Status of the Longnose Skate (*Raja rhina*)

off the continental US Pacific Coast in 2007

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EXECUTIVE SUMMARY

Stock

Longnose skates (*Raja rhina*) are found from Navarin Canyon in the Bering Sea and Unalaska Island in Alaska to Cedros Island, Baja California in Mexico. This assessment is for the population occupying the waters off California, Oregon and Washington, bounded by Canada in the north and Mexico in the south. Within this study area, the longnose skate population is treated as one stock, due to the lack of biological and genetic data supporting the presence of multiple stocks.

Catches

The longnose skate is not a commercially important target species. It is caught primarily as bycatch in trawl fisheries, where most are discarded. Although the landed catch of skates is documented through fish tickets, most records are for a combined-skate category. There are also apparent reporting inconsistencies with regard to the condition of landed skates (e.g., as whole fish or as wings). The extent to which landings in the combined-skate category were comprised by longnose skate is informed by limited periods of species-composition sampling in Oregon and Washington. Historical landed catch was reconstructed from variety of sources. Over the last 57 years, longnose skate landings ranged between 35 and 1,721 mt. Landings peaked in the mid-1990s, due to increased demand from Asian markets. Discards rates were estimated at 93% prior to 1995 and 53% after 1995, which corresponds to changes in skate markets in the mid-1990s.

Table ES-1. Recent landings (mt) for longnose skate by year and state.

Year	California	Oregon	Washington	Total (mt)
1997	779	771	171	1,721
1998	509	218	55	782
1999	518	562	97	1,177
2000	352	804	196	1,351
2001	380	410	71	860
2002	49	123	141	313
2003	74	629	145	848
2004	66	238	69	373
2005	55	508	51	615
2006	70	581	91	742

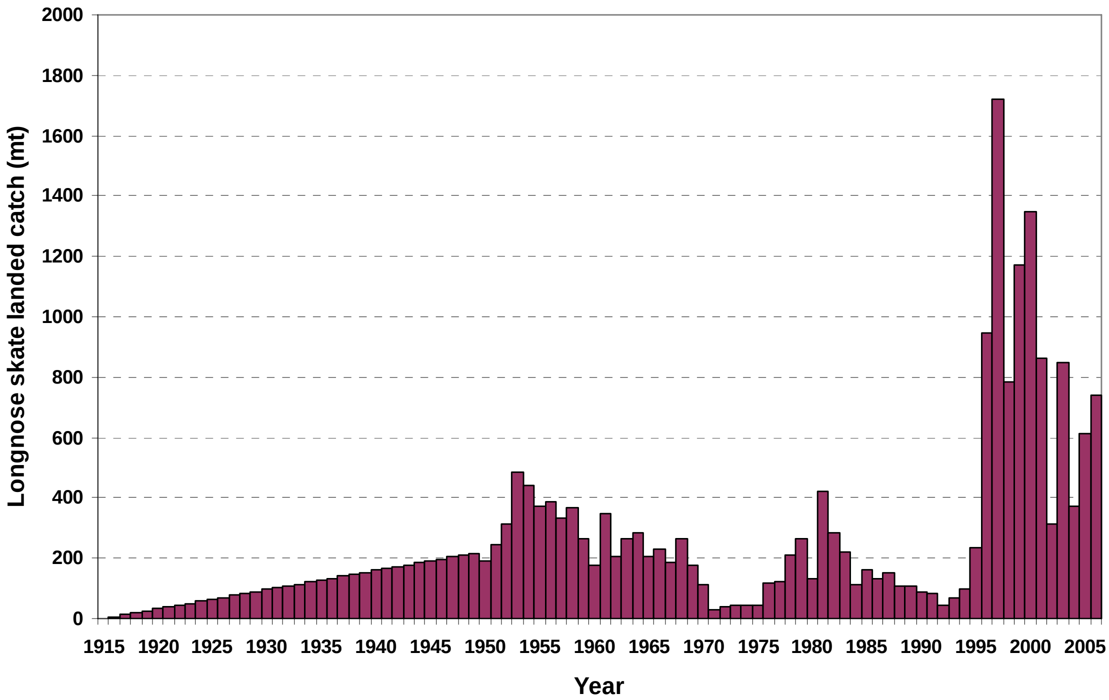

Figure ES-1. Reconstructed historical landings (mt) for longnose skate.

Data and Assessment

This is the first assessment for longnose skate on the U.S. West Coast. The Stock Synthesis 2 (version 2.00e) modeling program was used to conduct the analysis and to estimate model parameters and management quantities. Since there were no apparent differences found in biological and life history parameters as well as length and age frequencies between females and males, the assessment uses a single-sex model. The model starts in 1916, assuming an unfished equilibrium state of the stock in 1915. The assessment model includes one fishery that operates within the entire area of assessment. Fishery dependent data used in the assessment include combined-skate landings (1950-2006), fishery length compositions (1995-2006) and limited age data (2003-2004). Fishery independent data include biomass estimates (1980-2006) and length compositions (1997-2006) from four NMFS surveys conducted on the continental shelf and slope, as well as age data from one of the surveys (2003). The model uses discard data from Rogers and Pikitch's study (1986-1987), the Enhanced Data Collection Project (1996-1998), and the NMFS West Coast Groundfish Observer Program (2005).

Stock biomass

Using the base model, the unexploited level of spawning stock biomass for longnose skate is estimated to be 7,034 mt. At the beginning of 2007, the spawning stock biomass is estimated to be 4,634 mt, which represents 66% of the unfished stock level.

Table ES-2. Recent trend in longnose skate spawning biomass and depletion.

Year	Estimated spawning biomass (mt)	95% Confidence interval	Estimated depletion
1996	5,311	4,856-5,766	76%
1997	5,245	4,790-5,700	75%
1998	5,032	4,582-5,483	72%
1999	4,982	4,532-5,432	71%
2000	4,858	4,411-5,305	69%
2001	4,703	4,260-5,147	67%
2002	4,638	4,196-5,079	66%
2003	4,671	4,229-5,113	66%
2004	4,617	4,177-5,057	66%
2005	4,651	4,211-5,091	66%
2006	4,650	4,211-5,090	66%
2007	4,634	4,196-5,073	66%

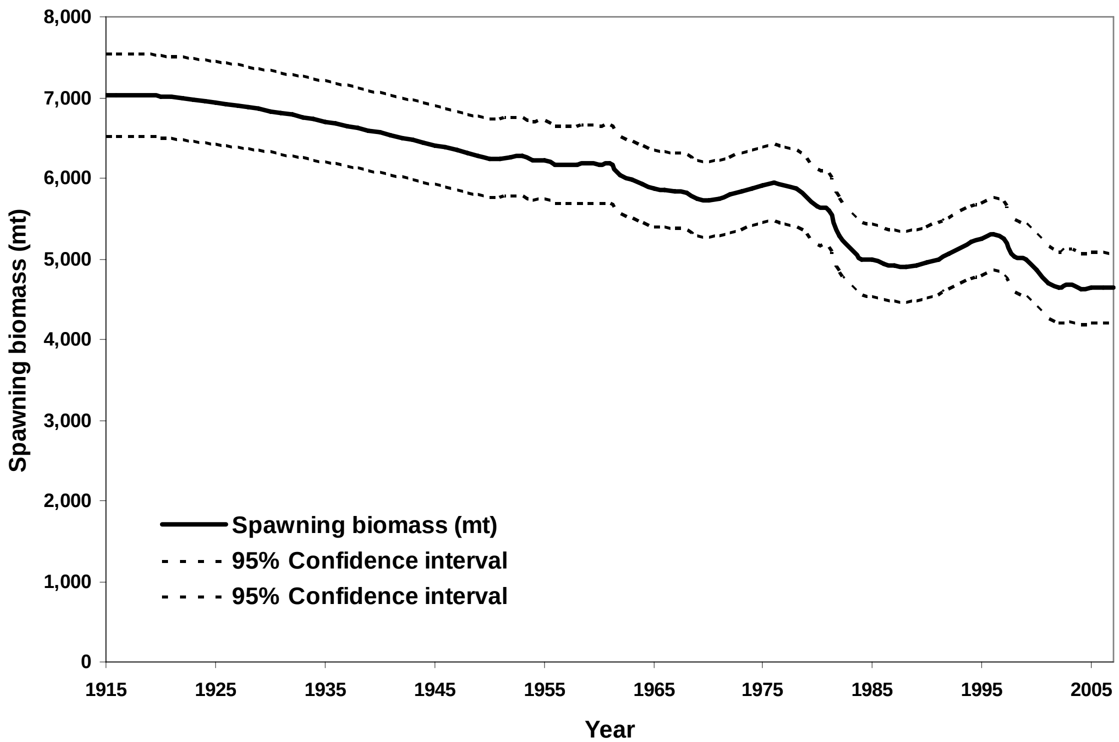

Figure ES-2. Estimated spawning biomass time-series with 95% confidence interval.

Recruitment

In the assessment, we used the Beverton-Holt model to describe the stock-recruitment relationship. Recruits were taken deterministically from the stock-recruit curve. The level of virgin recruitment R_0 was estimated to assess the magnitude of the initial stock size. Steepness of the stock-recruitment curve was fixed at a value of 0.4, to reflect the *K*-type reproductive strategy of the longnose skate.

Table ES-3. Recent estimated trend in longnose skate recruitment.

