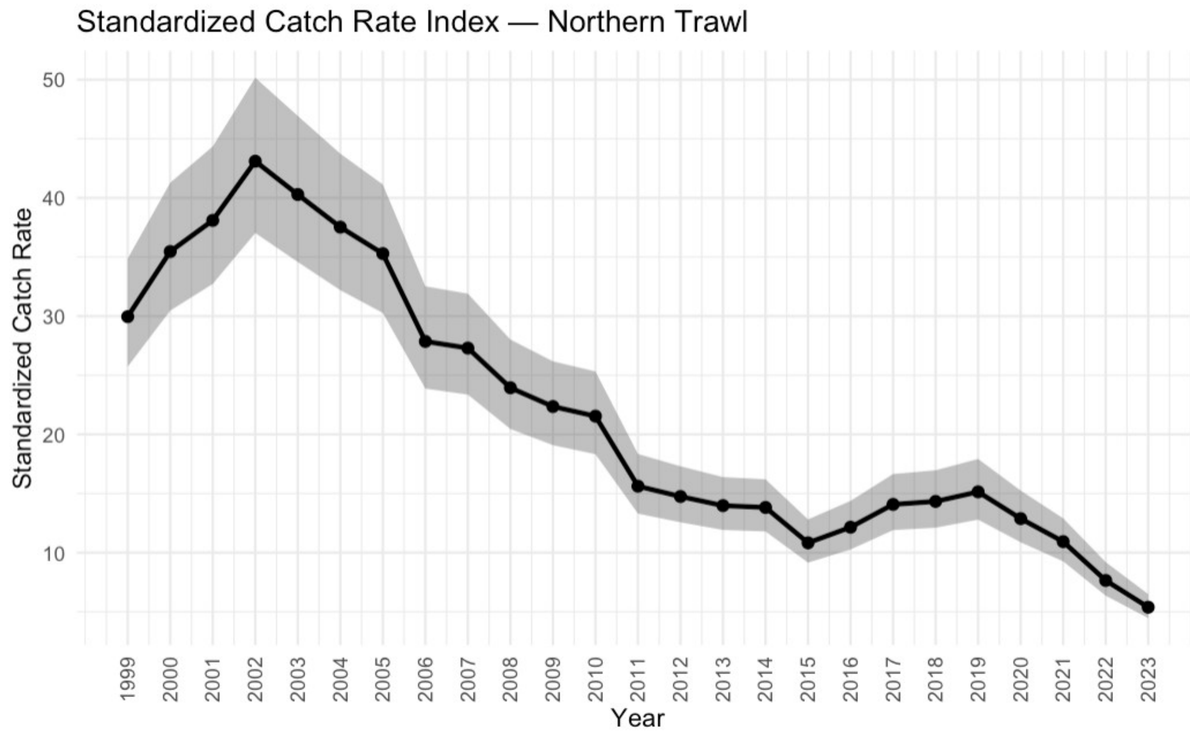

Figure 9. Northern trawl standardized catch rate index from logbook data.

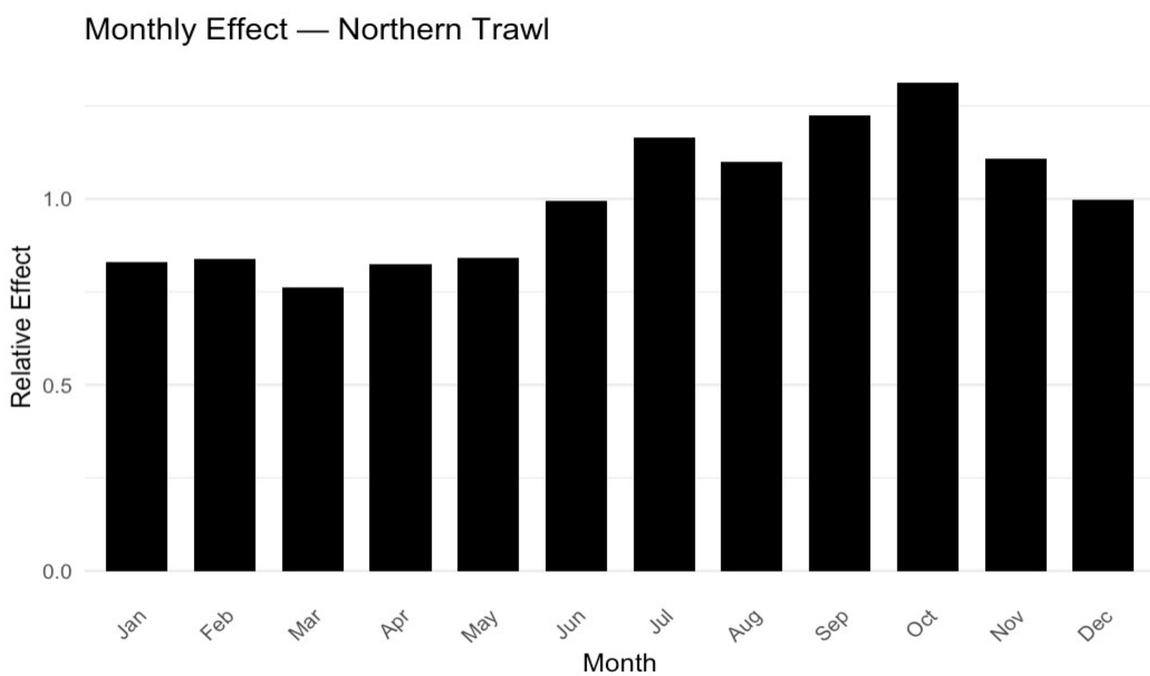

Figure 10. Northern trawl logbook model monthly effects.

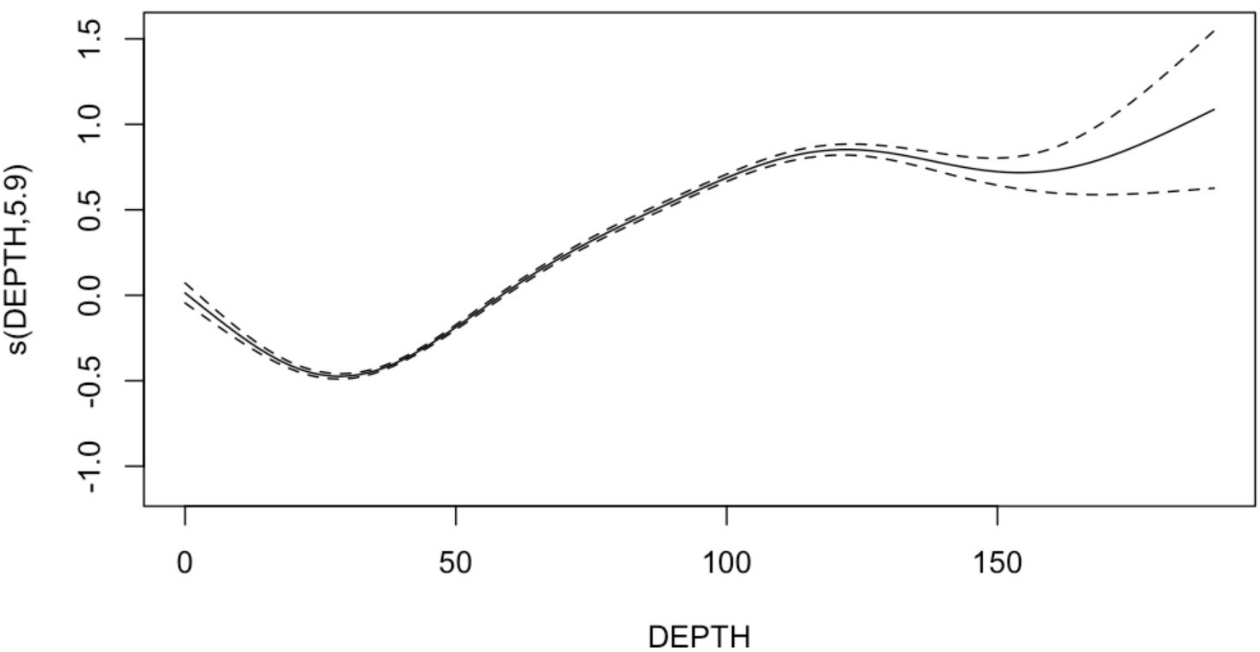

Figure 11. Northern trawl logbook model depth effect, s(DEPTH.3.98).

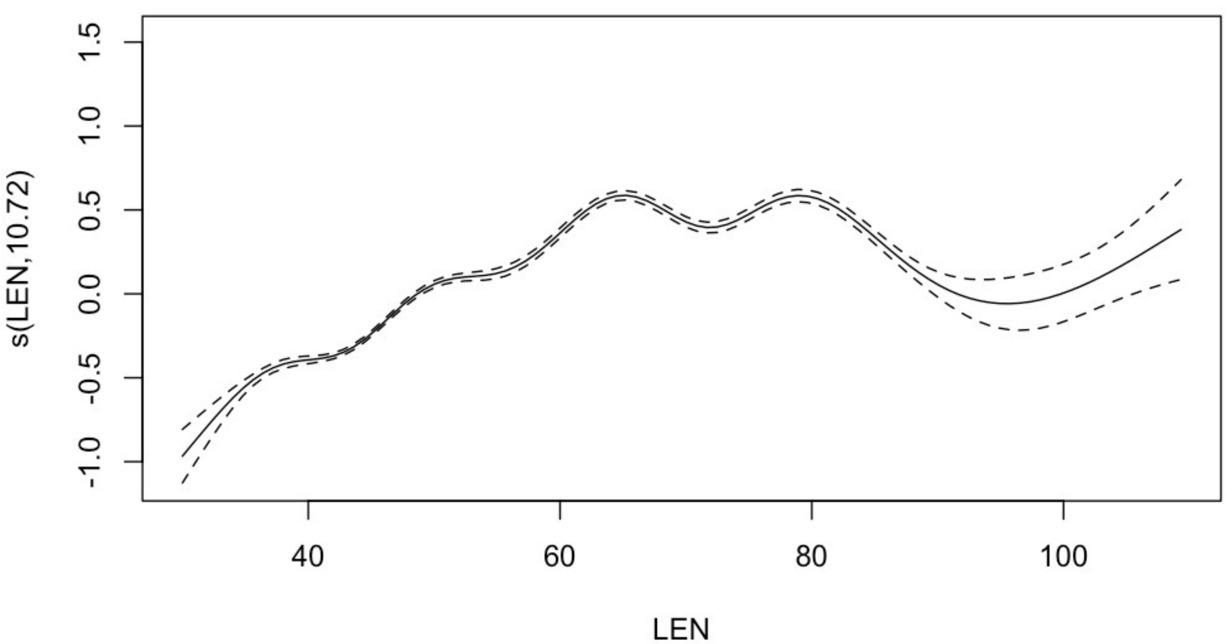

Figure 12. Northern trawl logbook model vessel length effect, s(LEN, 10.72).

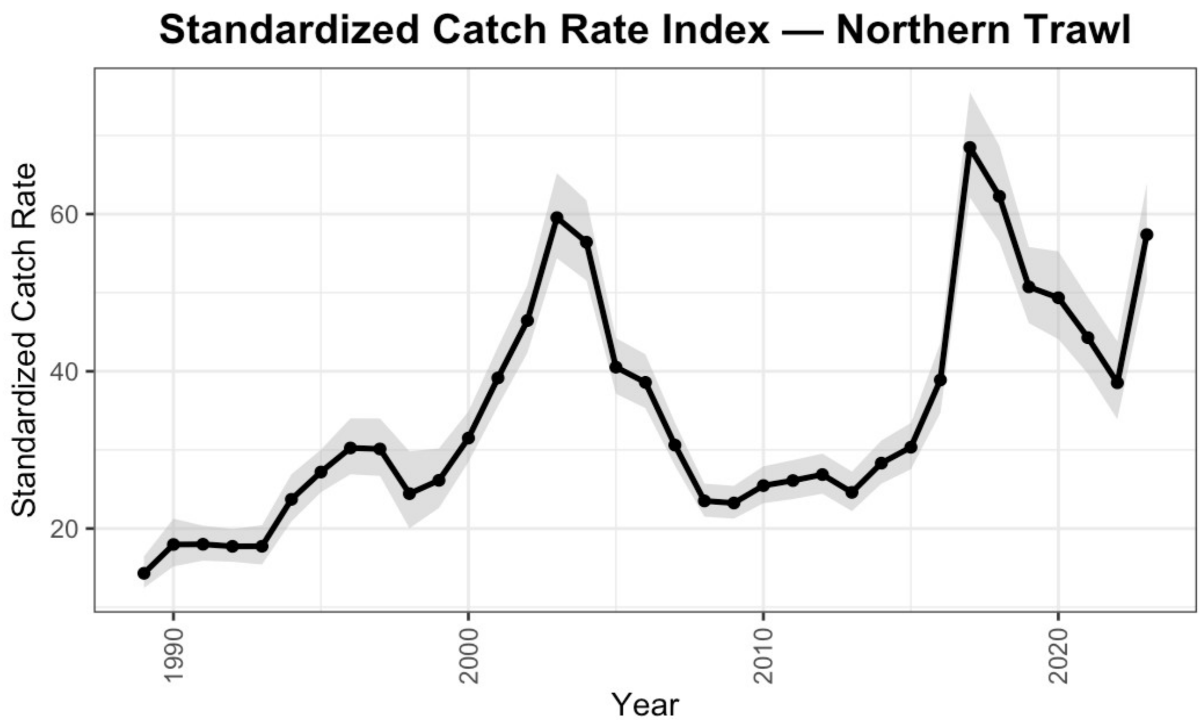

Figure 13. Northern trawl standardized catch rate index using observer data.

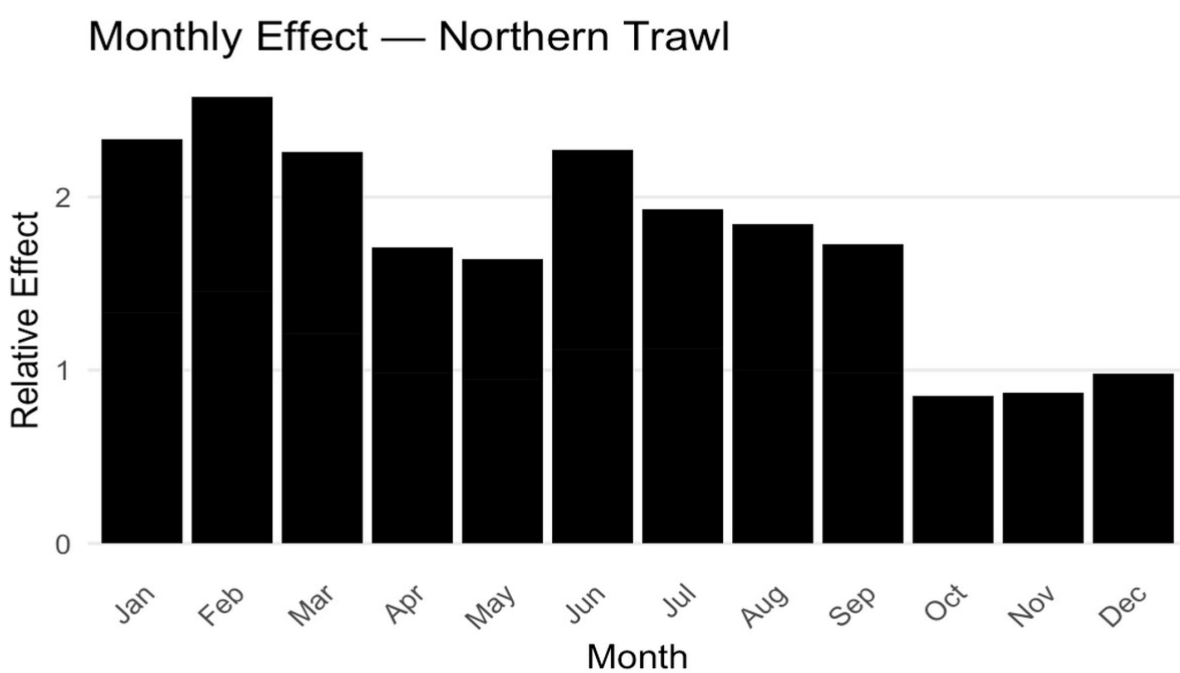

Figure 14. Northern trawl observer model month effects.

