Status of Shortspine Thornyhead (*Sebastolobus alascanus*) along the US West coast in 2023

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May 2023

Correct citation for this publication:

Zahner. J.A, M.A. Heller-Shipley, S. Beyer, A.L. Hayes, P-Y. Hernvann, A.N. Odell, H. Oleynik, J.Y. Sullivan, M. Veron. 2023. Status of Shortspine Thornyhead (*Sebastolobus alascanus*) along the US West coast in 2023. Pacific Fishery Management Council, Portland, Oregon. 48 p.

Contents

Executive summary

Stock

This assessment reports the status of shortspine thornyhead (*Sebastolobus alascanus*) off the US West coast using data through xxxx.

Catches

Replace text with trends and current levels. Include Table for last 10 years. Include Figure with long-term estimates.

Data and assessment

This assessment uses the stock assessment framework Stock Synthesis

(SS3).

Replace text with date of last assessment, type of assessment model, data available, new information, and information lacking.

Stock biomass and dynamics

Replace text with trends and current levels relative to virgin or historic levels and description of uncertainty. Include Table for last 10 years. Include Figure with long-term estimates.

Recruitment

Replace text with trends and current levels relative to virgin or historic levels and description of uncertainty. Include Table for last 10 years. Include Figure with long-term estimates.

Exploitation status

Replace text with total catch divided by exploitable biomass or SPR harvest rate. Include Table for last 10 years. Include Figure with trend in f relative to target vs. trend in biomass relative to the target.

Ecosystem considerations

Replace text with a summary of reviewed environmental and ecosystem factors that appear to be correlated with stock dynamics. These may include variability in they physical environment, habitat, competitors, prey, or predators that directly or indirectly affects the

stock's status, vital rates (growth, survival, productivity/recruitment) or range and distribution. Note which, if any, ecosystem factors are used in the assessment and how (e.g., as background information, in data preparations, as data inputs, in decisions about model structure).

Reference points

Replace text with management targets and definition of overfishing, including the harvest rate that brings the stock to equilibrium at $B_{40\%}$, i.e., the B_{MSY} proxy and the equilibrium stock size that results from fishing at the default harvest rate, i.e., the F_{MSY} proxy. Include Table of estimated reference points for ssb, SPR, exploitation rate, and yield based on SSB proxy for MSY, SPR proxy for MSY, and estimated MSY values.

Management performance

Include Table of most recent 10 years of catches in comparison with OFL, ABC, HG, and OY/ACL values, overfishing levels, actual catch and discard. Include OFL (encountered), OFL (retained), and OFL (dead) if different due to discard and discard mortality.

Unresolved problems and major uncertainties

Replace text with any special issues that complicate scientific assessment, questions about the best model scenario, etc.

Decision table and projections

Replace text with projected yields (OFL, ABC, and ACL), spawning biomass, and stock depletion levels for each year. OFL calculations should be based on the assumption that future catches equal ABCs and not OFLs.

Scientific uncertainty

Replace text with the sigma value and the basis for its calculation.

Research and data needs

Replace text with information gaps that seriously impede the stock assessment.

1 Introduction

1.1 Basic Information

This assessment reports the status of shortspine thornyhead (*Sebastolobus alascanus*) off the US West coast using data through xxxx.

Shortspine Thornyhead (*Sebastolobus alascanus*) are found in the waters off the West Coast of the United States from northern Baja California to the Bering Sea at depths of 20 meters to over 1,500 meters. The majority of the spawning biomass occurs in the oxygen minimum zone between 600 and 1,400 meters. The distribution of the smallest shortspine thornyhead suggests that they tend to settle at around 100–400 meters and are believed to have ontogenetic migration down the slope, although large individuals are found across the depth range. Higher densities (kg/ha) of shortspine thornyhead occur in shallower areas (under 500 meters) off Oregon and Washington, whereas in California, they occur in deeper areas (**above x meters;** Figure 1).

Despite variation in density across the coast, shortspine thornyheads are present in almost all trawlable areas below 500 meters. They are caught in 91% of trawl survey hauls deeper than 500 m and **XX%** of commercial bottom trawl hauls deeper than 500m. Camera-tows show that thornyheads are spaced randomly across the sea floor, indicating a lack of schooling and territoriality (Wakefield 1990; Du Preez and Tunnicliffe 2011).

1.2 Stock Structure

NOTE: This section was added.

Genetic studies of stock structure show few genetic differences among shortspine thornyhead along the Pacific coast, and thus do not suggest separate stocks Stepien (1995). Stepien (1995) suggested that there may be a separate population of shortspine thornyhead in the isolated area around Cortes Bank off San Diego, California. Stepien (1995) also pointed out that juvenile dispersion might be limited in the area where the Alaska and California currents split, which occurs towards the northern boundary of the assessment area, near 48° N.

Stepien et al. (2000), using a more discerning genetic material (mtDNA), found evidence of a pattern of genetic divergence in shortspine thornyhead corresponding to geographic distance. However, this study, which included samples collected from southern California to Alaska, did not identify a clear difference between stocks even at the extremes of the range. No such pattern was seen in longspine thornyhead, which suggests that the shorter pelagic stage (~1 yr vs. ~2 yrs) of shortspine thornyhead may contribute to an increased genetic separation with distance.

Dorval et al. (2022) applied otolith microchemistry to immature fish to redefine population structure of shortspine thornyhead on the west coast. Their results indicate that the population of immature shortspines belongs to two distinct groups distributed north and south of Cape Mendocino.

1.3 Life History

Shortspine Thornyheads along the West Coast spawn pelagic, gelatinous floating egg masses between December and May (Wakefield 1990; Erickson and Pikitch 1993; Pearson and Gunderson 2003). Cooper et al. (2005) and Pearson and Gunderson (2003) found no evidence for batch spawning in this species on the West Coast, but more recent histological examination of ovaries suggest that some shortspine thornyhead can be batch spawners with two to three batches developing simultaneously (Melissa Head, Northwest Fisheries Science Center (NWFSC), pers. comm.). Juveniles settle at around 1 year of age (22- 27 mm in length), likely in the range of 100-200 m (Vetter and Lynn 1997), and migrate down the slope with age and size, although large individuals are found across the depth range.

Shortspine Thornyhead are notoriously challenging to age, and a recent age validation study using 14C bomb radiocarbon was inconclusive (Kastelle et al. 2020). However, best available data suggests that the shortspine thornyhead life span may exceed 100 y (Butler 1995; Kline 1996). Estimates of natural mortality for shortspine thornyhead range from 0.013 (Pearson and Gunderson 2003) to 0.07 (Kline 1996). However, Pearson and Gunderson's estimate is based upon a regression model, using the gonadosomatic index as a proxy. Butler (1995) estimated M to be 0.05 based upon a maximum lifespan of 100 years for shortspine thornyhead. Butler (1995) also suggested that M may be lower for older, larger shortspine thornyhead residing in the oxygen minimum zone due to lack of predators. All estimates of M for thornyheads are highly uncertain.

Shortspine Thornyhead grow very slowly and may continue growing throughout their lives, reaching maximum lengths of over 70 cm. Females grow to larger sizes than males. Maturity in females has been estimated as occurring near 18 cm, with fish transitioning from immature to mature within a relatively narrow range of sizes between 15 and 20 cm Pearson and Gunderson (2003). However, more recent histological data collected in the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) and analyzed using current best practices suggests that functional maturation, which accounts for abortive maturation and skip spawning, occurs over a broader spectrum of sizes between 10 and 55 cm (length-at-50% maturity, L50 =31.4; personal communication, Melissa Head, NWFSC, pers. comm.).

1.4 Ecosystem Considerations

Shortspine Thornyheads have historically been caught alongside longspine thornyheads in a dover sole, thornyhead, and trawl-caught sablefish complex (DTS). Other groundfishes

that frequently co-occur in deep waters include a complex of slope rockfishes, Rex sole, longnose skate, roughtail skate, Pacific grenadier, giant grenadier, and Pacific flatnose. Non-groundfish species such as Pacific hagfish and a diverse complex of eelpouts also co-occur with shortspine thornyhead.

Shortspine Thornyheads typically occur in shallower water than the shallowest longspine thornyheads, and migrate to deeper water as they age. The majority of spawning shortspine thornyheads occur between 600 and 1,400 meters, where longspine thornyheads are most abundant (Jacobson and Vetter 1996; Bradburn et al. 2011). When shortspine thornyheads have reached a depth where they overlap with longspine thornyheads, they are typically larger than the largest longspine thornyheads.

Species distribution models developed by Liu et al. (in press) suggest that expected environmental changes over the next decades will lead to a decline in shortspine and increase in longspine abundance. Shortspine Thornyheads are also projected to shift offshore, into deeper waters, potentially decreasing their availability in fisheries. To date, shortspine thornyheads have been observed by cameras below the 1280 meter limit of the current fishery and survey, but their distribution, abundance, and ecosystem interactions in these deep waters are relatively unknown. Thornyheads spawn gelatinous masses of eggs which float to the surface, which may represent a significant portion of the upward movement of organic carbon from the deep ocean (Wakefield 1990).

Shortspine Thornyhead diet composition, as derived from stomach content collection in the 1980s and 1990s, varied by year (Bizzarro et al. 2023). In some years their diet consisted primarily of invertebrate species including pandalid shrimp, pink shrimp, and Tanner crab, while in others their stomach content was dominated by finfish species such as Pacific cod and Pacific Hake. As prey themselves, shortspine thornyheads were only found in the stomachs of other species in two years, 1991 and 1992 as recorded in the CA Current Trophic Database (CCTD), where shortspine thornyhead occurred in sablefish, Pacific hake, and other shortspine thornyhead stomachs (Bizzarro et al. 2023).

1.5 Historical and Current Fishery Information

Thornyhead harvest has experienced fluctuations over time due to increased depth range of the fisheries, variable markets, and changes in fisheries management. In the early 1900's, landings were minimal because there were few markets for thornyheads and relatively little trawling at depths where the majority of thornyheads occur. Beginning in the 1930s, thornyhead landings increased as they were landed as incidental catch in the California sablefish fishery. The first significant market for thornyheads began in northern California in the early 1960s, when larger (30-35 cm) thornyhead were sold as "ocean catfish". By the early 1980s, the minimum marketable size decreased to 25 cm, and in the late 1980s a market for small thornyheads (~20 cm) developed due to the depletion of a related species (*Sebastolobus machrochir*) off the coast of Japan. The fishery moved into deeper waters with the demand

for smaller thornyheads and began catching more longspine thornyheads. This is reflected in the changes in proportion of shortspine to total thornyheads through time, which decreased from around 90% in 1981 to 40% in 1994 Figure 2.

Landings of shortspine thornyheads off the coast of California peaked around 3,500 mt in 1989, and have exceeded those from further north in most years (Figure 3). In the northern area off of Oregon and Washington, the fishery grew in the early 1980s, with landings peaking in 1991 at around 2200 mt.

Non-trawl landings of shortspine thornyheads were relatively low prior to the mid-1990s, at which point non-trawl landings, dominantly longline, in California began to increase steadily from less than 5 mt in 1994 to 237 mt in 2011. The increase in non-trawl landings was driven by the development of live-fish markets for thornyheads and the fact that ex-vessel prices associated with the non-trawl landings are much higher than those for the trawl fishery.

Nominal prices for line-caught shortspine thornyhead increased steadily from $0.69/lb in 1993 to $3.81/lb in 2008, and have remained near or above that level since. Citation?

Trawl prices, on the other hand, changed from $0.46/lb to $0.72/lb in the same period, although, when Japanese demand was strong they were between $0.80 and $1.06/lb. In contrast, non-trawl landings of shortspine in Washington and Oregon have remained below the estimated peak of 54 mt in 1991.

The foreign fishery off of the West Coast is estimated to have caught approximately 7,400 mt of shortspine thornyhead during the 11 year period from 1966-1976 (Rogers 2003), which is on the order of the estimate of domestic catch (~8,600 mt) during that same period.

Management measures have contributed to a decline in coastwide landings from an estimated peak of 4,815 mt in 1989 to between 1,000 and 2,000 mt per year from 1995 through 1998. Landings fell below 1,000 mt per year from 1999 through 2006, then rose to 1,531 in 2009 and have declined since **(Table X)**.

In 2011, the west coast trawl fishery was rationalized, with the introduction of the Individual Fishing Quota (IFQ) Program. In order to provide more flexibility for fishers on the west coast, NOAA Fisheries implemented the West Coast Groundfish Trawl Fishery Catch Share Program, which allows for the division of catch allocated to the trawl fishery into shares controlled by individuals or cooperatives (West Coast Regional Office n.d.). All vessels that participate in the IFQ program are required to have 100% observer coverage at all times the vessels are at sea.(West Coast Regional Office n.d.)