Year	Estimated recruitment (1000s)	95% Confidence interval
1996	13,778	12,745-14,811
1997	13,701	12,667-14,735
1998	13,448	12,414-14,482
1999	13,386	12,351-14,421
2000	13,231	12,195-14,267
2001	13,032	11,995-14,069
2002	12,945	11,908-13,982
2003	12,989	11,951-14,027
2004	12,918	11,880-13,956
2005	12,963	11,926-14,000
2006	12,962	11,925-13,999
2007	12,941	11,905-13,978

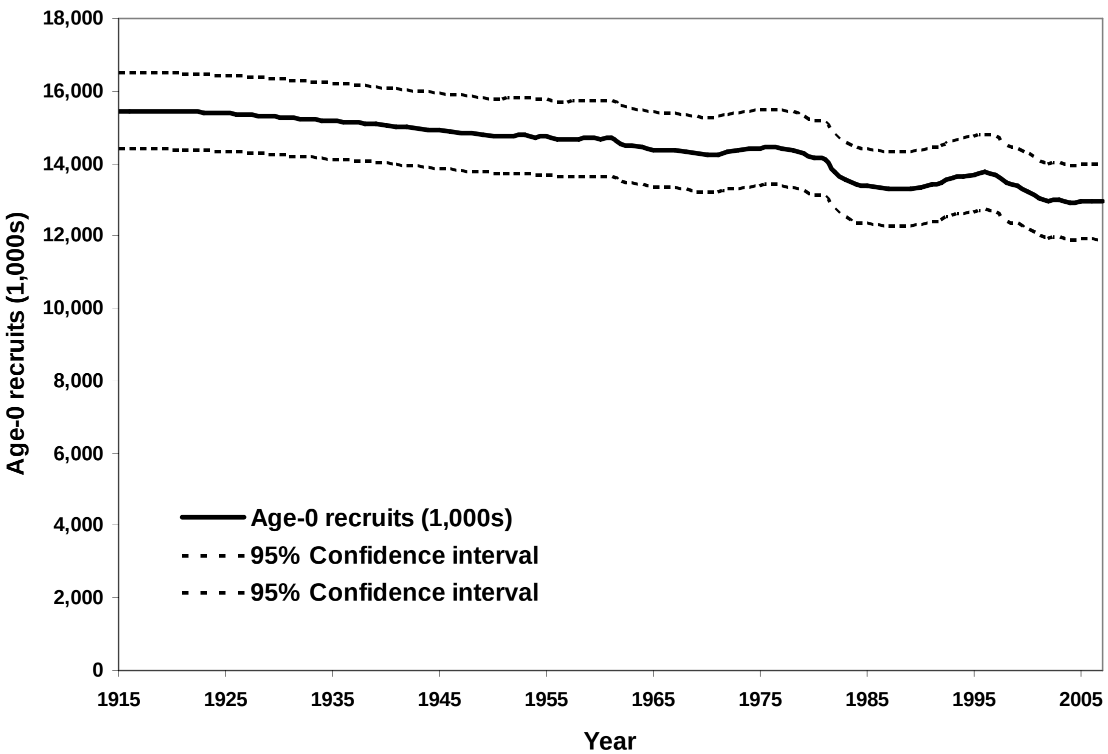

Figure ES-3. Estimated recruitment time-series with 95% confidence interval.

Reference Points

For the longnose skate, the management target is defined as 40% of the unfished spawning stock biomass ($SB_{40\%}$), which is estimated to be 2,814 mt (95% Confidence Interval: 2,608-3,019 mt) in the base model. The stock is declared overfished if the current spawning biomass is estimated to be below 25% of unfished level. The MSY-proxy harvest rate for longnose skate is SPR=F45%, which corresponds to an exploitation rate of 0.043. This harvest rate provides an equilibrium yield of 1,264 mt (95% Confidence Interval: 1,194-1,334 mt) at $SB_{40\%}$. The model estimate of maximum sustainable yield (MSY) is 1,268 mt (95% Confidence Interval: 1,198-1,338). The estimated spawning stock biomass at MSY is 2,626 mt (95% Confidence Interval: 2,433-2,819 mt). The exploitation rate corresponding to the estimated SPRmsy of F61% is 0.027.

Reference point results are calculated on both a per-recruit and total-recruits basis (Table ES-9). The total-recruits results take into account the spawner-recruitment relationship with the steepness as defined in the base model (*h*=0.4). Because of this low steepness and other reproductive characteristics of the stock, fishing at the target SPR of 45% is expected to reduce the spawning biomass to less than 12% of the unfished level over the long term. Conversely, fishing at a rate that would maintain spawning biomass near 40% of the unfished level would require a target SPR much higher than 45%. The Council's Scientific and Statistical Committee should consider the appropriateness of using the current proxy harvest rate for setting the Allowable Biological Catch for longnose skate.

Exploitation Status

The assessment shows that the stock of the longnose skate in the US West Coast is not overfished. Currently, the stock is at 66% of its unfished level. Historically, the exploitation rate for the longnose skate has been low. It reached its maximum level of 4.02 % in 1981. Currently, it is at the level of 1.25 %.

Table ES-4. Recent trend in longnose skate exploitation.

Year	Exploitation rate
1998	1.66%
1999	2.50%
2000	2.90%
2001	1.87%
2002	0.68%
2003	1.84%
2004	0.81%
2005	1.33%
2006	1.60%
2007	1.25%

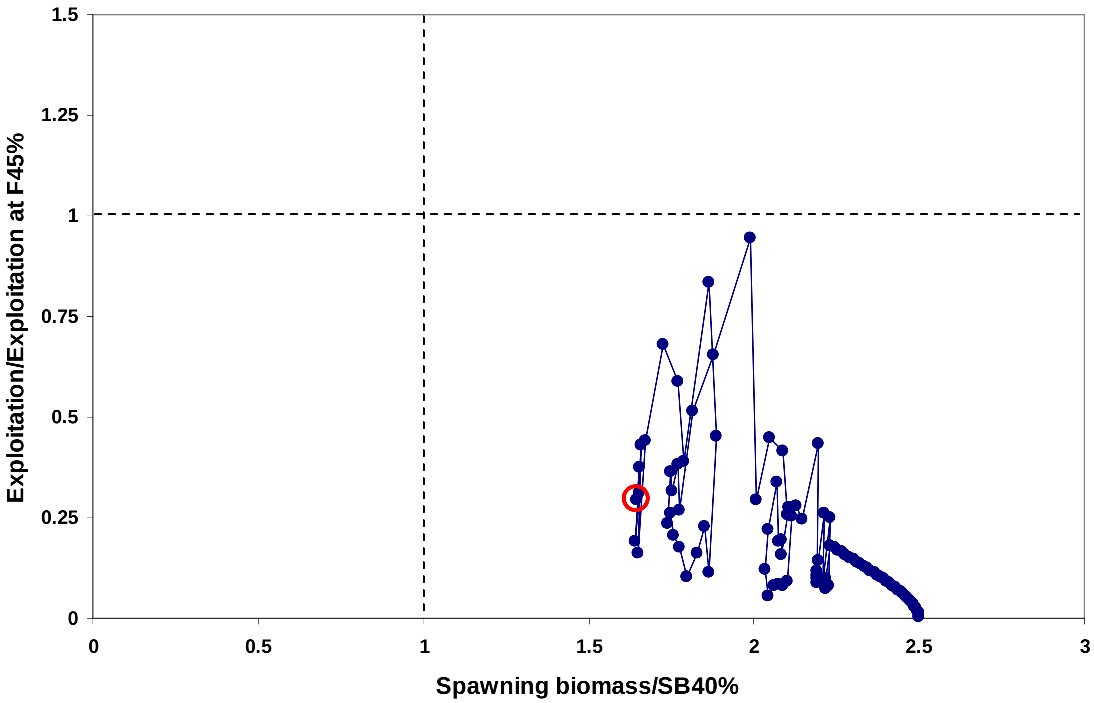

Figure ES-4. Exploitation rate and spawning biomass relative to their target values (circle indicates the point that corresponds to 2007).

Management

The longnose skate is grouped with other unrelated species ("Other Fish") for the purposes of specifying annual Allowable Biological Catches and Optimum Yields (OY). Combined landings of species within this category are typically well below the specified OY. As a result, landings of species in this category are not actively monitored throughout the year, nor have they been subject to trip-limit management. In most areas of the world, management of skates has generally been a low priority and where management and assessments are implemented, the available data are generally inadequate. The longnose skate, like other elasmobranches, presents an array of problems for fisheries management. Given the low economic value of skates, information about their fisheries and basic biology is scarce. However, skate life history characteristics, such as late maturity and low fecundity, make them more susceptible to overfishing than teleost fishes. Vulnerability of this group and the past history of elasmobranch fisheries collapses are general causes for concern. At the same time, the absence of a strong directed fishery for skates in this region, combined with reductions in trawl effort shoreward of 150 fm to promote rockfish stock rebuilding, reflect a different fishing environment than has characterized these other collapses.

Forecast

Projections of future catches, summary biomass, spawning biomass and stock depletion were made based on F45%, as well as the current rate of fishing mortality. The projected spawning biomasses are greater than 40% of the unfished level for both approaches. No

40:10 harvest control rule reductions were applied. Optimum yield catch values were equivalent to ABC values.

Table ES-5. 10-year forecast of longnose skate catch, summary biomass, spawning biomass and stock depletion estimated based on F45%.

