Stock assessment of the Longnose Skate (*Beringraja rhina*) in state and Federal waters off California, Oregon and Washington

by

Vladlena Gertseva[1], Sean E. Matson[2], Ian Taylor[1], Joe Bizzarro[3] and John Wallace[1]

[1]Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
Seattle, Washington 98112, USA

[2]West Coast Region
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
Seattle, Washington 98115, USA

[1]Southwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
Santa Cruz, California 95060, USA

2019

This report may be cited as:

Gertseva, V. Matson, S., Taylor, I. Bizzarro, J, Wallace, J. 2019. Stock assessment of the Longnose Skate (*Beringraja rhina*) in state and Federal waters off California, Oregon and Washington. Pacific Fishery Management Council, Portland, OR. Available from http://www.pcouncil.org/groundfish/stock-assessments/

Table of Contents

Acronyms used in this document ... 6

Executive Summary ... 7
- Stock ... 7
- Catches ... 7
- Data and assessment ... 8
- Stock biomass ... 9
- Recruitment ... 10
- Exploitation status ... 11
- Ecosystem considerations ... 15
- Reference points ... 15
- Management performance ... 17
- Unresolved problems and major uncertainties ... 18
- Scientific uncertainty ... 19
- Decision table ... 19
- Projected Landings, OFLs and Time-varying ACLs ... 20
- Research and data needs ... 20

1 Introduction ... 24
- 1.1 Basic Information ... 24
- 1.2 Map ... 25
- 1.3 Life History ... 25
- 1.4 Ecosystem Considerations ... 26
- 1.5 Fishery Information ... 26
- 1.6 Summary of Management History ... 27
- 1.7 Management Performance ... 28
- 1.8 Fisheries off Canada, Alaska, and/or Mexico ... 28

2 Assessment ... 28
- 2.1 Data ... 28
  - 2.1.1 Fishery removals ... 29
    - 2.1.1.1 Commercial landings ... 29
      - 2.1.1.1.1 California ... 29
      - 2.1.1.1.2 Oregon ... 30
      - 2.1.1.1.3 Washington ... 32
    - 2.1.1.2 Commercial discards ... 33
      - 2.1.1.2.1 Sources of discard information on the U.S. West Coast ... 33
      - 2.1.1.2.2 Method used to estimate discard ... 33
      - 2.1.1.2.3 Discard mortality ... 34
    - 2.1.1.3 Tribal catches ... 35
  - 2.1.2 Abundance Indices ... 35
    - 2.1.2.1 Fishery-Independent Indices ... 36
      - 2.1.2.1.1 Bottom Trawl Surveys ... 36
      - 2.1.2.1.2 Bottom trawl survey biomass indices ... 37
      - 2.1.2.1.3 International Pacific Halibut Commission Longline Survey ... 38
  - 2.1.3 Fishery-Dependent Biological Compositions ... 38
    - 2.1.3.1 Length Compositions ... 38

2.1.3.1.1 Length compositions of landings 38
2.1.3.1.2 Length compositions of discard 39
2.1.3.2 Age Compositions 40
2.1.4 Fishery-Independent Biological Compositions 40
2.1.4.1 Length Compositions 40
2.1.4.2 Age Compositions 41
2.1.5 Biological Parameters and Data 42
2.1.5.1 Length-Weight Relationships 42
2.1.5.2 Maturity 42
2.1.5.3 Fecundity 43
2.1.5.4 Ageing Error 43
2.1.6 Environmental or Ecosystem Data 44
2.2 Model 44
2.2.1 History of Modeling Approaches Used for this Stock 44
2.2.1.1 Previous Assessments 44
2.2.1.2 Responses to 2009 STAR Panel Recommendations 45
2.2.2 Model Description 47
2.2.2.1 Changes Made From the Last Assessment 47
2.2.2.2 Model Specifications 49
2.2.2.3 Data Weighting 50
2.2.2.4 Model Parameters 51
2.2.2.4.1 Growth 51
2.2.2.4.2 Natural Mortality 51
2.2.2.4.3 Stock -Recruitment Function and Compensation 52
2.2.2.4.4 Selectivity Parameters 53
2.2.2.4.5 Survey Catchability Parameters 53
2.3 Base Model Selection and Evaluation 54
2.3.1 Search for Balance Between Model Realism and Parsimony 54
2.3.2 Convergence 55
2.3.3 Evidence of Search for Global Best Estimates 55
2.4 Changes Made During the 2019 STAR Panel Meeting 56
2.5 Base-Model Results 56
2.6 Evaluation of Uncertainty 58
2.6.1 Sensitivity Analysis 58
2.6.1.1 Sensitivity to Assumptions Regarding Fishery Removals 58
2.6.1.2 Sensitivity to Updating Selected Parameters from the 2007 Model 59
2.6.1.3 Sensitivity to Model Specifications 59
2.6.2 Retrospective Analysis 60
2.6.3 Historical Analysis 61
2.6.4 Likelihood Profile Analysis 61
3 Reference Points 62
4 Harvest Projections and Decision Table 62
5 Regional Management Considerations 63
6 Research Needs 63
7 Acknowledgments 65
8 Literature Cited 66

9 Tables..71
10 Figures..104
11 Auxiliary Files 226
12 Appendix 1..227

Acronyms used in this document

ABC	Acceptable Biological Catch
ACL	Annual Catch Limit
AFSC	Alaska Fisheries Science Center
CDFW	California Department of Fish and Wildlife
DFO	Canada's Department of Fisheries and Oceans
DTS	Dover-Thorneyheads-Sablefish Complex
DOVR	Dover Sole Complex
DW	Disk Width
GMT	Groundfish Management Team
IFQ	Individual Fishing Quota
INPFC	International North Pacific Fisheries Commission
IPHC	International Pacific Halibut Commission
ISW	Interspiracular Width
NMFS	National Marine Fisheries Service
NWFSC	Northwest Fisheries Science Center
ODFW	Oregon Department of Fish and Wildlife
OFL	Overfishing Limit
OY	Optimum Yield
PacFIN	Pacific Fisheries Information Network
PFMC	Pacific Fishery Management Council
SPR	Spawning Potential Ratio
SSC	Scientific and Statistical Committee
SWFSC	Southwest Fisheries Science Center
TL	Total Length
VAST	Vector Autoregressive Spatio-Temporal Package
WCGBT Survey	West Coast Groundfish Bottom Trawl Survey
WCGOP	West Coast Groundfish Observer Program
WDFW	Washington Department of Fish and Wildlife

Executive Summary

Stock

This assessment reports the status of the Longnose Skate (*Beringraja rhina*) resource off the coast of the United States from Southern California to the U.S. - Canadian border using data through 2018. The species is modeled as a single stock, as there is currently no biological and genetic data supporting the presence of multiple stocks within the assessment region.

Catches

Longnose Skate historically have not been a prized catch. Commercially, they are caught incidentally in the trawl groundfish fishery and often discarded. Skate landings remained low through the mid-1990s, but increased after 1995, when the fishery started to retain skates following the appearance of a market for whole skates (not only the pectoral fins, often referred to as "wings"). Currently, West Coast skates are marketed both whole and as wings.

Landed catch for Longnose Skate is reported from 2009 forward. Prior to that, the landed catch of skates is documented through fish tickets, but most records are for a combined-skate category. Separating Longnose Skate from combined skate landings as well as estimating historical discard has been a challenge, as it has been for many skate species around the world. For this assessment, historical landings of Longnose Skate were reconstructed for each state, through a coordinated effort among NMFS and state agencies. Historical time series of Longnose Skate discards were also reconstructed from a variety of fishery-independent and fishery-dependent data sources.

Table ES-1: Recent Longnose Skate landings in commercial fisheries by state; tribal fishery landed catch reported separately.

Years	Washington landings (mt)	Oregon landings (mt)	California landings (mt)	Tribal fishery (mt)	Total dead catch (mt) (landings and dead discard*)
2009	136	675	128	27	1,152
2010	66	764	152	13	1,165
2011	76	550	171	22	916
2012	116	588	192	40	1,030
2013	85	654	151	68	1,051
2014	54	581	169	36	926
2015	41	546	170	72	904
2016	59	614	140	83	980
2017	78	547	147	67	913
2018	71	470	114	53	771

* The assessment assumes 50% survival of the discarded fish.

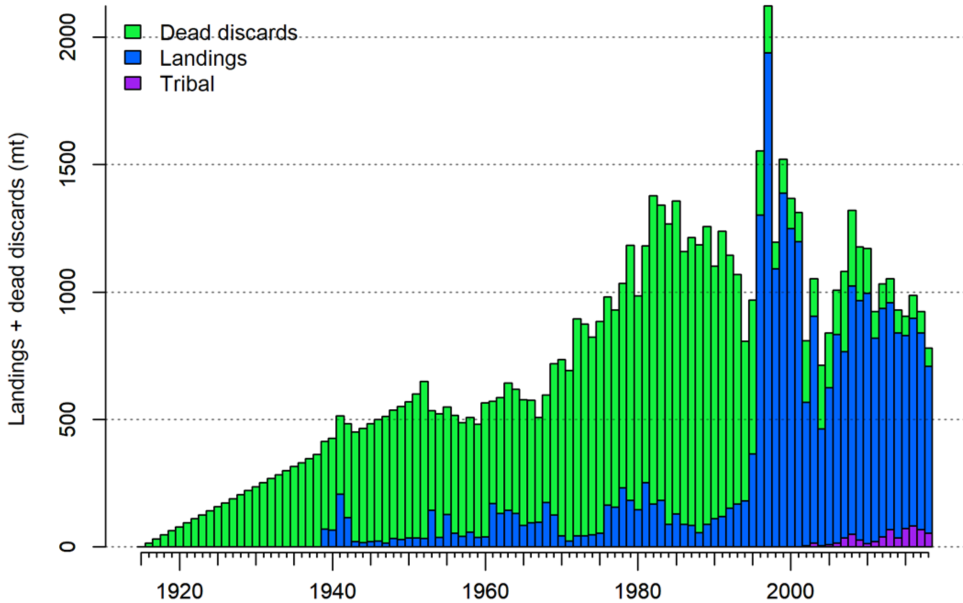

Figure ES-1: Longnose Skate catch history between 1916 and 2018, used in the assessment. Commercial catches (landings and dead discard) are shown separately tribal catches.

Data and assessment

The Longnose Skate population on the West Coast of the United States was assessed only once before, in 2007, using the Stock Synthesis 2 modeling framework. This current assessment uses Stock Synthesis version 3.30.13, released in March 2019.

The assessed period begins in 1916, when skate catch started to first appear in fisheries records, with the assumption that previously the stock was in an unfished equilibrium condition. Types of data that inform the model include catch, length and age frequency data from commercial and tribal fishing fleets. Commercial fishery data are divided among three coastwide fleets, which include the current fishery (1995-present), historical landings and historical discard. Fishery-dependent biological data used in the assessment originated from both port-based and on-board observer sampling programs. Relative biomass indices and information from biological sampling from four bottom trawl surveys were included; these trawl surveys were conducted by the Northwest Fisheries Science Center (NWFSC) and the Alaska Fisheries Science Center (AFSC) of the National Marine Fisheries Service (NMFS). Longnose Skate catch in the International Pacific Halibut Commission's (IPHC's) long-line survey is also included via an index of relative abundance; IPHC length frequency data are used.

Growth is assumed to follow the von Bertalanffy growth model, and the assessment explicitly estimates all parameters describing somatic growth. Females and males are combined in the model, since estimates of parameters for growth and the length-weight relationship did not differ between the sexes. Externally estimated life history parameters, including those defining the length-weight relationship and maturity schedule, were revised for this assessment to incorporate new information. Female fecundity is assumed to be proportional to spawning biomass. Recruitment dynamics are assumed to follow the Beverton-Holt stock-recruit function, and recruits are taken deterministically from the stock-recruit curve. Natural mortality and catchability of the current bottom trawl survey are estimated using prior probability distributions.

Stock biomass

The unexploited level of spawning stock output is estimated to be 12,252 metric tons (95 percent confidence interval: 9,155–15,350 metric tons) (Figure ES-2). At the beginning of 2019, the spawning stock output is estimated to be 6,923 metric tons (95 percent confidence interval: 3,283–10,563 metric tons), which represents 57 percent of the unfished spawning biomass.

The assessment described the dynamics of the Longnose Skate stock to be slowly declining from the unfished conditions, with a flat trend from the early 2000s (Figure ES-3).

Table ES-2: Recent trends in estimated Longnose Skate spawning biomass, recruitment and relative spawning biomass.

Years	Spawning Biomass	~95% Asymptotic Interval	Recruitment	~95% Asymptotic Interval	Estimated Depletion (%)	~95% Asymptotic Interval
2009	7,046	3,549–10,544	10,144	6,049–17,010	57.5	43.3–71.7
2010	7,009	3,499–10,518	10,116	6,018–17,004	57.2	42.8–71.6
2011	6,962	3,439–10,485	10,082	5,980–16,995	56.8	42.2–71.4
2012	6,966	3,428–10,504	10,084	5,977–17,015	56.9	42.1–71.6
2013	6,940	3,387–10,493	10,065	5,953–17,019	56.6	41.8–71.5
2014	6,908	3,339–10,476	10,041	5,923–17,020	56.4	41.3–71.5
2015	6,902	3,318–10,485	10,036	5,913–17,035	56.3	41.1–71.5
2016	6,902	3,303–10,500	10,036	5,907–17,053	56.3	41.0–71.7
2017	6,887	3,274–10,499	10,025	5,890–17,062	56.2	40.7–71.7
2018	6,888	3,262–10,514	10,026	5,885–17,080	56.2	40.6–71.8
2019	6,923	3,283–10,563	10,052	5,904–17,114	56.5	40.9–72.1

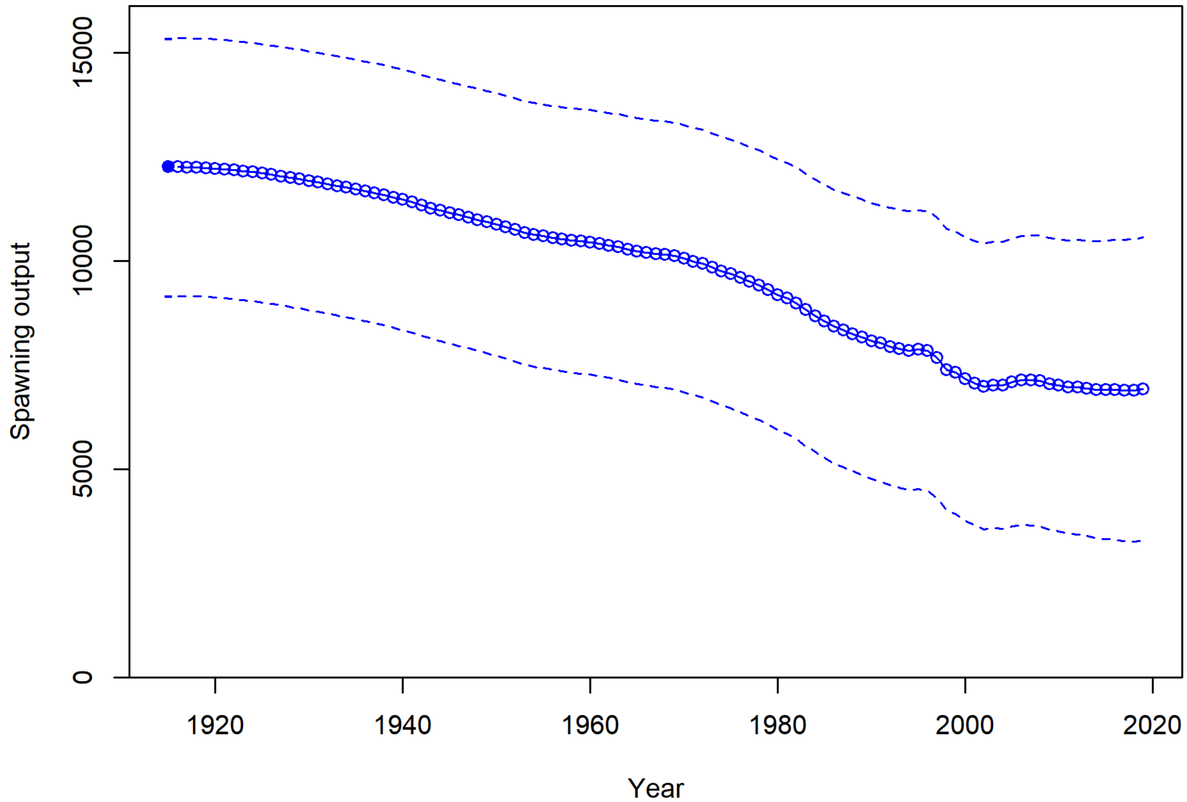

Figure ES-2: Time series of estimated spawning output for the base model (circles) with ~ 95 percent confidence interval (dashed lines). Spawning output is expressed in metric tons.

Recruitment

Recruitment dynamics of Longnose Skate are assumed to follow a Beverton-Holt stock-recruit function. The steepness parameter (*h*) is fixed at the value of 0.4, which was used in the previous assessment, to reflect the equilibrium life history strategy of the species. The level of virgin recruitment (R_0) is estimated to inform the magnitude of the initial stock size. Recruits are taken deterministically from the stock-recruit curve.

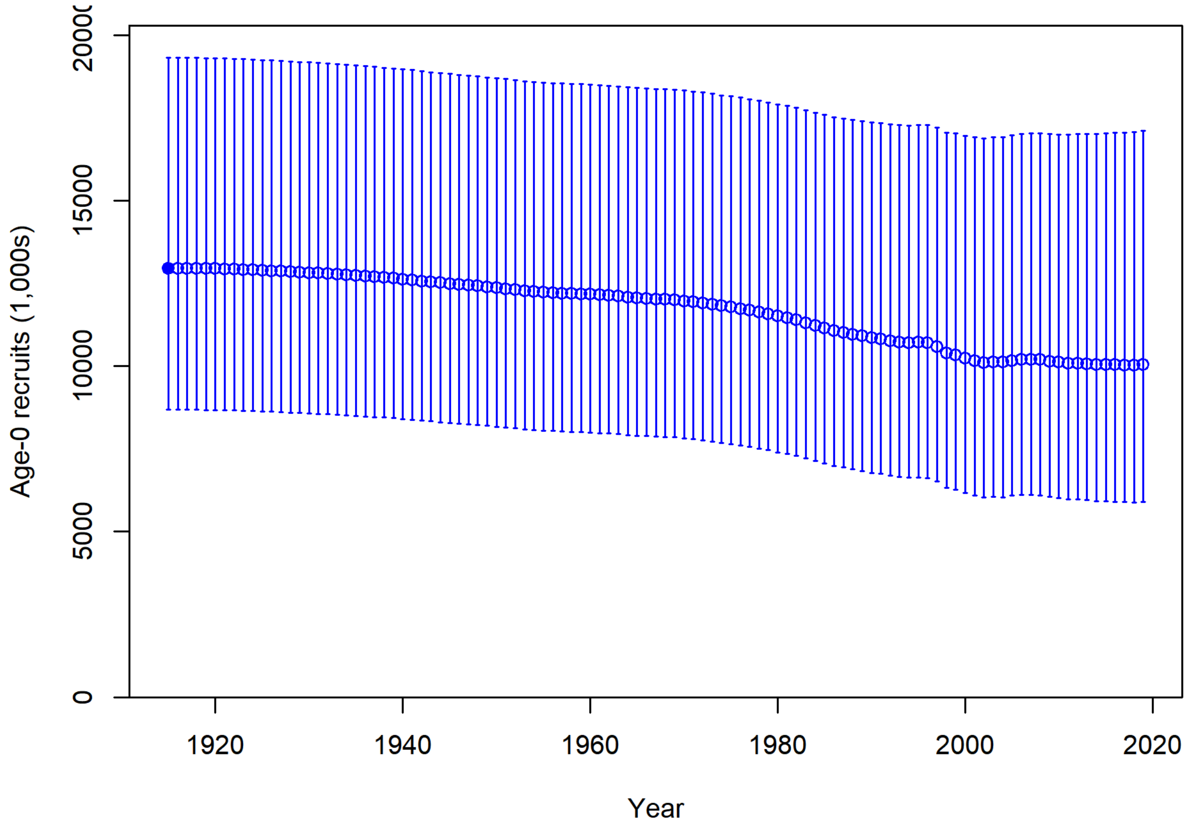

Figure ES-3: Time series of estimated Longnose Skate recruitments for the base model (circles) with approximate 95 confidence intervals (vertical lines).

Exploitation status

This assessment estimates that the stock of Longnose Skate off the continental U.S. Pacific Coast is currently at 57 percent of its unexploited level (Figure ES-4). This is above the overfished threshold of $SB_{25\%}$ and the management target of $SB_{40\%}$ of unfished spawning biomass.

The Spawning Potential Ratio (SPR) used for setting the OFL is 50 percent. Relative exploitation rates (calculated as dead catch/biomass of age-2 and older fish) are estimated to have been below one percent during the last decade (Figure ES-5). For the recent and historical period, the assessment estimates that Longnose Skate was fished at a rate below the relative SPR target (calculated as $1\text{-}SPR/1\text{-}SPR_{Target=0.5}$) (Figure ES-6). Relative SPR for 2018 is estimated to be 48 percent, which is below SPR target.

Table ES-3: Recent trend in relative spawning potential ratio and exploitation rate (dead catch divided by biomass of age-2 and older fish).

Years	Estimated (1-SPR)/(1-SPR_50%) (%)	95% Asymptotic Interval	Harvest Rate (proportion)	95% Asymptotic Interval
2009	65.05	39.93–90.18	0.023	0.012–0.034
2010	65.94	40.23–91.65	0.023	0.012–0.034
2011	54.79	31.97–77.62	0.018	0.009–0.027
2012	60.25	35.67–84.83	0.021	0.011–0.031
2013	61.4	36.31–86.49	0.021	0.011–0.031
2014	55.62	32.10–79.13	0.019	0.009–0.028
2015	54.52	31.28–77.76	0.018	0.009–0.027
2016	58.15	33.72–82.59	0.02	0.010–0.029
2017	54.99	31.45–78.53	0.018	0.009–0.027
2018	47.81	26.63–68.98	0.016	0.008–0.023

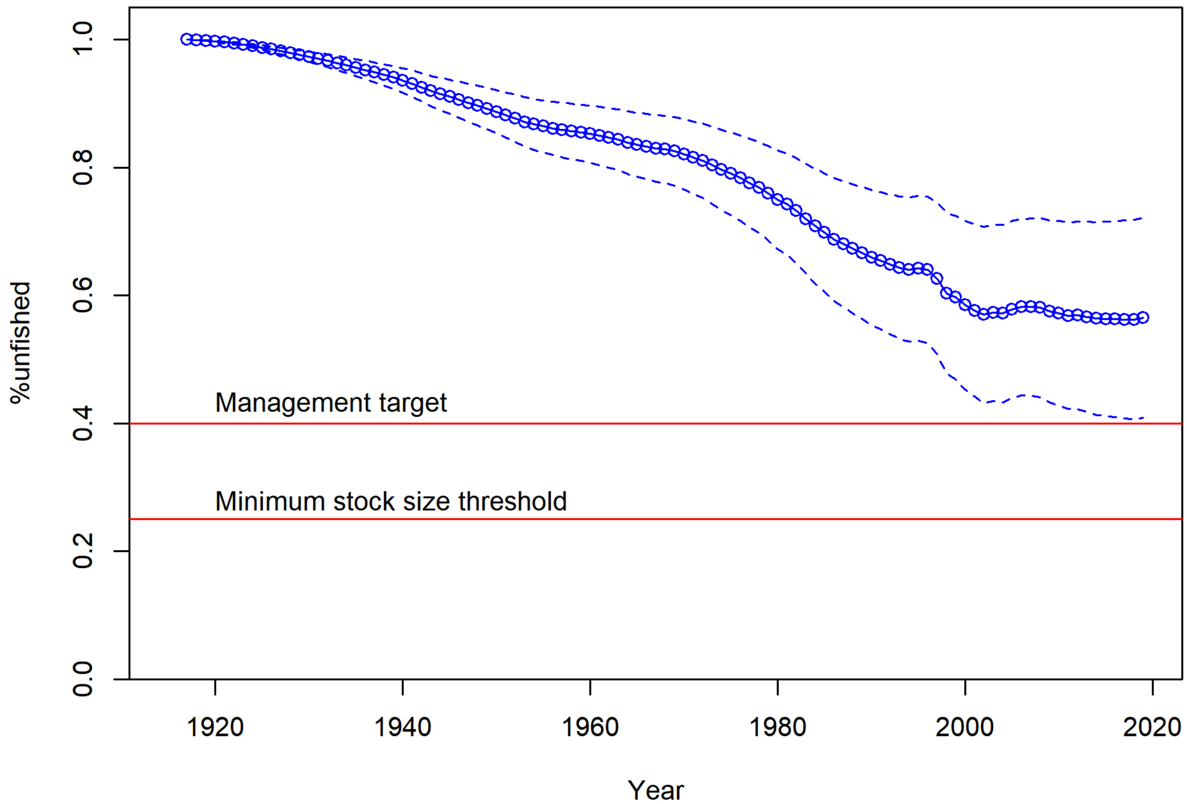

Figure ES-4: Estimated relative spawning biomass with approximate 95 percent asymptotic confidence intervals (dashed lines) for the base model.

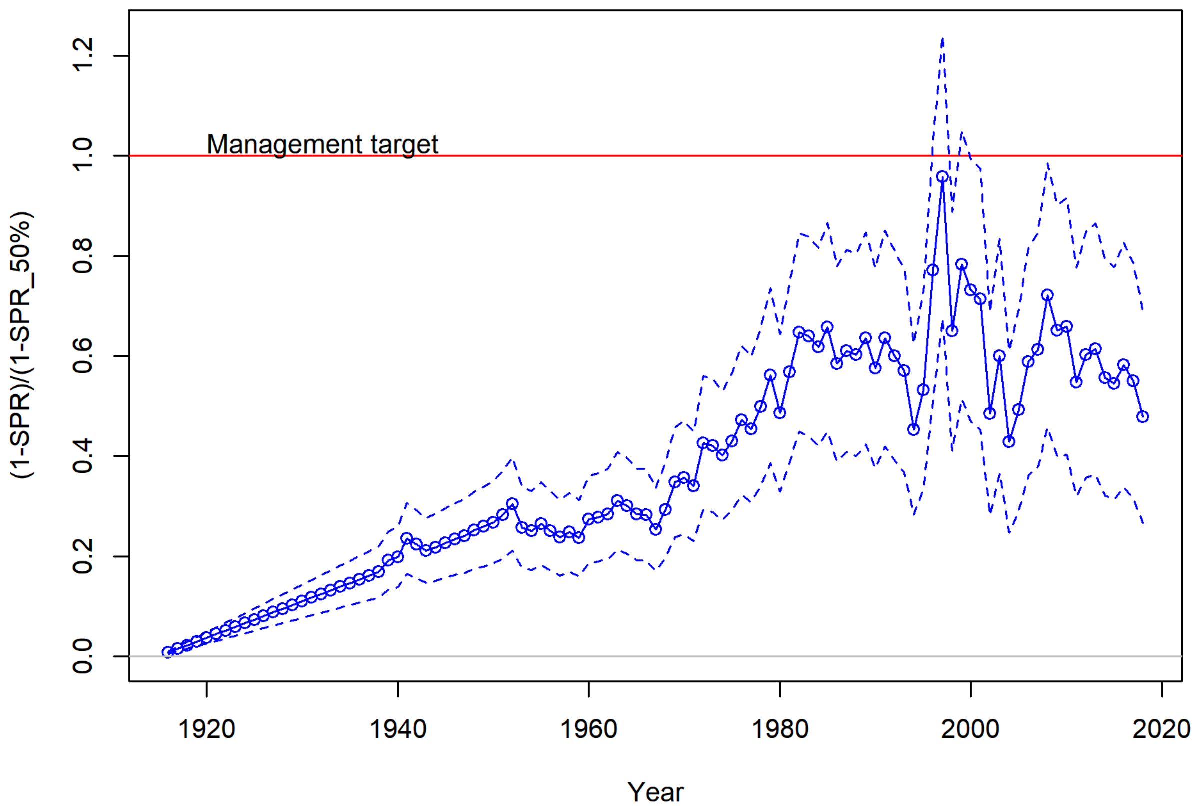

Figure ES-5: Estimated spawning potential ratio (SPR) for the base model with approximate 95 percent asymptotic confidence intervals. One minus SPR standardized to the target is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as the red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the $SPR_{50\%}$.

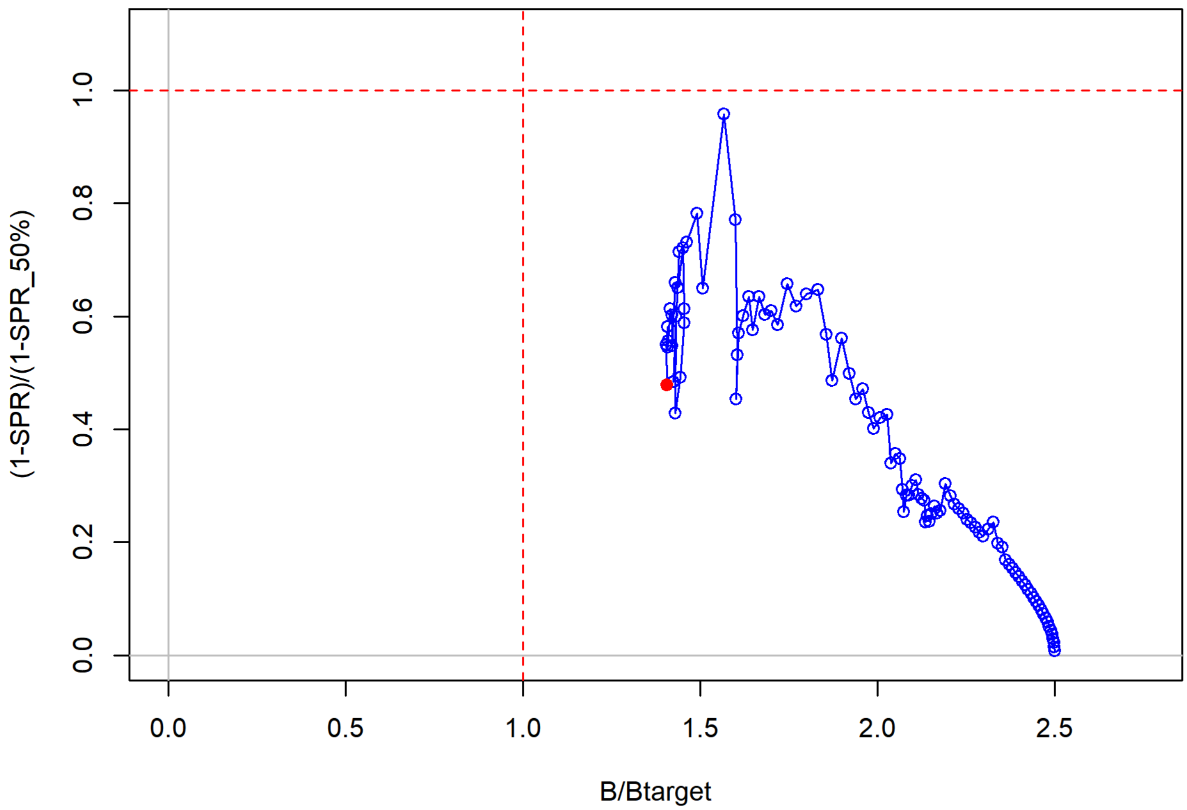

Figure ES-6: Phase plot of estimated relative (1-SPR) vs. relative spawning biomass for the base model. The relative (1-SPR) is (1-SPR) divided by 0.5 (the SPR target). Relative spawning output is the annual spawning biomass divided by the spawning biomass corresponding to 40 percent of the unfished spawning biomass. The red point indicates the year 2018.

Ecosystem considerations

In this assessment, ecosystem considerations were not explicitly included in the analysis. This is primarily due to a lack of relevant data that could contribute ecosystem-related quantitative information for the assessment.

Reference points

Unfished spawning stock output (biomass) for Longnose Skate was estimated to be 12,252 metric tons (95 percent confidence interval: 9,155–15,350 metric tons). The management target for Longnose Skate is defined as 40 percent of the unfished spawning output ($SB_{40\%}$), which is estimated by the model to be 4,901 metric tons (95 percent confidence interval: 3,662–6,140); this corresponds to an exploitation rate of 0.027. This harvest rate provides an equilibrium yield of 1,028 mt at $SB_{40\%}$ (95 percent confidence interval: 708–1,348 mt). The model estimate of maximum sustainable yield (MSY) is 2,812 mt (95 percent confidence interval: 2,042-3,582 mt). The estimated spawning stock output at MSY is 1,030 metric tons (95 percent confidence interval: 709–1,351 metric tons). The exploitation rate corresponding to the estimated SPR_{MSY} is 0.028. The equilibrium estimates of yield relative to biomass is provided in Figure ES-7.

Table ES-4: Summary of reference points for the base model.

Quantity	Estimate	~95% Asymptotic Interval
Unfished Spawning Biomass (mt)	12,252	9,155–15,350
Unfished Age 2+ Biomass (mt)	73,298	51,204–95,392
Spawning Biomass (2019)	6,923	3,283–10,563
Unfished Recruitment (R_0)	12,954	7,722–18,186
Fraction unfished (2019)	0.565	0.409–0.721
Reference Points Based $SB_{40\%}$		
Proxy Spawning Biomass ($SB_{40\%}$)	4,901	3,662–6,140
SPR resulting in $SB_{40\%}$	0.625	0.625–0.625
Exploitation Rate Resulting in $SB_{40\%}$	0.027	0.026–0.027
Yield with SPR Based On $SB_{40\%}$ (mt)	1,028	708–1,348
Reference Points based on SPR proxy for MSY		
Proxy Spawning Biomass ($SPR_{50\%}$)	2,450	1,831–3,070
SPR_{50}	0.5	NA
Exploitation rate corresponding to $SPR_{50\%}$	0.039	0.038–0.040
Yield with $SPR_{50\%}$ at SB_{SPR} (mt)	860	590–1,129
Reference points based on estimated MSY values		
Spawning Biomass at MSY (SB_{MSY})	4,632	3,472–5,792
SPR_{MSY}	0.611	0.610–0.612
Exploitation rate corresponding to SPR_{MSY}	0.028	0.027–0.028
MSY (mt)	1,030	709–1,351

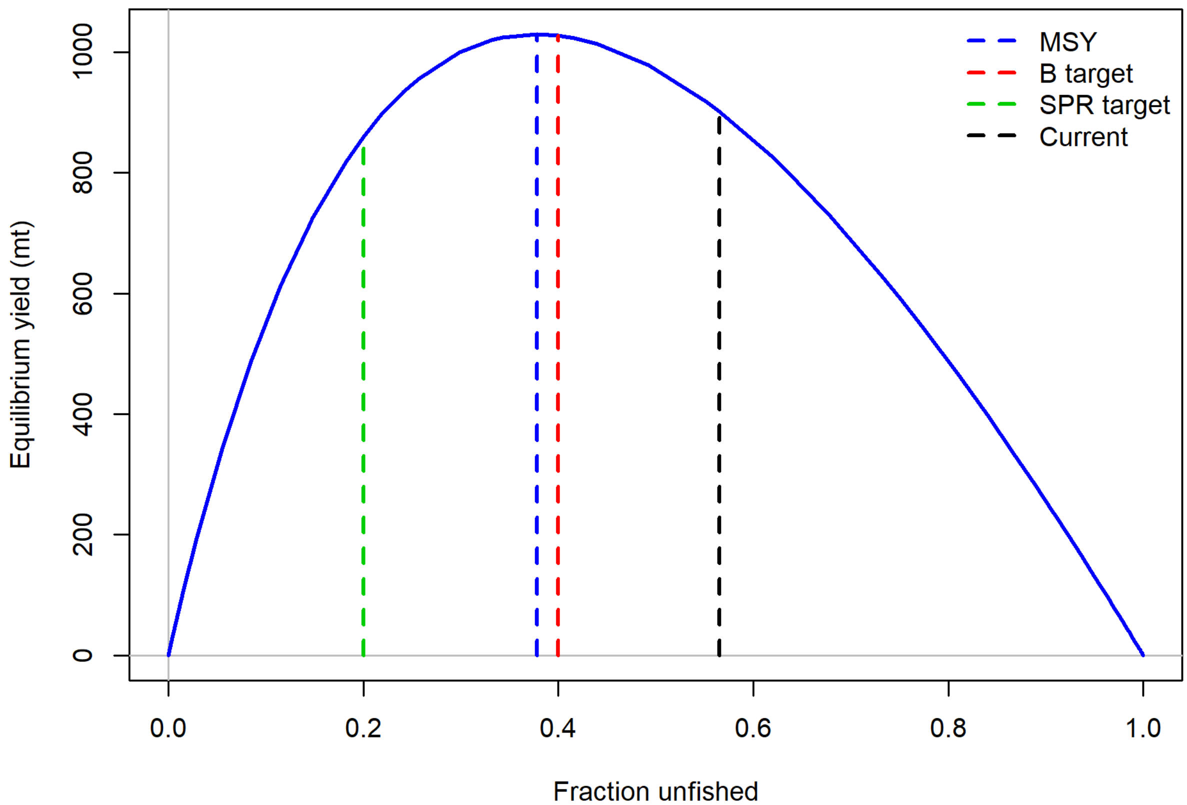

Figure ES-7: Equilibrium yield curve (derived from reference point values reported in Table ES-5) for the base model. Values are based on the 2018 fishery selectivity and distribution with steepness fixed at 0.4. The depletion is relative to unfished spawning output.

Management performance

Before 2009, Longnose Skate was managed together with many other species on the West Coast, in the "Other Fish" complex. Stocks in that complex have been generally managed without individual assessments and with harvest specifications determined through data-poor methods. Since landings have been routinely well below ABCs for this category, trip limits have not been used for inseason management.

Following the 2007 Longnose Skate assessment (Gertseva and Schirripa 2008), Longnose Skate was pulled out of the "Other Fish" category in 2009. Since then, there has been stock-specific management of Longnose Skate and total catch of this species has been below both the overfishing limit (OFL) and acceptable biological catch (ABC) for Longnose Skate each year (Table ES-5).

Table ES-5: Recent trend in total dead catch and commercial landings (mt) relative to the management guidelines*. Estimated total dead catch reflects commercial landings plus the model estimated discarded dead biomass. The estimates of total dead catch may differ from the official total mortality estimates produced by the West Coast Groundfish Observer Program.

Years	OFL	ABC	ACL	Landings	Total Catch
2009	3,428	NA	1,349	966	1,152
2010	3,269	NA	1,349	995	1,165
2011	3,128	2,990	1,349	819	916
2012	3,006	2,873	1,349	936	1,030
2013	2,902	2,774	2,000	958	1,051
2014	2,816	2,692	2,000	839	926
2015	2,449	2,341	2,000	829	904
2016	2,405	2,299	2,000	896	980
2017	2,556	2,444	2,000	840	913
2018	2,526	2,415	2,000	709	771
2019	2,499	2,389	2,000	NA	NA

* The current OFL was called the ABC prior to 2011. The ABCs provided in this table for 2011-2018 refer to the new definition of ABC implemented with FMP Amendment 23. The current ACL was called the OY prior to 2011.

Unresolved problems and major uncertainties

Approximate asymptotic confidence intervals were estimated within the model for key parameters and management quantities and reported throughout the assessment. To explore uncertainty associated with alternative model configurations and evaluate the responsiveness of model outputs to changes in key model assumptions, a variety of sensitivity runs were performed, including runs with different assumptions regarding fishery removals, life-history parameters, shape of selectivity curves, stock-recruitment parameters, and many others. Uncertainty in natural mortality, stock-recruit steepness and the unfished recruitment level was also explored through likelihood profile analysis. Additionally, a retrospective analysis was conducted where the model was run after successively removing data from recent years, one year at a time.

In this assessment, the WCGBT Survey catchability coefficient is highly influential upon the assessment output and continues to be a major source of uncertainty. The lack of contrast in the data resulted in implausible model results under a variety of configurations when the WCGBT Survey catchability was freely estimated. To aid in estimating catchability, a prior was used that relies on current understanding of factors affecting survey catchability, such as latitudinal, depth and vertical availability of Longnose Skate to the survey as well as the probability of being caught in the survey net's path. Alternative assumptions about this parameter were used to define alternative states of nature in the Decision table.

Stock-recruit curve steepness generally contributes significant uncertainty to stock assessments as it determines the productivity of the stock, and alternative values of this parameter were explored through both sensitivity and likelihood profile analyses.

Although significant progress has been made in reconstructing historical catches of Longnose Skate on the U.S. West Coast, survival rates of discarded skates continue to be uncertain, especially given that many factors, such as trawl time, handling techniques, and time spent on the deck certainly affect skate survival.

Several tagging studies have found that elasmobranchs, such as sharks and skates, can undertake extensive migrations within their geographic range (Martin and Zorzi 1993, McFarlane and King 2003). One tagging study of Big Skate described long-range movements (up to 2340km) undertaken by a percentage of the recaptured fish, when Big Skates tagged in British Columbia, Canada, were recaptured in waters off of Oregon, Washington, throughout the Gulf of Alaska and the Bering Sea (King and McFarlane 2010). No large-scale migrations or movements studies have been conducted for Longnose Skate, and, therefore uncertainty remains about possible movements (and their extent) of Longnose Skate between U.S. and Canadian waters. Genetic and tagging studies would help improve our understanding of stock structure and movement patterns of Longnose Skate and identify whether there is a need for a regional management approach.

Scientific uncertainty

The Sigma values associated with the 2019 spawning biomass (calculated from the normal approximation and converted to the log-standard deviation of a lognormal distribution) is 0.26, well below the minimum 1.0 value associated with Category 2, the most likely classification for this assessment. A sigma calculated in the same way for the estimated 2019 OFL is 0.26.

Decision table

The base model estimate for 2019 spawning depletion is 57%. The primary axis of uncertainty about this estimate used in the decision table was based on West Coast Groundfish Bottom Trawl (WCGBT) Survey catchability (*q*). WCGBT Survey *q* in the assessment model is estimated using the prior developed as described later in this report. The base model estimate has *q*=1.57, log(*q*) =0.45, with estimated standard deviation of log(q) = 0.237. The 12.5th and 87.5th quantiles of the log (*q*) were calculated to determine alternative states of nature. The low log(*q*) =0.178, *q* =1.19 was used to define the high state of nature. The 2019 biomass estimate resultant from the run with the low q value exceeded the 87.5th percentile of the 2019 spawning biomass estimated by the base model. The high *q* value (estimated from the q prior) was above the 12.5th percentile of the 2019 base model estimate of spawning biomass. Therefore, the model with log(*q*) =0.77, *q* = 2.16 was used as the low state of nature, as it provided a close match to the 12.5th percentile for the 2019 spawning biomass estimate in the base model.

Twelve-year forecasts for each state of nature were calculated for three catch scenarios. All three scenarios assumed the 2017-2018 average total dead catch for 2019 and 2020 catches. The first scenario assumed 1,000 metric tons per year for years between 2021 and 2030. The second scenario assumed 2,000 metric tons per year for years between 2021 and 2030. The third scenario assumed year-specific ACL = ABC (P* = 0.45) for years between 2021 and 2030. The sigma estimated from the base model is 0.26; therefore, the category 2 sigma schedule recommended by the SSC was used in this scenario.

Projected Landings, OFLs and Time-varying ACLs

Potential OFLs projected by the model are shown in Table ES-6. These values are based on an SPR target of 50%, a P* of 0.45, and a time-varying Category 2 Sigma which creates the buffer shown in the right-hand column. The OFL and ACL values for 2019 and 2020 are the current harvest specifications (also shown in Table ES-5) while the total mortality for 2019 and 2020 represent 2017-2018 average catch.

Table ES-6: Projections of landings, total mortality, OFL, and ACL values.

Years	Landings (mt)	Assumed total mortality (mt)	OFL (mt)	ACL (mt)	Buffer
2019	775	842	2,079	2,000	1.000
2020	775	842	2,082	2,000	1.000
2021	1,676	1,823	2,086	1,823	0.874
2022	1,618	1,761	2,036	1,761	0.865
2023	1,566	1,708	1,993	1,708	0.857
2024	1,520	1,660	1,955	1,660	0.849
2025	1,479	1,617	1,922	1,617	0.841
2026	1,443	1,578	1,895	1,578	0.833
2027	1,412	1,546	1,872	1,546	0.826
2028	1,383	1,515	1,852	1,515	0.818
2029	1,357	1,487	1,836	1,487	0.810
2030	1,335	1,462	1,821	1,462	0.803

Research and data needs

In this assessment, several critical assumptions were made based on limited information. The following research could improve the ability of future stock assessments to determine the status and productivity of the Longnose Skate population. The items are not ranked according to priority. It is also important to continue to collect species-specific information from the fishery, and monitor discard of Longnose Skate to improve the accuracy of fishery catch data.

Data needs:

1. Ages - Estimate additional ages for Longnose Skate, which would better inform the age-structured model. The NWFSC ageing lab is currently able to age skate vertebrae, and many structures have already been collected across several years in surveys and fisheries.
2. Maturity - Generate additional maturity data using the most accurate/precise method developed in Research Need #1, below.

Research needs:

1. Maturity - Conduct studies incorporating histological analysis into evaluation of skate maturity, which would evaluate error and bias in macroscopic evaluation, and develop a feasible method which would produce the most accurate and consistent maturity data.

Histological examination is widely accepted as the best available approach, while macroscopic evaluation (used up to this point) has been demonstrated to be less accurate, precise and more prone to reader bias (Vitale et al. 2006, Brown-Peterson et al. 2011, Kjesbu 2009).

2. Survey *q* - Develop a well-informed prior on survey catchability, as this parameter is highly influential upon the assessment model. Evaluate Longnose Skate behavior/interaction with trawl gear, and distribution among habitats, to better understand catchability by survey gear type, and ultimately provide more precise estimates of biomass from the surveys.
3. Life history – Conduct studies to better quantitatively understand life history of Longnose Skates; e.g. to inform time-varying estimation of natural mortality and recruitment. Research to better estimate growth, as well as enhanced understanding of reproduction (e.g., frequency, seasonality, number or eggs per year) is also needed. Studies to better understand Longnose Skate productivity, and accurately inform stock-recruit steepness for this species would also be beneficial.
4. Catch - Continue to explore methods to estimate historical removals of Longnose Skate and associated uncertainty, particularly model-based solutions where feasible;
5. Discard mortality - Conduct studies to evaluate survival rates of discarded Longnose Skate, especially with trawl gear, so that total fishing mortality can be estimated more accurately;
6. Movement and migration - Conduct spatial studies of movement and migration of Longnose Skate, with special attention to potential extent of movement across the U.S.-Canada border;
7. Genetics - Conduct genetic studies to evaluate the potential for stock structure of Longnose Skate in the waters off the U.S. Pacific Coast.

Table ES-7: 12-year projections for alternate states of nature defined based on WCGBT Survey catchability. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.

			States of nature					
			Low state: q =2.16		Base model: q =1.57		High state: q =1.19	
Management decision	Year	Catch (mt)	Spawning biomass	Depletion	Spawning biomass	Depletion	Spawning biomass	Depletion
2017-2018 average total catch for 2019 and 2020 catches; 1,000 mt/year after that	2019	842	4,787	45%	6,923	57%	9,371	65%
	2020	842	4,797	45%	6,943	57%	9,398	65%
	2021	1,000	4,807	45%	6,964	57%	9,425	65%
	2022	1,000	4,780	45%	6,947	57%	9,414	65%
	2023	1,000	4,752	45%	6,929	57%	9,401	65%
	2024	1,000	4,722	45%	6,910	56%	9,388	65%
	2025	1,000	4,690	44%	6,889	56%	9,373	65%
	2026	1,000	4,657	44%	6,867	56%	9,357	65%
	2027	1,000	4,624	44%	6,845	56%	9,340	65%
	2028	1,000	4,590	43%	6,823	56%	9,324	65%
	2029	1,000	4,558	43%	6,802	56%	9,308	65%
	2030	1,000	4,527	43%	6,782	55%	9,294	65%
2017-2018 average total catch for 2019 and 2020 catches; 2,000 mt/year after that	2019	842	4,787	45%	6,923	57%	9,371	65%
	2020	842	4,797	45%	6,943	57%	9,398	65%
	2021	2,000	4,807	45%	6,964	57%	9,425	65%
	2022	2,000	4,558	43%	6,724	55%	9,190	64%
	2023	2,000	4,310	41%	6,486	53%	8,957	62%
	2024	2,000	4,066	38%	6,251	51%	8,728	61%
	2025	2,000	3,829	36%	6,024	49%	8,506	59%
	2026	2,000	3,601	34%	5,806	47%	8,293	58%
	2027	2,000	3,386	32%	5,599	46%	8,092	56%
	2028	2,000	3,186	30%	5,407	44%	7,905	55%
	2029	2,000	3,000	28%	5,230	43%	7,733	54%
	2030	2,000	2,830	27%	5,067	41%	7,575	53%
2017-2018 average total catch for 2019 and 2020 catches; ACL = ABC (P* = 0.45) as in base model after that	2019	842	4,787	45%	6,923	57%	9,371	65%
	2020	842	4,797	45%	6,943	57%	9,398	65%
	2021	1,823	4,807	45%	6,964	57%	9,425	65%
	2022	1,761	4,597	43%	6,765	55%	9,229	64%
	2023	1,708	4,401	41%	6,581	54%	9,049	63%
	2024	1,660	4,219	40%	6,411	52%	8,883	62%
	2025	1,617	4,051	38%	6,255	51%	8,732	61%
	2026	1,578	3,899	37%	6,114	50%	8,597	60%
	2027	1,546	3,762	35%	5,990	49%	8,479	59%
	2028	1,515	3,642	34%	5,881	48%	8,376	58%
	2029	1,487	3,537	33%	5,788	47%	8,290	58%
	2030	1,462	3,448	33%	5,711	47%	8,220	57%

Table ES-8: Summary table of the results.

Years	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Landings (mt)	966	995	819	936	958	839	829	896	840	709	NA
Estimated Total catch (mt)	1,152	1,165	916	1,030	1,051	926	904	980	913	771	NA
OFL (mt)	3,428	3,269	3,128	3,006	2,902	2,816	2,449	2,405	2,556	2,526	2,499
ACL (mt)	1,349	1,349	1,349	1,349	2,000	2,000	2,000	2,000	2,000	2,000	2,000
1-SPR	0.65	0.66	0.55	0.60	0.61	0.56	0.55	0.58	0.55	0.48	NA
Exploitation_Rate	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	NA
Age 2+ Biomass (mt)	50,468	50,222	49,978	49,981	49,872	49,750	49,748	49,761	49,696	49,694	49,819
Spawning Biomass (mt)	7,046	7,009	6,962	6,966	6,940	6,908	6,902	6,902	6,887	6,888	6,923
95% Confidence Interval	3,549–10,544	3,499–10,518	3,439–10,485	3,428–10,504	3,387–10,493	3,339–10,476	3,318–10,485	3,303–10,500	3,274–10,499	3,262–10,514	3,283–10,563
Recruitment	10,144	10,116	10,082	10,084	10,065	10,041	10,036	10,036	10,025	10,026	10,052
95% Confidence Interval	6,049–17,010	6,018–17,004	5,980–16,995	5,977–17,015	5,953–17,019	5,923–17,020	5,913–17,035	5,907–17,053	5,890–17,062	5,885–17,080	5,904–17,114
Depletion (%)	57.5	57.2	56.8	56.9	56.6	56.4	56.3	56.3	56.2	56.2	56.5
95% Confidence Interval	43.3–71.7	42.8–71.6	42.2–71.4	42.1–71.6	41.8–71.5	41.3–71.5	41.1–71.5	41.0–71.7	40.7–71.7	40.6–71.8	40.9–72.1

1 Introduction

1.1 Basic Information

Skates are the largest and most widely distributed group of batoid fish (McEachran 1990, Ebert and Compagno 2007). Skates are found in all coastal waters but are most common in cold and polar waters (Ebert and Compagno 2007). There are about eleven species of skates present in the Northeast Pacific Ocean off California, Oregon and Washington (Ebert 2003). Of that number, Longnose Skate comprises the majority of fishery and survey catches (about 70 percent in both categories). Like other skates, Longnose Skate is a dorso-ventrally compressed animal with large pectoral fins, often called "wings". The species received its name because of the stiff, long, and acutely pointed snout, which distinguishes it from other skate species (Figure 1).

The Longnose Skate (*Beringraja rhina*) is broadly distributed, occurring from the southeastern Bering Sea (Mecklenburg et al. 2002) to southern Baja California (25.98º N, 113.28º W, Snytko 1987) and the Gulf of California (Eschmeyer and Herald 1983). It has been reported at depths of 9-1294 m (Love et al. 2005, Keller et al. 2006) but is most common off the U.S. Pacific Coast from 150–400 m (Tolimieri and Levin 2006, Bizzarro 2015). It does not exhibit a size-specific pattern in distribution relative to bottom depth; average fish size does not vary greatly with depth (Figure 2).

The Longnose Skate has extremely broad environmental tolerances, occurring over a wide range of depths, temperatures, and habitat types. They occur in water temperatures ranging from 2–12.7 º C (Love 2011, Bizzarro 2015). Longnose Skates are considered to be primarily benthic (Love 2011). The Longnose Skate is found mainly on soft (sand, mud) or mixed substrates (e.g., mud and cobble or boulder), with larger individuals occurring in more complex habitat types (Bizzarro 2015). It is sometimes found on or near rock substrates (Bizzarro 2015), including high relief rock outcrops (Ebert 2003). The Longnose Skate is one of the most abundant groundfishes on the outer continental slope and upper continental slope of the U.S. Pacific Coast by biomass and ranges from subtidal regions to the deep sea (Tolimieri and Levin 2006, Bizzarro 2015). Core habitat regions of Longnose Skate off the U.S. Pacific Coast and in the Gulf of Alaska are spatially segregated from those of other skate species (Bizzarro et al. 2014).

Currently, there is no information available that indicates the existence of multiple breeding units in the Northeast Pacific Ocean. Several tagging studies have found that elasmobranchs, such as sharks and skates, can undertake extensive migrations within their geographic range (Martin and Zorzi 1993, McFarlane and King 2003). No large-scale migrations or movements have been documented for Longnose Skate. However, a tagging study of Big Skate described long-range movements (up to 2340km) undertaken by an appreciable percentage of the recaptured fish, when Big Skate tagged in British Columbia, Canada, were recaptured in waters off of Oregon, Washington, throughout the Gulf of Alaska and the Bering Sea (King and McFarlane 2010). This behavior in other skate species suggests the likelihood that there is a high degree of genetic mixing within the Longnose Skate population as well, across its range. The Longnose Skate population off California, Oregon and Washington is modeled in this assessment as a single stock.

1.2 Map

A map of the assessment area that includes coastal waters off three U.S. West Coast states and five International North Pacific Fisheries Commission (INPFC) areas is presented in Figure 3. The spatial distribution of Longnose Skate catch along the U.S. West Coast, observed by the West Coast Groundfish Observer Program (WCGOP) from 2002 to 2017 is shown in Figure 4. The spatial distribution of Longnose Skate fisheries catch in the NWFSC bottom trawl survey is shown in Figure 5 and Figure 6.

1.3 Life History

Like all skates, Longnose Skate are oviparous (egg-laying) organisms. After fertilization, the female forms tough, but permeable egg cases that surround the fertilized eggs and then deposits these egg cases onto the sea floor at daily to weekly intervals for a period of several months or longer (Hamlet and Koob 1999). Egg deposition appears to occur throughout the year without an apparent peak (Thompson 2006, Ebert et al. 2008).

A nursery area (i.e., a concentrated, large-scale egg deposition site) for Longnose Skates was located on a rocky reef off southern California at depths of 125-151 m and temperatures of 9.1-10.1º C (Love et al. 2008). Size at birth is 12–17 cm in total length (*TL*) (Zeiner and Wolf 1993). The eggs within egg cases incubate for several months in a benthic habitat. Inside the egg cases, the embryos develop with nourishment provided by yolk. The Longnose Skate is known to have only a single embryo per egg case. Egg case survivorship appeared to be enhanced by the presence of structure-forming marine invertebrates (especially sponges) in the deposition habitats (Love et al. 2008). When the yolk is depleted and the juvenile is fully formed, it exits the egg case. Once hatched, the young skate is similar in appearance to an adult, but smaller in size. Upon reaching maturity, skates enter the reproductive stage, which lasts for the remainder of their lives (Frisk et al 2002, Pratt and Casey 1990).

Size at maturity has been variably estimated for Longnose Skate populations from California, the U.S. Pacific Coast, British Columbia, and Alaska. Off central California, first maturity was reported at 100 cm *TL* (females) and 61.5 cm *TL* (males) (Zeiner and Wolf 1993). A similar size at maturity was estimated for females from the Gulf of Alaska, but male estimates were considerably greater (Ebert et al. 2008). Populations of females and males south of Cape Mendocino matured at smaller sizes than those to the north (Thompson 2006). Considerably smaller sizes at first and 50 percent maturity were reported for the Longnose Skate population off British Columbia (McFarlane and King 2006); however, maturity evaluation criteria were flawed (subadults were considered to be mature), and these results are therefore not considered valid.

Age and growth estimates have been generated for Longnose Skate populations from California, British Columbia, the U.S. Pacific Coast, and the Gulf of Alaska. Longevity was reported at 13 years by Zeiner and Wolf (1993), but more recent literature suggests much greater maximum ages years. For example, maximum age estimates are reported as 26 years for British Columbia (McFarlane and King 2006) and as 25 years for Gulf of Alaska (Gburski et al. 2007). Age estimates of Gburski et al. (2007) were judged to be least biased among published studies, and had a 70 percent probability of being accurate to within 2 years based on bomb radiocarbon validation (King et al. 2017). Thompson (2006) estimated greater maximum ages and maturity estimates for Longnose Skate females and males north of Cape Mendocino relative to those to the south. Age at first maturity estimates from California (females = 10, males = 7) were similar to those reported by Thompson (2006), and lower than those reported from the Gulf of Alaska (Gburski et al. 2007). Age at maturity estimates are unreliable for the British Columbia Longnose Skate population because of flawed maturity estimates.

Based on their life history, Longnose Skates are classified as equilibrium strategists. This group is dominated by species that have low fecundity and late maturation, and, thus, low intrinsic rate of increase (Smith et al. 1998, King and McFarlane 2003). As such, equilibrium strategists exhibit steady population dynamics over time.

1.4 Ecosystem Considerations

Longnose Skates are opportunistic, generalist meso or upper trophic level predators with variable spatio-temporal trophic roles (Ebert and Bizzarro 2007, Bizzarro 2015). Longnose Skate diet composition varies with size and depth (Robinson et al. 2007, Bizzarro et al. 2007). Off California, small (< 50-60 cm *TL*) skates mainly consume shrimps and other small crustaceans, medium sized individuals eat a mixture of decapods and fishes, and large (> 100 cm *TL*) specimens are generally piscivorous (Robinson et al. 2007, Bizzarro et al. 2007, Bizzarro 2015). A greater amount of cephalopods are eaten at greater depths and larger sizes off California (Robinson et al. 2007). This pattern varies in the Gulf of Alaska, however, with a much greater reliance on crabs (especially Tanner Crabs) among medium and large specimens, comparatively less reliance on fishes, and only a trivial portion of cephalopods in the diet (Bizzarro 2015). Correspondingly, trophic level and general diet composition estimates differ significantly between California and Gulf of Alaska Longnose Skate populations (Bizzarro 2015).

Longnose Skates and their egg cases are preyed upon by a variety of vertebrates and invertebrates. Snails and other mollusks bore holes in egg cases to feed on the protein rich yolk-sac of developing embryos (Ebert 2003). Longnose Skate egg cases also are consumed by sperm whales, which probably target nursery grounds with high egg case densities (Ebert 2003, Love et al. 2008). Benthic sharks (e.g., sixgill, sevengill) and Stellar sea lions are known predators of juvenile and adult Longnose Skates (Ebert 2003, Love 2011).

1.5 Fishery Information

Historically, skates have not been high-priced fishery products. They are taken mostly as bycatch in other commercially important groundfish fisheries (Bonfil 1994). Although skates are caught in almost all demersal fisheries and areas off the U.S. West Coast, the vast majority (almost 97 percent) are caught with bottom trawl gear (Figure 7). Therefore, modeled catches from different gear types are combined into a single fleet in the assessment.

Historical catch records suggest that skates have been caught off the U.S. Pacific Coast at least since 1916 (Martin and Zorzi 1993). The catch of skate followed the development of the bottom trawl fishery, which was established in California in the early 1940s, when the United States became involved in World War II (Harry and Morgan 1961, Alverson et al. 1964). The increased demand caused the fishery to shift toward previously unexploited areas, and the California fishery moved north, to Oregon and Washington, and to deeper waters (Harry and Morgan 1961, Love 2002).

Historically, Longnose Skate landings have been reported, along with other skate species, under the market category "unspecified skates." Only since 2009, following the 2007 stock assessment (Gertseva and Schirripa 2008), Longnose Skate started to be managed separately and landings have been sorted and reported for this species alone. Prior to that, only limited species composition samples of combined skates' market categories were collected by state port samplers along the West Coast.

Historically, only the skinned pectoral fins or "wings" were sold, although a small portion of catch was marketed in the round (whole). Anecdotal evidence suggests that prior to 1995, the processors in most cases would accept wings only, and the wings would need to be cut onboard the boat and the remainder discarded. Most boats did not want to go to the effort of winging the skates at sea, so simply discarded them; the price was not high enough to justify the added work of at-sea processing (Craig Good, ODFW, pers. com.). Limited historical discard records support this anecdotal evidence. Pikitch (1988) and Rogers (1994) estimate discard of Longnose Skate in the mid-1980s to be as high a 96 percent, and marketing problems were indicated as the main reason for the skate discard.

However, it appears that in the mid-1990s, the processors in Oregon started to accept whole skate for landing, and boats started to retain skates if they had space to hold them and land them in ports (Craig Good, ODFW, pers. com.). Anecdotal evidence suggests that demand for whole skates also increased greatly in California during the mid-1990s (Peter Leipzig, Fishermen's Marketing Association, pers. com.), which also caused increase in the landed catch. This change in market is also supported by recent discard observations from the West Coast Groundfish Observer Program (WCGOP), as Longnose Skate discard rates ranged between 17% and 39% since 2009. After a few years, the whole skate market cooled, and currently, West Coast skates are marketed both whole and as wings. Skate wings are sold fresh or fresh-frozen, as well as dried or salted and dehydrated, predominantly in Asian markets (Martin and Zorzi 1993, Bonfil 1994).

In most areas of the world, management of skates has been a low priority, and where management and assessments are implemented, the available data are generally sparse (Sosebee 1998, Shotton 1999). The Longnose Skate, like other elasmobranches, present an array of potential problems for fisheries management. Skates' life history characteristics are thought to make them more susceptible to overfishing than teleost fishes. Examples of skate overexploitation have been observed in several areas of the world (Brander 1981, Casey and Myers 1998, Walker and Hislop 1998). However, given the low economic value of skates, information about their fisheries and even their basic biology is scarce, patchy and scattered (Bonfil 1994). The potential vulnerability of these species, combined with past collapses of elasmobranch fisheries elsewhere, underscores the importance of ascertaining the status of Longnose Skate on the West Coast.

1.6 Summary of Management History

Longnose Skate was managed together with many other species on the West Coast until 2009 in the "Other Fish" stock complex. Stocks in that complex have been generally managed without individual assessments and with harvest specifications determined through data-poor methods.

Since landings have been routinely well below ABCs for this complex, trip limits have not been used for inseason management.

The stock was assessed for the first time in 2007 (Gertseva and Schirripa 2008). Following that, it was pulled out of the "Other Fish" complex in 2009. Since then, there has been stock-specific management of Longnose Skate.

1.7 Management Performance

Recent trends in total dead catch and commercial landings of Longnose Skate relative to the management guidelines are shown in Table 1. Total catch of Longnose Skate has remained below both the annual OFLs (referred to as the ABC prior to 2011) and ACLs (referred to as the Optimum Yield (OY) prior to 2011).

1.8 Fisheries off Canada, Alaska, and/or Mexico

In British Columbia waters, Longnose Skate are incidentally captured by the commercial groundfish trawl and hook-and-line fisheries (King et al. 2015), and the trawl fishery is responsible for the largest amount of bycatch. Similarly to the U.S. West Coast, skate catches off British Columbia accelerated in the early 1990s (partly due to emerging Asian markets), and since 1996, there has been some reported targeting of Longnose Skate by the B.C. trawl fishery. The species is managed using harvest specifications that are based on mean historic catch, with consideration given to results of trend analyses of research survey biomass indices, since assessment models developed could not provide reliable estimates of biomass, preventing evaluation of current and future stock status relative to reference points (King et al. 2015).

In Alaska, there are currently no target fisheries for skates in the Gulf of Alaska (GOA), and directed fishing for skates is prohibited. Skates are taken as bycatch in both longline and trawl fisheries, and Longnose Skates, as well as Big Skates, comprise the majority of the skate biomass in the Gulf of Alaska. Incidental catches of skates are sufficiently high that Longnose Skate is managed using species specific harvest specifications, with OFL and ABC based on survey biomass estimates and the natural mortality rate (Ormseth 2017).

2 Assessment

2.1 Data

Data used in the Longnose Skate assessment are summarized in Figure 9. These data include both fishery-dependent and fishery-independent sources. Types of data that inform the model include catch, length and age frequency data from commercial and tribal fishing fleets. Fishery-dependent biological data used in the assessment originated from both port-based and on-board observer sampling programs. Relative biomass indices and information from biological sampling from four bottom trawl surveys were included as well; these trawl surveys were conducted by the Northwest Fisheries Science Center (NWFSC) and the Alaska Fisheries Science Center (AFSC) of the National Marine Fisheries Service (NMFS). Longnose Skate catch in the IPHC's long-line survey is also included in an index of relative abundance; IPHC length frequency data are also used.

2.1.1 Fishery removals

Catches of Longnose Skate were reconstructed back to 1916, when the first records of skate catches exist. The assessment assumes equilibrium unfished conditions of the stock prior to that.

The commercial fishery removals in the assessment are divided into two time periods. The recent fishery (1995-2018) and the historical fishery (1916-1994). For the recent fishery, the biological data (length and age compositions) are available, and for the historical fishery, only catch data (landings and dead discards) are available. For the recent fishery, discard is modelled within the assessment; a length-based retention curve is estimated and length compositions of both retained and discarded catch are used to estimate the selectivity of the fishing fleet. Selectivity of the historical fishery is mirrored to that of the current fishery. The historical fishery is divided into two fleets – one for landings and the second for dead discards. This was done to make the amounts of catch assigned to each fleet more transparent, as well as to simplify the process of testing assumptions specific to landings or discards, and discard mortality. In addition to commercial fishery fleets, Washington tribal catches are included as a separate fleet, and the catches are reported separately. Selectivity for the tribal fleet is also mirrored to the current fishery. Catches in all four fleets are shown in Figure 8 and provided in Table 2.

Until 2009, landings of Longnose Skate were reported in a combined skates' category. Following the 2007 assessment, and establishment of species-specific catch limits for Longnose Skate, landings of this species have been reported separately. Therefore, reconstruction of pre-2009 catches required collecting reliable landing records of all skates combined, and then dividing those among the different species of skates. Landings in both the historical and current time periods were reconstructed by state, and then combined into coastwide fleets. Methods employed to reconstruct landings in each state are described below.

Since skates are not a highly prized species, they are often discarded at sea. Historically, the majority of skate catch was discarded. The available data on discards within the groundfish trawl fishery from the mid-1980s indicates that 96 percent of Longnose Skate catch was discarded, due to the lack of a market (Pikitch 1988, Rogers 1994). Recent discard information (2009-2017) was obtained from the WCGOP. Historical removals of Longnose Skate (landings and total discards) were predicted based on a statistical relationship with removals of Dover sole. This relationship was estimated using recent fishery data, during the period when Longnose Skate landed catch was recorded directly, by species rather than in a mixed species category. This approach is described below. Dover sole is a commercially important stock, with which Longnose Skate is caught incidentally.

2.1.1.1 Commercial landings

Methods used to estimate Longnose Skate landings in each state are described below. These methods and data were reviewed and discussed at the skate historical reconstruction workshop (March 2019, Portland, OR) organized by the Pacific Fishery Management Council (PFMC), and additional information about them is available upon request. The workshop report is available from https://www.pcouncil.org/groundfish/stock-assessments/by-year/gf-2019/.

2.1.1.1.1 California

A reconstruction of historical landings of Longnose Skate, Big Skate and California Skate from California waters was developed by the NMFS Southwest Fisheries Science Center (SWFSC, Joe Bizzarro and John Field). Detailed descriptions of the methods and data used in the reconstruction are provided in Appendix 1.

For this reconstruction, a combination of commercial catch data (spatially explicit block summary catches and port sample data from 2009-2017) and fishery-independent survey data were used. Virtually all landings in California were of "unspecified skate" until a sorting requirement for Longnose Skate was implemented in 2009. From 2009 through 2017, catch estimates were based on these market category species' composition samples, and the average of those species compositions was "hindcast" to 2002 using a generalized additive model (GAM) (described in Appendix 1), based on the assumption that those data were representative of the era of large area closures in the post-2000 period. For the period from 1930 to 1980, spatially explicit landings data (the California Department of Fish and Wildlife (CDFW) block summary data) were merged with West Coast Groundfish Bottom Trawl (WCGBT) Survey data to provide species specific estimates, as described in Appendix 1. For the period from 1981 through 2001, a "blended" product of the two approaches to estimating species -specific catches was taken, in which a linear weighting scheme blended the two sets of catch estimates through that period (described in Appendix 1). Landings estimates were also scaled upwards by an expansion factor for those skates landed as "dressed", based on fish ticket data. Prior to 1981, these data were not reported and skate landings were scaled by the "average" percentage landed as dressed, through the 1981-1985 time period; by the late 1980s nearly all skates were landed in the round.

Distribution and abundance patterns differed among skate species based on WCGBT Survey data. Longnose Skate exhibit the greatest relative abundance off California, in the depths covered by the survey. It commonly occurs throughout the state, but exhibits the greatest average CPUE values north of Point Conception. Depth was a significant explanatory variable in single-species GAM models. Latitude also was significant for Longnose Skate and Big Skate, whereas distance from shore also was significant for California Skate. Longnose Skate landings were estimated to comprise over 60 percent of total skate landings during the 1916–2017 period, with the relative contribution of this species increasing steadily over time.

In the assessment, we used landings from this reconstruction for years prior to 2009, and obtained Longnose Skate landings for the recent period since 2009 forward from the Pacific Fisheries Information Network (PacFIN), a regional fisheries database that manages fishery-dependent information in cooperation with NMFS and West Coast state agencies. California landings for Longnose Skate used in the assessment are shown in Figure 10 and detailed in Table 3.

2.1.1.1.2 Oregon

A time series of Oregon landings of Longnose Skate was provided by ODFW, who recently reconstructed commercial landings for all skate species landed in Oregon for the period between 1978 and 2018. A brief description of the methods and data used in the reconstruction is provided below (A. Whitman, ODFW, pers. comm.). A detailed description of the methods is also available from T. Calavan (ODFW, pers. comm.).

Skates in Oregon are primarily landed by the bottom trawl sector, which includes multiple gear types, and accounts for more than 98 percent of skate landings. Minor amounts of skates are also caught with bottom longline gear, midwater trawl, hook and line, shrimp trawl, pot gear and scallop dredge. Historically, skates were landed in Oregon within an unspecified skate market category. In 2009, Longnose Skates were sorted into their own single-species landing category, and in 2014, Big Skates were also sorted with reporting of species-specific landings. The reconstruction methods differed among three time blocks (1978-2008; 2009-2014; 2015-2018) to account for changes in the number of skate landings categories and skate species composition sampling.

The reconstruction methods attempted to account for differences in skate species compositions by gear, area, market category, quarter and port, within each time block. However, available species composition data of combined skate categories from commercial port sampling program in Oregon was limited. As a result, strata variables such as quarter and port were excluded from the analysis; the analysis retained gear type, PMFC area, and market category for stratifying skate landings within the three time blocks.

For bottom trawl gear, catch areas and adjusted skate catches from logbook records were matched with strata-specific species compositions. In Time Block 1 (1978-2008), all bottom trawl gear types were aggregated into one category, due to a lack of gear type records from fish tickets. In Time Blocks 2 and 3, different bottom trawl gear types were treated separately in the reconstruction. When information (area- or gear-specific data) for some strata was lacking (which happened in 31% of strata included in the analysis), skate species compositions in those strata were informed by the data in the closest area or from the most similar gear type. Landings from longline gear were reconstructed using a similar approach, and in 25 percent of strata it was necessary to "borrow" data from other strata. Mid-water trawl landings have very few skate species composition samples. However, available data indicate that the proportion of Big Skates by weight within the unspecified skate complex drops to almost zero at approximately 100 fathoms, and an inverse relationship is observed for Longnose Skate, which proportion by weight is consistently at approximately one in depths beyond 100-150 fathoms. Big Skates exhibit shallower distribution, while Longnose Skates are distributed across a range of depths. Total skate landings from midwater trawl gear were divided among species according to depth-specific species compositions, which were determined from logbook data. Landings from shrimp trawls were handled similarly. Finally, the very minor landings which occurred from hook-and-line, pot gear and scallop dredges, which lack any gear-specific composition samples, were assigned to a single aggregated species composition.

After species compositions of skates were reconstructed for each time block, total skate landings from within each time block were apportioned by year using the proportion of the annual fish ticket landings. ODFW intends to incorporate reconstructed skate landings into PacFIN, to make the estimates easily accessible in the future (A. Whitman, ODFW; pers. comm.).

The reconstructed skate species landings were compared to skate species landings reported by Karnowski et al. (2014), who reconstructed Oregon commercial landings for a variety of species (including skates) between 1940 and 1986. The estimates were consistent between the two sources during the overlapping years. However, the current reconstruction of Oregon skate landings covers a later period than Karnowski et al. (2014), and focuses specifically on skates. Therefore, ODFW recommended to use Oregon Longnose Skate landings reconstructed as described above for years from 1978 forward and rely on Karnowski et al. (2014) for Longnose

Skate landings for the period before 1978. The Oregon Longnose Skate landings used in the assessment are shown in Figure 10 and detailed in Table 3.

2.1.1.1.3 Washington

Recent landings of Longnose Skate (for the period between 2004 and 2018) in Washington coastal waters were provided by the Washington Department of Fish and Wildlife (WDFW), for use in the stock assessment. These landings were estimated from limited state sampling of species compositions within the combined skate category. Also, WDFW provided a time series of combined skate landings from 1949 forward. These records included round weight of skates. When only skate wings were landed, their weight was converted to round (whole) skate weight by WDFW using conversion factors that were developed for different conditions of the landed fish. Also, the skate landings that were provided excluded foreign catches and catches in Puget Sound.

To determine the amount of Longnose Skate within combined skate landings, we relied on survey and logbook data to account for differences in depth distribution among skate species, as well as changes in depth of fishing by the fishery throughout the time series. The algorithm used in this approach is shown in Figure 11.

We used WCGBT Survey data to estimate the percentage of longnose in all skate catches by depth and year for the period of the survey (between 2003 and 2018). The average proportions of Longnose Skate, within total skate catches by the WCGBT Survey, are shown in Figure 12, by 100m depth bins. Trawl logbook data include information on the amount of retained catch of skate (all species combined) within each haul as well depth of catch. We extracted existing logbook data and assigned haul-specific skate catch into 100m depth bins. Then, we applied the proportion of Longnose Skate from survey skate catch to logbook skate catch in each haul. Next, we summed estimated Longnose Skate catches by year. When survey skate information was available (2003-2018), survey Longnose Skate proportions were applied by depth and year to account for interannual variability in those proportions. Prior to 2003, average proportions from 2003-2007 within each depth bin were applied.

Since not all trips are accompanied by logbook data, we expanded Longnose Skate landings from logbook data to the level of fish ticket landings (Figure 11). For this, we calculated the proportion of Longnose Skate in logbook skate catch data by year, and applied year-specific proportions to total Washington skate landings by year (provided by WDFW) to obtain year species-specific landings of Longnose Skate catch. Washington logbook data go back to 1987. Prior to 1987 (when no logbook data were available), the average proportion of Longnose Skate within the combined skate category, calculated from 1987-1992 logbook data, was applied to total skate landings in Washington. It was assumed reasonable to apply average proportions to historical combined skate catches for this time period, since major changes in depth of fishing started in response to management measures after 1992, as indicated by logbook data (Figure 13).

The reconstructed Washington landings of Longnose Skate using the methods described above are consistent with estimates derived by WDFW from available skate species composition sampling, during overlapping years (Figure 14). The dynamics of Longnose Skates also reflect shifts in depth of fishing, informed by logbook data (Figure 13). For the assessment, we used

Longnose Skate landings provided by WDFW for the period from 2004 forward, and for the period prior to 2004, we used Longnose Skate landings estimated as described above (Figure 10). The estimated landings are listed in Table 3.

2.1.1.2 Commercial discards

2.1.1.2.1 Sources of discard information on the U.S. West Coast

There are three main sources of discard information within the groundfish fishery. In 2001, the West Coast Groundfish Observer Program (WCGOP) was implemented on the West Coast of the United States, which began with gathering bycatch and discard information for the limited entry trawl and fixed gear fleets. Observer coverage has expanded to include the California halibut trawl, the nearshore fixed gear and pink shrimp trawl fisheries. Since 2011, many species have been harvested in the trawl with a catch share fishery, using Individual Fishing Quotas (IFQ), where each permit holder has an annual quota; before 2011, the current IFQ fishery was managed under a cumulative landing limit system. The WCGOP, together with Electronic Monitoring (EM) provides 100 percent at-sea observer monitoring of catch for this new, catch share based IFQ fishery.

Prior to WCGOP, there were two studies of discard in the trawl fishery, including the Enhanced Data Collection Project (EDCP) and the Pikitch study (Pikitch et al. 1988). The EDCP, which was administered by the ODFW, collected data on bycatch and discard of groundfish species off the Oregon coast from late 1995 to early 1999 (Sampson, pers.comm.). The project had limited spatial coverage (Oregon waters only) and skates species were recorded within a combined category, not by species, and thus no Longnose Skate specific discard rate estimates are available from the EDCP.

The Pikitch study was conducted between 1985 and 1987. The northern and southern boundaries of the study were 48°42' and 42°60' North latitude respectively, which is primarily within the Columbia INPFC area (Pikitch et al. 1988, Rogers and Pikitch 1992). Participation in the study was voluntary and included vessels using bottom, midwater and shrimp trawl gears. Observers of normal fishing operations on commercial fishing vessels collected the data, estimated the total weight of the catch by tow and recorded the weight of each species retained or discarded in the sample.

2.1.1.2.2 Method used to estimate discard

Limited information on skate discard suggests that historically, the majority of skates (96 percent) were discarded at sea (Pikitch 1988). Discard practices started to change in the mid-1990s (see Section 1.5), and therefore recent discard rates determined from WCGOP data have limited applicability in estimating discard rates over the historical period. Since Longnose Skate is a bycatch species, we wanted to find a relationship between catch of a targeted species (or species group) and catch of Longnose Skate, which could reliably inform Longnose Skate catch estimates. This predictor species would need to be targeted, so that the majority of catch would be retained (maximizing reliability of catch records). Historical catch time series would need to be readily available for the predictor species as well.

We examined WCGOP haul level data for the 2009-2017 period, and identified major "targets" which Longnose Skate is caught with, shown in Figure 15. The vast majority of longnose removals (70 percent) are caught when fisheries target the Dover-Thornyhead-Sablefish (DTS) complex, and Dover sole (DOVR) specifically. DTS and DOVR compositions are shown in Figure 16. To identify a relationship between catch of species within DTS and DOVR for a relationship with Longnose Skate catch, we used WCGOP annual estimates of the coastwide total catch (landings plus dead discards plus live discards) for the period 2009 to 2017, when Longnose Skate total catch estimates were available. We screened a number of species and found that Dover sole (that contributes the most by weight to both DTS and DOVR) showed a clear, strong, linear relationship with Longnose Skate. Linear regression between WCGOP annual estimates of coastwide total mortality of Dover sole (independent variable) and that of Longnose Skate (dependent variable) (Figure 17) demonstrated excellent predictive power ($R^2 = 0.957$) over the range of the Dover sole catches (6,500 to 12,500 mt). Dover sole has been consistently targeted since 1950, and mostly retained; therefore, we limited the application of our regression model to the period after 1950, when the Dover sole fishery was well established. Catch time series of Dover sole were obtained from the most recent stock assessment conducted in 2011 (Hicks and Wetzel 2011). Dover sole catches since 1950 fall within the range used to develop a relationship between Dover sole and Longnose Skate. We also limited the application of our model from 1950 forward, because this is when the bottom trawl fishery (which catches the vast majority of both Longnose Skate and Dover sole) extended to its current depth and latitudinal ranges.

Estimated total catch of Longnose Skate is shown in Figure 18. Table 4 shows total catch of Dover Sole for the period between 1950 and 2017, which was used to estimate total catch of Longnose Skate, also shown in the table. Total catch includes landings as well as dead and live discards. Therefore, amount of discarded catch (dead and live) can be easily obtained as the difference between total catch and landings, derived as described in Section 2.1.1.

To validate the results of the model against available discard observations, we compared the estimated discard rate of Longnose Skate based on the Dover sole catch, with observed Longnose Skate discard rate from the Pikitch study (Pikitch et al. 1988). Both sources produced identical rates of 96 percent discard for the 1985-1987 period (Figure 19). We also compared the trend in estimated discard rates based on Dover sole catches with skate discard rates observed in the EDCP. Despite the fact that the EDCP reported rates for all skate combined, and were limited to deeper areas, both sources produced very similar trends, indicating changes in discard practices for skate in the mid-1990s (Figure 19). The estimated total dead catch of Longnose Skate is also consistent with the history of the groundfish fishery, described in Section 1.5.

The first records of skate catch appeared in California in 1916. Therefore, prior to 1950, the total catch amount of Longnose Skate was linearly ramped to zero in 1915, when the stock was assumed to be in the unfished state.