1.6 Summary of Management History and Performance

Beginning in 1989, both thornyhead species were managed as part of a DTS. In 1991, the Pacific Fishery Management Council (PFMC) adopted separate Acceptable Biological Catch (ABC) levels for thornyheads and catch limits were imposed on the thornyhead complex. harvest guideline (HG) were instituted in 1992 along with an increase in the minimum mesh size for bottom trawl fisheries. In 1995 separate landing limits were placed on shortspine and longspine thornyheads and trip limits became more restrictive. Trip limits (predominantly 2-month limits on cumulative vessel landings) have often been adjusted during the year since 1995 in order to not exceed the HG or optimum yield (OY). At first, the HG for shortspine thornyhead was set higher than the ABC (1,500 vs. 1,000 mt in 1995-1997) in order to allow a greater catch of longspine thornyhead, which was considered relatively undepleted. In 1999 the OY was set at less than 1,000 mt and remained close to that level through 2006. As a result of the 2005 shortspine assessment, catch limits increased to about 2,000 mt per year and have remained near that level **to the present.**

Since early 2011, trawl harvest of each thornyhead species has been managed under the PFMC's catch share, or individual fishing quota (IFQ), program. Whereas the trip limits previously used to limit harvest restricted only the amount of fish each vessel could land, individual vessels fishing under the catch-share program are now held accountable for all of the quota-share species they catch.

Landings of shortspine thornyhead have been below the catch limits since 1999. The estimated total catch, including discards, has likewise remained below the limit during this period.

1.7 Foreign Fisheries

The Alaska Fisheries Science Center (AFSC) conducts assessments of thornyheads as a mixed stock complex, including shortspine and longspine thornyheads. Results of the 2022 Alaska Thornyhead complex assessment suggest that thornyheads are not being subjected to overfishing (Echave et al. 2022).

2 Data

Data comprise the foundational components of stock assessment models. The decision to include or exclude particular data sources in an assessment model depends on many factors. These factors often include, but are not limited to, the way in which data were collected (e.g., measurement method and consistency); the spatial and temporal coverage of the data; the quantity of data available per desired sampling unit; the representativeness of the data

to inform the modeled processes of importance; timing of when the data were provided; limitations imposed by the Terms of Reference; and the presence of an avenue for the inclusion of the data in the assessment model. Attributes associated with a data source can change through time, as can the applicability of the data source when different modeling approaches are explored (e.g., stock structure or time-varying processes). Therefore, the specific data sources included or excluded from this assessment should not necessarily constrain the selection of data sources applicable to future stock assessments for shortspine thornyhead. Even if a data source is not directly used in the stock assessment they can provide valuable insights into biology, fishery behavior, or localized dynamics.

Data from a wide range of programs were available for possible inclusion in the current assessment model. Descriptions of each data source included in the model (Figure 4) and sources that were explored but not included in the base model are provided below. Data that were excluded from the base model were explicitly explored during the development of this stock assessment or have not changed since their past exploration in a previous shortspine thornyhead stock assessment. In some cases, the inclusion of excluded data sources were explored through sensitivity analyses.

2.1   Fishery-Dependent Data

2.1.1   Catch History

Pacific Fisheries Information Network (PacFIN) data from 1981-present was used to estimate landings in the North (Oregon and Washington) and South (California) by gear type (Trawl and Non-Trawl) (Figure 3) All landings reported for the shortspine thornyhead and nominal shortspine thornyhead categories were considered shortspine thornyhead, whereas landings categorized as unidentified thornyheads were split between longspine thornyhead and shortspine thornyhead by the ratio of identified longspine and shortspine landings for each year-state-gear combination. The values of this ratio for each state and gear-type from 1981-2023 are shown in Figure 2.

Catches prior to 1981 are based on historical reconstructions provided by the respective states and a reconstruction of foreign fleet catch. Oregon landings for 1892-1986 are provided by ODFW and outlined in Karnowski et al. (2014) shortspine thornyhead landings are not present in the PacFIN data for Oregon for the years 1981-1986 and the state reconstruction is used for this period instead. Washington landings for 1954-1980 are provided by WDFW. Landings prior to the beginning of this data are assumed to be zero. California landings are provided by CDFW and SWFSC, and consist of California commercial data for 1969-1980, and a catch reconstruction documented by Ralston et al. (2010) for 1934-1968. As in the two previous assessments, catch data from Rogers (2003) is used to account for catches by foreign fleets during the years 1966-1976. Foreign catch in the Monterey and Eureka International North Pacific Fishery Commission (INPFC) areas is attributed to the Southern Trawl fleet,

while foreign catch in Columbia and Vancouver areas is attributed to the Northern Trawl fleet, as was the case in the 2013 assessment.

For historical catches prior to 1981, all shortspine thornyhead, nominal shortspine, and unidentified thornyhead landings in the state catch reconstructions are considered shortspine thornyhead. Neither California reconstructions prior to 1978, nor the Karnowski et al. (2014) reconstruction for Oregon, distinguish between shortspine and longspine thornyhead species. It is possible that assigning all thornyhead landings to shortspine overestimates shortspine landings, however, the overwhelming majority of thornyhead landings were shortspine until the late 1980s when vessels began to move into deeper waters and a distinct fishery targeting longspine thornyhead developed (Hamel 2005; Karnowski et al. 2014).

This treatment of unassigned thornyhead landings differs from the 2005 and 2013 assessments. The 2005 assessment did not have access to the historical reconstructions used here, and instead imputed shortspine landings as 30% of annual sablefish landings for the years 1901-1961. The 2013 assessment used the same imputed values as the 2005 assessment, but also conducted a sensitivity analysis in which all unassigned thornyheads in historical catch were considered shortspine thornyhead. Stock abundance estimates were found to be largely insensitive to which reconstructions were used (Taylor and Stephens 2013). The imputed historical values used for the 2005 and 2013 assessments will continue to be included as a sensitivity analysis here. Landings after 1961 remain very similar to the landings used in the 2013 assessment (Figure 3).

2.1.2 Discards and retention

Discards were informed by four data sources covering three different periods. Data sets included, 1) Pikitch et al. (1988) Discard and Mesh Studies, used to estimate both discard rates and length composition of the northern trawl fleet between 1985 and 1987 (J. R. Wallace, pers. comm.), 2) the TEST Enhanced Data Collection Project (EDCP) covering 1995-1999, which only informed discard rates of the northern trawl fleet, 3) the West Coast Groundfish Observer Program (WCGOP), which provided discard rates, length composition, and individual average weight for years between 2002 and 2021 for all fleets, and 4) the Groundfish Expanded Mortality Multi-Year (GEMM) data set, covering the same period and completing the WCGOP with catch-share participation information and estimates of discard survival rates.

While the estimates from the first two data sets were directly integrated into the model, fleet discard rates after 2011 were available separately for catch-share and non-catch-share programs. Final fleet-specific discard rates were thus computed as the average WCGOP discard rate weighted by the relative proportion of total landings belonging to the catch-share and non-catch-share, respectively. (Figure 6). Regardless of the type of data, all estimates derived from these data sets had associated uncertainty accounting for the variability observed within the sample of hauls and fishing trips of each fleet. WCGOP-derived discard rates are

an exception as, after the catch share program was initiated in 2011, 100% of hauls from catch share fleets were observed., while non-catch share vessels were only partially covered (cite).

The discard data sources were the same as those used in the 2013 assessment. The main improvements are the increased representativity of all 4 fleets (11 more years) and more accurate estimates of discard rates from EDCPthat were not ready at the time of the previous assessment. Last, some errors in the previous assessment were corrected regarding the weight units considered for the average individual weight (WCGOP provides weight as pounds and not as kg).

2.1.3 Fishery Length Compositions

Commercial fishery length-composition data were obtained from PacFIN for 1978-2023. Due to variations in sampling effort and because the number of fish sampled by port samplers is not proportional to the amount of landed catch in each trip, the observed length data were expanded using the following algorithm using the PacFIN.Utilities package in R:

1. Length data were acquired at the trip level by sex, year and state.
2. The raw numbers in each trip were scaled by a per-trip expansion factor calculated by dividing the total weight of trip landings by the total weight of the species sampled.
3. A per-year, per-state expansion factor was computed by dividing the total weight of state landings by the total weight of the species sampled for length in the state.
4. The per-trip expanded numbers were multiplied by the per-state expansion factor and summed to provide the coast-wide length-frequency distributions by year.

Only randomly collected samples were used. The sample sizes associated with the length compositions from the fishing fleets are shown in Table X (landings) and Table X (discards). Length samples from the Trawl North fleet in 1980, 1994, and 1995 showed a very different pattern than the surrounding years. The effective sample sizes for these years were substantially lower than other years (Neff < 15), so the observed differences are likely due to non-representative sampling.

Input sample sizes {N_{input}} for fishery length frequency distributions by year were calculated as a function of the number of trips and number of fish via the Stewart Method (Stewart, pers.com):

$$N_{input} = N_{trips} + 0.138 N_{fish} \qquad \text{when } \frac{N_{fish}}{N_{trips}} < 44$$

$$N_{input} = 7.06 N_{trips} \qquad \text{when } \frac{N_{fish}}{N_{trips}} \geq 44$$

The method is based on analysis of the input and model-derived effective sample sizes from west coast groundfish stock assessments. A piece-wise linear regression was used to estimate the increase in effective sample size per sample based on fish-per-sample and the maximum effective sample size for large numbers of individual fish.

All length data from commercial fisheries included in the model with sexes combined. This avoids the possibility of bias due to difficulty in sex determination of thornyheads.

2.1.4   Age Compositions

No age composition data was used for this assessment because thornyheads have proven very difficult to age (P. MacDonald, pers. comm.). Even in directed studies such as those done by Kline (1996) and Butler (1995), there are large inter-reader differences, and a second reading by the same ager can produce a markedly different result. Kline (1996) reported only about 60% of the multiple reads were within 5 years of each other, and inter-reader differences were as large as 24 years for a sample of 50 otoliths. No production ageing of thornyheads is undertaken at this time for the west coast, although shortspine thornyhead otoliths are routinely collected in the NWFSC trawl survey.

2.2   Fishery-Independent Data

Four trawl surveys have been conducted on the U.S. west coast over the past four decades.

2.2.1   AFSC/NWFSC West Coast Triennial Shelf Survey

The AFSC conducted a triennial groundfish trawl survey (the "triennial" survey) on the continental shelf from 1977 to 2001, although the 1977 survey had incomplete coverage and is not believed to be comparable to the later years. A final survey was conducted in 2004 by the NWFSC using the same survey design. In 1995, the timing of the survey shifted so that instead of occurring between mid-July and late September, it was conducted from early June through mid-August. The years 1980–1992 had a maximum depth of 366 m, while from 1995 onward, the maximum depth was extended to 500 m. The shallow limit of the survey was 55 m in all years, but for purposes of computing indices, only tows deeper than 100 m were used as shortspine thornyhead are rarely seen at shallower depths. The triennial survey consists of 9 data points, from surveys operating every third year from 1980–2004.

For some species, the shift in timing between the 1992 and 1995 surveys would be expected to influence their catchability, availability, or distribution. However, thornyheads are believed to be sedentary enough that the change in timing would not be as influential. On the other

hand, the increase in depth is expected to significantly increase the range of shortspine thornyhead habitat covered by the survey. In the 2013 assessment, the triennial survey was split into two-time series, separated by the 366 m depth contour, in order to preserve a time series of maximum length while eliminating the influence of the increased depth range. The first time series, "AFSC Triennial Shelf Survey 1", consists of 9 data points spanning the range 1980–2004 and covering the depths 100–366 m. The second, "AFSC Triennial Shelf Survey 2", consists of 4 data points spanning 1995–2004 and covering depths 366–500 m. This second time series is recognized as providing little information about stock status due to the limited number of points and depth range, but there was no compelling reason to exclude it from the assessment. However, in contrast to the 2013 assessment, this assessment will treat the triennial survey as a single time series for constructing the geostatistical model-based indices, and will use a different set of latitudinal and depth-based strata for survey length compositions.

2.2.2   AFSC and NWFSC Slope Surveys

Starting in the late 1990s, two slope surveys were conducted on the west coast. The AFSC Slope Survey (AFSC Slope Survey) was conducted during the years 1997 and 1999–2001 using the research vessel Miller Freeman. The NWFSC Slope Survey (NWFSC Slope Survey) was conducted from 1998–2002, and was conducted cooperatively using commercial fishing vessels. The AFSC Slope Survey was a source of valuable information on the depth distribution and overlap of shortspine and longspine thornyheads in the 1980s, but these early years had a very limited latitudinal range and will not be included. This survey also had a different net and larger roller gear than the NWFSC Slope Survey.

2.2.3   NWFSC West Coast Groundfish Bottom Trawl Survey

In 2003, the design of the NWFSC Slope Survey was modified, and the survey was expanded to cover the shelf and slope between 50 m and 1280 m. This combination shelf-slope survey, "NWFSC Combo Survey", more recently known as the WCGBTS, has been conducted every year from 2003 to present with consistent design (note that the survey was not conducted in 2020 due to ongoing concerns about COVID-19). Data for the years 2003–2021 were available for this assessment. The WCGBTS represents the largest number of survey observations, the largest depth range, and the most consistent groundfish sampling program in the history of west coast fisheries. Continuing this time series in a consistent manner is vital for improving estimates of current stock status and detecting any future changes in size distribution or abundance of west coast groundfish.