Year	Total catch (mt)	Summary biomass (mt)	Spawning Biomass (mt)	Depletion
2009	3,428	71,184	4,673	66%
2010	3,269	68,833	4,424	63%
2011	3,128	66,836	4,195	60%
2012	3,006	65,135	3,985	57%
2013	2,902	63,676	3,794	54%
2014	2,816	62,403	3,621	51%
2015	2,745	61,264	3,465	49%
2016	2,686	60,211	3,327	47%
2017	2,638	59,208	3,206	46%
2018	2,598	58,226	3,100	44%

Table ES-6. 10-year forecast of longnose skate catch, summary biomass, spawning biomass and stock depletion estimated based on current rate of fishing mortality.

Year	Total catch (mt)	Summary biomass (mt)	Spawning Biomass (mt)	Depletion
2009	901	71,184	4,673	66%
2010	902	71,129	4,697	67%
2011	902	71,060	4,721	67%
2012	902	70,986	4,743	67%
2013	900	70,914	4,763	68%
2014	899	70,848	4,778	68%
2015	897	70,794	4,789	68%
2016	895	70,754	4,795	68%
2017	894	70,727	4,797	68%
2018	892	70,714	4,794	68%

Rebuilding Projection

Since the longnose skate stock is estimated to be above the overfished level, no rebuilding is required.

Unresolved Problems and Major Uncertainties

The major uncertainties for the assessment include uncertainties in the longnose skate catch history, particularly in proportion of longnose skate in combined-skate landings, discard and discard mortality rates, and Northwest Fishery Science Center (NWFSC) shelf-slope survey catchability Q. To address uncertainties related to longnose skate catches, alternative catch histories were developed, which reflect variations in proportion of longnose skate in combined-skate landings, as well as discard and discard mortality rates. These alternative histories include the base scenario, which was reconstructed using the best information available, along with “low” and “high” catch scenarios. To explore uncertainty regarding the estimation of the NWFSC shelf-slope survey Q, the base-case model (with Q fixed at 0.83) results were contrasted with “low” and “high” Q scenarios.

Alternative catch histories and *Q* values were used to define alternative states of nature and develop the decision table.

Decision Table

Three states of nature were defined based on the alternative longnose skate catch history and values of NWFSC shelf-slope survey *Q*. The base scenario uses the base catch history and base *Q* (*Q*=0.83), the "low" scenario uses the low catch history and low *Q* (*Q*=0.654), and the "high" scenario uses the high catch history and high *Q* (*Q*=1.046). Ten-year forecasts for each state of nature were calculated based on F45% for the base scenario. Ten-year forecasts were also produced with future catch fixed at the average amount (using the base catch history) for last three years (2004-2006) and at 150% of that three-year average. Under the "high" scenario, the F45% harvest rate is projected to reduce the spawning stock biomass below 40% of the unfished level within two years. In all other scenarios covered by the decision table, the spawning biomass remains above the target level throughout the 10-year projection period. The current rate of fishing mortality is significantly lower than F45% (current exploitation rate is 1.25%). Therefore, it is very unlikely that the stock, even under the "high" scenario will fall below 40% of its virgin state in the next 10 years.

Research and Data Needs

This assessment reflects a data-moderate to data-poor circumstance with respect to several influential model elements, including catch history, survey catchability, and some life history characteristics. Consequently, some critical assumptions were based on very 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) Genetic studies to determine stock structure of longnose skate in the waters off the US Pacific Coast;
2) Age-determination and age-validation studies to improve the understanding of growth and size-at-age relationships;
3) Studies on life history characteristics, especially those related to maturity and reproduction, to address uncertainties in estimating longnose skate productivity;
4) Studies of longnose skate behavior and distribution to provide more precise estimates of abundance from the surveys;
5) Studies of survival rates of discarded longnose skate, especially with trawl gear, so that total fishing mortality can be estimated more precisely;
6) Studies of longnose skate catchability by survey gear types.

It is also very important to continue to conduct species-specific identification in fishery and monitor discard of the longnose skate to improve the accuracy of fishery catch data.

Table ES-7. Decision table based on three states of nature, defined based on alternative catch histories and levels of NWFSC shelf-slope survey catchability *Q*.

		Low Q (Q=0.654) Low historical catch			Q=0.83 BASE			High Q (Q=1.046) High historical catch		
Forecast	**Year**	**Total catch (mt) (landings and discard mortality)**	**SSB (mt)**	**Depletion**	**Total catch (mt) (landings and discard mortality)**	**SSB (mt)**	**Depletion**	**Total catch (mt) (landings and discard mortality)**	**SSB (mt)**	**Depletion**
F45% for base scanario 40-10	2009	3,428	5,855	80%	3,428	4,673	66%	3,428	4,021	41%
	2010	3,269	5,577	76%	3,269	4,424	63%	3,269	3,854	39%
	2011	3,128	5,321	72%	3,128	4,195	60%	3,128	3,699	37%
	2012	3,006	5,087	69%	3,006	3,985	57%	3,006	3,555	36%
	2013	2,902	4,874	66%	2,902	3,794	54%	2,902	3,422	35%
	2014	2,816	4,681	64%	2,816	3,621	51%	2,816	3,298	33%
	2015	2,745	4,508	61%	2,745	3,465	49%	2,745	3,185	32%
	2016	2,686	4,353	59%	2,686	3,327	47%	2,686	3,085	31%
	2017	2,638	4,217	57%	2,638	3,206	46%	2,638	2,997	30%
	2018	2,598	4,098	56%	2,598	3,100	44%	2,598	2,923	30%
Average landings and discard mortality for base scanario 2004-2006	2009	899	5,855	80%	899	4,673	66%	899	4,021	41%
	2010	899	5,850	80%	899	4,697	67%	899	4,125	42%
	2011	899	5,845	80%	899	4,721	67%	899	4,228	43%
	2012	899	5,840	80%	899	4,744	67%	899	4,327	44%
	2013	899	5,832	79%	899	4,764	68%	899	4,418	45%
	2014	899	5,823	79%	899	4,779	68%	899	4,500	46%
	2015	899	5,810	79%	899	4,790	68%	899	4,571	46%
	2016	899	5,795	79%	899	4,796	68%	899	4,630	47%
	2017	899	5,777	79%	899	4,797	68%	899	4,679	47%
	2018	899	5,757	78%	899	4,794	68%	899	4,720	48%
50% increase in average landings and discard mortality for base scanario 2004-2006	2009	1,349	5,855	80%	1,349	4,673	66%	1,349	4,021	41%
	2010	1,349	5,801	79%	1,349	4,649	66%	1,349	4,077	41%
	2011	1,349	5,749	78%	1,349	4,624	66%	1,349	4,130	42%
	2012	1,349	5,696	78%	1,349	4,599	65%	1,349	4,179	42%
	2013	1,349	5,643	77%	1,349	4,572	65%	1,349	4,220	43%
	2014	1,349	5,590	76%	1,349	4,542	65%	1,349	4,253	43%
	2015	1,349	5,536	75%	1,349	4,509	64%	1,349	4,277	43%
	2016	1,349	5,482	75%	1,349	4,475	64%	1,349	4,292	43%
	2017	1,349	5,429	74%	1,349	4,439	63%	1,349	4,300	44%
	2018	1,349	5,377	73%	1,349	4,402	63%	1,349	4,303	44%

Table ES-8. Summary of recent trends in longnose skate exploitation and estimated population levels.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Landings (mt)	782	1,177	1,351	860	313	848	373	615	742	*576
Estimated Discards (mt)	438	659	757	482	175	475	209	344	415	323
Estimated Total Catch (mt)	1,220	1,835	2,108	1,342	488	1,323	582	959	1,157	*899
ABC (mt)										
OY * (if different from ABC) (mt)										
SPR	74.28%	64.22%	59.83%	71.03%	87.96%	71.56%	85.99%	78.42%	74.81%	79.65%
Exploitation Rate (total catch/summary bi	1.66%	2.50%	2.90%	1.87%	0.68%	1.84%	0.81%	1.33%	1.60%	1.25%
Summary Age 2+ Biomass (B) (mt)	72,877	72,599	71,802	70,844	70,671	71,272	71,027	71,445	71,439	71,217
Spawning Stock Biomass (*SB*) (mt)	5,032	4,982	4,858	4,703	4,638	4,671	4,617	4,651	4,650	4,634
Uncertainty in Spawning Stock Biomass estimate	4,582-5,483	4,532-5,432	4,411-5,305	4,260-5,147	4,196-5,079	4,229-5,113	4,177-5,057	4,211-5,091	4,211-5,090	4,196-5,073
Recruitment at age 0	13,448	13,386	13,232	13,032	12,945	12,989	12,918	12,963	12,962	12,941
Uncertainty in Recruitment estimate	12,414-14,482	12,351-14,421	12,195-14,267	11,995-14,069	11,908-13,982	11,951-14,027	11,880-13,956	11,926-14,000	11,925-13,999	11,905-13,978
Depletion (SB/SB0)	71.54%	70.82%	69.06%	66.86%	65.93%	66.40%	65.64%	66.12%	66.13%	66.44%
Uncertainty in Depletion estimate									64.15%-68.11%	64.46%-68.41%

* indicates values calculated as the average for the last three years (2004-2006)

Table ES-9. Summary of longnose skate reference points.