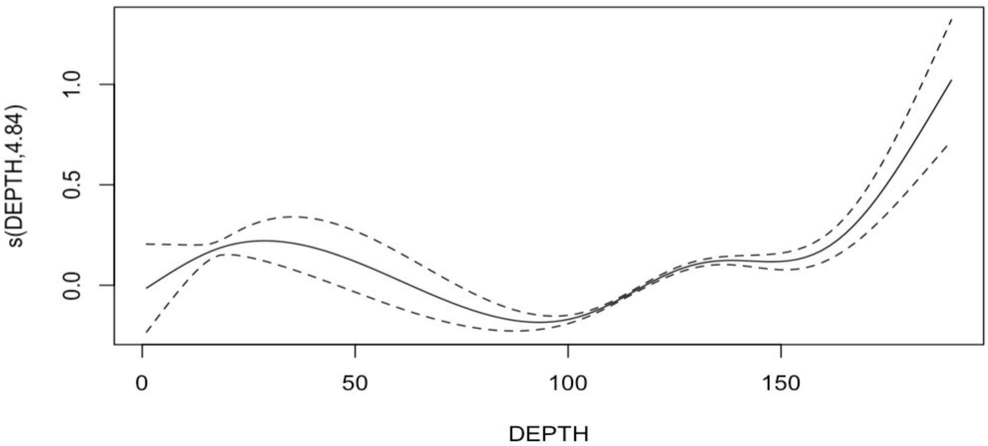

Figure 15. Northern trawl observer model depth effect, s(DEPTH,4.84).

South Gillnet	NEFSC N. Fall	NEFSC N. Spring	N. Trawl OB	N. Trawl VTR	StudyFleet N. Trawl	NEFSC S. Fall	NEFSC S. Spring	S. Gillnet OB	S. Gillnet VTR
NEFSC North Fall	1.00								
NEFSC North Spring	0.55	1.00							
North Trawl Observer	0.48	0.35	1.00						
North Trawl Logbook	0.23	0.76	-0.01	1.00					
StudyFleet North Trawl	0.51	0.86	0.65	0.67	1.00				
NEFSC South Fall	0.26	0.54	0.16	0.82	0.70	1.00			
NEFSC South Spring	0.29	0.35	0.22	0.35	0.50	0.24	1.00		
South Gillnet Observer	0.51	0.45	0.40	0.04	0.28	0.16	0.09	1.00	
South Gillnet Logbook	0.54	0.78	0.30	0.70	0.79	0.58	0.40	0.50	1.00
StudyFleet South Gillnet	0.11	0.38	0.01	0.46	0.31	0.31	0.11	0.29	0.54

Figure 16. Pairwise correlations among available monkfish stock indices. Upper left correlations are among northern indices, lower right correlations among southern indices, and lower left correlations are among northern and southern indices.

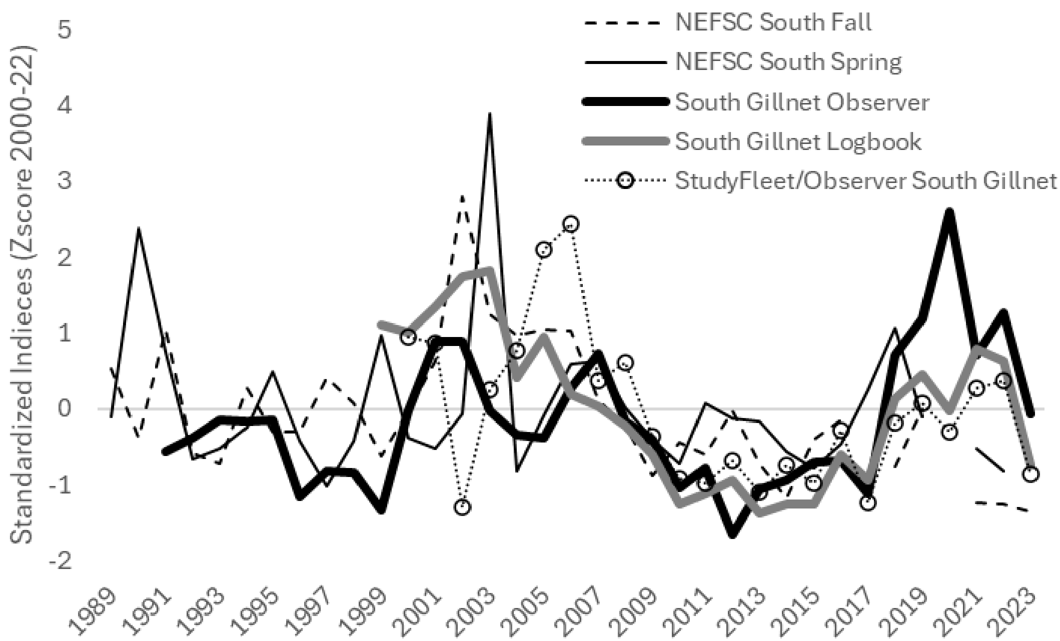

Figure 17. Time series comparing *z*-scores from southern gillnet indices from logbook data, observer data, NEFSC spring survey data, NEFSC fall survey data, and Andy Jones' combined study fleet/observer index.

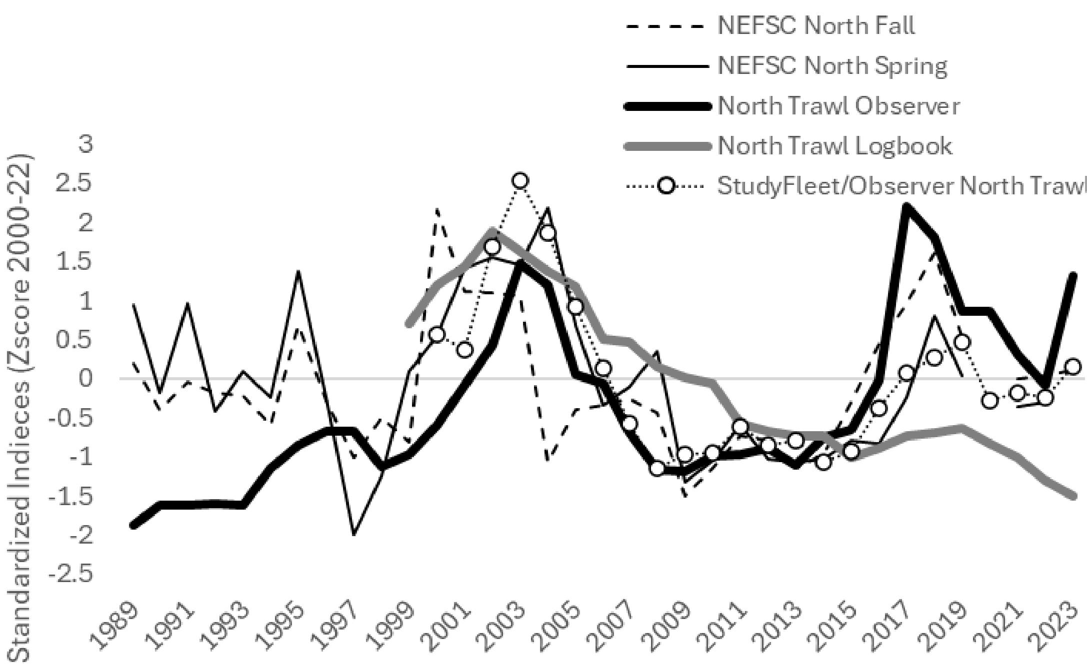

Figure 18. Time series comparing *z*-scores from northern trawl indices from logbook data, observer data, NEFSC spring survey data, NEFSC fall survey data, and Andy Jones' combined study fleet/observer index.

Tables

Table 1. Discussion summaries from industry workshops. Point Judith, NY/NJ, New Bedford, and Chatham workshops focused on gillnet in the southern management area. Gloucester and Portland workshops focused on trawl in the northern management area.

Location	Date	Summary of Discussion
Point Judith, RI	10/21/2024	Fishermen noted increased monkfish catch during 2018–2020, consistent with the strong 2015 year class observed in NEFSC surveys. Participants described regional differences, including declining northern trawl landings and improved southern stock conditions after 2004 possession limit changes. They emphasized that skate abundance has increased since 2008, contributing to the effect of closures and reduced gillnet effort. Key topics included mesh size (shifts from 10" toward 13" to reduce skate catch), variable soak durations by season and depth, and concentrated fishing between 20–100 fathoms. Participants also highlighted market drivers, including dealer rejection of small monkfish, overseas price impacts, and high-grading concerns. Discussions also addressed the importance of managing by area/month and tracking changes in days-at-sea allocations and regulations over time.
Virtual (NY/NJ)	10/22/2024	Participants described a major decline in monkfish landings driven by reduced effort, fewer vessels, management changes, and market pressures. They reported a shift in seasonality (monkfish arriving later in the year) and increased skate interference, which reduces monkfish catch rates. Mesh sizes have trended toward 13" and higher, which may target larger fish but miss smaller cohorts. Optimal soak times varied by season and temperature, with shorter soaks in warm months and longer soaks in winter when sea lice are absent. Fishermen emphasized that protected species and bycatch concerns also shape fishing patterns. They recommended standardizing soak duration by area and season and tracking "highliners" and operator-based vessel histories to better understand targeted effort.
New Bedford, MA	10/24/2024	Fishermen highlighted economic drivers and the importance of including price and cost considerations in CPUE standardization. Discussions focused on effort measurement, including soak duration, number of strings, and nets per string. Participants noted that soak durations vary seasonally and that skate-dominated winter trips can extend soak time up to a week. Mesh size choices were linked

		to skate avoidance and monkfish targeting (e.g., 12.5" and 13" used to reduce skate catch and retain larger monkfish). Depths were typically limited to 150–170 fathoms, and logbook data were discussed for accuracy and consistency. Participants suggested defining targeted monkfish trips based on annual catch thresholds and vessel behavior and highlighted the potential value of a highliner index for tracking consistent directed effort.
Portland, ME	11/04/2024	Participants described low directed monkfish effort and a recent increase in smaller monkfish in trawl catches. Discussions focused on gear and vessel characteristics that influence CPUE, including tow duration, door size, and vessel capabilities. Participants noted seasonal shifts in catch, with higher trawl catches in winter and seasonal gear conflicts with lobster fishermen. Preferred depths were centered around 90 fathoms (maximum ~140 fathoms), with tow durations typically 4–5 hours. Market conditions were highlighted as a major driver of targeting decisions, with reduced demand for monkfish livers and tails causing fishermen to target mixed species instead. Fishermen emphasized the need for standardization approaches that identify targeted trips using productive areas, seasonal timing, and gear type.
Chatham, MA	11/06/2026	Participants emphasized economic constraints and skate interference, noting that low monkfish prices and long steaming distances reduce directed effort. Heavy skate loads were described as clogging nets and reducing monkfish catchability. Discussion of logbook reporting highlighted effort calculation (soak duration × net length × strings), panel length (300 ft), and potential mesh-size reporting errors due to default values in eVTR. Fishermen also discussed soak durations (4-night typical; up to 7 nights in extreme conditions) and depth ranges (100–120 fathoms in late spring). They recommended tracking operator history rather than permit numbers due to vessel switching and stressed the need to verify VTR location accuracy using observer data.
Gloucester, MA	11/12/2024	Fishermen described declining vessel participation and shifting targeting behavior, especially during COVID when monkfish prices were higher. Participants discussed the influence of hake, skate, and other species on monkfish catch rates and expressed concern about survey sampling timing and location (e.g., zeros in areas/times where monkfish are absent). They noted that environmental factors (seals, sharks, temperature, and weather) influence

		distribution and fishing success and emphasized the importance of time-on-bottom and tow duration as more reliable effort metrics than discard data. Market price and regulations were described as primary drivers of fishing behavior, with skates targeted for bait when prices rise. Participants highlighted the need to identify targeted trips using highliner history, offshore areas, and tow-by-tow behavior, and recommended excluding inshore trips and unreliable logbook discard records.

Appendix A: Data Exploration and Filtering

Extensive data explorations were undertaken to understand and visualize the large datasets. To evaluate the precision of the data, data distributions were analyzed to visualize extreme outliers. Conversations during industry workshops solidified the use of depths within 200 fathoms to be used in analyses, as any deeper entries were not representative of true monkfish targeted effort. Figure A1 shows how the majority of the data is retained during this filtering, while extreme outliers ranging up to 2500 fathoms were removed to prevent skew. Similarly, misreported mesh sizes were identified in the data, with reports of unrealistically small meshes being removed initially (Figure A2). Because many mesh sizes were entered as "N/A," including it as an predictor was not viable in the final models, thus these entries were not removed. Similar misreporting occurred for gillnet panel lengths (GEARSIZE), with a large number of entries straying from the standard 300-foot net size. Figure A3 shows the filtering that was initially used to only include reasonable gear sizes in analyses that included GEARSIZE in the effort metric.

Additional conversations with gillnet fishermen highlighted optimal soak durations. It was clear across all ports that nobody was intentionally leaving their nets for more than a week, and those longer soak durations were extreme situations caused by poor weather conditions or difficulty accessing crew to retrieve the gear. Since soak duration was used as the effort metric for gillnets, non-representative soak durations were excluded in final models (A4).

Another way the relationships within the raw data were observed was through basic plots. Figures A5-A11 show the raw relationships between different variables and catch rates. Figure A5 displays tow speed vs catch rate for northern trawls, with extreme outliers highlighting unusually large catch rates and tow speeds. Discussions with fishermen narrowed our range of reasonable tow speeds to a maximum of 6 knots, though this was not included in final models. The relationship between depth and catch rate for northern trawls (Figure A6) helps identify outliers but also strengthens input from industry members since most reported strongest fishing within 0-200 fathoms.

Seasonality was identified as a major contributing factor for catch rates. For northern trawls, winter months seem to provide the best monkfish fishing. This is consistent with the raw relationships (Figure A7). Similarly, late spring tends to be the best for gillnets targeting monkfish, with an extreme decline in late summer (Figure A9).

To determine what measure of effort to use in the catch-per-unit-effort calculation, different catch rate plots were compared, including kept weight / soak duration, kept weight / soak duration x number of nets, and kept weight / days-at-sea. Visualizing these side by side was valuable during industry workshops, as the fishermen were able to see how the choice in effort affects analyses. Ultimately, soak duration and tow duration were selected for the gillnet and trawl models, respectively.

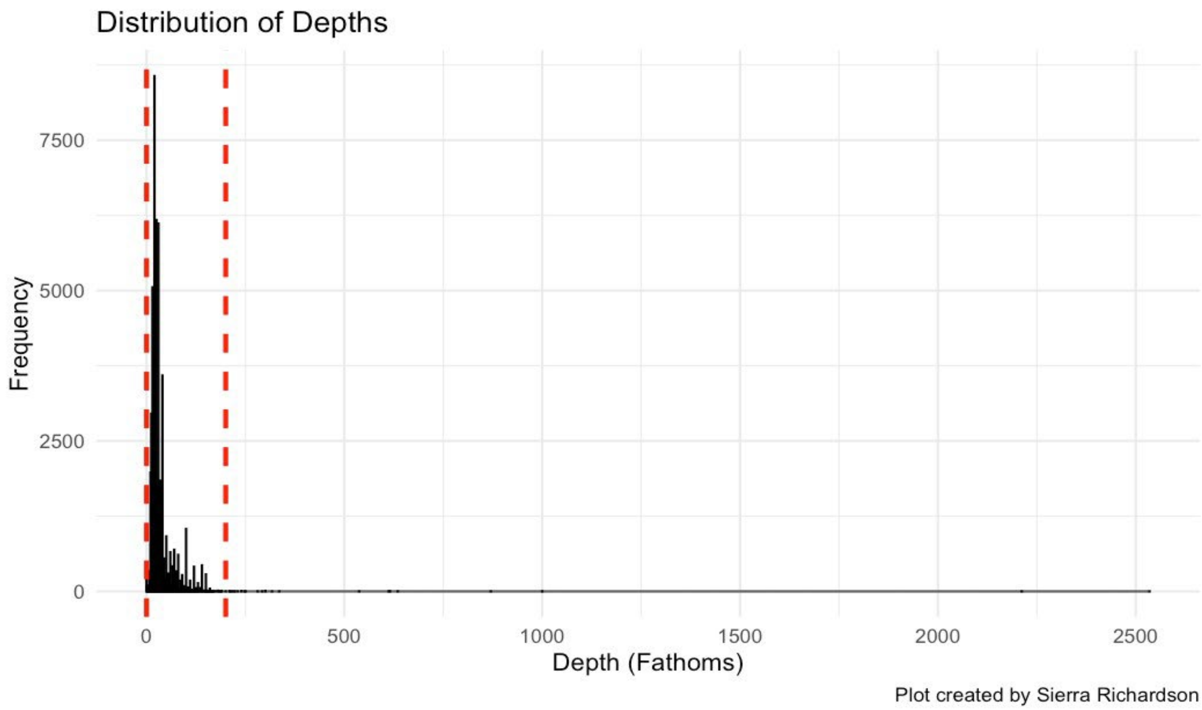

Figure A1. Distribution of depths in fathoms for southern gillnets using logbook data.