2.2.4 Survey Stratification

Data from these four (nominally five for design-based indices) fishery-independent surveys were considered for use in this assessment (Figure 7) to estimate abundance. Two distinct survey abundance estimation methods were considered: design-based and geostatistical model-based indices. The 2013 assessment utilized delta-GLMMs following the methods of Thorson and Ward (2013), but these methods are no longer considered best practice within the field and were not considered in this assessment.

The five surveys were stratified based on depth and latitude, similar to how they were in 2013 (Table X; Figure X–Map, should we include?). The AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) was divided into two distinct survey time series, split on the year 1995. The early-Triennial time series (1981-1992) was further stratified into four strata: north and south of 42 ° N, and shallower and deeper than 200m. The late-Triennial time series (1995-2004) was also further stratified into four strata: north and south of 40 ° N, and shallower and deeper than 200m. The AFSC Slope Survey was split into two coast-wide strata: shallow and deeper than 550m. The NWFSC Slope Survey was divided into 6 strata, with breaks dividing southern, central, and northern strata at 40.5º N and 43º N, each of which was further divided with a break at 550 m. The WCGBTS was divided into 7 strata, with two southern strata below 34.5º N, one covering 183–550 m and the other covering 550–1280 m. Two central strata, between 34.5º N and 40.5º N, had the same depth ranges. The latitudinal divide around 34.5º N is associated with changes in sampling intensity. North of 40.5º N, three strata were used, covering the ranges 100–183 m, 183–550 m, and the other covering 550–1280 m. The depth breaks at 183 m and 550 m are also associated with changes in the sampling intensity of the survey and are recommended to be used. South of 40.5º N, there are very few shortspine thornyhead shallower than 183 m, so no shallow stratum was used in these latitudes. The 2013 stratification was reused for the design-based indices as there was not sufficient evidence to support modifying the existing strata.

2.2.5 Design-based Indices of Abundance

Design-based indices of abundance were derived for all surveys. Note that for these indices of abundance, the Triennial Survey was split into two independent time series, separated by the year 1995. The construction of design-based indices mirrors a weighted average approach. For each survey year, an average CPUE is calculated across all tows within a stratum and expanded by area to determine the total estimated biomass. These values are then summed across all strata within the survey to create a time series of design-based indices of abundance. Design-based indices were computed using the official nwfscSurvey R package.

2.2.6 Geostatistical Model-based Indices of Abundance

Model-based indices of abundance for all surveys were derived using geostatistical models Thorson et al. (2015) developed using the R package sdmTMB Anderson et al. (2022). This approach utilizes geostatistical GLMMs with spatially and spatiotemporally correlated random effects, which can account for variables that cause correlations in the data across space and time. For this reason, the Triennial Survey survey can be, and was, treated as a single time series rather than split into two timeseries based on the introduction of additional sampling at greater depths. For the Triennial Survey and WCGBTS surveys, geostatistical models included spatial and spatiotemporal random effects and depth and depth squared as a scaled covariate. Geostatistical models for the NWFSC Slope Survey and AFSC Slope Survey were not run with depth.

Abundance indices were obtained for models using both gamma and log-normal error structures. There is limited agreement on how best to go about model selection for these types of geostatistical models, and both error structures were tested as sensitivity analyses alongside the simple design-based indices described above. The abundance indices derived from the gamma model were most similar to the design-based indices for the Triennial and WCGBT surveys and were thus used for the base model (indices derived from the log-normal model displayed a similar trend to the gamma model-based indices, and the design-based indices, but were consistently larger in scale).

2.2.7 Length Composition Data

Length-composition data were available for each year of each survey. In each haul, there is a set number of random samples regardless of the amount of catch, decoupling the sample and catch size. Therefore, the length compositions were calculated using an expansion factor to account for differences in the amount of catch that samples represent. An expansion factor (calculated as weight of caught fish divided by weight of fish sampled) is calculated for each haul, multiplied by the number of fish in each size bin, and then summed across hauls. This algorithm is repeated for each spatial stratum. Length composition data were compiled into *XX length bins, ranging from XX to XX cm.* Year-specific length frequency distributions generated for each survey are shown in Figure 8).

2.2.8 Frequency of Occurrence and Survey Information

The frequency of occurrence of shortspine and longspine thornyheads in trawl surveys remains extremely high. 91% of the tows in the WCGBTS below 500 m have at least one shortspine thornyhead in the catch (and 96% for longspine thornyhead), similar to the 2013 assessment. The number of survey hauls and shortspine thornyheads sampled available for this assessment is described in *Table X*.

2.3 Biological Data

2.3.1 Natural Mortality

THIS WILL BE UPDATED

Butler (1995) estimated the lifespan of shortspine thornyhead to exceed 100 years and suggested that M was likely less than 0.05. M may decrease with age as shortspine migrate ontogenetically down the slope to the oxygen minimum zone, which is largely devoid of predators for fish of their body size. The 2005 assessment fixed the natural mortality parameter at 0.05, while the 2013 assessment used a prior on natural mortality developed based on a maximum age of 100 years. The prior had a mean of 0.0505 and a standard deviation on a log scale of 0.5361 (Hamel, pers. comm.). For the base case, natural mortality was fixed at the mean of this prior distribution. This assessment uses an updated prior on M by Owen S. Hamel (2022), where the median of M is:

$$\frac{5.40}{Age_{max}} \tag{1}$$

This assessment assumed the same maximum age of 100 as in the previous assessments, with an updated prior of 0.054 (median value) and log-space standard deviation = 0.31 (Owen S. Hamel 2022). The 2023 assessment will explore estimating M and fixing M at the prior mean.

2.3.2 Maturation and Fecundity

2.3.2.1 Maturity Pearson and Gunderson (2003) estimated length at 50% maturity to be 18.2 cm on the West coast, with most females maturing between 17 and 19 cm. This was represented in the 2005 and 2013 assessments by the logistic function,

$$M(L) = (1 + e^{-2.3(L-18.2)}) - 1 \tag{2}$$

where L is the length in cm.

The 2013 assessment considered new (at the time) maturity information from ovaries collected for maturity analysis on the 2011 and 2012 WCGBTS. Histological analysis of those samples (M. Head, pers. comm.) indicated puzzling patterns of spawning by female size and by latitude, with a higher fraction of fish spawning in the north than in the south and a higher fraction of spawning fish in the 20-30cm than in the 30-40cm range. However, due to the complexity of these observed patterns and the known ontogenetic migrations of

shortspine, samples collected in 2011 and 2013 were not considered adequate for estimation of a new representative maturity curve for the entire shortspine thornyhead population in 2013. Nonetheless, such a maturity curve was considered in a sensitivity analysis. On the basis of the sensitivity analysis, the 2013 assessment suggested that the slow but steady rate of growth for TEST shortspine thornyheads, with growth still occurring at age 100, reduces the importance of assumptions about maturity because older individuals have significantly higher spawning output due to their much larger size, regardless of the fraction spawning.

New maturity analyses of samples collected on the WCGBTS in 2011, 2013, 2014, 2016 and 2018 were available for the 2023 assessment (M. Head, pers. comm.). The larger number (N=397) and better spatial coverage of these samples allowed the use of statistical modeling to better understand the spatial variation in the proportion of female spawning.

In the 2013 assessment, the exploration of maturity analyses from the WCGBTS samples highlighted maturity gradients along latitude and depth. To assess a potential relationship between fish location and the shape of the maturity curve, a general linear model (GLM) was designed for estimating maturity curve parameters while integrating latitude and depth as covariates. This GLM consists of a logistic regression in which the functional maturity of samples, modeled with a Bernoulli distribution, is expressed as a linear combination of fish length, latitude, squared latitude, depth and squared depth of collection. Once fitted, the GLM was used to predict the response of the probability of being mature along the range of individual shortspine length considered in the model. For the 2023 assessment, this model prediction was made while setting the latitude and depth at the values of the center of gravity (using number of fish as weighing factor) of the population of shortspine thornyhead sampled during the WCGBTS to develop a single curve for the coastwide population assessment. Thus, this response of functional maturity to length was considered the mean maturity curve of the west coast shortspine thornyhead population. The parameters of the maturity curve L50 and k were arithmetically derived from this response to fish length. The new maturity curve is expressed as follows:

$$M(L) = (1 + e^{-2.3(L-31.42)})^{-1} \tag{3}$$

Figure MAT-1 shows the fit of the maturity curve of the model per class of depth and latitude.

A sensitivity analysis will assess the impact of this change in the maturity curve on the model estimates by considering the newly estimated parameters, the Pearson and Gunderson's relationship from the 2013, and one intermediate option (FigureMAT-2).

2.3.2.2 Fecundity The previous assessments assumed spawning biomass was equivalent to spawning output. The 2023 assessment will explore using fecundity-at-length parameters reported in Cooper et al. (2005), where fecundity was modeled as a power function of

length. Cooper et al. (2005) estimated the fecundity of 54 females collected from the West Coast and Alaska. The study found no difference in the length-fecundity relationship by region and pooled the samples. The fecundity-at-length parameters in that study were:

$$F = 0.0544L_{3.978} \tag{4}$$

where F is fecundity in the number of eggs per female and L is length in cm. Fecundity information from Cooper et al. (2005) suggests that fecundity increases at a faster rate with length than body weight with length. This means larger females are likely to have greater relative fecundity compared to small females (i.e., large females produce more eggs per kg of body weight). This assessment will explore modeling a fecundity-at-length relationship using the fecundity parameters from Cooper et al. (2005) and scaling the fecundity intercept by one million in SS3 to report fecundity in billions of eggs.

Uncertainty remains in the spawning strategy of shortspine thornyhead. Cooper et al. (2005) and Pearson and Gunderson (2003) found no evidence for batch spawning in this species (i.e., a determinate, total spawning strategy). However, updated histology information suggests a possibility of batch spawning in this species (Melissa Head, NWFSC, pers. comm.). Batch spawning could influence the fecundity-at-length relationship if not properly accounted for and should be a focus of future research. The histology analysis also found evidence of parasites in the ovaries and atresia (degrading eggs), which could influence fecundity (Melissa Head, NWFSC, pers. comm.).

2.3.3 Length-Weight Relationship

Fisheries-independent length and weight specimen data are available from the AFSC Slope Survey (1997, 1999-2001; N=7,623) and the WCGBTS (2003-2021, excluding 2020; N=20,142). The WCGBTS data were used to estimate the length-weight relationship because it has the largest sample size and covers the greatest spatiotemporal resolution. The allometric function models weight (W) as an exponential function of length (L), where:

$$W = \alpha L^{\beta} \tag{5}$$

This function can be linearized by taking the natural logarithm of both sides. The predicted weight-at-length values were bias-corrected using a multiplier of 2 / 2. Length-weight was estimated for both sexes in R using the lm() function (R Core Team 2021).

The resulting allometric parameters for 2023 (females: $\alpha = 6.49e\text{-}6$, $\beta = 3.18$; males: $\alpha = 6.71e\text{-}6$, $\beta = 3.17$) were similar to the 2013 assessment values, which estimated a single length-weight relationship for males and females combined using WCGBTS data through 2012 (sexes combined: $\alpha = 4.77e\text{-}6$, $\beta = 3.26$). The β value was higher in the 2013 assessment, indicating a slightly higher weight-at-length for longer fish. We found no temporal trend in

the available data and were unable to account for these small differences in results. The available data suggest that length-weight is highly conserved in shortspine thornyhead; therefore, no sensitivity analysis was conducted for this set of parameters in the 2023 assessment.

2.3.4 Growth (Length-at-Age)

No validated ageing methodology currently exists for shortspine thornyhead; therefore, this species is not aged by the NWFSC or Southwest Fisheries Science Center (SWFSC) and length-at-age data are limited for this stock assessment. Two research age datasets exist for shortspine thornyhead in the West Coast region: (1) Kline (1996) includes 319 unsexed fish collected from Monterey Bay in central California in 1991, and (2) Butler (1995) includes 1,023 sexed fish collected in the waters off northern California and Oregon in 1978-1988 and 1990. The Kline specimens were aged by one age reader, and lengths were reported as total lengths, whereas the Butler specimens were aged independently by two separate age readers, and lengths are reported in fork length. The Butler data age data presented in this assessment are the mean ages between the two age readers.

The length-at-age curve developed in the 2005 stock assessment and used again in 2013 was based on a Schnute parameterization of the Von-Bertalanffy growth function fit to the Kline data. The resulting parameter estimates for this growth function were as follows: growth rate k was 0.018 for both males and females length at age-2 was 7 cm for both males and females, and length at age-100 was 67.5 cm for males and 75 cm for females based on the assumption that the asymptotic length for males should be 90% of the asymptotic length for females (Hamel 2005). The data and associated analysis from 2005 were lost; however, the original Kline and Butler datasets were obtained for use in this assessment (Donna Kline, pers. comm., March 2023). Using these newly obtained data, we could not reproduce the parameters used in the 2005 assessment.