	Point estimate	95% confidence interval
Unfished Spawning Stock Biomass (SB_0) (mt)	7,034	6,521-7,548
Unfished Summary Age 2+ Biomass (B_0) (mt)	90,955	
Unfished Recruitment (R_0) at age 0	15,454	14,403-16,505
Reference points based on $SB_{40\%}$		
MSY Proxy Spawning Stock Biomass ($SB_{40\%}$)	2,814	2,608-3,019
SPR resulting in $SB_{40\%}$ ($SPR_{SB40\%}$)	62.50%	62.4999%-62.500059%
Exploitation rate resulting in $SB_{40\%}$	2.57%	N/A
Yield with $SPR_{SB40\%}$ at $SB_{40\%}$ (mt)	1,264	1,194-1,334
Reference points based on SPR proxy for MSY		
Spawning Stock Biomass at SPR (SB_{SPR})(mt)	844	782-906
$SPR_{MSY\text{-}proxy}$	45%	
Exploitation rate corresponding to SPR	4.26%	N/A
Yield with $SPR_{MSY\text{-}proxy}$ at SB_{SPR} (mt)	787	744-831
Reference points based on estimated MSY values		
Spawning Stock Biomass at MSY (SB_{MSY}) (mt)	2,626	2,433-2,819
SPR_{MSY}	60.84%	60.80%-60.86%
Exploitation Rate corresponding to SPR_{MSY}	2.71%	N/A
MSY (mt)	1,268	1,198-1,338

INTRODUCTION

General information about the species

Skates are the largest and most widely distributed group of batoid fish with approximately 245 species ascribed to two families (McEachran 1990, Ebert and Compagno 2007). Skates are benthic fish that are found in all coastal waters but are most common in cold temperatures and polar waters (Ebert and Compagno 2007).

There are about eleven species of skates from either of three genera (*Amblyraja*, *Bathyraja* and *Raja*) present in the Northeast Pacific Ocean off California, Oregon and Washington (Ebert 2003). Of that number, just three species (longnose skate *Raja rhina*, big skate *Raja binoculata*, and sandpaper skate *Bathyraja interrupta*) make up over 95% of survey catches in terms of biomass and numbers, with the longnose skate leading in both categories (62% of biomass and 56% of numbers). Species compositions of fishery landings also show that longnose skate dominates commercial catches. On average, longnose skate represents 75% of total skate landings in Oregon for the last 12 years and 45% in Washington for the last three years. There are no species composition data available for commercial landings in California, but anecdotal evidence suggests that the majority of skates landed there are longnose skates.

The longnose skate or *Raja rhina* belongs to the family Rajidae (skates), the order Rajiformes (skates and rays), and the subclass Elasmobranchii (cartilaginous fish) that includes skates, rays and sharks (Compagno1999, McEachran and Aschliman 2004). Like other skates, longnose skate is a dorso-ventrally compressed animal with large pectoral fins, often called “wings”. The longnose skate received its name because of the stiff, long, and acutely pointed snout, which distinguishes it from other skate species. (Compagno 1999). A photograph of the longnose skate is shown in Figure 1.

The distribution of the longnose skate is limited to the eastern Pacific Ocean. It is found from southeastern Bering Sea to just below Punta San Juanico, southern Baja California, and Gulf of California at depths of 9-1,069 m (Love et al. 2005). Longnose skates do not exhibit a size-specific pattern in distribution relative to bottom depth; average fish size does not vary greatly with depth (Figure 2).

Currently, there is no information available that indicates the existence of multiple breeding units in the Northeast Pacific Ocean. Several tagging studies have found that elasmobranchs, such as sharks and skates, can undertake extensive migrations within their geographic range (Martin and Zorzi 1993, McFarlane and King 2003). This behavior suggests the likelihood that there is a high degree of genetic mixing within the population, across its range. As a result, the longnose skate population off California, Oregon and Washington is modeled in this assessment as a single stock. A map depicting the scope of the assessment is presented in Figure 3.

Life history of longnose skate

The life history of skates is characterized by late maturity, low fecundity and slow growth to large body size (King and McFarlane 2003, Moyle and Cech 1996, Walker and Hislop 1998). Skates invest considerable energy in developing a few large, well-protected embryos. These characteristics are associated with a *K*-type reproductive strategy, as opposed to *r*-type strategy, wherein reproductive success is achieved by high productivity and early maturity (Hoenig and Gruber 1990).

The longnose skate is oviparous (egg-laying) organism. After fertilization, the female forms tough, but permeable egg cases that surround eggs and then deposits these egg cases onto the sea floor at daily to weekly intervals for period of several months or longer (Hamlet and Koob 1999). The eggs within egg cases incubate for several months in a benthic habitat. Inside the egg cases, the embryos develop with nourishment provided by yolk. The longnose skate is known to have only a single embryo per egg case (David Ebert, Moss Landing Marine Laboratories, pers. com.). When the yolk is depleted and the juvenile is fully formed, it exits the egg case. Once hatched, the young skate is similar in appearance to an adult, but smaller in size. Upon reaching maturity, skates enter the reproductive stage, which lasts for the remainder of their lives (Frisk et al 2002, Pratt and Casey 1990). On average off the continental US Pacific Coast, female longnose skates mature between 11-18 years, which corresponds to 75-125 cm in total length (Thompson 2006). The life span of the longnose skate is not well known, although individuals up to 23 years of age have been found (Thompson 2006). In our study area, longnose skates attain a maximum length of about 145 cm, although individuals as large as 180 cm have been reported (Thompson 2006).

The reproductive cycle of oviparous skates has been observed for a few species but not for longnose skate. These studies indicate that egg production generally occurs throughout the year although there have been some instances where seasonality in egg laying was observed (Hamlett and Koob 1999). Information on fecundity of longnose skate is extremely limited. Holden (1974) found that species of family *Rajidae* are the most fecund of all elasmobranches and can lay 100 egg cases per year, although eggs may not be produced every year. Frisk et al. (2002) estimated that annual fecundity for skates similar in size with longnose may be less than 50 eggs per year; however, those eggs exhibit high survival rates due to the large parental investment. Overall, little is known about breeding frequency, egg survival, hatching success and other early life history characteristics of the longnose skate.

Fishery off the US west coast

Historically, skates in general, and longnose skate in particular, have not been high-priced fishery products. They are taken mostly as bycatch in other commercially important fisheries (Bonfil 1994). Although skates are caught in almost all demersal fisheries and areas off the U.S. West Coast, the vast majority (almost 97%) are caught with trawl gear. Figure 4 shows the distribution of skate landings among gears, averaged over the last 25 years.

Landing records indicate that skates have been retained on the U.S. Pacific Coast at least since 1916 (Martin and Zorzi 1993). Little is known about the species composition of West Coast skate fisheries, particularly prior to 1990. With few exceptions, longnose skate landings have been reported, along with other skate species, under the market category “unspecified skates.” In recent years, the species composition of this market category has been sampled by state port samplers in Oregon and Washington.

Historically, only the skinned pectoral fins or “wings” were sold, although a small portion of catch would be marketed round (whole). The wings were cut onboard the boat and the remainder discarded. Currently, West Coast skates are marketed both whole and as wings. Skates wings are sold fresh or fresh-frozen, as well as dried or salted and dehydrated, for sale predominantly in Asian markets (Bonfil 1994, Martin and Zorzi 1993). There is no information to suggest change in skate markets prior to the mid 1990s. However, it appears that the demand for whole skates did increase greatly during the mid-1990s, as evidenced by the increase in the number of trips where skates were landed (Figure 5). While skates were encountered predominantly as bycatch previously, landings data from this period reveal greater targeting of skates by some vessels. After a few years, the whole-skate market cooled due to downturns in Asian financial markets (Peter Leipzig, Fishermen's Marketing Association, pers. com.).

Fishery and assessment off Alaska and Canada

In Alaska, skates were primarily taken as bycatch in both longline and trawl fisheries until 2003 when a directed skate fishery developed in the Gulf of Alaska. Longnose skates, as well as big skates, comprise the majority of the skate biomass in the Gulf of Alaska. In 2003 skate species in the Gulf of Alaska, and the Bering Sea and Aleutian Islands were assessed as a group rather than as separate species. In 2005 the skate assessments were updated, with the recommendation that no directed fisheries for skates be conducted in the Gulf of Alaska due to high incidental catch in groundfish and halibut fisheries. Also, the area-specific Allowable Biological Catches for big and longnose skates were recommended (Gaichas et al. 2003, Matta et al. 2006).

In Canada historic information regarding skate catches goes back to the 1950’s. Prior to 1990’s skates were taken mostly as bycatch and landings were reported as part of a skate complex (not by species). As with the West Coast, the trawl fishery is responsible for the largest amount of bycatch. Skate catches off British Columbia accelerated in the early 1990’s, partly due to emerging Asian markets. Since 1996, longnose skate has been targeted by the B.C. trawl fishery and, as a result, catches have been more accurately reported. A longnose skate assessment has not been done for B.C., but in 2001 a review of elasmobranch biology, fisheries, assessment, and management was conducted to assess the current state of knowledge and to examine possible methods for assessing elasmobranch species, including longnose skates (Benson et al. 2001).

