Status of the Pacific Spiny Dogfish shark resource off the continental U.S. Pacific Coast in 2021

by

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2021

This report may be cited as:

Gertseva, V. Taylor, I.G., Wallace, J.R., Matson, S.E. 2021. Status of the Pacific Spiny Dogfish shark resource off the continental U.S. Pacific Coast in 2021. Pacific Fishery Management Council, Portland, OR. Available from http://www.pcouncil.org/groundfish/stock-assessments/

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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
CRFS	California Recreational Fisheries Survey
DFO	Canada's Department of Fisheries and Oceans
FL	Fork Length
GFSC	The Groundfish Subcommittee of the Scientific and Statistical Committee
GMT	Groundfish Management Team
IFQ	Individual Fishing Quota
INPFC	International North Pacific Fisheries Commission
IPHC	International Pacific Halibut Commission
LPC	Pre-Caudal Length
MRFSS	Marine Recreational Fisheries Statistic Survey
NMFS	National Marine Fisheries Service
NWFSC	Northwest Fisheries Science Center
ODFW	Oregon Department of Fish and Wildlife
OFL	Overfishing Limit
OSP	Washington Ocean Sampling Program
ORBS	Oregon Ocean Recreational Boat Survey
PacFIN	Pacific Fisheries Information Network
PFMC	Pacific Fishery Management Council
RecFIN	Recreational Fisheries Information Network
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

Pacific spiny dogfish (*Squalus suckleyi*) in the Northeast Pacific Ocean occur from the Gulf of Alaska, with isolated individuals found in the Bering Sea, southward to San Martin Island, in southern Baja California. They are extremely abundant in waters off British Columbia and Washington, but decline in abundance southward along the Oregon and California coasts. This assessment focuses on a portion of a population that occurs in coastal waters of the western United States, off Washington, Oregon and California, the area bounded by the U.S.-Canada border on the north and U.S.-Mexico border on the south. The assessment area does not include Puget Sound or any other inland waters. The population within this area is treated as a single coastwide stock, given the migratory nature of the species and the lack of data suggesting the presence of multiple stocks.

The spiny dogfish stock included in this assessment likely has interaction and overlap with dogfish observed off British Columbia. A spatial population dynamics model, which included data from several tagging studies in the Northeast Pacific Ocean, estimated movement rates of about 5% per year between the U.S. coastal sub-population of dogfish and that found along the west coast of Vancouver Island in Canada. Given this relatively low estimated rate of exchange, it was considered appropriate to proceed with the assessment for the limited area of the species range, recognizing that the scope of this assessment does not capture all of the removals and dynamics which likely bear on the status and trends of the larger, transboundary population.

Catches

In the coastal waters of the U.S. west coast, spiny dogfish has been utilized since early 20th century, and are caught by both trawl and non-trawl gears (Figure ES-1). The history of dogfish utilization included a brief but intense fishery in the 1940s, which started soon after it was discovered that livers of spiny dogfish contain high level of vitamin A. During the vitamin A fishery, removals averaged around 6,821mt per year reaching their peak of 16,876 mt in 1944. The fishery ended in 1950 with the advent of synthetic vitamins. In the mid-1970s, a food fish market developed for dogfish when the species was harvested and exported to other counties, primarily Great Britain. For the last 10 years landings ranged between 482 and 1,908 mt (Table ES-1). The landings of spiny dogfish were reconstructed back to 1916 from variety of published sources and databases.

Even though spiny dogfish was heavily harvested in the 1940s, this species is not highly prized and is mostly taken as bycatch in other commercially important fisheries. Gear-specific discards were reconstructed outside the model and included as separate fleets.

The fishery removals in the assessment were divided among eight fisheries, including bottom trawl landings, bottom trawl discard, midwater trawl removals, bycatch within the at-sea hake fishery, non-trawl landings, non-trawl discard, non-trawl catches within Vitamin A fishery, and recreational catches.

Table ES-1. Recent removals (mt) of spiny dogfish shark by fleet.

Year	Bottom trawl landings	Bottom trawl discard	Midwater trawl catch	Bycatch within at-sea-hake fishery	Nontrawl landings	Nontrawl discard	Recreational catch	Total Catch
2009	78	525	274	163	56	93	4	1,194
2010	60	368	282	278	10	127	2	1,127
2011	86	303	367	785	11	75	10	1,636
2012	52	291	162	178	2	111	3	799
2013	9	287	105	97	47	96	6	647
2014	53	315	81	60	19	89	2	619
2015	4	191	271	97	43	90	1	699
2016	1	248	203	194	1	134	1	781
2017	3	151	109	140	3	73	3	482
2018	7	228	462	957	2	247	4	1,908
2019	3	252	569	614	2	166	2	1,610
2020	2	210	250	94	1	162	2	721

* The assessment assumes 50% survival of fish in non-trawl discard.

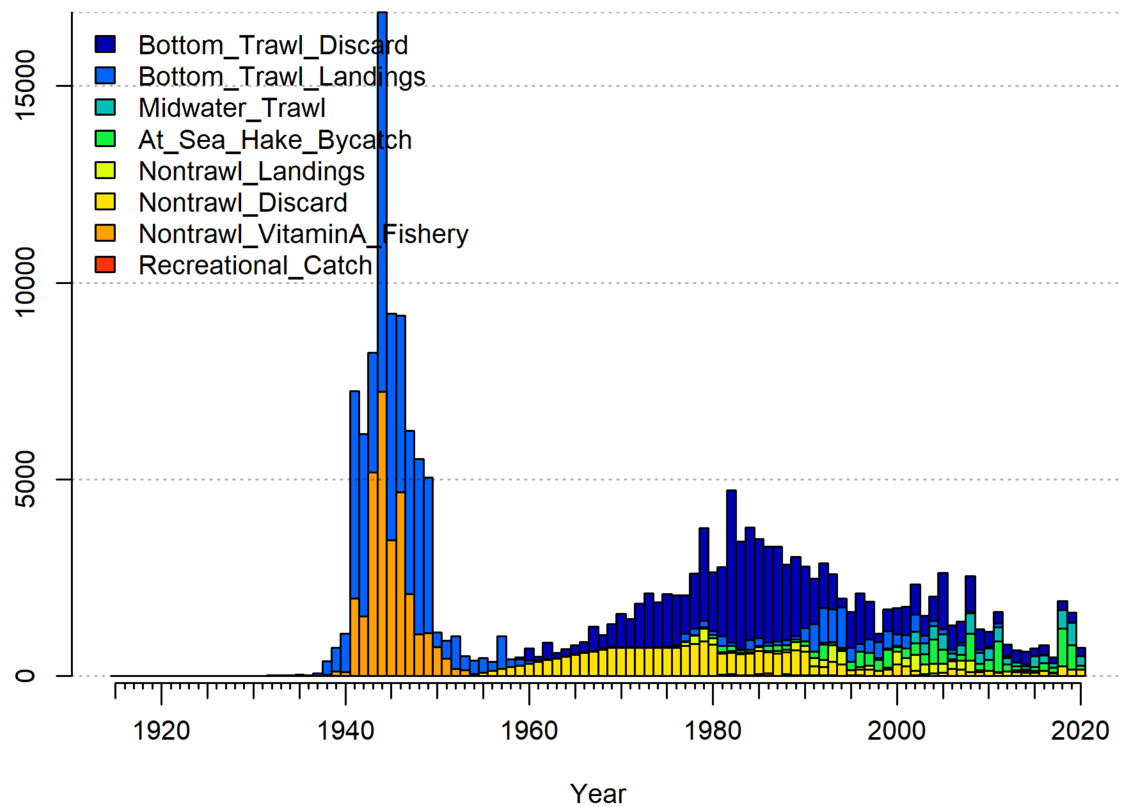

Figure ES-1. Pacific spiny dogfish shark catch history (mt) between 1916 and 2020, used in the assessment.

Data and assessment

The spiny dogfish shark population on the West Coast of the United States was assessed only once before, in 2011, using the Stock Synthesis 2 modeling framework. This current assessment uses Stock Synthesis version 3.30.16, released in September 2020.

The modeling period begins in 1916, assuming an unfished equilibrium state of the stock in 1915. The assessment treats females and males separately due to differences in biology and life history parameters between genders. Types of data that inform the model include catch, length frequency data from commercial and recreational fishing fleets. The model includes eight fishing fleets (bottom trawl landings, bottom trawl discard, midwater trawl catches, bycatch within at-sea hake fishery, non-trawl landings, non-trawl discard, non-trawl catches within Vitamin A fishery, and recreational catches) that operate within the entire area of assessment. 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). Spiny dogfish catch in the International Pacific Halibut Commission's (IPHC's) longline survey is also included via an index of relative abundance; IPHC length frequency data are used. Surveys data used in the assessment included abundance indices and fishery-independent length and age frequency data that together provide information on relative trend and demographics of spiny dogfish in the assessed area.

The spiny dogfish base model is highly sensitive to catchability (q) of the West Coast Groundfish Bottom Trawl (WCGBT) Survey. In the base model, WCGBT Survey q was estimated to be 0.586, but the profile over WCGBTS q is flat across a wide range of potential values. The Groundfish Subcommittee of the Scientific and Statistical Committee (GFSC) and a representative of the Center for Independent Experts (Dr. Matt Cieri) met via webinar on September 29 and 30, 2021, to review materials and additional analysis related to a hypothesis of potentially lower availability of spiny dogfish during the survey period than throughout the whole year due to seasonal migration. The analyses of seasonal patterns conducted using the available data did not provide a basis for an informative prior that could be included directly in the assessment model. However, the group agreed that a catchability value of $q = 0.9$ that was calculated as the 12.5 quantile of the likelihood distribution for the profile over the WCGBT Survey q to represent the low state of nature was too high in light of the dogfish seasonal migrations. Following a precedent set by the 2017 Pacific ocean perch assessment, the mean spawning output and depletion from a likelihood profile were used to identify a WCGBTS catchability value, which represented the expected population level associated with the range of models that included one with $q = 0.3$ (estimated from likelihood profile, 87.5 quantile, as the high state of nature), and another with $q = 0.586$ (that was assigned to low state of nature).

Values of spawning output and depletion were averaged for the profile models with $q = 0.30$, 0.35, 0.40, 0.45, 0.50, 0.55, and 0.586. The mean spawning output from this set was 13,825 pups and the mean depletion was 0.416. A model with $q = 0.43$, which had 2021 spawning output estimated at 13,613 pups and depletion estimated at 0.418, was found to be a close match to those mean values and chosen as a model that will be used to inform harvest specifications. This model with catchability set to $q = 0.43$ thus represents the expected ending spawning output and depletion given catchability values between $q = 0.3$ and $q = 0.586$ that were considered equally likely. The model with WCGBT Survey $q = 0.43$ was used as middle state of nature in the Decision Table, while models with $q = 0.586$ and $q = 0.3$ as low and high states of nature, respectively.

The tables and figures in the Executive Summary of this report represent the model selected for the middle state of nature (with WCGBT Survey $q = 0.43$), while the main document details the base model (with WCGBT Survey $q = 0.586$) that is used as low state of nature in the Decision Table.

The analysis of spiny dogfish catch rates in the bottom trawl fishery, conducted to explore a hypothesis of potentially lower availability of spiny dogfish during the survey period than throughout the whole year due to seasonal migration is included as an Appendix A in this report.

Stock spawning output

The spiny dogfish spawning output in the assessment is reported in thousands of pups. The unexploited level of spawning stock output when WCGBT Survey catchability is fixed at 0.43 is estimated to be 32,570 thousands of pups (95% confidence interval: 27,398–37,742). At the beginning of 2021, the spawning stock output is estimated to be 13,613 thousands of pups (95% confidence interval: 7,994–19,232), which represents 42% of the unfished spawning output level (Table ES-2).

Historically, the spawning output of spiny dogfish showed a relatively sharp decline in the 1940s, during the time of the intense dogfish fishery for vitamin A. During a 10-year period (between 1940 and 1950), the spawning output dropped from 99% to under 75% of its unfished level. Between 1950 and 1974 the catches of spiny dogfish were minimal, but given the low productivity of the stock, the spawning output continued to slowly decline. Since late 1970s decrease became a bit more pronounced due to fishery removals (an export food fish fishery developed in the mid-1970s) and low productivity of the stock, but in the last decade catches decreased and the stock decline also slowed down (Figure ES-2).

Table ES-2. Recent trend in estimated spiny dogfish spawning output (1000s of pups), recruitment (1000s of pups) and relative spawning output.

Year	Spawning Output	Interval	Recruitment	Interval	Fraction Unfished	Interval
2011	13,409	7,928–18,891	8984	6,584–12,260	0.4	0.3–0.5
2012	13,410	7,917–18,902	8984	6,581–12,267	0.4	0.3–0.5
2013	13,427	7,922–18,932	8995	6,587–12,282	0.4	0.3–0.5
2014	13,433	7,915–18,951	8999	6,587–12,293	0.4	0.3–0.5
2015	13,451	7,919–18,983	9010	6,594–12,310	0.4	0.3–0.5
2016	13,474	7,926–19,021	9024	6,604–12,330	0.4	0.3–0.5
2017	13,507	7,945–19,069	9044	6,620–12,356	0.4	0.3–0.5
2018	13,556	7,979–19,133	9074	6,646–12,389	0.4	0.3–0.5
2019	13,567	7,976–19,159	9081	6,648–12,404	0.4	0.3–0.5
2020	13,585	7,979–19,191	9092	6,654–12,423	0.4	0.3–0.5
2021	13,613	7,994–19,232	9109	6,666–12,446	0.4	0.3–0.5

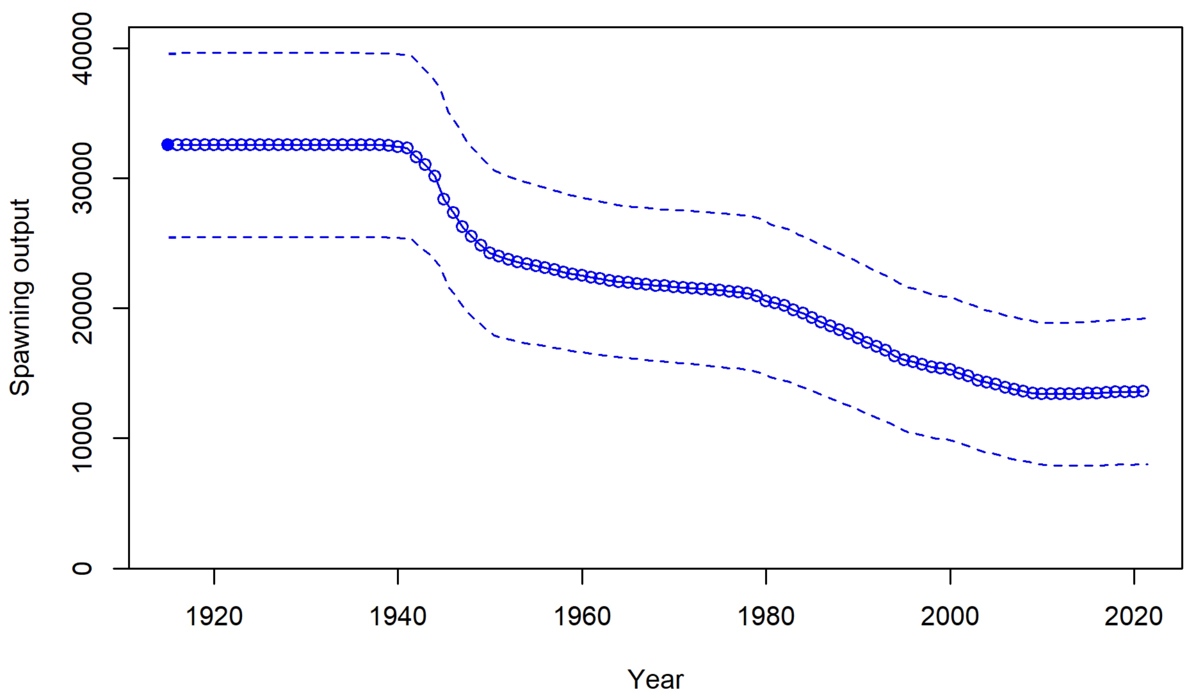

Figure ES-2. Time series of estimated spawning output (1,000s fish) of spiny dogfish (circles) with ~ 95 percent confidence interval (dashed lines).

Recruitment

The fecundity of dogfish in the Northeast Pacific Ocean has been well studied, with pregnant females having relatively few pups per litter (5 to 15), and with relatively little variability among individuals. Unlike fish producing millions of eggs, the low fecundity of dogfish suggests both low productivity in general and a more direct connection between spawning output and recruitment than for many species. Time series of estimated recruitment (in 1,000s of pups) are shown in Figure ES-3 and recent trends are presented in Table ES-2.

In the assessment, therefore, the spawner-recruit relationship was modeled using a functional form which allows a more explicit modeling of pre-recruit survival between the stage during which embryos can be counted in pregnant females to their recruitment as age 0 dogfish. The recruits were taken deterministically from the stock-recruit curve since the relatively large size of dogfish pups at birth (20-30cm) suggest that variability in recruitment would be lower than for a species with a larval stage, which is subject to higher mortality rates.

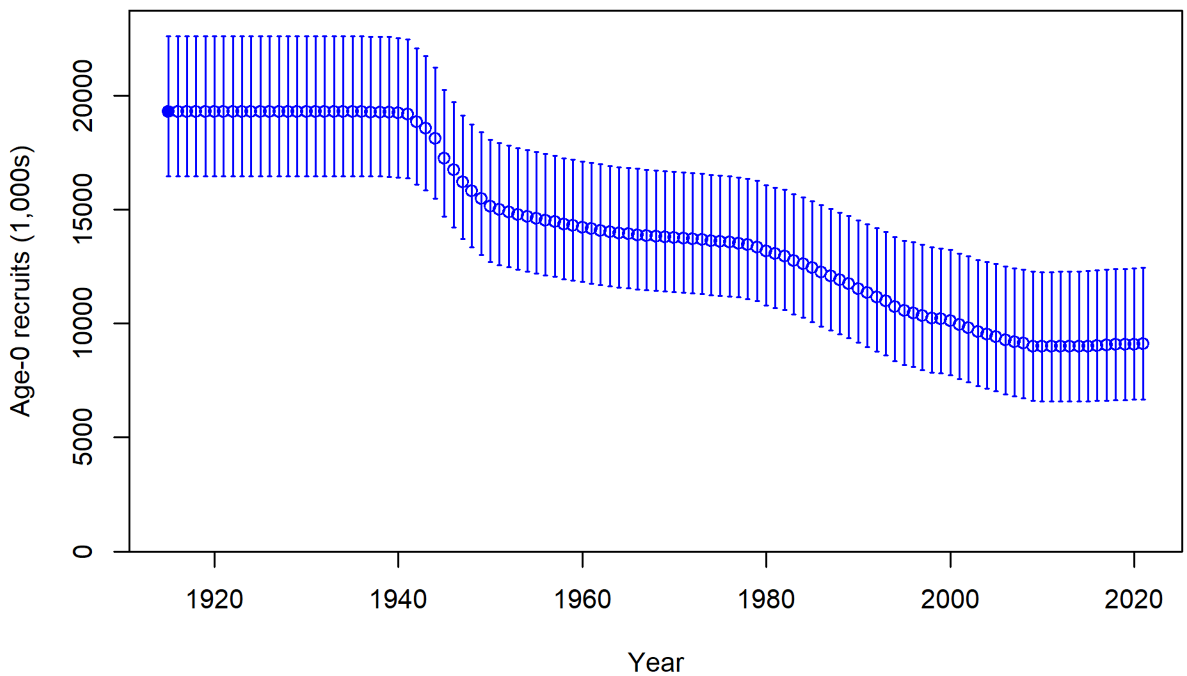

Figure ES-3. Time series of estimated recruitment (1,000s pups, circles) with approximate 95 confidence intervals (vertical lines).

Exploitation status

The model with WCGBTS catchability of 0.43 shows that the stock of spiny dogfish off the continental U.S. Pacific Coast is currently at 42% of its unexploited level (Table ES-2, Figure ES-4). This is above the overfished threshold of $SB_{25\%}$ and the management target of $SB_{40\%}$ of unfished spawning output. The Spawning Potential Ratio (SPR) used for setting the OFL is 50 percent. Through the history, the assessment estimates that spiny dogfish was fished at a rate that exceeded the relative SPR target in multiple periods, most notably during Vitamin A fishery, and also in 1990s and 2000s (Table ES-3, Figures ES-5 and ES-6). Equilibrium yield curve for spiny dogfish from the model with WCGBT Survey q of 0.43 is shown in Figure ES-7.

Table ES-3. Recent trends in estimated spawning potential ratio (SPR) and exploitation rate for spiny dogfish.

Year	(1-SPR)/ (1SPR_50%)	Interval	Exploitation Rate	Interval
2011	0.75	0.53–0.96	0.0141	0.0099–0.0184
2012	0.46	0.32–0.60	0.007	0.0048–0.0091
2013	0.42	0.29–0.56	0.0057	0.0039–0.0074
2014	0.41	0.28–0.54	0.0054	0.0038–0.0071
2015	0.42	0.28–0.55	0.0061	0.0042–0.0080
2016	0.44	0.30–0.58	0.0069	0.0047–0.0090
2017	0.29	0.19–0.38	0.0043	0.0029–0.0056
2018	0.84	0.60–1.09	0.0169	0.0116–0.0221
2019	0.75	0.52–0.98	0.0144	0.0098–0.0190
2020	0.43	0.29–0.58	0.0065	0.0044–0.0086

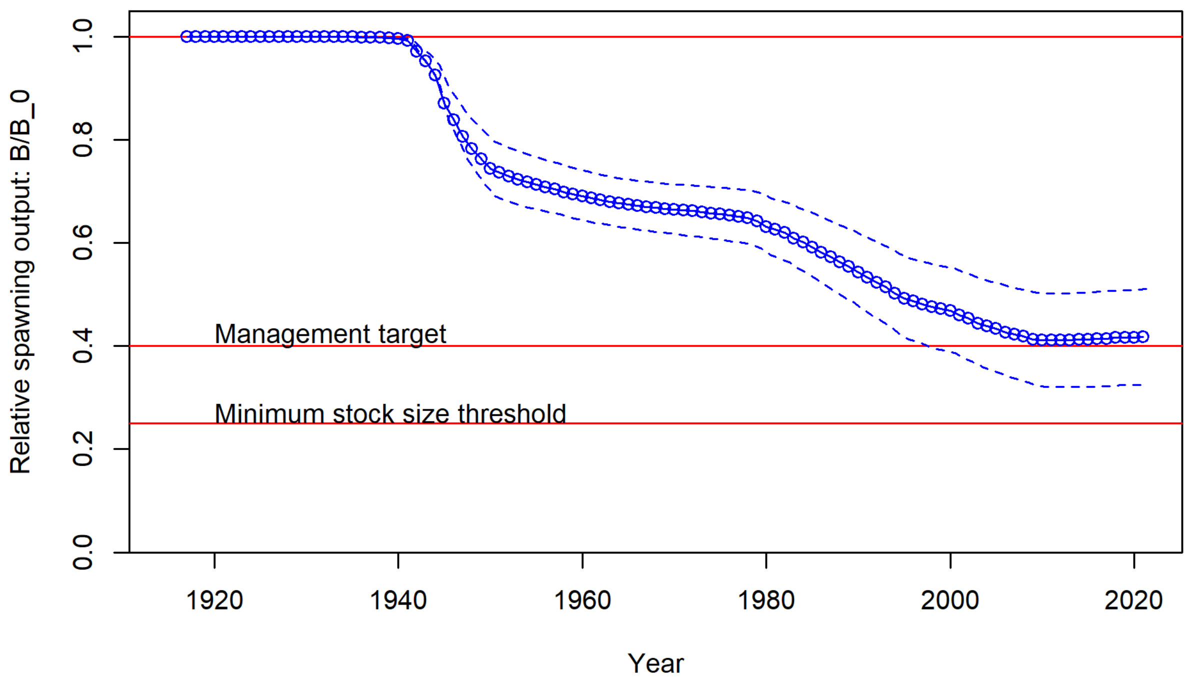

Figure ES-4. Estimated relative spawning output with approximate 95 percent asymptotic confidence intervals (dashed lines).

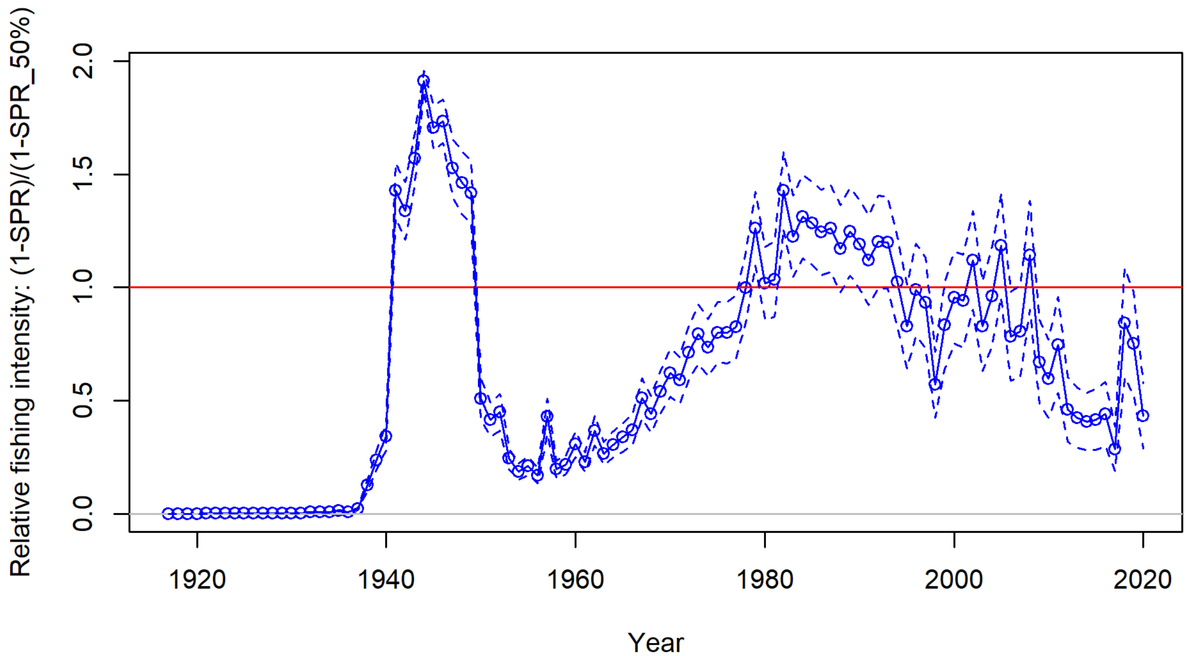

Figure ES-5. Estimated spawning potential ratio (SPR) with approximate 95 percent asymptotic confidence intervals. One minus SPR standardized to the target is plotted so that higher exploitation rates occur on the upper portion of the y-axis. The management target is plotted as the red horizontal line and values above this reflect harvests in excess of the overfishing proxy based on the SPR50%.

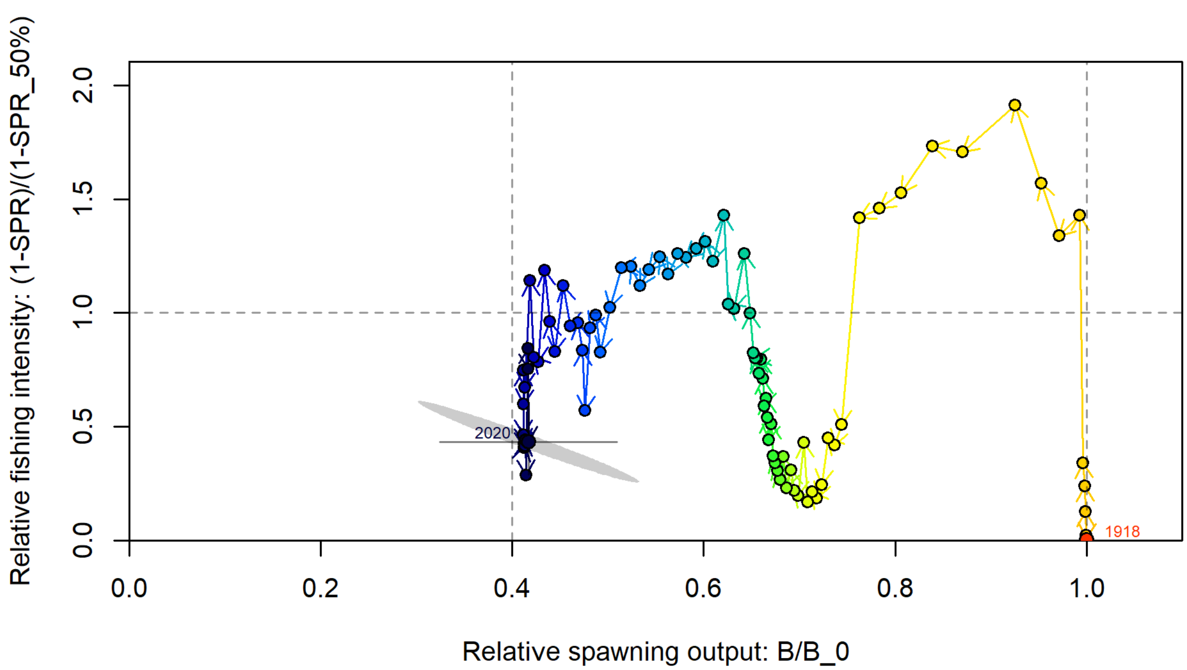

Figure ES-6. Phase plot of estimated relative (1-SPR) vs. relative spawning output. Fishing intensity is (1-SPR) divided by 0.5 (1 minus the SPR target, which is 0.5). Relative spawning output is the annual spawning output divided by the spawning output corresponding to 40 percent of the unfished spawning output. The shaded ellipse is a 95% region which accounts for the estimated correlation between the two quantities: -0.982.

Reference points

Reference points from the assessment model are summarized in Table ES-4, while summary of recent trends in estimated spiny dogfish exploitation and stock level are shown in Table ES-8.

Unfished spawning stock output for spiny dogfish is estimated to be 32,570 thousands of pups (95% confidence interval: 27,398–37,742). The stock is declared overfished if the current spawning output is estimated to be below 25% of unfished level. The management target for spiny dogfish is defined as 40% of the unfished spawning output ($SB_{40\%}$), which is estimated by the model to be 13,028 thousand of fish (95% confidence interval: 10,959–15,097), which corresponds to an exploitation rate of 0.003.

This harvest rate provides an equilibrium yield of 358 mt at $SB_{40\%}$ (95% confidence interval: 297–418 mt). The model estimate of maximum sustainable yield (MSY) is 371 mt (95% confidence interval: 307–434 mt). Equilibrium yield curve for spiny dogfish from the assessment model is shown in Figure ES-7. The estimated spawning stock output at MSY is 16,024 thousands of pups (95% confidence interval: 13,514–18,533). The exploitation rate corresponding to the estimated SPR_{MSY} of F90% is 0.003.

Because of the extremely low productivity and other reproductive characteristics of the stock, fishing at the target of SPR 50% does not appear sustainable and is expected to reduce the spawning output of spiny dogfish over the long term to zero. Conversely, fishing at a rate that would maintain spawning output near 40% of the unfished level would require a target SPR of about 88% as estimated by the assessment model. The Council's Scientific and Statistical Committee should consider the appropriateness of using the current proxy harvest rate for spiny dogfish.

Table ES-4. Summary of spiny dogfish reference points from the assessment model.

	Estimate	Interval
Unfished Spawning Output (1000s of pups)	32,570	27,398–37,742
Unfished Age 1+ Biomass (mt)	255,616	220,047–291,185
Unfished Recruitment (R0) (1000s pups)	19,291	16,228–22,354
Spawning Output (2021) (1000s of pups)	13,613	7,994–19,232
Fraction Unfished (2021)	0.42	0.33–0.51
Reference Points Based $SB_{40\%}$		
Proxy Spawning Output $SB_{40\%}$	13,028	10,959–15,097
SPR Resulting in $SB_{40\%}$	0.882	0.882–0.882
Exploitation Rate Resulting in $SB_{40\%}$	0.003	0.003–0.004
Yield with SPR Based On $SB_{40\%}$ (mt)	358	297–418
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	NA	NA
SPR50	0.5	NA
Exploitation Rate Corresponding to SPR50	0.018	0.016–0.021
Yield with SPR50 at SB SPR (mt)	NA	NA
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	16,024	13,514–18,533
SPR MSY	0.899	0.898–0.900
Exploitation Rate Corresponding to SPR MSY	0.003	0.002–0.003
MSY (mt)	371	307–434

Management performance

Recent management guidelines along with recent trends in catch (mt) for spiny dogfish are shown in Table ES-5.

Spiny dogfish on the west coast of the United States was managed under the Other Fish complex since implementation of the Groundfish Fishery Management Plan (FMP) in 1982 and managed with stock-specific harvest specifications beginning in 2015.

In 2005, a reduction in the acceptable biological catch (ABC) of the Other Fish complex was instituted due to removal of the California substock of cabezon from the complex. The same year, a 50% precautionary optimum yield (OY) reduction was implemented to accommodate uncertainty associated with managing unassessed stocks. In 2006, a trip limit for spiny dogfish was imposed for U.S. west coast waters, which varied between 100,000 and 200,000 lbs per two months for all gears. In 2009, another ABC reduction was implemented due to removal of longnose skate from the Other Fish complex and the 50% OY reduction was maintained.

In 2011, a reduction in the overfishing limit (OFL) was implemented due to removal of the Oregon substock of cabezon from the Other Fish complex. A 50% precautionary reduction of the annual catch limit (ACL) was maintained and a scientific uncertainty buffer was specified as an ABC of 7,742 mt under the Amendment 23 framework. The trawl trip limit was reduced to 60,000 lbs/2 months in 2011 to accommodate incidental bycatch.

In 2015, spiny dogfish were removed from the Other Fish complex and have been managed with stock-specific harvest specifications since then. Avoidance of spiny dogfish bycatch was encouraged in the trawl fishery and the industry adopted proactive measures to reduce their incidental take.

Table ES-5. Management guidelines, recent trends in landings and estimated total catch (mt) for spiny dogfish, in metric tons.

	OFL		**ABC/ACL**		
Year	Other Fish a/	Spiny Dogfish	Other Fish a/	Spiny Dogfish	**Catch**
2011	11,148	2,200	5,574	1,100	1,636.27
2012	11,150	2,200	5,575	1,100	798.94
2013	6,832	2,980	4,697	2,044	646.53
2014	6,802	2,950	4,717	2,024	618.92
2015	NA	2,523	NA	2,101	698.91
2016	NA	2,503	NA	2,085	781
2017	NA	2,514	NA	2,094	481.99
2018	NA	2,500	NA	2,083	1,907.51
2019	NA	2,486	NA	2,071	1,609.72
2020	NA	2,472	NA	2,059	721.44

a/ Spiny dogfish have been managed with stock-specific harvest specifications since 2015.

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.

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, survey catchability, stock-recruit parameters 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 was one of the major sources of uncertainty. Even though the base model was able to estimate a reasonable value the WCGBT Survey catchability, consistent with what we know about spiny dogfish latitudinal, depth and vertical availability to the survey, the likelihood profile indicated that the model has little information for this parameter. Therefore, to aid in exploring the base model, the WCGBT Survey catchability coefficient was fixed at the estimated value for model diagnostics.

Spiny dogfish is a transboundary stock, and there are high densities of dogfish close to the U.S.-Canada border, at the mouth of the Strait of Juan de Fuca which connects the outside coastal waters with the inside waters of Puget Sound and the Strait of Georgia. Limiting the assessment area to the U.S. West Coast coastal waters does not allow for including a full range of spatial and temporal dynamics for the species, and therefore results may possess additional uncertainty associated with not looking at the full scope of stock's distribution.

Scientific uncertainty

The Sigma values associated with the 2021 OFL (calculated from the normal approximation and converted to the log-standard deviation of a lognormal distribution) is 0.19, well below the minimum 1.0 value associated with Category 2, the most likely classification for this assessment.

Decision table

The primary axis of uncertainty used in the decision table (Table ES-7) was WCGBT Survey catchability (q). WCGBT Survey q in the base model was estimated (and then fixed) at 0.586. The 12.5% and 87.5% quantiles of the likelihood profile of WCGBTS q (the value of 0.66 reflects the chi square distribution with one degree of freedom) corresponded to q values of 0.9 and 0.3. The model with $q = 0.3$ was used as high state of nature, but the alternative approach was used to identify the low and middle states of nature.

Following a precedent set by the 2017 Pacific ocean perch assessment, the mean spawning output and depletion from a likelihood profile were used to identify a WCGBTS catchability value, which represented the expected population level associated with the range of models that included one with $q = 0.3$ (the high state of nature), and another with $q = 0.586$ (that was assigned to low state of nature). Values of spawning output and depletion were averaged for the profile models with $q = 0.30, 0.35, 0.40, 0.45, 0.50, 0.55$, and 0.586. The mean spawning output from this set was 13,825 pups and the mean depletion was 0.416. A model with $q = 0.43$, which had 2021 spawning output estimated at 13,613 pups and depletion estimated at 0.418, was found to be a close match to those mean values and chosen as a model that will be used to inform harvest specifications. This model with catchability set to $q = 0.43$ thus represents the expected ending spawning output and depletion given catchability values between $q = 0.3$ and $q = 0.586$ that were considered equally likely. The model with WCGBT Survey $q = 0.43$ was used as middle state of nature in the Decision Table, while models with $q = 0.586$ and $q = 0.3$ as low and high states of nature, respectively.

Twelve-year forecasts for each state of nature were calculated for three catch scenarios. All scenarios assumed full ACL catches for the 2021 and 2022, which are 1,621 mt and 1,585 mt, respectively. The low catch scenario assumed P* of 0.4 with 65% of ACL taken; the middle catch scenario was P* of 0.4 with full ACL taken for years between 2023 and 2032, and the high catch scenario was P* of 0.4 with full ACL taken from the new middle state ($q = 0.43$) for years between 2023 and 2032.

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 0.4, and a time-varying Category 2 Sigma which creates the buffer shown in the right-hand column. The OFL and ACL values for 2021 and 2022 are the current harvest specifications (also shown in Table ES-5) while the total mortality for 2021 and 2022 represent full ACL catch.

Table ES-6. Projections of OFL, and ACL values along with recruitment, spawning output and fraction unfished.

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 1+ Biomass	Spawning Output	Fraction Unfished
2021	1,974.91	1,620.99	110,047	13,613	0.42
2022	1,942.41	1,584.99	108,818	13,604	0.42
2023	1,911.16	1,456.30	107,636	13,591	0.42
2024	1,883.17	1,406.73	106,595	13,586	0.42
2025	1,857.04	1,361.21	105,616	13,578	0.42
2026	1,832.76	1,317.75	104,698	13,565	0.42
2027	1,810.37	1,278.12	103,839	13,548	0.42
2028	1,789.86	1,240.37	103,037	13,527	0.42
2029	1,771.20	1,204.42	102,289	13,500	0.41
2030	1,754.39	1,170.18	101,593	13,470	0.41
2031	1,739.37	1,137.55	100,949	13,434	0.41
2032	1,726.10	1,108.16	100,354	13,394	0.41

Research and data needs

In this assessment, several critical assumptions were made based on limited supporting data and research. There are several research and data needs which, if satisfied, could improve the assessment. These research and data needs include:

1) Continue all ongoing data streams used in this assessment. Continued sampling of lengths and ages from the landed catch and lengths and discard rates from the fishery will be very valuable for the years ahead. Also, a longer fishery independent index from a continued WCGBT Survey with associated compositions of length and age-at-length will improve understanding of dynamics of the stock.

2) Continue to refine historical catch estimates. A considerable uncertainty remains in the historic discard amounts, prior to the commencement of the West Coast Groundfish Observer Program. There is also the need to improve estimates of discard mortality. These issues are relevant for other West Coast stock assessments as well.

3) The ageing method for dogfish requires further research. The current assessment was able to estimate growth parameters for females and females, but understanding of maximum age especially for females continue to be uncertain. More research is needed on the topic of unreadable annuli that are missing due to wear on the spines of older dogfish. The efforts should be devoted to both improving current ageing techniques based on dogfish spines and developing new methods using other age structures. Ideally, an alternative method of ageing dogfish that does not rely on the estimation of ages missing from worn spines may be necessary. Improvement in ageing would contribute to better understanding of spiny dogfish longevity and help estimating natural mortality within the assessment model.

4) Poorly informed parameters, such as natural mortality and stock-recruit parameters will benefit from meta-analytical approaches until there is enough data to estimate them internal to the model.

5) There are high densities of dogfish close to the U.S.-Canada border, at the mouth of the Strait of Juan de Fuca which connects the outside coastal waters with the inside waters of Puget Sound and the Strait of Georgia. This distribution, combined with potential seasonal or directed movement patterns for dogfish suggest that U.S. and Canada should explore the possibility of a joint stock assessment in future years.

Most of the research needs listed above entail investigations that need to take place outside of the routine assessment cycle and require additional resources to be completed.

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 =0.586		Middle state: q =0.43		High state: q =0.3	
Management decision	Year	Catch (mt)	Spawning output	Depletion	Spawning output	Depletion	Spawning output	Depletion
Full ACL for 2021 and 2022 catches; P*0.4 with 65% of ACL from old base model taken after that	2021	1,621	9,895	0.344	13,613	0.418	20,067	0.513
	2022	1,585	9,876	0.343	13,604	0.418	20,068	0.513
	2023	655	9,854	0.342	13,591	0.417	20,066	0.513
	2024	635	9,868	0.343	13,614	0.418	20,100	0.514
	2025	616	9,879	0.343	13,634	0.419	20,130	0.515
	2026	598	9,888	0.344	13,652	0.419	20,158	0.515
	2027	581	9,893	0.344	13,666	0.420	20,182	0.516
	2028	565	9,896	0.344	13,677	0.420	20,202	0.516
	2029	549	9,895	0.344	13,684	0.420	20,219	0.517
	2030	535	9,892	0.344	13,688	0.420	20,232	0.517
	2031	520	9,885	0.343	13,689	0.420	20,241	0.517
	2032	507	9,875	0.343	13,686	0.420	20,246	0.518
Full ACL for 2021 and 2022 catches; P*0.4 with 100% of ACL from old base model taken after that	2021	1,621	9,895	0.344	13,613	0.418	20,067	0.513
	2022	1,585	9,876	0.343	13,604	0.418	20,068	0.513
	2023	1,001	9,854	0.342	13,591	0.417	20,066	0.513
	2024	970	9,859	0.343	13,595	0.417	20,092	0.514
	2025	941	9,861	0.343	13,596	0.417	20,114	0.514
	2026	913	9,860	0.343	13,594	0.417	20,132	0.515
	2027	887	9,855	0.342	13,588	0.417	20,147	0.515
	2028	862	9,847	0.342	13,579	0.417	20,157	0.515
	2029	839	9,834	0.342	13,566	0.417	20,162	0.515
	2030	816	9,817	0.341	13,550	0.416	20,164	0.516
	2031	794	9,797	0.340	13,530	0.415	20,160	0.515
	2032	774	9,773	0.340	13,506	0.415	20,152	0.515
Full ACL for 2021 and 2022 catches; P*0.4 with full ACL from new middle state (q = 0.43) after that	2021	1,621	9,895	0.344	13,613	0.418	20,067	0.513
	2022	1,585	9,876	0.343	13,604	0.418	20,068	0.513
	2023	1,456	9,854	0.342	13,591	0.417	20,066	0.513
	2024	1,407	9,839	0.342	13,586	0.417	20,072	0.513
	2025	1,361	9,821	0.341	13,578	0.417	20,074	0.513
	2026	1,318	9,798	0.340	13,565	0.416	20,072	0.513
	2027	1,278	9,771	0.340	13,548	0.416	20,066	0.513
	2028	1,240	9,740	0.338	13,526	0.415	20,055	0.513
	2029	1,204	9,705	0.337	13,500	0.414	20,039	0.512
	2030	1,170	9,664	0.336	13,470	0.414	20,018	0.512
	2031	1,138	9,620	0.334	13,434	0.412	19,993	0.511
	2032	1,108	9,571	0.333	13,394	0.411	19,962	0.510

Table ES-8. Summary of recent trends in estimated spiny dogfish exploitation and stock level from the assessment model.

Quantity	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
OFL Other Fish a/	11,148	11,150	6,832	6,802	NA	NA	NA	NA	NA	NA	NA
OFL Spiny Dogfish	*2,200*	*2,200*	*2,980*	*2,950*	2,523	2,503	2,514	2,500	2,486	2,472	2,479
ACL Other Fish a/	5,574	5,575	4,697	4,717	NA	NA	NA	NA	NA	NA	NA
ACL Spiny Dogfish	*1,100*	*1,100*	*2,044*	*2,024*	2,101	2,085	2,094	2,083	2,071	2,059	1,621
Total Catch	1636.269	798.94388	646.52739	618.91734	698.90689	781.000162	481.99312	1907.51277	1609.71551	721.43709	NA
1-SPR	0.75	0.46	0.42	0.41	0.42	0.44	0.29	0.84	0.75	0.43	NA
Exploitation Rate	0.01	0.01	0.01	0.01	0.01	0.01	0	0.02	0.01	0.01	NA
Age 1+ Biomass (mt)	115,646	114,506	114,192	114,014	113,845	113,577	113,209	113,128	111,600	110,373	255,602
Spawning Output	13,409	13,410	13,427	13,433	13,451	13,474	13,507	13,556	13,567	13,585	13,613
Interval	7,928–18,891	7,917–18,902	7,922–18,932	7,915–18,951	7,919–18,983	7,926–19,021	7,945–19,069	7,979–19,133	7,976–19,159	7,979–19,191	7,994–19,232
Recruits	8,984	8,984	8,995	8,999	9,010	9,024	9,044	9,074	9,081	9,092	9,109
Interval	6,584–12,260	6,581–12,267	6,587–12,282	6,587–12,293	6,594–12,310	6,604–12,330	6,620–12,356	6,646–12,389	6,648–12,404	6,654–12,423	6,666–12,446
Fraction Unfished	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Interval	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5

a/ Spiny dogfish have been managed with stock-specific harvest specifications since 2015.

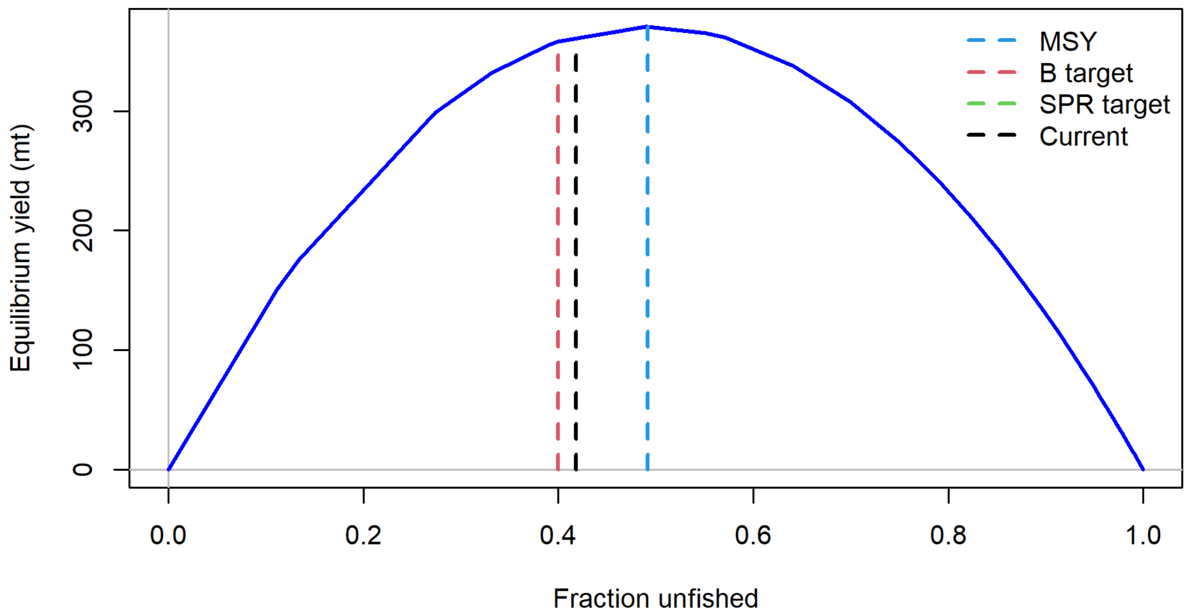

Figure ES-7. Equilibrium yield curve for spiny dogfish from the assessment model with WCGBT Survey q fixed at 0.43.

1 Introduction

The spiny dogfish is one of the most widely distributed sharks that inhabit temperate waters in both the Pacific and the Atlantic Oceans. It is a small to medium-sized cartilaginous fish that is generally found inshore areas to offshore depths of at least 1200 m (Figure 1, Ebert 2003). Although frequently observed as solitary individuals, spiny dogfish also form large localized schools of hundreds if not thousands of organisms (Compagno et al. 2005, Ebert 2003, Shepherd et al. 2002).

Taxonomically, it has been problematic as to whether spiny dogfish are monospecific or contains more than one species (Ebert et al. 2010, Verissimo et al. 2010). The North Pacific spiny dogfish was originally described by George Suckley from specimens collected in Puget Sound, and designated as *Squalus suckleyi* in 1854 (Girard 1854). The original description of the species was brief and did not provide details separating it from the North Atlantic *Squalus acanthias*, and it was later designated as a subspecies of the *Squalus acanthias* (Ebert et al. 2010, Verissimo et al. 2010).

Molecular studies, however, have consistently found strong evidence of genetic divergence between North Pacific (from the Koreas and Japan, northward to Russia, the Bering Sea and the Aleutian Islands, and eastwards in the Gulf of Alaska, British Columbia and Washington south to southern Baja California) and non-North Pacific spiny dogfish (Franks 2006, Ebert et al. 2010, Verissimo et al. 2010, Ward et al. 2007). Also, the most recent taxonomic re-evaluation of the status of the North Pacific *Squalus suckleyi* combining the use of meristic, morphological and molecular data confirmed this species to be clearly distinct from the widespread *Squalus acanthias* (Ebert et al. 2010). The genetic divergence between North Pacific and non-North Pacific groups is also consistent with distinct differences in life history characteristics; North Pacific fish mature at an older age, reach larger maximum sizes and live longer than fish occurring outside North Pacific waters.

1.1 Distribution and Movements

In North America, spiny dogfish occur from the Gulf of Alaska, with isolated individuals found in the Bering Sea, southward to San Martin Island, in southern Baja California. They are extremely abundant in waters off British Columbia and Washington, but decline in abundance southward along the Oregon and California coasts (Ebert 2003, Ebert et al. 2010).

This assessment focuses on a portion of a population that occurs in coastal waters of the western United States, off Washington, Oregon and California, the area bounded by the U.S.-Canada border on the north and U.S.-Mexico border on the south. The population within this area is treated as a single coastwide stock. A map depicting the spatial scope of the assessment is shown in Figure 2.

The spiny dogfish stock included in this assessment likely has interaction and overlap with dogfish observed off British Columbia, and it must be acknowledged that the scope of this assessment does not capture all of the dynamics which likely bear on the status and trends of the larger, transboundary population.

About 1300 dogfish were tagged along the coast of Washington from 1942-1946, during the period of the strong directed fishery for dogfish. Only 50 of these fish were recaptured and had tags returned (4%), of which 54% were recaptured within U.S. coastal waters, while 32% were recaptured in coastal Canada and 12% in the inside waters of Puget Sound and the Strait of Georgia. One fish was recaptured in coastal Japanese waters (7 years after being tagged). Because many of the releases were close to the U.S.-Canada border, and the fractions do not account for the relative fishing pressure within each area, this study is of limited use in providing reliable information about dogfish movement rates.

A spatial population dynamics model (Taylor 2008), which included these tagging data (along with much larger tagging experiments conducted in Canada and inside U.S. waters of Puget Sound), estimated movement rates of about 5% per year between the U.S. coastal sub-population of dogfish and that found along the west coast of Vancouver Island in Canada. The model also estimated movement rates of less than 1% per year between dogfish in the U.S. coastal sub-population of dogfish and that in the Puget Sound.

These sharks appear to prefer areas in which the water temperature ranges from 5 to 15^{o} C, often making latitudinal and depth migrations to follow this optimal temperature gradient (Brodeur et al. 2009). There is also evidence of seasonal movement along the coast based on both tagging data and timing of historical fisheries (Ketchen 1986). One estimate of the seasonal movement along the Pacific coast is a North-South shift of about 600 km from winter to summer (Taylor et al. 2009). This seasonal pattern is not as extreme as that found among spiny dogfish in Atlantic waters of the U.S., which are likely due to larger fluctuations in temperature. Dogfish have also been captured in high-seas salmon gillnets across the North Pacific between about 40^{o} and 50^{o} N latitude (Nakano and Nagasawa, 1996), but the extent of these wide-ranging pelagic movements is poorly understood.

1.2 Biology and Life History

The biology and life history of spiny dogfish are relatively well studied (Campana et al. 2009, Di Giacomo et al. 2009, Taylor 2008, Trubizio 2009, Tribuzio et al. 2009, Tribuzio et al. 2010, Vega et al. 2009, Taylor et al. 2013). This species is an opportunistic feeder that consumes a wide range of prey (whatever is abundant). Schooling pelagic fish, such as herring, make up the majority of its diet. They also feed on invertebrates such as shrimp, crab and squid. In turn, dogfish are preyed upon by larger cod, hake and other spiny dogfish (Beamish et al. 1992, Brodeur et al. 2009, Tanasichuk et al. 1991). Larger species of sharks as well as seals and killer whales also feed on dogfish.

Spiny dogfish have internal fertilization and ovoviviparous development. The internal development takes place over 22-24 months, the longest gestation period known for sharks. The number of pups in each litter ranges between 5 and 15 individuals depending on the size of the female (larger females bearing more pups). The size at birth is generally between 20 and 30 cm for both genders. Male spiny dogfish are reported to grow faster than females, but females reach larger sizes. This species is the latest maturing (with 50% female maturity reported at 35.5 years) and longest lived of all elasmobranchs (Cortés 2002, Saunders and McFarlane 1993, Smith et al. 1998, Taylor 2008). Life history traits of spiny dogfish make the species highly susceptible to overfishing and slow to recover from stock depletion since its slow growth, late maturation and low fecundity are directly related to recruitment and spawning stock biomass (Holden 1974, King and McFarlane 2003).

1.3 Fishery Information

Spiny dogfish in the west coast of the United States have been utilized for almost a thousand years, with those in Puget Sound first used by Native Americans (Bargmann 2009). The exploitation of spiny dogfish in coastal waters, however, started in the 20th century. Even though the history of spiny dogfish utilization on the U.S. west coast included a brief but intense commercial fishery in the 1940s, in general this species is not highly prized and is mostly taken as bycatch in other commercially important fisheries.

Prior to 1936, coastal catches of spiny dogfish were extremely minimal, but in 1936, shortly after it was discovered that livers of spiny dogfish have high levels of Vitamin A, the large scale fishery for dogfish developed in the Pacific Northwest. Before World War II, Northeast Pacific dogfish livers could not compete with the cheaper and more potent sources of vitamin A from Europe. But when World War II started and European supplies were cut, dogfish shark livers became the major source of vitamin A in the United States, and the spiny dogfish fishery grew rapidly along the Pacific coast. The processed liver oils were used in pharmaceuticals, food processing and animal feed (Bargmann 2009, Ketchen 1986).

During the liver fishery, dogfish were targeted by three major gear groups, including setlines (which are longlines with numerous attached baited hooks spread along the bottom), set nets (many of which were old salmon gill nets and were readily available for the newly developed dogfish fishery) and bottom trawls. The timing of the dogfish liver fishery coincided with the development of bottom trawling in the U.S. Northwest, and though at the onset of the fishery the catches by trawl were low, by the mid-1940s trawling was the dominant type of fishing for dogfish.

In 1945, a sharp decline in spiny dogfish catches began. This decline occurred despite continued strong demand for vitamin A and high prices for dogfish livers and has been attributed to decreased availability of the species in the Northeast Pacific Ocean (Bargmann 2009, Ketchen 1986). In 1950, with the advent of synthetic vitamins, demand for spiny dogfish livers declined and catches in the Northeast Pacific Ocean virtually ended.

Between 1950 and 1974, the landings of spiny dogfish remained minimal. By the late 1950s it was reported that species availability had increased. Also in the late 1950s-early 1960s, dogfish earned a bad reputation among fishermen. They were blamed for driving off commercially valuable species such as herring and mackerel, while consuming large numbers of them. Spiny dogfish have also been observed biting through nets to get to their fish prey, releasing many of them and damaging fishing gear in the process. They were also reported damaging gear when become entangled in commercial nets. As a result, fishermen were trying to avoid areas with higher chances of dogfish catches to prevent encountering dogfish and potentially damaging their gear.

A market opportunity for dogfish opened in the mid-1970s. In Europe, spiny dogfish has long been used as an inexpensive commodity, for fish and chips in particular. A decline in European dogfish supply provided an opportunity for developing an export dogfish food fishery in the U.S. Pacific coast. Also, during the late 1970s, shark cartilage started to be used in cancer treatment, and a portion of spiny dogfish catches have since been sold for medical research and treatment (Gregory Lippert, WDFW, pers. com.).

Spiny dogfish is a common bycatch species, often caught in other fisheries and largely discarded. For instance, it has long been incidentally caught in the Pacific hake fishery, which is exclusively conducted with mid-water trawls. Large-scale harvesting of Pacific hake in the U.S. began in 1966, when factory trawlers from the Soviet Union and other countries began targeting this stock. After the 200-mile U.S. Exclusive Economic Zone was declared in 1977, a Joint-Venture fishery was initiated between United States trawlers and Soviet factory trawlers acting as mother-ships (larger, slower ships for fish processing and storage while at sea). By 1989 the U.S. fleet capacity had grown to a level sufficient to harvest the entire quota, and no further foreign fishing was allowed. The Pacific hake fishery is currently 100% observed by the at-sea hake observer program (A-SHOP) and data on bycatch species, including spiny dogfish, is being routinely collected.

1.4 Management Performance

Since 2015, spiny dogfish have been managed with stock-specific harvest specifications. Recent trends in total dead catch and commercial landings of spiny dogfish relative to the management guidelines are shown in Table 1.

Prior to 2015, this species had been managed under the Other Fish complex since implementation of the Groundfish Fishery Management Plan (FMP) by the Pacific Fishery Management Council in 1982. In 2005, the Other Fish ABC was reduced due to removal of the California substock of cabezon from the complex. A 50% precautionary OY reduction was implemented to accommodate uncertainty associated with managing unassessed stocks. In 2006, spiny dogfish trip limits of 100,000 – 200,000 lbs/2 months were implemented for all sectors of the groundfish fishery. In 2009, another ABC reduction was implemented due to removal of longnose skate from the Other Fish complex and the 50% OY reduction was maintained. In 2011, a new harvest framework was implemented where the old acceptable biological catch (ABC) was redefined as an overfishing limit, the ABC was redefined as a level of harvest below the OFL to account for scientific uncertainty in estimating the OFL, and OY was redefined as an annual catch limit (ACL). Also in 2011, the Other Fish OFL was reduced due to removal of the Oregon substock of cabezon from the complex. The trawl trip limit was reduced to 60,000 lbs/2 months in 2011 to accommodate incidental bycatch.

In 2015, spiny dogfish were removed from the Other Fish complex and have been managed with stock-specific harvest specifications since then. Avoidance of spiny dogfish bycatch was encouraged in the trawl fishery and the industry adopted proactive measures to reduce their incidental take.

1.5 Fisheries off Canada, Alaska, and/or Mexico

Fisheries for dogfish off the West Coast of Canada have largely paralleled those on the West Coast of the U.S. (Ketchen 1986, King et al. 2017). They have been characterized by a large fishery targeting dogfish for livers in the 1940s, a lack of markets in the 1950s-1970s, and a smaller fishery in recent decades. Dogfish fisheries in British Columbia include both the inside waters of the Strait of Georgia and coastal waters from extending throughout the coast from the U.S.-Canada border through the Queen Charlotte Islands. In the 1940s, the largest fraction of landings occurred in Northern British Columbia, but in the past two decades, the West Coast of Vancouver Island has made up the largest component of the landings in British Columbia (Ketchen 1986, Taylor 2008). Like the fisheries in U.S. waters, fluctuations in landings in Canada have largely been driven by market forces rather than availability. Although dogfish occur throughout the Gulf of Alaska, there has never been a commercial fishery in Alaskan waters (Tribuzio 2010, King et al. 2017).

2 Assessment

2.1 Data

The data used in the assessment are summarized in Figure 3. Descriptions of the data sources are in the following sections.

2.1.1 Fishery removals

The fishery removals in the assessment were divided in the assessment among eight fleets, that include 1) bottom trawl landings, 2) bottom trawl discard, 3) midwater trawl total catches, 4) bycatch within at sea hake fishery, 5) non-trawl landings, 6) non-trawl discard, 7) historical non-trawl catches within Vitamin A fishery, and 8) recreational catches. Fleets were defined based on exploitation history of this species in the Northeast Pacific ocean and available biological data for each fleet (needed to describe fleet selectivity).

Catches of spiny dogfish in each fleet were reconstructed back to 1916. The time series of spiny dogfish catches by fleet are shown in Figure 4 and Table 2. The methods used to reconstruct removals in each fleet are described below.

2.1.1.1 Commercial landings

2.1.1.1.1 Recent landings

Estimates of recent commercial landings of spiny dogfish (between 1981 and 2020) were obtained from the Pacific Fisheries Information Network (PacFIN), a regional fisheries database that manages fishery-dependent information in cooperation with west coast state agencies and NOAA Fisheries (www.pacfin.com). Catch data were extracted by gear type and then combined into the fishing fleets used in the assessment. Time series of recent (PacFIN era) landings by state and major gear group are shown in Figure 5 and Figure 6, respectively.

The vast majority of spiny dogfish commercial landings during the last 40 years have been made in Washington (Figure 5). Until the 2000s, the majority of landings were made by bottom trawl gear, followed by non-trawl landings. However, in the last 20 years, the contribution of shore-based midwater trawl catches grew, and now they constitute the majority of dogfish landed catch (Figure 6). These shore-based midwater trawl dogfish catches consist of bycatch within shore-based fishery targeting hake and within midwater rockfish fishery. The U.S. shore-based hake fishery started in the early 1990s and grew over the years (Figure 7). The rockfish midwater fishery also grew within the last ten years after widow rockfish was declared rebuilt in 2013 (He at al. 2011).

2.1.1.1.2 Historical landings
The time series of historical (pre-1981) landings were reconstructed as part of the 2011 assessment by fleet for each state separately and then combined to produce annual coastwide estimates. For this assessment, we used the same landings as reconstructed in the 2011 assessment, since no new historical catch information was available. The methods used to reconstruct historical landings are described below.

2.1.1.1.2.1 Washington
The records of spiny dogfish landings in Washington since 1939 were available. Landings between 1939 and 1940 were estimated from the 1939 and 1941 issues of Bulletins of the Washington Department of Fisheries, which reported the total Washington landings, Puget Sound and the coastal area together along with early catch records from Puget Sound provided by WDFW (Gregory Lippert, WDFW, pers. com.). The differences between values from the two sources were used to estimate the 1939 and 1940 coastal landings.

Records of spiny dogfish landings from 1941 were recently compiled by Bargmann (2009) based on earlier publications by Alverson and Stansby (1963) and Ketchen (1986). Between 1941 and 1956, it was a common practice not to land dogfish in the round (with processors removing the livers in their plants), but to land only the dogfish livers and discard the carcasses at sea (Bergman, 2003). To convert the liver weight to round weight, a variety of expansion factors (ranging between 8.33 and 10) were developed for different areas and periods (Alverson and Stanley 1963, Holland 1957, Ketchen 1986). Bargmann (2009) reports dogfish landings in round weight. In Bargmann (2009) landings are not attributed to specific gears. Therefore, we used the Fisheries Statistics of the United States (which reports dogfish landings by gear, but in liver weight) to calculate the proportions of removals by different gears and applied these proportions to the Bargmann (2009) time series. The Fisheries Statistics of the United States were available only through 1977. For 1978-1980 (the last three years of the pre-PacFIN era), we used the 1975-1980 average gear proportions reported in Bargmann (2009) to apportion Washington dogfish landings time series among gears.

2.1.1.1.2.2 Oregon
Oregon records of dogfish landings go back to 1940. Historically, spiny dogfish was reported in Oregon as both “Grayfish” and “Shark, Grayfish.” The time series of Oregon historical landings of spiny dogfish were obtained from Karnowski et al. (2014), that summarizes reconstruction of historical groundfish landings in Oregon conducted by the Oregon Department of Fish and Wildlife (ODFW) in collaboration with Northwest Fisheries Science Center (NWFSC). A variety of data sources were used in that reconstruction, including Oregon Department of Fish and Wildlife’s Pounds and Value reports derived from the Oregon fish ticket (landing receipt) line data (1969-1989), Fisheries Statistics of the United States (1927-1977), Fisheries Statistics of

Oregon (Cleaver 1951, Smith 1956), Reports of the Technical Sub-Committee of the International Trawl Fishery Committee (now the Canada-U.S. Groundfish Committee) (1942-1975) and many others.

It appears that (unlike Washington) Oregon landings of spiny dogfish sharks in the Fisheries Statistics in the United States were reported as round weights. The footnotes in the Fisheries Statistics of the United States indicate that although most carcasses of spiny dogfish prior to 1956 were discarded at sea, the poundage reported includes the total volume of "grayfish" caught. The Oregon records of spiny dogfish landings in the Fisheries Statistics of the United States were consistent with Bargmann (2009), who provided the total landed catch of spiny dogfish in Oregon as well.

A small portion of spiny dogfish in Oregon was also landed within the Animal Food market category, a portion of various fish that went to feed mink for the fur trade. Prior to World War II, mink food mainly consisted of red meat and when meat became increasingly difficult and expensive to obtain, Oregon mink ranchers started to use fish fillet carcasses as a protein source for mink (Niska 1969). When the demand for fish fillet carcasses exceeded the supply, whole fish were specifically targeted to supplement the carcasses (Niska 1969). Spiny dogfish landings within the Animal Food market category were reconstructed by Karnowski et al. (2011) back to 1942 from Jones and Harry (1961), Niska (1969), reports of the Technical Sub-Committee of the International Trawl Fishery Committee, Fisheries Statistics of the United States and ODFW Pounds and Values reports. Spiny dogfish was reported in the Animal Food between 1942 and 1979, and the estimated values by year were added to bottom trawl landings since Animal Food was landed exclusively by bottom trawl.

2.1.1.1.2.3 California

The time series of California gear-specific landings of spiny dogfish during the most recent "historical" period (between 1969 and 1980) were available from the California Cooperative Groundfish Survey (CalCOM) database.

Earlier landing records (between 1931 and 1968) were reconstructed by the Southwest Fisheries Science Center (SWFSC; Ralston et al. 2010), but as is the case with Washington, these landings were not apportioned to specific gear. To apportion early historical landings among gears, we applied Oregon dogfish gear proportions by year between 1940 and 1968 to California dogfish landings. Between 1931 and 1939, the gear compositions were assumed to be an average of the earliest three years of Oregon gear compositions.

2.1.1.2 Commercial Discard

Spiny dogfish has not been targeted since the end of vitamin A fishery. However, it had been incidentally caught in fisheries for other commercially valuable species. When caught, it is primarily discarded. Recent and historical estimates of discard often reach 98-99% of total catch. A lack of market was identified as the main reason for discarding dogfish (Rogers and Pikitch 1992). Spiny dogfish are generally avoided due to their value and the damage to fishing gear when encountering them.

2.1.1.2.1 Sources of Discard Information on the U.S. West Coast

There are three main sources of discard information for the groundfish fishery. In 2002, 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, trawl fisheries have been managed with catch shares under a system of annual individual fishing quotas (IFQs) for the shoreside sector (i.e., vessels delivering to shoreside processors) and harvest cooperatives for the at-sea hake sectors (catcher-processors who catch and process hake at sea; and Motherships, factory processors that take delivery of hake from catcher vessels at sea). A 100 percent at-sea monitoring of catch using observers and electronic monitoring (EM) is required to participate in the trawl catch share fishery.

There are two studies of discard in the trawl fishery in years prior to the WCGOP, the Enhanced Data Collection Project (EDCP) and the Pikitch study (Pikitch et al. 1988). The EDCP, which was administered by the ODFW, collected bycatch and discard data 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 spiny dogfish was reported within the "Shark" category (no species composition samples were collected). Also, the EDCP primarily focused on the deepwater complex, or "DTS" (Dover sole, thornyheads and sablefish), and since spiny dogfish mostly occur on the shelf, the project estimates of "Shark" discard rates might be not representative of overall trawl discards.

The Pikitch study was conducted between 1985 and 1987 between 48°42' and 42°60' N. latitude, 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. At-sea observers 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 Methods Used to Estimate Discard

To reconstruct historical discard, we followed the method described by Gertseva and Matson (2021) when a bycatch species catch is predicted from the catch of a high attainment target species that bycatch species of often caught with. The process-flow chart describing the method for reconstructing historical removals of bycatch species is shown in Figure 8.

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.

Recent catch information, including discard amount, is available from the WCGOP. The WCGOP collects haul-specific data on all species caught in commercial groundfish fisheries on the West Coast of the United States, in waters off Washington, Oregon and California, which includes discard amounts of groundfish species for observed hauls, along with haul duration, depth, location, gear type, and other details. It also includes records of the intended "target" species of each haul as stated by the vessel captain for the logbook. The WCGOP primarily focuses on the discarded portion of catch, but also collects haul-specific retained catch information. It cooperates with PacFIN to reconcile haul-level retained catch with trip-level fish ticket information in PacFIN and generates year-specific total mortality estimates for each species in commercial groundfish fisheries. These total mortality estimates represent the best available information of fishery removals within groundfish fisheries and are used to evaluate official harvest guidelines.

Based on haul-specific WCGOP data, we identified several target species and complexes with which spiny dogfish has been bycaught. Since multiple species co-occur within the same habitat and are caught together in the demersal groundfish fishery, each intended target (as stated by the vessel captain and reported by WCGOP) includes a combination of individual species. Therefore, we first identified target categories within which spiny dogfish is caught, and then explored the species composition of these target categories, to identify individual species that spiny dogfish is caught with.

Then, using WCGOP total mortality estimates from 2002 forward (without any assumption about discard survival), we screened several of the thus far qualifying targets for meaningful relationships with spiny dogfish catch. Next, we investigated which of the potential predictor stocks had the longest and reliable time series of historical catch records available. We also ensured that historical catch records of predictor species fell within the range of catches used to develop the statistical model to avoid potential extrapolative prediction errors, and that the spatial extent of the fishery for the historical period considered was similar to that of recent fishery data used to develop the statistical model. Finally, we used historical catch time series of predictor species selected to reconstruct historical removals of spiny dogfish using established relationship and estimated prediction intervals around the year species predicted values of spiny dogfish historical catches.

Matrix of scatter plots illustrating relationships in annual total catch (mt), among selected potential target predictor species, from WCGOP data, 2002-2019, are shown in Figure 9. Among potential targets that spiny dogfish is often caught with and whose catch has a meaningful relationship with dogfish catch, only sablefish has a reliable historical catch records. Therefore, the linear model between annual total mortality of sablefish (independent variable) and that of spiny dogfish (dependent variable) ($R^2 = 0.55$) was used to predict spiny dogfish catches over the range of the sablefish catches. This relationship is shown in Figure 10. The residuals of the total catch relationship between sablefish and spiny dogfish from the WCGOP data as well as residuals time series are shown in Figure 11 and Figure 12, resistively; they are unbiased and do not exhibit any obvious pattern.

Sablefish is an important target species that has been consistently targeted since 1950s, and mostly retained; we limited the application of our regression model to the period from 1960 forward, when the sablefish fishery was well established. Catch time series of sablefish were obtained from the most recent stock assessment conducted in 2019 (Haltuch et al. 2019).

Reconstructed time series of spiny dogfish total catch within bottom trawl fleet, based on sablefish catch, with predicted intervals are shown in Figure 13. Total catch includes landings as well as dead and live discards. Therefore, amount of discarded catch (dead and live) can be obtained as the difference between total catch and landings, derived as described above.

To validate the results of the model against available discard observations, we compared the estimated discard rate of spiny dogfish based on the sablefish catch, with observed spiny dogfish discard rate from the Pikitch study (Pikitch et al. 1988). Both sources produced identical rates of 98-99 percent discard for the 1985-1987 period (Figure 14). We also compared the trend in estimated discard rates based on sablefish catches with sharks discard rates observed in the EDCP. Despite the fact that the EDCP reported rates for all sharks combined, and were limited to deeper areas, both sources indicate decrease in discard rates for sharks in the 1990s (Figure 14). The estimated total dead catch of spiny dogfish is also consistent with the history of the groundfish fishery.

For the non-trawl fleet, no target species or species group (including Pacific halibut), with a meaningful relationship with catch of spiny dogfish was found. Since available information suggest that discarding for spiny dogfish within bottom trawl and non-trawl fleets was driven by the same market forces, it is reasonable to assume that the discard rates between bottom trawl and non-trawl fleets were similar. Therefore, we used the discard rate within bottom trawl fishery as a proxy for the discards within the non-trawl fleet.

We first explored applying the annual bottom trawl discard rates to the annual non-trawl landings, which resulted in an implausibly high degree of annual variability among the estimates, with the extreme spikes that exceeded removals during the vitamin A fishery. Therefore, we followed approach developed by Taylor et al (2019) in the big skate assessment, another bycatch elasmobranch species in the Northeast Pacific ocean, when mean discard rate of a proxy species within a specific time period was applied to a mean of landings of a bycatch species within the same time period, to obtain total catch.

The reconstructed non-trawl landings of spiny dogfish for the period had a mean of 70, 75 and 171 mt, respectively. The mean discard rate within bottom trawl fleet in these periods were 95%, 94%, and 60%, respectively. An estimate of the mean annual discard amount can, therefore, be calculated from the mean discard rate and the mean landings. These mean discard amounts (with 50% discard mortality rate applied) were then added to estimated non-trawl landings by year within each of the three time periods (1969-1980, 1981-1990 and 1991-2001). For more details on this approach, please see Taylor et al. (2019). Reconstructed time series of spiny dogfish total catch along with spiny dogfish landings within the non-trawl fleet are shown in Figure 15.

The landings from shore-based midwater fishery available from 1992, the time when U.S. shore-based fishery targeting hake started (Figure 7). No information about catches of spiny dogfish by midwater trawl prior to that was found. There was a widow rockfish midwater trawl on the U.S. West coast since late 1970s (Love et al. 2002), but that fishery was very specifically targeting large concentrations that widow rockfish form at night (Love et al. 2002). Also, Rogers and Pikitch (1992) conducted groundfish assemblages analysis in the mid-1980s and found that widow rockfish assemblage caught by midwater trawl gear was dominated by a single species (widow rockfish); therefore, it is reasonable to assume that possible occasional catches (and discard) of dogfish within that fishery were minimal. Total catch of spiny dogfish within shore-based midwater trawl fishery (which include landings and discard) from 2002 forward was obtained from WCGOP. However, discard within the midwater trawl fishery was not fully observed until 2011. After 2011 (when discard within the midwater trawl fleet was observed), the discard of spiny dogfish was minimal (almost none). Therefore, we chose not to make additional assumptions about discard for the period between 1992 and 2001.

Figure 16 shows the comparison of spiny dogfish catch as used in this assessment along with catch used in 2011 assessment. The catch used in this assessment is consistent to what we know about development of commercial groundfish fishery on the U.S. West Coast. Figure 17 is from Miller et al. (2014) and it illustrates progression of California groundfish landings as groundfish fisheries was developing. Groundfish fishery started earlier in California, but after World War II (period for which we reconstructed dogfish catches), groundfish fishery progressed similarly in all three states along with U.S. west coast (Warlick et al. 2018), and the peak in the 1980s is consistent with estimated total catch of spiny dogfish catch reconstructed as part of this assessment (Figure 16).

2.1.1.2.3 Discard mortality

There are no studies performed on estimating discard mortality of spiny dogfish in the Northeast Pacific Ocean for neither bottom trawl nor non-trawl fleet. Many factors, such as trawl time, handling techniques, and time spent on the deck affect shark survival. In spiny dogfish assessments conducted elsewhere, assumed discard mortality rates ranged from 5% to 50% for bottom trawl and from 6% to 75% for non-trawl gears, but all sources noted considerable uncertainty in these estimates.

In the 2011 assessment, bottom and midwater trawl discard mortality were assumed to be 100%, and non-trawl discard mortality to be 50%. Figure 18 shows spiny dogfish bycatch in an at-sea hake trawl to support the assumption of 100% trawl discard morality. Since no new study of dogfish discard mortality has been conducted since 2011, the same assumptions are made in this assessment. Alternative assumptions regarding discard mortality by gear type were explored in sensitivity analyses (see Section 2.5.1).

2.1.1.3 Bycatch in Pacific Hake Fishery

Annual amounts of spiny dogfish bycatch in the Pacific hake fishery are available from the North Pacific Database Program (NORPAC). That time series covers the period between 1977 and 2020 and include catches removed by foreign and domestic fisheries as well as those obtained during the time of Joint Ventures (JV).

In recent years (1991-2020) virtually 100% of hauls in hake fisheries are sampled for catch and species composition by the at-sea hake observer program (A-SHOP). Total catches (retained and discarded) are estimated for all trawl caught species. Prior to 1991, not every haul was sampled. For these years, NORPAC provides total catches estimated from annual ratios of sampled hauls to total hauls.

2.1.1.4 Recreational catches

Recreational catches contributed a very small amount to overall removals of spiny dogfish (Figure 4). Unlike commercial catches, the vast majority of recreational removals occurred in California (Figure 19). The data on recreational removals of spiny dogfish were obtained from RecFIN (www.recfin.com), a regional database managed by the Pacific States Marine Fisheries Commission (PSMFC) and directly from state agencies. RecFIN reports catches by fishing mode, including shore modes (man-made, beach and bank) and boat modes (party and charter boats, private and rental boats). The majority of spiny dogfish recreational catches came from the boat modes, and all recreational removals in the assessment were combined and reported as one fishery. Recreational catches were reconstructed by state, and the approaches used to derive recreational catches are described below. This year we arrived to the same estimates of recreational catch as used in 2011 assessment (Figure 20).

2.1.1.4.1 Washington

The records of spiny dogfish recreational catches in the coastal waters of Washington go back to 1980. No mention of a coastal recreational harvest of dogfish was found prior to that (Gregory Lippert, WDFW, pers. com.). Dogfish are encountered sporadically in the ocean fisheries, and are almost always released (96% average release rate). The total estimated removals have been minimal (on average 0.4 mt per year since 1980). Information on recreational catches has been collected by both state (WDFW Ocean Sampling Program (OSP)) and federal (Marine Recreational Fisheries Statistic Survey (MRFSS)) programs. From 1980-2003 (excluding the years 1990-1992), the MRFSS program provided effort information from a random-digit dialing protocol and catch/trip information from intercept interviews. OSP has estimated total ocean recreational catch and effort by boat type, port and catch area since the 1960s (with the spiny dogfish information available since 1990). Boat trip sampling is conducted randomly by OSP to generate catch estimates for most ocean-caught species, including sharks. The OSP reports removals of spiny dogfish within the “Shark/Skate” catch category, but anecdotal evidence suggests that the majority of this category is comprised of spiny dogfish (with a small number of blue and sixgill sharks and skates). Since 2002 release data on all marine fish by species have also been estimated within OSP from angler interviews.

MRFSS data were obtained via the RecFIN database and OSP data were received directly from WDFW (Wendy Beeghley, pers. com.). From 1995 to present, the RecFIN database contains catch estimates generated by the OSP while prior to 1995 mostly MRFSS-generated catch estimates were available. WDFW expressed several concerns with MRFSS dogfish data. Particularly, between 1980 and 1986 and in 1989, MRFSS focused on bottom fish effort alone (and not on salmon effort), and dogfish caught and released by salmon anglers were not included in the estimate of recreational removals. Between 1995 and 2003, even though all anglers were interviewed, there have been concerns with the allocation of sampling effort between the coast and the Puget Sound. Therefore, we used data collected by OSP where possible (1990-2010) and MRFSS data when OSP data were not available (1980-1989).

To estimate the proportion of spiny dogfish within the OSP “Shark/Skate” category, we compared MRFSS removals of spiny dogfish relative to removals of other sharks and skates. We found that no other sharks and skates were reported by MRFSS, and, therefore, assumed removals of OSP “Shark/Skate” to be entirely comprised of spiny dogfish removals.

To estimate the amount of released fish in OSP data for the 1990-2001 period (prior to when OSP started to sample released catch), we calculated an average release rate from OSP data for 2002-2010 period and applied this rate to the 1990-2001 retained catch data. Finally, to estimate the proportion of dead discard in OSP data on released catch (this type of information has never been collected by OSP), we applied the ratio of dead discard to total discard from MRFSS to the entire OSP data series (1990-2020).

2.1.1.4.2 Oregon

The records of Oregon recreational catch of spiny dogfish go back to 1979, and reported removals were minimal through the entire time series (with the average of 0.1 mt). The information on Oregon recreational catches was collected by the Oregon Ocean Recreational Boat Survey (ORBS) (1979- present) and by the federal MRFSS program (between 1980 and 2003, excluding the years 1990-1992).

The MRFSS data and the most recent ORBS data (2004 forward) were obtained via the RecFIN database. The early ORBS data (1979-2000) were provided by ODFW (Mark Freeman, pers. com.), but these early data included only the number of fish landed, neither discard nor average fish weights were reported. RecFIN provides data on the total amount of fish landed (catch type A) as well as dead (catch type B1) and alive (catch type B2) discard. No dead discard was reported for spiny dogfish (but there were records of alive discard); therefore Oregon recreation removals were equal to type A catch.

In the assessment, we used ORBS data (received from ODFW) for the period between 1979 and 2000 and the data from RecFIN for the period between 2001 and 2020. Since ORBS catch data reported the number of fish retained, we converted these numbers into weight using average fish weight from RecFIN to estimate the time series of Oregon removals in metric tons by year.

2.1.1.4.3 California

California catches comprised the largest portion of spiny dogfish recreation removal with an average of 18 mt by year since 1981. Information on recreational catches has been collected by both the California Recreational Fisheries Survey (CRFS) and federal MRFSS programs. MRFSS program ended in 2003. In 2004, the California Department of Fish and Wildlife (CDFW), in cooperation with the Pacific States Marine Fisheries Commission (PSMFC), started the California Recreational Fisheries Survey (CRFS) program to replace the MRFSS sampling program in California. This program aims to increase sampling effort for better catch and effort estimation, to increase spatial resolution of catches, and to identify targeted species.

The data from both programs are available via the RecFIN database, and these data were used to reconstruct time series of California recreational dogfish removals (retained catch plus dead discard, A+B1). Removal in 1980 (93 mt) was found to be much higher than catches in other years. The RecFIN removals for other species in the 1980 were also found to be higher than those in other years. Anecdotal evidence suggests that effort during 1980, the first year of the MRFSS program, was likely poorly estimated, and therefore, the 1980 data point was excluded from the California time series of recreation catches. The average value of 1989 and 1993 was used for 1990-1992, the years when MRFSS data were not available.

Limited information on historical (prior to 1980) recreation catches in California is available from annual reports from the Commercial Passenger Fishing Vessel (CPFV) sampling program, but none of those contained records of spiny dogfish catches.

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 spiny dogfish 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 3. The hook-and-line survey was conducted by the International Pacific Halibut Commission (IPHC).