Because the Butler data were sex-specific, had a higher sample size, were aged by two readers instead of one, and were collected from a larger geographic area and over more years compared to the Kline data, we determined that Butler was the preferred dataset to estimate the length-at-age relationship for the 2023 stock assessment. We fit sex-specific Schnute growth functions to the Butler data:

$$\hat{L}_a = L_{a_1} + \frac{(L_{a_2} - L_{a_1})(1 - exp(-k(a_2 - a_1)))}{(1 - exp(-k(a_2 - a_1)))} \tag{6}$$

where: L_{a_1} and L_{a_2} are the lengths at reference ages a_1 and a_2 where $a_1 = 1; a_2 = 100$ and k is the growth rate. Growth curve estimation was conducted in R using the optim() function (R Core Team 2021). Errors were assumed to be lognormally distributed and predicted length-at-age was bias-corrected using a multiplier of $\frac{\sigma_2}{2}$.

Shortspine Thornyhead are slow-growing fish that appear to continue to grow throughout their lifespan (i.e., the growth curve does not asymptote). The new growth curves estimated using the Bulter dataset exhibited similar trends to those assumed in the 2005 and 2013 assessments (Figure 9; Table X-LAA-1). The male curves were almost identical, with the 2005/2013 curve exhibiting slightly lower length-at-age at young ages and slightly higher length-at-age at older ages. The 2005/2013 female curve was defined by a higher growth rate, leading to the higher length-at-age in the intermediate age range.

Two alternative sensitivity analyses were developed for the 2023 assessment. During the exploratory data analysis phase, we found that specimens collected in the Kline study exhibited higher size-at-age when compared to the Butler specimens (Figure 10). It is unknown if these differences should be attributed to spatial differences in growth between central California and northern California/Oregon, bias among age readers, or discrepancies between the total and fork length measurements (Donna Kline, pers. comm., March 2023). In order to account for this alternative growth pattern, we increased the lengths at ages 2 and 100 by 25% in the upper sensitivity analysis (Figure 10). The lower sensitivity analysis was defined by decreasing the lengths at ages 2 and 100 by 10% from the base model.

2.3.5   Ageing Precision and Bias

REPEAT WITH CLARITY

2.4   Environmental and Ecosystem Data

No ecological or environmental information was used in this assessment.

2.5   Changes in data from the 2013 assessment

Most of the data used in the previous assessment has been newly extracted and processed, including length compositions from each fishing fleet and survey, indices of abundance derived from new geostatistical models of survey data, discard rates from both the 1980s Pikitch study and the current WCGOP, and the time series of catch from 1900-2023.

New data or uses of data for this assessment include the geostatistical model-based indices of abundance for the four fisheries independent surveys, the histological maturity samples from the WCGBTS survey, and the historical state catch reconstructions. Previous assessments have treated the AFSC Triennial Shelf Survey as two separate indices of abundance separated by the 366m depth contour, but the transition to using geostatistical model-based indices have rendered this separation unnecessary by implicitly accounting for changes in

depth sampling within the model. State-level historical reconstructions also replace previous analyses that imputed historical shortspine thornyhead catch as a fixed proportion of sablefish catch.

3 Assessment Model

3.1 Summary of Previous Assessments and Reviews

3.1.1 History of Modeling Approaches (not required for an update assessment)

Shortspine Thornyhead was first assessed in 1990 by Jacobson (1990) and Jacobson (1991), and subsequently by Ianelli et al. (1994), Rogers et al. (1998), and Piner and Methot (2001). What would now be called a data-moderate assessment was conducted in 2005 Hamel (2005) using Stock Synthesis (SS2). More recently, shortspine thornyhead were assessed by Taylor and Stephens (2013) using SS3. The 2013 model retained many of the assumptions made by Hamel (2005) including a four fisheries fleet structure, sex-specific growth, and no fecundity relationship. A catch-only projection was conducted in 2019 (Taylor 2019).

3.1.2 Most Recent STAR Panel and SSC Recommendations (not required for an update assessment)

3.1.3 Response to Groundfish Subcommittee Requests (not required in draft)

3.2 Model Structure and Assumptions

3.2.1 Model Changes from the Last Assessment (not required for an update assessment)

The most notable changes from the previous assessment, conducted in 2013, include significant modifications to the fleet and survey structure, and major changes to the maturity and fecundity relationships that underlie the model's biological assumptions.

The 2013 assessment consisted of four fisheries fleets, and used information from four (nominally five) scientific surveys, while the new assessment uses a condensed structure consisting

of just three fisheries fleets and only two (nominally three) surveys (**see 3.2.2 for more details**).

This assessment assumes a new fecundity relationship, in which fecundity increases with body size, as well as a new maturity relationship, in which fish mature at much larger sizes and thus older ages, than were assumed in the 2013 assessment. Further details on the fecundity and maturity relationships can be found in **Section 2.3.2**. A sensitivity analysis was performed to determine the effect of different maturity assumptions on the final model output **(Figure XX)**.

3.2.2 Modeling Platform and Structure

This new assessment, including all exploratory models, profiles, and related analyses, was performed using Stock Synthesis Version 3.30.21 [Methot and Wetzel (2013); Methot et al. (2020)). The majority of analyses were performed using multiple recent versions of R (R Core Team 2021), and relied heavily on the 'r4ss' R package (Taylor et al. 2021) among others. The assessment model was developed and tested across multiple operating systems, including recent versions of Windows and macOS.

Commercial fisheries landings were divided into three distinct fisheries fleets: a northern trawl fleet (Trawl_N) operating off the coasts of Oregon and Washington, a southern trawl fleet (Trawl_S) operating off the coast of California, and a coastwide non-trawl fleet (Non-trawl).

Data from two fisheries-independent scientific surveys were used in this model: the AFSC Slope Survey from 1980-2003, and the more recent WCGBTS from 2004-2022. The triennial survey was further divided into an early (pre-1995) and late period (post-1995) survey to account for the change in depth-sampling that occurred during the 1995 season. These two periods for the triennial survey were treated as separate surveys in the model.

3.2.3 Model Parameters

There are 180 estimated parameters in this assessment. The log of unfished recruitment, $\log(R0)$, controls the overall scale of the population, while annual deviations in recruitment about the assumed stock-recruit relationship (135 parameters) allow for additional uncertainty in the population trajectory. Selectivity and retention parameters (43 parameters) for three fisheries fleets and three scientific surveys allow for estimation of annual length compositions and discards rates. Two catchability parameters are analytically computed from the data, and one additional parameter, representing additional variability in the early Triennial survey, is directly estimated by the model.

3.2.3.1 Growth, Maturity, Fecundity, Mortality, and Recruitment
Growth, maturity, and fecundity parameters were fixed at values determined by external analyses (**see 2.3 for more information**). Due to a lack of aging data, growth could not be modeled internally by the assessment, though, like in the 2005 and 2013 models, there is no systematic misfit to the data suggesting that the externally derived growth curves were misspecified. Sensitivity analyses were performed to determine the overall effect of different assumptions regarding growth or maturity (**Figure XX, Figure XX**).

For this assessment, natural mortality was fixed at a value of 0.04. A likelihood profile exploring alternative natural mortality parameters was also conducted (Figure XX). When naturaly mortality was estimated in the model, the value was **XX**, which was close to the fixed value of 0.04. This marks a change from the 2013 asessment, where natural mortality was fixed at 0.0505 and a standard deviation on a log scale of 0.5361 (Taylor and Stephens 2013)

As in the previous shortspine thornyhead assessment, a Beverton-Holt stock recruitment relationship was assumed. Unlike the 2013 assessment, where steepness was fixed at a value of 0.60, this assessment fixed steepness at 0.72, as recommended by Thorson et al. (2019). A likelihood profile exploring alternative steepness parameters was conducted and the model results were found to be largely insensitive to the assumed value (**Figure XX**).

The overall scale of the population is estimated through the log of the initial recruitment parameter (R0). Recruitment deviations were additionally estimated for the years 1901-2022. Recruitment bias adjustments were phased in beginning in 1950, and were adjusted by a factor of **0.75 in the years 1982-2022** (Taylor and Methot 2013). The R parameter which controls the variability in recruitment deviations was fixed at 0.5 as in the previous assessment. Past assessments performed likelihood profiles over R, finding the model results to be relatively insensitive to its value, and thus further profiles over the parameter were not conducted here.

3.2.3.2 Selectivity and Retention Gear selectivity parameters used in this assessment were specified as a function of size with the additional assumption that age 0 fish were not selected, regardless of their size. Separate size-based selectivity curves were fit to each fishery fleet and survey.

The selectivity curves for all fisheries and surveys were allowed to be dome-shaped and modeled with double-normal selectivity. The double-normal selectivity curve was used in a configuration that has six parameters, including: (1) peak, the length at which selectivity is first fully selected, (2) width of the selectivity plateau, (3) width of the ascending part of the curve, (4) width of the descending part of the curve, (5) starting selectivity, and (6) final selectivity. Parameters 5 and 6 were not estimated and fixed at 0.0. The 2013 model allowed for all selectivity parameters to be estimated, regardless of whether one or more were estimated to be on the parameter bound. This model fixed parameter 2 (the plateau width) to the value of -15 for the North Trawl and Non-trawl fleets to alleviate it hitting the

lower parameter bound. Though exploratory models run with the plateau width on its lower bound still converged, fixing the parameter had negligible impact on the fits to the length composition data for those fleets. Sex-specific selectivity curves were fit to the WCGBTS length composition data.

Retention curves are defined as a logistic function of size. These are controlled by four parameters: (1) inflection, (2) slope, (3) asymptotic retention, and (4) male offset to inflection. Male offset to retention was fixed at 0 (i.e. no male offset was applied). The parameters for inflection and asymptotic retention were modeled as time-varying quantities via use of time blocks, as was done in the 2013 assessment. Therefore, both North Trawl and South Trawl fleets were broken into three periods: (1) 1901–2006, (2) 2007–2010, (3) 2011–2022. The first break was based on observation of a strong reduction in discard rates for both North and South Trawl in this year, while the later break was associated with the beginning of the IFQ program.

Alternative retention blocking schemes were investigated as part of a sensitivity analysis. Notably, a sequence of four-year blocks beginning in 2007 was investigated in order to better fit noticeably lower discards rates in the mid 2010s. Additionally, a short, 2-year, timeblock for the years **2021 and 2022** was also attempted, as discard rates were noticeably higher in those years than in previous. [**...**]

3.2.3.3 Catchability Catchability coefficients (q) were calculated for each of the two survey abundance time series. Unlike in the 2013 model, which estimated catchability for each survey, this model computes catchability analytically for each survey using the Stock Synthesis "floatQ" option (Methot et al. 2020).

This model depends on the assumptions that thornyheads are long-lived, slow-growing, and relatively sedentary groundfish. They are assumed to represent a single stock within the area considered for this assessment. If the assumptions about growth, natural mortality, or stock structure turn out to be far from the true life history and ecology of shortspine thornyheads, this assessment will be highly inaccurate.

3.2.4 Key Assumptions and Structural Choices

3.3 Base Model Results

3.3.1 Parameter Estimates

A complete set of parameter estimates are available in **Table XX**.

3.3.1.1 Recruitment The model estimated 135 annual recruitment deviations (1901-2034) as well as the log of unfished recruitment LN(R0). Unfished recruitment was estimated to be ~11,000,000 annual age-0 recruits (LN(R0) = 9.34) while annual log deviations were generally estimated between -0.5 and 0.5 (**Figure XX; Table XX**). Deviations in 2003 and 2007 were estimated to be substantially larger than other years. As in the 2013 assessment, uncertainty in the scale of annual deviations was substantially larger than the variation between the deviations. Recruitment bias adjustments were performed following the advice of Methot et al. (2011).

3.3.1.2 Selectivity and Retention Selectivity curves for all three fisheries fleets and the three scientific surveys were estimated as dome-shaped.

The early- and late-period Triennial survey possessed the highest degree of dome-shape, with peak selectivity occurring at relatively small length (~26 cm, and ~22 cm respectively), before quickly declining. This shape is consistent with the design of the survey which focused its sampling on the relatively shallow shelf, where younger, smaller, shortspine thornyhead live before migrating to deeper waters as they age and mature . and tThere was little difference in the estimated selectivity curves between male and female fish. Meanwhile, the WCGBTS was estimated to have a wide plateau (beginning at ~30cm) over which the species is fully selected for, including the lengths over which the species spends the bulk of its lifespan. This indicates that the WCGBTS is sampling a large proportion of the stock, and that annual length composition data from the survey is likely a good representation of the true distribution of lengths in the population.

The North Trawl fleet was estimated to have a dome-shaped curve with a small plateau around 28 cm in length, and a long tail that spanned nearly the entire range of observed lengths. The South Trawl fleet was estimated to have a very large selectivity plateau (beginning at ~30cm, ranging from 30-55cm, with very steep ascending and descending limbs. Finally the Non-Trawl fleet was estimated to have a relatively small plateau beginning at a much higher length than any other fleet or survey (~45 cm). This fits with the assumption that the hook and line gear that is primarily used by the Non-Trawl fleet would not select small shortspine thornyhead.