Management

On the West Coast, longnose skate has been grouped with other species in an “Other Fish” category, for purposes of setting Allowable Biological Catches and Optimum Yields (OY). Since landings are routinely well below OYs for this category, trip limits have not been used for inseason management. In most areas of the world, management of skates has been a low priority, and where management and assessments are implemented, the available data are generally inadequate (Shotton 1999, Sosebee 1998). The longnose skate, like other elasmobranches, present an array of potential problems for fisheries management. Skates’ life history characteristics make them more susceptible to overfishing than teleost fishes. Examples of skate overexploitation have been already observed in several areas of the world (Brander 1981, Casey and Myers 1998, Walker and Hislop 1998). However, given the low economic value of skates, information about their fisheries and even their basic biology is scarce, patchy and scattered (Bonfil 1994).

The vulnerability of these species, combined with past collapses of elasmobranches fisheries elsewhere, underscores the importance of ascertaining the status of longnose skate on the West Coast.

ASSESSMENT

DATA

For this assessment we used the following data sources: (1) commercial landings (1950-2006), (2) fishery biological data (1995-2006), (3) NWFSC slope survey (1999-2002), (4) NWFSC shelf-slope survey (2003-2006), (5) AFSC shelf (triennial) survey (1980-2004), and (6) AFSC slope survey (1997-2001). These data sources are divided into two major categories: fishery-dependent and fishery-independent data. Summaries of the fishery-dependent and fishery-independent data used in this assessment, by source and year, are presented in Tables 1 and 2, respectively.

Fishery dependent data

Landed catch

Historically, landed catch of longnose skate has been reported under the market category "unspecified skates" along with other skate species. Hence, skate landings records, themselves, are not species-specific. In order to reconstruct landed catch of longnose skate we first, reconstructed the historical landings of "unspecified skates" market category, and then estimated the proportion of the longnose skate within this category.

To reconstruct the time series of combined-skate landed catch, we used several data sources that included both published reports and databases. The most recent and detailed information, for the period between 1981 and 2006, was obtained from the Pacific Fisheries Information Network database or PacFIN (Daspit et al. 1997). For the period between 1950 and 1980, combined-skate landings were obtained from annual publications of Fisheries Statistics of US. From historical data, we excluded all skate catches landed in any other areas, except for five INPFC areas covered by this assessment (these five INPFC areas included US Vancouver, Columbia, Eureka, Monterey and Conception). Overall combined-skate landings between 1950 and 2006 are shown in Figures 6.

In recent years, the Oregon and Washington Department of Fish & Wildlife (ODFW and WDFW) have started to collect species compositions of the "unspecified skates" market category. From ODFW and WDFW we obtained data for species compositions of skate catches landed in Oregon in 1995-2006 and in Washington in 2004-2006 respectively. No species-specific information was available for California landings.

To estimate the proportion of longnose skates within the "unspecified skates" market category between 1950 and 2006, we used data from ODFW and WDFW for years when skate species compositions were available. For other relatively recent (since 1981) years/areas, species-composition data from the NMFS shelf (triennial) survey, conducted principally by the Alaska Fisheries Science Center (AFSC), were used to represent species proportions in the fisheries. This survey was conducted every third year from 1980 to 2004. For each of these years, the survey's proportion of total skate catch comprised by longnose skates was calculated for the area off each state. These proportions were applied directly to the commercial landings data from the same year. For years in which the survey was not conducted, the proportions of longnose skate were estimated using a linear function connecting the two closest available data points. The final percentages of longnose skate that were applied to generic skate landings since 1981, by year and state, are shown in Table 3. For the period between 1950 and 1980, when we did not have any survey catches available, we applied the overall average percentage of the longnose skate within the "unspecified skates" market category (62%) for the last 25 years. The resultant time series of longnose skate landed catch for the years 1950-2006 are shown in Figure 7. These time series show the increase in landings in the mid-1990's, which corresponds to the time of increased demand from the Asian skate market.

Gear

As a bycatch species, skates have been caught on the West Coast by a variety of gears. The vast majority (almost 97%), however, are caught in trawl gear (Figure 4). Consequently, this assessment focuses on the catch of longnose skate by the trawl fishery. Other fisheries are assumed to have the same fishery characteristics and selectivity.

Condition code

As described above, most skates have been landed as either "wings" or "round". PacFIN records indicate that skates were landed as wings, round, alive, dressed (head on), dressed (general), dressed (head off), and dressed (head and tail off). To be able to convert landed weight into round weight correctly, we discussed the ways in which skates were landed with representatives of the State agencies, who helped us refine the use of condition code information. For example, we discovered that in Oregon, the condition code "dressed" was used for "wings" because, at the time when differentiating skate wings was initiated, there were no available new codes to be used. For Washington, PacFIN data also included "dressed" records which were actually "wings." In California, prior to 1995, the only condition code used to describe how skates were landed was "wings" (Gerry Kobylinski, California PacFIN Coordinator, pers. com.) although PacFIN data contain several condition codes for this period.

Conversion factor

Since "wings" comprise only a portion of total skate body, state agencies use a conversion factor to convert landed weight into round weight. Based on research conducted by ODFW a conversion factor of 2.6 is used for Oregon (Johnson and Hosie 1996). Other states relied upon literature reviews to determine their conversion factors. Currently, Washington uses conversion factor of 3, and California 3.1 (prior to this year, California was using the value of 4.3).

Discard

Discard rate

For this assessment, we used three sources of information to characterize fishery discards. The first source was a discard study in Oregon and Washington in 1986 and 1987 (Rogers and Pikitch 1992). This study found that 93% of the trawl fishery longnose skate catch (by weight) was discarded. Marketing problems were indicated as the main reason for the skate discard. The second source of discard data was the Enhanced Data Collected Project (EDCP), conducted by ODFW between 1996 and 1998 in the waters off Oregon. The discard rate for skates was 53% on trips included in this project, although most observed trips were directed at deep-water species. The third source of discard data is the NMFS West Coast Groundfish Observer Program (WCGOP), which provided discard rate data for 2005. As in the EDCP observations, analysis of WCGOP data indicates that the discard rate for the skates in 2005 was 53%. None of the sources collected size-specific discard information.

Since the rate of skate discard is highly dependent on market acceptance (Rogers and Pikitch 1992), we modeled discard mortality for two time periods – one is before 1995, and the second is from 1995 till present time, when skate market demands increased. In the base model, for the first period we assumed the discard rate of 93% estimated in Rogers and Pikitch (1992); for the second period we used the discard rate of 53% estimated from EDCP and WCGOP data.

Discard mortality

To date, no studies have been conducted to estimate the mortality of discarded longnose skate or any other skate. In tagging studies conducted in Canada (Gordon McFarlane, Pacific Biological Station, Fisheries and Oceans Canada, pers. com.), tagged skates were recovered several times in trawl surveys, indicating that skates can survive trawl capture and on-deck sorting time. Anecdotal evidence from commercial fisheries also indicates that skates are generally durable, and can handle capture and release well. However, many factors, such as trawl time, handling techniques, and time spent on the deck certainly affect skate survival. For the base model in this assessment, we assumed that 50% of discarded skates die, and performed a sensitivity analyses on this assumption.

Biological data

Very limited biological data on longnose skate have been collected over the years. For this assessment, biological information was provided primarily by ODFW and WDFD.

Size

Size-composition data was provided by ODFW for Oregon catches landed between 1995 and 2006 and by WDFW for Washington catches landed between 2004 and 2006. No size-composition data were available for California landings. In the assessment we combined the data from Oregon and Washington and used it to represent the size compositions of the longnose skate caught in coast-wide commercial fishery. Sizes of longnose skates were recorded as total length (TL) from the tip of the snout to the end of the tail. TL of longnose skates in fishery catches ranged from 40 to 140 cm, except for two fish with recorded TLs of 165 and 180 cm. These two lengths are considerably larger than any recorded longnose skates in the area, and were subsequently excluded from our analysis, due to the likelihood that they represent data entry errors. Size data were aggregated into 5-cm length bins. Fishery skate size compositions for longnose skate, by year, are shown in Figure 8.

Age

No fishery age-composition data are available for longnose skate. Thompson (2006) conducted a study on age and growth of longnose skate as a part of her MS research. For this study, she drew two small samples of longnose skate from catches landed in Oregon (one in 2003 and one in 2004). Since elasmobranches do not have otoliths, the most common structure used to age cartilaginous species is vertebrae (Cailliet and Goldman 2004). The ages of longnose skates collected in these samples were identified through the analysis of annual rings, or "annuli," on the vertebra centra. Since the sample sizes of Thompson's data were small (N=38 for 2003 and N=102 for 2004) and represented only a small portion of the study area of the assessment, we used these data only to calculate mean size-at-age in the model and not to describe age composition of fisheries data.

Fishery independent data

In this assessment we used four surveys conducted by NMFS as fishery-independent data sources. These surveys are the NWFSC slope and shelf-slope surveys, and the AFSC shelf (triennial) and slope surveys. Details on latitudinal and depth ranges of these surveys, by year, are presented in Table 4. Below we give an overview of each survey and describe data that were used in our assessment.

NWFS slope survey

The NWFSC slope survey was conducted annually from 1999 to 2002. Survey methods are described in Keller et al. (2006). This survey was conducted between 35^o and 48^{o}07' N Latitudes, encompassing all of the US Vancouver, Columbia, Eureka, Monterey INPFC areas, and a portion of the Conception area. The survey covered depths from 183 to 1280 m (100-700 fathoms).

Biological information

No biological data on longnose skate was collected during this survey.