2.1.1.2.3 Discard mortality

To date, no studies are known to have estimated the discard mortality rate of Longnose Skate specifically. In tagging studies conducted in Canada (Gordon McFarlane, Pacific Biological Station, Fisheries and Oceans Canada, pers. comm.), tagged skates were recovered several times in trawl surveys, indicating that skates can survive trawl capture and on-deck sorting time. Several studies have looked at discard mortality rates for skates in general, caught in trawl fisheries (Enever et al. 2009, Laptikhovsky 2004, Stobutzki et al. 2002), and the reported discard mortality rates for skates ranging between 40 and 60 percent. Anecdotal evidence from commercial fisheries also indicates that skates are generally durable, and can handle capture and release well. However, many factors, such as trawl time, handling techniques, and time spent on the deck certainly affect skate survival.

A discard mortality rate of 50 percent was assumed for the 2007 Longnose Skate assessment. The same rate has been used for skates in the trawl fishery in British Columbia, based on an approximate average of these reported rates. In 2015, PFMC's Groundfish Management Team (GMT) conducted a comprehensive literature review of skate discard mortality, and concluded that the current assumption regarding Longnose Skate discard mortality is consistent with existing reported rates for other similar species. Thus, considering the currently available information, we retained the same assumption from the 2007 assessment that 50 percent of discarded skates die, and explored the consequences of alternative assumptions via sensitivity analyses.

2.1.1.3 Tribal catches

A portion of skate catch in Washington State came from the tribal fishery, and a time series of Longnose Skate landings from the tribal fishery was provided by WDFW. The landings were estimated from limited state sampling of species compositions in the combined skate category. These catches are listed in Table 3. Anecdotal evidence suggests that most of the catch in tribal fishery is retained (a maximal retention fishery), and discard is minimal. The assessment assumes there is no discard of skate by the tribal fishing fleet.

2.1.2 Abundance Indices

Indices of abundance provide an indicator of population dynamics by tracking portions of the population through time. All indices currently available for Longnose Skate are treated as relative measures of abundance, as modified by index-specific selectivity, and none of the sampling provides an absolute measure of population size along the spatial extent of the current stock assessment.

This assessment utilizes fishery-independent data from four bottom trawl surveys and one hook-and-line survey. The bottom trawl surveys were conducted on the continental shelf and slope of the Northeast Pacific Ocean by the AFSC and NWFSC and include the AFSC West Coast Shelf Survey (often called Triennial Survey, since it was conducted every third year), the AFSC West Coast Slope Survey (AFSC Slope Survey), the NWFSC West Coast Slope Survey (NWFSC Slope Survey) and the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBT Survey). The latter survey (WCGBT Survey) is the only current survey, the other surveys were discontinued. Details on the latitudinal and depth coverage of these surveys by year are presented in Table 5. The hook-and-line survey was conducted by the International Pacific Halibut Commission (IPHC).

Longnose are skate commonly encountered by the bottom trawl surveys. Percentage of positive hauls for Longnose Skate within WCGBT Survey ranges between 54 percent and 65 percent (Table 6). The map of the distribution of the Longnose Skate catch within the WCGBT Survey is shown in Figure 5 and Figure 6.

2.1.2.1 Fishery-Independent Indices

2.1.2.1.1 Bottom Trawl Surveys

2.1.2.1.1.1 AFSC Triennial Survey

The AFSC Triennial Survey was conducted every third year between 1977 and 2004. In 2004 this survey was conducted by the NWFSC. Survey methods are most recently described in Weinberg et al. (2002). The basic design was a series of equally spaced east-west transects from which searches for tows in specific depth strata were initiated. Over the years, the survey area varied in depth and latitudinal range (Table 5). Prior to 1995, the depth range was limited to 366 m (200 fm) and the surveyed area included four INPFC areas (Monterey, Eureka, Columbia and U.S. Vancouver). After 1995, the depth coverage was expanded to 500 m (275 fm) and the latitudinal range included not only the four INPFC areas covered in the earlier years, but also part of the Conception area with a southern extent of 34°50' N. latitude. For all years, except 1977, the shallower surveyed depth limit was 55 m (30 fm); in 1977 no tows were conducted shallower than 91 m (50 fm). The data from the 1977 survey were not used in the assessment, because of the differences in depths surveyed and the large number of "water hauls", when the trawl footrope failed to maintain contact with the bottom (Zimmermann et al. 2001). The tows conducted in Canadian and Mexican waters were also excluded. The timing of the AFSC Triennial Survey also slightly shifted starting in 1995. Prior to 1995, the survey was conducted from mid-summer to early fall, and from 1995 forward it was conducted at least a full month earlier in the later time period (Figure 20). In the assessment, separate Triennial survey catchability coefficients (q) were estimated for the period before and after 1995, to account for changes in the spatial coverage and timing of the survey that started in 1995.

2.1.2.1.1.2 AFSC Slope Survey

The AFSC Slope Survey was initiated in 1984. The survey methods are described in Lauth (2000). Prior to 1997, the survey was conducted in different latitudinal ranges each year (Table 5). In this assessment, only data from 1997, 1999, 2000 and 2001 were used – these years were consistent in latitudinal range (from 34°30' N. latitude to the U.S.-Canada border) and depth coverage (183-1280 m; 100-700 fm).

2.1.2.1.1.3 NWFSC Slope Survey

The NWFSC Slope Survey was conducted annually from 1999 to 2002 (Keller et al. 2007). The surveyed area ranged between 34°50' and 48°07' N. latitude, encompassing the U.S. Vancouver, Columbia, Eureka, Monterey INPFC areas, and a portion of the Conception area, and consistently covered depths from 100 to 700 fm (183-1280 m) (Table 5).

2.1.2.1.1.4 NWFSC West Coast Groundfish Bottom Trawl Survey

The NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBT Survey) has been conducted annually since 2003, and the data between 2003 and 2018 were used in this assessment. The survey consistently covered depths between 55 and 1280 m (30 and 700 fm) and the latitudinal range between 32°34' and 48°22' N. latitude, the extent of all five INPFC areas on the U.S. West Coast (Table 5). The survey is based on a random-grid design, and four industry chartered vessels per year are assigned an approximately equal number of randomly selected grid cells. The survey is conducted from late May to early October, and is divided into two passes, with two vessels operating during each pass. The survey methods are most recently described in detail in Keller et al. (2017).

2.1.2.1.2 Bottom trawl survey biomass indices

We analyzed data from the four bottom trawl surveys using the Vector Autoregressive Spatial Temporal (VAST) delta-model (Thorson et al. 2015), implemented as an R package and publicly available online (https://github.com/James-Thorson/VAST). We specifically include spatial and spatio-temporal variation in both encounter probability and positive catch rates, a logit-link for the encounter probability, and a log-link for the positive catch rates. We also included vessel-year effects for each unique combination of vessel and year in the database, to account for the random selection of commercial vessels used during sampling (Helser et al. 2004, Thorson and Ward 2014). We approximated spatial variation using 250 knots, and used the bias-correction algorithm (Thorson and Kristensen 2016) in Template Model Builder (Kristensen et al. 2016). Further details regarding model structure are available in the user manual (https://github.com/James-Thorson-NOAA/VAST/blob/master/manual/VAST_model_structure.pdf). To confirm convergence of the model estimation algorithm, we confirmed that the Hessian matrix was positive definite and that the absolute-value of the final gradient of the log-likelihood with respect to each fixed effect was <0.0001 for each fixed effect.

Following advice from the PFMC's Scientific and Statistical Committee (SSC), we used the following three diagnostics for model fit:

1) The Quantile-Quantile (Q-Q) plot, generated by comparing each observed datum with its predicted distribution under the fitted model, calculating the quantile of that datum, and comparing the distribution of quantiles with its expectation under a null model (i.e., a uniform distribution). This Q-Q plot shows no evidence that the model failed to capture the shape of dispersion shown in the positive catch rate data (Figure 21 through Figure 24).
2) A comparison of predicted and observed proportion encountered when binning observations by their predicted encounter probability. This comparison showed no evidence that the encounter probabilities were over-estimated for low-encounter-probability observations, or vice versa.
3) A visualization of Pearson residuals for encounter probability and positive catch rates associated with each knot (Figure 25 through Figure 32). This comparison showed no evidence of residual spatial patterns for either model component.

Lognormal and gamma errors structures were considered for the model component representing positive catches, and the gamma model was selected for all indices. Estimated biomass indices for the bottom trawl surveys are shown in Figure 33 through Figure 36 and provided in Table 7. All indices indicate relatively flat trend or slight increase in WCGBT Survey.

Comparison of VAST biomass indices for bottom trawl surveys used in the assessment with estimates calculated using the designed-based area swept approach are provided in Figure 37 though Figure 40, and the estimates between the methods are consistent. The area swept biomass estimates are also listed in Table 8. These area-swept estimates were calculated using spatial strata defined by state, and depth, with depth breaks at 183 and 549 meters.

2.1.2.1.3 International Pacific Halibut Commission Longline Survey
The International Pacific Halibut Commission (IPHC) has conducted an annual longline survey for Pacific halibut off the coast of Oregon and Washington (IPHC area "2A") since 1997 (no surveys were performed in 1998 or 2000). Beginning in 1999, this has been a fixed station design, with roughly 1,800 hooks deployed at each of 84 locations. The gear used to conduct the survey was designed to efficiently sample Pacific Halibut and used 16/0 (#3) circle hooks baited with Chum Salmon. Some variability in exact sampling location is unavoidable, and leeway is given in the IPHC methods to center the set on the target coordinates but to allow wind and currents to dictate the actual direction in which the gear is deployed. This can result in different habitats accessed at each fixed location among years. The number of skates used can also differ somewhat from year to year; skates hauled (i.e., 100 hooks/skate) is thus used as the unit of effort for all years. This has been the standard effort used in other stock assessments.

Since 2011, additional stations were added to the survey to sample yelloweye rockfish (Gertseva and Cope 2017). These stations as well as stations added in 2013, 2014, and 2017 off the coast of California (south of 42 degrees latitude) were excluded from the analysis. In most years, bycatch of non-halibut species has been recorded during this survey on the first 20 hooks of each 100-hook group. In 2003, only 10 percent of the hooks were observed for bycatch, and since 2012, some stations had 100 percent of the hooks observed for bycatch. This resulted in most stations having 80, 100, 120, 140, or 160 hooks observed, with a mean of 144 hooks and a maximum of 800 hooks observed.

Spatial distribution of Longnose Skate catches by year within the IPHC is shown in Figure 41. The IPHC longline survey catch data were standardized using a Generalized Linear Model (GLM) with binomial error structure. Catch-per-hook was modeled, rather than catch per station due to the variability in the number of hooks deployed and observed each year. The binomial error structure was considered logical, given the binary nature of capturing (or not) a Longnose Skate on each longline hook. The modeling approach is identical to that which has been applied in the past for yelloweye rockfish (Stewart et al. 2009), and spiny dogfish (Gertseva and Taylor 2011). MCMC sampling of the GLM parameters was used to estimate the variability around each index estimate. The median index estimates themselves were approximately equal to the observed mean catch rate in each year. The estimated index is shown in Figure 42 and provided in Table 7.

Figure 43 shows standardized indices from all surveys used in the assessment overlaid.

2.1.3 Fishery-Dependent Biological Compositions
Since size and age data and estimates of growth parameters for Longnose Skate did not indicate sexual dimorphism in growth, length and age frequency distributions were generated by year; for females and males combined.

2.1.3.1 Length Compositions

2.1.3.1.1 Length compositions of landings
Length composition data of Longnose Skate in commercial fisheries landings were obtained from PacFIN (extracted on February 25, 2019). Sampling statistics (number of samples and

number of individual fish) for state and year, used to create length frequency distributions, are shown from Table 9.

The lengths of Longnose Skate have not always been measured as total length TL (from tip of the nose to the end of the tail). Alternative length measurements has been used because body length measurements for larger fish (>100 cm TL) are not always convenient to take for port samples.

In California, length composition data of Longnose Skate landings have been collected since 2004 (Table 9). The measurements were taken of disk width (*DW*), which is the distance between the tips of skate pectoral fins. To convert the *DW* to TL, we used data collected by the WCGBT Survey, which collected both types of length (TL and *DW*) in 2006 and 2007 from selected fish. From those data, we developed a linear conversion between *DW* and TL (Figure 44). The formula for the conversion (for both sexes combined) was $TL\ (cm) = 1.4044 \cdot DW(cm) + 0.7005$. In Oregon, length composition data of Longnose Skate landings have been collected since 1995 (Table 9), and lengths were reported as TL. In Washington, length composition data for commercial landings of Longnose Skate have been collected since 2009. Most lengths were measured as interspiracular width (*ISW*), which is the distance from the cartilage knob of one spiracle to the cartilage knob of the other spiracle, measured across the top of the head (Downs and Cheng 2013). To convert *ISW* to TL, we used conversion developed by Downs and Cheng (2013) who found a strong linear relationship between *ISW* and TL ($R^2 = 0.97$) and developed a conversion for Longnose Skate, using data from commercial fishery landings along the coast of Washington state.

We only used randomly collected samples. The data were compiled into 33 length bins, ranging from five to 165 cm, with 5-cm bin width. The observed length composition data were expanded, to account for non-proportional sampling of Longnose Skate among trips and states. The fishery length frequency distributions of Longnose Skate (generated as described above) by year are shown in in Figure 45.

The initial input sample sizes for length frequency distributions of Longnose Skate in commercial fishery were calculated by year as a function of the number of trips and number of fish sampled, following Stewart and Miller (pers. comm.):

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

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

This method was developed based on analysis of the input and model-derived effective sample sizes from West Coast groundfish stock assessments. A step-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.

2.1.3.1.2 Length compositions of discard

Length frequency distributions of Longnose Skate that were discarded at sea were obtained from the WCGOP for the period between 2006 and 2017. The fish were measured in TL. The discard length composition data were expanded, to account for non-proportional sampling of Longnose Skate among hauls and trips. The length frequency distributions of Longnose Skate discard by year are shown in Figure 45.

2.1.3.2 Age Compositions

Age estimation for skates, as well as other elasmobranchs, is limited by the lack of bony structures, and the current methodology for age estimation for Longnose Skate relies on thin sectioning of vertebrae for growth and counting of annual rings, or "annuli," on the vertebra centra (Zeiner and Wolf 1993, King et al 2017).

The only source of fishery age data came from Thompson (2006), as a part of her Master's thesis. For this study, Thompson (2006) collected Longnose Skate biological samples from catches landed in Oregon. Her sampling efforts are summarized in Table 10. Thompson (2006) followed methods and criteria for skate age determination employed by the Pacific Shark Research Center at Moss Landing Marine Laboratories (MLML). These same methods are used by the AFSC ageing laboratory, and were recently validated using bomb radiocarbon study, when radiocarbon (^{14}C) signals from bomb testing conducted in the late-1960s was used to establish dates of growth band formation in Longnose Skate historical samples (King et al. 2017).

Age composition data were assembled into 24 age bins, ranging from age 0 to age 23 and compiled in the model as conditional distributions of ages at length. The conditional ages at length approach uses an age-length matrix, in which columns correspond to ages and rows to length bins. The distribution of ages in each column then is treated as a separate observation, conditioned on the corresponding length bin (row). The conditional ages-at-length approach has been used in most stock assessments on the West Coast of the United States in the last decade, since it has several advantages over the use of marginal age frequency distributions. Age structures are usually collected from the individuals that have been measured for length. If the standard age compositions are used along with length frequency distributions in the assessment, the information on year class strength may be double-counted since the same fish are contributing to likelihood components that are assumed to be independent. The use of conditional age distributions within each length bin allows avoiding such double-counting. Also, the use of conditional ages at length distributions allows the reliable estimation of growth parameters within the assessment model.

The conditional age-at-length data from the fishery shown in Figure 47. The initial sample sizes for conditional ages-at-length data were the actual numbers of fish on which each composition is based.

2.1.4 Fishery-Independent Biological Compositions

2.1.4.1 Length Compositions

Length composition data were available from WCGBT Survey, AFSC Triennial Survey, AFSC Slope Survey and IPHC Survey. A summary of sampling efforts (number of hauls and number of individual fish) in trawl surveys is provided in Table 11. Limited length samples of Longnose

Skate were available from IPHC survey; they were collected as a part of a special study, conducted in 2014 by AFSC.

Most length samples of Longnose Skate within surveys were collected as TL, but in a few years DW were measured instead. In 2006 and 2007, WCGBT Survey recorded DW for most skates, and we used a linear conversion, that was developed from subsample of organisms (N =875) for whom both TL and DW measurements were taken (Figure 44). The formula for the conversion for all fish (both sexes combined) was $TL\ (cm) = 1.4044 \cdot DW(cm) + 0.7005$.

In the 1998 Triennial survey, skates were also measured as DW. In the assessment, we did not use samples from the 1998 survey, since only 49 individuals were sampled, and several of those organisms were bigger than those measured in other surveys, which raised a concern that TL and not DW might have been reported for some of the samples. We conducted the sensitivity analysis, running the model, with 1998 length samples included, and found those samples did not impact the assessment results.

In the NWFSC Slope Survey, there were few length samples collected but only within a single year and by a single boat within limited geographic area. These samples were not used in the assessment, as they do not represent selectivity of the survey. The selectivity of NWFSC Slope Survey was mirrored to the selectivity of the AFSC Slope Survey, since the two surveys overlap in depth, latitude and survey years (Table 5). A sensitivity analysis was conducted, in which the model was run while the selectivity of NWSFC Slope Survey was mirrored to the WCGBT Survey (instead of the AFSC Slope Survey), and the model results were insensitive to this change.

Length composition data were compiled into 33 length bins, ranging from five to 165 cm, with 5-cm bin width. The observed length compositions from the surveys were expanded, to account for differences in catches among hauls and different spatial strata. Strata were defined by state, and depth (with depth breaks at 183 and 549 meters). The length frequency distributions of Longnose Skate by survey and year are shown in Figure 45 and Figure 46.

The initial input sample sizes for the survey length frequency distribution data were calculated as a function of both the number of fish and number of hauls sampled using the method developed for survey compositional data by Stewart and Hamel (2015).

2.1.4.2 Age Compositions

Age composition data were available only from the WCGBT Survey (Table 10). Thompson (2006) conducted a special study where she collected Longnose Skate vertebrae during the 2003 WCGBT Survey, as a part of her Master's thesis at Oregon State University. Age data from 2011 and 2012 WCGBT Surveys were generated as a part of the NMFS Improved Stock Assessment (ISA) project.

In both cases, age data were produced using thin sectioning of vertebrae, following methodology described in Gburski et al. (2007). As mentioned earlier, Longnose Skate ageing methods were recently validated using bomb radiocarbon study when radiocarbon (^{14}C) signals from bomb testing conducted in the late-1960s was used to establish dates of growth band formation in

Longnose Skate historical samples (King et al. 2017). While comparing age determination criteria used by multiple agencies responsible for skate research or management across their population range, King et al. (2017) concluded that the Gburski et al. (2007) ageing criteria produced the least between reader variability and the most accurate age estimates.

Survey age composition data were assembled into 24 age bins, ranging from age 0 to age 23. In the model, age composition data from the surveys were compiled as conditional distributions of ages at length (5-cm bins) by survey and year. Conditional age-at-length data from survey are shown in Figure 48. The initial sample sizes for the conditional age-at-length data were the actual numbers of fish on which each composition is based.

2.1.5 Biological Parameters and Data

Several biological parameters used in the assessment were estimated outside the model. Their values were treated in the model as fixed, and therefore uncertainty reported for the stock assessment results does not include uncertainty in these quantities (however, some were investigated via sensitivity analyses described later in this report). These parameters include length-weight relationship parameters, maturity and fecundity parameters, as well as ageing error and imprecision. The methods used to derive these parameters in the assessment are described below.

Description of parameters that were estimated within the assessment model, including natural mortality (*M*) and growth parameters, is provided in Section 2.2.2.4.

2.1.5.1 Length-Weight Relationships

Weight-at-length data collected from fisheries sampling and by the WCGBT and AFSC Triennial Surveys were used to estimate a length-weight relationship for Longnose Skate. Weight-at-length data was similar among sources (Figure 49) and all the sources were used to estimate the relationship.

Length-weight curve was fitted using the following relationship:

$$W = \alpha(L)^{\beta}$$

Where W is individual weight (kg), L is total natural length (cm) and α and β are coefficients used as constants.

The weight-length relationship was very similar for females and males (Figure 50), and in the model sexes were combined. The parameters derived from this analysis were as follows: α = $4.288369 \cdot 10^{-6}$, and β = 3.068629. These parameters were used in the assessment as fixed. We conducted a sensitivity run using length-weight parameters from the 2007 assessment (Figure 112 and Figure 113).

2.1.5.2 Maturity

Length at maturity was calculated from 211 samples collected and scored by the WCGBT Survey. Individual maturity was assessed based on macroscopic examination of internal structures, and each individual being assigned to one of four maturity stages. For females, in immature/juveniles (Stage 1), the ovaries are small, homogeneous, and undifferentiated. In developing/adolescents (Stage 2), eggs are more visible, but small and white. In pre-spawn/adults (Stage 3), the ovaries contain large eggs with yellow yolks. If egg cases are present inside the female's body, it is assigned to maturity stage 4. Animals assigned to Stages 3 and 4 were considered mature.

The logistic form was assumed for the maturity ogive (cumulative frequency function), and a generalized linear model was used to calculate the slope and length at 50 percent maturity (Figure 51). Female length at 50 percent maturity was estimated to be 101.5 cm, and we used this estimate in the assessment. We conducted a sensitivity analysis using the maturity values from the 2007 assessment (Figure 112 and Figure 113). Maturity parameters used in the 2007 assessment were informed by Thompson (2006), which we did not use in the current model. Within those data, a portion of even the very largest individuals in the population were still scored as immature, which is not consistent with life history of this species, or skate maturity estimates from other sources. This biased the parameter value unrealistically high, for those data. The WCGBT Survey data did not exhibit this problem, so we determined them to be more reliable, and used parameters derived from those data to inform the model.

The examination of maturity data from different sources within this assessment highlighted the importance of adding histological analysis to evaluation of skate maturity, which produces more accurate and consistent data within and among readers than strictly macroscopic evaluation, which is less accurate, less precise and more prone to reader bias (Vitale et al. 2006, Brown-Peterson et al. 2011, Kjesbu 2009).

2.1.5.3 Fecundity

At present, there are no studies that report eggs per female per year in Longnose Skate or describe eggs per year as a function of size or age. In this assessment, spawning output was assumed to be proportional to weight, which is the same as spawning biomass, and is reported here. The same assumption was used in the previous assessment.

2.1.5.4 Ageing Error

Age estimation for elasmobranchs is limited by their lack of bony structures. The current methodology for age estimation for Longnose Skate relies on thin sectioning of vertebrae for growth band counts (Zeiner and Wolf 1993, Gburski et al. 2007). Ages derived from these structures can vary within and between readers (i.e., imprecision), and may not contain the true age (i.e., bias). Stock assessment outputs can be affected by bias and imprecision in ageing, thus quantifying and including ageing error is an important consideration when using ages.

This assessment included age data (from the WCGBT 2003 survey and from the fishery) used in 2007 assessment (Gertseva and Schirripa 2008). New age estimates were also generated from samples collected by the WCGBT Surveys in 2011 and 2012. To account for both bias and imprecision in age reads, we estimated ageing error matrices for each dataset (old and new) using multiple-read data of the same vertebrae and following approach of Punt et al. (2008). Reader 1, the primary reader of the ages in the dataset, is always considered unbiased, but may be imprecise. Several model configurations are available for exploration based on either the functional form (e.g., constant CV, curvilinear standard deviation, or curvilinear CV) of the bias in Reader 2 and 3 or in the precision of the readers. Model selection uses AIC corrected for small sample size (AICc), which converges to AIC when sample sizes are large. Bayesian Information Criterion (BIC) was also considered when selecting a final model.

Evaluation of triple reads associated with the Thompson (2006) dataset revealed no bias among multiple reads (Figure 52 and Figure 53). Evaluation of the new age dataset showed no bias between Reader 1 and Reader 2 (Figure 54), but ages from Reader 3 were consistently higher than those from Reader 1 (Figure 55). Reader 3 is specializing on samples from GOA skates, while the main reader (Reader 1) on samples from U.S. West Coast, and therefore, in the model, we assumed Reader 1 to be unbiased. Readers 1, 2 and 3 in Figure 52 and Figure 53 are specific to the Thompson (2006) dataset. Readers 1, 2 and 3 in Figure 54 and Figure 55 are specific to the new dataset only, and are not the same as Readers 1, 2 and 3 in Figure 52 and Figure 53.

Distributions of observed age at true age, for ageing error matrix 1 and ageing error matrix 2, used in the assessment are shown in Figure 56 and Figure 57, respectively.

2.1.6 Environmental or Ecosystem Data

Ecosystem considerations were not explicitly included in this assessment. This is primarily due to a lack of relevant data that could contribute ecosystem-related quantitative information for the assessment.

2.2 Model

2.2.1 History of Modeling Approaches Used for this Stock

2.2.1.1 Previous Assessments

Longnose Skate stock on the West Coast of the United States has been assessed once before, in 2007 (Gertseva and Schirripa 2008). The assessment used the Stock Synthesis 2 modelling framework, version 2.00e (Methot 2007).

It was a coastwide model, and the stock was modeled with a single fishing fleet. Since there were no apparent differences found between females and males in their biological parameters or fishery and survey length and age frequencies, the assessment used a single sex model.

The modelling period started in 1916, assuming unfished equilibrium conditions prior to that. The total catch time series included both landed catch and discard mortality. A 93 percent discard rate was assumed for catches prior to 1995, and 53 percent from 1995 forward, to reflect skate market changes. Also, discard mortality rate of 50 percent was assumed for the entire time series.

Growth was fully estimated within the assessment model, while natural mortality (M) was fixed at 0.2, the value informed by Hoenig (1983) and based on a maximum age of 22 years. Weight-at-length, maturity-at-length and fecundity-at-weight, were also fixed at the levels estimated outside the model. Stock-recruitment relationship was modeled with a Beverton-Holt model and recruits were taken deterministically from the stock-recruit curve. The level of virgin recruitment (R_0) was estimated, while steepness h was fixed at a value of 0.4, to reflect the K-type reproductive strategy of this species. Catchability for the WCGBT Survey (q) was fixed at a value of 0.83, estimated as the mid-point of the range of factors potentially affecting q, including 1) whether fish are buried in the substrate (longnose are known to exhibit this behavior), 2) whether they are "herded" by the net, 3) whether they can swim to escape the net, etc.

The 2007 assessment described the dynamics of the Longnose Skate as a stock slowly declining from an unfished condition, with a flat trend since early 2000. The assessment estimated depletion of the stock in 2007 to be at 66 percent of its unfished level (Figure 122). The 2007 assessment model was the starting point for this assessment, and a bridging analysis was done to investigate the impact of increment changes made to the assessment model (Figure 59). Major changes made are described in Section 2.2.2.1.

2.2.1.2 Responses to 2009 STAR Panel Recommendations

The STAR panel report from the last (and the only) full assessment (conducted in 2007) identified a number of recommendations for the next assessment. Below, we list the 2007 STAR panel recommendations and explain how these recommendations were taken into account in this assessment.

Prioritized recommendations for future research and data collection:

1) Re-create catch history (best estimates plus uncertainty) based on fishing effort.

For this assessment, historical landings of Longnose Skate were re-estimated for each state using landing records for combined skate categories, while accounting for variability in skate species compositions among depths, and year-specific information where available. This approach allowed us to account for recent changes in depth of fishing by the fishery, throughout the time series, in response to management measures.

For this assessment, we also estimated the amount of total Longnose Skate removals, based on a statistical relationship with removals of Dover sole. This relationship was estimated using recent fishery data, during the period when Longnose Skate catch was recorded directly, by species rather than in a mixed species category. Dover sole is a commercially important stock, with which Longnose Skate is caught incidentally. The methods for this are described in Section 2.1.1.2.2. The results of this reconstruction are consistent with available historical estimates of discard rates for Longnose Skate.

2) Investigate anomalous 2004 AFSC triennial survey Longnose Skate (and possibly other flatfish) catches.

A number of flatfish species, including Dover sole, petrale sole, English sole and Arrowtooth flounder exhibited substantially higher index values in the 2004 AFSC Triennial Survey. There has not been a coordinated effort to evaluate the 2004 anomalous catch estimate and identify reasons behind it. As described in Section 2.1.2.1.1.1, this survey during 2004was conducted by the NWFSC (rather than AFSC), and although the same protocol was followed, there is potential that this change might have affected the data collection protocol and the subsequent index estimate.

For the assessment, we evaluated the sensitivity of the assessment model to the 2004 data by running it with the AFSC Triennial Survey index estimated, while excluding 2004 data. Those model results were nearly identical to the base run, with the 2004 estimate included (Figure 114 and Figure 115).

3) Ageing (validation) studies and maturation rate studies.

An age validation study for Longnose Skate was conducted by King et al. (2017). This study was a collaboration among multiple agencies responsible for skate research or management across their population range: California, USA; British Columbia, Canada; and Alaska, USA. As part of this study, archived specimens of Longnose Skate collected in Monterey Bay, CA, during 1980 and 1981, were used to analyze radiocarbon (^{14}C) signals from bomb testing conducted in the late-1960s. King et al. (2017) measured $\Delta^{14}C$, estimated year of growth band formation, and compared Longnose Skate $\Delta^{14}C$ data to reference chronology for the California Current System. The main goals of the study were to determine which age estimates produced by each agency were most accurate relative to the $\Delta^{14}C$ chronology, and identify the best age determination criteria for counting growth bands based on the latter. The study concluded that the ageing criteria of Gburski et al. (2007) produced the smallest between-reader variability (100 percent agreement for ± 2 years) and the most accurate age estimates. These criteria were used for age determination of age data used in this assessment.

No maturation rate study was conducted since last assessment. However, WCGBT Survey collected new coastwide maturity data for Longnose Skate in 2018. The maturity criteria used are the same as developed by the Pacific Shark Research Center at Moss Landing Marine laboratory. The same criteria are being used by AFSC. We used these new data to estimate maturity parameters for this assessment.

4) Continue skate species identification in the fishery

Since 2009, Longnose Skate has had its own landing category, and is now consistently identified directly by species in commercial fishery landings. These landing records are incorporated in this assessment.

5) Continue discard monitoring.

Discard of Longnose Skate is monitored by the West Coast Groundfish Observer Program (WCGOP) and WCGOP data are incorporated in this assessment.

6) Studies to estimate discard rates and discard mortality

Discard rate estimates are available from WCGOP beginning in 2009. However, no new information is available as to discard *mortality* rates of skates. In 2015, PFMC's Groundfish Management Team (GMT) conducted a comprehensive literature review of skate discard mortality. They identified ten peer-reviewed publications that reported an estimate of skate discard mortality for fifteen *Rajidae* identified to the species level, and a suite of species identified to genus. That literature search revealed that several studies have looked at discard mortality rates for skates in general caught in trawl fisheries (Enever et al. 2009, Laptikhovsky 2004, Stobutzki et al. 2002), and the reported discard mortality rates for skates ranging between 40 and 60 percent (see Section 2.1.1.2.3), of which the 50 percent value used for Longnose Skate is the mean, and maintaining that value was deemed reasonable based on current information. We evaluated the sensitivity of the assessment model to alternative assumptions about discard mortality by running the model assuming 40 and 60 percent discard mortality rates. Terminal relative spawning biomass in these runs were 59 and 54 percent, respectively (Figure 111), indicating that the model in not very sensitive to this assumption.

2.2.2 Model Description

2.2.2.1 Changes Made From the Last Assessment

The last full assessment of Longnose Skate was conducted in 2007. The 2007 assessment model was the starting point for this assessment, and a bridging analysis was done to investigate the impact of increment changes to the assessment model. For this assessment, we retained a number of features of the 2007 assessment and also included a number of improvements related to use of data and modeling techniques. Below, we describe the most important changes made since the last full assessment and provide rationale for each change:

1) Upgraded to Stock Synthesis version 3.30.13 (released on March 13, 2019).
   Rationale: This is standard practice to capitalize on newly developed features and corrections to older versions as well as improvements in computational efficiency. Model results were nearly identical before and after this change.

2) Changed the fleet structure of the assessment, and divided catches into four fleets, instead of one combined fleet as it was in 2007. Commercial fishery removals are divided into three fleets, which include the current fishery (1995-2018) and the historical landings (1915-1994) and historical discards(1915-1994). In addition to commercial fishery fleets, Washington tribal catches are included as a separate fleet, and the catches are reported separately.
   Rationale: Since the last assessment, new information about recent amounts and size composition of discard has been collected by WCGOP, which allowed us to estimate discard fractions and a retention curve within the model for the recent period. Removals during this recent period (1995-2018) were included in the model as the current fishery. The removals prior 1995 were included in the model as the historical fishery. The historical fishery was divided into historical landings and historical discard, to make the amounts of catch assigned to each fleet more transparent, as well as simplify the process of testing assumptions specific to landings or discards, and about discard mortality.

3) Updated fishery landings estimates.
   Rationale: Until very recently, catch of Longnose Skates were reported within unspecified skates categories. The improved estimates of landings for Longnose Skate were generated for this assessment. The methods to generate these estimates are described in Section 2.1.1.

4) Updated historical discard estimates.
   Rationale: Only limited information is available about skate discards. Available information suggest that most of the skate catch was discarded at sea until the mid-1990s, since processors only accepted skate “wings” and most boats did not want to go to the effort of winging the skates at sea. In the mid-1990s, the processors started to accept whole skate for landing, and boats started to retain skates if they had space to hold them and land in ports. In the absence of other information, the 2007 assessment assumed a

constant discard rate before and after 1995, to reflect that change in market. Before 1995, the discard rate was assumed to be 97 percent based on Pikitch et al. (1988), and from 1995 forward, it was assumed to be 47 percent based on a combination of EDCP and WCGOP data. However, this approach resulted in a somewhat unrealistic perception of removals, where small differences in landings among years would be inflated by the discard rate applied across the years (Figure 58). For this assessment, we were able to estimate the amount of total Longnose Skate removals, based on a statistical relationship with removals of Dover sole. This relationship was estimated using recent fishery data, during the period when Longnose Skate catch was recorded directly, by species rather than in a mixed species category. Dover sole is a commercially important stock, with which Longnose Skate is caught incidentally. The results of this reconstruction are consistent with available historical estimates of discard rates for Longnose Skate. The methods for this reconstruction are described in Section 2.1.1.2.2.

5) Used the VAST approach to estimate biomass indices from the bottom trawl survey data.
Rationale: Recent research suggests that spatial models can explain a substantial portion of variability in catch rates via the location of samples (i.e., whether located in high- or low-density habitats), and thus use available catch-rate data more efficiently than conventional "design-based" or stratified estimators. This new method uses spatially referenced data information on the location of samples to explain a portion of the variability in catch rates, and thus indirectly incorporates information on habitat quality, which, in many respects, shapes spatial distribution of organisms and determines their density of occurrence. The PFMC's SSC has evaluated and approved VAST for use in constricting relative biomass indices survey data.

6) Included index from IPHC hook-and-line survey.
Rationale: Only five years of data, distributed inconsistently among years, were available from this survey at the time of the last assessment. Twelve years of additional data are now available, making these data potentially more informative and valuable to the assessment.

7) Included new length composition data from fishery-dependent and fishery-independent sources.
Rationale: Additional data have been collected from fishery landings and the WCGBT Survey since the last assessment, plus we now have species-specific discard length compositions available from the WCGOP. There were none available from discarded catch at the time of the 2007 assessment.

8) Included additional age data and estimated additional ageing error.
Rationale: For this assessment, new age estimates were generated from samples collected by the WCGBT Surveys in 2011 and 2012. These ages were generated as part of the NMFS Improved Stock Assessment (ISA) program. The methods used to generate these ages followed Gburski et al. (2007), whose ageing criteria were found to produce the smallest between-reader variability and the most accurate age estimates, based on Longnose Skate age validation study by King et al (2017). An ageing error matrix was generated for the new estimates using multiple-read data of the same vertebrae.

9) Natural mortality (*M*) was estimated within the model using the Hamel (2015) prior instead of fixing *M* at the value of 0.2 derived using Hoenig (1983).
Rationale: The available data allowed us to estimate natural mortality within the model. The maximum age used to generate the prior corresponds to 26 years, reported for Longnose Skate in multiple studies (Love et al. 2002, Ebert 2005, McFarlane and King 2006, Gburski et al. 2007). The maximum age within the main age dataset included in this model was 22, and among multiple reads used to estimate the ageing error matrix, the maximum age was 26.

10) WCGBT Survey catchability (*q*) was estimated within the model using a prior developed as part of the 2007 assessment instead of fixing it at the mean value.
Rationale: In 2007 the value of *q* for the WCGBT Survey was fixed at 0.83, which is the mean of the prior developed as described in Section 2.2.2.3.5. Fixing the catchability parameter was a strong assumption based on limited supporting information. Although the current assessment uses the same prior, estimating the catchability parameter rather than fixing it at a particular value allows corresponding uncertainty to be propagated through the model to the assessment output.

11) Updated maturity parameters.
Rationale: The new maturity data collected from the WCGBT Survey along the entire coast became recently available. These data are the most comprehensive for Longnose Skate, and were used in the assessment to estimate female maturity parameters.

The list above documents only the most important changes made to this assessment relative to the previous one. The impact of these changes to the assessment results are shown in Figure 59 and Table 12.

Despite the large number of changes made to data sources and model configuration, these two assessments have largely drawn the same conclusions regarding historical trends (Figure 121, Figure 122), when the population was slowly decreasing through the end of the 1990s, and then plateaued since the early 2000s. The 2007 assessment described slightly more dynamic changes in stock biomass and depletion over the years, which can be attributed to more dynamic estimates of removals (Figure 58). The current assessment estimates higher initial spawning biomass and lower depletion, primarily due to increased WCGBT Survey catchability.

2.2.2.2 Model Specifications

This assessment uses the Stock Synthesis modeling framework written by Dr. Richard Methot at the NWFSC (described in Methot and Wetzel 2013). This assessment uses the Stock Synthesis version 3.30.13, released in March, 2019.This version includes many improvements in the output statistics for producing assessment results and several corrections to versions used previously.

This assessment focuses on a portion of a population of Longnose Skate that occurs in coastal waters of the western United States, off Washington, Oregon and California, the area bounded by the U.S.-Canada border to the north, and the U.S.-Mexico border to the south. The population is treated as a single coastwide stock (same as in the 2007 assessment). Females and males are combined, since estimates of growth and weigh-at-length parameters did not differ between sexes. Natural mortality is estimated within the model using the natural mortality prior developed by Hamel (2015). Recruitment dynamics are assumed to be governed by a Beverton-Holt stock-recruit function, and recruitment deviations are taken deterministically from the spawner-recruit curve.

The modeling period begins in 1916, and we assume the stock was in an unfished equilibrium condition prior to that time. Fishery removals are divided among four fleets: 1) Current commercial fishery (1995-2018), 2) Historical commercial landings, 3) Historical commercial discard, and 4) Tribal fishery. Discard in the current fishery is estimated within the model, and length composition of landings and discard are used to estimate retention and selectivity curves. Selectivity of the historical and tribal fleets are mirrored to that of current fishery.

The model includes five indices of abundance that provide relative measures of abundance, as modified by index-specific selectivity. The WCGBT Survey catchability (q) is estimated with the prior developed during the 2007 STAR Meeting, which accounts for factors potentially affecting q. The method used to develop the prior is described in Section 2.2.2.4.5.

The length composition data are stratified into thirty three, 5-cm bins, ranging between 5 and 165 cm. The age data are treated as conditional age-at-length compositions summarized into twenty four bins, ranging being age 0 and age 23. For the internal population dynamics, ages 0-30 are individually tracked, with the accumulator age of 30 determining when the 'plus-group' calculations are applied. This is a relatively large age, but was necessary to ensure that some growth could be predicted to occur (but not be modeled) at and beyond this age, since the model does not allow growth to continue in the plus-group.

2.2.2.3 Data Weighting

This assessment uses a Dirichlet-Multinomial likelihood (Thorson et al. 2017) for composition data weighting. The primary benefit of this approach over alternative Francis (Francis 2011) and McAllister-Ianelli (McAllister and Ianelli 1997) methods is that instead of manually iterating the sample size multiplier, an estimated parameter (θ) serves to automatically adjust the weight given to the composition data. As the estimated parameter (θ) increases, the ratio $\theta/(1+\theta)$ (which is similar to the sample size adjustment estimated in the other data weighting methods) approaches one, the θ parameter is fixed at the upper bound, which avoids upweighting the input sample sizes above 100 percent. This was the case for AFSC triennial and IPHC survey length composition data and fishery and WCGBT Survey age composition data (Table 14).

The Dirichlet-Multinomial approach is currently used in a number of groundfish assessments, including the stock assessment of Pacific Hake (Berger et al. 2019). Integration of the Dirichlet-Multinomial data weighting increases the efficiency of the assessment process, removes the subjective choice of how many iterations are required, and also ensures that the results of model sensitivities, retrospective analyses, and likelihood profiles are automatically tuned, rather than having the same weight as the base model. In this assessment, we provide sensitivities to alternative data-weighting approach, when iterative re-weighting of age- and length-composition data are accomplished using the Francis and the McAllister-Ianelli methods.

The weight given to the indices of abundance was adjusted in the assessment automatically through the estimation of an additional standard deviation parameter for each index, which was added to the standard deviation values estimated within the index standardization process. For the WCGBT Survey, NWFSC Slope Survey and AFSC Slope Survey this parameter was estimated to be at the lower bound and, therefore, fixed at zero value in the model. No data weighting algorithm was applied to the discard rate or mean body weight observations.

2.2.2.4 Model Parameters

A full list of all parameters used in the assessment is provided in Table 14. These parameters were either fixed or estimated within the model. Fixed parameters (and how the values for fixed parameters were derived) are described in Section 2.1.3. Here, we discuss parameters estimated within the model.

2.2.2.4.1 Growth

The von Bertalanffy growth function (von Bertalanffy 1938) was used to model the relationship between length and age in Longnose Skate. This is the most widely applied somatic growth model in fisheries (Haddon 2001), and has been commonly used to model growth in skates, including Longnose Skates (McFarlane and King 2006, Thompson 2006, Gburski et al. 2007).

The Stock Synthesis modeling framework uses the following version of the von Bertalanffy function:

$$L_A = L_\infty + (L_1 - L_\infty)e^{-k(A-A_1)}$$

Where asymptotic length, L_∞, is calculated as:

$$L_\infty = L_1 + \frac{L_2 - L_1}{1 - e^{-k(A_2-A_1)}}$$

In these equations, L_A is length (cm) at age A, k is the growth coefficient, L_∞ is asymptotic length, and L_1 and L_2 are the sizes associated with a minimum A_1 and maximum A_2 reference ages.

Parameters L_1, L_2, growth coefficient k and standard deviations associated with L_1 and L_2 estimates were estimated in the model. Ages A_1 and A_2 were set to be zero and 30 years, respectively. Based on preliminary analyses, this choice had little effect on estimated growth curves as the growth curve is robustly estimated. Conditional age-at-length data are the main source of information to estimate growth. Female and male Longnose Skate have shown very similar growth curves in the past assessment. Similar growth between the sexes in Longnose Skates were also reported by Gburski et al (2007). Data in this assessment also support a common growth curve for both sexes, therefore, a single sex growth model is assumed for parsimony.

2.2.2.4.2 Natural Mortality

In the model, natural mortality (M) is estimated within the model, using "Hamel-Then" natural mortality estimator developed based on the meta-analytic approach to estimating M through longevity developed by Hamel (2015). The "Hamel-Then" estimator also uses the data set of longevity to M values from Then et al. (2015).

Then et al. (2015) evaluated different meta-analytical approaches to predict the natural mortality rate from other life-history traits and concluded that a longevity-based estimator performed the best among all estimators evaluated. Then et al. (2015) specifically recommended using the updated Hoenig non-linear least squares (nls) estimator of $M = 4.899A_{max}^{-.916}$. However, while providing their relationship of longevity to M, Then et al. (2015) did not consistently apply the log-transformation in the estimation even though one would expect substantial heteroscedasticity in both the observation and process error associated with the relationship of M to A_{max} in real space (Hamel, pers. comm.). Fitting both the nls and one-parameter $M = \frac{C}{Amax}$ equations in untransformed space gives far too much weight to high M (low A_{max}) cases (Hamel, pers. comm.). Hamel (pers. comm.) reevaluated the data used in Then et al. (2015), while fitting the one-parameter A_{max} model under a log-log transformation (such that the slope is forced to be -1 in the transformed space as in Hamel (2015)) , resulting in the following point estimate for M:

$$M = \frac{5.4}{Amax}$$

The above is the median of the lognormal prior and assumes a log-scale standard deviation of 0.438. The "Hamel-Then" M estimator has slightly higher value of C (5.4) than the value of C (5.1) when models were fitted in untransformed space.

For Longnose Skate, the oldest individual in the age sample including double reads was 26 years old. A number of studies reported the same age as the maximum observed for this species (Gburski et al. 2007, Thompson 2006, McFarlane and King 2006, Love et al. 2002, Ebert 2005). Therefore, we used this value as $Amax$, and thus M = 5.4/26 = 0.2077.

Figure 60 shows the Hamel prior input into the assessment model along with the model-estimated value of M, indicating the model has enough data to inform the estimated value. Natural mortality is estimated in assessment to be 0.22 yr^{-1}, which is consistent with maximum ages observed for this species.

2.2.2.4.3 Stock -Recruitment Function and Compensation

Recruitment dynamics in the assessment are assumed to be governed by a Beverton-Holt stock-recruit function, which was also the case in the previous assessment. This relationship is parameterized to include two quantities: the log of unexploited equilibrium recruitment (R_0) and steepness (h). A "steepness" parameter is defined as the proportion of average recruitment for an unfished population expected for a population at 20% of its unfished spawning output. This is a difficult parameter to estimate, and several methods to derive a prior for steepness have been proposed (Myers et al. 1995, Dorn 2002).

In this assessment the log of R_0 was estimated, while h was fixed at the value of 0.4, which reflects the fact that skates are thought to be less productive than teleost fish. The same value was used in the 2007 assessment. Stock-recruit steepness has been estimated at similar values in other skate species. For example, it was estimated by the assessment model at 0.44 in the Alaska skate (Ormseth and Matta, 2007), and at assumed at 0.54 in Chilean Yellownose skate (Wiff et al. 2018). Since no new information has been accumulated that would suggest a different value, we retained the same assumption for steepness in this assessment. The influence of this parameter on model output was explored via a likelihood profile analysis (Figure 123). The likelihood profile suggests that the best fit occurred at steepness of around 0.4, indicating that a model with steepness estimated would have been similar to the base model where *h* was fixed at 0.4.

Recruits in the assessment were taken deterministically from the stock-recruit curve, as the model was not able to reliable estimate recruitment deviations. The age data in the model are limited to a few recent years, while the length distributions reflect not only the differences in the recruitment, but also changes in discarding and retention practices, as well as reporting of landings. However, given the biology of the species, skates are classified as equilibrium strategists who exhibit steady population dynamics over time (King and McFarlane 2003). Therefore, we do not expect extreme recruitment deviations because of the Longnose Skate's life history traits.

2.2.2.4.4 Selectivity Parameters

Selectivity parameters for fisheries and surveys in the assessment were specified as a function of length, using double-normal selectivity curves. The double-normal selectivity curve has six parameters, including: 1) peak, which is the length at which selectivity is fully selected, 2) width of the plateau on the top, 3) width of the ascending part of the curve, 4) width of the descending part of the curve, 5) selectivity at the first size bin, and 6) selectivity at the last size bin.

The selectivity curves were estimated for four out of the five fishery-independent surveys. Since no length composition data were available for the NWFSC Slope Survey, its selectivity was mirrored to that of AFSC Slope Survey, as both slope surveys had the same spatial coverage and even overlapped in years when the surveys were conducted (Table 3). We explored model sensitivity to allowing selectivity of the NWFSC Slope Survey to be mirrored to the WCGBT Survey, and the model produced virtually identical results.

Selectivity for the current fishery was assumed to be asymptotic, as available length compositions indicate that the fishery selects the largest fish (larger than 200 cm), and no information on Longnose Skate habitat suggests that larger organisms are undetected within untrawlable areas. We conducted a sensitivity analysis run that allowed fishery selectivity to be dome-shaped, and model output was nearly identical to the base model output (Figure 114 and Figure 115). Selectivity of the other fisheries were mirrored for that of the current fishery.

For the current fishery, retention was modeled as a logistic function of length, with three parameters being estimated: 1) ascending inflection, 2) ascending slope, and 3) asymptotic retention fraction. The asymptotic retention fraction was allowed to vary interannually, to reflect changes in observed discard among years. Discard mortality was also modeled using a logistic function of length, but all fish were assumed to have the same 50% discard mortality regardless of their size (see Section 2.1.1.2.3).

2.2.2.4.5 Survey Catchability Parameters

For WCGBT Survey and AFSC Triennial Survey indices of biomass, separate catchability parameters were estimated, while for AFSC Slope, NWFSC Slope and IPHC Surveys catchability parameters were solved for analytically.

The lack of contrast in the data resulted in unstable model results under a variety of configurations when WCGBT Survey catchability was freely estimated. Therefore, we estimated the catchability parameter for the WCGBT Survey using the prior that was developed within the 2007 assessment (Gertseva and Schirripa 2008), as a product of the multiple factors affecting survey catchability. These factors included latitudinal, depth and vertical availably of Longnose Skate to the survey as well as probability of catch in survey net path.

The WCGBT Survey covers the full latitudinal range of Longnose Skate modeled in the assessment, and thus, the latitudinal availability factor was assumed to be one (complete latitudinal coverage). The survey coverage appears to exceed the maximum depth distribution of Longnose Skate but may not fully cover the shallow end of the skate distribution. A range of 95 to 100 percent was assumed for the depth availability. A range of 75 to 95 percent was assumed for vertical availability on the basis that Longnose Skate are known to bury in the mud and, therefore, some may be unavailable to the bottom trawl gear. The largest bounds were placed on the probability of capture, given a fish is in the net path. It is known that flatfish can be herded by trawl gear, and it is possible that this could also occur for skates. However, it is also possible that skate could avoid the trawl nets. For capture probability, a range of 75 to 150 percent was assumed. Best estimates for each factor were set at the midpoint of the range for individual factors, except for the probability of capture, which was given a value of one. The overall estimate for the survey catchability was, thus, estimated to be 0.83 and the consequent bounds on catch, and the best assumption are: (0.53, 1.43) and 0.83 respectively (Table 13). The best estimate was equated to the median of a lognormal distribution and the bounds to 99th percentiles of that distribution. This resulted in a normal prior on log(q), with a mean of -0.19, and standard deviation of 0.187.

This model estimated the catchability as 1.57 (Figure 61), which is much larger than the best guess value (0.83) but nonetheless considered plausible for several reasons. First, investigation of the catchability of flatfish species within the same survey (Bryan et al. 2013) showed that flatfish exhibit herding behavior in response to the trawl sweeps. The study did not look into skate species, but they also might exhibit herding. Second, extrapolation of density in trawlable areas to untrawlable habitat can result in higher estimate of catchability for skate, which are generally associated with soft (sand, mud) or mixed substrates (e.g., mud and cobble or boulder). Model results were strongly influenced by assumptions regarding catchability, therefore developing a well-informed prior on survey catchability is a priority for this species. In this assessment, q for the WCGBT Survey is a major axis of uncertainty, and is used to define low and high states of nature in the Decision Table.

2.3 Base Model Selection and Evaluation

2.3.1 Search for Balance Between Model Realism and Parsimony

The structure of the base model was selected to balance model realism and parsimony. A large number of alternate model formulations were evaluated during the assessment process. Structural choices were made to be as objective as possible, and follow generally accepted methods of approaching similar modeling problems and data issues. The precise effect of each of these incremental choices on assessment results is often unknown; however, extensive efforts were made to evaluate effects of structural choices upon model output prior to selecting the base model.

We thoroughly evaluated the year of division between the historical and current fisheries, assuming it to start in 1995 (as in base model), but also tried starting in 2004, when length composition data became available from Washington, and in 2009 from California. We explored starting the current fishery in 1996 and 2006, when WCGOP length data became available. In all cases, the assessment outputs were not different, and we decided to start the current fishery in 1995, to take advantage of the maximum amount of fishery length composition data available in that case. We also evaluated the structure of the historical fleets, separating landings and discard (as in base model), as well as combining them into a single fleet, but settled on separating landings from discards, to make the amounts of catch assigned to each fleet more transparent, as well as to simplify the process of testing assumptions specific to either landings or discards, and assumptions about discard mortality.

We thoroughly explored the treatment of the AFSC Triennial Survey index and different ways to account for changes that occurred in the spatial coverage and timing of the survey (described in Section 2.1.2.1.1.1). These included calculating separate indices for early and late time series, estimating a single catchability parameter value for the entire time series, as well as allowing catchability to differ before and after 1995. The model output was not sensitive to any of these assumptions.

We also explored two-sex versus single sex model configurations, since growth and length-weight parameters were almost identical between females and males, and the sex ratio in the data did not deviate from 50/50. Treating the sexes as combined did not deteriorate the model's ability to accurately describe the stock dynamics, and a single sex model yielded almost the same results with greater parsimony.

We explored the potential of estimating recruitment deviations, but the results were unreasonable, since the available age data are limited, and changes in length data often reflect changes in discarding practices rather than the recruitment signal. In the base model, the recruitment deviations are not estimated. However, given the biology of the species, when skates invest considerable energy in developing a few large, well-protected embryos, it is reasonable to expect low contrast in the recruitment signal over time; i.e. we do not expect extreme recruitment deviations because of Longnose Skate life history traits.

2.3.2 Convergence

A number of tests were done to verify convergence of the base model. Following conventional AD Model Builder methods (Fournier et al. 2012), we checked that the Hessian matrix for the base model was positive-definite. We also confirmed that the final gradient was below 0.001.

2.3.3 Evidence of Search for Global Best Estimates

To confirm that the reported estimates were from the global best fit, we assessed the model's ability to recover similar likelihood estimates when initialized from dispersed starting points (jitter option in SS). We performed 25 trials using a 'jitter' value of 0.1 for the base model. This perturbs the initial values used for minimization with the intention of causing the search to traverse a broader region of the likelihood surface. Twenty two of these trials returned to exactly the same objective function value as in the base model, inverting the Hessian and producing small gradients. Results of these runs showed identical levels of ending absolute and relative spawning output. The remaining runs exhibited worse fit than the base model. The spread of this search indicates that the jitter was sufficient to search a large portion of the likelihood surface, and that the base model is in a global minimum.

2.4 Changes Made During the 2019 STAR Panel Meeting

During the 2019 STAR Panel meeting, analysis and evaluation of the assessment model were performed to further explore data sources and model assumptions, and to better understand model performance. The STAR Panel provided useful recommendations that were incorporated into the base model. Specifically, evaluation of model fit to length-at-age data revealed that using the Dirichlet-Multinomial data weighting approach resulted in much better fit of the estimated growth curve to length-at-age data (Figure 62). In the pre-STAR version of the model a combination of Francis and McAllister-Ianelli methods was used for compositional data weighting. The Francis method was used in fleets with more than one year of data, and the McAllister-Ianelli method was used in fleets with only a single year of data (IPHC length data and fishery age data).

The model with the Dirichlet-Multinomial data weighting also resulted in more reasonable estimates of natural mortality and growth parameters than the pre-STAR model, which used a combination of Francis and McAllister-Ianelli methods for data weighting (Table 20). Specifically, natural mortality was estimated to be 0.22 with the Dirichlet-Multinomial, which corresponds to a maximum age of 22, versus 0.13 with the Francis method, which corresponds to maximum age of 40 years. The maximum reported age for Longnose Skate is between 22 and 26 years, in agreement with results of the Dirichlet method. The Von Bertalanffy growth coefficient was estimated to be lower, and asymptotic length higher using the Dirichlet-Multinomial approach, versus the model using the Francis method; results of the Dirichlet approach are in agreement with other Longnose Skate life history studies. Given the improvement of fit to length-at-age data, as well as more realistic estimates of life history parameters than alternative weighting methods, we used the Dirichlet-Multinomial likelihood method in the base model.

2.5 Base-Model Results

The list of all the parameters in the assessment model and their values (either fixed or estimated) is provided in Table 14. The life history parameters, such as natural mortality and growth, estimated within the model are consistent with what we know about the species (Table 15). The growth parameters are relatively precisely estimated, in terms of the asymptotic standard error estimates. Figure 63 shows the estimated growth curve. Length-weight and maturity-at-length relationships as used in the assessment are shown in Figure 64 and Figure 65, respectively. Spawning output-at-length is shown in Figure 66. Spawning output in the assessment is expressed as spawning biomass. The estimated stock-recruit function for the assessment model is shown in Figure 67. No deviations were estimated, as described earlier.

The total dead catch time series for Longnose Skate is shown in Figure 8. For the current fishery, total catch includes dead discard amounts estimated by the model. The model fit to the discard rates observed are shown in Figure 68. From 2009, discards estimates were derived from WCGOP data; prior to that, discard rates were predicted from total catch estimates based on total catch of Dover sole and reconstructed Longnose Skate landings, as described earlier. The fits to average individual weight of discarded fish are shown in Figure 69. The model was able to track well the decreasing trend in average individual weight (Figure 69), with decreasing discard rates (Figure 68).

Length-based selectivity curves estimated in the assessment are shown for all fleets together in Figure 70 and for each fleet and survey separately from Figure 71 through Figure 77. Selectivity, retention and discard mortality parameters for the current fishery are shown in Figure 71. Time varying retention is shown in Figure 72, with year-specific differences reflecting changes in discard rates. Selectivity for the current fishery was assumed to be asymptotic, since Longnose Skates are associated with soft habitats, have a wide ranging distribution across depth and latitude, and do not show size-specific depth distribution (Love et al. 2005). Also, available compositions indicate that the fishery selects the largest fish (larger than 200 cm). Selectivity of the surveys, which did not catch the large fish, were estimated to be dome-shaped.

Model fits to the survey indices are presented in Figure 78 through Figure 82. The WCGBT Survey and the AFSC Triennial Survey both indicate a slightly increasing trend, with underfitting of the 2004 data point, which appears to be anomalously high for a number of species. The AFSC and NWFSC Slope Surveys indices follow a flat trajectory, while the IPHC Survey shows a slight decline.

The model fits to the length frequency distributions by fleet are shown in Figure 83, and for each fleet by year in Figure 84 through Figure 90. Pearson residuals for the fits by fleet and year are shown in Figure 91 through Figure 96. The length data, aggregated across years, are well fitted for all fleets. The fits by year reflect the differences in the quantity and quality of the data. Fits to the landings length compositions between 2004 and 2008 reveal a relatively sharp truncation of the smaller sizes, and an accordingly poor fit for shorter lengths. State port biologists reported that high-grading was occurring during those years because of a new market upswing; it is possible that small skates were being reported as weighback and dockside discard. For several years, this portion of the landings was not sorted for species or sampled for length composition; thus, they were not reported as Longnose Skate, and the smaller piece of the length distribution is missing from the data. It took a few years for this issue to be widely identified and corrected. By 2009, the issue appears largely resolved, and by 2011 looks to be completely resolved, and showing excellent fits of the smaller fish.

Neither length composition data nor the Pearson residuals, which reflect the noise in the data both within and among years, exhibit any obvious patterns for any fleet. Input sample sizes for length composition data were tuned down using the Dirichlet-Multinomial likelihood method (Thorson et al. 2017). The estimated Dirichlet weighting coefficients are provided in Table 14. The effects of the Dirichlet-Multinomial weighting on the fits to the mean lengths for each fleet by year are shown in Figure 97 through Figure 100.

Pearson residuals for the fit to the conditional age-at-length data from current fishery and from the WCGBT Survey are shown in Figure 101 and Figure 102, respectively. Input sample sizes for the WCGBT Survey conditional age-at-length composition data were tuned down using the Dirichlet-Multinomial likelihood method. The weighting index fits of the conditional age-at-length data for survey by year are shown in Figure 103.

The estimated time series of spawning biomass for the Longnose Skate stock are shown in Figure 104. Relative (to SB_0) spawning output is shown in Figure 105. Total biomass, summary biomass and recruitment are shown in Figure 106, Figure 107 and Figure 108, respectively. They are also presented in Table 16. Trends in total and summary biomass, absolute and relative spawning output track one another very closely. The spawning biomass of Longnose Skate is estimated to be gradually decreasing throughout the modeling time period until about 2000, where the trend in spawning biomass started to flatten out (Figure 104), most likely in response to management measures directed to other groundfish species. OFLs, ABCs and ACLs for Longnose Skate in recent years are summarized in Table 1, which also includes landings and total dead catch.

2.6 Evaluation of Uncertainty

2.6.1 Sensitivity Analysis

To explore uncertainty associated with alternative model configurations and evaluate the responsiveness of model outputs to changes in key model assumptions, a variety of sensitivity runs were performed, including runs with different assumptions regarding fishery removals, shape of the selectivity curves, life-history parameters, and many others. Selected sensitivity runs are summarized Figure 109. Figure 109 shows the relative error between each sensitivity run and base model in several metrics that describe the absolute and relative abundance of the stock, as well as stock productivity. Relative error is defined as the difference in a given metric between the alternative model in the sensitivity run and the base model, divided by the base model value. Boxes in Figure 109 correspond to the 95% confidence interval of a derived quantity (indicated by color) in the base model. Values outside the box would indicate significant uncertainty in the removal of data from the uncertainty provided in the base model. Parameter values, likelihoods for each data source and management qualities associated with each sensitivity run in Figure 109 are provided in Table 17 through Table 20.

2.6.1.1 Sensitivity to Assumptions Regarding Fishery Removals

Substantial progress has been made for this assessment in reconstructing landings and discard of skates on the U.S. West Coast. At the same time, there is still significant uncertainty surrounding historical catch estimates for Longnose Skate. Within the current assessment, one source of that uncertainty is in predicting the historical removals from the relationship between catches of Dover sole and Longnose Skate from recent WCGOP data. Although we were able to provide some information as prediction intervals from the linear model, these intervals do not encompass all relevant sources of uncertainty. The intervals are narrow, as they only reflect uncertainty in the strong relationship between the Dover catch and longnose catch over recent years (in accordance with the high R^2 value). They do not contain information about uncertainty in the historical catch estimates of the predictor, Dover sole (which are not available), or how this relationship may have differed over the time series due to unknown events. There is also only limited information about historical discard mortality.

To explore model sensitivity to assumptions made regarding Longnose Skate removals, we conducted a number of model runs, including: 1) assuming increased historical removals of Longnose Skate, when we increased total catch estimates of Longnose Skate (derived from the Dover sole catch approach) by 50%, 2) assuming reduced historical removals Longnose Skate, when we decreased the total catch estimates of Longnose Skate (derived from Dover sole catch approach) by 50 percent, 3) inflating discard mortality from the base model (60 percent instead of 50 percent used in the base model), and 4) deflating discard mortality from the base model (40 percent instead of 50 percent used in the base model). The results are presented in Table 17, Figure 110 and Figure 111. We further explored uncertainty in historical catch using the relatively new "catch multiplier" option in Stock Synthesis, when we allowed adjustment to the catch in the model by estimating multipliers over a variety of time blocks.

None of these runs exceeded the uncertainty estimated in stock status, scale and productivity metrics estimated within the base model (Figure 109). The comparison between absolute and relative spawning biomass time series are shown in Figure 110 and Figure 111. As expected, runs with reduced removals and lower discard mortality rates resulted in higher relative spawning biomass estimates, and vice versa (Figure 110, Figure 111).

2.6.1.2 Sensitivity to Updating Selected Parameters from the 2007 Model

For this assessment, we updated several life history parameters based on new information. These changes included: 1) estimating WCGBT Survey catchability (*q*) using a prior, instead of fixing it at value 0.83, 2) updating the length-weight parameters, 3) estimating natural mortality (*M*) using the Hamel prior, instead of fixing it at 0.2, as in 2007 assessment, and 4) using new maturity parameters estimated from recently collected WCGBT Survey data. The comparison between absolute and relative spawning biomass time series are shown in Figure 112 and Figure 113. Parameter values, likelihoods for each data source and management qualities associated with each of these sensitivity runs are provided in Table 18.

The model was not sensitive to the changes in the length-weight parameters. The model was also not sensitive to using *M* from the 2007 assessment since the new *M* value is very close to value used in 2007; *M* in 2007 was fixed at 0.2 (estimated using the Hoeing (1983) method outside the assessment model) and in this assessment *M* was estimated within the model using the Hamel (2015) prior to be 0.22. However, changes in maturity parameters and WCGBT Survey *q* resulted in an appreciable change in scale of the stock.

2.6.1.3 Sensitivity to Model Specifications

We explored model sensitivity to different assumptions related to model specifications, including fleet structure and selectivity. We ran the model while allowing fishery selectivity to be dome-shaped, and assuming WCGBT Survey to be asymptotic. We also explored sensitivity of the model to removing the 2004 data from AFSC Triennial Survey, which appears to be outside of what is expected for species with skate biology, and we ran the model while assuming no offset (abrupt change between 1992 and 1995) in the AFSC Triennial Survey catchability. Time series of absolute and relative spawning biomass for these runs are shown in Figure 114 and Figure 115. Parameter values, likelihoods for each data source and management qualities associated with each sensitivity run in Figure 108 are provided in Table 19.

None of these runs resulted in depletion estimates outside of the uncertainty estimated within the base model (Figure 109, Table 17). As expected, assuming dome-shaped fishery selectivity resulted in more optimistic status (63 percent) of the stock, as the model assumed larger fish not being selected (Figure 115), and a large change in the estimated scale of the population (Figure 114), while the run assuming asymptotic selectivity for the WCGBT Survey estimated higher depletion (50 percent). The model was not sensitive to excluding the 2004 estimate from the AFSC Triennial index and to removing the offset in the AFSC Triennial Survey catchability (Figure 114 and Figure 115).

We ran the model while estimating the stock-recruit steepness parameter instead of fixing it at the value of 0.4. The model was not sensitive to this change either (Table 20, Figure 116, Figure 117), and the steepness estimate as well as model output was close to those of base model (Figure 109, Table 20). For further exploration of model sensitivity to changes in spawner-recruit steepness, see the likelihood profile analysis in Section 2.6.4. We also ran the model while estimating recruitment deviations, and the estimated deviations are shown in Figure 118. Absolute and relative spawning biomasses are very close between runs with and without recruitment deviations estimated (Figure 116, Figure 117).

The base model uses the Dirichlet-Multinomial likelihood method (Thorson et al. 2017) for composition data weighting, to achieve consistency between the input sample sizes and the effective sample sizes for length and age composition data based on model fit and to reduce the potential for particular data sources to have a disproportionate effect on total model fit. We conducted sensitivity runs using the Francis and McAllister-Ianelli weighting approaches. Tuning the sample sizes using the Francis and McAllister-Ianelli method resulted in similar weights for length data as the Dirichlet-Multinomial approach, but lower weights for the age data, which resulted in worse fits to the length-at-age data and less reasonable estimates of natural mortality and growth parameters (Table 20). Specifically, in these alternative runs, natural mortality was estimated to be 0.13, which corresponds to maximum age of 40 years, while maximum reported age for Longnose Skate is between 22 and 26 years. The Von Bertalanffy growth coefficient was estimated to be higher, while asymptotic length to be lower than those in the base model (and other Longnose Skate life history studies). Alternative values in life history parameter estimates resulted in three-fold increase of scale of the spawning biomass and spawning depletion of around 80 percent (Figure 116, Figure 117). Given the lack of fit to the length-at-age data and less realistic estimate of life history parameters when using alternative weighting methods, we retained the Dirichlet-Multinomial likelihood method for the base model.

2.6.2 Retrospective Analysis

As part of the base model diagnostics, a retrospective analysis was conducted, where the model was fitted to a series of truncated input data sets, with the most recent years of input data sequentially dropped. A 5-year retrospective analysis was conducted by running the model using data only through 2017, 2016, 2015, 2014 and 2013, respectively. Comparisons of the time series of absolute and relative spawning biomass for the runs are shown in Figure 119 and Figure 120, respectively. No systematic pattern was apparent after any of these removals, indicating that the new data are consistent with previous values, or the sample sizes are too small to have any impact.

2.6.3 Historical Analysis

The second type of retrospective analysis addresses assessment error, at least in the historical context of the current result, given previous analyses. Figure 121 shows the comparison of spawning biomass time series for this and for the 2007 assessment, while Figure 122 shows the comparison of relative spawning output time series between this and the 2007 assessment. These assessments have largely drawn the same conclusions regarding historical trends, when the population was slowly decreasing through the end of 1990s, and plateaued since the early 2000s. The 2007 assessment described slightly more dynamic changes in stock biomass and depletion over the years, which can be attributed to more dynamic estimates of removals (Figure 58). The current assessment estimates higher initial spawning biomass and lower depletion, primarily due to increased value of catchability for the WCGBT Survey.

2.6.4 Likelihood Profile Analysis

Likelihood profiles were conducted over the parameter controlling unfished equilibrium recruitment $\ln(R_0)$, catchability of the WCGBT Survey (q), stock-recruit steepness (h) and natural mortality (M), to explore how informative the data in the model are in regard to these parameters. For the likelihood profile analysis, Dirichlet parameters were fixed at the values estimated for the base model, to maintain a consistent likelihood scale. Results of the analyses are shown in Figure 125 through Figure 129.

The WCGBT Survey catchability is estimated within the model using a prior, which was developed as described in Section 2.2.2.4.5. We ran the model with different fixed q values, in order to explore what sources of information determine its value. The values considered for the parameter log(q) ranged between ln(q)=-0.2 and ln(q)= 0.9, which correspond to q = 0.82 to q = 2.5. Values of q less than one correspond to the observed survey biomass being less than the true population after accounting for selectivity of the survey, and values higher than one correspond to the survey observations being larger than the true population. The profile (Figure 125) shows that the model optimizes at a value of approximately 0.45 (which corresponds to q=1.57), used in the base model. Figure 126 shows a time series of spawning biomass at different q values, and illustrates that catchability strongly influences the scale of the stock, with lower q values corresponding to higher stock size.

The likelihood profile for spawner-recruit steepness is shown in Figure 123, when steepness ranges between 0.3 and 0.9. The best fit occurred at steepness of around 0.4, indicating that a model with steepness estimated would have been similar to the base model where h was fixed at 0.4. The change in likelihood associated with values of h between 0.3 and 0.5 is within two units. However, the likelihood profile provides reasonably strong evidence that h is not greater than about 0.5. A comparison of spawning depletion time series associated with different steepness values are shown in Figure 124.

The natural mortality (M) in the model is estimated using the Hamel (2015) prior, and the estimated value of M is 0.22. The likelihood profile over natural mortality is shown in Figure 127. The length and age composition data have the most influence on M, and the best fit occurred at M of around 0.2 used in the base model.

The results of the likelihood profile analysis on $\ln(R_0)$ are shown in Figure 128. The change in likelihood over a broad range of $\ln(R_0)$ values is relatively small, with a total change in likelihood of less than 4 units over a range of 9.0 to 10. The negative log-likelihood is optimized at a value of approximately 9.5 for the base model. The length data are best fit at the lower $\ln(R_0)$ considered while the index and the priors are best fit at the higher $\ln(R_0)$ values. The spawning biomass estimates from the models in the profile are shown in Figure 129, and indicate that different values of $\ln(R_0)$ scale the spawning biomass.

3 Reference Points

This assessment estimates that the stock of Longnose Skate off the continental U.S. Pacific Coast is currently at 57 percent of its unexploited level. This is above the overfished threshold of 25 percent of unfished spawning biomass ($SB_{25\%}$) and above the management target 40 percent of unfished spawning biomass (of $SB_{40\%}$) (Figure 105).

The SPR used for setting the OFL is 50 percent. Relative exploitation rates (calculated as catch/biomass of age-2 and older fish) are estimated to have been below 1 percent during the last decade (Figure 130). For the recent and historical period, the assessment estimates that Longnose Skate was fished at a rate below the relative SPR target (calculated as 1-SPR/1-SPRTarget=0.5) (Figure 131). Relative SPR for 2018 is estimated to be 47.81 percent, which is below SPR target.

Reference points for the base model are summarized in Table 21. Unfished spawning stock output for Longnose Skate was estimated to be 12,252 metric tons (95 percent confidence interval: 9,155–15,350 metric tons). The management target for Longnose Skate is defined as 40 percent of the unfished spawning output ($SB_{40\%}$), which is estimated by the model to be 4,901 metric tons (95 percent confidence interval: 3,662–6,140); this corresponds to an exploitation rate of 0.027. This harvest rate provides an equilibrium yield of 1,028 mt at $SB_{40\%}$ (95 percent confidence interval: 708–1,348 mt). The model estimate of maximum sustainable yield (MSY) is 1,030 mt (95 percent confidence interval: 709–1,351 mt). The estimated spawning stock output at MSY is 4,632 metric tons (95 percent confidence interval: 3,472–5,792 metric tons). The exploitation rate corresponding to the estimated SPR_{MSY} is 0.028. The equilibrium estimates of yield relative to biomass is provided in Figure 132.

4 Harvest Projections and Decision Table

The base model estimate for 2019 spawning depletion is 57%. The primary axis of uncertainty about this estimate used in the decision table was based on West Coast Groundfish Bottom Trawl (WCGBT) Survey catchability (q). WCGBT Survey q in the assessment model is estimated using the prior developed as described later in this report. The base model estimate has q=1.57, log(q) =0.45, with the standard deviation of log(q) = 0.237. The 12.5 and 87.5 quantiles of the log (q) were calculated to determine alternative states of nature. The low log(q) =0.178, q =1.19 was used to define high state of nature. The 2019 biomass estimate resultant from the run with low q value exceeded the 87.5th percentile of the 2019 spawning biomass estimated by the base model. The high q value (estimated from the q prior) was above the 12.5th percentile of the 2019 base model estimate of spawning biomass. Therefore, the model with log(q) =0.77, q = 2.16 was used as a low state of nature, as it was a match to the 12.5th percentile in 2019 spawning biomass estimate in the base model.

Twelve-year forecasts for each state of nature were calculated for three catch scenarios (Table 23). All three scenarios assumed the 2017-2018 average total dead catch for 2019 and 2020 catches. The first scenario assumed 1,000 metric tons per year for years between 2021 and 2030. The second scenario assumed 2,000 metric tons per year for years between 2021 and 2030. The third scenario assumed year specific ACL = ABC (P* = 0.45) for years between 2021 and 2030. Sigma estimated from the base model is 0.26; therefore, the category 2 sigma schedule recommended by the SSC was used in this scenario. Category 2 for this assessment was used because the model does not estimate recruitment deviations, due to sparse age compositional data available.

Potential OFLs projected by the model are shown in Table 24. These values are based on an SPR target of 50%, a P* of 0.45, and a time-varying Category 2 Sigma which creates the buffer shown in the right-hand column. The OFL and ACL values for 2019 and 2020 are the current harvest specifications (also shown in Table ES-5) while the total mortality for 2019 and 2020 represent 2017-2018 average catch.

5 Regional Management Considerations

The Longnose Skate is broadly distributed from the southeastern Bering Sea (Mecklenburg et al. 2002) to southern Baja California (25.98º N, 113.28º W, Snytko 1987) and the Gulf of California (Eschmeyer and Herald 1983). In this assessment, the Longnose Skate population off California, Oregon and Washington is modeled in this assessment as a single stock, since there is no information available that indicates the existence of multiple breeding units in the Northeast Pacific Ocean.

Several tagging studies have found that elasmobranchs, such as sharks and skates, can undertake extensive migrations within their geographic range (Martin and Zorzi 1993, McFarlane and King 2003). One tagging study of Big Skate described long-range movements (up to 2340km) undertaken by a percentage of the recaptured fish, when Big Skates tagged in British Columbia, Canada, were recaptured in waters off of Oregon, Washington, throughout the Gulf of Alaska and the Bering Sea (King and McFarlane 2010). No large-scale migrations or movements have been documented for Longnose Skate. Genetic and tagging studies would help improve our understanding of stock structure and movement patters of Longnose Skate, identify whether there is a need for a regional management approach and develop regional management measures if needed.

6 Research Needs

In this assessment, several critical assumptions were made based on limited supporting information. The following research could improve the ability of future stock assessments to determine the status and productivity of the Longnose Skate population. The items are not ranked according to priority. It is also important to continue to collect species-specific information from the fishery, and monitor discard of Longnose Skate to improve the accuracy of fishery catch data.

Data needs:

1) Ages - Estimate additional ages for Longnose Skate, which would better inform the age-structured model. The NWFSC ageing lab is currently able to age skate vertebrae, and many structures have already been collected across several years in surveys and fisheries.
2) Maturity - Generate additional maturity data using the most accurate/precise method developed in Research Need #1, below.

Research needs:

3) Maturity - Conduct studies incorporating histological analysis into evaluation of skate maturity, which would evaluate error and bias in macroscopic evaluation, and develop a feasible method which would produce the most accurate and consistent maturity data. Histological examination is widely accepted the best available approach, while macroscopic evaluation (used up to this point), has been demonstrated to be less accurate, precise and more prone to reader bias (Vitale et al. 2006, Brown-Peterson et al. 2011, Kjesbu 2009).
4) Survey *q* - Develop a well-informed prior on survey catchability, as this parameter is highly influential upon the assessment model. Evaluate Longnose Skate behavior/interaction with trawl gear, and distribution among habitats, to better understand catchability by survey gear types, and ultimately provide more precise estimates of biomass from the surveys.
5) Life history – Conduct studies to better quantitatively understand life history of Longnose Skates; e.g. to inform time-varying estimation of natural mortality and recruitment. Research to better estimate of growth, as well as enhanced understanding of reproduction (e.g. frequency, seasonality, number or eggs per year) is also needed. Studies to better understand Longnose Skate productivity, and accurately inform stock-recruit steepness for this species would also be beneficial.
6) Catch - Continue to explore methods to estimate historical removals of Longnose Skate and associated uncertainty, particularly model-based solutions where feasible;
7) Discard mortality - Conduct studies to evaluate survival rates of discarded Longnose Skate, especially with trawl gear, so that total fishing mortality can be estimated more accurately;
8) Movement and migration - Conduct spatial studies of movement and migration of Longnose Skate, with special attention to potential extent of movement across the U.S.-Canada border;
9) Genetics - Conduct genetic studies to evaluate the potential for stock structure of Longnose Skate in the waters off the U.S. Pacific Coast.

7 Acknowledgments

Many people assisted with assembling the data included in this assessment, and we are grateful to everyone who was directly or indirectly involved in providing and processing the data. We also appreciate everyone who was involved in assessment review process. We thank STAR panel members (Drs. David Sampson, Robin Cook, Henrik Sparholt and Cody Szuwalski) for making a week long review a productive and enjoyable process. We also thank our GMT and GAP representatives (Jessi Doerpinghaus and Gerry Richter) as well as John DeVore for their valuable comments during the STAR panel review. We also thank Jim Hastie, Stacey Miller and John DeVore and for their comments on the draft of this document.

8 Literature Cited

Alverson, D.L., Pruter, A.T., Ronholt, L.L. 1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. Institute of Fisheries, University of British Columbia.

Berger, A.M., A.M. Edwards, C.J. Grandin, Johnson, K.F. 2019. Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2019. Prepared by the Joint Technical Committee of the U.S. and Canada Pacific Hake/Whiting Agreement, National Marine Fisheries Service and Fisheries and Oceans Canada.

Bertalanffy, L. von. 1938. A quantitative theory of organic growth (Inquiries on growth laws. II). Human Biology, 10: 181-213.

Bizzarro, J.J., Robinson, H.J., Rinewalt, C.S., Ebert, D.A. 2007. Comparative feeding ecology of four sympatric skate species off central California, USA. Environmental Biology of Fishes, 80: 197–220.

Bizzarro, J.J., Broms, K.M., Logsdon, M., Yoklavich, M.M., Kuhnz, L., Summers, A.P. 2014. Spatial segregation in eastern North Pacific skate assemblages. PLOS ONE, 9: e109907.

Bizzarro, J.J. 2015. Comparative resource utilization of eastern North Pacific skates (*Rajiformes: Rajidae*) with applications for ecosystem–based fisheries management. Ph.D. Dissertation. University of Washington, School of Aquatic & Fishery Sciences. Seattle, WA.

Bonfil, R. 1994. Overview of world elasmobranch fisheries. FAO Fisheries Technical Paper No 341.

Brown-Peterson, N.J., Wyanski, D.M., Saborido-Rey, F., Macewicz, B.J. and Lowerre-Barbieri, S.K., 2011. A standardized terminology for describing reproductive development in fishes. Marine and Coastal Fisheries, 3(1): 52-70.

Brander, K. 1981. Disappearance of common skate *Raja batis* from Irish Sea. Nature 290: 48-49.

Casey, J.M. and Myers, R.A. 1998. Near extinction of a large, widely distributed fish. Science, 281(5377): 690-692.

Dorn, M. W. 2002. Advice on West Coastrockfish harvest rates from Bayesian meta-analysis of stock-recruit relationships. North American Journal of Fisheries Management, 22: 280-300

Downs, D.E., Cheng, Y.W. 2013. Length–Length and Width–Length Conversion of Longnose Skate and Big Skate Off the Pacific Coast: Implications for the Choice of Alternative Measurement Units in Fisheries Stock Assessment. North American journal of fisheries management, 33(5): 887-893.

Ebert, D.A. 2003. Sharks, rays and chimaeras of California. Berkeley: University of California Press.

Ebert, D.A., and Bizzarro, J.J. 2007. Standardized diet compositions and trophic levels of skates (*Chondrichthyes: Rajiformes: Rajoidei*). Environmental Biology of Fishes, 80: 221–237.

Ebert D. A., Compagno, L. J. V. 2007. Biodiversity and systematics of skates (*Chondrichthyes: Rajiformes: Rajoidei*). Environmental Biology of Fishes, 80 (2-3): 111-124.

Ebert, D.A., Smith, W.D., and Cailliet, G.M. 2008. Reproductive biology of two commercially exploited skates, *Raja binoculata* and *R. rhina*, in the western Gulf of Alaska. Fisheries Research, 94: 48–57.

Enever, R., Catchpole, T.L., Ellis, J.R. and Grant, A. 2009. The survival of skates (*Rajidae*) caught by demersal trawlers fishing in UK waters. Fisheries Research, 97: 72-76.