2.1.2.1 Bottom Trawl Surveys

2.1.2.1.1 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 using the same protocols). Survey methods are most recently described in Weinberg et al. (2002). The basic design was a series of equally spaced transects from which searches for tows in a specific depth range were initiated. Over the years, survey area varied in depth and latitudinal range (Table 3). 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 four INPFC areas covered by the earlier years, but also part of the Conception area with a southern border of 34°50' N. For all years, except 1977, the shallower surveyed depth was 55 m (30 fm); in 1977 no tows were conducted shallower than 91 m (50 fm). Because of the differences in depth surveyed in 1977 and the large number of "water hauls", when the trawl footrope failed to maintain contact with the bottom (Zimmermann et al. 2001) the data from the 1977 survey were not used in the assessment. The tows conducted in Canadian and Mexican waters were also excluded.

In the assessment, separate catchability coefficients (q) were estimated for the Triennial Survey for the period between 1980 and 1992, and between 1995 and 2004. This was done to account for differences in spatial coverage before and after 1995 (Table 4) and to reflect a change in the timing of the survey. In its early years, the survey was conducted from mid-summer to early fall, but from 1995 on, the survey began at least a full month earlier (Figure 21).

2.1.2.1.2 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 4). 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).

2.1.2.1.3 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, and consistently covered depths from 100 to 700 fm (183-1280 m) (Table 3).

2.1.2.1.4 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 2019 were used in the 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 4). 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).

2.1.2.2 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).

Gamma and lognormal error structures were considered for the positive catch rates, and the lognormal model was chosen. The VAST estimates with Gamma error showed large changes in abundance throughout the survey time series, most notably for the 2019 WCGBT Survey, when abundance of spiny dogfish was estimated to be increased more than five times from 2018

(Figure 34), Such pattern is not consistent with what is known about the dynamics of K-strategy organisms, such as spiny dogfish. Such fish exhibit slow growth, late maturation, a long gestation period and low fecundity, and most likely reflects patchiness in the spatial distribution of spiny dogfish.

The spiny dogfish often forms large schools, and extreme variation in density of fish (among hauls) often occurs, when survey can encounter either a large school, only diffusely scattered individuals, or none at all ("zero tows"). Figure 22 and Figure 23 show density of spiny dogfish within the WCGBT Survey relative to the distribution of all hauls for all years of combined and by year. The average amount of spiny dogfish in a positive haul was 45 kg, and 95% of positive hauls were less than 85 kg. However, a few hauls had between 4,000 and 16,585 kg of dogfish, and the estimates for survey index with gamma error structure in years with those large hauls are the highest (Figure 34). This indicates that the gamma model within the VAST cannot adequately describe the abundance of schooling fish such as spiny dogfish.

This pattern of unrealistically large changes in abundance from you to year is not present in indices with lognormal error structure, and the lognormal model is able to account for outliers (such as extreme catch events) more efficiently, and the lognormal model was chosen while generating abundance indices for bottom trawl surveys.

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.

Quantile-quantile (Q-Q) diagnostic plots for four bottom trawl surveys are shown in Figure 24 through Figure 27. The Q-Q plots are 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. Examination of spatial patterns of the residuals for the encounter probability and catch rate for each of the indices showed no obvious pattern of misfit to spatial patterns in the observed data.

Estimated biomass indices for the bottom trawl surveys are shown in Figure 28 through Figure 31 and provided in Table 4. The VAST estimates were also compared with indices used in 2011 assessment. The scale of estimated indices are similar among methods; 2011 assessment indices exhibit greater inter-annual variability as well as uncertainty in estimates (Figure 32 through Figure 35).

2.1.2.3 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 spiny dogfish catches by year within the IPHC is shown in Figure 36. The IPHC 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 spiny dogfish 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 37 and provided in Table 4; the index trend has been slightly declining over the last ten years, with the lowest estimate in 2019.

Figure 38 shows standardized indices from all surveys used in the assessment overlaid.

2.1.3 Biological compositions

2.1.3.1 Measurement Details and Conversion Factors

In the assessment, size of spiny dogfish was included as total natural length (LTnat), from the tip of the snout to the tip of the tail with the tail in the natural position. Size measurements of spiny dogfish are not always total-length measurements, and some size measurements in the data are recorded as either fork length (LF), from the tip of the snout to the deepest point of the fork between the caudal lobes, and pre-caudal length (LPC), from the tip of the snout to dorsal pre-caudal notch. When size was reported not as total natural length conversion factors were applied as estimated and reported in Tribuzio and Kruse (2012).

2.1.3.2 Fishery-Dependent Biological Compositions

Length information for commercial landings was extracted from PacFIN (on March 5, 2021). Commercial discard length composition information was obtained from WCGOP. The biological data from the Pacific hake fishery collected by the A-SHOP were available through NORPAC. Recreational fishery data were obtained via the RecFIN and also directly from state agencies. Age data (multiple measurement of dorsal spines) was obtained directly from WDFW.

2.1.3.3 Length Compositions

2.1.3.3.1 Length Compositions of Landings

The summary of sampling efforts by fleet, state and year which were used to generate length frequency distributions for commercial landings are shown in Table 5. We used only randomly collected samples. Majority of length samples in Oregon and California were of total natural length and in Washington of fork length (and therefore were converted to total natural length in the assessment). Vast majority of the length data were reported for females and males separately, and sex-specific compositions were used in the assessment.

Visual representation of sampling effort by state is provided in Figure 39. Majority of the length samples from landed catch over the years were collected in Washington, since the vast majority of spiny dogfish landings were made in Washington as well. In recent years the contribution of samples taken from Oregon increased. Sampling effort by gear is shown in Figure 40. Despite the fact that most spiny dogfish over the years have been taken by trawl gear, the size compositions samples are minimal, most likely because the majority of the catch (up to 99%) in bottom trawl fishery is discarded. Non-trawl samples are also not very abundant, especially in most recent years, also most likely because not much catch has been landed. It is evident that the contribution of midwater trawl shore-based samples (these do not include samples taken within at-sea hake fishery) grew over the years, which is consistent with the increase in dogfish midwater trawl landings discussed earlier.

The data were compiled into 31 length bins, ranging from 12 to 132 cm, with 4-cm bin width. The observed length composition data were expanded, to account for non-proportional sampling of spiny dogfish among trips and states. The fishery length frequency distributions of spiny dogfish (generated as described above) by year are shown in Figure 41 and Figure 42.

The initial input sample sizes (N_{input}) for length frequency distributions by year were calculated as a function of the number of trips and number of fish via the Stewart Method (Stewart 2019):

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

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

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

Limited recreational size composition samples were available for both sexes combined, and number of fish were used as initial sample size by year.

2.1.3.3.2 Length Compositions of Discard

Length frequency distributions of spiny dogfish that were discarded at sea were obtained from the WCGOP for the period between 2006 and 2019. The summary of sampling efforts by fleet and year which were used to generate length frequency distributions for commercial landings are shown in Table 5. Discard in both trawl and non-trawl fleets were well sampled. The fish were measured in total natural length. The discard length composition data were expanded, to account for non-proportional sampling of spiny dogfish among hauls and trips. The number of trips were used as initial sample size by year. The length frequency distributions of spiny dogfish discard by year are shown in Figure 41 and Figure 42.

2.1.3.3.3 Length Compositions of Bycatch within at-sea Hake Fishery

The length composition data for spiny dogfish bycatch within at-sea hake fishery was available from NORPAC. The summary of sampling efforts by year within this fleet are shown in Table 5. Length frequency distributions generated using these data are shown in Figure 41.

2.1.3.3.4 Length Compositions of Recreational Catch

The length composition data for spiny dogfish caught by recreational fishery were obtained directly from state agencies and from RecFIN. Most samples were from California, which is consistent with majority of recreational catches (Figure 19). The summary of sampling efforts by fleet and year which were used to generate length frequency distributions for recreational catch are shown in Table 5. Length frequency distributions generated using these data are shown in Figure 42.

2.1.3.4 Survey Biological Composition

2.1.3.4.1 Length Compositions

Length frequency distributions were derived by year for four out of five surveys (for which data were available). A summary of sampling efforts by survey and year used to generate length frequency distributions are shown in Table 6. Most biological data for spiny dogfish was reported by sex, expect for the 1998 AFSC Slope Survey, and therefore compositions were also developed for females and males separately.

Lengths in WCGBT Survey as well 2001 and 2004 Triennial Surveys were collected as total length. In AFSC Slope Survey and 1998 Triennial Survey length were measured as folk lengths, and thus were converted to total lengths. In IPHC Survey, the samples were measured as pre-caudal length (LPC), and were also converted using Tribuzio and Kruse (2012).

As in case of fishery lengths, survey length composition data were compiled into 31 length bins, ranging from 12 to 132 cm, with 4-cm bin width. The observed length compositions from the bottom trawl surveys were expanded, to account for differences in catches among hauls and different spatial strata. For WCGBT Survey and AFSC Triennial Survey, we used a spatio-temporal approach to estimating compositional data (Thorson and Haltuch 2018) that was demonstrated to improve precision while remaining unbiased. This approach is implemented in R package VAST (www.github.com/James-Thorson/VAST), which has been routinely used for index-standardization in stock assessments in the Pacific and North Pacific fisheries management regions. We used lognormal error structure to construct length compositions, as it is able to handle outliers (extreme catch events) better, producing more biologically reasonable results. For AFSC Slope Survey the length samples were not sufficient to construct compositions using a spatio-temporal approach, therefore, we used a design based approach, commonly used in the groundfish assessment on the U.S. west coast, to expand length composition data and account for difference sin catches among hauls and strata. For this purpose, strata were defined by state, and depth (with depth breaks at 183 and 549 meters). 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). For the IPHC Survey only a limited amount of data were available; the number of fish were used for initial sample sizes.

The length frequency distributions of spiny dogfish by survey and year are shown in Figure 42 and Figure 43.

2.1.3.4.2 Age Compositions

Age composition data was available for 2010 WCGBT Survey.

Ageing spiny dogfish shark continues to be a challenge. Unlike teleost fish, dogfish lacks hard structures commonly used for age determination (Ketchen 1975, Gallagher and Nolan 1999), and the traditional method of estimating the age of dogfish has been to count the growth bands visible on the surface of their second dorsal fin spine (Ketchen 1975, Beamish and McFarlane 1987). These bands are deposited annually, as validated using recaptures of tagged dogfish injected with oxytetracycline (McFarlane and Beamish 1987), and bomb radiocarbon studies (Campana et al. 2006, MacFarlane and King 2009).

The dorsal spines are subject to breakage and natural wear, when bands on the distal tip of the spine become indistinguishable. Two methods have been proposed to account for these lost annuli, that involve statistical extrapolation based on several measurements of a spine (Figure 45). The first method was proposed by Ketchen in 1975. Ketchen (1975) assumes that the relationship between spine diameter at the least readable point and the number of missing ages can be approximated by an exponential relationship between the base diameter and number of ages counted on the spines of younger dogfish that were determined to be unworn. The other method has been proposed by Cheng (2012). This approach assumes that the spine diameter grows according to a von Bertalanffy growth curve (von Bertalanffy, 1938) and estimates the number of missing ages as a random effect in a nonlinear mixed effects model fit to three diameter measurements along the unworn part of the dorsal spine.

Taylor et al. (2013) evaluated both methods, and concluded that Ketchen method performs superior to Cheng method. Taylor et al. (2013) also found that for either age extrapolation method, female length-at-age data also do not appear to follow the von Bertalanffy function well. Larger females form an odd cloud shape of length at age estimates that do not fit into the growth curve (Figure 44), implying that ages of larger individuals might be underestimated by both methods, with the degree of age underestimation increasing with age in the larger females. It is notable that the cloud of aberrant points for both methods lies largely beyond the 80 cm estimated length at which 50 percent of female spiny dogfish shark are mature (Taylor and Gallucci, 2009).

Taylor et al (2013) explained this peculiar pattern in female length at age data by a change in spine allometry related to female reproduction. A physiological explanation for such a change is that during pregnancy, materials needed for spine growth are also used for production of developing embryos (and their egg cases, made of similar material as spines), and thus maternal spine growth is temporarily retarded, due to re-allocation of resources to build egg cases for the young. A similar phenomenon is seen in humans, where maternal bone density diminishes during pregnancy, and its extent is highly correlated with baby birth weight (Yoneyama and Ikeda, 2000). A reduction in the rate of spine growth during pregnancy would translate into a population level average reduction in band width following the age of maturity, which could produce the pattern observed in female length at age data (Figure 46). Therefore, the relationship between spine diameter and the number of missing ages derived from unworn female spines, which were collected from immature individuals, might not be applicable for mature females. Following this conclusion, in the model, we limited female age data to individuals not exceeding 80 cm in lengths and used a full range of male age data from the WCGBT Survey.

Age composition data were assembled into 72 age bins, ranging from age 0 to age 71 and compiled in the model as conditional distributions of ages at length (Figure 47). 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 initial sample sizes for conditional ages-at-length data were the actual numbers of fish on which each composition is based.

2.1.4 Data Sources Considered but Not Used

2.1.4.1 Individual Mean Weight from Discard Fleets

Mean weight of discarded fish is routinely provided by WCGOP for groundfish assessments. This source of data gives an idea of how the mean individual weight of discarded fish changes over the years. This source of information is somewhat redundant when length composition data from discarded catch is also available. In the case of spiny dogfish, discard fleet length composition is well sampled (since a substantial amount of catch is discarded), and we chose to rely on individual samples of lengths and not to include a cumulative measure of individual weight by year.

In a number of initial runs, we evaluated the fit to mean weight of discarded fish and confirmed that the model was able to track mean weight very well. Also, evaluation of these data sources showed that it is consistent with discard rates when larger mean weight corresponding to higher discard rates between 2002 and 2005, the mean weight also increased, which is expected.

Likelihood profiles for models with mean weight included showed that this data type was having a disproportionately large influence on quantities of interest. Excluding mean weight allowed the model to instead be more influenced by the data sources, which are expected to be more informative about stock dynamics: indices, length compositions, and age compositions.

2.1.4.2 Age Data from Commercial Fleets

In the assessment, we used age data collected from the WCGBT Survey. Age data was also available from the fishery, and it was evaluated for using in the assessment to estimate growth. These fishery age data are shown in Figure 48. These data in addition to being very noisy, did not include smaller organisms needed to estimate shape of the growth curve and von Bertalanffy coefficient k.

We explored estimating growth parameters using all age data available (and not only survey data), which resulted in flatter growth curves estimated (with lower von Bertalanffy growth coefficient and larger asymptotic lengths). Models with these data also produced multiple convergence warnings, likely because they had troubles reconciling very noisy age data.

2.1.5 Biological Parameters

Several biological parameters used in the assessment were fixed at the externally estimated values, which were either derived from the available data or obtained from published sources. The data and approaches used to estimate biological parameters (fixed in the model) are described below.

2.1.5.1 Natural Mortality

Attempts to estimate natural mortality indicated there was no information in the model to do so, so this parameter was fixed in the reference model. Since the maximum age of females is uncertain, natural mortality in the model was fixed in the assessment at the value of 0.065 yr^{-1}, estimated by Smith et al. (1998) based on a demographic analysis of 26 shark species including Pacific spiny dogfish. The same value was assumed for both sexes and a variety of sensitivities were run to explore alternative assumptions about natural mortality.

2.1.5.2 Maturity and Fecundity

The relationship between female size and maturity was taken from recently published work (Taylor and Gallucci 2009), based on 499 fish collected in Puget Sound in the 2000s. The logistic function used was:

$$M\% = \frac{1}{1 + e^{\beta(L - L50\%)}}$$

Where $M\%$ is the proportion of mature females in the stock, β= -0.27 is a parameter controlling the rate of increase in maturity and $L50\%$ = 88.2 cm is the length at 50% maturity.

The fecundity of mature fish was also set equal to values from Taylor and Gallucci (2009), which were calculated from 106 pregnant fish from the maturity study for which counts of embryos were available (Figure 57). A linear relationship between female length (L) and fecundity (expressed in number of pups) was assumed:

$$Pups = \alpha + \beta L$$

with estimated parameters α = -14.7 and β = 0.214. This relationship results in an increase from 0 pups at the size of 66 cm (when maturity is less than 0.3%) to about 7 pups per litter at 100 cm (when maturity is 97%) and about 15 pups per litter at the largest size of 136 cm. Since gestation period of spiny dogfish last for 2 years (22-24 months), half of all mature females were assumed to have pups in any given years and the estimated fecundity parameters were divided by 2, resulting in α = -7.35 and β = 0.107, which were used in the assessment.

2.1.5.3 Length-Weight Relationships

Weight-at-length data collected from fisheries sampling and by the WCGBT Survey were used to estimate a length-weight relationship for spiny dogfish. 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. Based on the length and weight observations from 4243 females and 5142 males, the parameters α were estimated as $2.2602 \cdot 10^{-6}$ for females and $3.6138 \cdot 10^{-6}$ and for males, and the parameters β as 3.155 for females and 3.026 for males (Figure 49).

2.1.5.4 Ageing Error

Due to uncertainty in ageing process of spiny dogfish, and also uncertainty whether this assessment would be able to incorporate age data, no new double readings were produced compared to the 2011 assessment. Therefore, we retained the same ageing error matrix as estimated within the 2011 assessment, using double readings of 98 dogfish spines produced by WDFW, which included repeated counts of annuli and repeated measurements of spine diameter. Based on those double reads, ageing error matrix was estimated using the approach of Punt et al. (2008).

This ageing error provided estimates of the standard deviation in estimated age as a function of true age. The estimates were standard deviations of less than 1 year for ages 0-9, increasing smoothly to 2 years at age 19, 5 years at age 38, and 10 years at age 52, and reaching 20 years at age 63, which was the oldest estimated age in the double-read dataset. To satisfy the Stock Synthesis requirement of inputs for standard deviation at age for all ages in the modeled population, a simplifying assumption was made that this value was 20 years for all ages beyond 63 (Figure 50).

2.2 Model

The tables and figures in the Executive Summary of this report represent the model selected for the middle state of nature (with WCGBT Survey q = 0.43), while the main document details the base model (with WCGBT Survey q = 0.586) that is used as low state of nature in the Decision Table.

2.2.1 Previous Assessments

Spiny dogfish stock on the West Coast of the United States has been assessed once before, in 2011 (Gertseva and Taylor 2012). The assessment used the earlier version of Stock Synthesis modelling framework (version 3.21e).

It was a coastwide model. The modeling period started in 1916, assuming an unfished equilibrium prior to that. Fishery removals were divided among 8 fleets (6 catch and 2 discard fleets), and the time series of landings and discard were reconstructed outside the model. Size based selectivity was estimated for fleets with available length compositions data, and asymptotic selectivity was assumed for bottom trawl and non-trawl landings and discard fleets, as well as WCGBT Survey. No sex offset in selectivity parameters was used.

It was a sex-specific model. Females and males had separate growth curves and sex-specific weight-at-length parameters. Age data was not used in the model, due to uncertainty in ageing methods, and growth parameters were fixed at values estimated outside the model. The model assumed a constant natural mortality of 0.064 yr-1 for both sexes. The stock-recruitment relationship was based on three parameter spawner-recruit curve (Taylor et al. 2013) with log(R0) estimated within the model.

The assessment estimated depletion of the stock in 2011 to be at 63 percent of its unfished level. The 2011 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 51). Major changes made are described in Section 2.2.3.1.

2.2.2 Responses to 2011 STAR Panel Recommendations

The STAR panel report from the last (and the only) full assessment (conducted in 2011) identified a number of recommendations for the next assessment. Below, we list the 2011 STAR panel recommendations and explain how these recommendations were taken into account in this assessment.

Prioritized recommendations for future research and data collection:

1. *Improve age estimates and aging methods.*

Taylor et al. (2019) conducted and published a thorough examination of the existing methods for statistical extrapolation of annuli beyond "no wear point" on the spiny dogfish second dorsal spine, which is commonly used for shark ageing. The study concluded that the Ketchen (1975) method performs better than Cheng (2012) method, but neither method is able to produce reasonable estimates for large mature females, due to a change in spine allometry related to female reproduction. Following findings of Taylor et al (2013), in this assessment, we used male age data collected within the WCGBT Survey but limited female age data to mostly immature females (lengths of 80 and smaller). With this approach and having selectivity of non-trawl landings fleet (that contains the largest organisms) assumed asymptotic, we were able to fully estimate growth with the model, and the estimates are consistent with published estimates for the same species elsewhere. Further investigation of ageing methods for dogfish is needed to allow for reliable estimation of ages for large mature females.

2. *Examine the uncertainties regarding the catch data and discard mortalities. In particular bycatch estimations are very important, given that they are larger than the recorded landings over recent years.*

In this assessment, we used the approach described by Gertseva and Matson (2021) to reconstruct spiny dogfish bycatch based on the historical catch of an important target species. For the bottom trawl fleet, sablefish was used as a predictor species, and the estimates produced are consistent with limited discard information available and what we know about the history of groundfish fishery on the U.S. West Coast.

3. *Research on dogfish movement. This would be informative not only in providing a better definition of the unit stock, but also aid addressing # 4 (below)*

No new large scale movement study across the range of spiny dogfish distribution has been conducted.

4. *Linkage with fish on Canadian side of the border and exploration of a joint assessment process for this stock*

The exploration of linkage of spiny dogfish shark in the waters off the U.S. West Coast with B.C. waters is ongoing. Currently the large scale project (led by Canadian colleagues) is being pursued to look at coastwide (California to Alaska) dynamics of spiny dogfish combining the all available indices using geostatistical modeling while empirically accounting for inter-survey calibration.

5. *Continuation of the commercial catch and bycatch sampling*

Sampling did continue of both landed and discarded portion of the catch, and these new data was included in this assessment. The newly accumulated data allowed to estimate sex-specific selectivity for each fleet and estimate growth within the assessment model.

6. *Examination of catchability priors in the New Base model as well as a method for deriving future priors*

Further work on the WCGBT Survey prior was done as a part of other elasmobranch assessments (longnose and big skates). In this assessment, the base model was able to estimate reasonable WCGBT Survey catchability value (0.586), which is consistent with what we know about latitudinal, vertical, depth and habitat availability of the dogfish in the survey area as well as its behavior on the path of the net.

7. *Examination of the Beverton-Holt derivation, as it relates to dogfish, and comparison with new stock-recruitment model used in this report.*

This was done and published in the journal Fishery Research (Taylor et al. 2013). In this assessment, we continue to use the pre-recruit based survival model.

2.2.3 Model Description

2.2.3.1 Changes Made From the Last Assessment

The last full assessment of Spiny dogfish was conducted in 2011. The 2011 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 2011 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 3.30.16 (released in September 2020).
   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) Updated historical discard estimates.
   Rationale: Very limited information is available about spiny dogfish historical discards. For this assessment, we had almost 20 years of observer data that we used to develop a relationship between catch of spiny dogfish and a target species (sablefish). The results of this reconstruction are consistent with available historical estimates of discard rates for spiny dogfish, and history of groundfish fishery on the U.S. west coast. The methods for this reconstruction are described in Section 2.1.1.2.2.

3) 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.

4) Included new length composition data from fishery-dependent and fishery-independent sources, accumulated since the 2011 assessment.

Rationale: Additional data have been collected from the commercial fishery and survey since the last assessment.

5) Updated selectivity assumptions. In this assessment, we estimated dome-shaped selectivity curves for several fleets that were fixed asymptotic in the 2011 assessment. We also estimated additional selectivity parameters to estimate a sex-specific offset to selectivity in each fleet.
   Rationale: To achieve better fit to length composition data and account for sex-specific habitat preferences observed for this species.

6) Included age data and estimated growth parameters.
   Rationale: 2011 assessment did not have any age data included. Following findings of Taylor et al. (2013), we included WCGBT Survey ages and use those to estimate growth parameters in the assessment.

7) Updated biology parameters.
   Rationale: Based on new data and information, weight-length parameters were re-estimated, natural mortality slightly changed and fecundity parameters updated, to account for 2-year gestation period. These updated fecundity parameters were explored as sensitivity in 2011 assessment (and did not make a substantial difference in the model results). However, in this assessment, together with all the other data collected over the last ten years, these parameters contribute to a more depleted state of the stock than in the 2011 assessment.

The list above documents only the most important changes made to this assessment relative to the previous one. In both 2011 and the current assessment, the population sharply declined during the Vitamin A fishery in the 1940s and continued to slowly decline after that. The current assessment estimates lower initial spawning output and lower depletion. We conducted a thorough bridging analysis, to identify reasons behind the changes. The results of bridging analysis are shown in Figure 51 through Figure 54, and parameters and management quantities associated with each of the runs are provided in Table 7.

Table 7 indicates that with addition of every data component, the estimate of WCGBT Survey catchability varies substantially (from 3% to 62%), and this change causes the change in estimated scale of the stock and its spawning depletion. To explore how informative data in the model is about this parameter we conducted the profile over catchability of the WCGBT Survey (q); the results are shown in Figure 129. The index data are best fit at the higher log(q) while the length data are best fit at the lower log(q). However, the difference in likelihood over a wide range of log(q) values is within 1.92 units, indicating that the model has little information for this parameter, which explains changes in estimated value of this parameters with changes in model data or parameters. In the base model, the WCGBT Survey catchability is estimated to be 0.586. This value is consistent with what we know about latitudinal, vertical and depth availability of the species in the surveyed area and also with what we know about species behavior of the way of the net path.

2.2.3.2 Model Specifications

This assessment uses the Stock Synthesis modeling framework (Methot and Wetzel 2013), version 3.30.16, released in September 2020. This version includes many improvements in the output statistics for producing assessment results and several corrections to versions used previously.

The assessment focuses on coastal waters of the United States west coast, off Washington, Oregon and California, bounded by the U.S.-Canadian border on the north and U.S.-Mexican border on the south. The assessment area does not include Puget Sound or any other inland waters. The spiny dogfish population within this area is treated as a single coastwide stock, given the migratory nature of the species and the lack of data suggesting the presence of multiple stocks.

The stock included in this assessment very likely has interaction and overlap with spiny dogfish observed off British Columbia. A spatial population dynamics model (Taylor 2008), which included data from a tagging study in the 1940s and from much larger tagging experiments conducted in Canada and inside U.S. waters of Puget Sound, estimated movement rates of about 5% per year between the U.S. coastal sub-population of dogfish and that found along the west coast of Vancouver Island in Canada. Given this relatively low estimated rate of exchange, it was considered appropriate to proceed with the assessment for the limited area of species range, recognizing that the scope of this assessment does not capture all of the removals and dynamics which very likely bear on the status and trends of the larger, transboundary population.

The modeling period begins in 1916, and assume the stock prior to that is assumed to be in an unfished equilibrium condition. Fishery removals are divided among 8 fleets (6 catch and 2 discard fleets). These fleets are: 1) Bottom trawl landings, 2) Bottom trawl discard, 2) Midwater trawl catches, 4) Bycatch in at-sea Pacific hake fishery, 5) Non-trawl landings, 6) Non-trawl discard, 7) Non-trawl catches within historical Vitamin A fishery, and 8) Recreational removals. The time series of catches for each fleet were reconstructed outside the model. For each fleet, selectivity curves were estimated based on available length compositions, except for non-trawl catch within historical Vitamin A fishery, which selectivity was assumed equal to that of non-trawl discard. Since discard in included in the model as separate fleets, no retention curves were estimated in the model.

The model uses five indices of abundance (four from bottom trawl surveys and one longline survey) that provide relative measures of abundance, as modified by index-specific selectivity. Selectivity curve is estimated for each survey except for NWFSC Slope Survey, for which length composition data was not available. NWFSC Slope Survey selectivity was assumed equal to that of AFSC Slope Survey that had the same spatial coverage as NWFSC Slope Survey.

This is a sex-specific model. The sex-ratio at birth is assumed to be 1:1. Females and males have separate growth curves (fully estimated within the model) and sex-specific weight-at-length parameters. The model assumes a constant natural mortality of 0.065 yr^{-1} for both sexes. The length frequency distributions are represented as thirty one 4-cm bins ranging between 12 and 132 cm. Length is expressed as total natural length measured without extending the fish tail.

Population length bins are defined at a finer 2-cm scale, ranging between 10 and 136 cm. Age data collected with WCGBT Survey included as conditional age-at length compositions with 72 bins ranging between 0 and 71 years.

Recruitment dynamics are assumed to be governed by pre-recruit survival based stock-recruit function (Taylor et al. 2013), that allows explicit modeling of pre-recruit survival between the stage during which embryos can be counted in pregnant females to their recruitment as age 0 dogfish. The recruits were taken deterministically from the stock-recruit curve since the relatively large size of dogfish pups at birth (20-30cm) suggest that variability in recruitment would be lower than for a species with a larval stage, which is subject to higher mortality rates.

2.2.3.3 Data Weighting

The Francis data weighting method (Francis 2011), as implemented in the r4ss package was used to achieve consistency between the input sample sizes and the effective sample sizes in composition data and to reduce the potential for particular data sources to have a disproportionate effect on total model fit. This method is based on adjusting the input sample sizes to make the variability in mean length or age around the model expectation match the variability expected based on the adjusted input sample size. The exception was age composition data, where only a single year of data was available and the Francis method could not be used. Therefore, the sample size for age data was tuned using the McAllister-Ianelli harmonic mean method (McAllister and Ianelli 1997).

We also explored the use of new model-based estimates of effective sample size using the Dirichlet-multinomial distribution (Thorson et al. 2017), but encountered model convergence issues. Sensitivity analyses to using only McAllister-Ianelli tuning method and a Dirichlet-Multinomial approach were also explored.

The weight given to the indices of abundance was adjusted 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.

2.2.3.4 Model Parameters

A list of all parameters used in the assessment is provided in Table 8. 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 2.1.5. Here, we discuss parameters estimated within the model.

2.2.3.4.1 Growth

The von Bertalanffy growth function (von Bertalanffy 1938) was used to model the relationship between length and age in spiny dogfish. This is the most widely applied somatic growth model in fisheries (Haddon 2001), and has been commonly used to model growth in spiny dogfish (Vega 2009, Tribuzio 2010).

The growth was fully estimated in the assessment. The estimated parameters included length at an initial reference age (set to age 0 for spiny dogfish), the asymptotic length where growth ceases (L_∞), growth coefficient (k) and standard deviations associated with initial and asymptotic sizes. The male growth parameters were estimated as offset from the female parameters, an approach used in multiple assessments. The offset for male length at age 0 was fixed at 0 under the assumption that pups of both sexes are equal in size.

The estimated growth parameters are consistent with other growth studies conducted on spiny dogfish in the Northeast Pacific Ocean, with females growing a bit slower but reaching larger sizes than males.

Models that had dome-shaped selectivity for all fleets did not have reasonable estimates for female L_∞. However, setting the selectivity for non-trawl landings and the IPHC Survey as asymptotic in the base model (as discussed under Selectivity Parameters below) allowed that parameter to be well estimated.

2.2.3.4.2 Stock -Recruitment Function

The fecundity of dogfish in the Northeast Pacific Ocean has been well studied (Ketchen 1972, Tribuzio 2004, Taylor and Gallucci 2009), with pregnant females having relatively few pups per litter, and with relatively little variability between individuals. Unlike fish producing millions of eggs, the low fecundity of dogfish suggests both low productivity in general and a more direct connection between spawning output and recruitment than for many species.

The spawner-recruit relationship was modeled using a new functional form that was recently added to SS, which allowed a more explicit modeling of pre-recruit survival between the stage during which embryos can be counted in pregnant females to their recruitment as age 0 dogfish (Richard Methot and Mark Maunder, pers.com.). This new method may be useful for a variety of low fecund species, as well as providing additional flexibility in the spawner-recruit relationship that may be explored for any stock. The method is an expansion and improvement on similar approaches previously applied to dogfish (Wood et al. 1979, Taylor 2008), which assumed a linear decline in age 0 survival as a function of population density.

The survival of pre-recruit dogfish at equilibrium is calculated as:

$$S_0 = \frac{R_0}{B_0}$$

Where R_0 is the recruitment at equilibrium, resulting from the exponential of the estimated $\log(R_0)$ parameter, and B_0 is the equilibrium spawning output (in units of number of embryos), calculated by projecting the numbers at age forward under natural mortality, starting with R_0 at age 0, then converting to numbers at length for the estimated growth parameters and variability in length at age, and finally applying the maturity and fecundity relationships to get total spawning output.

Recruitment for each year in the time series is then calculated as:

$$R_y = S_y B_y$$

Where B_y is the spawning output in year y, and S_y is the pre-recruit survival given by the equation:

$$S_y = \exp\left(-z_0 + (z_0 - z_{min})\left(1 - \left(\frac{B_y}{B_0}\right)^{\beta}\right)\right)$$

Where

$z_0 = -\log(S_0)$
is the pre-recruit mortality rate at equilibrium,

$z_{min} = z_0(1 - z_{frac})$
is the limit of the pre-recruit mortality as depletion approaches 0, parameterized as a function of z_{frac} (which represents the reduction in mortality as a fraction of z_0) so the expression is well defined over a parameter range $0 < z_{frac} < 1$, and,

β is a parameter controlling the shape of the density-dependent relationship between spawning depletion and pre-recruit survival.

The steepness (h) of the spawner-recruit curve (defined as recruitment relative to R_0 at a spawning depletion level of 0.2) can be derived from the parameters above according to the relationship

$$h = 0.2\exp\left(z_0 z_{frac}(1 - 0.2^{\beta})\right)$$

By modeling the relationship in terms of mortality instead of survival (as in Taylor 2008), annual deviations in recruitment can be modeled (implemented in SS by replacing B_y in the equation above with $B_y e^{r_y}$ where r_y is the deviation in recruitment in year y). Attempts to model recruitment deviations in this assessment indicated that the data did not provide adequate detail to get reasonable estimates. Furthermore, the relatively large size of dogfish pups at birth (20-30cm, Tribuzio 2004) would suggest that variability in recruitment would be lower than for a species with a larval stage, which is subject to higher mortality rates.

2.2.3.4.3 Selectivity Parameters

A double-normal selectivity function was used for all fleets to allow consideration of both dome-shaped and asymptotic patterns. Non-trawl landings and IPHC Survey have the largest individuals. Assuming selectivity for these fleets asymptotic also allowed estimating asymptotic length of females (L_∞) within the model. The L_∞ parameter is confounded with the degree of dome-shape because models with dome-shaped selectivity can have estimates of very large L∞ values with little impact on the likelihood as these individuals are not included with the selected population. The exclusion of ages associated with females over 80 cm due to issues with the ageing (as discussed under "Age Compositions" above) further compounds this problem. Furthermore, results of model runs assuming either dome-shaped or asymptotic patterns with L_∞ fixed were virtually identical. Therefore, selectivity of these two fleets was fixed asymptotic.

Selectivity of non-trawl catches during vitamin A fishery was assumed equal to non-trawl discard fleet since current non-trawl discard represent the majority of non-trawl removals. Also, there were no length composition available for NWFSC Slope Survey, and its selectivity was assumed to be equal to AFSC Slope Survey that had the same spatial coverage. Midwater trawl fleet and at-sea hake fishery operate with the same gear (midwater trawl), and length compositions in these fleets are very similar. Therefore, a shared selectivity curve was estimated for these two fleets.

In order to fit strong differences in the length compositions between sexes and account for sex specific habitat preferences observed for this species, it was necessary to estimate a sex-specific offset to selectivity in each fleet, which included estimation of four additional selectivity parameters for each fleet.

Different assumptions regarding shape of selectivity curves were explored via sensitivity analysis (Section 7.1.4).

2.2.3.4.4 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.

Catchability from the WCGBT Survey was estimated at 0.586, which (as we mentioned earlier) is consistent to what we know about latitudinal, vertical and depth availability of the species in the surveyed area and also with what we know about species behavior of the way of the net path. However, the likelihood profile analysis indicated that the model has little information for this parameter. Therefore, to aid in exploring the base model, the WCGBT Survey catchability coefficient was fixed at the estimated value for model diagnostics.

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. Numerous alternative configurations of different levels of complexity were explored for growth, selectivity, mortality, and historical discards. Structural choices were generally made to be as objective as possible, and follow generally accepted methods of approaching similar modeling problems and data issues. The relative effect on assessment results of each of these choices is often unknown; however, extensive efforts were made to evaluate effects of structural choices on model output prior to selecting the base model.

Prior to arriving at the base model, we extensively evaluated fleet structure and devoted substantial amount of effort to explore a possibility of estimating discards as well as retention curves within the model. However, large scale of discarding (historical and recent) and very limited amount of length composition samples of landed catch available resulted in implausible model estimates of both discard rates and shape of the retention curves. Therefore, we included discards in the assessment as catch fleets.

We also attempted to estimate natural mortality within the model (with Hamel (2014) prior and without it). However, none of these efforts yielded plausible values of natural mortality consistent with what is known about the life history of spiny dogfish. Therefore, in the model natural mortality was fixed at the values (0.065) derived from a demographic study of multiple life history characteristics published in Smith et al. (1965).

We extensively experimented with using different sources of age data and ability to estimate growth parameters within the model and with using different shaped selectivity curves, before arriving to those used in the assessment, which produced the most sensible estimated and best fits to the data.

A selection of these alternative approaches were retained as sensitivity analyses, described below.

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. Seventeen 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 Base-Model Results

The list of the explicit parameters used in the base model and their values (either fixed or estimated) is provided in Table 8. The life history parameters estimated within the model are reasonable and consistent with what we know about the species. Both sexes follow the same trajectory in their growth (Figure 55). Males grow slightly faster than females, with females reaching larger sizes. Linf was estimated at 119 cm for females and 98 for males (based on an exponential offset of -0.18685). The log(R0) parameter was estimated at 9.74675, corresponding to an unfished equilibrium recruitment of 17.1 million. Figure 56 through Figure 59 show weight-at-length relationships by sex, female maturity-at-length, fecundity-at-weight and spawning output-at-length generated based on fixed parameters that were derived from data outside the model. Female fecundity and spawning output are expressed in number of pups.

The base model was able to capture general trends for indices in all surveys, which were either stable or decreasing (Figure 60 through Figure 64). These declining trends are consistent with those observed in other areas of the species' distribution, including waters off British Columbia.

Declining trends are also reported for spiny dogfish in the Puget Sound (Anderson et al 2019, Essington et al. 2021).

The base model fits the length frequency distributions well. Figure 65 shows fit to length-frequency distributions of spiny dogfish aggregated across time by fleet, and Figure 66 through Figure 98 showed year specific fits to length-frequency distributions by fleet along with Pearson residuals for the fit of the length-frequency distributions. The quality of fit varies among years and fleets, which reflects the differences in quantity and quality of data. The Pearson residuals, which reflect the noise in the data both within and among years, did not exhibit any strong trends. Francis weighting fits to the mean lengths for each fleet by year (with 95% confidence intervals) are shown in Figure 68 through Figure 99.

Mean length in composition data from WCGBT Survey and bottom trawl discards exhibits increasing trends in both observed and expected values. The increasing mean length along with declining index trend, suggests a potential decline in recruitment and explains why the WCGBT Survey length compositions are best fit at higher catchability values associated with lower stock sizes as shown in the likelihood profiles.

Selectivity curves for each fleet by sex as used in the assessment are shown in Figure 100 through Figure 108. Selectivity was fixed asymptotic for non-trawl landings and IPHC Survey. For the rest of the fleets, selectivity was estimated to have a various degree of dome-shape, except for the recreational fleet, which was estimated to be asymptotic; selection of males within AFSC Slope Survey was also estimated asymptotic, based on available data. This estimates are reasonable as recreational fleet uses with hook-and-line gear that operate within various habitat type, making large female in the rocks accessible to the fleet.

For the bottom trawl discard and non-trawl discard fleets, the model estimated higher selectivity for smaller fish than those of corresponding catch fleets (bottom trawl and hook-and-line), which is consistent with the fact that smaller fish are more frequently discarded. The AFSC triennial, AFSC slope and NWFSC Slope Survey selectivity curves were estimated as dome-shaped, which is consistent with the fact that those survey had only a limited spatial coverage of the assessment area and species range within the assessment area (Table 3).

The time series of total and summary biomass, spawning output, recruitment and depletion relative to B_0 are presented in Figure 109 though Figure 113 and Table 9. The spawning output showed a relatively sharp decline in the 1940s, during the time of the intense dogfish fishery for vitamin A. During a 10-year period (between 1940 and 1950), the spawning output dropped from 99% to under 70% of its unfished level. Between 1950 and 1974 the catches of spiny dogfish were minimal, and the spawning output flattened (mostly as a result of maturation of younger dogfish that were not selected by the vitamin A fishery). For the last forty-five years, spawning output of spiny dogfish has been slowly but steadily declining due to fishery removals (an export food fish fishery developed in the mid-1970s) and low productivity of the stock. Currently, the spawning output is estimated to be at the level of 34% of its unfished level (Figure 113). Predicted numbers at age from the base case for females and males are provided in Supplementary Tables file provided along with this report.

2.5 Evaluation of Uncertainty

Parameter uncertainty in the assessment is explicitly captured in the asymptotic confidence intervals estimated within the model and reported throughout this assessment for key parameters and management quantities. These intervals reflect the uncertainty in the model fits to the data sources in the assessment, but do not include the uncertainty associated with alternative model configurations and fixed parameters. To explore uncertainty associated with alternative model configurations and evaluate the responsiveness of model outputs to changes in model assumptions, a variety of sensitivity runs were performed.

2.5.1 Sensitivity Analysis

A large number of configurations of the base model addressing alternative assumptions regarding key model parameters and structural choices were explored via the sensitivity analysis. Only the most relevant ones are reported here. Results of these selected sensitivity runs are summarized in Table 10 and Figure 114 through Figure 123.

2.5.1.1 Sensitivity to Assumptions Regarding Fishery Removals

Commercial landings of spiny dogfish are relatively well documented because of dogfish utilization history on the U.S. west coast and unique appearance of this species. However, there is an uncertainty associated with discard estimates used in the model as well as discard mortality rates applied (landings and discard (with associated discard mortality) together comprise the total fishery removals). To explore the model sensitivity to uncertainty in spiny dogfish removals, we ran the model assuming:

- 2011 assessment discard estimates
- 50% increase in bottom trawl and non-trawl discards,
- 50% decrease in bottom trawl and non-trawl discard

Although these runs differed in the absolute estimate of B_0 (Figure 114), the trends in spawning depletion as well as estimated depletion levels varied only slightly (Figure 115).

We also explored the model sensitivity to the alternative assumptions regarding dogfish discard mortality. In the base model, 100% discard mortality was assumed for trawl discard fleet and 50% for hook-and-line discard. In the alternative runs, we assumed:

- 100% discard mortality for bottom trawl and non-trawl discard fleets,
- 50% discard mortality for bottom trawl and non-trawl discard fleets.
- 35% discard mortality in non-trawl fleet.
- 6% mortality for non-trawl discard fleet and 5% for bottom trawl discard fleet. This sensitivity was explored in 2011 assessment, because these discard mortality values were used by the Integrated Fisheries Management Plan (IFMP) for Pacific Canadian groundfish fisheries (except for the fact that IFMP uses 5% discard mortality for the first two hours of a trawl fishing event with 5% for each additional hour (no historical data on tow length were available for this assessment)).

The runs with both fleets having 100% and 50% did not produce large differences in comparison with the base model in the sense of depletion level, but the run with the lowest discard mortality rates produced more depleted stock that estimated by the base model (Figure 114 and Figure 115). In general, most of the model results in this sensitivity and others show a slight declining trend in the most recent years. The model with the lowest discard mortality has the lowest B_0 and exhibit slight increase in the 1970s, the stock under this scenario is also less depleted since most of discarded fish survive.

2.5.1.2 Sensitivity to Assumptions about Biology

For this assessment, we updated several life history parameters based on new information. These changes included: 1) updating the length-weight parameters, 2) updating fecundity parameters, 3) updating natural mortality (*M*), and 4) growth parameters. We run the model using the values from 2011 assessment:

- 2011 weight-length relationship
- 2011 fecundity
- 2011 natural mortality (0.064)
- 2011 growth parameters

The model was not sensitive to the changes in the length-weight parameters. The model was also not sensitive to using *M* from the 2011 assessment since the new *M* value is very close to value used in 2011; *M* in 2011 was fixed at 0.064 (estimated using the Hoeing (1983) method outside the assessment model, based on maximum age of 71 years) and in this assessment *M* was fixed at 0.065, based on demographic analysis conducted by Smith et al. (1998). However, changes in fecundity in an appreciable change in scale of the spawning stock (Figure 116 and Figure 117).

We also ran the model while estimating:

- Natural mortality for males while keeping female natural mortality fixed at 0.065
- Natural mortality estimated for females while males are assumed to have the same M as females.
- Growth parameters all age data from all sources.

The first run from this group did not produce appreciable change, but the estimated value of male *M* (0.064) was lower than the fixed value of female *M* (0.065), which is opposite to what is expected when males grow faster but reach smaller asymptotic sizes.

Estimating a single value for females and males (with and without a Hamel prior) resulted in the unrealistic estimate of natural mortality of 0.03, which corresponds to a maximum age of 160 years, much higher than ever observed in Pacific spiny dogfish. With this value of *M*, the stock has higher B0 and more depleted status (Figure 116 and Figure 117).

Finally, estimating growth using all age data available estimated flatter growth curve (lower von Bertalanffy growth coefficient *k*), since fishery age data is missing smaller individuals, larger asymptotic lengths, and also produced maximum convergence warnings, likely because model had troubles reconciling very noisy age data.

2.5.1.3 Sensitivity to Assumptions about Spawner-Recruit Relationship

Sensitivities were conducted to explore alternative assumptions about the spawner-recruit relationships. The relationship used in this model is parameterized in terms pre-recruit survival. The parameters controlling the relationship, which may be estimated or fixed, are equilibrium recruitment (R_0), a parameter controlling the potential decrease in pre-recruit mortality as spawning output is reduced (z_{frac}), and a parameter controlling the shape of the mortality-depletion relationship (β). The base model uses the survival-based relationship with $z_{frac} = 0.4$ and $\beta = 1.0$. This is unlike the Beverton-Holt spawner-recruit relationship, which is parameterized in terms of R_0 and steepness (h), representing the recruitment at a spawning depletion of 0.2, as a fraction of R_0.

Sensitivity conducted included:

- z_{frac} fixed at 0.2, and $\beta = 0.5$
- z_{frac} fixed at 0.6, and $\beta = 2.0$
- Running the model with Beverton-Holt spanner-recruit relationship, with steepness (h) fixed at 0.283 (the values chosen to match the base model output)
- Running the model with Beverton-Holt spanner-recruit relationship, with steepness (h) estimated

Results are presented in Figure 118 and Figure 119. The two sensitivity analyses for z_{frac} and β were chosen after running models spanning a grid of values in both dimensions and choosing the combinations that produced the results most different from the base model. Overall, all these combinations produced similar results to the base model. The best likelihood was the least productive model with lower z_{frac} and lower β, but the difference among likelihoods across the grid of $z_{frac} = 0.2$ to 0.6 and $\beta = 0.5$ to 2.0 was only 1.4 units of negative log likelihood, indicating that there was little information in the data about these parameters.

Likewise, when steepness of the Beverton-Holt model was estimated, the parameter hit the lower bound (0.2) which is implausible, and the likelihood profile analysis indicated that the model does not have information to reliably estimate this parameter.

2.5.1.4 Sensitivity to Assumptions about Selectivity and Catchability

Sensitivities to assumptions about selectivity and catchability included (but not limited to) the following:

- Removing the sex-specific offset on the selectivity curves
- Estimating a single catchability for all years in the Triennial Survey
- Non-trawl vitamin A selectivity assumed equal to non-trawl landings fleet
- Non-trawl vitamin A selectivity assumed equal to bottom trawl fleet
- Allowing non-trawl landings and IPHC Survey selectivity curves to be dome-shaped

Removing sex specific offsets resulted in poor fit to length compositions data and more depleted stock status (Figure 120 and Figure 121). Estimating a single catchability in AFSC Triennial Survey did not produce a noticeable change.

In the model, non-trawl removals during vitamin A fishery assumed equal to non-trawl discard fleet, since most of the recent non-trawl catch is being discarded. However, since during vitamin A the entire catch was retained, and thus there is an uncertainty associated with selectivity assumption. We ran the model assuming selectivity in non-trawl vitamin A fishery equal to non-trawl landings selectivity and selectivity of bottom trawl fleet. Assuming non-trawl vitamin A fleet selectivity equal to that of bottom trawl fleet did not produce much change but assuming non-trawl vitamin A fleet selectivity equal to non-trawl landings made a difference for both initial spawning output and also shape of the curve describing the dynamics of spawning stock output (Figure 120 and Figure 121).

2.5.1.5 Sensitivity to Data Weighting
These sensitivities included:

- Tuning the sample sizes using the Dirichlet-Multinomial likelihood
- Tuning the sample sizes using the McAllister-Ianelli method
- Removing the extra standard deviation parameter added to the index uncertainty
- Using design base expansion for WCGBT Survey and Triennial Survey

The base model sample size adjustments from the Francis (2011) method for the length composition data. Tuning the sample sizes using the McAllister-Ianelli (1997) and Dirichlet-Multinomial methods both resulted in more depleted stock status (Figure 122 and Figure 123), mostly due to less reasonable estimates of growth parameters with larger estimates of asymptotic sizes and lower estimates of growth coefficients.

Removing the extra standard deviation parameter added to the index uncertainty did not produce much difference from the base model (Figure 122 and Figure 123). Using the model with WCGBT Survey and AFSC Triennial Survey with length compositions created via design-based expansion did not produce much effect on the model output as well (Figure 122 and Figure 123), but resulted in less smooth shape of a selectivity curve for AFSC Triennial Survey from spiky length compositions generated via design-based expansion.

For exploration purposes, the same sensitivity runs were conducted using the model with WCGBT Survey catchability being estimated, and the results of those runs were similar to sensitivity analysis results of the base model.

2.5.2 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 2019, 2018, 2017, 2016 and 2015, respectively. Comparisons of the time series of absolute and relative spawning output for the runs are shown in Figure 124 and Figure 125,

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.

2.5.3 Historical Analysis

The second type of retrospective analysis addresses assessment error, or at least in the historical context of the current result, given previous analyses. Figure 126 and Figure 127 show the comparison of relative spawning output and spawning for this and for 2011 and 2021 assessments, respectively. The current assessment estimates lower depletion (34% vs 63% in 2011 assessment), and lower spawning output in the beginning and in the end of the time series.

2.5.4 Likelihood Profile Analysis

Likelihood profiles were conducted over the parameter controlling unfished equilibrium recruitment log(R_0), catchability of the WCGBT Survey (q), stock-recruit steepness (h) and natural mortality (M). Results of these profiles are shown in Figure 128 through Figure 135. The contribution of different data sources to the changes in likelihood within the profiles were considered in the context of a change of less than 1.92 units of negative log-likelihood, which were considered small, based on half of the 95% quantile of a Chi-squared distribution with 1 degree of freedom.

The results of the likelihood profile analysis on ln(R0) are shown in Figure 128. The negative log-likelihood is optimized at a value of approximately 9.75 for the base model, with no obvious conflicts among data sources that would pull to opposite directions.

The profile over catchability of the WCGBT Survey (q) is shown in Figure 129. The range considered for the parameter log(q) corresponded to q = 0.18 to q = 1.3. The value estimated in the model is q=0.586. The index data is best fit at the higher log(q) while the length data are best fit at the lower log(q). However, the difference in likelihood over a wide range of log(q) values is within 1.92 units, indicating that the model has little information for this parameter. At the same time, this parameter has a large influence on the scale of the stock (Figure 130) and its status (Figure 131).

Even though the model uses pre-recruit survival based spawner-recruit curve, we conducted likelihood profile analysis over steepness (*h*) for the model version with Beverton-Holt model. Figure 132 shows likelihood profile over *h* ranging between *h*=0.21 and *h*=0.5 indicating that index, length and age data fit the best with lowest value of steepness. However, the difference in spawning output (Figure 133) and depletion (Figure 134) is not substantial for values of steepness explored.

The profile over natural mortality (M) shows that most of the information in the likelihood about M was from the length, with best fit around M value of 0.03 (Figure 135). However, this value of M corresponds to maximum age of 160 years, never observed in Pacific spiny dogfish, and therefore, considered implausible. Alternative values of M resulted in changes in spawning output estimated by the model (Figure 136), however, depletion did not substantial vary with different values of M explored. (Figure 137).

3 Decision Table and Harvest Projections

The decision table is shown in Table 11. The primary axis of uncertainty used in the decision table was WCGBT Survey catchability (q). WCGBT Survey q in the base model was estimated (and then fixed) at 0.586. The 12.5% and 87.5% quantiles of the likelihood profile of WCGBTS q (the value of 0.66 reflects the chi square distribution with one degree of freedom) corresponded to q values of 0.9 and 0.3. The model with $q = 0.3$ was used as high state of nature, but the alternative approach was used to identify the low and middle states of nature.

Following a precedent set by the 2017 Pacific ocean perch assessment, the mean spawning output and depletion from a likelihood profile were used to identify a WCGBTS catchability value, which represented the expected population level associated with the range of models that included one with $q = 0.3$ (the high state of nature), and another with $q = 0.586$ (that was assigned to low state of nature). Values of spawning output and depletion were averaged for the profile models with $q = 0.30, 0.35, 0.40, 0.45, 0.50, 0.55$, and 0.586. The mean spawning output from this set was 13,825 pups and the mean depletion was 0.416. A model with $q = 0.43$, which had 2021 spawning output estimated at 13,613 pups and depletion estimated at 0.418, was found to be a close match to those mean values and chosen as a model that will be used to inform harvest specifications. This model with catchability set to $q = 0.43$ thus represents the expected ending spawning output and depletion given catchability values between $q = 0.3$ and $q = 0.586$ that were considered equally likely. The model with WCGBT Survey $q = 0.43$ was used as middle state of nature in the Decision Table, while models with $q = 0.586$ and $q = 0.3$ as low and high states of nature, respectively.

Twelve-year forecasts for each state of nature were calculated for three catch scenarios. All scenarios assumed full ACL catches for the 2021 and 2022, which are 1,621 mt and 1,585 mt, respectively. The low catch scenario assumed P* of 0.4 with 65% of ACL taken; the middle catch scenario was P* of 0.4 with full ACL taken for years between 2023 and 2032, and the high catch scenario was P* of 0.4 with full ACL taken from the new middle state ($q = 0.43$) for years between 2023 and 2032.

Potential OFLs projected by the model are shown in Table 12. These values are based on an SPR target of 50%, a P* of 0.4, and a time-varying Category 2 Sigma which creates the buffer shown in the right-hand column. The OFL and ACL values for 2021 and 2022 are the current harvest specifications while the total mortality for 2021 and 2022 represent full ACL catch.

4 Reference Points and Exploitation Status

Summary of spiny dogfish reference points from the model with q of 0.43 are shown in Table 13, while summary of recent trends in estimated spiny dogfish exploitation and stock level from the assessment model are shown in Table 14.

Unfished spawning stock output for spiny dogfish is estimated to be 32,570 thousands of pups (95% confidence interval: 27,398–37,742). The stock is declared overfished if the current spawning output is estimated to be below 25% of unfished level. The management target for spiny dogfish is defined as 40% of the unfished spawning output ($SB_{40\%}$), which is estimated by the model to be 13,028 thousand of fish (95% confidence interval: 10,959–15,097), which corresponds to an exploitation rate of 0.003.

The model with WCGBTS Survey *q* of 0.43 shows that the stock of spiny dogfish off the continental U.S. Pacific Coast is currently at 42% of its unexploited level. This is above the overfished threshold of $SB_{25\%}$ and the management target of $SB_{40\%}$ of unfished spawning output.

This harvest rate provides an equilibrium yield of 358 mt at $SB_{40\%}$ (95% confidence interval: 297–418 mt). The model estimate of maximum sustainable yield (MSY) is 371 mt (95% confidence interval: 307–434 mt). The estimated spawning stock output at MSY is 16,024 thousands of pups (95% confidence interval: 13,514–18,533). The exploitation rate corresponding to the estimated SPR_{MSY} of $F_{90\%}$ is 0.003.

The Spawning Potential Ratio (SPR) used for setting the OFL is 50 percent. Through the history, the assessment estimates that spiny dogfish was fished at a rate that exceeded the relative SPR target in multiple periods, most notably during Vitamin A fishery, and also in 1990s and 2000s. Because of the extremely low productivity and other reproductive characteristics of the stock, fishing at the target of SPR 50% is expected to reduce the spawning output of spiny dogfish over the long term to zero abundance. Conversely, fishing at a rate that would maintain spawning output near 40% of the unfished level would require a target SPR of about 88% as estimated by the assessment model. The Council's Scientific and Statistical Committee should consider the appropriateness of using the current proxy harvest rate for spiny dogfish.

5 Regional Management Considerations

Spiny dogfish is a migratory species found in the U.S. west coast from Alaska to Southern California. They are extremely abundant in waters off British Columbia and Washington, but decline in abundance southward along the Oregon and California coasts.

The stock included in this assessment (from the U.S.-Canada border on the north to U.S.-Mexico border on the south) very likely has substantial interaction and overlap with dogfish observed off British Columbia. From a seasonal perspective, this is particularly important, because spring aggregations of dogfish that have been targeted off Washington may well have migrated to areas north of the border by the time that trawl surveys have commenced off the US coast. In a population sense, it must be acknowledged that the scope of this assessment does not capture all of the removals and dynamics which very likely bear on the status and trends of the larger, transboundary population.

It was considered appropriate to proceed with the assessment for the limited area of the U.S. west coast based on the recent estimated annual directed (not seasonal) movement rates of about 5% per year between the U.S. coastal sub-population of dogfish and that found along the west coast of Vancouver Island in Canada (Taylor 2008). Nevertheless, it is extremely important to pursue collaborative efforts between the U.S. and Canada to more accurately describe the dynamics and access the status of stock, especially given the vulnerability of the stock, which exhibits slow growth, the longest gestation period known for sharks and is the latest maturing of all elasmobranchs.

6 Research and Data Needs

In this assessment, several critical assumptions were made based on limited supporting data and research. There are several research and data needs which, if satisfied, could improve the assessment. These research and data needs include:

1) Continue all ongoing data streams used in this assessment. Continued sampling of lengths and ages from the landed catch and lengths and discard rates from the fishery will be very valuable for the years ahead. Also, a longer fishery independent index from a continued WCGBT Survey with associated compositions of length and age-at-length will improve understanding of dynamics of the stock.

2) Continue to refine historical catch estimates. Considerable uncertainty remains in the historic discard amounts, prior to the commencement of the West Coast Groundfish Observer Program. There is also the need to improve estimates of discard mortality. These issues are relevant for other West Coast stock assessments as well.

3) The ageing method for dogfish requires further research. The current assessment was able to estimate growth parameters for females and females, but understanding of maximum age especially for females continues to be uncertain. More research is needed on the topic of unreadable annuli that are missing due to wear on the spines of older dogfish. The efforts should be devoted to both improving current ageing techniques based on dogfish spines and developing new methods using other age structures. Ideally, an alternative method of ageing dogfish that does not rely on the estimation of ages missing from worn spines may be necessary. Improvement in ageing would contribute to better understanding of spiny dogfish longevity and help estimating natural mortality within the assessment model.

4) Poorly informed parameters, such as natural mortality and stock-recruit parameters will benefit from meta-analytical approaches until there is enough data to estimate them internal to the model.

5) There are high densities of dogfish close to the U.S.-Canada border, at the mouth of the Strait of Juan de Fuca which connects the outside coastal waters with the inside waters of Puget Sound and the Strait of Georgia. This distribution, combined with potential seasonal or directed movement patterns for dogfish suggest that the U.S. and Canada should explore the possibility of a joint stock assessment in future years.

Most of the research needs listed above entail investigations that need to take place outside of the routine assessment cycle and require additional resources to be completed.

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8 Tables

Table 1. Management guidelines, recent trends in landings and estimated total catch (mt) for spiny dogfish.

Year	**OFL**		**ABC/ACL**		**Catch**
	Other Fish a/	Spiny Dogfish	Other Fish a/	Spiny Dogfish	
2011	11,148	2,200	5,574	1,100	1,636.27
2012	11,150	2,200	5,575	1,100	798.94
2013	6,832	2,980	4,697	2,044	646.53
2014	6,802	2,950	4,717	2,024	618.92
2015	NA	2,523	NA	2,101	698.91
2016	NA	2,503	NA	2,085	781
2017	NA	2,514	NA	2,094	481.99
2018	NA	2,500	NA	2,083	1,907.51
2019	NA	2,486	NA	2,071	1,609.72
2020	NA	2,472	NA	2,059	721.44

a/ Spiny dogfish have been managed with stock-specific harvest specifications since 2015.

Table 2. Time series of reconstructed spiny dogfish removals (mt) by fleet.

Year	Bottom trawl discard	Botton trawl landings	Midwater trawl catch	Bycatch within at-sea hake fishery	Nontrawl landings	Nontrawl discard	Nontrawl vitamin A fishery	Recreational catch	Total Catch
1916	0	0	0	0	0	0	0	0	0
1917	0	1	0	0	0	0	0	0	1
1918	0	1	0	0	0	0	0	0	1
1919	0	2	0	0	0	0	0	0	2
1920	0	2	0	0	0	0	0	0	3
1921	0	3	0	0	0	0	0	0	3
1922	0	4	0	0	0	0	0	0	4
1923	0	4	0	0	0	0	1	0	5
1924	0	5	0	0	0	0	1	0	5
1925	0	5	0	0	0	0	1	0	6
1926	0	6	0	0	0	0	1	0	7
1927	0	7	0	0	0	0	1	0	7
1928	0	7	0	0	0	0	1	0	8
1929	0	8	0	0	0	0	1	0	9
1930	0	8	0	0	0	0	1	0	9
1931	0	9	0	0	0	0	1	0	10
1932	0	20	0	0	0	0	2	0	23
1933	0	19	0	0	0	0	2	0	21
1934	0	20	0	0	0	0	2	0	23
1935	0	39	0	0	0	0	5	0	44
1936	0	21	0	0	0	0	3	0	23
1937	0	57	0	0	0	0	7	0	64
1938	0	334	0	0	0	0	40	0	374
1939	0	610	0	0	0	0	112	0	722
1940	0	975	0	0	0	0	96	0	1,072
1941	0	5,287	0	0	0	0	1,965	0	7,252
1942	0	4,635	0	0	0	0	1,525	0	6,160
1943	0	3,036	0	0	0	0	5,185	0	8,221
1944	0	9,644	0	0	0	0	7,232	0	16,876
1945	0	5,766	0	0	0	0	3,446	0	9,212
1946	0	4,503	0	0	0	0	4,667	0	9,170
1947	0	4,145	0	0	0	0	2,090	0	6,235
1948	0	4,452	0	0	0	0	1,066	0	5,519
1949	0	3,946	0	0	0	0	1,100	0	5,047
1950	0	366	0	0	0	0	741	0	1,107
1951	0	462	0	0	0	0	436	0	899
1952	0	818	0	0	0	0	188	0	1,006
1953	0	363	0	0	0	0	152	0	515
1954	0	348	0	0	0	45	0	0	392
1955	0	367	0	0	0	90	0	0	457

Year	Bottom trawl discard	Botton trawl landings	Midwater trawl catch	Bycatch within at-sea hake fishery	Nontrawl landings	Nontrawl discard	Nontrawl vitamin A fishery	Recreational catch	Total Catch
1956	0	219	0	0	0	135	0	0	354
1957	0	825	0	0	0	180	0	0	1,005
1958	0	195	0	0	0	225	0	0	420
1959	44	156	0	0	0	269	0	0	469
1960	309	73	0	0	0	314	0	0	697
1961	99	40	0	0	0	359	0	0	499
1962	437	16	0	0	0	404	0	0	857
1963	124	17	0	0	0	449	0	0	590
1964	182	19	0	0	0	494	0	0	695
1965	222	18	0	0	0	539	0	0	778
1966	256	20	0	0	0	584	0	0	861
1967	616	13	0	0	0	629	0	0	1,257
1968	351	22	0	0	0	674	0	0	1,046
1969	579	30	0	0	1	718	0	0	1,329
1970	849	11	0	0	1	718	0	0	1,579
1971	723	3	0	0	9	722	0	0	1,458
1972	1,117	3	0	0	1	719	0	0	1,840
1973	1,386	2	0	0	1	719	0	0	2,109
1974	1,145	12	0	0	0	718	0	0	1,877
1975	1,330	22	0	0	7	721	0	0	2,080
1976	1,259	62	0	0	7	722	0	0	2,050
1977	975	200	0	12	96	766	0	0	2,051
1978	1,400	174	0	8	211	823	0	0	2,615
1979	2,361	167	0	20	329	883	0	1	3,760
1980	1,493	93	0	76	167	802	0	0	2,632
1981	1,768	232	1	167	28	546	0	33	2,775
1982	3,864	95	0	130	35	550	0	46	4,720
1983	2,735	25	0	65	30	547	0	18	3,420
1984	2,863	240	0	65	39	552	0	16	3,775
1985	2,533	196	0	23	102	583	0	52	3,490
1986	2,437	83	0	123	33	549	0	62	3,287
1987	2,412	93	0	138	71	568	0	7	3,289
1988	1,910	134	0	108	64	564	0	48	2,828
1989	2,016	84	0	55	208	636	0	25	3,024
1990	1,557	347	0	112	137	601	0	25	2,779
1991	1,169	694	0	159	209	228	0	25	2,484
1992	1,144	880	43	385	177	212	0	25	2,867
1993	892	843	8	74	419	333	0	25	2,594
1994	223	1,030	25	53	337	292	0	11	1,972
1995	915	359	0	198	8	128	0	20	1,627
1996	1,287	193	4	401	54	151	0	19	2,109
1997	961	336	3	328	86	167	0	5	1,885
1998	215	410	50	275	3	125	0	1	1,078
1999	556	434	32	470	48	148	0	11	1,700
2000	660	286	36	117	326	286	0	10	1,720
2001	718	333	13	237	219	233	0	9	1,762
2002	762	437	293	299	409	111	0	15	2,327
2003	502	196	268	271	246	35	0	12	1,529
2004	609	136	345	613	240	73	0	3	2,019
2005	1,439	129	387	355	240	73	0	4	2,628

Year	Bottom trawl discard	Botton trawl landings	Midwater trawl catch	Bycatch within at-sea hake fishery	Nontrawl landings	Nontrawl discard	Nontrawl vitamin A fishery	Recreational catch	Total Catch
2006	620	85	146	58	197	172	0	4	1,284
2007	533	63	239	155	217	165	0	6	1,379
2008	899	43	522	672	296	101	0	3	2,536
2009	525	78	274	163	56	93	0	4	1,194
2010	368	60	282	278	10	127	0	2	1,127
2011	303	86	367	785	11	75	0	10	1,636
2012	291	52	162	178	2	111	0	3	799
2013	287	9	105	97	47	96	0	6	647
2014	315	53	81	60	19	89	0	2	619
2015	191	4	271	97	43	90	0	1	699
2016	248	1	203	194	1	134	0	1	781
2017	151	3	109	140	3	73	0	3	482
2018	228	7	462	957	2	247	0	4	1,908
2019	252	3	569	614	2	166	0	2	1,610
2020	210	2	250	94	1	162	0	2	721

Table 3. Latitudinal and depth ranges by year of four bottom trawl surveys used in the assessment.

Survey	Year	Latitudes	Depths (fm)
AFSC Shelf (Triennial)	1977	34° 00'- Canadian border	50-250
	1980	36° 48'- 49° 15'	30-200
	1983	36° 48'- 49° 15'	30-200
	1986	36° 48'- Border	30-200
	1989	34° 30'- 49° 40'	30-200
	1992	34° 30'- 49° 40'	30-200
	1995	34° 30'- 49° 40'	30-275
	1998	34° 30'- 49° 40'	30-275
	2001	34° 30'- 49° 40'	30-275
	2004	34° 30'- Canadian border	30-275
AFSC Slope	1988	44° 05'- 45° 30'	100-700
	1990	44° 30'- 40° 30'	100-700
	1991	38° 20'- 40° 30'	100-700
	1992	45° 30'- Border	100-700
	1993	43° 00'- 45° 30'	100-700
	1995	40° 30'- 43° 00'	100-700
	1996	43° 00'- Canadian border	100-700
	1997	34° 00'- Canadian border	100-700
	1999	34° 00'- Canadian border	100-700
	2000	34° 00'- Canadian border	100-700
	2001	34° 00'- Canadian border	100-700
NWFSC Slope	1999	34° 50'- 48° 10'	100-700
	2000	34° 50'- 48° 10'	100-700
	2001	34° 50'- 48° 10'	100-700
	2002	34° 50'- 48° 10'	100-700
WCGBT Survey	2003	32° 34'- 48° 27'	30-700
	2004	32° 34'- 48° 27'	30-700
	2005	32° 34'- 48° 27'	30-700
	2006	32° 34'- 48° 27'	30-700
	2007	32° 34'- 48° 27'	30-700
	2008	32° 34'- 48° 27'	30-700
	2009	32° 34'- 48° 27'	30-700
	2010	32° 34'- 48° 27'	30-700
	2011	32° 34'- 48° 27'	30-700
	2012	32° 34'- 48° 27'	30-700
	2013	32° 34'- 48° 27'	30-700
	2014	32° 34'- 48° 27'	30-700
	2015	32° 34'- 48° 27'	30-700
	2016	32° 34'- 48° 27'	30-700
	2017	32° 34'- 48° 27'	30-700
	2018	32° 34'- 48° 27'	30-700
	2019	32° 34'- 48° 27'	30-700

Table 4. Estimated indices of abundance and standard errors of the natural log of biomass for the surveys used in the assessment.

Year	AFSC Triennial		AFSC Slope		NWFSC		WCGBTS		IPHC	
	Index	se_log	Index	se_log	Index	se_log	Index	se_log	Index	se_log
1980	23,822	0.2294								
1983	24,448	0.1342								
1986	11,608	0.1057								
1989	32,756	0.1408								
1992	32,378	0.1330								
1995	12,453	0.1264								
1997			183,179	0.3629						
1998	36,184	0.1120	88,122	0.3848	5,368	0.3130				
1999			56,833	0.4986	1,295	0.3341			0.1085	0.0418
2000			42,027	0.5335	2,317	0.3322				
2001	9658.887534	0.1640			1,395	0.3896			0.1107	0.0558
2002					2,333	0.2803			0.1344	0.0598
2003							46,146	0.2122	0.0889	0.0577
2004	18,215	0.166731966					45,946	0.2386	0.0712	0.0666
2005							45,289	0.1961	0.0822	0.0446
2006							49,512	0.1954	0.1008	0.0615
2007							34,901	0.1972	0.1776	0.0406
2008							39,971	0.1879	0.1032	0.0499
2009							17,526	0.2045	0.0623	0.0489
2010							22,580	0.2011	0.0641	0.0481
2011							29,577	0.2099	0.0832	0.0468
2012							35,181	0.2598	0.1320	0.0346
2013							10,667	0.2570	0.1220	0.0277
2014							25,485	0.2141	0.0847	0.0339
2015							16,018	0.2234	0.1113	0.0263
2016							19,491	0.2521	0.1108	0.0352
2017							8,998	0.2552	0.0973	0.0338
2018							26,029	0.2668	0.1037	0.0323
2019							28,598	0.3647	0.0451	0.0465

Table 5. Summary of sampling efforts used to generate length-frequency distributions for the assessment model by fishing fleet.

Years	Bottom trawl discard		Botton trawl landings		Midwater trawl		Bycatch within at-sea hake		Nontrawl landings		Nontrawl discard		Recreational catch
	N trips	N fish	N trips	N fish	N trips	N fish	N hauls	N fish	N trips	N fish	N trips	N fish	N fish
1980													25
1981													39
1982													58
1983													18
1984													20
1985													56
1986													43
1987													11
1988													53
1989													26
1993													51
1994													10
1995													
1996													22
1997													7
1998													5
1999													23
2000													12
2001													5
2002													11
2003			1	25					4	100			19
2004									2	94			39
2005					3	200							45
2006	253	1,660	3	250	9	549			10	772	70	964	77
2007	182	1,206	5	422	15	1,009	748	3,265	8	659	108	1,190	46
2008	240	1,773	4	4	4	200	1,312	19,995	15	785	123	1,508	28
2009	340	2,274	8	152	4	181	663	4,900	5	250	101	888	31
2010	186	1,115			11	588	1,129	9,807	1	3	152	2,016	18
2011	564	4,213	1	30	11	832	1,805	15,048	1	1	194	2,114	25
2012	604	4,653	3	83	7	340	535	5,751	1	3	152	2,843	22
2013	564	4,109	5	82	5	369	389	4,081	2	64	66	1,145	19
2014	551	4,048	14	339	12	366	796	4,704	2	11	88	1,771	19
2015	474	3,086	15	96	24	830	856	3,889	7	157	124	2,224	17
2016	434	2,630	17	137	31	565	1,178	7,381	4	7	128	2,336	6
2017	386	2,129	8	58	23	422	686	3,908	3	5	102	1,432	22
2018	429	2,787	2	2	30	526	875	5,749	1	12	153	2,665	17
2019	423	2,680	2	10	28	331	660	3,284			158	2,659	19
2020			9	54	29	436	48	2,261					

Table 6. Summary of sampling effort used to generate survey length-frequency distributions used in the assessment.

Years	AFCS Triennial		AFCS Slope		WCGBT		IPHC
	N hauls	N fish	N hauls	N fish	N hauls	N fish	N fish
1986							
1989							
1992							
1995							
1997			62	3,009			
1998							
1999			56	1,872			
2000			36	1,454			
2001	191	1,626	37	671			
2002							
2003					178	3,787	
2004	138	2,416			160	2,480	
2005					251	3,565	
2006					224	3,882	
2007					224	2,419	
2008					249	2,847	
2009					205	1,658	
2010					226	1,723	
2011					200	1,635	346
2012					173	1,507	266
2013					94	613	264
2014					154	1,474	347
2015					145	669	321
2016					119	771	183
2017					100	532	345
2018					135	774	440
2019					65	489	230

Table 7. Bridging analysis results.

This table is provided in supplementary Excel file, tab "Bridging".

Table 8. List of parameter values used in the base model.

This table is provided in supplementary Excel file, tab “Parameters”.

Table 9. Time series of estimated total and summary biomass (mt), spawning output (1,000s fish), depletion, recruitment (1,000s fish) and exploitation rate.

This table is provided in supplementary Excel file, please see tab "Derived output times series".

Table 10. Base model sensitivity to alternative assumptions about input data, parameters and model structure.

This table is provided in supplementary Excel file, tab "Sensitivities".

Table 11. 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=0.586		Middle state: q=0.43		High state: q=0.3	
Management decision	Year	Catch (mt)	Spawning output	Depletion	Spawning output	Depletion	Spawning output	Depletion
Full ACL for 2021 and 2022 catches; P*0.4 with 65% of ACL from old base model taken after that	2021	1,621	9,895	0.344	13,613	0.418	20,067	0.513
	2022	1,585	9,876	0.343	13,604	0.418	20,068	0.513
	2023	655	9,854	0.342	13,591	0.417	20,066	0.513
	2024	635	9,868	0.343	13,614	0.418	20,100	0.514
	2025	616	9,879	0.343	13,634	0.419	20,130	0.515
	2026	598	9,888	0.344	13,652	0.419	20,158	0.515
	2027	581	9,893	0.344	13,666	0.420	20,182	0.516
	2028	565	9,896	0.344	13,677	0.420	20,202	0.516
	2029	549	9,895	0.344	13,684	0.420	20,219	0.517
	2030	535	9,892	0.344	13,688	0.420	20,232	0.517
	2031	520	9,885	0.343	13,689	0.420	20,241	0.517
	2032	507	9,875	0.343	13,686	0.420	20,246	0.518
Full ACL for 2021 and 2022 catches; P*0.4 with 100% of ACL from old base model taken after that	2021	1,621	9,895	0.344	13,613	0.418	20,067	0.513
	2022	1,585	9,876	0.343	13,604	0.418	20,068	0.513
	2023	1,001	9,854	0.342	13,591	0.417	20,066	0.513
	2024	970	9,859	0.343	13,595	0.417	20,092	0.514
	2025	941	9,861	0.343	13,596	0.417	20,114	0.514
	2026	913	9,860	0.343	13,594	0.417	20,132	0.515
	2027	887	9,855	0.342	13,588	0.417	20,147	0.515
	2028	862	9,847	0.342	13,579	0.417	20,157	0.515
	2029	839	9,834	0.342	13,566	0.417	20,162	0.515
	2030	816	9,817	0.341	13,550	0.416	20,164	0.516
	2031	794	9,797	0.340	13,530	0.415	20,160	0.515
	2032	774	9,773	0.340	13,506	0.415	20,152	0.515
Full ACL for 2021 and 2022 catches; P*0.4 with full ACL from new middle state (q = 0.43) after that	2021	1,621	9,895	0.344	13,613	0.418	20,067	0.513
	2022	1,585	9,876	0.343	13,604	0.418	20,068	0.513
	2023	1,456	9,854	0.342	13,591	0.417	20,066	0.513
	2024	1,407	9,839	0.342	13,586	0.417	20,072	0.513
	2025	1,361	9,821	0.341	13,578	0.417	20,074	0.513
	2026	1,318	9,798	0.340	13,565	0.416	20,072	0.513
	2027	1,278	9,771	0.340	13,548	0.416	20,066	0.513
	2028	1,240	9,740	0.338	13,526	0.415	20,055	0.513
	2029	1,204	9,705	0.337	13,500	0.414	20,039	0.512
	2030	1,170	9,664	0.336	13,470	0.414	20,018	0.512
	2031	1,138	9,620	0.334	13,434	0.412	19,993	0.511
	2032	1,108	9,571	0.333	13,394	0.411	19,962	0.510

Table 12. Projections of OFL, and ACL values along with recruitment, spawning output and fraction unfished.

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 1+ Biomass	Spawning Output	Fraction Unfished
2021	1,974.91	1,620.99	110,047	13,613	0.42
2022	1,942.41	1,584.99	108,818	13,604	0.42
2023	1,911.16	1,456.30	107,636	13,591	0.42
2024	1,883.17	1,406.73	106,595	13,586	0.42
2025	1,857.04	1,361.21	105,616	13,578	0.42
2026	1,832.76	1,317.75	104,698	13,565	0.42
2027	1,810.37	1,278.12	103,839	13,548	0.42
2028	1,789.86	1,240.37	103,037	13,527	0.42
2029	1,771.20	1,204.42	102,289	13,500	0.41
2030	1,754.39	1,170.18	101,593	13,470	0.41
2031	1,739.37	1,137.55	100,949	13,434	0.41
2032	1,726.10	1,108.16	100,354	13,394	0.41

Table 13. Summary of spiny dogfish reference points from the assessment model.

	Estimate	Interval
Unfished Spawning Output (1000s of pups)	32,570	27,398–37,742
Unfished Age 1+ Biomass (mt)	255,616	220,047–291,185
Unfished Recruitment (R0) (1000s pups)	19,291	16,228–22,354
Spawning Output (2021) (1000s of pups)	13,613	7,994–19,232
Fraction Unfished (2021)	0.42	0.33–0.51
Reference Points Based $SB_{40\%}$		
Proxy Spawning Output $SB_{40\%}$	13,028	10,959–15,097
SPR Resulting in $SB_{40\%}$	0.882	0.882–0.882
Exploitation Rate Resulting in $SB_{40\%}$	0.003	0.003–0.004
Yield with SPR Based On $SB_{40\%}$ (mt)	358	297–418
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	NA	NA
SPR50	0.5	NA
Exploitation Rate Corresponding to SPR50	0.018	0.016–0.021
Yield with SPR50 at SB SPR (mt)	NA	NA
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	16,024	13,514–18,533
SPR MSY	0.899	0.898–0.900
Exploitation Rate Corresponding to SPR MSY	0.003	0.002–0.003
MSY (mt)	371	307–434

Table 14. Summary of recent trends in estimated spiny dogfish exploitation and stock level from the assessment model.

Quantity	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
OFL Other Fish a/	11,148	11,150	6,832	6,802	NA	NA	NA	NA	NA	NA	NA
OFL Spiny Dogfish	*2,200*	*2,200*	*2,980*	*2,950*	2,523	2,503	2,514	2,500	2,486	2,472	2,479
ACL Other Fish a/	5,574	5,575	4,697	4,717	NA	NA	NA	NA	NA	NA	NA
ACL Spiny Dogfish	*1,100*	*1,100*	*2,044*	*2,024*	2,101	2,085	2,094	2,083	2,071	2,059	1,621
Total Catch	1636.269	798.94388	646.52739	618.91734	698.90689	781.000162	481.99312	1907.51277	1609.71551	721.43709	NA
1-SPR	0.75	0.46	0.42	0.41	0.42	0.44	0.29	0.84	0.75	0.43	NA
Exploitation Rate	0.01	0.01	0.01	0.01	0.01	0.01	0	0.02	0.01	0.01	NA
Age 1+ Biomass (mt)	115,646	114,506	114,192	114,014	113,845	113,577	113,209	113,128	111,600	110,373	255,602
Spawning Output	13,409	13,410	13,427	13,433	13,451	13,474	13,507	13,556	13,567	13,585	13,613
Interval	7,928–18,891	7,917–18,902	7,922–18,932	7,915–18,951	7,919–18,983	7,926–19,021	7,945–19,069	7,979–19,133	7,976–19,159	7,979–19,191	7,994–19,232
Recruits	8,984	8,984	8,995	8,999	9,010	9,024	9,044	9,074	9,081	9,092	9,109
Interval	6,584–12,260	6,581–12,267	6,587–12,282	6,587–12,293	6,594–12,310	6,604–12,330	6,620–12,356	6,646–12,389	6,648–12,404	6,654–12,423	6,666–12,446
Fraction Unfished	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Interval	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5

a/ Spiny dogfish have been managed with stock-specific harvest specifications since 2015.

9 Figures

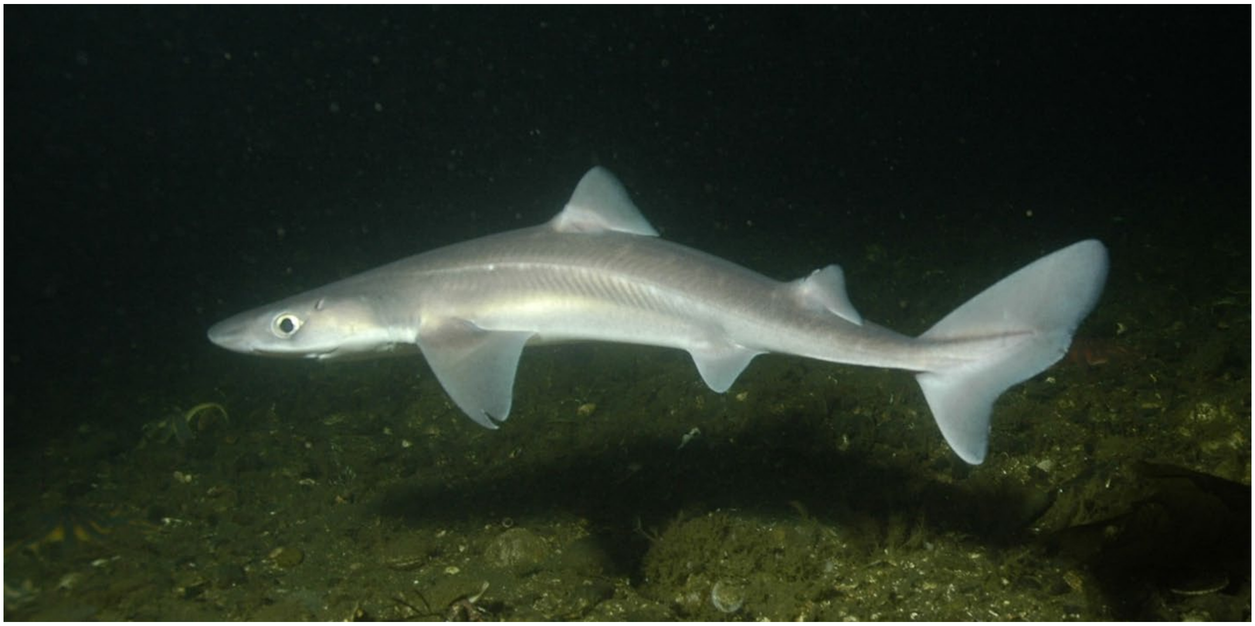

Figure 1. Photo of Pacific spiny dogfish (photo credit: Greg Amptman, Seattle diver).