NWFSC shelf-slope survey

The NWFSC shelf-slope survey was conducted annually from 2003 to 2006. Survey methods are described in Keller et al. (2007). This survey ranged from 32^{o}34' to 48^{o}22' N Latitudes, encompassing all five INPFC areas included in the scope of this assessment (US Vancouver, Columbia, Eureka, Monterey, Conception). The survey covered depths between 55 and 1280 m (30-700 fathoms), which is almost the entire depth distribution of longnose skate.

Biological information

Size

Size data were collected in all years. In 2003, 2004, and 2005, longnose skates were measured in total length (TL), while in 2006 in disc width (DW), which is the distance across pectoral fins. To convert DW data to TL, we used the conversion equation, derived from the AFSC slope survey in 1999, when a sample of 457 longnose skates was measured in both TL and DW. Figure 9 shows the relationship between TL and DW for longnose skate obtained from that study ($TL = 7.36 + 1.41 \cdot DW$, r^2=0.99). Size of longnose skates collected in this survey ranged from 15 to 140 cm.

Age

A limited-sample of longnose skate age structures (vertebra) was collected from 2003 NWFSC shelf-slope survey and processed by Thompson (2006) as a part of her MS research. The ages of longnose skates were identified through the analysis of annuli on the vertebra centra of skates. The degree of age-reader agreement was explored through comparing the readings of the same age structures by two other readers (Thompson 2006). Although this provides some information regarding the precision of the age determinations, they have not been validated with regard to potential bias.

AFSC shelf (triennial) survey

The AFSC shelf (triennial) survey was conducted every third year between 1977 and 2004 (in 2004 this survey was conducted by the NWFSC). Survey methods are described in Weinberg et al. (1994), Zimmermann et al. (1994), Wilkins et al. (1998) and Winberg et al. (2002). Over this period, the survey area varied in depth and latitudinal range (Table 4). In order to utilize as many years as possible, we used data only from the common depth and latitude range for analysis. Our analysis included data from four INPFC areas (Monterey, Eureka, Columbia and U.S. Vancouver) and depths between 55 and 366 meters.

Biological information

Longnose skate size data were collected in 1998, 2001 and 2004. In 1998, sample size was very small and was not included in our analysis. In 2001 and 2004, individuals were measured in total length (TL). Size of longnose skates collected in this survey ranged from 15 to 145 cm. No age data for longnose skate was available for this assessment.

AFSC slope survey

The AFSC slope survey was initiated in 1984. The survey methods are described in Lauth (1999, 2000). Prior to 1997, this survey was conducted in different latitudinal ranges in each year (Table 4). Therefore, in this assessment we used data from surveys conducted in 1997, 1999, 2000 and 2001, which were consistent in latitudinal range (from 34^{o}30’ to the U.S.-Canadian border) and depth (183-1280 m; 100-700 fathoms).

Biological information

Longnose skate size data were collected in 1997, 1999, 2000 and 2001. In 1997, longnose skates were measured in disc width (DW), while all other years (1999, 2000 and 2001) were measured in total length (TL). In 1999, longnose skates (457 individuals) were measured in both TL and DW. These data were used as the basis for converting 1997 DW data to TL. Figure 9 shows the relationship between TL and DW for longnose skate that we used ($TL = 7.36 + 1.41 \cdot DW$, r^2=0.99). Size of longnose skates collected in this survey ranged from 15 to 140 cm.

Survey biomass indices and length compositions

For each survey, a biomass index was estimated for areas included in the analysis (Weinberg et al. 1994, Zimmermann et al. 1994, Wilkins et al. 1998, Winberg et al. 2002, Lauth 1999, 2000, Keller et al. 2006, Keller et al. 2007).

Survey biomass indices (mt) and standard deviation of log (index), calculated as $\sqrt{\ln\left(1+CV^2\right)}$ are presented in Table 5. Biomass indices are also shown in Figures 10-13.

The size data were aggregated into 27 size bins, with 5-cm bin length. Size compositions were calculated as described in Weinberg et al. (1994), Zimmermann et al. (1994), Wilkins et al. (1998), Winberg et al. (2002), Lauth (1999, 2000), Keller et al. (2006), Keller et al. (2007) and Hamel (2005). The size compositions for each survey, by year, are presented in Figures14-16. Age composition for 2003 NWFSC shelf-slope survey from Thompson (2006) are shown in Figure 17. The size-at-age data plotted for fishery and NWFSC shelf-slope survey are presented in Figures 18-19. Sample sizes of organisms measured in all length and age samples by year are given in Tables 6-7.

Biological Parameters

Using the data described above, biological parameters, such as somatic growth parameters, maturity-at-length, and the length-weight relationships were estimated. There were no apparent differences found between females and males in any of these parameters.

Growth

Several studies of longnose skate growth (Zeiner and Wolf 1993, Thompson 2006, McFarlane and King 2006, Gburski et al. 2007) showed that growth of longnose skate is best described by von Bertalanffy growth model (Bertalanffy 1938). Growth parameters of von Bertalanffy model estimated in different studies are summarized in Table 8.

SS2 uses the following version of the von Bertalanffy growth model:

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

Where asymptotic length, L_∞, is calculated as:

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

In these equations, L_A is length (cm) at age A, K is growth coefficient, L_∞ is asymptotic length, and L_1 and L_2 are the sizes associated with a reference ages - near the youngest A_1 and the oldest A_2 ages that are well represented in the data. For longnose skate, the reference ages A_1 and A_2 were 1 and 17 correspondingly.

Maturity

To estimate the relationship between size and maturity, SS2 employs the logistic function:

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

Where $M\%$ is the proportion of mature organisms in the stock, β is coefficient used as a constant, and $L50\%$ is the length at 50% maturity. For longnose skate, β was estimated as -0.0986, and $L50\%$ as 120 cm (Thompson 2006).

McFarlane and King (2006), while studying maturity of longnose skate in the British Columbia waters, estimated β for maturity logistic function as -0.078, and $L50\%$ as 83cm, which is significantly lower than estimated by Thompson (2006). Criteria to distinguish mature individuals from immature differed between Thompson's and McFarlane and King's studies. Neither approach, however, could be considered superior to the other. For the base model, we used Thompson's data, which is more likely to underestimate the proportion of mature skates. However, we explored the uncertainly of this estimation through the sensitivity analysis, as described later in this report.

Length-weight relationships

To establish the relationship between length and weight, the following equation was used:

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

Where W is weight (kg), L is length (cm) and α and β are coefficients used as constants. For longnose skate α was estimated as 0.00000428 and β as 3.05975.

MODEL DESCRIPTION

This report describes the latest version of the assessment model for the longnose skate, which includes changes made according to STAR Panel requests. The list of STAR Panel requests is presented in Appendix 1.

Overview

This assessment uses the Stock Synthesis 2 (SS2) modeling program developed by Richard Methot at the NWFSC. We used the most recent version of the program (version 2.00e) distributed on April 18, 2007 (Methot 2007).

In this assessment, it was assumed that one stock of longnose skate occupies the waters off the continental West Coast area, from the US-Canadian border in the north to US-Mexican border in the south. The vast majority of longnose skates (97%) are caught in trawl fisheries; therefore this stock was modeled with a single fishery. Since there were no apparent differences found between females and males in their biological parameters or fishery and survey length and age frequencies, the assessment uses a single sex model.

The likelihood components of the model included (1) survey abundance indices, (2) fishery and survey length compositions, (3) NWFSC shelf-slope survey age compositions, and (4) fishery and NWFSC shelf-slope survey mean size-at-age. In the model, likelihood estimates for the various data components were obtained by comparing expected values from the model with the actual observations from sample data based on "goodness of fit" procedures for log (L). Emphasis levels were set to 1.0 for each likelihood component listed above.

The earliest record of skate catches in the US west coast is dated at 1916 (Martin and Zorzi 1993, Bonfil 1994). Therefore, the modeling period of our assessment begins in 1916, assuming that in 1915 the population was in an unfished equilibrium condition. To fill the historical catches between unfished equilibrium in 1915 and the time when longnose skate catch data were available (1950-2006), we linearly ramped data from zero in 1915 up to the average catch level for the period of 1950-1980 in 1949 (we assumed catch in 1949 to be the average for the period between 1950-1980).

In the assessment, we reconstructed a time series of total catch for the longnose skate outside of SS2 and then entered these time series in the SS2 data file. The total catch time series included both landed catch and discard mortality. For the base model, we assumed a 93% discard rate prior to 1995 and 53% from 1995 forward to reflect skate market changes. We also assumed 50% discard mortality for the entire time series. Figure 20 shows longnose skate total catch over time as used in the base model. The uncertainties associated with discard and discard mortality assumptions were explored in the sensitivity analysis, the results of which are presented later in this report.

Model parameters

The model utilizes 32 parameters. No prior assumptions were made regarding the estimated parameters (the emphasis level “lambda” on all prior distributions was set to 0). However, bounds were established on all parameters, including life history, stock-recruitment, and selectivity. Based on the information about survey coverage and behavior of longnose skate in the natural environment, the catchability coefficient Q for the NWFSC shelf-slope survey was fixed at the level of 0.83. The determination of this value is described later in the report. Values of Q for other surveys were estimated within the model. Ageing error was input as data to the model and was not estimated. Input variance factors were adjusted for length sample sizes in fishery and surveys as well as AFSC shelf (triennial) survey CV.

All the explicit parameters used for the base model and their values are given in Table 9. If parameters were estimated, initial values as well as parameters bounds are also given. The phases in which estimated parameters were calculated by the model are indicated in parentheses.