Eschmeyer, W. N. and E. S. Herald. 1983. A field guide to Pacific Coast fishes of North America

From the Gulf of Alaska to Baja California. Houghton Mifflin, Boston.
Francis, R.C., 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences, 68(6): 1124-1138.
Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27: 1–17.
Gburski, C.M., Gaichas, S.K., and Kimura, D.K., 2007. Age and growth of big skate (*Raja binoculata*) and Longnose Skate (*R. rhina*) in the Gulf of Alaska. Environmental Biology of Fishes, 80: 337–349.
Gertseva, V., Cope, J.M. 2017. Stock assessment of the yelloweye rockfish (*Sebastes ruberrimus*) in state and Federal waters off California, Oregon and Washington. Pacific Fishery Management Council, Portland, OR
Gertseva, V.V., Schirripa, M.J. 2008. Status of the Longnose Skate (*Raja rhina*) off the continental US Pacific Coast in 2007. Pacific Fishery Management Council, Portland, OR.
Gertseva, V. Taylor, I. 2011. Status of spiny dogfish shark resource off the continental US Pacific Coast in 2011. Pacific Fishery Management Council, Portland, OR.
Hamel, O.S. 2015. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES Journal of Marine Science, 72: 62-69.
Harry, G., Morgan, A.R. 1961. History of the trawl fishery, 1884-1961. Oregon Fish Commission Research Briefs, 19: 5-26.
Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin, 82(1): 898-902.
Karnowski, M., Gertseva, V.V., Stephens, A. 2014. Historical Reconstruction of Oregon's Commercial Fisheries Landings. 2014-02, Oregon Department of Fish and Wildlife, Newport, Oregon.
Keller, A.A., Horness, B.H., Tuttle, V.J., Wallace, J.R., Simon, V.H., Fruh, E.L., Bosley, K.L., and Kamikawa, D. J. 2006. The 2002 U. S. West Coast upper continental slope trawl survey of groundfish resources. NOAA Tech. Memo. NMFS–NWFSC–75.
Keller, A.A., Horness, B.H., Simon, V.H., Tuttle, V.J., Wallace, J.R., Fruh, E.L., Bosley, K.L., Kamikawa, D.J., Buchanan, J.C. 2007. The U.S. West Coast trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition in 2004. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC.
Keller, A. A., J. R. Wallace, R. D. Methot. 2017. The Northwest Fisheries Science Center's West CoastGroundfish Bottom Trawl Survey: History, Design, and Description. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-136.
King, J.R. and McFarlane, G.A. 2003. Marine fish life history strategies: applications to fishery management. Fisheries Management and Ecology, 10(4): 249-264.
King, J.R. and McFarlane, G.A. 2010. Movement patterns and growth estimates of big skate (Raja binoculata) based on tag-recapture data. Fisheries Research, 101(1-2): 50-59.
King, J.R., Surry, A.M., Garcia, S., Starr, P.J. 2015. Big Skate (*Raja binoculata*) and Longnose Skate (*R. rhina*) stock assessments for British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/070.

King, J.R., Helser, T., Gburski, C., Ebert, D.A., Cailliet, G. and Kastelle, C.R., 2017. Bomb radiocarbon analyses validate and inform age determination of Longnose Skate (Raja rhina) and big skate (Beringraja binoculata) in the north Pacific Ocean. Fisheries Research, 193: 195-206.

Kjesbu, O.S., 2009. Applied fish reproductive biology: contribution of individual reproductive potential to recruitment and fisheries management. Fish reproductive biology: implications for assessment and management, pp.293-332.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., and Bell, B.M. 2016. TMB: Automatic Differentiation and Laplace Approximation. Journal of Statistical Software, 70(5): 1-21.

Laptikhovsky, V. 2004. Survival rates for rays discarded by the bottom trawl squid fishery off the Falkland Islands. Fishery Bulletin, 102: 757 – 759.

Lauth, R.R. 2000. The 2000 Pacific west coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. NTIS No. PB2001-105327.

Love, M.S. 2011. Certainly more than you want to know about the fishes of the Pacific Coast. Really Big Press. Santa Barbara, CA.

Love, M.S., Schroeder, D.M., Snook, L., York, A., and Cochrane, G. 2008. All their eggs in one basket: a rocky reef nursery for Longnose Skate (*Raja rhina* Jordan & Gilbert, 1880) in the southern California Bight. Fishery Bulletin, 106: 471–475.

Love, M. S., M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley.

Martin, L., Zorzi, G.D. 1993. Status and review of the California skate fishery. In Conservation biology of elasmobranchs (Ed. Branstetter, S.), p 39-52. NOAA Technical Report NMFS 115.

McAllister, M.K. and Ianelli, J.N. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Canadian Journal of Fisheries and Aquatic Sciences, 54(2): 284-300.

Mecklenburg, C. W., T. A. Mecklenburg, and L. K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland.

Methot, R.D. 2007. User Manual for the Integrated Analysis program Stock Synthesis 2 (SS2). Version 2.00a. NOAA Fisheries, NWFSC, Seattle.

Methot, R.D. and Wetzel, C.R., 2013. Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research, 142: 86-99.

McEachran, J.D. 1990. Diversity of rays: why are there so many species? Chondros, 5(2): 1-6.

McEachran, J.D., Aschliman, N. 2004. Phylogeny of Batoidea. In Biology of Sharkes and Their Relatives (Eds. Carrier, J.C., Musick, J.A., Heithaus, R.), pp. 79-114. New York, CRC Press.

McFarlane, G.A., King, J.R., 2006. Age and growth of big skate (*Raja binoculata*) and Longnose Skate (*Raja rhina*) in British Columbia waters. Fisheries Research, 78: 169–178.

Robinson, H.J., Cailliet, G.M., and Ebert, D.A. 2007. Food habits of the Longnose Skate, *Raja rhina* (Gilbert, 1880), in California waters. Environmental Biology of Fishes, 80: 165–179.

Myers, R.A., Barrowman, N.J., Hutchings, J.A. and Rosenberg, A.A. 1995. Population dynamics of exploited fish stocks at low population levels. Science, 269 (5227): 1106-1108.

Ormseth, O. 2017. Assessment of the skate stock complex in the Gulf of Alaska. Alaska Fisheries Science/Center North Pacific Fishery Management Council.

Ormseth, O., Matta, B. 2007. Chapter 17: Bering Sea and Aleutian Islands Skates. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage, pp. 909-1010.

Pikitch, E.K., Erickson, D.L., Wallace, J.R. 1988. An evaluation of the effectiveness of trip limits as a management tool. NWAFC Processed Report 88-27. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, US Department of Commerce.

Punt, A.E., Smith, D.C., KrusicGolub, K. and Robertson, S., 2008. Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Canadian Journal of Fisheries and Aquatic Sciences, 65(9): 1991-2005.

Rogers, J.B. 1994. Assemblages of groundfish caught using commercial fishing strategies off the coasts of Oregon and Washington from 1985-1987. Ph.D. Dissertation, Oregon State University, Oregon.

Rogers, J.B., Pikitch, E.K., 1992. Numerical definition of groundfish assemblages caught off the coasts of Oregon and Washington using commercial fishing strategies. Canadian Journal of Fisheries and Aquatic Sciences 49: 2648-2656.

Shotton, R. (Ed). 1999. Case studies of the management of elasmobranch fisheries. FAO Fish Tech Paper No 378 (1 and 2) Tome, FAO.

Smith, S.E., Au, D.W., Show, C. 1998. Intrinsic rebound potentials of 26 species of Pacific sharks. Marine and Freshwater Research, 49(7): 663-678.

Snytko, V.A. 1987. New data on the distribution of some species of fish in the North Pacific. Journal of Ichthyology, 27:142–146.

Sosebee, K. 1998. Skates. In Status of Fishery Resources off the Northeastern United States for 1998. (Ed.Clark, S.H.), pp. 114-115. NOAA Technical Memorandum NMFS-NE-115.

Steward, I.J., Wallace, J., McGilliard, C. 2009. Status of the U.S. yelloweye rockfish resource in 2009. Pacific Fishery Management Council, Portland, OR.

Stewart, I.J., and Hamel, O.S. 2014. Bootstrapping of sample sizes for length-or age composition data used in stock assessments. Canadian Journal of Fisheries and Aquatic Sciences, 71(4): 581-588.

Stobutzki, I.C., Miller, M.J., Heales, D.S., and Brewer, D.T. 2002. Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) trawl fishery. Fishery Bulletin, 100: 800-821.

Then, A.Y., Hoenig, J.M., Hall, N.G. and Hewitt, D.A. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science, 72(1): 82-92.

Thompson, J.E. 2006. Age, Growth and Maturity of the Longnose Skate (*Raja rhina*) for the U.S. West Coast and Sensitivity to Fishing Impacts. MS Thesis. Oregon State University. Corvallis, OR.

Thorson, J.T., Shelton, A.O., Ward, E.J., Skaug, H.J. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES Journal of Marine Science, 72(5), 1297–1310.

Thorson, J.T., and Barnett, L.A.K. 2017. Comparing estimates of abundance trends and distribution shifts using single-and multispecies models of fishes and biogenic habitat. ICES Journal of Marine Science, 74(5):1311-1321.

Thorson, J. T., K. F. Johnson, R. D. Methot, I. G. Taylor. 2017. The next link will exit from

NWFSC web site Model-based estimates of effective sample size in Stock Synthesis using the Dirichlet-multinomial distribution. Fisheries Research, 192:84-93.

Thorson, J.T., Kristensen, K. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fisheries Research, 175: 66-74.

Tolimieri, N., and Levin, P.S. 2006. Assemblage structure of eastern Pacific groundfishes on the U.S. continental slope in relation to physical and environmental variables. Transactions of the American Fisheries Society, 135: 115-130.

Vitale, F., Svedäng, H. and Cardinale, M., 2006. Histological analysis invalidates macroscopically determined maturity ogives of the Kattegat cod (Gadus morhua) and suggests new proxies for estimating maturity status of individual fish. ICES Journal of Marine Science, 63(3), pp.485-492.

Walker, P.A. and Hislop, J.R.G. 1998. Sensitive skates or resilient rays? Spatial and temporal shifts in ray species composition in the central and north-western North Sea between 1930 and the present day. ICES Journal of Marine Science, 55(3): 392-402.

Wiff, R., Flores, A., Neira, S. and Caneco, B., 2018. Estimating steepness of the stock-recruitment relationship in Chilean fish stocks using meta-analysis. Fisheries Research, 200, pp.61-67.

Weigmann, S. 2016. Annotated checklist of the living sharks, batoids and chimaeras (*Chondrichthyes*) of the world, with a focus on biogeographical diversity. Journal of Fish Biology, 88: 837–1037.

Weinberg, K.L., Wilkins, M. E., Shaw, F. R., Zimmermann, M. 2002. The 2001 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, and length and age composition. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-128.

Zeiner, S.J., and Wolf, P.G. 1993. Growth characteristics and estimates of age at maturity of two species of skates (*Raja binoculata* and *Raja rhina*) from Monterey Bay, California, p 87-. In: Branstetter, S. (Ed.), Conservation Biology of Elasmobranchs. NOAA Technical Report, NMFS 115. pp. 87–99.

Zimmerman, M. 2001. Retrospective analysis of suspiciously small catches in the National Marine Fisheries Service West Coast Triennial bottom trawl survey. AFSC Processed Rep. 2001-03, AFSC/NMFS, Seattle.

9 Tables

Table 1. Recent Longnose Skate Overfishing Limits (OFLs), Allowable Biological Catch (ABCs) and Annual Catch Limits (ACLs) relative to recent total landings and total dead catch*.

Years	OFL	ABC	ACL	Landings	Total Catch
2009	3,428	NA	1,349	966	1,152
2010	3,269	NA	1,349	995	1,165
2011	3,128	2,990	1,349	819	916
2012	3,006	2,873	1,349	936	1,030
2013	2,902	2,774	2,000	958	1,051
2014	2,816	2,692	2,000	839	926
2015	2,449	2,341	2,000	829	904
2016	2,405	2,299	2,000	896	980
2017	2,556	2,444	2,000	840	913
2018	2,526	2,415	2,000	709	771
2019	2,499	2,389	2,000	NA	NA

* The current OFL was called the ABC prior to 2011. The ABCs provided in this table for 2011-2018 refer to the new definition of ABC implemented with FMP Amendment 23. The current ACL was called the OY prior to 2011.

Table 2. Time series of Longnose Skate catches by fleet used in the assessment.

Year	Fishery current	Fishery historical discard	Fishery historical landings	Fishery tribal	Total Landings	Total Dead Discard	Total Dead
1916	0	16	0	0	0	16	16
1917	0	32	0	0	0	32	32
1918	0	47	0	0	0	47	47
1919	0	63	0	0	0	63	63
1920	0	79	0	0	0	79	79
1921	0	95	0	0	0	95	95
1922	0	110	0	0	0	110	110
1923	0	126	0	0	0	126	126
1924	0	142	0	0	0	142	142
1925	0	158	0	0	0	158	158
1926	0	173	0	0	0	173	173
1927	0	189	0	0	0	189	189
1928	0	205	0	0	0	205	205
1929	0	221	0	0	0	221	221
1930	0	236	0	0	0	236	236
1931	0	252	0	0	0	252	252
1932	0	268	0	0	0	268	268
1933	0	284	0	0	0	284	284
1934	0	299	0	0	0	299	299
1935	0	315	0	0	0	315	315
1936	0	331	0	0	0	331	331
1937	0	347	0	0	0	347	347
1938	0	362	0	0	0	362	362
1939	0	343	71	0	71	343	414
1940	0	361	66	0	66	361	427
1941	0	306	208	0	208	306	514
1942	0	368	114	0	114	368	483
1943	0	431	21	0	21	431	452
1944	0	449	17	0	17	449	465
1945	0	463	20	0	20	463	483
1946	0	478	22	0	22	478	500
1947	0	497	14	0	14	497	512
1948	0	504	33	0	33	504	537
1949	0	521	30	0	30	521	551
1950	0	534	35	0	35	534	569
1951	0	566	34	0	34	566	601

Year	Fishery current	Fishery historical discard	Fishery historical landings	Fishery tribal	Total Landings	Total Dead Discard	Total Dead
1952	0	615	34	0	34	615	649
1953	0	391	144	0	144	391	536
1954	0	484	38	0	38	484	522
1955	0	423	127	0	127	423	550
1956	0	462	54	0	54	462	516
1957	0	446	41	0	41	446	487
1958	0	450	59	0	59	450	509
1959	0	445	37	0	37	445	482
1960	0	525	40	0	40	525	565
1961	0	401	170	0	170	401	571
1962	0	454	132	0	132	454	586
1963	0	499	144	0	144	499	643
1964	0	488	131	0	131	488	619
1965	0	494	84	0	84	494	578
1966	0	479	96	0	96	479	575
1967	0	412	97	0	97	412	509
1968	0	421	175	0	175	421	596
1969	0	594	124	0	124	594	719
1970	0	692	44	0	44	692	736
1971	0	670	23	0	23	670	693
1972	0	852	43	0	43	852	895
1973	0	831	44	0	44	831	875
1974	0	774	48	0	48	774	823
1975	0	831	55	0	55	831	886
1976	0	817	164	0	164	817	981
1977	0	774	156	0	156	774	930
1978	0	803	232	0	232	803	1,034
1979	0	1,001	183	0	183	1,001	1,184
1980	0	839	146	0	146	839	985
1981	0	931	251	0	251	931	1,183
1982	0	1,211	168	0	168	1,211	1,379
1983	0	1,157	183	0	183	1,157	1,341
1984	0	1,181	88	0	88	1,181	1,268
1985	0	1,229	130	0	130	1,229	1,358
1986	0	1,069	89	0	89	1,069	1,158
1987	0	1,130	83	1	84	1,130	1,214
1988	0	1,129	56	1	57	1,129	1,185
1989	0	1,168	89	0	89	1,168	1,257
1990	0	991	110	1	111	991	1,102

Year	Fishery current	Fishery historical discard	Fishery historical landings	Fishery tribal	Total Landings	Total Dead Discard	Total Dead
1991	0	1,121	118	1	119	1,121	1,240
1992	0	993	152	0	153	993	1,146
1993	0	901	167	1	168	901	1,069
1994	0	627	180	0	180	627	807
1995	363	0	0	1	364	613	977
1996	1,301	0	0	1	1,301	270	1,572
1997	1,938	0	0	0	1,938	177	2,116
1998	1,090	0	0	1	1,091	102	1,193
1999	1,389	0	0	1	1,389	130	1,519
2000	1,248	0	0	1	1,249	118	1,367
2001	1,197	0	0	0	1,198	114	1,312
2002	565	0	0	4	568	233	801
2003	890	0	0	15	906	141	1,047
2004	458	0	0	4	463	235	698
2005	618	0	0	8	626	203	828
2006	820	0	0	14	834	199	1,034
2007	730	0	0	36	766	319	1,085
2008	974	0	0	50	1,024	312	1,335
2009	939	0	0	27	966	186	1,152
2010	982	0	0	13	995	169	1,165
2011	797	0	0	22	819	97	916
2012	896	0	0	40	936	94	1,030
2013	890	0	0	68	958	93	1,051
2014	804	0	0	36	839	87	926
2015	757	0	0	72	829	75	904
2016	814	0	0	83	896	83	980
2017	773	0	0	67	840	73	913
2018	656	0	0	53	709	62	771

Table 3. Reconstructed Longnose Skate landings by state, years 1939-2018.

Years	Washington commercial fishery landings (mt)	Oregon commercial fishery landings (mt)	California commercial fishery landings (mt)	Tribal fishery landings (mt)
1939	0	0	71	0
1940	0	14	52	0
1941	0	151	57	0
1942	0	92	22	0
1943	0	2	18	0
1944	0	4	12	0
1945	0	1	20	0
1946	0	5	17	0
1947	0	0	14	0
1948	0	15	18	0
1949	9	0	21	0
1950	3	6	26	0
1951	5	13	17	0
1952	10	0	24	0
1953	2	3	139	0
1954	2	6	30	0
1955	2	95	30	0
1956	4	7	44	0
1957	3	0	38	0
1958	0	0	58	0
1959	1	0	37	0
1960	1	0	39	0
1961	6	109	55	0
1962	6	75	51	0
1963	3	81	60	0
1964	3	76	52	0
1965	4	34	45	0
1966	1	54	41	0
1967	8	42	47	0
1968	11	121	43	0
1969	8	90	26	0
1970	0	32	12	0
1971	0	8	15	0
1972	0	5	37	0
1973	0	2	42	0

Years	Washington commercial fishery landings (mt)	Oregon commercial fishery landings (mt)	California commercial fishery landings (mt)	Tribal fishery landings (mt)
1974	0	16	32	0
1975	0	5	49	0
1976	1	84	79	0
1977	5	84	67	0
1978	38	103	91	0
1979	6	108	68	0
1980	8	49	89	0
1981	18	24	210	0
1982	11	24	134	0
1983	2	58	123	0
1984	6	22	60	0
1985	11	5	114	0
1986	24	9	57	0
1987	13	8	63	1
1988	7	2	47	1
1989	18	4	68	0
1990	26	1	84	1
1991	14	3	102	1
1992	28	1	124	0
1993	26	1	140	1
1994	29	6	145	0
1995	30	77	257	1
1996	115	423	763	1
1997	40	656	1,242	0
1998	71	185	835	1
1999	132	455	802	1
2000	54	605	590	1
2001	91	475	631	0
2002	89	387	88	4
2003	65	713	112	15
2004	24	336	98	4
2005	14	515	89	8
2006	81	569	171	14
2007	73	562	95	36
2008	107	716	151	50

Years	Washington commercial fishery landings (mt)	Oregon commercial fishery landings (mt)	California commercial fishery landings (mt)	Tribal fishery landings (mt)
2009	136	675	128	27
2010	66	764	152	13
2011	76	550	171	22
2012	116	588	192	40
2013	85	654	151	68
2014	54	581	169	36
2015	41	546	170	72
2016	59	614	140	83
2017	78	547	147	67
2018	71	470	114	53

Table 4. Total catch (landings and live and dead discards) of Dover Sole, which was used to estimate total catch of Longnose Skate, also shown in the table. Values for years 1950-1983 are shown in the left panel, and those for 1984-2017 are shown in the right panel.

Years	Dover Sole total catch (mt)	Longnose Skate total catch (mt)	**Years**	Dover Sole total catch (mt)	Longnose Skate total catch (mt)
1950	8,215	1,103	1984	24,371	2,449
1951	8,977	1,167	1985	26,029	2,587
1952	10,142	1,264	1986	21,710	2,227
1953	6,099	927	1987	23,094	2,343
1954	7,042	1,006	1988	22,734	2,313
1955	6,645	972	1989	24,087	2,425
1956	6,712	978	1990	20,087	2,092
1957	6,168	933	1991	23,299	2,360
1958	6,481	959	1992	20,638	2,138
1959	6,099	927	1993	18,609	1,969
1960	8,065	1,091	1994	12,177	1,433
1961	6,647	973	1995	13,704	1,560
1962	7,451	1,040	1996	15,108	1,677
1963	8,685	1,142	1997	12,613	1,470
1964	8,250	1,106	1998	9,920	1,245
1965	7,838	1,072	1999	11,202	1,352
1966	7,624	1,054	2000	10,715	1,311
1967	6,020	920	2001	8,422	1,120
1968	7,176	1,017	2002	7,697	1,060
1969	10,735	1,313	2003	8,651	1,140
1970	12,121	1,429	2004	7,429	1,038
1971	11,335	1,363	2005	7,592	1,051
1972	15,940	1,747	2006	6,548	964
1973	15,446	1,706	2007	10,171	1,266
1974	14,143	1,597	2008	12,245	1,439
1975	15,579	1,717	2009	12,574	1,477
1976	16,566	1,799	2010	10,945	1,333
1977	15,435	1,705	2011	7,979	1,026
1978	17,022	1,837	2012	7,441	1,098
1979	21,200	2,185	2013	8,117	1,090
1980	16,869	1,824	2014	6,610	1,013
1981	20,345	2,114	2015	6,459	939
1982	26,059	2,590	2016	7,357	1,036
1983	24,961	2,498	2017	7,547	1,012

Table 5. Latitudinal and depth ranges by year of four NMFS groundfish bottom trawl surveys used in the assessment.

Survey	Year	Latitudes	Depths (fm)
AFSC shelf	1977	34º 00'- Canadian border	50-250
	1980	36º 48'- 49º 15'	30-200
	1983	36º 48'- 49º 15'	30-200
	1986	36º 48'- Border	30-200
	1989	34º 30'- 49º 40'	30-200
	1992	34º 30'- 49º 40'	30-200
	1995	34º 30'- 49º 40'	30-275
	1998	34º 30'- 49º 40'	30-275
	2001	34º 30'- 49º 40'	30-275
	2004	34º 30'- Canadian border	30-275
AFSC slope	1988	44º 05'- 45º 30'	100-700
	1990	44º 30'- 40º 30'	100-700
	1991	38º 20'- 40º 30'	100-700
	1992	45º 30'- Border	100-700
	1993	43º 00'- 45º 30'	100-700
	1995	40º 30'- 43º 00'	100-700
	1996	43º 00'- Canadian border	100-700
	1997	34º 00'- Canadian border	100-700
	1999	34º 00'- Canadian border	100-700
	2000	34º 00'- Canadian border	100-700
	2001	34º 00'- Canadian border	100-700
NWFSC slope	1999	34º 50'- 48º 10'	100-700
	2000	34º 50'- 48º 10'	100-700
	2001	34º 50'- 48º 10'	100-700
	2002	34º 50'- 48º 10'	100-700
NWFSC shelf-slope	2003	32º 34'- 48º 27'	30-700
	2004	32º 34'- 48º 27'	30-700
	2005	32º 34'- 48º 27'	30-700
	2006	32º 34'- 48º 27'	30-700
	2007	32º 34'- 48º 27'	30-700
	2008	32º 34'- 48º 27'	30-700
	2009	32º 34'- 48º 27'	30-700
	2010	32º 34'- 48º 27'	30-700
	2011	32º 34'- 48º 27'	30-700
	2012	32º 34'- 48º 27'	30-700
	2013	32º 34'- 48º 27'	30-700
	2014	32º 34'- 48º 27'	30-700
	2015	32º 34'- 48º 27'	30-700
	2016	32º 34'- 48º 27'	30-700
	2017	32º 34'- 48º 27'	30-700
	2018	32º 34'- 48º 27'	30-700

Table 6. Percentage of Longnose Skate positive hauls with WCGBT Survey.

Years	N survey hauls	N positive hauls	% positive hauls
2003	542	295	54%
2004	471	279	59%
2005	637	389	61%
2006	641	386	60%
2007	687	417	61%
2008	679	396	58%
2009	681	366	54%
2010	714	410	57%
2011	695	428	62%
2012	698	427	61%
2013	469	297	63%
2014	682	423	62%
2015	668	432	65%
2016	692	428	62%
2017	707	437	62%
2018	702	426	61%

Table 7. Time series of relative abundance indices and uncertainty (standard error of $\log_e$(index)) for the surveys used in the assessment.

Year	AFSC Triennial		AFSC Slope		NWFSC Slope		WCGBTS		IPHC	
	Index	se_log	Index	se_log	Index	se_log	Index	se_log	Index	se_log
1980	2,202	0.2362								
1983	1,958	0.1612								
1986	2,370	0.1632								
1989	3,565	0.1560								
1992	1,904	0.1803								
1995	2,467	0.1317								
1997			2,306	0.1284						
1998	4,828	0.0922	1,835	0.1223						
1999			1,519	0.1239	25,086	0.1286			0.0082	0.0869
2000			1,820	0.1216	21,933	0.1353				
2001	4,960	0.0899			19,806	0.1187			0.0096	0.0961
2002					26,615	0.1183			0.0050	0.1447
2003							50,568	0.0728	0.0074	0.1285
2004	10,518	0.0880					60,644	0.0752	0.0084	0.0886
2005							54,405	0.0625	0.0083	0.0870
2006							59,758	0.0631	0.0038	0.1385
2007							60,211	0.0605	0.0048	0.1784
2008							64,052	0.0624	0.0075	0.1132
2009							53,451	0.0654	0.0043	0.1195
2010							61,998	0.0609	0.0042	0.1162
2011							58,981	0.0599	0.0054	0.1278
2012							64,564	0.0596	0.0072	0.1093
2013							70,011	0.0717	0.0031	0.1609
2014							65,562	0.0603	0.0026	0.1343
2015							58,002	0.0586	0.0056	0.0877
2016							69,496	0.0608	0.0044	0.0965
2017							60,150	0.0601	0.0047	0.0751
2018							66,264	0.0598	0.0056	0.0832

Table 8. Time series of relative biomass indices and uncertainty (standard error of log_e(index)) for the bottom trawl surveys, estimated using the area-swept method. These estimates are provided for comparison with the VAST generated estimates (listed in Table 7) used in the base model.

Year	AFSC Triennial		AFSC Slope		NWFSC Slope		WCGBTS	
	Index	se_log	Index	se_log	Index	se_log	Index	se_log
1980	2,155	0.1888						
1983	2,095	0.1530						
1986	2,186	0.1880						
1989	4,425	0.1811						
1992	2,251	0.1723						
1995	2,256	0.1044						
1997			20,019	0.1279				
1998	5,078	0.1425	15,429	0.1149				
1999			14,687	0.1208	28,431	0.1289		
2000			17,196	0.1272	24,002	0.1654		
2001	4,763	0.0799			24,150	0.1439		
2002					27,022	0.0980		
2003							51,448	0.0761
2004	10,471	0.0927					55,258	0.0735
2005							51,948	0.0639
2006							54,875	0.0887
2007							53,283	0.0539
2008							61,093	0.0725
2009							52,024	0.0717
2010							62,639	0.0889
2011							54,514	0.0668
2012							57,666	0.0636
2013							61,568	0.1333
2014							56,835	0.0627
2015							60,276	0.0629
2016							60,921	0.0678
2017							57,884	0.0601
2018							59,709	0.0627

Table 9. Summary of fishery sampling effort by state (number of trips and fish sampled) used to create length frequency distributions.

Year	CA fishery		OR fishery		WA fishery		Discard	
	N trips	N fish	N trips	N fish	N trips	N fish	N trips	N fish
1995			6	174				
1996			4	99				
1997			22	461				
1998			5	84				
1999			16	295				
2000			20	356				
2001			14	332				
2002			7	235				
2003			19	521				
2004			5	92	2	49		
2005			15	233	1	15		
2006			43	870	6	255	274	1,934
2007			57	1,079	15	381	254	1,768
2008			51	694	26	972	342	2,284
2009	31	727	45	685	13	456	422	2,742
2010	30	638	62	1,110	3	100	261	1,621
2011	58	1,272	46	889	14	735	695	5,401
2012	60	1,196	52	1,118	13	600	713	6,067
2013	47	948	38	943	21	1,012	790	6,616
2014	39	662	43	991	13	401	737	5,878
2015	42	831	54	917	12	448	674	4,196
2016	45	969	42	892	24	746	679	4,211
2017	44	1,039	56	1,240	25	543	638	3,612
2018	34	554	52	865	25	250		

Table 10. Summary of fishery and survey sampling effort (number of fish sampled) used to create conditional ages at length compositions.

Year	Fishery N fish	WCGBTS N fish
2003	140	
2004		257
2011		323
2012		330

Table 11. Summary of survey sampling effort (number of trips and fish sampled) used to create length frequency distributions.

Years	AFCS Triennial		AFCS Slope		WCGBT	
	N hauls	N fish	N hauls	N fish	N hauls	N fish
1986						
1989						
1992						
1995						
1997			82	1,175		
1998						
1999			86	1,026		
2001	266	808	83	909		
2002			84	781		
2003					289	2,655
2004	175	822			273	2,599
2005					382	3,259
2006					385	3,307
2007					413	3,840
2008					395	3,383
2009					364	3,116
2010					408	3,462
2011					423	2,991
2012					427	3,650
2013					297	2,492
2014					421	3,722
2015					429	4,067
2016					428	4,004
2017					437	3,679
2018					426	3,610

Table 12. Bridging of major changes from the 2007 assessment to 2019 assessment model.

	2007 model	Updated indices	New catches	New/updated comps	New maturity	M estimated	WCGBTS q estimated
Parameter							
Natural mortality (M)	0.2	0.2	0.2	0.2	0.2	0.23	0.22
Length at A1	18.77	20.65	19.68	20.80	20.82	21.11	21.22
Length at A2	105.77	105.40	102.24	137.95	138.15	145.31	146.03
von Bertalanffy K	0.07	0.07	0.07	0.05	0.05	0.04	0.04
CV of length at A1	0.14	0.14	0.16				
CV of length at A2	0.07	0.07	0.08				
SD of length at A1				3.89	3.90	4.12	4.18
SD of length at A2				8.95	8.92	7.73	7.56
Length at 50% maturity	120.75	120.75	120.75	120.75	101.53	101.53	101.53
Maturity curve slope	-0.10	-0.10	-0.10	-0.10	-0.13	-0.13	-0.13
Steepness (h)	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Ln(R0)	9.63	9.71	9.53	9.75	9.73	10.04	9.47
Ln(Q) – WCGBT Survey	-0.19	-0.19	-0.19	-0.19	-0.19	-0.19	0.45
Derived quantity							
SB0	7,306	7,800	5,430	10,641	20,362	18,484	12,252
SB 2007	4,737						
SB 2019		5,367	3,414	7,507	15,152	13,791	6,923
Bratio 2007	65%						
Bratio 2019		69%	63%	71%	74%	75%	57%
SPRratio 2006	53%						
SPRratio 2018		39%	48%	31%	26%	26%	48%

Table 13. Factors and their values used in calculation of the prior for WCGBT Survey catchability (q).

	Min	Max	Assumed best
Depth availability	0.95	1	0.975
Latitudinal availability	1	1	1
Vertical availability	0.75	0.95	0.85
Probability of capture (given in net path)	0.75	1.5	1
Product of all factors	*0.53*	*1.43*	*0.83*

Table 14. List of parameter values used in the base model.

Parameter	Value	Phase	Low bound	High bound	Initial value	Estimated or fixed	Parameter SD
Natural mortality (M)	0.22	2	0.01	0.8	0.21	Estimated with Hamel prior, see Section 2.2.2.4.2	0.01
Individual growth							
Length at A1	21.22	2	0	40	26.96	Estimated	0.24
Length at A2	146.03	2	70	150	109.74	Estimated	1.63
von Bertalanffy K	0.04	1	0.04	0.15	0.05	Estimated	0.00
SD of length at A1	4.18	5	0.5	15	3.99	Estimated	0.22
SD of length at A2	7.56	5	0.5	15	7.38	Estimated	0.67
Weight at length							
Coefficient	0.00	-3	-3	3	0.00	Fixed	_
Exponent	3.07	-3	2	4	3.07	Fixed	_
Maturity at length							
Inflection	101.53	-3	10	140	101.53	Fixed	_
Slope	-0.13	-3	-0.1	-0.05	-0.13	Fixed	_
Fecundity at length							
Slope	0	-3	-3	3	0	Fixed	_
CohortGrowDev	1	-5	0	2	1	Fixed	_
FracFemale_GP_1	0.5	-99	0	1	0.5	Fixed	_
Stock and recruitment							
Ln(R0)	9.47	1	5	15	13	Estimated	0.21
Steepness (h)	0.4	-3	0.2	1	0.4	Fixed	_
Recruitment SD (σr)	0.3	-2	0	0.4	0.3	Fixed	_
Catchability and variability							
Ln(Q) – WCGBT Survey	0.45	1	-7	5	-0.19	Estimated with prior, see Section 2.2.2.4.5	0.24
Extra additive SD for – WCGBT Survey	0	-5	0	5	0	Fixed	_
Ln(Q) – AFSC Triennial Survey	-3.00	1	-7	0	-0.6	Estimated	0.31
Extra additive SD for – AFSC Triennial Survey	0.29	5	0	5	0	Estimated	0.10
Ln(Q) – AFSC Slope Survey	-3.06	-1	-7	0	-0.6	Fixed	_
Extra additive SD for – AFSC Slope Survey	0	-5	0	5	0	Fixed	_
Ln(Q) – NWFSC Slope Survey	-0.52	-1	-7	0	-0.6	Fixed	_
Extra additive SD for – NWFSC Slope Survey	0	-5	0	5	0	Fixed	_
Ln(Q) – IPHC Survey	-13.66	-1	-7	0	-0.6	Fixed	_
Extra additive SD for – IPHC Survey	0.22	5	0	5	0	Estimated	0.05
Ln(Q) – AFSC Triennial Survey 1995-2004	-2.11	1	-7	0	-0.6	Estimated	0.32

Parameter	Value	Phase	Low bound	High bound	Initial value	Estimated or fixed	Parameter SD
Selectivity							
Fishery current (double-normal)							
Peak	102.07	4	60	150	85	Estimated	1.72
Top: width of plateau	-15	-5	-15	4	-15	Fixed	_
Ascending slope	7.17	4	-1	9	5.8	Estimated	0.04
Descending slope base	6.31	5	-1	20	8.3	Estimated	16.30
Selectivity at first bin	-5	-4	-5	9	-5	Fixed	_
Selectivity at last bin	9	-5	-999	9	9	Fixed	_
Fishery retention							
Ascending inflection	71.08	2	15	150	27	Estimated	0.30
Ascending slope	6.72	2	0.1	10	2	Estimated	0.17
Retention asymptote	10	-3	-10	10	10	Fixed	_
Discard mortality	0	-3	0	0	0	Fixed	_
Descending inflection	5	-4	5	15	5	Fixed	_
Descending slope	0.1	-4	0.001	10	0.1	Fixed	_
Maximum discard mortality	0.5	-5	0	1	0.5	Fixed	_
Male offset	0	-5	0	0	0	Fixed	_
WCGBT Survey (double-normal)							
Peak	91.18	4	22.5	100	50	Estimated	2.48
Top: width of plateau	-15	-5	-15	4	-15	Fixed	_
Ascending slope	8.49	4	-1	9	9	Estimated	0.13
Descending slope base	6.75	5	-1	20	6	Estimated	0.21
Selectivity at first bin	-5	-4	-5	9	-5	Fixed	_
Selectivity at last bin	-999	-5	-999	9	-999	Fixed	_
AFSC Triennial Survey (double-normal)							
Peak	115.34	4	40	130	75	Estimated	21.63
Top: width of plateau	-15	-5	-15	4	-15	Fixed	_
Ascending slope	9.52	4	-1	20	9	Estimated	0.93
Descending slope base	14.81	5	-1	20	7.2	Estimated	76.77
Selectivity at first bin	-5	-4	-5	9	-5	Fixed	_
Selectivity at last bin	-999	-5	-999	9	-999	Fixed	_
AFSC Slope Survey (double-normal)							
Peak	85.30	4	20	100	45	Estimated	7.69
Top: width of plateau	-15	-5	-15	4	-15	Fixed	_
Ascending slope	8.19	4	-1	9	5	Estimated	0.41
Descending slope base	6.89	5	-1	20	7.7	Estimated	0.73
Selectivity at first bin	-5	-4	-5	9	-5	Fixed	_
Selectivity at last bin	-999	-5	-999	9	-999	Fixed	_

Parameter	Value	Phase	Low bound	High bound	Initial value	Estimated or fixed	Parameter SD
IPHC Survey (double-normal)							
Peak	87.78	4	20	150	45	Estimated	3.43
Top: width of plateau	-15	-5	-15	4	-15	Fixed	_
Ascending slope	4.23	4	-1	9	5	Estimated	0.69
Descending slope base	15.30	5	-1	20	7.7	Estimated	70.49
Selectivity at first bin	-5	-4	-5	9	-5	Fixed	_
Selectivity at last bin	-999	-5	-999	9	-999	Fixed	_
Dirichlet multinomial parameters							
ln(EffN mult) Fishery lengths	0.70	2	-5	5	0	Estimated	0.13
ln(EffN mult) WCGBTS lengths	2.58	2	-5	5	0	Estimated	0.74
ln(EffN mult) AFSC Triennial lengths	-0.16	2	-5	5	0	Estimated	0.33
ln(EffN mult) AFSC Slope lengths	5	-2	-5	5	5	Fixed	_
ln(EffN mult) IPHC Survey lengths	5	-2	-5	5	5	Fixed	_
ln(EffN mult) Fishery ages	5	-2	-5	5	5	Fixed	_
ln(EffN mult) WCGBTS ages	5	-2	-5	5	5	Fixed	_
Time varying parameters							
Retention asymptote 1995	-1.00	4	-10	10	0.23	Estimated	0.06
Retention asymptote 1996	1.61	4	-10	10	0.78	Estimated	0.44
Retention asymptote 1997	9.67	4	-10	10	1	Estimated	9.02
Retention asymptote 1998	6.66	4	-10	10	0.88	Estimated	35.76
Retention asymptote 1999	9.65	4	-10	10	1	Estimated	9.46
Retention asymptote 2000	9.70	4	-10	10	0.95	Estimated	8.43
Retention asymptote 2001	9.70	4	-10	10	1	Estimated	8.23
Retention asymptote 2002	0.63	4	-10	10	0.53	Estimated	0.26
Retention asymptote 2003	2.23	4	-10	10	0.78	Estimated	0.49
Retention asymptote 2004	0.35	4	-10	10	0.44	Estimated	0.20
Retention asymptote 2005	0.92	4	-10	10	0.59	Estimated	0.24
Retention asymptote 2006	1.37	4	-10	10	0.85	Estimated	0.17
Retention asymptote 2007	0.53	4	-10	10	0.58	Estimated	0.16
Retention asymptote 2008	0.95	4	-10	10	0.68	Estimated	0.15
Retention asymptote 2009	1.72	4	-10	10	0.61	Estimated	0.18
Retention asymptote 2010	2.00	4	-10	10	0.75	Estimated	0.22
Retention asymptote 2011	3.03	4	-10	10	0.78	Estimated	0.17
Retention asymptote 2012	3.86	4	-10	10	0.83	Estimated	0.29
Retention asymptote 2013	3.93	4	-10	10	0.83	Estimated	0.30
Retention asymptote 2014	3.71	4	-10	10	0.81	Estimated	0.27
Retention asymptote 2015	4.57	4	-10	10	0.83	Estimated	0.47
Retention asymptote 2016	4.17	4	-10	10	0.81	Estimated	0.39
Retention asymptote 2017	5.70	4	-10	10	0.78	Estimated	1.19

Table 15. Regional comparison of life history parameter estimates of Longnose Skate.

Region	Sex	50% Maturity (TL cm)	Max Age (year)	Linf	VBGM *k*	Min Length (TL cm)	Max Length (TL cm)
California (Zeiner and Wolf 1993)	Female	None	12	106.9	0.16	30.3	106.8
California (Zeiner and Wolf 1993)	Male	None	13	96.7	0.25	35.9	132.2
Canada-Cape Mendocino (Thompson 2006)	Female	120.0	22	180.9	0.051	16	135
Canada-Cape Mendocino (Thompson 2006)	Male	108.0	20	207.2	0.042	27	130
Cape Mendocino-Mexico (Thompson 2006)	Female	90.0	16				
Cape Mendocino-Mexico (Thompson 2006)	Male	81.0	15				
British Columbia (McFarlane and King 2006)	Female	83.0	26	137.2	0.06	18.4	124.6
British Columbia (McFarlane and King 2006)	Male	65.0	23	131.5	0.07	18.6	122
Gulf of Alaska (Gburski et al. 2007, Ebert et al. 2008)	Female	137.1	24	234.1	0.037	98	140
Gulf of Alaska (Gburski et al. 2007, Ebert et al. 2008)	Male	102.9	25	168.8	0.056	100	129
U.S. West Coast (This assessment)	Sexes combined	101.5 (female)	22	202.6	0.039	10	219

Table 16.Time series of total biomass, summary biomass, spawning output, spawning output relative to SB_0, recruitment, and exploitation rate estimated in the base model. This table is also provided in supplementary Excel file, please see tab "Derived output times series".

Year	Total Biomass (mt)	Spawning Biomass (mt)	Summary Biomass 2+ (mt)	Depletion (%)	Age-0 Recruits	Total Catch (mt)	(1-SPR)/(1-SPR_50%)	Relative Exploitation Rate
1916	75,400	12,252	73,298	100	12,954	15.76	0.007	0.000
1917	75,385	12,249	73,283	100	12,953	31.52	0.015	0.000
1918	75,356	12,241	73,255	99.9	12,950	47.28	0.022	0.001
1919	75,315	12,230	73,214	99.8	12,945	63.04	0.029	0.001
1920	75,262	12,216	73,162	99.7	12,940	78.8	0.037	0.001
1921	75,197	12,198	73,098	99.6	12,933	94.56	0.044	0.001
1922	75,123	12,178	73,025	99.4	12,924	110.32	0.051	0.002
1923	75,038	12,154	72,942	99.2	12,915	126.08	0.059	0.002
1924	74,945	12,128	72,850	99	12,904	141.84	0.066	0.002
1925	74,842	12,099	72,749	98.7	12,893	157.6	0.073	0.002
1926	74,731	12,068	72,640	98.5	12,880	173.36	0.08	0.002
1927	74,611	12,035	72,522	98.2	12,867	189.12	0.088	0.003
1928	74,484	12,000	72,397	97.9	12,853	204.88	0.095	0.003
1929	74,349	11,964	72,265	97.6	12,838	220.64	0.102	0.003
1930	74,207	11,925	72,125	97.3	12,822	236.4	0.11	0.003
1931	74,058	11,886	71,978	97	12,806	252.16	0.117	0.004
1932	73,901	11,845	71,825	96.7	12,789	267.92	0.124	0.004
1933	73,739	11,803	71,665	96.3	12,772	283.68	0.132	0.004
1934	73,570	11,759	71,498	96	12,754	299.44	0.139	0.004
1935	73,394	11,715	71,326	95.6	12,735	315.2	0.146	0.004
1936	73,213	11,669	71,148	95.2	12,716	330.96	0.154	0.005
1937	73,027	11,622	70,965	94.9	12,696	346.72	0.161	0.005
1938	72,834	11,574	70,776	94.5	12,675	362.48	0.168	0.005
1939	72,637	11,524	70,582	94.1	12,654	413.56	0.191	0.006
1940	72,402	11,466	70,350	93.6	12,629	426.9	0.198	0.006
1941	72,166	11,407	70,118	93.1	12,604	513.57	0.236	0.007
1942	71,861	11,331	69,818	92.5	12,571	482.63	0.224	0.007
1943	71,601	11,265	69,564	91.9	12,542	451.62	0.211	0.006
1944	71,385	11,210	69,351	91.5	12,518	465.44	0.218	0.007
1945	71,165	11,155	69,135	91	12,493	483.01	0.226	0.007
1946	70,938	11,099	68,912	90.6	12,468	499.59	0.234	0.007
1947	70,705	11,042	68,684	90.1	12,443	511.55	0.24	0.007
1948	70,471	10,986	68,454	89.7	12,417	536.5	0.252	0.008
1949	70,224	10,927	68,211	89.2	12,391	550.84	0.259	0.008
1950	69,974	10,868	67,966	88.7	12,364	568.91	0.268	0.008
1951	69,718	10,808	67,714	88.2	12,336	600.55	0.282	0.009

Year	Total Biomass (mt)	Spawning Biomass (mt)	Summary Biomass 2+ (mt)	Depletion (%)	Age-0 Recruits	Total Catch (mt)	(1-SPR)/(1-SPR_50%)	Relative Exploitation Rate
1952	69,444	10,744	67,444	87.7	12,306	648.85	0.304	0.010
1953	69,137	10,672	67,142	87.1	12,272	535.56	0.257	0.008
1954	68,951	10,628	66,961	86.7	12,252	521.58	0.251	0.008
1955	68,785	10,590	66,798	86.4	12,234	549.67	0.264	0.008
1956	68,597	10,548	66,613	86.1	12,214	516.19	0.25	0.008
1957	68,446	10,516	66,466	85.8	12,199	486.78	0.237	0.007
1958	68,328	10,493	66,349	85.6	12,188	508.7	0.248	0.008
1959	68,190	10,466	66,214	85.4	12,175	482.22	0.236	0.007
1960	68,082	10,447	66,107	85.3	12,166	565.4	0.274	0.009
1961	67,897	10,410	65,924	85	12,148	571.44	0.277	0.009
1962	67,714	10,372	65,744	84.7	12,130	585.86	0.284	0.009
1963	67,526	10,332	65,560	84.3	12,110	643.26	0.31	0.010
1964	67,293	10,280	65,330	83.9	12,085	618.52	0.301	0.009
1965	67,095	10,234	65,136	83.5	12,062	577.81	0.284	0.009
1966	66,946	10,199	64,990	83.2	12,045	574.77	0.283	0.009
1967	66,804	10,166	64,851	83	12,028	508.71	0.254	0.008
1968	66,731	10,148	64,780	82.8	12,020	595.76	0.293	0.009
1969	66,575	10,113	64,626	82.5	12,002	718.74	0.348	0.011
1970	66,310	10,051	64,365	82	11,971	736.29	0.357	0.011
1971	66,041	9,987	64,101	81.5	11,939	693.16	0.34	0.011
1972	65,827	9,936	63,892	81.1	11,912	894.75	0.426	0.014
1973	65,432	9,841	63,502	80.3	11,864	874.79	0.421	0.014
1974	65,077	9,754	63,155	79.6	11,819	822.62	0.401	0.013
1975	64,788	9,682	62,873	79	11,781	885.66	0.43	0.014
1976	64,453	9,599	62,544	78.3	11,737	981.4	0.471	0.016
1977	64,041	9,499	62,141	77.5	11,684	930.33	0.453	0.015
1978	63,697	9,414	61,804	76.8	11,638	1034.29	0.499	0.017
1979	63,267	9,311	61,382	76	11,582	1184.01	0.561	0.019
1980	62,713	9,179	60,839	74.9	11,509	985.03	0.486	0.016
1981	62,373	9,097	60,508	74.2	11,463	1182.5	0.568	0.020
1982	61,855	8,977	60,000	73.3	11,395	1379	0.647	0.023
1983	61,173	8,819	59,330	72	11,304	1340.67	0.64	0.023
1984	60,556	8,676	58,728	70.8	11,220	1268.33	0.618	0.022
1985	60,032	8,555	58,217	69.8	11,148	1358.4	0.657	0.023
1986	59,440	8,421	57,636	68.7	11,066	1158.37	0.585	0.020
1987	59,055	8,336	57,263	68	11,013	1213.66	0.61	0.021
1988	58,624	8,244	56,841	67.3	10,956	1185.2	0.603	0.021
1989	58,227	8,164	56,453	66.6	10,906	1257.28	0.635	0.022

Year	Total Biomass (mt)	Spawning Biomass (mt)	Summary Biomass 2+ (mt)	Depletion (%)	Age-0 Recruits	Total Catch (mt)	(1-SPR)/(1-SPR_50%)	Relative Exploitation Rate
1990	57,768	8,074	56,002	65.9	10,849	1102.09	0.576	0.020
1991	57,465	8,021	55,707	65.5	10,814	1239.91	0.635	0.022
1992	57,033	7,941	55,282	64.8	10,763	1145.64	0.6	0.021
1993	56,700	7,885	54,956	64.4	10,726	1069.09	0.571	0.019
1994	56,443	7,847	54,705	64	10,701	806.82	0.453	0.015
1995	56,436	7,865	54,700	64.2	10,713	976.833	0.532	0.018
1996	56,258	7,842	54,521	64	10,698	1571.61	0.771	0.029
1997	55,527	7,676	53,798	62.6	10,587	2115.58	0.958	0.039
1998	54,330	7,387	52,625	60.3	10,388	1193.02	0.649	0.023
1999	54,072	7,311	52,390	59.7	10,335	1519.34	0.782	0.029
2000	53,510	7,166	51,840	58.5	10,231	1366.68	0.731	0.026
2001	53,111	7,063	51,456	57.6	10,156	1311.58	0.714	0.025
2002	52,768	6,978	51,124	57	10,094	801.061	0.484	0.016
2003	52,902	7,017	51,262	57.3	10,122	1046.52	0.6	0.020
2004	52,771	7,007	51,129	57.2	10,114	697.748	0.429	0.014
2005	52,952	7,080	51,308	57.8	10,168	828.115	0.492	0.016
2006	52,980	7,126	51,328	58.2	10,202	1033.55	0.588	0.020
2007	52,799	7,128	51,144	58.2	10,203	1085.21	0.613	0.021
2008	52,572	7,117	50,917	58.1	10,195	1335.16	0.722	0.026
2009	52,119	7,046	50,468	57.5	10,144	1152.38	0.651	0.023
2010	51,866	7,009	50,222	57.2	10,116	1164.66	0.659	0.023
2011	51,617	6,962	49,978	56.8	10,082	915.616	0.548	0.018
2012	51,617	6,966	49,981	56.9	10,084	1029.86	0.602	0.021
2013	51,507	6,940	49,872	56.6	10,065	1051.319	0.614	0.021
2014	51,381	6,908	49,750	56.4	10,041	925.957	0.556	0.019
2015	51,377	6,902	49,748	56.3	10,036	903.765	0.545	0.018
2016	51,389	6,902	49,761	56.3	10,036	979.813	0.582	0.020
2017	51,324	6,887	49,696	56.2	10,025	913.283	0.55	0.018
2018	51,321	6,888	49,694	56.2	10,026	771.365	0.478	0.016
2019	51,447	6,923	49,819	56.5	10,052	NA	NA	NA

Table 17. Sensitivity of the base model to assumptions about fishery removals.

	Base model	Historical removals increased	Historical removals reduced	Discard mortality 0.4	Discard mortality 0.6
TOTAL Likelihood	1,583.37	1,579.30	1,581.10	1,577.16	1,576.68
Survey Likelihood Components					
ALL	-53.71	-56.14	-50.82	-52.93	-54.36
WCGBT	-26.91	-29.72	-23.61	-26.04	-27.63
Triennial	-3.24	-3.34	-3.11	-3.22	-3.27
AFSC Slope	-5.92	-5.85	-6.01	-5.94	-5.90
NWFSC Slope	-6.52	-6.53	-6.51	-6.52	-6.52
IPHC	-11.11	-10.70	-11.58	-11.21	-11.04
Length Likelihood Components					
ALL	1230.03	1233.49	1231.60	1229.17	1229.55
Fishery	850.39	848.88	852.92	850.31	849.50
WCGBT	279.15	280.71	277.79	278.24	279.76
Triennial	51.94	51.65	52.22	52.00	51.75
AFSC Slope	39.88	39.78	39.98	39.94	39.85
IPHC	8.68	12.47	8.70	8.68	8.70
Age Likelihood Components					
ALL	462.85	462.97	462.86	462.86	462.87
Parameter					
Natural mortality (M)	0.22	0.21	0.22	0.22	0.22
Length at A1	21.22	21.20	21.22	21.22	21.21
Length at A2	146.03	145.67	146.22	146.12	145.83
von Bertalanffy K	0.04	0.04	0.04	0.04	0.04
SD of length at A1	4.18	4.17	4.19	4.19	4.18
SD of length at A2	7.56	7.62	7.55	7.54	7.59
Ln(R0)	9.47	9.50	9.44	9.45	9.49
Ln(Q) WCGBT Survey	0.45	0.45	0.45	0.45	0.45
Derived quantities					
SB0	12,252	13,977	10,915	11,616	12,931
SB 2019	6,923	7,177	6,726	6,851	6,989
Bratio 2019	57%	51%	62%	59%	54%
MSY SPR	429.81	470.08	397.16	414.09	446.03
F SPR	0.04	0.04	0.04	0.04	0.04

Table 18. Sensitivity of the base model to parameter values used in 2007 assessment.

	Base model	2007 WCGBT q	2007 WL	2007 M	2007 maturity
TOTAL Likelihood	1,583.37	1,586.69	1,582.35	1,583.32	1,578.14
Survey Likelihood Components					
ALL	-53.71	-55.61	-53.70	-53.66	-52.12
WCGBT	-26.91	-29.16	-26.90	-26.84	-25.08
Triennial	-3.24	-3.45	-3.24	-3.26	-3.19
AFSC Slope	-5.92	-5.75	-5.92	-5.92	-5.96
NWFSC Slope	-6.52	-6.51	-6.52	-6.52	-6.52
IPHC	-11.11	-10.75	-11.11	-11.11	-11.37
Length Likelihood Components					
ALL	1230.03	1239.65	1230.78	1227.60	1229.05
Fishery	850.39	857.78	851.13	848.11	850.31
WCGBT	279.15	281.22	279.13	278.33	278.21
Triennial	51.94	52.12	51.95	52.13	51.97
AFSC Slope	39.88	39.76	39.89	40.39	39.87
IPHC	8.68	8.77	8.67	8.64	8.69
Age Likelihood Components					
ALL	462.85	464.04	462.76	470.77	462.91
Parameter					
Natural mortality (M)	0.22	0.23	0.22	0.20	0.22
Length at A1	21.22	21.11	21.22	21.09	21.22
Length at A2	146.03	145.31	146.07	141.93	146.01
von Bertalanffy K	0.04	0.04	0.04	0.04	0.04
SD of length at A1	4.18	4.12	4.18	4.05	4.18
SD of length at A2	7.56	7.73	7.56	8.33	7.60
Ln(R0)	9.47	10.04	9.50	9.26	9.53
Ln(Q) WCGBT Survey	0.45	-0.19	0.45	0.45	0.45
Derived quantities					
SB0	12,252	18,484	12,275	13,333	6,723
SB 2019	6,923	13,791	6,931	7,523	3,402
Bratio 2019	57%	75%	56%	56%	51%
MSY SPR	429.81	699.44	429.54	423.39	380.43
F SPR	0.04	0.04	0.04	0.04	0.03

Table 19. Sensitivity of the base model to assumptions about selectivity and catchability.

	Base model	Fishery dome-shaped	WCGBT asymptotic	No 2004 triennial index	No Triennial q offset
TOTAL Likelihood	1,583.37	1,498.28	1,600.40	1,580.91	1,575.06
Survey Likelihood Components					
ALL	-53.71	-54.54	-52.70	-56.16	-50.56
WCGBT	-26.91	-27.95	-25.72	-26.91	-26.92
Triennial	-3.24	-3.37	-3.15	-5.69	-0.09
AFSC Slope	-5.92	-5.86	-6.01	-5.92	-5.92
NWFSC Slope	-6.52	-6.52	-6.53	-6.52	-6.52
IPHC	-11.11	-10.85	-11.29	-11.11	-11.11
Length Likelihood Components					
ALL	1230.03	1150.83	1240.91	1230.04	1240.32
Fishery	850.39	770.33	799.93	850.39	850.45
WCGBT	279.15	283.05	341.72	279.15	279.11
Triennial	51.94	50.09	52.81	51.94	62.15
AFSC Slope	39.88	39.77	37.86	39.88	39.93
IPHC	8.68	7.59	8.59	8.68	8.68
Age Likelihood Components					
ALL	462.85	457.85	470.56	462.87	462.86
Parameter					
Natural mortality (M)	0.22	0.15	0.22	0.22	0.22
Length at A1	21.22	21.24	21.96	21.22	21.14
Length at A2	146.03	150.00	148.20	146.03	145.73
von Bertalanffy K	0.04	0.04	0.04	0.04	0.04
SD of length at A1	4.18	4.16	4.90	4.18	4.16
SD of length at A2	7.56	7.83	6.87	7.56	7.61
Ln(R0)	9.47	8.78	9.39	9.47	9.45
Ln(Q) WCGBT Survey	0.45	0.45	0.45	0.45	0.45
Derived quantities					
SB0	12,252	28,783	11,287	12,254	12,341
SB 2019	6,923	18,147	5,721	6,923	6,977
Bratio 2019	57%	63%	51%	57%	57%
MSY SPR	429.81	463.89	388.03	429.82	429.72
F SPR	0.04	0.03	0.04	0.04	0.04

Table 20. Sensitivity of the base model to selected model specifications.

	Base model	Stepness estimated	Recdevs estimated	Francis-McAllister-Ianelli tuning	McAllister-Ianelli tuning
TOTAL Likelihood	1,583.37	1,577.34	1,375.78	115.51	340.43
Survey Likelihood Components					
ALL	-53.71	-52.74	-51.27	-55.13	-54.97
WCGBT	-26.91	-25.78	-21.76	-28.54	-28.35
Triennial	-3.24	-3.20	-2.87	-3.41	-3.39
AFSC Slope	-5.92	-5.95	-6.25	-5.80	-5.82
NWFSC Slope	-6.52	-6.52	-6.31	-6.51	-6.51
IPHC	-11.11	-11.29	-14.09	-10.87	-10.91
Length Likelihood Components					
ALL	1230.03	1229.05	957.67	201.07	380.21
Fishery	850.39	849.89	637.60	115.68	163.57
WCGBT	279.15	278.64	232.37	33.17	149.93
Triennial	51.94	51.93	41.80	13.05	24.07
AFSC Slope	39.88	39.90	37.82	31.79	35.26
IPHC	8.68	8.69	8.08	7.37	7.38
Age Likelihood Components					
ALL	462.85	462.85	544.92	37.82	80.94
Parameter					
Natural mortality (M)	0.22	0.22	0.15	0.13	0.13
Length at A1	21.22	21.22	19.25	16.07	18.47
Length at A2	146.03	146.02	123.69	118.61	118.70
von Bertalanffy K	0.04	0.04	0.07	0.09	0.09
SD of length at A1	4.18	4.18	3.59	3.48	3.48
SD of length at A2	7.56	7.56	8.76	9.65	9.95
Ln(R0)	9.47	9.51	8.90	8.63	8.59
Ln(Q) WCGBT Survey	0.45	0.45	0.45	0.45	0.45
Derived quantities					
SB0	12,252	12,523	18,597	23,042	22,058
SB 2019	6,923	6,865	9,797	15,564	14,545
Bratio 2019	57%	55%	53%	68%	66%
MSY SPR	429.81	292.04	504.07	518.48	496.54
F SPR	0.04	0.04	0.04	0.04	0.04

Table 21. Summary of reference points for the base model.

Quantity	Estimate	~95% Asymptotic Interval
Unfished Spawning Biomass (mt)	12,252	9,155–15,350
Unfished Age 2+ Biomass (mt)	73,298	51,204–95,392
Spawning Biomass (2019)	6,923	3,283–10,563
Unfished Recruitment (R_0)	12,954	7,722–18,186
Fraction unfished (2019)	0.565	0.409–0.721
Reference Points Based $SB_{40\%}$		
Proxy Spawning Biomass ($SB_{40\%}$)	4,901	3,662–6,140
SPR resulting in $SB_{40\%}$	0.625	0.625–0.625
Exploitation Rate Resulting in $SB_{40\%}$	0.027	0.026–0.027
Yield with SPR Based On $SB_{40\%}$ (mt)	1,028	708–1,348
Reference Points based on SPR proxy for MSY		
Proxy Spawning Biomass ($SPR_{50\%}$)	2,450	1,831–3,070
SPR_{50}	0.5	NA
Exploitation rate corresponding to $SPR_{50\%}$	0.039	0.038–0.040
Yield with $SPR_{50\%}$ at SB_{SPR} (mt)	860	590–1,129
Reference points based on estimated MSY values		
Spawning Biomass at MSY (SB_{MSY})	4,632	3,472–5,792
SPR_{MSY}	0.611	0.610–0.612
Exploitation rate corresponding to SPR_{MSY}	0.028	0.027–0.028
MSY (mt)	1,030	709–1,351

Table 22. Summary of recent trends in estimated Longnose Skate exploitation and stock level from the base model.

Years	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Landings (mt)	966	995	819	936	958	839	829	896	840	709	NA
Estimated Total catch (mt)	1,152	1,165	916	1,030	1,051	926	904	980	913	771	NA
OFL (mt)	3,428	3,269	3,128	3,006	2,902	2,816	2,449	2,405	2,556	2,526	2,499
ACL (mt)	1,349	1,349	1,349	1,349	2,000	2,000	2,000	2,000	2,000	2,000	2,000
1-SPR	0.65	0.66	0.55	0.60	0.61	0.56	0.55	0.58	0.55	0.48	NA
Exploitation_Rate	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	NA
Age 2+ Biomass (mt)	50,468	50,222	49,978	49,981	49,872	49,750	49,748	49,761	49,696	49,694	49,819
Spawning Biomass (mt)	7,046	7,009	6,962	6,966	6,940	6,908	6,902	6,902	6,887	6,888	6,923
95% Confidence Interval	3,549–10,544	3,499–10,518	3,439–10,485	3,428–10,504	3,387–10,493	3,339–10,476	3,318–10,485	3,303–10,500	3,274–10,499	3,262–10,514	3,283–10,563
Recruitment	10,144	10,116	10,082	10,084	10,065	10,041	10,036	10,036	10,025	10,026	10,052
95% Confidence Interval	6,049–17,010	6,018–17,004	5,980–16,995	5,977–17,015	5,953–17,019	5,923–17,020	5,913–17,035	5,907–17,053	5,890–17,062	5,885–17,080	5,904–17,114
Depletion (%)	57.5	57.2	56.8	56.9	56.6	56.4	56.3	56.3	56.2	56.2	56.5
95% Confidence Interval	43.3–71.7	42.8–71.6	42.2–71.4	42.1–71.6	41.8–71.5	41.3–71.5	41.1–71.5	41.0–71.7	40.7–71.7	40.6–71.8	40.9–72.1

Table 23. 12-year projections for alternate states of nature defined based on WCGBT Survey catchability. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.

			States of nature					
			Low state: *q* =2.16		Base model: *q* =1.57		High state: *q* =1.19	
Management decision	Year	Catch (mt)	Spawning biomass	Depletion	Spawning biomass	Depletion	Spawning biomass	Depletion
2017-2018 average total catch for 2019 and 2020 catches; 1,000 mt/year after that	2019	842	4,787	45%	6,923	57%	9,371	65%
	2020	842	4,797	45%	6,943	57%	9,398	65%
	2021	1,000	4,807	45%	6,964	57%	9,425	65%
	2022	1,000	4,780	45%	6,947	57%	9,414	65%
	2023	1,000	4,752	45%	6,929	57%	9,401	65%
	2024	1,000	4,722	45%	6,910	56%	9,388	65%
	2025	1,000	4,690	44%	6,889	56%	9,373	65%
	2026	1,000	4,657	44%	6,867	56%	9,357	65%
	2027	1,000	4,624	44%	6,845	56%	9,340	65%
	2028	1,000	4,590	43%	6,823	56%	9,324	65%
	2029	1,000	4,558	43%	6,802	56%	9,308	65%
	2030	1,000	4,527	43%	6,782	55%	9,294	65%
2017-2018 average total catch for 2019 and 2020 catches; 2,000 mt/year after that	2019	842	4,787	45%	6,923	57%	9,371	65%
	2020	842	4,797	45%	6,943	57%	9,398	65%
	2021	2,000	4,807	45%	6,964	57%	9,425	65%
	2022	2,000	4,558	43%	6,724	55%	9,190	64%
	2023	2,000	4,310	41%	6,486	53%	8,957	62%
	2024	2,000	4,066	38%	6,251	51%	8,728	61%
	2025	2,000	3,829	36%	6,024	49%	8,506	59%
	2026	2,000	3,601	34%	5,806	47%	8,293	58%
	2027	2,000	3,386	32%	5,599	46%	8,092	56%
	2028	2,000	3,186	30%	5,407	44%	7,905	55%
	2029	2,000	3,000	28%	5,230	43%	7,733	54%
	2030	2,000	2,830	27%	5,067	41%	7,575	53%
2017-2018 average total catch for 2019 and 2020 catches; ACL = ABC (P* = 0.45) as in base model after that	2019	842	4,787	45%	6,923	57%	9,371	65%
	2020	842	4,797	45%	6,943	57%	9,398	65%
	2021	1,823	4,807	45%	6,964	57%	9,425	65%
	2022	1,761	4,597	43%	6,765	55%	9,229	64%
	2023	1,708	4,401	41%	6,581	54%	9,049	63%
	2024	1,660	4,219	40%	6,411	52%	8,883	62%
	2025	1,617	4,051	38%	6,255	51%	8,732	61%
	2026	1,578	3,899	37%	6,114	50%	8,597	60%
	2027	1,546	3,762	35%	5,990	49%	8,479	59%
	2028	1,515	3,642	34%	5,881	48%	8,376	58%
	2029	1,487	3,537	33%	5,788	47%	8,290	58%
	2030	1,462	3,448	33%	5,711	47%	8,220	57%

Table 24. Projected Landings, OFLs and Time-varying ACLs.

Years	Landings (mt)	Estimated total mortality (mt)	OFL (mt)	ACL (mt)	Buffer
2019	775	842	2,079	2,000	1.000
2020	775	842	2,082	2,000	1.000
2021	1,676	1,823	2,086	1,823	0.874
2022	1,618	1,761	2,036	1,761	0.865
2023	1,566	1,708	1,993	1,708	0.857
2024	1,520	1,660	1,955	1,660	0.849
2025	1,479	1,617	1,922	1,617	0.841
2026	1,443	1,578	1,895	1,578	0.833
2027	1,412	1,546	1,872	1,546	0.826
2028	1,383	1,515	1,852	1,515	0.818
2029	1,357	1,487	1,836	1,487	0.810
2030	1,335	1,462	1,821	1,462	0.803

10 Figures

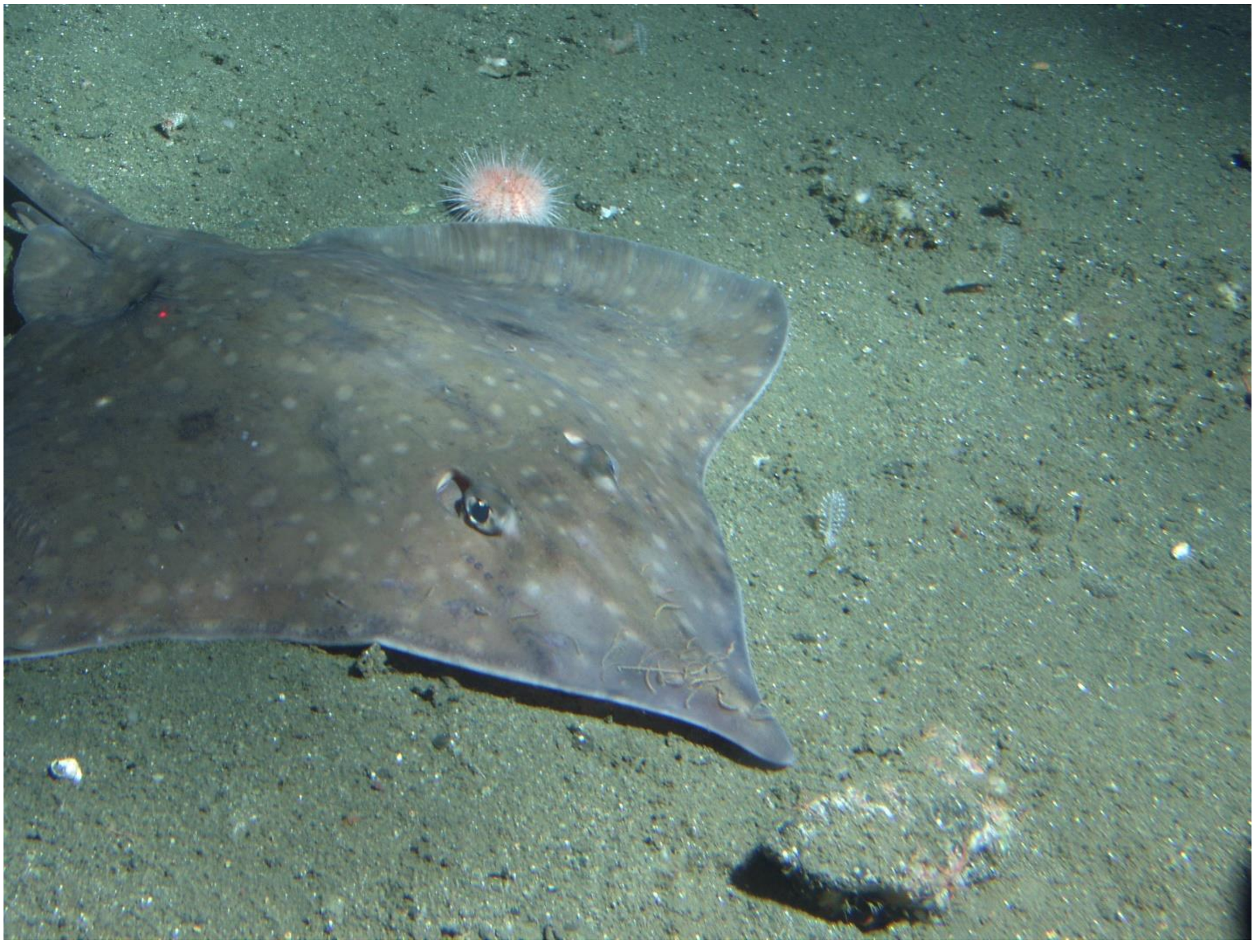

Figure 1. Photo of Longnose Skate.

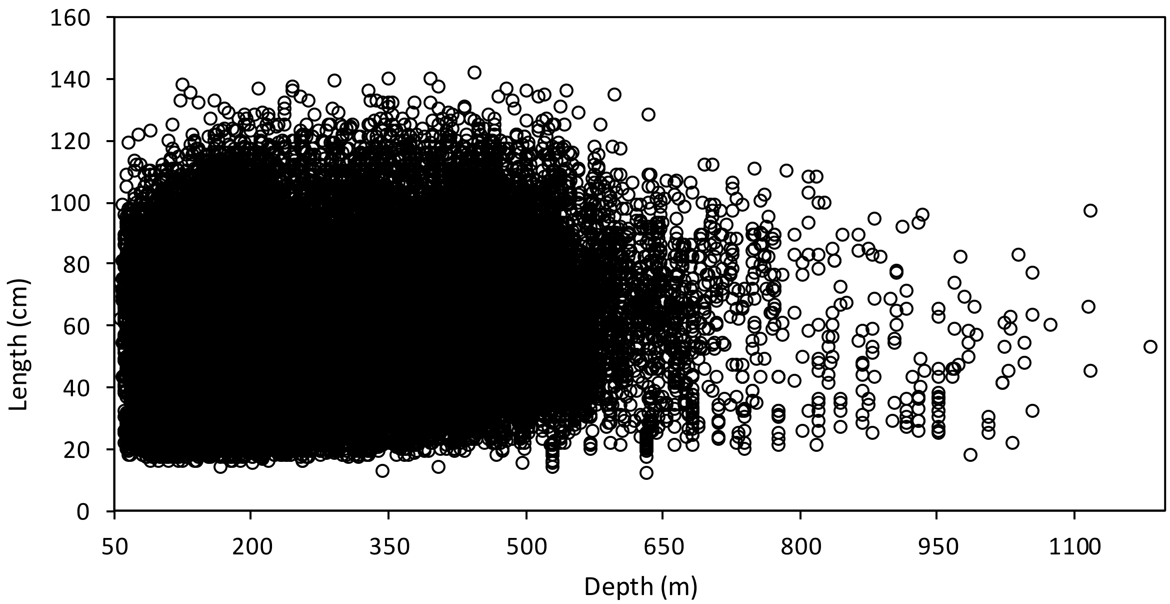

Figure 2. Distribution of length of Longnose Skate by depth, indicating a lack of ontogenetic movement, when fish migrate to deeper waters as they mature and increase in size and age.

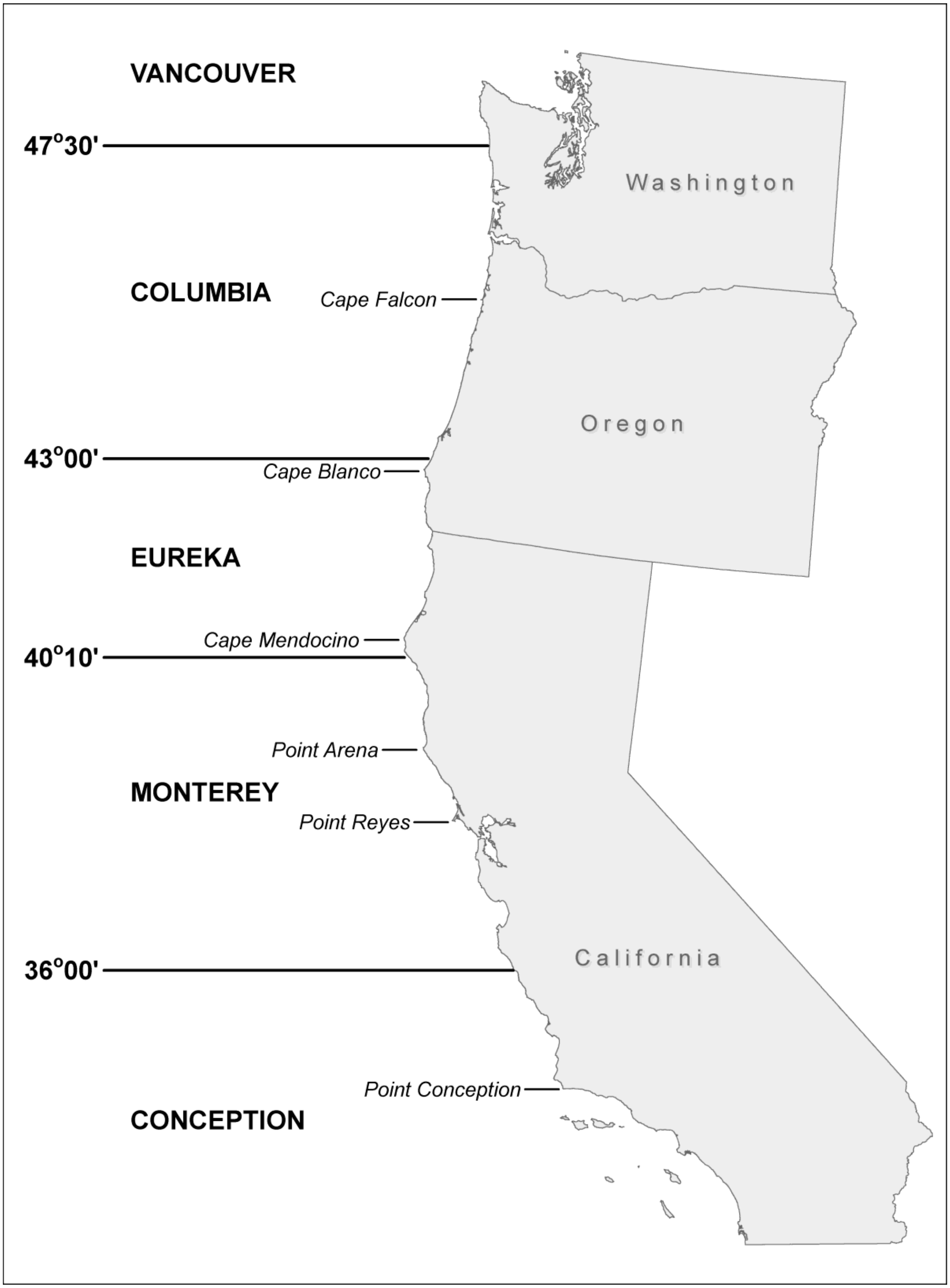

Figure 3. A map of the assessment area that includes coastal waters off three U.S. west coast states and five International North Pacific Fisheries Commission (INPFC) areas.

Figure 4. Spatial distribution of Longnose Skate catch observed by the West Coast Groundfish Observer Program and the summary area of all observed fishing events.

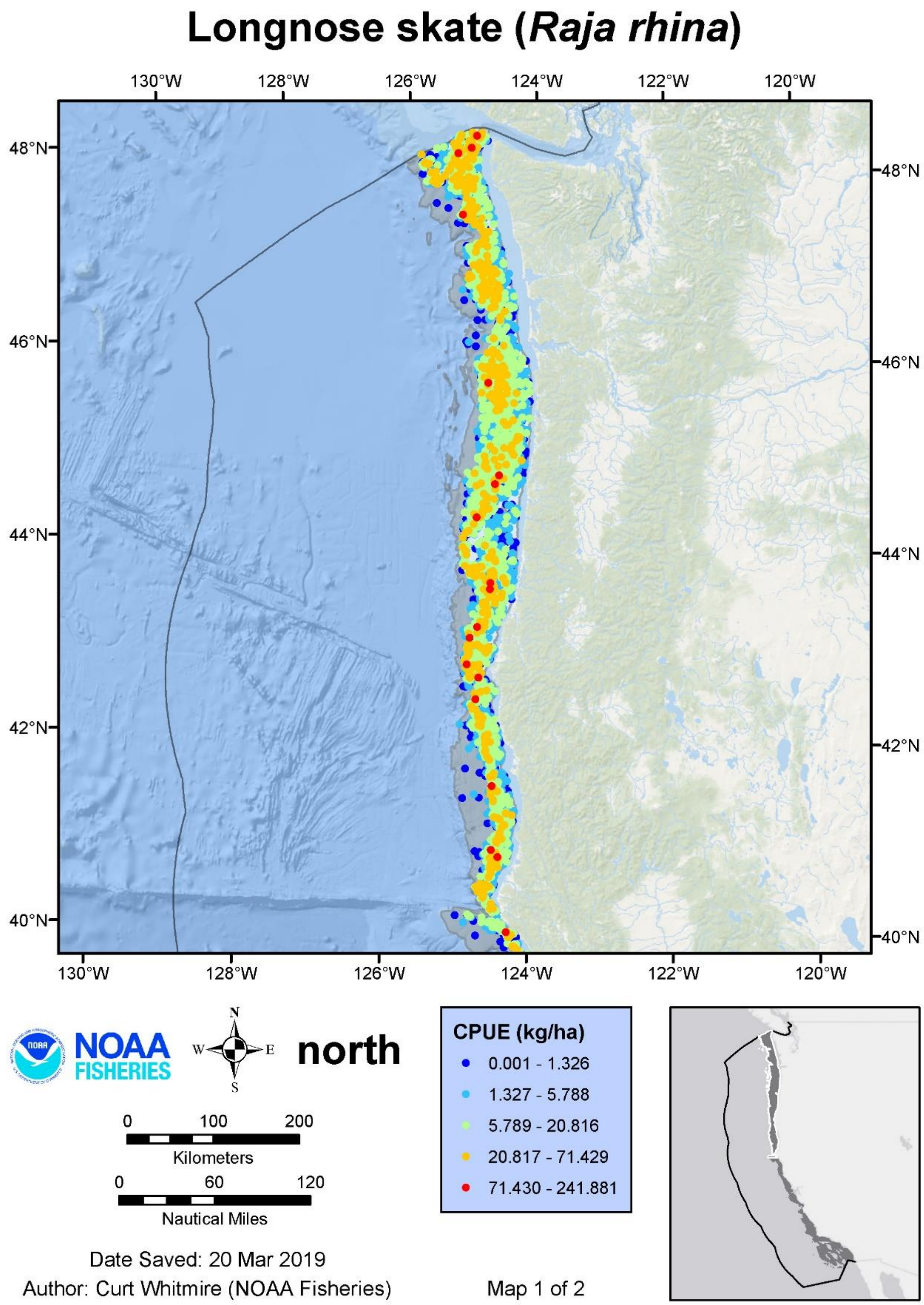

Figure 5. Spatial distribution of Longnose Skate catch in the NWFSC West Coast Groundfish Bottom Trawl Survey g (2003-2018), in the northern area.