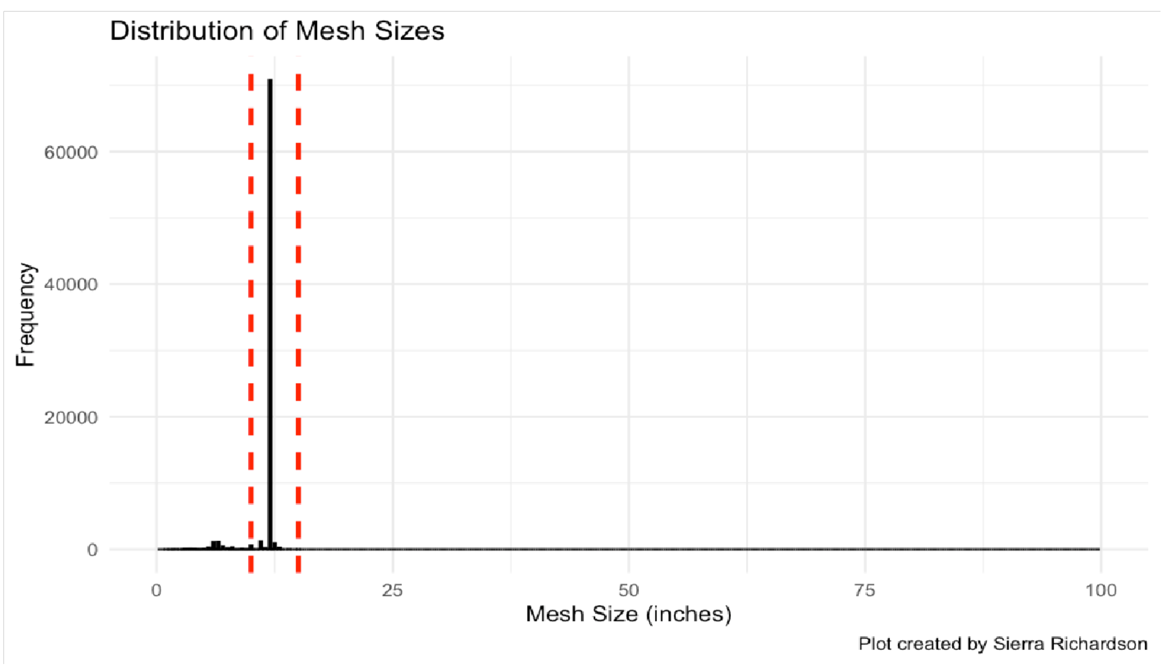

Figure A2. Distribution of mesh sizes in inches for southern gillnets using logbook data.

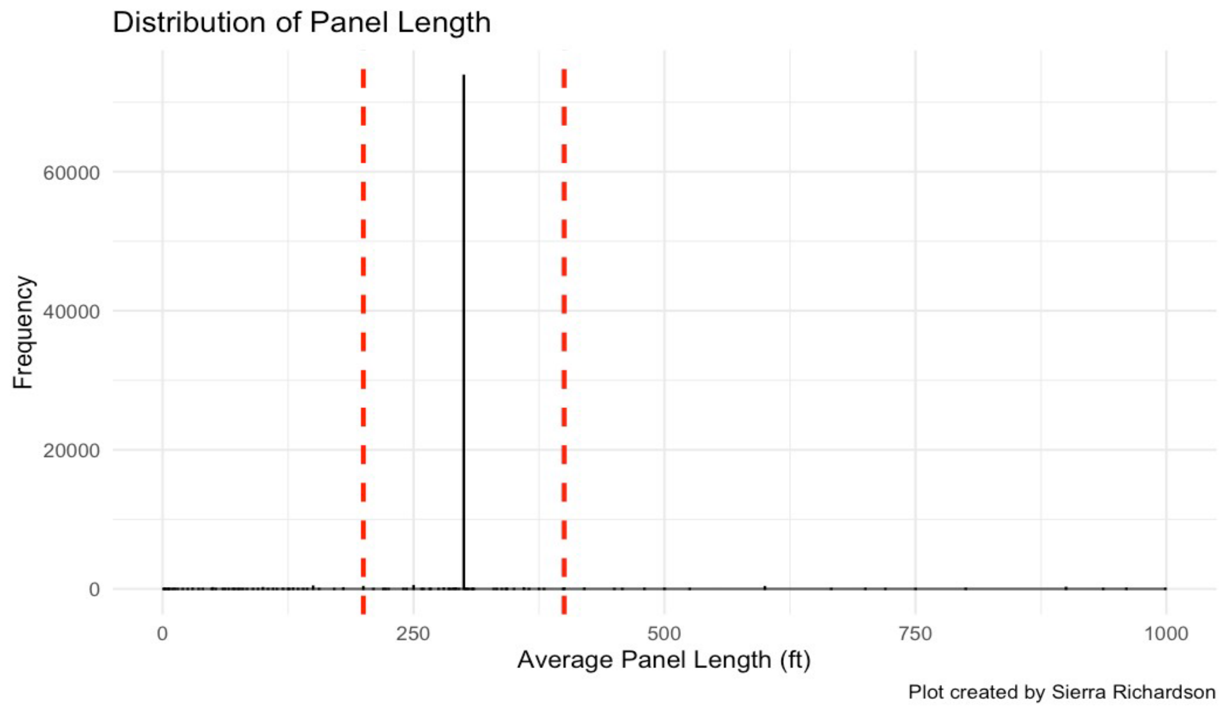

Figure A3. Distribution of gillnet panel lengths in feet for southern gillnets using logbook data.

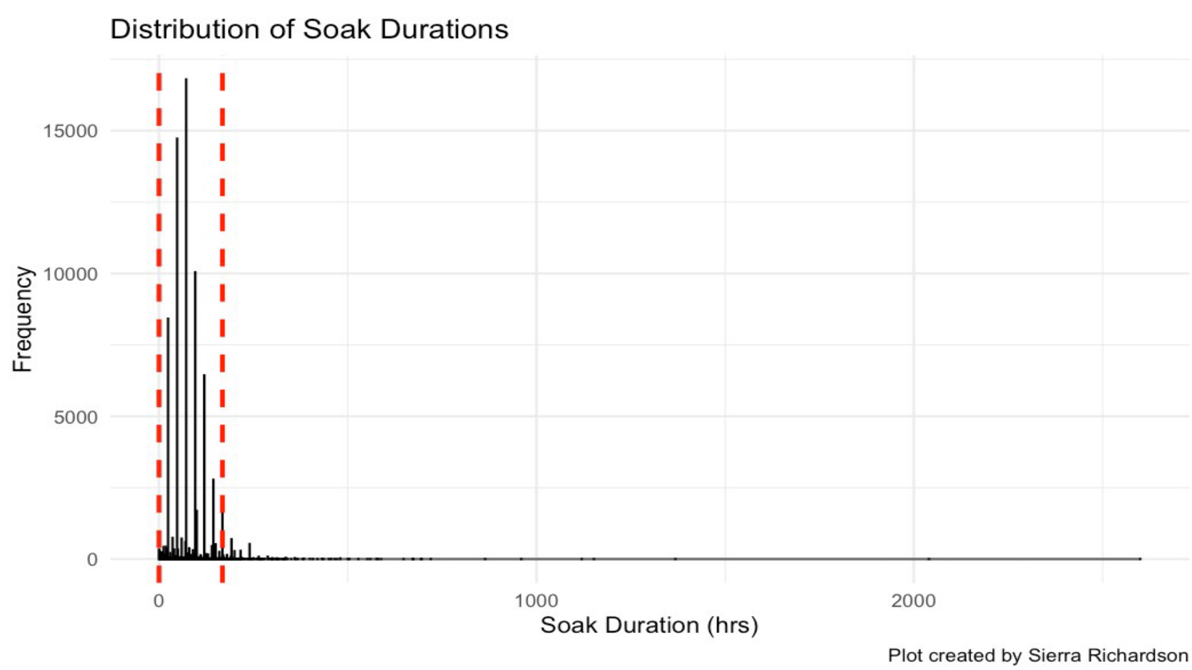

Figure A4. Distribution of soak duration in hours for southern gillnets using logbooks.

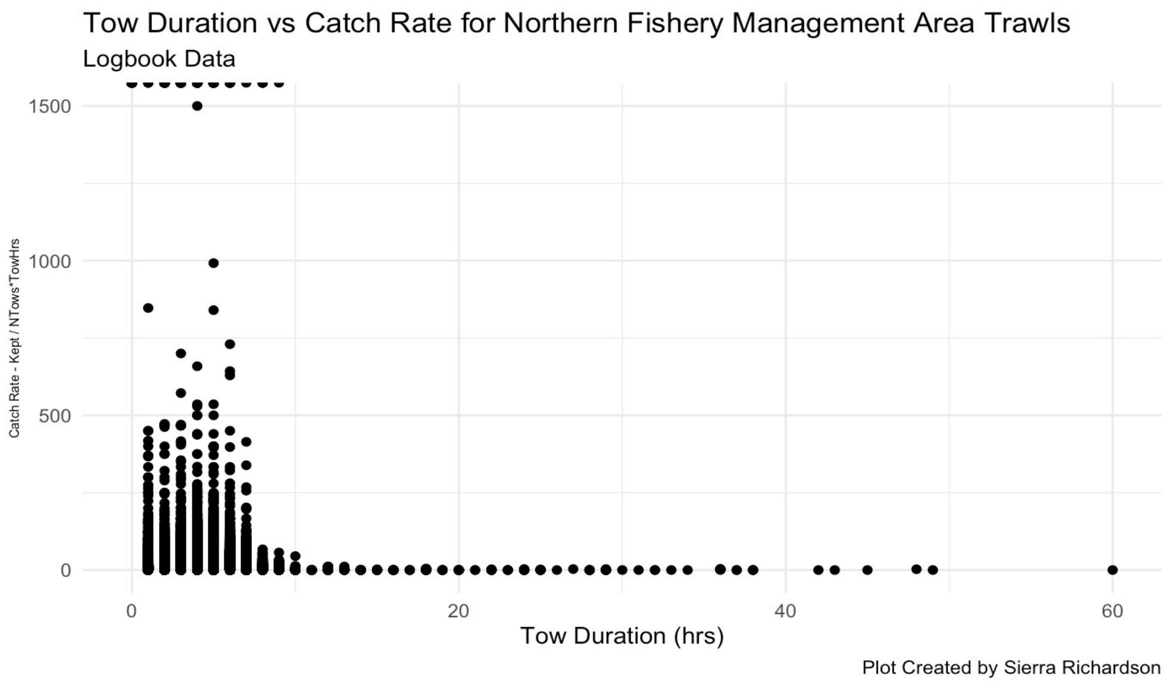

Figure A5. Relationship of tow duration vs raw catch rate (kept weight / number of tows*tow duration) for northern trawls using logbook data.

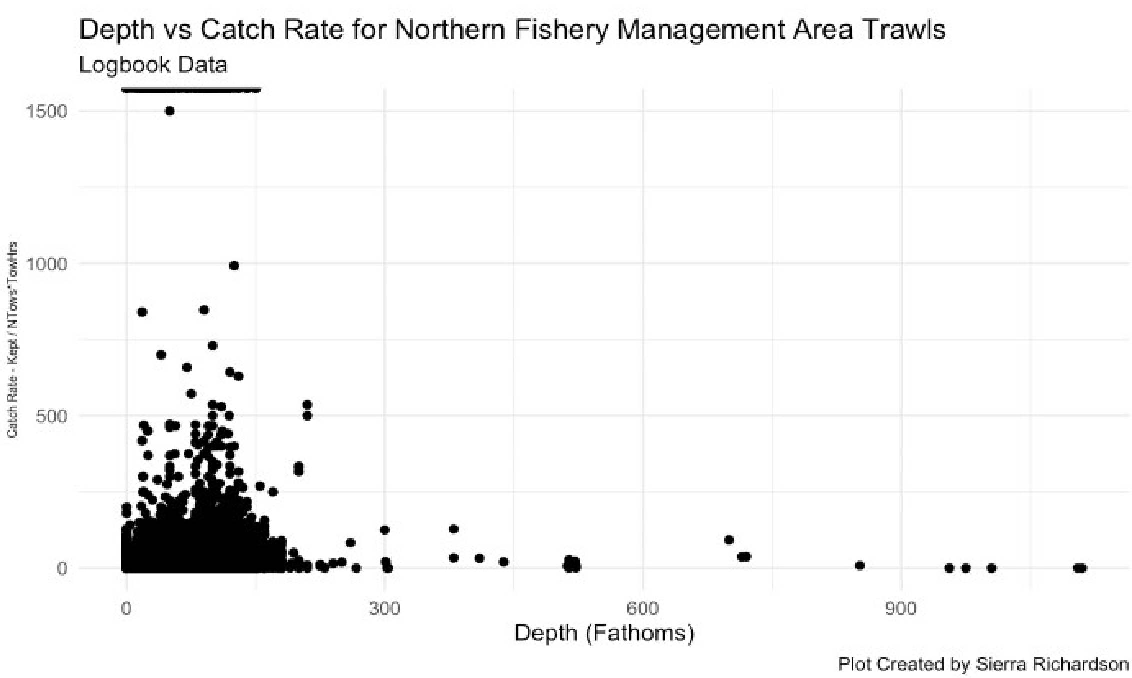

Figure A6. Relationship between depth and raw catch rate (kept weight / number of tows*tow duration) for northern trawls using logbook data.

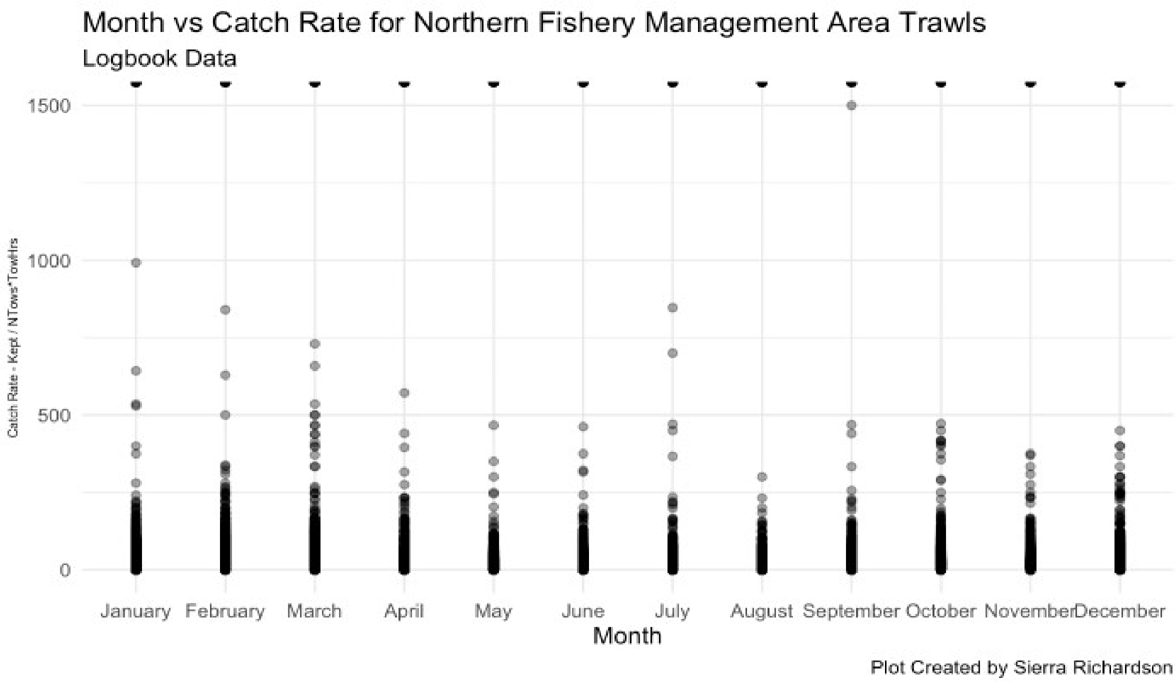

Figure A7. Relationship between month and raw catch rates (kept weight/number of tows*tow duration) for northern trawls using logbook data.