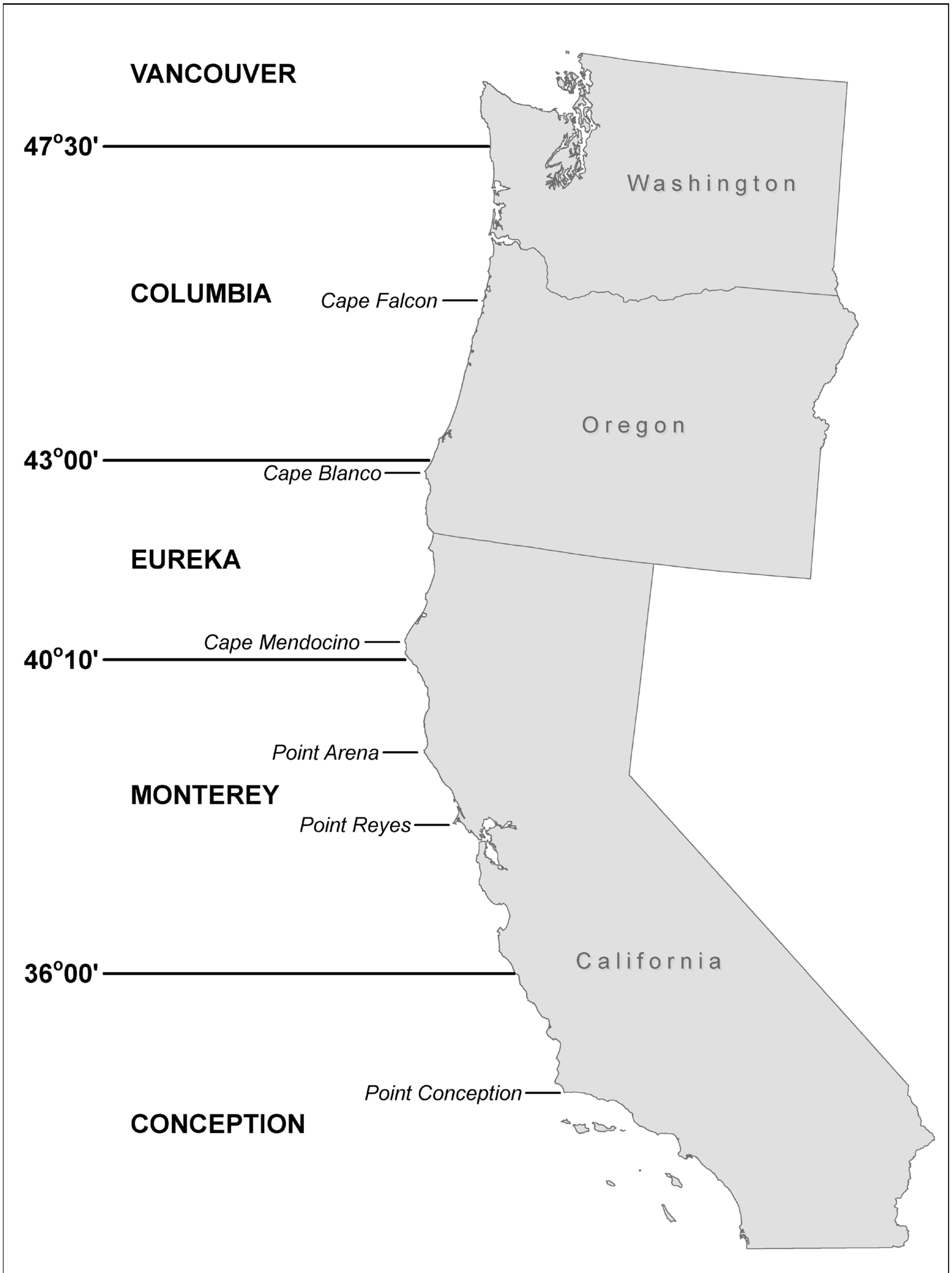

Figure 2. A map of the assessment area that includes coastal waters off three U.S. west coast states and five International North Pacific Fisheries Commission (INPFC) areas.

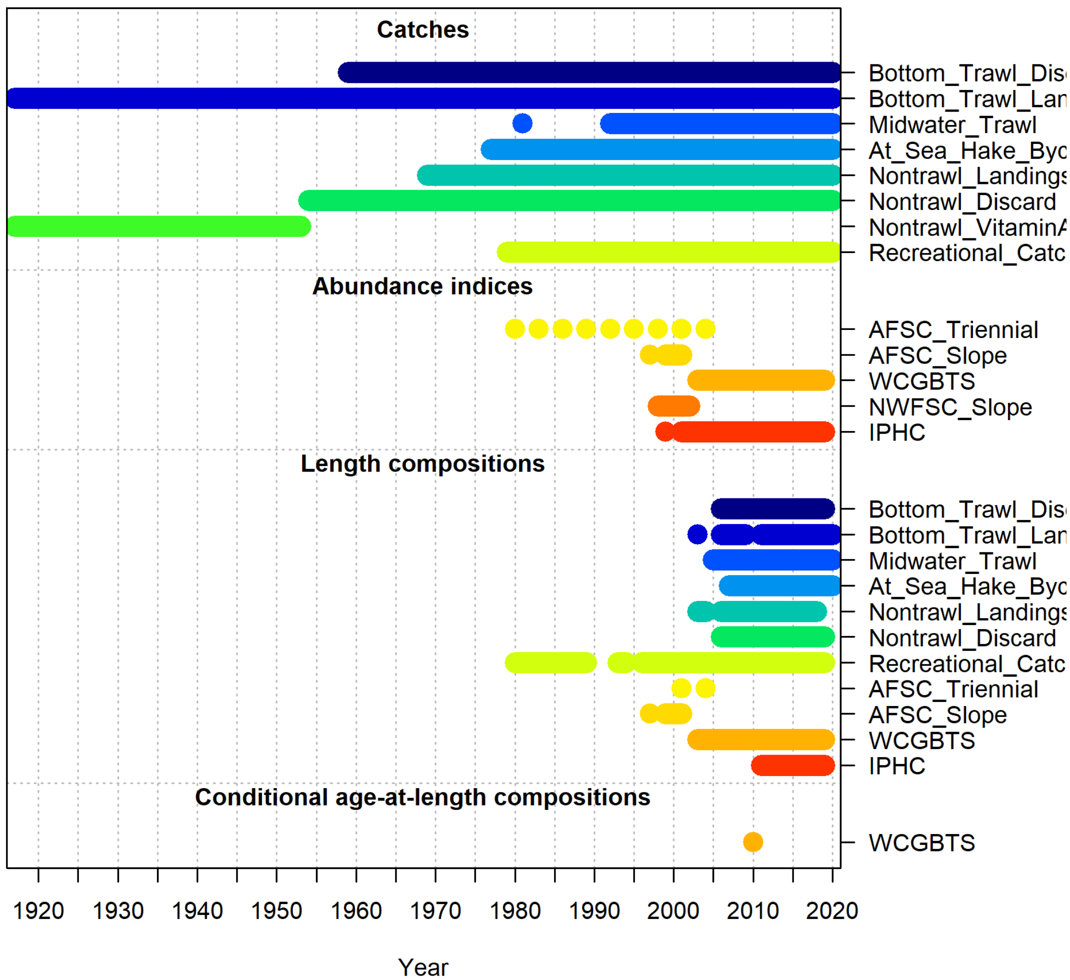

Figure 3. The summary of fishery-dependent and fishery-independent data used in the assessment.

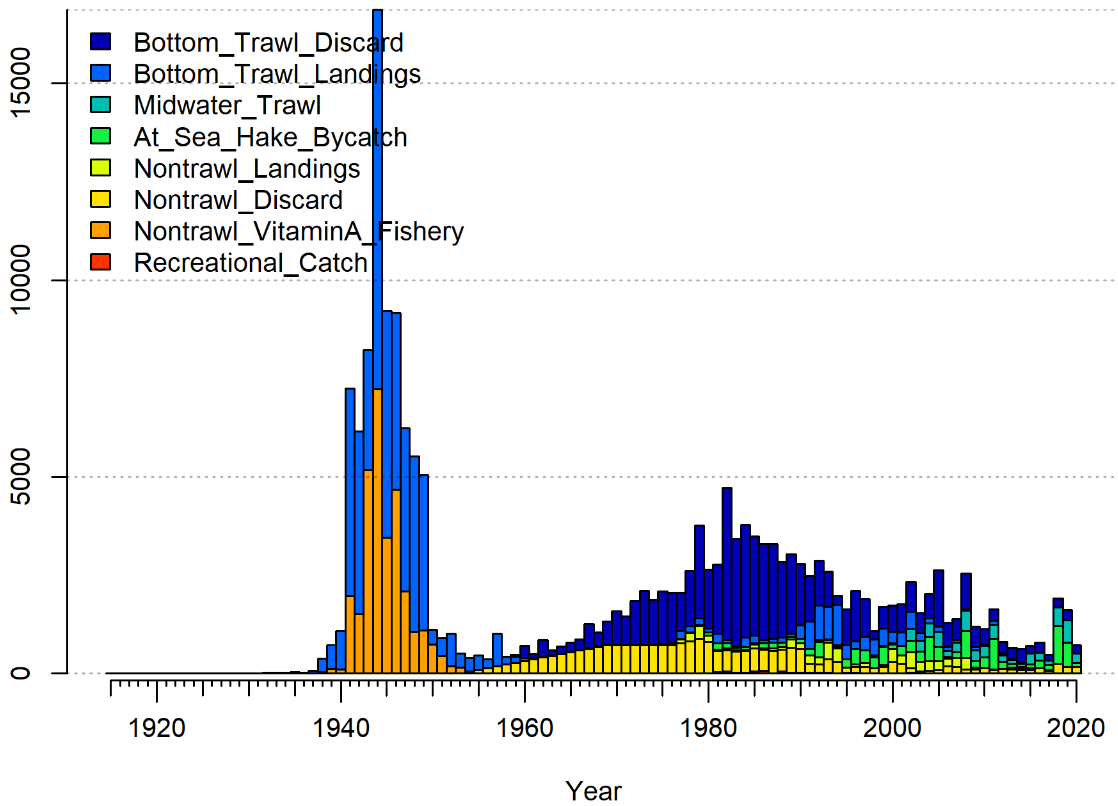

Figure 4. The reconstructed time series of spiny dogfish removals (mt) by fleet.

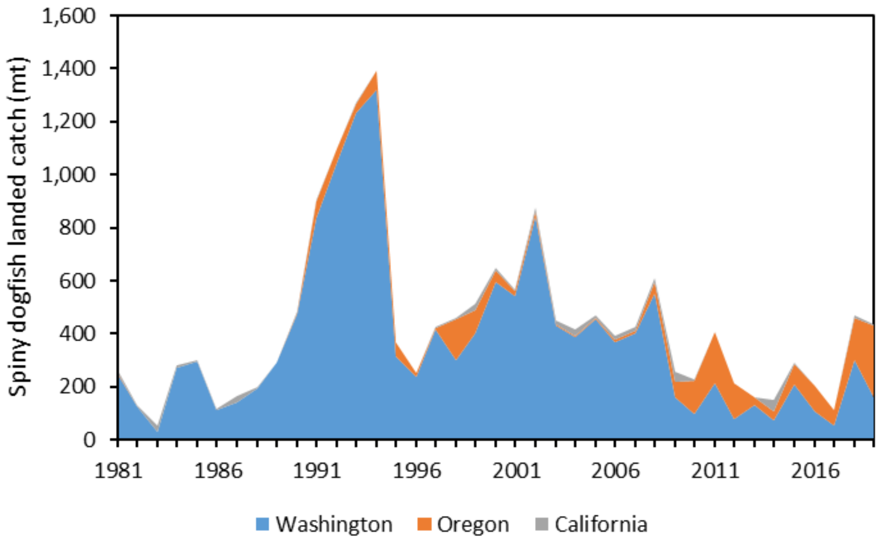

Figure 5. Recent commercial landings of spiny dogfish by state, reported in PacFIN.

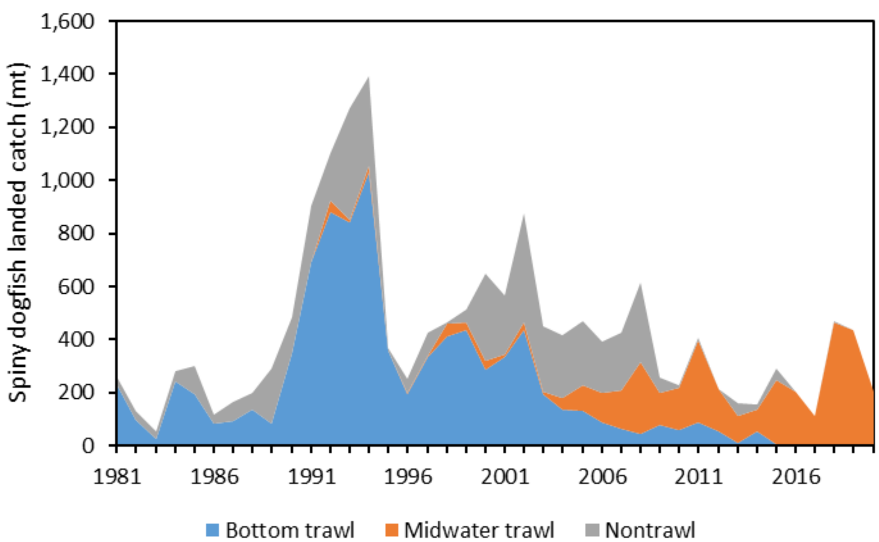

Figure 6. Recent commercial landings of spiny dogfish by major gear group, reported in PacFIN.

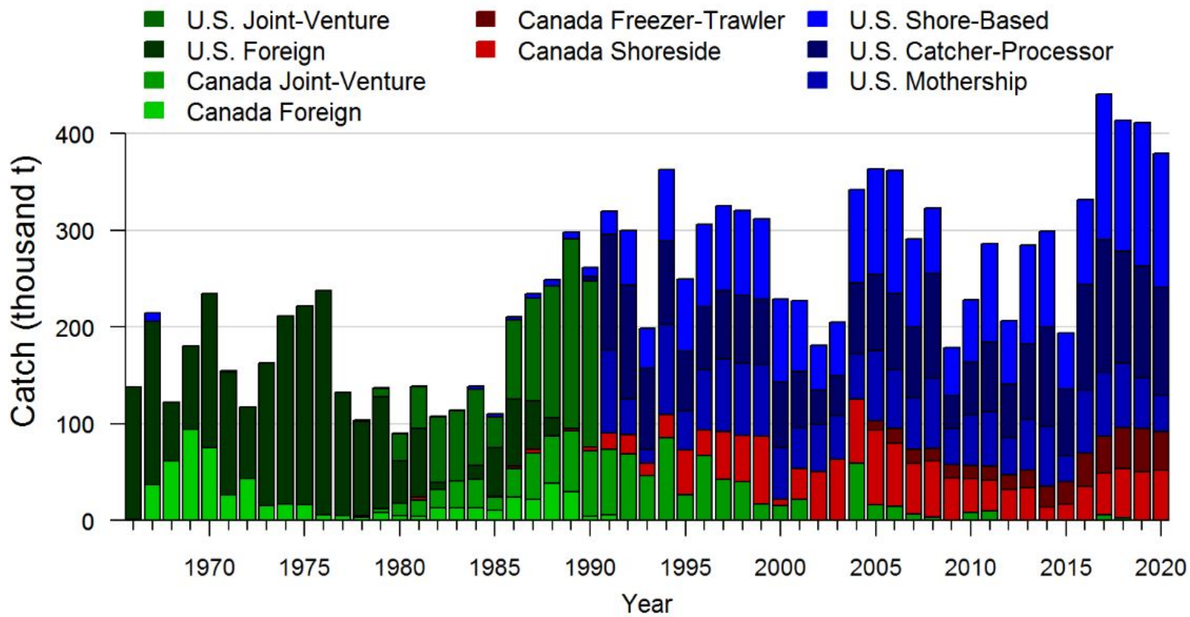

Figure 7. Pacific hake catch time series by sector, as presented in 2021 hake assessment (Johnson et al. 2021).

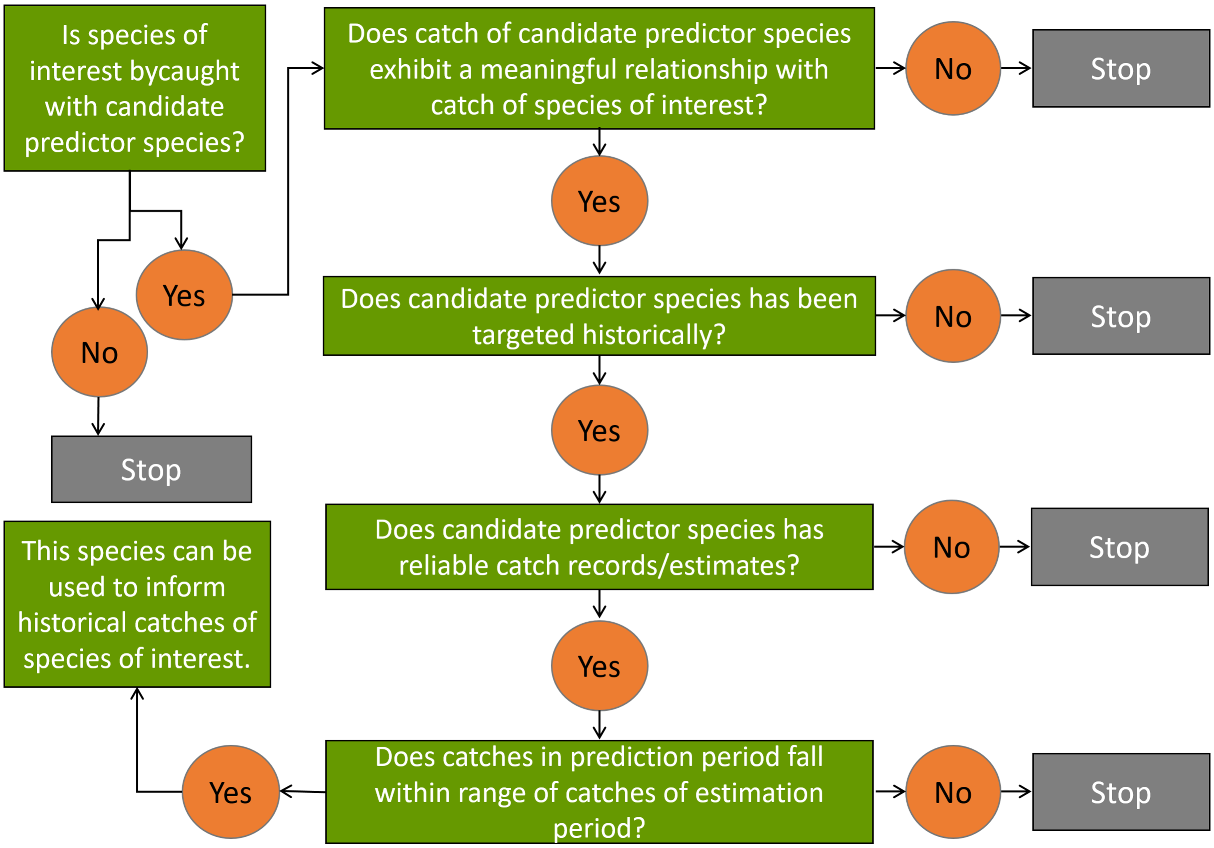

Figure 8. Process-flow chart, overviewing screening method for reconstructing historical spiny dogfish catch.

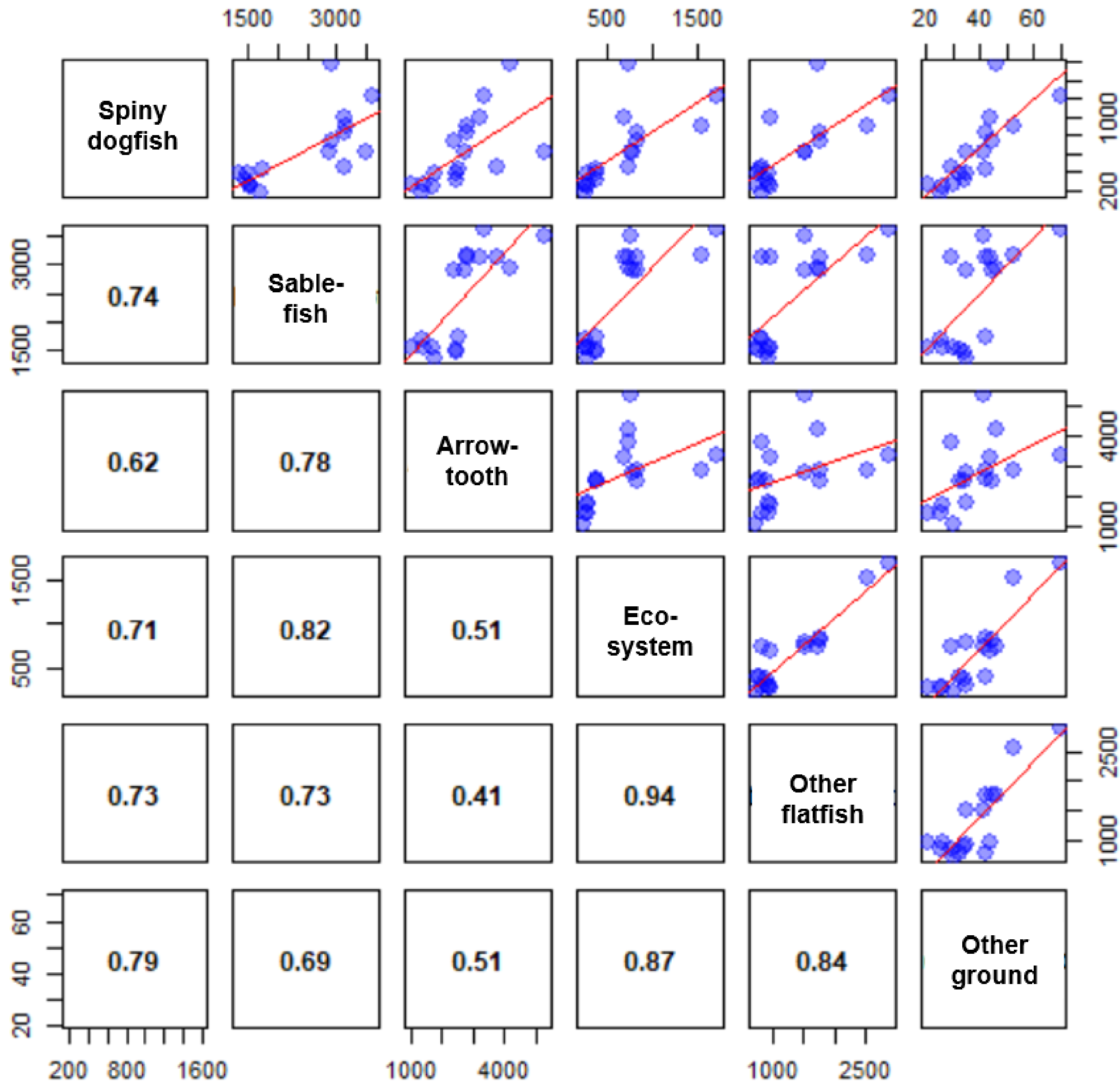

Figure 9. Matrix of scatter plots illustrating relationships in annual total catch (mt), among selected potential target predictor species, from observer data, 2002-2019. Pearson's correlation coefficients appear in the lower panels, and scatterplots with linear trendlines (red) in the upper panels.

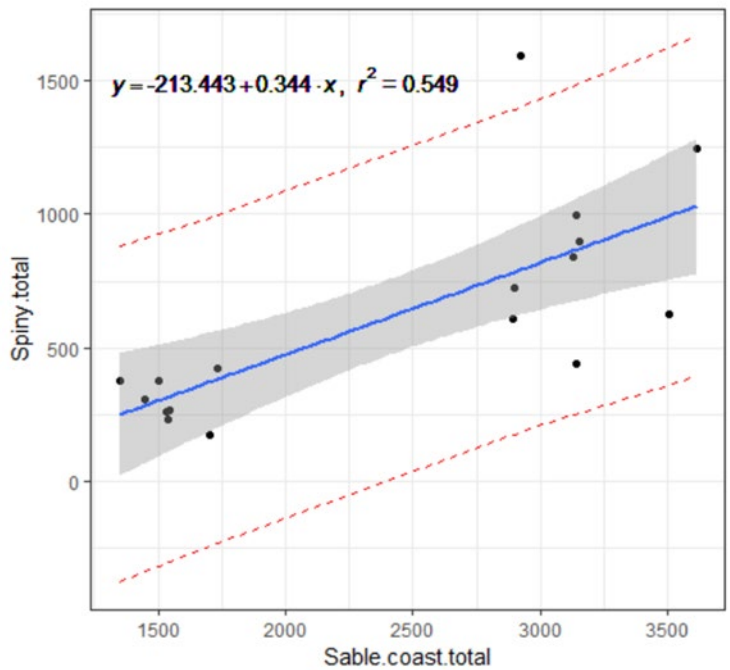

Figure 10. Relationship between catches by bottom trawl of spiny dogfish and sablefish used to inform historical discard of spiny dogfish in the assessment.

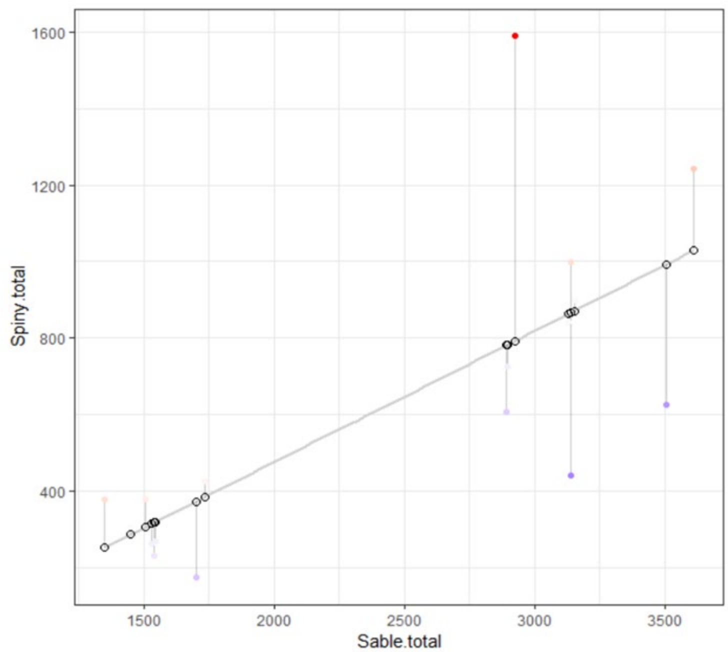

Figure 11. The residuals of the total catch relationship between sablefish and spiny dogfish from the WCGOP data used to reconstruct historical spiny dogfish catch.

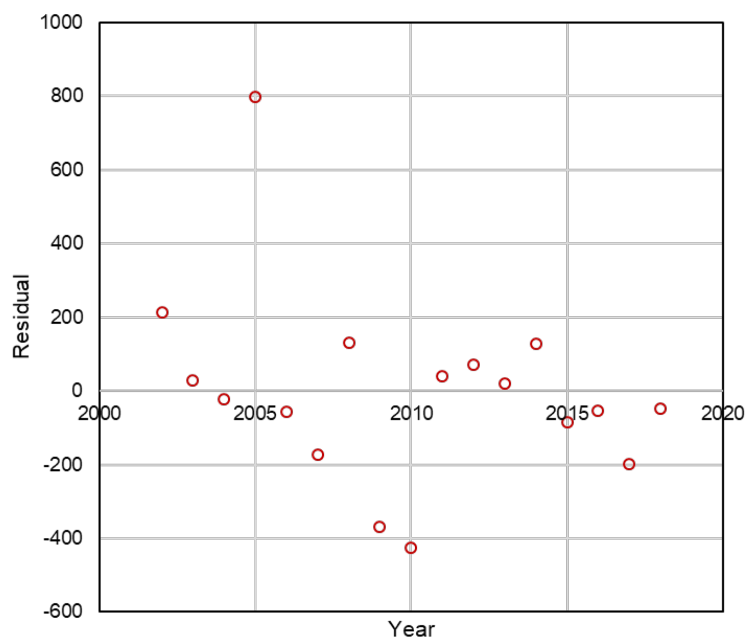

Figure 12. Time series of the residuals of the total catch relationship between sablefish and spiny dogfish from the WCGOP data used to reconstruct historical spiny dogfish catch.

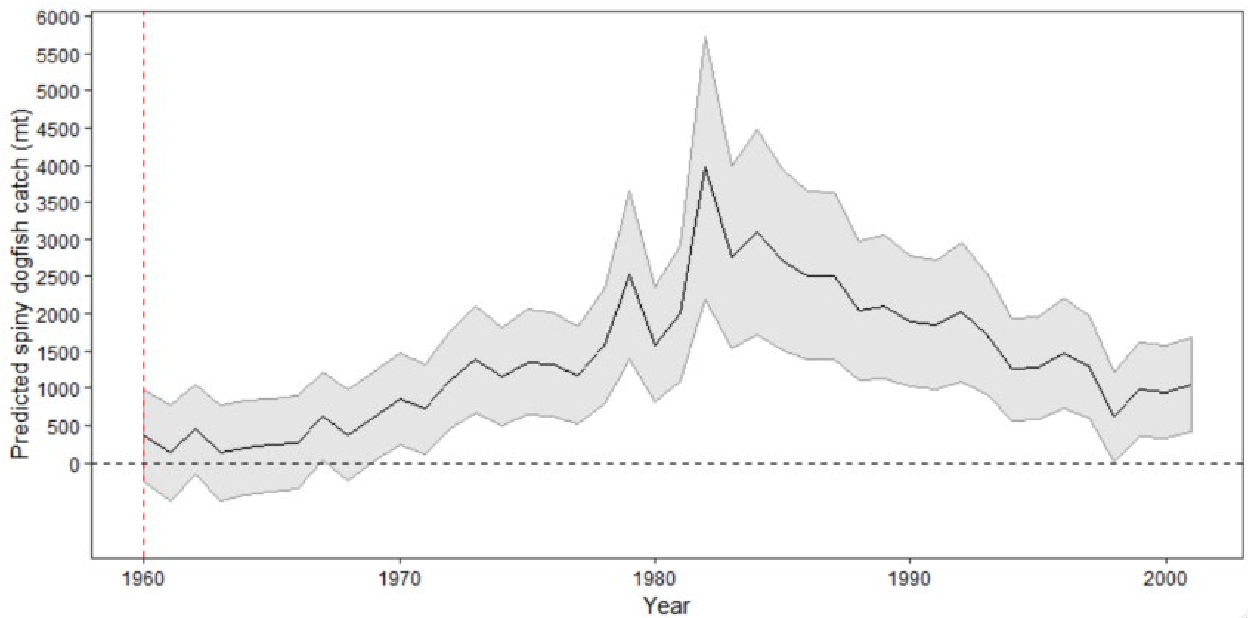

Figure 13. Reconstructed time series of spiny dogfish total catch within bottom trawl fleet, based on sablefish catch, with predicted intervals.

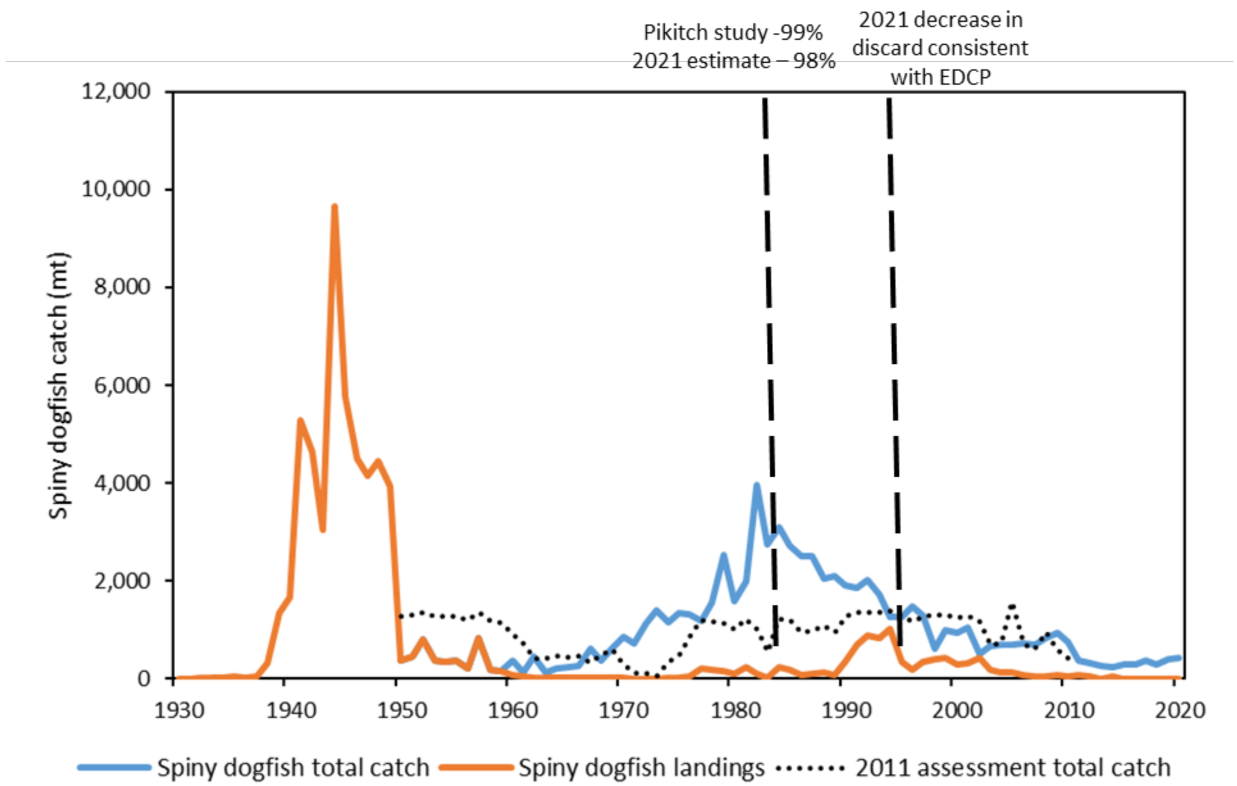

Figure 14. Reconstructed (based on sablefish catch) time series of spiny dogfish total catch along with spiny dogfish landings within bottom trawl fleet. Small dashed line shows the total catch used in 2011 assessment. Large dashed vertical line indicate time periods of historical discard studies, including Pikitch study and Enhanced Data Collection Project (EDCP).

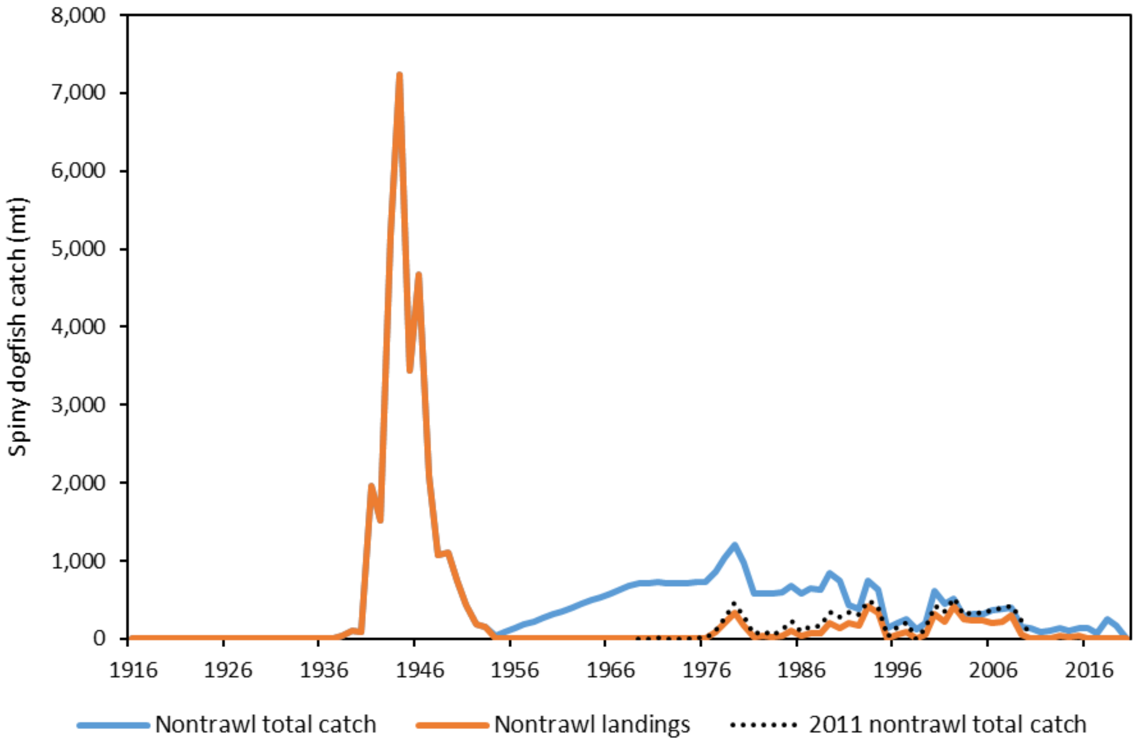

Figure 15. Reconstructed time series of spiny dogfish total catch along with spiny dogfish landings within the non-trawl fleet. Small dashed line shows the total catch used in the 2011 assessment.

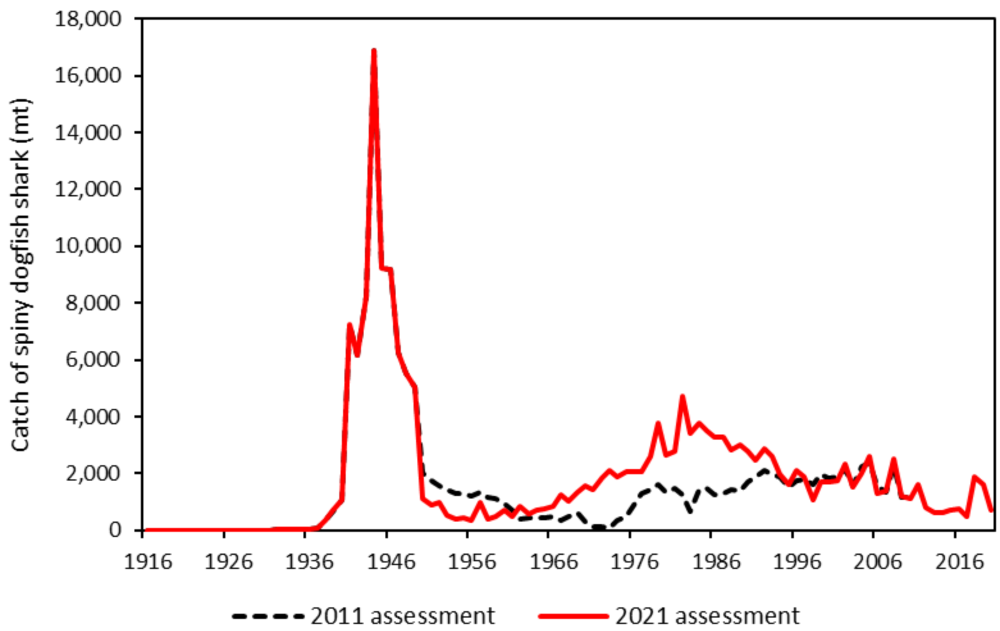

Figure 16. Comparison of spiny dogfish total catch between the 2021 and 2011 assessments.

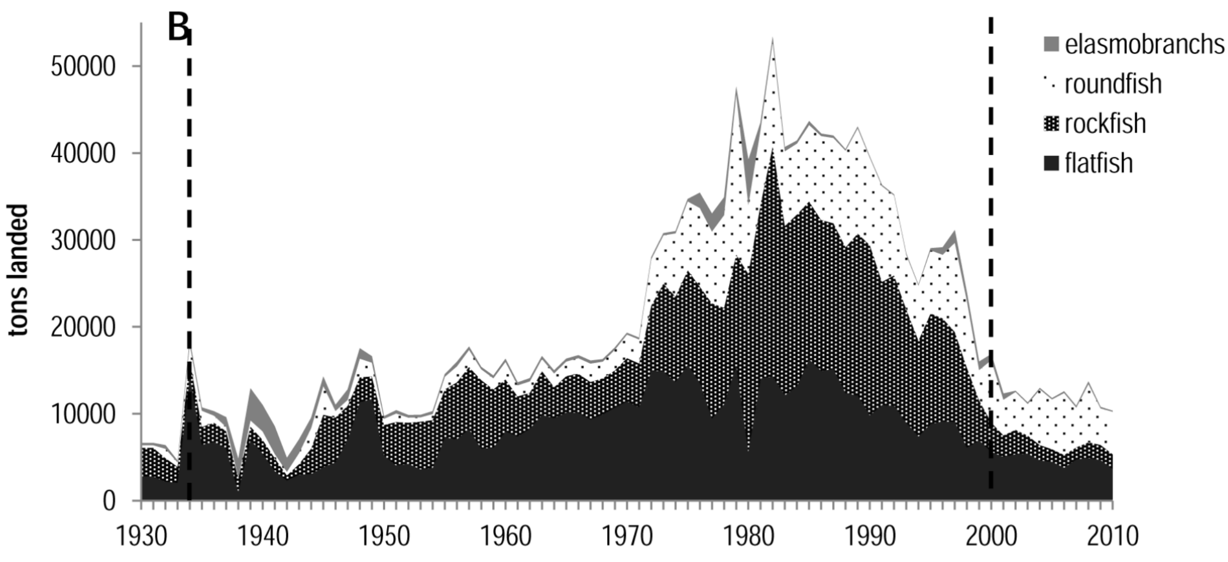

Figure 17. California commercial groundfish landings (mt) as reported in Miller et al. (2014) illustrating the development of groundfish fisheries along the U.S. West Coast. The peak in fishery in the 1980s is consistent with estimated total catch of spiny dogfish catch reconstructed as part of this assessment (shown in Figure 16).

Figure 18. Spiny dogfish bycatch within at-sea Pacific hake fishery.

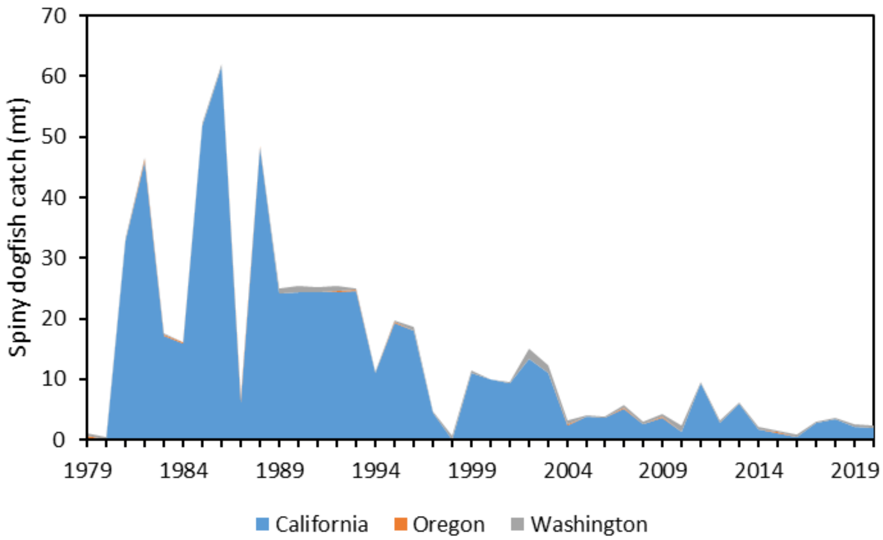

Figure 19. Recreational removals of spiny dogfish by state.

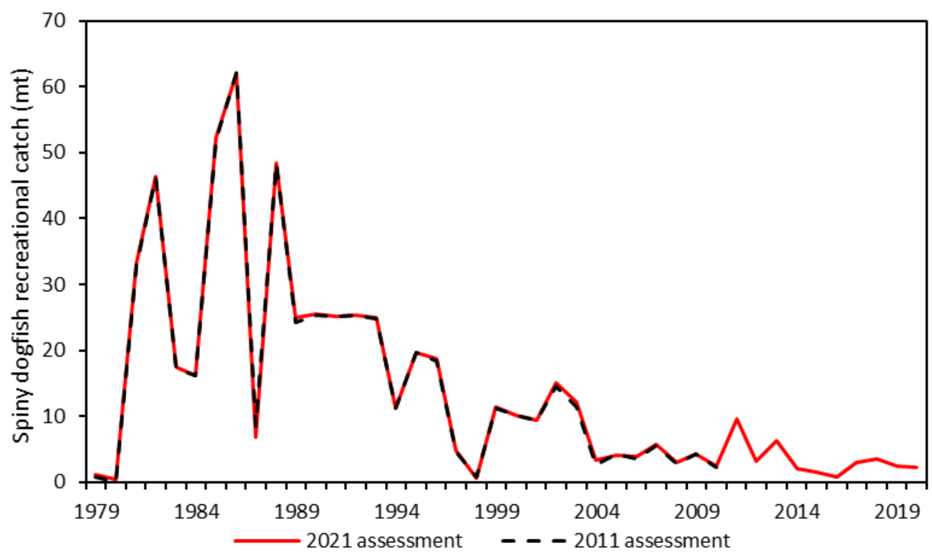

Figure 20. Comparison of recreational catch time series used in this and 2011 assessments.

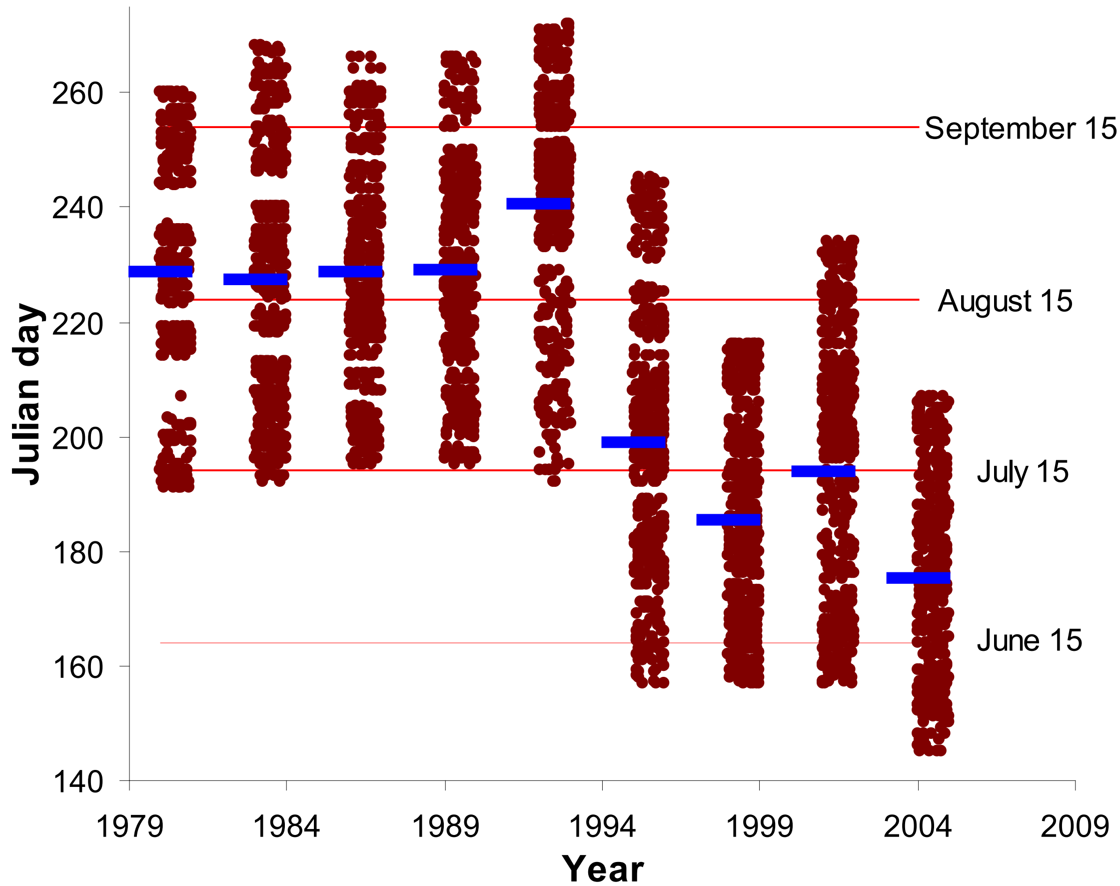

Figure 21. Timing of the AFSC Triennial Survey (1980-2004): solid bars represent the mean date for each survey year, points - individual hauls dates, jittered to allow better delineation of the distribution of individual points.

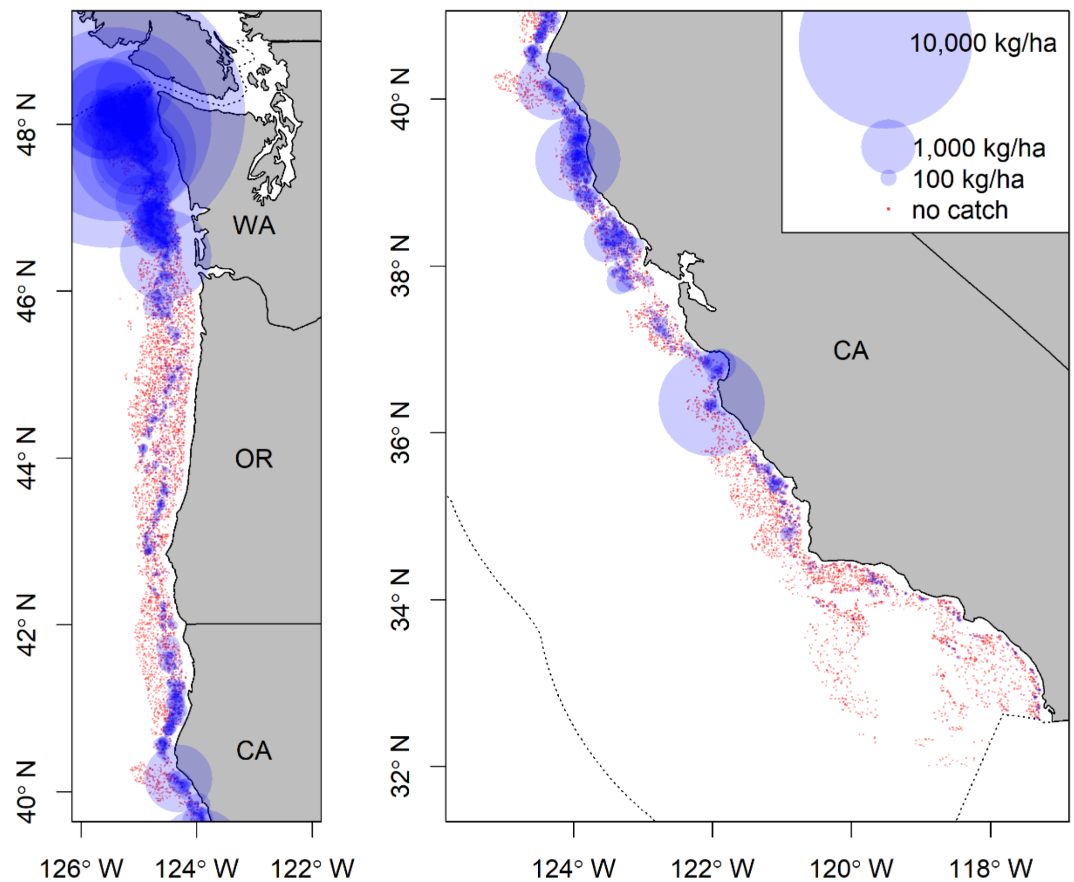

Figure 22. Density of spiny dogfish (blue) relative to the distribution of all hauls (red) for all years of the WCGBT Survey (2003-2019). The U.S. EEZ is shown by the dotted black line.

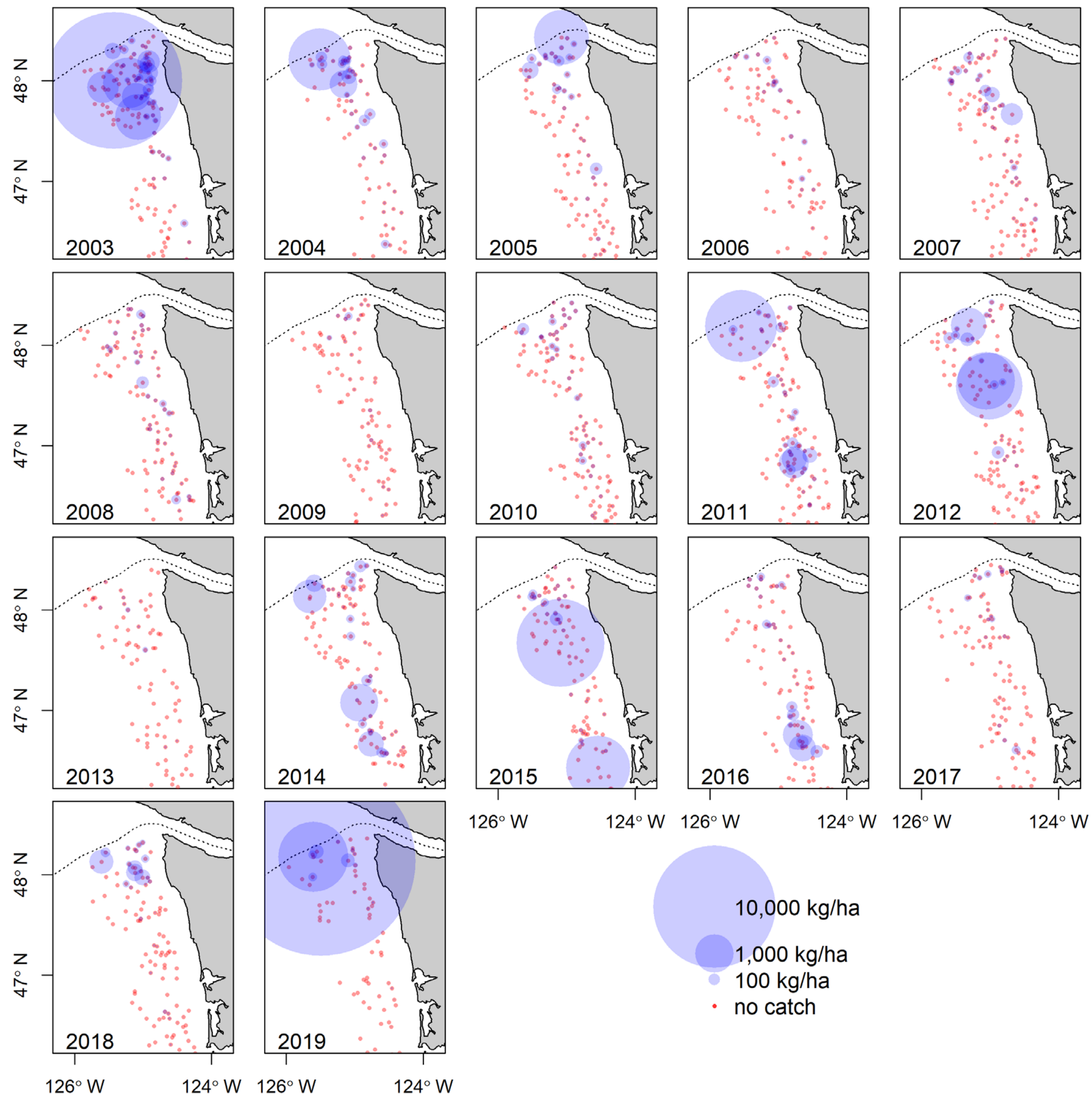

Figure 23. Density of spiny dogfish (blue) relative to the distribution of all hauls (red) off the coast of Washington State for each year of the WCGBT Survey. The U.S. EEZ is shown by the dotted black line.

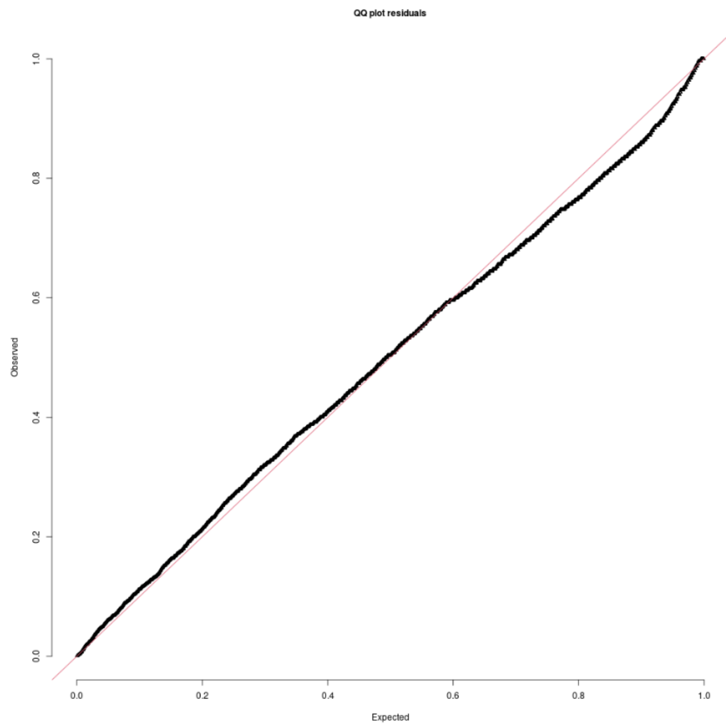

Figure 24. Q-Q plot for lognormal model used in VAST for the AFSC Triennial Survey.

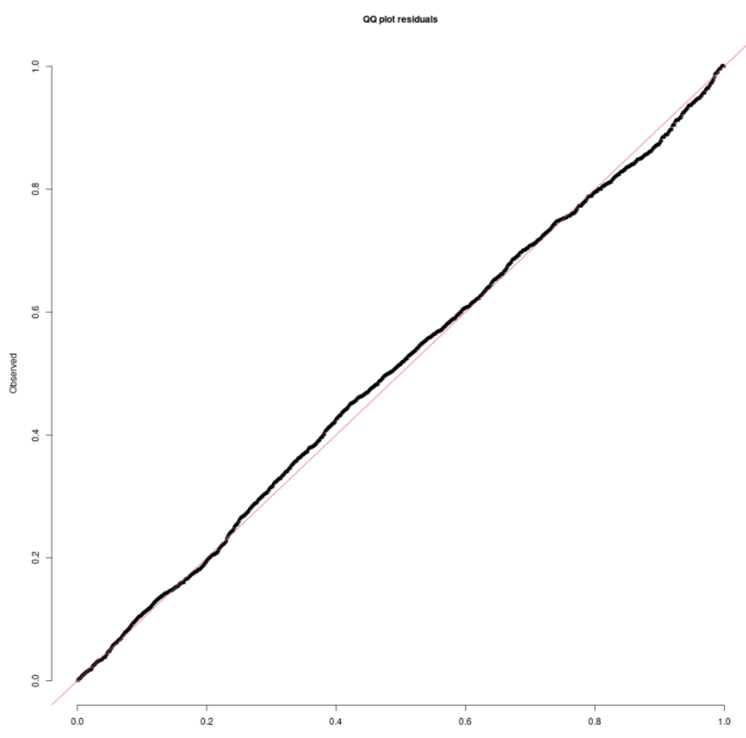

Figure 25. Q-Q plot for lognormal model used in VAST for the AFSC Slope Survey.

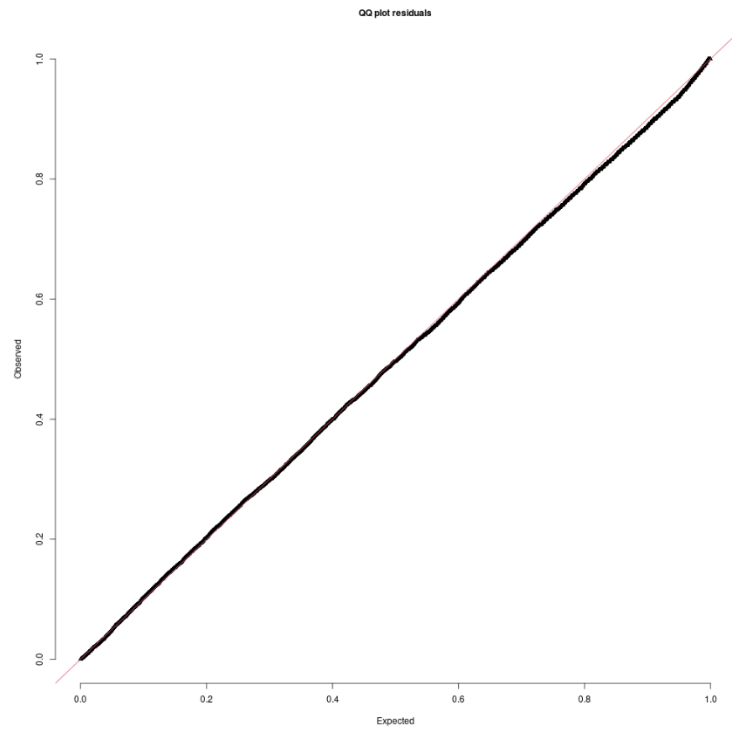

Figure 26. Q-Q plot for lognormal model used in VAST for the WCGBT Survey.

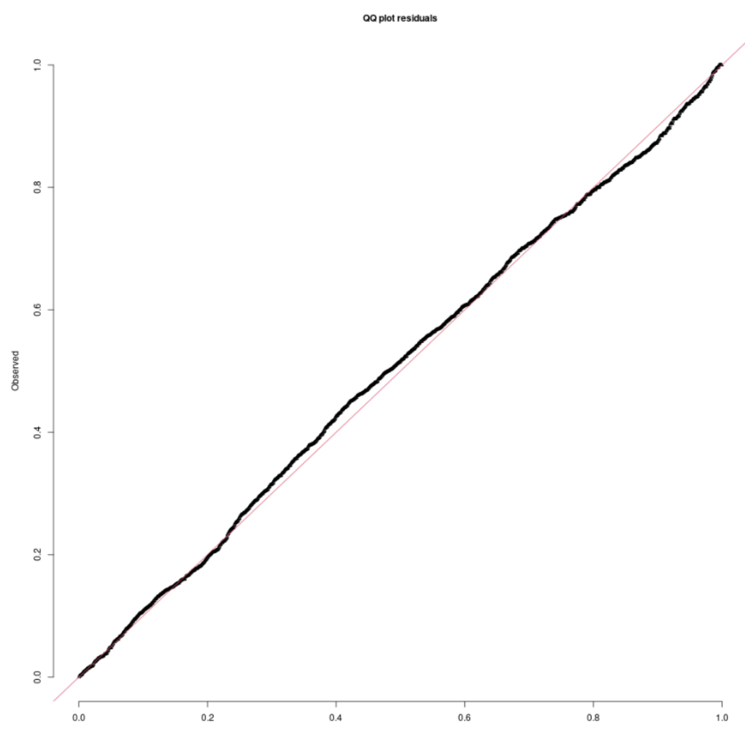

Figure 27. Q-Q plot for lognormal model used in VAST for the NWFSC Slope Survey.

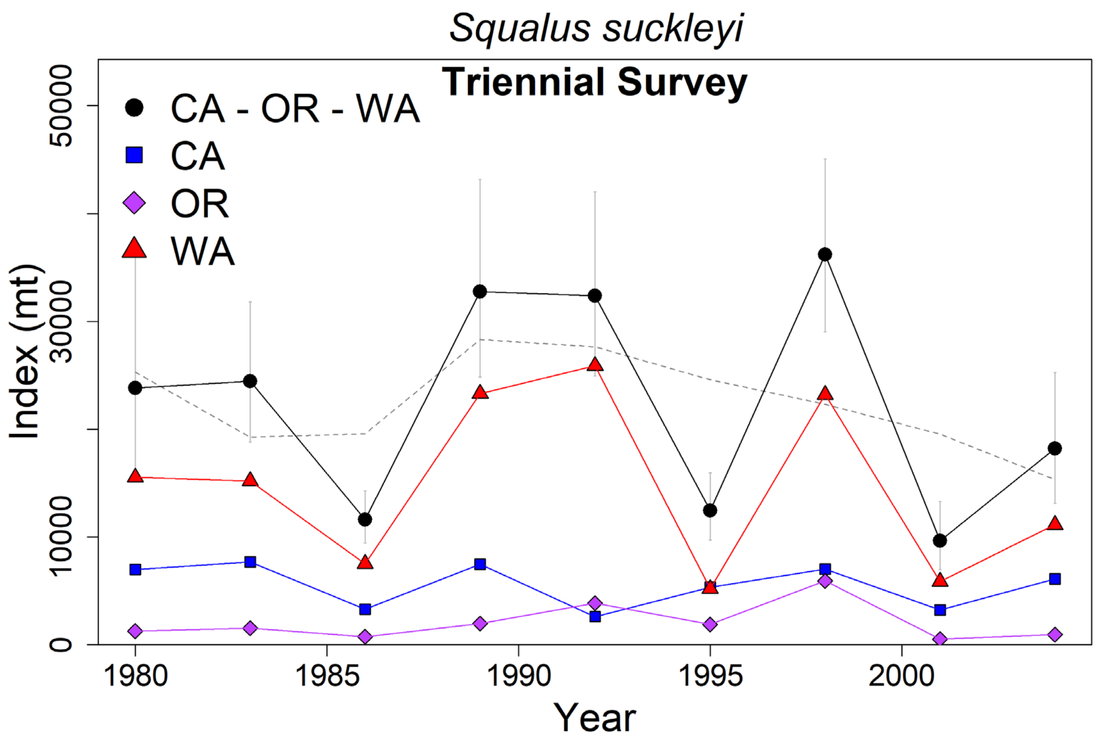

Figure 28. Estimated index of biomass for AFSC Triennial Survey.

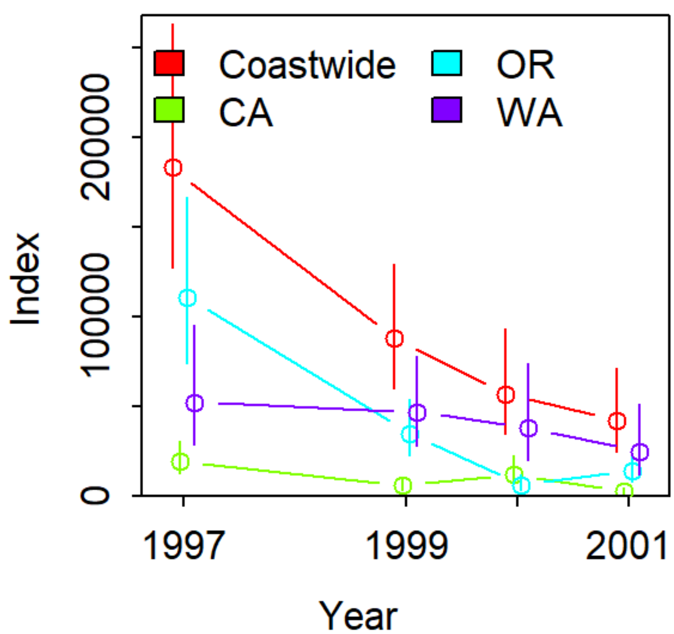

Figure 29. Estimated index of biomass for AFSC Slope Survey.

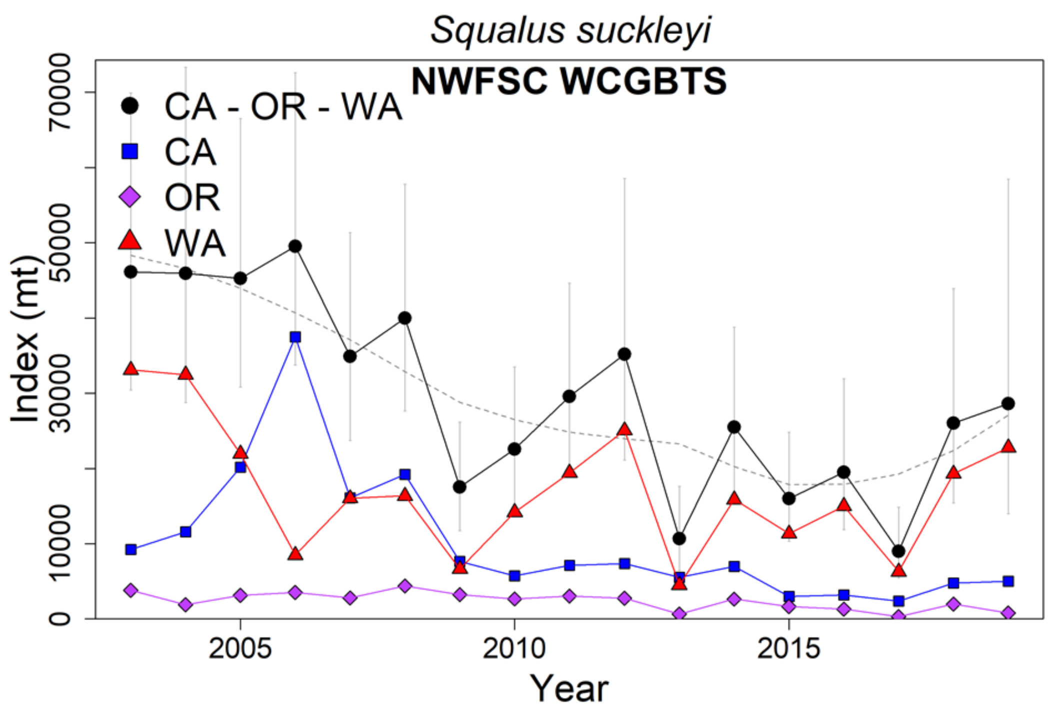

Figure 30. Estimated index of biomass for WCGBT Survey.

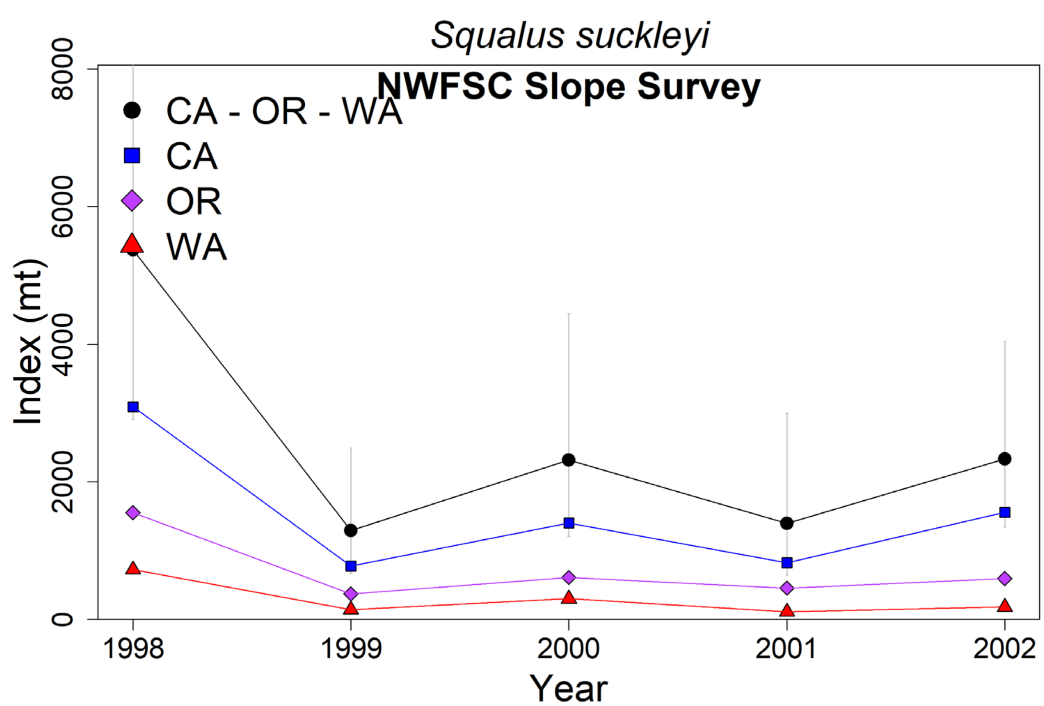

Figure 31. Estimated index of biomass for NWFSC Slope Survey.

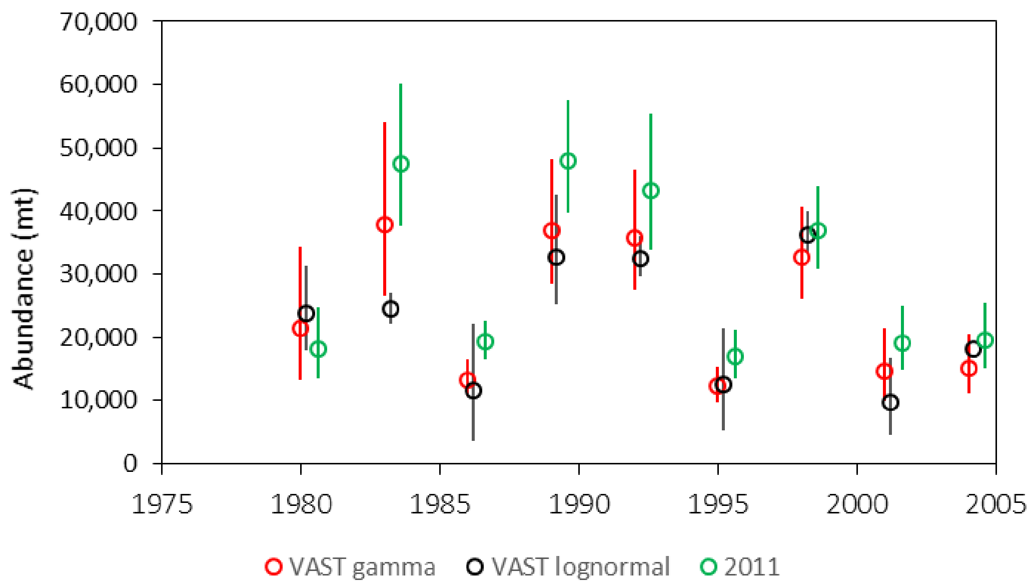

Figure 32. Comparison of AFSC Triennial Survey index estimated using VAST with lognormal and gamma error structure, and index used in 2011.

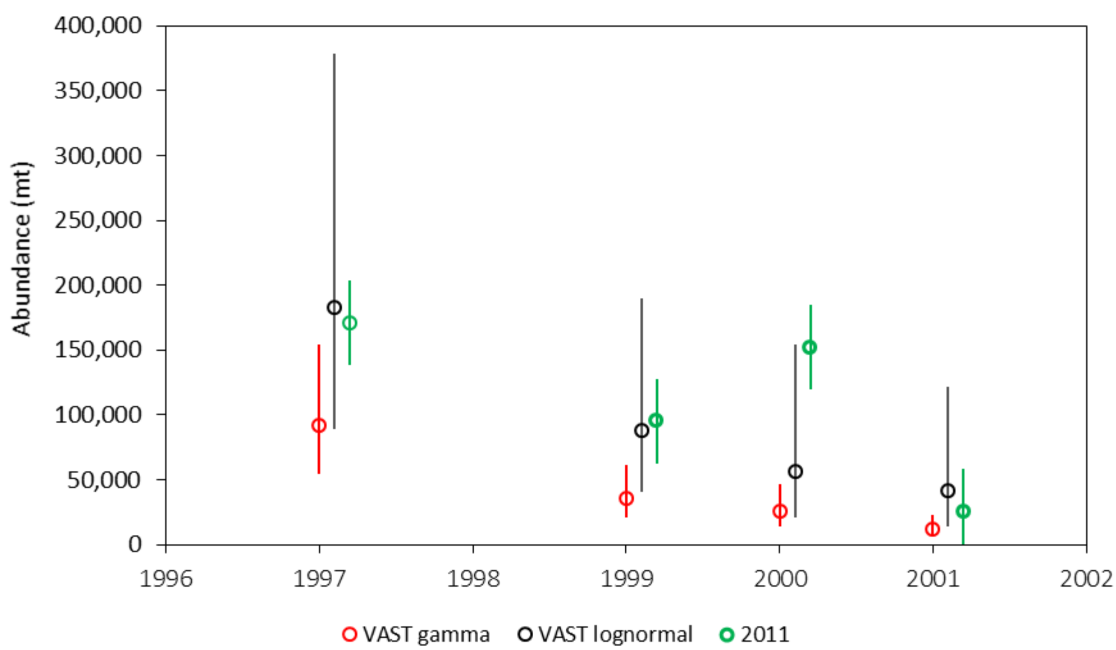

Figure 33. Comparison of AFSC Slope Survey index estimated using VAST with lognormal and gamma error structure, and index used in 2011.

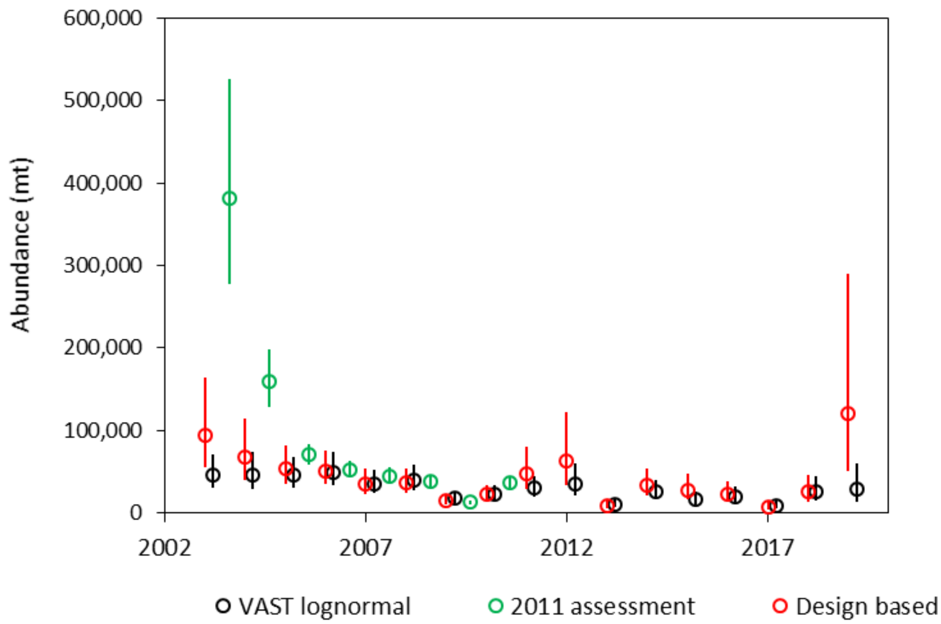

Figure 34. Comparison of WCGBT Survey index estimated using VAST with lognormal and gamma error structure, and index used in 2011.

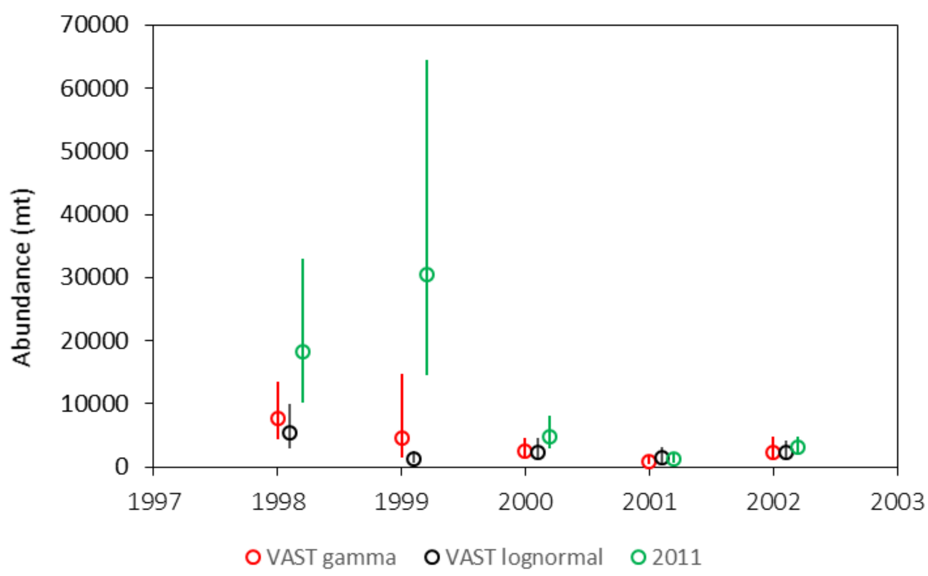

Figure 35. Comparison of NWFSC Slope Survey index estimated using VAST with lognormal and gamma error structure, and index used in 2011.

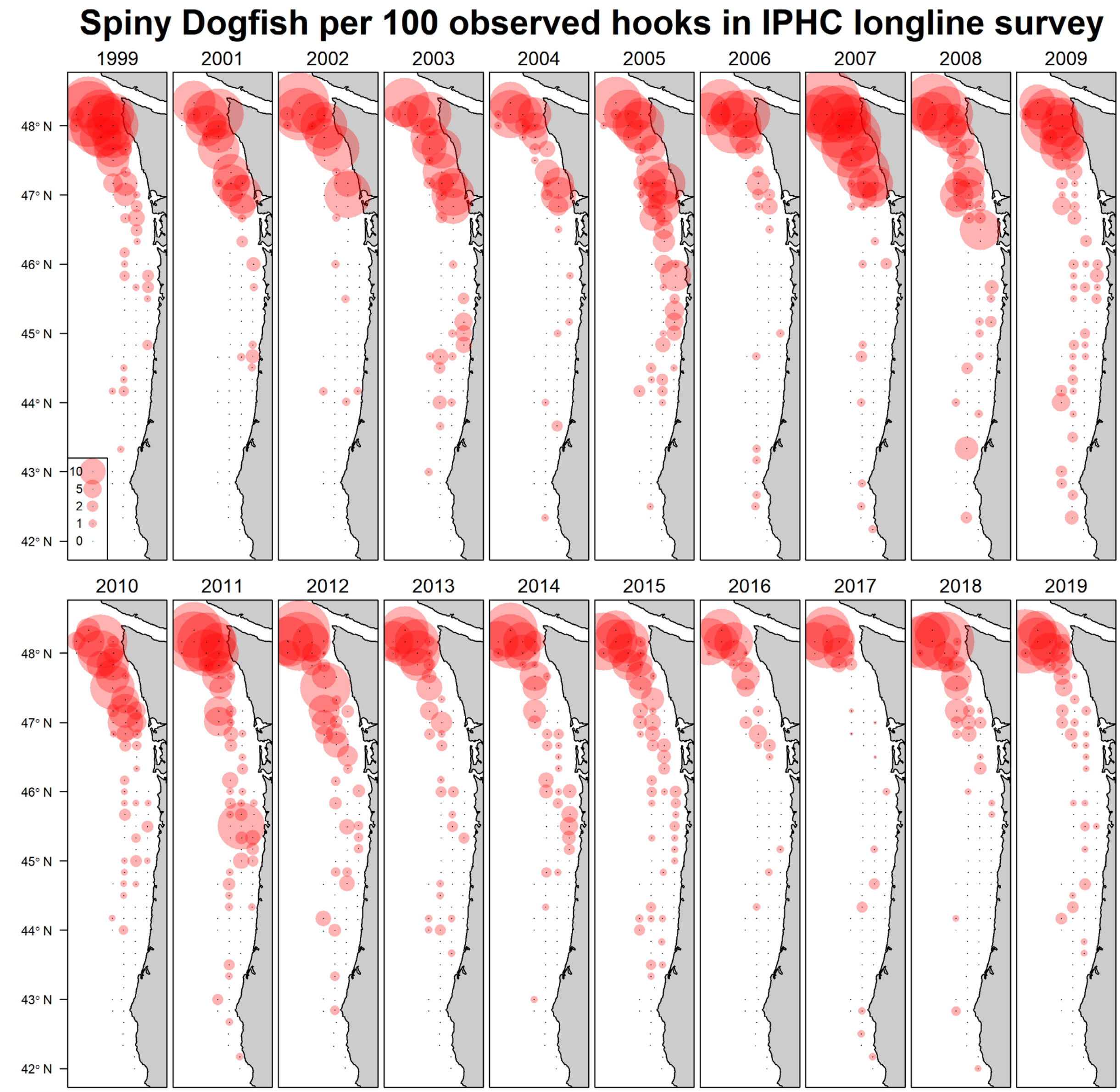

Figure 36. Spatial distribution of spiny dogfish catches by year within the International Pacific Halibut Commission (IPHC) hook-and-line survey (expressed as the number of dogfish per 100 observed hooks).