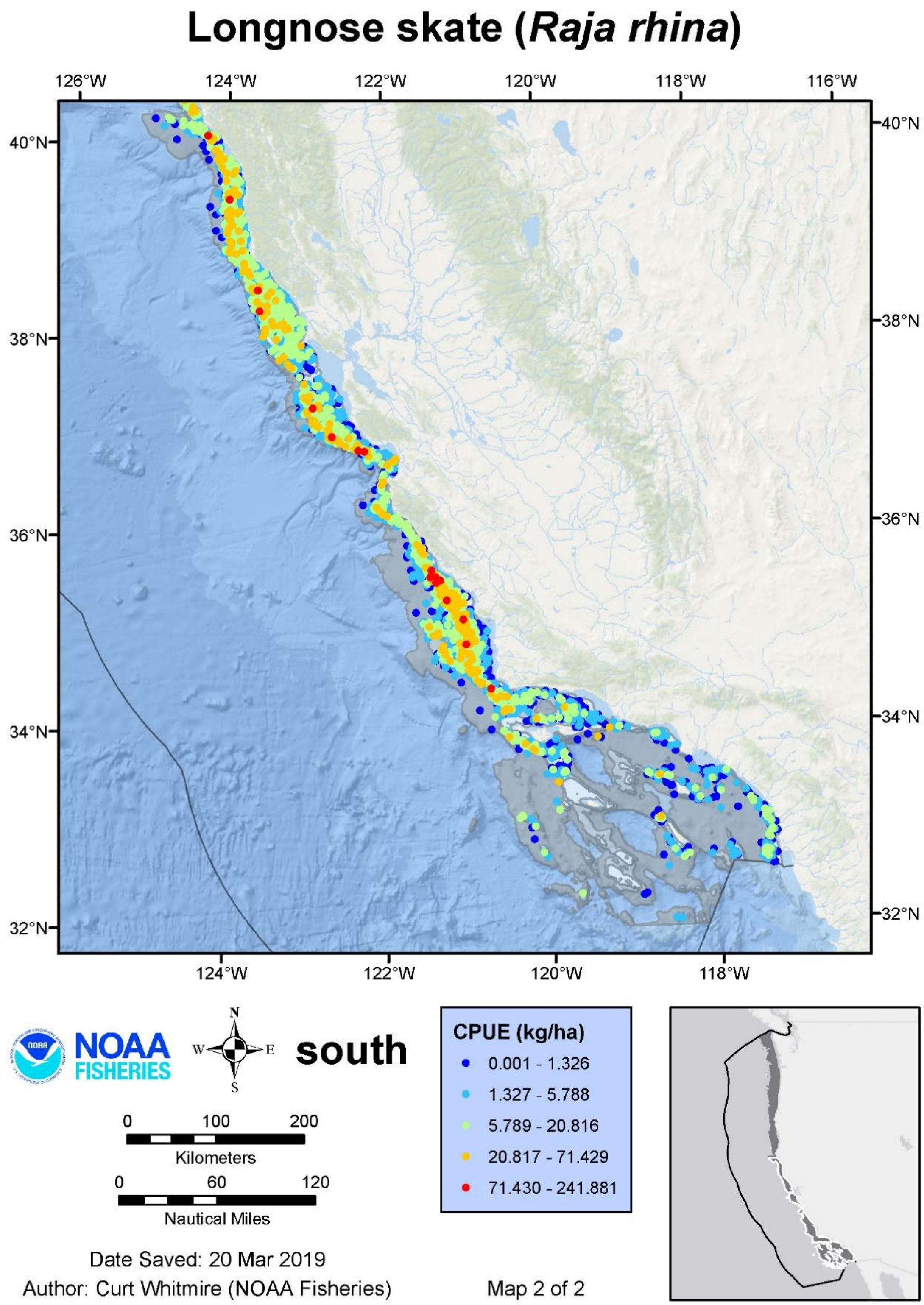

Figure 6. Spatial distribution of Longnose Skate catch in the NWFSC West Coast Groundfish Bottom Trawl Survey (2003-2018), in the southern area.

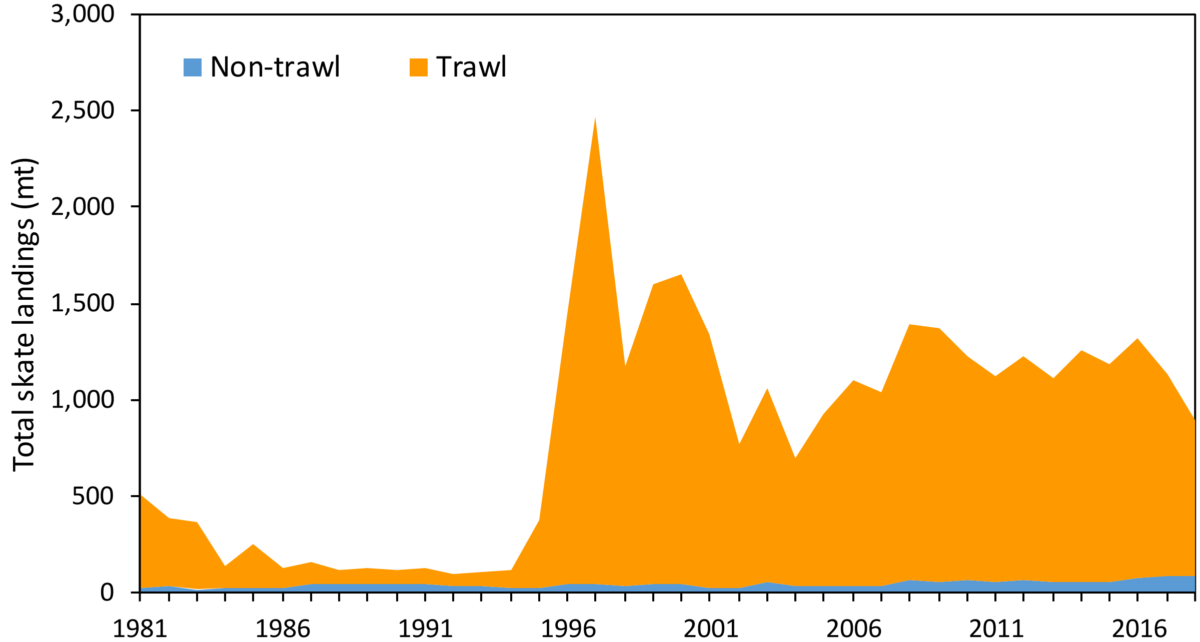

Figure 7. Total skate landings on the West Coast of the United States by gear.

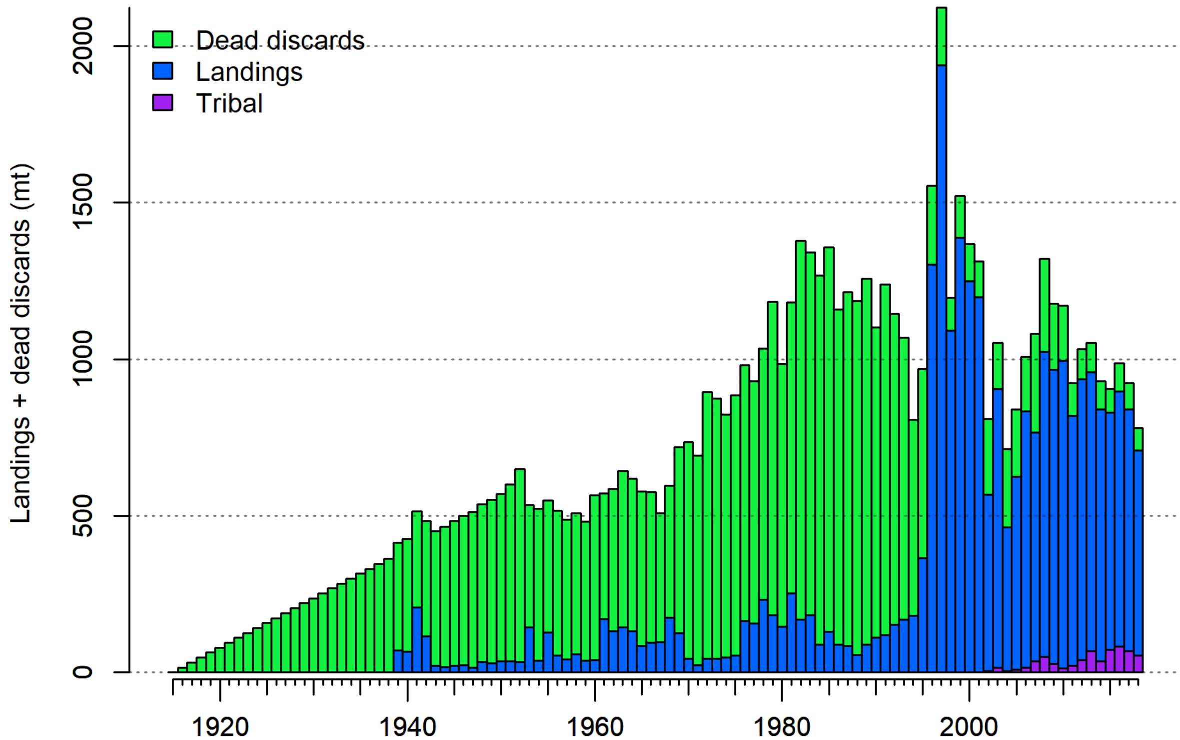

Figure 8. Longnose Skate catch time series, as used in the assessment. For historical period (1916-1994) landings and dead discard amounts are “hardwired” in the model. For the current period (1995-2018) landings are “hardwired”, discard rates are estimated within the model, and a 50% discard mortality rate is applied within the model. Tribal fishery removals are included separately.

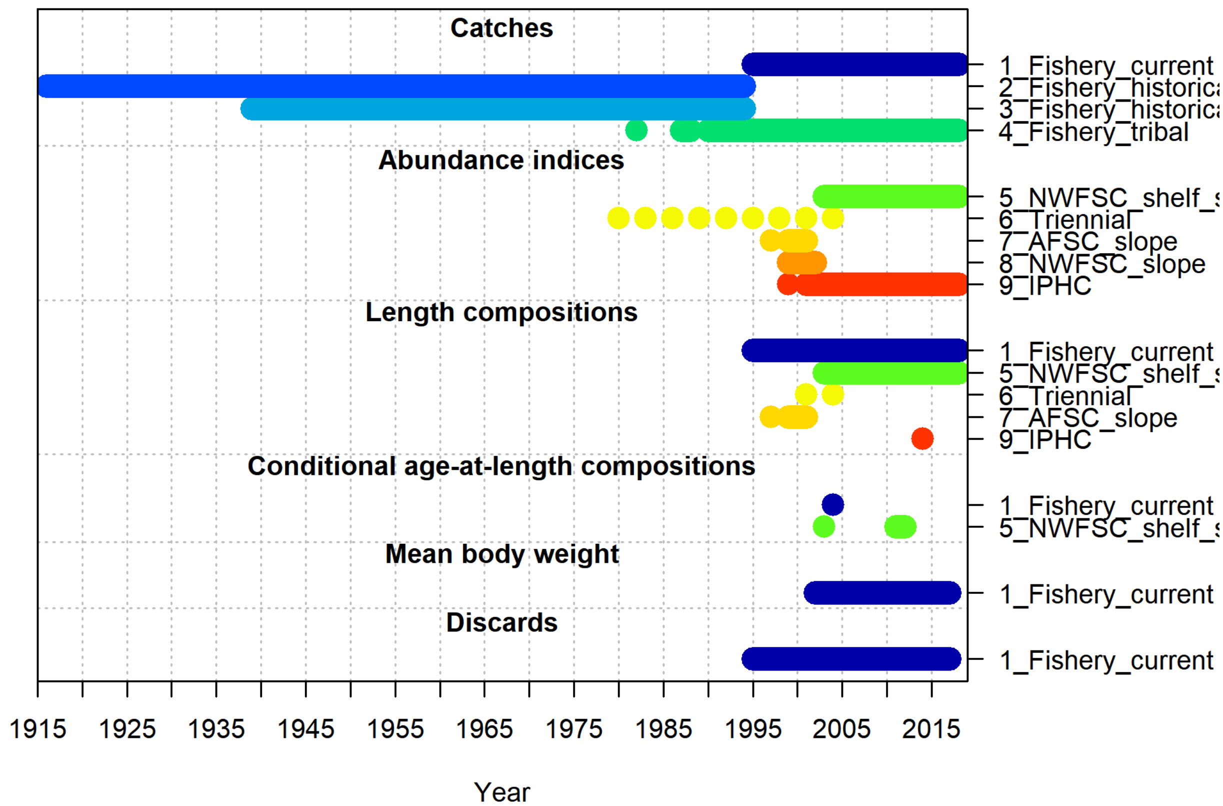

Figure 9. Summary of sources and data used in the assessment.

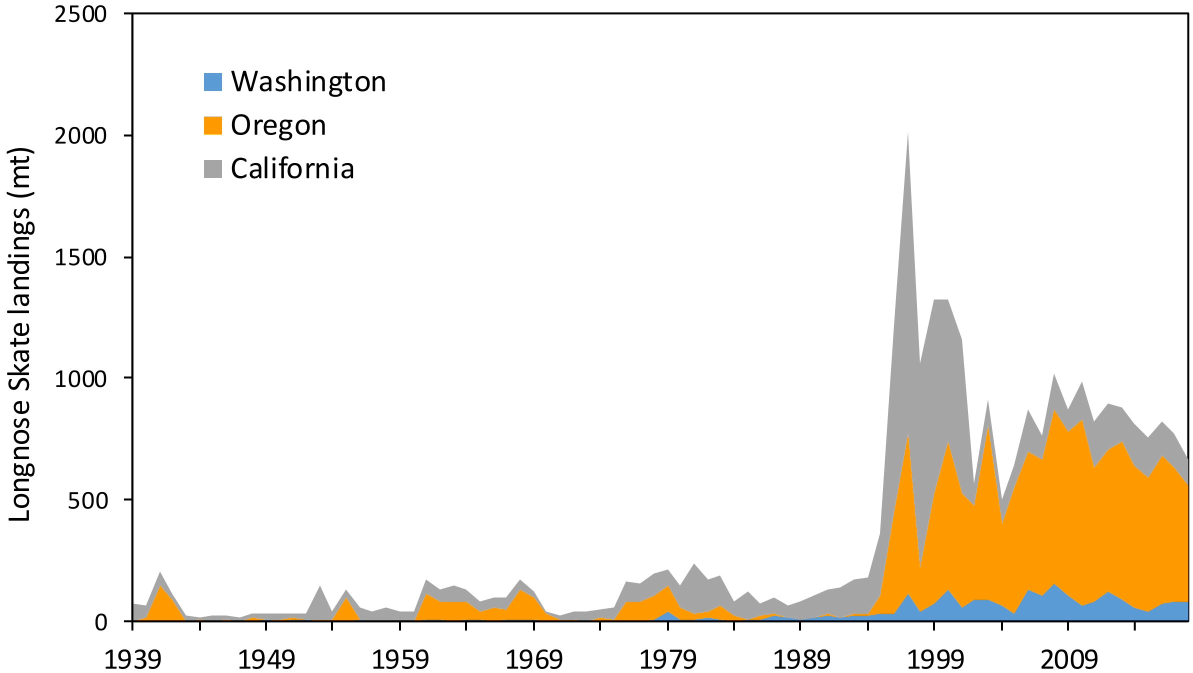

Figure 10. Estimated landings of the Longnose Skate by state.

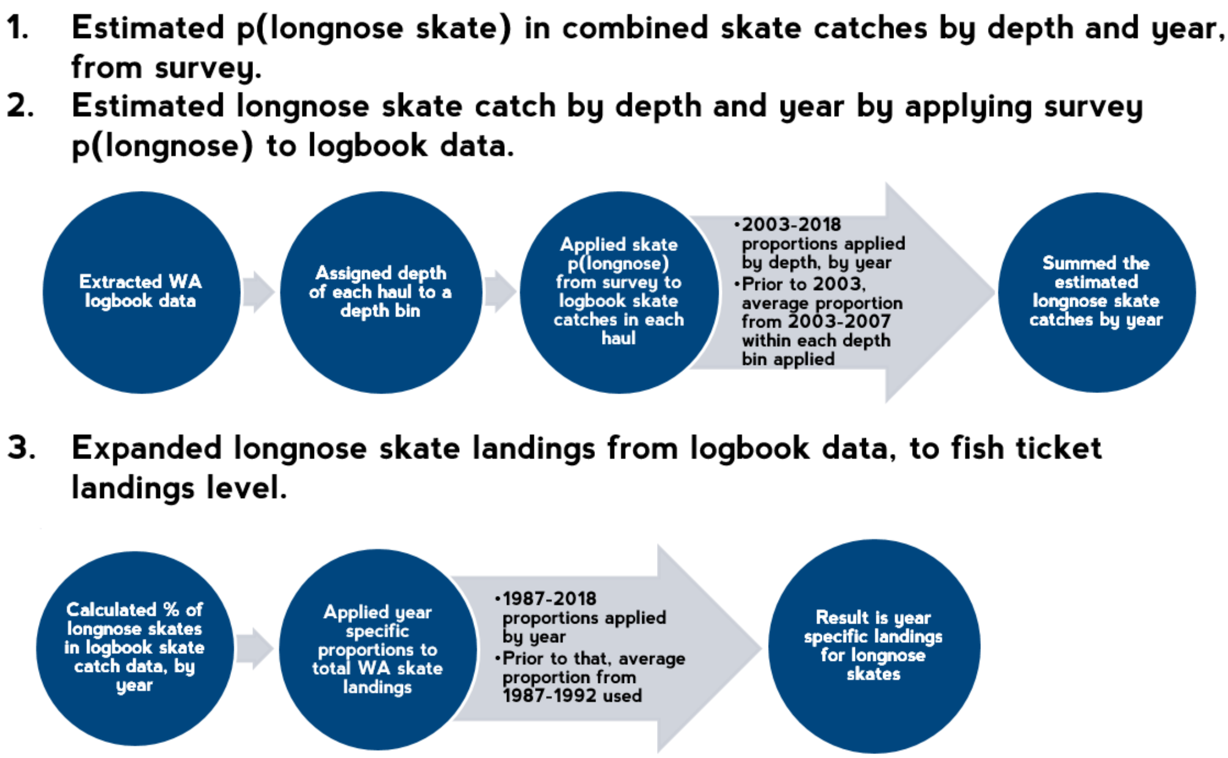

Figure 11. Algorithm used to estimated Longnose Skate landings in Washington coastal waters.

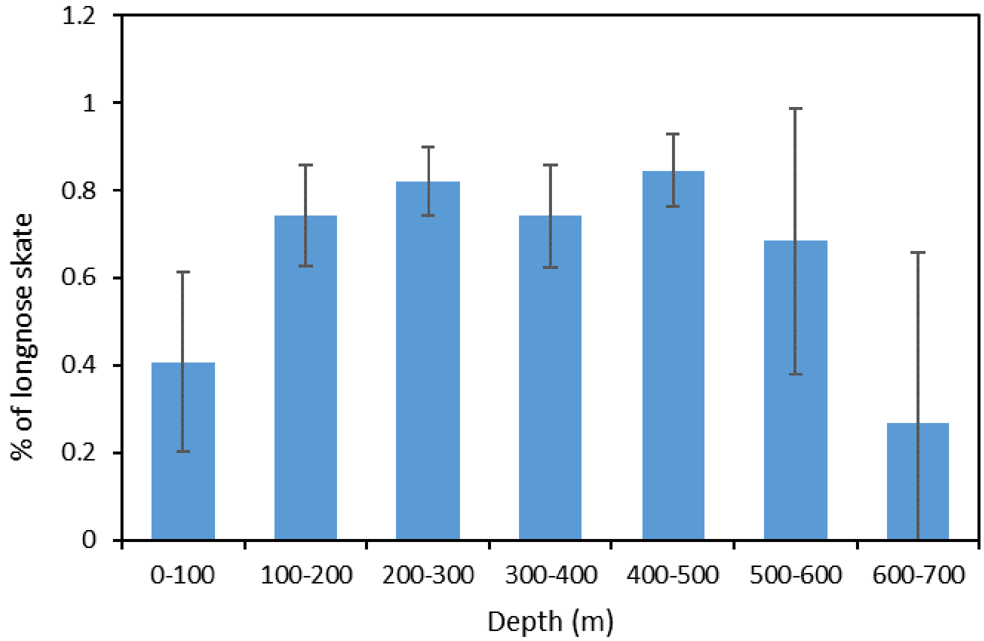

Figure 12. Percentage of Longnose Skate in all skate catch by depth bin, as observed in WCGBT Survey.

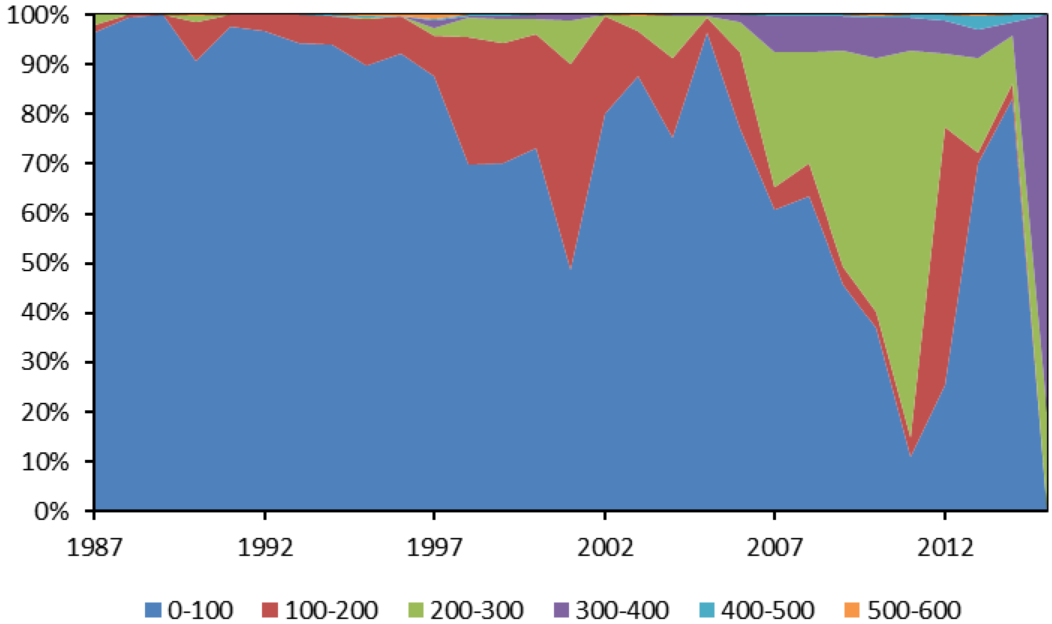

Figure 13. Percentage of total skate catch by depth in Washington coastal waters as reported in trawl logbooks.

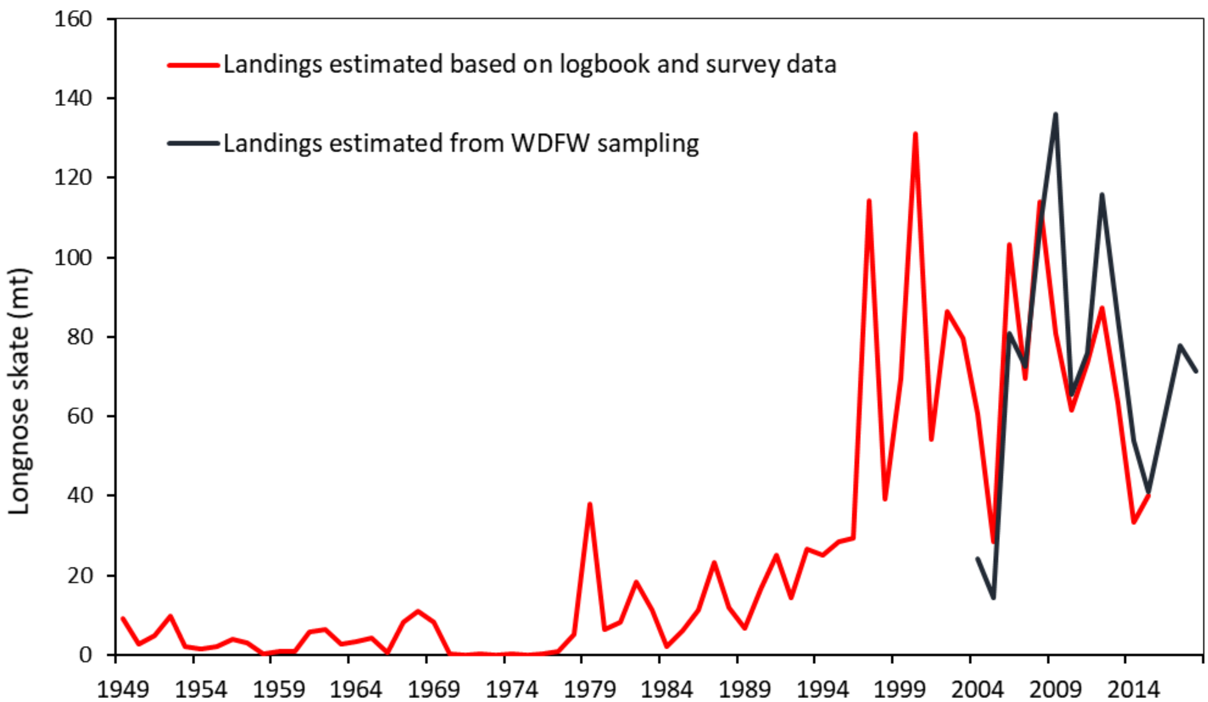

Figure 14. Comparison of reconstructed Longnose Skate landings based on combination of survey and logbook data with estimated from available WDFW species composition sampling.

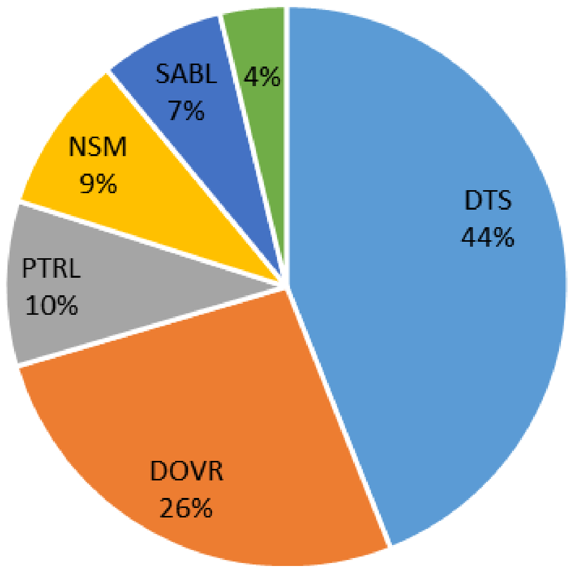

Figure 15. Percentage of Longnose Skate caught in difference groundfish fisheries target categories, as reported by WCGOP.

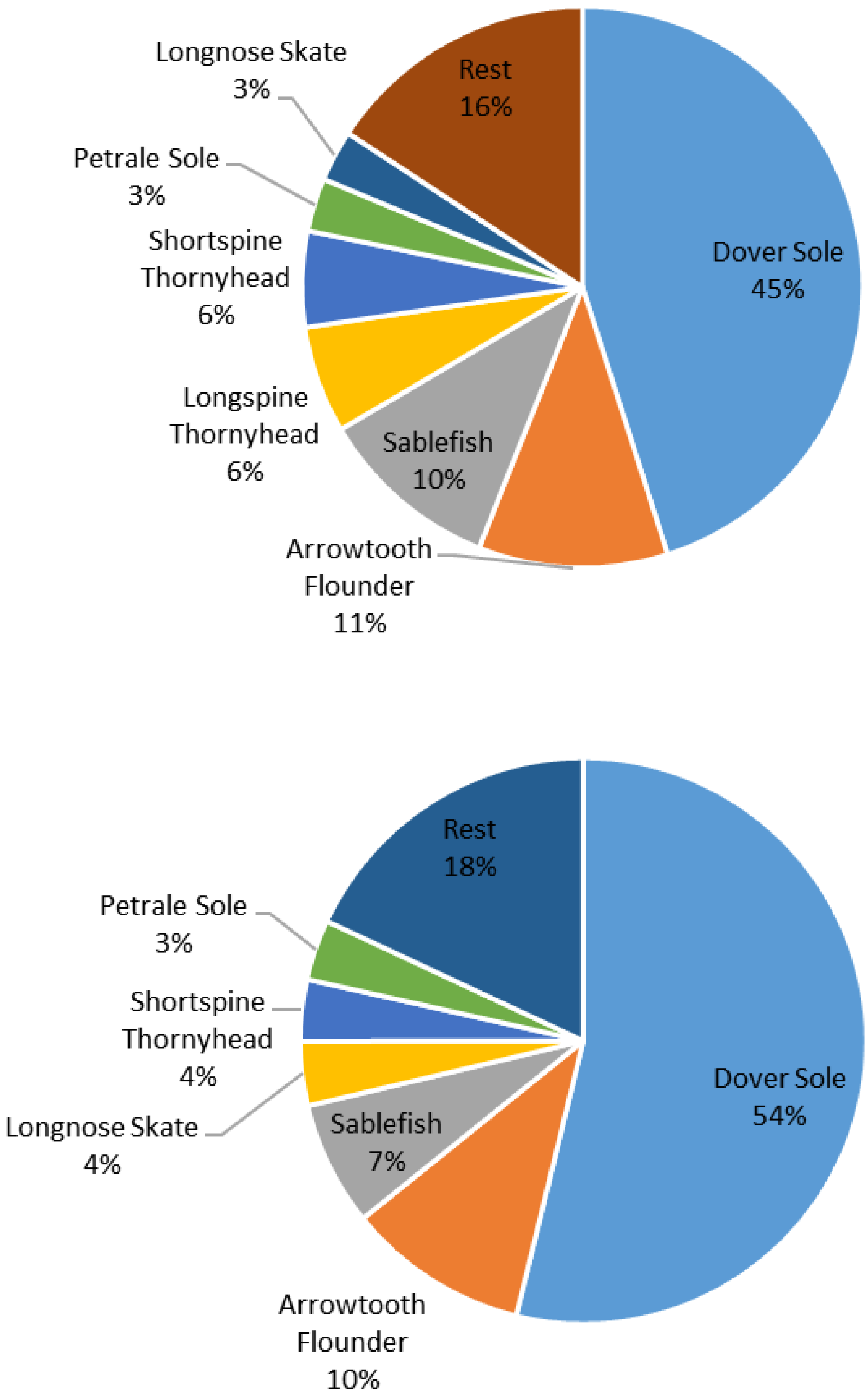

Figure 16. Percentage of species that contribute to Dover-Thornyheads-Sablefish (DTS, upper panel) and Dover sole (DOVR, lower panel) target categories.

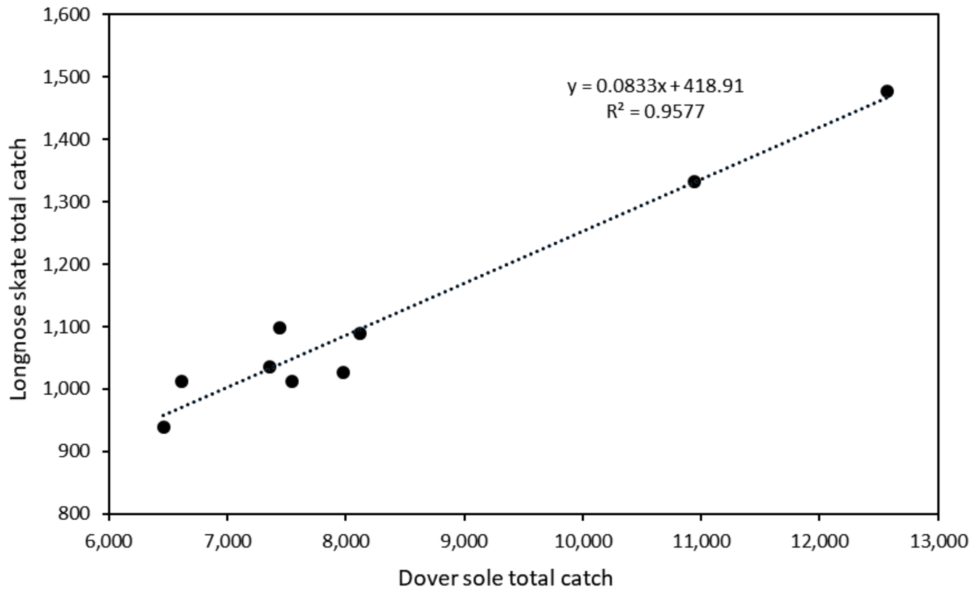

Figure 17. Relationship between total catch of Dover sole and total catch of Longnose Skate, estimated using WCGOP estimates for catch for both species, for 2009-2017.

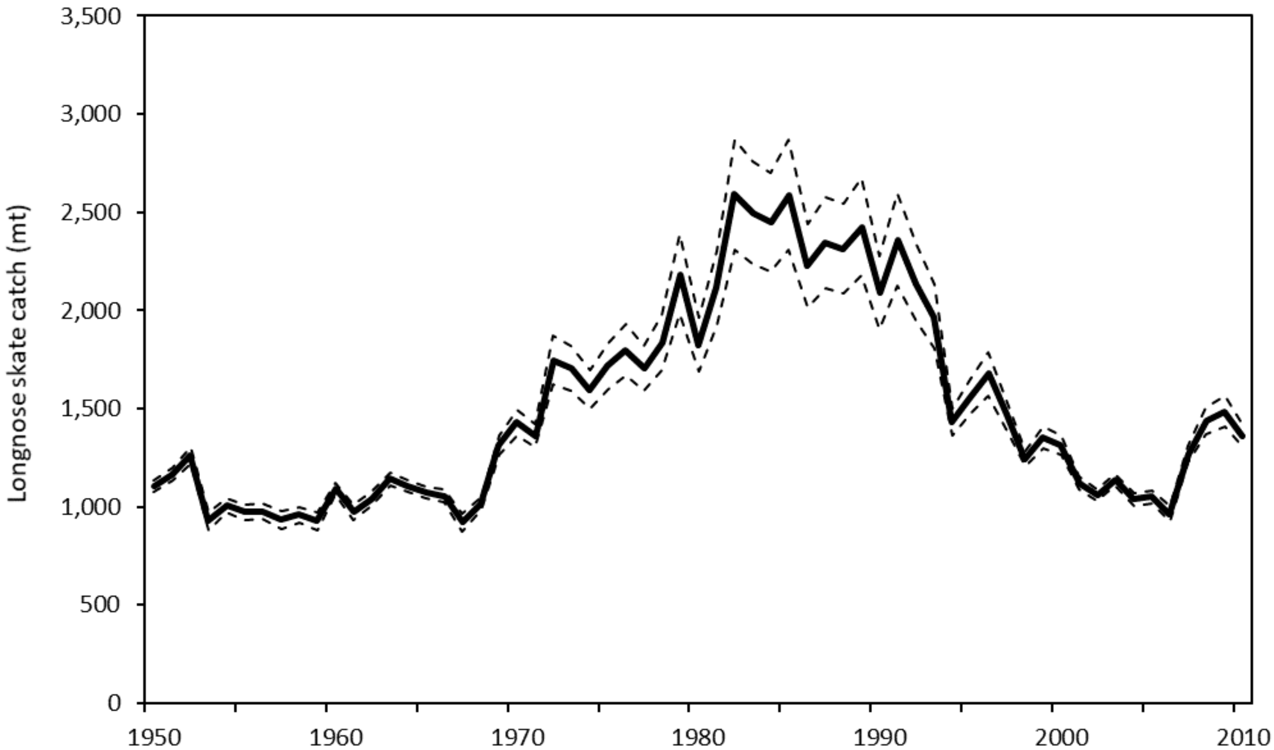

Figure 18. Total catch of Longnose Skate (black line) as estimated by the Dover sole catch based approach.

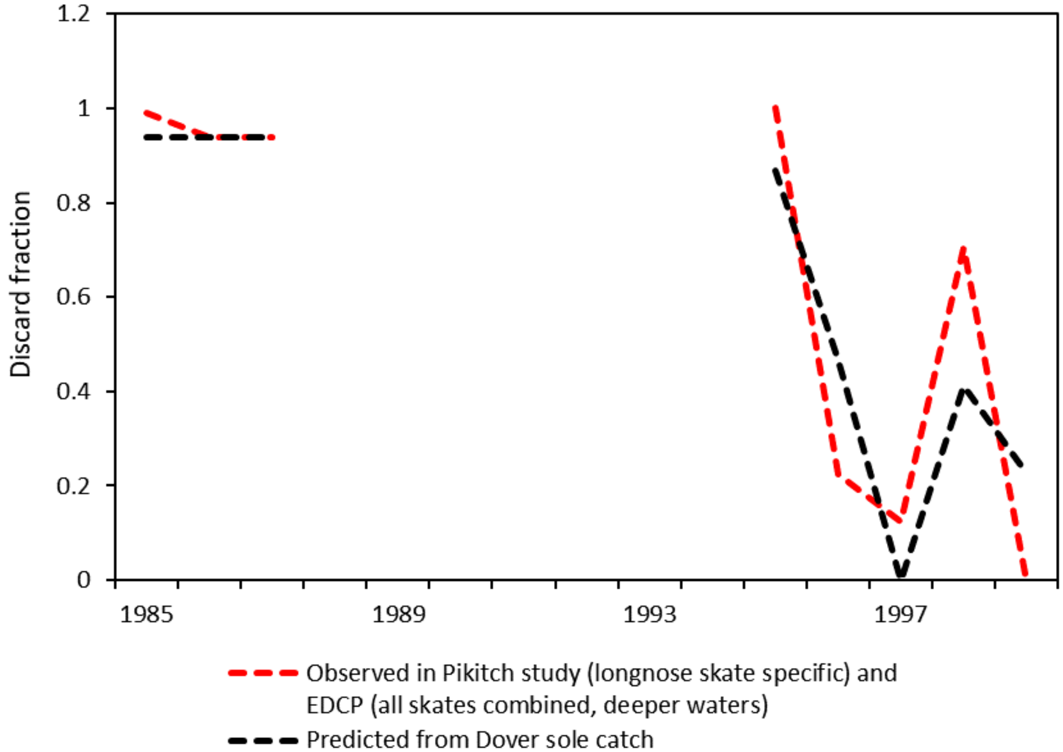

Figure 19. Comparison of estimated discard rates and observed rates in Pikitch study and EDCP. Pikitch study reports Longnose Skate specific discard, while EDCP reported discard of all skates combined.

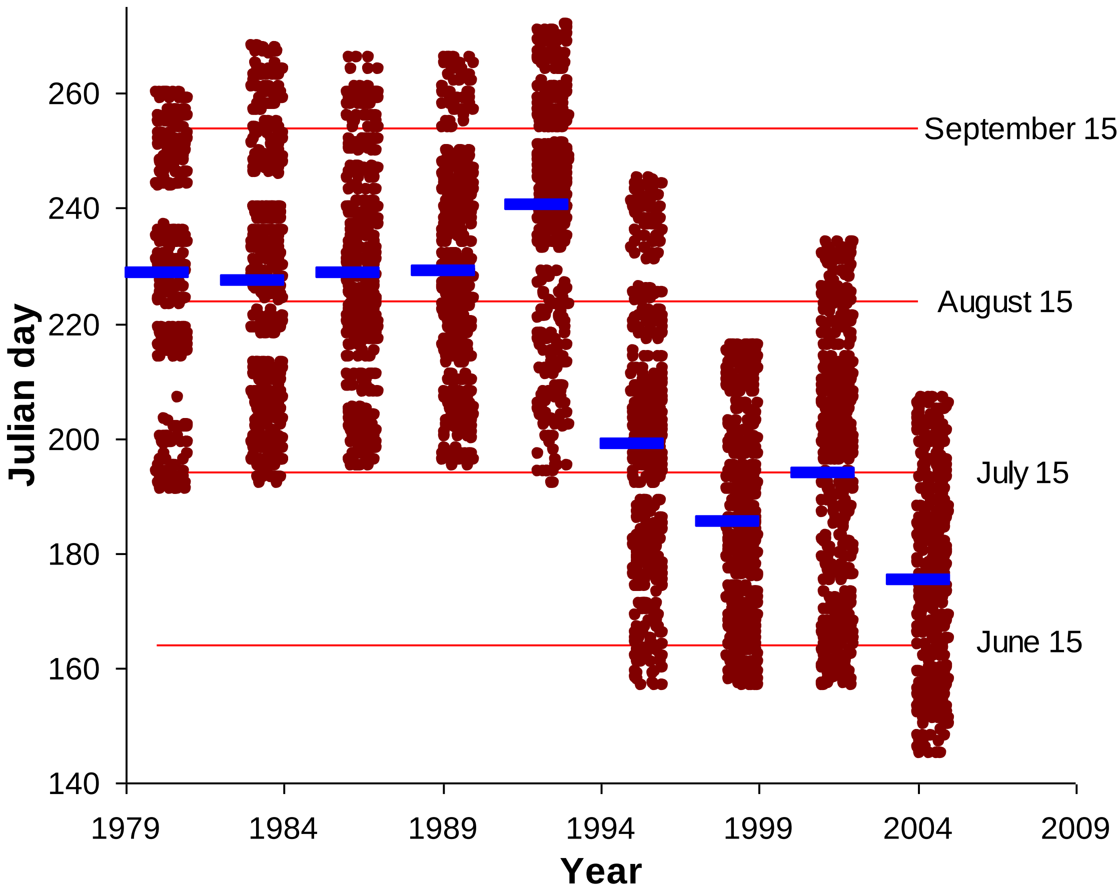

Figure 20. Distribution of dates of operation for the AFSC Triennial Survey (1980-2004). Solid bars show the mean date for each survey year, points represent individual hauls dates, but are jittered to allow better delineation of the distribution of individual points.

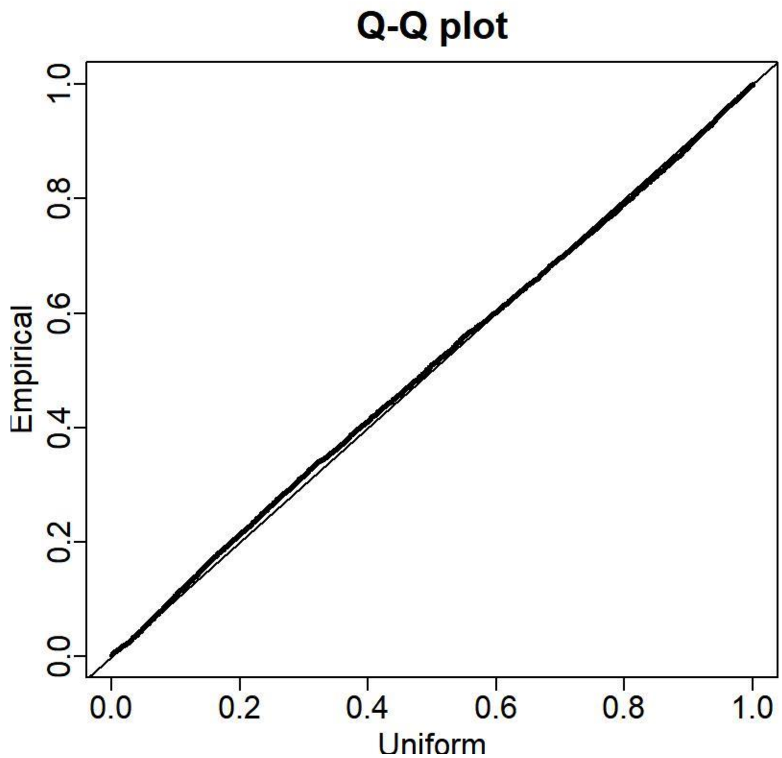

Figure 21. Q-Q plot for gamma model used in VAST for the WCGBT Survey.

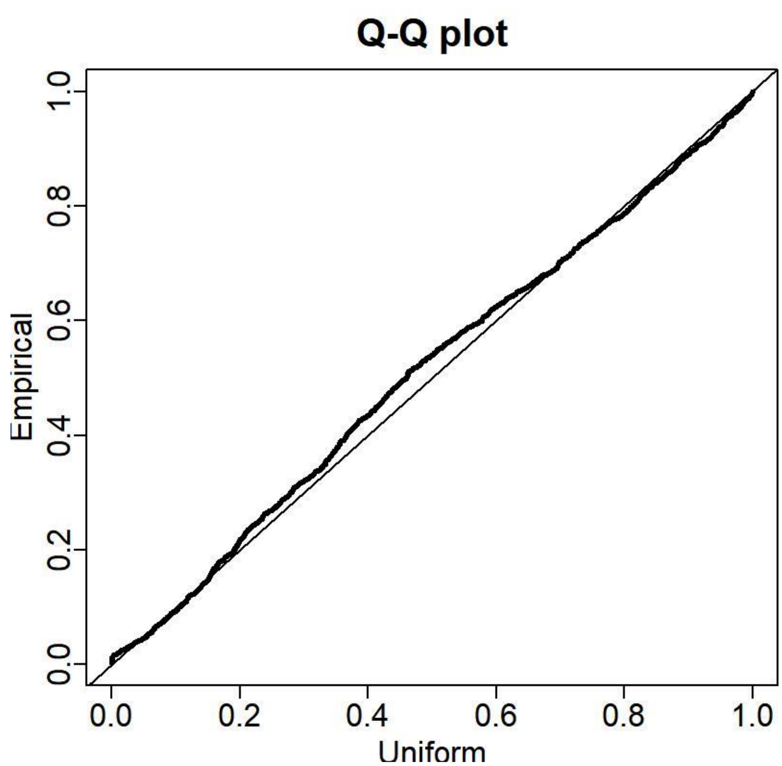

Figure 22. Q-Q plot for gamma model used in VAST for the AFSC Triennial Survey.

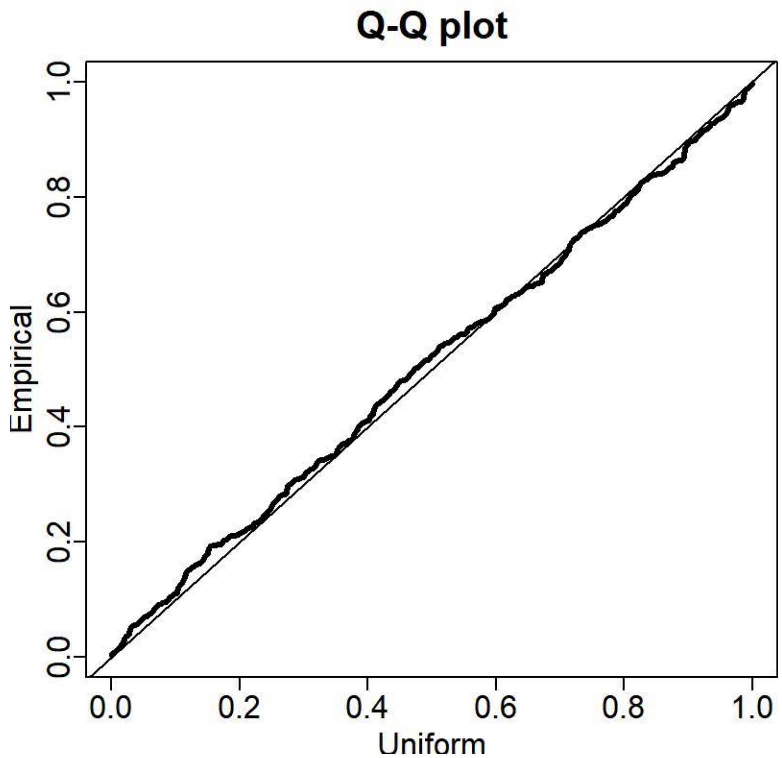

Figure 23. Q-Q plot for gamma model used in VAST for the AFSC Slope survey.

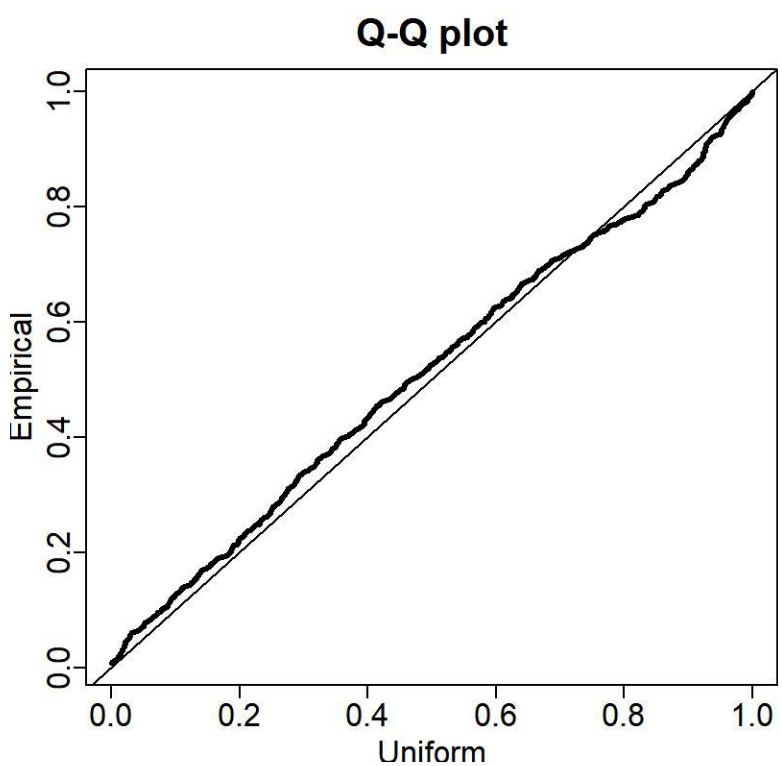

Figure 24. Q-Q plot for gamma model used in VAST for the NWFSC Slope survey.

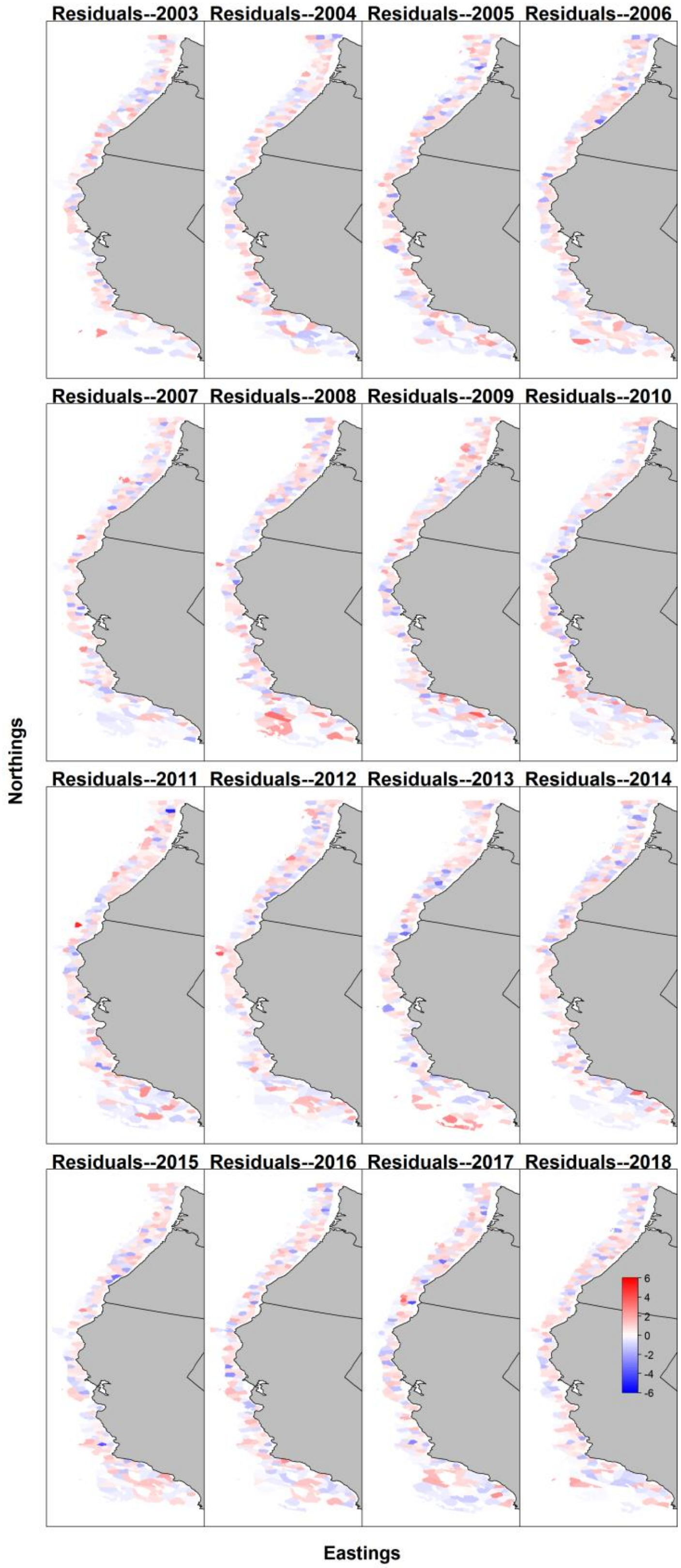

Figure 25. Pearson residuals for encounter probability of Longnose Skate in WCGBT Survey associated with each knot.

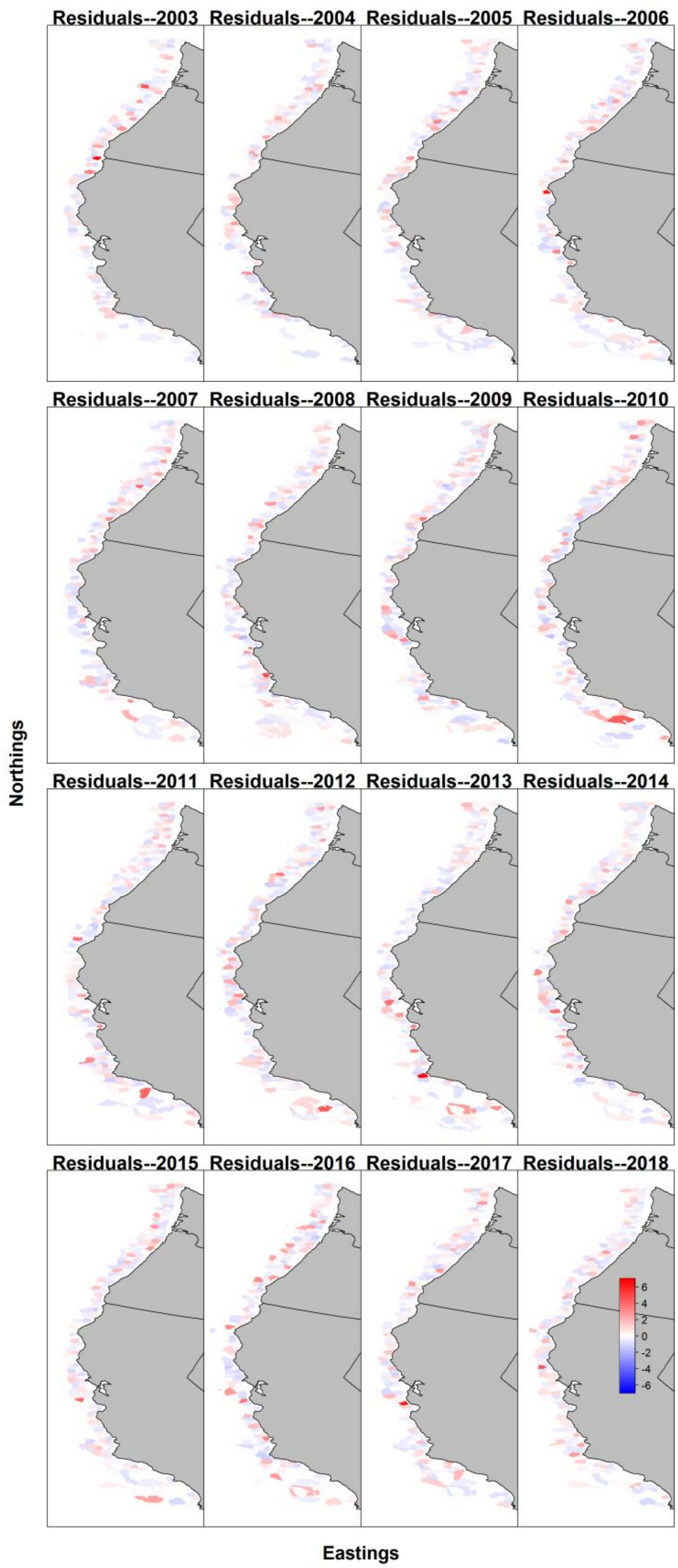

Figure 26. Pearson residuals for catch rate of Longnose Skate in WCGBT Survey associated with each knot.

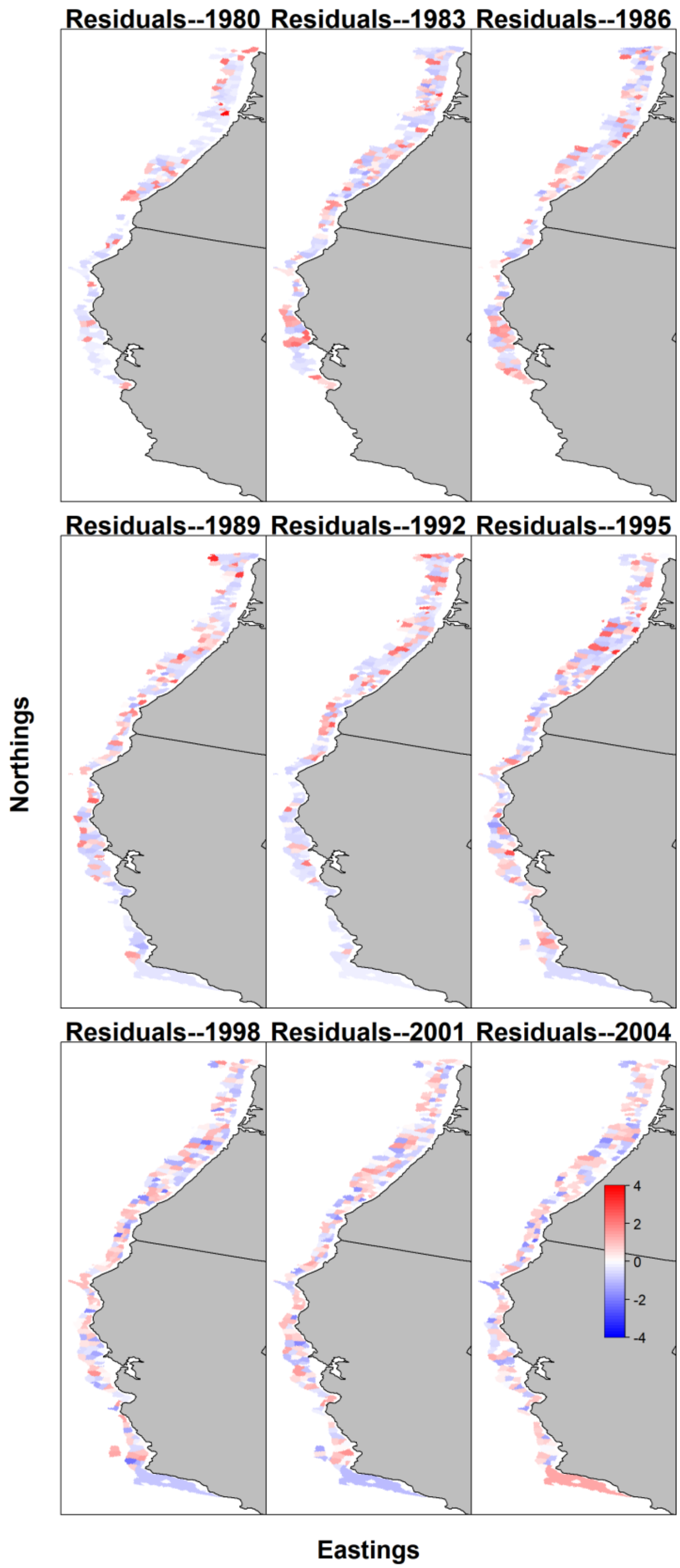

Figure 27. Pearson residuals for encounter probability of Longnose Skate in AFSC Triennial Survey associated with each knot.

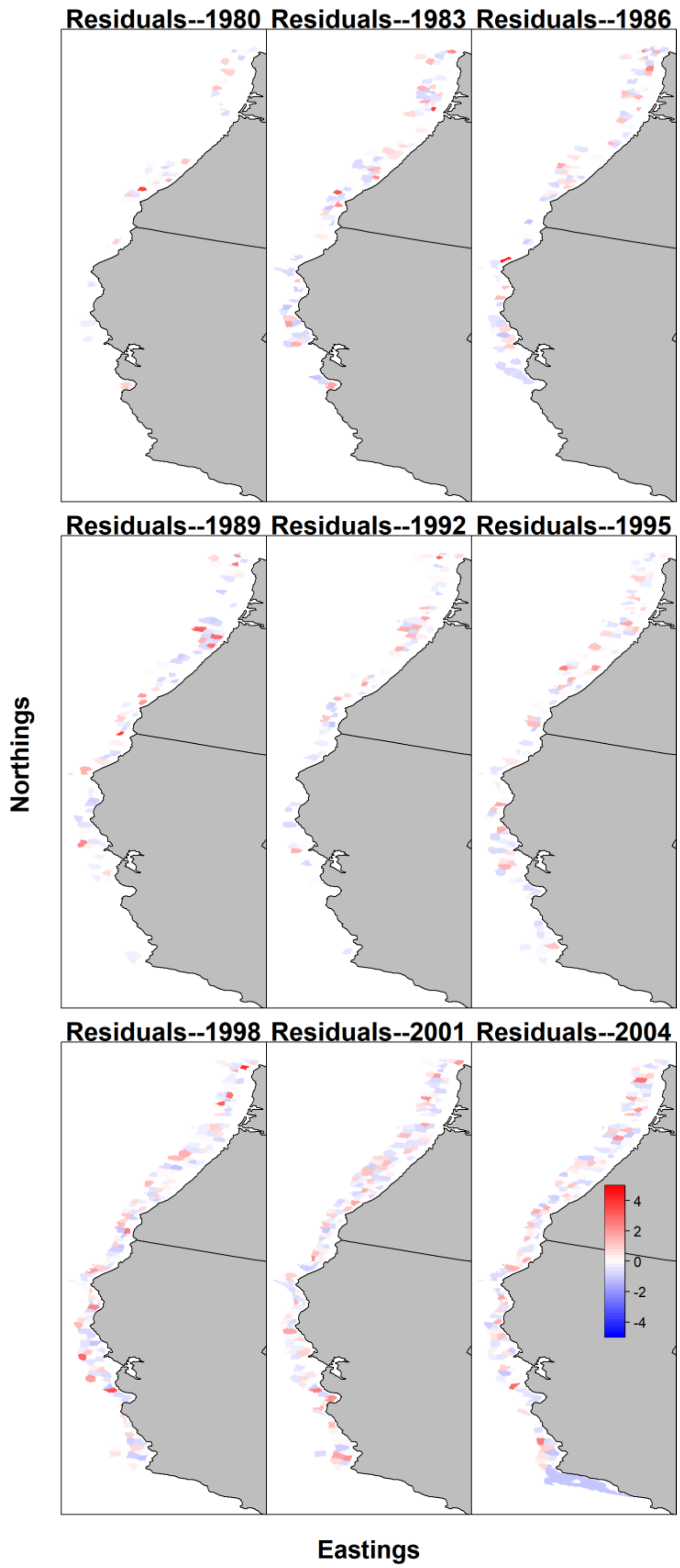

Figure 28. Pearson residuals for positive catch rates of Longnose Skate in AFSC Triennial Survey associated with each knot.

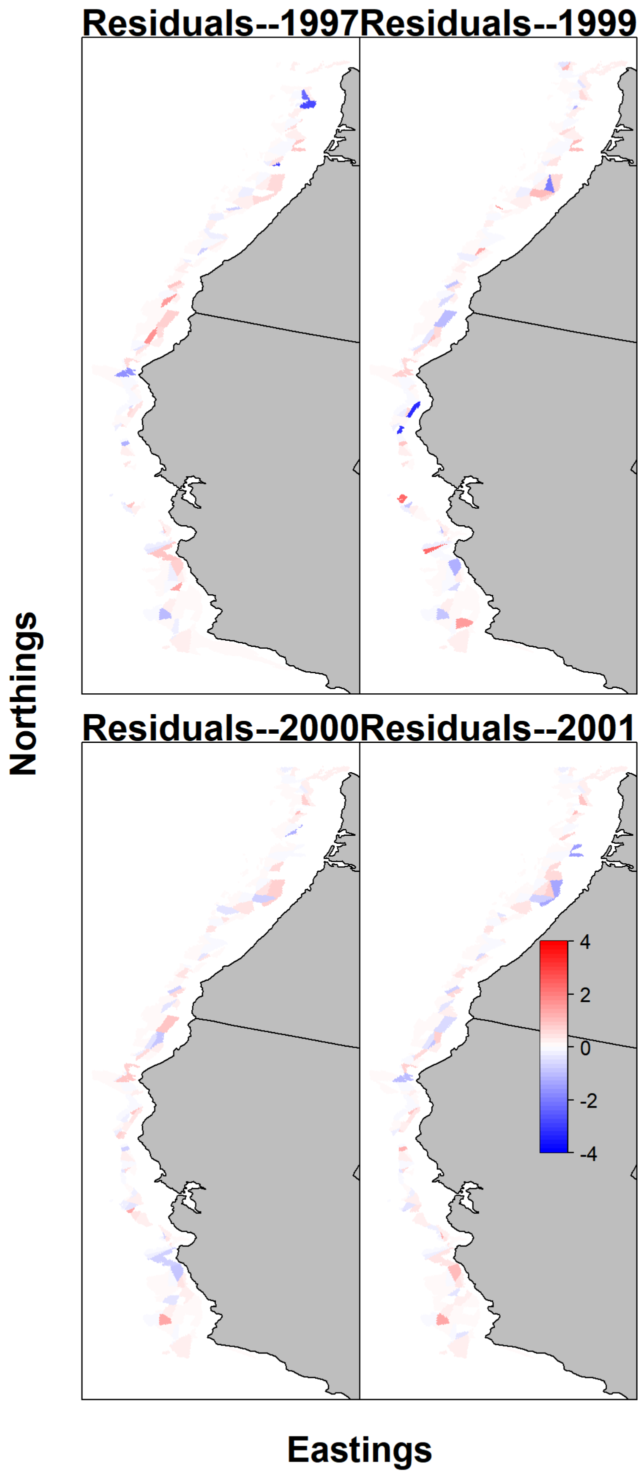

Figure 29. Pearson residuals for encounter probability of Longnose Skate in AFSC Slope Survey associated with each knot.

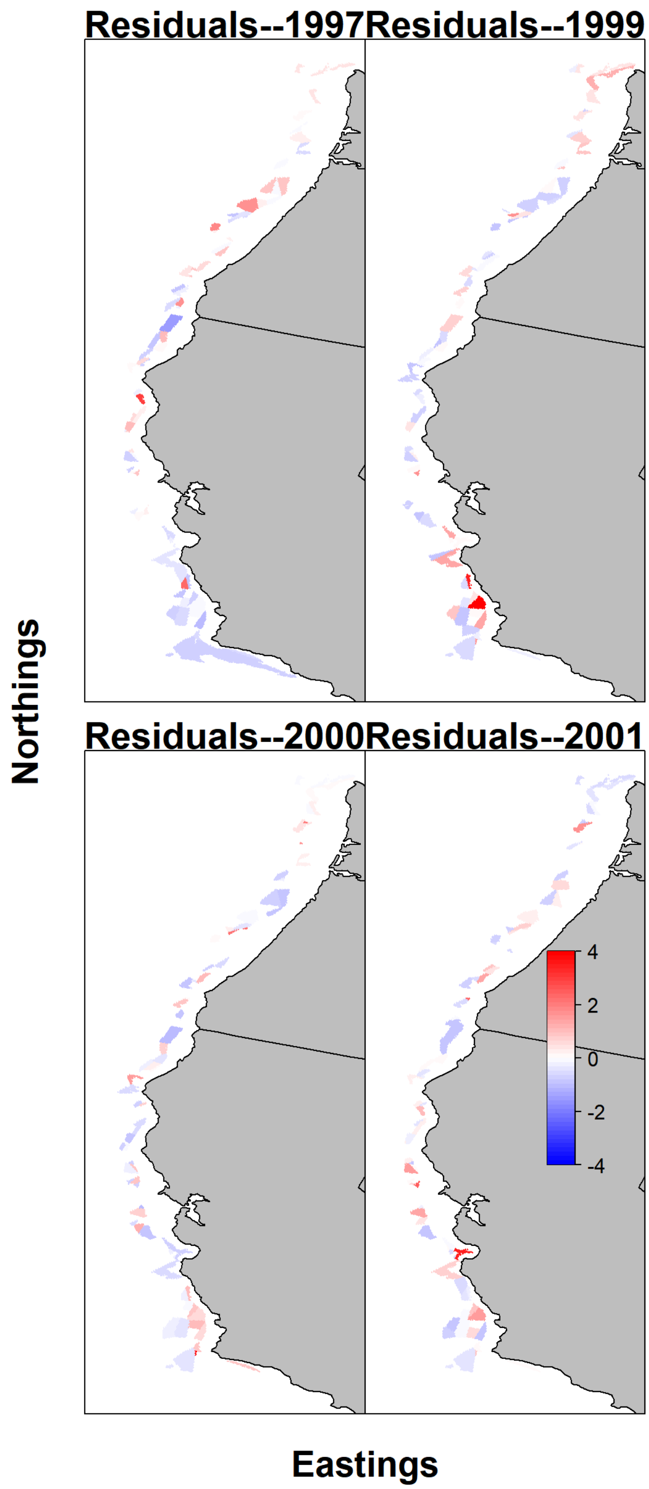

Figure 30. Pearson residuals for positive catch rates of Longnose Skate in AFSC Slope Survey associated with each knot.

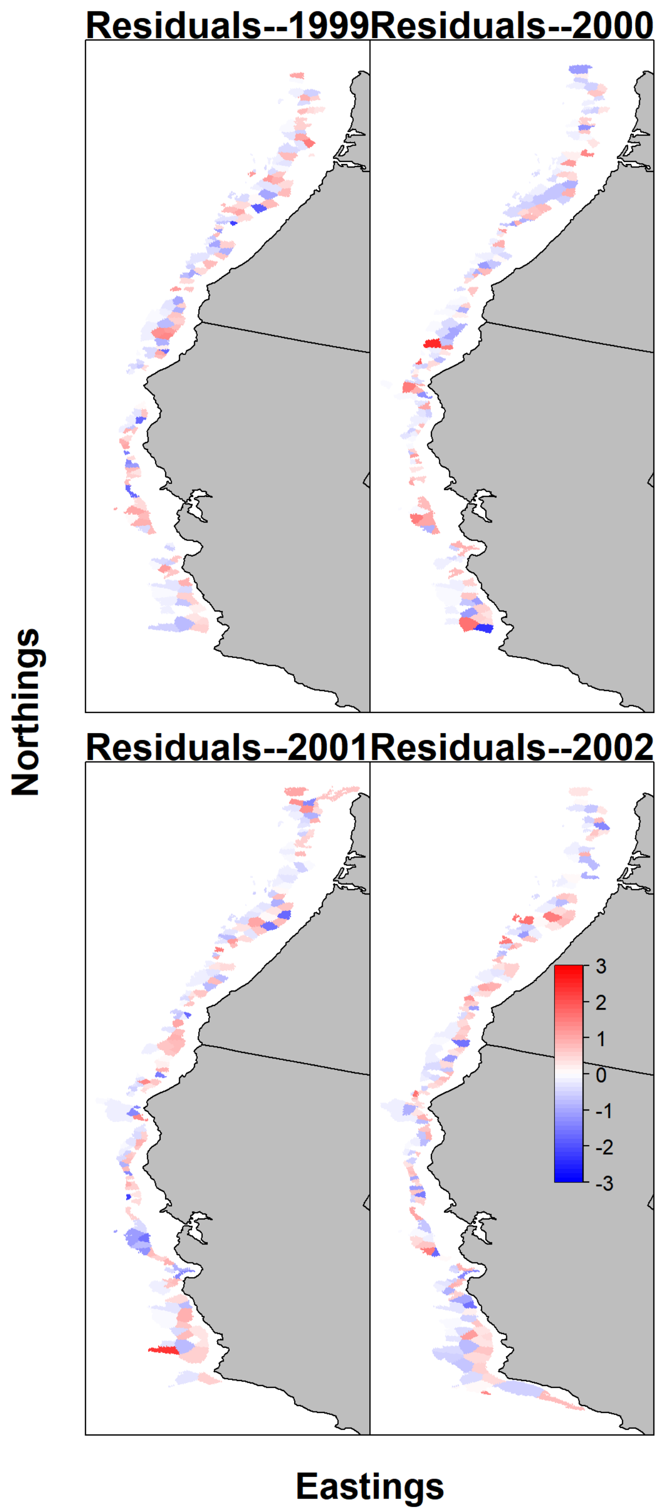

Figure 31. Pearson residuals for encounter probability of Longnose Skate in NWFSC Slope Survey associated with each knot.

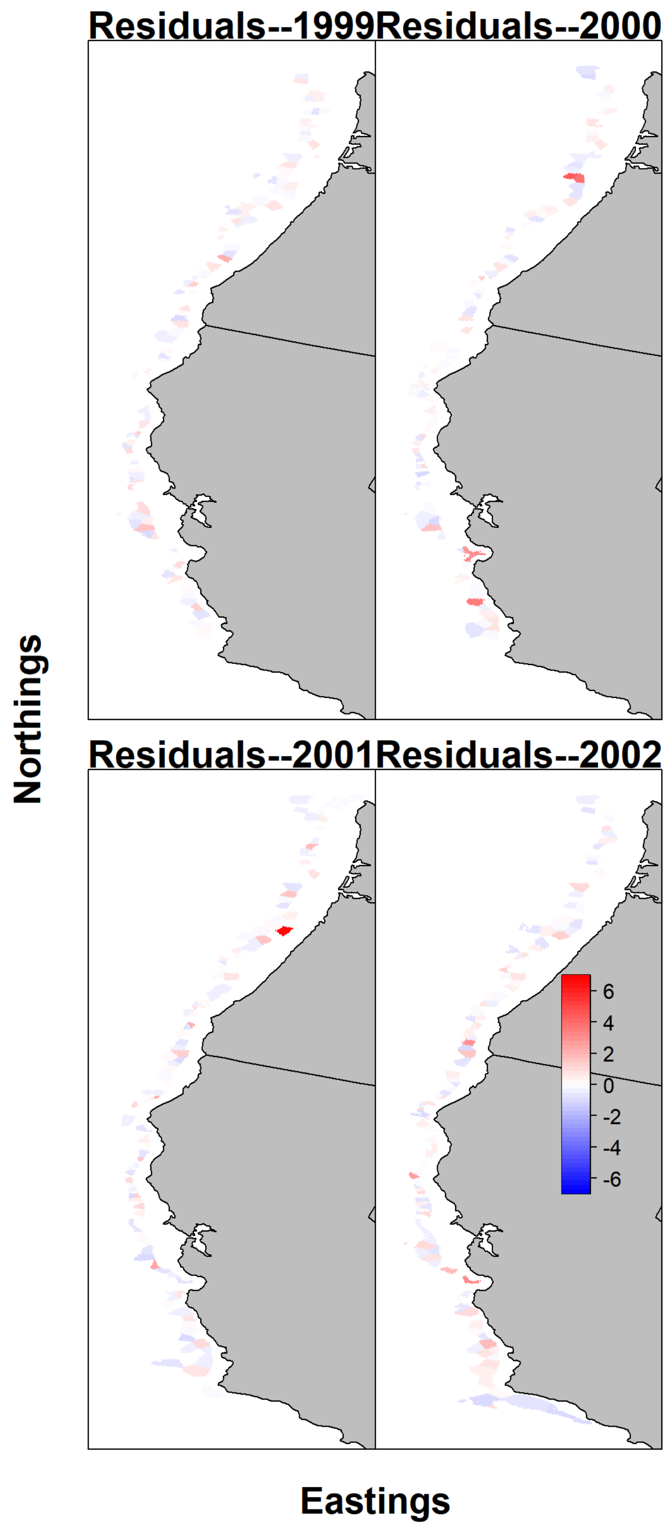

Figure 32. Pearson residuals for positive catch rates of Longnose Skate in NWFSC Slope Survey associated with each knot.

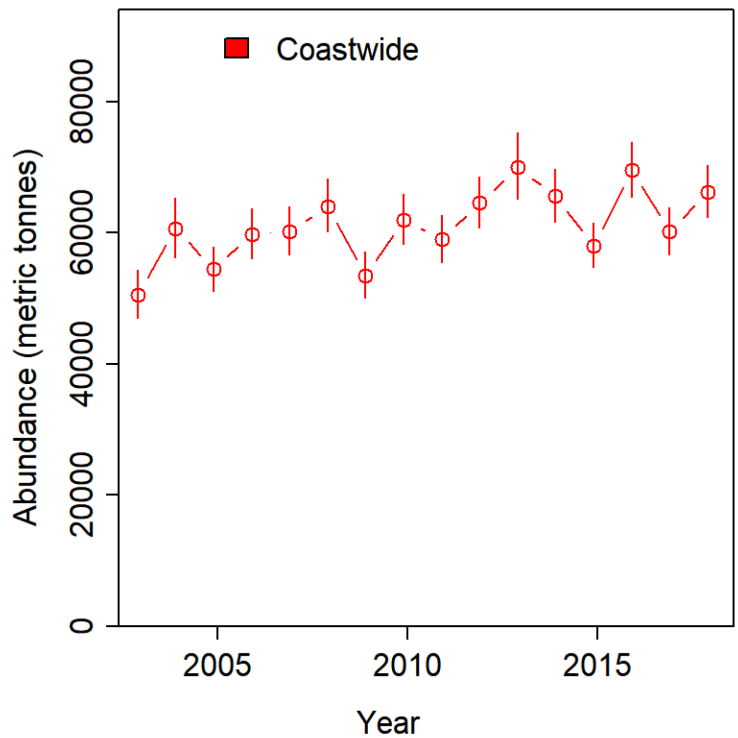

Figure 33. Estimated index of biomass for WCGBT Survey.

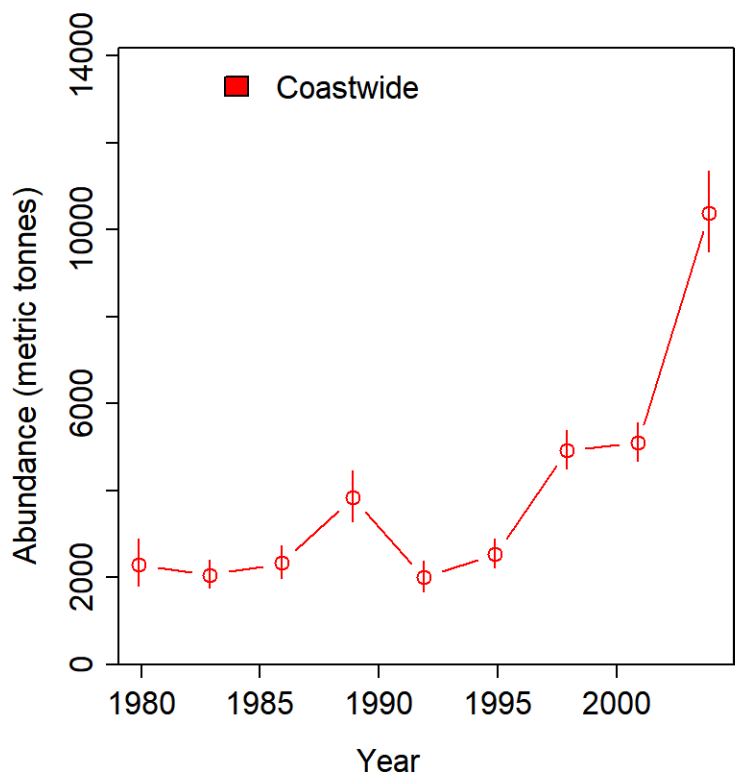

Figure 34. Estimated index of biomass for AFSC Triennial Survey.

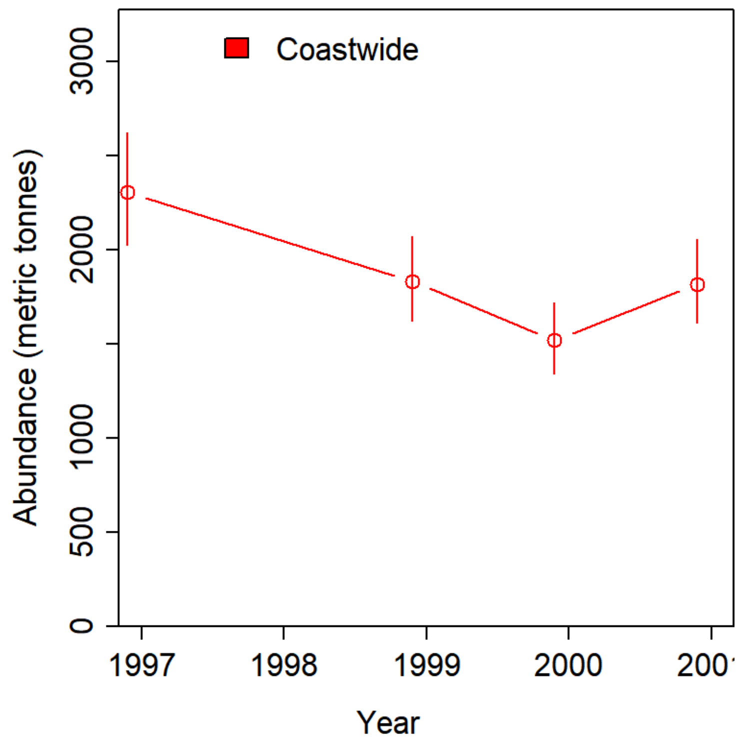

Figure 35. Estimated index of biomass for AFSC Slope survey

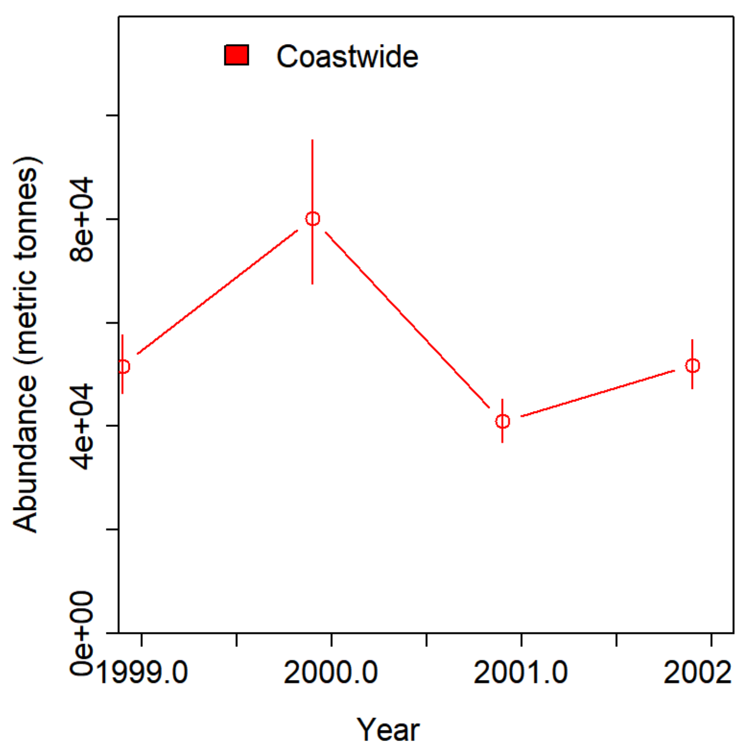

Figure 36. Estimated index of biomass for NWFSC Slope survey.