3.3.2 Fits to the Data

3.3.2.1 Abundance Indices The base model reasonably fit the available index data with the exception of the most recent two years of the WCGBTS. The fit to the Triennial survey was relatively flat across the entire timeseries (1980-2004; **Figure XX**). An extra parameter was used to estimate additional variance beyond that estimated by the geostatistical model for this survey. The model fit to the WCGBTS indices appropriately captured the lack of trend in the early and middle portions of the timeseries, but struggled to accurately capture the recent increase in abundance displayed by the indices (**Figure XX**). The

model fit for this survey fails to fall within the estimated confidence interval for the 2021 and 2022 indices. This could be, in part, due to the lack of index data from 2020 (surveys were not conducted due to the ongoing COVID-19 pandemic), which may have helped the model more accurately capture the increase.

3.3.2.2 Fishery Discard Rates The model reasonably fit the discard rates for all three fisheries fleets. The three timeblocks, carried over and extended where necessary from the 2013 model, allowed for the declining trend in discards for the North Trawl fleet to be adequately captured, however, there is a period from 2015-2018 where discards rates for the North Trawl fleet are exceptionally low, that the model fails to fully capture (**Figure XX**). Discards rates in the Southern Trawl fleet are well fit 2006-2014, before and after which the model systematically underestimates the observed discards rates (**Figure XX**). The discard rates for the coastwide Non-Trawl fleet are exceptionally well fit by the model, and there is no evidence that time blocking is necessary for this fleet (**Figure XX**).

3.3.2.3 Fishery Length Compositions The base model fit the fishery and discard length compositions reasonably well in aggregate (**Figure XX**), though there was significant annual variability in the quality fit, often due to difference in effective sample sizes. The Southern Trawl and Non-Trawl fleets were exceptionally well fit by the model, while the model fit to the length compositions from the Northern Trawl fleet underestimated the scale of the peak of the distribution. This type of misfit was similarly observed in the model fits on an annual basis, with all years 2018-2022 displaying a similar underestimation of either the location or scale of the peak of the distribution (**Figure XX**). The exact causes of this under-estimation remain unknown at this time, but could be due to subtle changes in selectivity or availability. The effect of including time-varying selectivity was assessed in a sensitivity analysis (**see 3.4.4.2 for details**).

Trawl discards length compositions were well fit by the model in both the north and south regions, while the model struggled to adequately fit discard compositions from the Non-Trawl fleet (**Figure XX**). The Non-Trawl discards were of a larger size and were generally more dispersed than the discard compositions in the two trawl fleets, a feature the model did pick up on, but the model fitted a wide plateau rather than narrow peak to these composition data. This is likely due to the wide variability in annual length compositions seen in this fleet, as well as the wide spatial coverage.

3.3.2.4 Survey Length Compositions Like the fishery derived length compositions, survey-derived length compositions were reasonably well fit in aggregate by the base model, though there was considerable annual variability in the quality of the model fit (**Figure XX**). The early-period Triennial survey length composition data for both sexes were exceptionally well fit by the model. Length compositions from the late-period Triennial survey were slightly less well fit, with the model under-estimating the location of

23

the peak for both sexes. For the WCGBTS length compositions, the male, female, and unsexed location of the compositional peaks were well estimated, though the overall scales were slightly underestimated. Pearson residuals did not demonstrate any obvious trends that would indicate systematic misfits to the data (**Figure XX**); as such, time varying selectivity was not included in the base model.

3.3.2.5 Mean Body Weight Mean body weight of discarded fish was well fit in the two trawl fleets, and no major trends were observed in either the data of the model estimates. Mean discard weight in the Non-Trawl fleet was observed to have increased in the last ten years, but this trend was not captured by the model. The model, instead, fit a declining trend in discard weight to the Non-Trawl fleet data. The reason for this disparity between the observed data and the model fit is unclear.

3.3.3 Population Trajectory

Unfished equilibrium spawning output (B0) is estimated to be 20,262 eggs, with a 95% confidence interval of 16,291–24,232 eggs. The B0 estimate is not directly comparable to estimates made in previous assessments, which assumed no fecundity relationship, and thus calculated B0 in terms of biomass rather than egg production. Spawning biomass is estimated to have remained stable until the mid-1960s and then declined in the 1970s to about 80% in the mid-1980s, followed by a slower decline under the lower catch levels in the 2000s (**Table XX**, **Figure XX**). While the spawning output of the stock has declined near linearly since 1975, total biomass has stabilized in recent decades around ~85,000 mt. The estimated spawning output in 2023 is **8,204 eggs**, which represents a stock status or "depletion" of 40% (**Figure XX**). The depletion estimated for 2013 is 43.5%, which is significantly lower than the 74.2% estimated for 2013 in the previous assessment.

Twelve-year projections predict that the population is unlikely to experience a large increase in spawning output or spawning biomass in the near future, if the full annual catch limit (ACL) is taken each year (**Figure XX**).

3.3.4 Reference Points

Reference points were calculated using the estimated catch distribution in the final year of the model (2023). In general, the population is on the boundary between "precautionary" (B/B0 = 0.40) and "healthy" status relative to the reference points (Figure XX). Sustainable total yield (landings plus discards) was estimated at 1,060 mt when using an SPR50% reference harvest rate and ranged from 870–1,250 mt based on estimates of uncertainty (Table XX). The spawning output equivalent to 40% of the unfished spawning output (B40%) was **8,105 eggs**.

The most recent catches (landings plus discards) have been lower than the estimated long-term yields calculated using an SPR50% reference point, but not as low as the lower bound of the 95% uncertainty interval. However, this is due to the fishery not fully attaining the full ACL. The overfishing limit (OFL) and ACL values over the past 6 years have been approximately 2,400 mt and 2,000 mt, respectively.

Both of those values are higher than the OFL and ACL values predicted in short-term forecasts, which are around 853 mt and 420 mt respectively for 2023–2024 (**Table XX**). This is reflected in the timeseries of low harvest rates (**Figure XX**), low 1-SPR values (**Figure XX**), and the phase plot showing the history of being above the target biomass and below the target fishing intensity reference points (**Figure XX**).

3.4 Model Diagnostics

Describe all diagnostics

3.4.1 Convergence

3.4.2 Sensitivity Analyses

3.4.3 Retrospective Analysis

3.4.4 Likelihood Profiles

3.4.5 Unresolved Problems and Major Uncertainties

4 Management

4.1 Reference Points

4.2 Unresolved Problems and Major Uncertainties

4.3 Harvest Projections and Decision Tables

4.4 Evaluation of Scientific Uncertainty

4.5 Research and Data Needs

5 Acknowledgments

Here are all the mad props!

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7 Tables

These will likely need reordering

Table 1: Summary of catches by fleet from 2013-2022

Year	Trawl_N	Trawl_S	Non.trawl	Total.Land-ings	Total.Dead
2013	547.98	294.83	166.40	1,009.21	1,085.33
2014	433.12	254.05	147.81	834.98	900.35
2015	503.14	244.29	131.30	878.73	944.89
2016	577.19	185.73	168.94	931.86	1,012.17
2017	606.86	158.30	223.82	988.97	1,085.14
2018	525.04	105.07	184.48	814.60	895.10
2019	402.95	127.94	143.48	674.37	736.75
2020	248.47	87.99	85.17	421.64	458.94
2021	226.00	73.39	78.74	378.13	411.82
2022	261.16	97.61	66.22	424.98	456.93

Table 2: SSB.

Year	Spawn-ing.Output	Interval	Fraction.Un-fished	Interval.1
2013	8,127	5,496–10,759	0.4	0.3–0.5
2014	8,007	5,390–10,624	0.4	0.3–0.5
2015	7,907	5,303–10,511	0.4	0.3–0.5
2016	7,809	5,217–10,401	0.4	0.3–0.5
2017	7,713	5,132–10,294	0.4	0.3–0.5
2018	7,616	5,045–10,188	0.4	0.3–0.5
2019	7,541	4,978–10,104	0.4	0.3–0.5
2020	7,483	4,928–10,039	0.4	0.3–0.5
2021	7,453	4,903–10,003	0.4	0.3–0.5
2022	7,433	4,887–9,979	0.4	0.3–0.5
2023	7,418	4,874–9,961	0.4	0.3–0.5

Table 3: Recruitment

Year	Recruitment	Interval	Recruit-ment.Devia-tions	Interval.1
2013	5,867	2,437–14,122	-0.422	-1.321–0.478
2014	4,763	2,044–11,099	-0.627	-1.487–0.234
2015	4,928	2,099–11,571	-0.590	-1.459–0.279
2016	5,386	2,263–12,821	-0.499	-1.384–0.387
2017	5,128	2,164–12,153	-0.545	-1.425–0.335
2018	4,491	1,920–10,506	-0.675	-1.539–0.189
2019	7,350	3,126–17,281	-0.204	-1.074–0.667
2020	8,652	3,513–21,308	-0.062	-0.988–0.864
2021	9,662	3,779–24,702	0.026	-0.946–0.997
2022	9,689	3,762–24,951	0.005	-0.975–0.986
2023	9,632	3,742–24,793	0.000	-0.980–0.980

Table 4: Reference Points

X	Estimate	Interval
Unfished Spawning Output	19,597	15,956–23,238
Unfished Age 1+ Biomass (mt)	189,270	154,106–224,434
Unfished Recruitment (R0)	11,169	9,094–13,244
Spawning Output (2023)	7,418	4,874–9,961
Fraction Unfished (2023)	0.38	0.30–0.45
Reference Points Based SB40%		
Proxy Spawning Output SB40%	7,839	6,382–9,295
SPR Resulting in SB40%	0.458	0.458–0.458
Exploitation Rate Resulting in SB40%	0.012	0.012–0.012
Yield with SPR Based On SB40% (mt)	1,039	863–1,215
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	8,743	7,119–10,368
SPR50	0.500	-
Exploitation Rate Corresponding to SPR50	0.010	0.010–0.011
Yield with SPR50 at SB SPR (mt)	993	825–1,160
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	5,423	4,423–6,423
SPR MSY	0.347	0.345–0.350
Exploitation Rate Corresponding to SPR MSY	0.017	0.017–0.017
MSY (mt)	1,100	914–1,286

Table 5: Management

Year	OFL	ABC	ACL	Landings	Total.Mortality
2013	fill in	fill in	fill in	1,009.21	1,085.33
2014	fill in	fill in	fill in	834.98	900.35
2015	fill in	fill in	fill in	878.73	944.89
2016	fill in	fill in	fill in	931.86	1,012.17
2017	fill in	fill in	fill in	988.97	1,085.14
2018	fill in	fill in	fill in	814.60	895.10
2019	fill in	fill in	fill in	674.37	736.75
2020	fill in	fill in	fill in	421.64	458.94
2021	fill in	fill in	fill in	378.13	411.82
2022	fill in	fill in	fill in	424.98	456.93

Table 6: Projections

Year	Predicted.OFL..mt.	ABC.Catch..mt.	Age.1..Biomass..mt.	Spawning.Output	Fraction.Unfished
2023	759.92	745.62	79,336.10	7,417.58	0.38
2024	773.32	757.70	79,577.70	7,388.20	0.38
2025	786.24	769.46	79,817.90	7,364.16	0.38
2026	798.53	780.75	80,055.30	7,345.13	0.37
2027	810.09	791.49	80,288.90	7,330.73	0.37
2028	820.87	801.62	80,518.10	7,320.54	0.37
2029	830.87	811.13	80,742.50	7,314.09	0.37
2030	840.13	820.04	80,962.00	7,310.89	0.37
2031	848.69	828.38	81,176.70	7,310.45	0.37
2032	856.61	836.19	81,386.60	7,312.30	0.37
2033	863.94	843.50	81,592.20	7,315.99	0.37
2034	870.74	850.35	81,793.50	7,321.11	0.37

Table 7: Summary table

Year	Predicted.OFL..mt.	ABC.Catch..mt.	Age.1..Biomass..mt.	Spawning.Output	Fraction.Unfished
2023	759.92	745.62	79,336.10	7,417.58	0.38
2024	773.32	757.70	79,577.70	7,388.20	0.38
2025	786.24	769.46	79,817.90	7,364.16	0.38

Table 7: Summary table *(continued)*

Year	Pre-dicted.OFL..mt.	ABC.Catch..mt.	Age.1..Biomass..mt.	Spawn-ing.Output	Frac-tion.Un-fished
2026	798.53	780.75	80,055.30	7,345.13	0.37
2027	810.09	791.49	80,288.90	7,330.73	0.37
2028	820.87	801.62	80,518.10	7,320.54	0.37
2029	830.87	811.13	80,742.50	7,314.09	0.37
2030	840.13	820.04	80,962.00	7,310.89	0.37
2031	848.69	828.38	81,176.70	7,310.45	0.37
2032	856.61	836.19	81,386.60	7,312.30	0.37
2033	863.94	843.50	81,592.20	7,315.99	0.37
2034	870.74	850.35	81,793.50	7,321.11	0.37