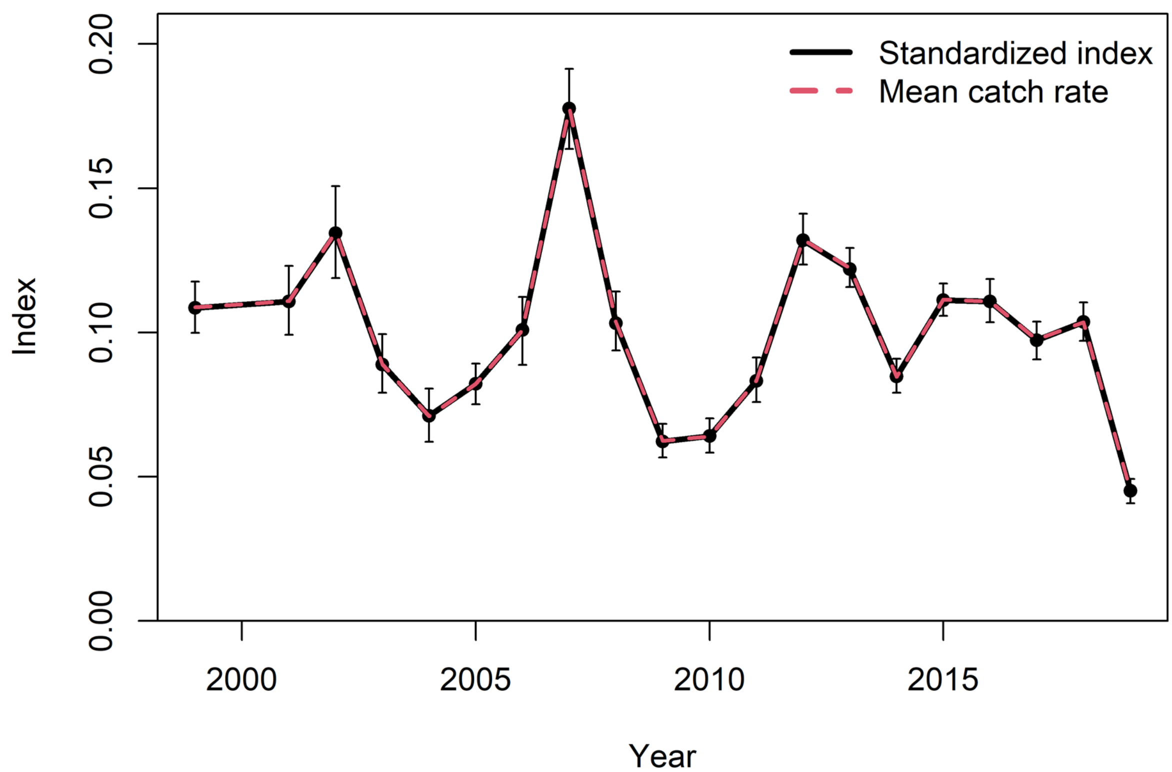

Figure 37. Estimated index of abundance for IPHC Survey.

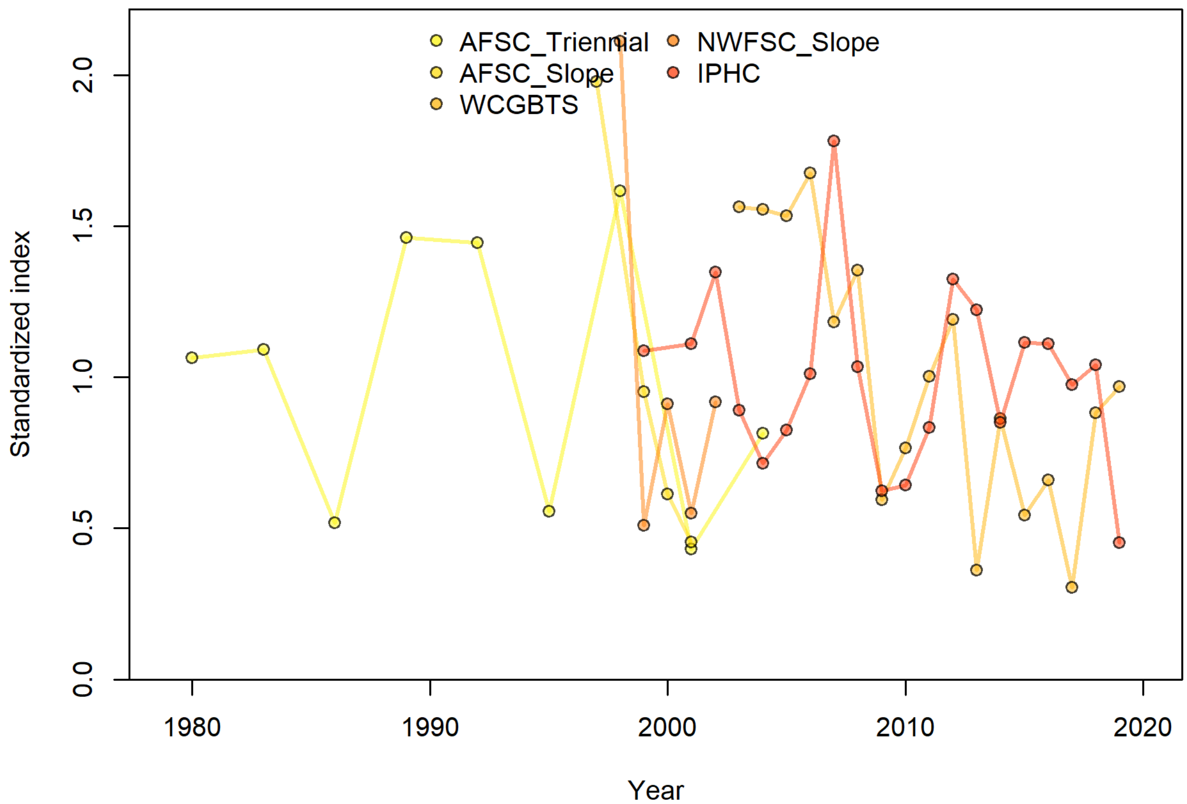

Figure 38. Standardized indices overlaid. Each index is rescaled to have mean observation = 1.0.

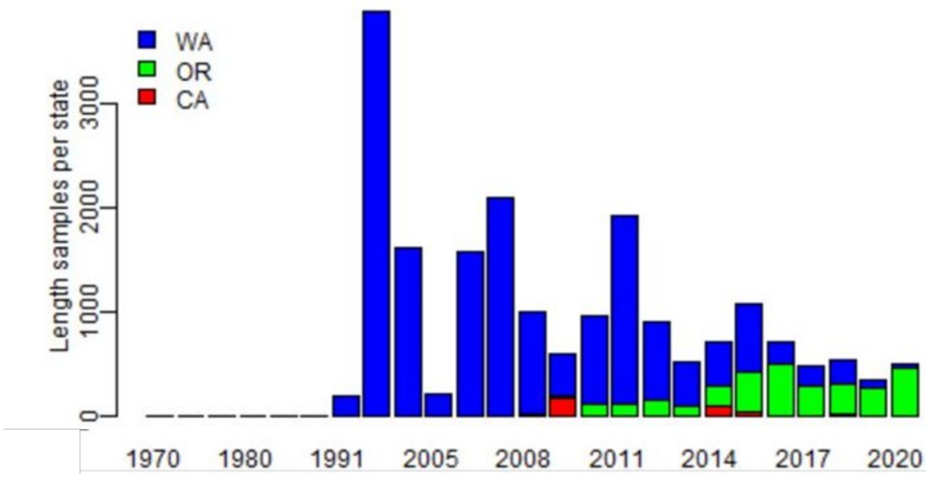

Figure 39. Commercial fishery length samples extracted from PacFIN, by state.

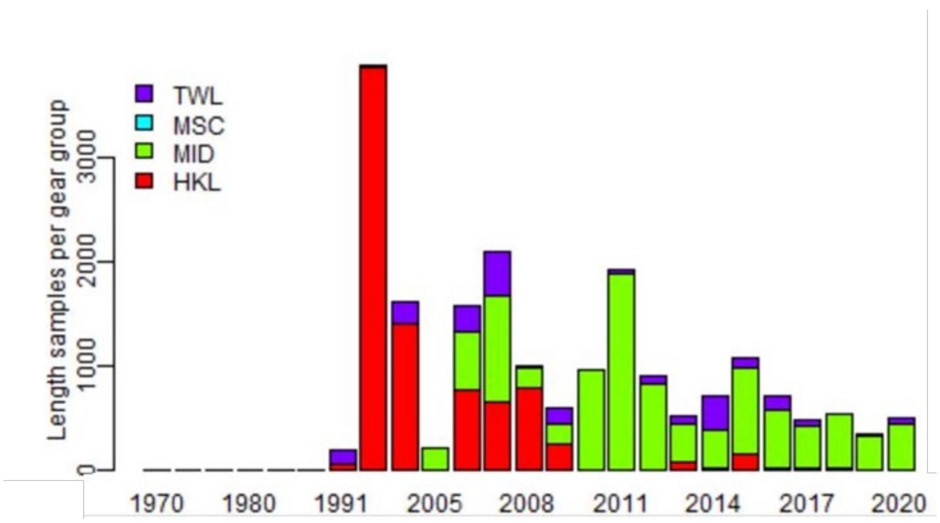

Figure 40. Commercial fishery length samples extracted from PacFIN, by major gear group.

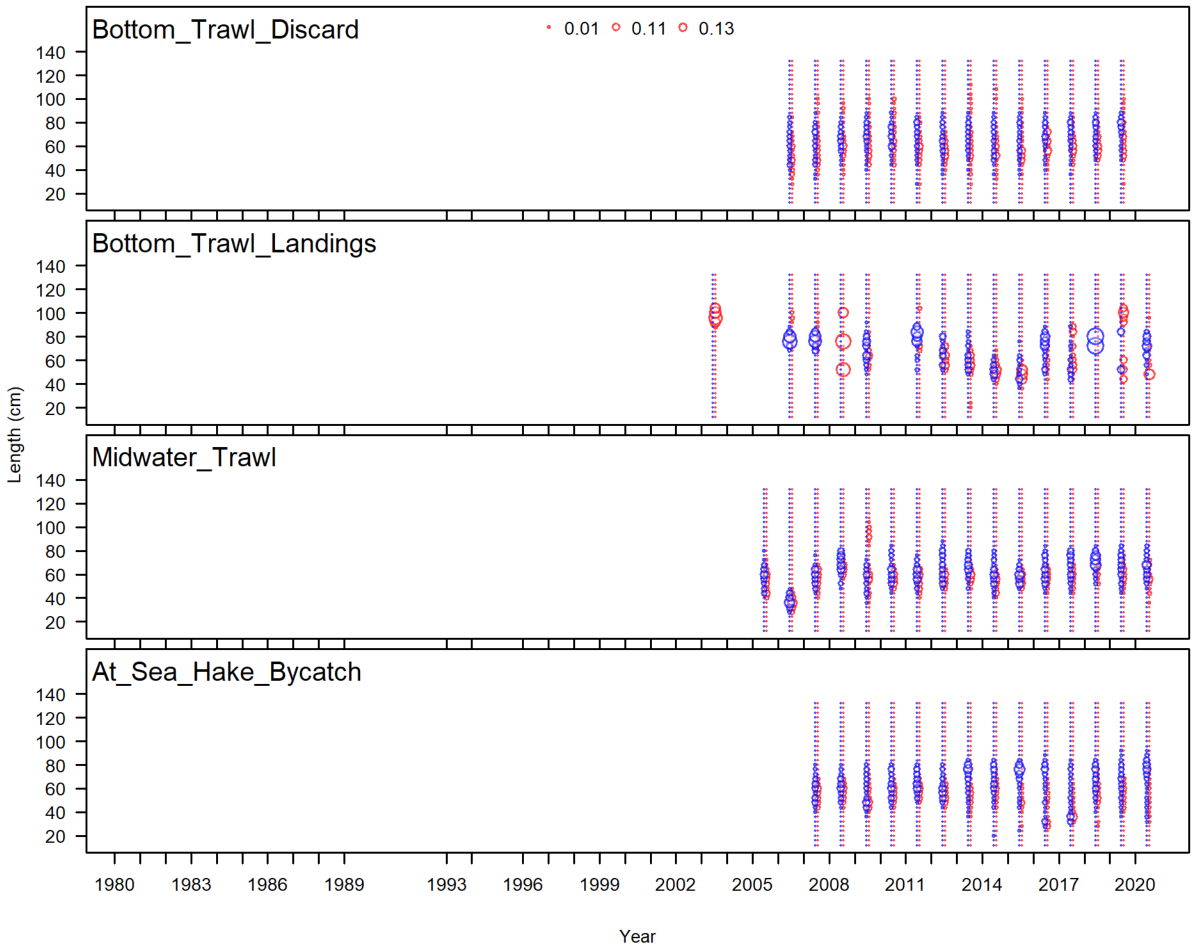

Figure 41. Length-frequency distributions for spiny dogfish catch by year from bottom trawl discard and landings, midwater trawl catches and bycatch within at-sea hake fishery.

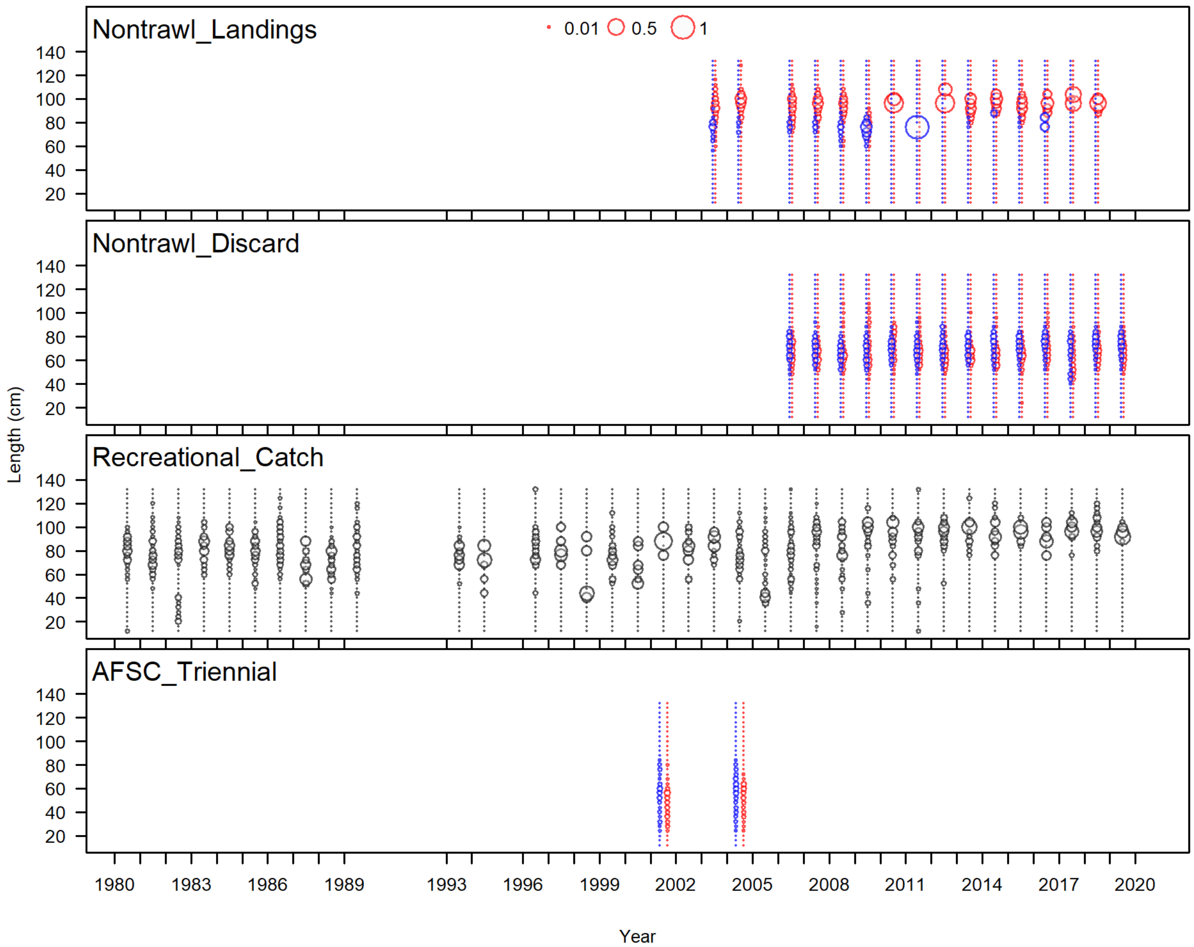

Figure 42. Length-frequency distributions for spiny dogfish catch by year from non-trawl landings and discard, recreational catches and AFSC Triennial Survey.

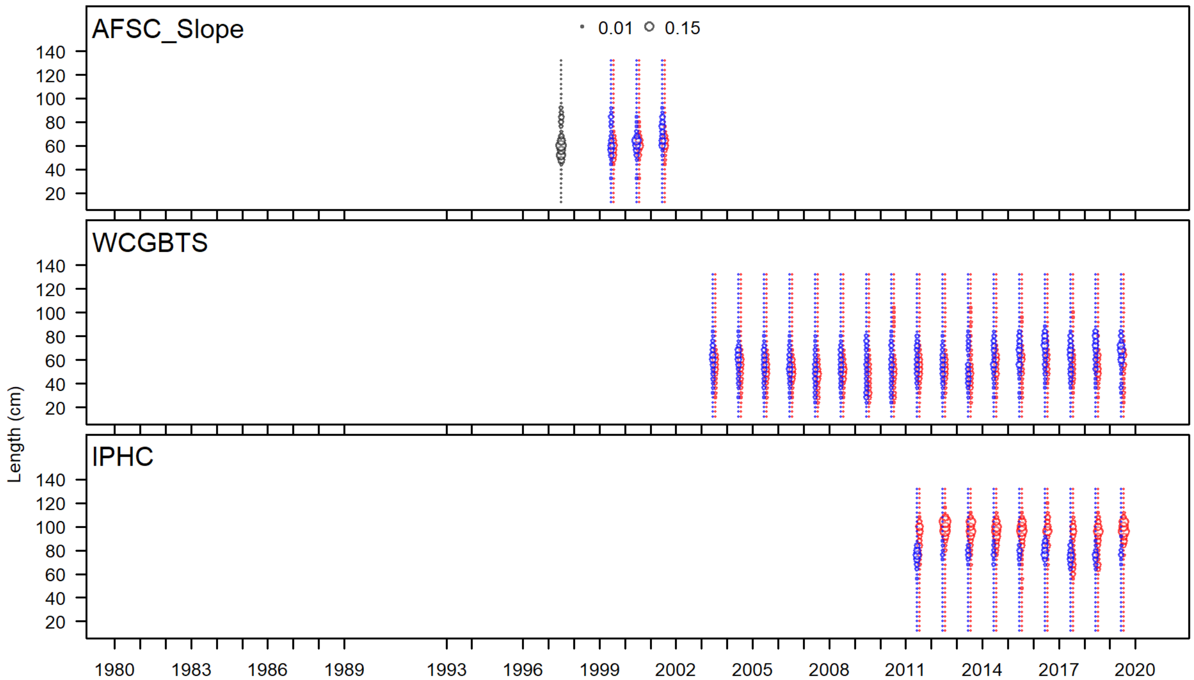

Figure 43. Length-frequency distributions for spiny dogfish catch by year from AFSC Slope Survey, WCGBT Survey and IPHC Survey.

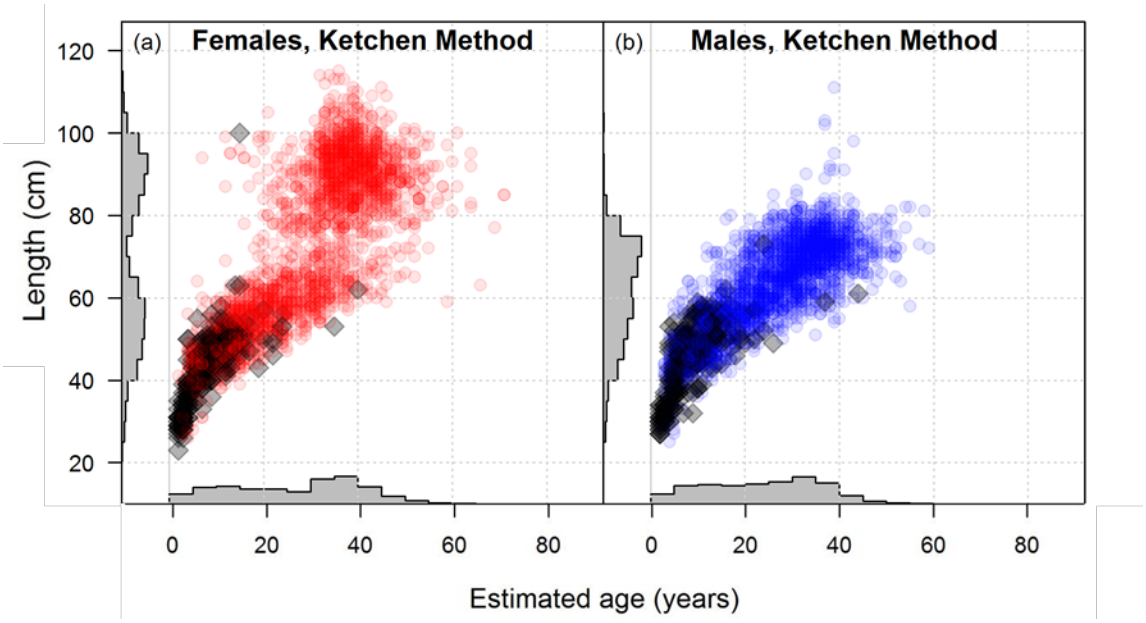

Figure 44. Age vs. length for males and females. Black points represent ages estimated from unworn spine (no extrapolation added), red and blue points represent ages based worn spiny (with extrapolation added).

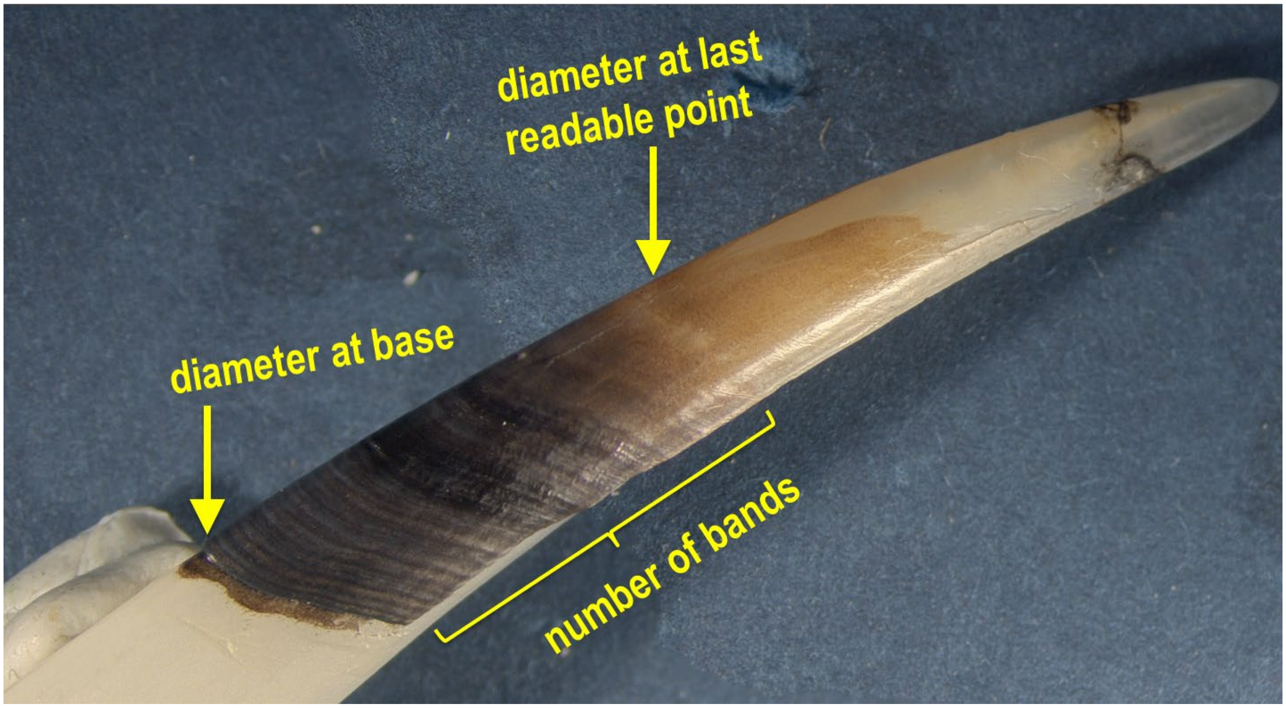

Figure 45. Spine measurements used for statistical extrapolation of ages (photo of the spine by Cindy Tribuzio, AFSC).

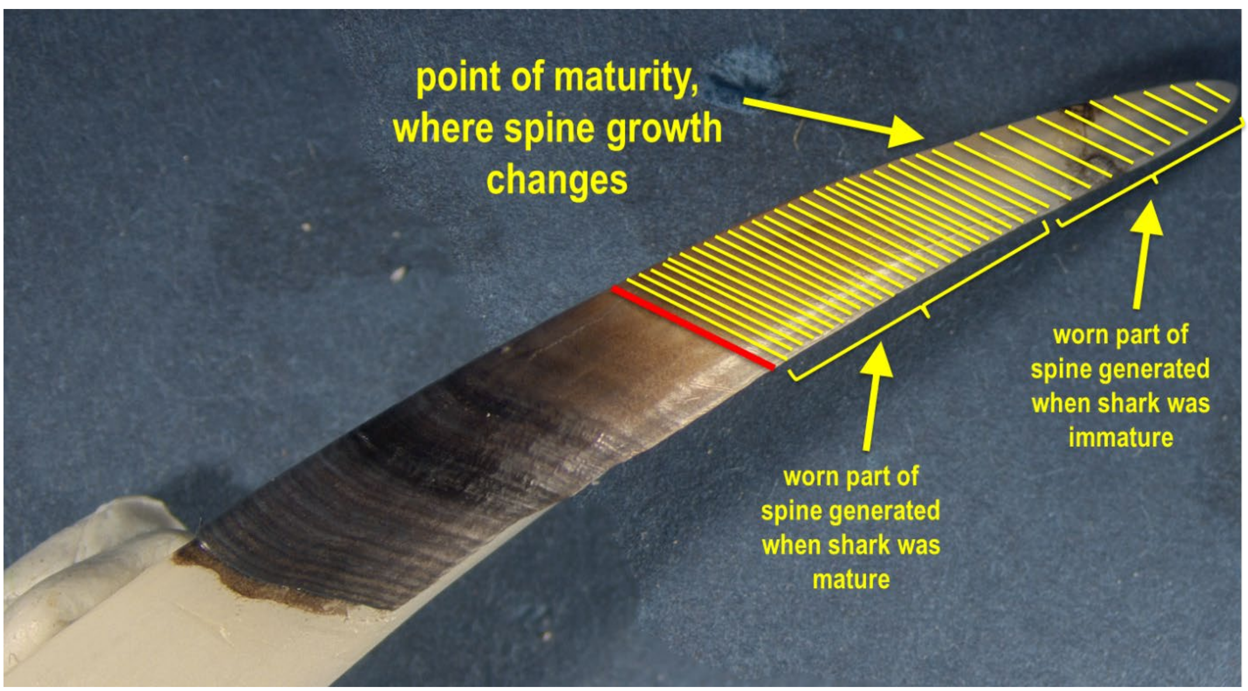

Figure 46. Illustration of a change in female spine allometry hypothesis for underestimation of age in females (photo of the spine by Cindy Tribuzio, AFSC).

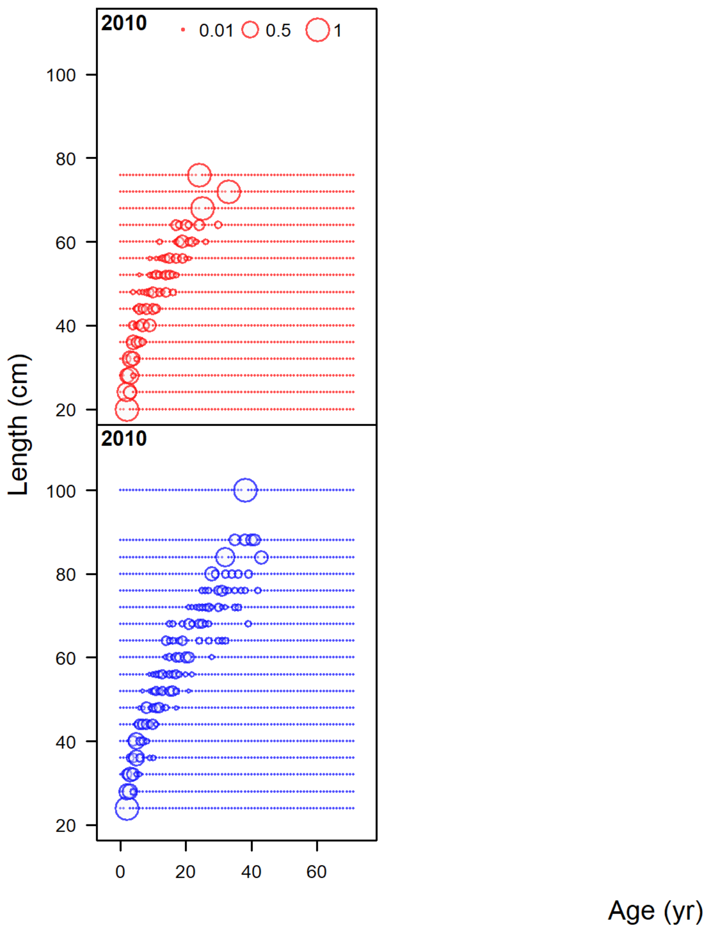

Figure 47. Conditional age-at-length data from WCGTB Survey.

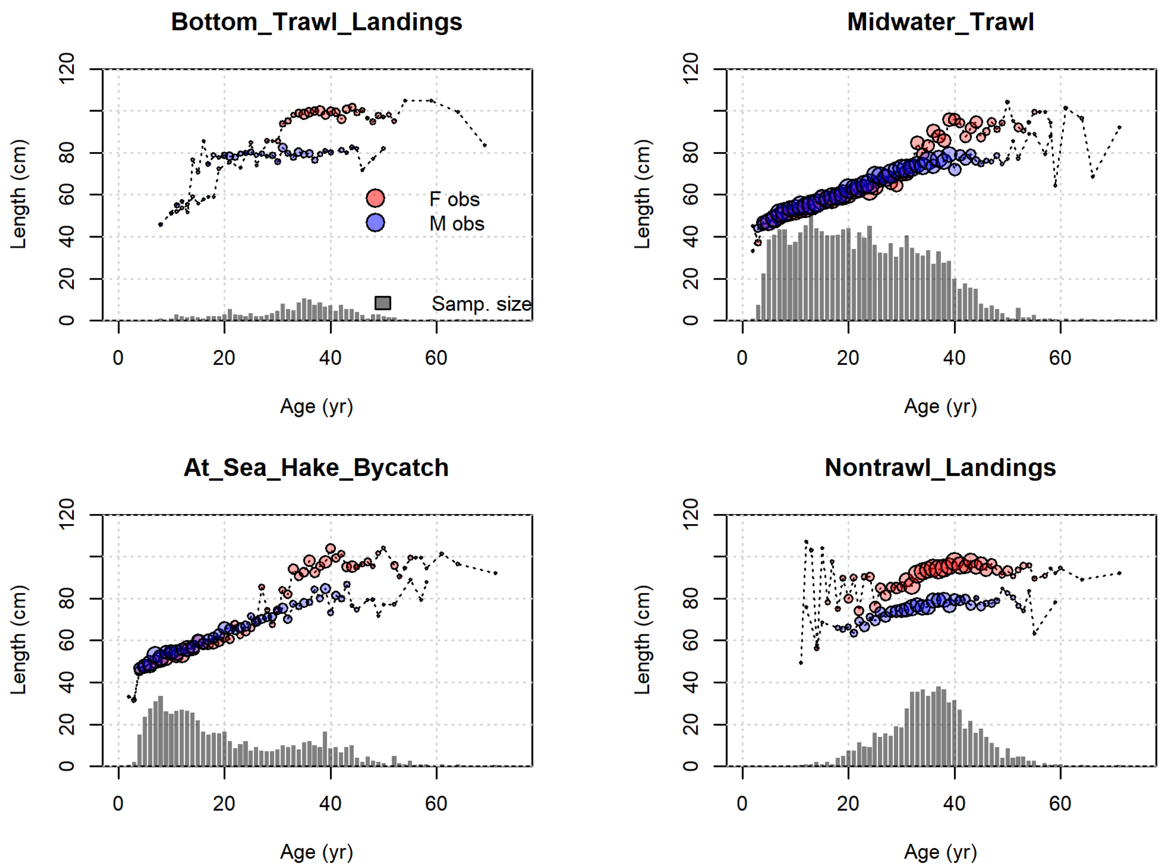

Figure 48. Mean length at age data summarized by fishing fleet. These data were, considered but not used. Bubbles sizes are proportional to relative sample size (also indicated by the gray bars).

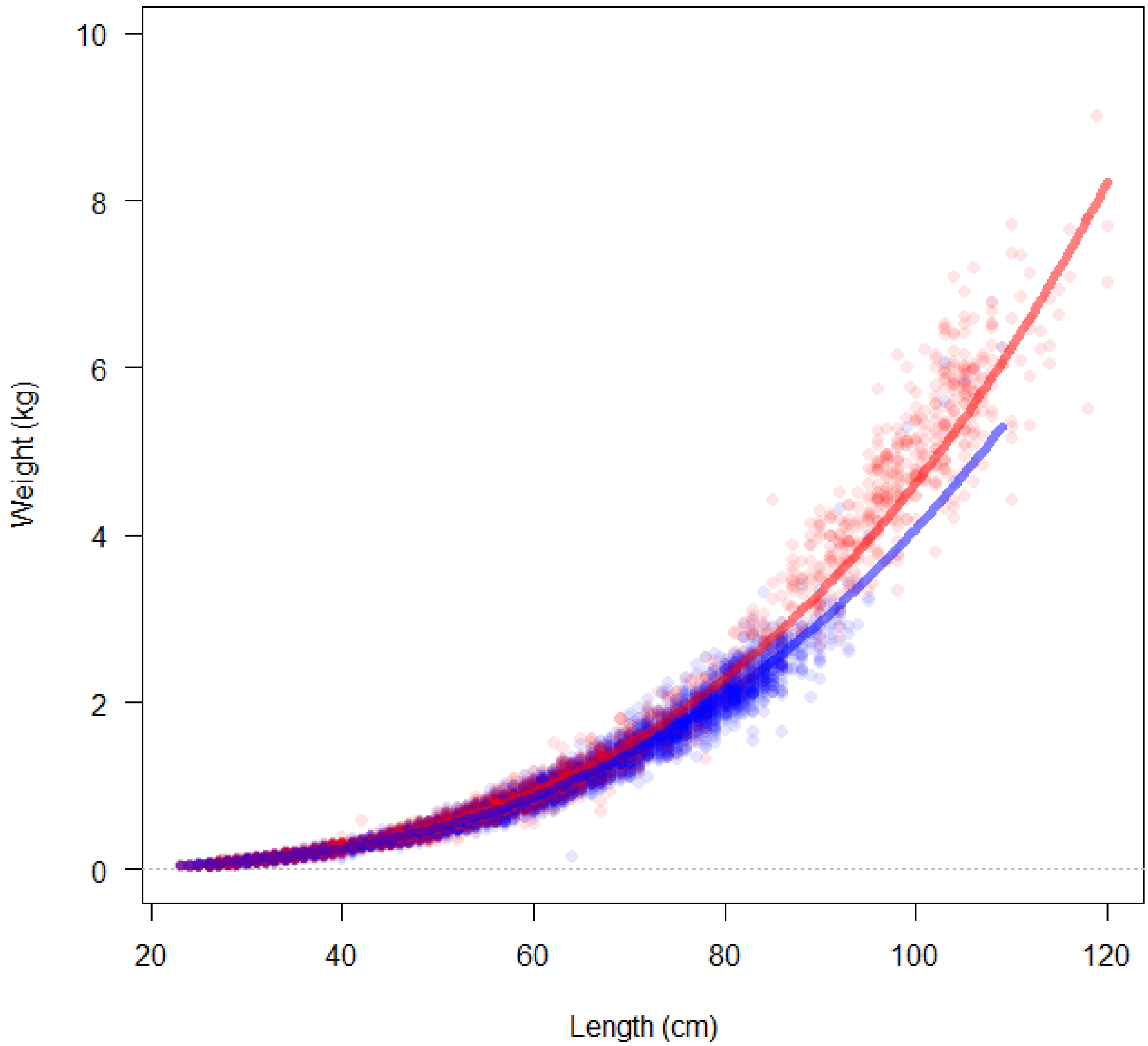

Figure 49. Weight-length relationships for females (red) and males (blue) shown with fit to the data from the WCGBT Survey samples (shaded points).

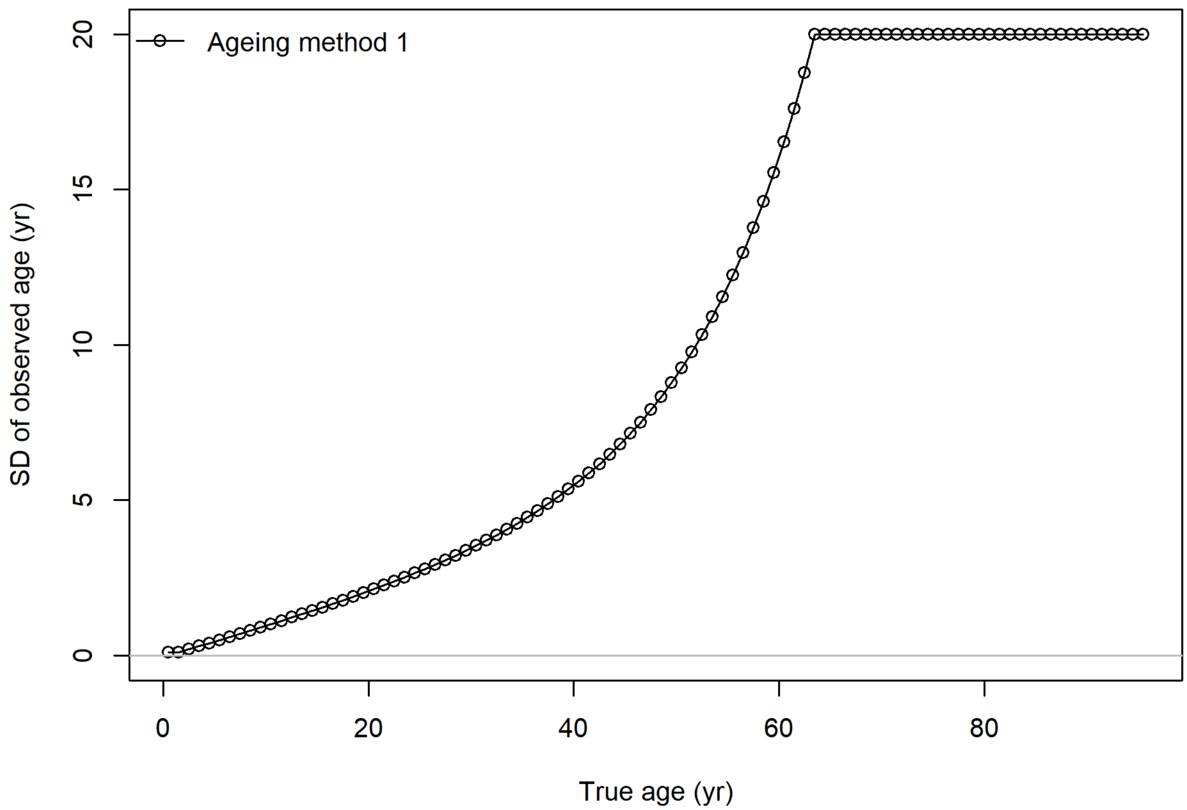

Figure 50. Ageing imprecision: SD of observed age (yr)

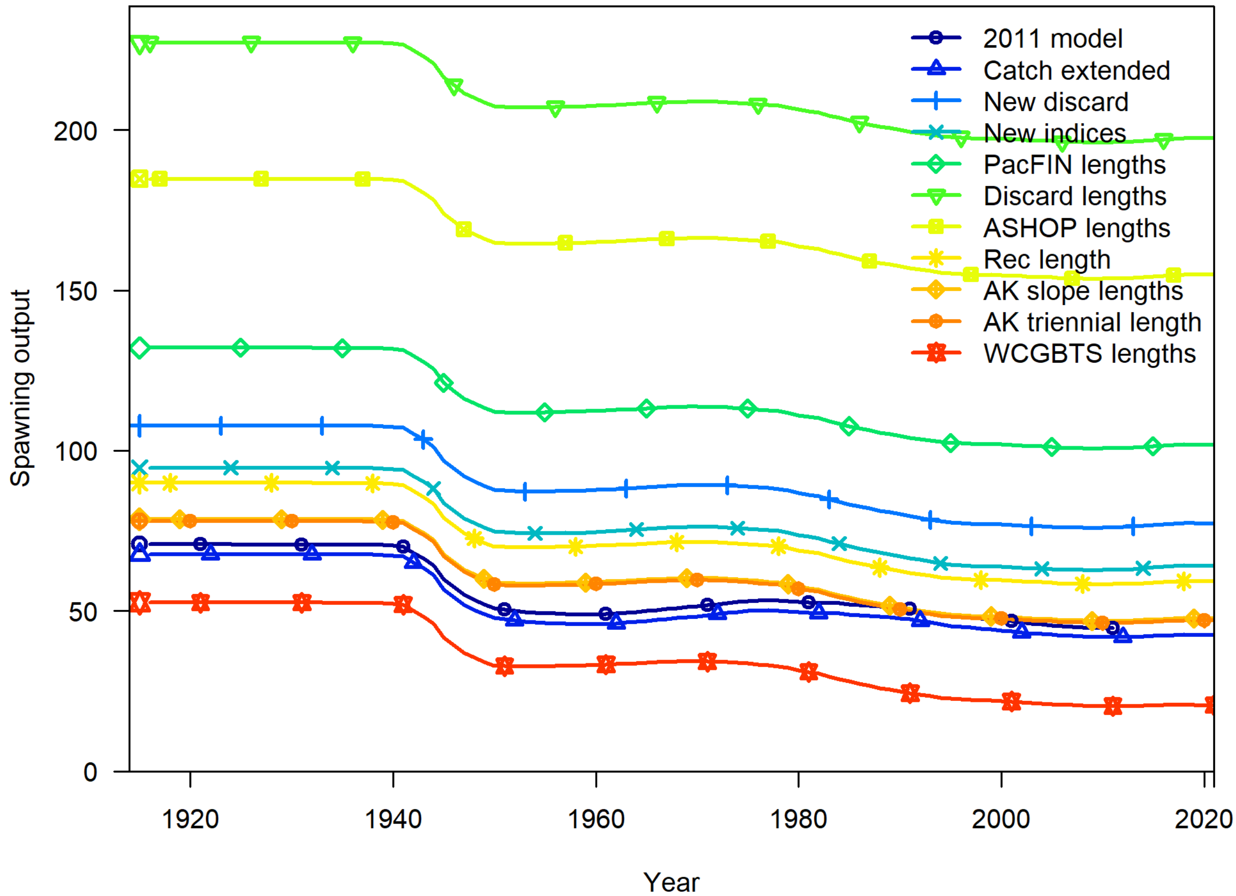

Figure 51. Sequential bridging of major changes in data sources from the 2011 assessment to 2021 assessment model. Time series of spawning output (in millions of pups) for each of the updates.

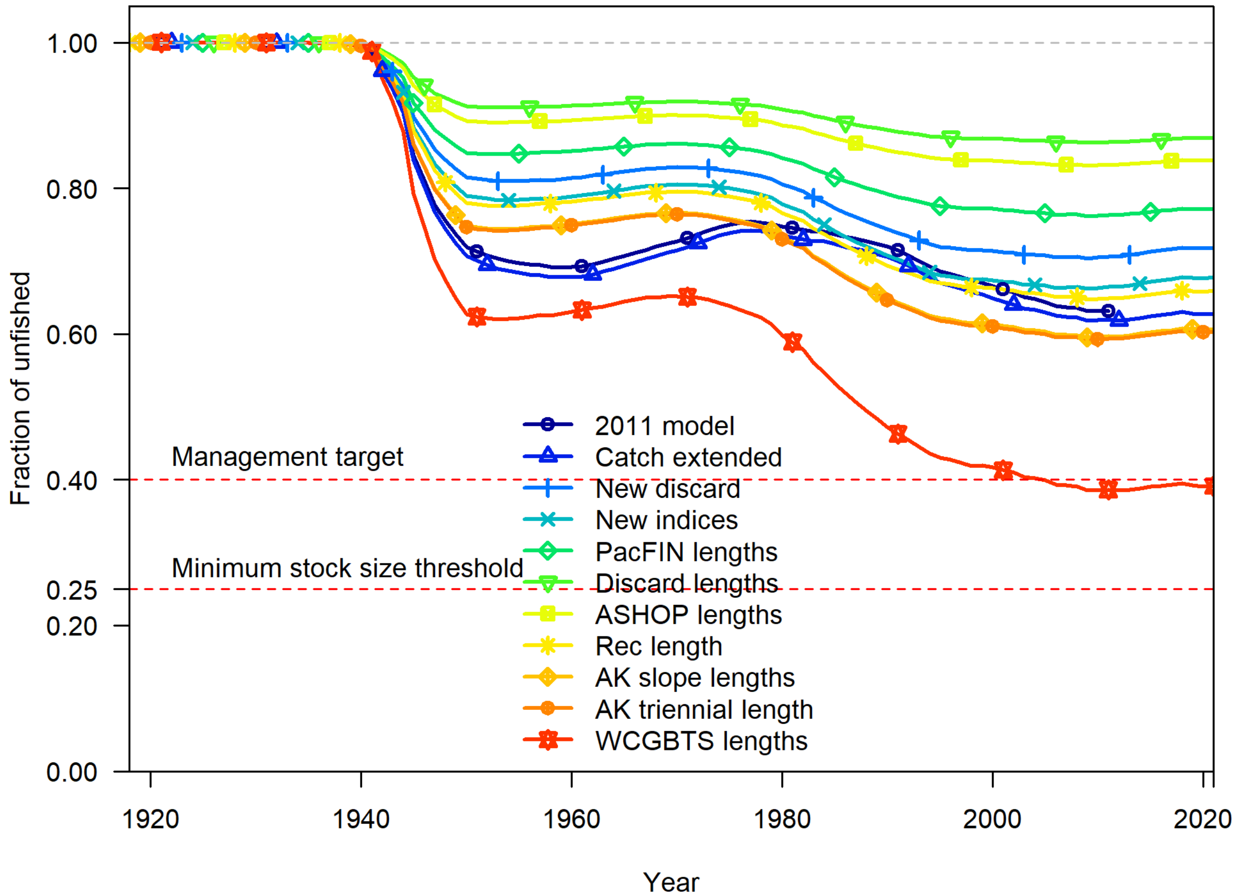

Figure 52. Sequential bridging of major changes in data sources from the 2011 assessment to 2021 assessment model. Time series of spawning depletion under each of the updates.

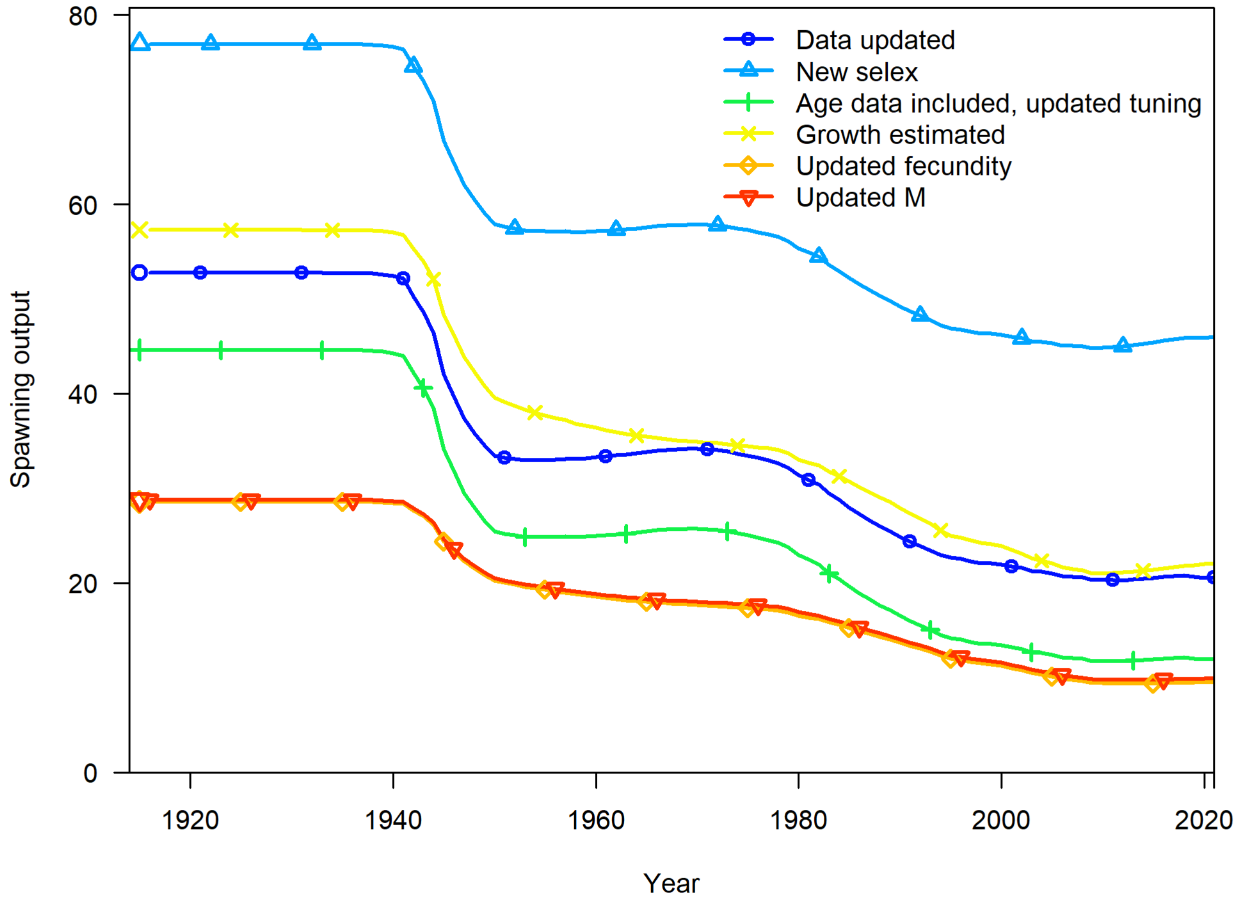

Figure 53. Sequential bridging of major changes in parameters from the 2011 assessment to 2021 assessment model. Time series of spawning output (in millions of pups) for each of the updates.

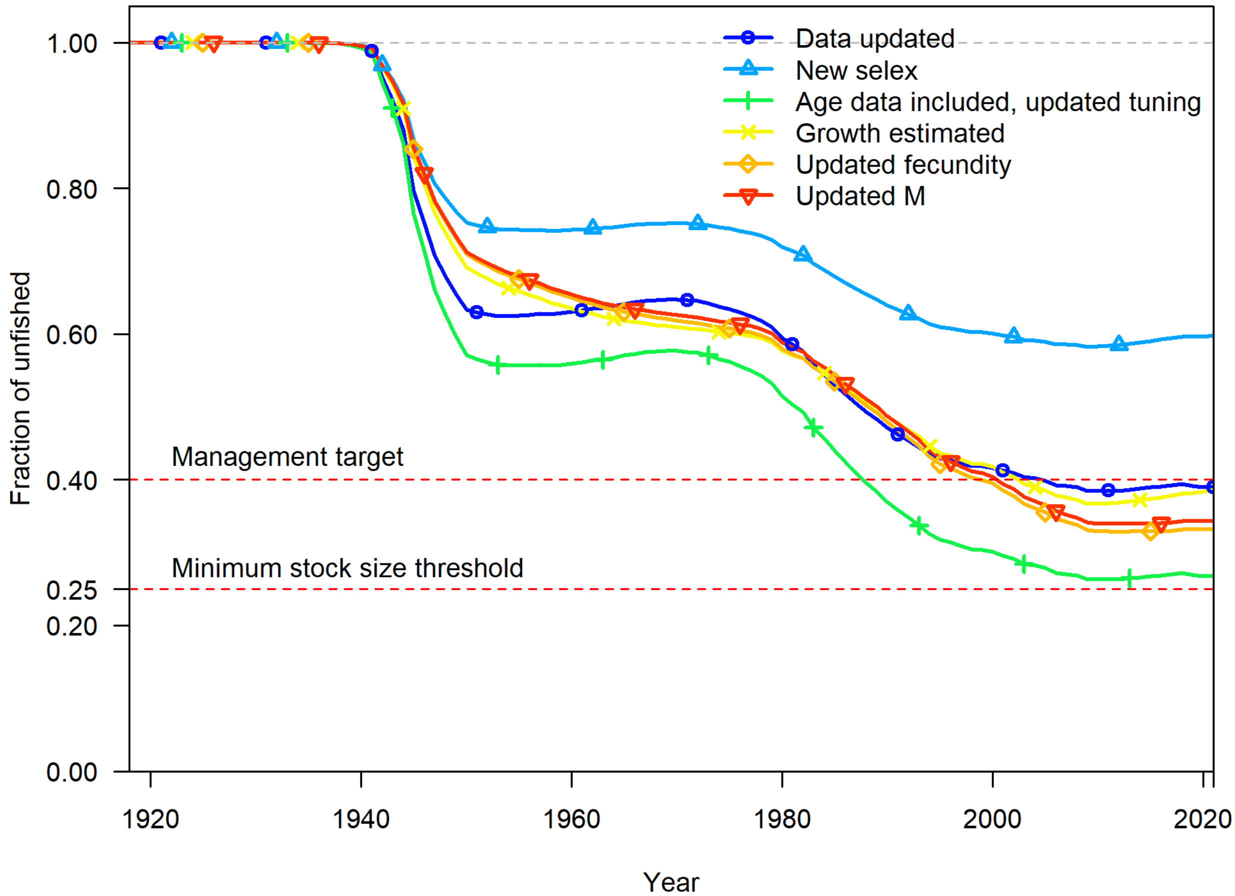

Figure 54. Sequential bridging of major changes in parameters from the 2011 assessment to 2021 assessment model. Time series of spawning depletion for each of the updates.

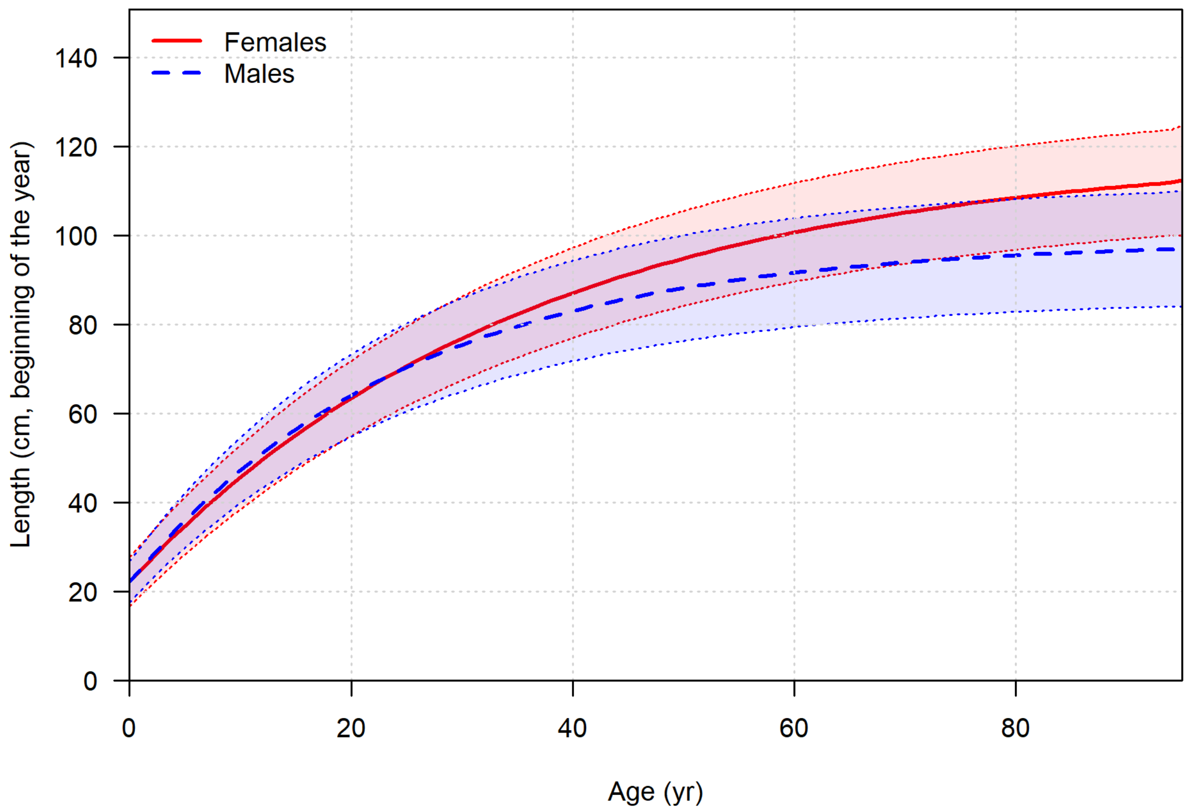

Figure 55. Growth curves for females and males of spiny dogfish shark used in the base model.

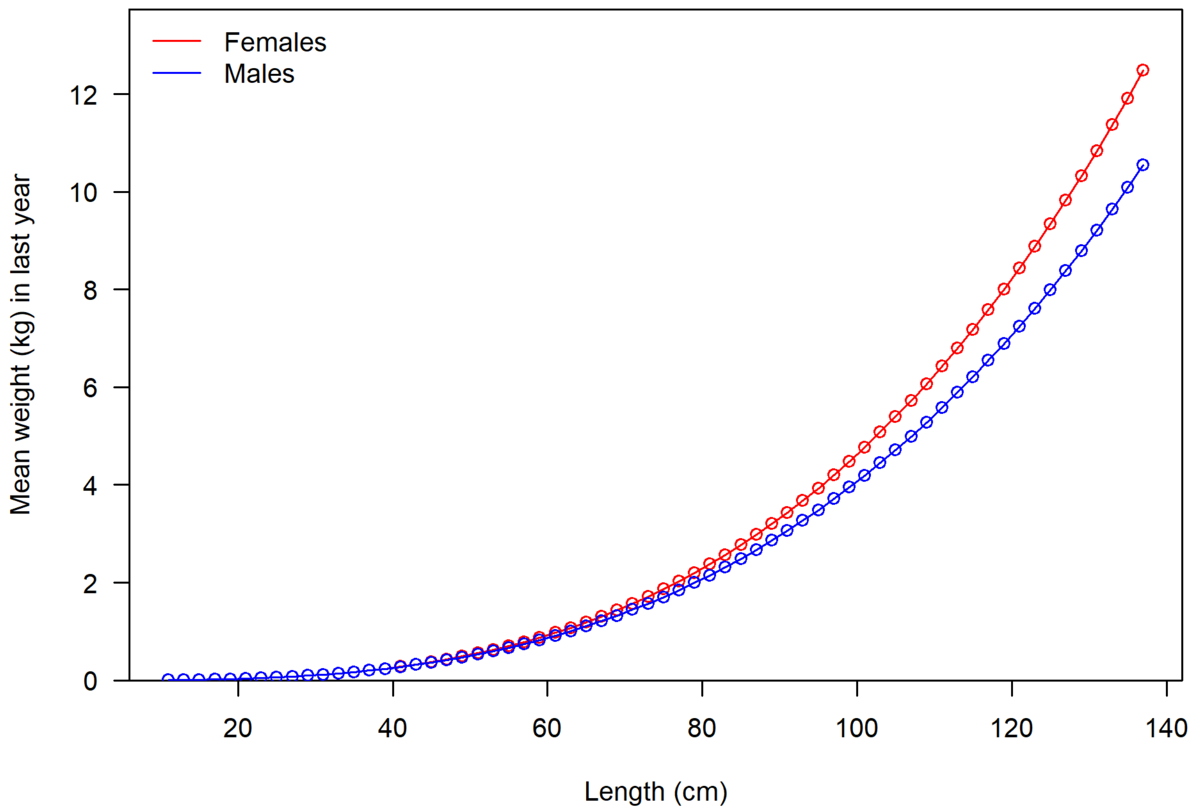

Figure 56. Weight-at-length relationship for females and males of spiny dogfish used in the base model.

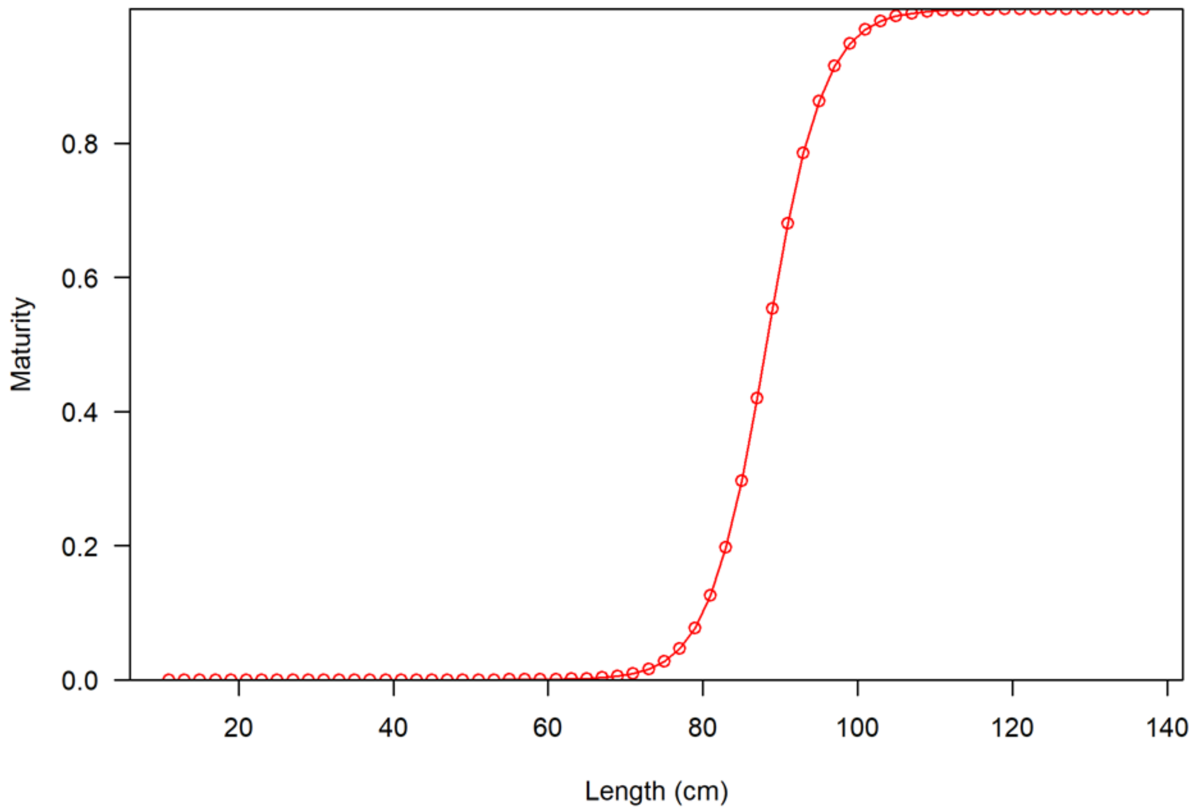

Figure 57. Spiny dogfish female maturity-at-length relationship used in the base model.

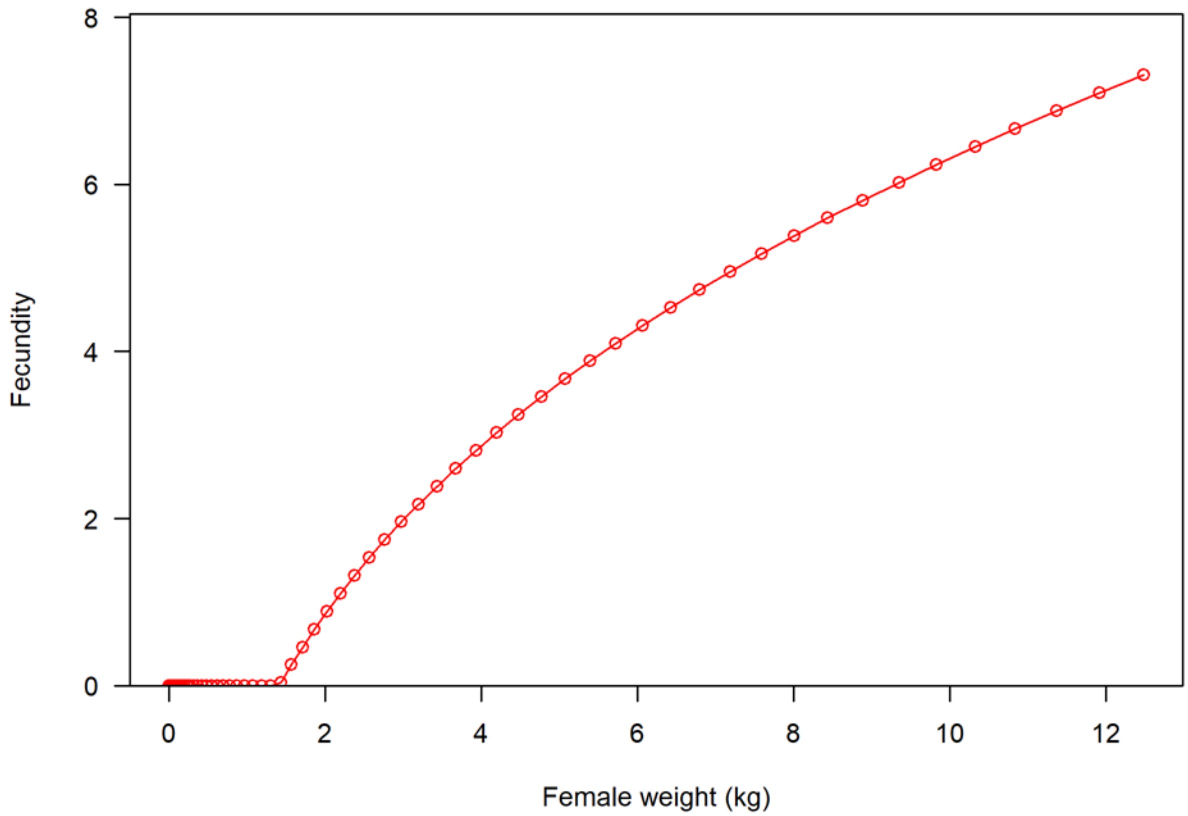

Figure 58. Spiny dogfish female fecundity-at-weight relationship used in the base model.

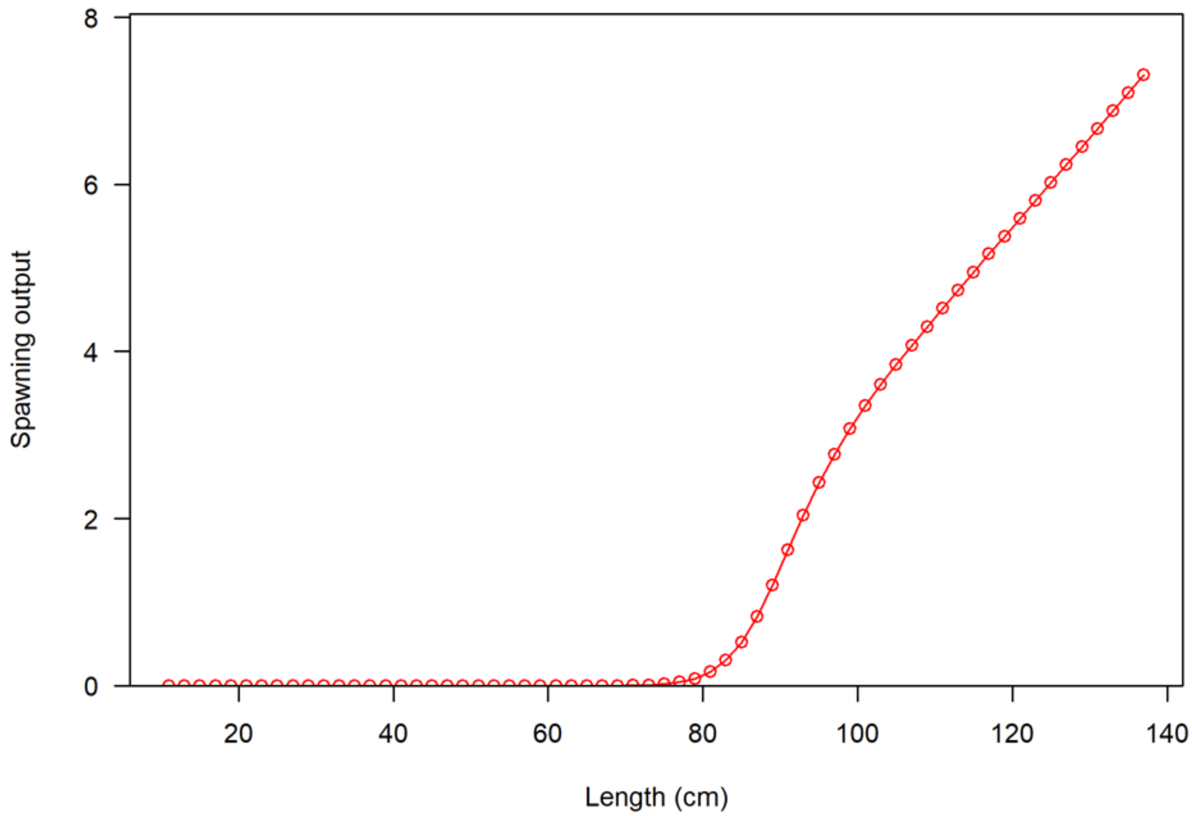

Figure 59. Spiny dogfish female spawning output-at-length relationship used in the base model.

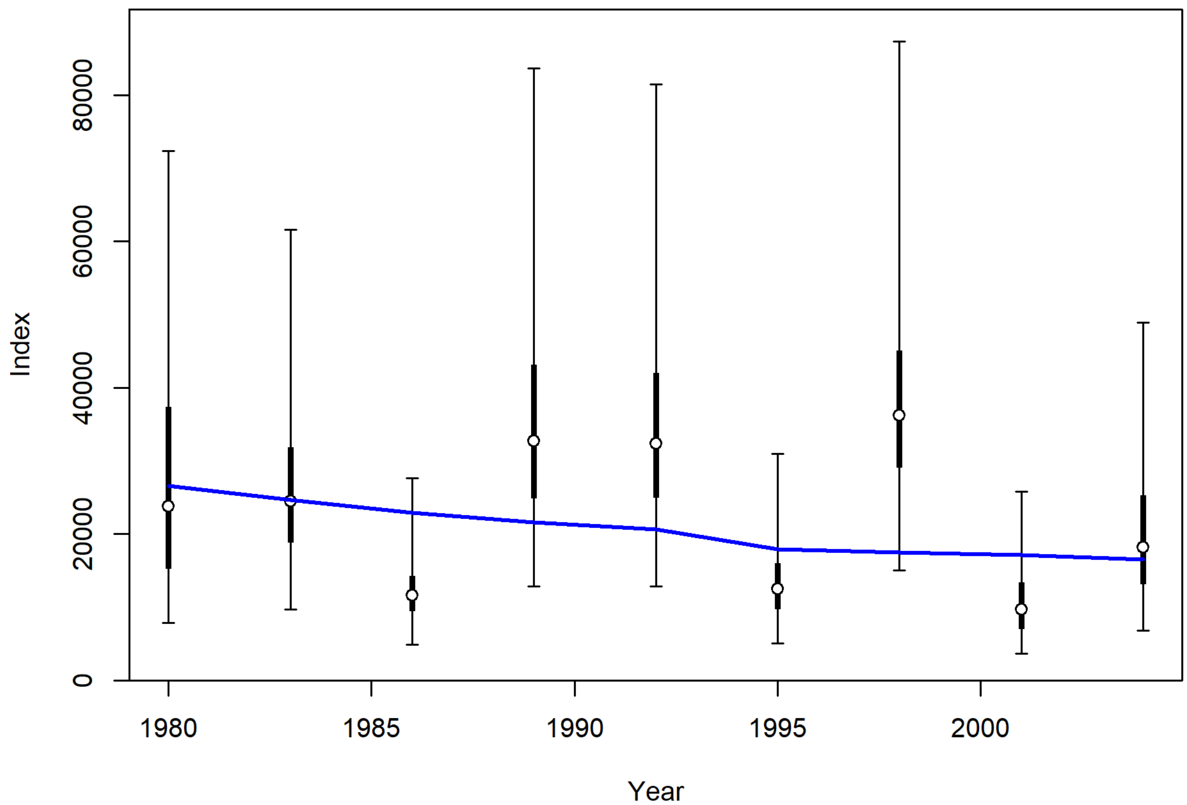

Figure 60. Observed and expected values of spiny dogfish biomass index (mt) for the AFSC Triennial Survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines indicate input uncertainty before addition of the estimated additional uncertainty parameter.

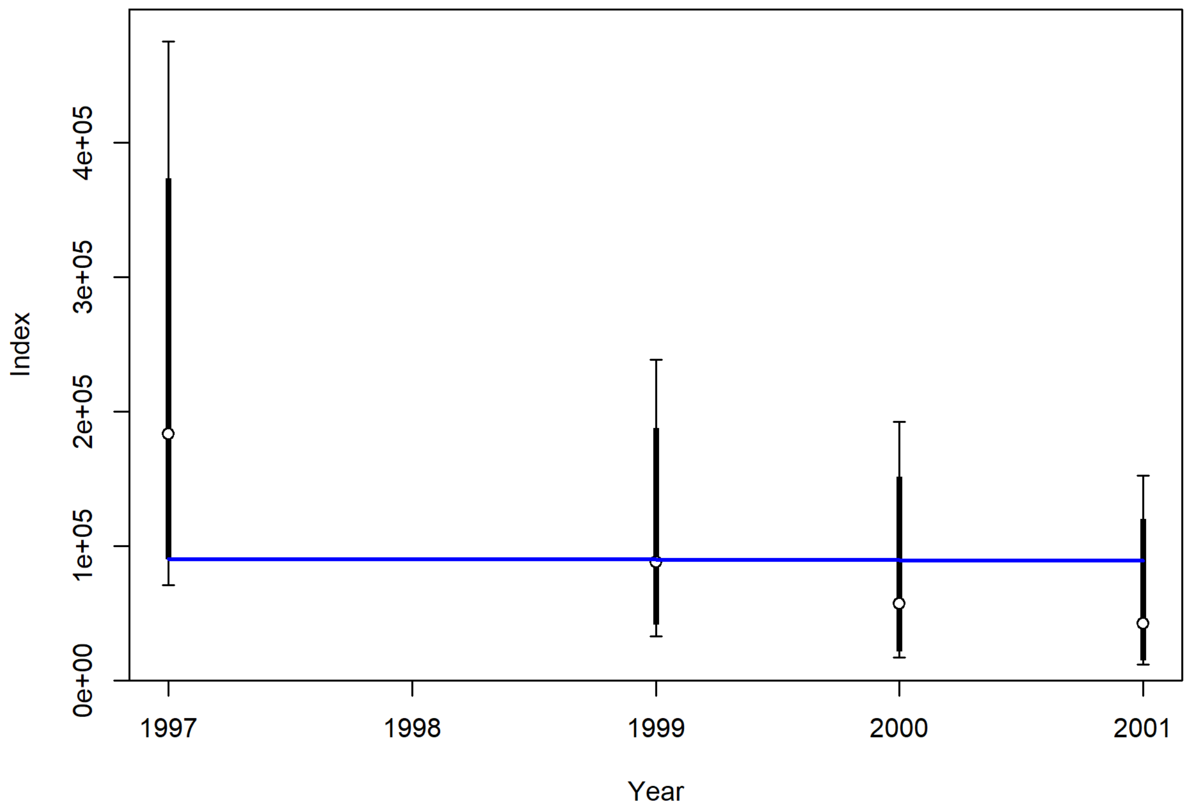

Figure 61. Observed and expected values of spiny dogfish biomass index (mt) for the AFSC Slope Survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines indicate input uncertainty before addition of the estimated additional uncertainty parameter.

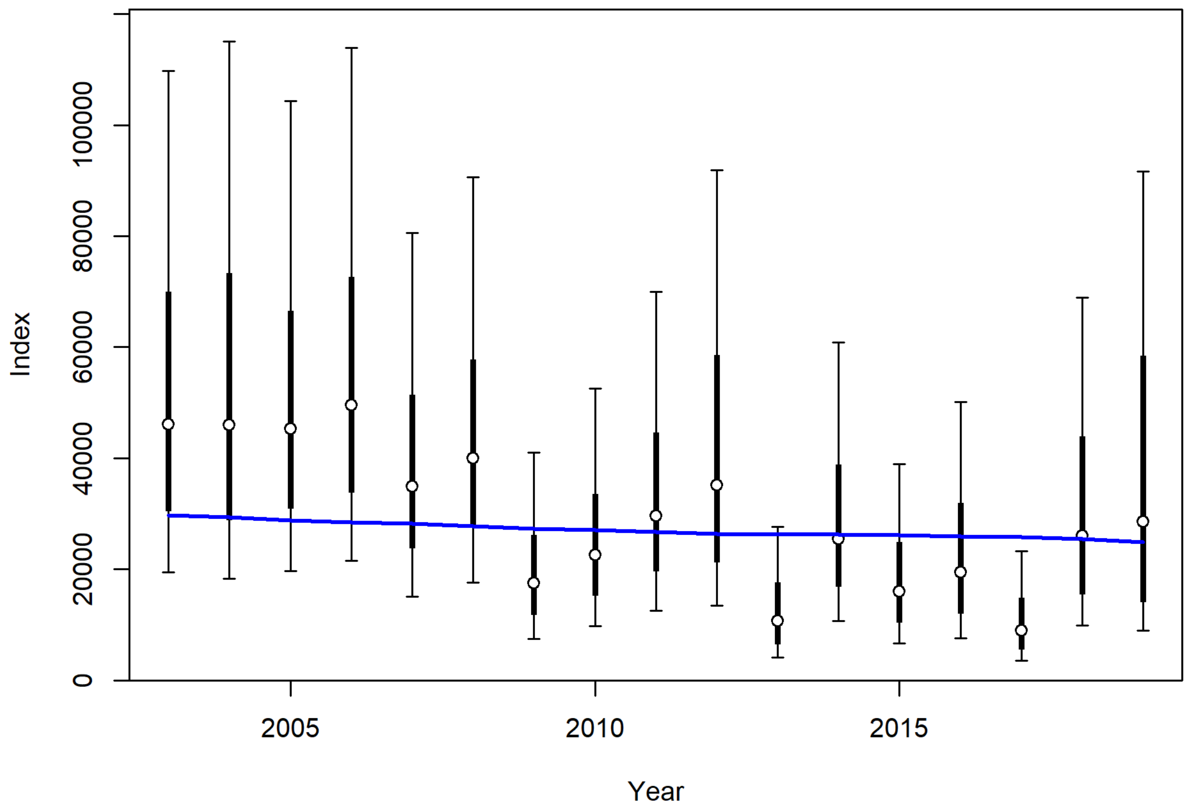

Figure 62. Observed and expected values of spiny dogfish biomass index (mt) for the WCGBT Survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines indicate input uncertainty before addition of the estimated additional uncertainty parameter.

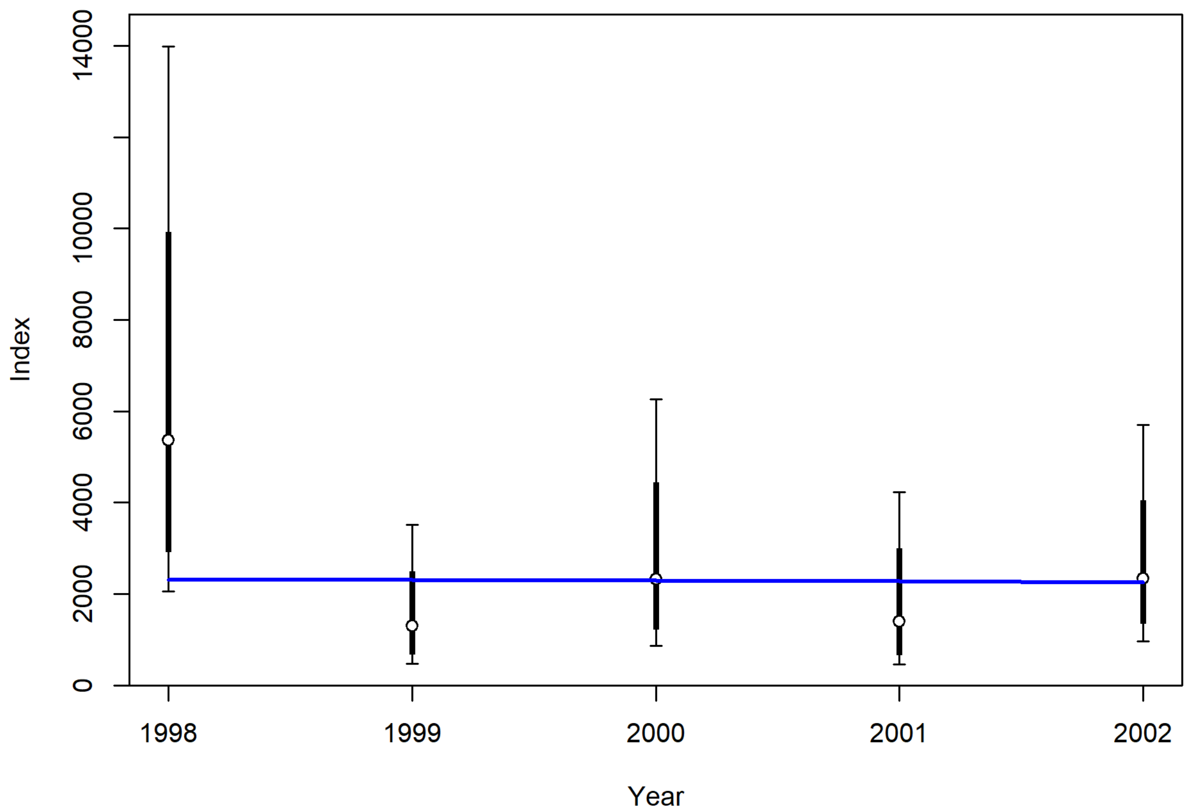

Figure 63. Observed and expected values of spiny dogfish biomass index (mt) for the NWFSC Slope Survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines indicate input uncertainty before addition of the estimated additional uncertainty parameter.