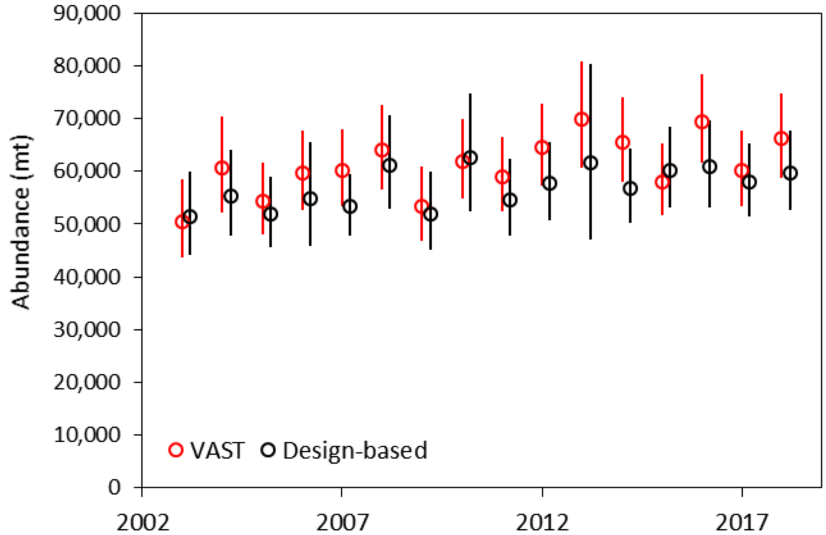

Figure 37. Comparison of WCGBT Survey index estimated using VAST with design-based swept area biomass estimates.

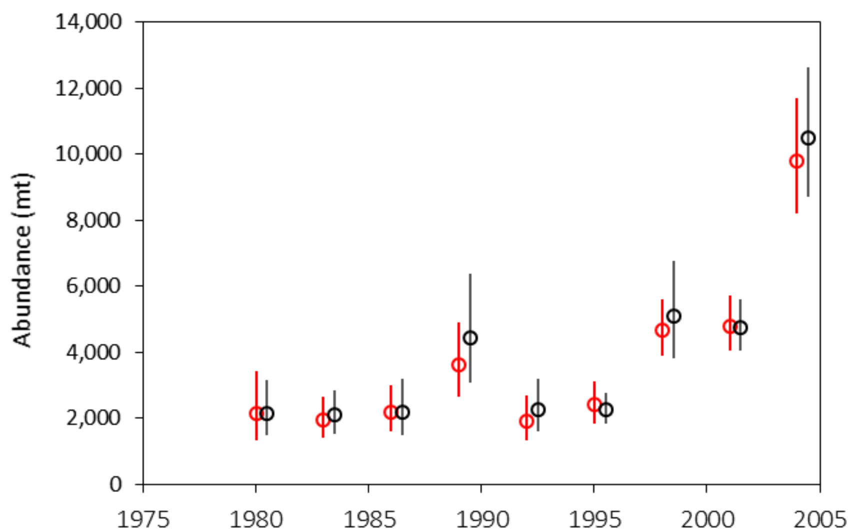

Figure 38. Comparison of AFSC Triennial Survey index estimated using VAST with design-based swept area biomass estimates.

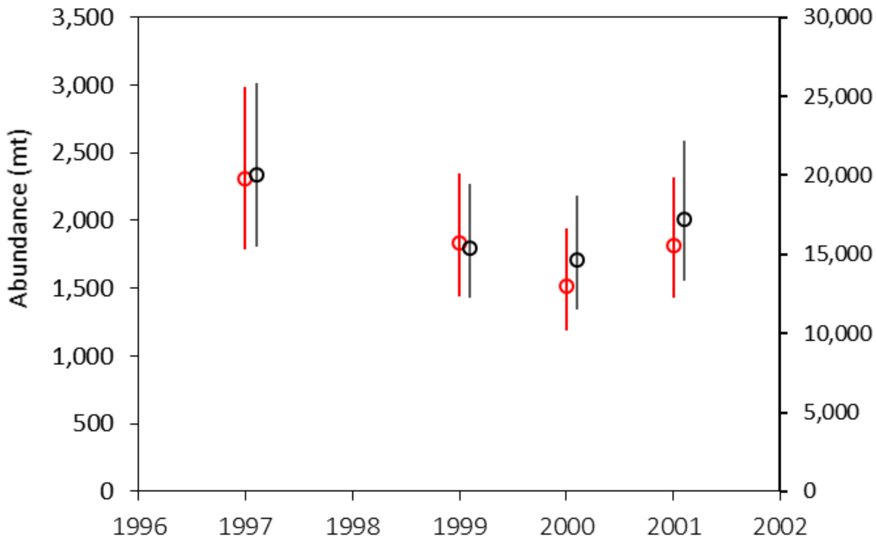

Figure 39. Comparison of AFSC Slope survey index estimated using VAST with design-based swept area biomass estimates.

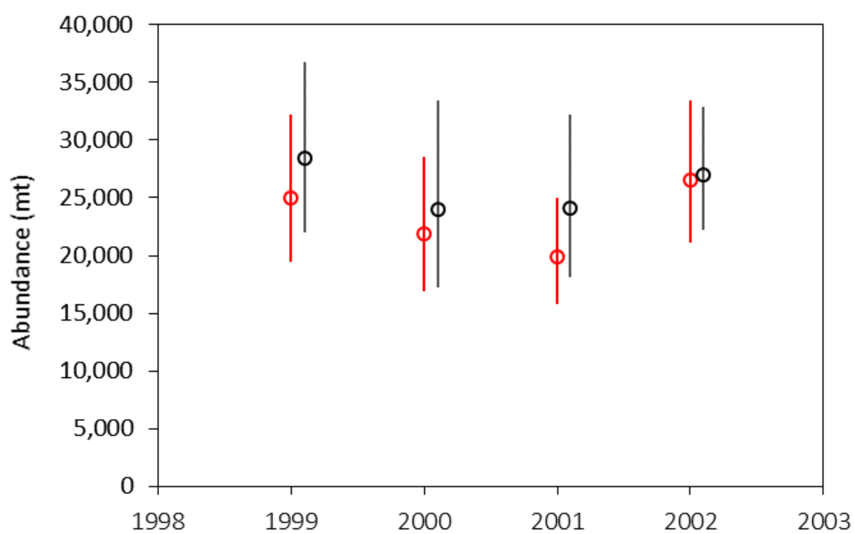

Figure 40. Comparison of NWFSC Slope survey index estimated using VAST with design-based swept area biomass estimates.

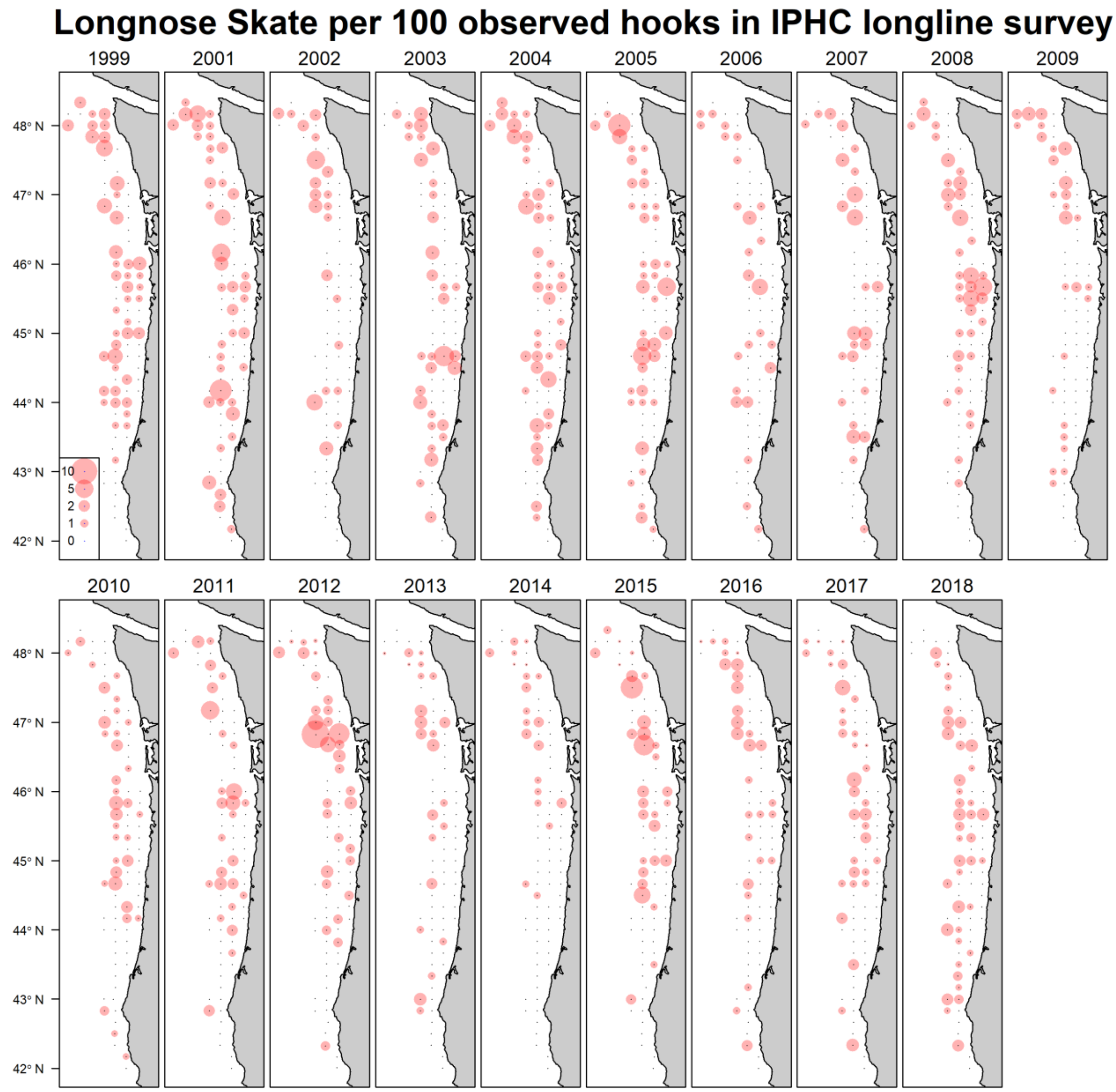

Figure 41. Spatial distribution of Longnose Skate catches by year within the International Pacific Halibut Commission (IPHC) hook-and-line survey (expressed as the number of Longnose Skates per 100 observed hooks).

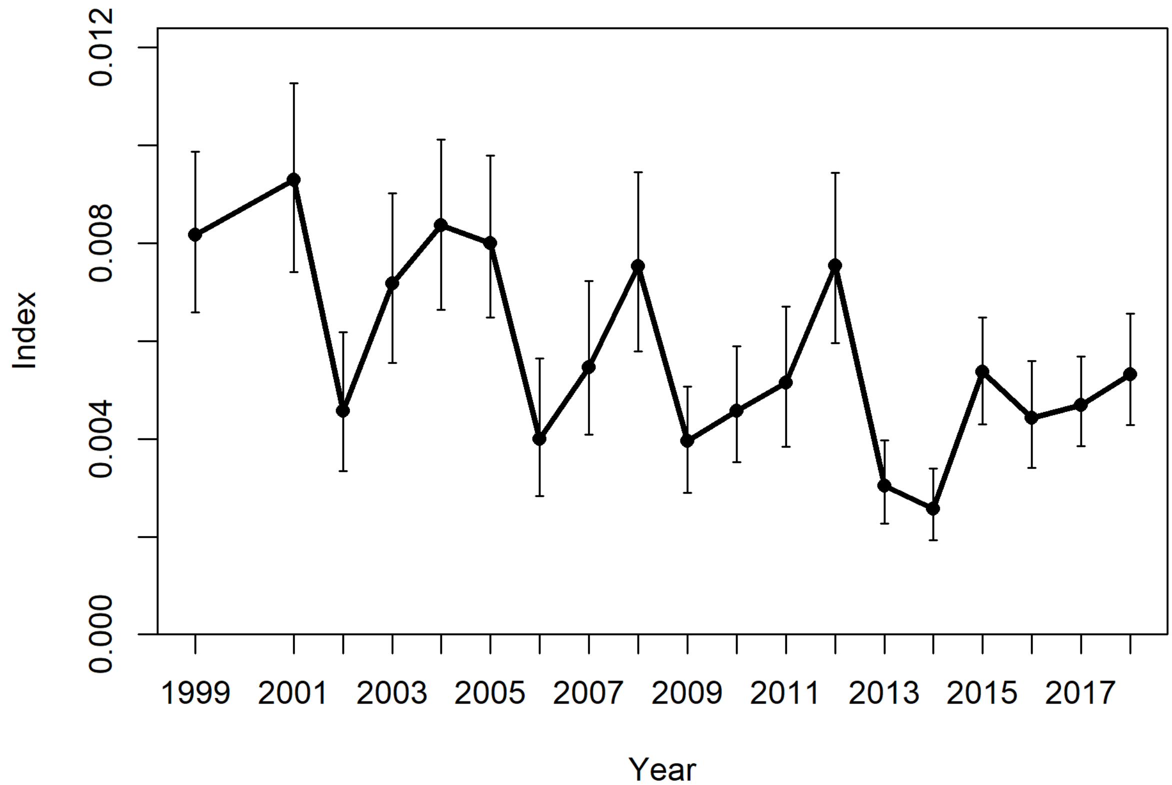

Figure 42. Estimated index of abundance for IPHC survey.

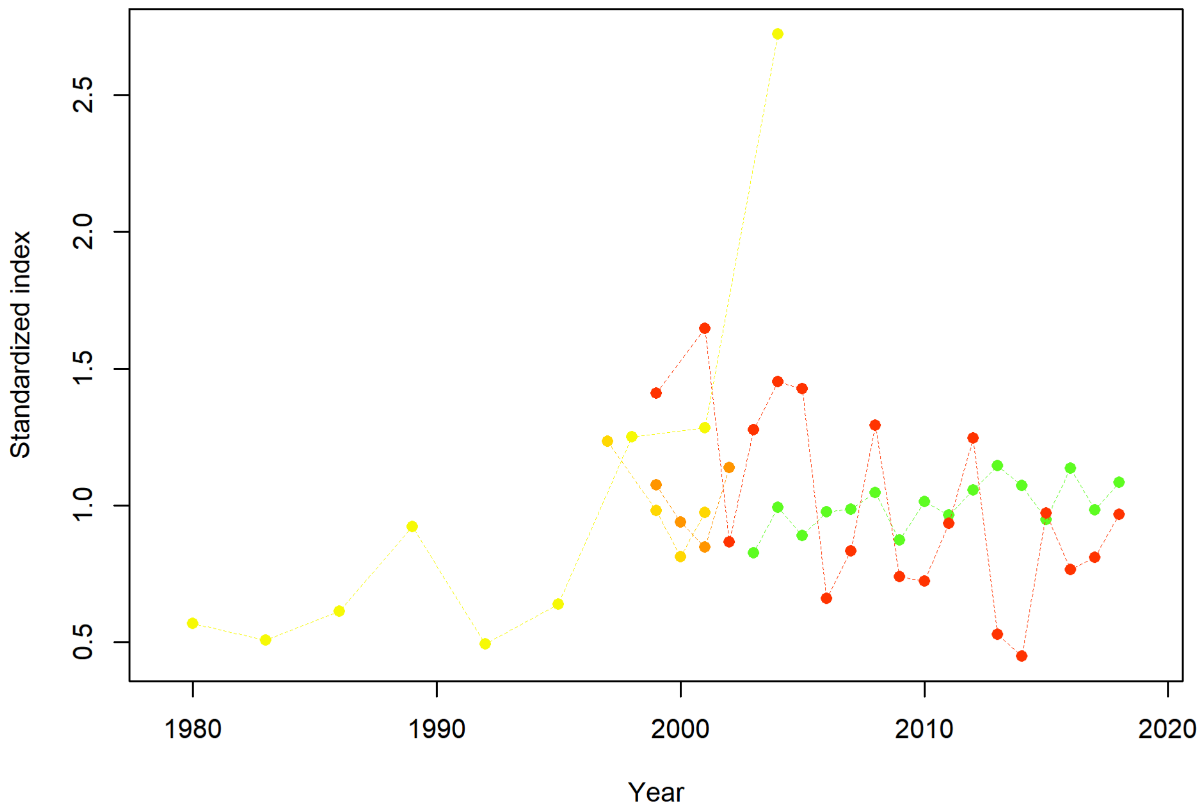

Figure 43. Standardized indices from all surveys used in the assessment overlaid.

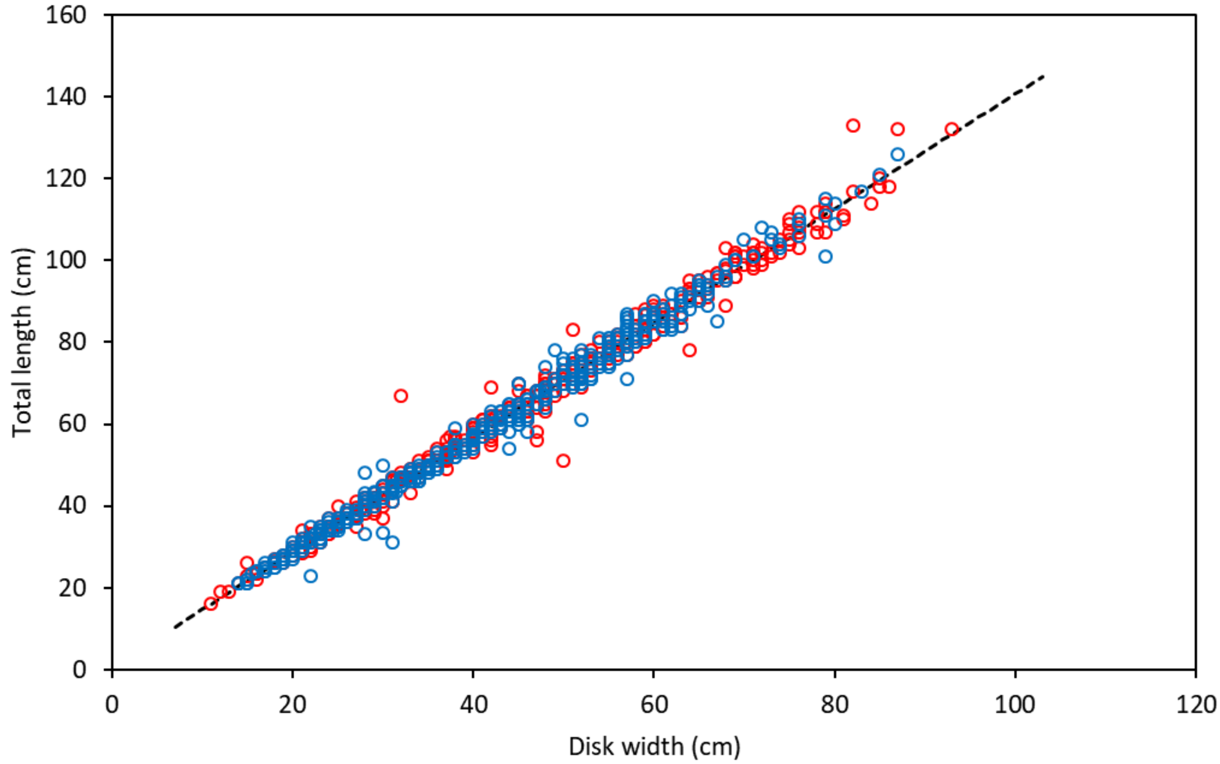

Figure 44. Estimated relationship between disc width (*DW*) and total length (*TL*) for Longnose Skate. Points show observed values (N=875) for females (red) and males (blue) and the black line indicates the estimated relationship: $TL\ (cm) = 1.4044 \cdot DW\,(cm) + 0.7005$.

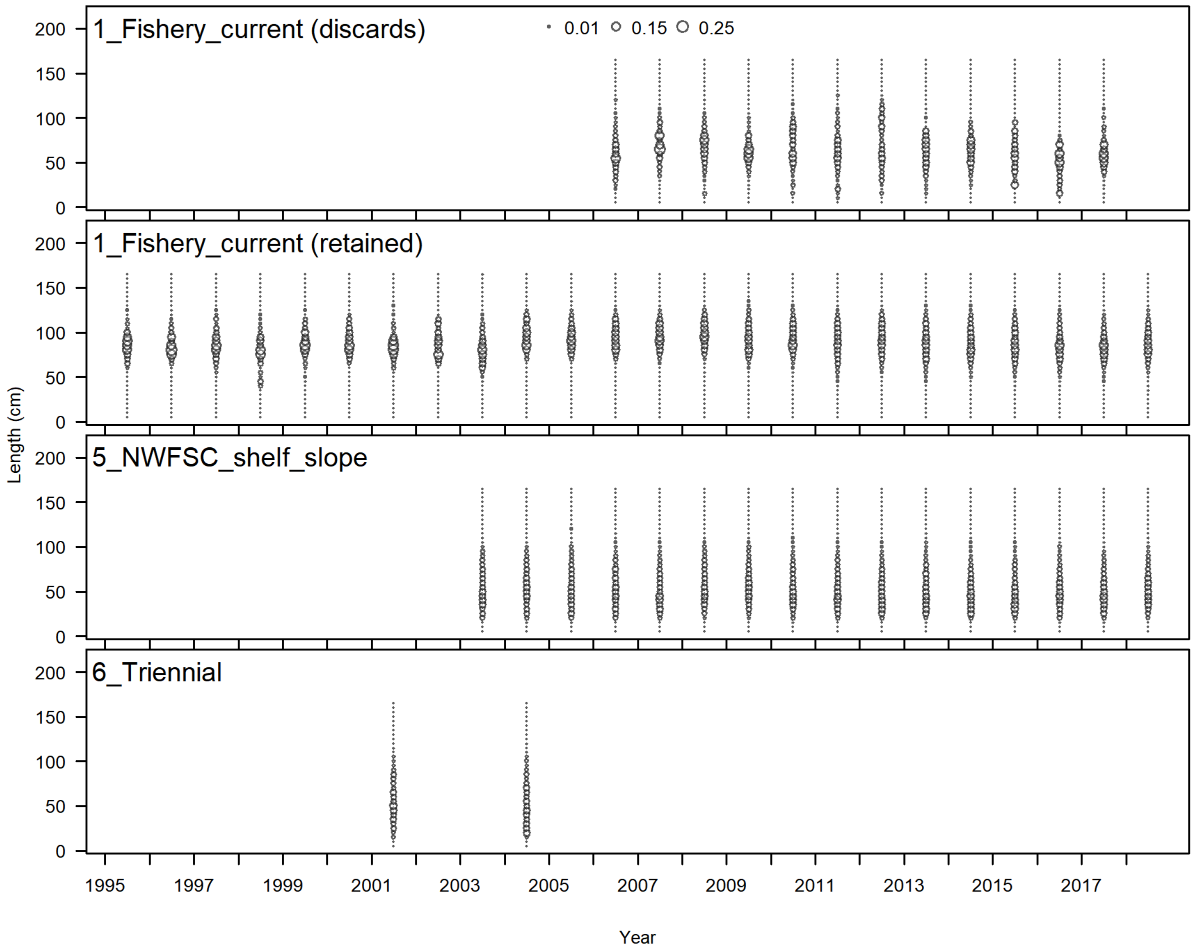

Figure 45. Length-frequency distributions for Longnose Skate catch by year from commercial fishery discard and landings as well as from WCGBT Survey and AFSC Triennial Survey.

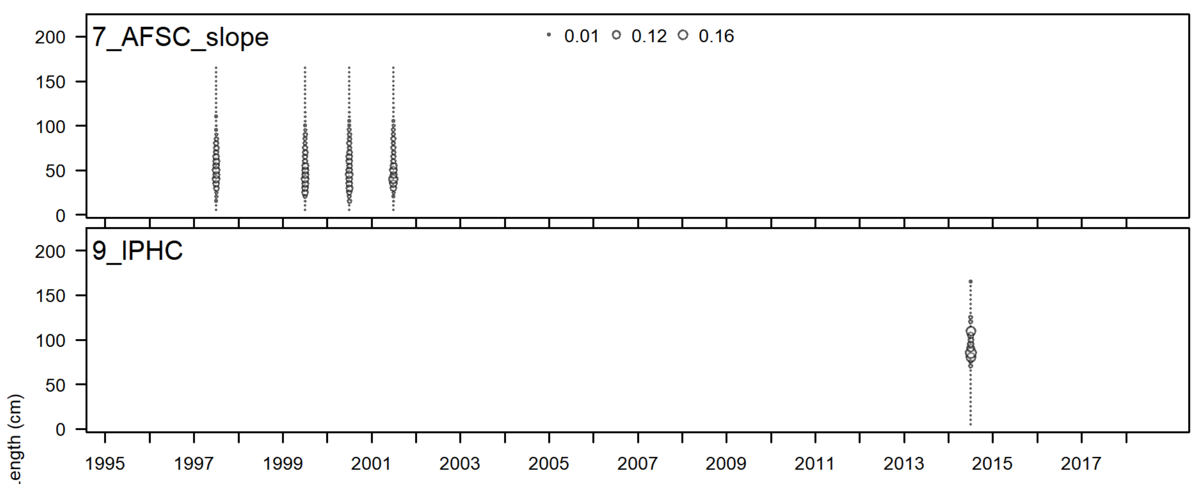

Figure 46. Length-frequency distributions for Longnose Skate catch by year from AFSC Slope Survey and IPFC survey.

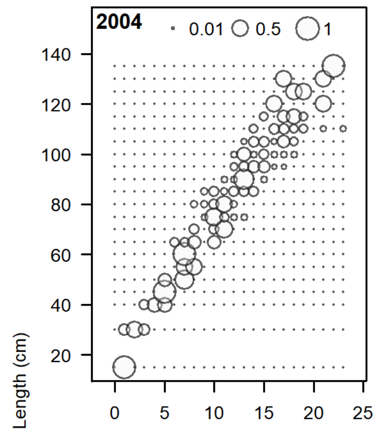

Figure 47. Conditional age-at-length data from the current fishery.

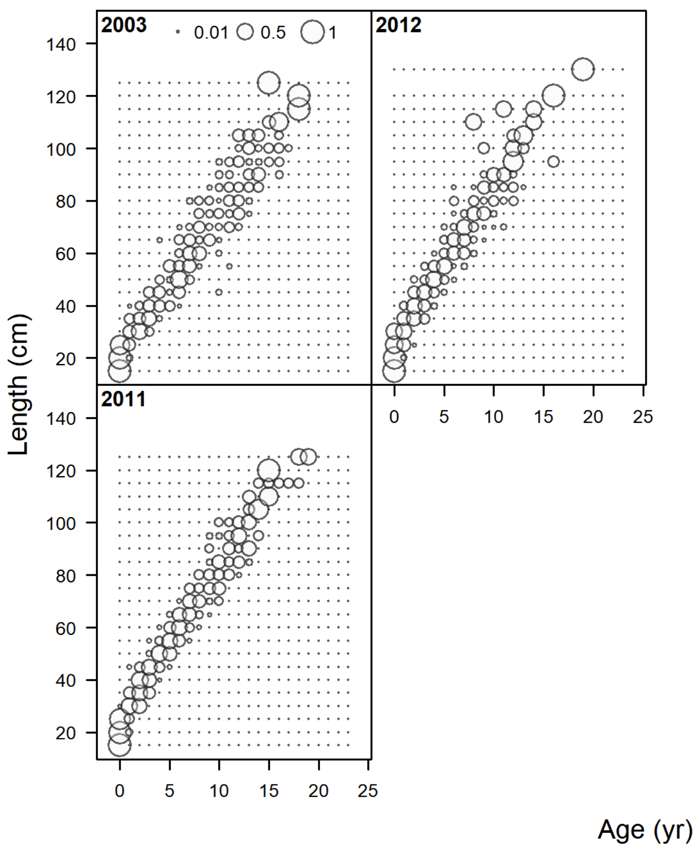

Figure 48. Conditional age-at-length data from WCGTB Survey.

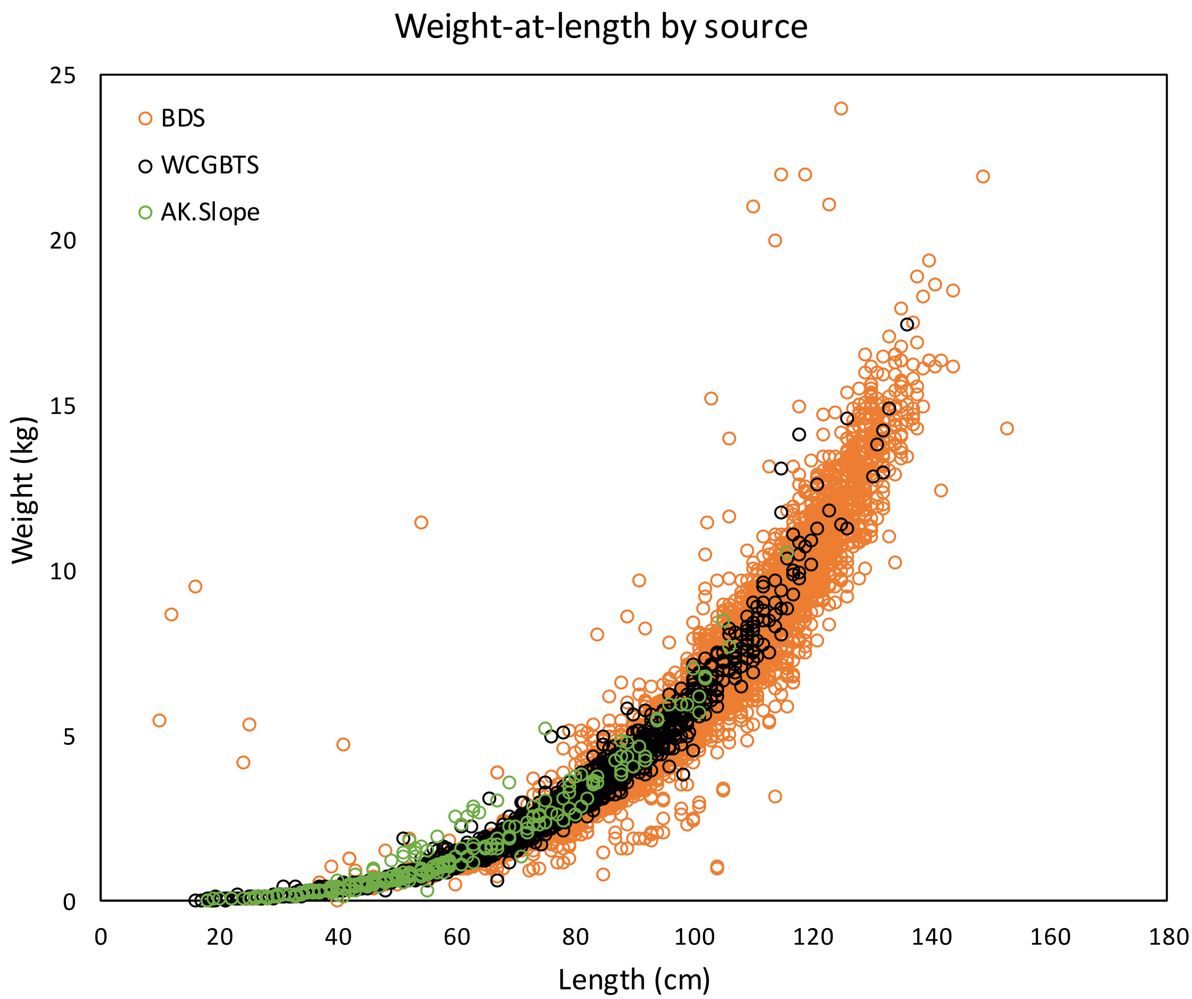

Figure 49. Length-weight data available by data source.

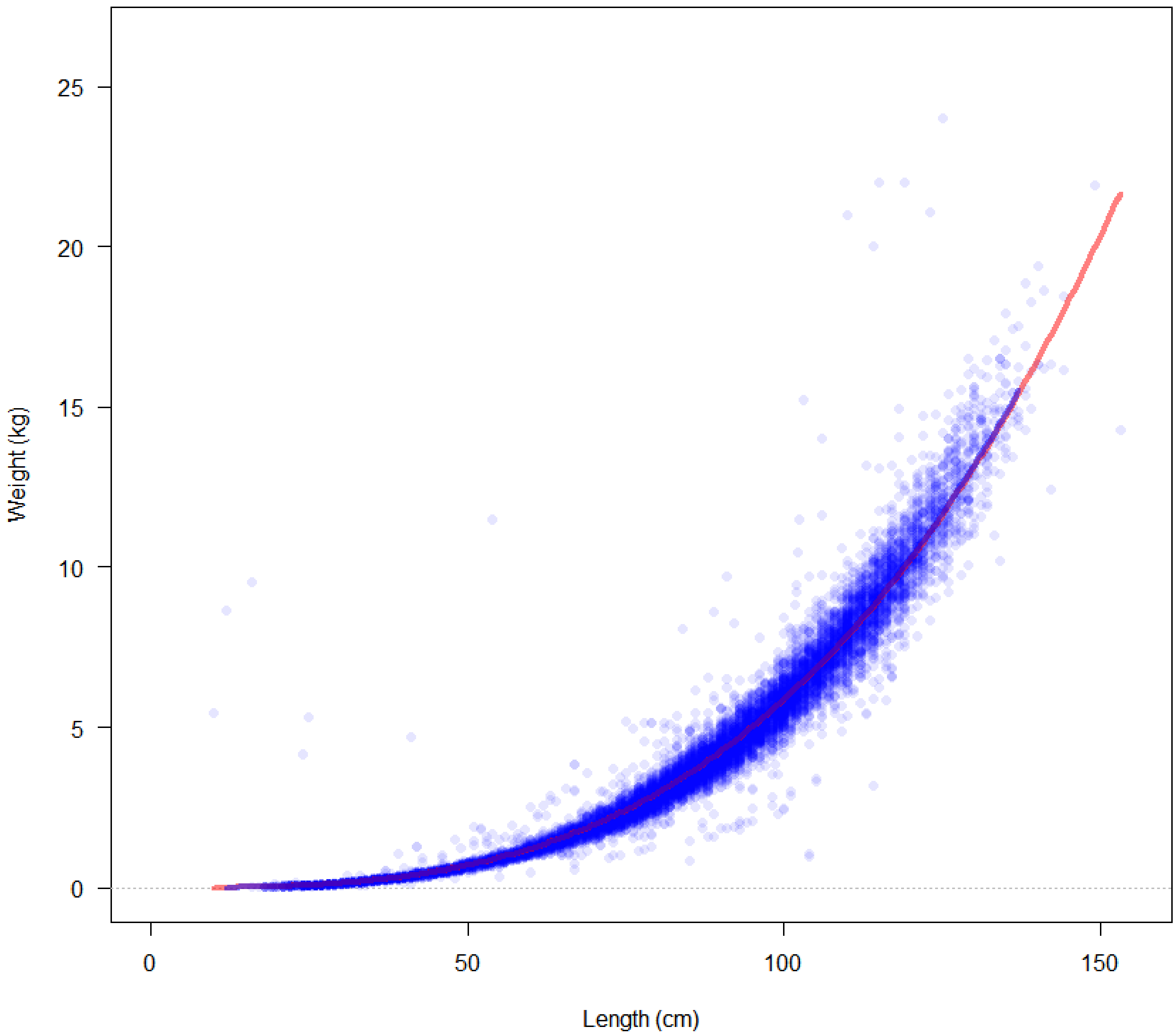

Figure 50. Length-weight relationship estimated for females (red) and males (blue).

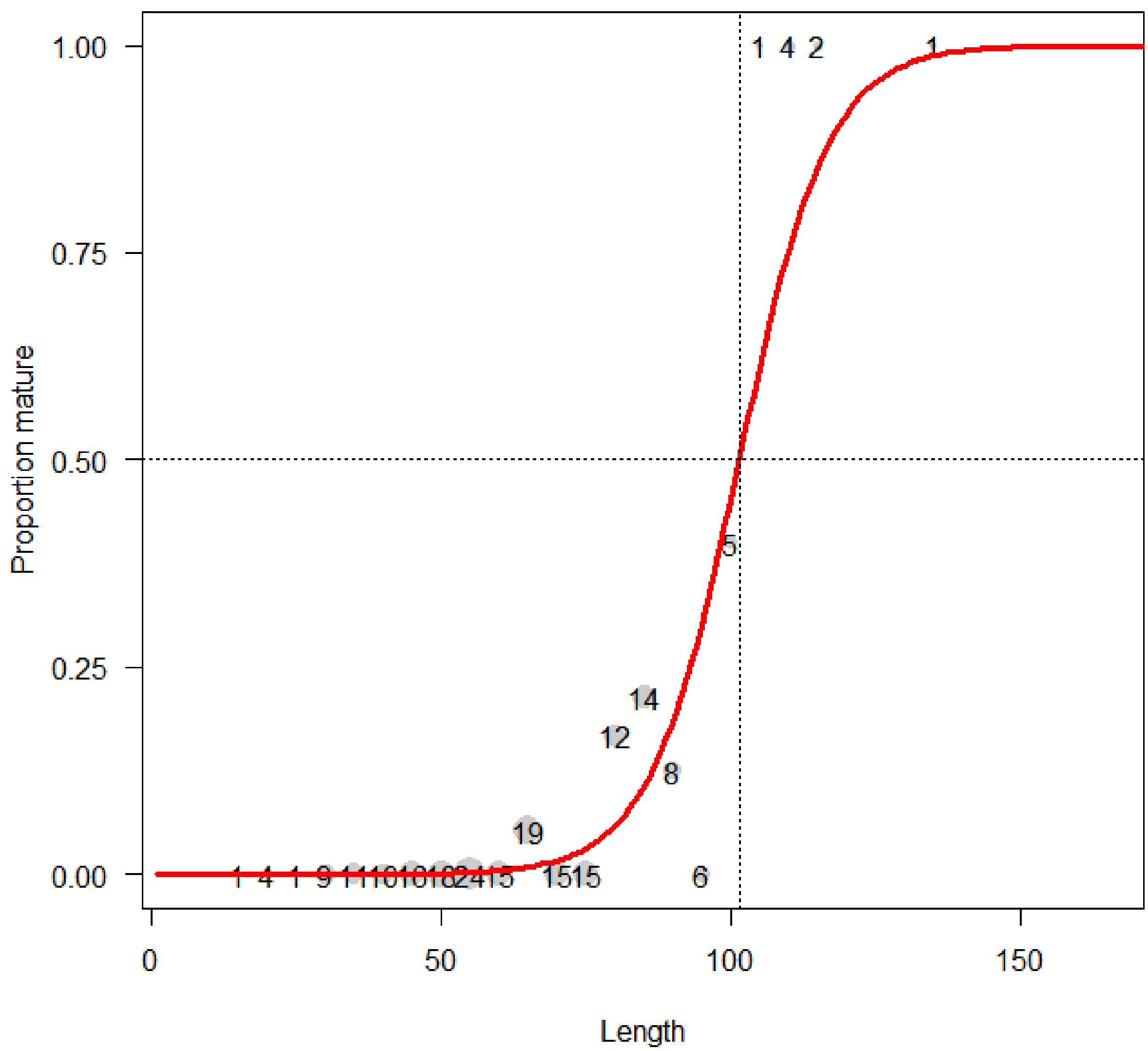

Figure 51. Maturity at length relationship used in the base model for Longnose Skate (numbers in grey circles corresponds to sample sizes).

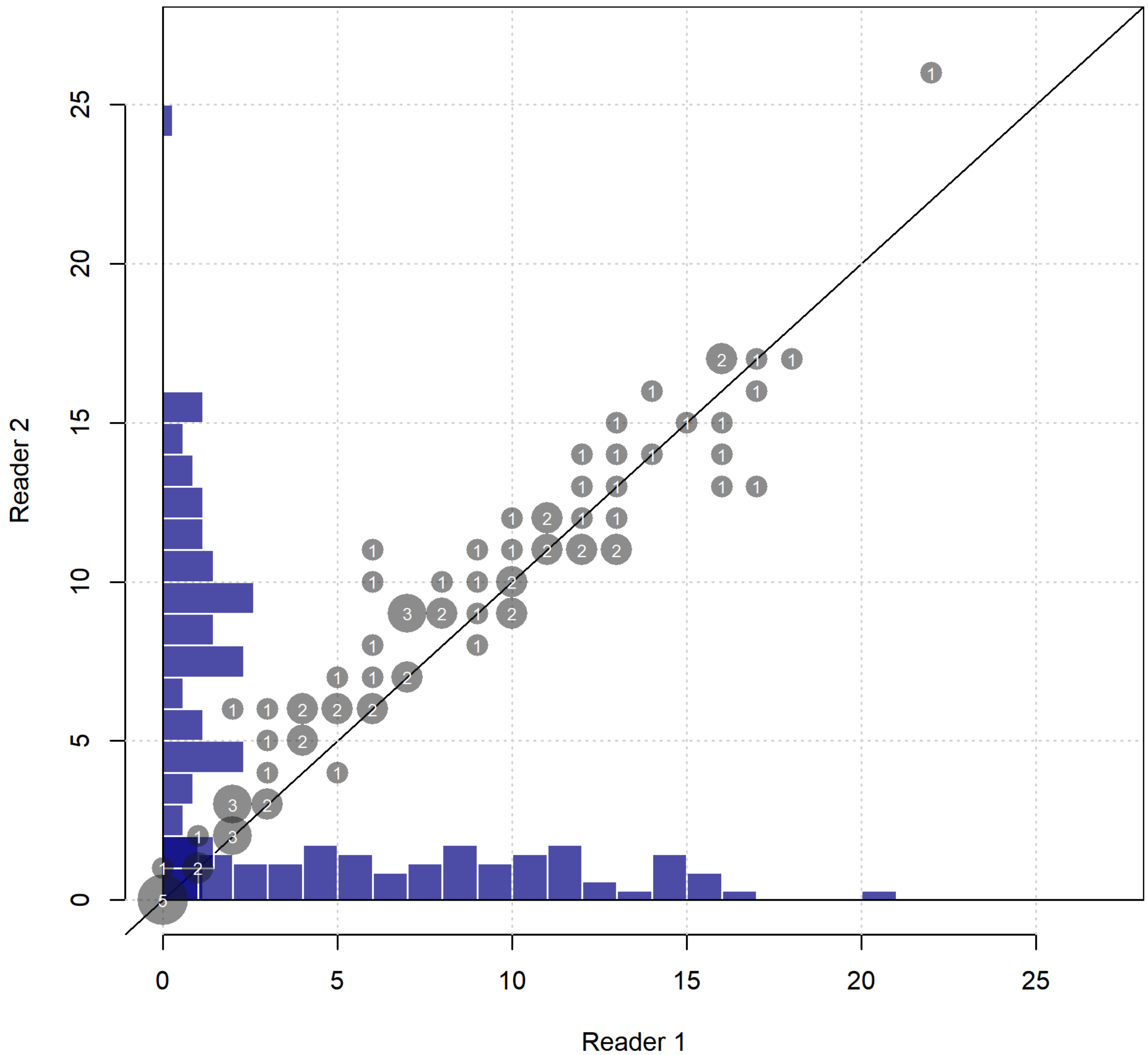

Figure 52. Age estimates comparison between Reader 1 (main, unbiased reader) and Reader 2, for the 2003 survey and 2004 fishery data.

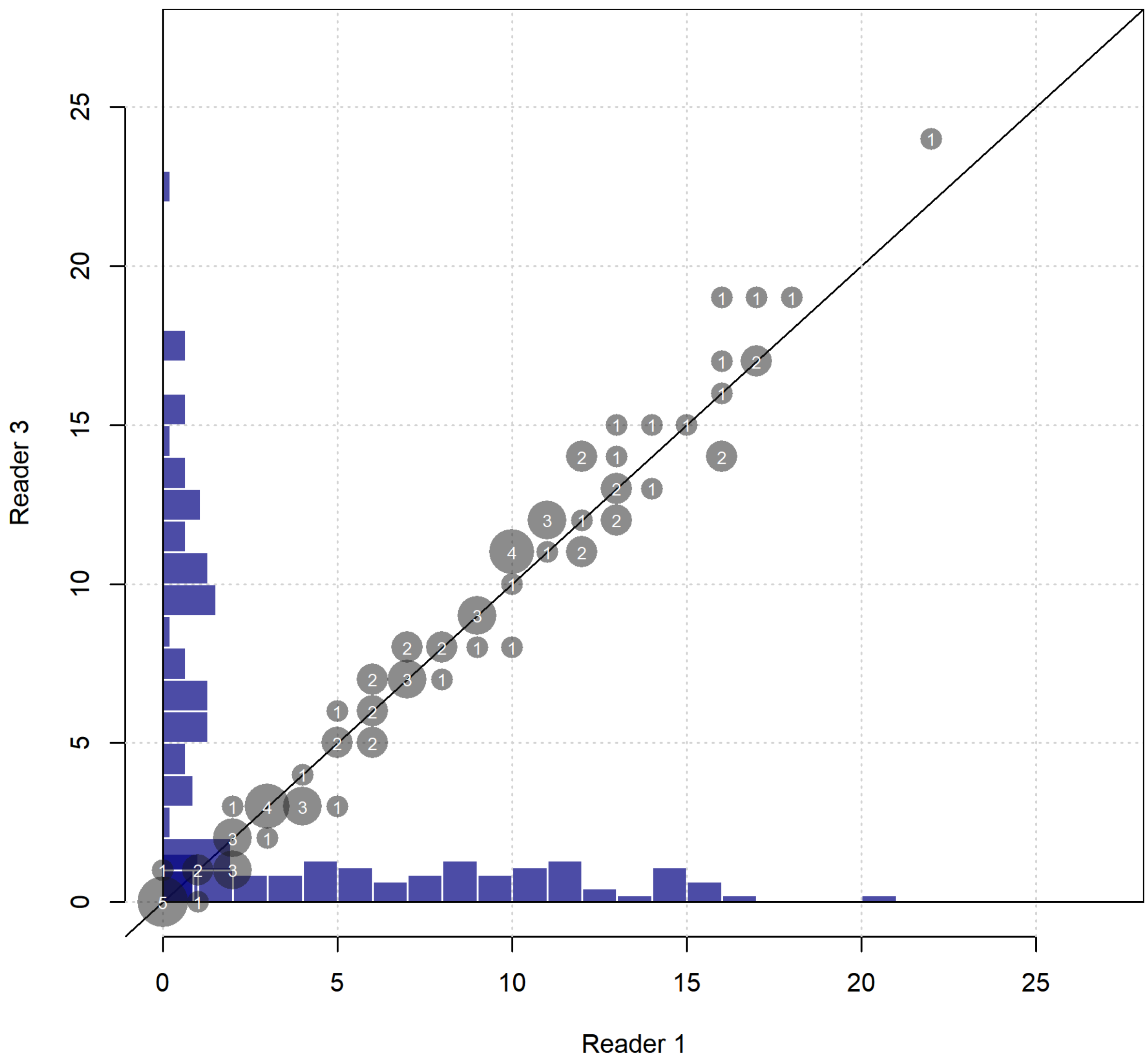

Figure 53. Age estimates comparison between Reader 1 (main, unbiased reader) and Reader 3, for 2003 survey and 2004 fishery data.

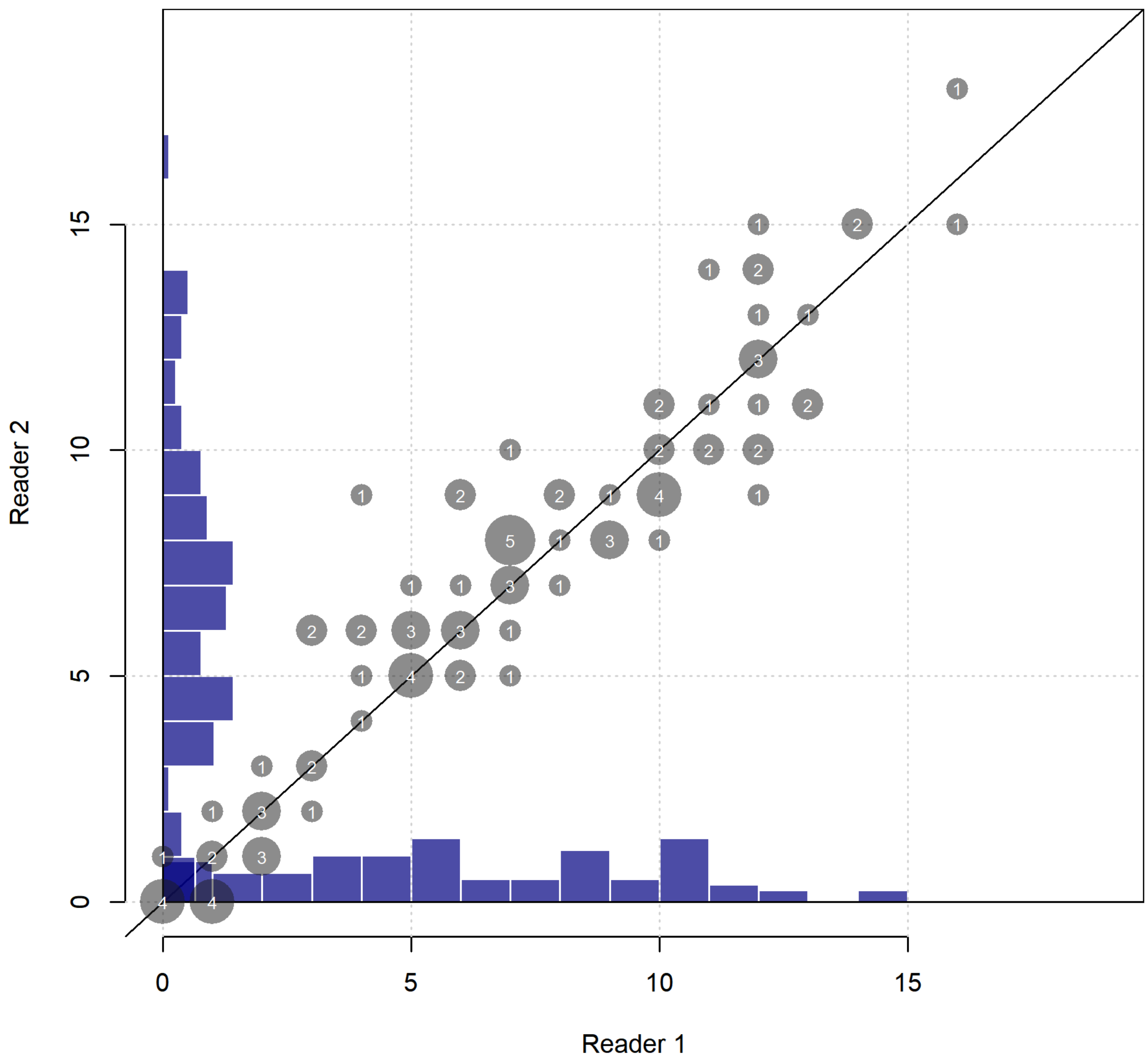

Figure 54. Age estimates comparison between Reader 1 (main, unbiased reader) and Reader 2, for 2011-2012 WCGBT Survey data.

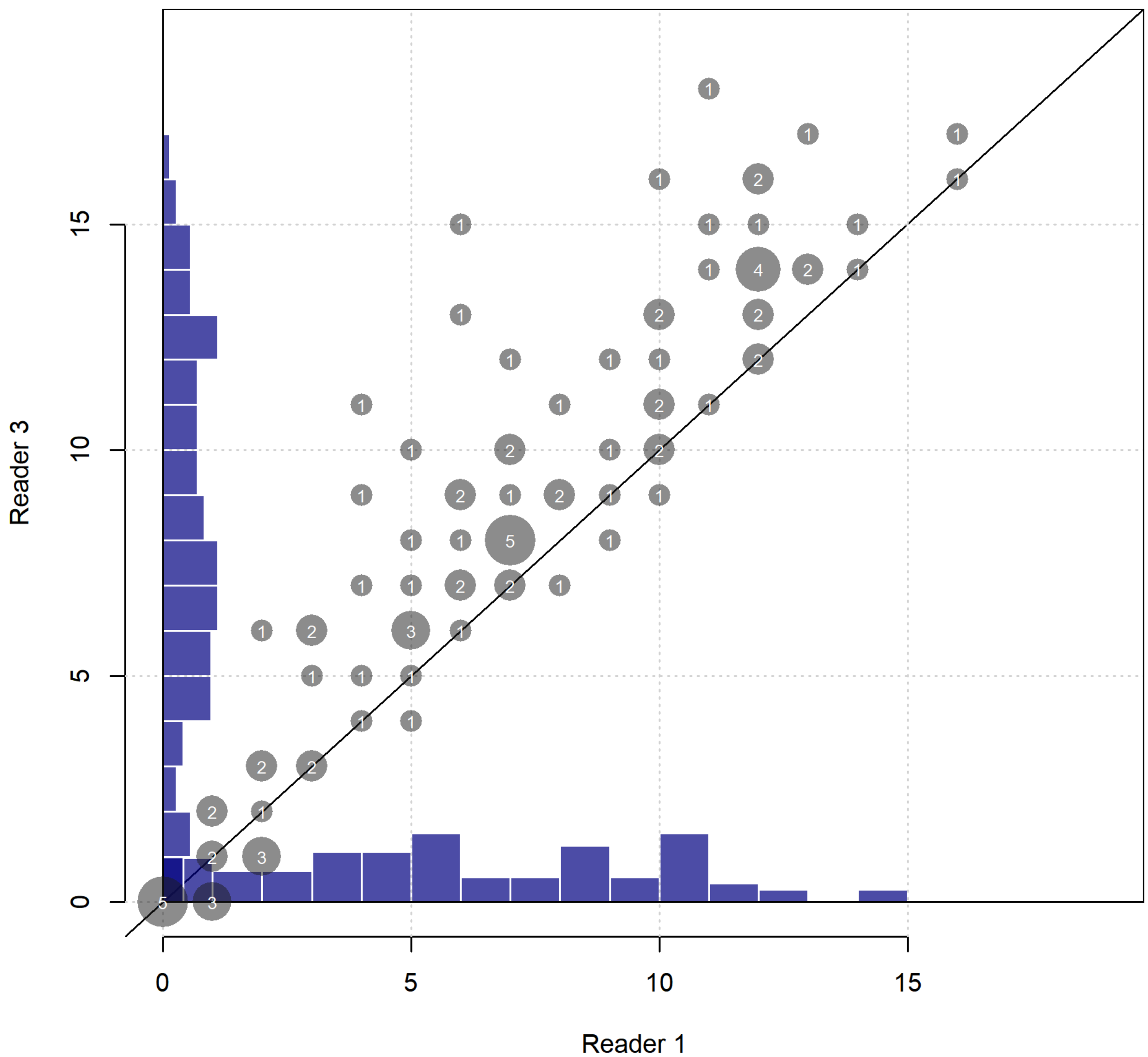

Figure 55. Age estimates comparison between Reader 1 (main, unbiased reader) and Reader 3, for 2011-2012 WCGBT Survey data.

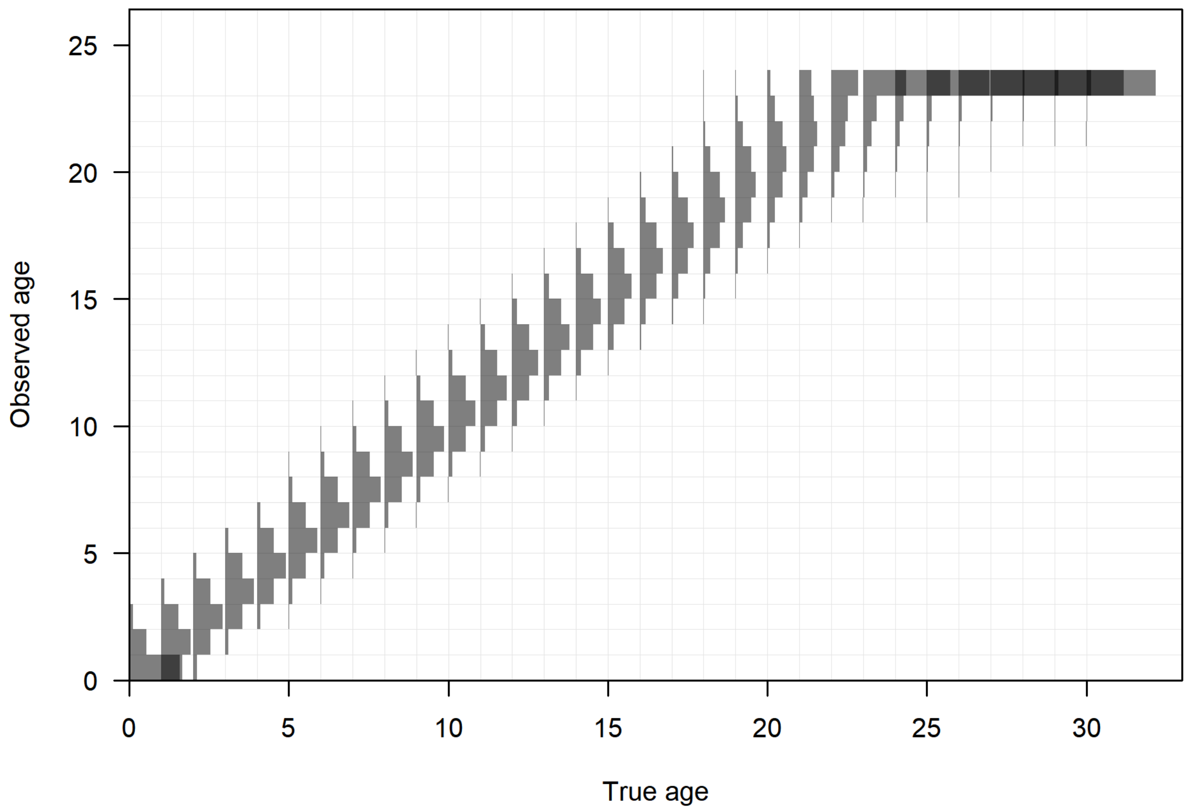

Figure 56. Distribution of observed age at true age for ageing error matrix 1 used in the assessment.

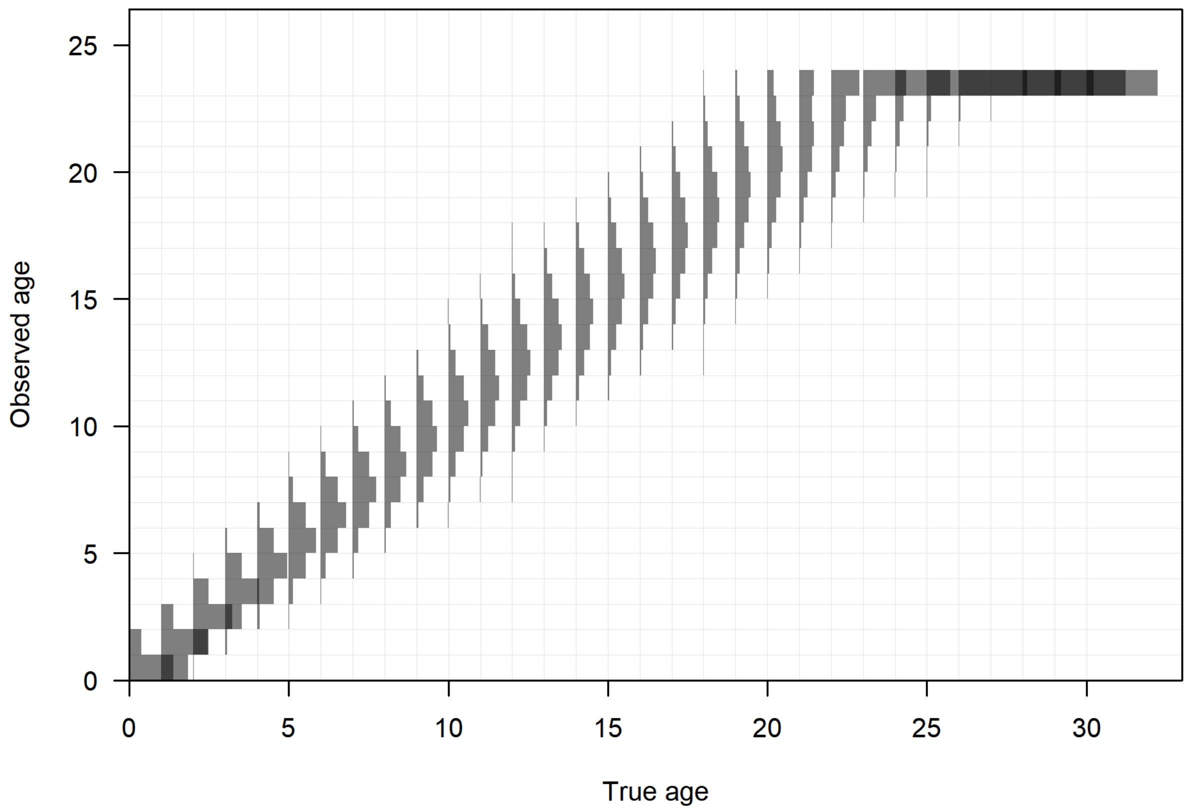

Figure 57. Distribution of observed age at true age for ageing error matrix 2 used in the assessment.

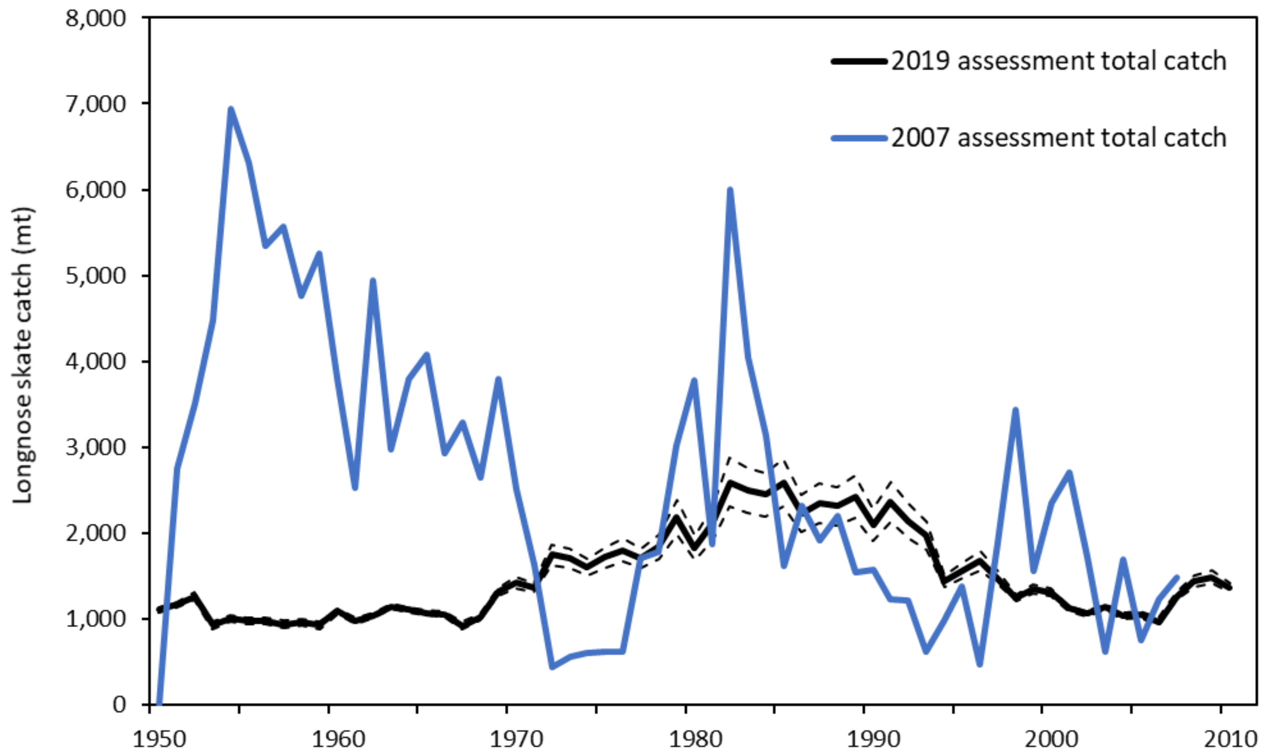

Figure 58. Comparison of estimated Longnose Skate total removals from the 2007 and 2019 assessments.

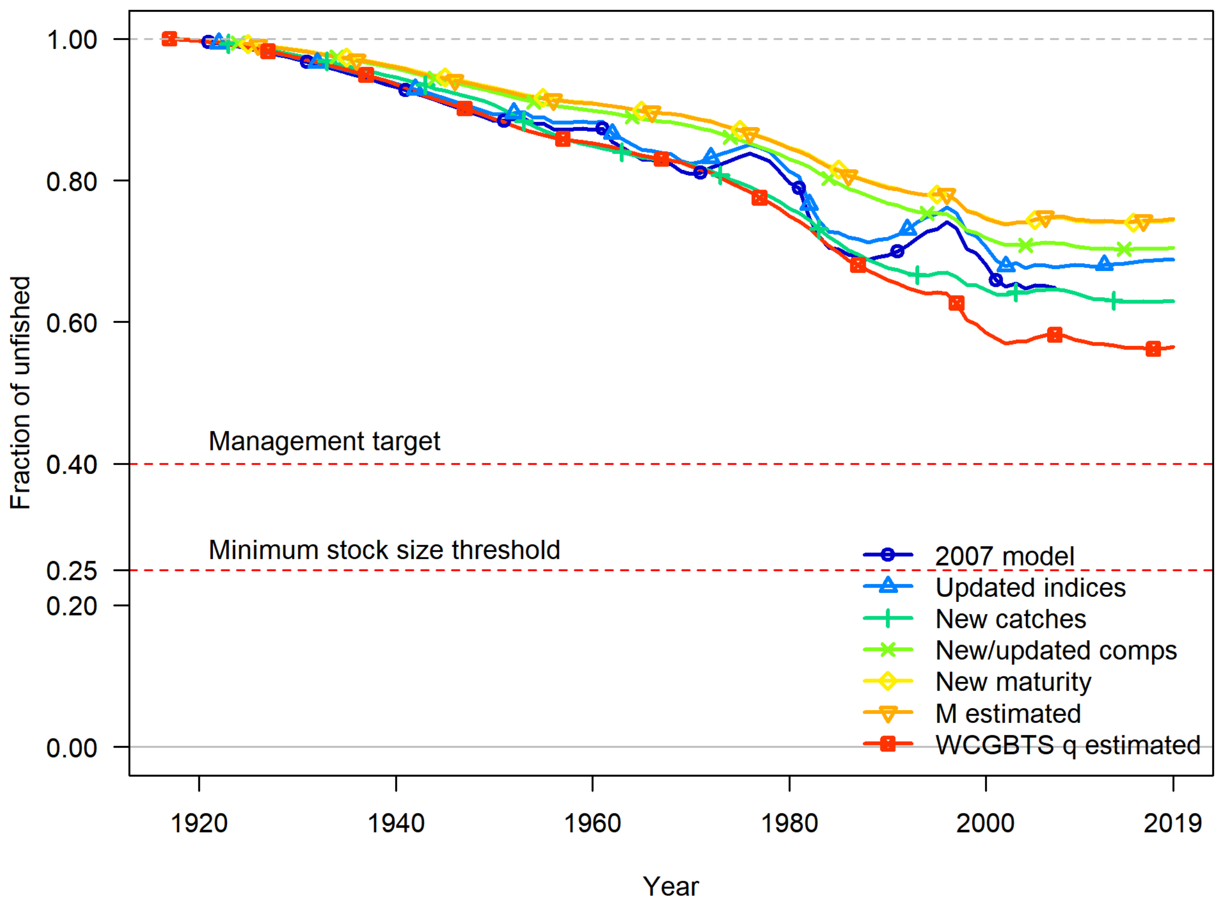

Figure 59. Bridging of major changes from the 2007 assessment to 2019 assessment model.

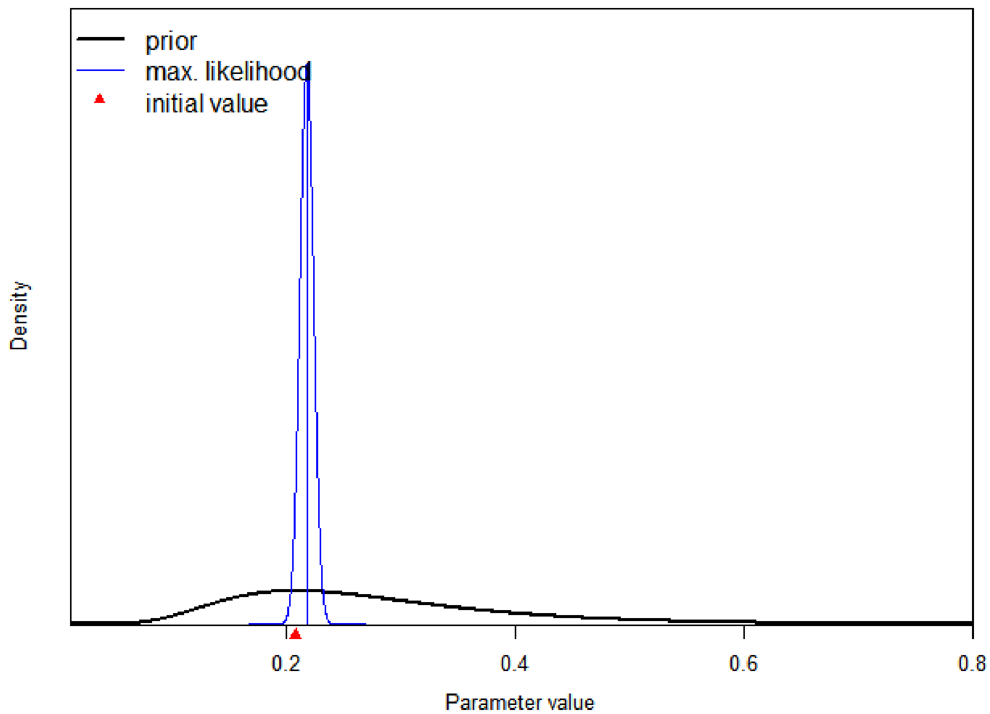

Figure 60. Natural mortality Hamel prior used in the assessment, along with estimated value.

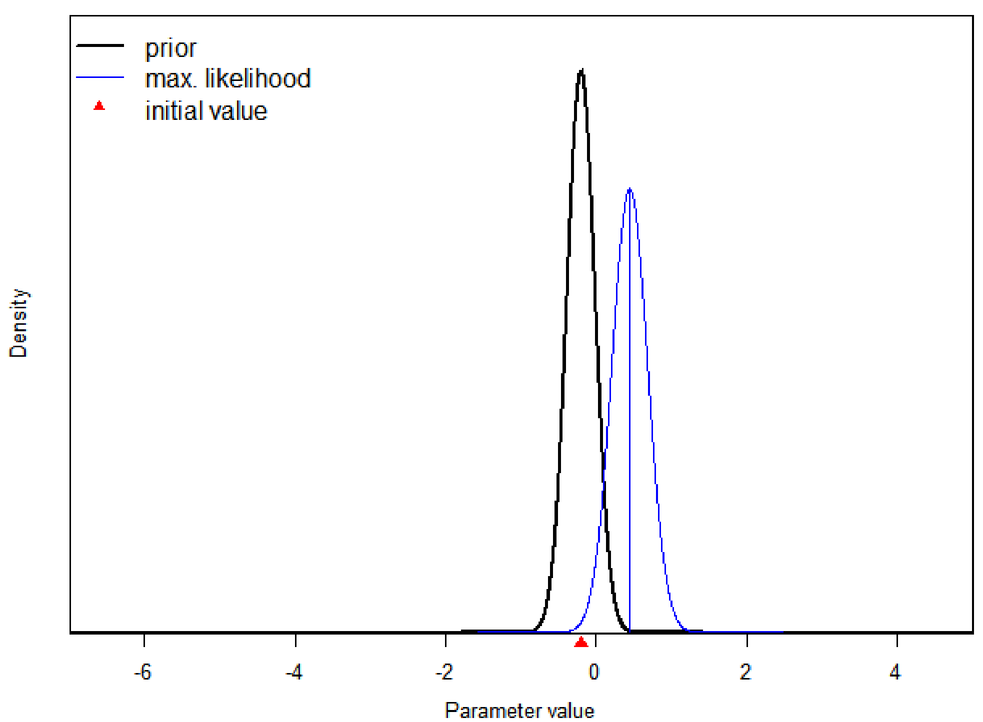

Figure 61. WCGBT Survey catchability prior used in the assessment, along with estimated value.

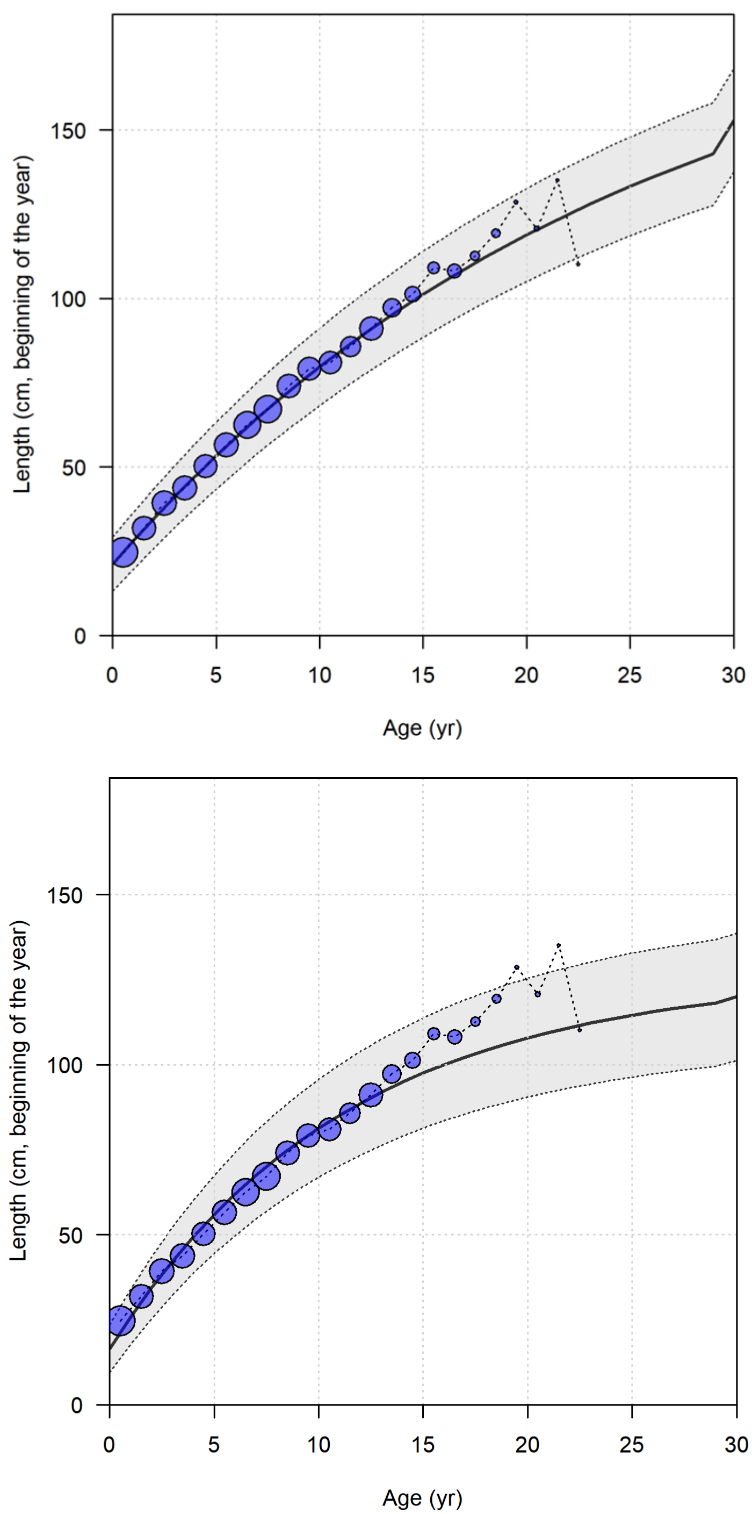

Figure 62. Fit of growth curve to length-at-age data in the base model with Dirichlet-Multinomial data weighting (upper panel) and the model that uses combination of Francis and McAllister-Ianelli method (lower panel).

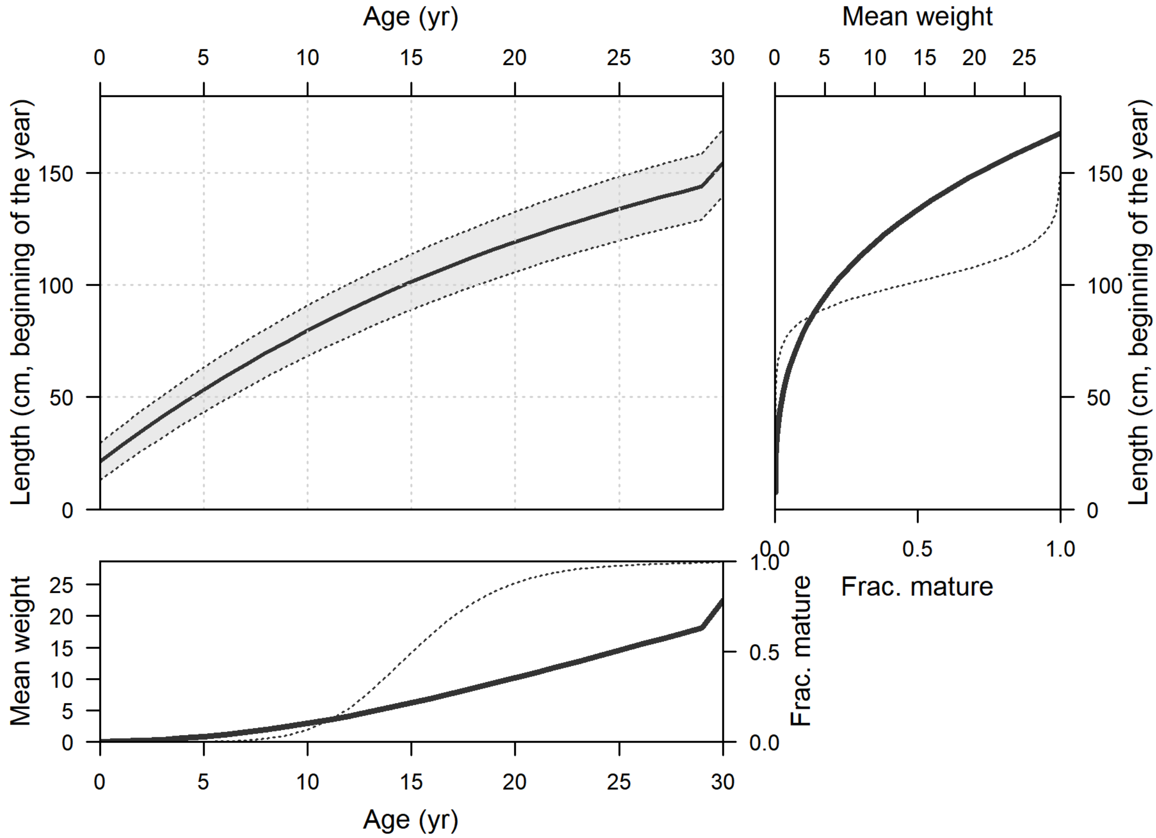

Figure 63. Estimated length-at-age for Longnose Skate (top left panel). Shaded areas indicate 95% intervals for distribution of lengths at each age. Values represent beginning-of-year growth. Weight (thick line) and maturity (thin line) are shown in the top-right and lower-left panels as a function of length and age, respectively, where the values-at-age are calculated by mapping the length-based relationships through the estimated distribution of length at each age.

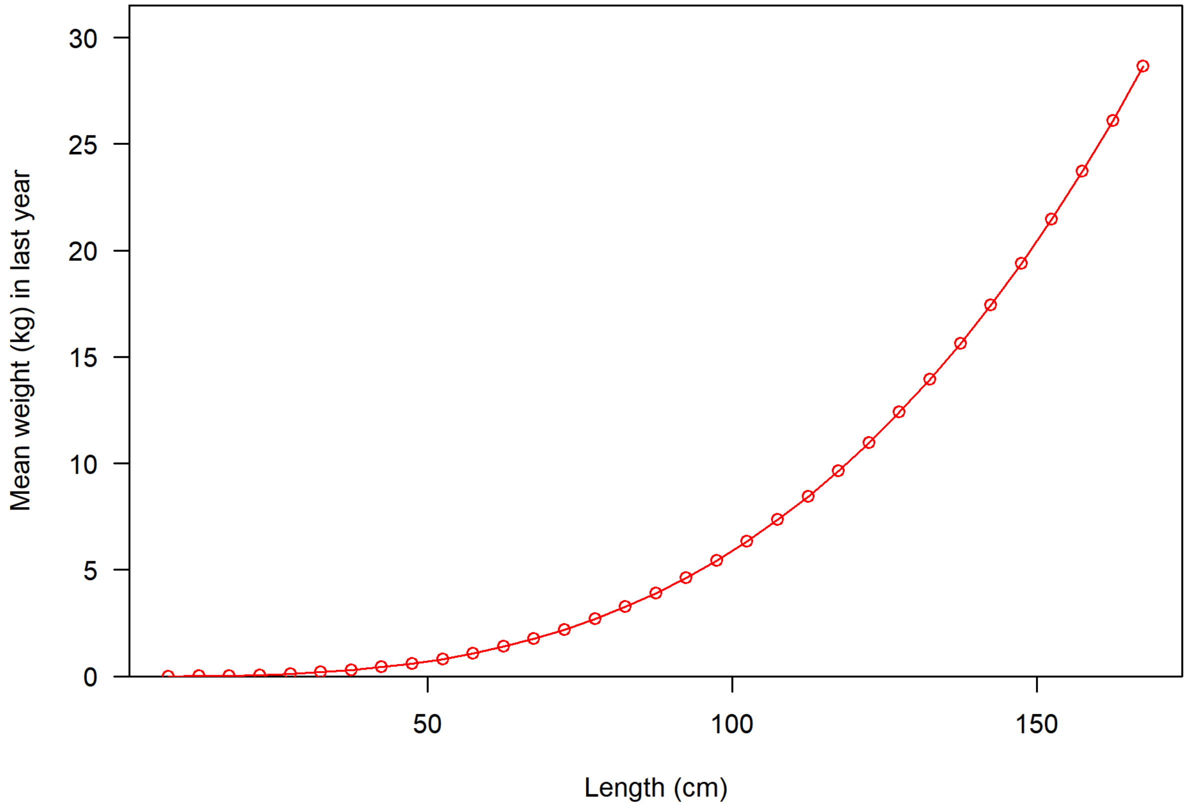

Figure 64. Relationship between individual length and weight, as used in the base model.