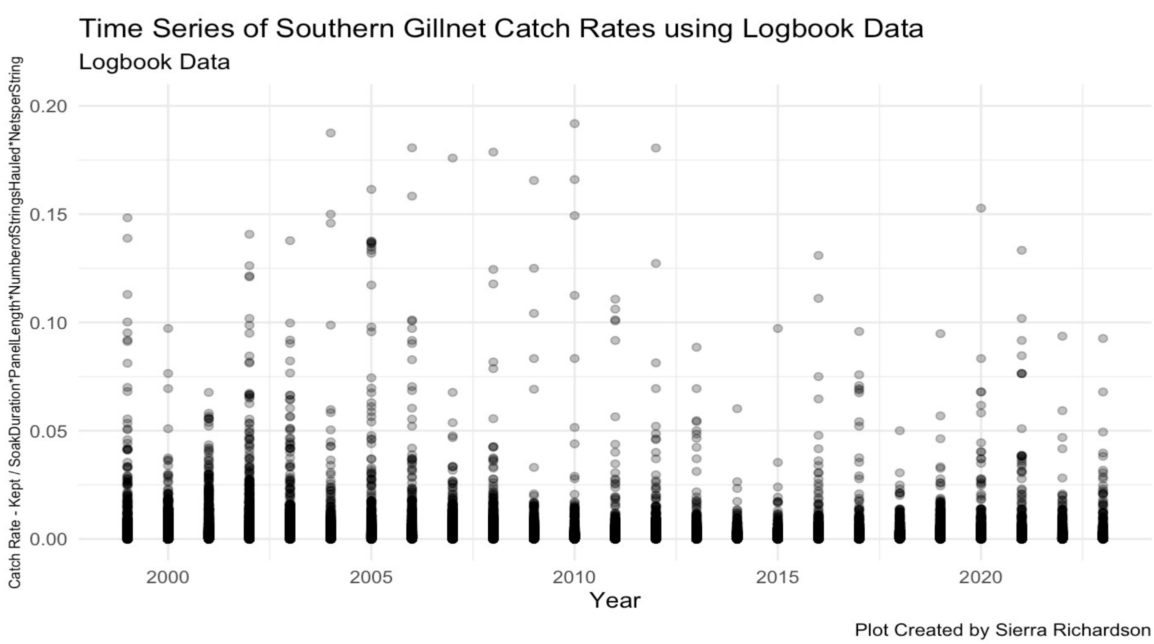

Figure A8: Time series of raw catch rates (kept weight/soak duration*panel length*number of strings hauled*nets per string) for southern gillnets using logbook data.

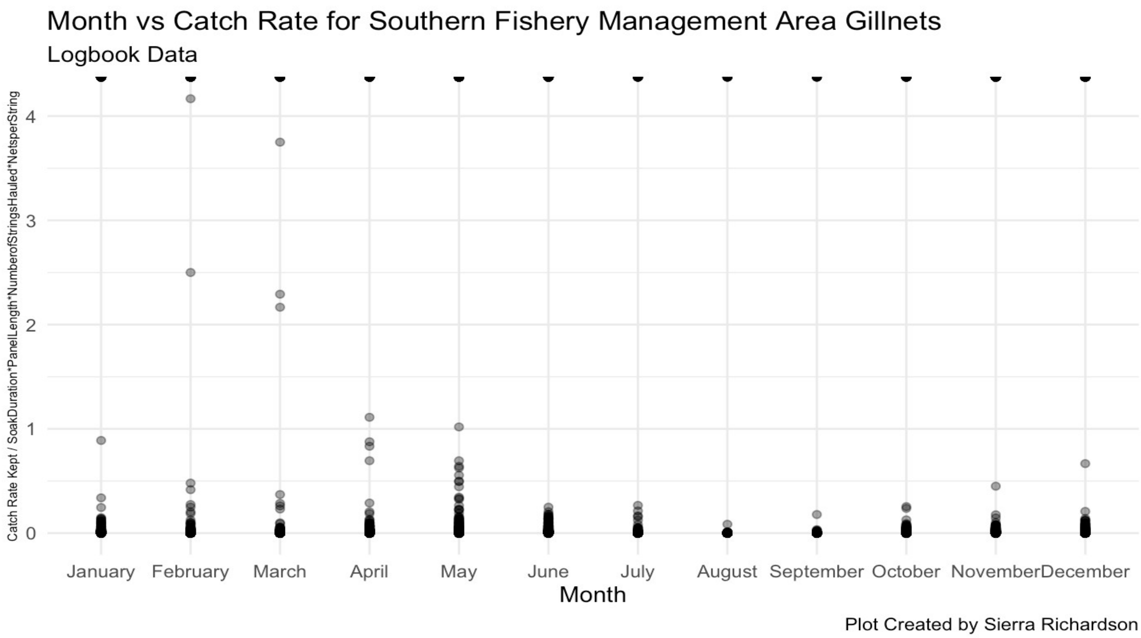

Figure A9: Relationship between month and raw catch rate (kept weight/soak duration*panel length*number of strings hauled*nets per string) for southern gillnets using logbook data.

Appendix B: Model Exploration

Several candidate model configurations were evaluated throughout this analysis. Based on feedback from industry participants regarding the influence of skate bycatch on monkfish catchability, an alternative southern gillnet GAM was developed that included skate catch rate (lbs/hour) as a predictor variable. Although this model did not yield improved statistical performance, it provided additional insight into factors shaping catch trends. Relative to the model excluding skate catch rate (Figure 12), the resulting standardized index displayed a more stable trend in recent years (Figure B1). This pattern supports fishermen's reports that reduced monkfish catchability in the gillnet fleet is driven not by declining stock abundance, but by gear saturation and operational challenges associated with increasing skate densities.

Additional models were explored to evaluate the effect of filtering trips based on skate composition. Gillnet trips in which skates comprised more than 50% of the total catch were excluded in one set of models, and separate configurations compared all monkfish positive tows with "monkfish-targeted" trips, defined as those where monkfish represented more than 50%, 60%, or 70% of the total catch. These filters slightly improved residual structure and reduced extreme outliers but did not meaningfully change the temporal patterns in the standardized index. Because these approaches increased model complexity while discarding valid data, they were not carried forward into the final model selection.

Building on insights from the industry workshops, a wide range of additional factors identified by fishermen was also tested during model development. These included mesh size, vessel length, vessel tonnage, horsepower, tow speed, tiedown usage, latitude and longitude, and interaction terms such as depth-by-area and area-by-month. Fishermen emphasized many of these variables as major determinants of catchability and operational behavior; however, incorporating them into the GAMs did not improve model fit or yield stable parameter estimates. Several k-values were also tested for the depth smooth term, and k = 5 was selected to balance smoothness, interpretability, and consistency with observed fishery patterns.

Together, these exploratory models informed the selection of the final candidate configurations presented in the main text. While none of the alternative structures outperformed the final models statistically, they provided valuable context for understanding how operational and ecological factors interact with monkfish catch rates and reinforced the importance of the variables retained in the final GAM formulations.

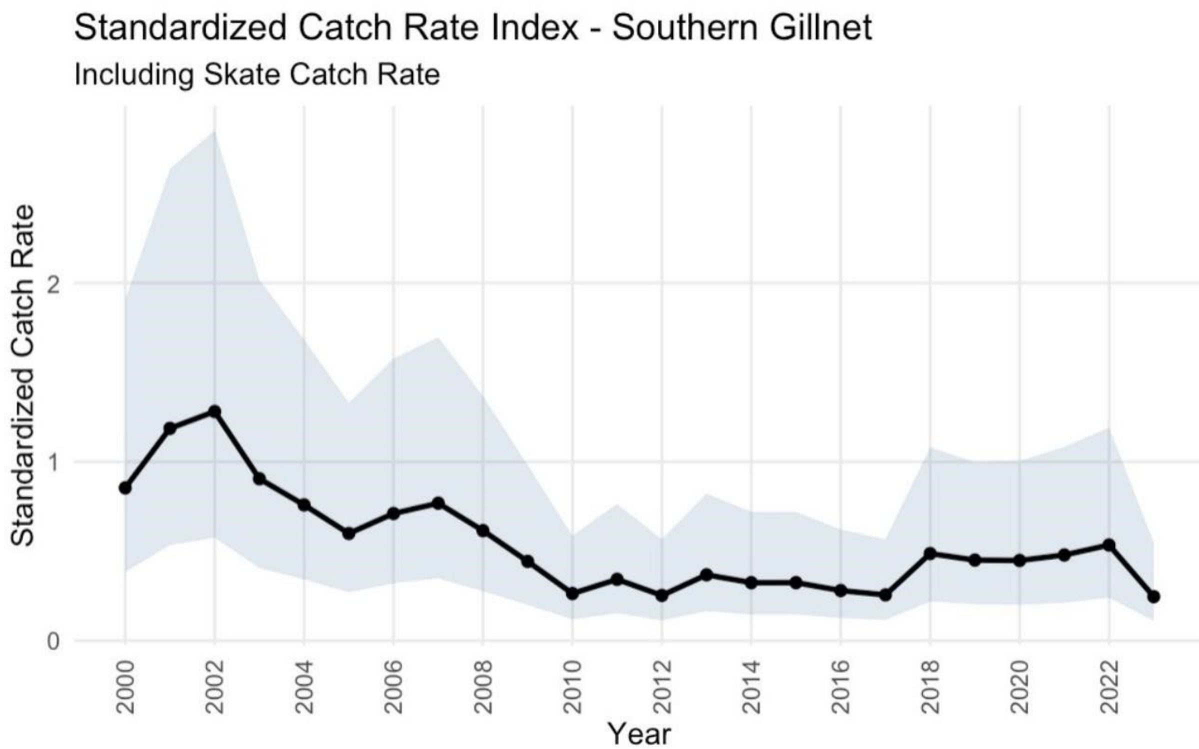

Figure B1. Southern gillnet standardized catch rates index from observer data, including skate catch rate (lbs/hour) as a predictor variable.

Appendix C: Summary of Industry Workshops

During each workshop, the project team presented project goals, background, preliminary data visualizations and trends, and facilitated a discussion with the industry on factors related to catch rates, including:

- fishing strategies (or fishing behavior) and fishing gear modifications that target or avoid certain species or stocks
- interpretation of gear codes in logbooks
- port, horsepower and captain impacts on catch rates
- quality/size range of discards
- effect of regulations over time
- changes in markets
- seasonality
- impact of groundfish quota lease prices on monk
- environmental conditions

<u>Port: Narragansett, RI</u>
Date: Oct 21, 2024
Fishermen in attendance: 3
Other govt/NGO in attendance: 1

Discussion topics of note:

- Fishermen noted increased monkfish catch during 2018, 2019, 2020. NEFSC bottom trawl survey picked up a strong 2015 year class for a few years during their surveys
- In the North, trawl landings of monkfish have dropped significantly, while in the South, stock health improved after a possession limit increase in 2004, but skate populations began to increase in 2008, leading to several closures.
- Recently, there has been a decrease in the number of gillnet vessels.
- When exploring factors impacting catch rates:
    - Mesh Size - Fishermen suggested breaking the data out by ½ inch size for data analysis. X-large mesh being 10-13 inch mesh. Preferred mesh has shifted away from 10 inches towards 13, which decreases the amount of skates and increases monkfish catch.
    - Soak Duration - Soak durations vary by season, area and depth. In Southern New England, fishermen discussed the importance of May/June, fall season, and winter (longer soak time when temperatures are colder).
- They mentioned gillnetters fish the continental slope and canyons, as well as Coxes Ledge (hard bottom).
- Depth plays a role in how long they soak the gear. Around 40-50 fathoms (shorter soak time) around 72-96 hours (3-4 days).
- Depth - Gillnet efforts are concentrated between 20-100 fathoms, with the highest catch rates in shallower depths. During the winter depths are around 80-150 fathoms, compared to summer fishing (15-30 fathoms). It was recommended to look at catch

rates by area/month, plotting skate and monkfish catch on the same graph. Looking at 30-40 fathoms vs 40-60 fathoms depth.

- Market Dynamics - Dealers do not want small monkfish. In 2020, the cut off for large monkfish was around 12-14 lbs. Discussion of high grading and to look at observer data and discards. Prices are being impacted by overseas markets
- Temperature - Suggestion to look at what temperatures skates prefer, and to explore if there is any literature to help figure out preferred temperature for monkfish
- Trip type - Discussion about how vessels are reporting their trips, and target species. Important to know how guys are declaring into the fishery on a given day.
- Data - It was suggested to consider 3 year time blocks, similar to how fishery specifications area set (e.g., 2005-2008). Also to consider how DAS allocations have changed over time (12 days to 28 DAS).
- Management Aeras/Closures - There were discussions about the effect of management area regulations, water temperature, and seasonal closures, with considerations for marine mammal protections and other ocean uses like windfarms. (Ex. NY/NJ marine mammal closures, Nantucket Lightship, South of Islands)
- Other key topics included the number of vessels participating, price fluctuations, and how catchability has evolved, particularly with restrictions on monkfish days and the increasing challenge of leasing those days. Overall, the meeting emphasized the need for continued correlation between monkfish and skate data, taking into account the ongoing impacts of environmental and regulatory changes.

Port: New Jersey/New York (virtual)
Date: Oct 22, 2024
Fishermen in attendance: 6
Other govt/NGO in attendance: 4

The meeting discussed the decline in monkfish landings, attributed to factors such as closures, reduced fishing effort, and management changes. The number of vessels has decreased, leading to fewer fishing trips and a drop in catch rates. Overall, fishing with 3X less gear and fewer vessels makes it harder to maintain catch rates, while changing management measures and market conditions continue to impact the fishery's dynamics. For 20 years, things were consistent, but in the last few years, it is dramatically different.

Discussion topics of note:

- New Jersey has noted a shift in seasonality: normally Oct to Feb but now monkfish not around until the end of December, and larger skates occupying net space, further lowering monkfish catch.
- Impact of management changes, including limits on monk and skate catches, have led to the loss of foreign markets and price fluctuations. Skates have also seen a dramatic reduction in possession limits.

- Mesh sizes are evolving, with a shift towards 13-inch mesh, potentially targeting larger, while younger fish are missed. Smaller monkfish do spawn (see the veils). 12" seems best for both small and big monks. 14" result in empty nets if no big monks around
- Optimal soak times range from 12 hours to 3 days, with longer soaks in colder months. In warm weather, 48 hrs is too long. Bad weather could cause a 3rd night. Avoid 5-6 days or you're just picking trash. If no sea lice, can get away with longer soak. Winter has cold water and no lice, can soak 4-5 days.
- Monthly catch rates have changed, with increased sturgeon bycatch and the impact of protected species like sandbar sharks and sea turtles influencing fishing patterns. Monkfish leave when the sandbar sharks show up (low 60 degree water). Skate presence changes monkfish catch rates – object of the monk fishery is to avoid skate.
- Monkfish are typically found inshore in warmer months and move offshore as temperatures drop.
- Depths vary depending on the season, with monkfish being found at shallower depths in the spring and deeper in the fall. In general, they seem to be staying further offshore.
- Discards are mostly due to species like sharks (depredation/unmarketable) or small monkfish, and high grading doesn't usually happen.
- The industry is struggling with fewer young people entering the fishery, leading to concerns about long-term sustainability.
- VTR: as a port, have agreed on standardized reporting for effort
- they used to report number of hauls as number of panels being hauled (not strings)
- New: number of panels per string (panel = 300 ft)
- To investigate:
    - Are there correlations between changes in seasonality and temperature? Patterns now are more like quick migration.
    - Price / Economic impacts – when the price is horrible, it isn't cost effective to try to catch monkfish offshore (20+ fathoms)
    - Standardize the soak duration cut off by fishing area and season and inshore vs. offshore, since each region has different "normal"
    - Overlap with other fisheries – when squid and scallop vessels show up, the monkfish fleet has to move deeper to avoid the dragger fleet.
    - May be missing some Shinnecock data due to confidentiality issues (only one vessel left)
    - The more skates there are, the lower efficiency of gillnet to catch monkfish - try different thresholds how much lbs of skate per net… compensate for lower efficiency of gear.
    - The more nets you fish, the more monks you catch … is there a threshold number of nets needed to get big monk catches?

<u>Port: New Bedford, MA</u>
Date: Oct 24, 2024
Fishermen in attendance: 3

Discussion topics of note:

- Ex vessel price for monkfish and economics of fishery should be considered for standardization
- Measuring Effort: Monk per effort, Nets per string, # of strings and soak duration, reporting # of panels and # of hauls VTR data
- Soak duration is usually 3 days but in winter it is mostly skates and can go a week because cold water preserves quality. longest valid soak 3-4 days
- Mesh size: 12.5" helps cull out the skates and would be used to target monks, 13" catches really big female monkfish and less skate, 12" is good for targeting skates
- Depth: usually no deeper than 150-170 fathoms
- Net length: should be around 300 ft. Other lengths are likely incorrect VTR data.
- Catch trends for southern gillnet:
- More monkfish on forward end of soak time, and more skate at end of soak time – first 48 hours you catch 25% monk and 75% skate. But when there are too many skates around, there don't catch monkfish because the nets are full of skate.
- Consider comparing year to year or season to season to see if soak times have changed. Oct/Nov for Coxes and Feb/Mar for offshore 100 fathom trips
- The only reason they discard monkfish is if it is not marketable (depredation or other factors that would make it not suitable for sale/consumption)
- Identifying targeted monk trips:
- A vessel targeting monks should have an annual catch of at least 10,000 lbs of monkfish
- If catching less than 500 lbs per trip, that is likely not a targeted trip.
- Could look at permit category – Monk A, B, C, D target monks but E is incidental
- Consider a Highliner index within the directed fishery and see how their catch rates change when you know they are targeting throughout the time series.
- Investigate:
  - How many northern area permits are A&B vs. C&D?
  - Highliner Index – target monkfish throughout the time series, focus on directed fisheries
  - How observer discard data in the southern gillnet fishery is coded. It should be not marketable. There is no other reason to discard a monkfish.