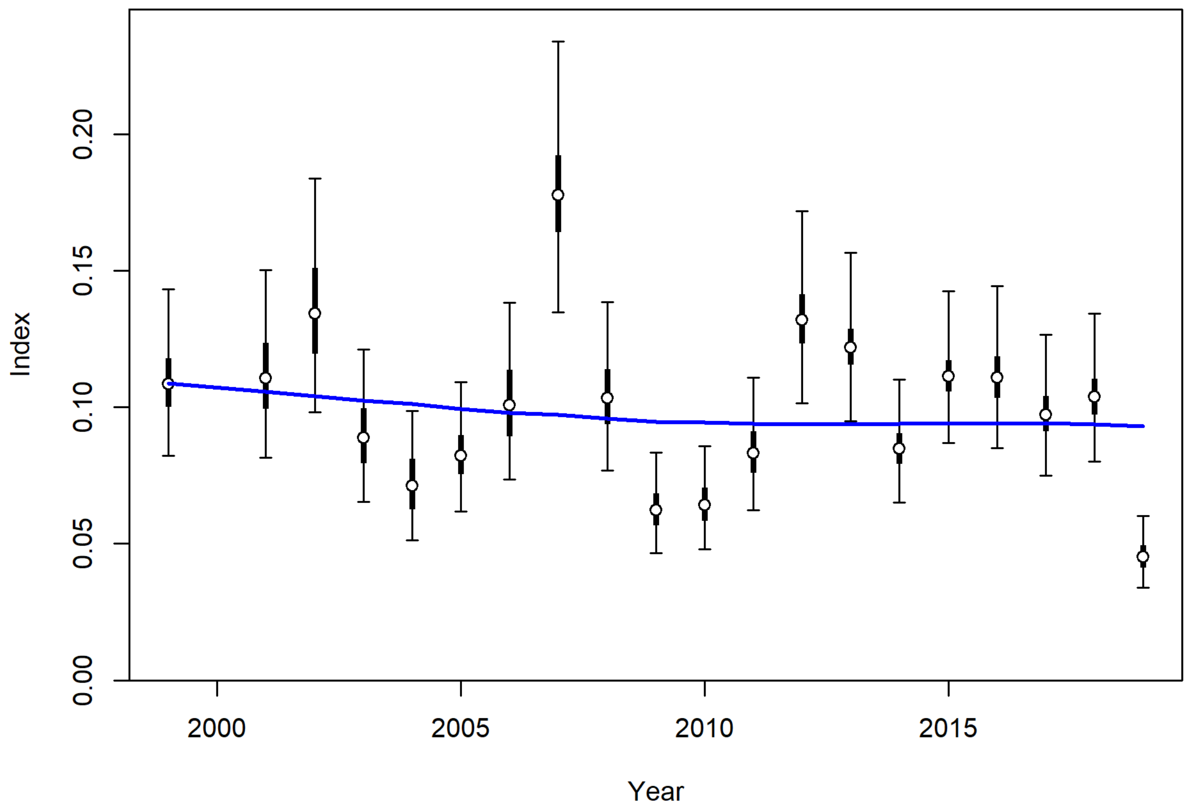

Figure 64. Observed and expected values of spiny dogfish abundance index (number of fish) for the IPHC Survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines indicate input uncertainty before addition of the estimated additional uncertainty parameter.

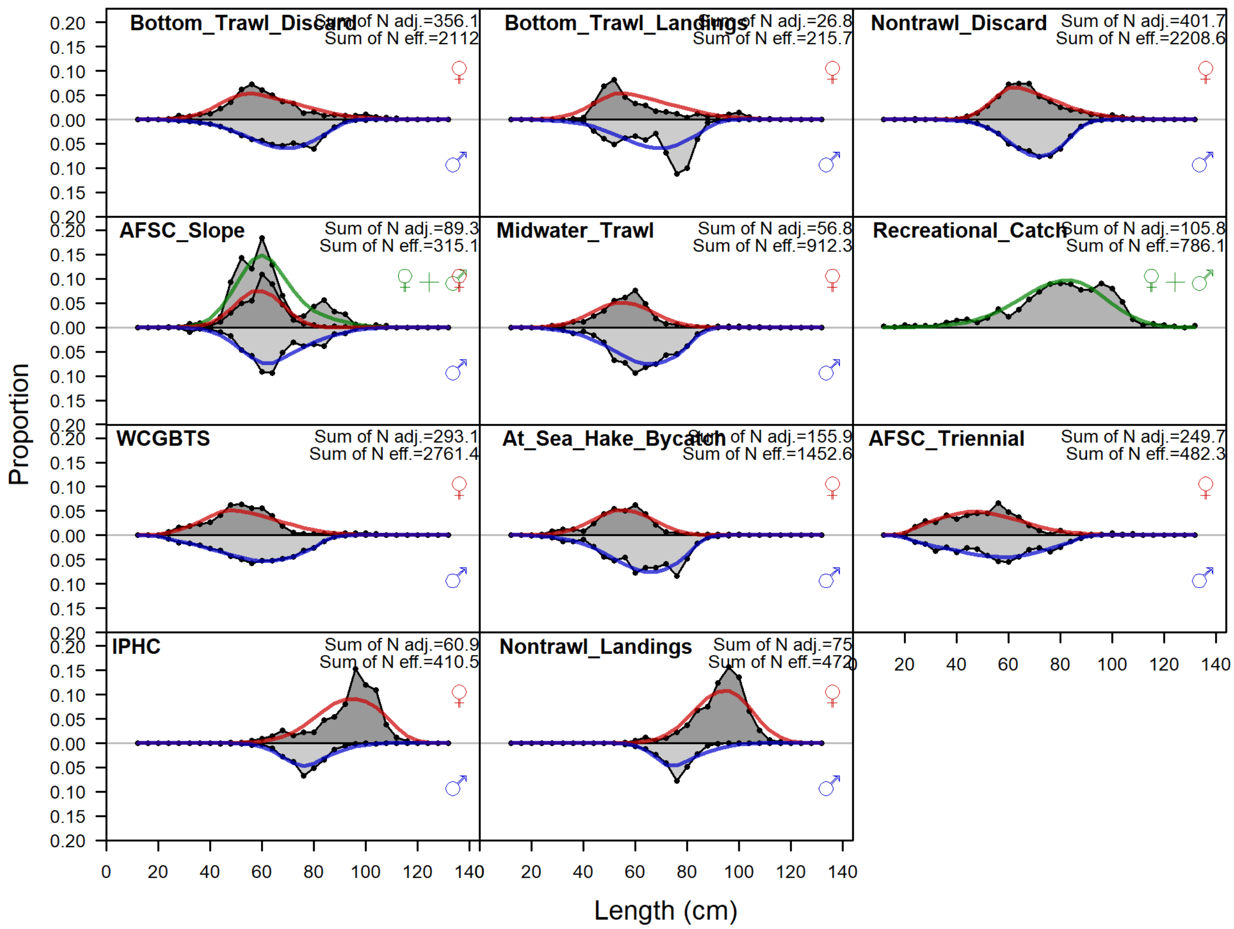

Figure 65. Fit to length-frequency distributions of spiny dogfish aggregated across time by fleet.

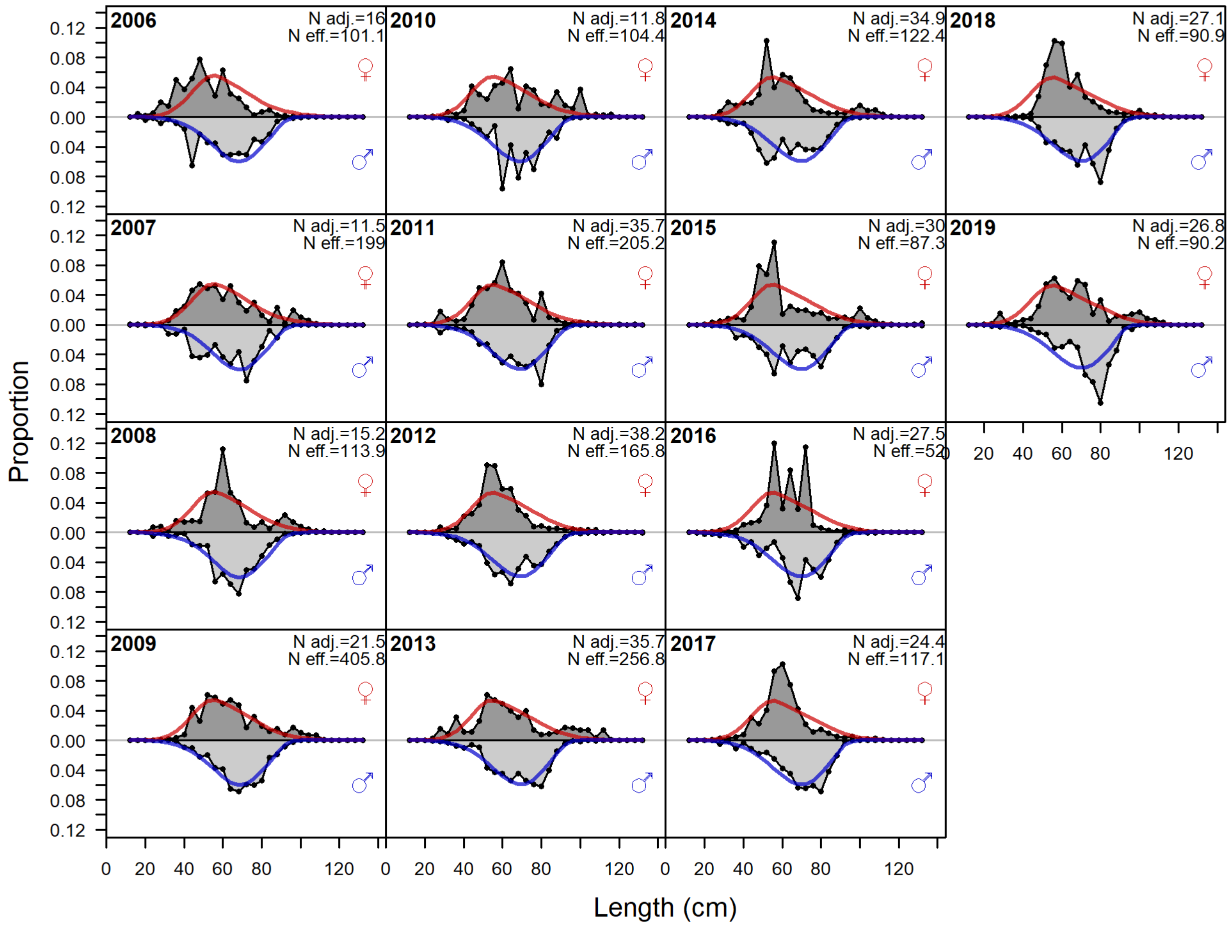

Figure 66. Fit to length-frequency distributions of spiny dogfish for the bottom trawl discard fleet.

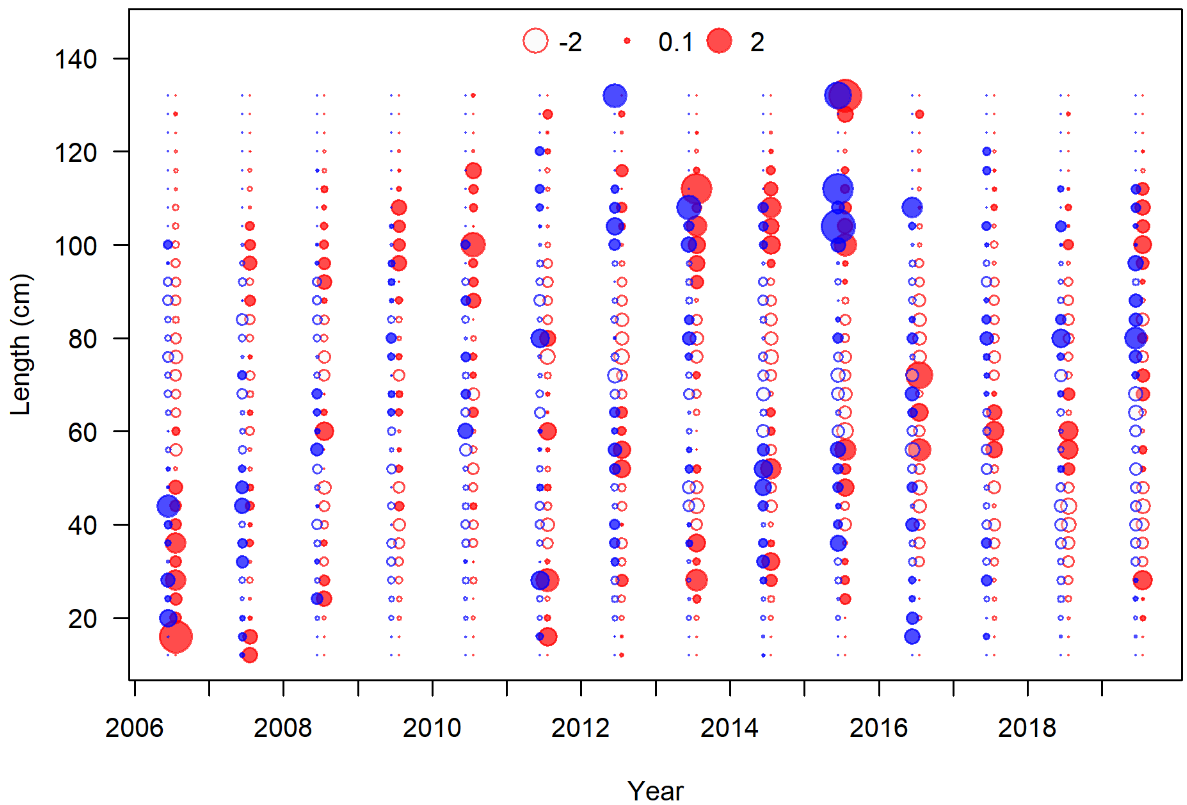

Figure 67. Pearson residuals for the fit of the length-frequency distributions for the bottom trawl discard fleet.

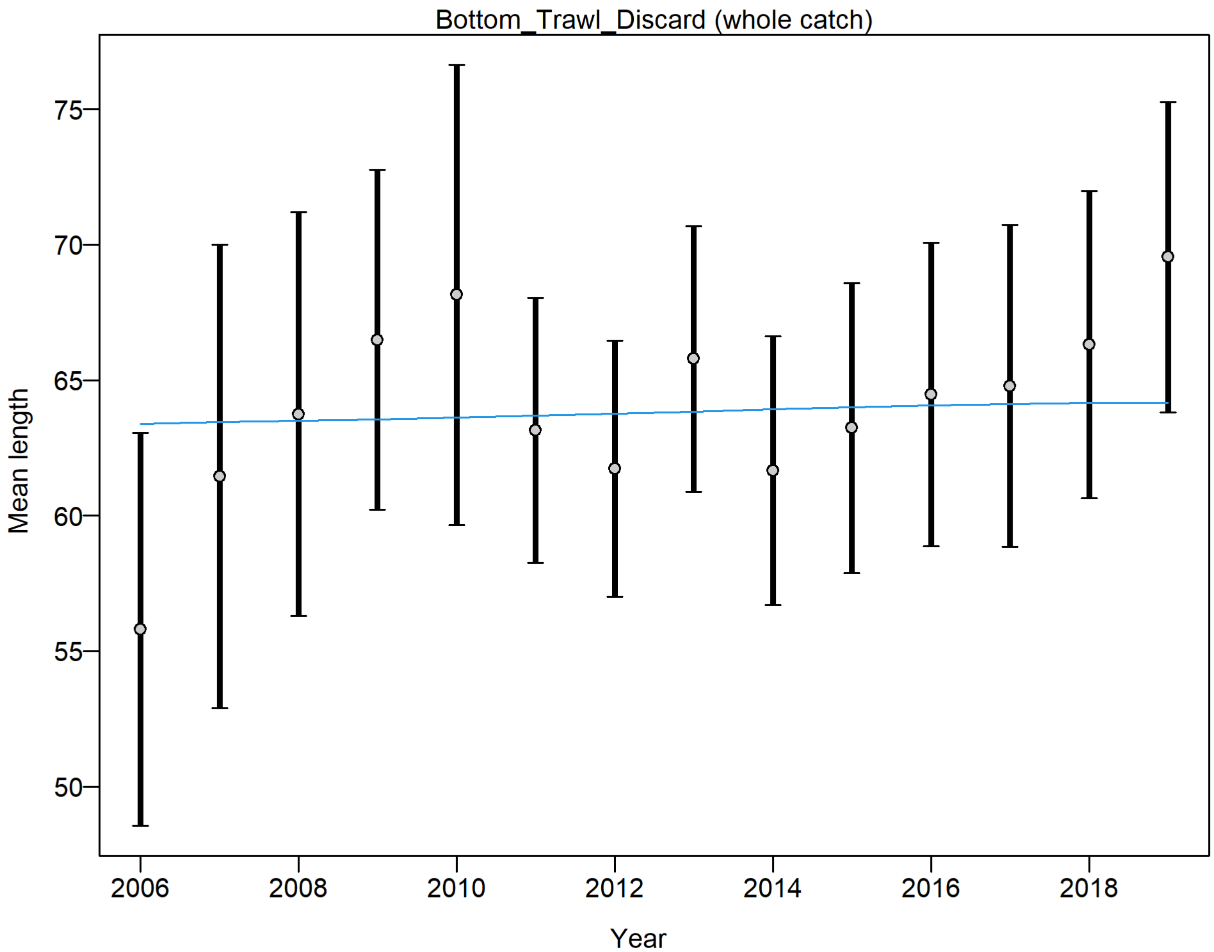

Figure 68. Francis weighting fits to the mean lengths by year for the for the bottom trawl discard fleet. Vertical lines are 95% confidence intervals.

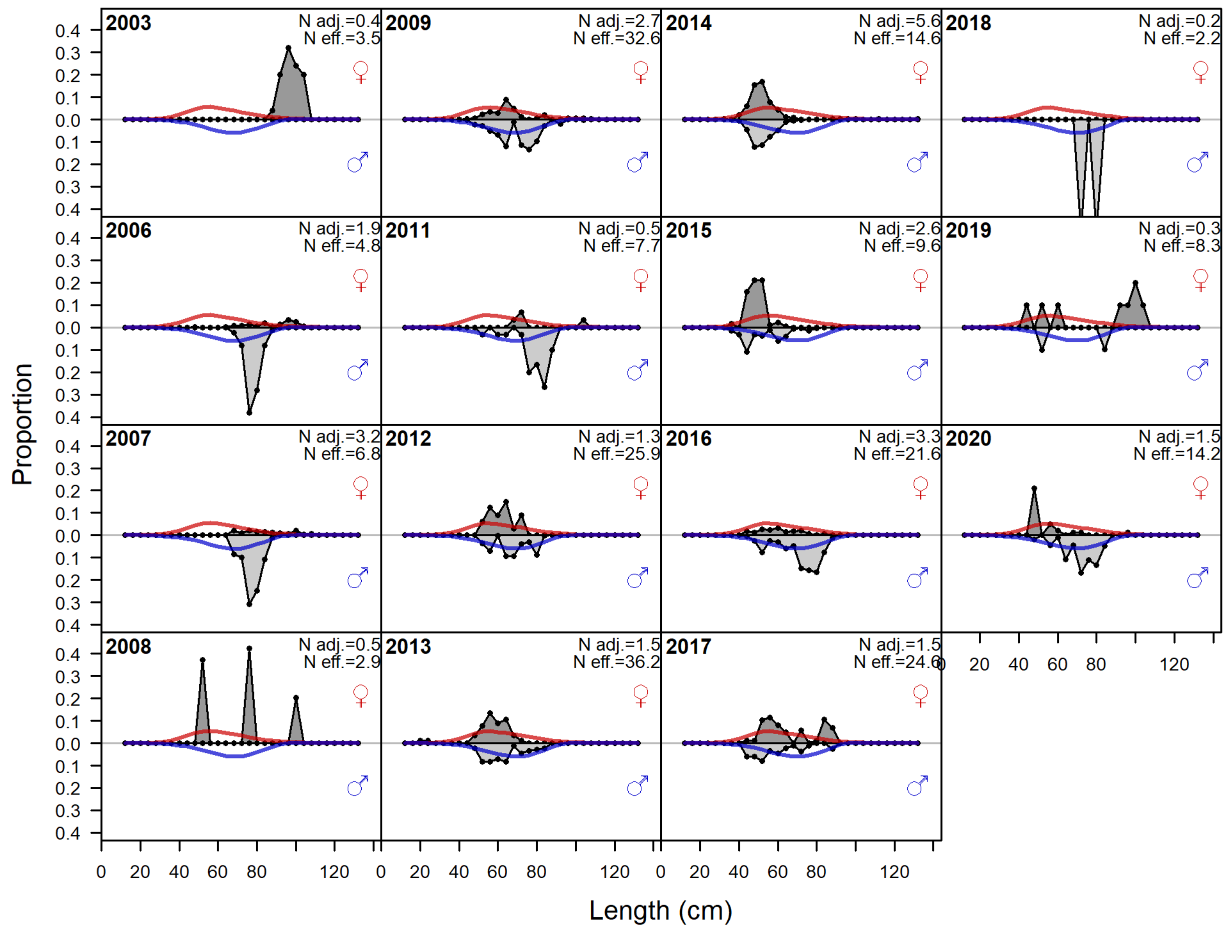

Figure 69. Fit to length-frequency distributions of spiny dogfish for the bottom trawl fleet.

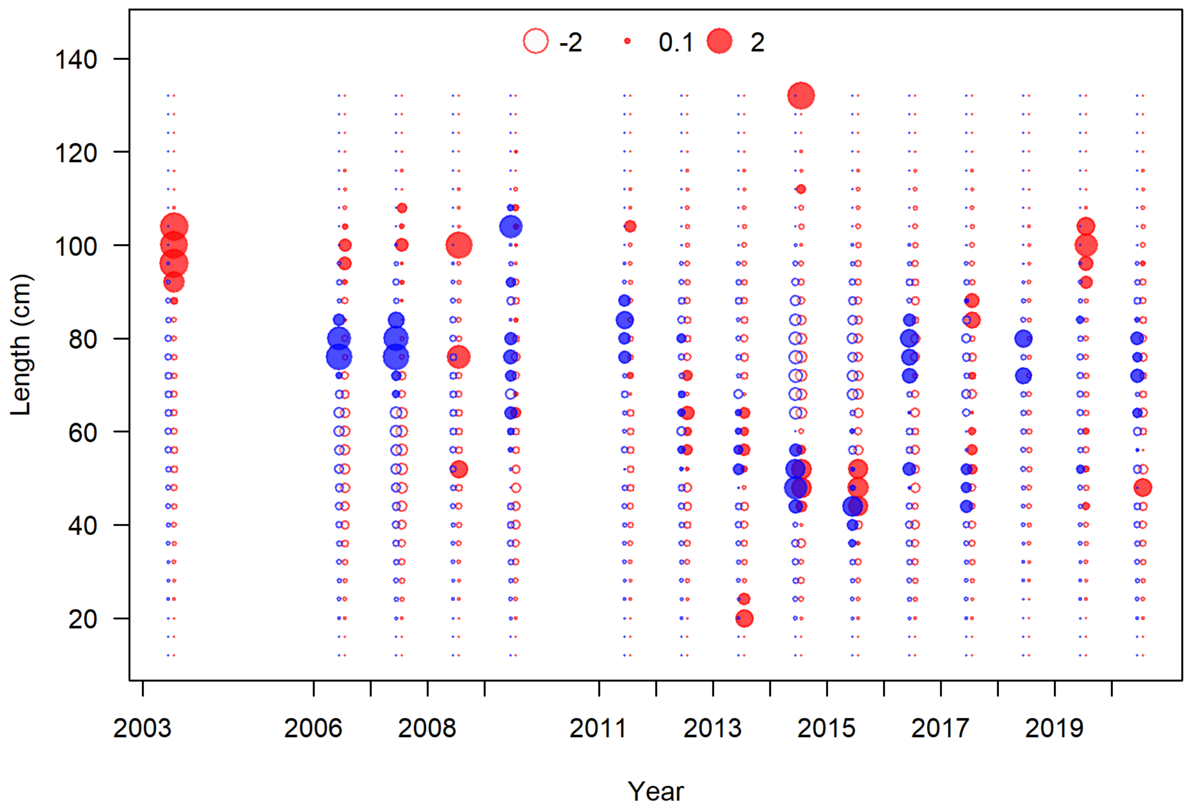

Figure 70. Pearson residuals for the fit of the length-frequency distributions for the bottom trawl fleet.

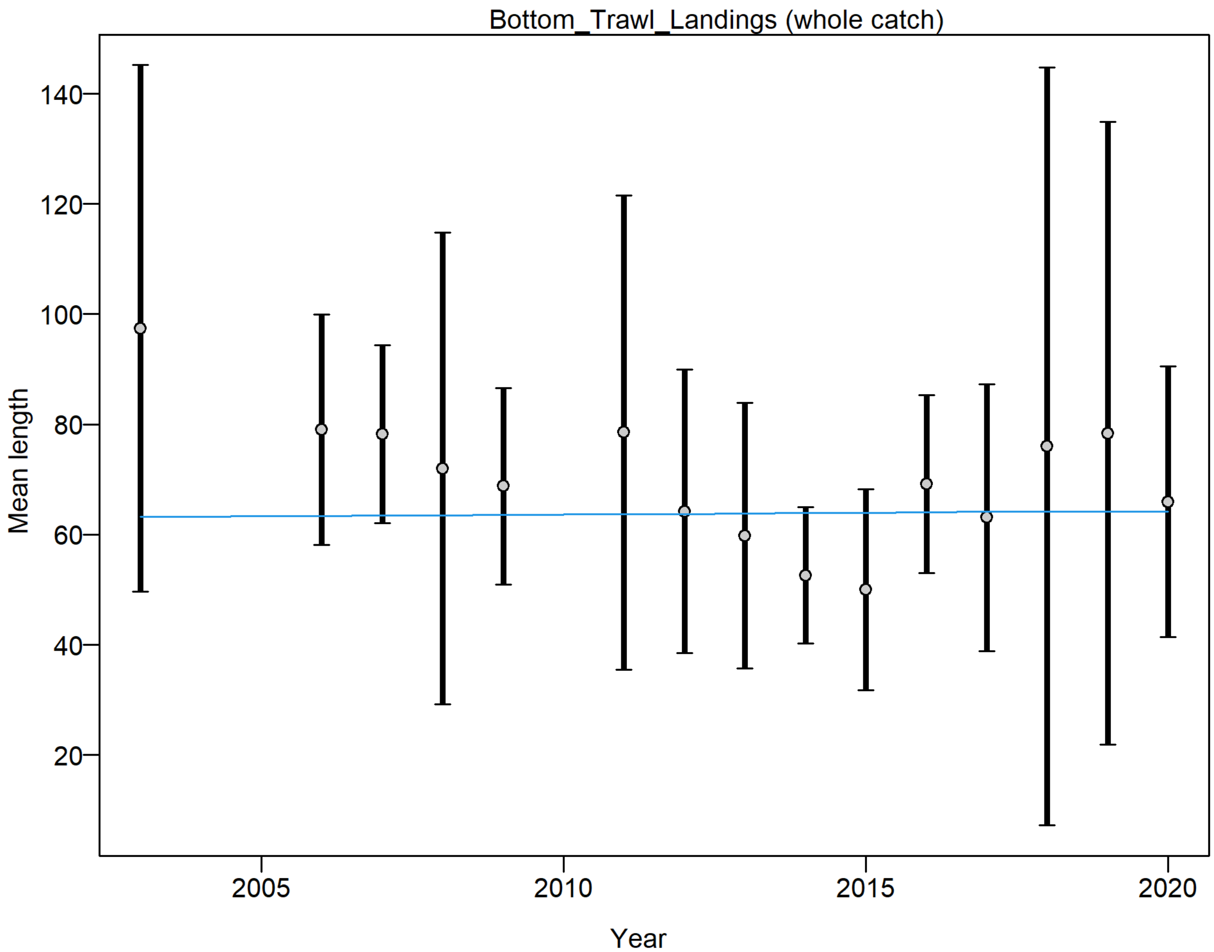

Figure 71. Francis weighting fits to the mean lengths by year for the bottom trawl fleet. Vertical lines are 95% confidence intervals.

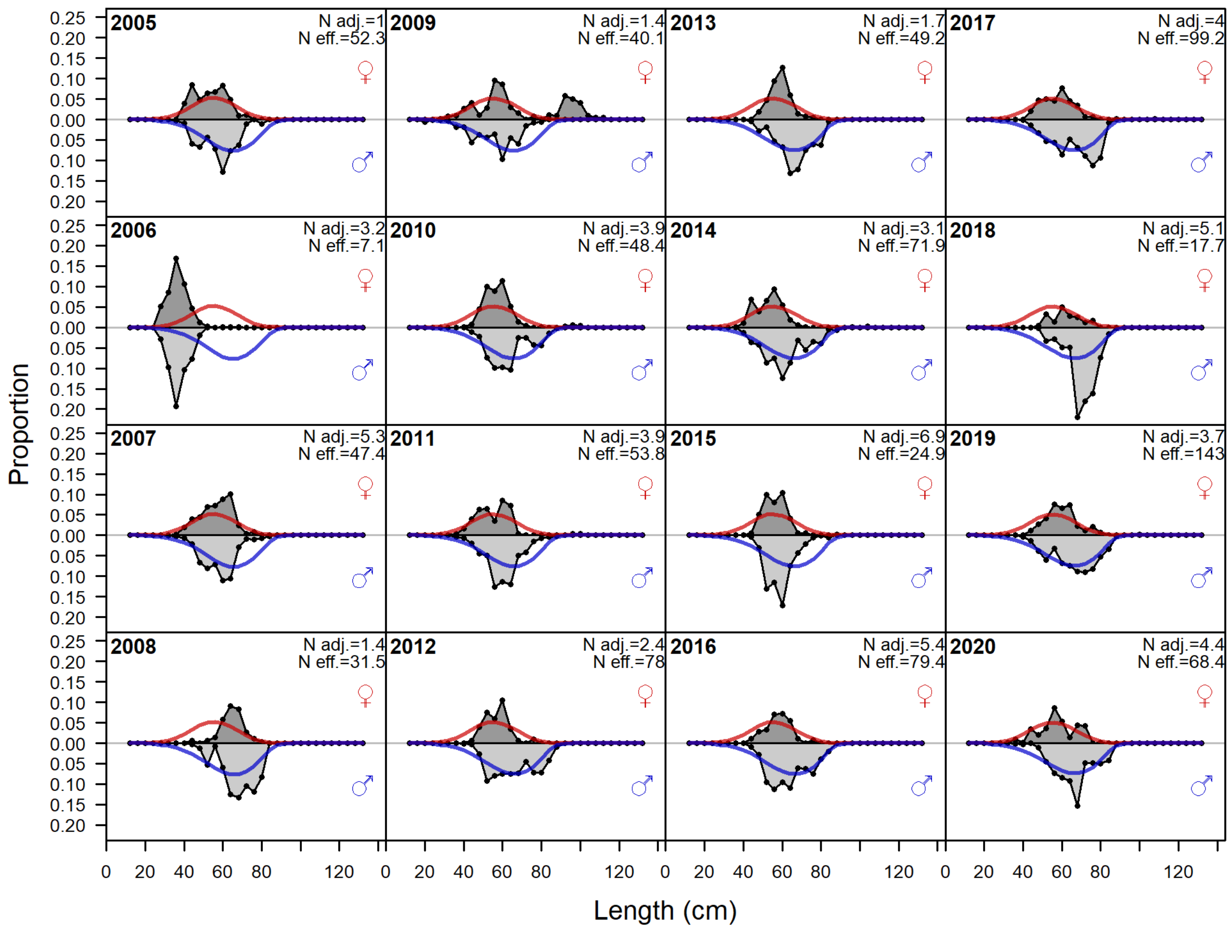

Figure 72. Fit to length-frequency distributions of spiny dogfish for the midwater trawl fleet.

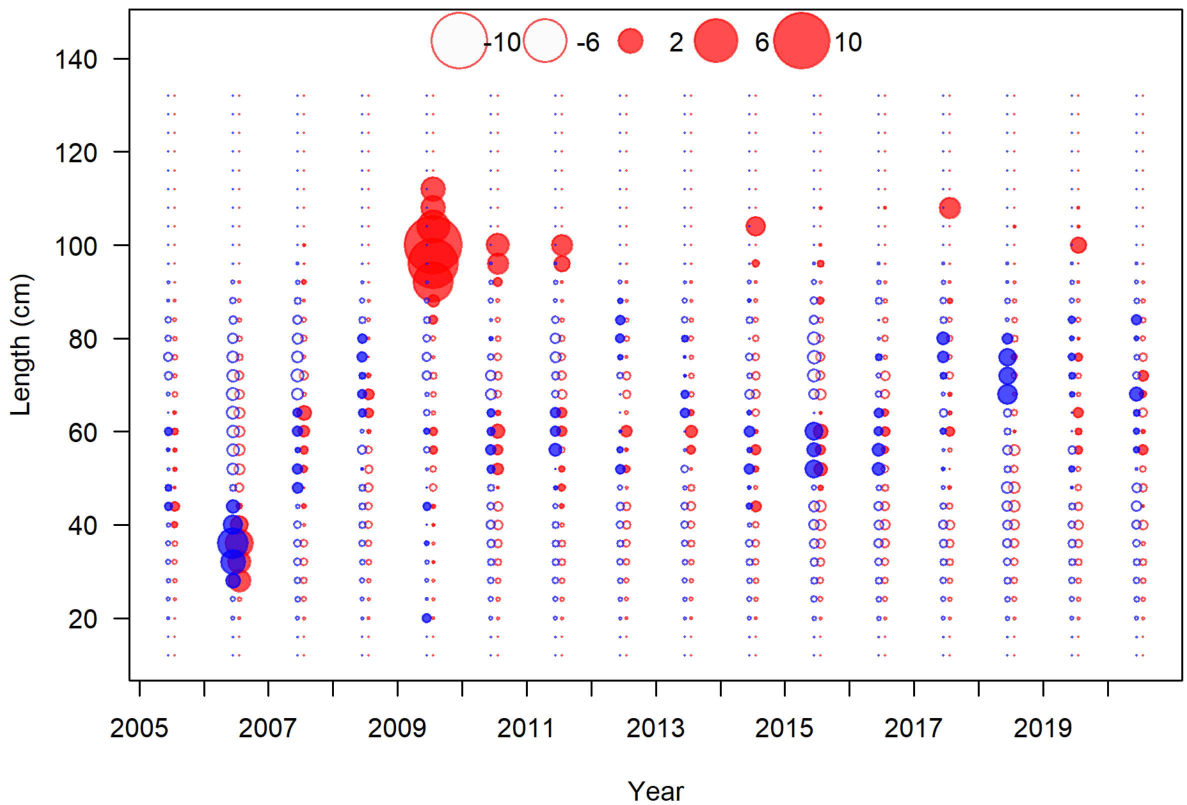

Figure 73. Pearson residuals for the fit of the length-frequency distributions for the midwater trawl fleet.

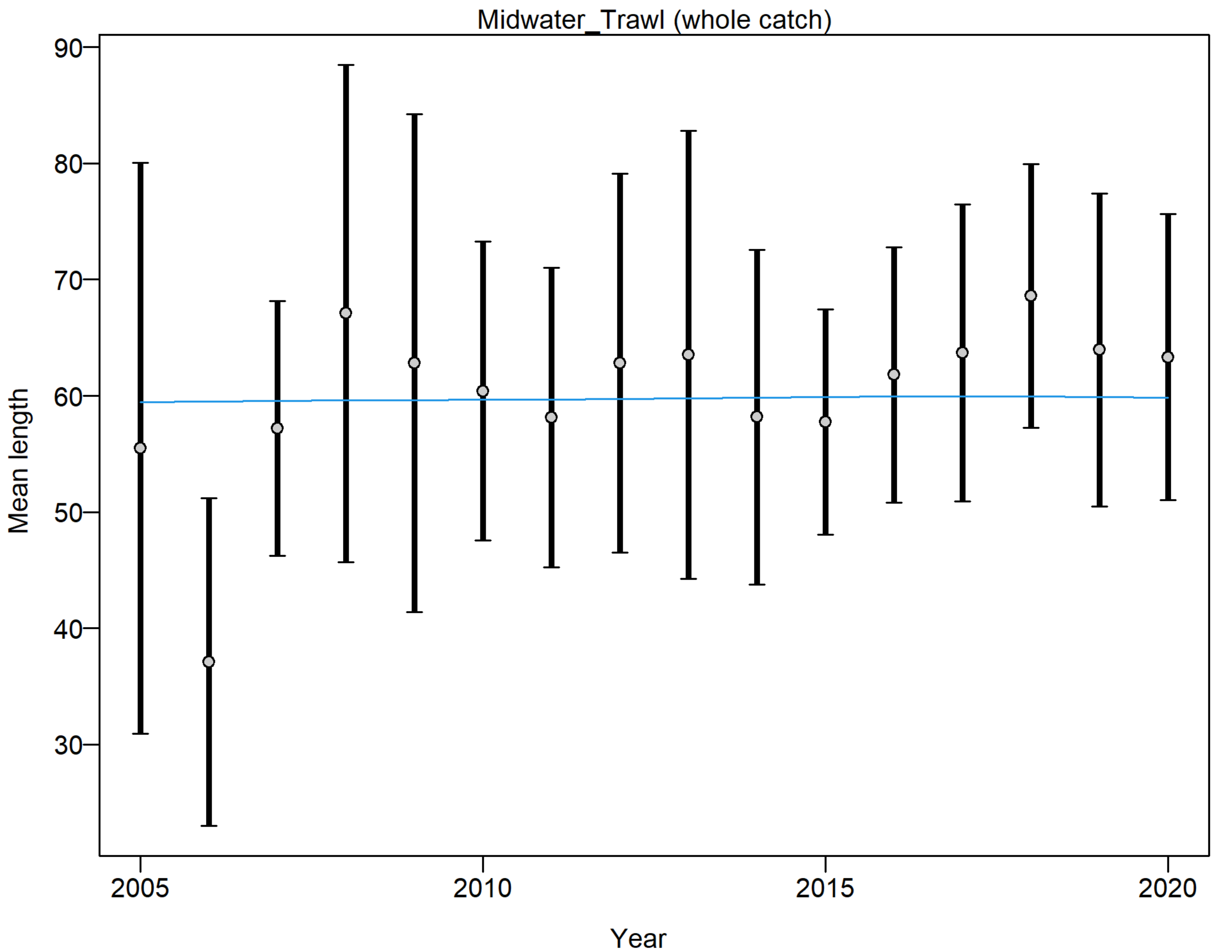

Figure 74. Francis weighting fits to the mean lengths by year for the midwater trawl fleet. Vertical lines are 95% confidence intervals.

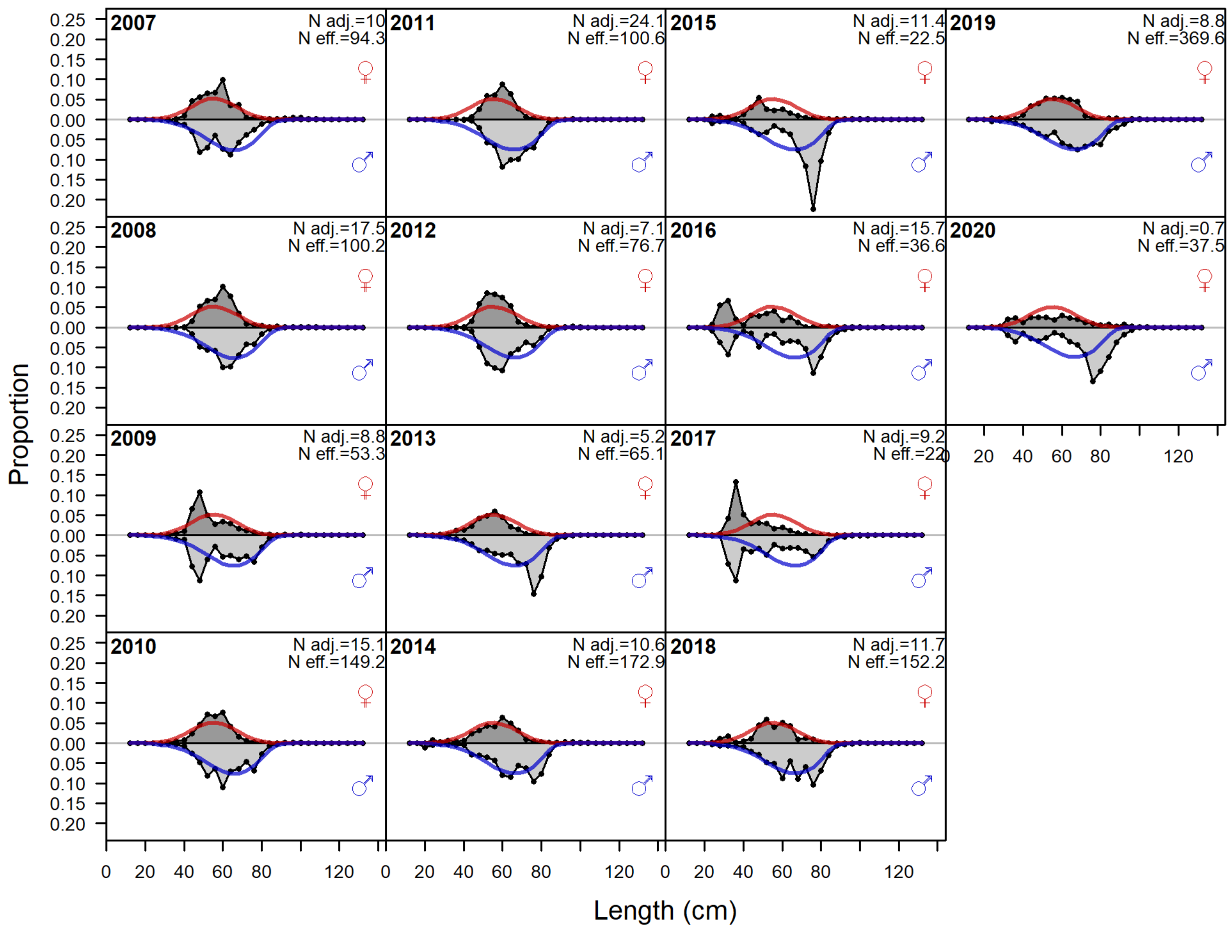

Figure 75. Fit to length-frequency distributions of spiny dogfish for the at-sea hake bycatch fleet.

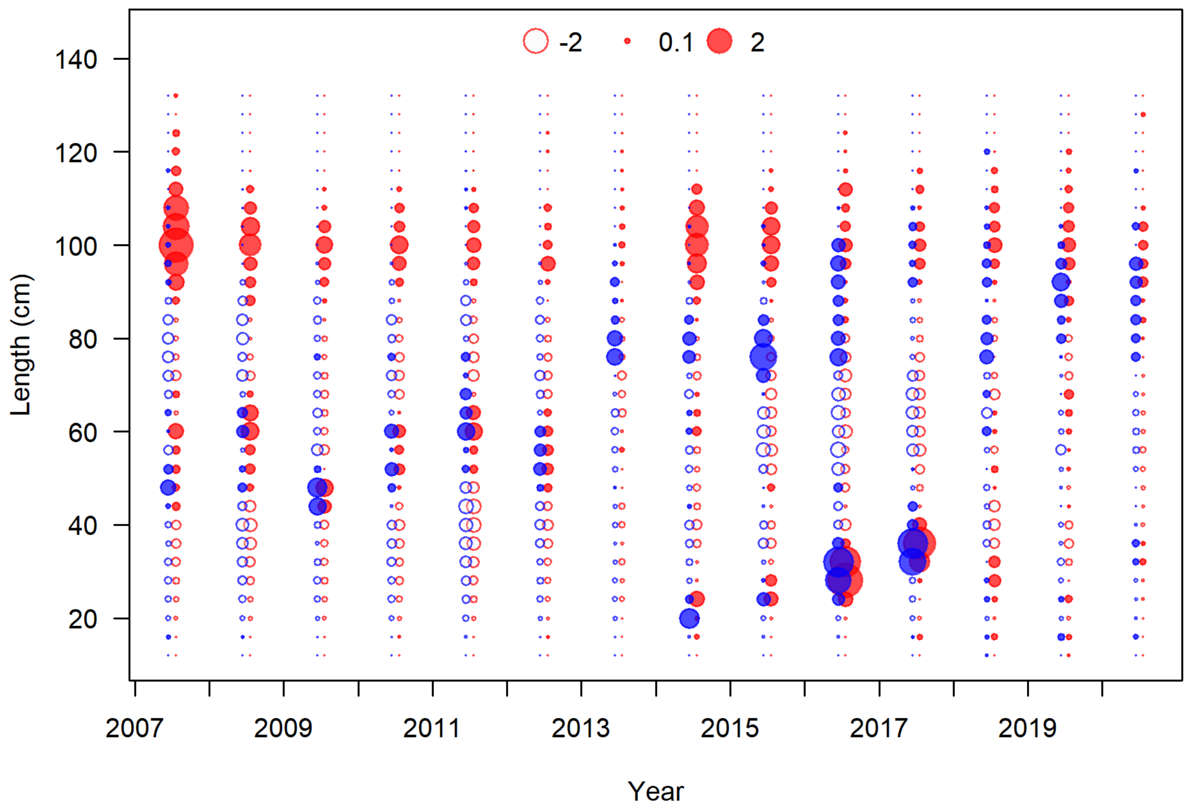

Figure 76. Pearson residuals for the fit of the length-frequency distributions for the at-sea hake bycatch fleet.

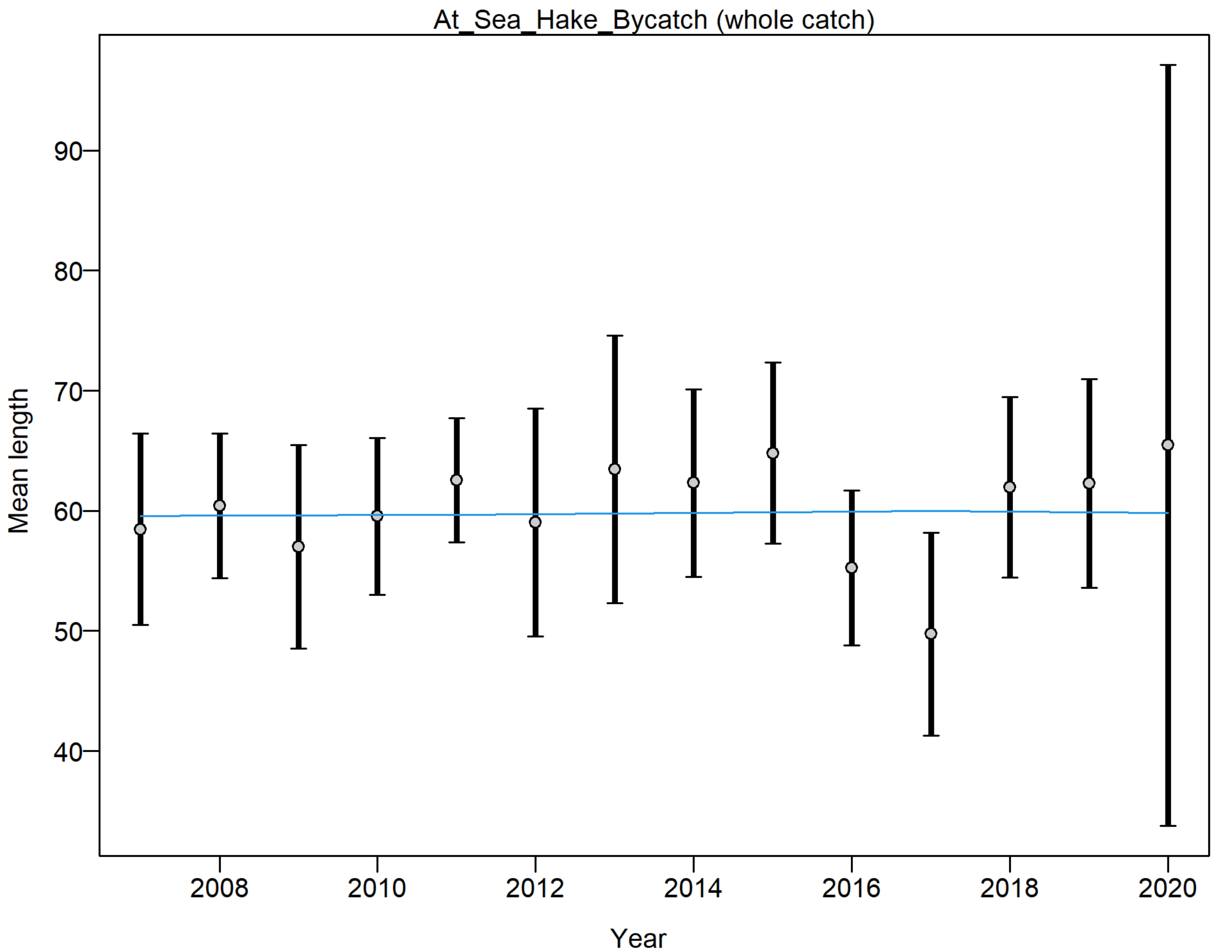

Figure 77. Francis weighting fits to the mean lengths by year for the at-sea hake bycatch fleet. Vertical lines are 95% confidence intervals.

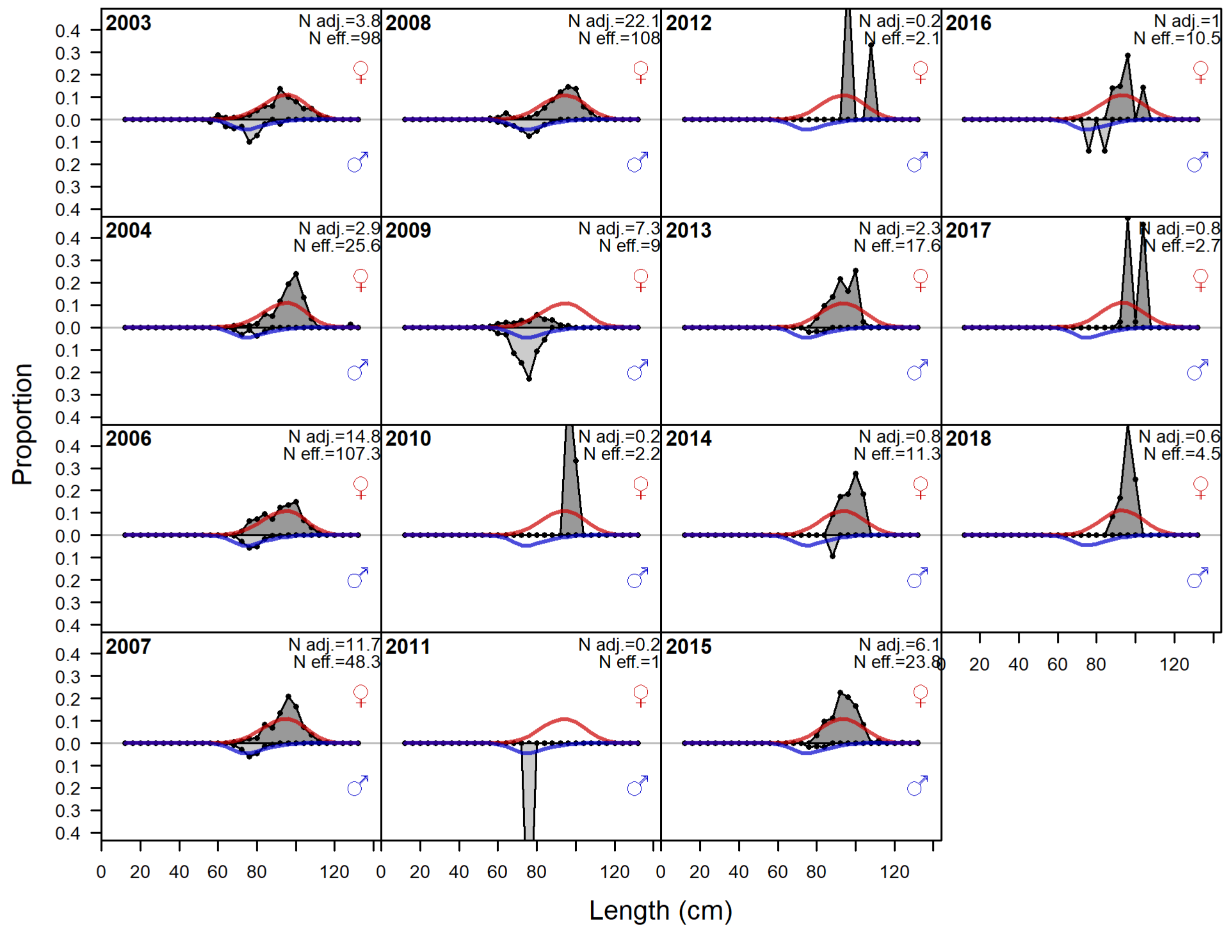

Figure 78. Fit to length-frequency distributions of spiny dogfish for the non-trawl landings fleet.

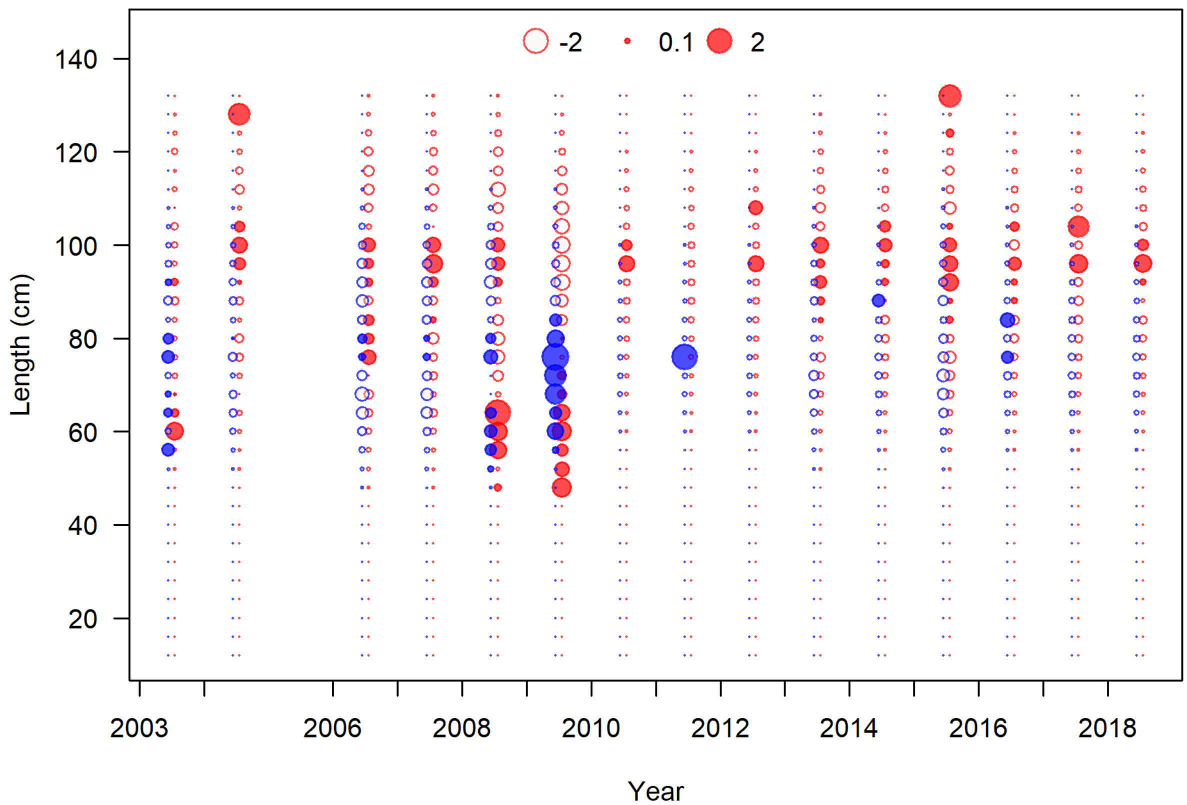

Figure 79. Pearson residuals for the fit of the length-frequency distributions for the non-trawl landings fleet.

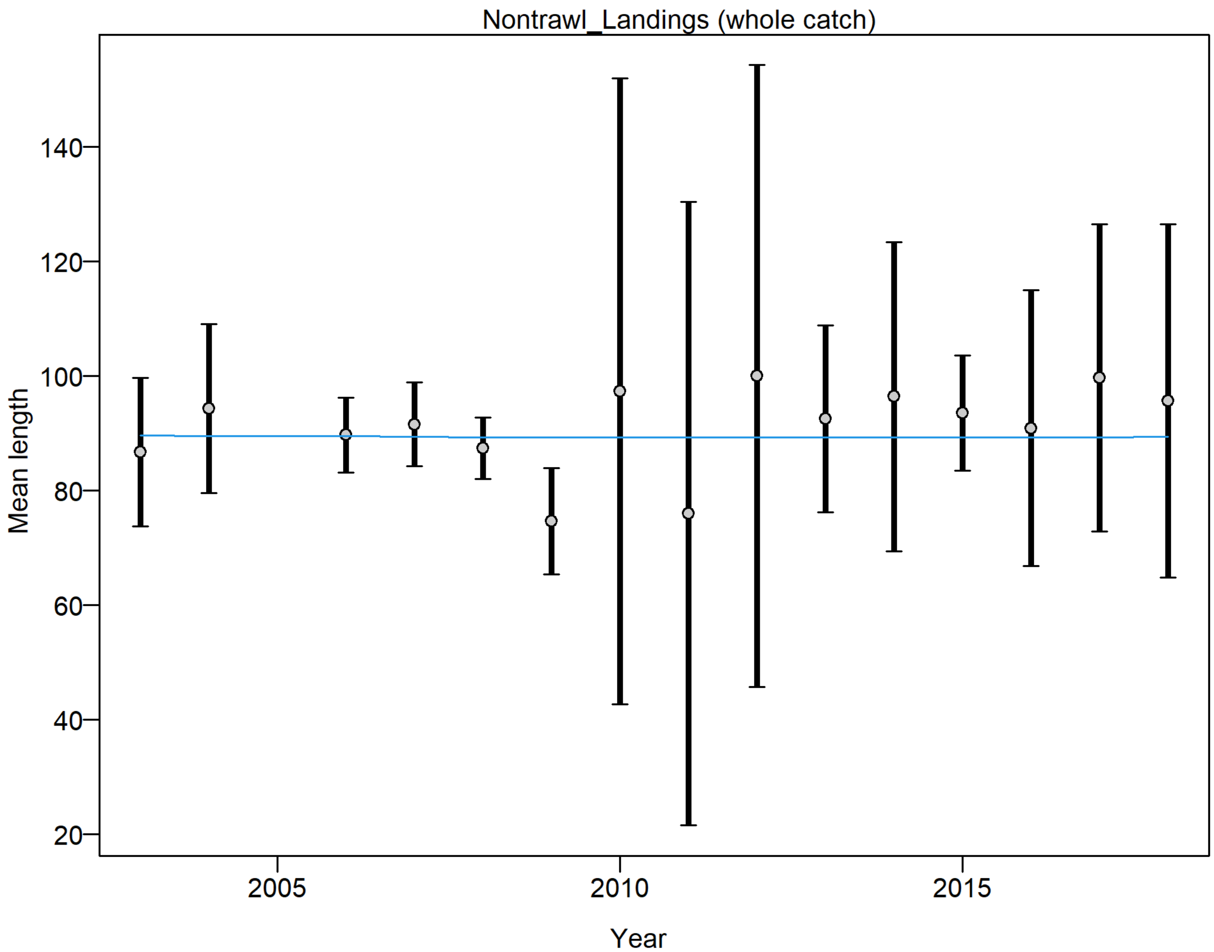

Figure 80. Francis weighting fits to the mean lengths by year for the non-trawl landings trawl fleet. Vertical lines are 95% confidence intervals.

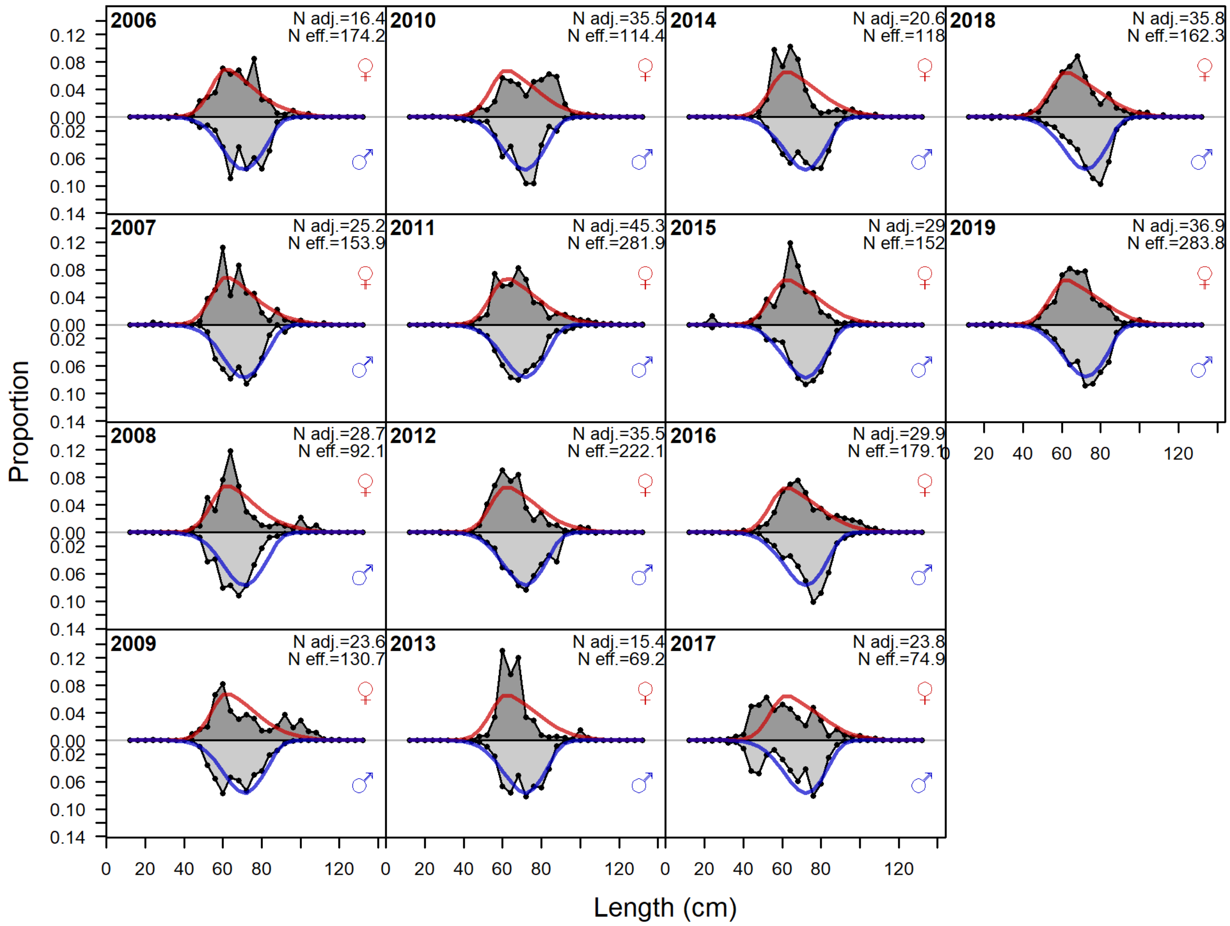

Figure 81. Fit to length-frequency distributions of spiny dogfish for the non-trawl discard fleet.

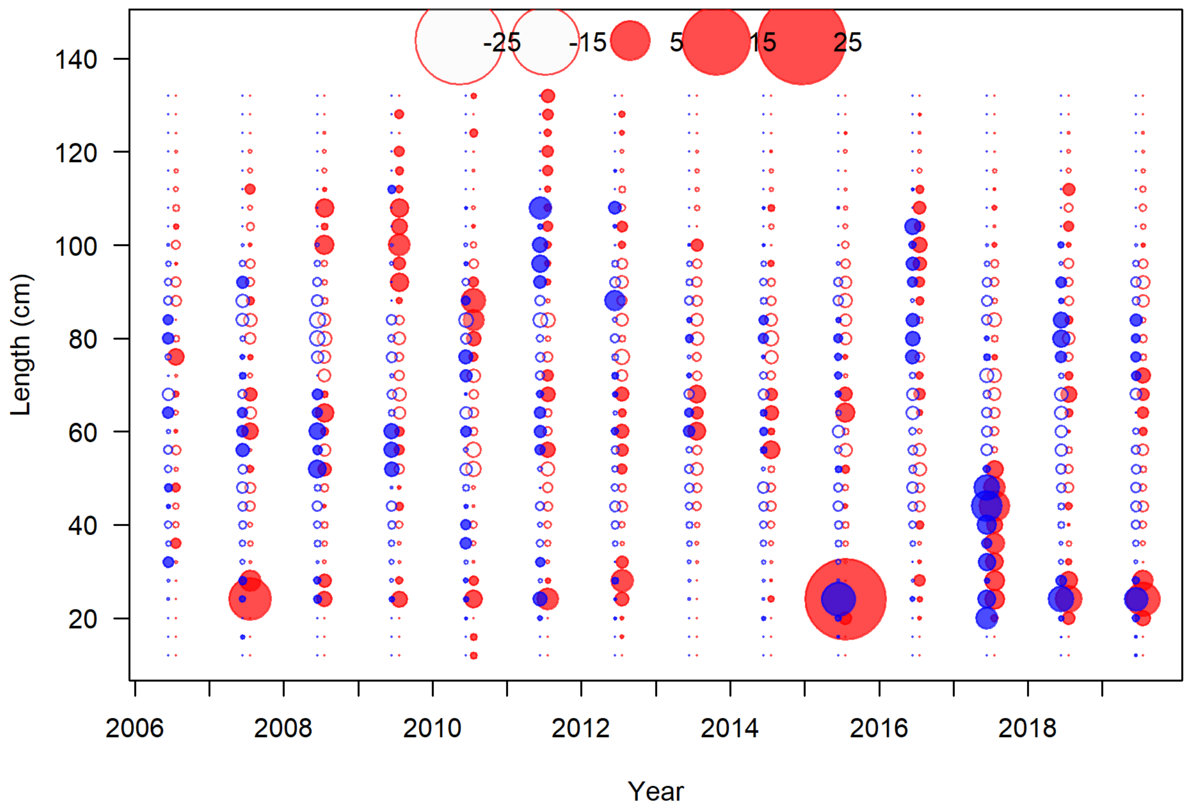

Figure 82. Pearson residuals for the fit of the length-frequency distributions for the non-trawl discard fleet.

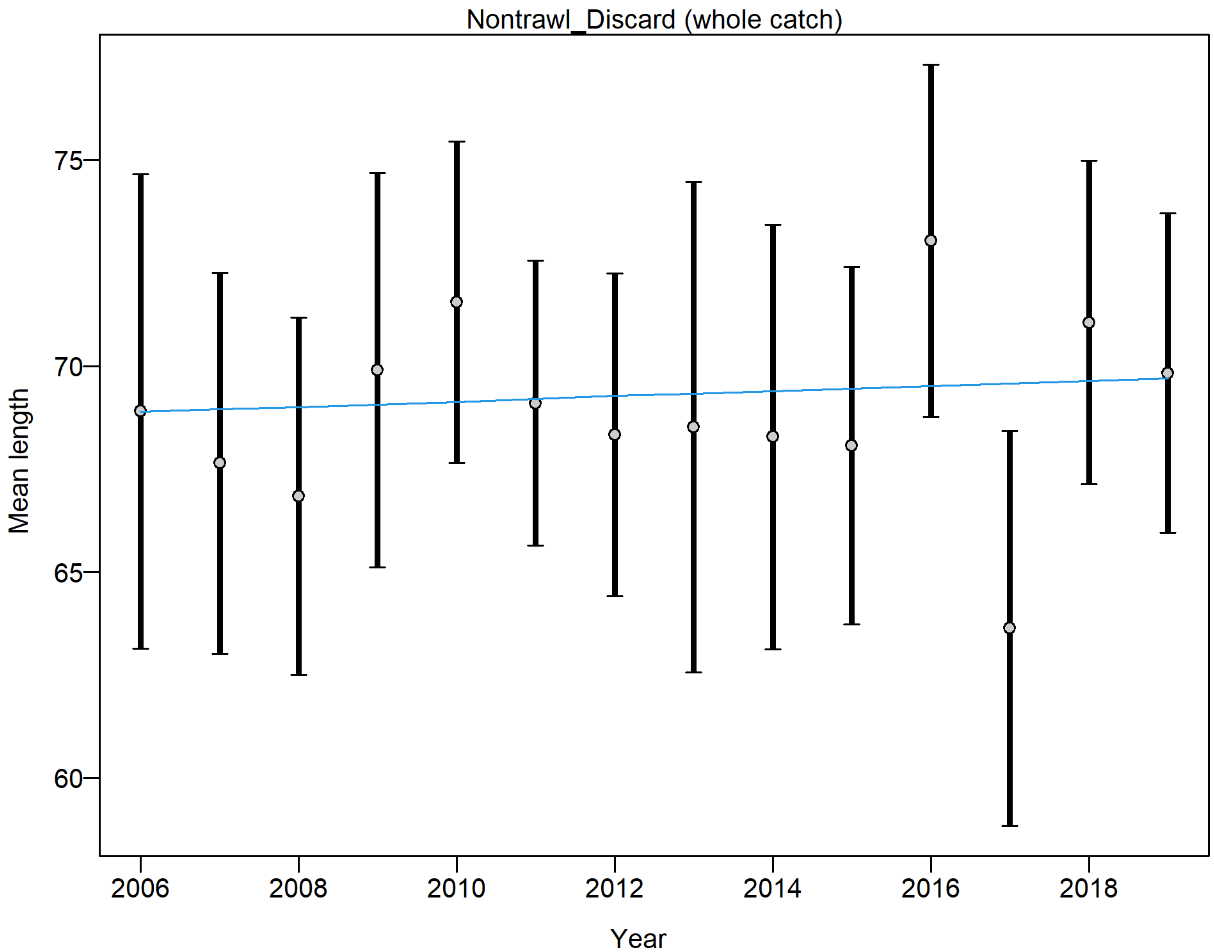

Figure 83. Francis weighting fits to the mean lengths by year for the non-trawl discard trawl fleet. Vertical lines are 95% confidence intervals.

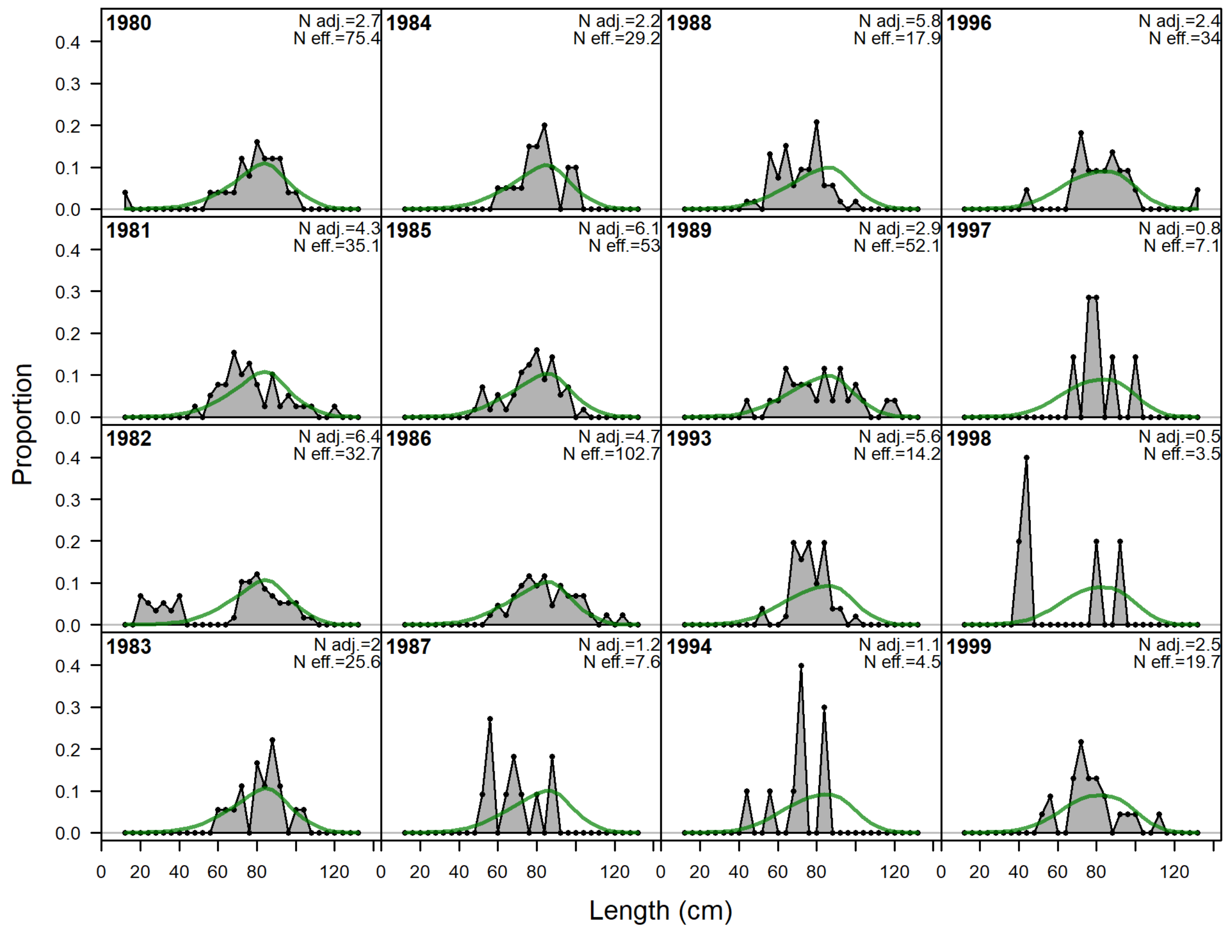

Figure 84. Fit to length-frequency distributions of spiny dogfish (both sexes combined) for the recreational fleet, 1980-1999.

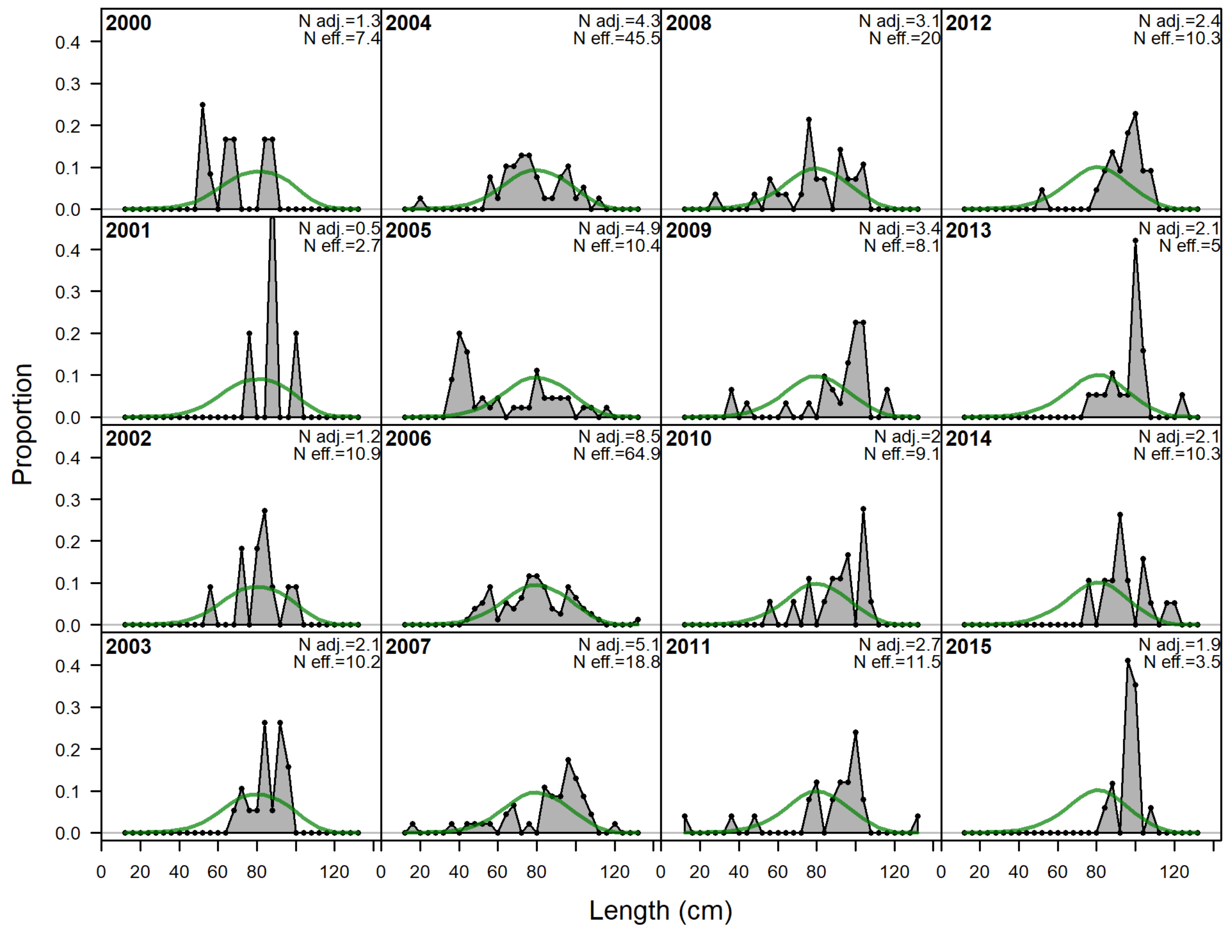

Figure 85. Fit to length-frequency distributions of spiny dogfish (both sexes combined) for the recreational fleet, 2000-2015.

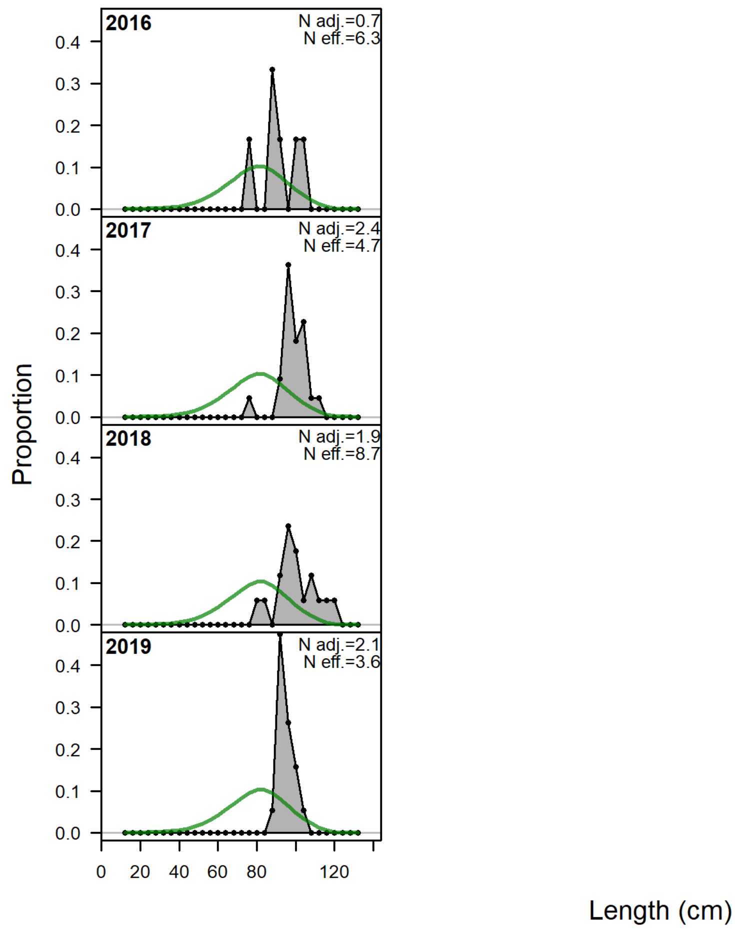

Figure 86. Fit to length-frequency distributions of spiny dogfish (both sexes combined) for the recreational fleet, 2016-2019.

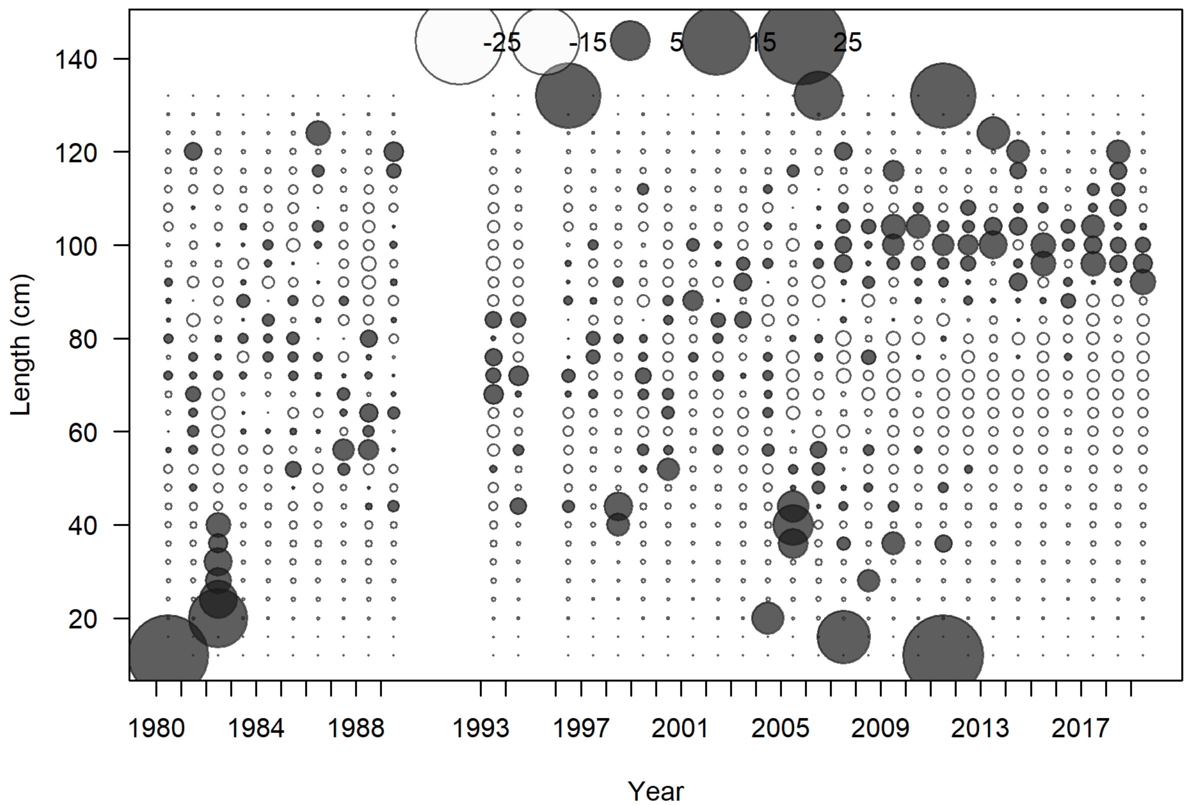

Figure 87. Pearson residuals for the fit of the length-frequency distributions (both sexes combined) for the recreational fleet.