Natural mortality

To estimate natural mortality M, we explored several methods that relate M with different life history parameters, including time of sexual maturation and longevity (Charnov 1993, Frisk et al. 2001, Hoenig 1983, Rikhter and Efanov 1976, Roff 1986).

Based on published life-history parameters of skates, sharks and rays over a wide geographic range, Frisk et al. (2001) developed models that relate natural mortality of elasmobranch fishes with maximum age and age of maturity. Based on both of these models, the natural mortality of longnose skate was estimated at 0.2. Hoenig (1983) developed a model that related total mortality to the maximum age of fish. Since Hoenig’s analysis was based largely on unexploited fish stocks, total mortality in his model is often assumed to be natural mortality. Based on Hoenig’s model, longnose skate natural mortality was also estimated as 0.2. In our model, natural mortality was thus fixed at the level of 0.2.

Growth and maturity parameters

The von Bertalanffy growth parameters (K), length at age 1 (L_1) and length at age 17 (L_2) were estimated within the model. Age 1 and age 17 were chosen for L_1 and L_2 because they are extreme points that are still well represented in the data. All three von Bertalanffy parameters were estimated within the model. Other growth and maturity parameters, such as CVs for L_1 and L_2, weight-at-length, maturity-at-length and fecundity-at-weight, were fixed at the levels estimated outside of SS2.

Stock-recruitment relationship

A Beverton-Holt model was used to describe the stock-recruitment relationship for longnose skate. The level of virgin recruitment (R_0) was estimated using this relationship, in order to estimate the magnitude of the initial spawning biomass. In the assessment model, recruits were taken deterministically from the stock-recruit curve, largely due to extremely limited age data and in order to avoid fitting noise. Steepness h was fixed at a value of 0.4, to reflect the K-type reproductive strategy of this species.

Selectivity

Selectivity parameters used in this assessment are specified as functions of size. Separate size-based selectivity curves were fit to the fishery and each survey, except for the NWFSC slope survey, which was assumed to have the same selectivity as the NWFSC shelf-slope survey and, therefore, was set to mirror it. To depict selectivity for the fishery and the three surveys (except for the NWFSC slope survey), we used a double-normal function, which has six parameters, including (1) peak, which is the length at which selectivity is fully selected; (2) width of plateau on the top; (3) width of the ascending part of the curve (4) width of the descending part of the curve; (5) selectivity at first size bin; and (6) selectivity at last size bin.

In all cases, we fixed the selectivity of the first size bin (parameter 5), based on the examination of size-composition data. Also, the size selectivity of NWFSC shelf-slope survey (and, therefore, NWFSC slope survey) and AFSC slope survey were assumed to be asymptotic. Figure 21 shows frequency of occurrence of longnose skate in the AFSC slope survey catches by depth. In the last depth stratum of the survey (between 1098 and 1280 m), longnose skate was not found, which indicates that the survey went deep enough and can be assumed to be asymptotic. NWFSC shelf-slope and slope surveys extended to the same depth as the AFSC slope survey (Table 4). We fixed the selectivity at last size bin (parameter 6) and width of the descending part of the curve (parameter 4) at their maximum values to allow selectivity of these surveys to be asymptotic. All other size selectivity parameters were estimated in the model. Since we had limited age information, age-based selectivity was set to 1.0 for all ages beginning at age 1.

NWFSC shelf-slope survey catchability Q

The value of the NWFSC shelf-slope survey catchability Q used for the base model was calculated during the STAR Panel. First, a prior for Q was developed following the methodology presented by Patrick Cordue. Catchability depends on several factors such as latitudinal, vertical and depth availabilities of fish to the survey gear and the probability of spatially “available” fish being caught and retained by the gear. To develop a prior on Q, the potential range in the proportion of vulnerable skates for each factor was specified and “best guesses” for each range were assumed. Latitudinal and depth availability was specified based on the survey coverage of the assessment area. Vertical availability and probability of catch was specified based on the known behavior of the longnose skate.

The NWFSC shelf-slope survey covers the entire latitudinal range of the assessment (Table 4); therefore latitudinal availability was assumed to be 1. The survey appears to exceed the maximum depth distribution of longnose skate (Figure 21) but may not fully cover the shallow end of the skate distribution. Therefore, the range for the depth availability was assumed between 0.95 and 1. Longnose skates are known to bury in the sand to escape predators, which might cause a portion of skates be unavailable to the bottom trawl gear. Therefore a range for vertical availability was assumed between 0.75 and 0.95. Finally, the probability of spatially available skates being captured and retained was assumed to be between 0.75 and 1.5, since it is possible that longnose skate might either avoid trawl nets or (similar to some flatfish) be herded by trawl gear. “Best guess” estimates were set at the mid-point of the range for individual factors and the overall best guess for the survey Q was 0.83. The minimum, maximum and mid-point values for each category used to develop prior on Q is summarized in Table 10.

We did not use an informative prior on Q for the base model, but fixed Q at 0.83, estimated as described above. The normal prior on log(Q) was used to provide “low” and “high” Qs for different states of nature used to address uncertainty in survey catchability.

Age-determination error

To establish the level of accuracy of age determination, we used age readings of the same age structures made by three different readers and calculated standard deviations of age determination for each true age (assumed as read by reader 1).

MODEL SELECTION AND EVALUATION

Alternative model configurations

We explored many alternative model configurations of varying levels of complexity in order to realistically describe the population dynamics of the longnose skate with a parsimonious model and the best available data. We evaluated the alternative models based on overall model fit and convergence criteria. The alternative configurations included two-sex versus single-sex models; models that estimates recruitment deviations versus treating recruits deterministically; and configurations starting in 1980 in a non-zero equilibrium state versus starting in 1915 with unfished equilibrium. We explored asymptotic versus dome-shaped size selectivities, as well as fixed versus estimated von Bertalanffy growth parameters.

The base run model reflects the best aspects from these exploratory analyses. It appears to be parameterized enough to fit the observed data, while maintaining reasonable parameter values and parsimonious explanations for the underlying model processes. A summary of likelihood components for the base model is presented in Table 11.

Conversion criteria

We assessed convergence of the base run model according to the model's ability to recover similar likelihood estimates when initialized from dispersed starting points. Results from a set of 15 convergence tests showed minor variability in the objective function and current depletion. The Hessian matrix was positive definite for all tests and the maximum gradient component for the base run was 0.000201095.

Likelihood profile analysis

The chosen base model included several key parameters for which assumptions had to be made in the absence of data. These parameters were fixed based on general information about the species. The key model parameters that were fixed included natural mortality *M*, steepness of stock-recruitment curve *h*, and catchability coefficient *Q* of NWFS shelf-slope survey and discard mortality. Uncertainties in NWFS shelf-slope survey *Q* and discard mortality were addressed through sensitivity analyses described later in this report. To explore how informative the data were with regard to natural mortality and steepness of the stock-recruitment curve, we performed likelihood profile analyses where we varied the values of *M* and *h* and recorded the overall fit of the model. We also looked at how sensitive model outcome was to these variations.

Likelihood profiles of *M* and *h* along with subsequent changes in the stock depletion are presented in Figures 22 and 23. For natural mortality, the best fit of the model was achieved with *M* values of 0.18 and 0.2 (in the base model *M* is fixed at 0.2). For these values of *M*, the levels of spawning biomass depletion are essentially the same (65% and 66% respectively). Likelihood profiles on steepness (values from 0.3-1) showed better fit for the model with high values of *h*. However, all available information about elasmobranches suggests that the longnose skate is not likely to be a highly productive species. The depletion rates for various levels of *h* ranged between 61% and 74 % (Figure 23). Since little is known about longnose skate productivity, in the base model we selected a value for *h* (0.4) that is towards the low end of the examined range. This value is precautionary, relative to values with better fits, but it is also more consistent with the productivity of other elasmobranches.

BASE RUN RESULTS

Model fit

Comparisons between observed and estimated survey biomasses are shown in Figures 24-27. The model was able to capture general trends for indices in all surveys except for the AFSC shelf (triennial). The estimated biomass in the 2004 AFSC shelf (triennial) appeared to be twice as high as any other estimates in the survey time series. Other surveys conducted around this time did not detect an increase in stock biomass. In 2004, the shelf (triennial) survey was conducted by the NWFSC, not by the AFSC, as in all previous years. Although an effort was made to replicate AFSC protocols as closely as possible, this change may have contributed to the substantial increase in the longnose skate biomass index. Based on similar observed increases in the indices for several flatfish stocks during the 2005 assessment cycle, a review of 2004 survey implementation was conducted by the NWFSC. However, that review did not find any obvious implementation reasons for the increases in flatfish CPUE. We will explore this issue in the future.

Fit to length- and age-frequency data are shown in Figures 28-32. Fits to length compositions was good. However, the estimated age compositions did not exhibit a very good fit, which could be explained by the combination of deterministic recruitment and variations in catch history. Fit to size-at-age data is presented in Figures 33-34.

Model estimates

Figures 35-37 show growth and maturity curves, as well as length-weight relationship estimated by the model. Table 12 and Figures 38-43 show the total, summary, and spawning biomass, as well as depletion rate relative to B_0, recruitment and harvest rate time-series, as estimated by the base model. Population numbers-at-age by year are given in Table 13. The stock-recruitment relationship is presented in Figure 44. Selectivity estimates for the fishery and surveys are shown in Figures 45-49.