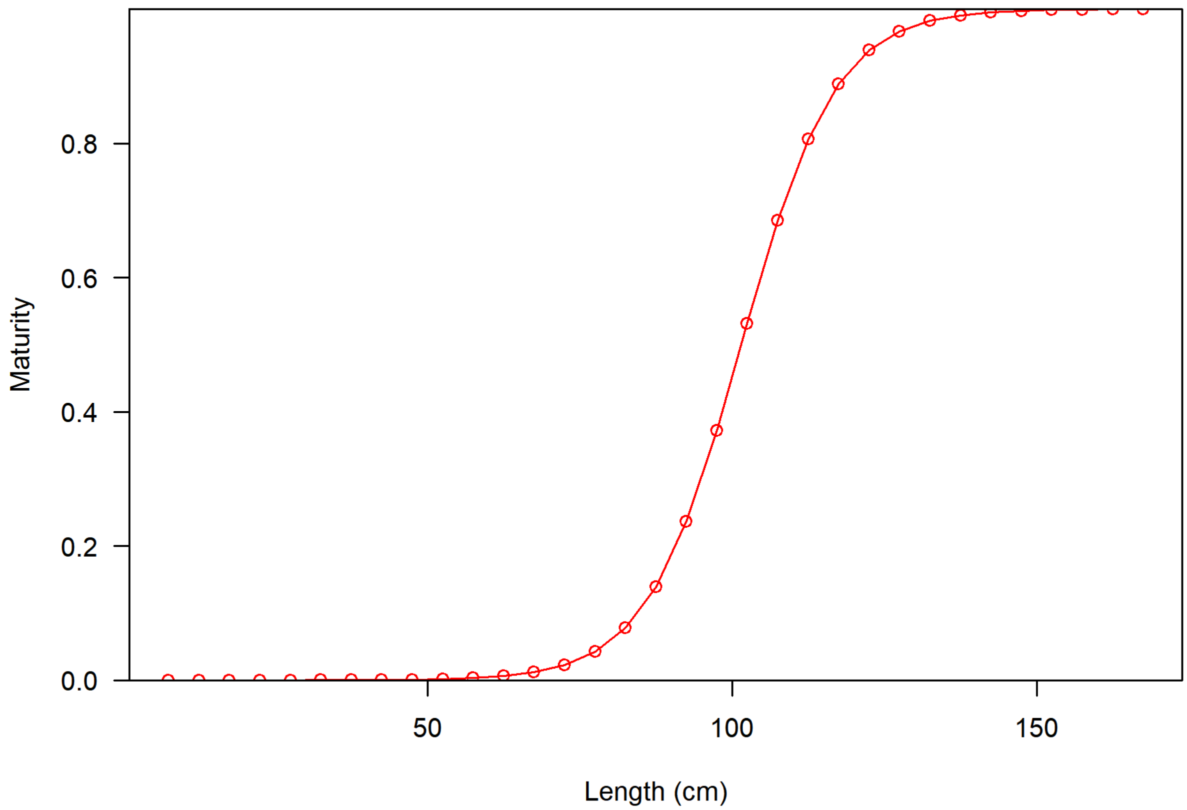

Figure 65. Relationship between individual female length and maturity, as used in the base model.

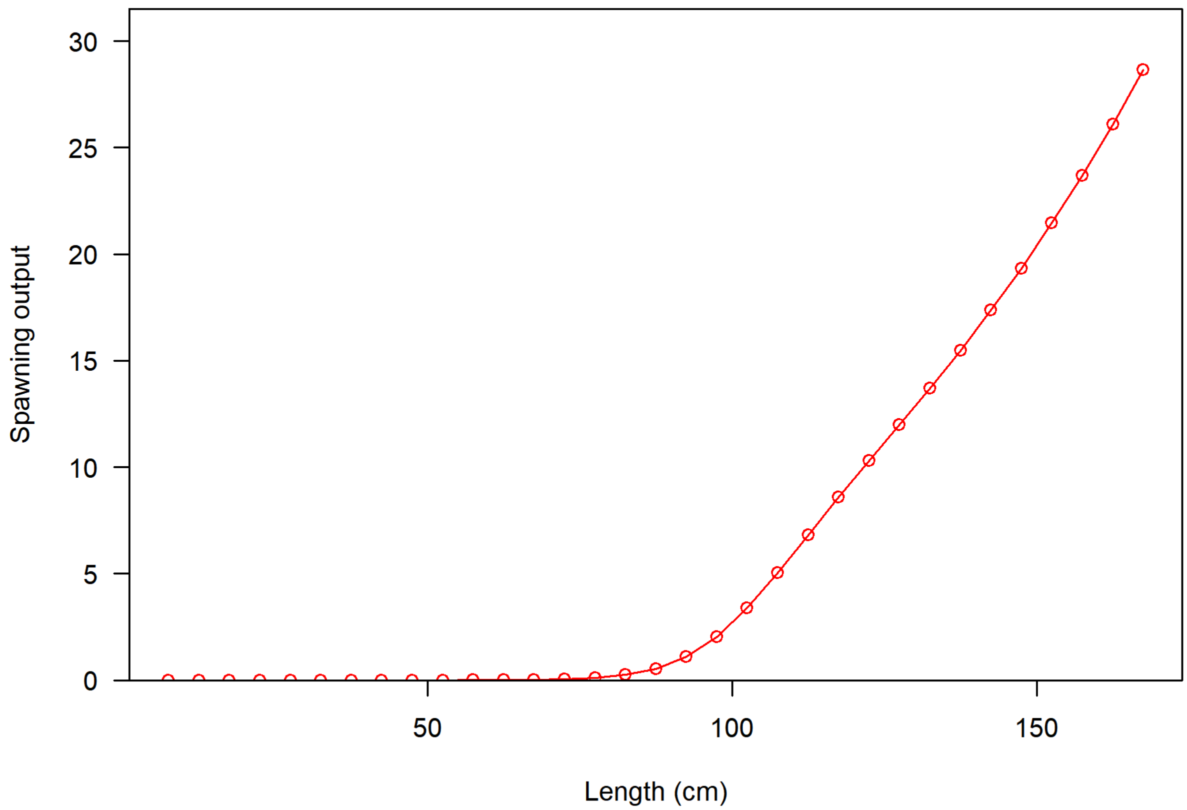

Figure 66. Spawning biomass at length.

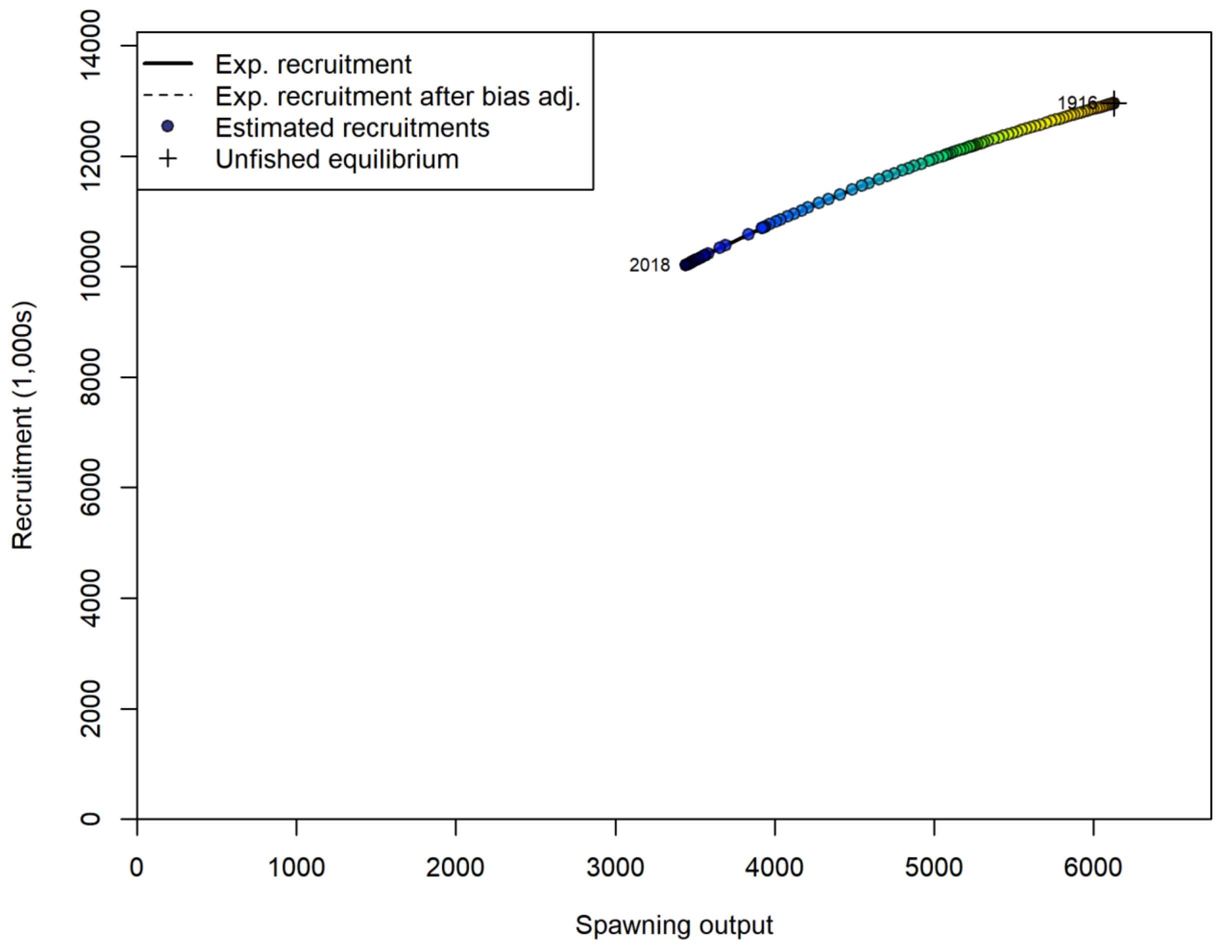

Figure 67. Estimated stock-recruit function for the assessment model.

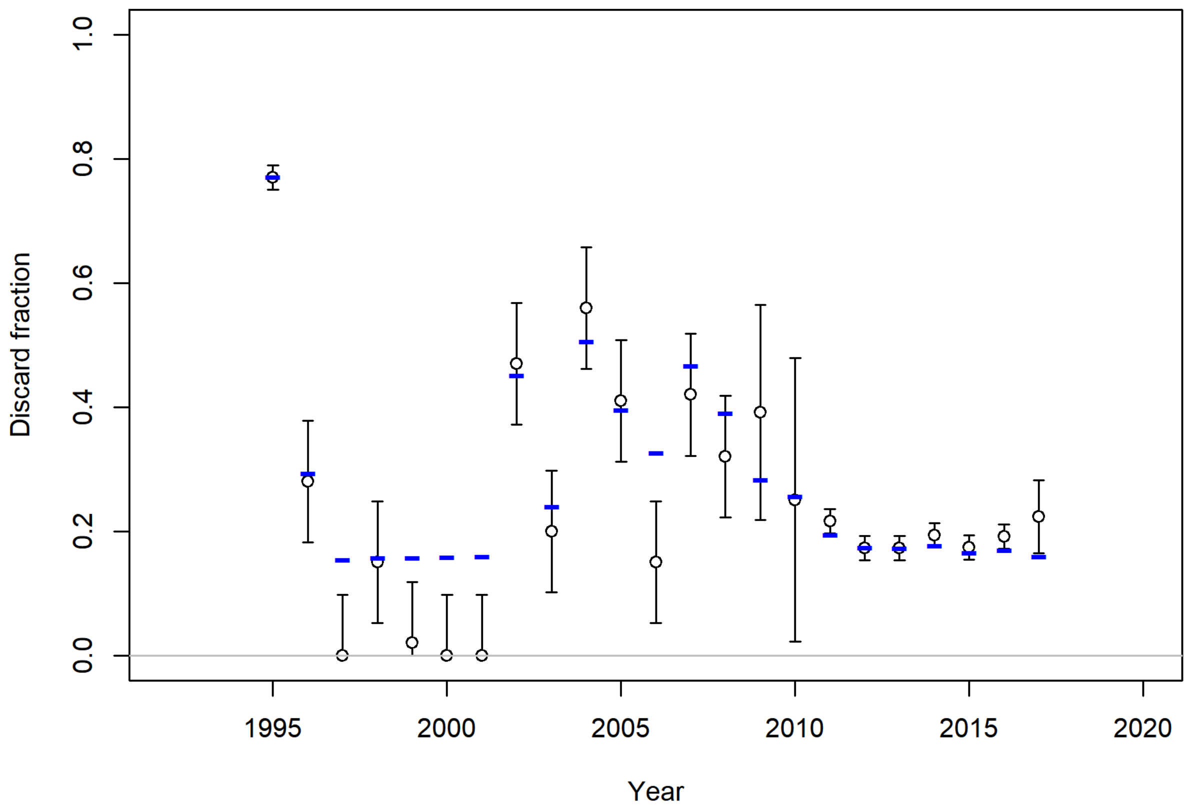

Figure 68. Base model fit to the discard fraction data.

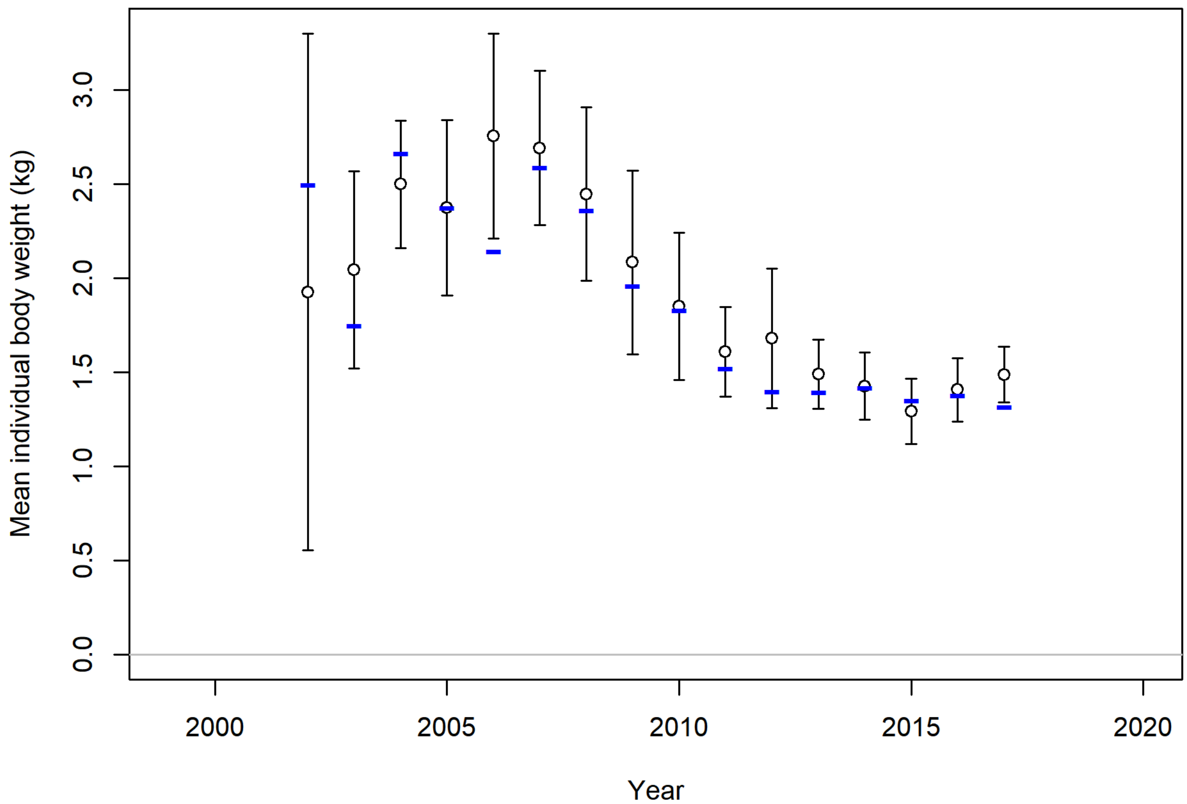

Figure 69. Base model fit to the average weight of discarded fish.

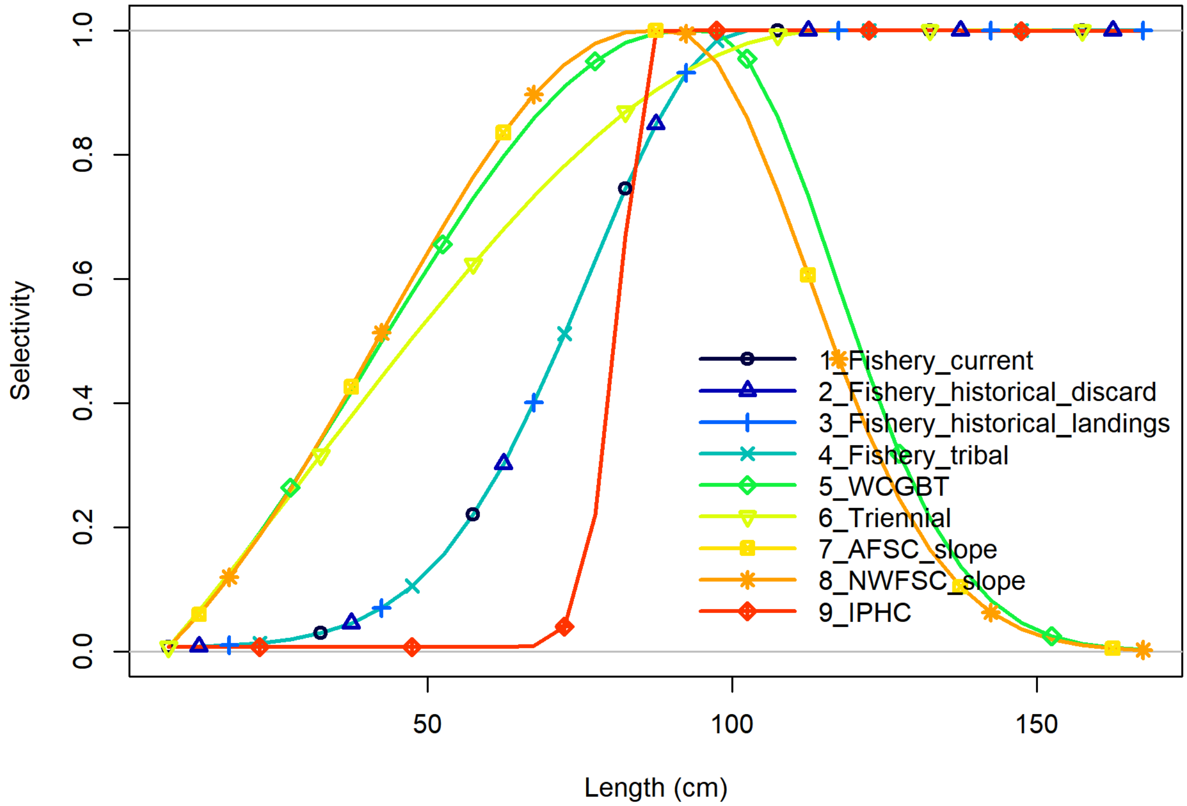

Figure 70. Base model estimates of length-based selectivity by fleet and survey.

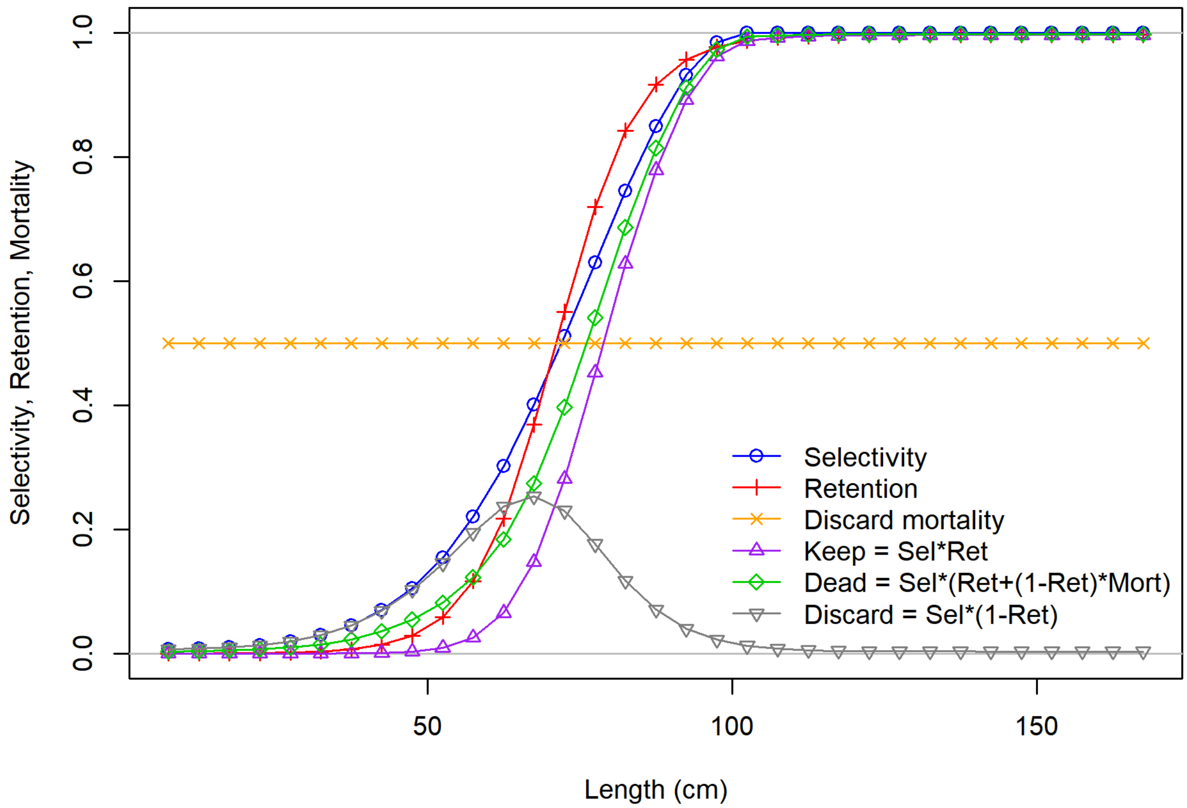

Figure 71. Current fishery selectivity, along with estimated retention. Discard mortality value is fixed in the model.

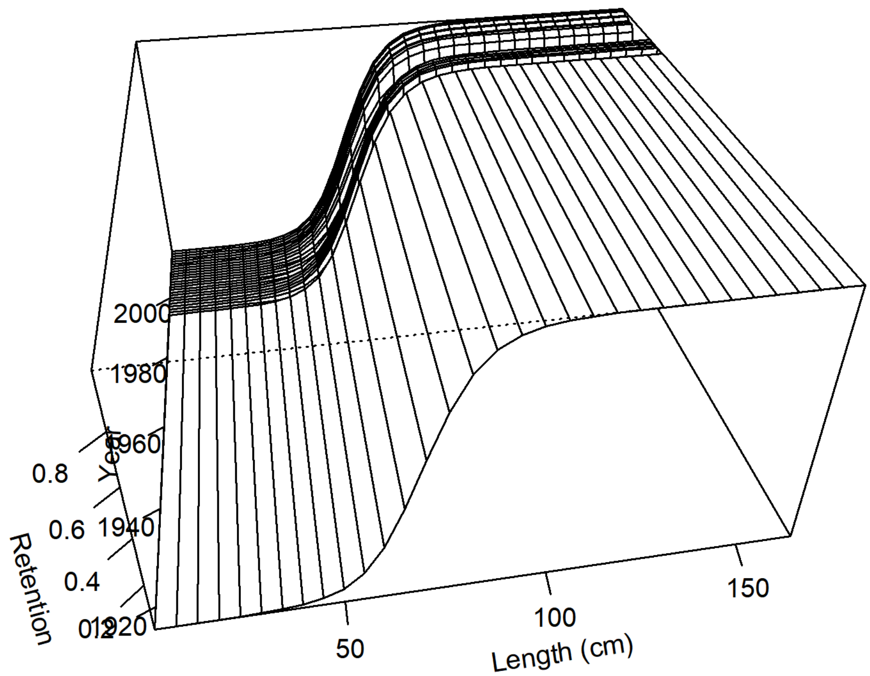

Figure 72. Year specific retention estimated for current fishery in the base model.

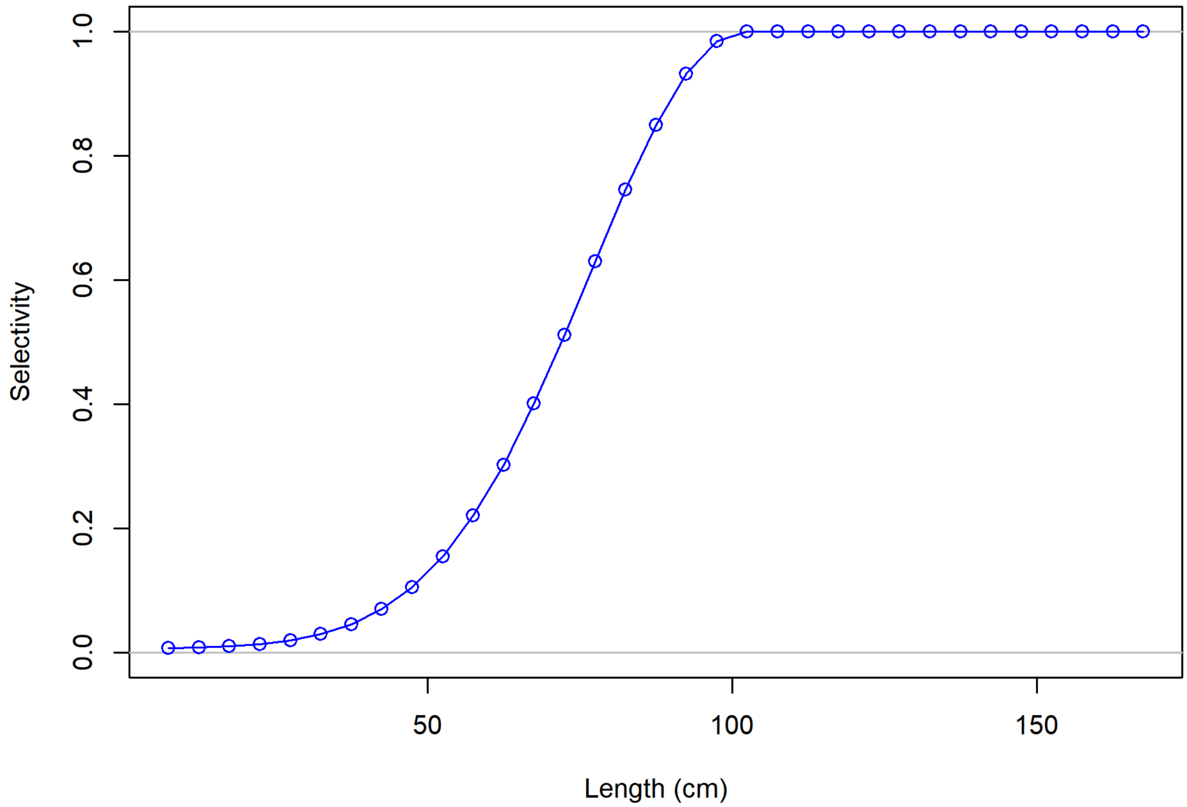

Figure 73. Historical fishery selectivity and selectivity of tribal fishery in the base model. Selectivity curves of historical and tribal fisheries are mirrored to that of current fishery.

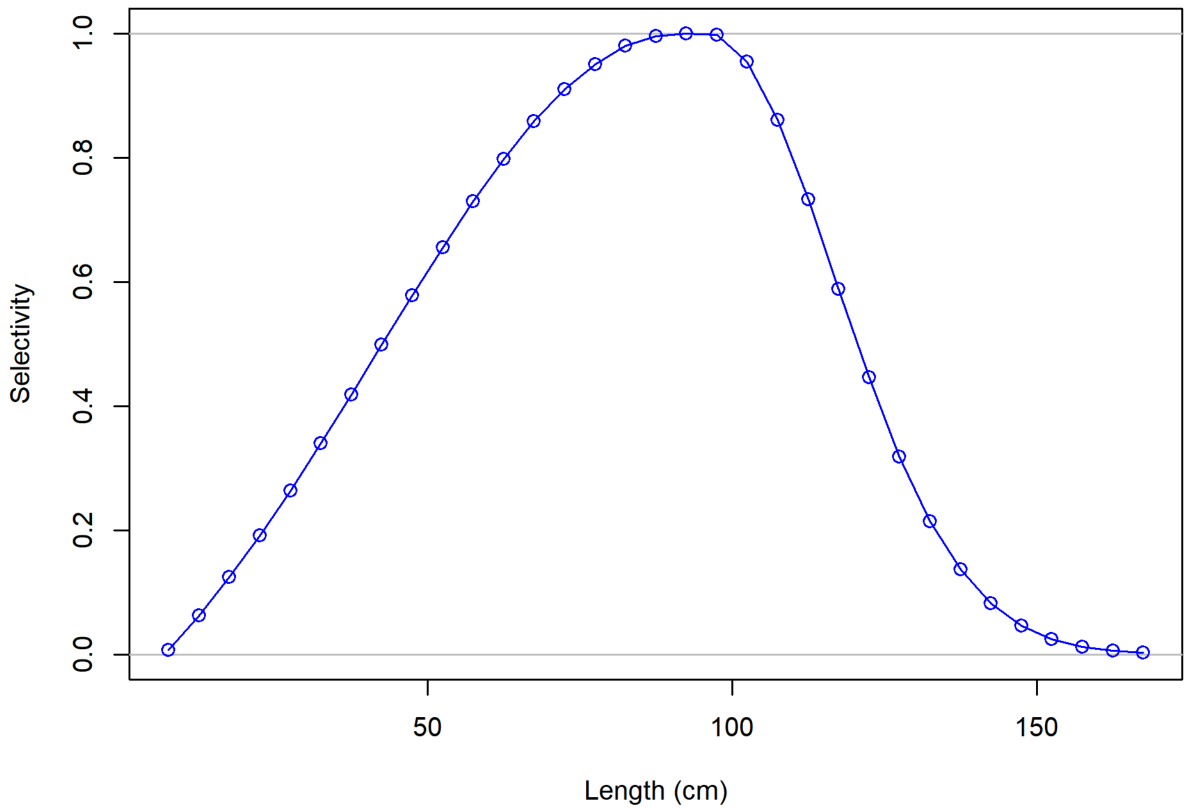

Figure 74. WCGBT Survey selectivity estimated in the base model for Longnose Skate.

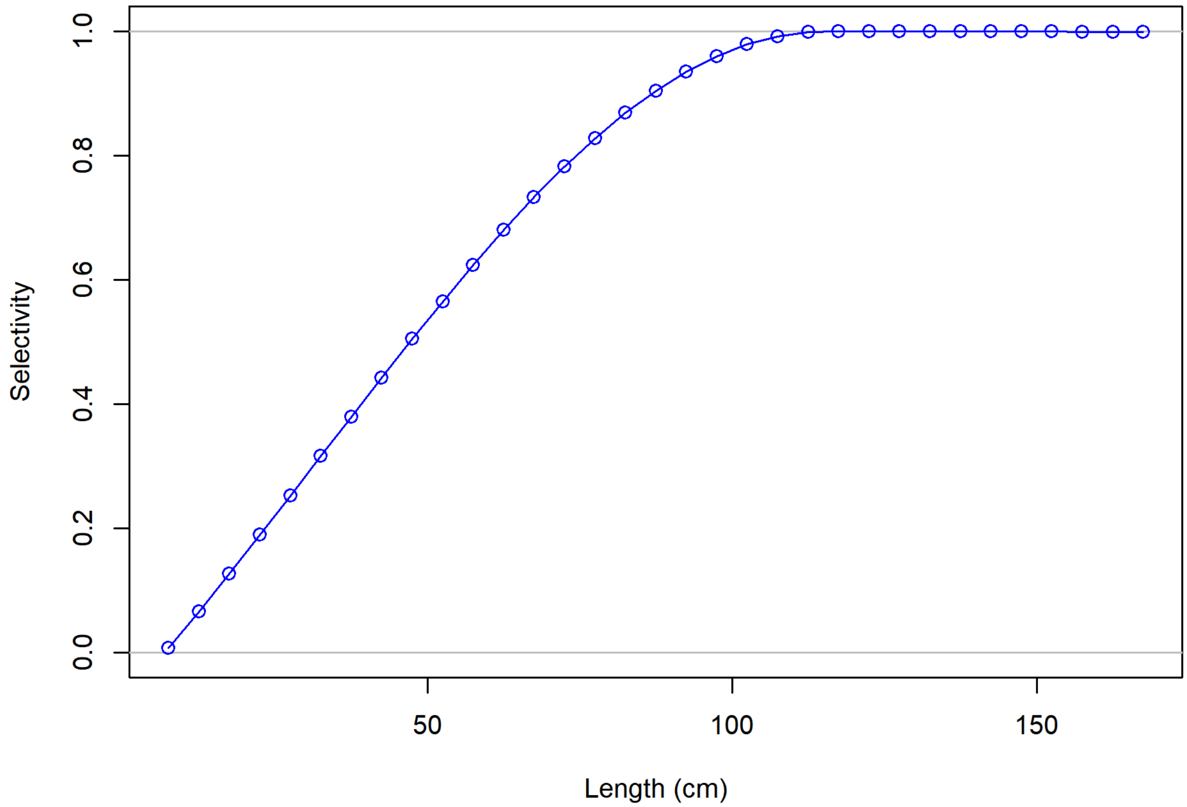

Figure 75. AFSC Triennial Survey selectivity estimated in the base model for Longnose Skate.

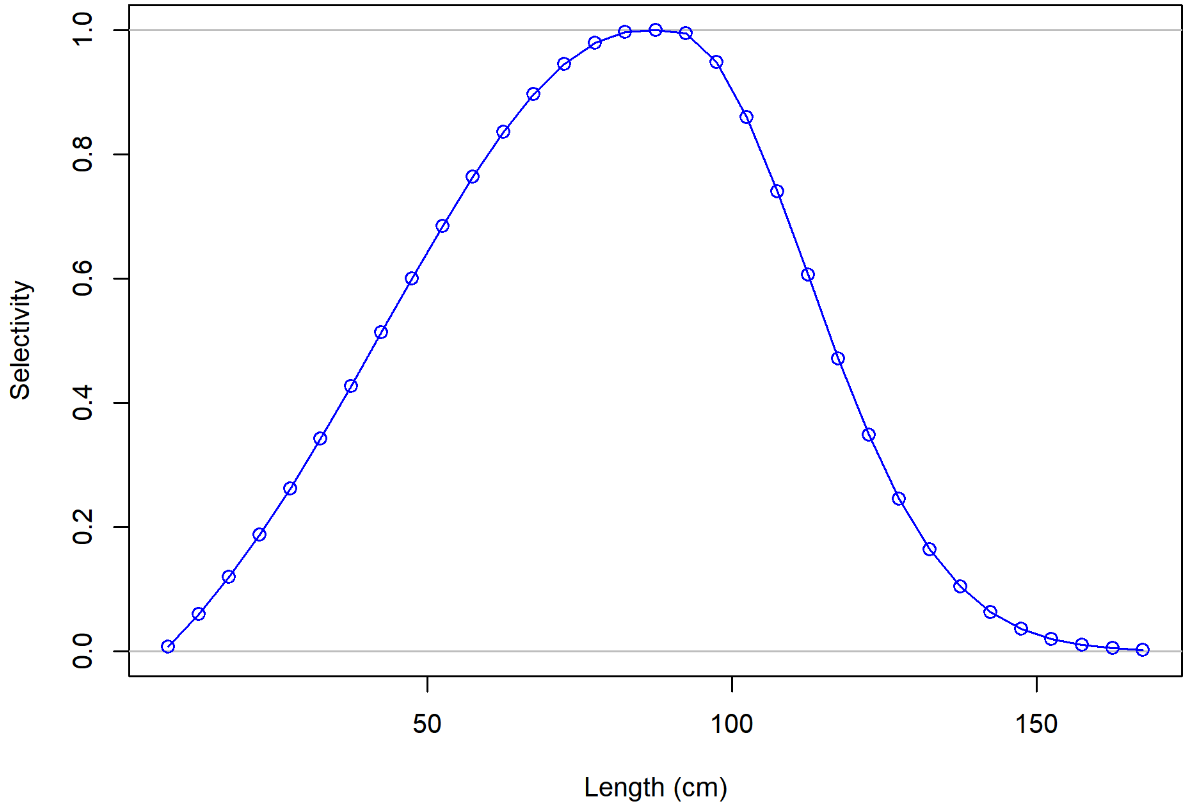

Figure 76. AFSC Slope survey selectivity estimated in the base model for Longnose Skate. The selectivity curve of the NWFSC Slope survey is mirrored to that of the AFSC Slope survey.

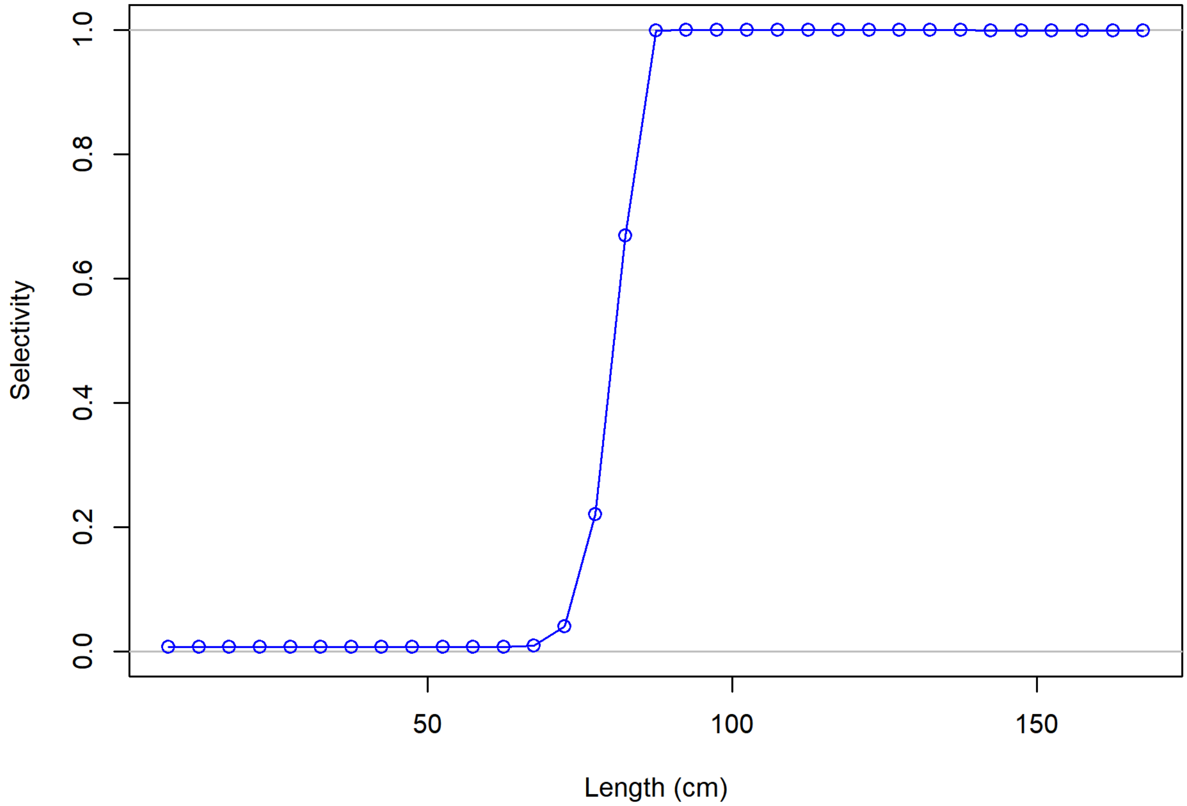

Figure 77. IPHC survey selectivity estimated in the base model for Longnose Skate.

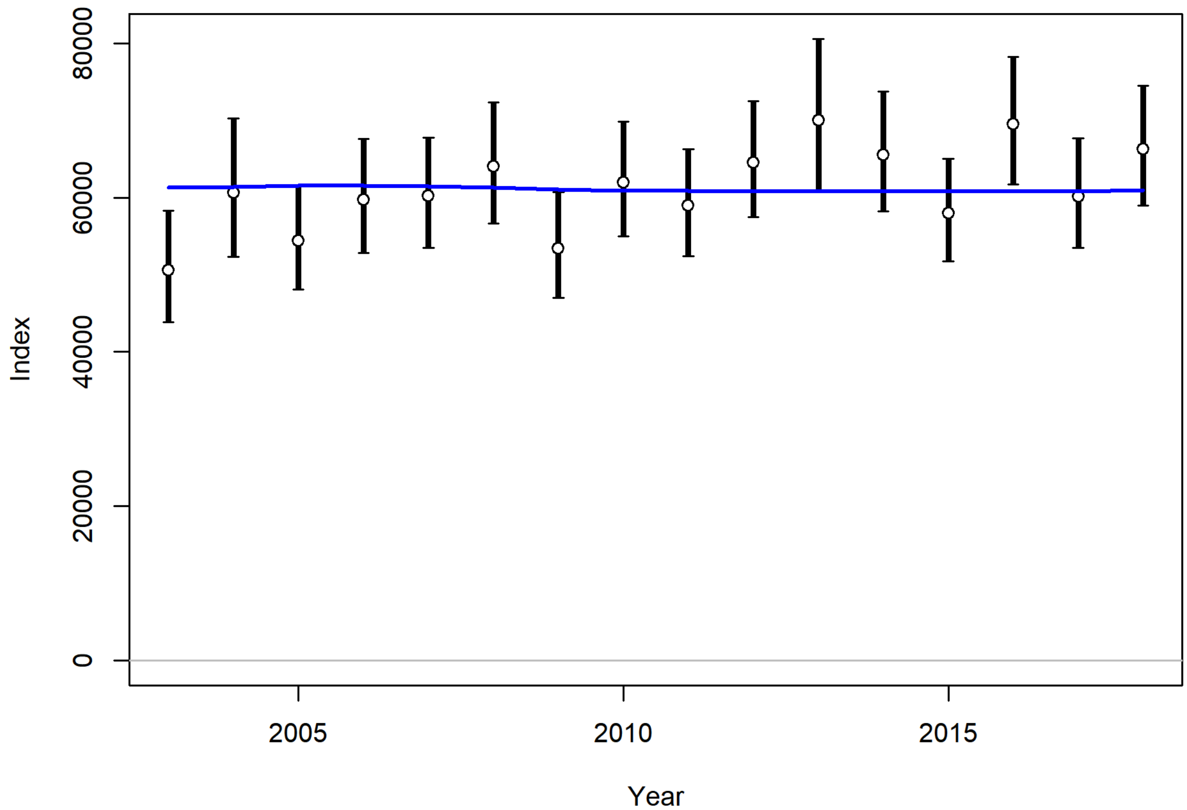

Figure 78. Base model fit to the WCGBT Survey index.

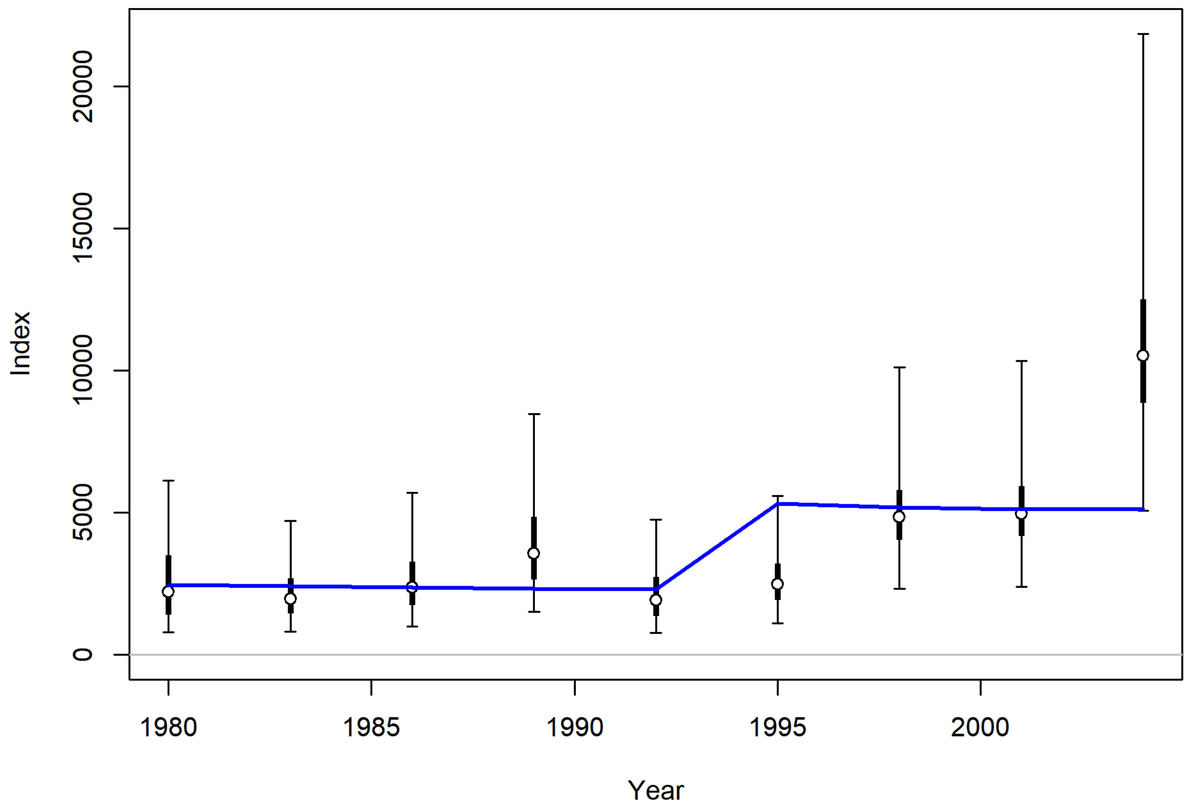

Figure 79. Base model fit to the ASFC Triennial Survey index.

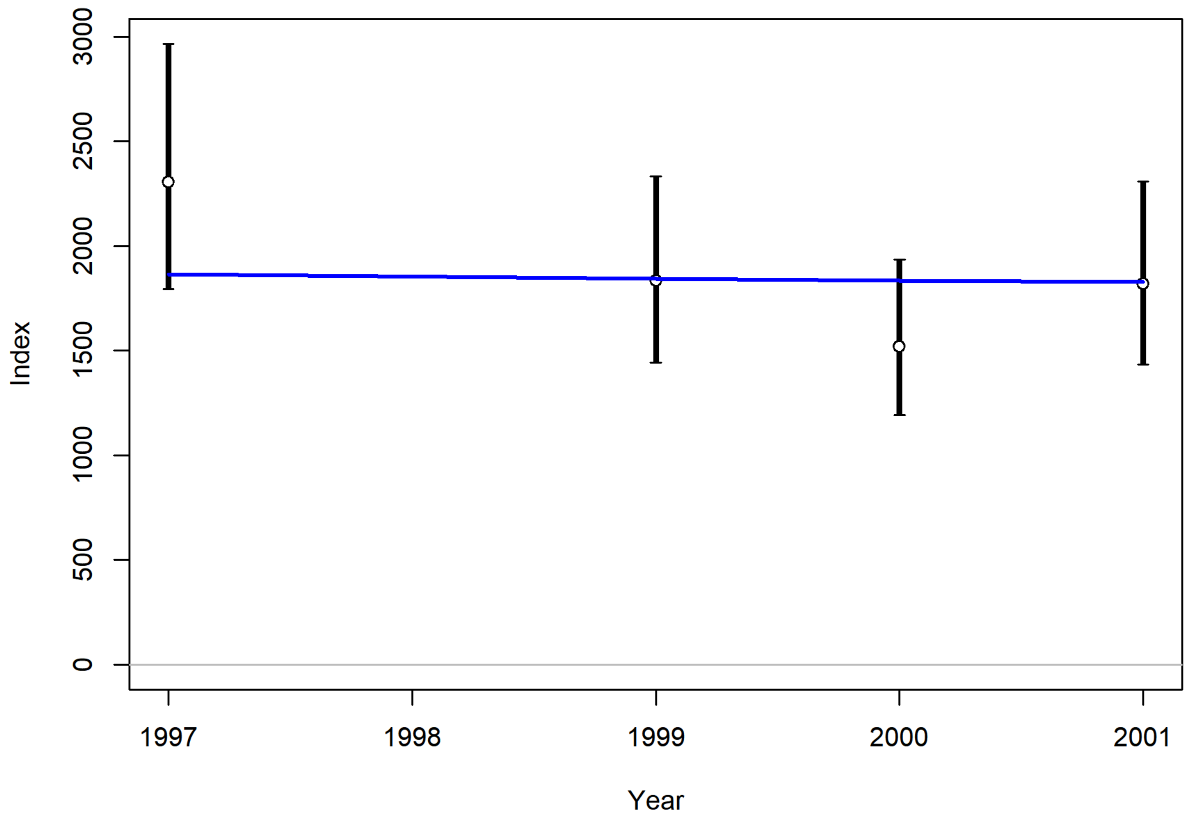

Figure 80. Base model fit to the ASFC Slope survey index.

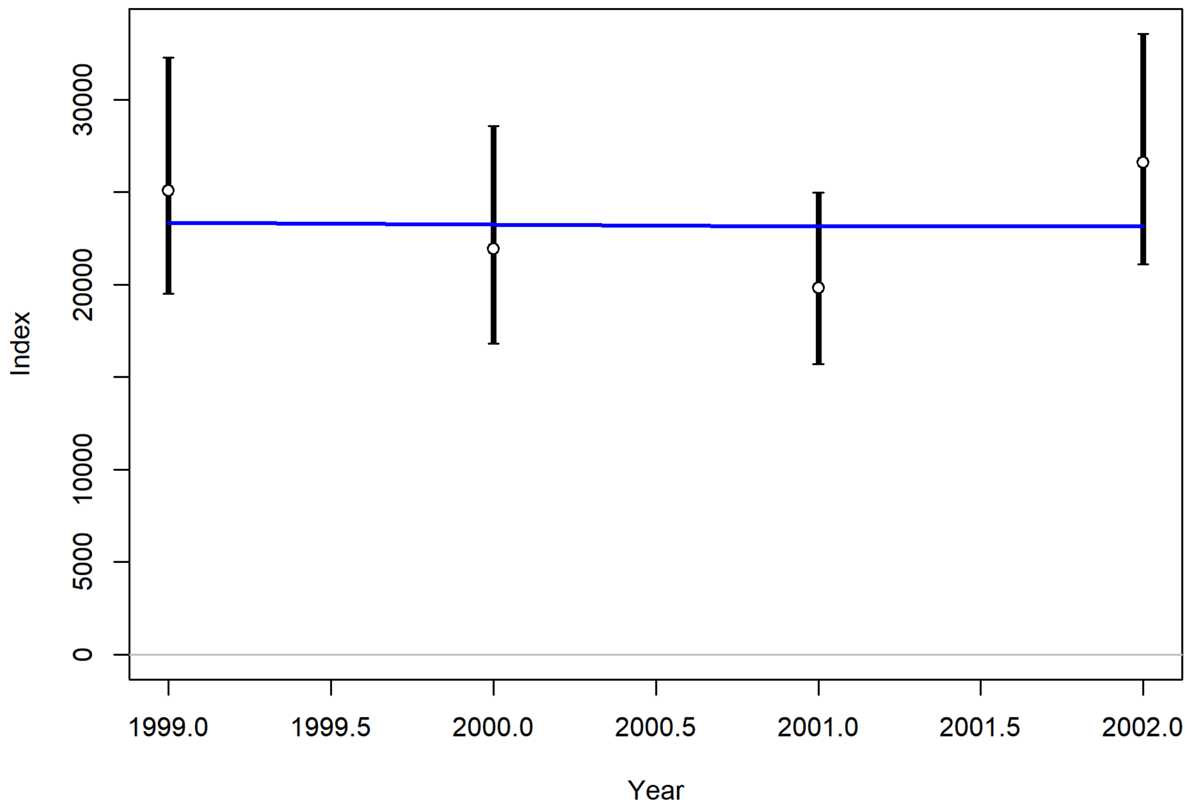

Figure 81. Base model fit to the NWFSC Slope survey index.

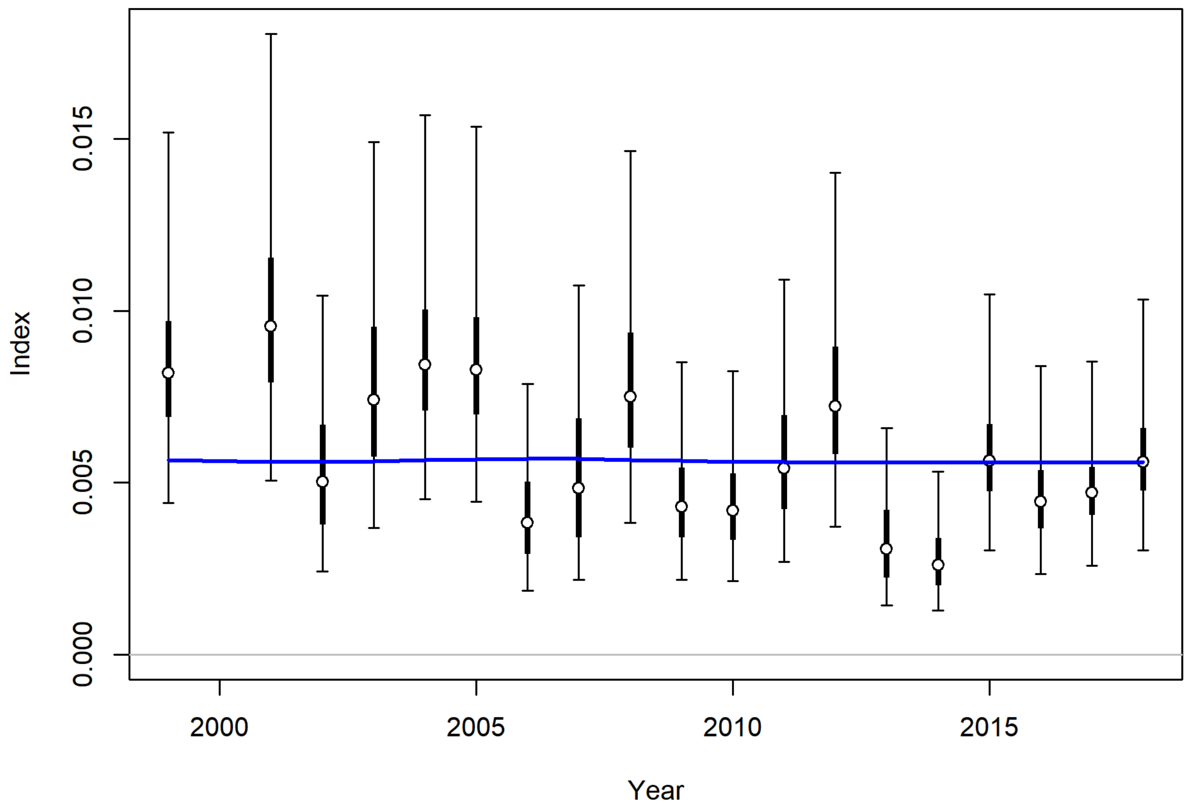

Figure 82. Base model fit to the IPHC survey index.

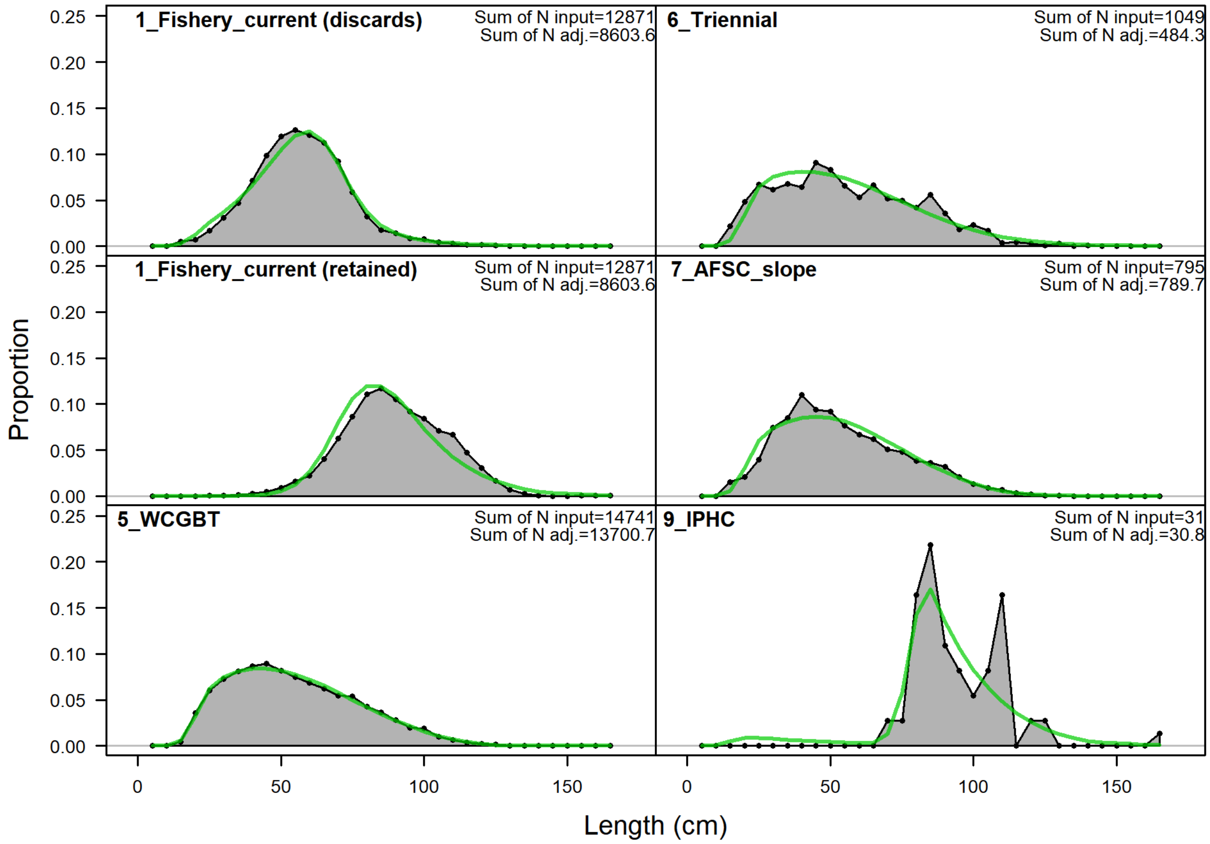

Figure 83. Fits to the length compositions by fleet.

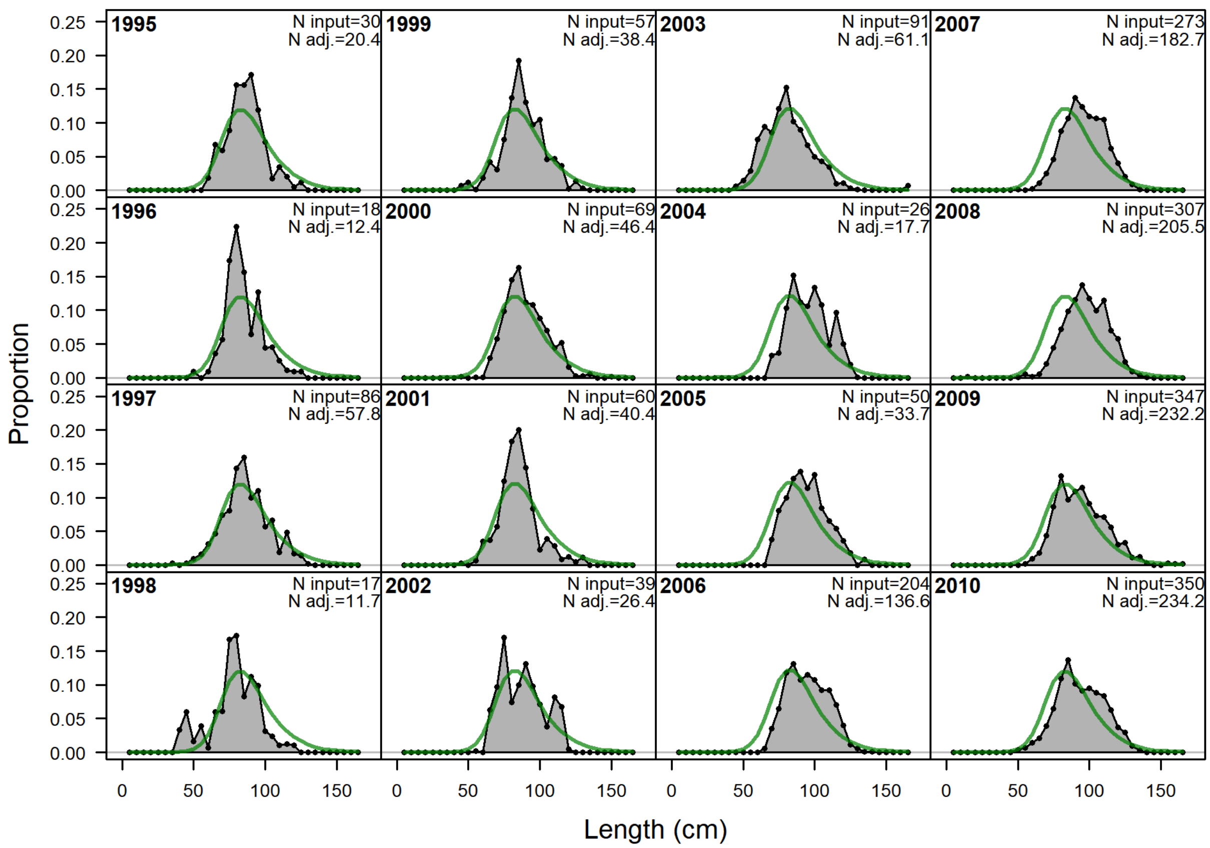

Figure 84. Fits to the fishery landings length compositions, years 1995-2010.

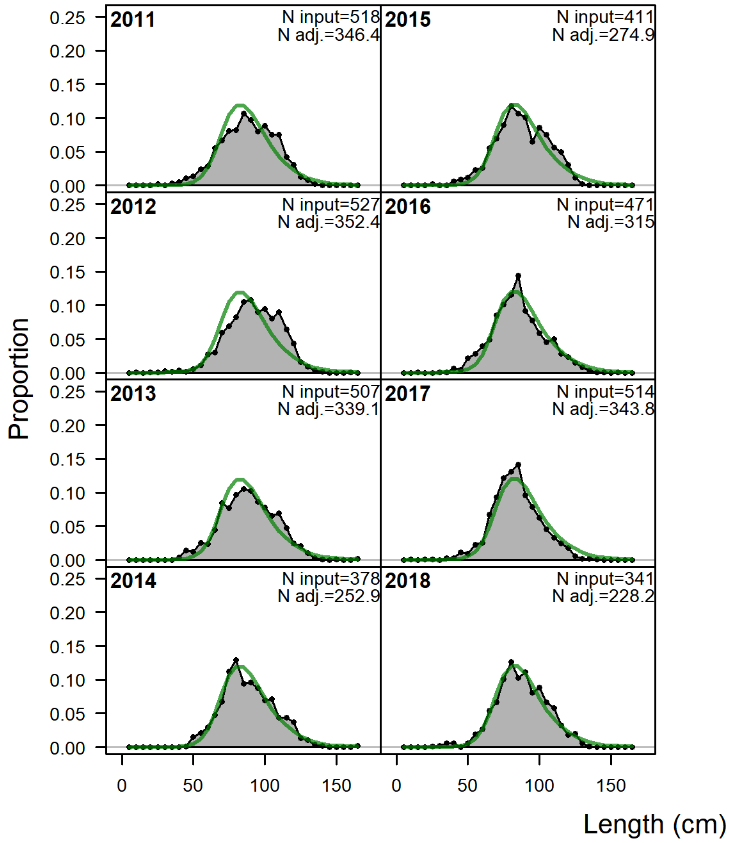

Figure 85. Fits to the fishery landings length compositions, years 2011-2018.

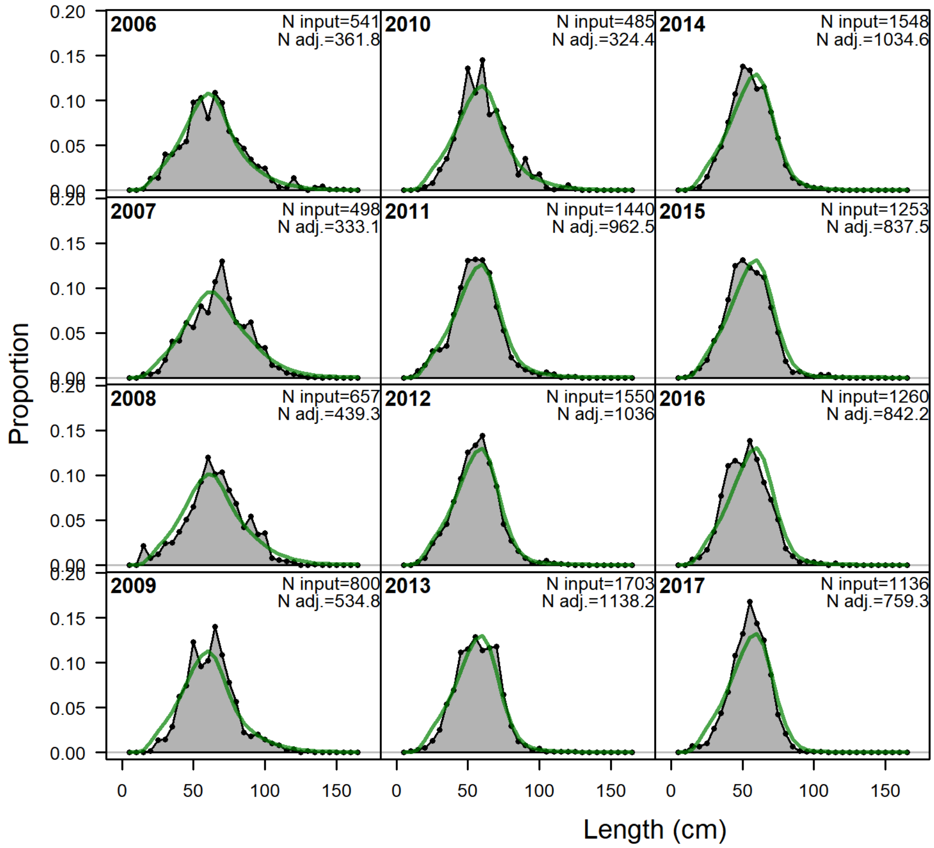

Figure 86. Fits to the fishery discard length compositions, by year.

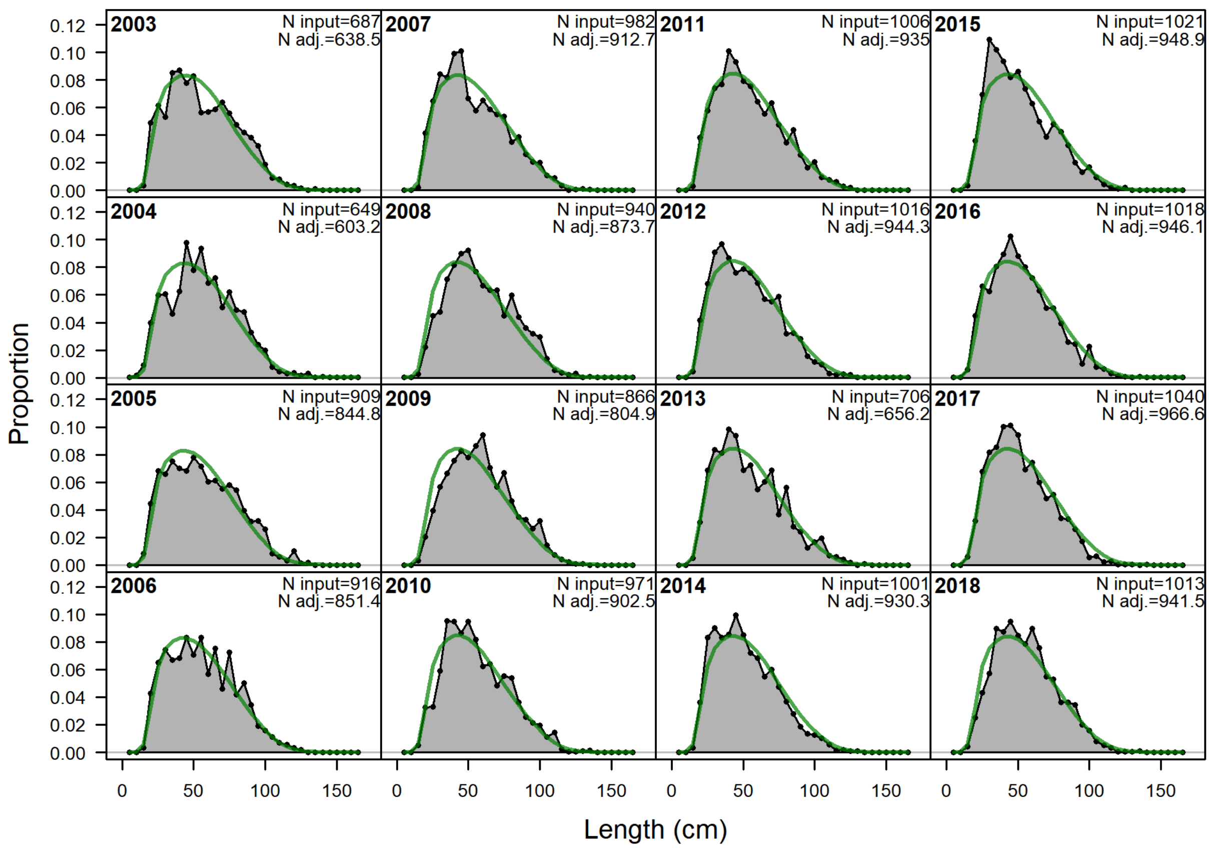

Figure 87. Fits to the WCGBT Survey length compositions, by year.

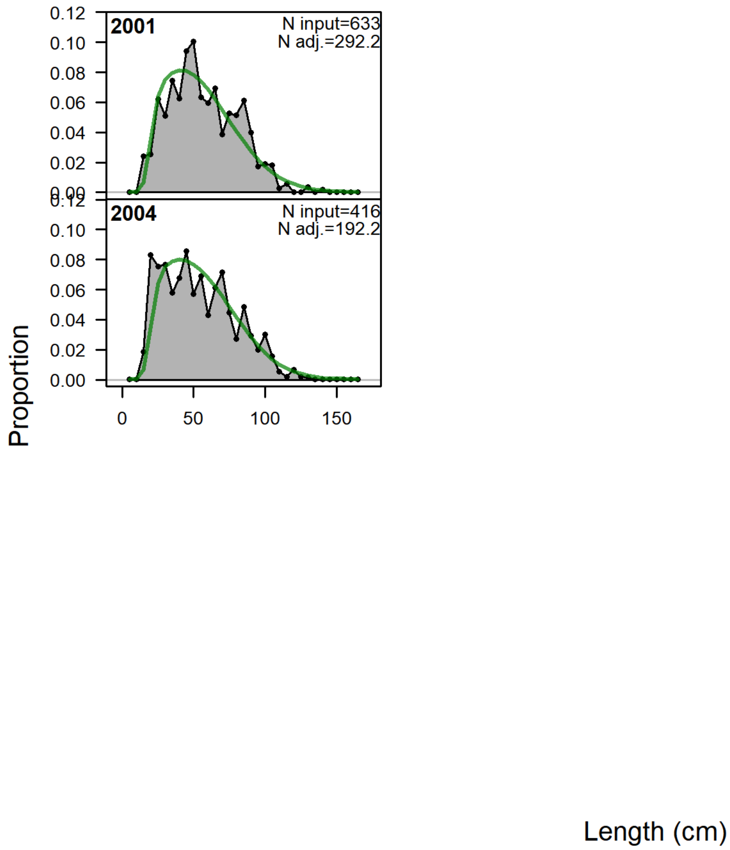

Figure 88. Fits to the AFSC Triennial Survey length compositions, by year.

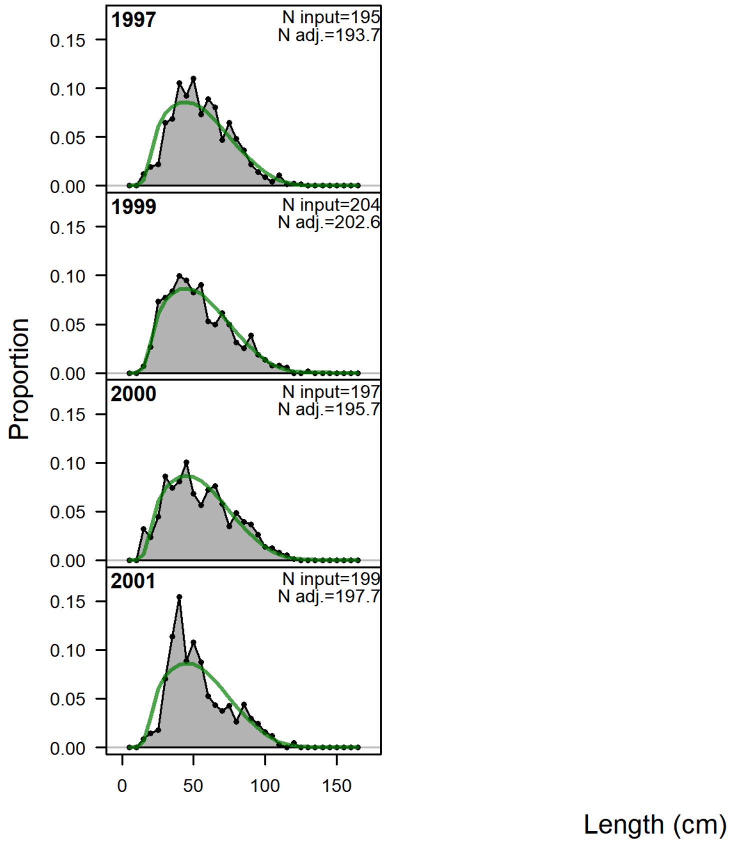

Figure 89. Fits to the AFSC Slope Survey length compositions, by year.

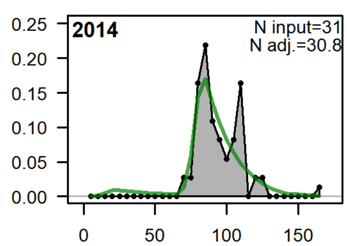

Figure 90. Fits to the IPHC Survey length compositions.

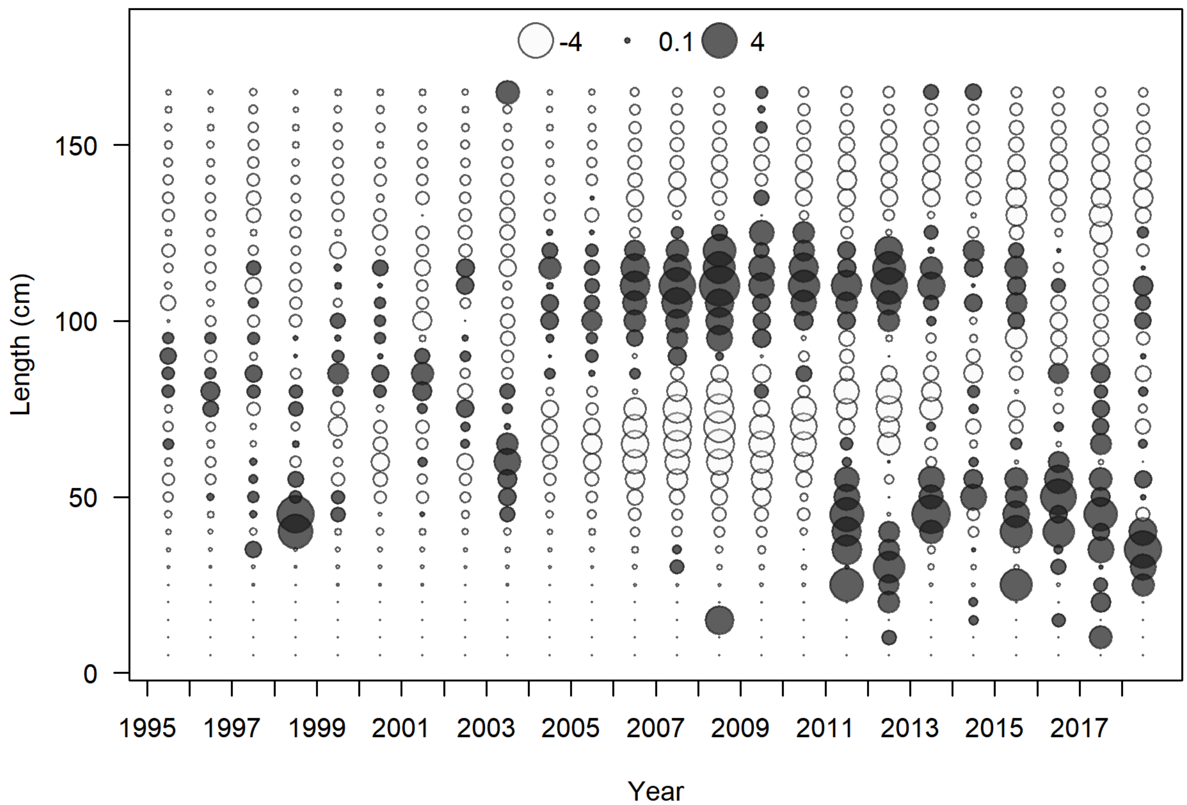

Figure 91. Pearson residuals plots of length compositions for the current fishery.

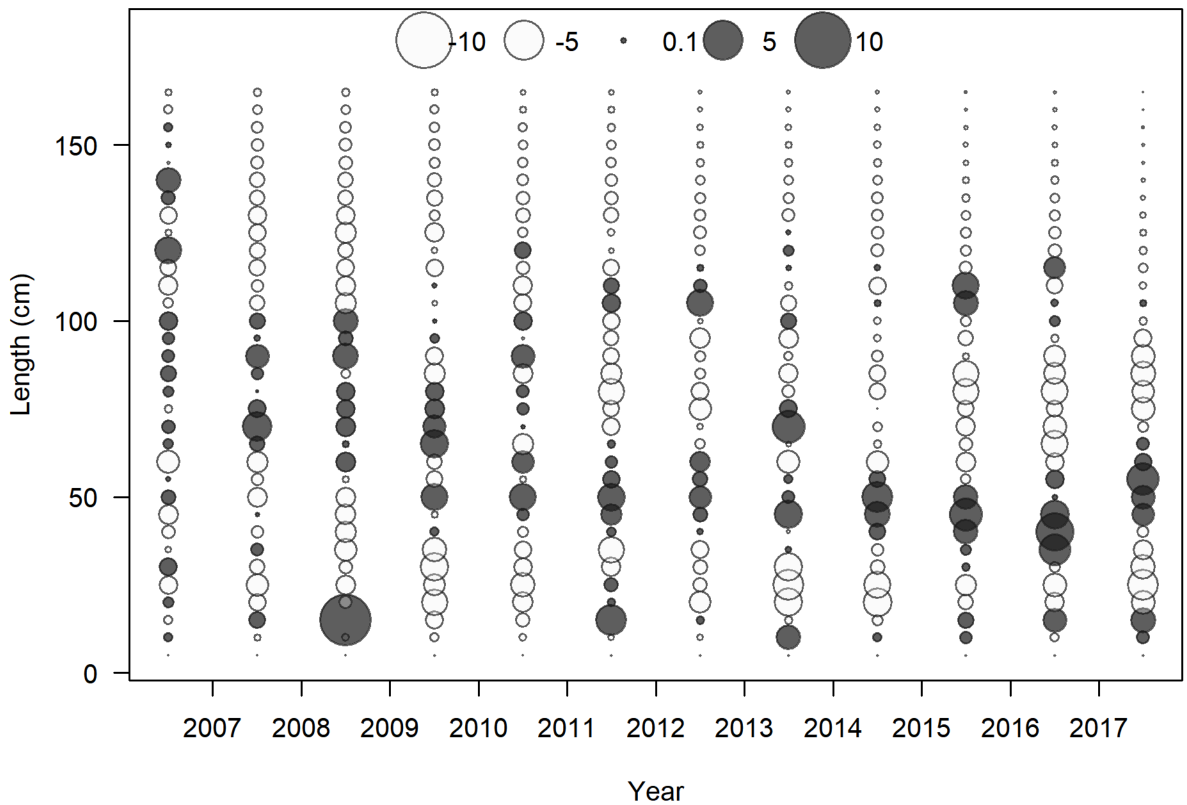

Figure 92. Pearson residuals plots of length compositions for fishery discard.

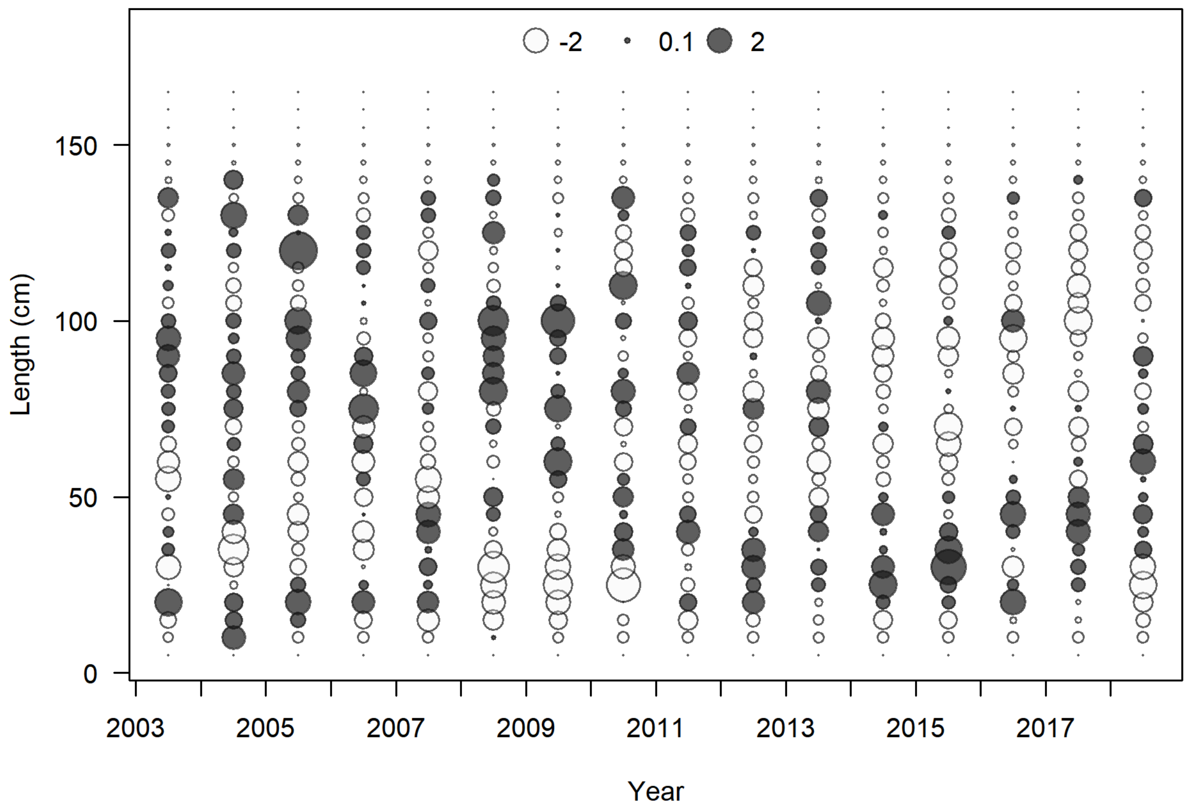

Figure 93. Pearson residuals plots of length compositions for WCGBT Survey.