<u>Port: Portland, ME</u>
Date: Nov 4, 2024
Fishermen in attendance: 3
Other industry in attendance: 1

The meeting addressed various aspects of monkfish fishing in the Northern Management Area, focusing on shifts in catch characteristics and gear-related factors. Overall, effort directed at monkfish has been low.

Discussion topics of note:

- There has been a recent increase in the ratio of small monkfish for trawl gear, while gillnets continue to target larger fish.
- Key drivers of catch rates, such as vessel size, mesh size, and trip catch rates were discussed, with a focus on standardizing highliners as reference points.
- Logbook data showed fluctuations in catch, with a spike in monkfish landings around 2018 and seasonal variations, particularly higher catches from January to March.
- There is a noticeable gear conflict with lobster fishermen during the spring and summer months.
- Area-based variations in catch rates were discussed, including seasonal closures and depth preferences, with a sweet spot around 90 fathoms and a maximum depth of 140 fathoms.
- Tow duration is typically around 4-5 hours, with longer tows reducing fish quality and damaging gear.
- Gear efficiency varies and can impact CPUE. Newer gillnet gear is more effective; vessel size/door size/roller frame all influence tow duration and CPUE. Many of these types of gear metrics have limited data availability (observers should record door size and codend mesh size)
- The number of vessels has decreased, with many Maine boats switching to Gloucester for lobster fishing around 2010.
- Market trends are important. Demand for haddock versus monkfish; demand for monkfish livers used to be high, now hardly a market; when monkfish tail market isn't strong, fishermen focus on catching a mix of species instead of targeting monks to ensure a profitable trip. Fishermen feel like there are plenty of monkfish out there, they aren't being caught because the market demand is low. The monkfish market has been less profitable, leading some to use heads as bait.
- In identifying monkfish targeted trips, focus on productive areas like Platts Bank during peak months (June-August gillnet gear), deeper than 100 fathoms, or Wilkinson Basin (Jan- March trawl gear)
- The discussion also highlighted the importance of CPUE standardization for pollock assessment and the available number of days at sea for fishing.

<u>Port: Chatham, MA</u>
Date: Nov 6, 2024
Fishermen in attendance: 1
Other industry in attendance: 1

Discussion topics of note:

- Consider the impact of economics on effort – the price for monkfish has tanked, especially when they have to steam 100 miles to the fishing grounds in bad winter weather.
- Consider the impact of skate landing limits on monkfish catch. The nets fill up with skate and clog the nets so they can't catch as much monkfish.

- VTR data - Effort should be soak duration x net length x number of strings , Gear quantity = number of panels hauled, Panel length is 300 ft in the Chatham fleet
- Stared out with 12" mesh but catch more skates with 11", so switched to 11" to target skates. Caution- fleet may have been reporting 12" on eVTR when actually fishing 11" because 12" was the default for FLDRS/eVTR
- Soak duration: 4 night soak is ideal for SNE trips, 7 nights is typically the max for normal effort, barring extreme weather or vessel breakdown
- Depth- late spring is 100-120 fathoms. Deepest is 120 fathoms
- The fall peak in average catch rates by month (observer) is likely the RI fleet, not Chatham. Highest catch rates for Chatham fleet are April, May, June
- Using Monk DAS should indicate a targeted monkfish trip (use declaration codes to track)
- Discussion of tracking highliners. Reminder that a lot of the highliners switched vessels, so the vessel permit numbers associated with highliners may change over time. Should instead track operator number and determine which permits the highliner had over time. Worth evaluating the captain's location accuracy before analyzing/including their VTR data – if the location on the VTR never changes (always 69 N, 42 W), it is likely not accurate. Can also check against observer location data.

<u>Port: Gloucester, MA</u>
Date: Nov 12, 2024
Fishermen in attendance: 5
Other industry in attendance: 2

Discussion topics of note:

- Major factors in the fishery including the decline in vessel numbers over time (decrease of 2/3), changes in targeting behavior (especially during COVID when market prices were higher), and the influence of species like hake and skate on monkfish catch.
- Concern over using zeros from the trawl survey in areas where you would never expect to catch monkfish at that time of year or area.
- The timing of Bigelow tows was also discussed, as monkfish are off the bottom at night, making night tows less effective.
- Environmental factors, such as seals and porbeagle sharks, were noted for altering monkfish distribution, which impacts where/when fishermen can target monks (By October the inshore monk have moved down to 90 fathoms). Could you use depredation data from observer records to track seal interactions?
- Seasonal changes (such as migrations to deeper waters in the fall), water temperature, and weather conditions (like hurricanes and full moons) also affect catch rates.
- Tow duration, depth (with the ideal range being 80-120 meters), and gillnet soak duration (2-3 days ideally) were identified as critical variables in determining catch success.
- Additionally, effort-related metrics, such as time on the bottom and number of tows, are more reliable than discard data from VTRs.

- Market price continues to drive fishing decisions, with species like skates being targeted for bait when their value rises. They never throw away monk but may not target them when the price is relatively lower than other options.
- The discussion highlighted the need for more accurate data collection to better understand the dynamics of the monkfish fishery.
- Regulations in a given year drive catch – in 2013, they could land unlimited amounts of monkfish
- Gear notes: Rock hoppers are not used to target monkfish but you can use a disc net or loose hung roller net
- Identifying targeted monkfish trips: They are not targeting monkfish on redfish, pollock or haddock trips. They could be targeting monks when they are catching dabs or flounders.
- Consider tracking highliners who historically have and continue to target monks (they provided us with names). Inshore (west of 70 15') trips are not targeting monkfish – focus analysis on offshore boats. Can't monkfish during the rolling closures (lobster pots cover the bottom). 100 lbs of tails per day would be considered bycatch on a non-target trip.
- Targeting can be tow by tow, not always trip by trip
- VTR notes: Don't use discard data – they are putting zeros regardless. Tow duration is accurate but number of tows isn't always accurate. 4-5 hr average tow duration for a monkfish trip; exclude anything over 10 hrs.

Appendix D. Model Diagnostics

Model assumptions and performance were evaluated using the diagnostic tools implemented in mgcv, including QQ-plots, histograms of residuals, and residuals versus fitted or linear predictors plots. These visual assessments help ensure that the selected Tweedie GAMs appropriately represent underlying catch rate dynamics and that remaining structure in the data is minimal.

Across all four models, QQ-plots (Figures D1, D5, D9, and D13) demonstrated generally good agreement between residual distributions and the assumed Tweedie error structure, with only minor right-tail deviations consistent with the positive skew typical of fishery dependent catch data. Residuals versus linear predictor plots (Figures D2, D6, D10, and D14) did not show strong patterns or violations of variance assumptions, indicating that the log link and included covariates sufficiently captured relationships between catch rate and predictors. Histograms of residuals (Figures D3, D7, D11, and D15) confirmed this pattern and showed no evidence of multimodal structure. Smooth term diagnostics (Figures D4, D8, D12, and D16) demonstrated sufficient flexibility in depth and vessel length relationships without evidence of overfitting.

Diagnostic plots for the northern trawl logbook model indicate that the Tweedie GAM provided an appropriate fit to the data, with no major violations of model assumptions. The Q–Q plot showed good alignment between observed and theoretical quantiles, with only mild upward deviation in the extreme upper tail, which is expected given the occasional large monkfish catches present in logbook records. Residuals displayed moderate heteroscedasticity, with greater variance at high fitted CPUE values, a common feature of commercial catch-rate data that does not indicate model misspecification. The histogram of residuals reflected the right-skew expected under the Tweedie distribution, and the residuals-versus-linear predictor plot showed no strong curvature or remaining structure. Smooth terms behaved well, showing realistic ecological patterns without evidence of overfitting. Overall, the diagnostics support the reliability of this model and suggest that the standardized index produced from logbook data accurately captures broad-scale abundance trends despite inherent variability in commercial CPUE.

Diagnostics for the northern trawl observer model revealed a reasonable fit but with greater variability than observed in the logbook model, reflecting the smaller and more heterogeneous observer dataset. The Q–Q plot showed moderate departures in both upper and lower tails, consistent with right-skewed distributions and occasional high-catch events typical of observer-monitored tows. Residuals exhibited substantial scatter around the linear predictor but no discernible patterns, suggesting that the model successfully captured the main drivers of CPUE even with incomplete effort variables. Slight heteroscedasticity was present, particularly at high fitted values, though the residual spread remained within acceptable limits for a Tweedie CPUE model. Depth smooths behaved as expected, with no irregularities or indications of undersmoothing or oversmoothing. Despite explaining a smaller proportion of deviance than the logbook model, the diagnostics show that the observer model provides a valid standardized index given the constraints of the data.

Diagnostic evaluation of the southern gillnet logbook model showed strong performance and good adherence to GAM assumptions. The Q–Q plot displayed close correspondence between observed and theoretical quantiles across most of the distribution, with minor tail deviations typical of fisheries CPUE data. Residuals were well dispersed across the range of fitted values, with no evidence of systematic bias or missing structure. Some heteroscedasticity was present in the highest CPUE observations, reflecting occasional high catches and the strong influence of soak duration and gear quantity in the gillnet fishery. Smooth terms, including depth, showed stable, interpretable nonlinear relationships that aligned with fishermen's descriptions of habitat-use patterns. Together, the diagnostic results support the conclusion that this model effectively standardized CPUE in the southern gillnet fishery and produced a reliable relative abundance index.

Diagnostics for the southern gillnet observer model revealed greater noise and more pronounced tail deviations than the corresponding logbook model, reflecting the limited and spatially patchy nature of observer coverage in this fleet. The Q–Q plot showed departure from linearity in the upper tail, indicating sensitivity to rare large-catch events that disproportionately influence fitted values. Residual-versus-fitted plots showed scattered residuals and some uneven spread, but no patterns that suggested the model was fundamentally mis-specified. As with the northern observer model, missing or inconsistently recorded effort variables likely contributed to residual variability. Smooth terms behaved reasonably and did not show wiggly or unstable patterns. While the observer gillnet model explained a smaller portion of deviance and exhibited noisier diagnostics, the model outputs remain informative and provide a valuable complementary perspective to the larger logbook dataset when interpreting CPUE-based abundance trends.

Overall, the diagnostic results across all four models indicate that, while none of the models achieved a perfect fit, they performed well within the expectations of fishery dependent CPUE standardization, where high variability, heteroscedasticity, and occasional extreme catch events are unavoidable. Each model showed minor deviations in the upper tails of the Q–Q plots and some heteroscedasticity in residuals, but none exhibited structural patterns that would indicate serious violations of model assumptions or unaccounted sources of bias. Importantly, these candidate models performed substantially better than the many exploratory models evaluated earlier in the analysis, particularly those with alternative link functions, distributional assumptions, or covariate structures that produced unstable smooths, severe residual patterns, or unrealistic temporal effects. The selected models therefore represent the most parsimonious and statistically defensible formulations for extracting robust standardized CPUE indices from the available data.

Table D1. Coefficient estimates from the southern gillnet logbook model.

Term	Estimate	Std. Error	t value	p-value
factor(YEAR)1999	3.016	0.061	49.21	0.00E+00
factor(YEAR)2000	3.002	0.061	49.21	0.00E+00
factor(YEAR)2001	3.051	0.061	50.22	0.00E+00
factor(YEAR)2002	3.106	0.061	51.09	0.00E+00
factor(YEAR)2003	3.117	0.061	51.49	0.00E+00
factor(YEAR)2004	2.906	0.061	47.49	0.00E+00
factor(YEAR)2005	2.991	0.061	49.03	0.00E+00
factor(YEAR)2006	2.872	0.061	46.99	0.00E+00
factor(YEAR)2007	2.842	0.061	46.52	0.00E+00
factor(YEAR)2008	2.797	0.061	45.69	0.00E+00
factor(YEAR)2009	2.723	0.062	44.24	0.00E+00
factor(YEAR)2010	2.585	0.062	41.97	0.00E+00
factor(YEAR)2011	2.616	0.061	42.63	0.00E+00
factor(YEAR)2012	2.654	0.061	43.31	0.00E+00
factor(YEAR)2013	2.558	0.062	41.47	0.00E+00
factor(YEAR)2014	2.587	0.062	41.83	0.00E+00
factor(YEAR)2015	2.587	0.062	41.76	0.00E+00
factor(YEAR)2016	2.724	0.062	43.96	0.00E+00
factor(YEAR)2017	2.655	0.062	42.61	0.00E+00
factor(YEAR)2018	2.861	0.063	45.75	0.00E+00
factor(YEAR)2019	2.915	0.063	46.43	0.00E+00
factor(YEAR)2020	2.831	0.064	44.19	0.00E+00
factor(YEAR)2021	2.966	0.066	45.02	0.00E+00
factor(YEAR)2022	2.942	0.066	44.32	0.00E+00
factor(YEAR)2023	2.698	0.066	40.66	0.00E+00
factor(MONTH)2	-0.237	0.016	-14.53	9.13E-48
factor(MONTH)3	-0.097	0.019	-5.01	5.49E-07
factor(MONTH)4	0.01	0.015	0.7	4.81E-01
factor(MONTH)5	0.151	0.011	13.12	2.91E-39
factor(MONTH)6	0.134	0.012	11.41	3.88E-30
factor(MONTH)7	-0.272	0.018	-15.2	4.15E-52
factor(MONTH)8	-0.575	0.036	-16.03	1.02E-57
factor(MONTH)9	-0.393	0.039	-10.07	7.67E-24
factor(MONTH)10	-0.022	0.018	-1.26	2.09E-01
factor(MONTH)11	0.042	0.013	3.27	1.07E-03
factor(MONTH)12	-0.043	0.012	-3.47	5.17E-04
factor(CAREA)526	0.184	0.065	2.83	4.66E-03
factor(CAREA)537	0.177	0.059	2.99	2.81E-03
factor(CAREA)538	-0.385	0.073	-5.26	1.45E-07
factor(CAREA)539	0.198	0.06	3.28	1.04E-03
factor(CAREA)552	0.478	0.171	2.79	5.28E-03
factor(CAREA)562	-0.342	0.178	-1.92	5.51E-02
factor(CAREA)611	0.317	0.066	4.79	1.63E-06
factor(CAREA)612	0.303	0.06	5.06	4.18E-07
factor(CAREA)613	0.462	0.06	7.73	1.06E-14
factor(CAREA)614	0.175	0.063	2.78	5.41E-03
factor(CAREA)615	0.277	0.06	4.64	3.53E-06
factor(CAREA)616	0.355	0.064	5.6	2.21E-08
factor(CAREA)621	0.554	0.062	8.86	8.36E-19
factor(CAREA)622	0.385	0.078	4.95	7.31E-07
factor(CAREA)623	0.559	0.218	2.57	1.03E-02
factor(CAREA)625	0.42	0.064	6.56	5.26E-11
factor(CAREA)626	0.67	0.061	10.96	6.36E-28
factor(CAREA)627	0.666	0.123	5.41	6.37E-08
factor(CAREA)631	0.143	0.076	1.87	6.11E-02
factor(CAREA)632	-0.202	0.218	-0.93	3.55E-01
factor(CAREA)635	0.464	0.067	6.9	5.41E-12
factor(CAREA)636	-0.107	0.104	-1.03	3.03E-01

Table D2: Coefficient estimates from the southern gillnet observer model.