Table 8: Catches in all years

Year	Pre-dicted.OFL..mt.	ABC.Catch..mt.	Age.1..Biomass..mt.	Spawn-ing.Output	Frac-tion.Un-fished
2023	759.92	745.62	79,336.10	7,417.58	0.38
2024	773.32	757.70	79,577.70	7,388.20	0.38
2025	786.24	769.46	79,817.90	7,364.16	0.38
2026	798.53	780.75	80,055.30	7,345.13	0.37
2027	810.09	791.49	80,288.90	7,330.73	0.37
2028	820.87	801.62	80,518.10	7,320.54	0.37
2029	830.87	811.13	80,742.50	7,314.09	0.37
2030	840.13	820.04	80,962.00	7,310.89	0.37
2031	848.69	828.38	81,176.70	7,310.45	0.37
2032	856.61	836.19	81,386.60	7,312.30	0.37
2033	863.94	843.50	81,592.20	7,315.99	0.37
2034	870.74	850.35	81,793.50	7,321.11	0.37

Table 9: Likelihood table

Year	Pre-dicted.OFL..mt.	ABC.Catch..mt.	Age.1..Biomass..mt.	Spawn-ing.Output	Frac-tion.Un-fished
2023	759.92	745.62	79,336.10	7,417.58	0.38
2024	773.32	757.70	79,577.70	7,388.20	0.38
2025	786.24	769.46	79,817.90	7,364.16	0.38

Year	Pre-dicted.OFL..mt.	ABC.Catch..mt.	Age.1..Biomass..mt.	Spawn-ing.Output	Frac-tion.Un-fished
2026	798.53	780.75	80,055.30	7,345.13	0.37
2027	810.09	791.49	80,288.90	7,330.73	0.37
2028	820.87	801.62	80,518.10	7,320.54	0.37
2029	830.87	811.13	80,742.50	7,314.09	0.37
2030	840.13	820.04	80,962.00	7,310.89	0.37
2031	848.69	828.38	81,176.70	7,310.45	0.37
2032	856.61	836.19	81,386.60	7,312.30	0.37
2033	863.94	843.50	81,592.20	7,315.99	0.37
2034	870.74	850.35	81,793.50	7,321.11	0.37

Table 10: Table of

caption
Recent landings by fleet, total landings summed across fleets, and the total mortalit
Estimated recent trend in spawning output and the fraction unfished and the 95
Estimated recent trend in recruitment and recruitment deviations and the 95 p
Estimated recent trend in the (1-SPR)/(1-SPR 50\%) where SPR is the spawning potential ratio the expl
Summary of reference points and management quantities, including estimates of the
Recent trend in the overfishing limits (OFLs), the acceptable biological catches (ABCs), the annual catch limits (
Projections of potential OFLs (mt), ABCs (mt), estimated spawning output, and
Summary of recent estimates and managment quantities
Landings (mt) by fleet for all years, total landings (mt), and total mortality (mt)
Time series of population estimates from the base model.
Likelihood components by source.

Table 11: Times series

Year	Total.Biomass..mt.	Spawning.Output	Total.Biomass..mt.	Fraction.Unfished	Age.0.Recruits	Total.Mortality..mt.	X.1.SPR...1.SPR_50..	Exploitation.Rate
1901	189,269	19,597	189,269	100.0	11,003	0.1122950	0.000	0.0000006
1902	189,269	19,597	189,269	100.0	10,982	0.1382090	0.000	0.0000007
1903	189,267	19,597	189,267	100.0	10,959	0.1628900	0.000	0.0000009
1904	189,264	19,597	189,264	100.0	10,927	0.1888040	0.000	0.0000010
1905	189,260	19,597	189,260	100.0	10,888	0.2134840	0.000	0.0000011
1906	189,256	19,597	189,256	100.0	10,849	0.2393980	0.000	0.0000013
1907	189,249	19,597	189,249	100.0	10,818	0.2653130	0.000	0.0000014
1908	189,241	19,597	189,241	100.0	10,786	0.2899930	0.000	0.0000015
1909	189,231	19,597	189,231	100.0	10,742	0.3159070	0.000	0.0000017
1910	189,219	19,597	189,219	100.0	10,704	0.3405870	0.000	0.0000018
1911	189,204	19,596	189,204	100.0	10,658	0.3665000	0.000	0.0000019
1912	189,187	19,596	189,187	100.0	10,624	0.3911800	0.000	0.0000021
1913	189,167	19,596	189,167	100.0	10,615	0.4170920	0.000	0.0000022
1914	189,144	19,596	189,144	100.0	10,612	0.4417700	0.000	0.0000023
1915	189,117	19,596	189,117	100.0	10,573	0.4676810	0.000	0.0000025
1916	189,087	19,596	189,087	100.0	10,529	0.4923570	0.000	0.0000026
1917	189,054	19,595	189,054	100.0	10,506	0.5182640	0.000	0.0000027
1918	189,016	19,595	189,016	100.0	10,492	0.5429360	0.000	0.0000029
1919	188,974	19,594	188,974	100.0	10,477	0.5688400	0.000	0.0000030
1920	188,928	19,593	188,928	100.0	10,454	0.5935070	0.000	0.0000031
1921	188,878	19,592	188,878	100.0	10,440	0.6194060	0.000	0.0000033
1922	188,823	19,591	188,823	100.0	10,419	0.6453020	0.000	0.0000034
1923	188,763	19,590	188,763	100.0	10,411	0.6699610	0.000	0.0000035
1924	188,699	19,588	188,699	100.0	10,413	0.6958510	0.000	0.0000037
1925	188,629	19,587	188,629	99.9	10,412	0.7205040	0.001	0.0000038
1926	188,555	19,585	188,555	99.9	10,418	0.7463890	0.001	0.0000040
1927	188,477	19,582	188,477	99.9	10,429	0.7735040	0.001	0.0000041
1928	188,393	19,580	188,393	99.9	10,448	1.2903600	0.001	0.0000068
1929	188,305	19,577	188,305	99.9	10,474	2.0428000	0.001	0.0000108
1930	188,211	19,574	188,211	99.9	10,509	1.7121400	0.001	0.0000091
1931	188,114	19,570	188,114	99.9	10,554	1.3975400	0.001	0.0000074
1932	188,013	19,566	188,013	99.8	10,608	0.5166419	0.000	0.0000027
1933	187,909	19,561	187,909	99.8	10,673	0.7646253	0.001	0.0000041
1934	187,802	19,556	187,802	99.8	10,749	5.5738870	0.004	0.0000297
1935	187,688	19,550	187,688	99.8	10,835	7.3338649	0.006	0.0000391
1936	187,569	19,544	187,569	99.7	10,931	4.5716704	0.003	0.0000244
1937	187,452	19,537	187,452	99.7	11,035	7.3666203	0.006	0.0000393
1938	187,331	19,530	187,331	99.7	11,145	7.4312900	0.006	0.0000397

Table 11: Times series *(continued)*

Year	Total.Biomass..mt	Spawning.Output	Total.Biomass..mt	Fraction.Unfished	Age.0.Recruits	Total.Mortality..mt.	X.1.SPR...1.SPR_50..	Exploitation.Rate
1939	187,210	19,522	187,210	99.6	11,255	6.5069903	0.005	0.0000348
1940	187,091	19,513	187,091	99.6	11,362	3.1637620	0.002	0.0000169
1941	186,977	19,505	186,977	99.5	11,456	5.6164170	0.004	0.0000300
1942	186,862	19,496	186,862	99.5	11,532	6.5045270	0.005	0.0000348
1943	186,750	19,486	186,750	99.4	11,577	17.5220900	0.013	0.0000938
1944	186,629	19,475	186,629	99.4	11,584	8.5984910	0.007	0.0000461
1945	186,522	19,465	186,522	99.3	11,542	7.9877000	0.007	0.0000428
1946	186,420	19,454	186,420	99.3	11,448	6.5296970	0.006	0.0000350
1947	186,324	19,442	186,324	99.2	11,297	6.3834310	0.006	0.0000343
1948	186,232	19,431	186,232	99.2	11,092	16.6526470	0.015	0.0000894
1949	186,132	19,419	186,132	99.1	10,840	15.9824768	0.014	0.0000859
1950	186,036	19,406	186,036	99.0	10,550	8.9854703	0.008	0.0000483
1951	185,950	19,394	185,950	99.0	10,206	13.5833230	0.012	0.0000730
1952	185,860	19,381	185,860	98.9	9,851	16.2945130	0.015	0.0000877
1953	185,766	19,368	185,766	98.8	9,497	6.3777980	0.005	0.0000343
1954	185,680	19,356	185,680	98.8	9,153	130.1630280	0.114	0.0007010
1955	185,459	19,333	185,459	98.7	8,829	78.1098160	0.069	0.0004212
1956	185,287	19,315	185,287	98.6	8,531	161.2407510	0.140	0.0008702
1957	185,019	19,289	185,019	98.4	8,265	74.4015780	0.066	0.0004021
1958	184,835	19,272	184,835	98.3	8,036	42.1065330	0.037	0.0002278
1959	184,675	19,256	184,675	98.3	7,849	66.8688320	0.056	0.0003621
1960	184,476	19,239	184,476	98.2	7,708	190.3624630	0.149	0.0010319
1961	184,133	19,211	184,133	98.0	7,617	91.9920480	0.075	0.0004996
1962	183,881	19,192	183,881	97.9	7,580	143.7440130	0.114	0.0007817
1963	183,558	19,169	183,558	97.8	7,600	239.3941490	0.182	0.0013042
1964	183,116	19,136	183,116	97.6	7,677	208.8467030	0.163	0.0011405
1965	182,691	19,106	182,691	97.5	7,801	353.7137820	0.266	0.0019361
1966	182,094	19,063	182,094	97.3	7,957	1275.8495380	0.837	0.0070065
1967	180,495	18,939	180,495	96.6	8,115	1325.6063800	0.845	0.0073443
1968	178,822	18,806	178,822	96.0	8,252	2126.4637330	0.141	0.0118915
1969	176,275	18,597	176,275	94.9	8,355	691.2991200	0.517	0.0039217
1970	175,239	18,516	175,239	94.5	8,449	822.3422540	0.593	0.0046927
1971	174,048	18,422	174,048	94.0	8,563	1021.9492690	0.722	0.0058717
1972	172,629	18,309	172,629	93.4	8,722	1864.1213810	0.093	0.0107984
1973	170,298	18,116	170,298	92.4	8,907	3186.7461060	0.470	0.0187128
1974	166,540	17,799	166,540	90.8	9,041	1427.8569900	0.937	0.0085737
1975	164,647	17,636	164,647	90.0	9,043	2376.8869030	0.295	0.0144363
1976	161,733	17,384	161,733	88.7	8,867	1991.2206700	0.172	0.0123118
1977	159,225	17,162	159,225	87.6	8,595	1650.2270000	0.059	0.0103641

Year	Total.Biomass..mt	Spawning Output	Total.Biomass..mt	Fraction.Un-fished	Age.0.Recruits	Total.Mortality..mt.	X.1.SPR...1.SPR_50..	Exploitation.Rate
1978	157,078	16,969	157,078	86.6	8,358	1244.215790	0.894	0.0079210
1979	155,364	16,810	155,364	85.8	8,251	1844.315030	0.152	0.0118709
1980	153,007	16,593	153,007	84.7	8,269	1444.475930	0.010	0.0094406
1981	151,081	16,411	151,081	83.7	8,341	1806.178770	0.166	0.0119550
1982	148,771	16,192	148,771	82.6	8,386	2038.105490	0.272	0.0136996
1983	146,219	15,950	146,219	81.4	8,397	2008.252190	0.290	0.0137346
1984	143,704	15,709	143,704	80.2	8,390	3083.582720	0.593	0.0214579
1985	140,044	15,366	140,044	78.4	8,584	3570.554920	0.681	0.0254960
1986	135,865	14,974	135,865	76.4	8,646	3115.146250	0.620	0.0229282
1987	132,183	14,618	132,183	74.6	8,728	2125.985500	0.419	0.0160837
1988	129,576	14,353	129,576	73.2	9,003	3071.713600	0.653	0.0237059
1989	125,970	13,998	125,970	71.4	9,175	5186.744900	0.875	0.0411744
1990	120,109	13,444	120,109	68.6	9,147	4446.283000	0.861	0.0370187
1991	115,054	12,956	115,054	66.1	8,771	3913.577100	0.850	0.0340151
1992	110,582	12,517	110,582	63.9	8,453	3666.814200	0.834	0.0331592
1993	106,384	12,094	106,384	61.7	8,587	4020.758200	0.876	0.0377948
1994	101,821	11,638	101,821	59.4	8,421	3707.046000	0.873	0.0364075
1995	97,615	11,209	97,615	57.2	9,215	2163.713200	0.669	0.0221659
1996	95,086	10,921	95,086	55.7	6,787	1813.974000	0.587	0.0190772
1997	92,967	10,666	92,967	54.4	8,112	1582.158500	0.519	0.0170184
1998	91,124	10,435	91,124	53.2	8,996	1394.035700	0.449	0.0152982
1999	89,523	10,224	89,523	52.2	11,177	853.3116000	1.126	0.0095317
2000	88,553	10,064	88,553	51.4	13,712	936.4408000	1.189	0.0105749
2001	87,549	9,900	87,549	50.5	10,935	615.4450000	0.918	0.0070297
2002	86,952	9,769	86,952	49.9	10,850	877.0320000	1.148	0.0100864
2003	86,126	9,618	86,126	49.1	20,516	949.4630000	1.210	0.0110241
2004	85,276	9,465	85,276	48.3	11,143	879.9250000	1.163	0.0103186
2005	84,594	9,322	84,594	47.6	9,980	773.9670000	1.078	0.0091492
2006	84,054	9,192	84,054	46.9	8,322	835.314000	1.133	0.0099379
2007	83,523	9,061	83,523	46.2	44,689	1106.195000	0.335	0.0132441
2008	82,771	8,913	82,771	45.5	11,278	1571.492000	0.569	0.0189860
2009	81,744	8,731	81,744	44.6	12,612	1682.771000	0.615	0.0205859
2010	80,574	8,544	80,574	43.6	11,019	1490.250000	0.548	0.0184953
2011	79,633	8,376	79,633	42.7	8,228	1070.019000	0.331	0.0134369
2012	79,186	8,246	79,186	42.1	7,141	987.4390000	1.276	0.0124698
2013	78,869	8,127	78,869	41.5	5,867	1085.334000	0.340	0.0137612
2014	78,490	8,007	78,490	40.9	4,763	900.3480000	1.208	0.0114709
2015	78,340	7,907	78,340	40.3	4,928	944.8940000	1.238	0.0120615
2016	78,174	7,809	78,174	39.8	5,386	1012.168000	1.280	0.0129475