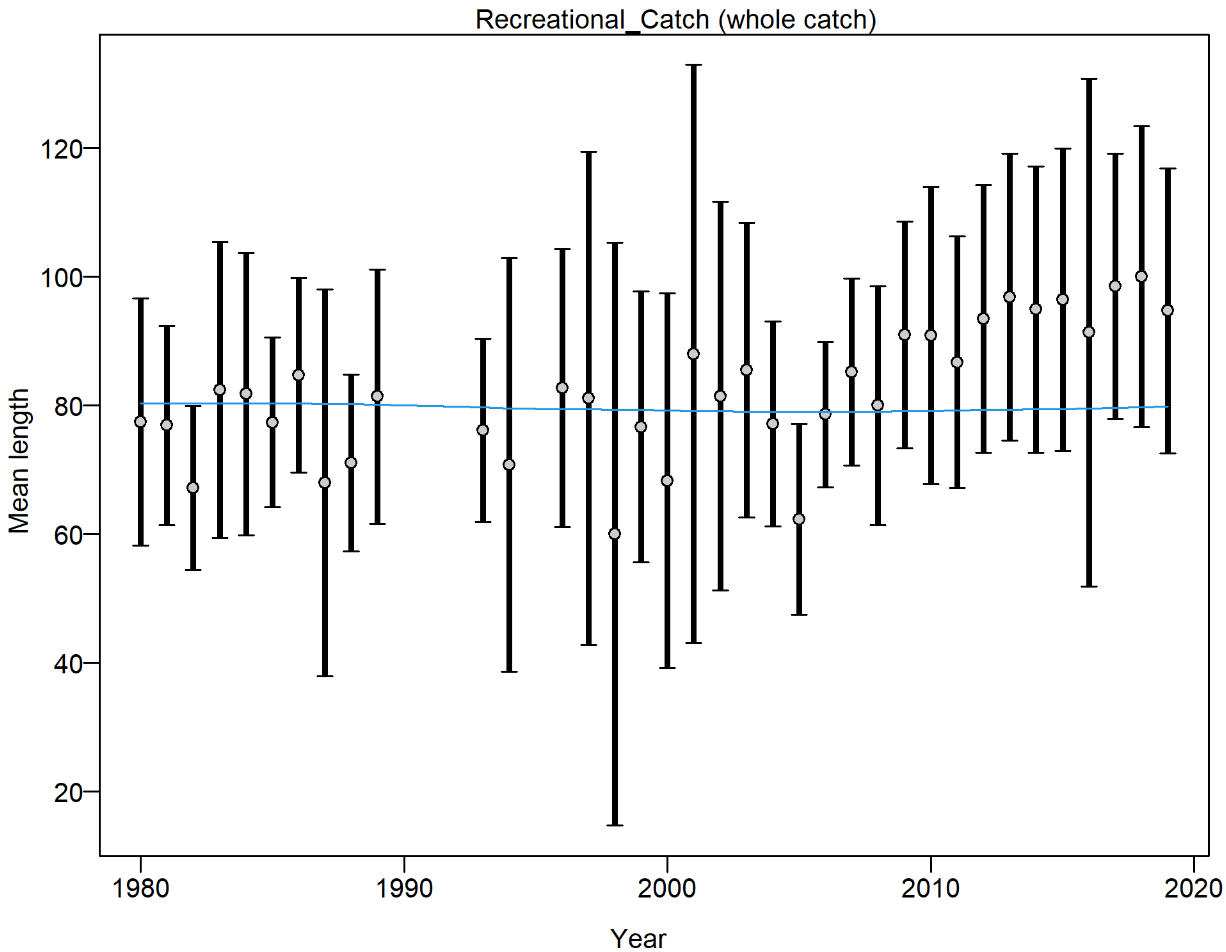

Figure 88. Francis weighting fits to the mean lengths by year for the recreational fleet. Vertical lines are 95% confidence intervals.

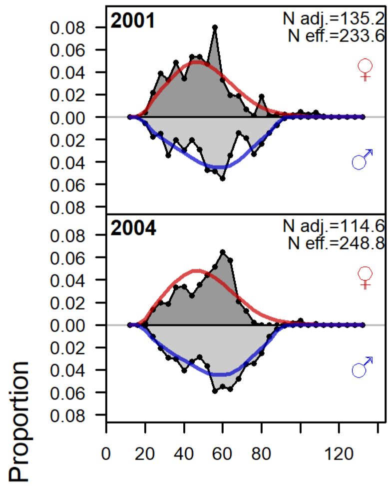

Figure 89. Fit to length-frequency distributions of spiny dogfish for the AFSC Triennial Survey.

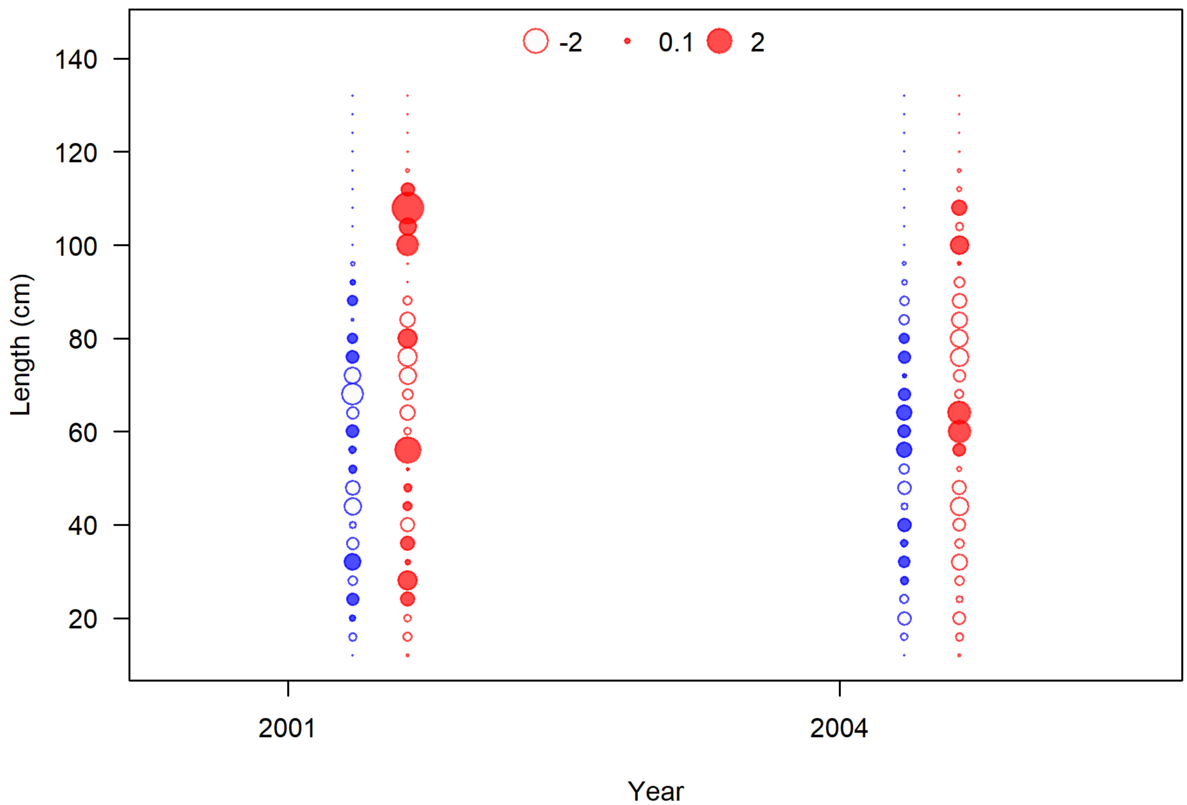

Figure 90. Pearson residuals for the fit of the length-frequency distributions for the AFSC Triennial Survey.

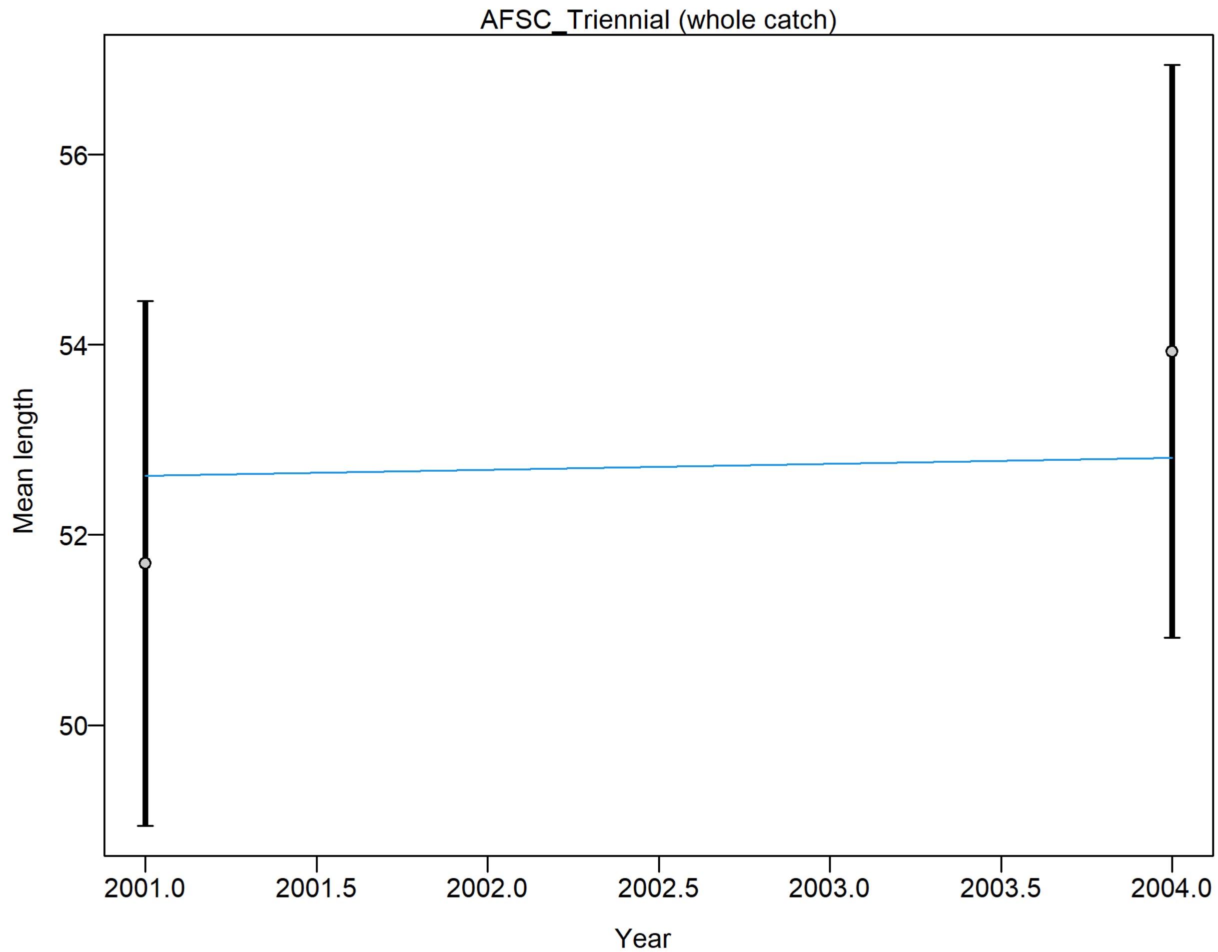

Figure 91. Francis weighting fits to the mean lengths by year for the AFSC Triennial Survey. Vertical lines are 95% confidence intervals.

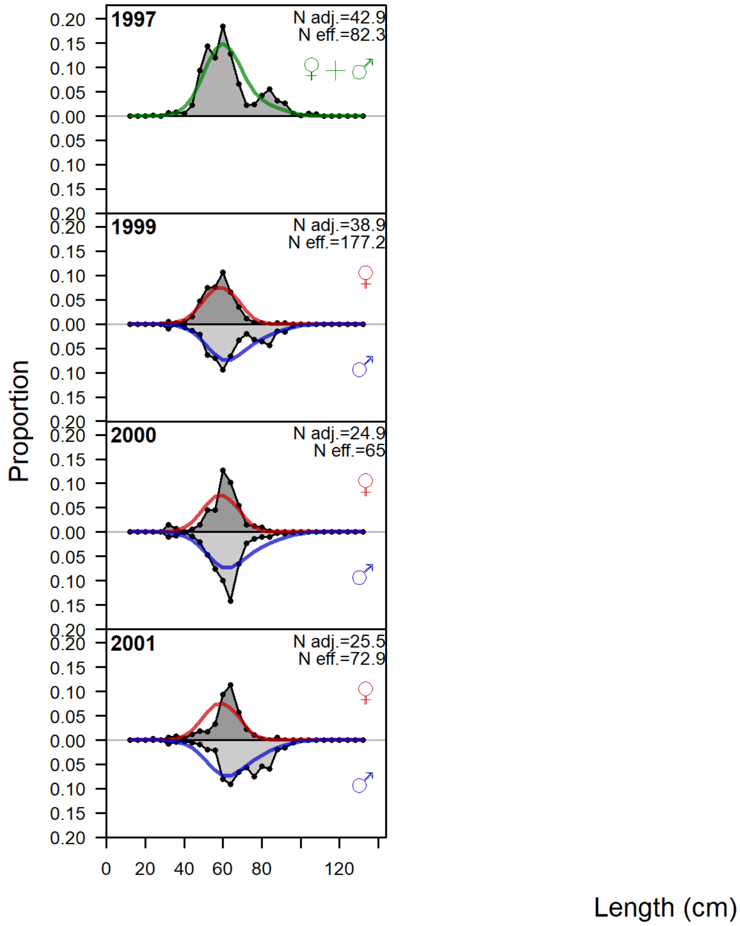

Figure 92. Fit to length-frequency distributions of spiny dogfish for the AFSC Slope Survey.

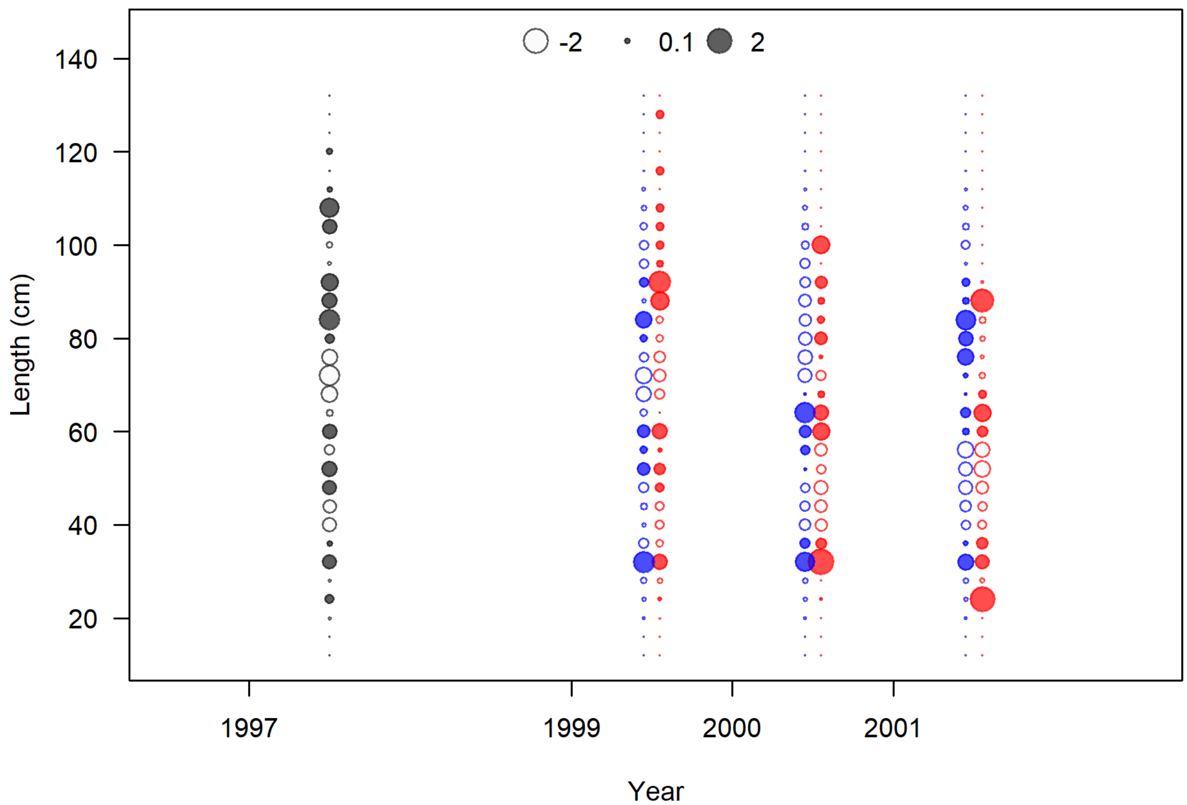

Figure 93. Pearson residuals for the fit of the length-frequency distributions for the AFSC Slope Survey.

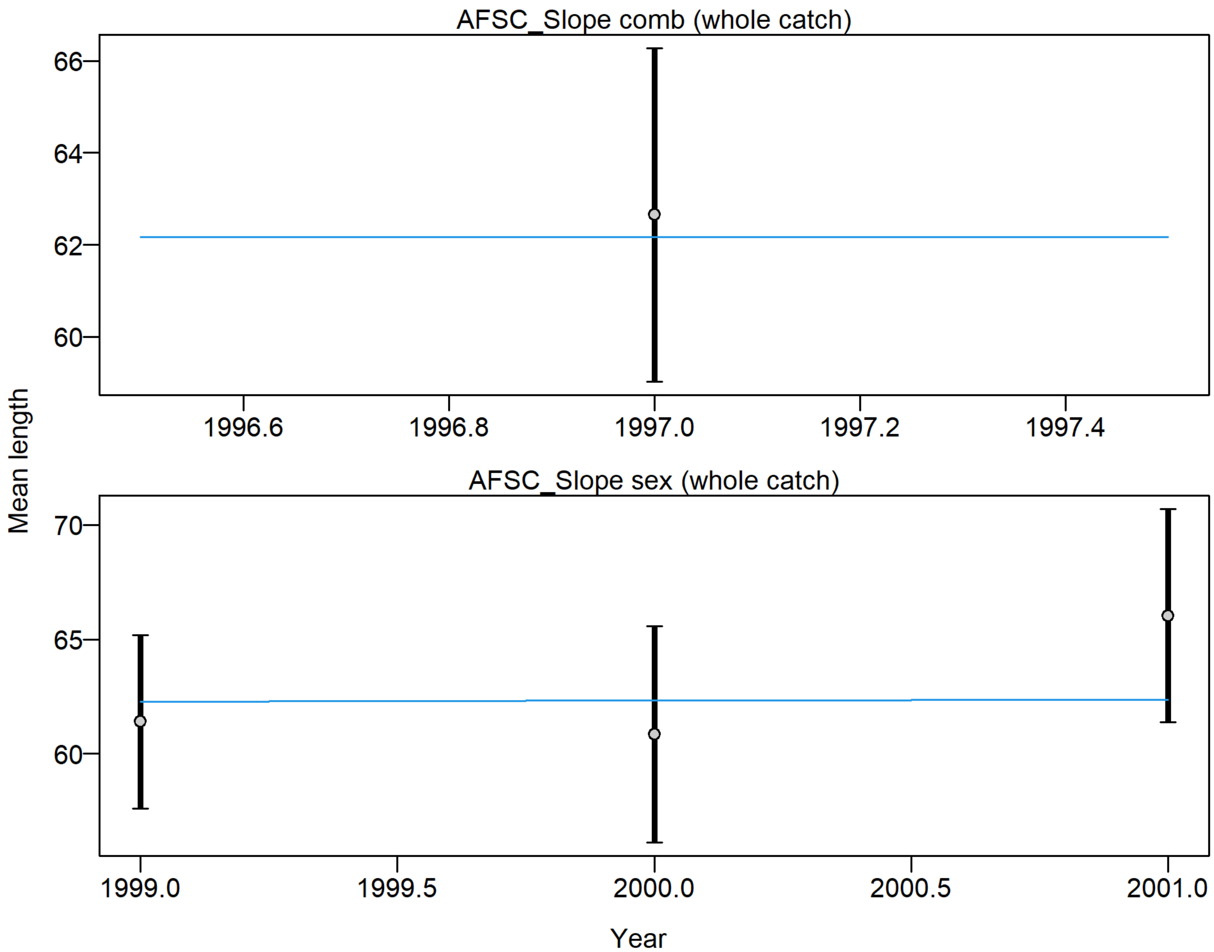

Figure 94. Francis weighting fits to the mean lengths by year for the AFSC Slope Survey. Vertical lines are 95% confidence intervals.

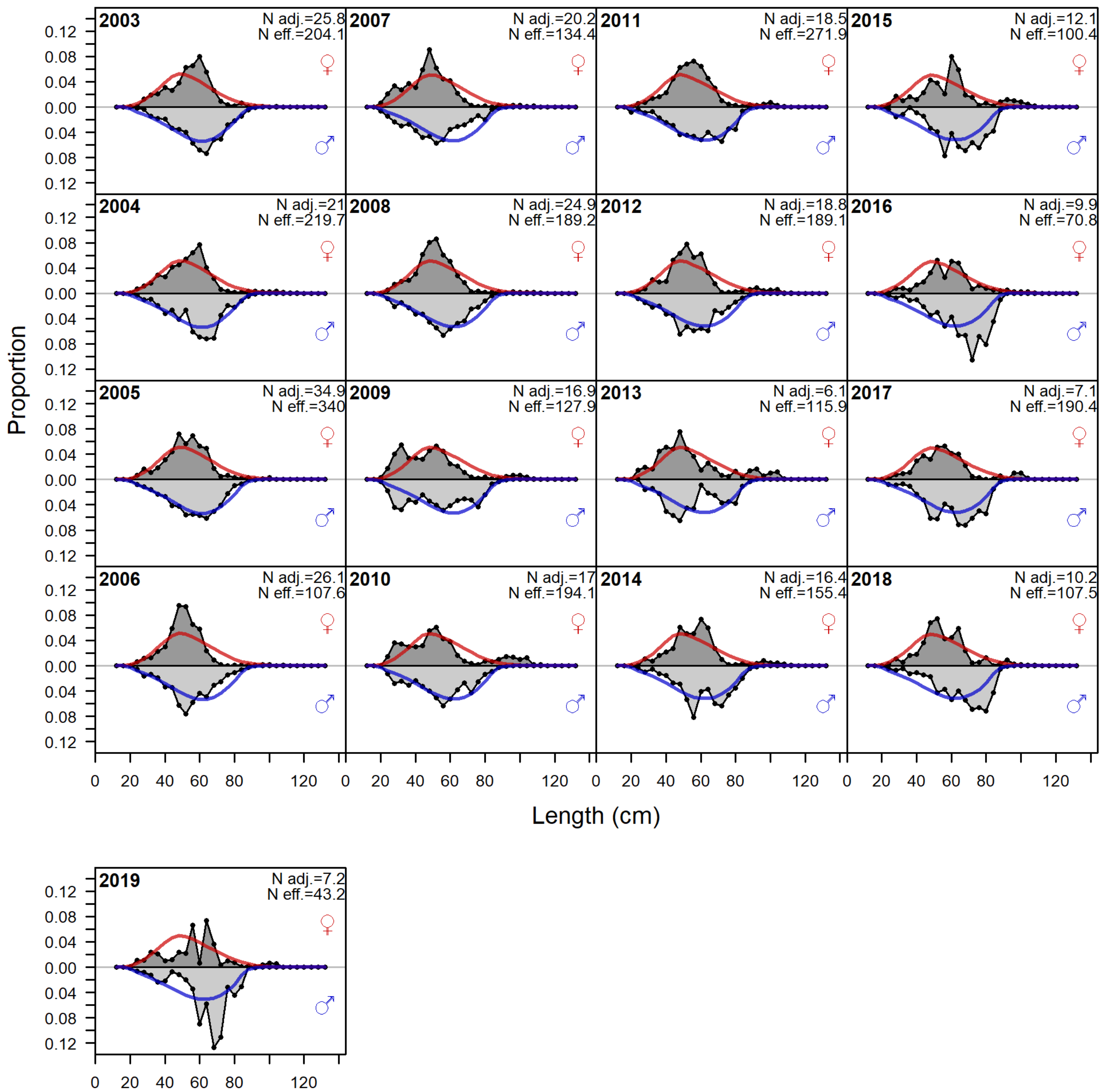

Figure 95. Fit to length-frequency distributions of spiny dogfish for the WCGBT Survey.

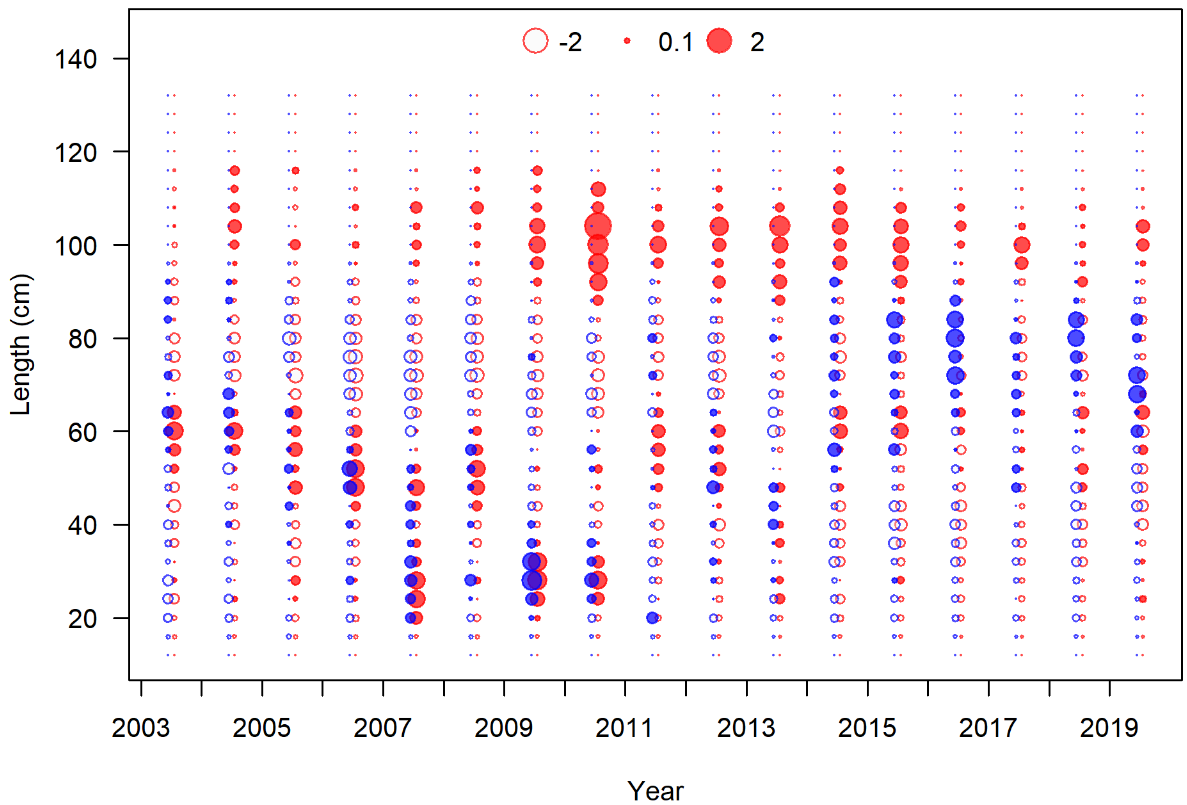

Figure 89. Pearson residuals for the fit of the length-frequency distributions for the WCGBT Survey.

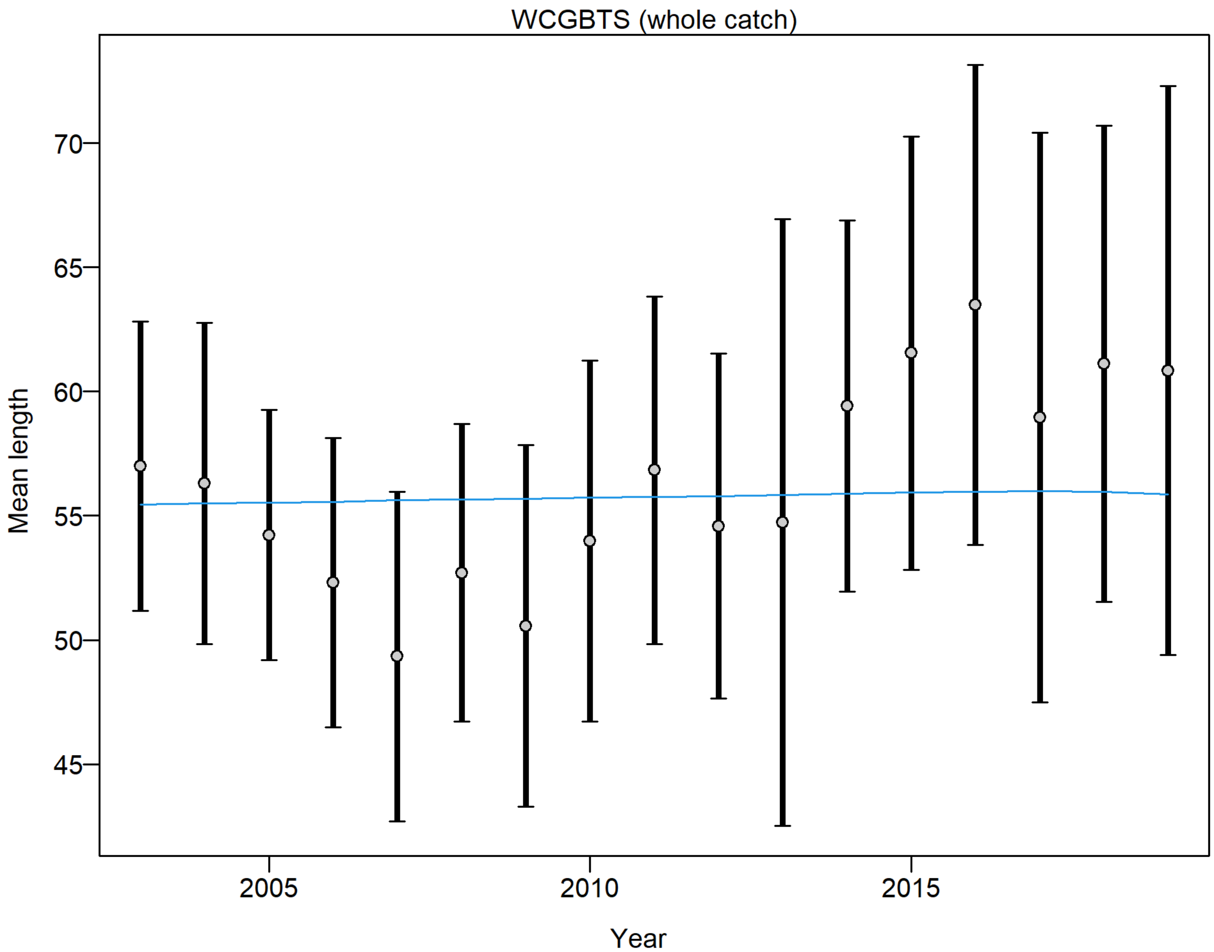

Figure 96. Francis weighting fits to the mean lengths by year for the WCGBT Survey. Vertical lines are 95% confidence intervals.

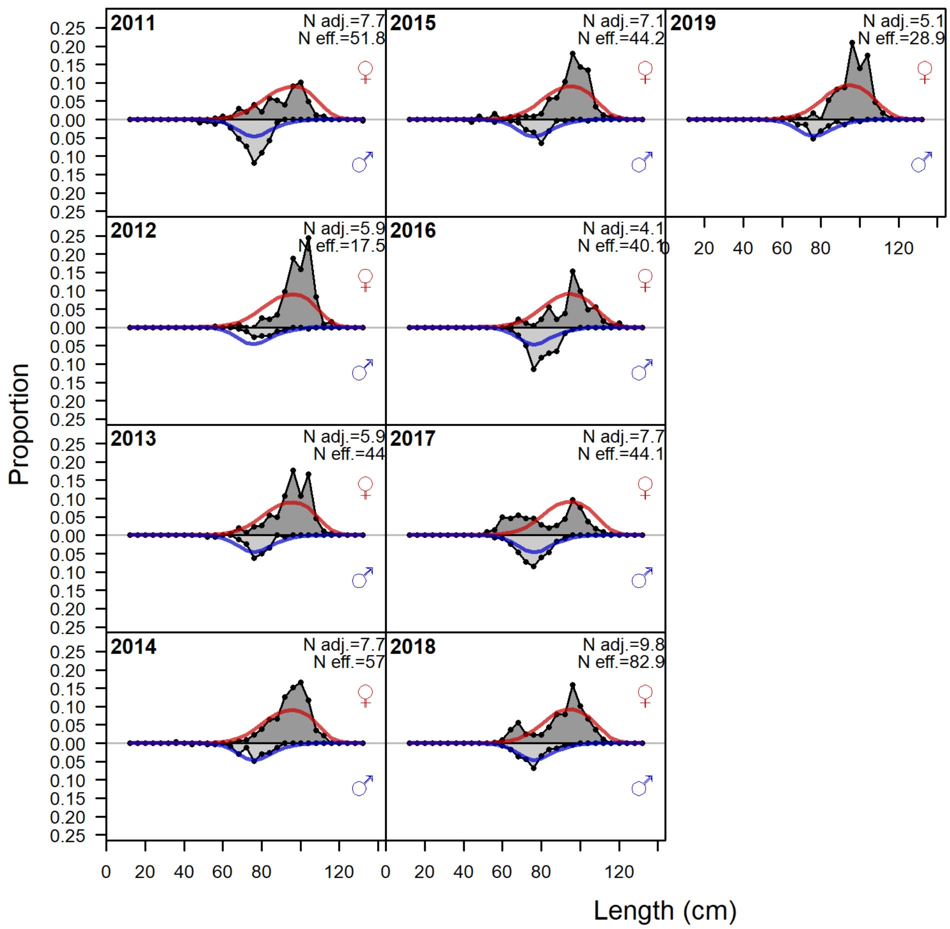

Figure 97. Fit to length-frequency distributions of spiny dogfish for the IPHC Survey.

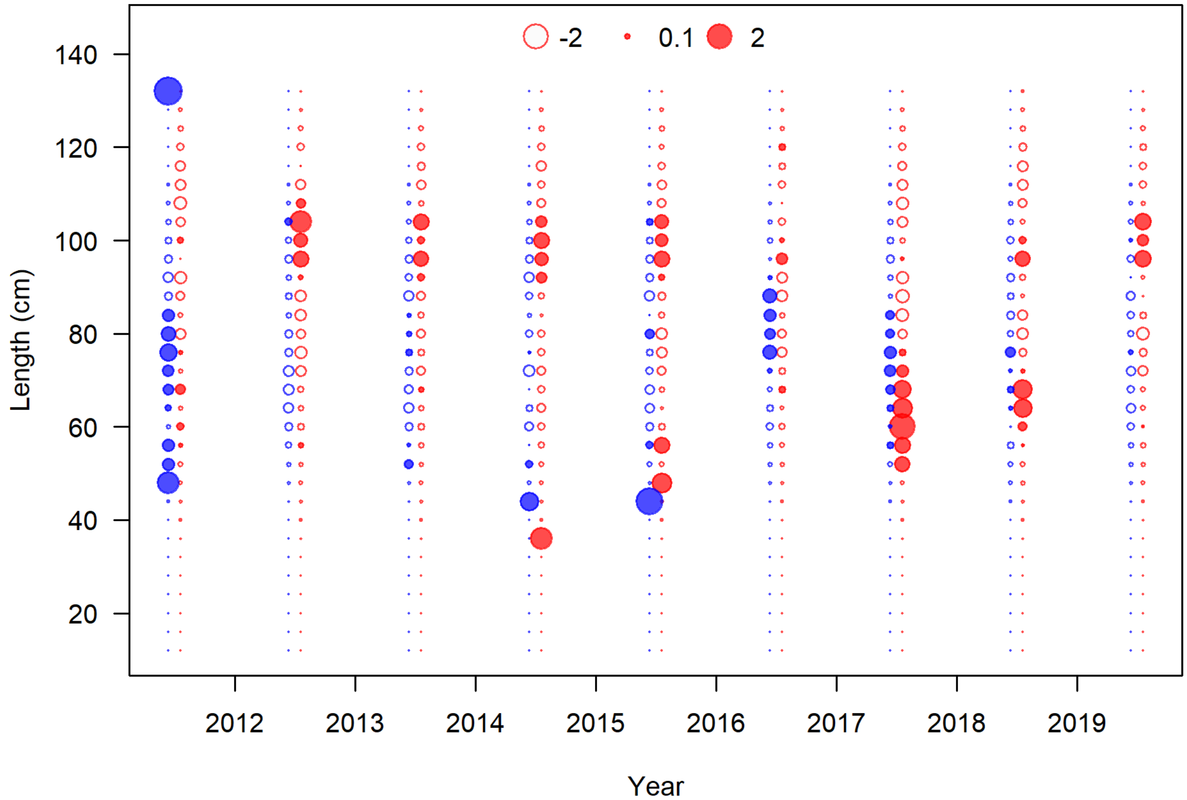

Figure 98. Pearson residuals for the fit of the length-frequency distributions for the IPHC Survey.

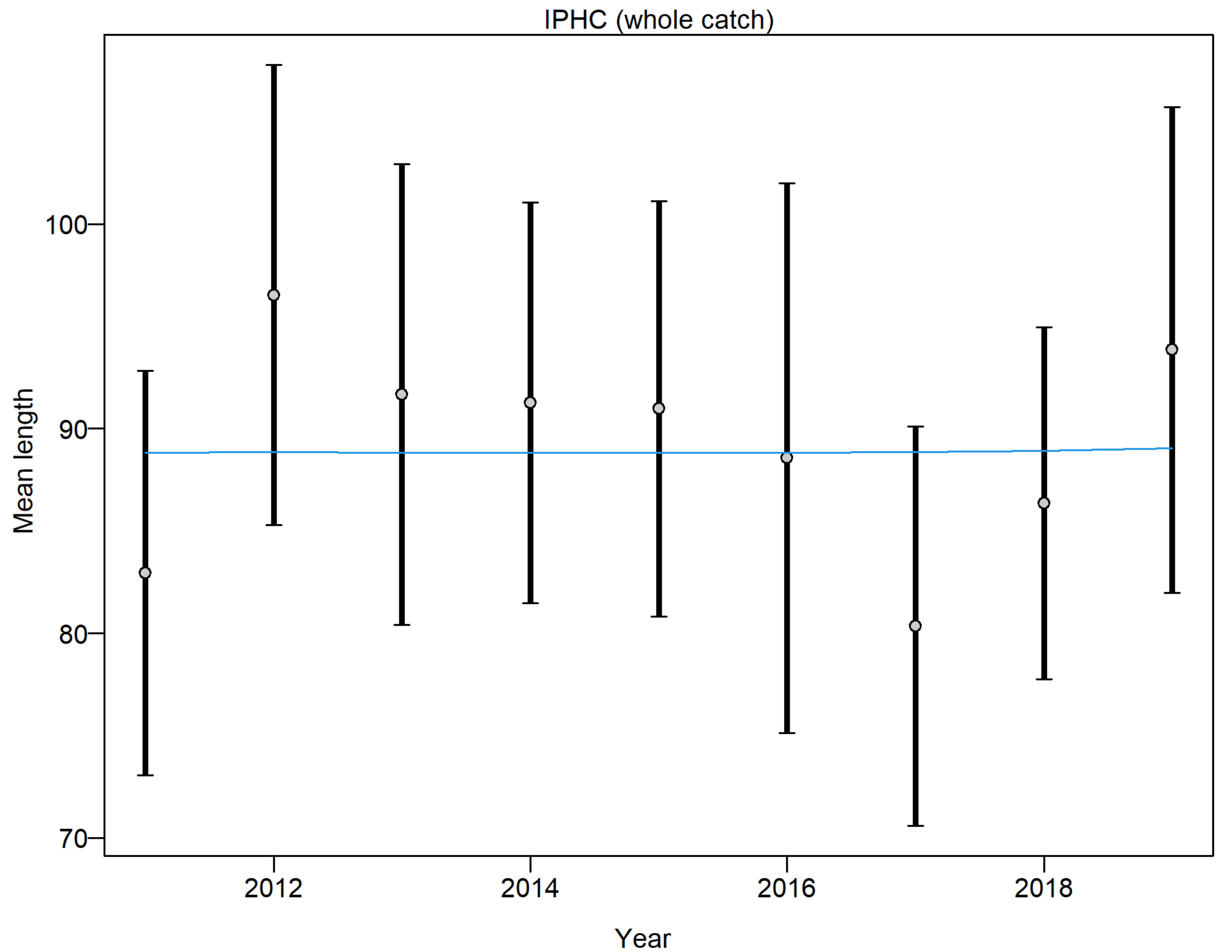

Figure 99. Francis weighting fits to the mean lengths by year for the IPHC Survey. Vertical lines are 95% confidence intervals.

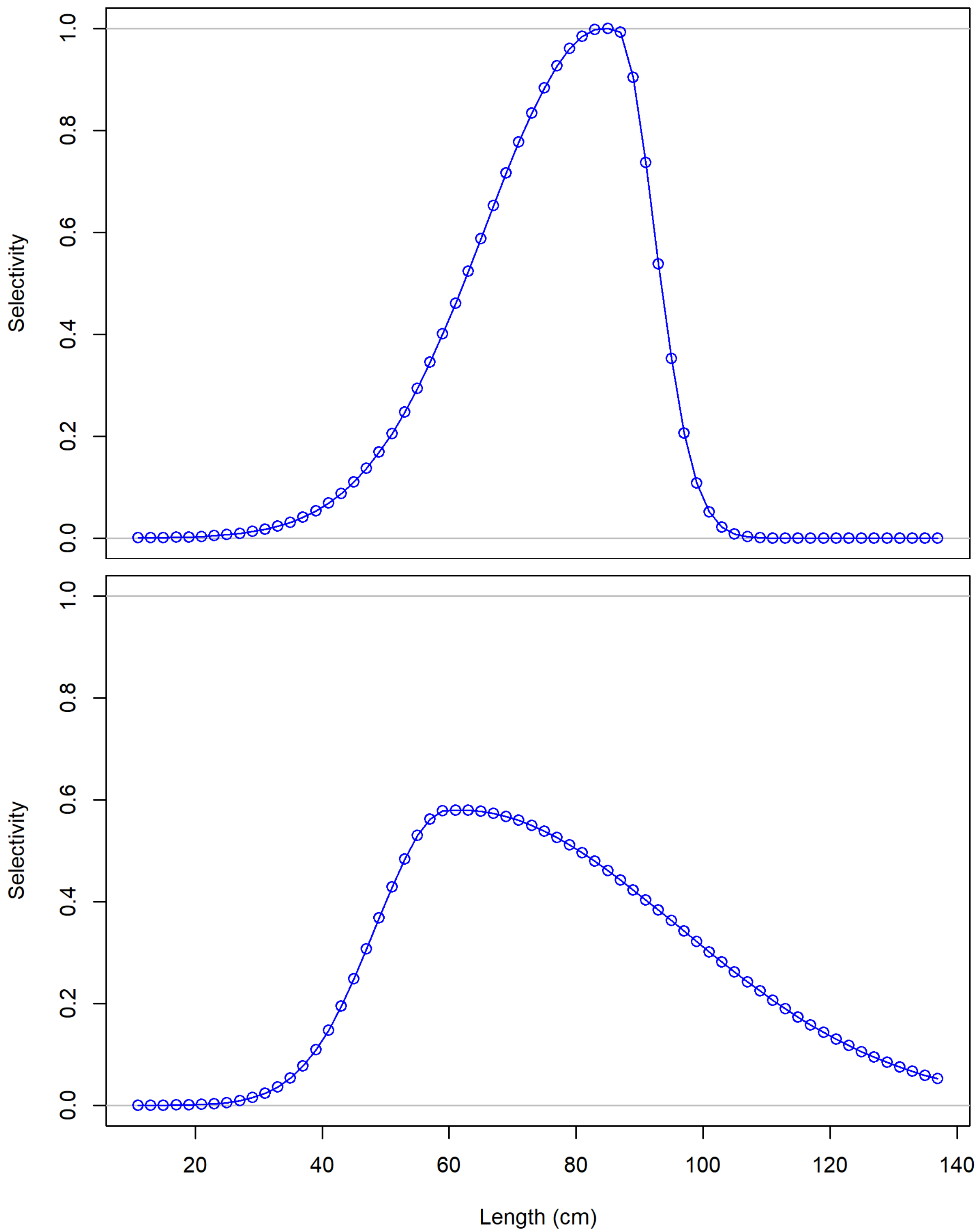

Figure 100. Length-based selectivity curve estimated for the bottom trawl discard and bottom trawl landings fleets for females (top panel) and males (bottom panel).

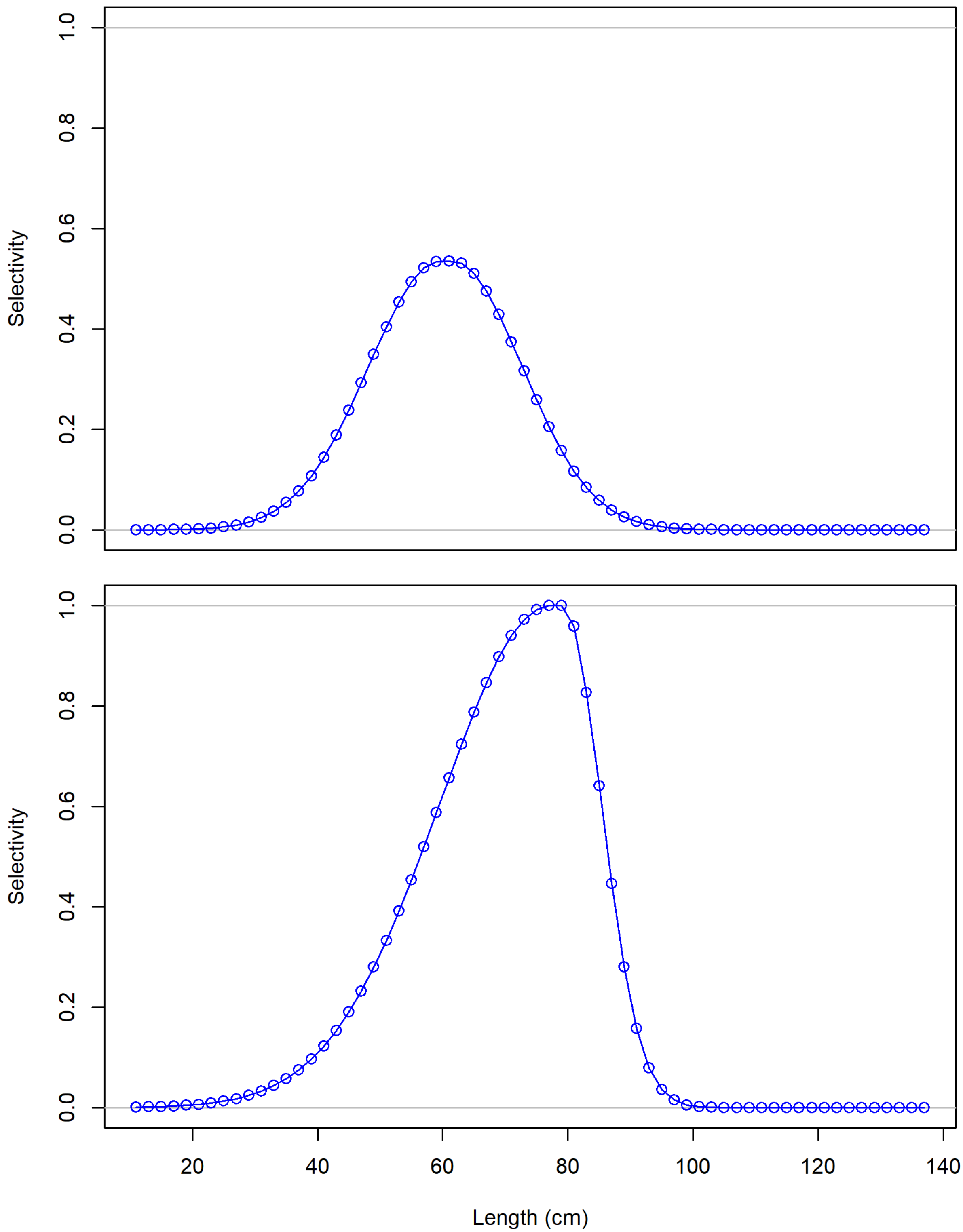

Figure 101. Length-based selectivity curve estimated for the midwater trawl and at-sea hake fishery bycatch fleets for females (top panel) and males (bottom panel).

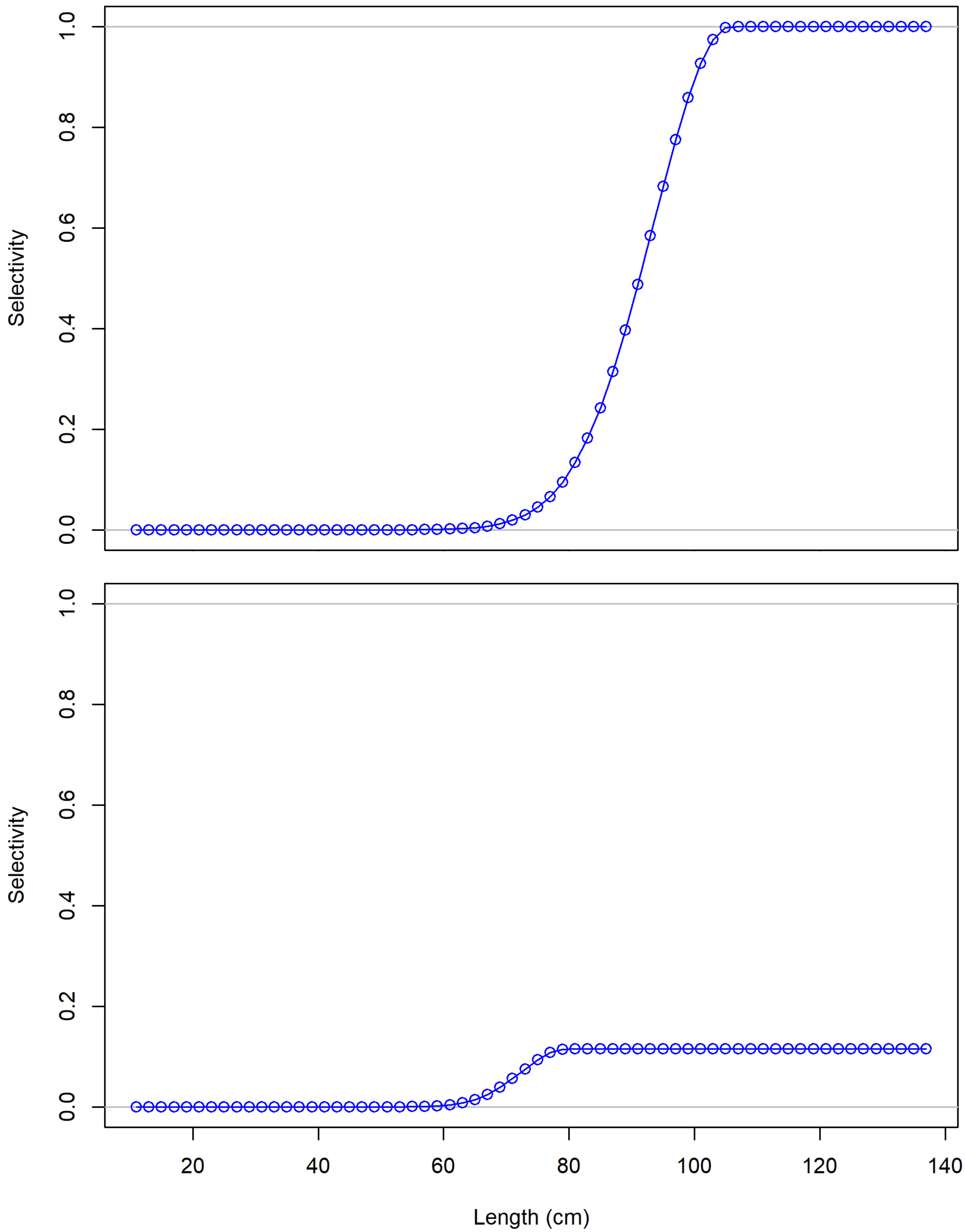

Figure 102. Length-based selectivity curve estimated for the non-trawl landings fleet for females (top panel) and males (bottom panel).

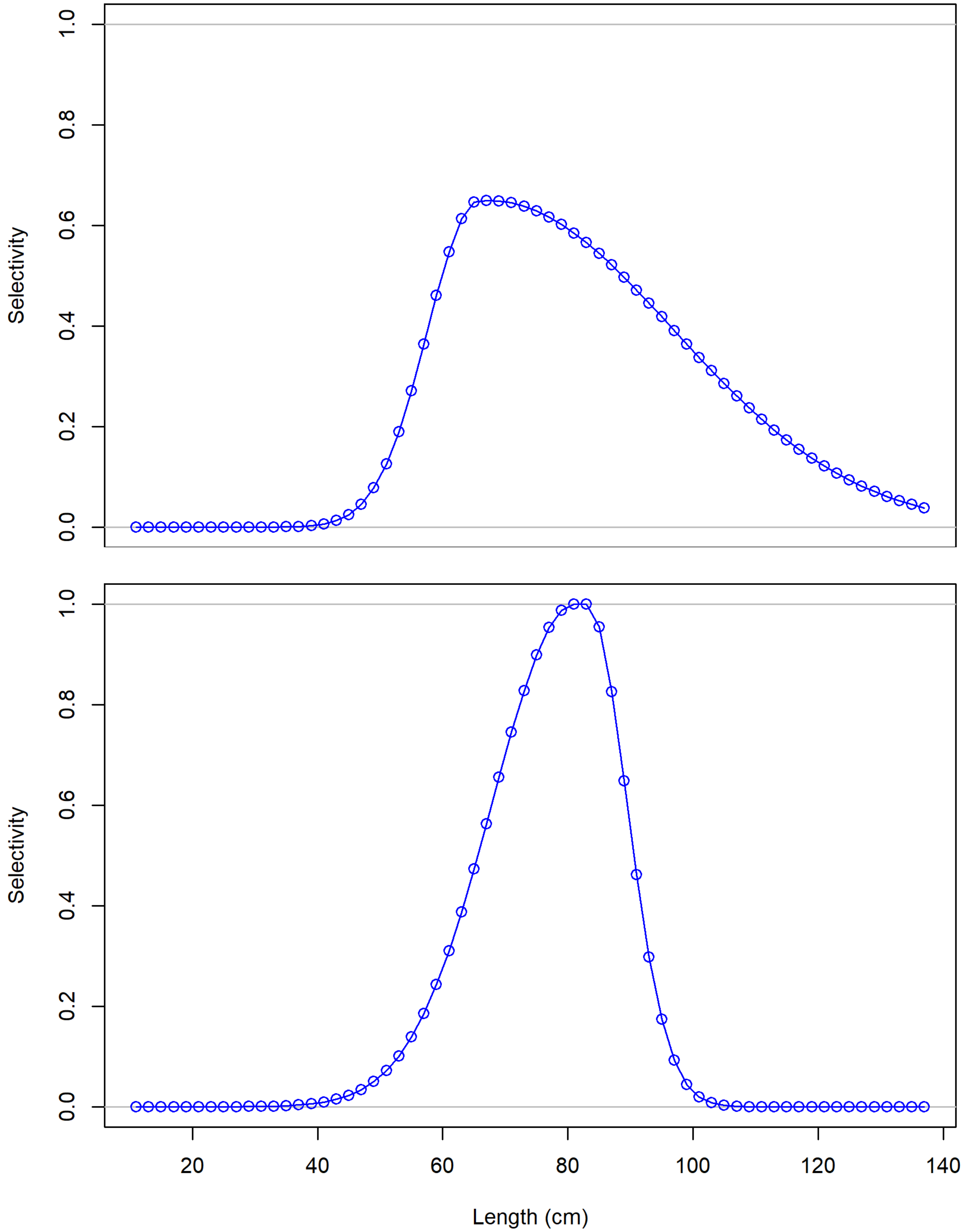

Figure 103. Length-based selectivity curve estimated for the non-trawl discard fleet and non-trawl Vitamin A fishery for females (top panel) and males (bottom panel).

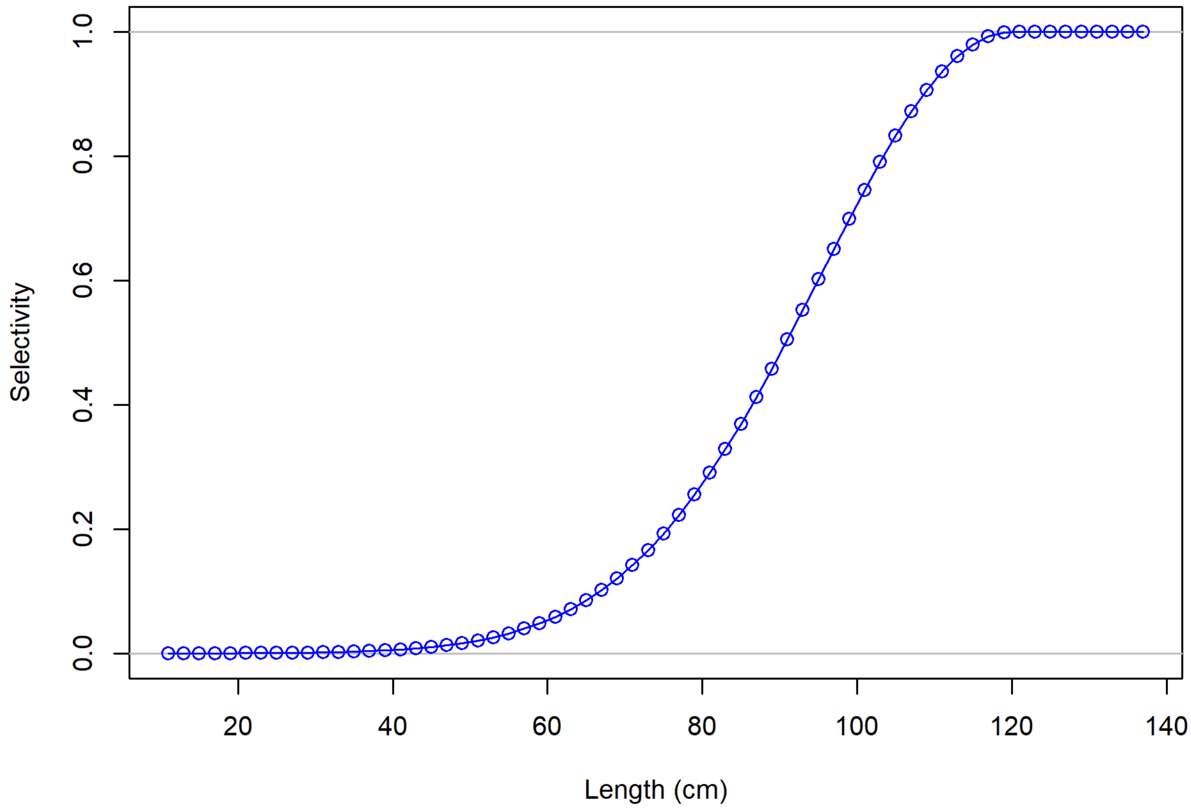

Figure 104. Length-based selectivity curve estimated for the recreational fleet for females and males.

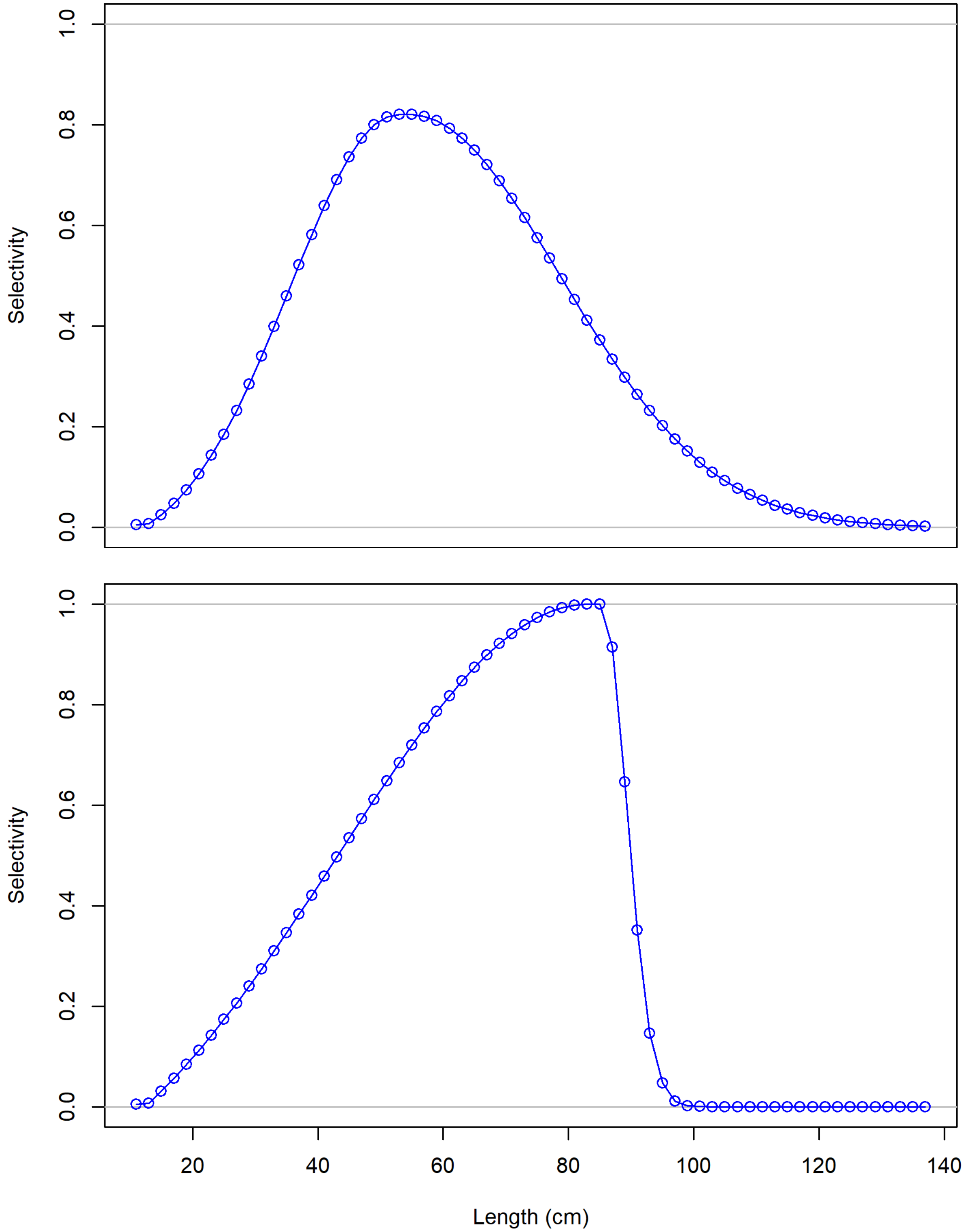

Figure 105. Length-based selectivity curve estimated for the AFSC Triennial Survey for females (top panel) and males (bottom panel).

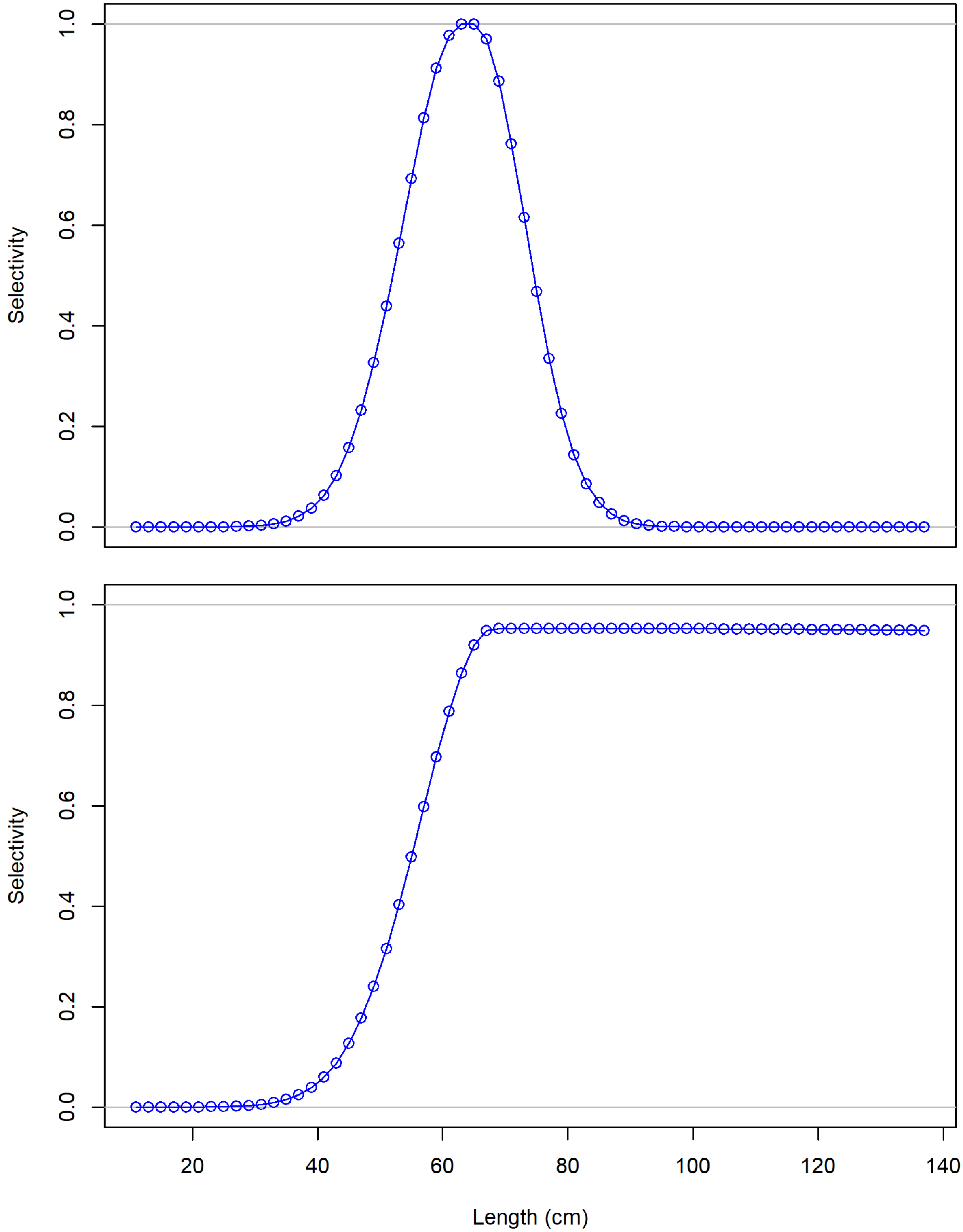

Figure 106. Length-based selectivity curve estimated for the AFSC Slope and NWFSC Slope Surveys for females (top panel) and males (bottom panel).

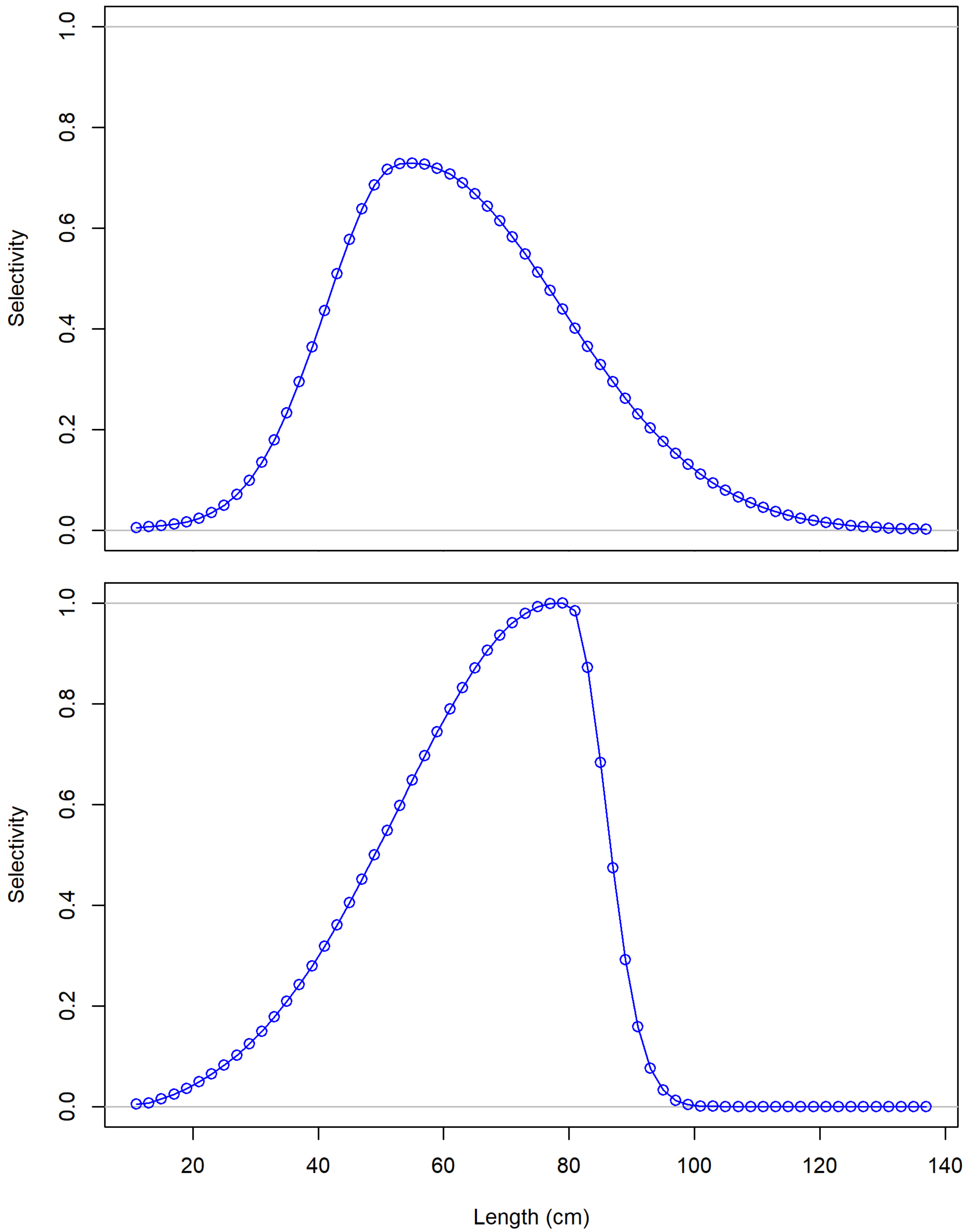

Figure 107. Length-based selectivity curve estimated for the WCGBT Survey for females (top panel) and males (bottom panel).

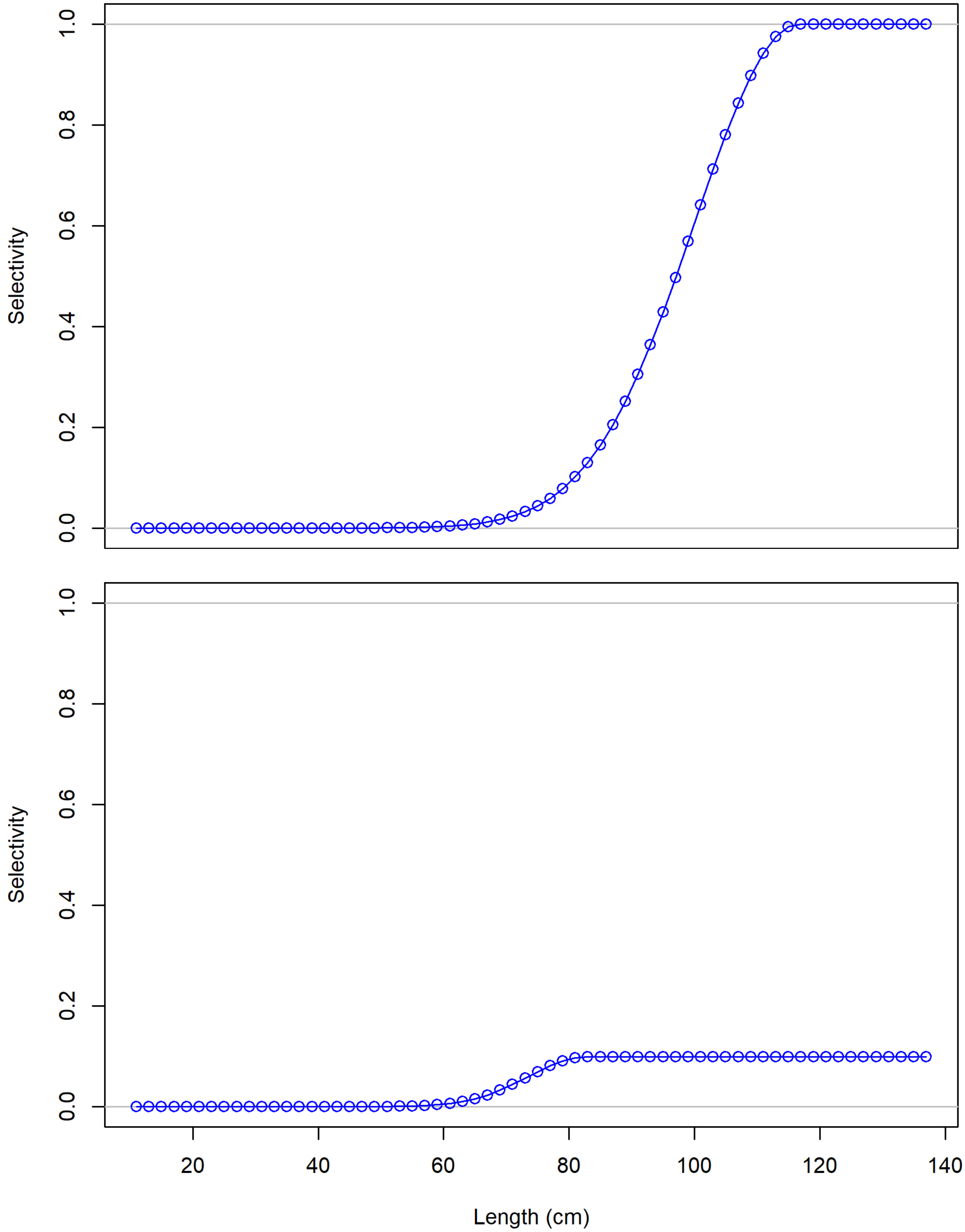

Figure 108. Length-based selectivity curve estimated for the IPHC Survey for females (top panel) and males (bottom panel).

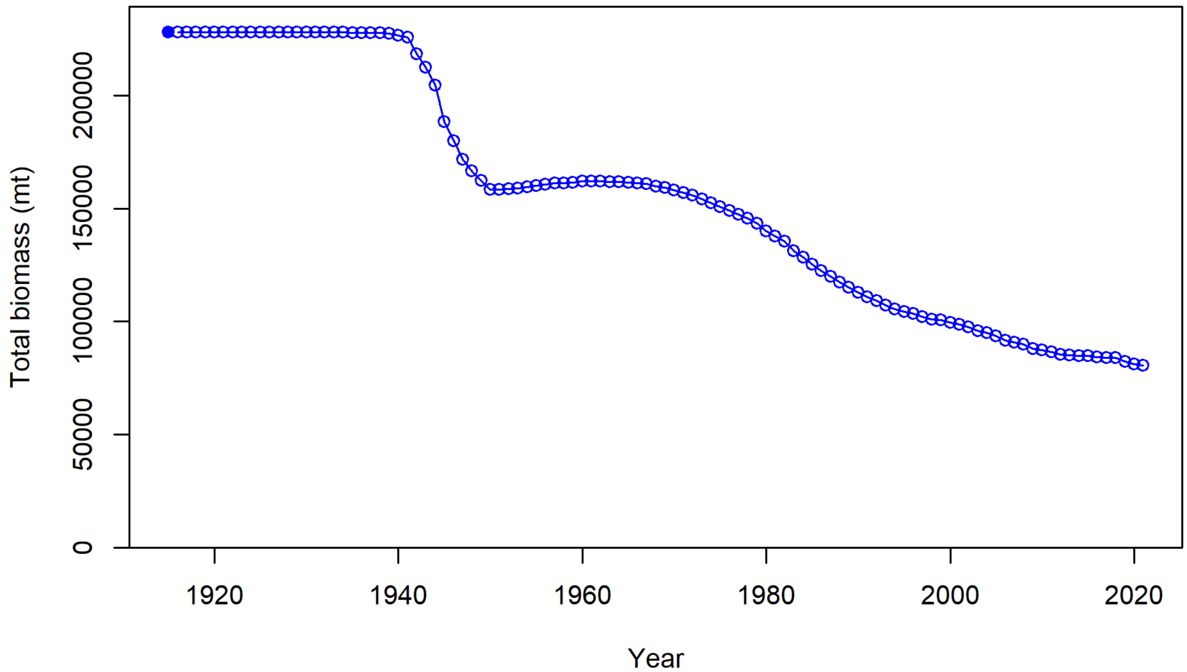

Figure 109. Time series of total biomass of spiny dogfish estimated by the base model.

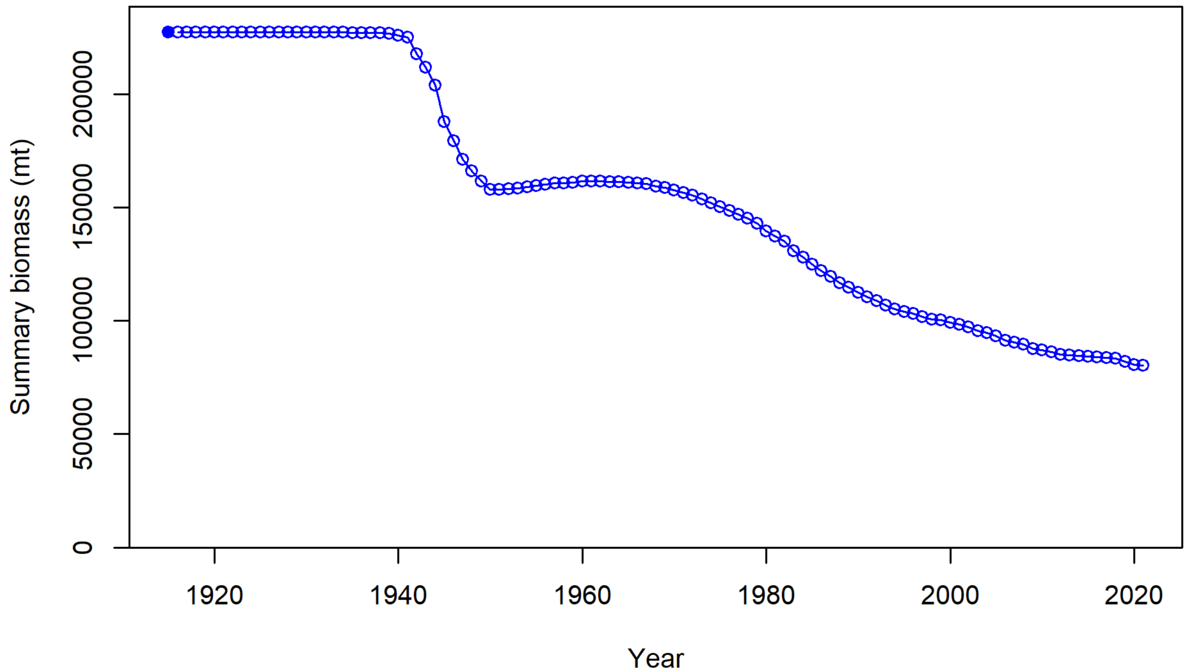

Figure 110. Time series of summary biomass of spiny dogfish estimated by the base model.

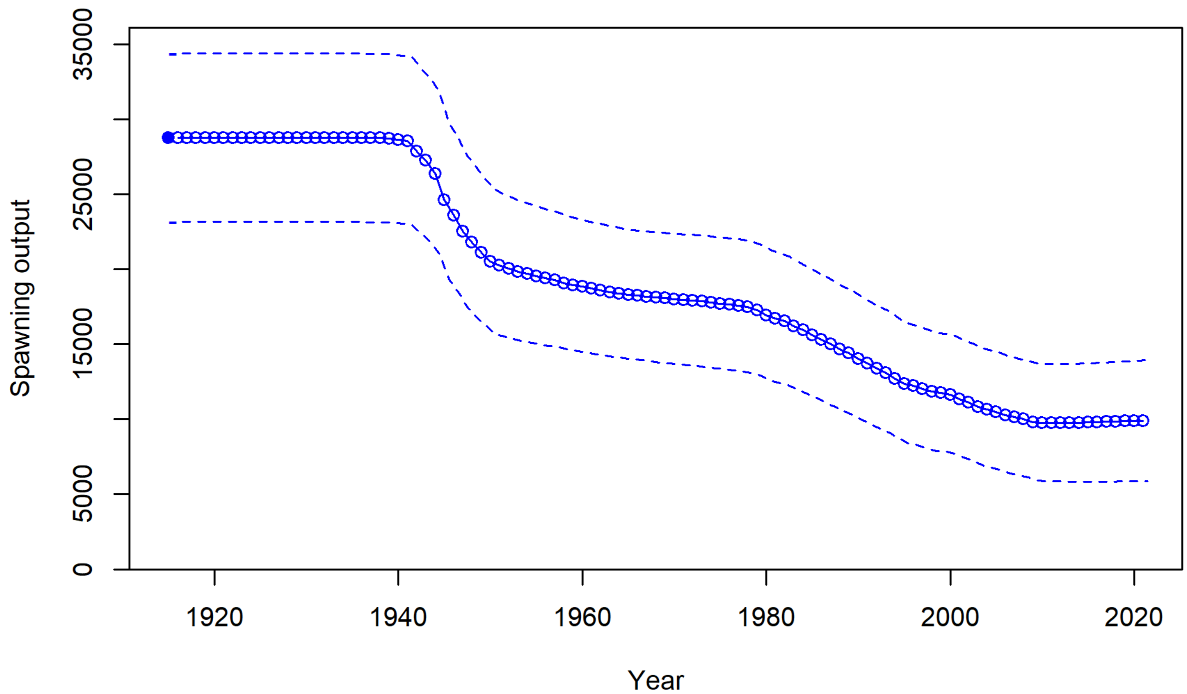

Figure 111. Time series of estimated spawning output of spiny dogfish with 95% confidence interval.