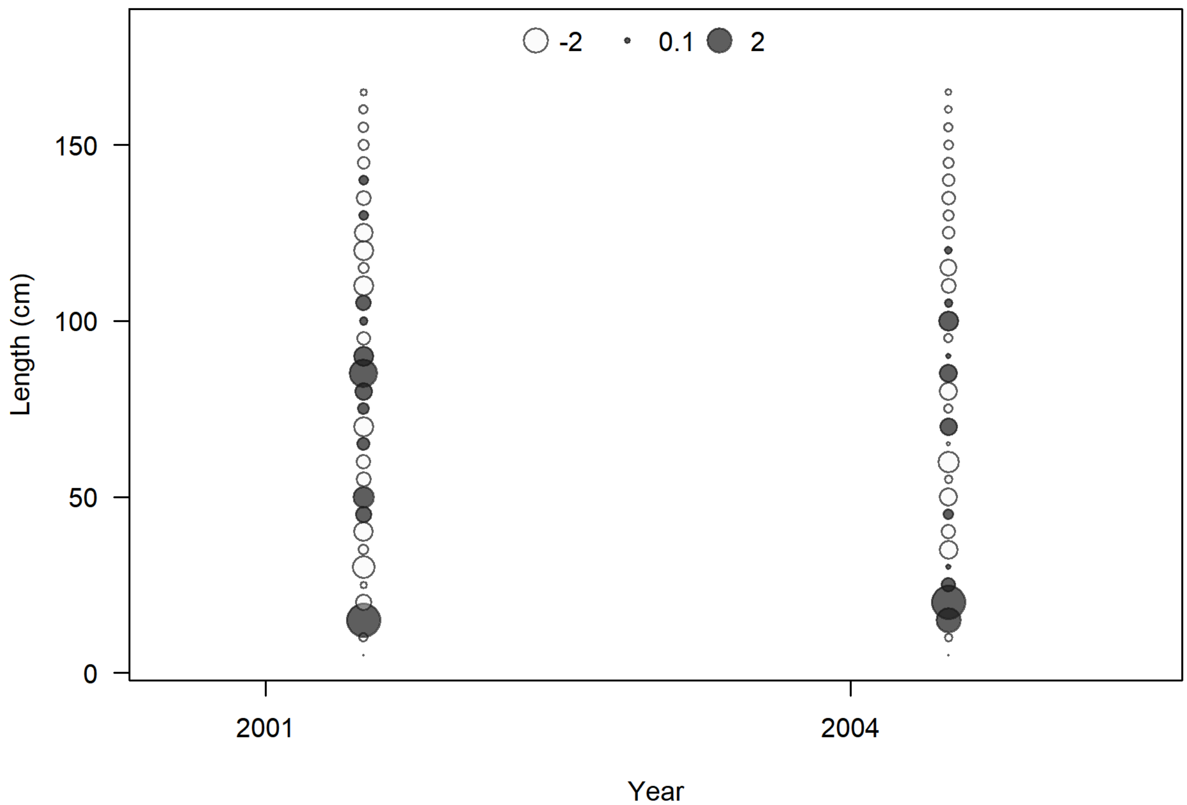

Figure 94. Pearson residuals plots of length compositions for AFSC Triennial Survey.

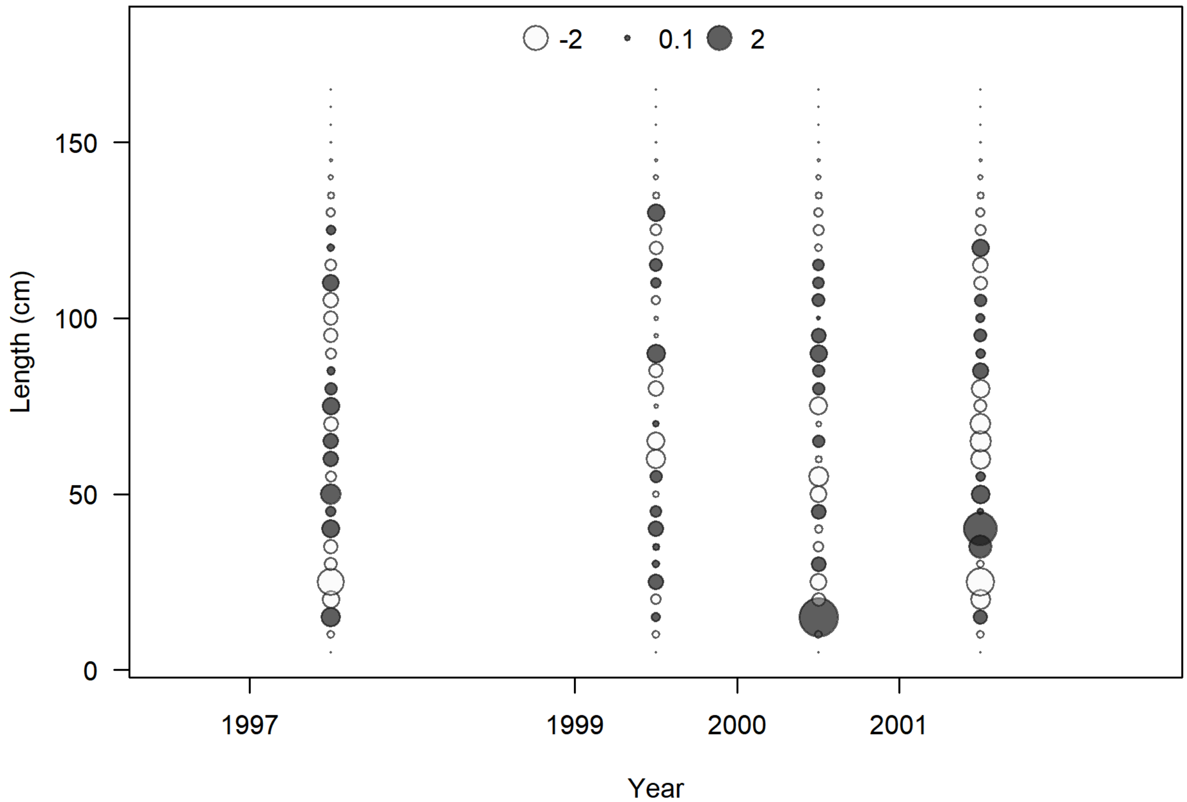

Figure 95. Pearson residuals plots of length compositions for AFSC Slope survey.

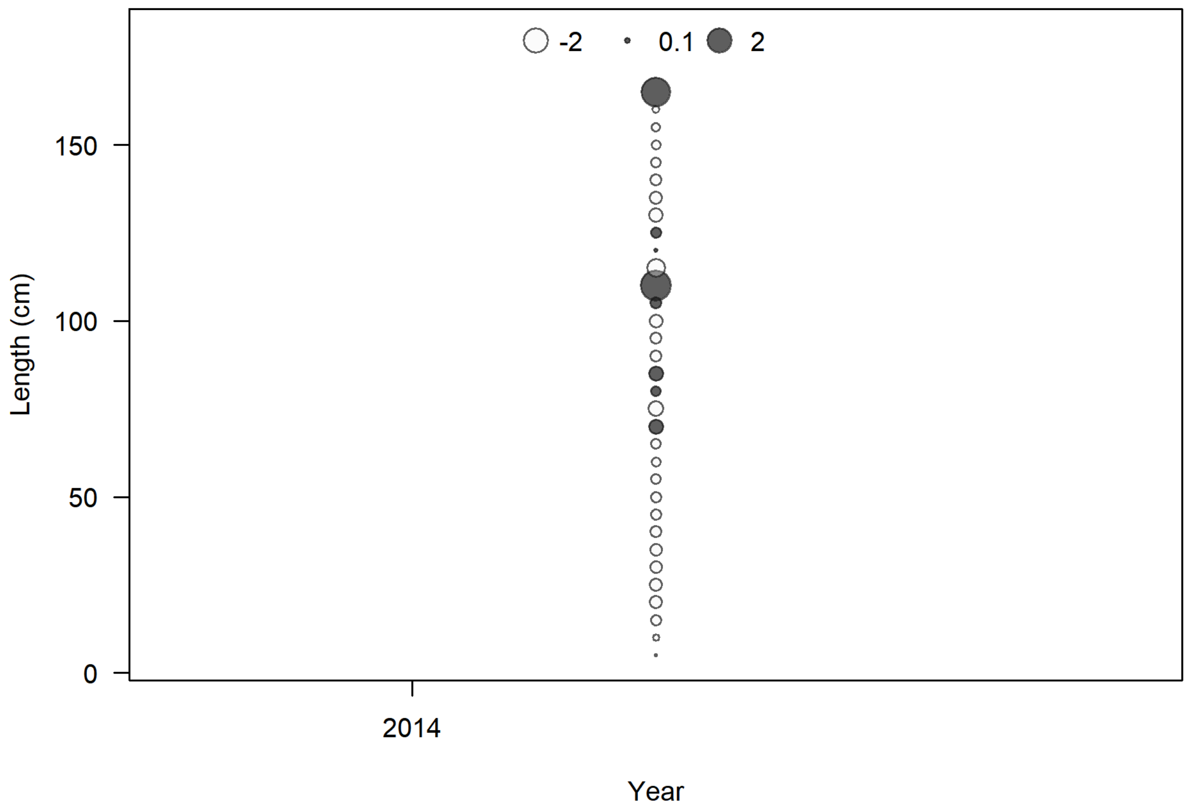

Figure 96. Pearson residuals plots of length compositions for IPHC survey.

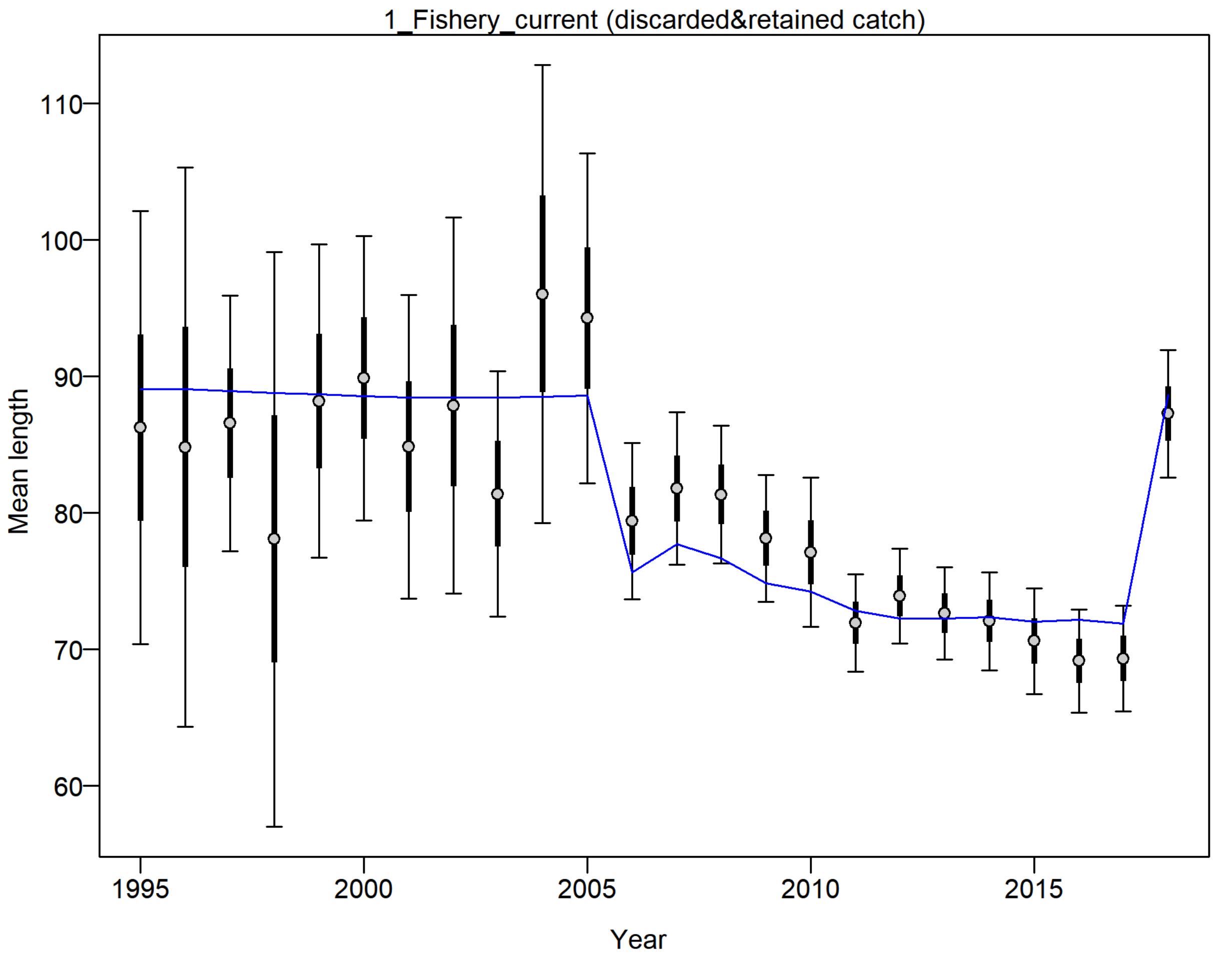

Figure 97. Dirichlet-Multinomial weighting fits to the mean lengths by year for current fishery. Vertical lines are 95% confidence intervals.

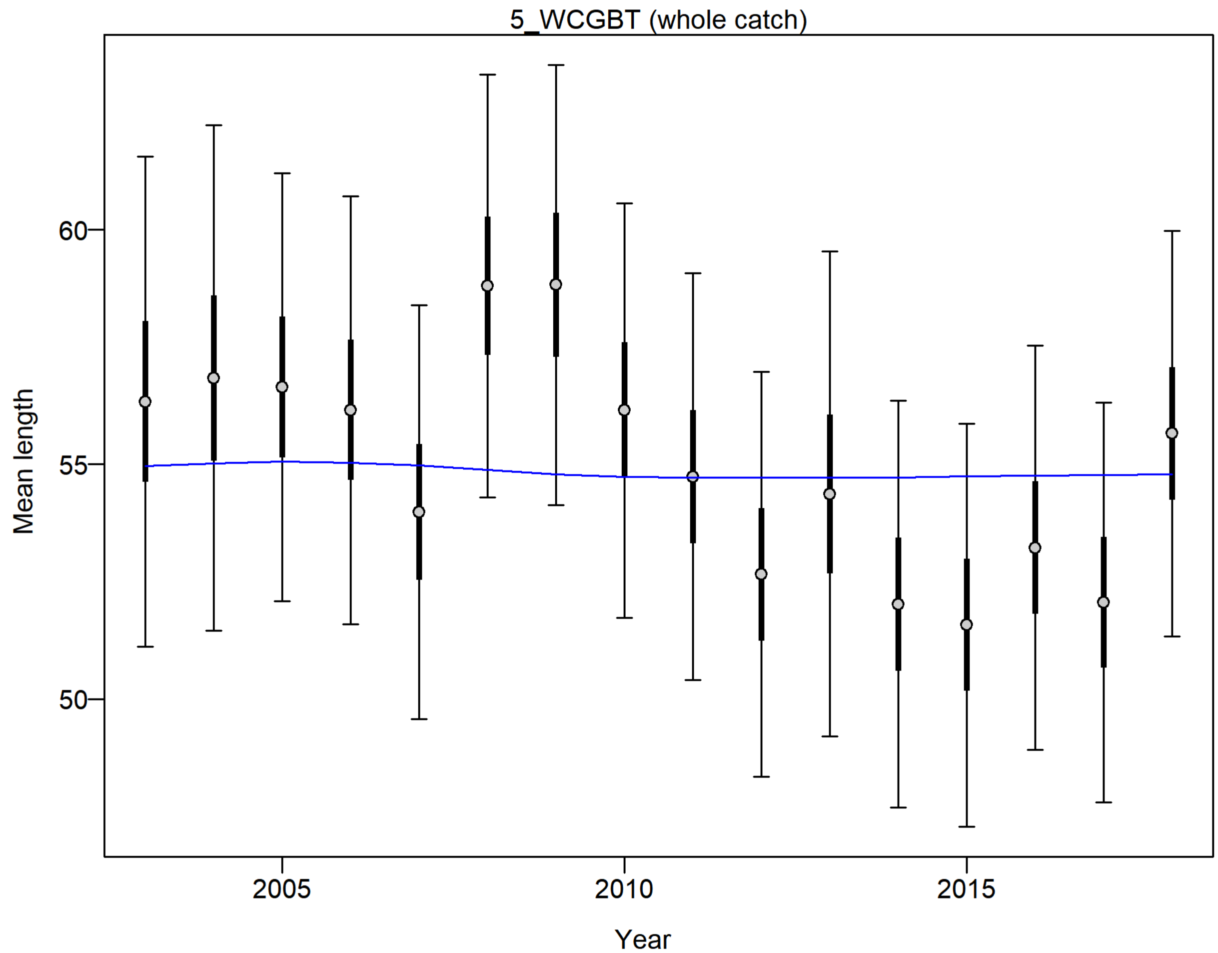

Figure 98. Dirichlet-Multinomial weighting fits to the mean lengths by year for WCGBT Survey. Vertical lines are 95% confidence intervals.

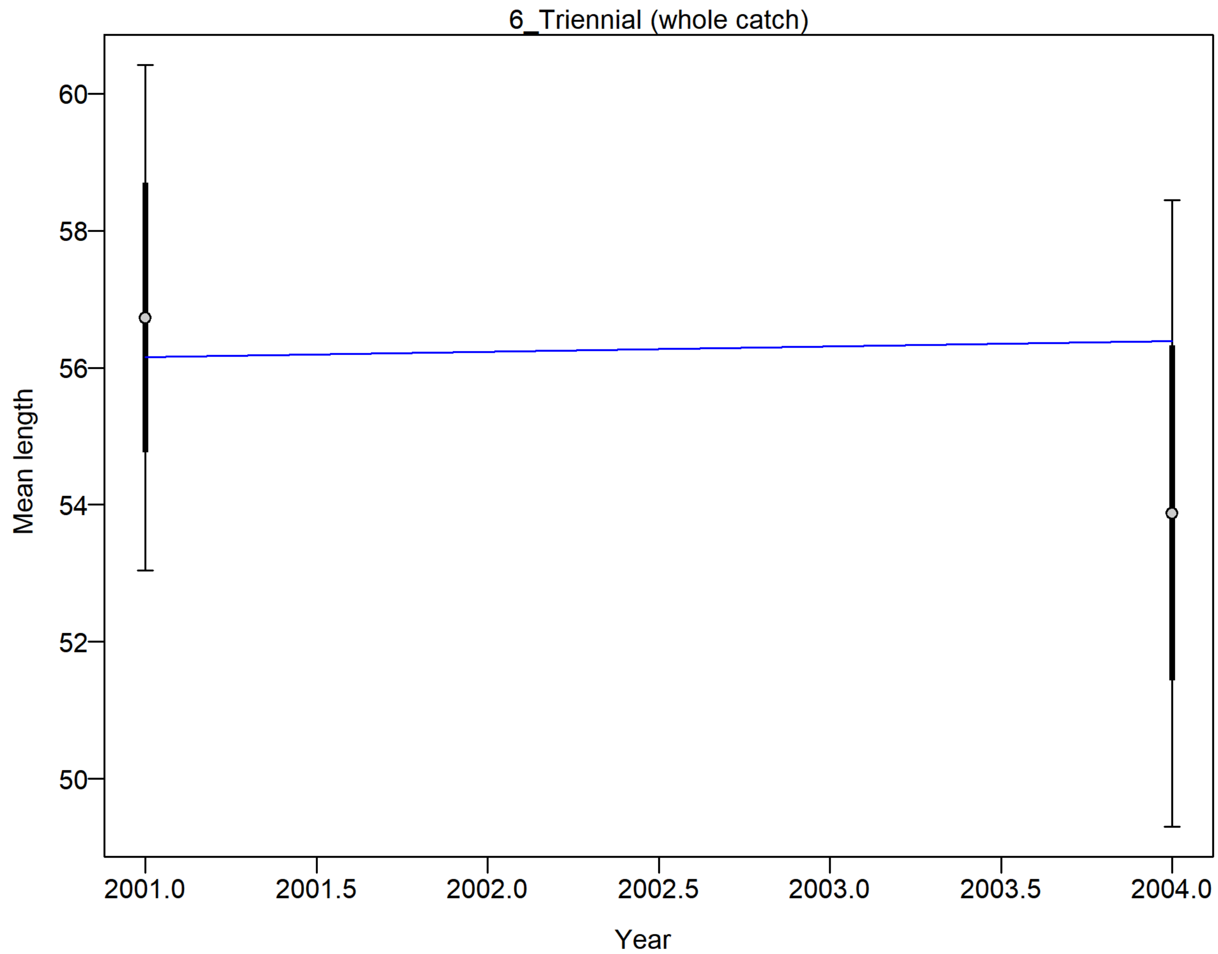

Figure 99. Dirichlet-Multinomial weighting fits to the mean lengths by year for AFSC Triennial Survey. Vertical lines are 95% confidence intervals.

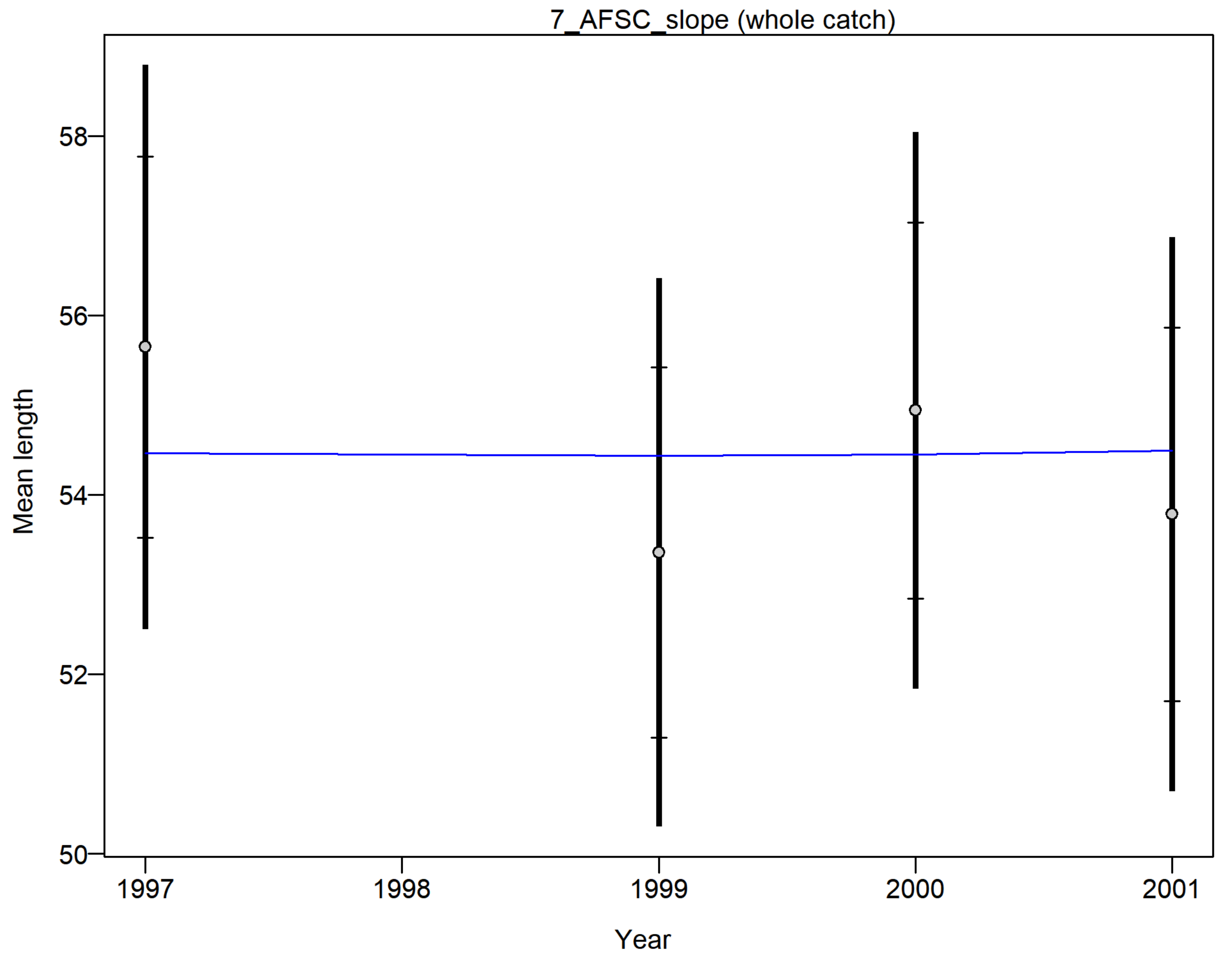

Figure 100. Dirichlet-Multinomial weighting fits to the mean lengths by year for AFSC Slope Survey. Vertical lines are 95% confidence intervals.

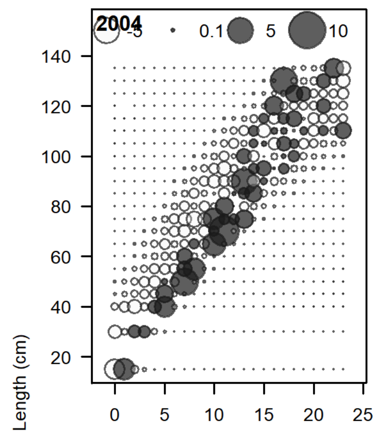

Figure 101. Pearson residuals for the fit to conditional ages-at-length compositions of Longnose Skate from current fishery.

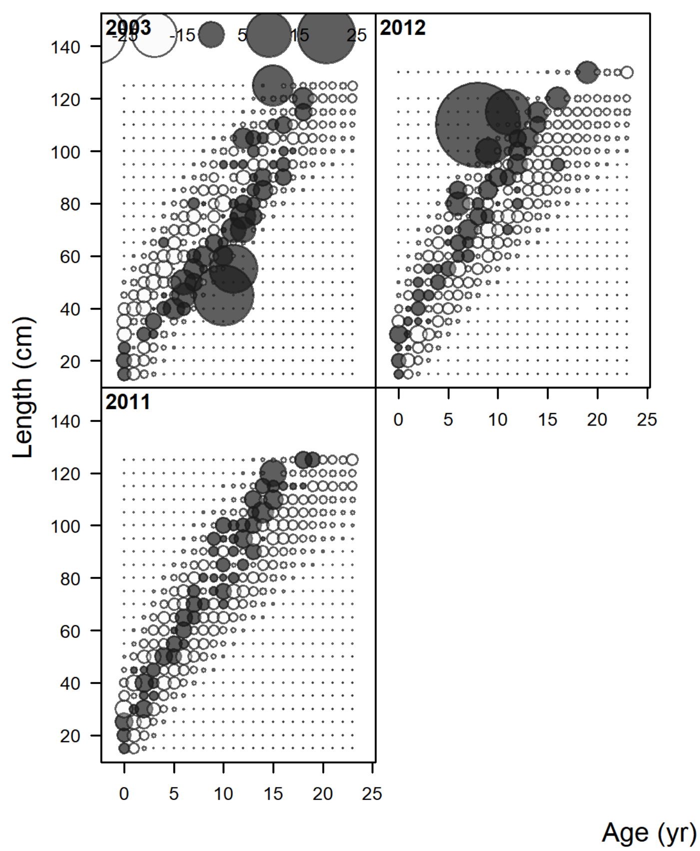

Figure 102. Pearson residuals for the fit to conditional ages-at-length compositions of Longnose Skate from WCGBT Survey.

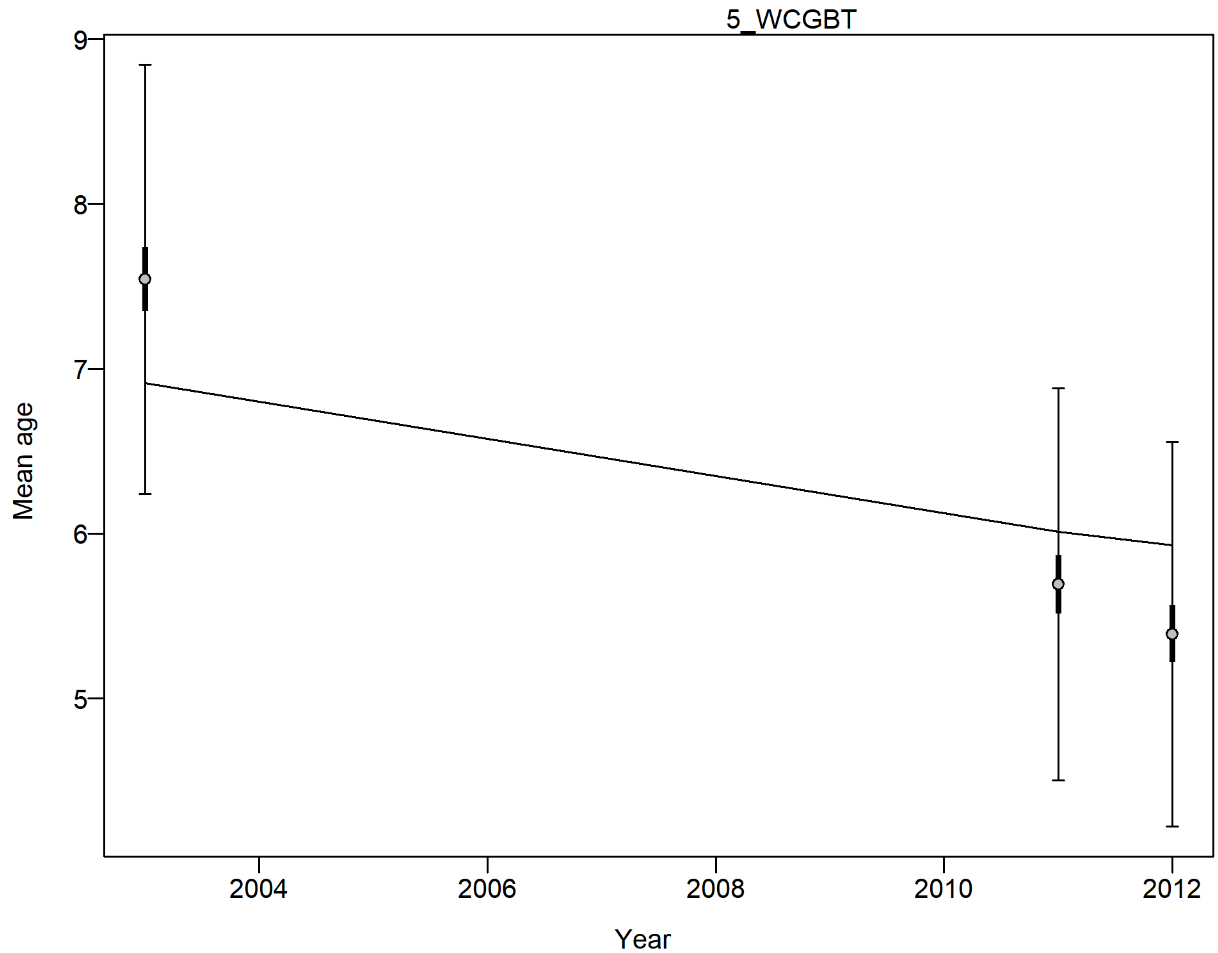

Figure 103. Dirichlet-Multinomial weighting fits to the mean ages by year for WCGBT Survey. Vertical lines are 95% confidence intervals.

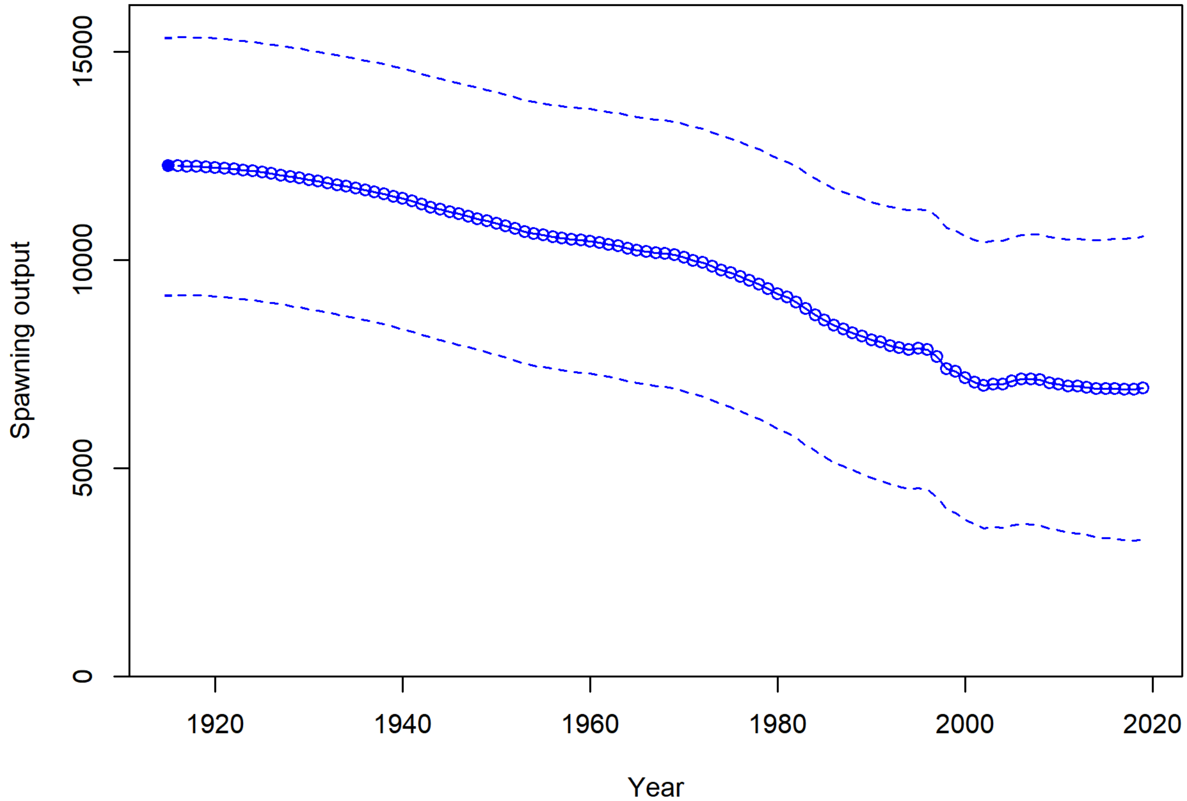

Figure 104. Time series of spawning biomass estimated in the assessment model (solid line) with ~ 95% interval (dashed lines).

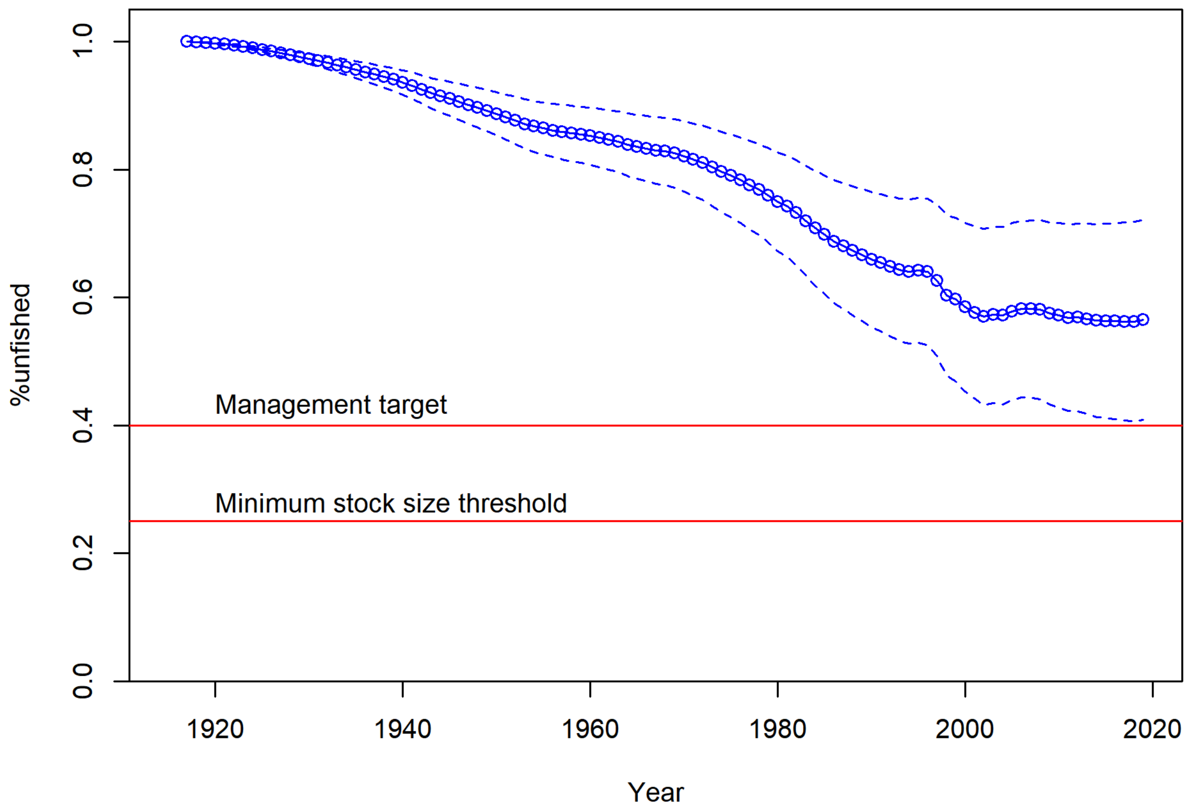

Figure 105. Time series of relative spawning biomass estimated in the assessment model (solid line) with ~95% interval (dashed lines).

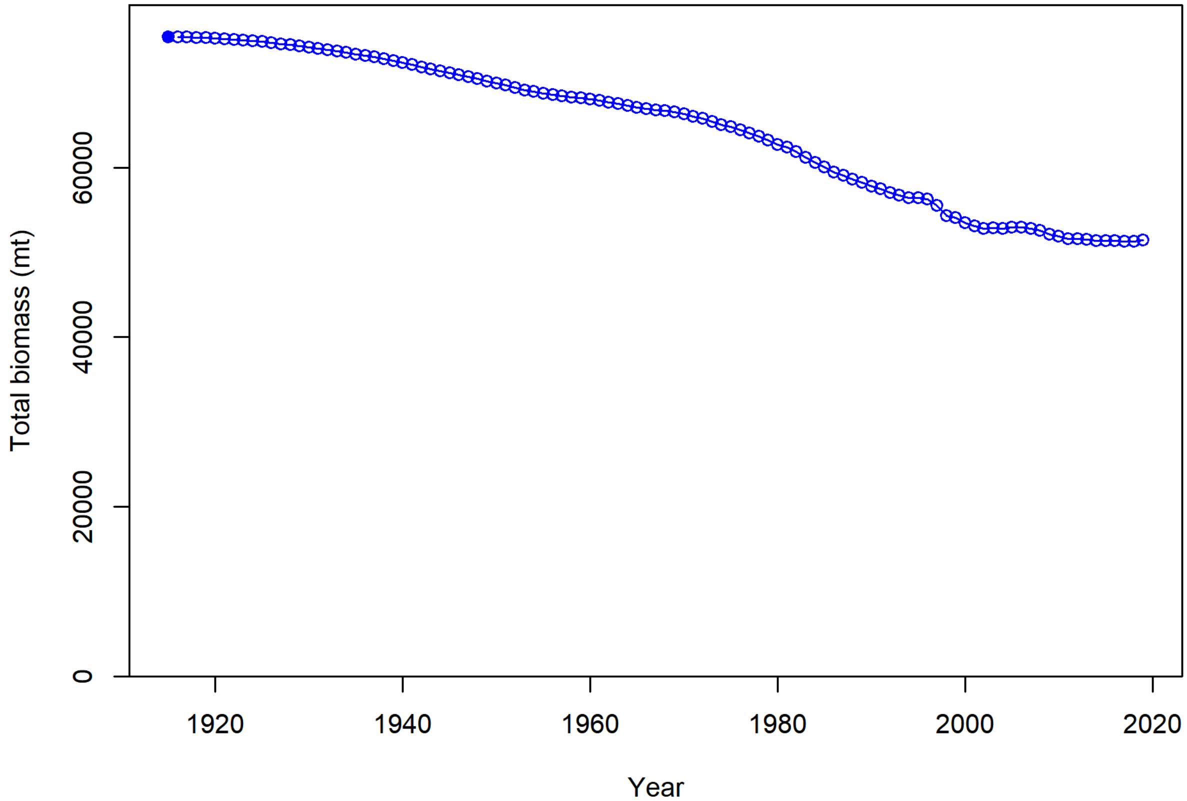

Figure 106. Time series of total biomass estimated in the assessment model.

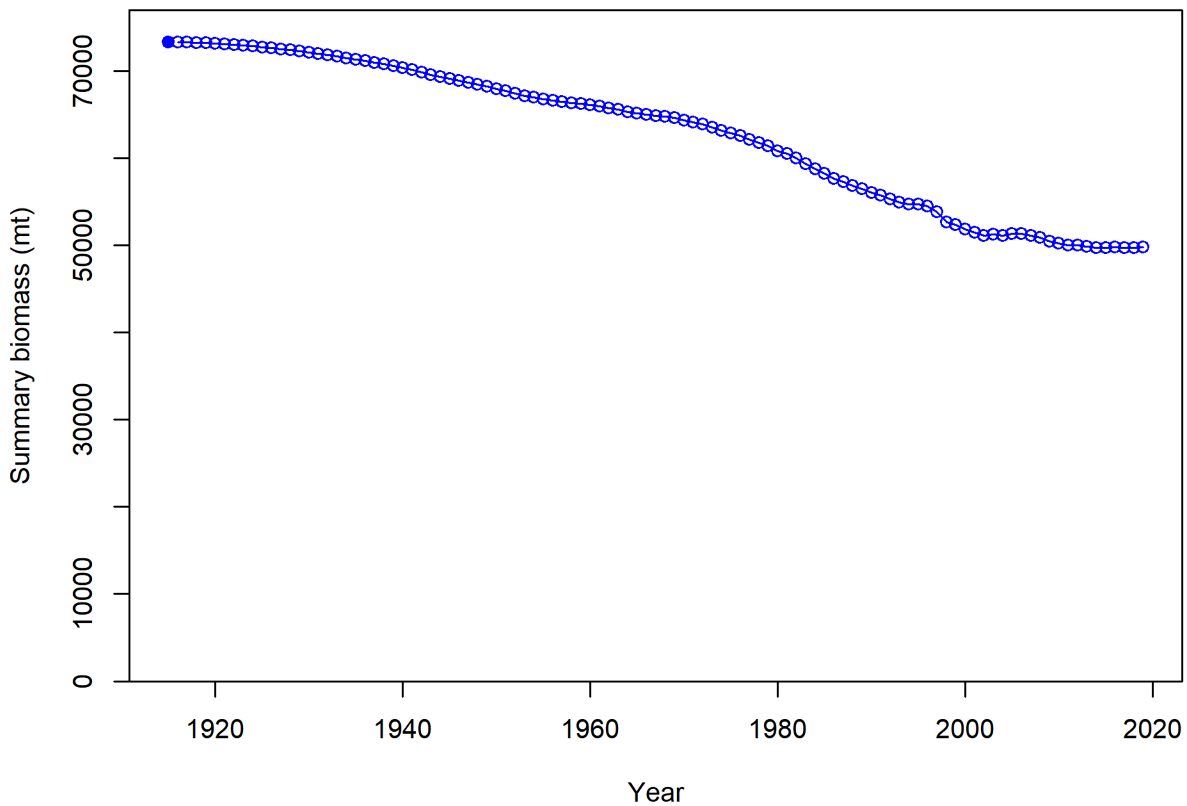

Figure 107. Time series of summary biomass estimated in the assessment model.

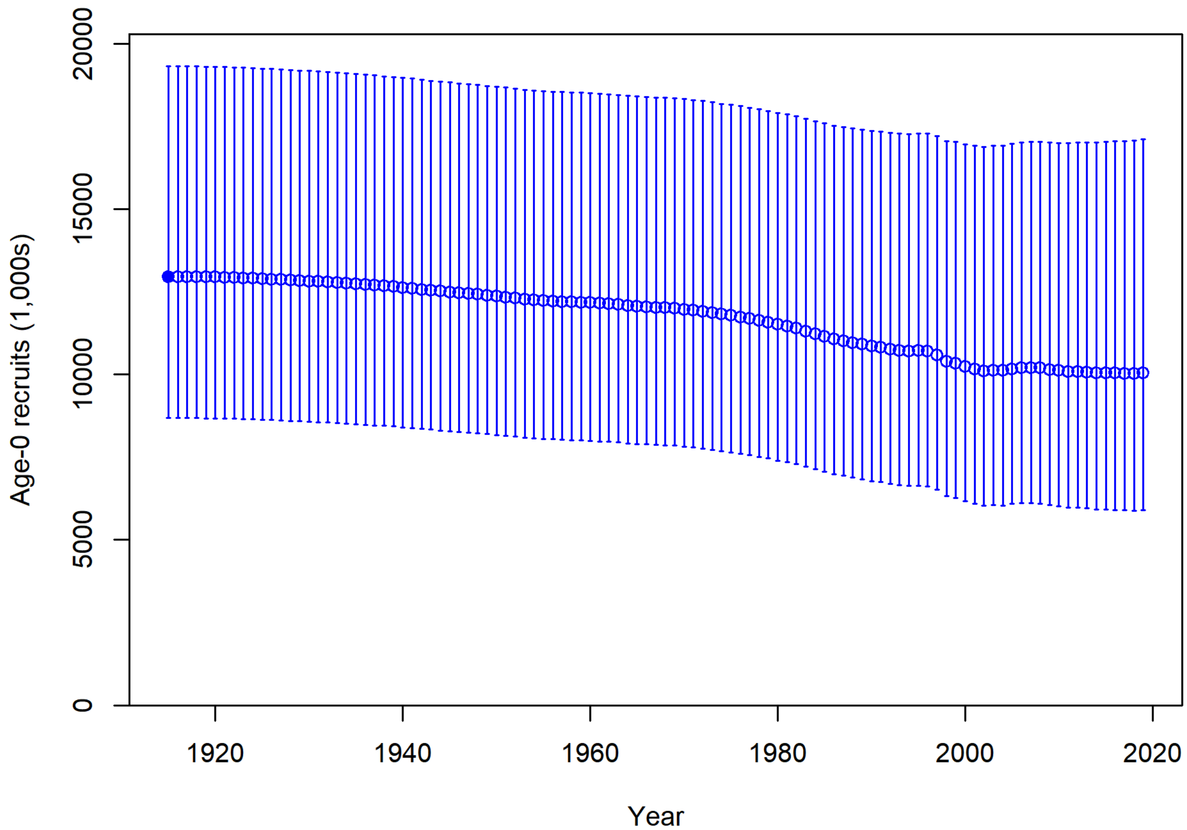

Figure 108. Time series of recruitment estimated in the assessment model with ~ 95% interval.

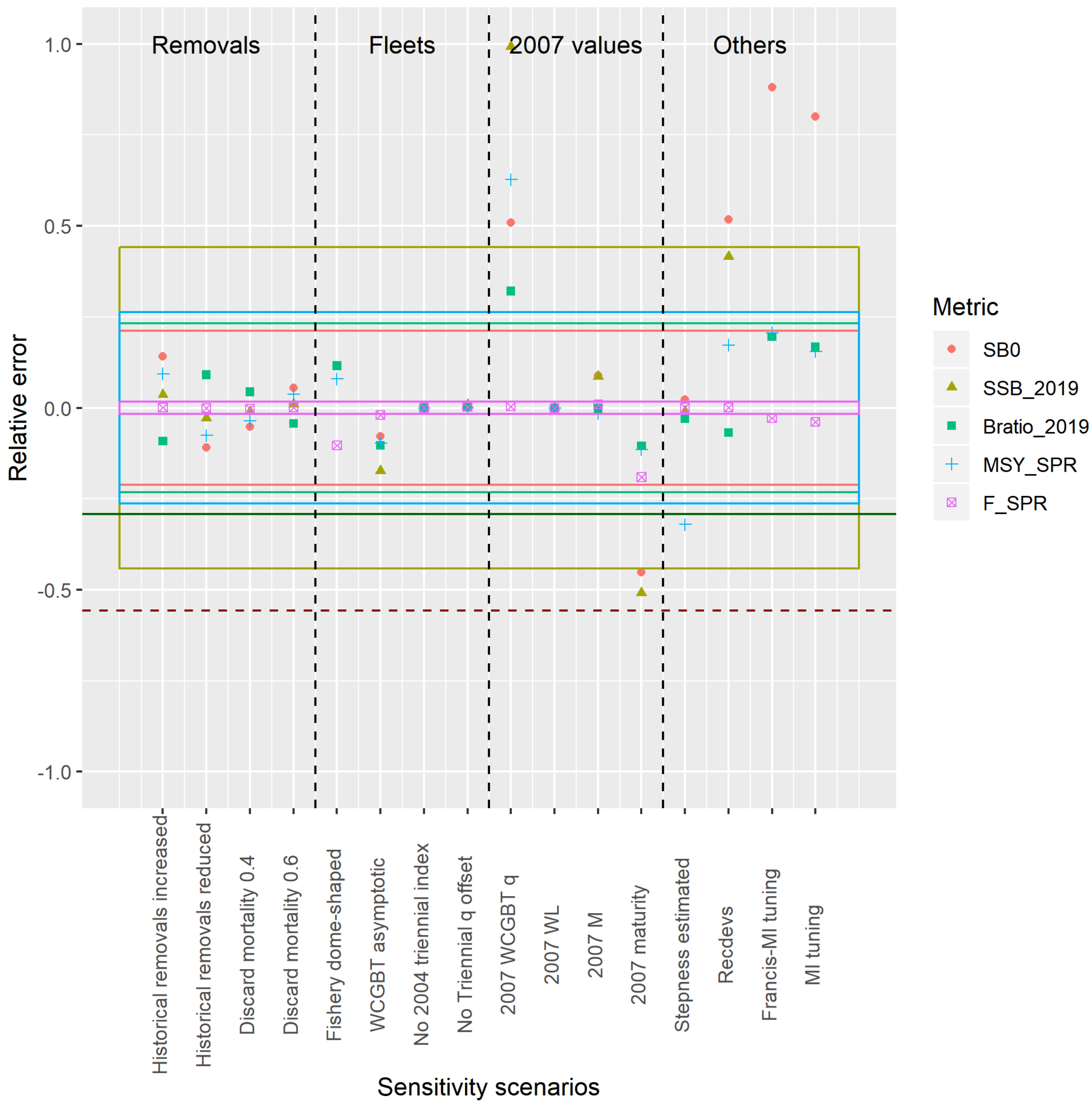

Figure 109. Sensitivity of the base model to alternative model specifications. Relative error is defined as the difference in a given metric between the proposed model and the base model, divided by the base model value. Boxes correspond to the 95% confidence interval of a derived quantity (indicated by color) in the base model. Values outside the box would indicate significant uncertainty in the sensitivity run from the uncertainty provided in the base model.

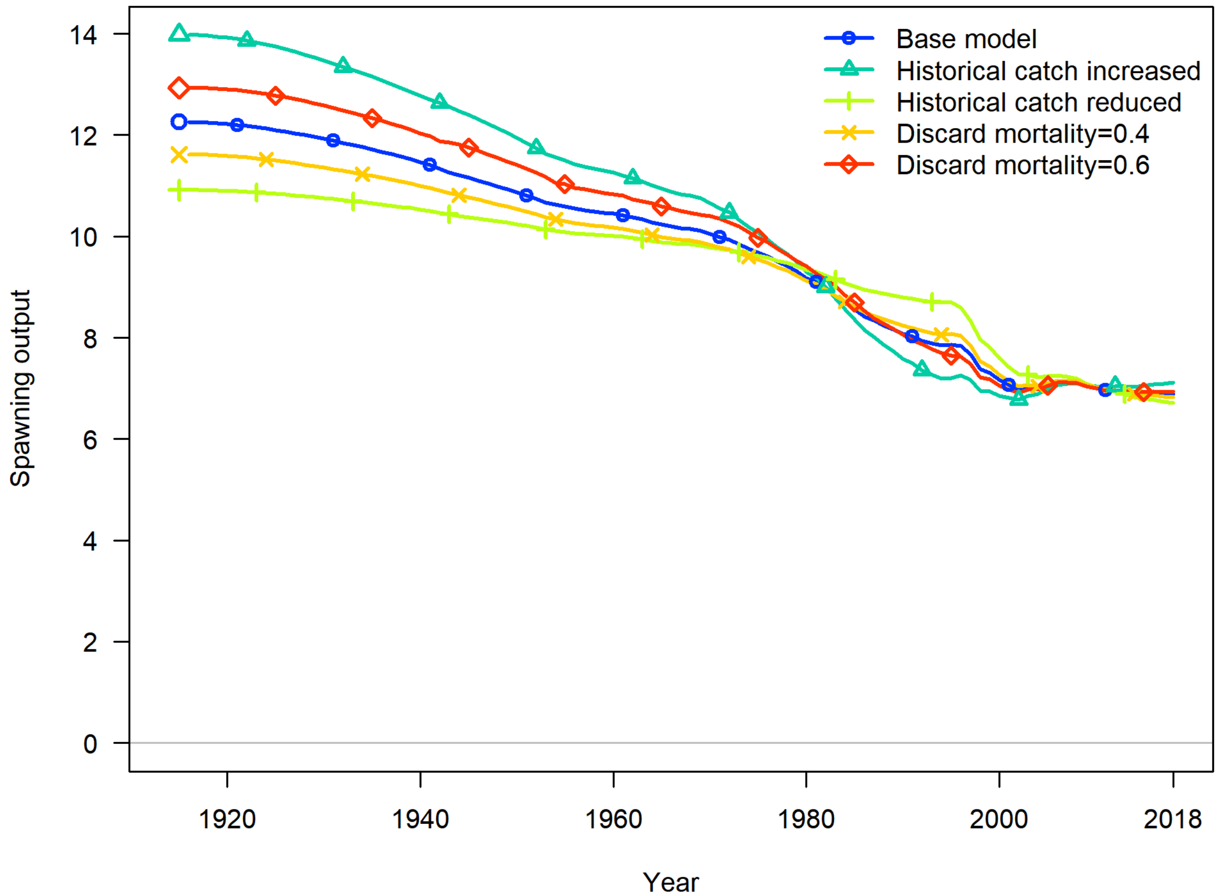

Figure 110. Sensitivity of Longnose Skate spawning biomass to alternative catch time series.

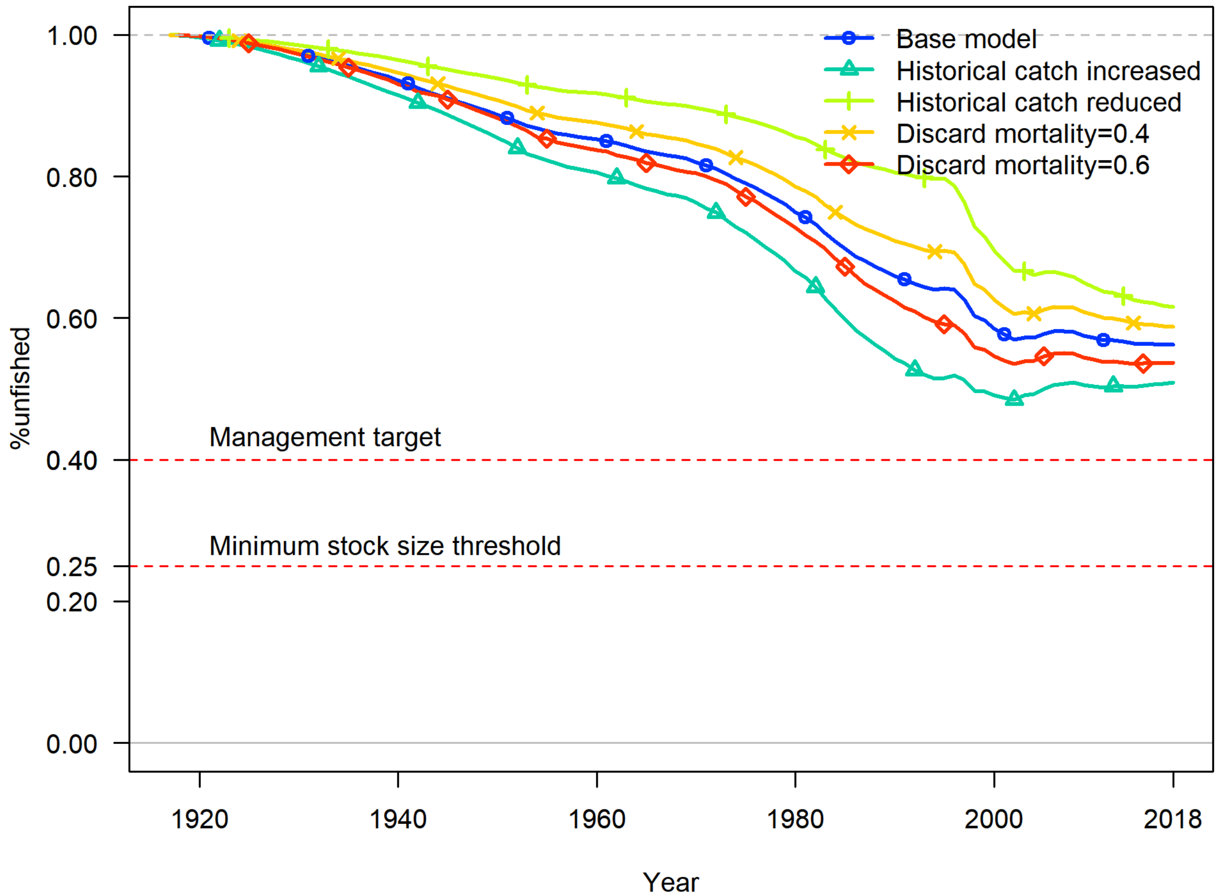

Figure 111. Sensitivity of Longnose Skate relative spawning biomass to alternative catch time series.

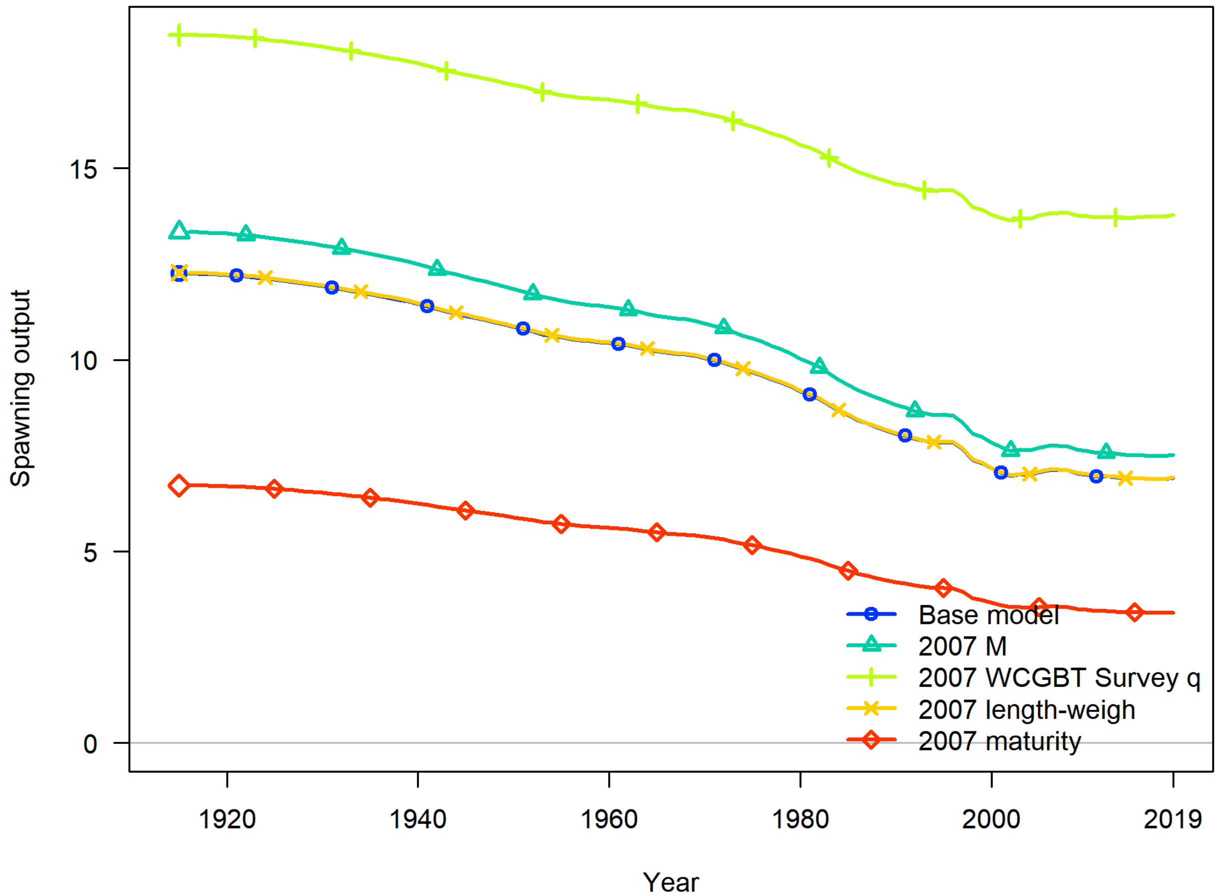

Figure 112. Sensitivity of Longnose Skate spawning biomass to updating selected parameters from 2007 assessment.

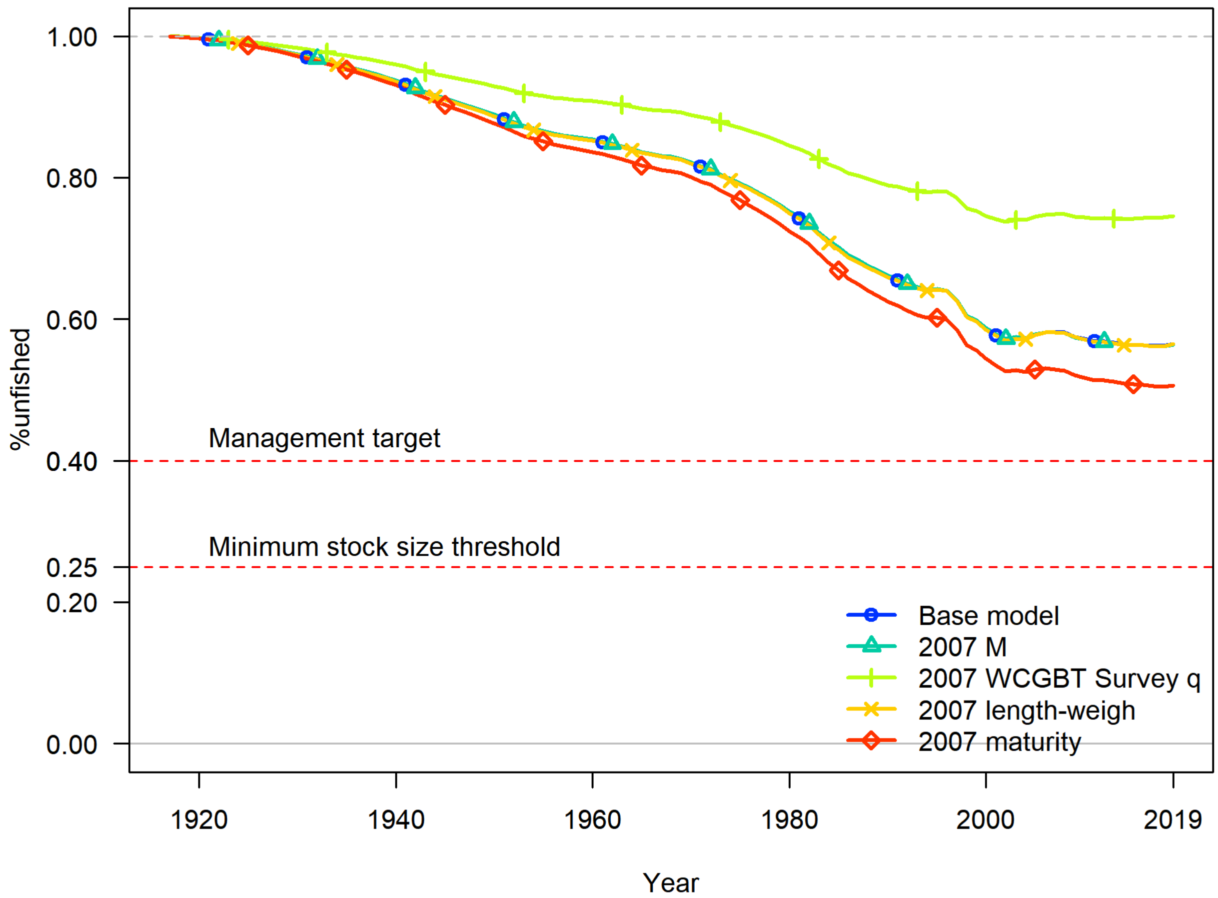

Figure 113. Sensitivity of Longnose Skate relative spawning biomass to updating selected parameters from 2007 assessment.

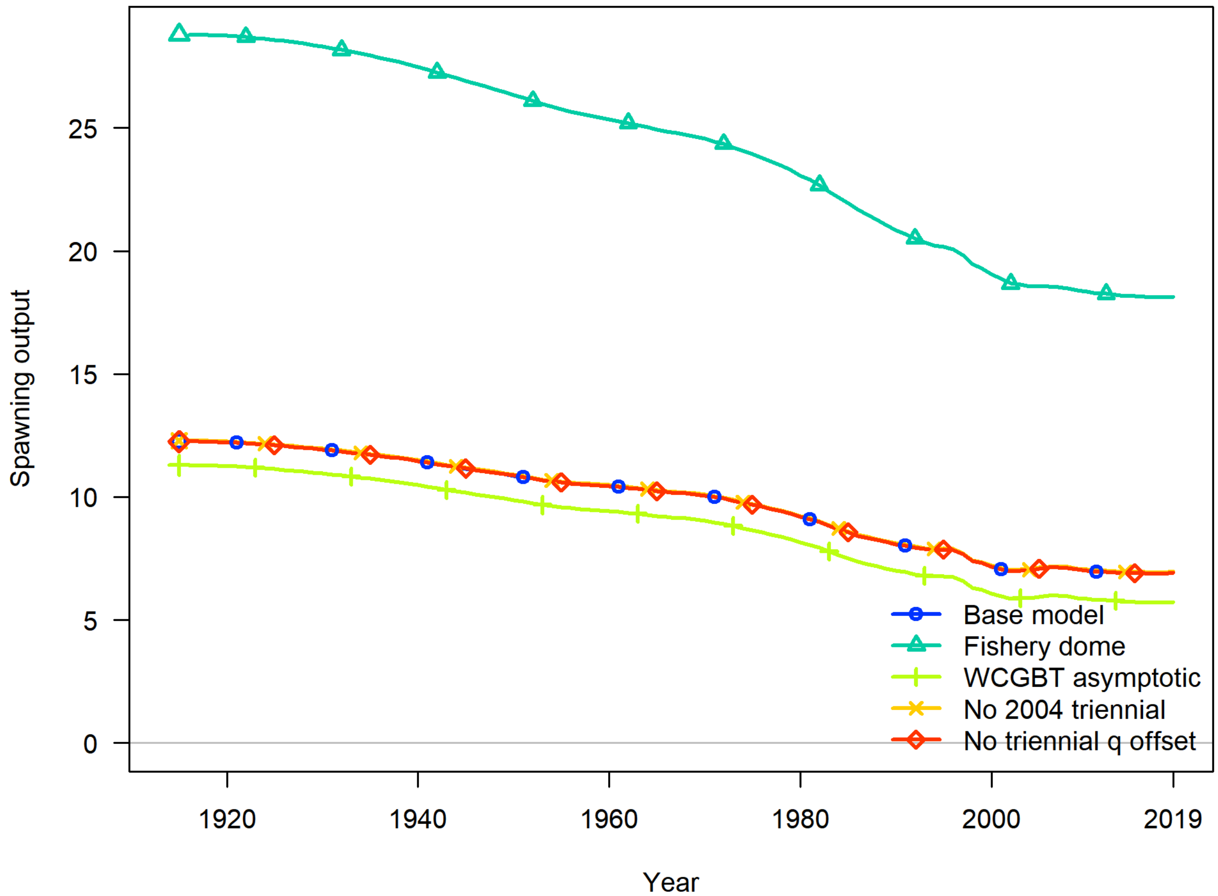

Figure 114. Sensitivity of Longnose Skate spawning biomass to alternative assumptions about fleet structure and selectivity.

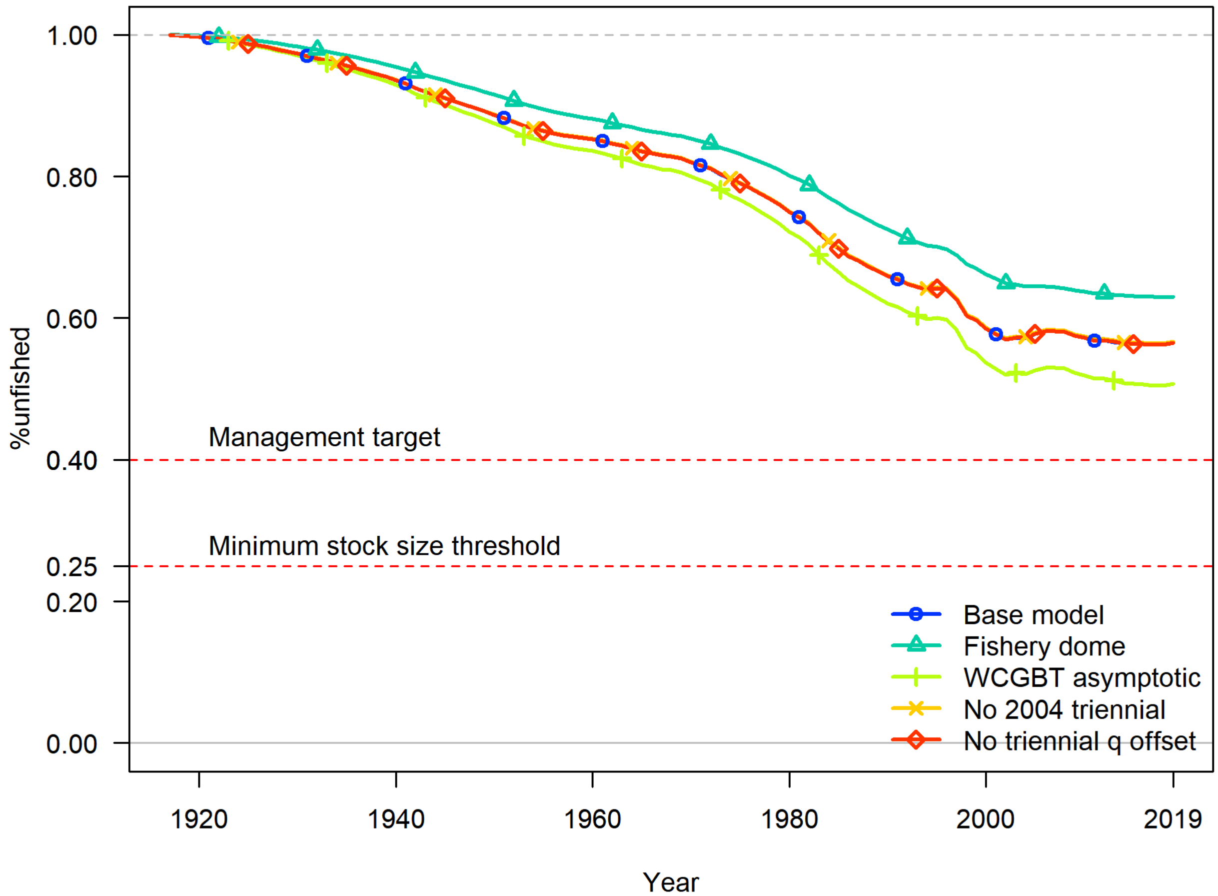

Figure 115. Sensitivity of Longnose Skate relative spawning biomass to alternative assumptions about fleet structure and selectivity.

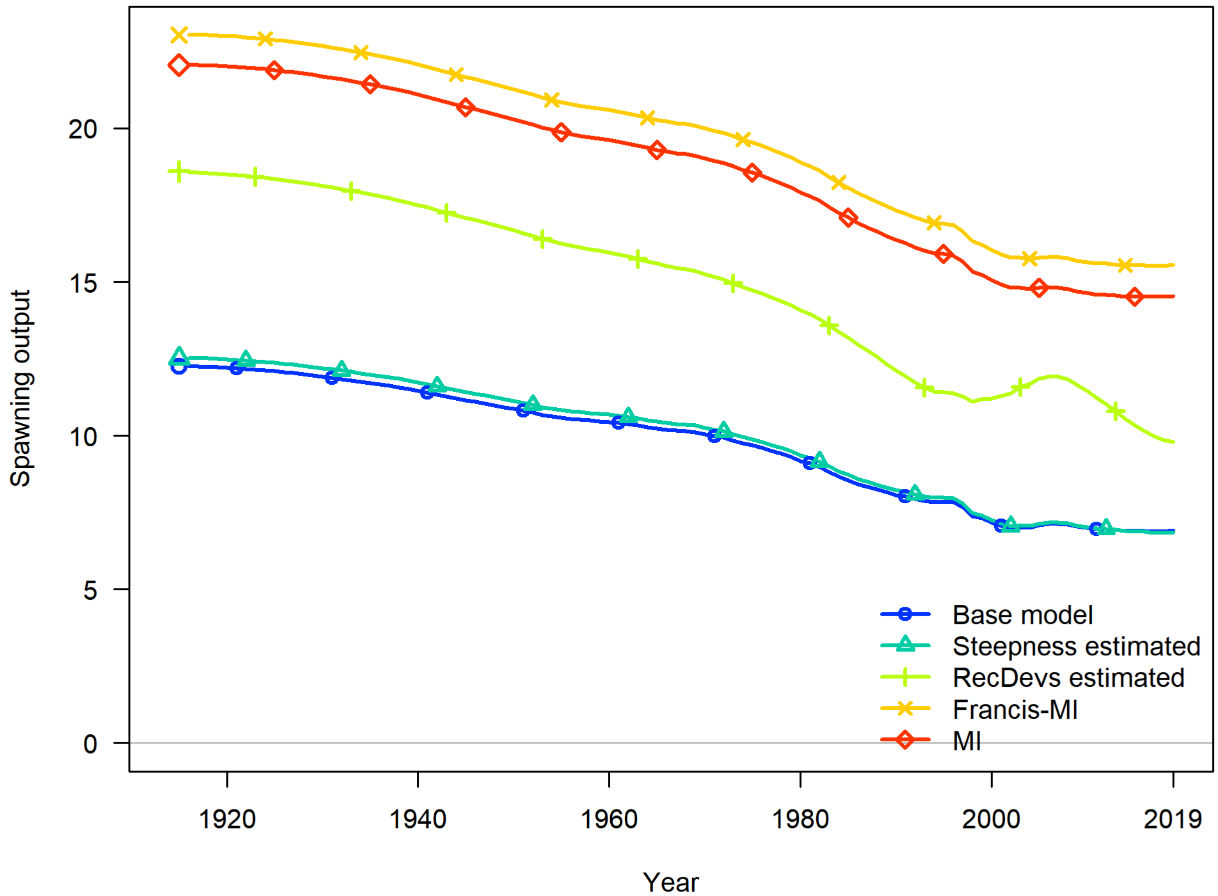

Figure 116. Sensitivity of Longnose Skate spawning biomass to alternative assumptions about selected model specifications.

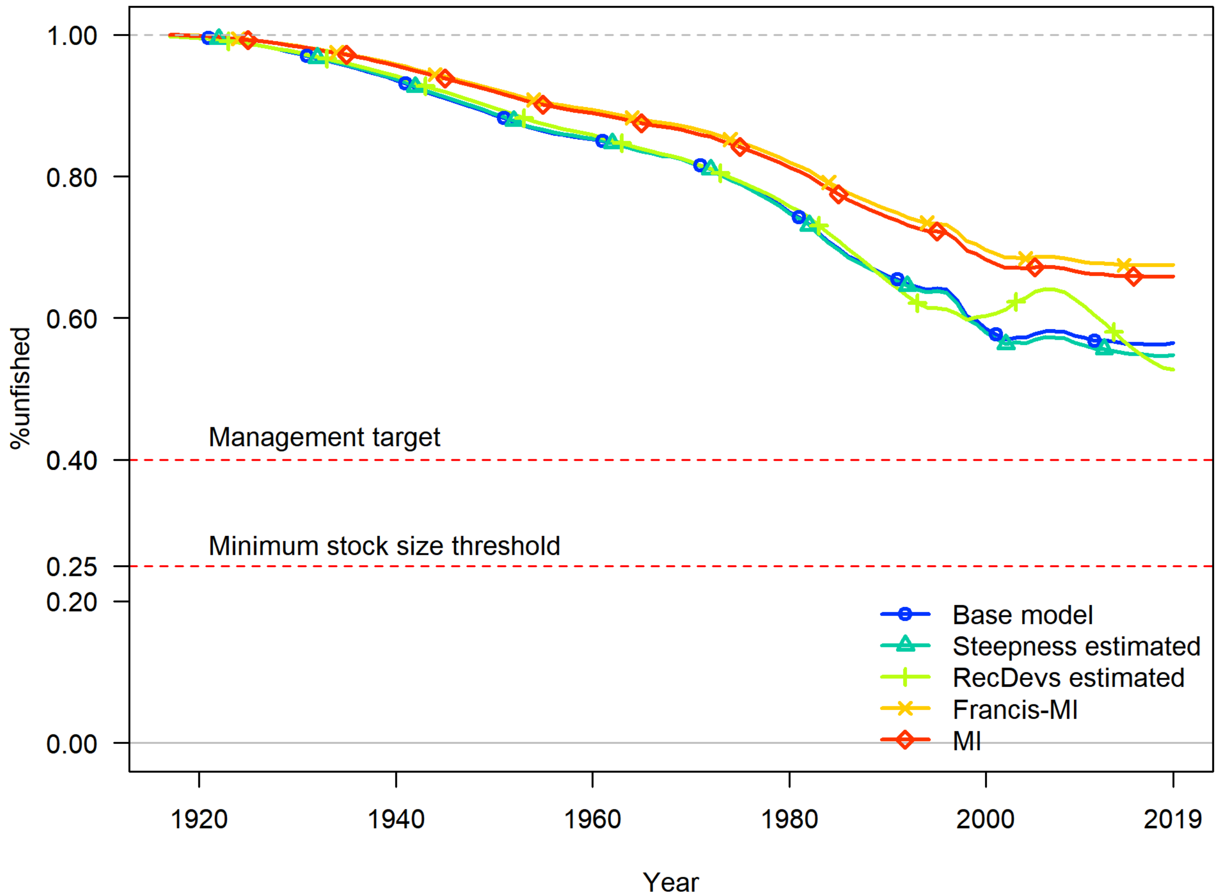

Figure 117. Sensitivity of Longnose Skate relative spawning biomass to alternative assumptions about selected model specifications.

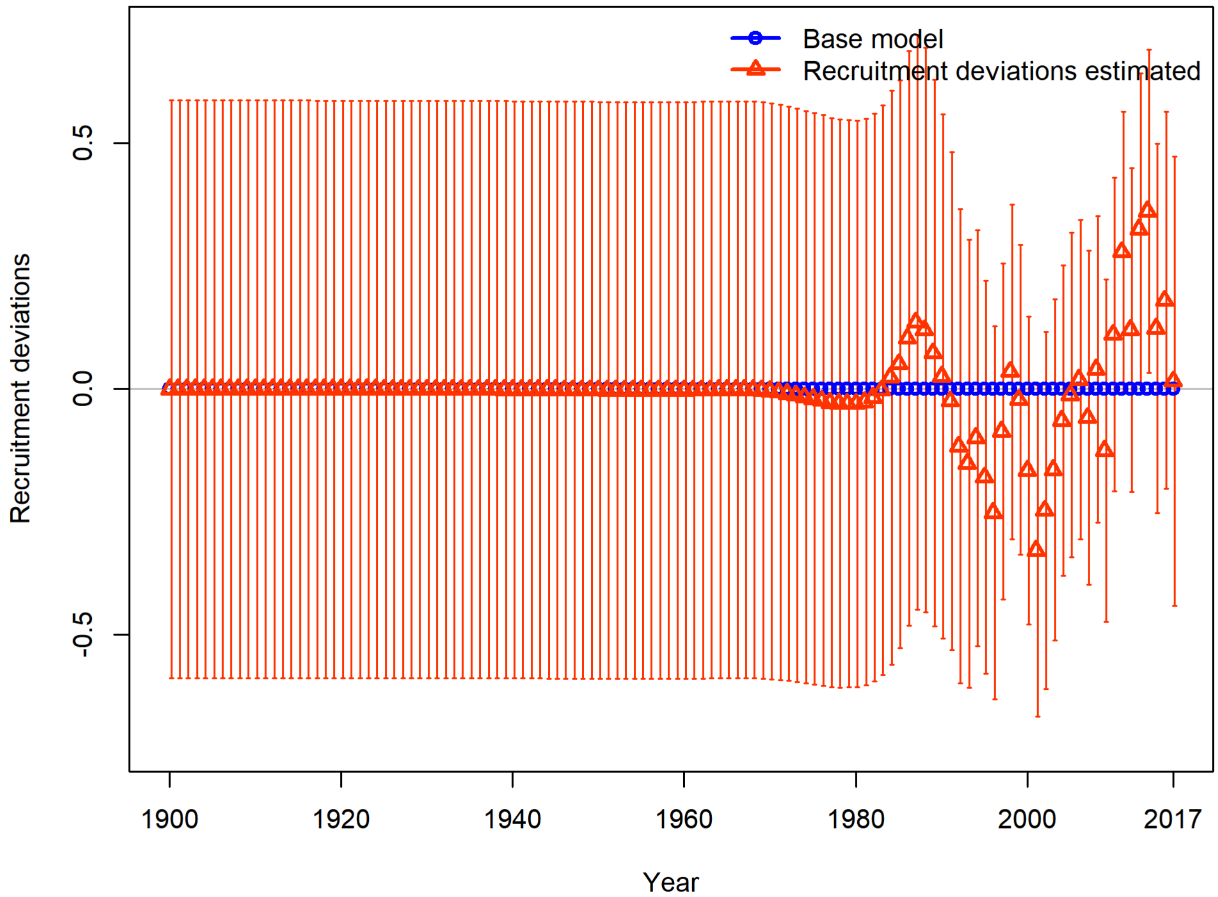

Figure 118. Recruitment deviations estimated in one of the model sensitivity runs.