Table 11: Times series *(continued)*

| Year	Total.Biomass.mt	Spawning.Output	Total.Biomass.mt	Fraction.Unfished	Age.0.Recruits	Total.Mortality..mt.	X.1.SPR...1.SPR_50..	Exploitation.Rate
2017	77,968	7,713	77,968	39.4	5,128	1085.144	0.322	0.0139177
2018	77,711	7,616	77,711	38.9	4,491	895.097	1.183	0.0115183
2019	77,671	7,541	77,671	38.5	7,350	736.749	1.038	0.0094855
2020	77,812	7,483	77,812	38.2	8,652	458.9371	0.731	0.0058980
2021	78,273	7,453	78,273	38.0	9,662	411.8235	0.659	0.0052614
2022	78,815	7,433	78,815	37.9	9,689	456.9348	0.702	0.0057976
2023	79,336	7,418	79,336	37.9	9,632	745.621	0.987	0.0093983
2024	79,578	7,388	79,578	37.7	9,623	757.697	0.986	0.0095215
2025	79,818	7,364	79,818	37.6	9,616	769.455	0.986	0.0096401
2026	80,055	7,345	80,055	37.5	9,611	780.751	0.985	0.0097526
2027	80,289	7,331	80,289	37.4	9,606	791.491	0.985	0.0098580
2028	80,518	7,321	80,518	37.4	9,603	801.621	0.984	0.0099558
2029	80,742	7,314	80,742	37.3	9,602	811.134	0.984	0.0100459
2030	80,962	7,311	80,962	37.3	9,601	820.042	0.984	0.0101287
2031	81,177	7,310	81,177	37.3	9,600	828.380	0.984	0.0102047
2032	81,387	7,312	81,387	37.3	9,601	836.187	0.984	0.0102743
2033	81,592	7,316	81,592	37.3	9,602	843.501	0.984	0.0103380
2034	81,794	7,321	81,794	37.4	9,604	850.354	0.984	0.0103964

8 Figures

9 Data figures
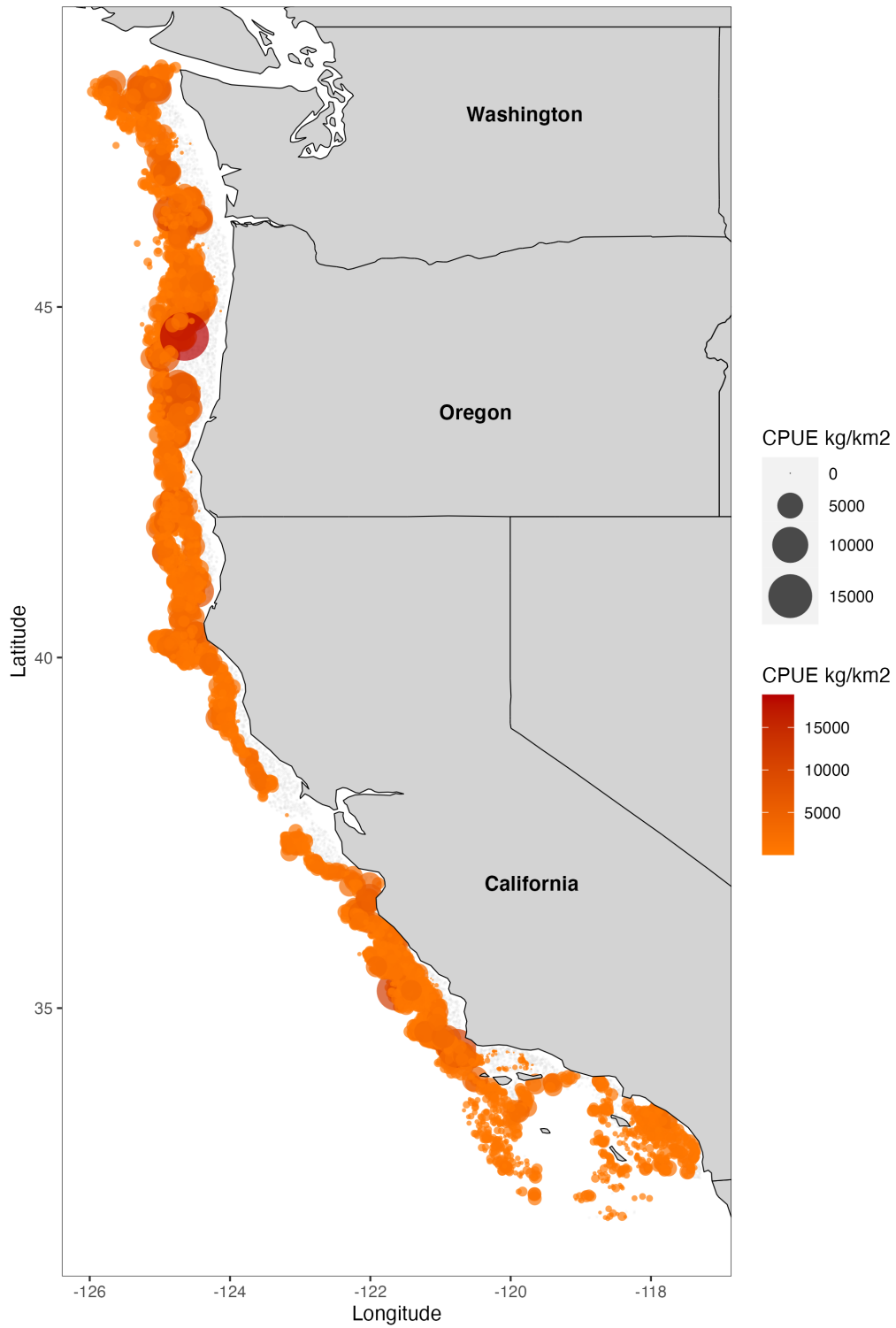
Figure 1: Biomass of shortspine thornyhead found in the NWFSC West Coast Groundfish Bottom Trawl Survey annual survey (2003-2022) coastwide.
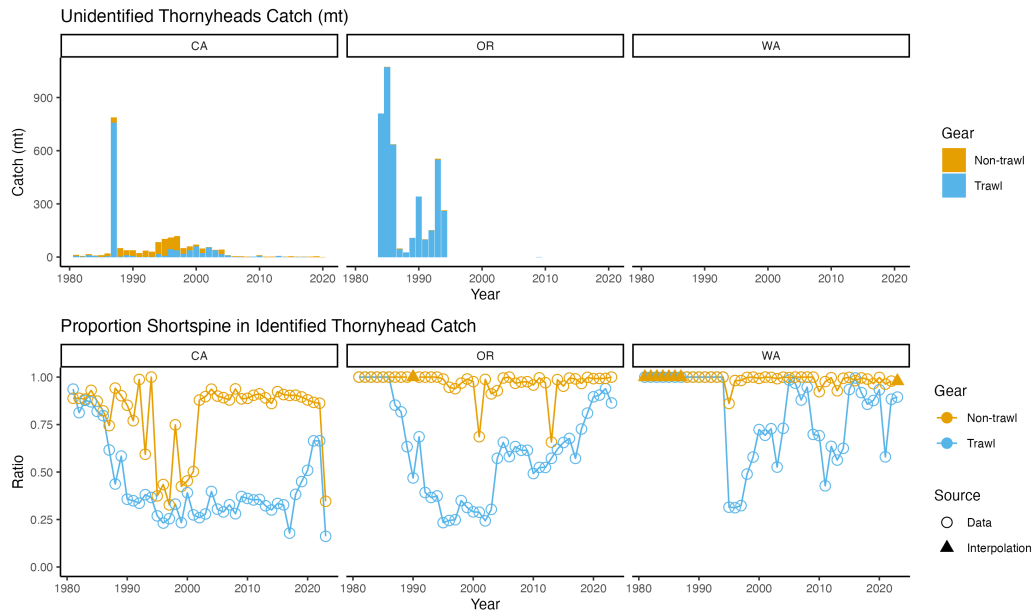
Figure 2: Unidentified thornyhead catches (mt) and the proportion identified as short-spines, calculated as the ratio of shortspine thornyhead catches and longspine and shortspine catches.
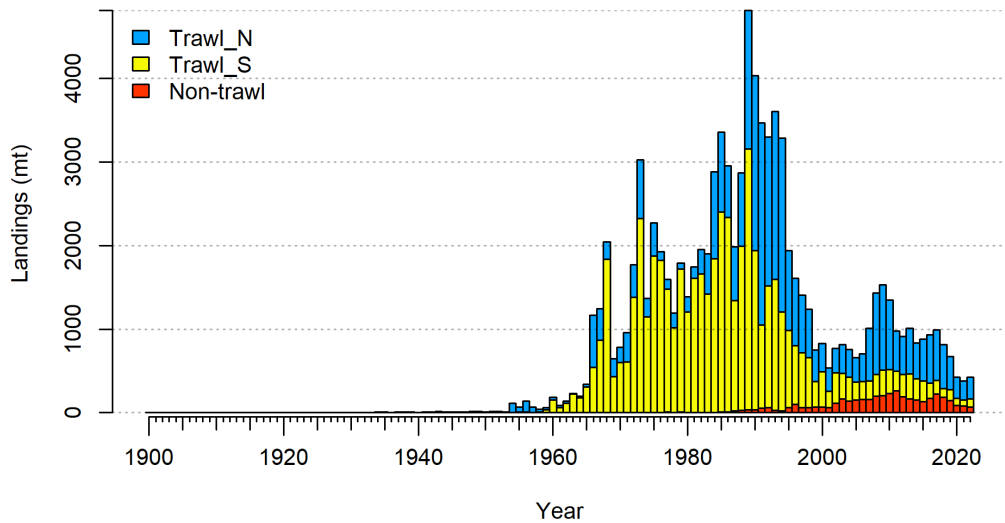

Figure 3: Estimated landing history for shortspine thornyhead.
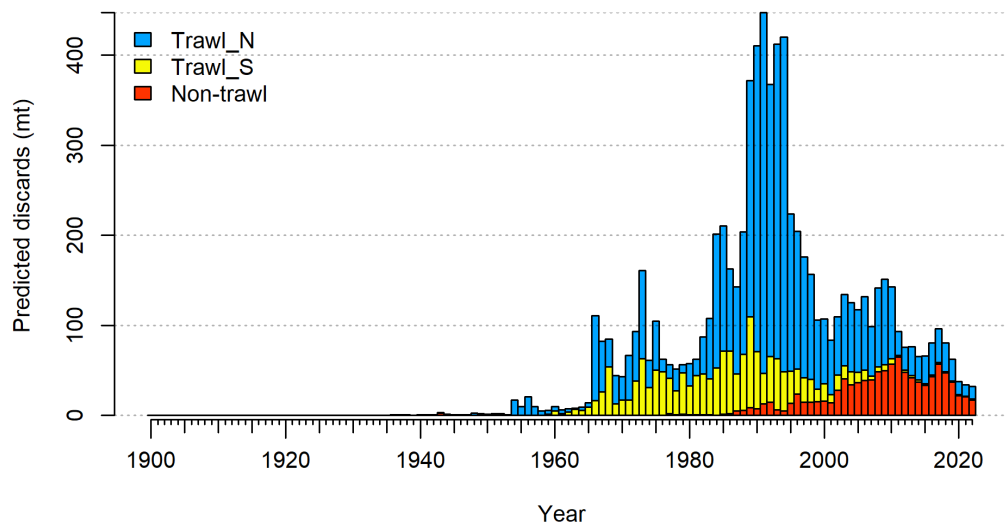
Figure 4: Summary of data sources used in the base model.