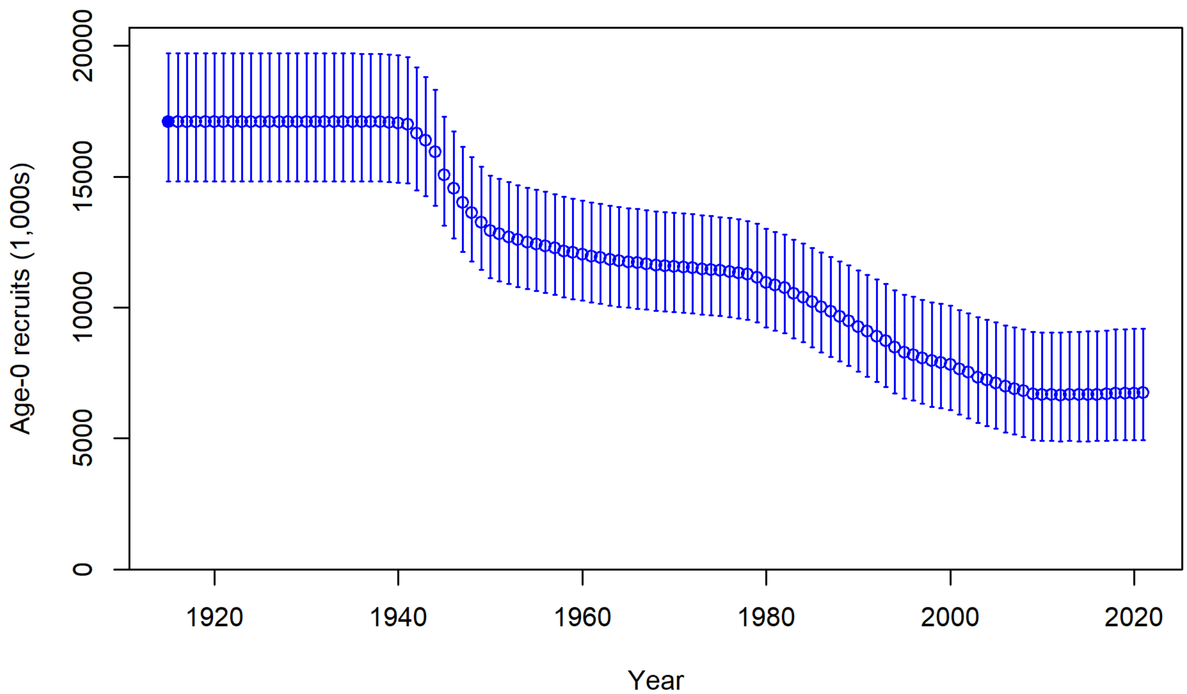

Figure 112. Time series of estimated recruitment of spiny dogfish with 95% confidence interval.

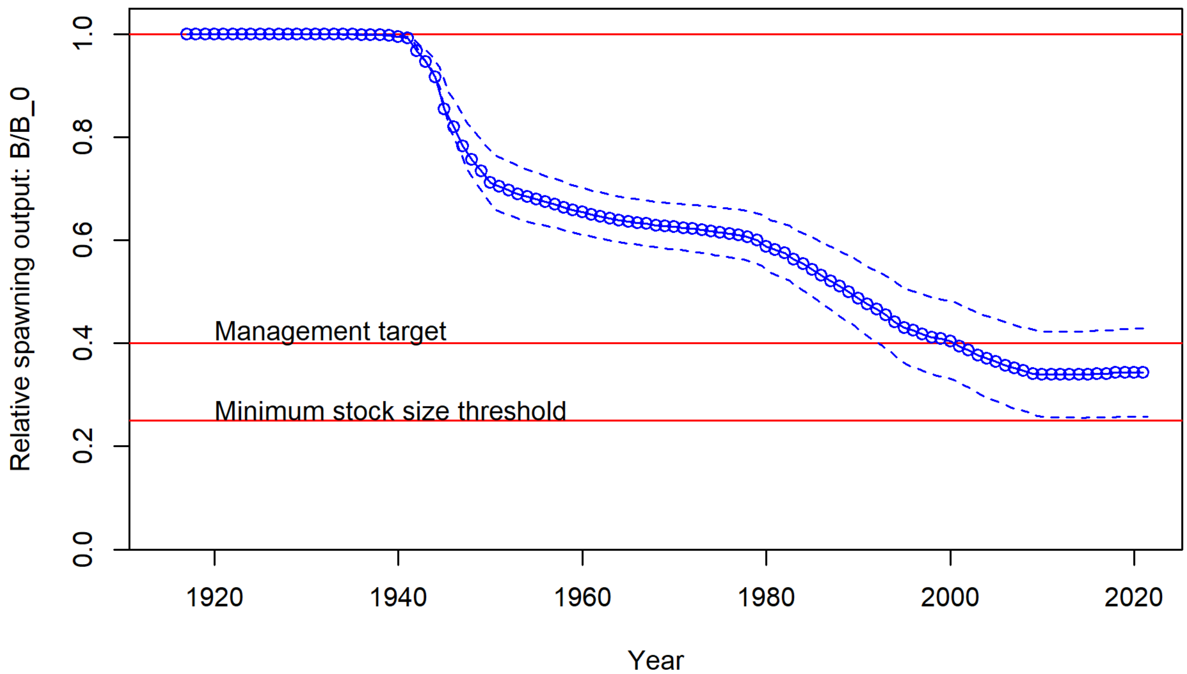

Figure 113. Time series of the estimated spawning depletion of spiny dogfish with 95% confidence interval.

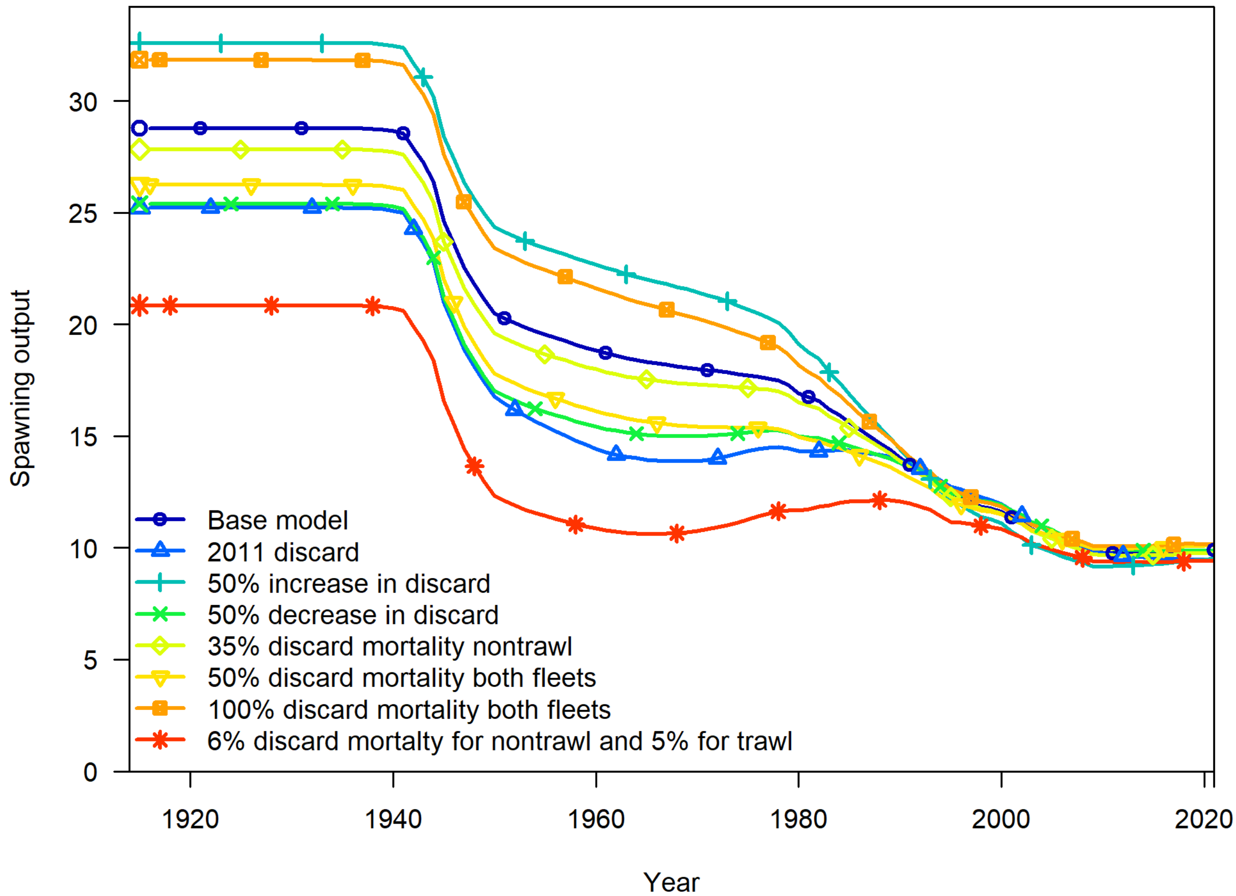

Figure 114. Sensitivity of spawning output time series (in millions of pups) to alternative assumptions regarding spiny dogfish fishery removals.

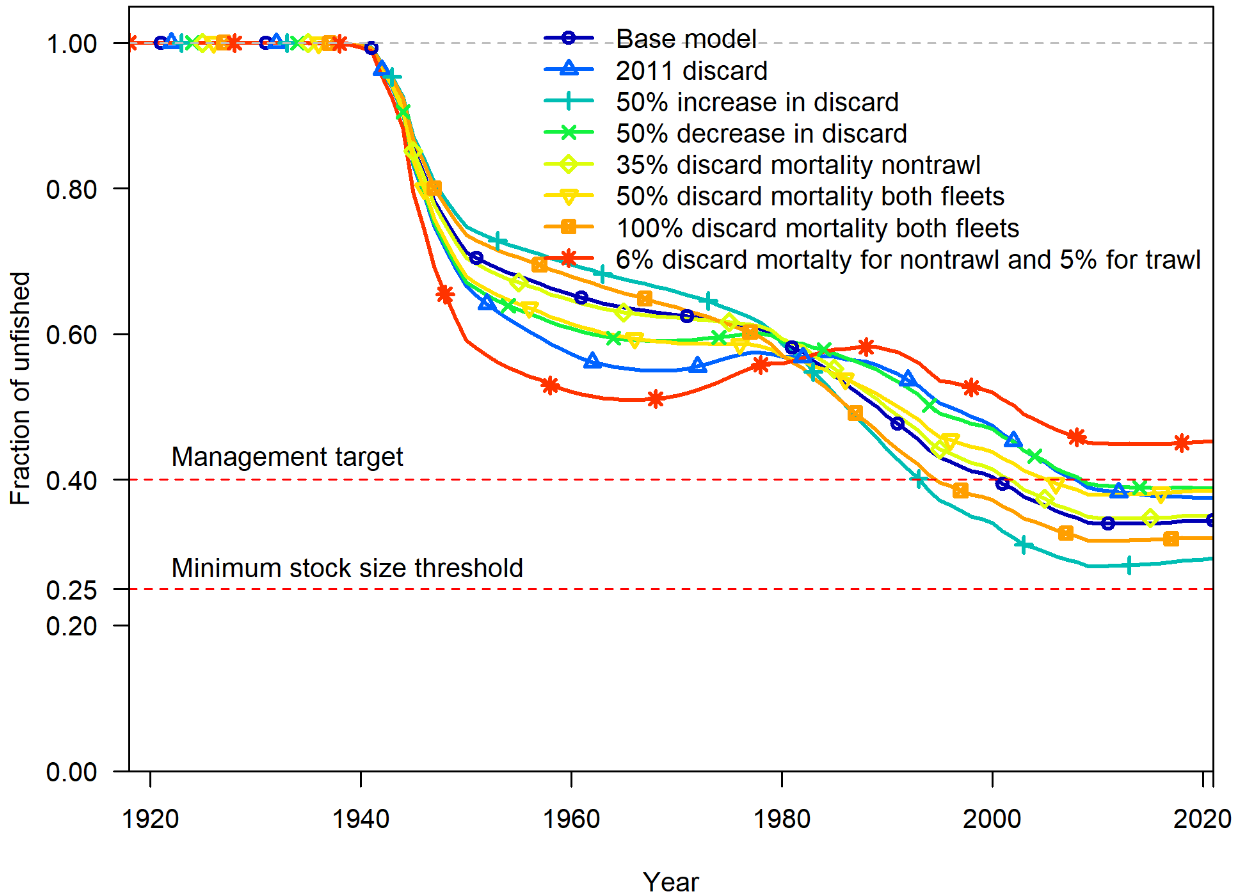

Figure 115. Sensitivity of spawning depletion time series to alternative assumptions regarding spiny dogfish fishery removals.

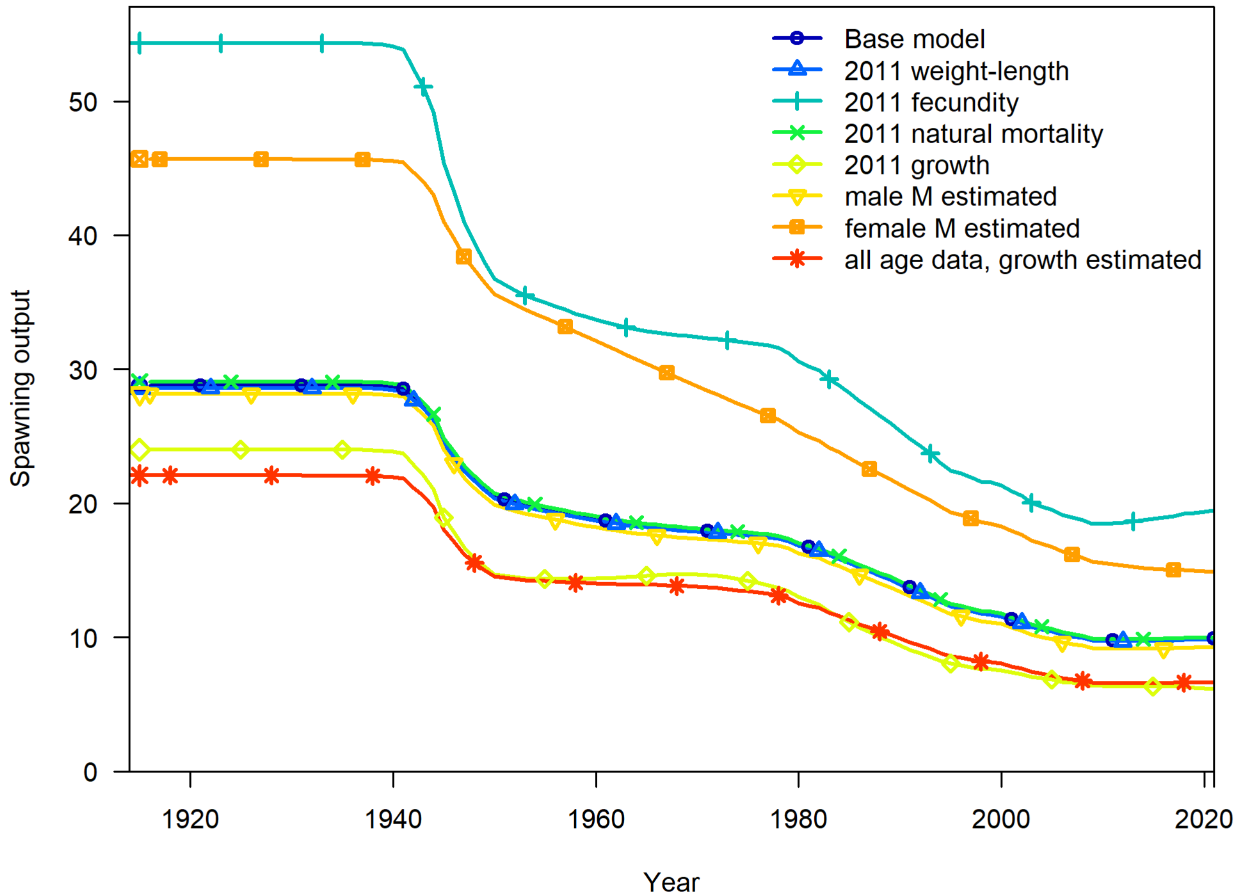

Figure 116. Sensitivity of spawning output time series (in millions of pups) to alternative assumptions regarding spiny dogfish biology.

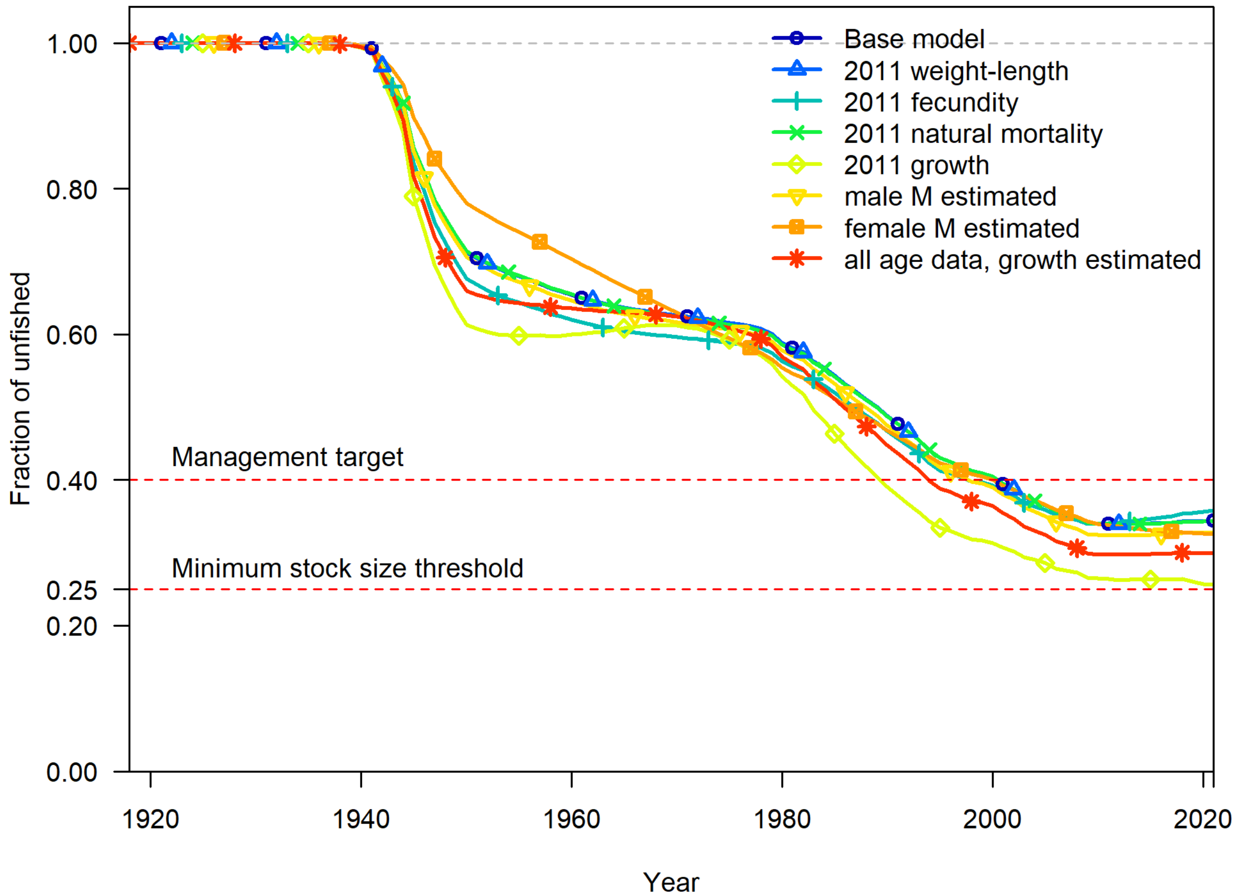

Figure 117. Sensitivity of spawning depletion time series to alternative assumptions regarding spiny dogfish biology.

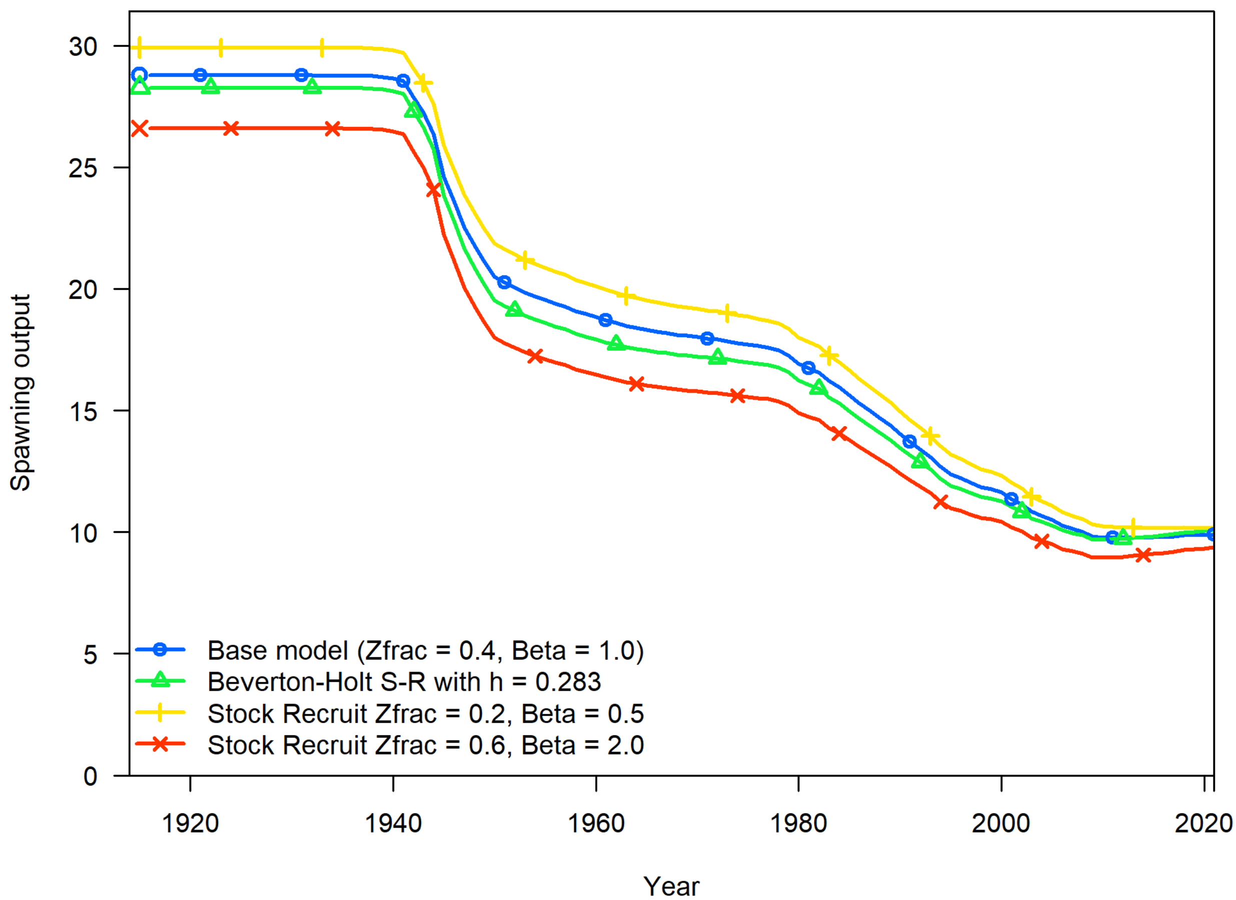

Figure 118. Spawning output (in millions of pups) for sensitivity analyses exploring alternative spawner-recruit relationships.

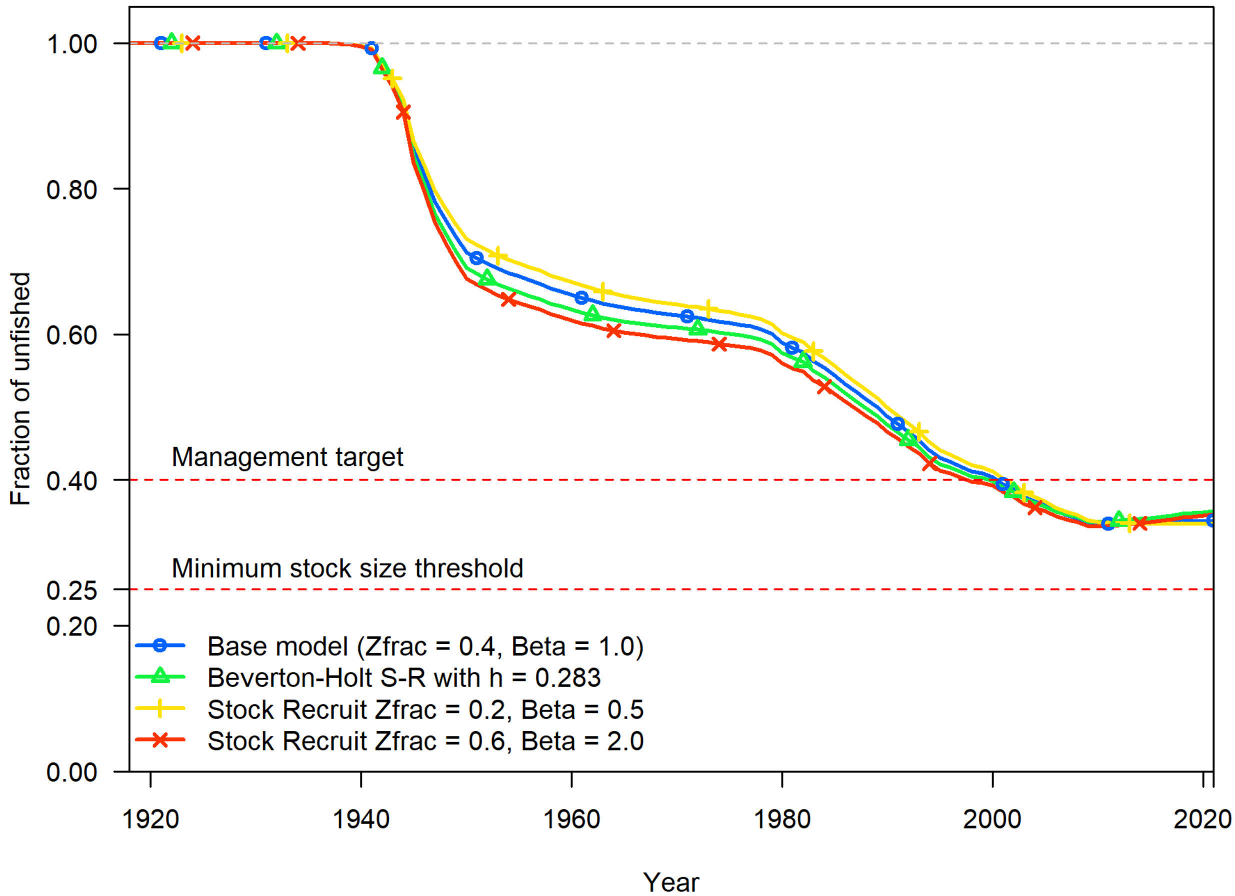

Figure 119. Spawning depletion for sensitivity analyses exploring alternative spawner-recruit relationships.

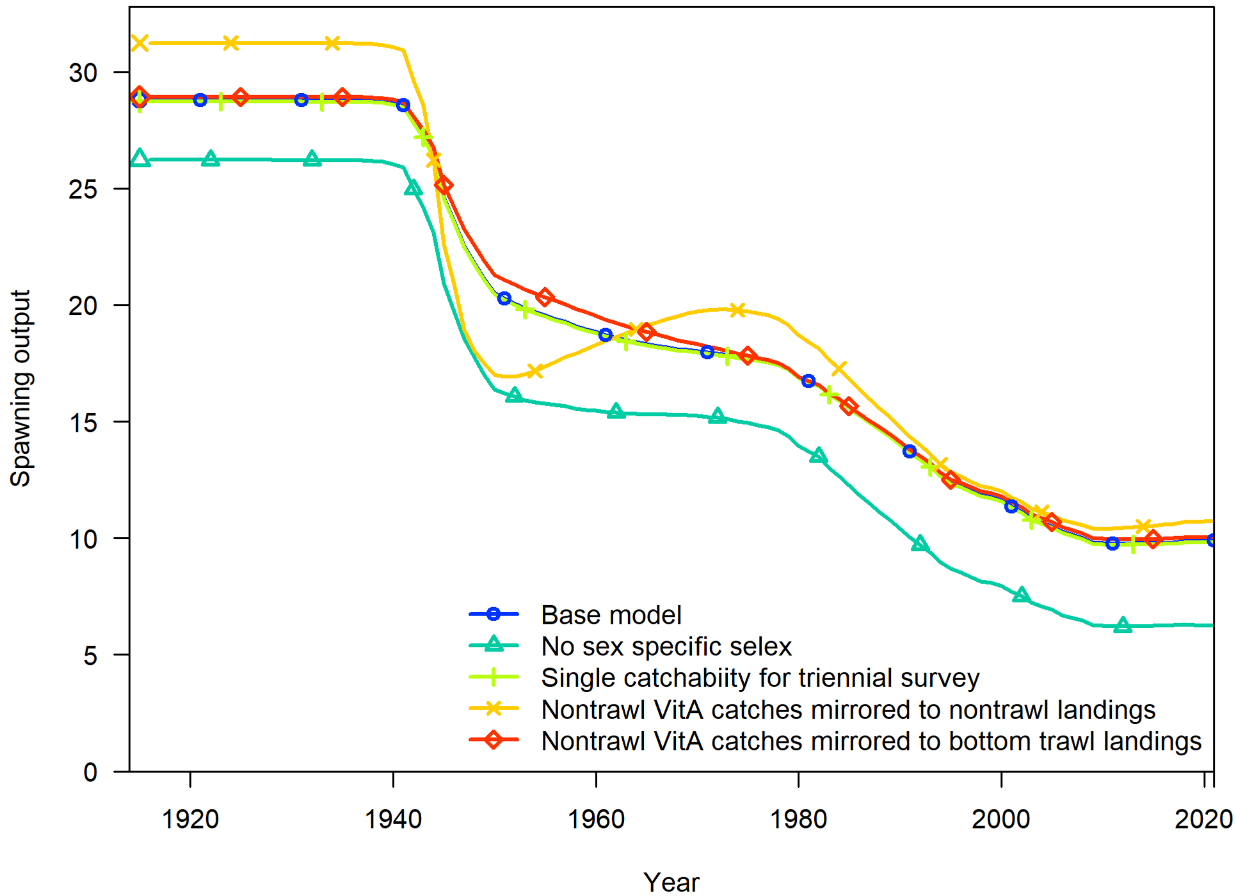

Figure 120. Spawning output (in millions of pups) for sensitivity analyses exploring alternative selectivity and catchability.

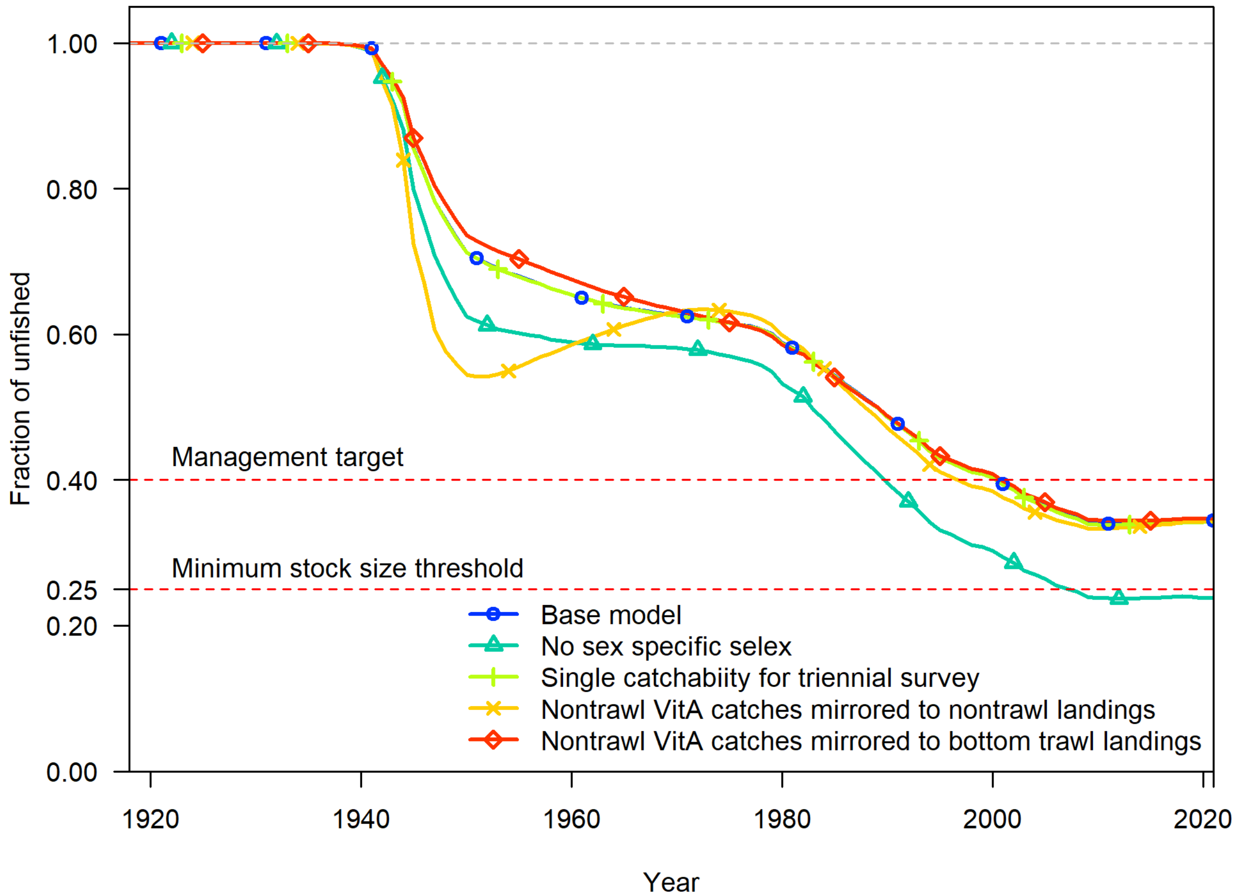

Figure 121. Spawning depletion for sensitivity analyses exploring alternative selectivity and catchability.

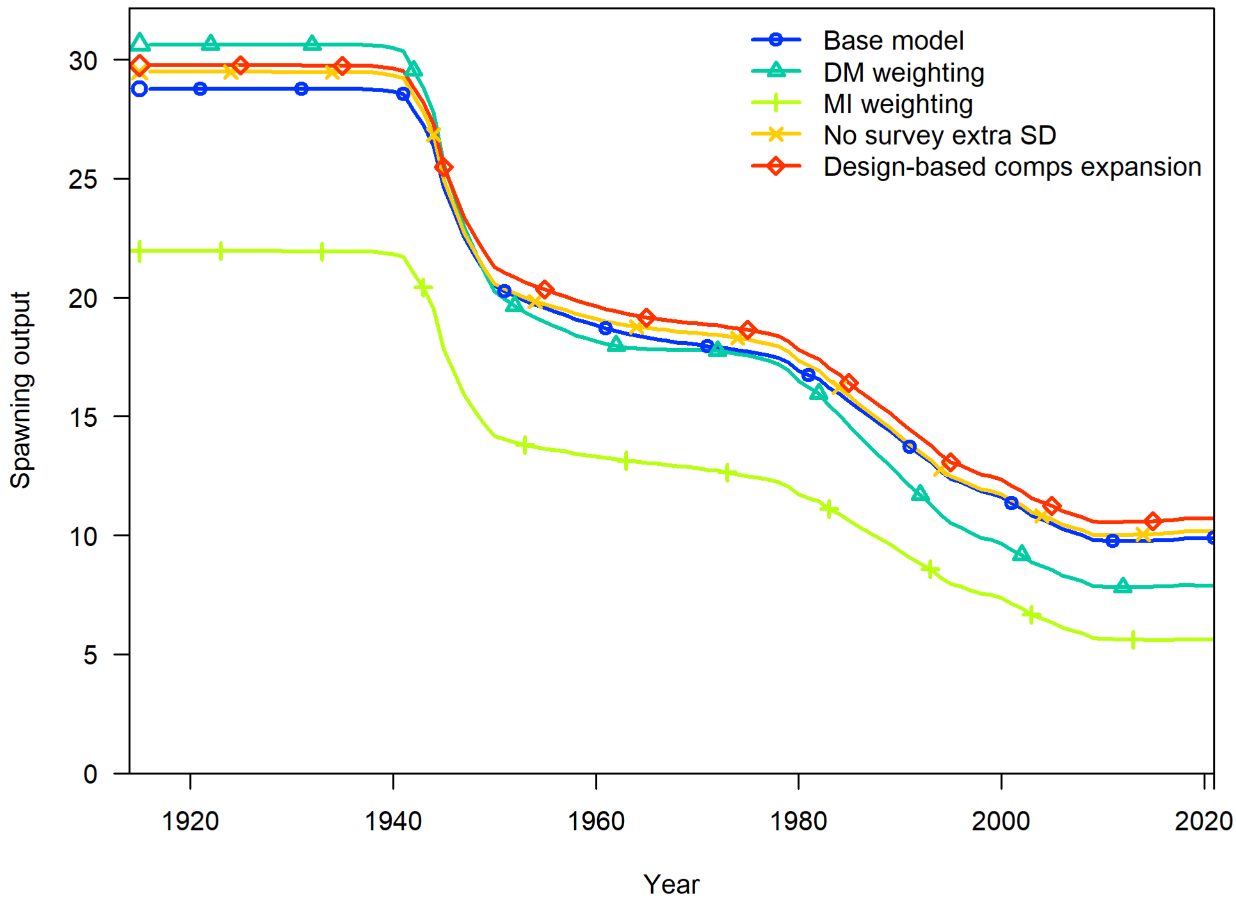

Figure 122. Spawning output (in millions of pups) for sensitivity analyses exploring alternative data weighting.

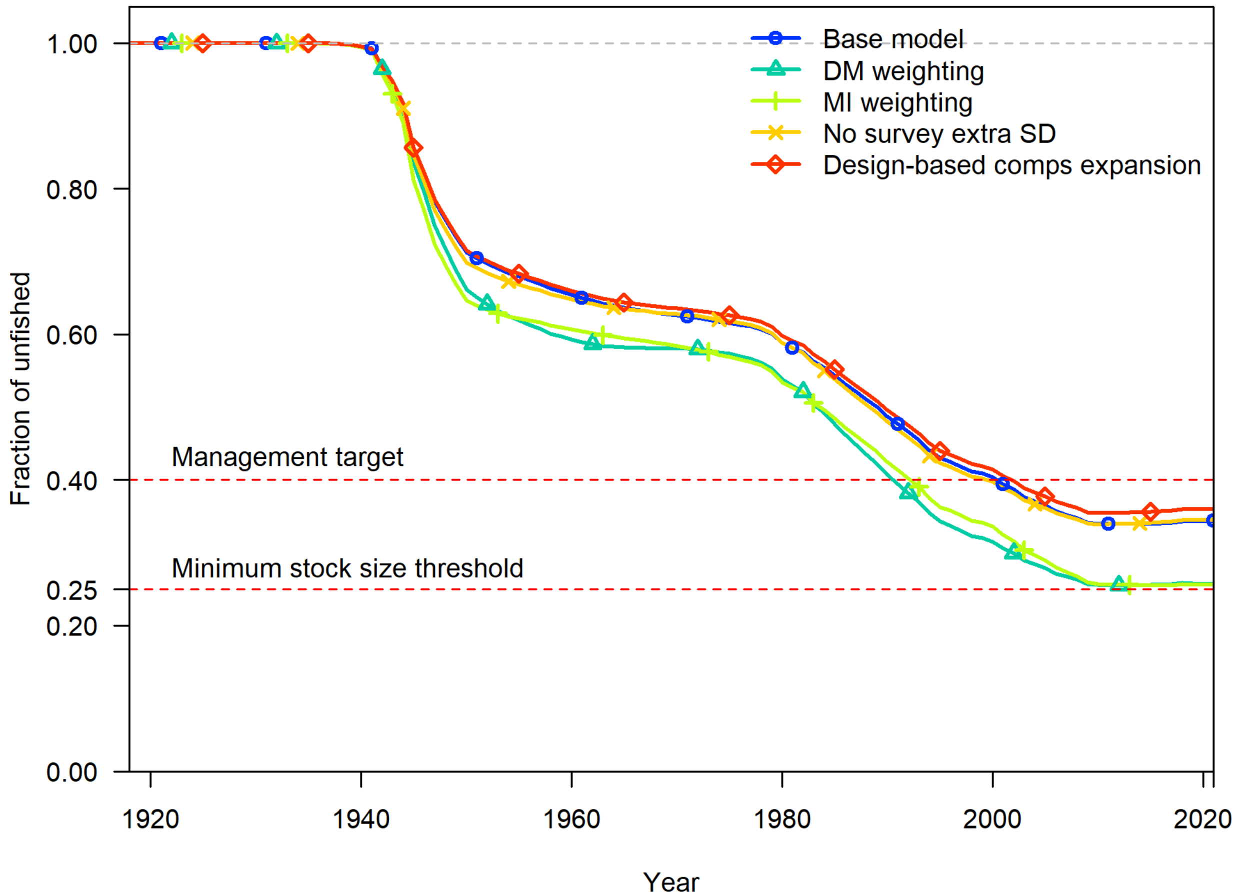

Figure 123. Spawning depletion for sensitivity analyses exploring alternative data weighting.

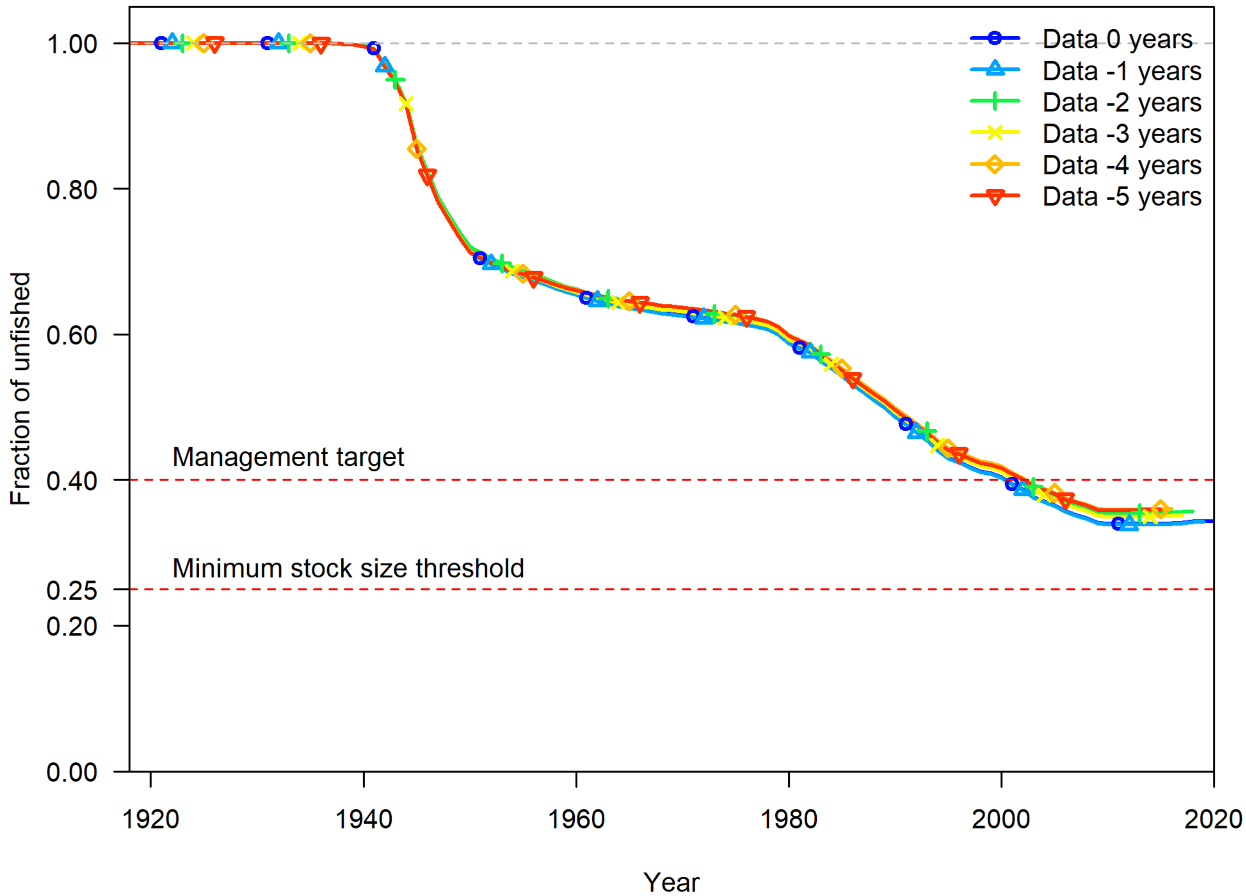

Figure 124. Spawning depletion for retrospective analysis. Each year of retrospective is performed as if the assessment were conducted in that year.

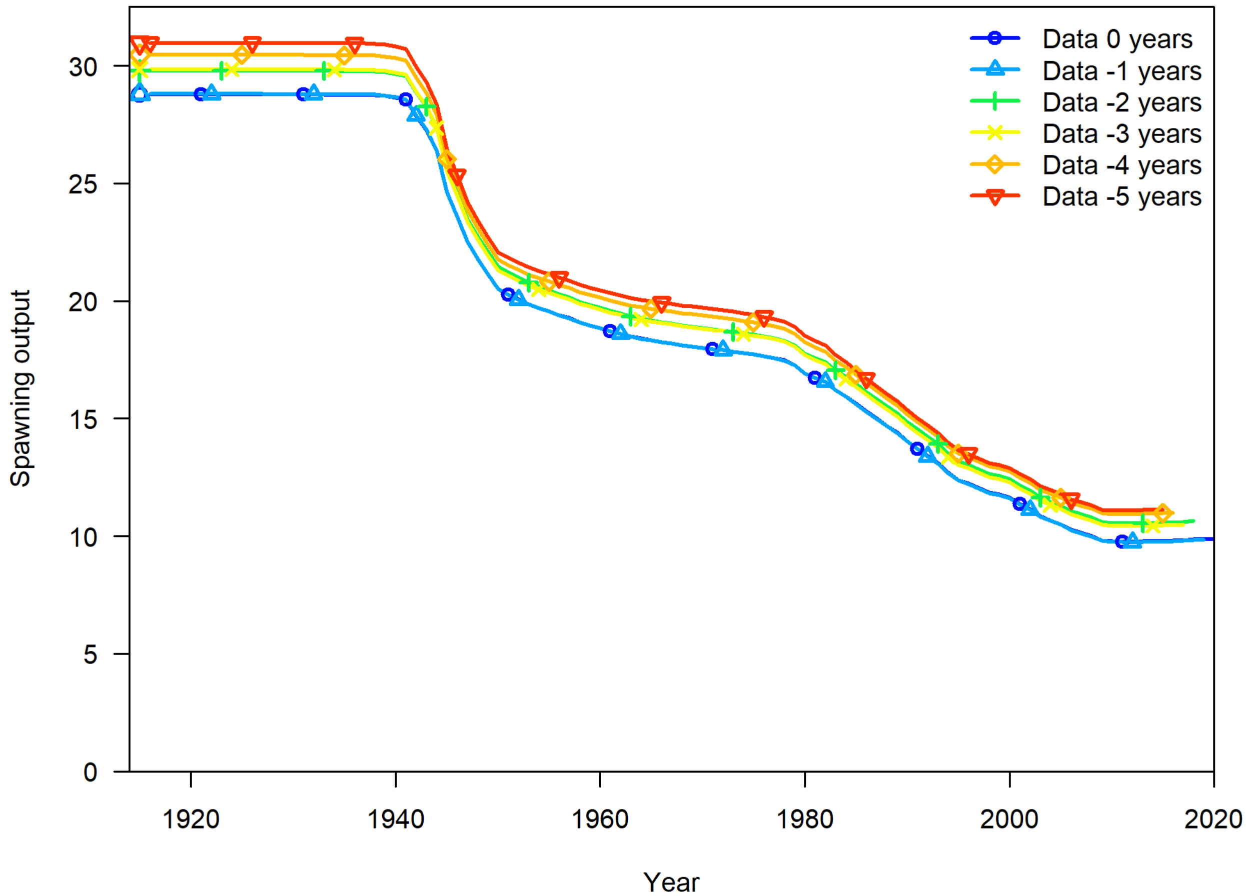

Figure 125. Spawning output (in millions of pups) for retrospective analysis. Each year of retrospective is performed as if the assessment were conducted in that year.

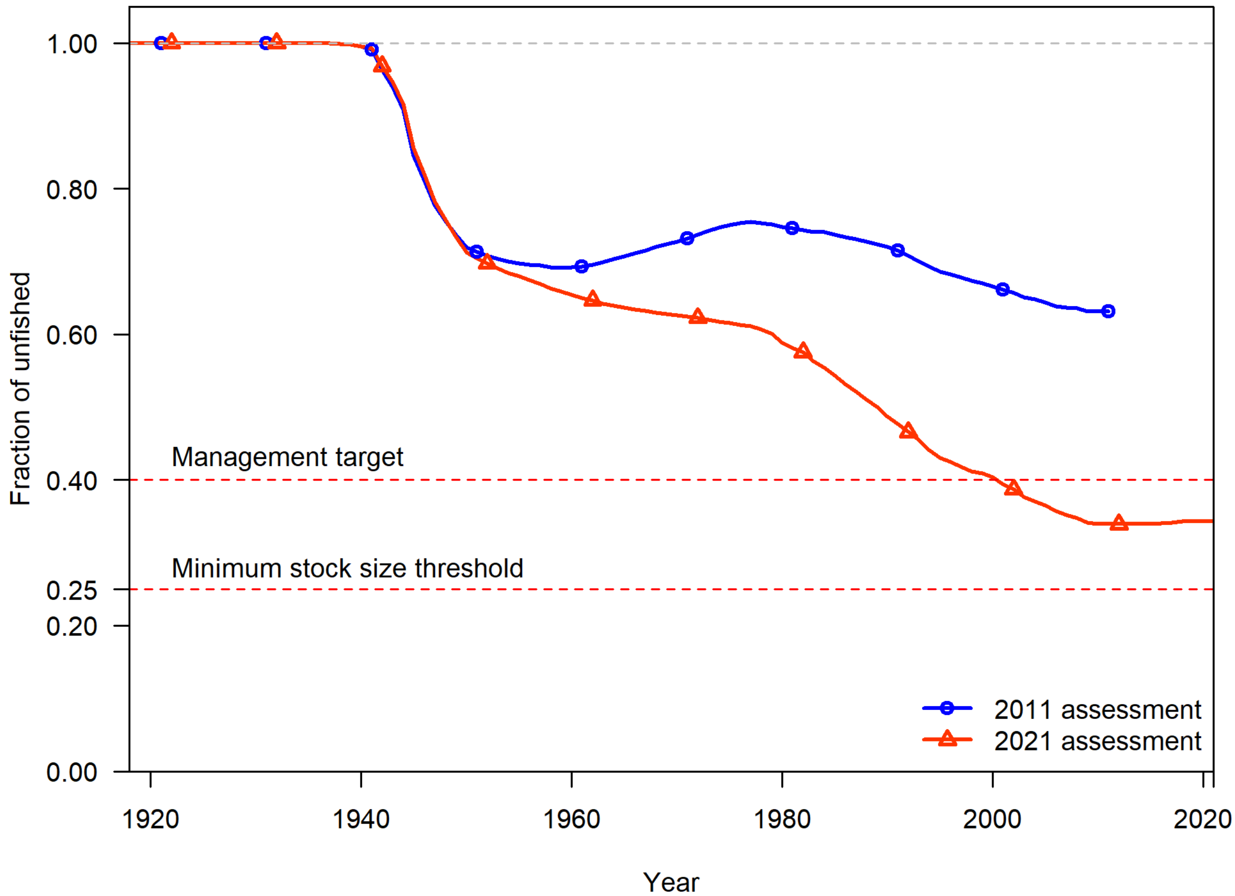

Figure 126. Comparison of spawning depletion time series among spiny dogfish assessments.

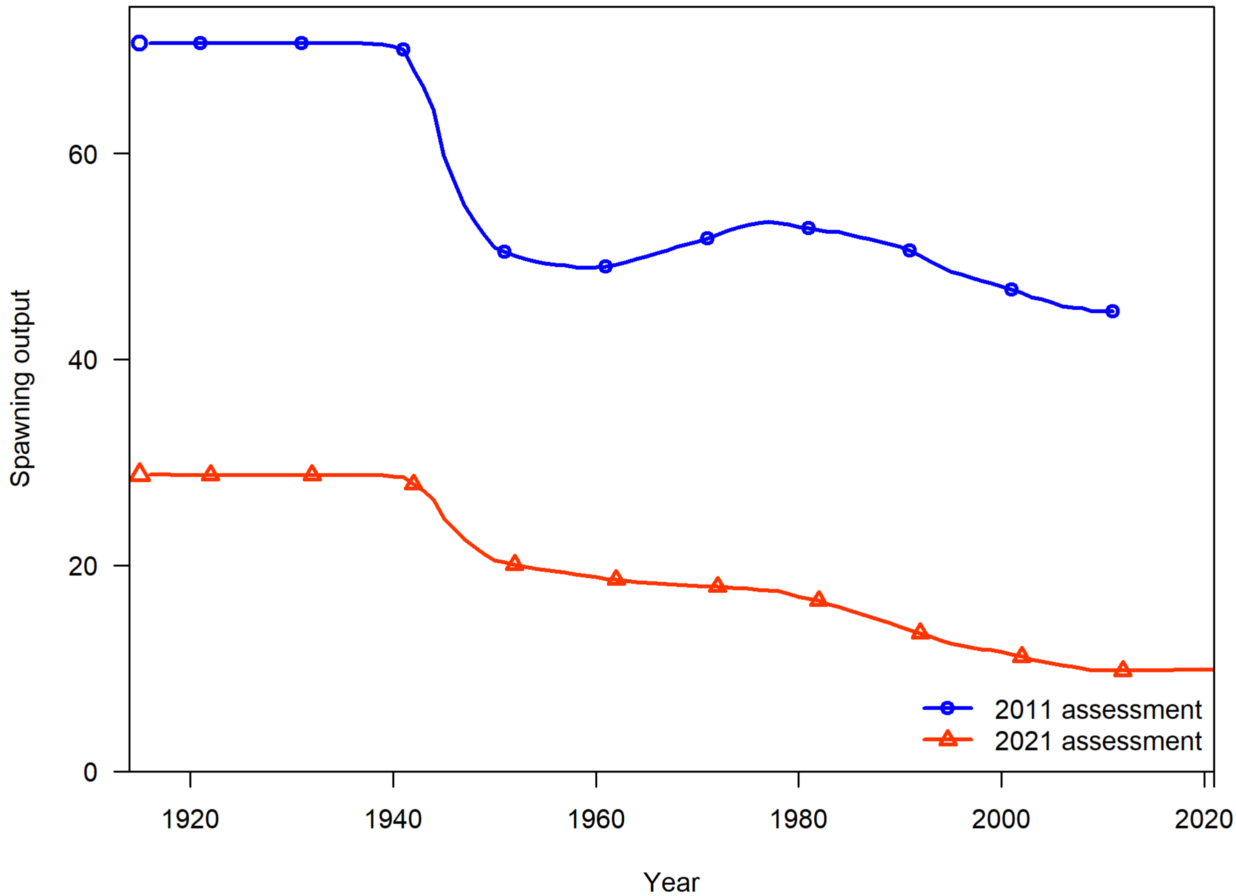

Figure 127. Comparison of spawning output time series (in millions of pups) among spiny dogfish assessments.

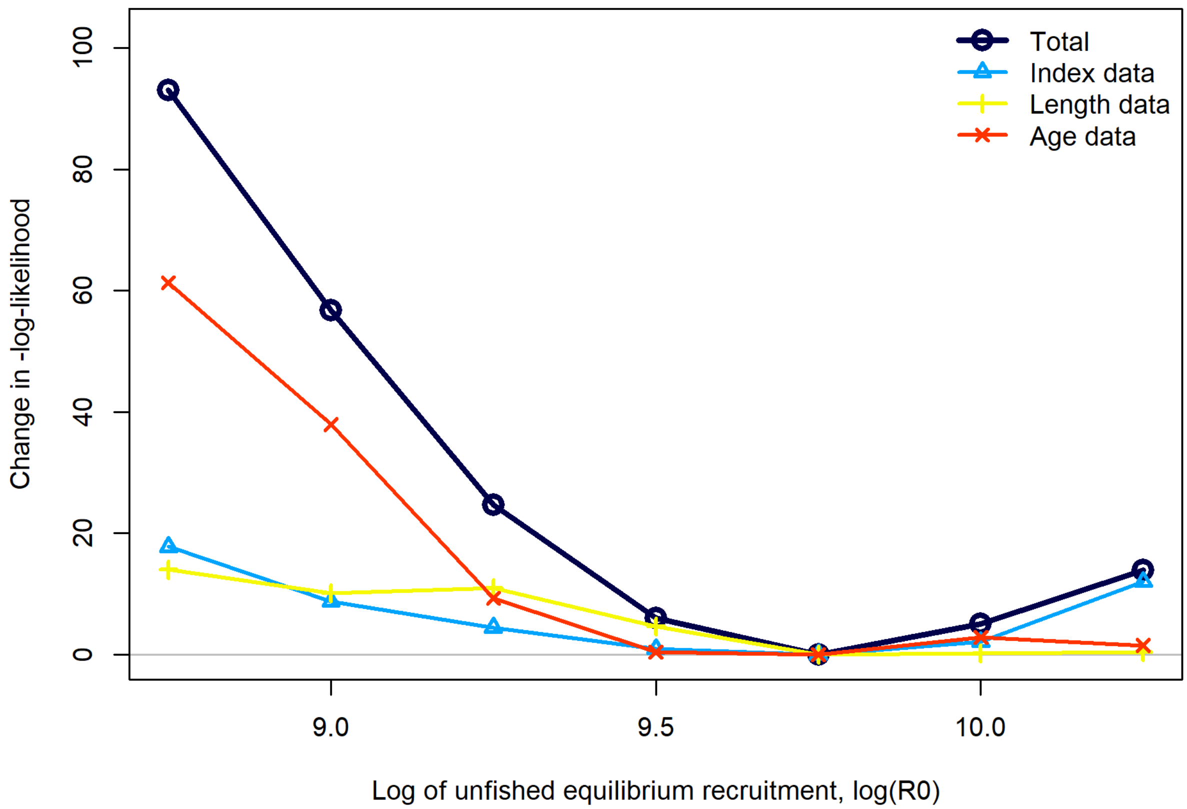

Figure 128. Likelihood profile for log initial recruitment (ln(R0)) by likelihood component.

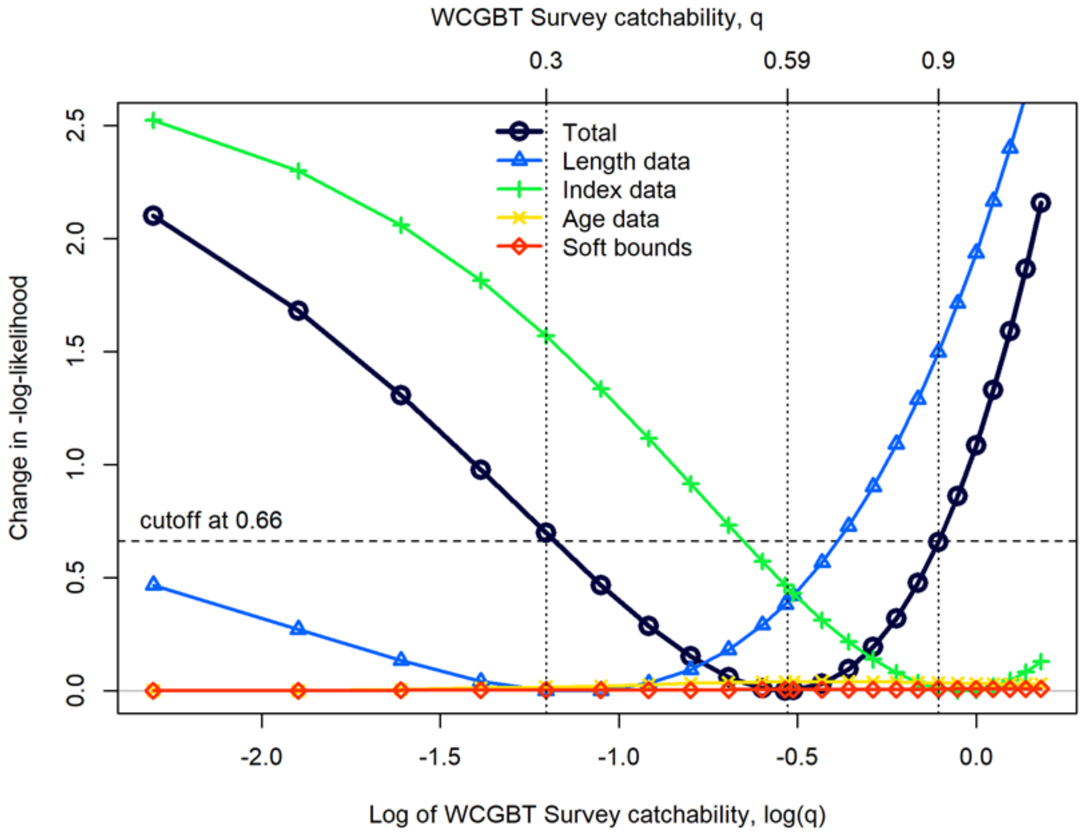

Figure 129. Likelihood profile over log(q) showing contributions of likelihood components. All values are represented as the change relative to the lowest negative log-likelihood for that component within the range of log(q) values shown in the figure.

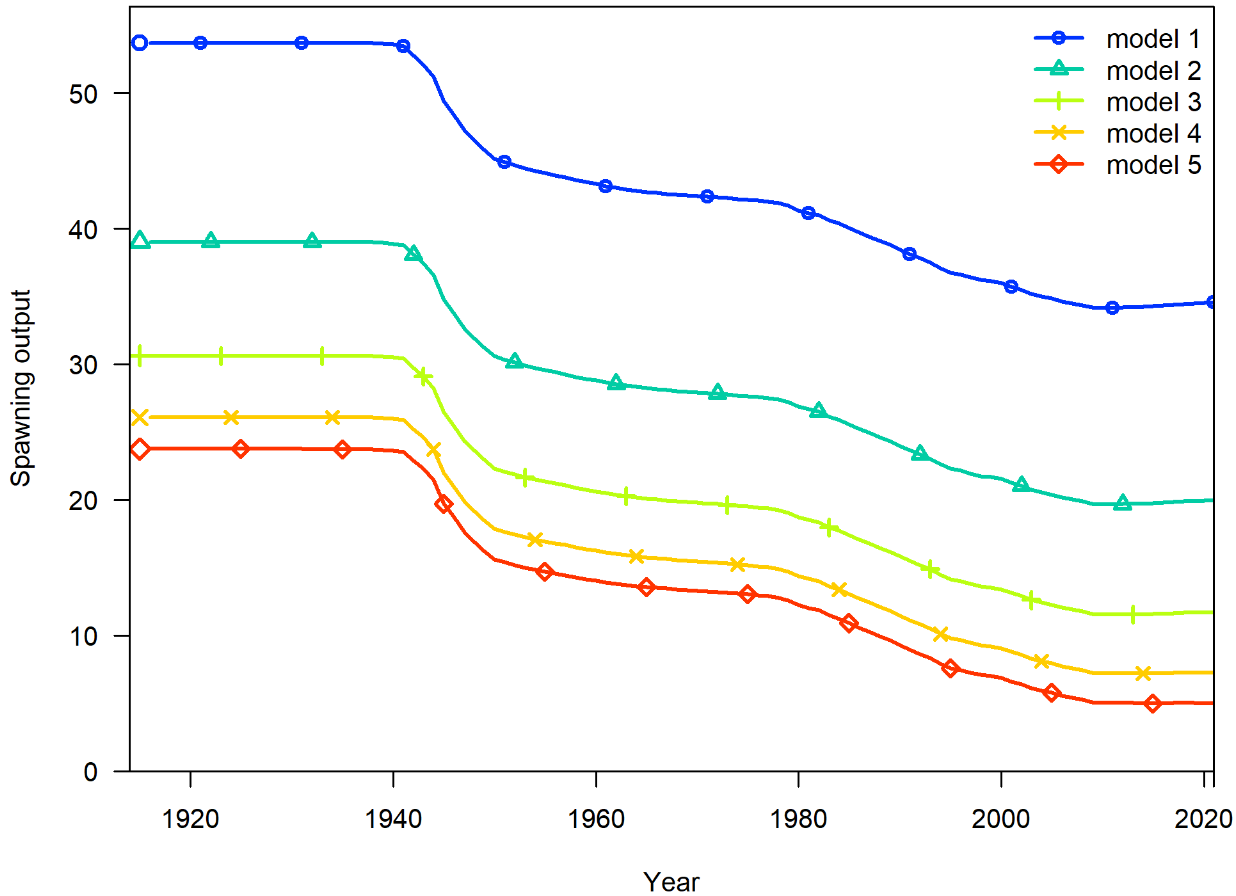

Figure 130. Time series of spawning output (in millions of pups) associated with different values of WCGBT Survey log(q), ranging from -1.7 (Model 1) to 0.3 (Model 5) by increment of 0.5.

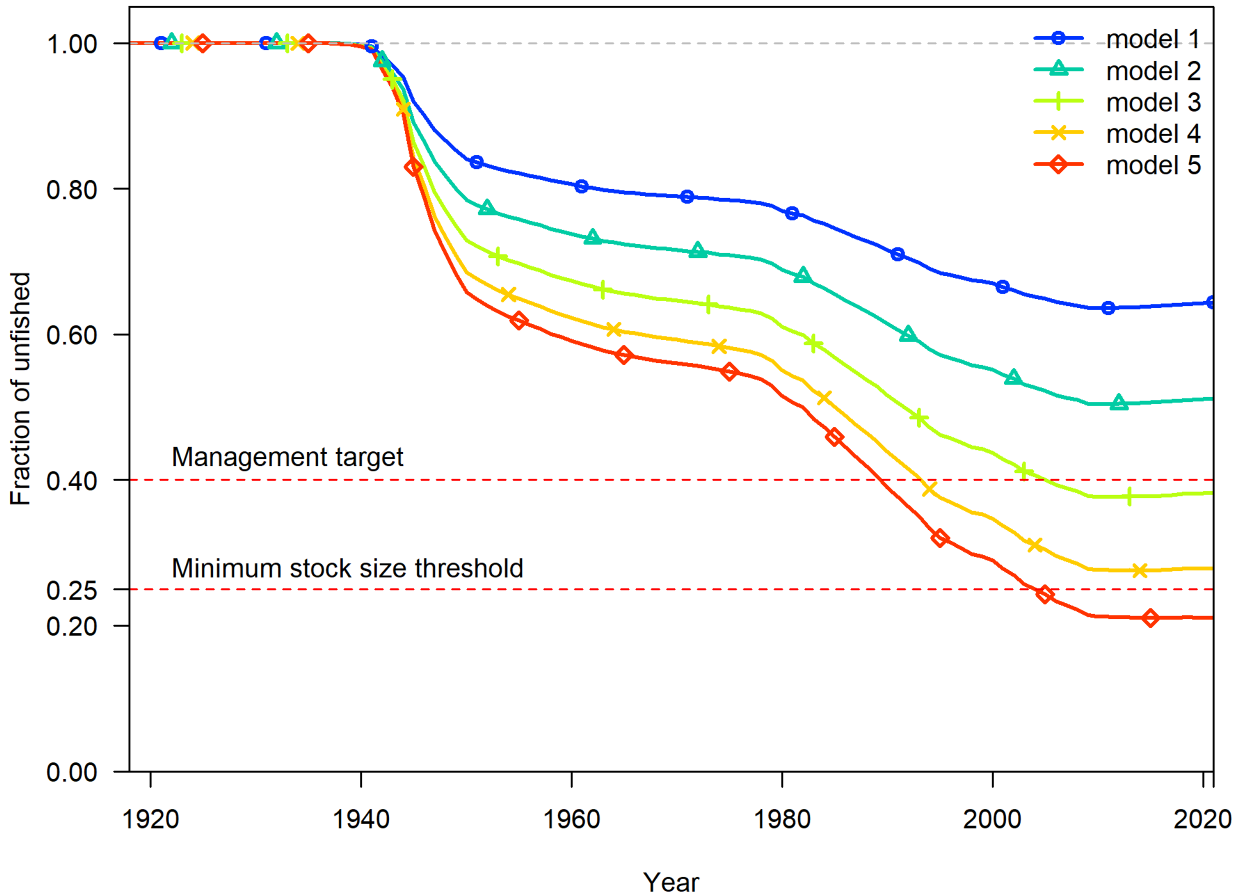

Figure 131. Time series of spawning depletion associated with different values of WCGBT Survey log(q), ranging from -1.7 (Model 1) to 0.3 (Model 5) by increment of 0.5.

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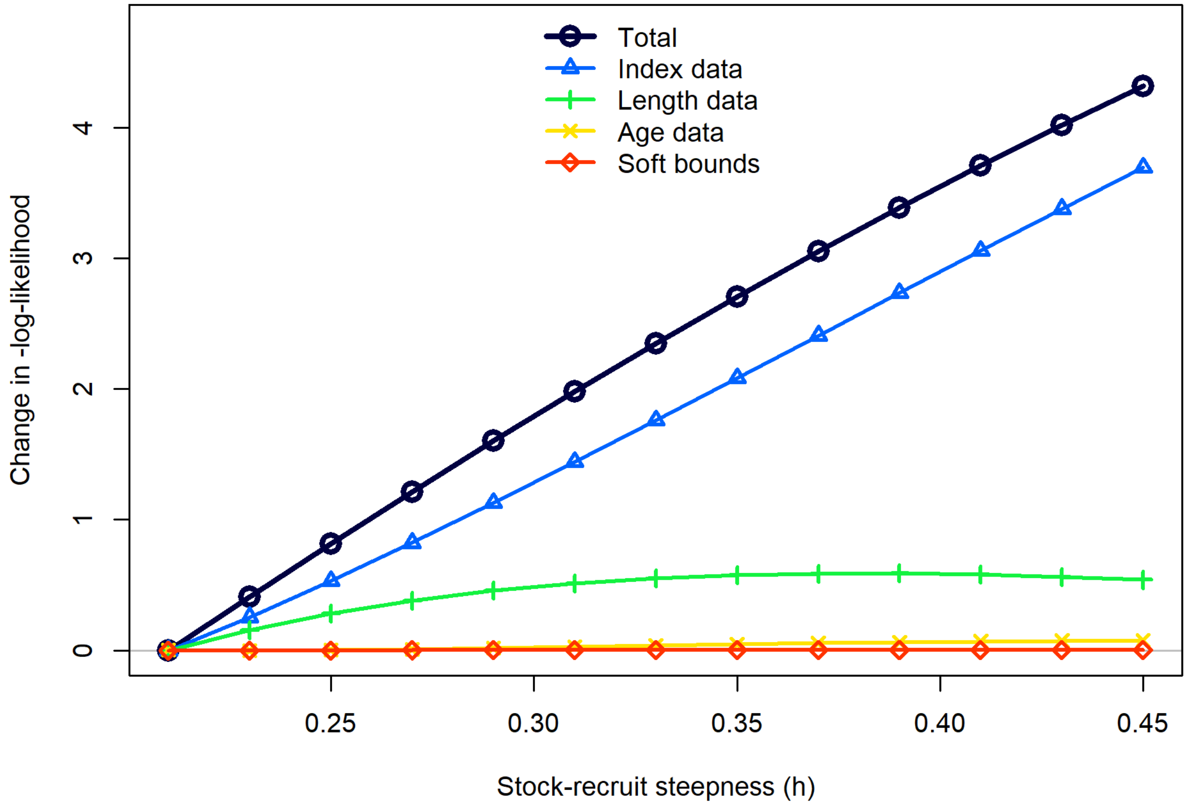

Figure 132. Negative log-likelihood profile for each data component and in total given different values of stock-recruit steepness.

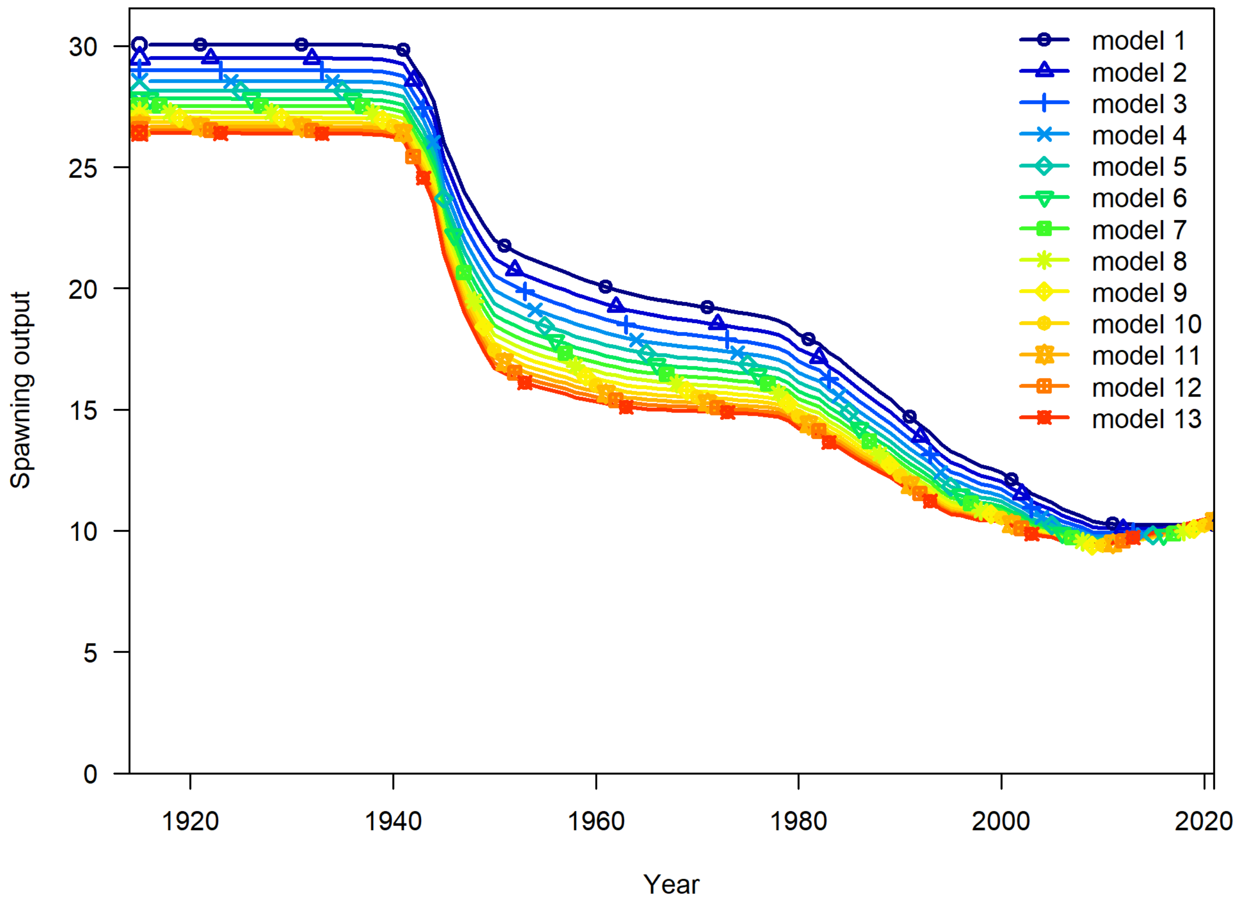

Figure 133. Time series of spawning output (in millions of pups) associated with different values of steepness ranging from 0.21 (Model 1) to 0.45 (Model 13) by increments of 0.02.

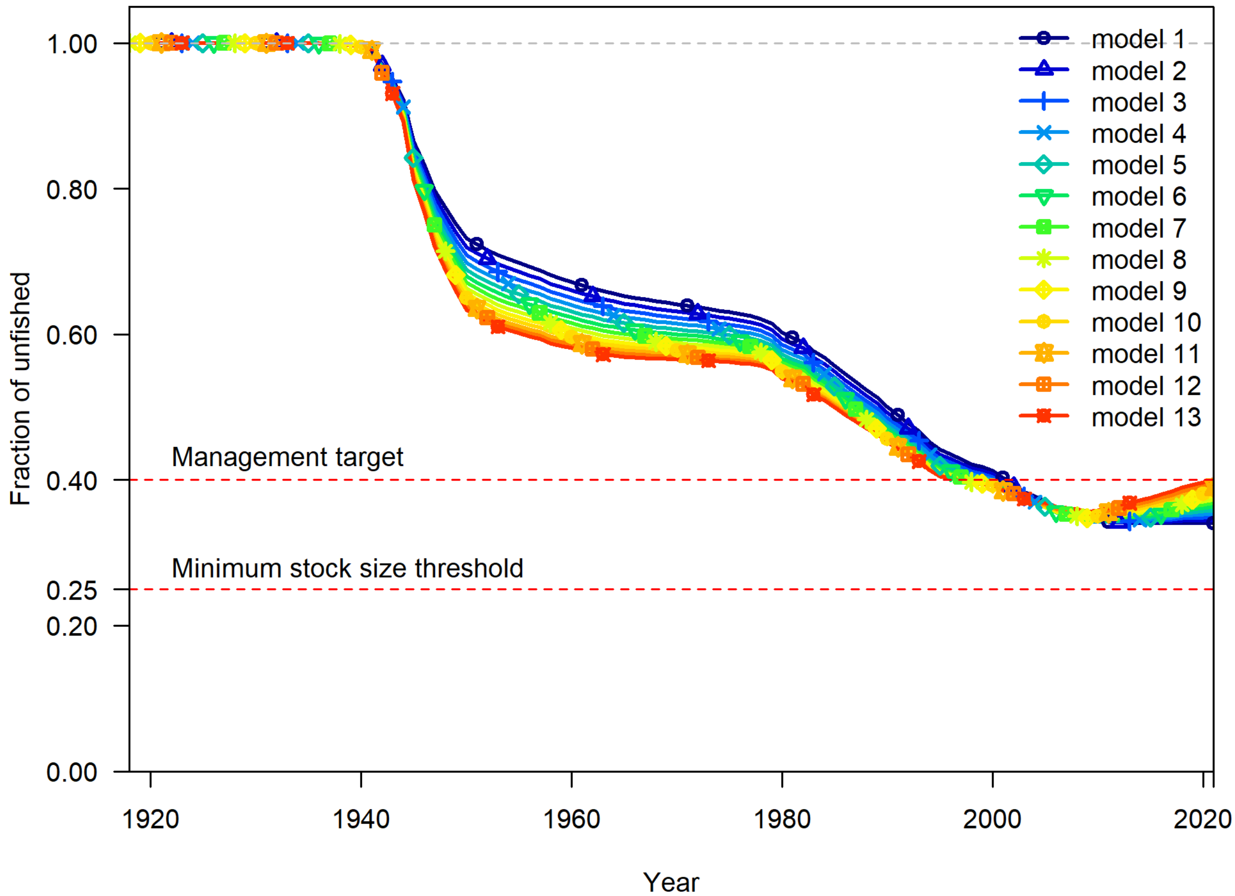

Figure 134. Time series of spawning depletion associated with different values of steepness ranging from 0.21 (Model 1) to 0.45 (Model 13) by increments of 0.02.

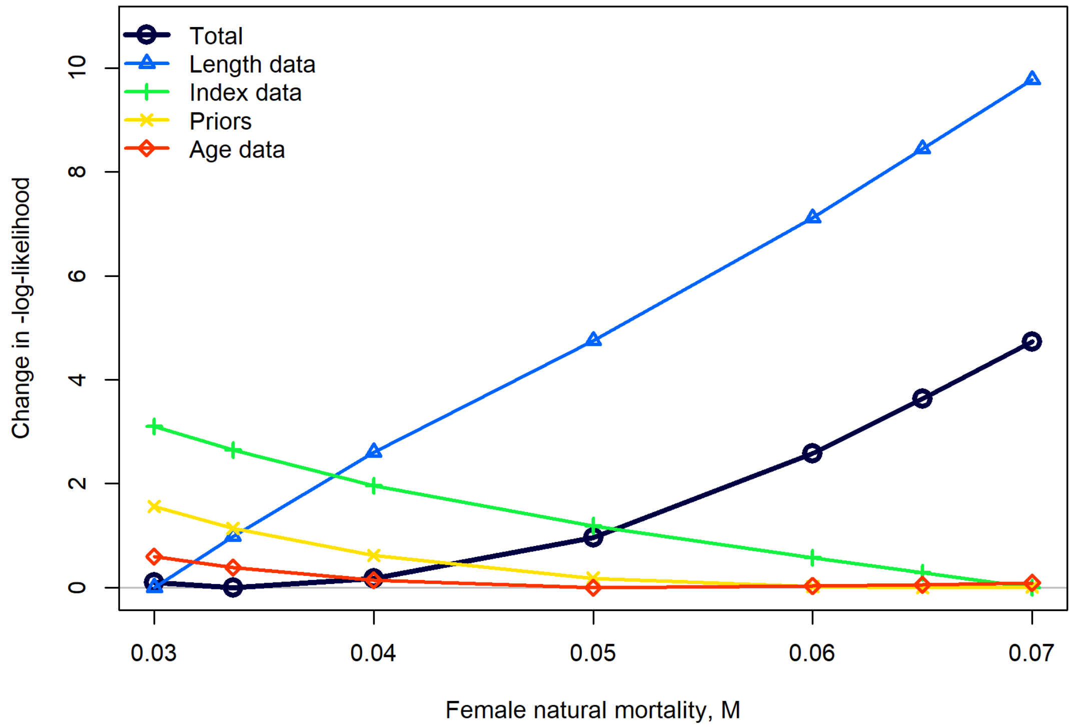

Figure 135. Likelihood profile over natural mortality (M) showing contributions of likelihood components. All values are represented as the change relative to the lowest negative log-likelihood for that component within the range of M values shown in the figure.