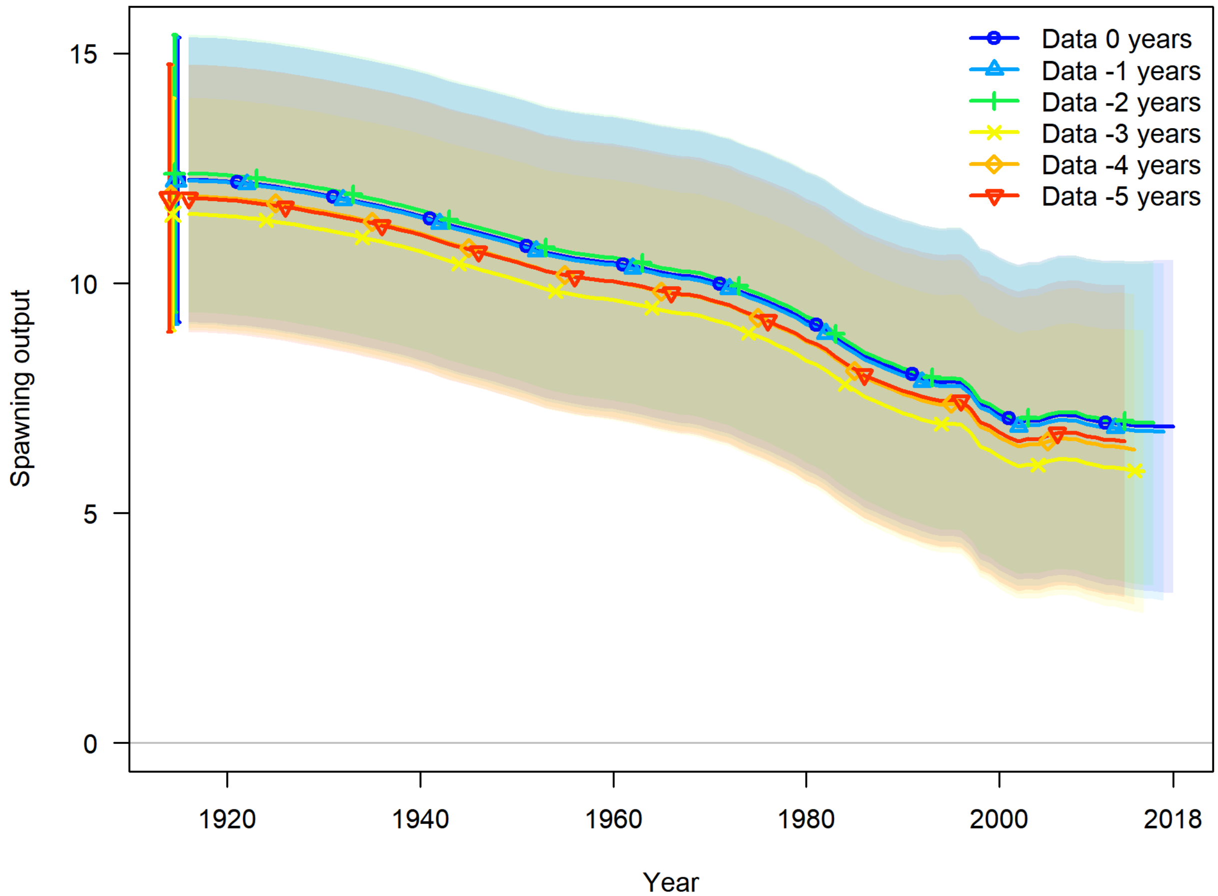

Figure 119. Results of retrospective analysis. Spawning biomass time series of this assessment base model are provided with ~ 95% interval.

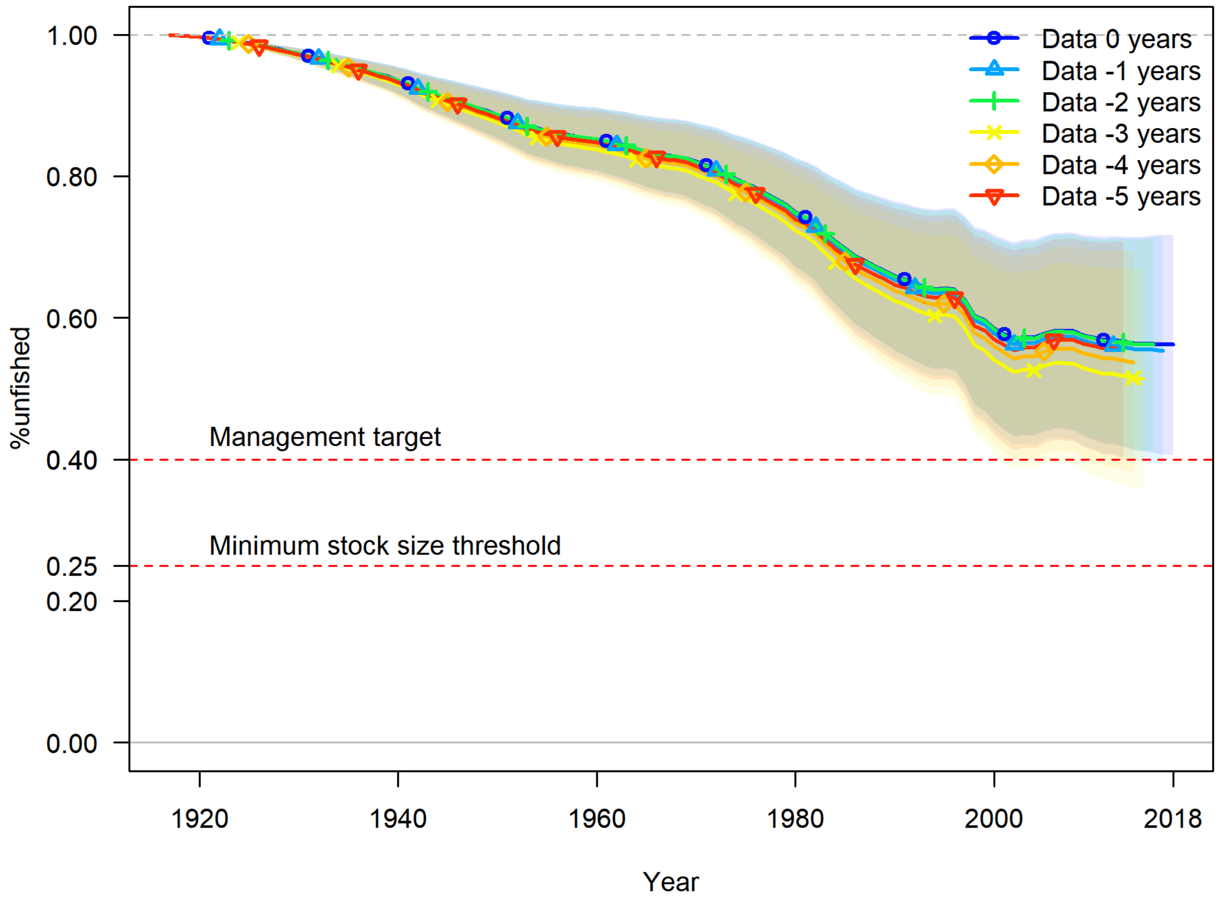

Figure 120. Results of retrospective analysis. Relative spawning biomass time series of this assessment base model are provided with ~95% interval.

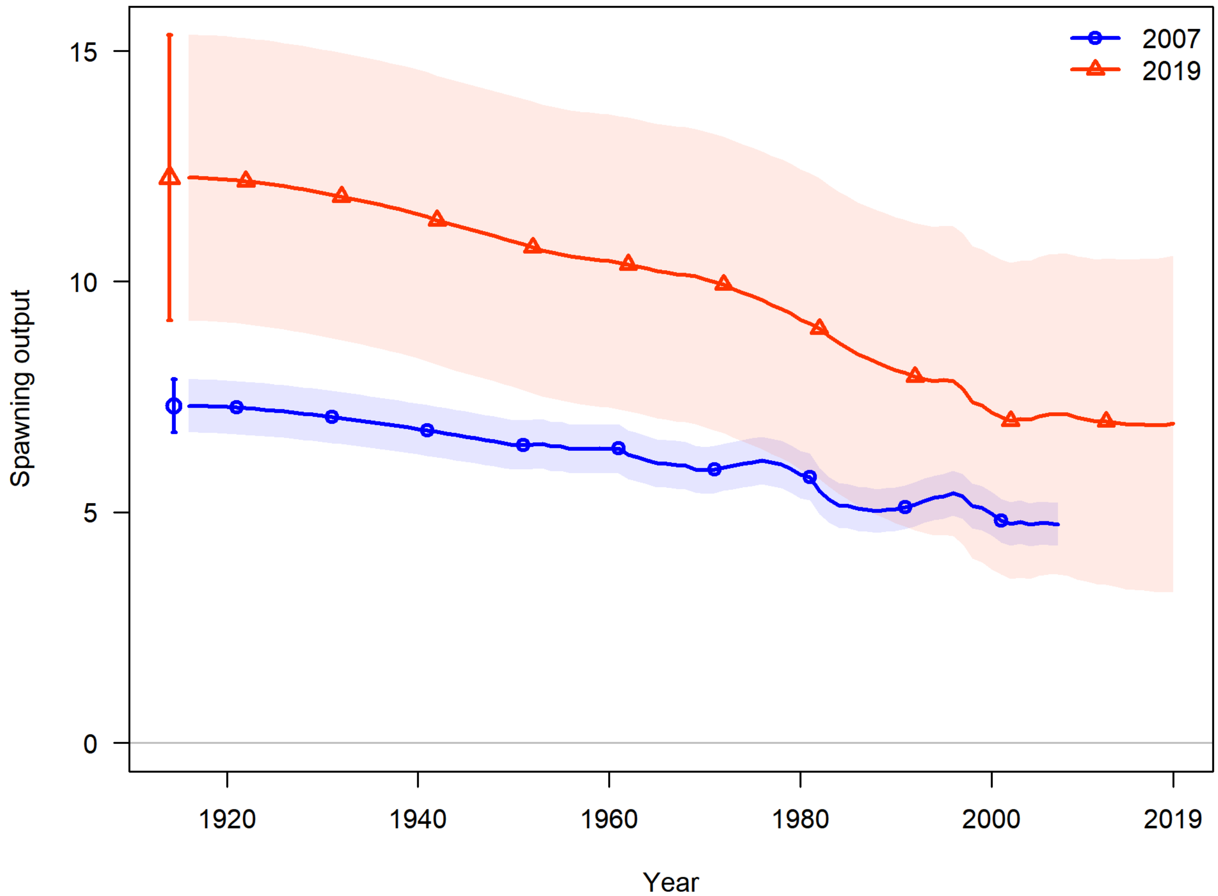

Figure 121. Comparison of spawning biomass time series among Longnose Skate assessments.

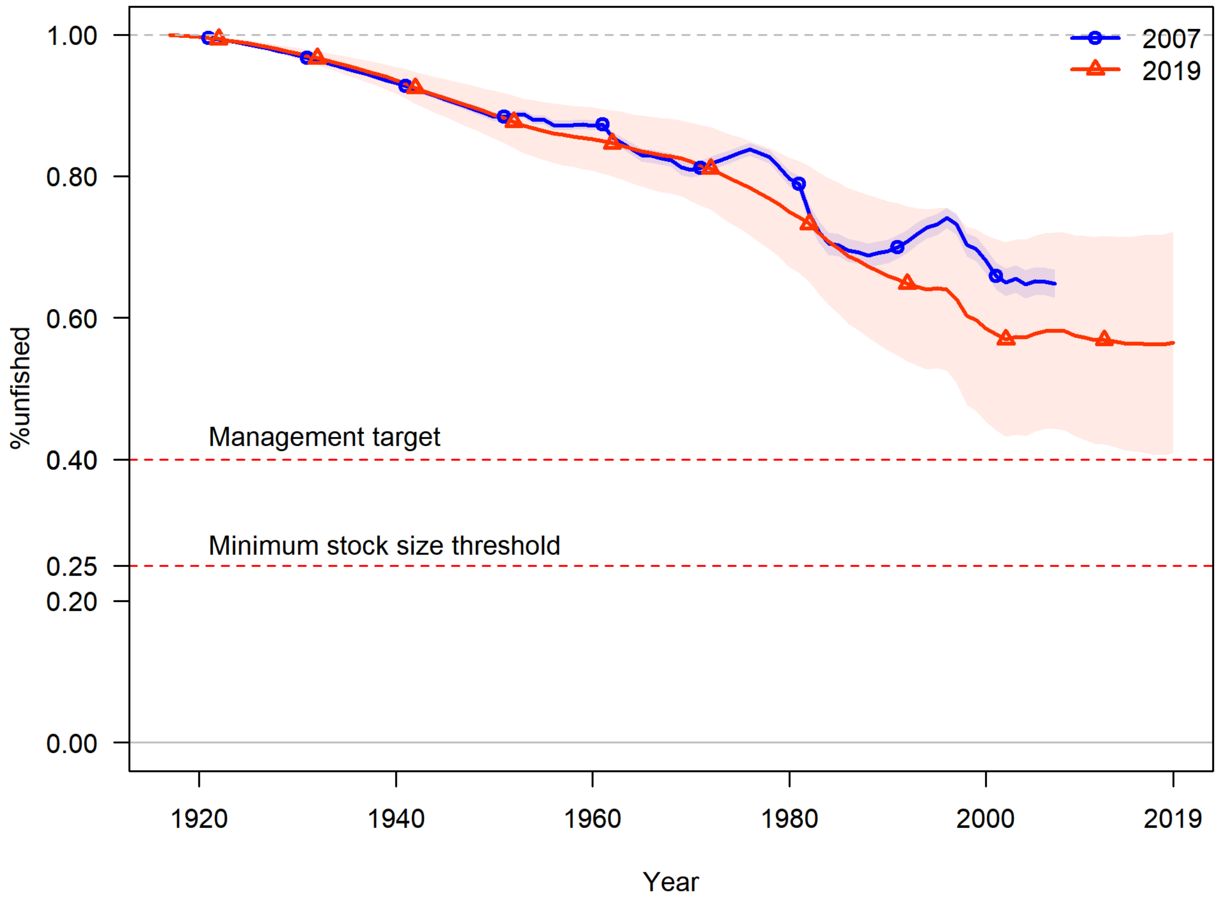

Figure 122. Comparison of relative spawning output time series among Longnose Skate assessments.

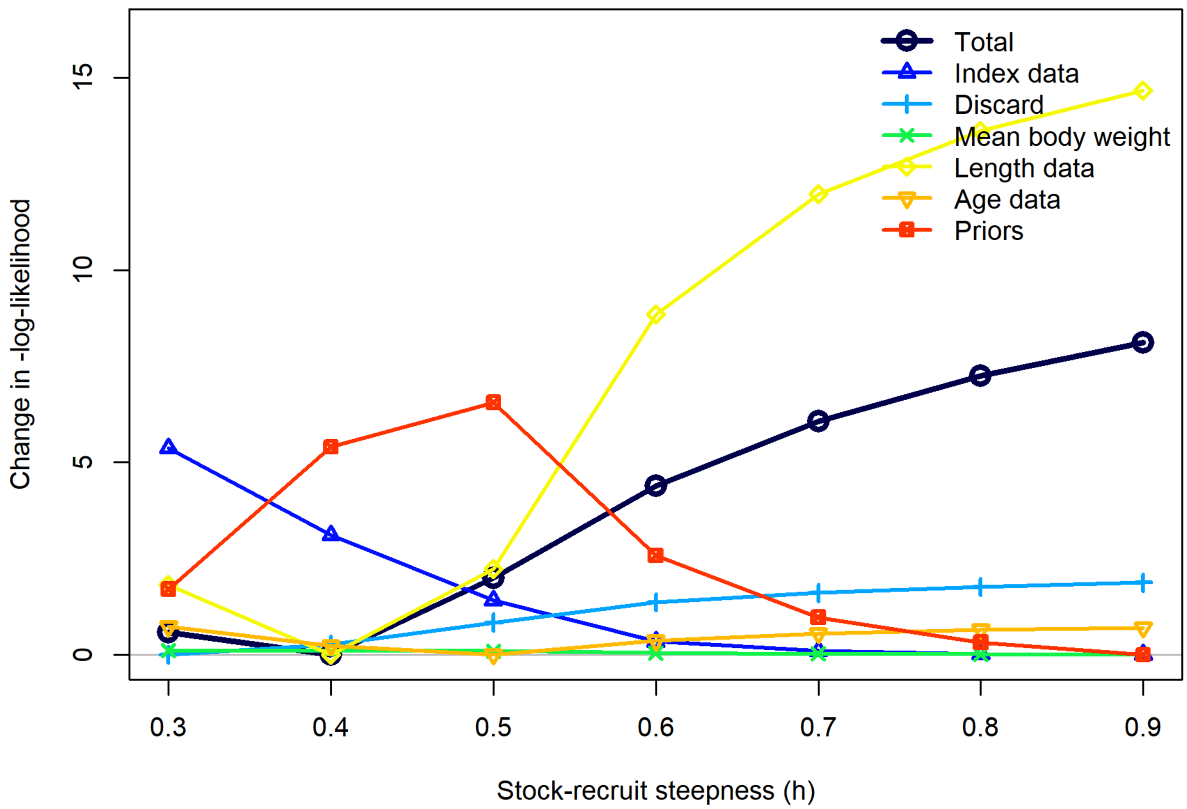

Figure 123. Negative log-likelihood profile for each data component and in total given different values of stock-recruit steepness ranging from 0.3 to 0.9 by increments of 0.1.

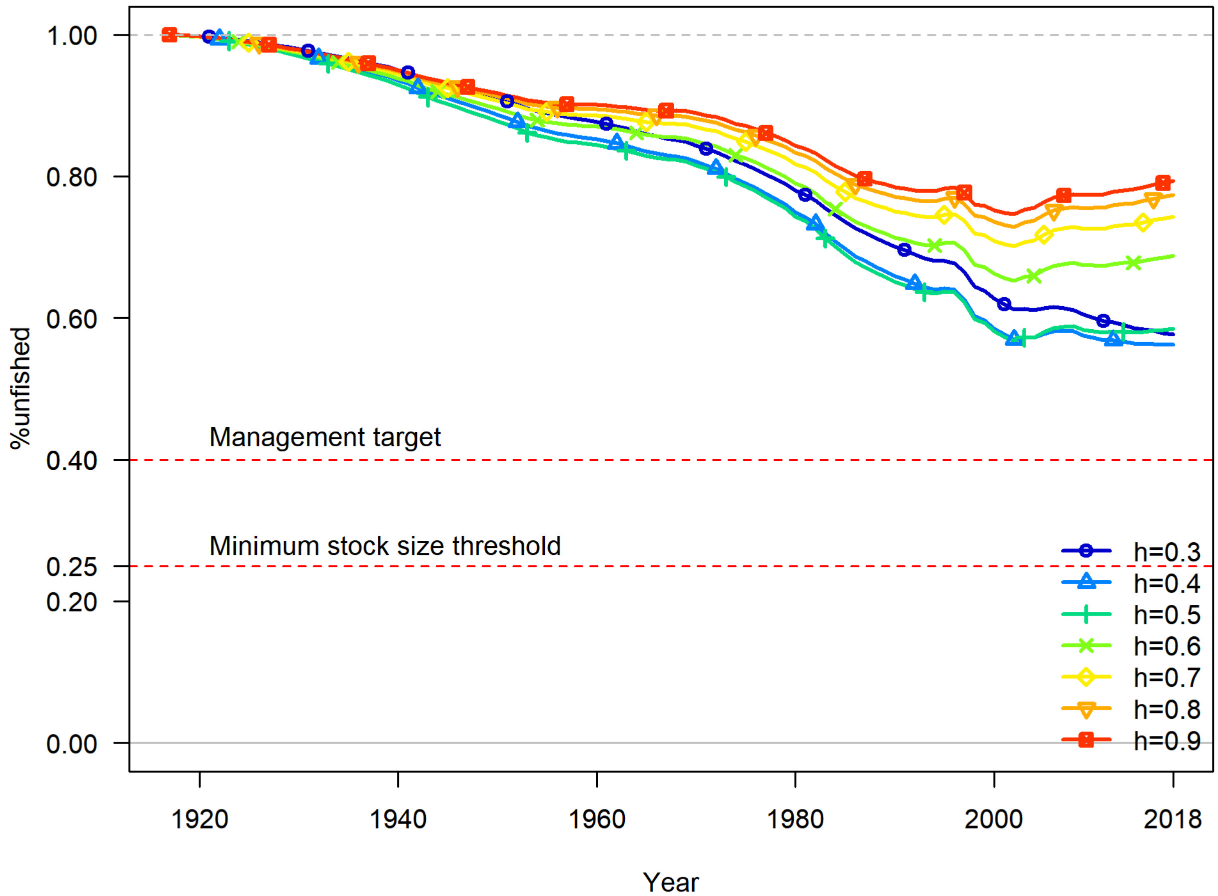

Figure 124. Time series of relative spawning depletion associated with different values of steepness ranging from 0.3 to 0.9 by increments of 0.1.

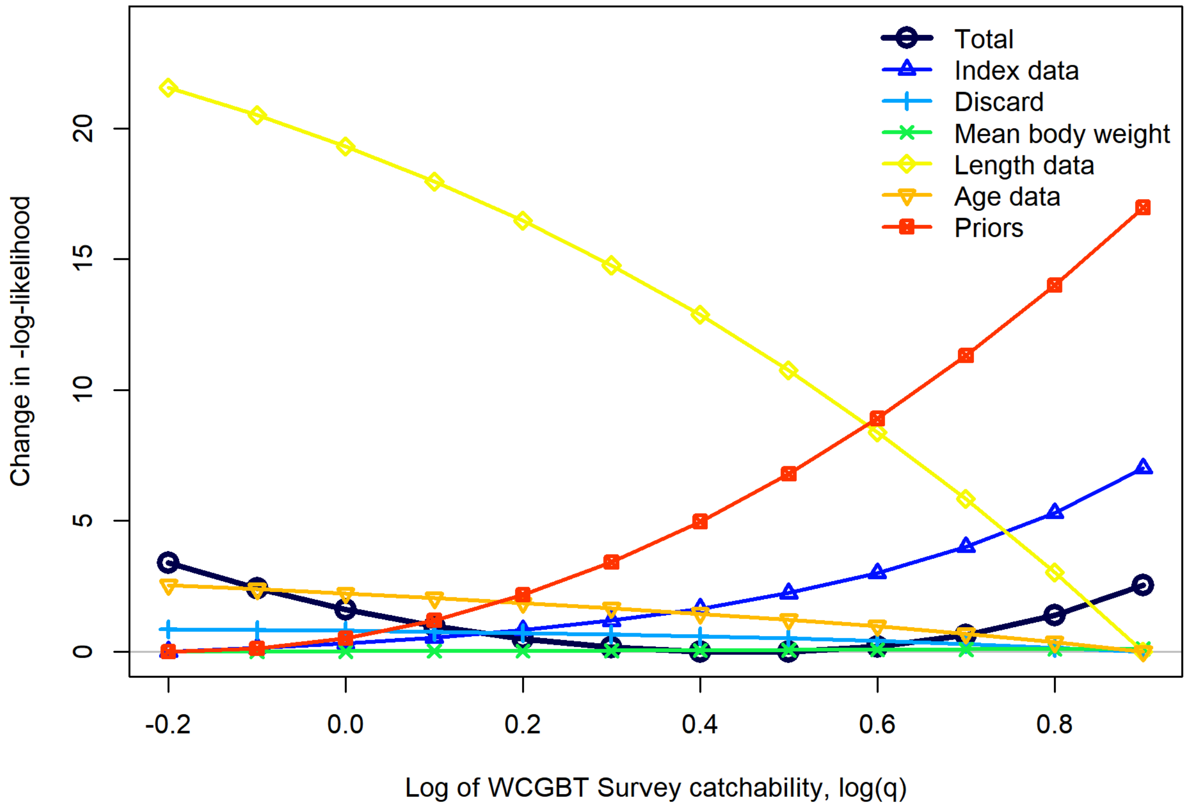

Figure 125. Likelihood profile for log WCGBT Survey catchability ($\ln(q)$) by likelihood component, with priors on.

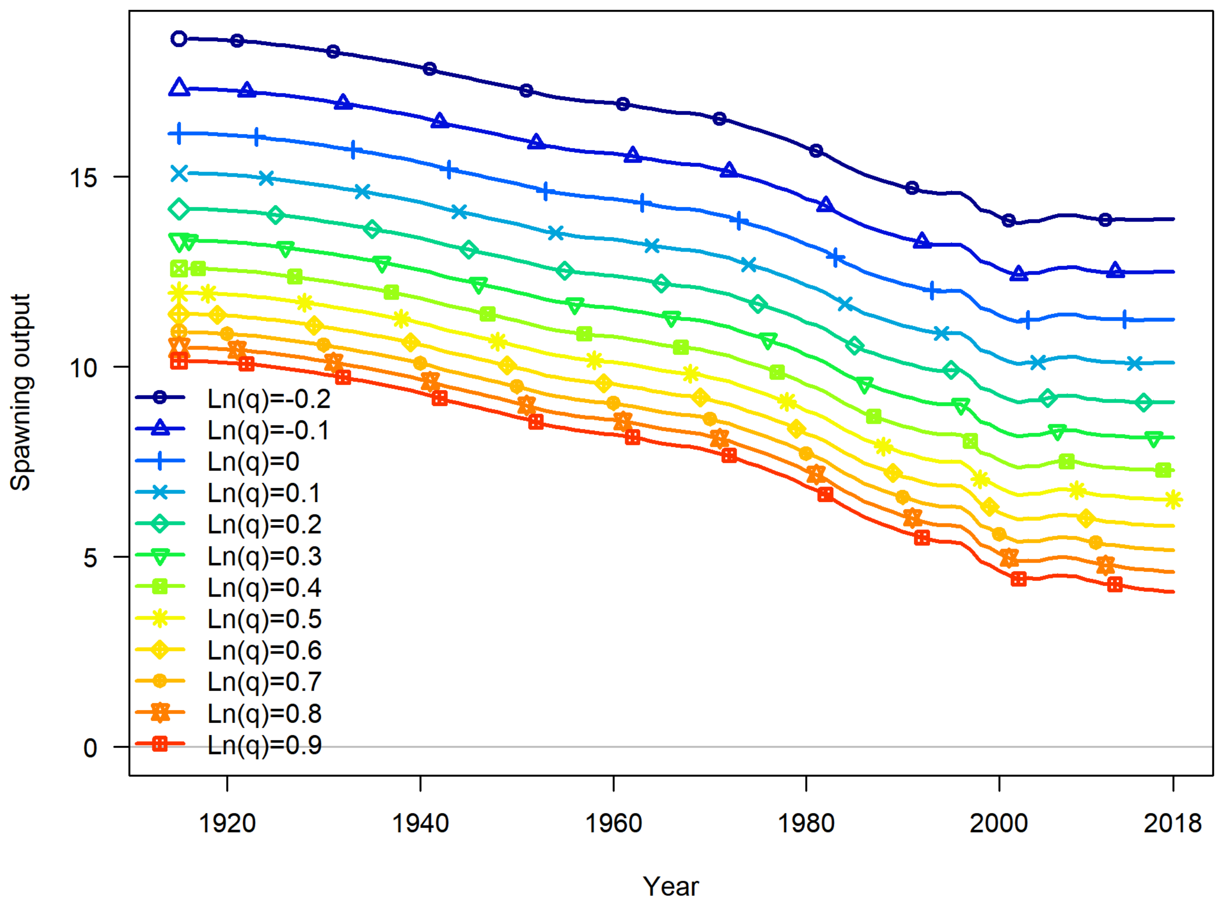

Figure 126. Time series of spawning biomass associated with different values of WCGBT Survey catchability.

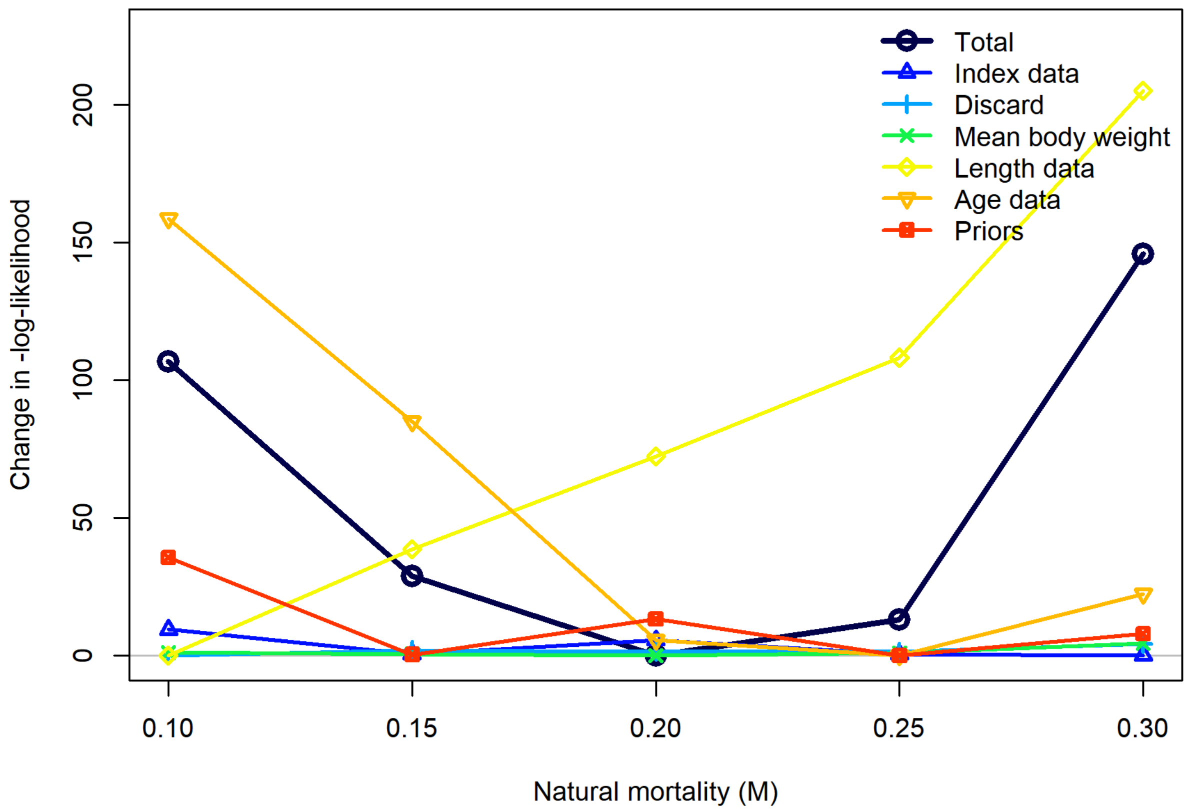

Figure 127. Likelihood profile for natural mortality (*M*) by likelihood component. In the model, *M* is estimated using Hamel (2015) prior.

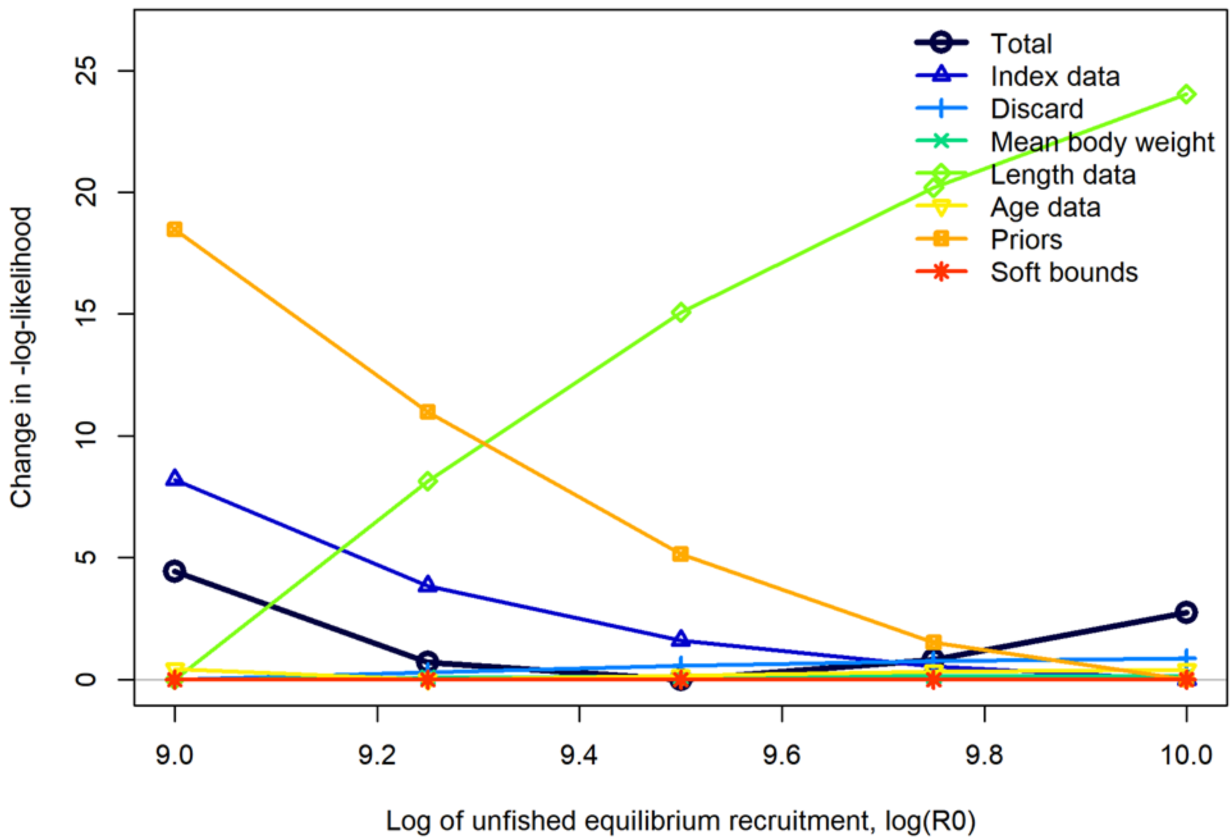

Figure 128. Likelihood profile for log initial recruitment ($ln(R_0)$) by likelihood component.

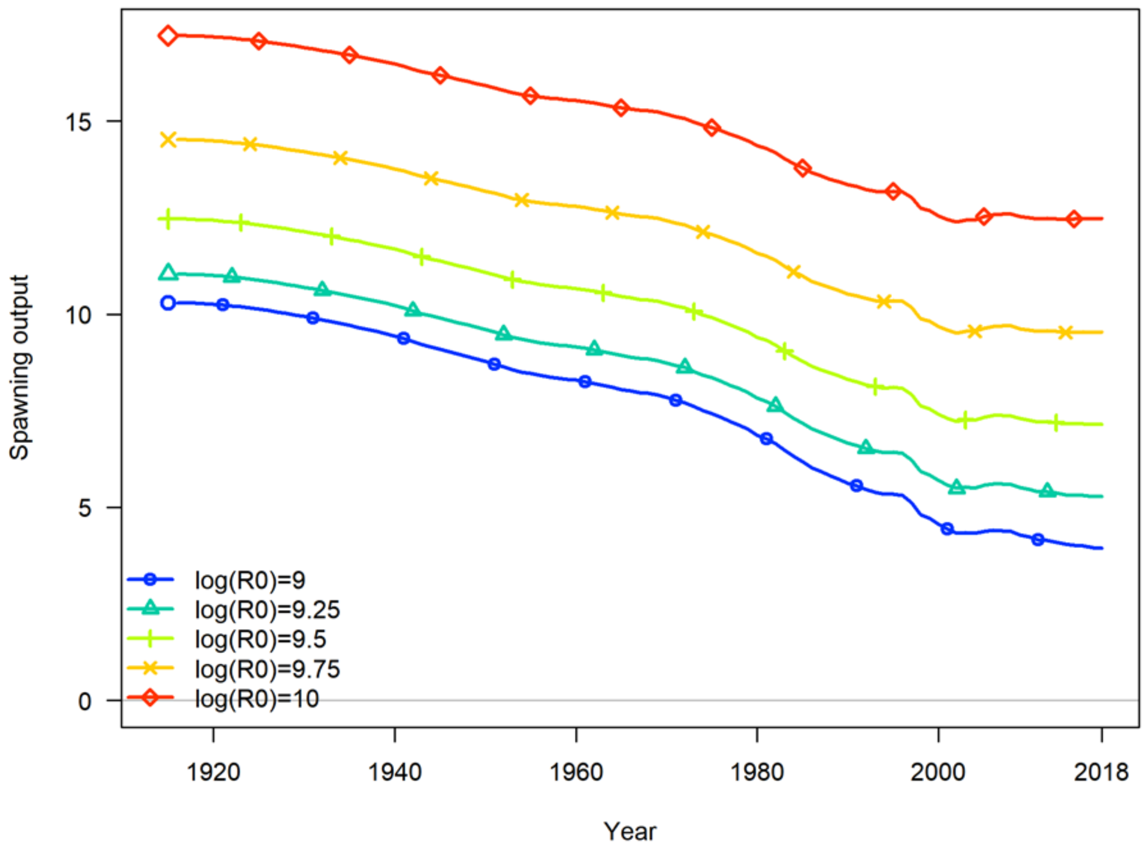

Figure 129. Spawning biomass as profiled over values of $\ln(R_0)$.

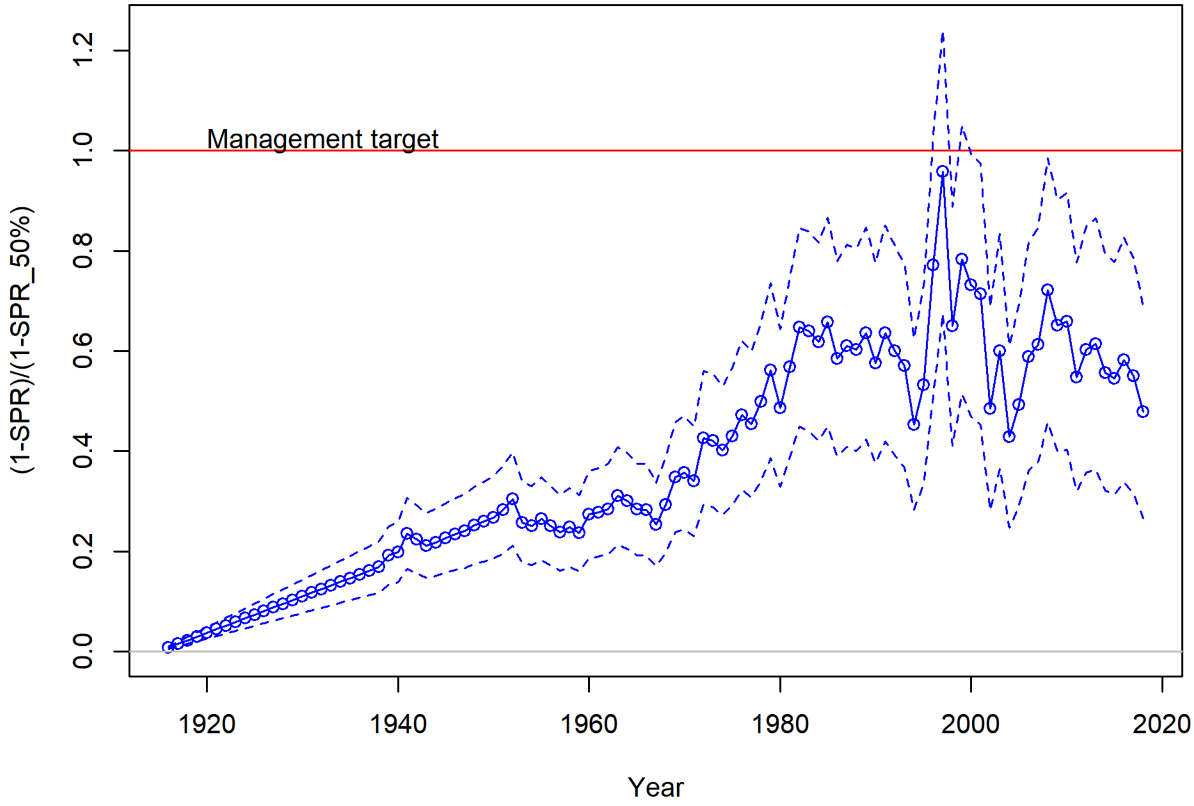

Figure 130. Estimated spawning potential ratio (SPR) for the base model with approximate 95 percent asymptotic confidence intervals. One minus SPR standardized to the target is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR50%.

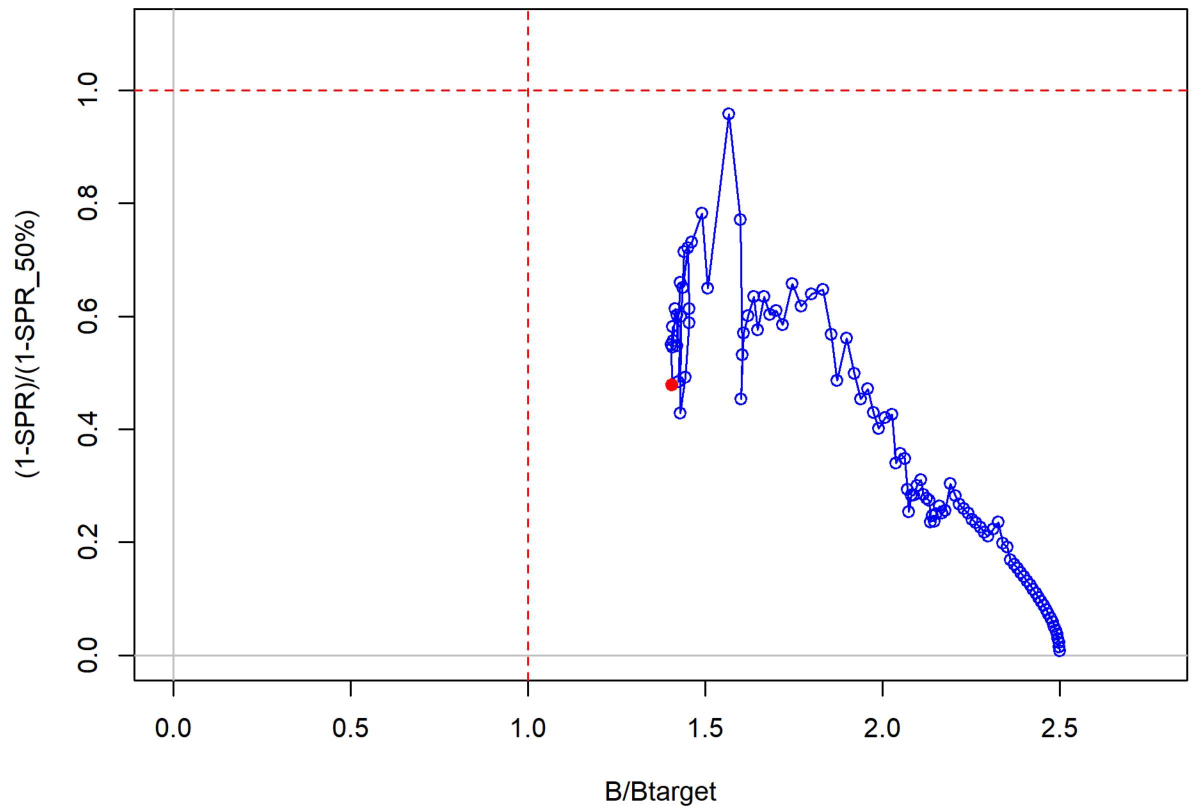

Figure 131. Phase plot of estimated relative (1-SPR) vs. relative spawning biomass for the base model. The relative (1-SPR) is (1-SPR) divided by 0.5 (the SPR target). Relative spawning output is the annual spawning biomass divided by the spawning biomass corresponding to 40 percent of the unfished spawning biomass. The red point indicates the year 2018.

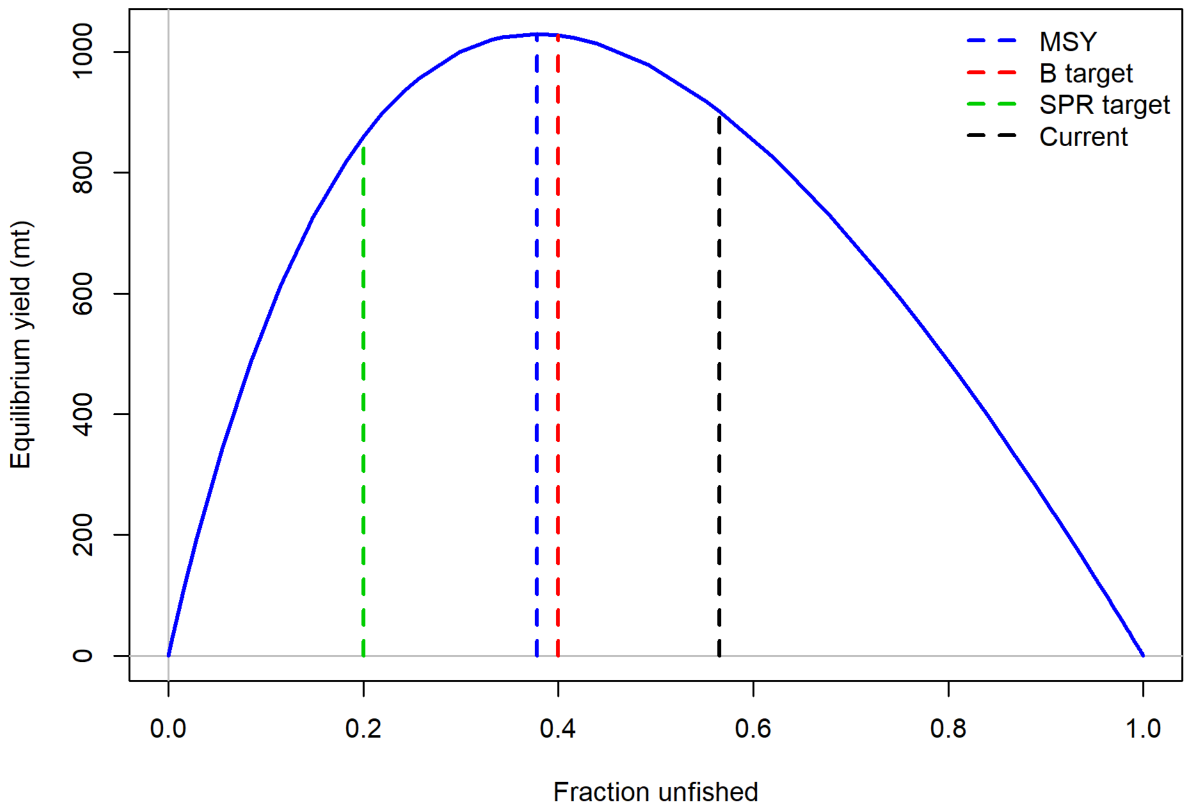

Figure 132. Equilibrium yield curve (derived from reference point values) for the base model. Values are based on 2018 fishery selectivity and distribution with steepness fixed at 0.4. The relative spawning biomass is relative to unfished spawning biomass

11 Auxiliary Files

LSKT2019 Numbers at age table – Excel file that includes numbers at age table.

Base model files – a folder with model input files.

12 Appendix 1

Skate Catch Reconstruction for California Waters

By Joe Bizzarro and john Field

Overview

A reconstruction of historical skate landings from California waters was developed for the 1916–2017 time period using a combination of commercial catch data (spatially explicit block summary catches and port sample data from 2009-2017) and fishery-independent survey data. Virtually all landings in California were of "unspecified skate" until species composition of skate market categories was implemented in 2009. From 2009 through 2017, catch estimates were based on these market category species composition samples, and the average of those species compositions was "hindcast" to 2002, based on the assumption that those data were representative of the era of large area closures in the post-2000 period. For the period from 1930 to 1980, spatially explicit landings data (the CDFW block summary data) were merged with survey data to provide species-specific estimates, as described below. For the period from 1981 through 2001, a "blended" product of the two approaches to estimating species specific catches was taken, in which a linear weighting scheme blended the two sets of catch estimates through that period. Landings estimates were also scaled upwards by an expansion factor for skates landed as "dressed" based on fish ticket data (prior to 1981 these data were not reported and skate landings were scaled by the "average" percentage landed as dressed in the 1981-1985 time period, by the late 1980s nearly all skates were landed round).

Data and Methods

Historical commercial landings data (1931–2010) were available from California Department of Fish and Wildlife (CDFW) block summary data, which include landings estimates reported to a 10 x 10 minute grid of fishing blocks that extends throughout the California coast and to 180 kilometers offshore (Fig. 1, see Ralston et al. 2010,Miller et al. 2014 for a more detailed description of block summary data). For the 1916–1930 period, total unspecified skate landings were based on Martin and Zorzi (1993).

West Coast Groundfish Bottom Trawl (WCGBT) Survey catch-per-unit-effort data (kg/ha) for Big Skate (*Beringraja binoculata*), Longnose Skate (*Beringraja rhina*), and California Skate (*Beringraja inornata*), and total survey effort data were compiled from the FRAM data warehouse website https://www.nwfsc.noaa.gov/data/map). Data were collected between May and October during 2003–2017, a period that reflects the first year of the modern, standardized WCGBT Survey and the most recently available data. All hauls that were considered to be unsuitable ("unsatisfactory") for relative abundance estimates were omitted from the data set prior to analysis, resulting in 9818 satisfactory hauls.

Species-specific skate data from the WCGBT Survey were merged with total survey effort data (i.e., all satisfactory hauls) to produce data sets that were used to estimate block-specific CPUE values and to model the recent distribution and abundance patterns of each skate species. Data were imported into ArcGIS, projected in Teale-Albers with a NAD 1983 datum, and saved as shapefiles. The spatial join function (Analysis Toolbox/Overlay Toolset) was used to associate each haul location with a CDFG fishing block. CPUE data for each block were then averaged and added to the CDFG grid block shapefile to create final species-specific files.

GAM models were fit in ArcGIS using Marine Geospatial Ecology Tools, an open source geoprocessing toolbox designed for modeling spatially explicit data (Roberts et al. 2010), to estimate CPUE in fishing blocks that had no WCGBT Survey effort. CPUE was the response variable and three environmental explanatory values were included: bathymetry, distance from shore, and latitude. All variables, like CPUE data, were summarized by fishing block. Block centroids were used to generate distance from shore and latitude estimates, whereas an average bathymetery value was calculated from all 90 x 90 m bathymetry pixels contained in each block. Quasi-Poisson GAM models were initially fit using all three variables. Non-significant variables were removed from analysis and a final model was run for each species. GAM predictions then were generated for each block across the spatial extent of the data set using final species-specific models and raster data sets of significant variables. Because the WCGBT Survey was limited to depths of 55–1280, some nearshore and far offshore blocks were not sampled. CPUE estimates for these blocks were averaged from those of adjacent blocks, or from the closest adjacent block when all other neighboring blocks were located farther offshore.

Species-specific CPUE values were summed by block and the percentage of each total was apportioned to species. These proportional, species-specific data were then multiplied by block-specific fish ticket information and summed to provide annual species-specific landing estimates from 1935–2000. As no spatial information on catch is available from 1916-1930, and the block summary data were very sparse in the first few years of the CDFW fish ticket program (1931–1934), the 1936, 1937, 1939 and 1940 spatial climatology was used to hindcast back to 1916–1935 time period, as well as to provide spatial estimates for 1938, for which no data are available. Finally, to account for the discrepancies between these catch estimates and the catch estimates based on port sampler species composition sampling of skate market categories from the 2009–2017 period, a "blended" product of the two approaches to estimating species specific catches was taken for the 1980-2010 period, in which a linear weighting scheme blended the two sets of catch estimates through that period.

As noted in the summary, landings estimates were also scaled upwards by an expansion factor for skates landed as "dressed" based on fish ticket data. In the 1981–1985 period, between 18 and 65% of skate landings were reported as "dressed" on fish tickets, with the fraction falling to minimal levels in the post-1986 period, and with regulations prohibiting the landing of dressed skates beginning in 2009. Prior to 1981, fish tickets did not include codes distinguishing dressed from round landings; however some landings were known to have been dressed (Martin and Zorzi 1993). Therefore, the average ratio of dressed to round landings was hindcast back to 1916 to account for likely landings of dressed skate, with the ratio of dressed:round being 1:2.6 (based on previously published data from Oregon).

The species composition of skate landings for the 2009–2017 period was based on port sampling data of skate market categories. Currently used market categories include Longnose Skate (374 samples 2009-2017), Big Skate (70 samples 2009-2017), California Skate (3 samples 2009-

2017) and unspecified skate (32 samples 2009–2017). In general, market category samples are relatively pure for Longnose Skate (98%) and Big Skate (99%) but less clean for California Skate (67%), which is infrequently landed and sampled. The unspecified skate market category between 2009 and 2017 was primarily composed of Longnose Skate. Market category species composition samples were applied to market category landings following the procedures described by Pearson and Irwin (1997). Annual estimates from port sampling data applied to landings were used for the 2009–2017 time period, the average species composition over that entire time period was used to hindcast to the 2002–2008 time period (during the time of significant reductions in fishing opportunities, particularly area closures), and the hindcast species composition was part of the blended product used to estimate the species composition of landings in the 1981–2002 time period.

Results

Distribution and abundance patterns differed among skate species based on WCGBT Survey results. Longnose Skate exhibited the greatest relative abundance off California. It commonly occurred throughout the state, but exhibited the greatest average CPUE values north of Point Conception (Fig. 2). Big Skate was generally distributed inshore of Longnose Skate, and average catch rates were greatest from Monterey Bay northward (Fig. 3). California Skate average catch rates were greatest nearshore, and the region of greatest abundance occurred between Monterey Bay and ~39º N (Fig. 4). Depth was a significant explanatory variable in all three single-species GAM models. Latitude also was significant for Big Skate and Longnose Skate, whereas distance from shore also was significant for California Skate. The relative interspecific differences in distribution and abundance patterns are exemplified by standardizing CPUE estimates among species in their most common area of co-occurrence (Fig. 5).

Longnose Skate landings were estimated to comprise over 60% of total skate landings during the 1916–2017 period (Fig. 6), with the relative contribution of this species increasing steadily over time (Fig. 7). Big Skate contributed an estimated 25% of historical landings with California Skate accounting for an additional 13%. The relative proportion of Big Skate landings was not highly variable by decade for most of the reconstruction time period, although it did decline in recent decades, particularly in association with closures of shelf break habitat that began in the early 2000s. The relative proportion of California Skate landings is estimated to have declined steadily over time (Fig. 7).

Future Directions

There are several additional approaches that we could take to improve our rather crude estimates of historical landings. A more robust regression analysis of the bottom trawl survey data would use individual hauls as replicates and zero-inflated models or hurdle models, which seems most appropriate for the WCGBT Survey skate CPUE data (Bizzarro 2015). Additional species could be added to the time series because a minor fraction of the catch is likely to consist of Starry Skate (*Beringraja stellulata*), Sandpaper Skate (*Bathyraja kincaidii*), or Roughtail Skate (*Bathyraja trachura*). Trawl logbook data, which include more robust spatial information than the block summary data, could be used for the 1980–2010 time period to more accurately account for depth-based differences in species compositions. California Skate may be more depleted than Big Skate or Longnose Skate based on the historical catch reconstruction, and greater investigations into this possibility should be conducted. Early accounts suggest that California and Big Skate were important components of historical landings in California waters and were likely more desirable than Longnose Skate from a marketing perspective (Roedel and Ripley 1950). .A sensitivity analysis could adjust the nominal abundance of California Skate in trawl surveys (e.g., double) to gauge the effect on historical catch estimates. Unknown skate landings could be estimated to species based on the relative probability of co-occurrence among skates and sympatric fishes with identified market categories (e.g., flatfishes) (Stephens and MacCall 2004). Finally, a vector-autogregressive spatio-temporal (VAST) modeling approach could be used to develop better distribution models of trawl catch for the skate species of interest (Thorson 2019). Time constraints have prevented deeper explorations of these approaches for the current assessment cycle, but we intend to pursue several of these avenues for improving historical catch estimates in upcoming years.

Literature Cited

Bizzarro, Joseph J. 2015. Comparative resource utilization of eastern North Pacific skates with applications for fisheries management. Ph.D. Dissertation. University of Washington, School of Aquatic and Fishery Sciences. Seattle, WA.

Martin, L.K., and Zorzi, G.D. 1993. Status and review of the California skate fishery, p. 39-52. In: Conservation Biology of Elasmobranchs. S. Branstetter, ed. NOAA Technical Report NMFS-115.

Miller, R.R., Field, J.C., Santora, J.A., Schroeder, I.D., Huff, D.D., Key, M., Pearson, D.E., and MacCall, A.D. 2014. A spatially distinct history of the development of California groundfish fisheries. PLOS ONE 9: e99758. doi:10.1371/journal.pone.0099758

Ralston, S., D. Pearson, J. Field and M. Key. 2010. Documentation of the California commercial catch reconstruction project. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-461.

Roberts, J., Best, B., Dunn, D., Treml, E., Halpin, P. 2010. Marine Geospatial Ecology Tools: An integrated framework for ecological geoprocessing with ArcGIS, Python, R, MATLAB, and C++. Environmental Modelling & Software 25: 1197–1207.

Roedel, P.M. and W.E. Ripley. 1950. California sharks and rays. California Department of Fish and Game Fish Bulletin No. 75.

Pearson, D. E., and B. Erwin. 1997. Documentation of California's commercial market sampling data entry and expansion programs. NOAA Technical Memorandum NMFS-SWFSC-240. 62 p

Stephens, A., and MacCall, A. 2004. A multispecies approach to subsetting logbook data for purposed of estimating CPUE. Fisheries Research 70: 299–310.

Thorson, J.T. 2019. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. Fisheries Research 210: 142–161.

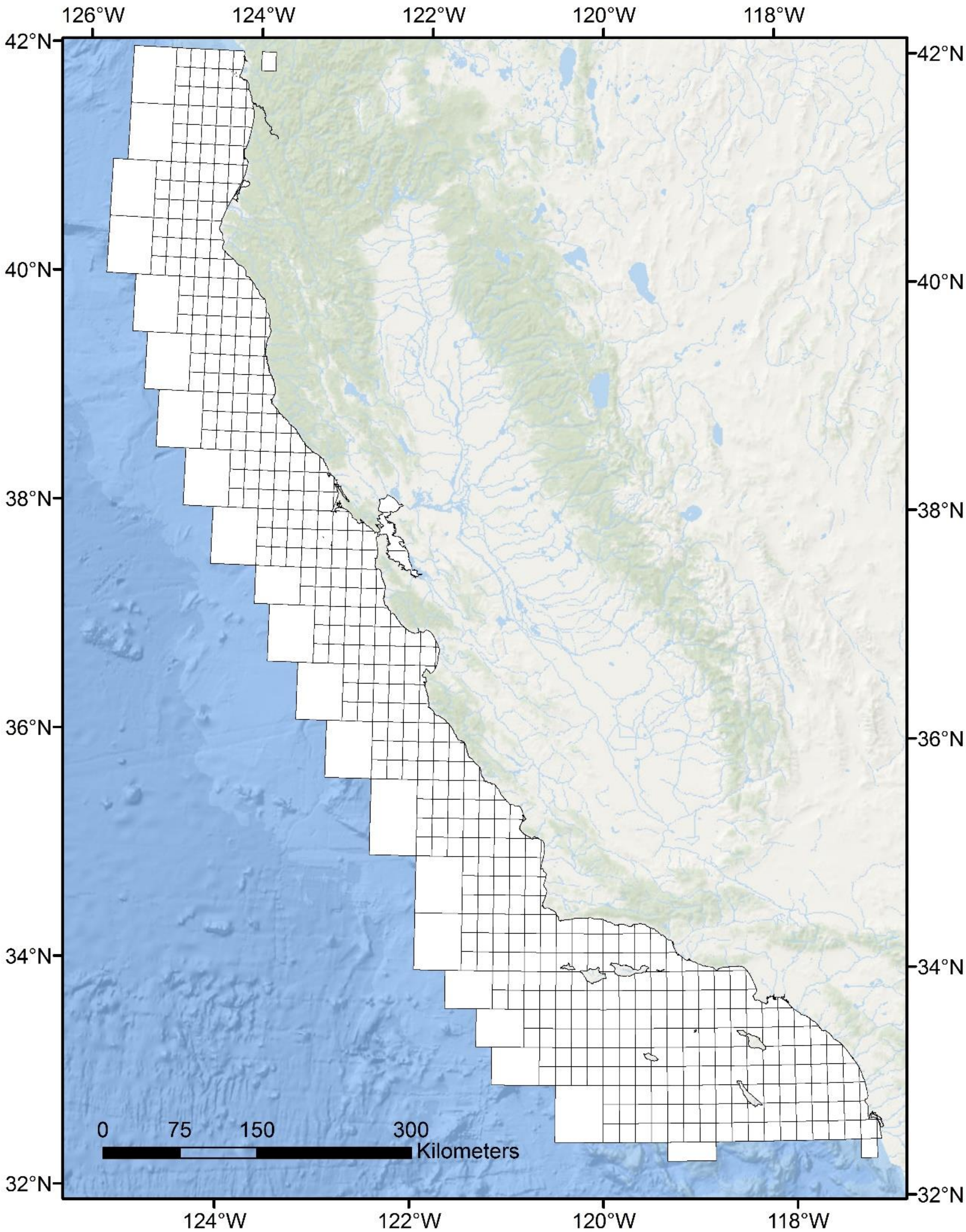

Figure A1. Grid of 10' x 10' California Department of Fish and Game fishing blocks. Port landed catches have been historically reported to fishing block on fish tickets.

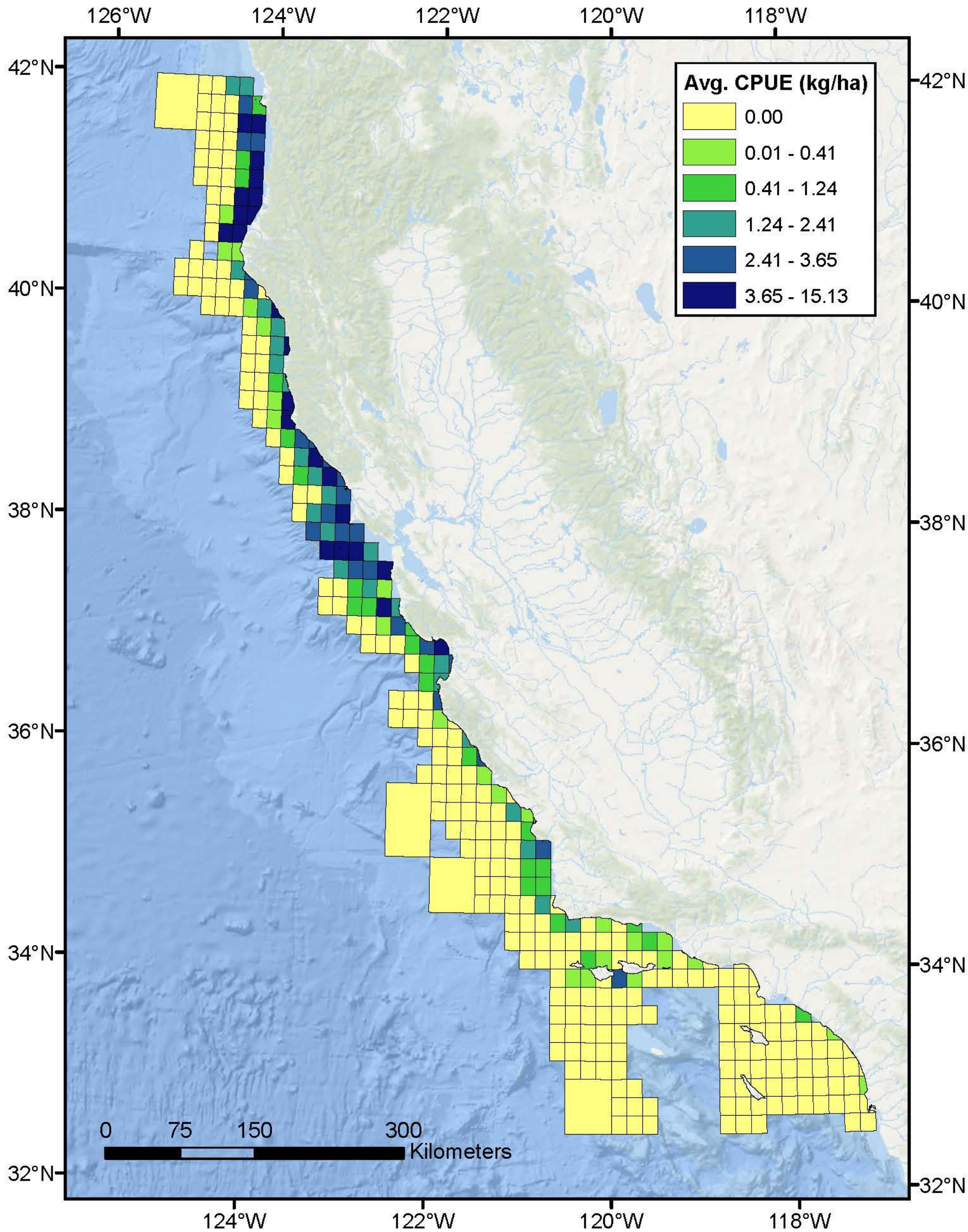

Figure A2. Big Skate average catch-per-unit-effort (kg/ha) estimates per fishing block based on West Coast Groundfish Bottom Trawl Survey data from 2003–2017 and reported as quantiles.

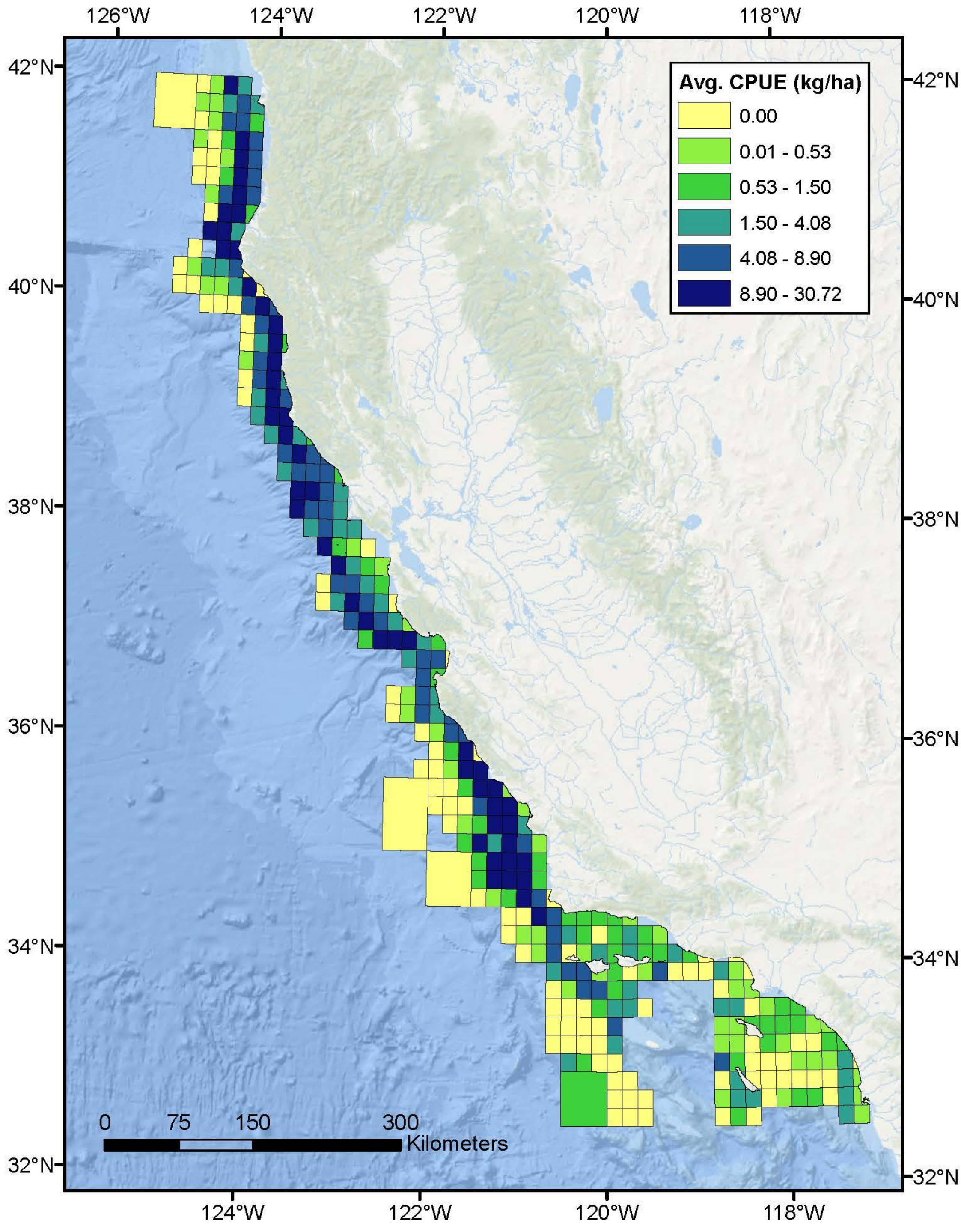

Figure A3. Longnose Skate average catch-per-unit-effort (kg/ha) estimates per fishing block based on West Coast Groundfish Bottom Trawl Survey data from 2003–2017 and reported as quantiles.

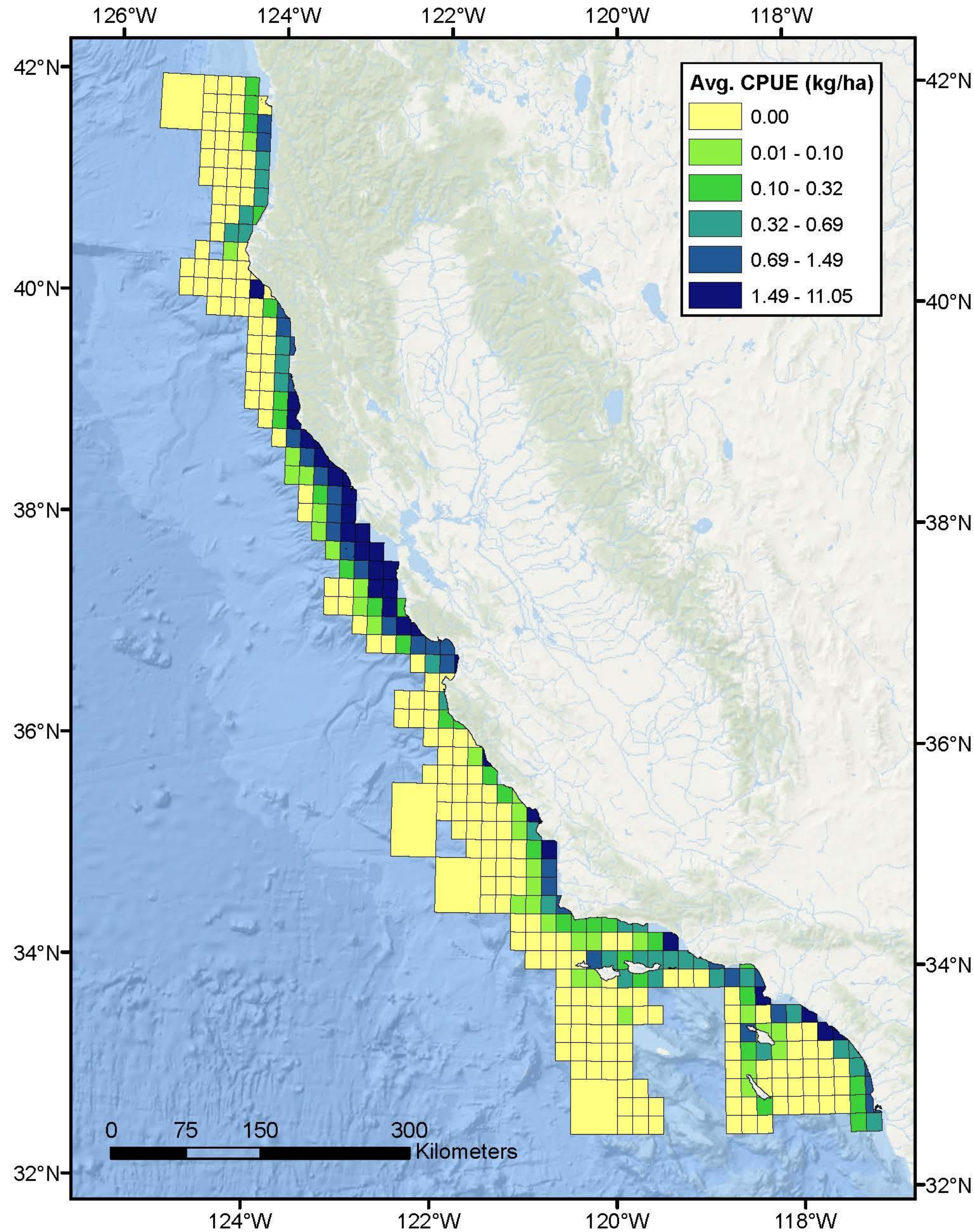

Figure A4. California Skate average catch-per-unit-effort (kg/ha) estimates) per fishing block based on West Coast Groundfish Bottom Trawl Survey data from 2003–2017 and reported as quantiles.

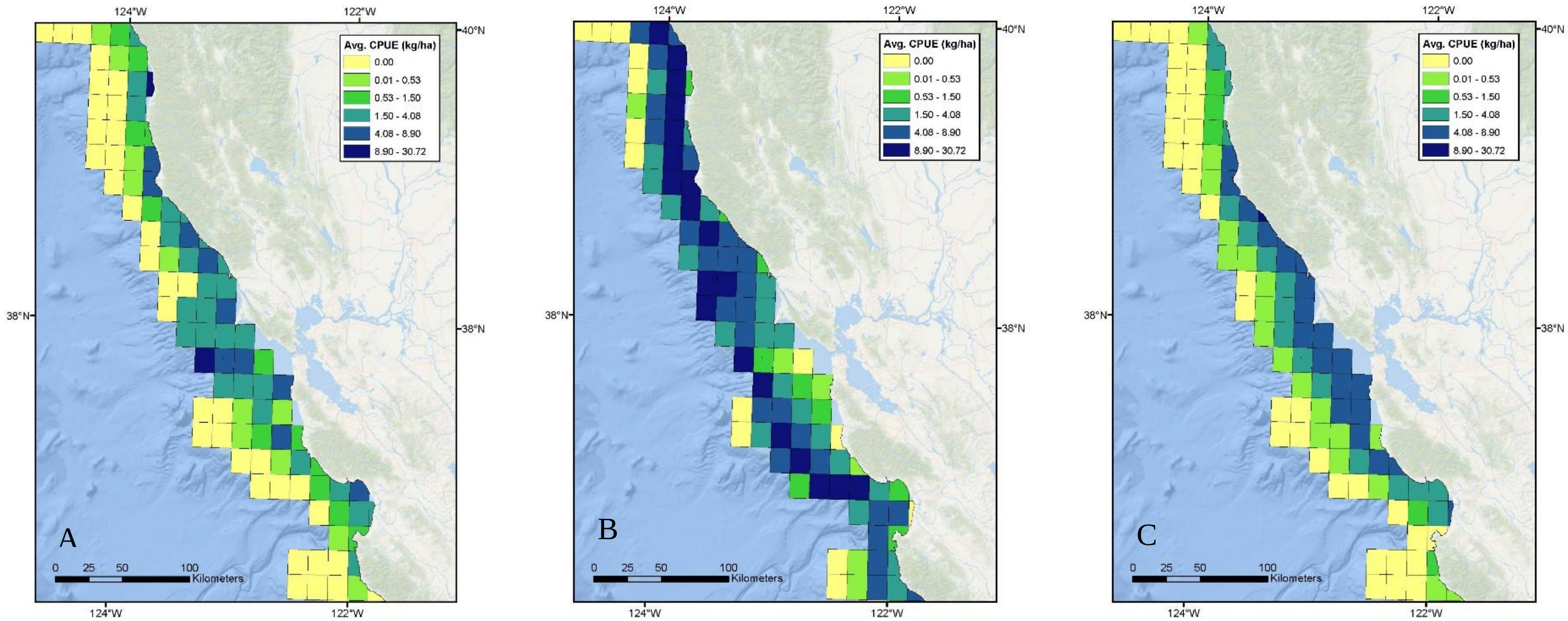

Figure A5. Average catch-per-unit-effort (kg/ha) estimates) of Big Skate (A), Longnose Skate (B), and California Skate (C) per fishing block based on West Coast Groundfish Bottom Trawl Survey data collected in central and northern California from 2003–2017, standardized and reported as quantiles.

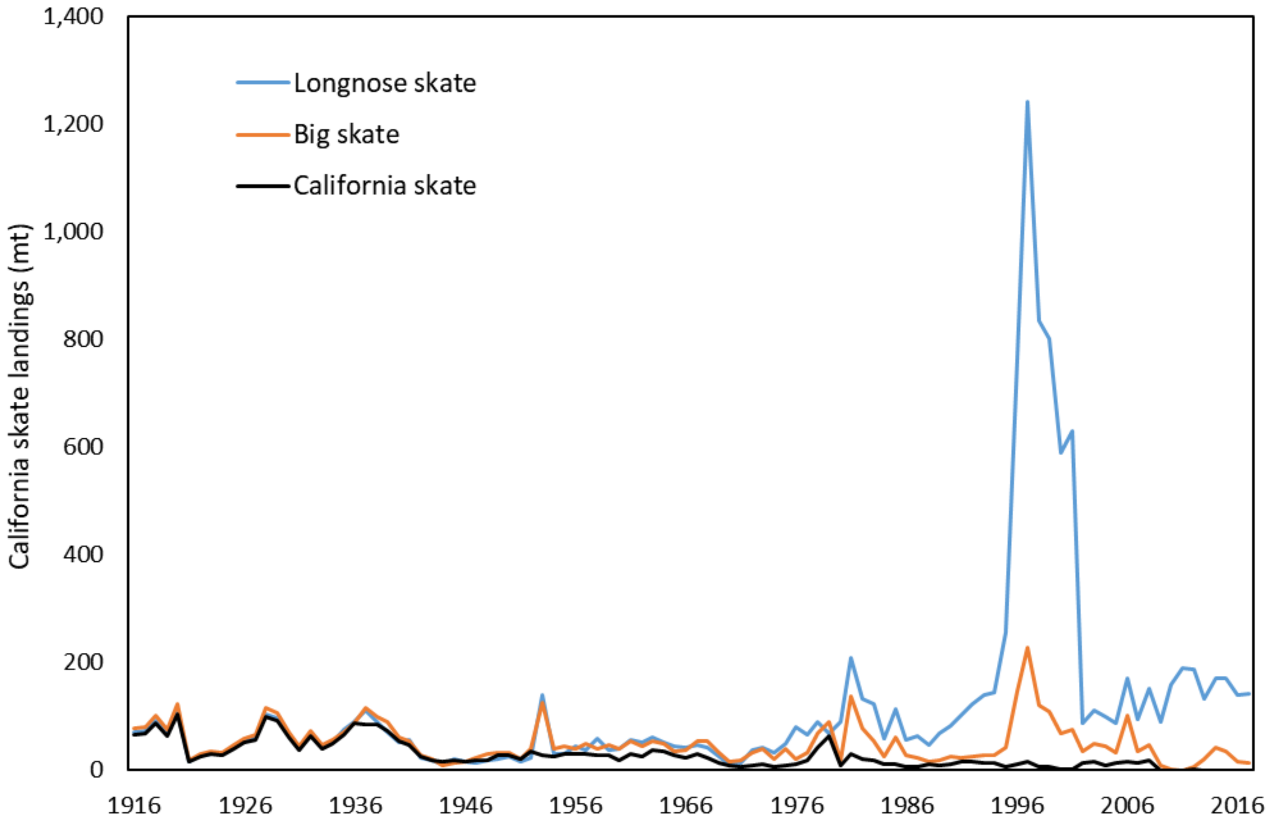

Figure A6. California reconstruction skate landed catch estimates by species.

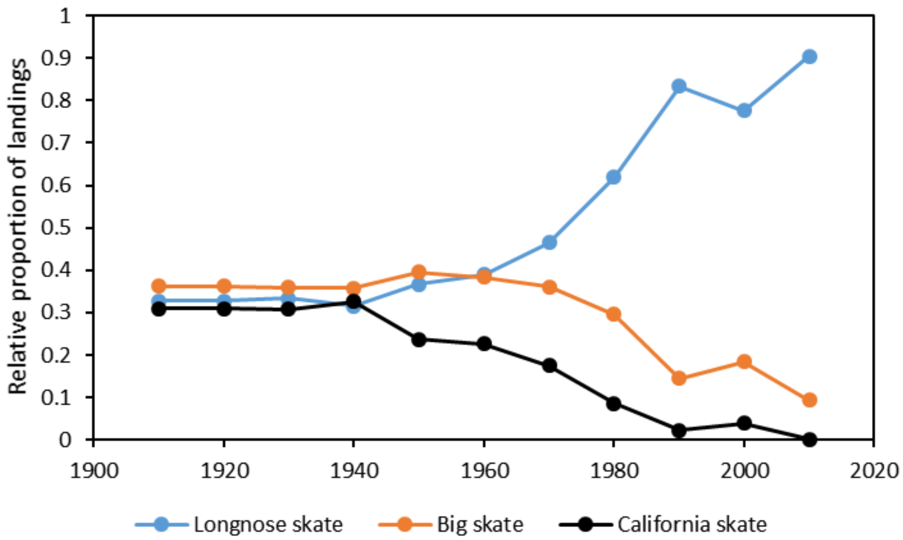

Figure A7. Relative proportion of total estimated landings comprised of Longnose Skate, Big Skate, and California Skate by decade.