Figure 5: Predicted discards based estimated retention and selectivity for each fleet.
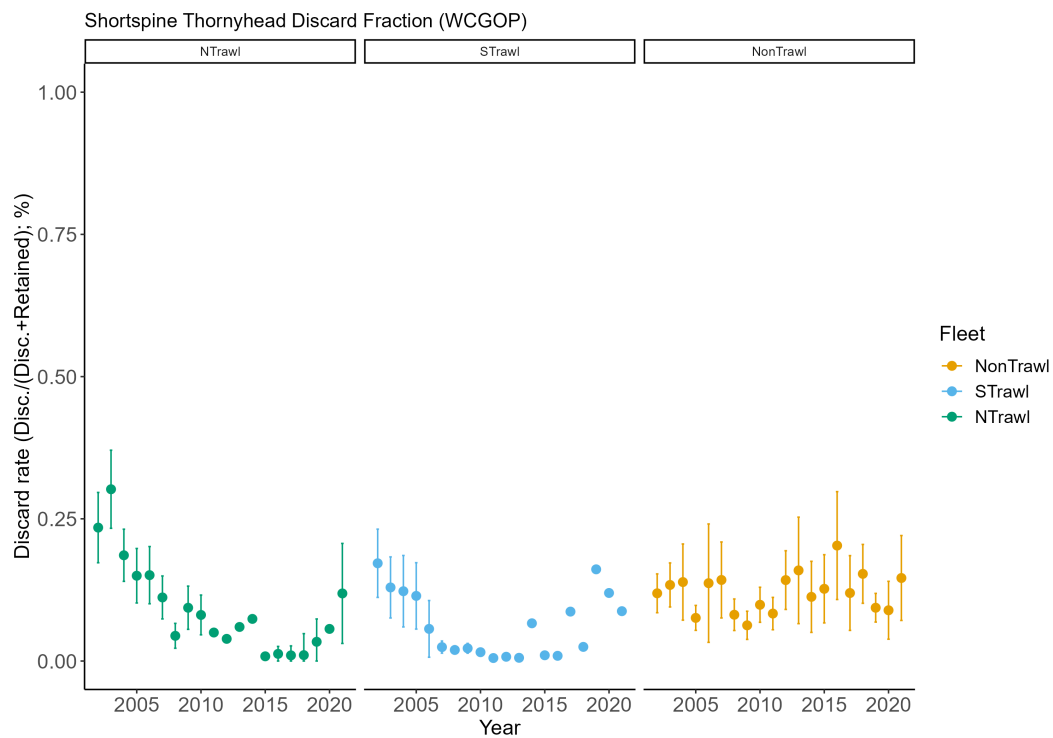
Figure 6: Discard rates from the WCGOP data set with catch share and non-catch share considerations from the GEMM dataset.
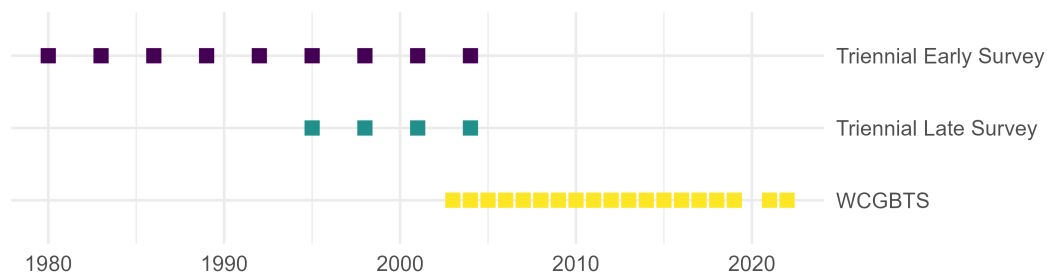
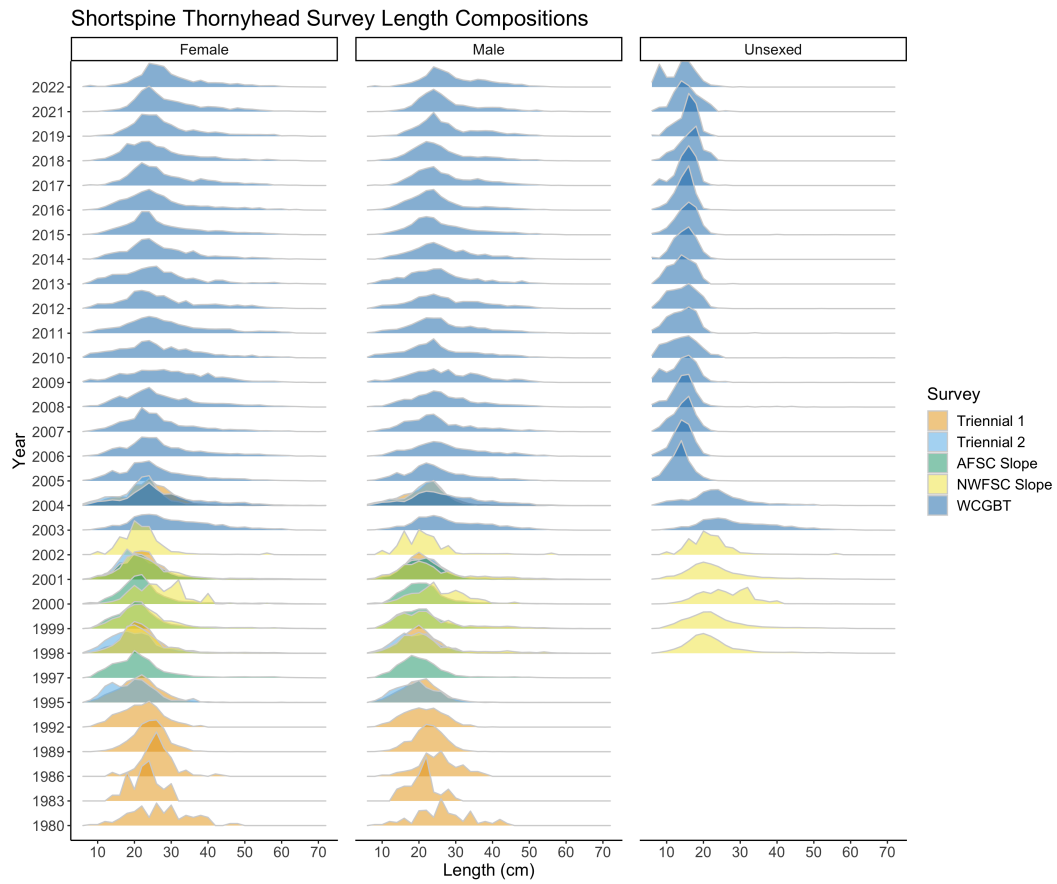**Figure 7:** Summary of survey data sources used in the base model.
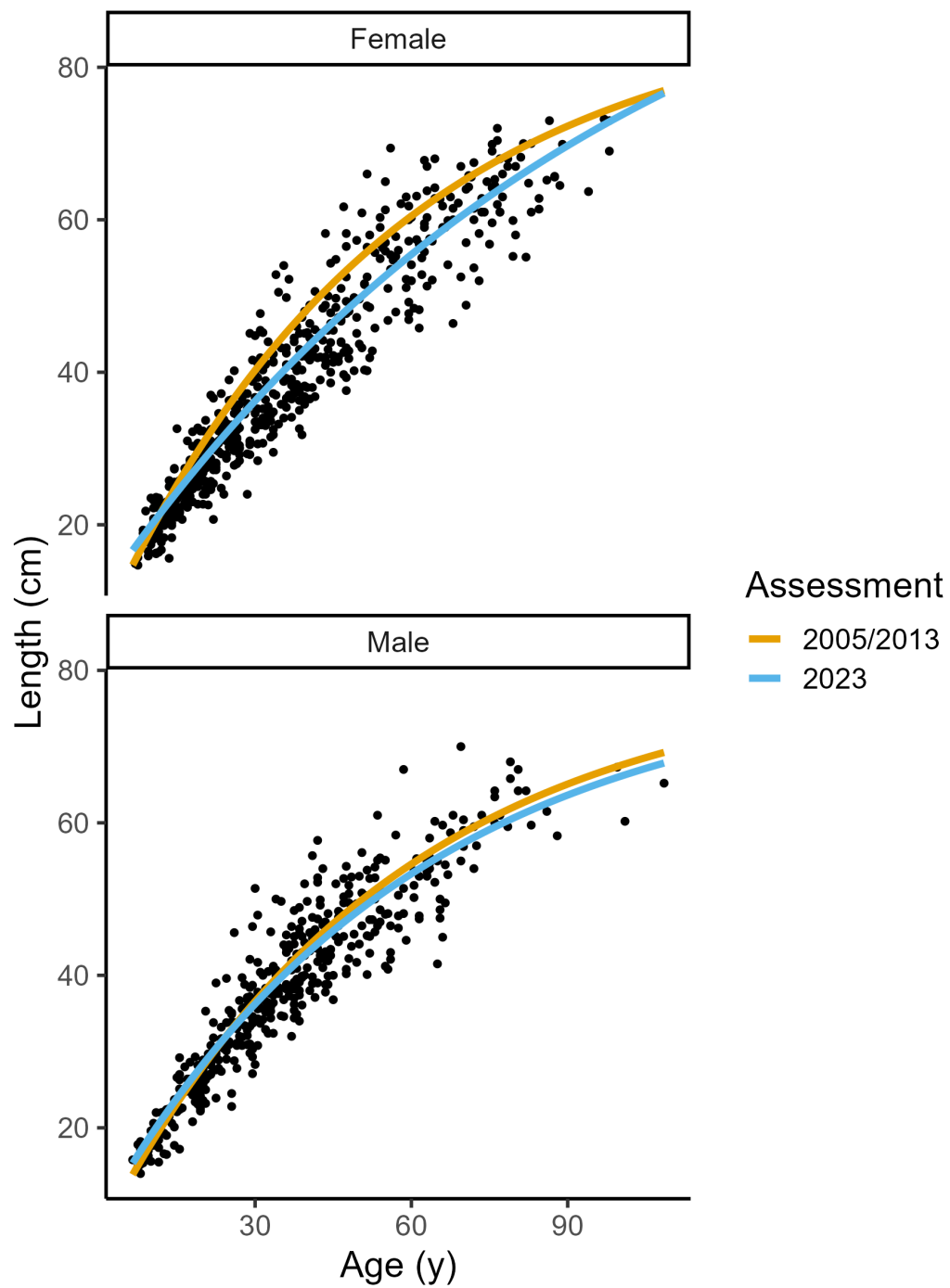
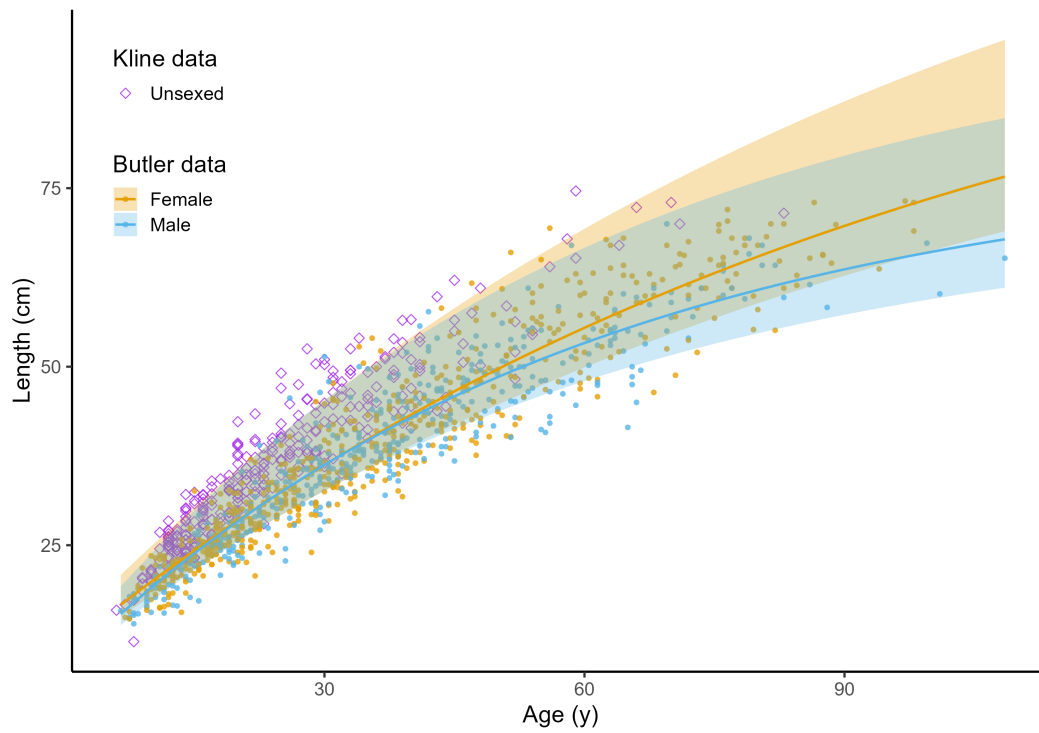**Figure 8:** Survey length composition data.

Figure 9: Growth curve comparison. .

Figure 10: Growth curve sensitivities.