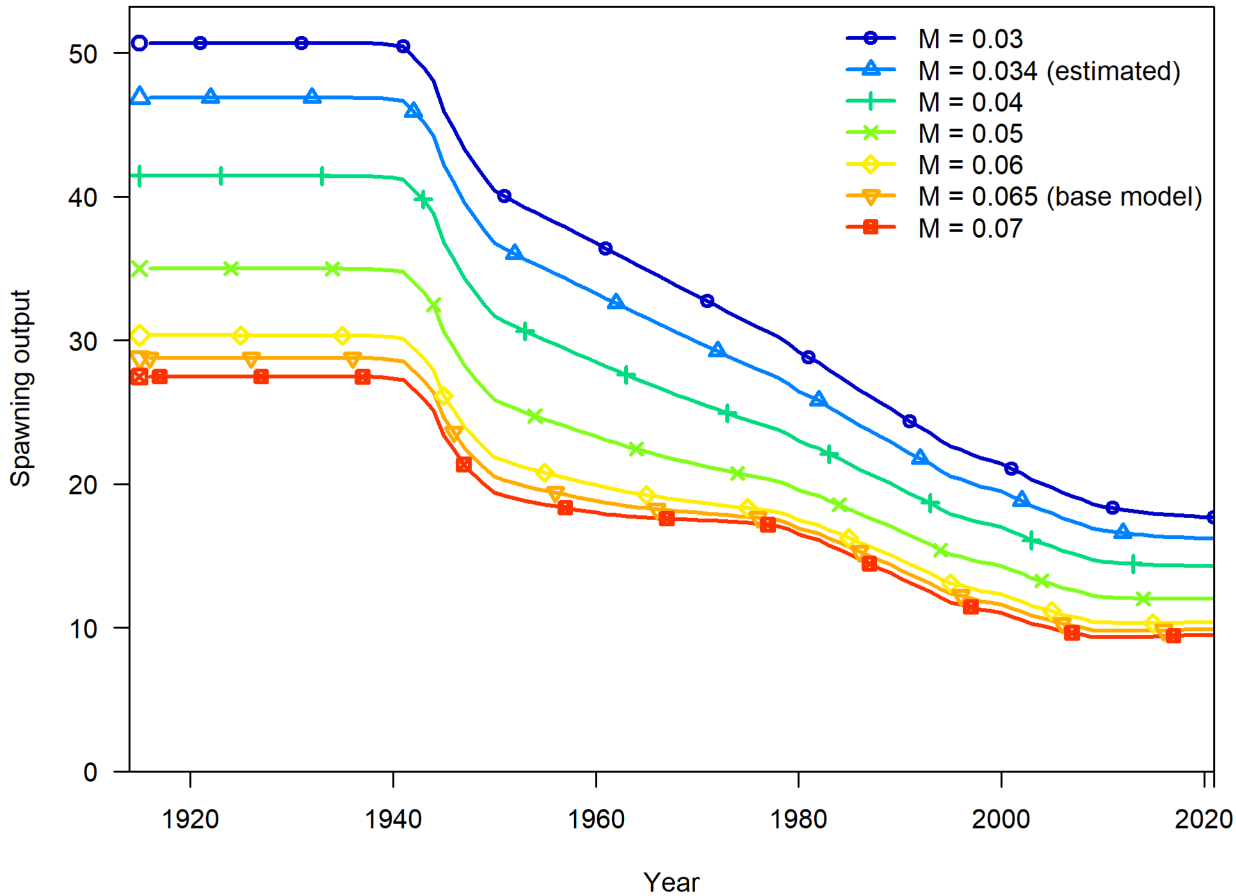

Figure 136. Time series of spawning output (in millions of pups) associated with different values of natural mortality (M).

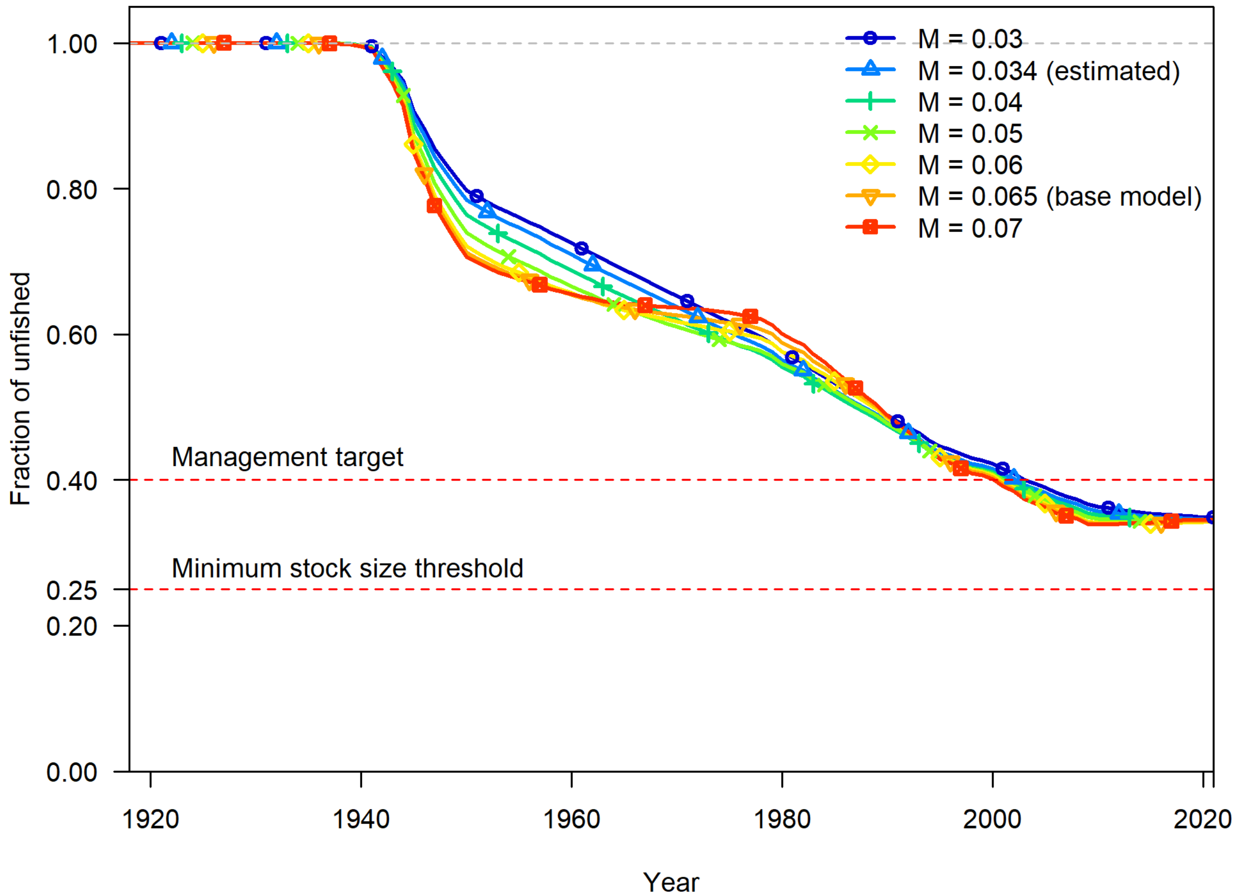

Figure 137. Time series of spawning depletion associated with different values of natural mortality (M).

10 Appendix A

Additional analysis in response to GCFSC request regarding spiny dogfish seasonal migration.

Request: The GFSC suggests that an analysis of the seasonality of bycatch rates of spiny dogfish from WCGOP and other available data sources (e.g., ASHOP, Pikitch et al. bycatch study) should be conducted to evaluate whether the data indicate a strong seasonal availability of spiny dogfish as bycatch to fisheries. A reasonable way to do this would be to examine haul-specific catch rates in a General Linear Model (GLM) or delta-GLM (depending on the frequency of occurrence of dogfish in a given dataset), with the primary factor of interest being month (or some other seasonal variable, such as Julian day bins, two month periods, etc. as appropriate given the data) as a factor, along with appropriate covariates that were determined by the analyst. These might include year, depth, latitude/state or region, vessel size or power, gear type, stated fishing strategy or comparable information. Alternatively, it may be feasible to explore the use of modeling frameworks such as VAST or 'sdmTMB' (see https://pbs-assess.github.io/sdmTMB/index.html) to develop this analysis. It may also be appropriate to do separate analyses by region (e.g., WA coast, OR coast, Northern CA coast), in addition, depending on data availability, in order to facilitate interpretation of model results. As with any such model an exploration of available information and relevant covariates will require some exploratory work, but GLMs and delta-GLMs are standard tools for any assessment analyst and the precise approach should be at the analyst's discretion.

***Rationale**: The results should provide an indication, albeit imperfect as there will certainly be challenges associated with developing a conclusive result from these data sources, of the relative differences in catch rates of dogfish by fisheries participants. This alone should provide some insights to the SSC and to the PFMC (who made the formal request) with respect to how encounter and catch rates in the fisheries themselves appear to change seasonally, and thus the extent to which the model-estimated q was consistent with seasonal fluxes in catch rates. For example, if catch rates were on average 10x greater between November and March than those between April and October, then a survey estimated q greater than 0.5 for a survey that exclusively takes place between April and October may be a questionable model result. In such a scenario, there may be the potential to develop a weakly informative "upper bound" prior for catchability based on the ratio of bycatch rates during the months during which the survey takes place relative to the months in which spiny dogfish are likely to be more abundant. This request does not include an explicit request to develop such a prior, but rather will provide the SSC with a basis for considering whether such an approach might be feasible and worthwhile in light of the limited time remaining in this stock assessment cycle.*

Highlights:

- We analyzed spiny dogfish catch rates in the bottom trawl fishery, observed by the NMFS West Coast Groundfish Observer Program (WCGOP), to explore a hypothesis of potentially lower availability of spiny dogfish during the survey period than throughout the whole year due to seasonal migration.
- Generalized Linear Models, which we ran with multiple factors, showed that season, defined as survey vs non-survey weeks, was a significant predictor of dogfish CPUE. In an alternative model using month as the temporal variable, month was significant and all months were significantly different from the reference month. Due to large sample sizes (>100,000 hauls), even very small differences in variables were significant in the GLM. Raw data were also explored for catch rate trends and uncertainty, reported in tables and figures.
- GLMs were run with seasonality defined in two different ways. We defined season as being within or outside of the WCGBT Survey period, by week; which addressed the immediate question at hand: whether availability of spiny dogfish during the survey period was representative of the year. Defining survey period by week used a reasonable level of precision, and the results showed little difference in catch rate between survey and non-survey periods.
- Additionally, we defined seasonality by month. Analyzing catch rates by month showed more granularity of trend throughout the year, and larger coefficient values during four winter months (November through February), versus eight non-winter months, but examining months is misleading for the question of representativeness of survey period catch rates, since months do not align with survey start and stop dates, and thus do not adequately capture survey vs non-survey periods.
- The ratio of aggregate spiny dogfish catch rates calculated from raw data during the survey season (survey weeks) versus the entire year was 0.8994, which implies a seasonal component of WCGBTS survey catchability of around 0.9. Importantly, when this ratio was calculated as annual average, the average of the annual averages was very similar (0.8410), but showed high inter-annual variability. CPUE for survey and non-survey weeks changed ranks frequently among years.
- Fishery data, particularly for a mixed target fishery such as West Coast bottom trawl, possess multiple caveats, potentially confounding factors owing to the number of different targets pursued throughout the year and their temporal distribution, varying fisher behavior, variability in economic and weather conditions, making it challenging to reliably inform survey catchability. See text for discussion of data sources considered.
- Conclusion: Based on these results, it is difficult to make a defensible argument for a value of WCGBT Survey catchability being lower than that estimated in the assessment model (0.586).

Methods

We examined spiny dogfish catch rates in the bottom trawl fishery as observed by WCGOP from years 2002-2019, with an objective of shedding light upon a hypothesis of potentially lower availability of spiny dogfish during the survey period than throughout the whole year.

We implemented a Generalized Linear Model (GLM) to examine which factors were significant in predicting spiny dogfish CPUE in this trawl fishery sector. Due to very restricted time, the GLM was performed without hierarchical treatment (zero vs non-zero). For the GLM, the log of the dependent variable (metric tons per hour) was used with identity link and Gaussian errors. A vanishingly small amount was added to each zero haul to enable the log of the dependent variable– half the minimum of the non-zero values was added to all the zero values (3.532e-10). Adding up all of these 57,912 adjusted zero values equals 2.045e-05, and should be quite inconsequential to results of the analysis.

There was not sufficient time to develop a VAST procedure (e.g. that would estimate an abundance index based on CPUE), nor a delta-GLM; results of hierarchical GLM would also be of less value for interpretation, separated between zero and non-zero hauls.

GLMs were run with seasonality defined in two different ways. We defined season as being within or outside of the WCGBT Survey period, by week; which addressed the immediate question at hand: whether availability of spiny dogfish during the survey period was representative of the year. Additionally, we defined seasonality by month.

We examined year, latitude (North and South of 45°46' N.), survey season and depth (fm), as factors in the GLM. The latitude of 45°46' N. (the southern border of PSMFC area 3A) represented a break identified in CPUE in the data, near Cape Falcon, OR, and reflected the much higher northern catch of spiny dogfish. Survey season was defined by weeks, as weeks 20 through 42. Defining survey season by weeks was much more precise than analyzing by month, as survey season begins and ends mid-month. In the other GLM, we examined the same factors, except we used month as the temporal (seasonal) variable, instead of survey season.

In both models, we fitted depth as a polynomial function to reflect the overall depth profile in the spiny dogfish data. The depth polynomial with a degree of eight was selected using AIC. We also included month by area interaction to reflect spiny dogfish movements within year and area. Interaction between depth and other variables was not modeled, due to concern of confounding with fishing behavior by area and time. A final model specification includes a reasonable set of variables, and shows their relative importance and contrast within them. Including additional interactions would lead to an overly complicated model, with potentially misleading results from overfitting.

Finally, using raw catch rate data, we calculated ratios of average spiny dogfish CPUE during the WCBGT Survey season, versus the full fishing year; both in aggregate with all years combined, and by year.

Results

A map of catch rates of spiny dogfish for bottom trawl fishery hauls is shown by months in Figure A1.

We found (based on GLM) that survey season was a significant predictor of dogfish CPUE ($p=<<0.05$). The output for the model is summarized in Table A1, and the contrast in estimated factor coefficients with standard errors around them is shown Figure A2. Defining survey period by week used a reasonable level of precision, and the results showed little contrast between survey and non-survey periods.

We also found (based on alternative GLM) that month was a significant predictor of dogfish CPUE (p=<<0.05, Table A2), and all months were significantly different from the reference month (January). Latitude (area) was also significant (p=<<0.05). Most years were significantly different from the reference year (2002). The GLM output for the model (with month as a factor) summarized in Table A2, and the contrast in estimated factor coefficients with standard errors around them is shown Figure A3. Analyzing catch rates by month showed more granularity of trend throughout the year, and larger coefficient values during four winter months (November through February), versus eight non-winter months, but examining months is misleading for the question of representativeness of survey period catch rates, since months do not align with survey start and stop dates, and thus do not adequately capture survey vs non-survey periods.

The ratio of average spiny dogfish catch rates as calculated from raw data (for all hauls combined, 2002-2019) during the survey season (week 20 through week 42) versus the entire year was 0.8994 (Table A3), which implies a seasonal component of WCGBTS survey catchability of around 0.9.

The average annual catch rate of spiny dogfish, calculated during survey weeks, versus non-survey weeks vary considerably among years (Table A4, Figure A4), changing rank regularly, although most values were within one standard deviation (Table A5).

Spiny dogfish CPUE (mt per hour) was highly skewed to overwhelmingly zero and near-zero values (Figure A5). This may partially reflect lack of targeting by fishers (32 hauls out of over 100,000 were declared as spiny dogfish targeted in WCGOP data). At the same time, a substantial amount of extreme catch events were present in every year and in both survey and non-survey months (Figure 6), which could reflect schooling behavior of the species, showing through sporadic extreme bycatch events.

On average, the percentage of positive hauls was higher between Nov and February (Table A7), and catch rates were higher during those four months, but with very large uncertainty intervals (Table A6, Figure A7). Percent positive hauls and catch rates among other months were similar. Mean spiny dogfish CPUE by year *and* month are shown in Table A6.

We found that when looking at only larger hauls (those with catch larger than 0.25mt and then larger than 2.5 mt), catch rates are higher in summer (Figure A8 and Figure A9), potentially indicating that larger aggregations of spiny dogfish occur during summer months.

Average annual CPUE of spiny dogfish varies considerably among years, from 0.0064 to 0.0451 mt/hr, with a mean of 0.0148, and a CV of 0.5862. Haul counts (n) were within the range of from 2,600 to 10,000 per year, with an average of 5,707.

Discussion and interpretation

Fishery catches occur primarily in the North, consistently, year-round (Figure A1), and there are high catch rates during winter as well as summer (at the time of WCGBTS survey).

GLM results generally reflected the same trends we see in summaries of raw data. Highest CPUE was in north of 45°46′ N lat.; CPUE varies substantially by year, and average CPUE per year between survey, non-survey weeks, and the whole year vary little from one another.

Although we see that CPUE during survey weeks is overall slightly lower than the whole year, and non-survey weeks, annual survey vs non-survey CPUE means change ranks regularly from year-to-year over the time series (Fig. A4), and generally are within one standard deviation of one another (Table A5), reflecting both the small difference, and the inter-annually variable nature of spiny dogfish catch rates, both overall and among seasons.

Despite the highly skewed distribution of dogfish CPUE toward zero and non-zero hauls, extreme catch or bycatch events are consistent among years and seasons, likely reflecting both fishery (lack of targeting) and schooling behavior of the species.

Whether we calculate the ratio of CPUE (survey season vs. all year) using the aggregate of all data (0.9), or taking the average of mean annual CPUE (0.84), the two metrics are very similar; and most importantly reflect the similarity of CPUE among these periods.

These findings are consistent with Taylor (2008), who based on historical tagging data, estimated movement rates of approximately 5% per year, between the U.S. coastal sub-population of dogfish, and that found along the west coast of Vancouver Island in Canada.

It is difficult to make a strong argument for a value of q which is lower than that estimated in the assessment model based on these results, which suggest an availability of spiny dogfish to the survey trawl of around 90 percent.

It is also important to remember the generally low suitability of fishery data for estimating a parameter such as catchability, with all of the fishery data's caveats and potentially confounding factors owing to the number of different targets pursued throughout the year, varying fisher behavior, differences among vessels, variability in economic and weather conditions, and so on.

Results of these analysis indicate that spatial dynamics of spiny dogfish may be more complex than previously thought. For instance, the map of catch rates by months suggest that there could be three potential migration curves present, each with limited latitudinal range (Figure A10). Similar patterns of limited latitudinal migrations were recently reported for Atlantic spiny dogfish, *Squalus acanthias* (Carlson et al. 2014). Timing of these smaller scale distribution shifts north and south among several groups is consistent with Taylor (2008).

We relied on bottom trawl fishery data, as other sources that we considered, including at-sea hake fishery (observed by ASHOP) midwater trawl fishery data (observed by WCGOP), and historical Pikitch study were not suitable for seasonal analysis. The Pikitch study was limited geographically to the Columbia INPFC area, while at-sea hake and midwater trawl fishery data had limited latitudinal range and limited seasonality (Figures A11-A12), making each insufficient to show geographic movement through either a sufficient geographic range (coast), or seasonal range (year), respectively. The current whiting fishery season begins on May 15, and often finishes before the end of the year.

References

Carlson, A. E., Hoffmayer, E.R., Tribuzio, C.A., Sulikowski, J.A. 2014. The use of satellite tags to redefine movement patterns of spiny dogfish (*Squalus acanthias*) along the US east coast: implications for fisheries management. PLoS One 28; 9(7):e103384.

Taylor, I.G., 2008. Modeling spiny dogfish population dynamics in the Northeast Pacific (Doctoral dissertation, University of Washington).

Table A1. GLM results (with year, survey season, depth and area as factors).

Coefficients:	Estimate	Std.Error	tvalue	Pr(>|t|)
(Intercept)	-9.51E+00	1.90E-01	-50.01	<2e-16
DYEAR2003	6.71E-02	1.80E-01	0.372	0.70962
DYEAR2004	6.08E-01	1.64E-01	3.72	0.0002
DYEAR2005	2.98E+00	1.62E-01	18.358	<2e-16
DYEAR2006	1.94E+00	1.71E-01	11.376	<2e-16
DYEAR2007	1.23E+00	1.77E-01	6.945	3.80E-12
DYEAR2008	1.62E+00	1.68E-01	9.639	<2e-16
DYEAR2009	1.57E+00	1.59E-01	9.848	<2e-16
DYEAR2010	1.35E+00	1.78E-01	7.545	4.57E-14
DYEAR2011	1.35E+00	1.41E-01	9.559	<2e-16
DYEAR2012	1.42E+00	1.41E-01	10.041	<2e-16
DYEAR2013	8.30E-03	1.39E-01	0.06	0.95245
DYEAR2014	1.01E+00	1.43E-01	7.072	1.54E-12
DYEAR2015	-3.73E-01	1.44E-01	-2.592	0.00955
DYEAR2016	-6.11E-01	1.46E-01	-4.195	2.73E-05
DYEAR2017	-1.64E+00	1.46E-01	-11.258	<2e-16
DYEAR2018	-2.86E-02	1.49E-01	-0.191	0.84842
DYEAR2019	-3.61E-01	1.51E-01	-2.389	0.01691
North_45_deg_46_minSouth	-2.63E+00	1.85E-01	-14.247	<2e-16
Survey_weeksWeeks_20:42	-7.82E-01	1.04E-01	-7.523	5.40E-14
poly(AVG_DEPTH,degree=8)1	-625.1	7.90E+00	-79.174	<2e-16
poly(AVG_DEPTH,degree=8)2	-364.7	7.25E+00	-50.336	<2e-16
poly(AVG_DEPTH,degree=8)3	580.7	6.90E+00	84.108	<2e-16
poly(AVG_DEPTH,degree=8)4	-160.8	7.01E+00	-22.953	<2e-16
poly(AVG_DEPTH,degree=8)5	-170.2	6.98E+00	-24.389	<2e-16
poly(AVG_DEPTH,degree=8)6	132.1	6.90E+00	19.135	<2e-16
poly(AVG_DEPTH,degree=8)7	15.73	6.91E+00	2.277	0.02281
poly(AVG_DEPTH,degree=8)8	-54.48	6.93E+00	-7.864	3.74E-15
North_45_deg_46_minNorth:DMONTH2	-1.61E+00	1.97E-01	-8.208	2.28E-16
North_45_deg_46_minSouth:DMONTH2	-2.23E+00	1.49E-01	-14.974	<2e-16
North_45_deg_46_minNorth:DMONTH3	-3.43E+00	1.90E-01	-18.049	<2e-16
North_45_deg_46_minSouth:DMONTH3	-4.64E+00	1.40E-01	-33.169	<2e-16
North_45_deg_46_minNorth:DMONTH4	-3.82E+00	1.80E-01	-21.233	<2e-16
North_45_deg_46_minSouth:DMONTH4	-5.65E+00	1.42E-01	-39.787	<2e-16
North_45_deg_46_minNorth:DMONTH5	-6.41E+00	1.88E-01	-34.172	<2e-16
North_45_deg_46_minSouth:DMONTH5	-5.60E+00	1.57E-01	-35.568	<2e-16
North_45_deg_46_minNorth:DMONTH6	-6.37E+00	2.08E-01	-30.712	<2e-16
North_45_deg_46_minSouth:DMONTH6	-4.50E+00	1.80E-01	-24.943	<2e-16
North_45_deg_46_minNorth:DMONTH7	-5.50E+00	2.09E-01	-26.312	<2e-16
North_45_deg_46_minSouth:DMONTH7	-4.86E+00	1.78E-01	-27.348	<2e-16
North_45_deg_46_minNorth:DMONTH8	-5.17E+00	2.11E-01	-24.576	<2e-16
North_45_deg_46_minSouth:DMONTH8	-5.26E+00	1.75E-01	-30.112	<2e-16
North_45_deg_46_minNorth:DMONTH9	-1.52E+00	2.19E-01	-6.943	3.86E-12
North_45_deg_46_minSouth:DMONTH9	-5.33E+00	1.76E-01	-30.338	<2e-16
North_45_deg_46_minNorth:DMONTH10	-1.98E+00	2.17E-01	-9.136	<2e-16
North_45_deg_46_minSouth:DMONTH10	-4.02E+00	1.58E-01	-25.476	<2e-16
North_45_deg_46_minNorth:DMONTH11	-1.72E+00	2.44E-01	-7.055	1.74E-12
North_45_deg_46_minSouth:DMONTH11	-9.41E-01	1.51E-01	-6.229	4.71E-10
North_45_deg_46_minNorth:DMONTH12	-9.49E-01	2.40E-01	-3.952	7.75E-05
North_45_deg_46_minSouth:DMONTH12	-4.23E-01	1.62E-01	-2.61	0.00905

Table A2. GLM results (with year, month, depth and area as factors).

Coefficients:	Estimate	Std.Error	tvalue	Pr(>|t|)
(Intercept)	-9.52164	0.19023	-50.052	<2e-16
DYEAR2003	0.07869	0.18033	0.436	0.662557
DYEAR2004	0.6027	0.16355	3.685	0.000229
DYEAR2005	2.99007	0.16219	18.435	<2e-16
DYEAR2006	1.93591	0.17083	11.332	<2e-16
DYEAR2007	1.2443	0.17688	7.035	2.01E-12
DYEAR2008	1.61549	0.16807	9.612	<2e-16
DYEAR2009	1.54938	0.15907	9.741	<2e-16
DYEAR2010	1.34401	0.17837	7.535	4.92E-14
DYEAR2011	1.34387	0.14077	9.546	<2e-16
DYEAR2012	1.41239	0.1414	9.989	<2e-16
DYEAR2013	0.01432	0.13925	0.103	0.918105
DYEAR2014	1.01598	0.14264	7.123	1.06E-12
DYEAR2015	-0.38349	0.14395	-2.664	0.007724
DYEAR2016	-0.61139	0.1457	-4.196	2.72E-05
DYEAR2017	-1.63065	0.14608	-11.163	<2e-16
DYEAR2018	-0.0312	0.14946	-0.209	0.834654
DYEAR2019	-0.34117	0.1513	-2.255	0.024143
North_45_deg_46_minSouth	-2.62706	0.18453	-14.237	<2e-16
DMONTH2	-1.61195	0.19675	-8.193	2.58E-16
DMONTH3	-3.42676	0.18994	-18.042	<2e-16
DMONTH4	-3.81222	0.17997	-21.182	<2e-16
DMONTH5	-6.86468	0.17767	-38.637	<2e-16
DMONTH6	-7.13345	0.18125	-39.357	<2e-16
DMONTH7	-6.2587	0.18296	-34.208	<2e-16
DMONTH8	-5.93214	0.18472	-32.114	<2e-16
DMONTH9	-2.28081	0.1942	-11.745	<2e-16
DMONTH10	-2.51848	0.20521	-12.273	<2e-16
DMONTH11	-1.71393	0.24387	-7.028	2.11E-12
DMONTH12	-0.94659	0.24016	-3.941	8.11E-05
poly(AVG_DEPTH,degree=8)1	-621.91147	7.88611	-78.862	<2e-16
poly(AVG_DEPTH,degree=8)2	-366.80679	7.24233	-50.648	<2e-16
poly(AVG_DEPTH,degree=8)3	580.61296	6.9057	84.077	<2e-16
poly(AVG_DEPTH,degree=8)4	-159.71447	7.00591	-22.797	<2e-16
poly(AVG_DEPTH,degree=8)5	-171.27991	6.98113	-24.535	<2e-16
poly(AVG_DEPTH,degree=8)6	133.11536	6.90226	19.286	<2e-16
poly(AVG_DEPTH,degree=8)7	15.24981	6.91282	2.206	0.027385
poly(AVG_DEPTH,degree=8)8	-55.1925	6.929	-7.965	1.66E-15
North_45_deg_46_minSouth:DMONTH2	-0.6148	0.24657	-2.493	0.012651
North_45_deg_46_minSouth:DMONTH3	-1.20963	0.2356	-5.134	2.84E-07
North_45_deg_46_minSouth:DMONTH4	-1.83285	0.22837	-8.026	1.02E-15
North_45_deg_46_minSouth:DMONTH5	0.79763	0.22688	3.516	0.000439
North_45_deg_46_minSouth:DMONTH6	1.86802	0.23026	8.113	5.00E-16
North_45_deg_46_minSouth:DMONTH7	0.6305	0.22933	2.749	0.005974
North_45_deg_46_minSouth:DMONTH8	-0.0979	0.22846	-0.429	0.66826
North_45_deg_46_minSouth:DMONTH9	-3.8274	0.23792	-16.087	<2e-16
North_45_deg_46_minSouth:DMONTH10	-1.99706	0.24864	-8.032	9.70E-16
North_45_deg_46_minSouth:DMONTH11	0.77112	0.2867	2.69	0.007155
North_45_deg_46_minSouth:DMONTH12	0.52169	0.28902	1.805	0.07107

Table A3. Spiny dogfish average catch rates calculated for survey season (week 20 through week 42), non-survey season and the entire year (for all years combined).

	Mean	SE	N
Survey season	0.01280324	0.001011615	52228
Non survey season	0.01571525	0.000983506	50506
Year	0.01423484	0.000705895	102734
Survey season/Year	**0.89942985**		

Table A4. Average annual CPUE (mean per haul) of spiny dogfish, calculated during survey weeks, versus non-survey weeks. Most values are w/in one S.D. of one another.

Year	Non-survey	Survey	All	Survey/All
2002	0.02276779	0.01926025	0.021058	0.914623
2003	0.01321884	0.00664692	0.010329	0.643496
2004	0.01046075	0.01608786	0.013382	1.2022
2005	0.01051235	0.0692943	0.045087	1.536916
2006	0.01541151	0.01865452	0.017479	1.067239
2007	0.01334199	0.00635932	0.009452	0.672812
2008	0.01549387	0.01559429	0.015549	1.002883
2009	0.01595565	0.0066839	0.01095	0.610399
2010	0.00944747	0.00496199	0.006952	0.713771
2011	0.01825857	0.00760031	0.012767	0.595329
2012	0.02146823	0.00791999	0.014278	0.554716
2013	0.01624698	0.00408252	0.010719	0.380884
2014	0.02890651	0.00825366	0.019367	0.426177
2015	0.01007033	0.00600467	0.008207	0.731644
2016	0.00862107	0.01379425	0.011096	1.243139
2017	0.0077604	0.00497066	0.006431	0.772956
2018	0.01336901	0.02489742	0.019443	1.280543
2019	0.01707489	0.01115338	0.014152	0.788108
Mean				**0.840991**

Table A5. Average annual CPUE (mean per haul) of spiny dogfish, calculated during survey weeks, versus non-survey weeks, with standard deviation. Most values are w/in one S.D. of one another.

Year	Non-survey mean CPUE	Survey mean CPUE	StdDev non-survey	StdDev survey
2002	0.022767789	0.019260253	0.166546839	0.25024174
2003	0.013218838	0.006646923	0.068624957	0.066178131
2004	0.010460747	0.016087863	0.065983805	0.173741039
2005	0.010512349	0.069294295	0.10055901	0.575679995
2006	0.01541151	0.018654517	0.052396648	0.162070491
2007	0.013341987	0.00635932	0.043761359	0.028141967
2008	0.015493872	0.015594288	0.058033329	0.080342733
2009	0.01595565	0.006683903	0.070603449	0.038790899
2010	0.009447471	0.004961988	0.043828526	0.030012195
2011	0.018258571	0.007600306	0.188195798	0.063530955
2012	0.021468234	0.00791999	0.259784458	0.098556709
2013	0.016246976	0.004082517	0.348248988	0.028903908
2014	0.028906515	0.008253662	0.387550673	0.090434024
2015	0.010070326	0.006004673	0.186470001	0.044861283
2016	0.008621066	0.013794254	0.207965065	0.186425644
2017	0.007760404	0.004970661	0.088076093	0.090211313
2018	0.013369008	0.024897419	0.188941392	0.650539394
2019	0.01707489	0.011153381	0.183637076	0.174402409

Table A6. Number of zero and positive spiny dogfish hauls by month.

Month	N of zero hauls	N of positive hauls	Total
1	2156	3928	6084
2	3417	3969	7386
3	5689	3780	9469
4	6186	4243	10429
5	6943	3846	10789
6	6469	3585	10054
7	6500	3844	10344
8	6849	3941	10790
9	5273	3902	9175
10	4535	3492	8027
11	2285	3279	5564
12	1612	3013	4625

Table A7. Mean spiny dogfish CPUE (mt/hr) by month, among all years, 2002-2019, in the bottom trawl fishery.

Month	Mean CPUE (mt/hr)	S.D.	CV	Haul count
1	0.03483	0.44989	1292%	6084
2	0.01876	0.19375	1033%	7386
3	0.00771	0.11642	1510%	9469
4	0.01149	0.17214	1498%	10429
5	0.00560	0.08127	1451%	10789
6	0.01309	0.37377	2855%	10054
7	0.01376	0.25240	1835%	10344
8	0.01070	0.12042	1125%	10790
9	0.01811	0.21218	1171%	9175
10	0.01348	0.14505	1076%	8027
11	0.01843	0.17990	976%	5564
12	0.01996	0.23515	1178%	4625

Table A8. Mean spiny dogfish CPUE (mt/hr) by year and month, among all years, 2002-2019, in the bottom trawl fishery.

Year	Month	Mean CPUE (mt/hr)	S.D.	CV	Haul count
2002	1	0.01926	0.06937	360%	205
2002	2	0.03058	0.27381	896%	276
2002	3	0.01932	0.20914	1083%	290
2002	4	0.03128	0.14452	462%	449
2002	5	0.01054	0.03283	311%	290
2002	6	0.00809	0.03841	475%	350
2002	7	0.05787	0.52526	908%	349
2002	8	0.01044	0.04862	466%	303
2002	9	0.00160	0.01262	790%	64
2002	10	0.00428	0.01653	386%	455
2002	11	0.02089	0.10305	493%	152
2002	12	0.03471	0.09151	264%	38
2003	1	0.00867	0.06735	777%	127
2003	2	0.00609	0.02839	466%	228
2003	3	0.00131	0.00654	499%	236
2003	4	0.02495	0.10560	423%	488
2003	5	0.00171	0.00762	445%	236
2003	6	0.00103	0.00616	597%	327
2003	7	0.00450	0.03360	747%	205
2003	8	0.02404	0.14847	618%	213
2003	9	0.00491	0.01563	318%	159
2003	10	0.00653	0.01741	267%	218
2003	11	0.01879	0.05958	317%	151
2003	12	0.00863	0.01445	167%	39
2004	1	0.01028	0.03813	371%	195
2004	2	0.01484	0.05154	347%	227
2004	3	0.01126	0.10832	962%	458
2004	4	0.00929	0.03553	383%	554
2004	5	0.01446	0.08018	555%	256
2004	6	0.02128	0.07047	331%	280
2004	7	0.00980	0.03603	368%	473
2004	8	0.02572	0.30505	1186%	609
2004	9	0.01350	0.07699	570%	324
2004	10	0.00113	0.00949	840%	212
2004	11	0.00489	0.03141	642%	181
2004	12	0.00869	0.03198	368%	149
2005	1	0.01929	0.09219	478%	194

2005	2	0.00750	0.01744	233%	283
2005	3	0.00251	0.01043	416%	392
2005	4	0.02450	0.20968	856%	334
2005	5	0.01259	0.04262	339%	472
2005	6	0.08690	0.61560	708%	554
2005	7	0.09293	0.87515	942%	690
2005	8	0.02997	0.11956	399%	622
2005	9	0.11271	0.40568	360%	274
2005	10	0.00103	0.00723	703%	85
2005	11	0.00896	0.04096	457%	92
2005	12	0.00180	0.00873	485%	85
2006	1	0.02999	0.04113	137%	97
2006	2	0.01302	0.03671	282%	278
2006	3	0.00084	0.00202	241%	64
2006	4	0.00470	0.02432	518%	327
2006	5	0.00238	0.00750	315%	357
2006	6	0.01289	0.04062	315%	256
2006	7	0.02003	0.19507	974%	539
2006	8	0.01129	0.06608	585%	559
2006	9	0.03540	0.27224	769%	391
2006	10	0.02915	0.11711	402%	151
2006	11	0.03871	0.10765	278%	138
2006	12	0.03995	0.08198	205%	99
2007	1	0.02116	0.06293	297%	278
2007	2	0.01713	0.03637	212%	154
2007	3	0.00372	0.01454	391%	49
2007	4	0.01115	0.03435	308%	184
2007	5	0.00309	0.00911	295%	347
2007	6	0.01089	0.04560	419%	222
2007	7	0.00570	0.01963	344%	373
2007	8	0.00635	0.02965	467%	406
2007	9	0.00373	0.01595	428%	260
2007	10	0.01276	0.04541	356%	301
2007	11	0.01157	0.04089	354%	191
2007	12	0.01132	0.03544	313%	89
2008	1	0.04825	0.08092	168%	120
2008	2	0.03367	0.10029	298%	234
2008	3	0.00712	0.02661	374%	251
2008	4	0.00652	0.04841	743%	361
2008	5	0.00971	0.04254	438%	477
2008	6	0.00418	0.01530	366%	363
2008	7	0.00037	0.00142	387%	297

2008	8	0.00679	0.04831	711%	310
2008	9	0.04333	0.14115	326%	463
2008	10	0.01180	0.06560	556%	341
2008	11	0.01197	0.04421	369%	163
2008	12	0.01781	0.04928	277%	157
2009	1	0.02706	0.07401	274%	246
2009	2	0.02882	0.07462	259%	278
2009	3	0.01516	0.04908	324%	305
2009	4	0.00818	0.03607	441%	496
2009	5	0.01347	0.08619	640%	676
2009	6	0.00388	0.02484	640%	694
2009	7	0.00887	0.03265	368%	307
2009	8	0.00516	0.01457	282%	341
2009	9	0.00378	0.01499	396%	384
2009	10	0.00370	0.01818	491%	290
2009	11	0.02209	0.11417	517%	261
2009	12	0.00639	0.02550	399%	236
2010	1	0.02108	0.06824	324%	133
2010	2	0.01547	0.05498	355%	219
2010	3	0.00972	0.04500	463%	264
2010	4	0.00341	0.01038	305%	264
2010	5	0.00457	0.03161	691%	525
2010	6	0.00673	0.03484	517%	401
2010	7	0.01023	0.04847	474%	314
2010	8	0.00191	0.00717	375%	209
2010	9	0.00061	0.00287	472%	271
2010	10	0.00457	0.02575	563%	193
2011	1	0.06724	0.42837	637%	473
2011	2	0.04249	0.32458	764%	625
2011	3	0.00693	0.05153	744%	699
2011	4	0.00206	0.00976	473%	928
2011	5	0.00116	0.00615	529%	1029
2011	6	0.00688	0.06136	892%	930
2011	7	0.00811	0.05347	659%	946
2011	8	0.01475	0.10709	726%	1060
2011	9	0.00352	0.01271	362%	925
2011	10	0.00744	0.04836	650%	689
2011	11	0.01341	0.06424	479%	483
2011	12	0.01445	0.08326	576%	767
2012	1	0.02950	0.17036	577%	426
2012	2	0.04671	0.31722	679%	496
2012	3	0.00990	0.08532	862%	733

2012	4	0.02916	0.45309	1554%	1062
2012	5	0.00297	0.02960	998%	999
2012	6	0.00388	0.01627	420%	1009
2012	7	0.00498	0.02928	588%	960
2012	8	0.00358	0.02143	598%	1023
2012	9	0.01726	0.18942	1097%	894
2012	10	0.01672	0.14974	896%	601
2012	11	0.01283	0.05009	391%	507
2012	12	0.02099	0.07021	335%	462
2013	1	0.07424	0.99502	1340%	651
2013	2	0.00615	0.02838	462%	689
2013	3	0.00452	0.06418	1421%	1468
2013	4	0.00197	0.00848	429%	924
2013	5	0.00344	0.01338	389%	942
2013	6	0.00254	0.01907	751%	837
2013	7	0.00427	0.02354	551%	882
2013	8	0.00135	0.00556	412%	1104
2013	9	0.00218	0.00806	370%	709
2013	10	0.01139	0.05762	506%	958
2013	11	0.02991	0.18735	626%	586
2013	12	0.01637	0.09494	580%	508
2014	1	0.07035	0.76761	1091%	768
2014	2	0.04442	0.41540	935%	746
2014	3	0.00620	0.07482	1207%	966
2014	4	0.02424	0.22262	919%	830
2014	5	0.01467	0.26015	1774%	789
2014	6	0.00463	0.01489	322%	721
2014	7	0.00550	0.02230	405%	855
2014	8	0.01652	0.18087	1095%	857
2014	9	0.01176	0.06708	570%	709
2014	10	0.00548	0.02492	455%	488
2014	11	0.00797	0.02150	270%	422
2014	12	0.00763	0.01887	247%	303
2015	1	0.01271	0.10518	828%	953
2015	2	0.00286	0.01330	466%	853
2015	3	0.00260	0.02304	887%	932
2015	4	0.00821	0.11583	1410%	575
2015	5	0.00422	0.08351	1977%	870
2015	6	0.00500	0.02528	505%	714
2015	7	0.00493	0.01455	295%	715
2015	8	0.00269	0.00825	307%	629
2015	9	0.01074	0.02181	203%	525

2015	10	0.00929	0.02579	278%	551
2015	11	0.04273	0.55322	1295%	423
2015	12	0.01161	0.02249	194%	159
2016	1	0.01544	0.16686	1081%	336
2016	2	0.00367	0.05448	1485%	668
2016	3	0.00107	0.00411	386%	619
2016	4	0.00347	0.05587	1611%	937
2016	5	0.00132	0.00543	412%	716
2016	6	0.00219	0.00970	443%	694
2016	7	0.00520	0.01892	364%	698
2016	8	0.02340	0.22100	945%	707
2016	9	0.03288	0.34839	1060%	704
2016	10	0.00907	0.03737	412%	494
2016	11	0.01506	0.16600	1103%	334
2016	12	0.03804	0.62018	1630%	364
2017	1	0.00472	0.01613	342%	335
2017	2	0.00241	0.01426	593%	562
2017	3	0.00812	0.14867	1830%	613
2017	4	0.00516	0.08922	1728%	724
2017	5	0.00081	0.00394	486%	664
2017	6	0.00146	0.00536	368%	627
2017	7	0.00128	0.00609	476%	701
2017	8	0.00110	0.00570	519%	648
2017	9	0.00789	0.06056	767%	802
2017	10	0.02037	0.22411	1100%	580
2017	11	0.01457	0.09019	619%	409
2017	12	0.01414	0.06057	428%	525
2018	1	0.02752	0.14034	510%	259
2018	2	0.00495	0.01149	232%	260
2018	3	0.00343	0.01607	469%	508
2018	4	0.00330	0.02172	659%	531
2018	5	0.00428	0.03806	889%	621
2018	6	0.06853	1.49820	2186%	526
2018	7	0.00348	0.01577	454%	527
2018	8	0.00812	0.09725	1198%	596
2018	9	0.03477	0.51971	1495%	737
2018	10	0.01793	0.15270	851%	738
2018	11	0.01106	0.05152	466%	620
2018	12	0.05241	0.51648	985%	369
2019	1	0.01499	0.03432	229%	288
2019	2	0.00997	0.07082	711%	310
2019	3	0.02772	0.34895	1259%	622

2019	4	0.00239	0.01473	616%	461
2019	5	0.00476	0.02579	542%	523
2019	6	0.00715	0.06886	963%	549
2019	7	0.00519	0.06257	1207%	513
2019	8	0.00169	0.02165	1280%	594
2019	9	0.00732	0.04271	583%	580
2019	10	0.03936	0.37871	962%	682
2019	11	0.02170	0.09563	441%	451
2019	12	0.02197	0.06360	289%	276

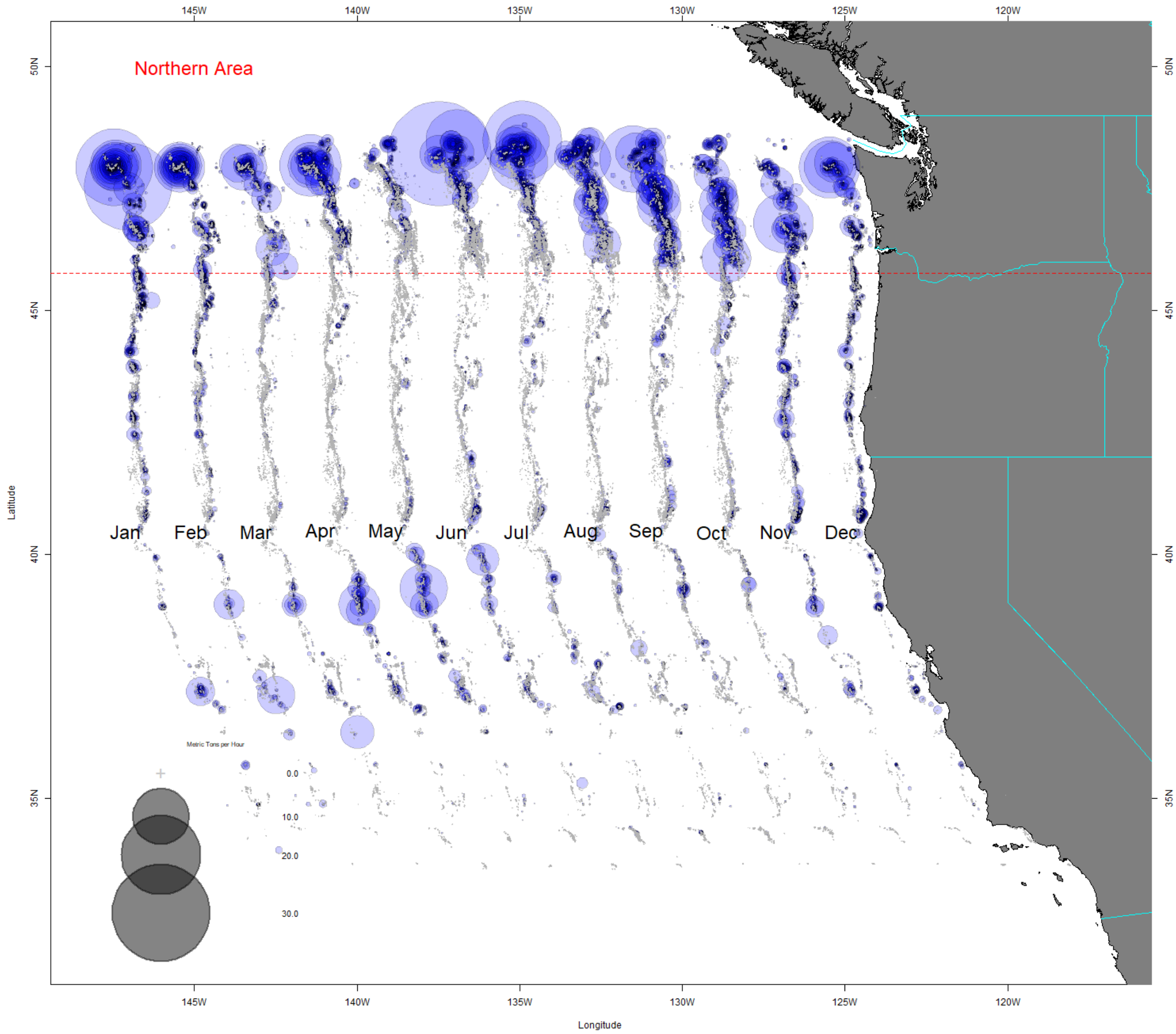

Figure A1. Map of catch rates for bottom trawl fishery hauls (as observed by WCGOP) by month (2002-2019 combined).

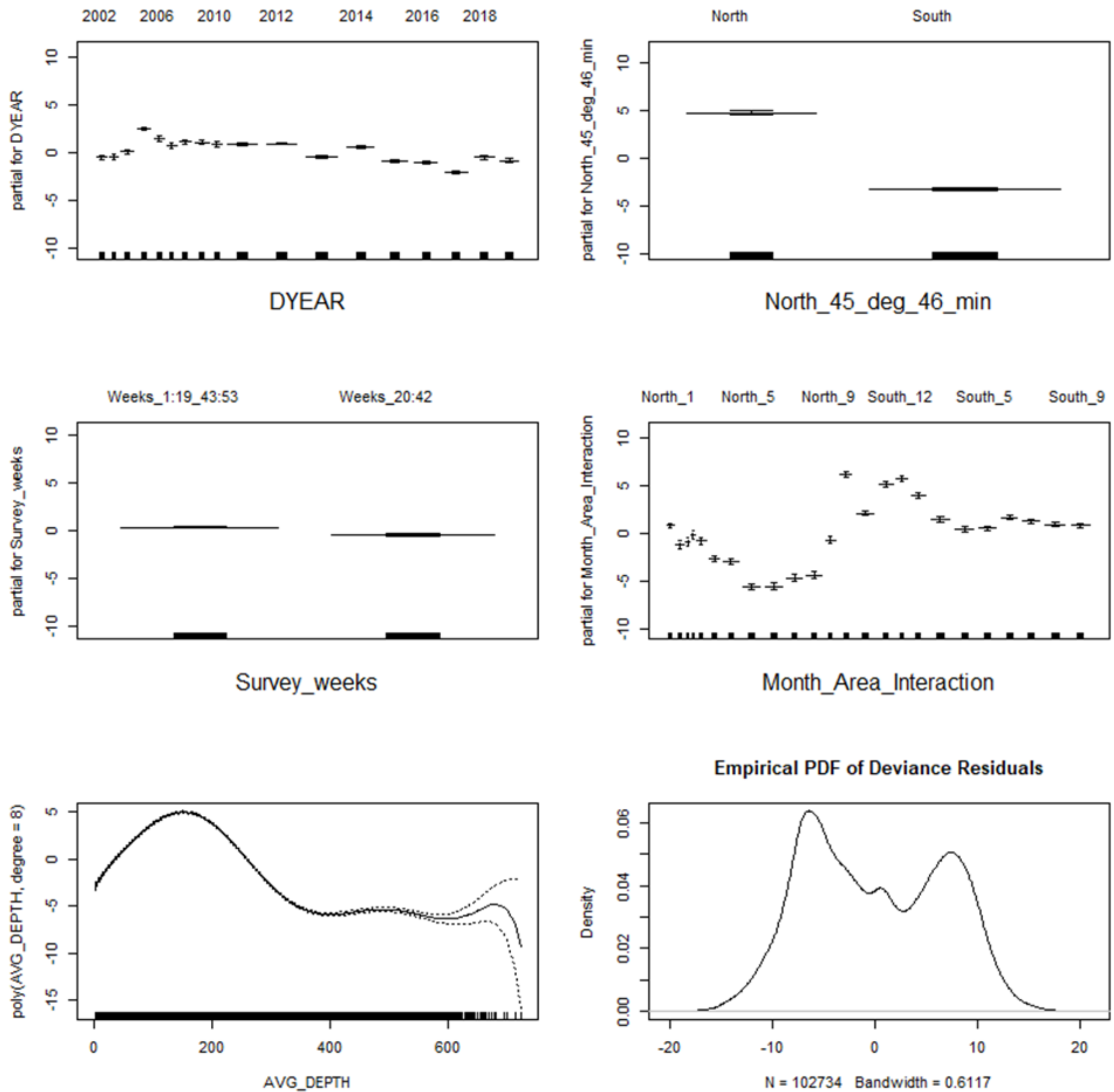

Figure A2. GLM output showing contrast in estimated coefficients for individual years, areas, survey vs non-survey weeks; uncertainty is expressed as standard error, which are very small since the N is large. In the model with the survey weeks as a factor, fewer degrees of freedom are used, and the month-area interaction is included to fully show the difference in months within area. Within the figure, R's default treatment contrasts, which sets the first level within a categorical factor to zero, are changed to the contrasts that sum to zero so that all levels within a factor are shown. (Applying R's plot.Gam() function to the glm() output does this automatically.)

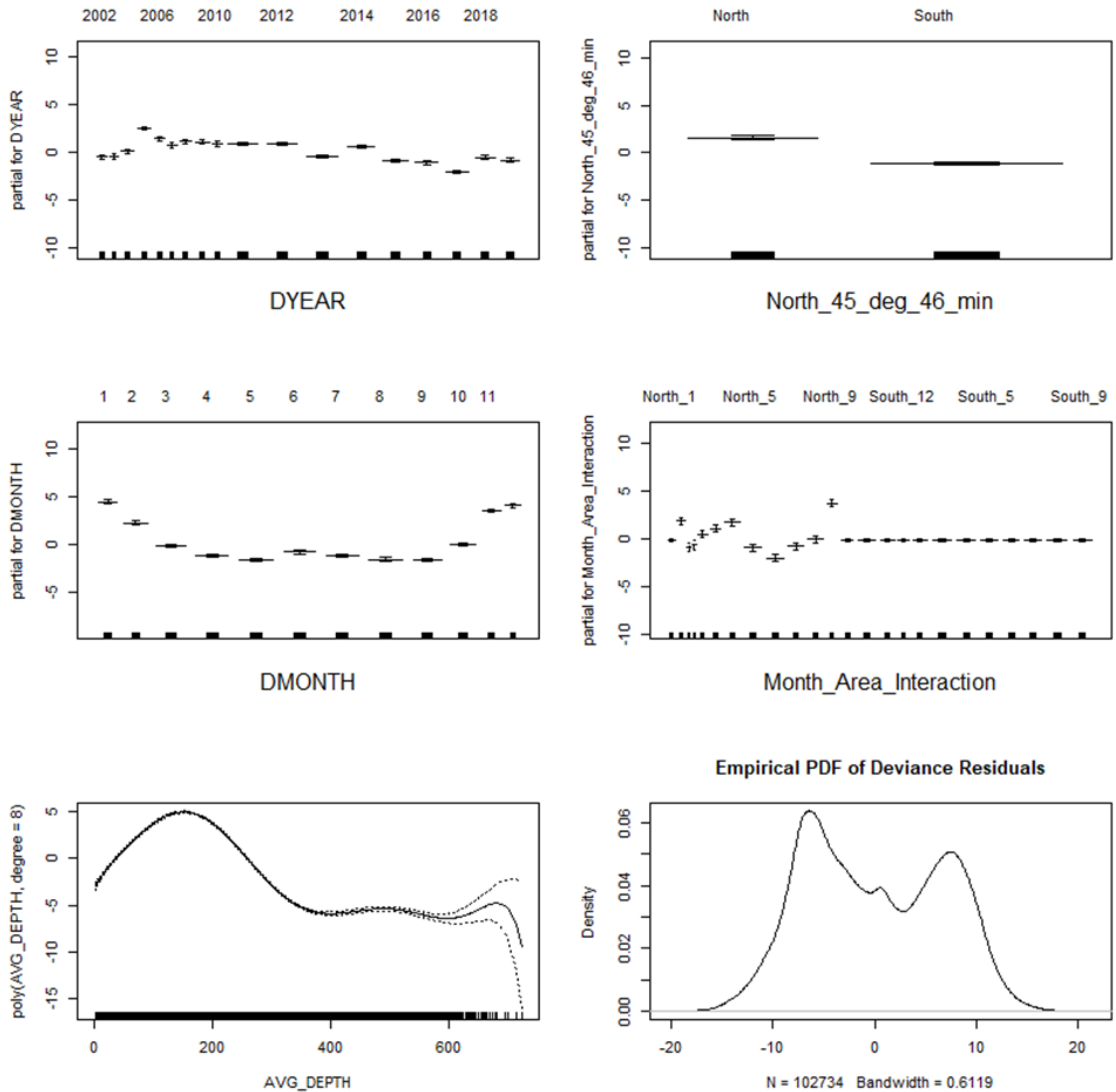

Figure A3. GLM results showing contrast in estimated factor coefficients (these are not catch rates); uncertainty is expressed as standard error, which are very small since the N is large. For the month-area interaction (middle right panel), degrees of freedom become exhausted, and as a result, the Southern area-months are all forced to be zero.

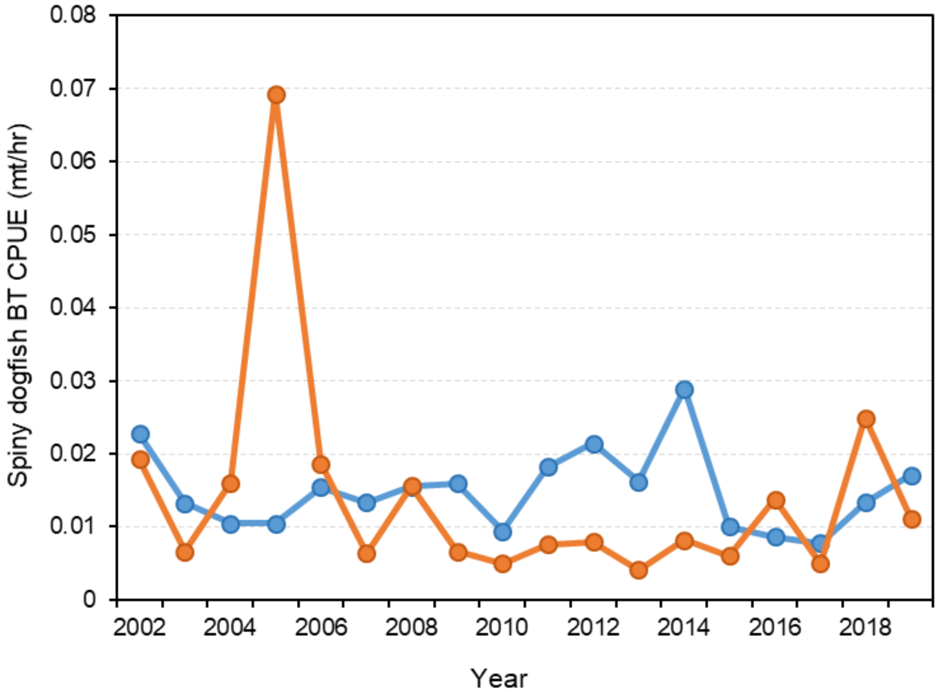

Figure A4. Average annual CPUE of spiny dogfish, calculated during survey weeks, versus non-survey weeks. Orange = survey weeks, blue = non-survey weeks. Most values are w/in one S.D. of one another.

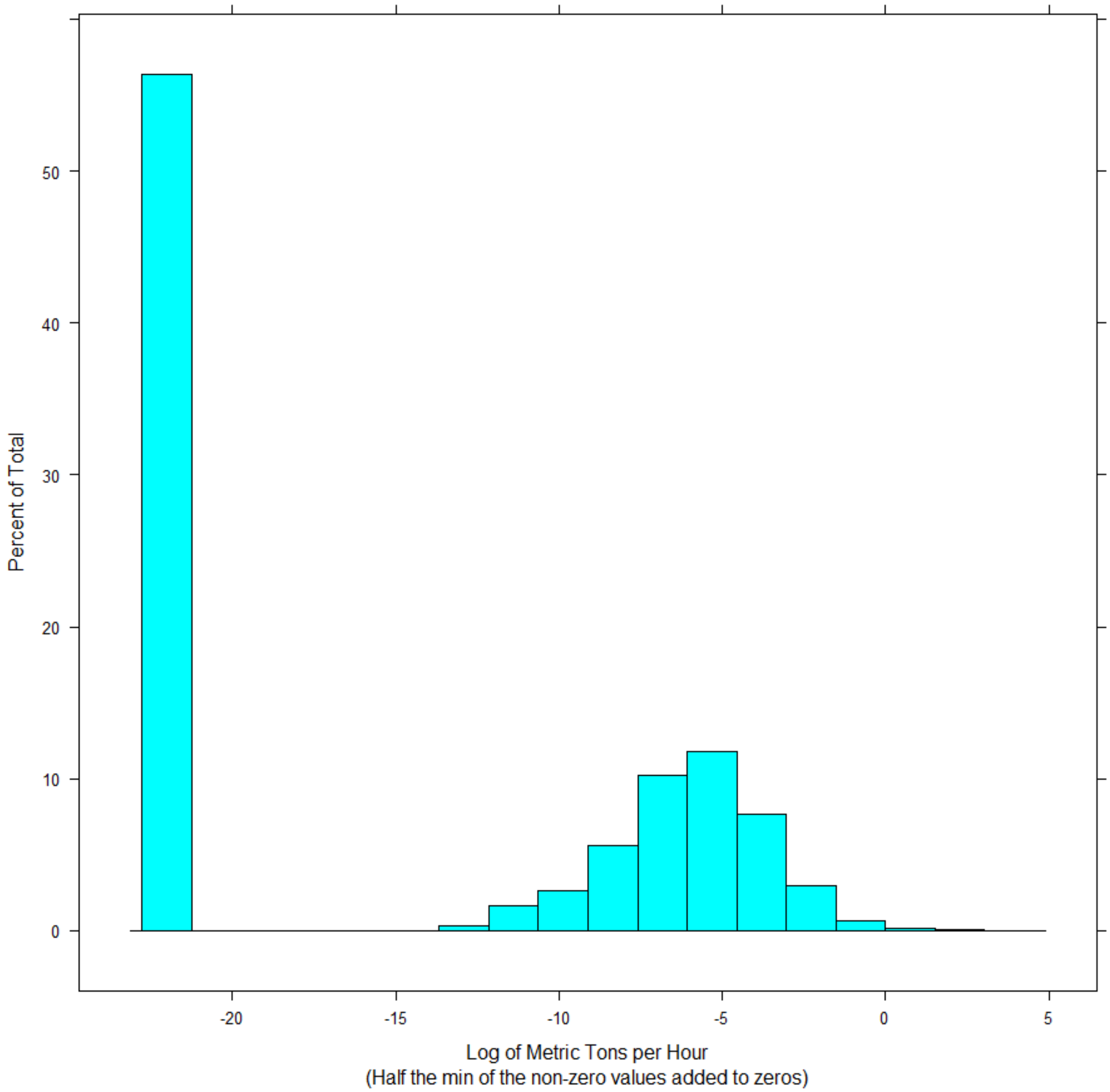

Figure A5. Histogram of spiny dogfish catch rates.

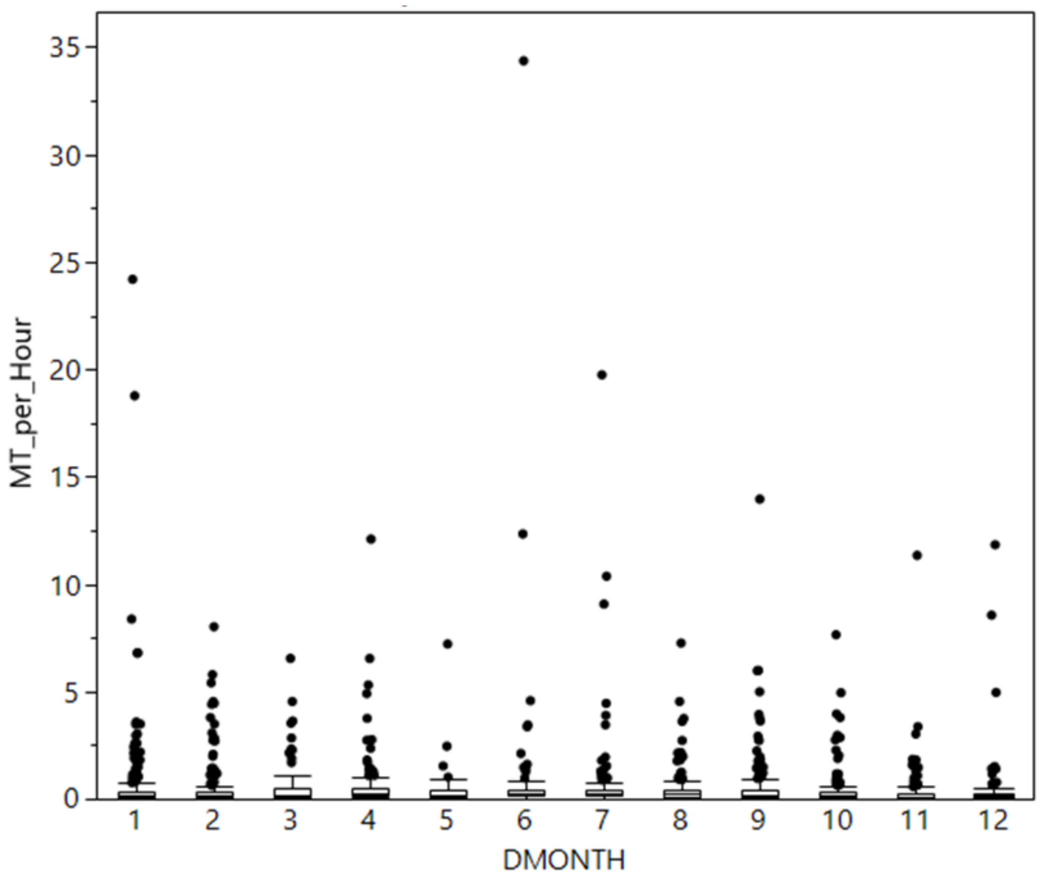

Figure A6. Spiny dogfish CPUE by haul (showing all hauls, zero and positive).

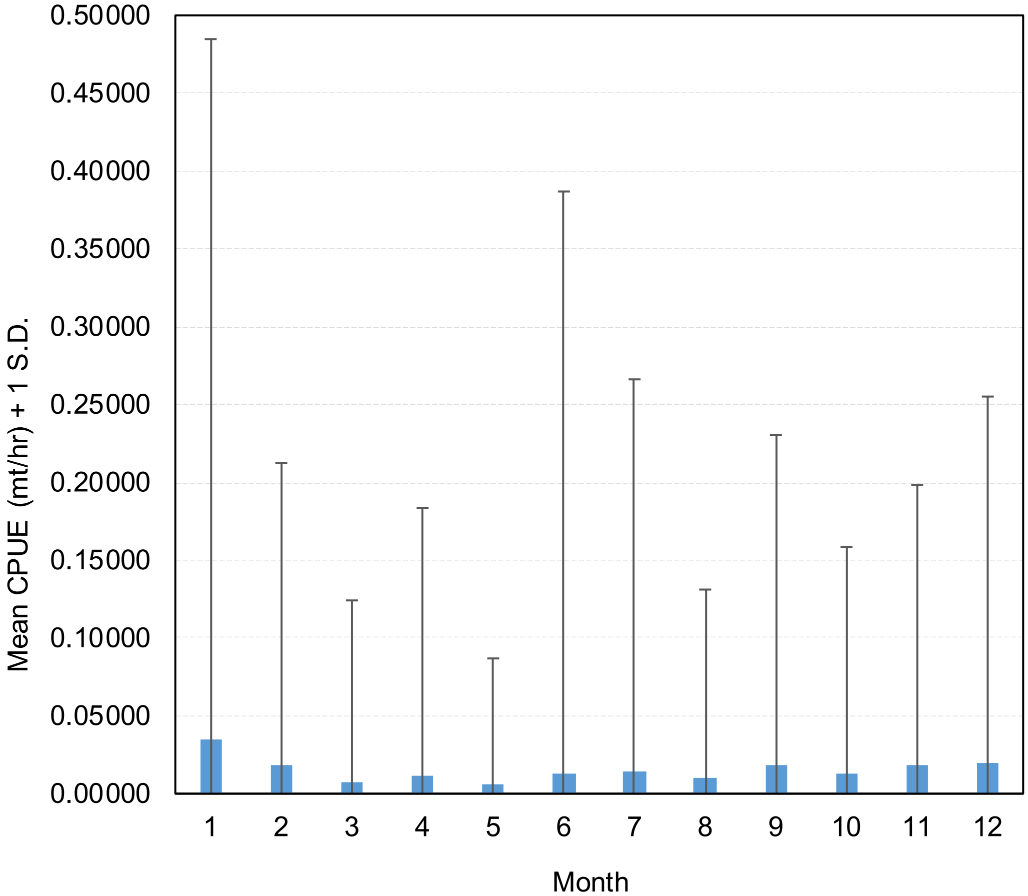

Figure A7. Mean spiny dogfish CPUE (mt/hr) by month, +-1 S.D., among all years, 2002-2019, in the bottom trawl fishery.

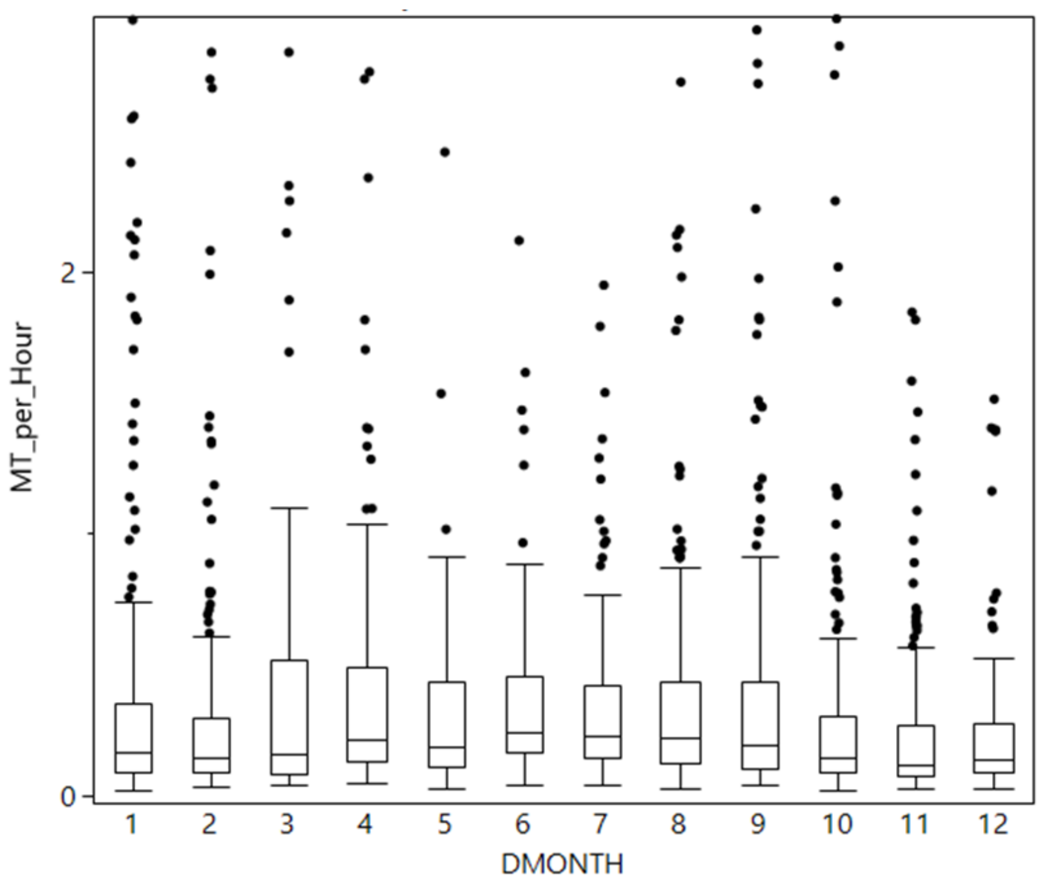

Figure A8. Spiny dogfish CPUE by haul, showing only hauls with catch of 0.25 mt or larger (reduced y axis max to not show most outliers).

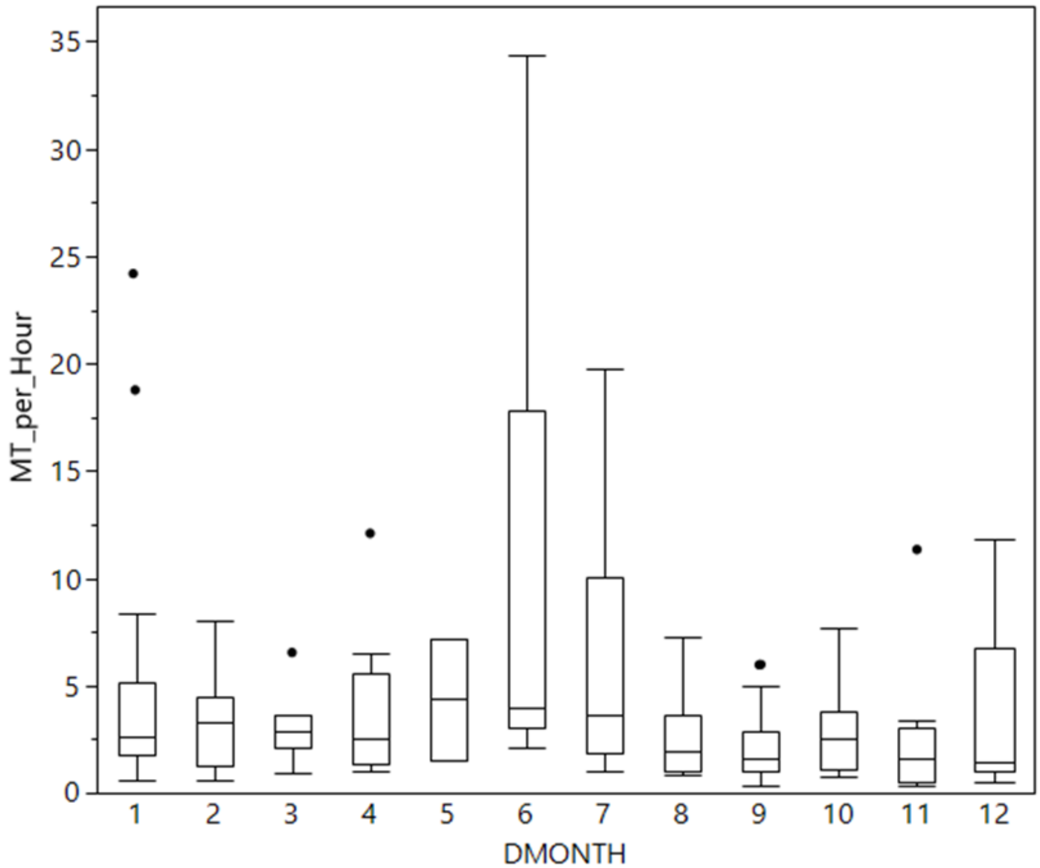

Figure A9. Spiny dogfish CPUE by haul, showing only hauls with catch of 2.5 mt or larger (reduced y axis max to not show most outliers).

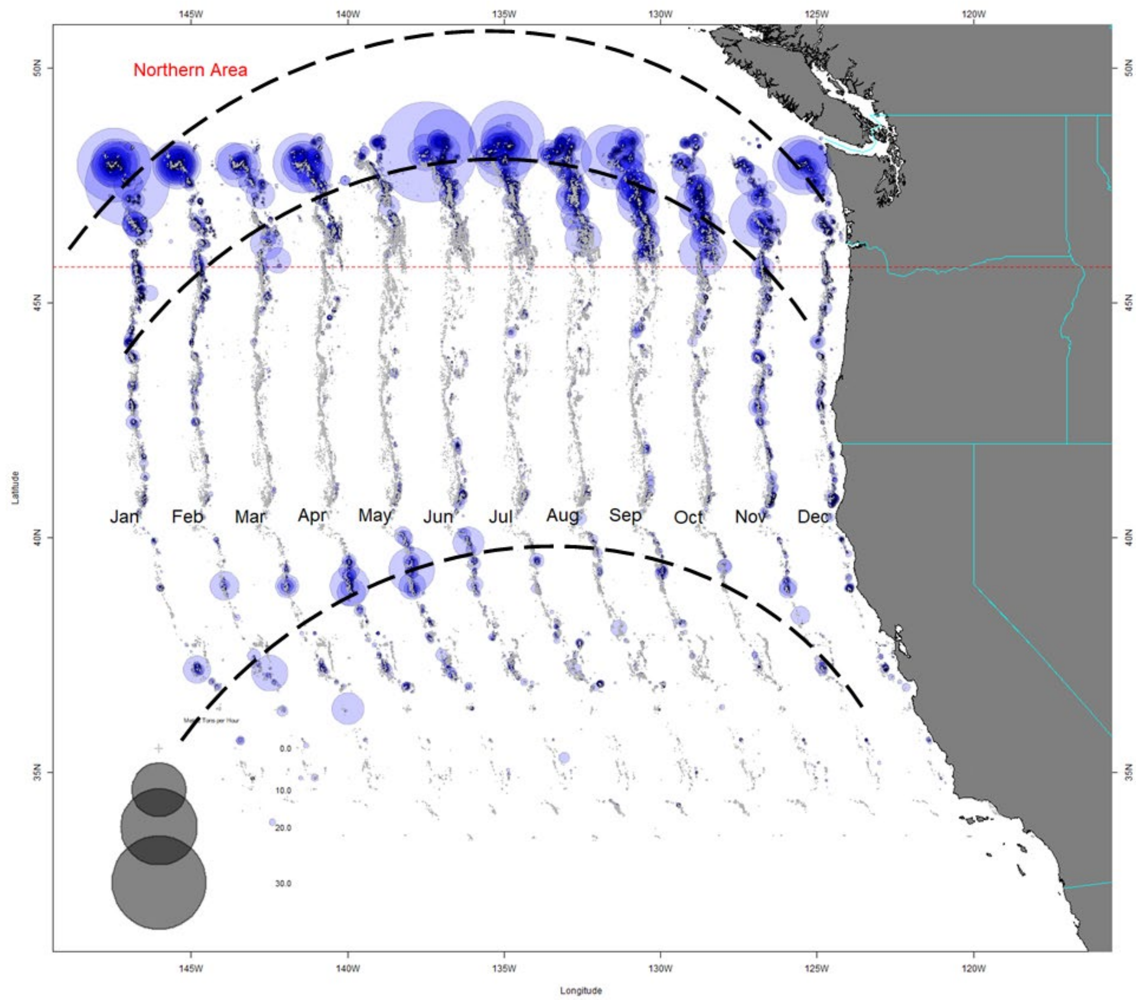

Figure A10. Map of catch rates for bottom trawl fishery hauls (as observed by WCGOP) by month with three potential migration curves shown with dashed lines.

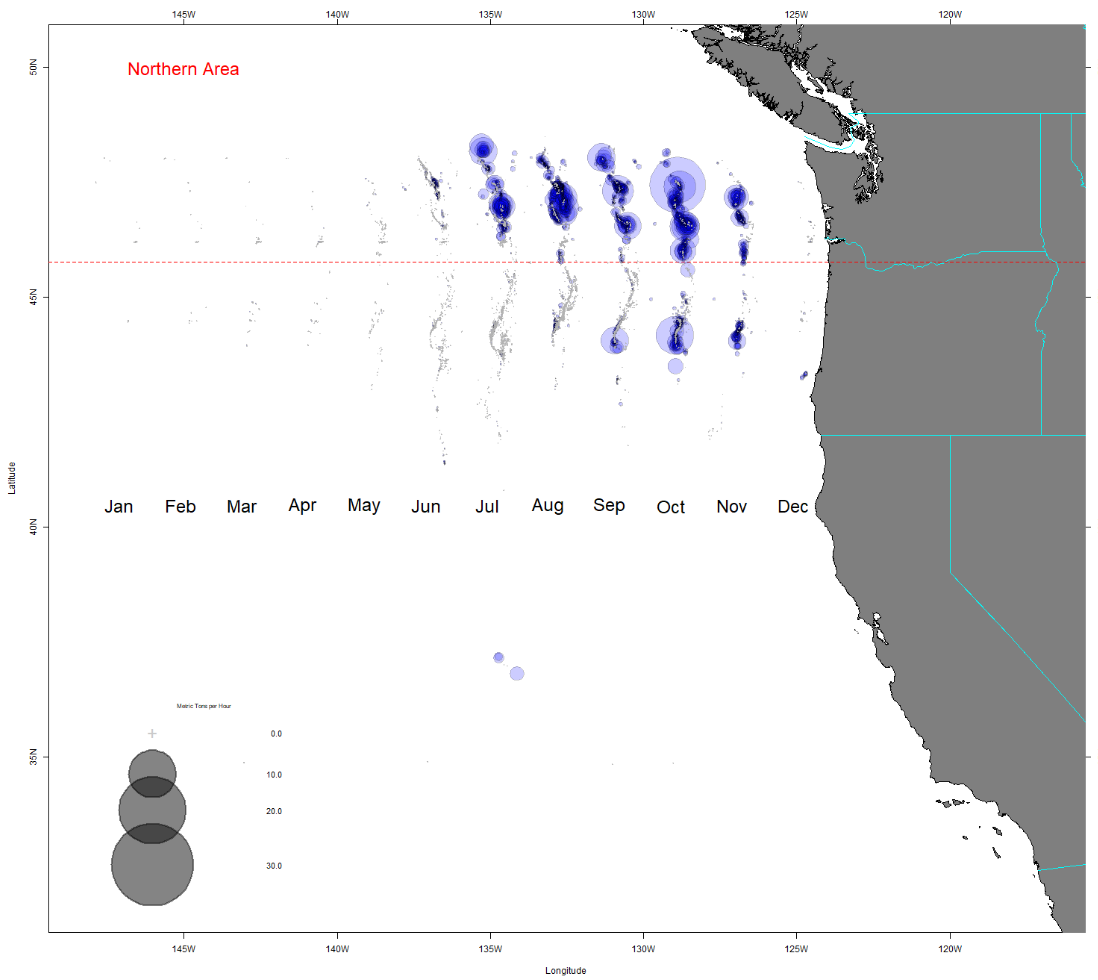

Figure A11. Map of catch rates for midwater trawl fishery hauls (as observed by WCGOP) by month (2002-2019 combined).

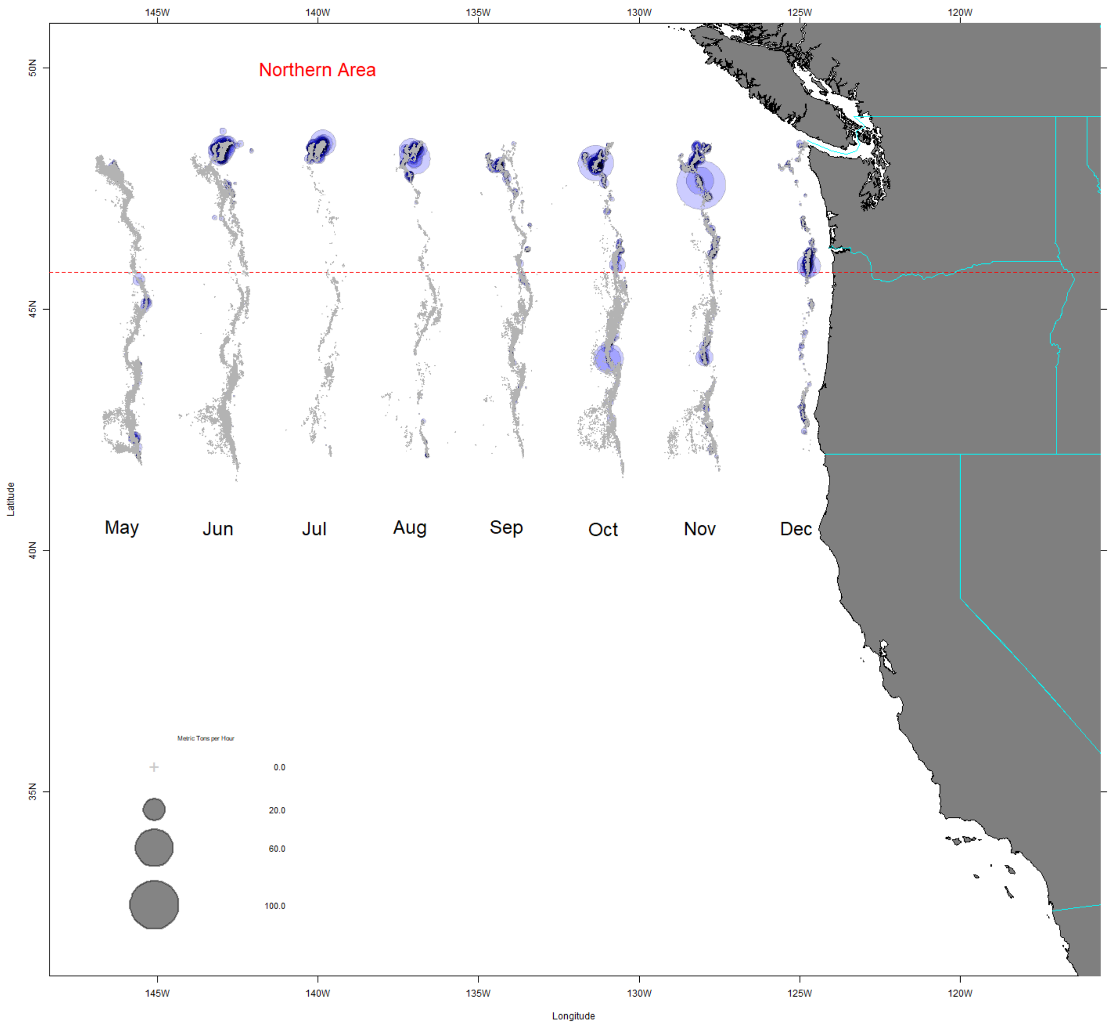

Figure A12. Map of catch rates for at-sea hake fishery hauls (as observed by ASHOP) by month.