Term	Estimate	Std. Error	t value	p-value
YEAR1992	0.061	1.353	0.05	9.64E-01
YEAR1993	0.14	1.354	0.1	9.18E-01
YEAR1994	0.135	1.354	0.1	9.21E-01
YEAR1995	0.142	1.353	0.1	9.17E-01
YEAR1996	-0.24	1.353	-0.18	8.59E-01
YEAR1997	-0.099	1.353	-0.07	9.41E-01
YEAR1998	-0.108	1.353	-0.08	9.36E-01
YEAR1999	-0.324	1.354	-0.24	8.11E-01
YEAR2000	0.175	1.354	0.13	8.97E-01
YEAR2001	0.423	1.353	0.31	7.55E-01
YEAR2002	0.421	1.354	0.31	7.56E-01
YEAR2003	0.178	1.353	0.13	8.96E-01
YEAR2004	0.077	1.353	0.06	9.55E-01
YEAR2005	0.065	1.353	0.05	9.62E-01
YEAR2006	0.265	1.353	0.2	8.45E-01
YEAR2007	0.386	1.353	0.28	7.76E-01
YEAR2008	0.135	1.353	0.1	9.20E-01
YEAR2009	0.056	1.354	0.04	9.67E-01
YEAR2010	-0.191	1.354	-0.14	8.88E-01
YEAR2011	-0.084	1.354	-0.06	9.51E-01
YEAR2012	-0.502	1.354	-0.37	7.11E-01
YEAR2013	-0.194	1.354	-0.14	8.86E-01
YEAR2014	-0.149	1.353	-0.11	9.12E-01
YEAR2015	-0.055	1.353	-0.04	9.68E-01
YEAR2016	-0.041	1.353	-0.03	9.76E-01
YEAR2017	-0.223	1.353	-0.16	8.69E-01
YEAR2018	0.377	1.353	0.28	7.81E-01
YEAR2019	0.491	1.353	0.36	7.17E-01
YEAR2020	0.761	1.355	0.56	5.74E-01
YEAR2021	0.379	1.355	0.28	7.80E-01
YEAR2022	0.508	1.353	0.38	7.07E-01
YEAR2023	0.163	1.354	0.12	9.04E-01
MONTH2	-0.253	0.036	-7.13	1.01E-12
MONTH3	-0.314	0.039	-8.07	7.43E-16
MONTH4	-0.055	0.033	-1.67	9.49E-02
MONTH5	0.357	0.028	12.79	2.33E-37
MONTH6	0.305	0.033	9.36	8.64E-21
MONTH7	-0.15	0.053	-2.84	4.47E-03
MONTH8	-0.196	0.108	-1.81	7.01E-02
MONTH9	-0.64	0.102	-6.3	2.97E-10
MONTH10	-0.085	0.046	-1.84	6.62E-02
MONTH11	0.058	0.033	1.78	7.45E-02
MONTH12	0.047	0.031	1.54	1.24E-01
AREA526	0.824	0.229	3.6	3.16E-04
AREA537	0.772	0.223	3.47	5.24E-04
AREA538	0.41	0.319	1.28	1.99E-01
AREA539	0.662	0.224	2.96	3.06E-03
AREA562	0.879	0.911	0.96	3.35E-01
AREA611	0.187	0.467	0.4	6.90E-01
AREA612	1.137	0.224	5.08	3.76E-07
AREA613	1.072	0.223	4.8	1.56E-06
AREA614	0.681	0.242	2.82	4.80E-03
AREA615	1.236	0.223	5.53	3.20E-08
AREA616	1.352	0.229	5.91	3.51E-09
AREA621	0.954	0.226	4.22	2.49E-05
AREA622	1.181	0.29	4.07	4.77E-05
AREA625	1.479	0.229	6.46	1.04E-10
AREA626	1.278	0.225	5.67	1.44E-08
AREA631	1.067	0.239	4.47	8.02E-06
AREA635	1.593	0.229	6.97	3.20E-12
AREA636	2.375	0.279	8.52	1.69E-17

Table D3. Coefficient estimates from the northern trawl logbook model.

Term	Estimate	Std. Error	t value	p-value
factor(YEAR)1999	3.189	0.08	39.97	0.00E+00
factor(YEAR)2000	3.353	0.08	42.07	0.00E+00
factor(YEAR)2001	3.42	0.08	42.9	0.00E+00
factor(YEAR)2002	3.555	0.08	44.67	0.00E+00
factor(YEAR)2003	3.497	0.08	43.69	0.00E+00
factor(YEAR)2004	3.434	0.08	42.77	0.00E+00
factor(YEAR)2005	3.372	0.08	41.94	0.00E+00
factor(YEAR)2006	3.146	0.081	38.82	0.00E+00
factor(YEAR)2007	3.121	0.082	38.29	2.13e-316
factor(YEAR)2008	3.026	0.082	36.77	2.85E-292
factor(YEAR)2009	2.978	0.083	36.06	2.64E-281
factor(YEAR)2010	2.889	0.085	34.14	1.21E-252
factor(YEAR)2011	2.577	0.084	30.6	8.53E-204
factor(YEAR)2012	2.474	0.084	29.41	1.23E-188
factor(YEAR)2013	2.469	0.083	29.63	2.51E-191
factor(YEAR)2014	2.454	0.083	29.39	2.20E-188
factor(YEAR)2015	2.254	0.088	25.67	1.90E-144
factor(YEAR)2016	2.282	0.088	25.9	5.37E-147
factor(YEAR)2017	2.405	0.088	27.36	1.13E-163
factor(YEAR)2018	2.445	0.089	27.62	1.09E-166
factor(YEAR)2019	2.524	0.089	28.3	7.24E-175
factor(YEAR)2020	2.295	0.089	25.66	2.34E-144
factor(YEAR)2021	2.185	0.087	25.19	3.44E-139
factor(YEAR)2022	1.789	0.097	18.53	2.12E-76
factor(YEAR)2023	1.45	0.097	14.92	2.95E-50
factor(MONTH)1	0.517	0.018	28.28	1.26E-174
factor(MONTH)2	-0.209	0.017	-12.48	1.08E-35
factor(MONTH)3	-0.328	0.017	-19.74	2.02E-86
factor(MONTH)4	-0.015	0.017	-0.92	3.55E-01
factor(MONTH)5	0.033	0.017	1.95	5.17E-02
factor(MONTH)6	-0.057	0.017	-3.46	5.36E-04
factor(MONTH)7	0.051	0.016	3.1	1.93E-03
factor(MONTH)8	0.079	0.016	5.02	5.13E-07
factor(MONTH)9	0.061	0.015	4.06	4.95E-05
factor(MONTH)10	-0.071	0.015	-4.63	3.72E-06
factor(MONTH)11	-0.022	0.013	-1.66	9.70E-02
factor(CAREA)465	0.311	0.108	2.87	4.05E-03
factor(CAREA)511	0.065	0.097	0.66	5.06E-01
factor(CAREA)512	0.38	0.083	4.61	4.01E-06
factor(CAREA)513	0.127	0.079	1.6	1.09E-01
factor(CAREA)514	-0.355	0.079	-4.48	7.57E-06
factor(CAREA)515	0.344	0.08	4.32	1.58E-05
factor(CAREA)521	0.338	0.079	4.28	1.88E-05
factor(CAREA)522	0.427	0.08	5.36	8.41E-08
factor(CAREA)561	0.354	0.083	4.26	2.06E-05

Table D4. Coefficient estimates from the northern trawl observer model.

Term	Estimate	Std. Error	t value	p-value
YEAR1990	0.233	0.092	2.53	1.14E-02
YEAR1991	0.237	0.072	3.31	9.26E-04
YEAR1992	0.248	0.07	3.56	3.70E-04
YEAR1993	0.232	0.08	2.91	3.67E-03
YEAR1994	0.557	0.073	7.6	3.01E-14
YEAR1995	0.706	0.062	11.47	1.94E-30
YEAR1996	0.794	0.069	11.48	1.75E-30
YEAR1997	0.795	0.072	11.08	1.55E-28
YEAR1998	0.563	0.107	5.25	1.56E-07
YEAR1999	0.65	0.081	8.02	1.09E-15
YEAR2000	0.83	0.062	13.29	2.95E-40
YEAR2001	1.033	0.06	17.17	5.33E-66
YEAR2002	1.198	0.058	20.56	8.69E-94
YEAR2003	1.472	0.058	25.57	7.10E-144
YEAR2004	1.41	0.057	24.53	1.30E-132
YEAR2005	1.082	0.057	19.13	1.73E-81
YEAR2006	1.042	0.057	18.24	3.28E-74
YEAR2007	0.789	0.057	13.77	3.92E-43
YEAR2008	0.542	0.057	9.46	3.12E-21
YEAR2009	0.532	0.058	9.24	2.52E-20
YEAR2010	0.638	0.059	10.9	1.16E-27
YEAR2011	0.648	0.059	10.9	1.17E-27
YEAR2012	0.694	0.06	11.61	3.72E-31
YEAR2013	0.576	0.062	9.27	1.96E-20
YEAR2014	0.761	0.06	12.67	9.66E-37
YEAR2015	0.8	0.06	13.31	2.16E-40
YEAR2016	1.052	0.067	15.65	3.85E-55
YEAR2017	1.63	0.061	26.85	2.43E-158
YEAR2018	1.547	0.061	25.38	9.62E-142
YEAR2019	1.321	0.06	22.16	1.44E-108
YEAR2020	1.325	0.067	19.68	4.06E-86
YEAR2021	1.163	0.066	17.69	6.12E-70
YEAR2022	1.032	0.074	13.93	4.24E-44
YEAR2023	1.437	0.065	22.01	3.70E-107
MONTH2	0.039	0.016	2.42	1.56E-02
MONTH3	-0.119	0.015	-7.91	2.58E-15
MONTH4	-0.281	0.017	-16.87	8.57E-64
MONTH5	-0.228	0.02	-11.41	3.75E-30
MONTH6	-0.127	0.017	-7.34	2.08E-13
MONTH7	0.005	0.018	0.28	7.80E-01
MONTH8	0.038	0.017	2.2	2.79E-02
MONTH9	0.003	0.017	0.2	8.41E-01
MONTH10	0.006	0.017	0.35	7.30E-01
MONTH11	-0.046	0.017	-2.78	5.45E-03
MONTH12	-0.022	0.017	-1.29	1.97E-01
AREA465	-0.222	0.061	-3.65	2.63E-04
AREA511	-0.332	0.077	-4.31	1.66E-05
AREA512	-0.056	0.048	-1.16	2.45E-01
AREA513	-0.026	0.045	-0.58	5.59E-01
AREA514	-0.199	0.044	-4.53	5.96E-06
AREA515	0.026	0.043	0.59	5.53E-01
AREA521	-0.183	0.043	-4.2	2.62E-05
AREA522	0.125	0.043	2.88	3.95E-03
AREA561	-0.168	0.046	-3.68	2.34E-04

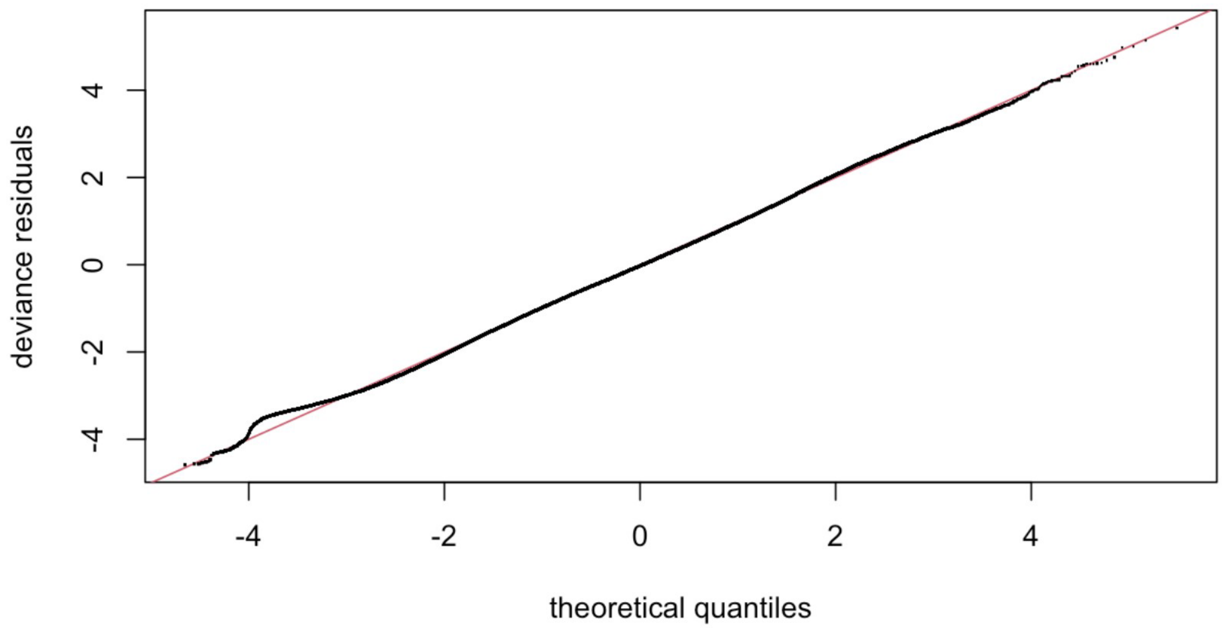

Figure D1. Southern gillnet logbook model Q-Q plot.

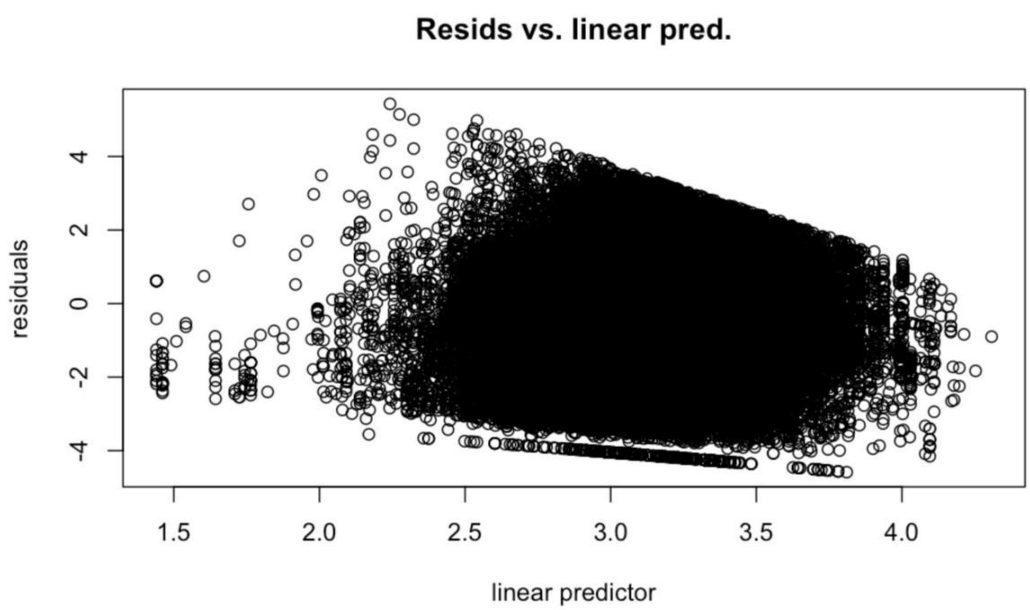

Figure D2. Southern gillnet logbook model residuals vs. linear predictor plot.

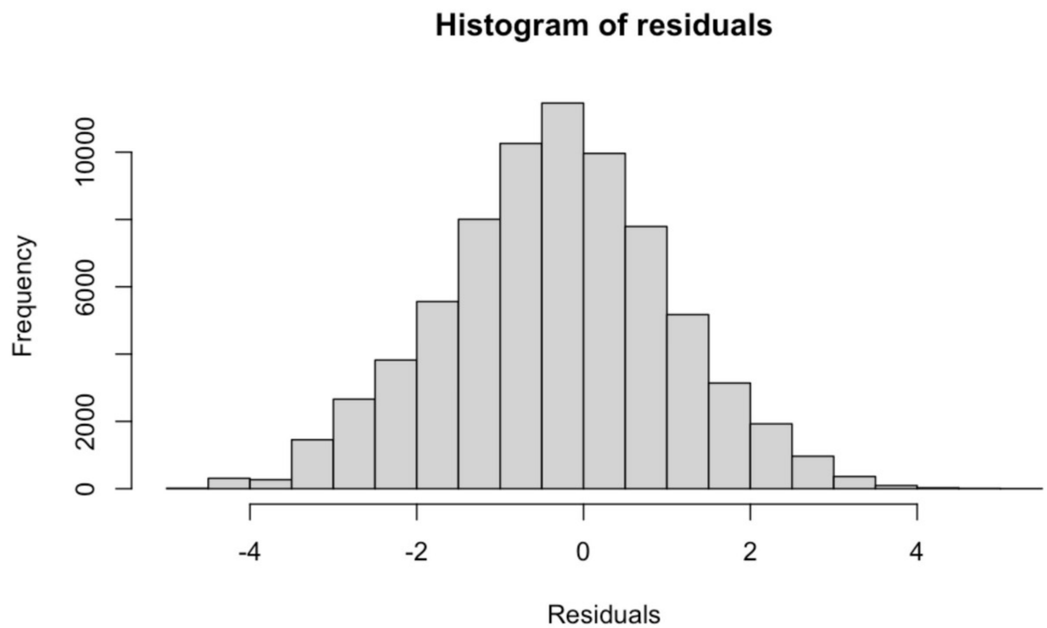

Figure D3. Southern gillnet logbook model histogram of residuals.

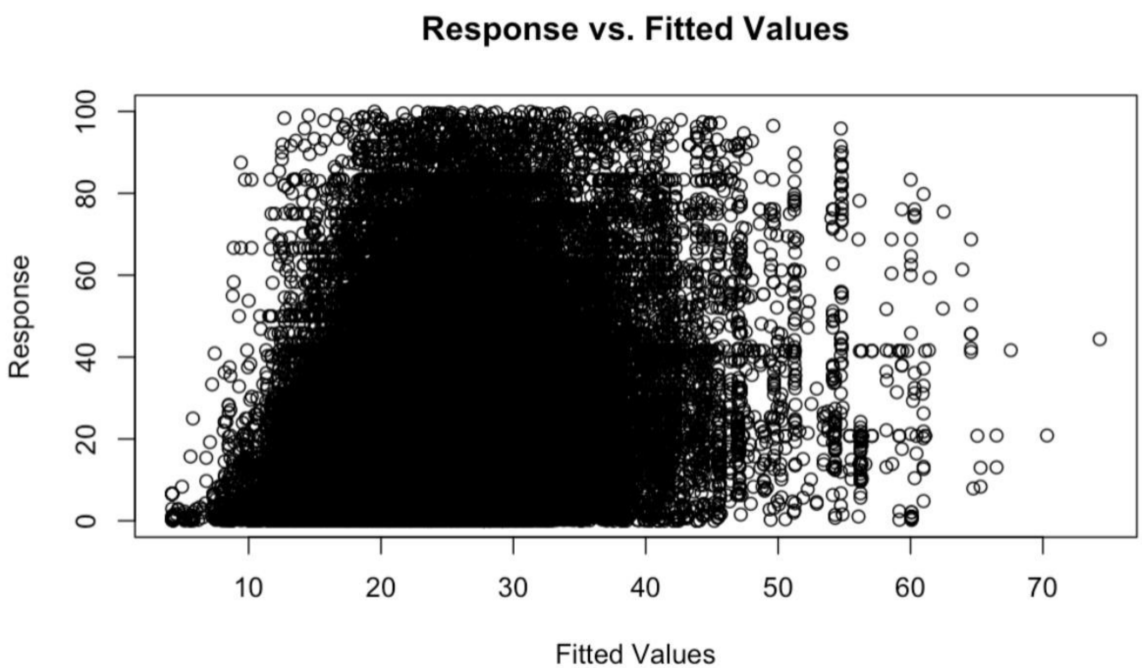

Figure D4. Southern gillnet logbook model response vs. fitted values plot.

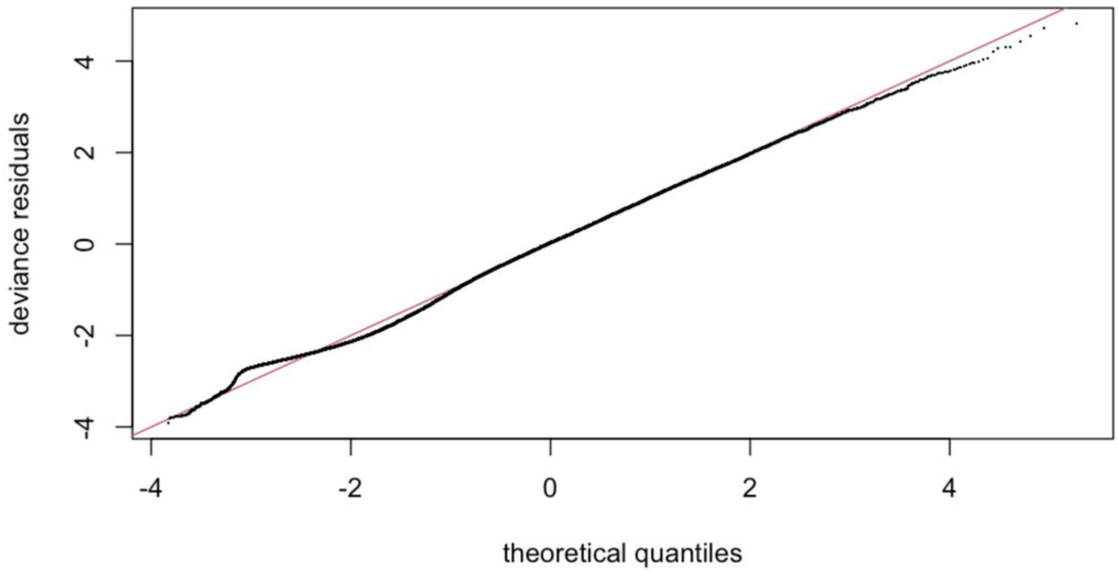

Figure D5. Southern gillnet observer model Q-Q plot.

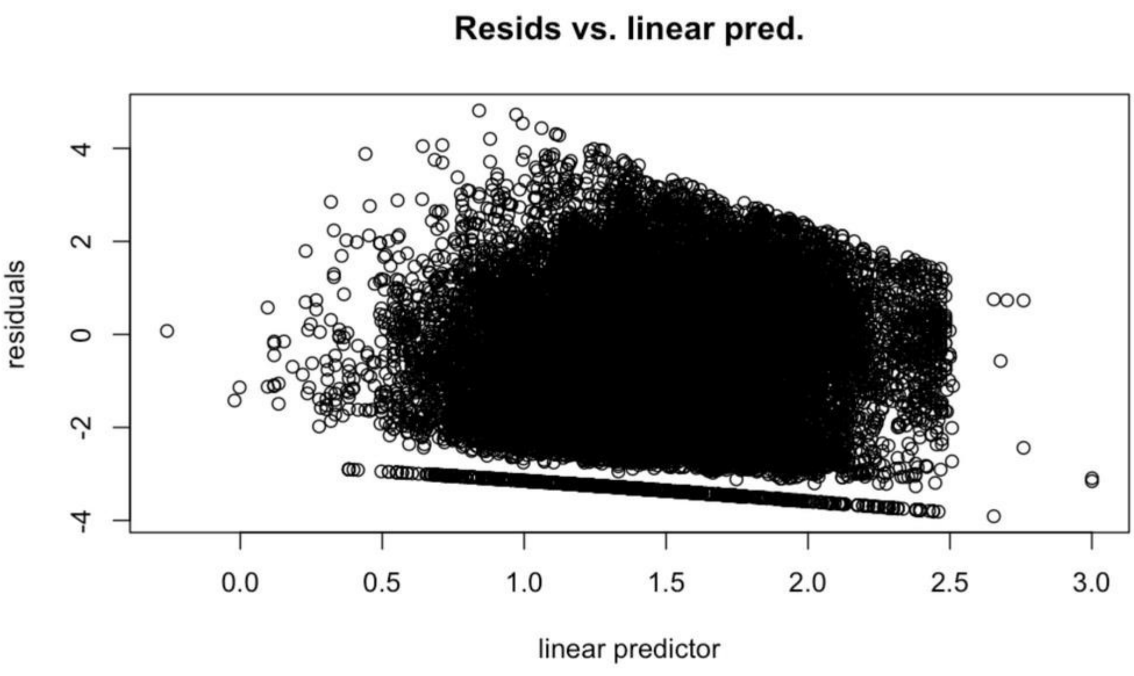

Figure D6. Southern gillnet observer model residuals vs. linear predictor plot.

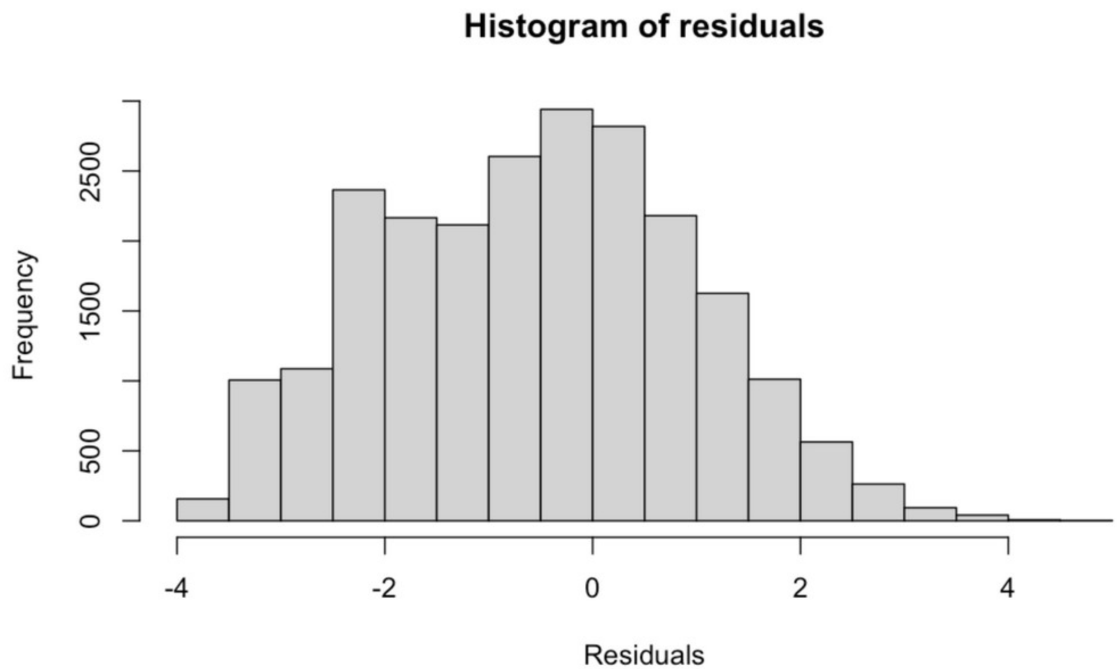

Figure D7. Southern gillnet observer model histogram of residuals.

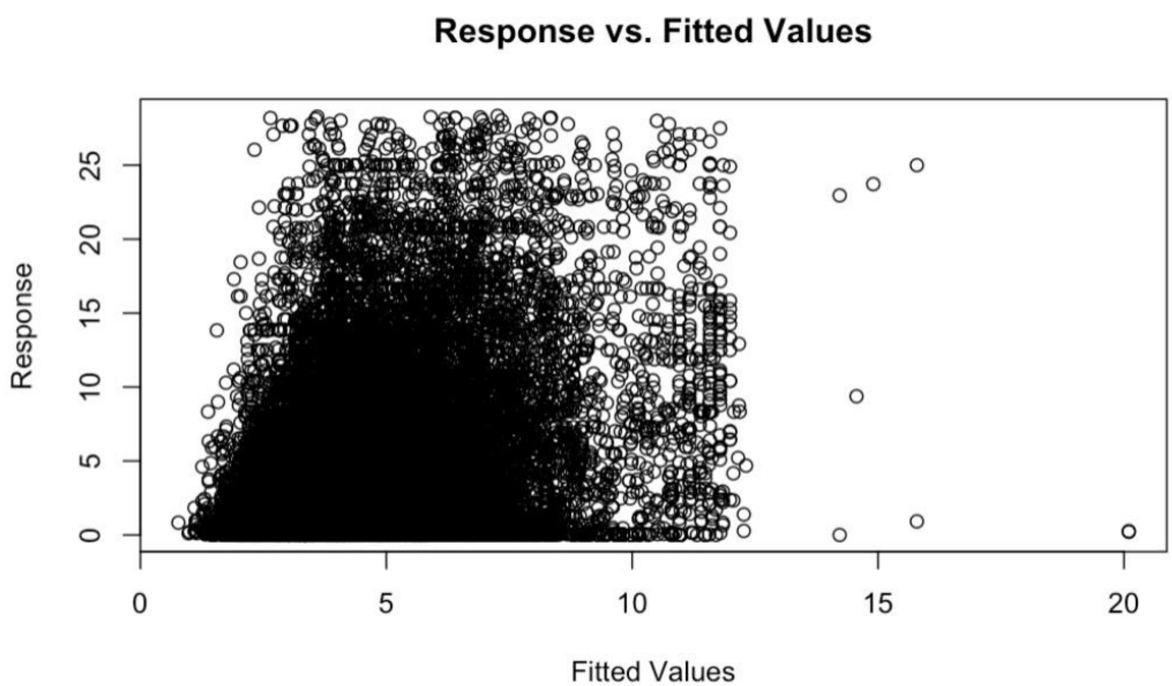

Figure D8. Southern gillnet observer model response vs. fitted values plot.

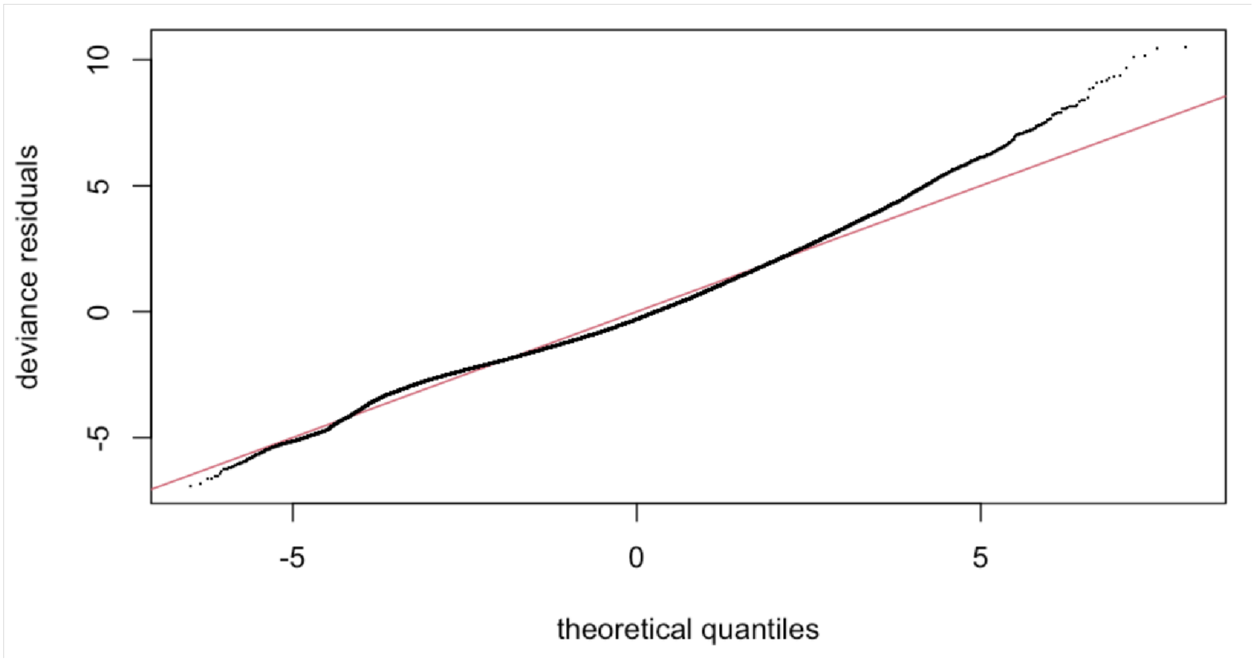

Figure D9. Northern trawl logbook model Q-Q plot.

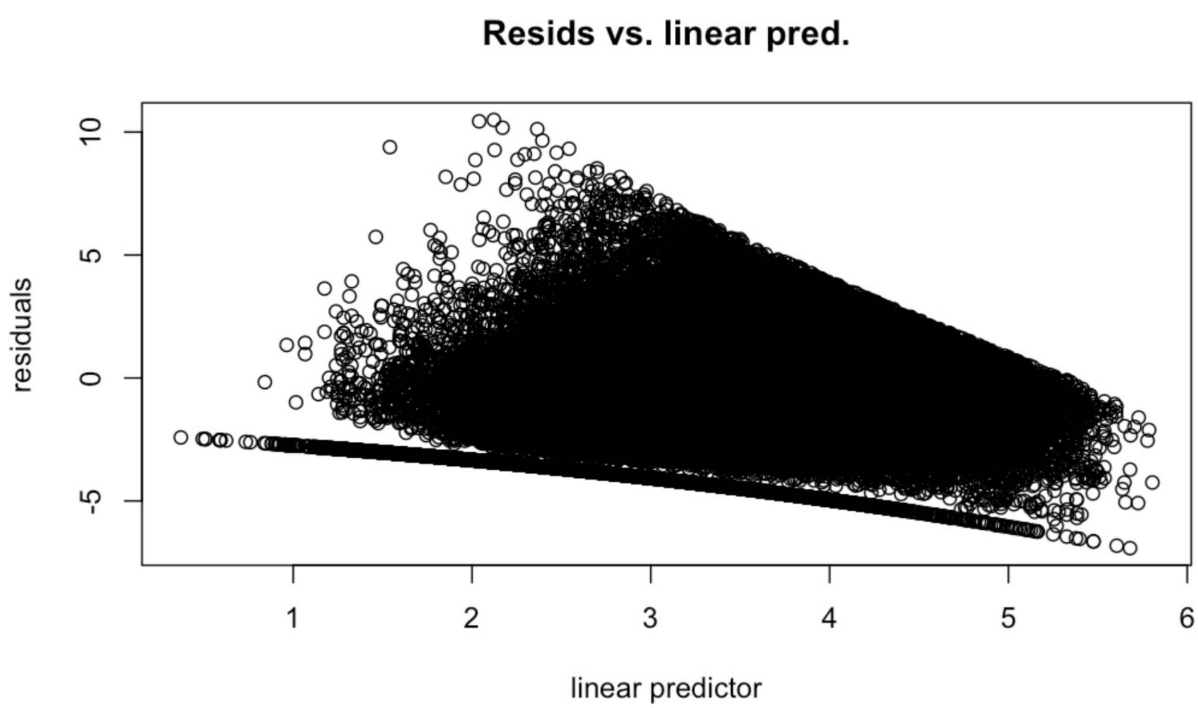

Figure D10. Northern trawl logbook model residual vs. linear predictor plot.

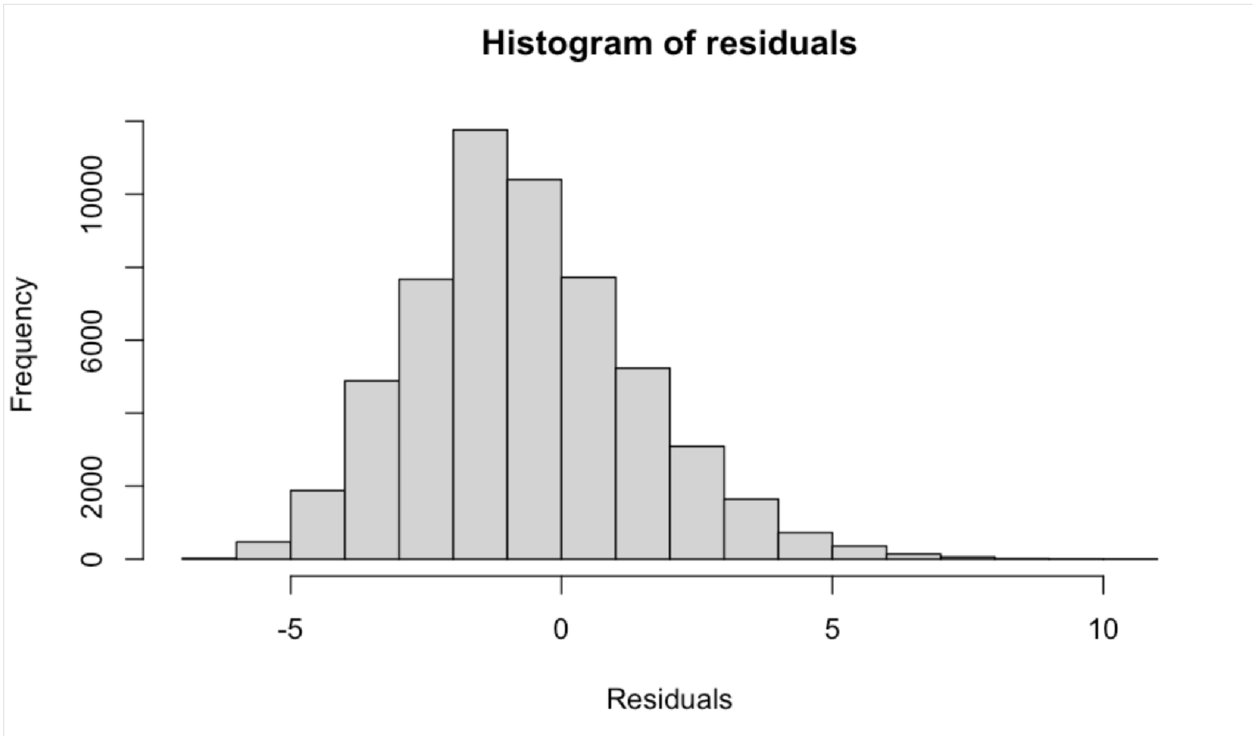

Figure D11. Northern trawl logbook model histogram of residuals.

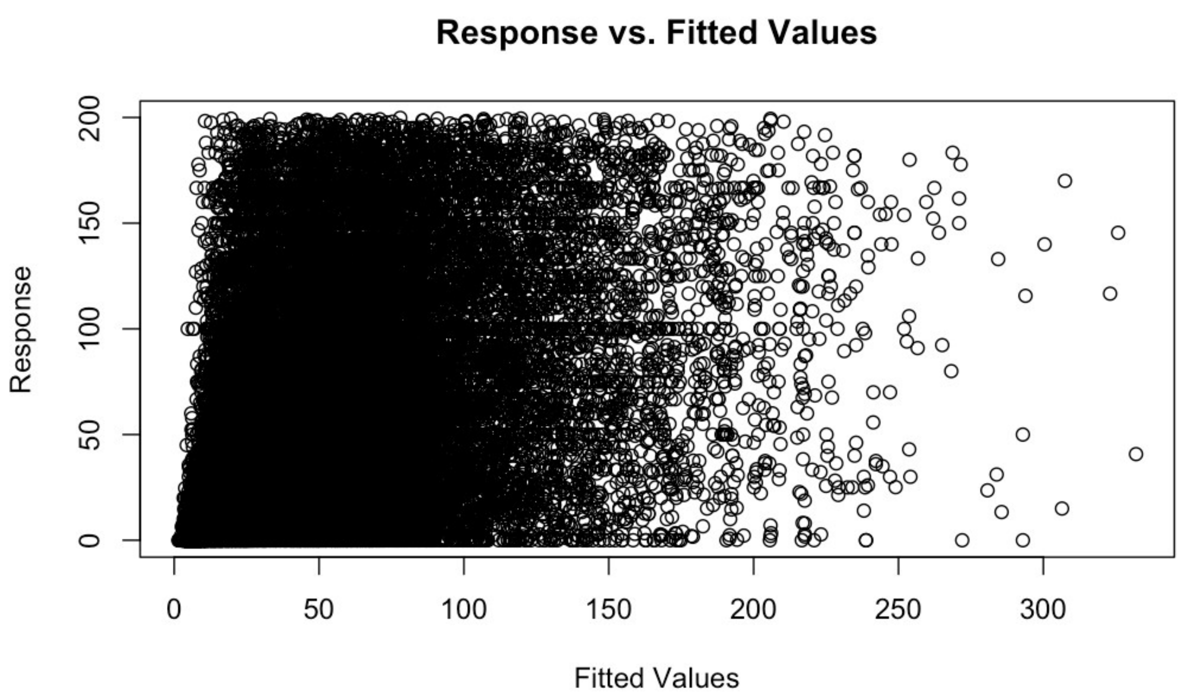

Figure D12. Northern trawl logbook model response vs. fitted values plot.

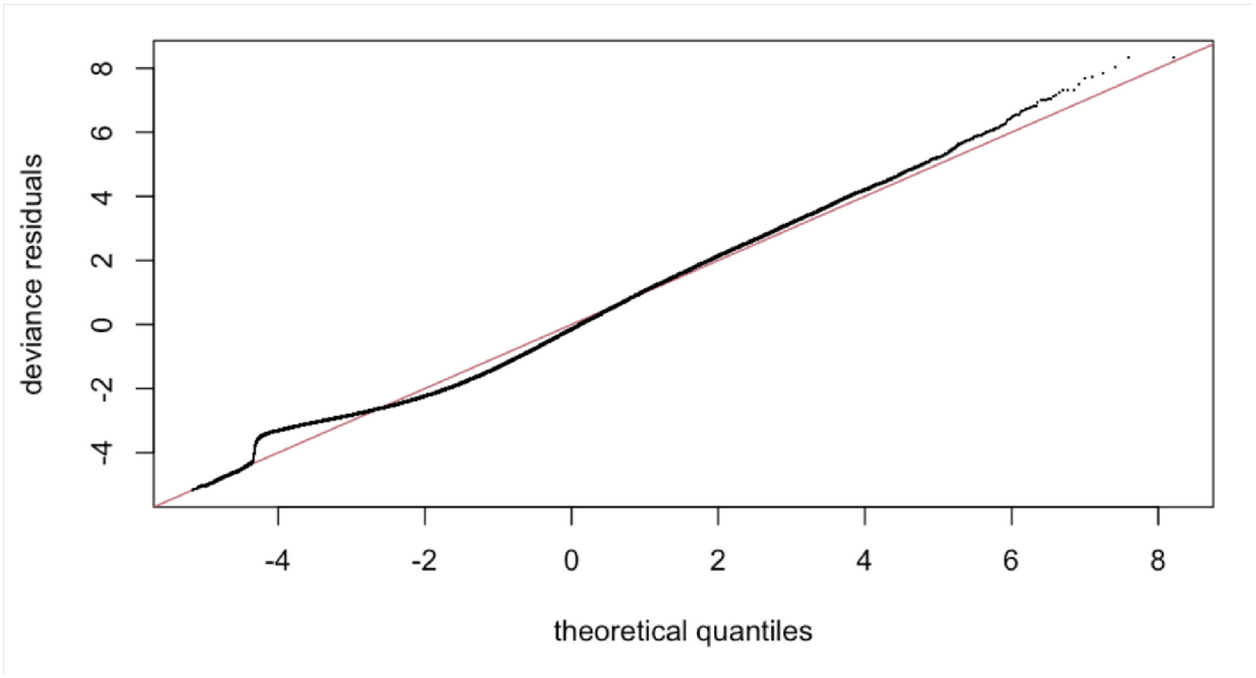

Figure D13. Northern trawl observer model Q-Q plot.

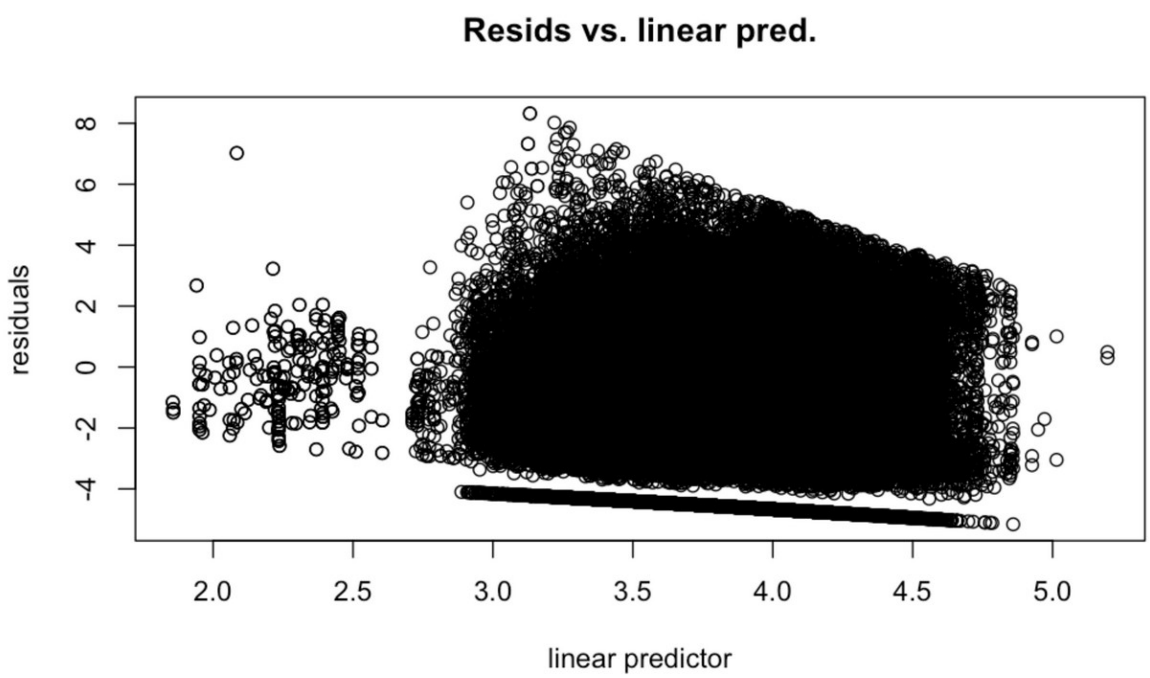

Figure D14. Northern trawl observer residuals vs. linear predictor plot.

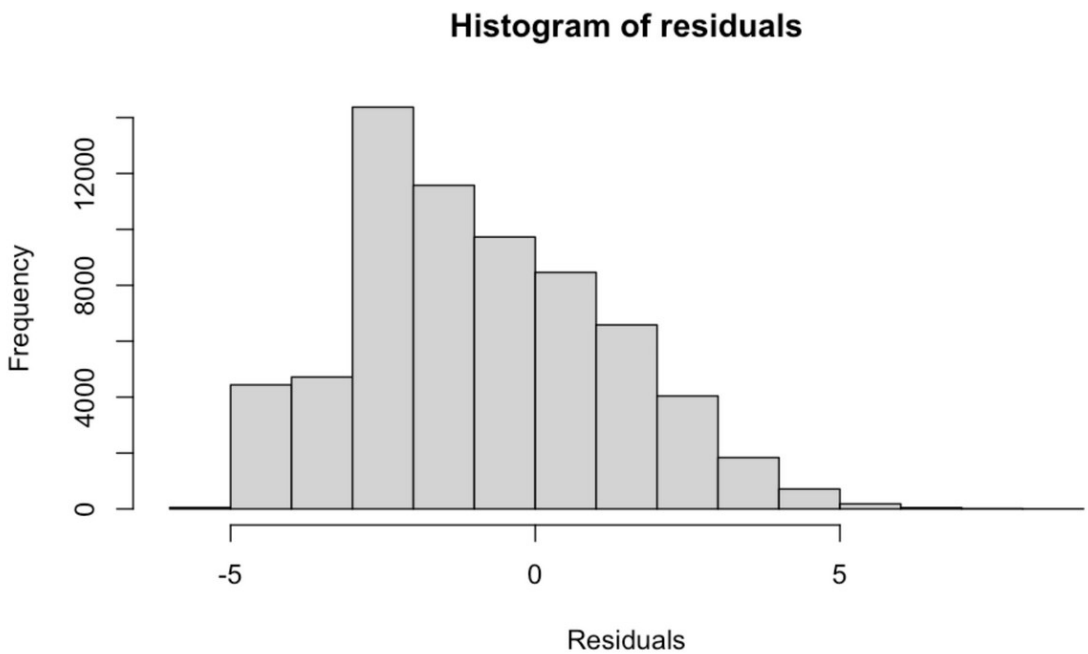

Figure D15. Northern trawl observer model histogram of residuals.

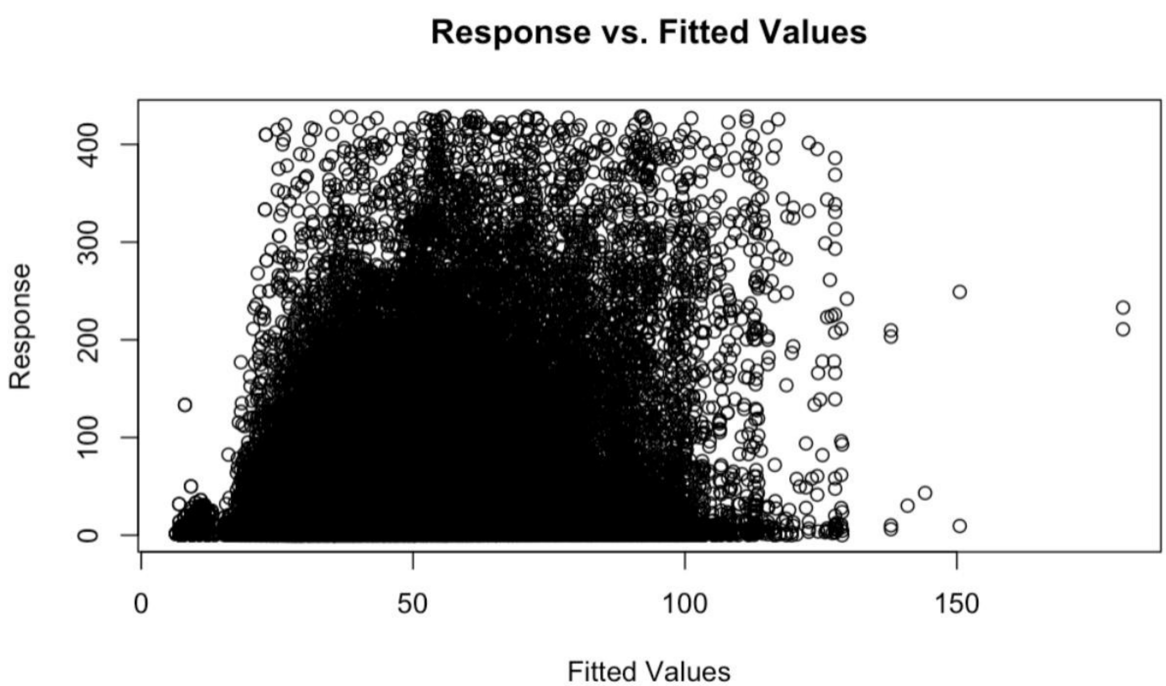

Figure D16. Northern trawl observer model response vs. fitted values plot.