State of the stock

The summary of the recent trends in longnose skate exploitation and estimated population levels are presented in Table 14. Currently, the stock of the longnose skate in the US West Coast is not overfished (Figure 50). Historically, the exploitation rate for the longnose skate has been low. It reached its maximum level of 4.02 % in 1981. Currently, the stock is at 66% of its unfished level. Since the longnose skate stock is estimated to be above the overfished level, no rebuilding is required.

UNCERTAINTY AND SENSITIVITY ANALYSIS

This assessment reflects a data-moderate to data-poor circumstance with respect to several influential model elements. The major uncertainties for the assessment include the longnose skate catch history, Northwest Fishery Science Center (NWFSC) shelf-slope survey catchability *Q* and the female maturity schedule.

Catch history

The catch history of longnose skate reflects retained catch (catch that was retained and landed), discard and discard mortality. In addition to uncertainty in those estimates, uncertainty is involved in estimating the proportion of longnose skate in combined-skate landings, since historically landings were recorded within the "unspecified skates" market category. For recent years, the data on longnose skate landings and discards are reasonably good. However, since the discard rate is high and discard mortality is essentially unknown, there is still considerable uncertainty about the level of fishing mortality. To address uncertainties related to longnose skate catch, alternative catch histories that reflect variations in the proportion of longnose skate in combined-skate landings, discard and discard mortality rates were developed by the STAR Panel. These alternative catch histories included "low" and "high" histories, compared with the base model scenario. Figures 51-53 show base, "low" and "high" longnose skate catch histories respectively.

The "low" and "high" catch histories were constructed from the landings estimates presented earlier in this report, but used different assumptions regarding the proportion of longnose skate in the combined-skate landings, the discard, and discard mortality rates. As catch history in base model, the "low" and "high" catch histories were constructed outside the model and entered into an SS2 data file as total catch. The following formula, developed by STAR Panel, was used to translate combined-skate landings into longnose skate total catch:

$$TC = e\frac{p}{b}\left[1+\frac{dm}{1-d}\right]$$

Where *TC* is total catch of longnose skate; *e* is estimated longnose skate landings, *b* is the proportion of longnose skate in the combined- skate landings, used to get *e* from a combined-skate landings; *p* is proportion of longnose skates in the total skate landings, *d* is discard rate, and *m* is discard mortality rate.

Based on the quality of landed catch records (prior to 1981 records were less detailed and involve more uncertainty that after 1981) and changes in skate markets (skate market increased in 1995), three time periods were defined for the catch history of longnose skate: years up through 1980, between 1981 and 1994, and from 1995 until present.

In the base model, for the first time period, a constant value for proportion of longnose skate in the combined-skate landing (*b* = 0.62) had been used. Since 1981 annual values for *b* were estimated from fishery species compositions and survey catches (as described earlier in this report). Prior to 1995 (when the skate market changed) discard rate *d* was assumed to be equal 93% based on Rogers and Pikitch's study (1992), while since 1995 forward *d* was equal to 53%, based on the data from ODCP and WCGOP. Discard mortality rate for the entire time of the assessment was assumed to be 50%. For the "low" and "high" catch histories, alternative values of *b*, *d* and *m*, calculated by STAR Panel and shown in Table 15, were used.

Using the parameter values presented in the Table15 for corresponding time periods, we reconstructed time series for "low" and "high" catch histories, and conducted alternative runs for each of these scenarios, tiering off the base model specification. Depletion was estimated to be 75% and 46% for the "low" and "high" catch histories, respectively (depletion for the base model was estimated as 66%). We used the alternative catch histories (along with different values of NWFSC shelf-slope survey catchability *Q*) to define three different states of nature and to develop decision table (Table 19).

NWFSC shelf-slope survey catchability *Q*

To address uncertainty in NWFSC shelf-slope survey *Q*, model runs were performed under base, "low", and "high" levels of *Q*. The value of *Q* used for the base model was 0.83. For the "low" and "high" levels, we used values of *Q* calculated by STAR Panel based on the normal prior on log(*Q*). A random sample of size 10,000 was generated from the normal distribution and the mean of the samples below the 25th percentile of the normal distribution was exponentiated to provide the "low" *Q* (low *Q*=0.654). The mean of the samples above the 75th percentile was exponentiated to provide the "high" *Q* (high *Q*=1.046). Alternative values of NWFSC shelf-slope survey catchability *Q* (along with alternative catch histories) were used to define three different states of nature and to develop the decision table (Table 19).

Maturity

Uncertainty in female maturity was also explored. A maturity study of the longnose skate, conducted by McFarlane and King (2006) in the British Columbia waters, reported that parameters of the maturity curve were significantly lower than those used in our assessment, as estimated by Thompson (2006). McFarlane and King (2006) estimated slope of the maturity function β as -0.078, and length at 50% maturity (L50%) as 83 cm, while Thomson (2006) estimated β as -0.098 and L50% as 120 cm. Criteria to distinguish mature individuals from immature differed between Thompson's and McFarlane and King's studies, but neither approach could be considered superior to the other. We ran our model with the values of the maturity function estimated by Thompson (2006) and then with the values estimated by McFarlane and King (2006). The depletion of longnose skate in these two runs was 66% and 78% respectively. For the base model, we used Thompson's data, which is more likely to studereste the proportion of mature skates. However, we recommend conducting an additional study of longnose skate maturity to clarify this issue.

REFERENCE POINTS

The summary of reference points for the longnose skate is presented in Table 16. For the longnose skate, the management target is defined as 40% of the unfished spawning stock biomass ($SB_{40\%}$), which is estimated to be 2,814 mt (95% Confidence Interval: 2,608-3,019 mt) in the base model. The stock is declared overfished if the current spawning biomass is estimated to be below 25% of unfished level. The MSY-proxy harvest rate for longnose skate is SPR=F45%, which corresponds to an exploitation rate of 0.043. This harvest rate provides an equilibrium yield of 1,264 mt (95% Confidence Interval: 1,194-1,334 mt) at $SB_{40\%}$. The model estimate of maximum sustainable yield (MSY) is 1,268 mt (95% Confidence Interval: 1,198-1,338). The estimated spawning stock biomass at MSY is 2,626 mt (95% Confidence Interval: 2,433-2,819 mt). The exploitation rate corresponding to the estimated SPRmsy of F61% is 0.027.

Reference point results are calculated on both a per-recruit and total-recruits basis. The total-recruits results take into account the spawner-recruitment relationship with the steepness as defined in the base model (h=0.4). Because of this low steepness and other reproductive characteristics of the stock, fishing at the target SPR of 45% is expected to reduce the spawning biomass to less than 12% of the unfished level over the long term. Conversely, fishing at a rate that would maintain spawning biomass near 40% of the unfished level would require a target SPR much higher than 45%. The Council's Scientific and Statistical Committee should consider the appropriateness of using the current proxy harvest rate for setting the Allowable Biological Catch for longnose skate.

HARVEST PROJECTIONS

Tables 17 and 18 show projections of future catches, summary biomass, spawning biomass and stock depletion made based on the current rate of fishing mortality, as well as on F45%. The projected spawning depletion based on the current level of fishing and F 45% is shown in Figures 54 and 55. The projected spawning biomass was greater than 40% of unfished level in both cases; therefore no 40:10 harvest control rule adjustment was made. Optimum yield catch values were equivalent to the values of ABC.

For this assessment, three states of nature were defined based on the alternative longnose skate catch histories and NWFSC shelf-slope survey *Q*s. The base scenario uses the base catch history and base *Q* (*Q*=0.83), the "low" scenario uses the low catch history and low *Q* (*Q*=0.654), and the "high" scenario uses the high catch history and high *Q* (*Q*=1.046). Ten-year forecasts for each state of nature were calculated based on F45% for the base scenario. Ten-year forecasts were also produced with future catch fixed at the average amount (using the base catch history) for last three years (2004-2006) and at 150% of that three-year average. Under the "high" scenario, the F45% harvest rate is projected to reduce the spawning stock biomass below 40% of the unfished level within two years. In all other scenarios covered by the decision table, the spawning biomass remains above the target level throughout the 10-year projection period. The current rate of fishing mortality is significantly lower than F45% (current exploitation rate is 1.25%). Therefore, it is very unlikely that the stock, even under the "high" scenario will fall below 40% of its virgin state in the next 10 years.

RESEARCH AND DATA NEEDS

This assessment reflects a data-moderate to data-poor circumstance with respect to several influential model elements, including catch history, survey catchability, and some life history characteristics. Consequently, some critical assumptions were based on very 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) Genetic studies to determine stock structure of longnose skate in the waters off the US Pacific Coast;
2) Age-determination and age-validation studies to improve the understanding of growth and size-at-age relationships;
3) Studies on life history characteristics, especially those related to maturity and reproduction, to address uncertainties in estimating longnose skate productivity;
4) Studies of longnose skate behavior and distribution to provide more precise estimates of abundance from the surveys;
5) Studies of survival rates of discarded longnose skate, especially with trawl gear, so that total fishing mortality can be estimated more precisely;
6) Studies of longnose skate catchability by survey gear types.

It is also very important to continue to conduct species-specific identification in fishery and monitor discard of the longnose skate to improve the accuracy of fishery catch data.

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TABLES AND FIGURES

LIST OF TABLES

TABLES

Table 1. Summary of fishery-dependent data used in the assessment by source and year since 1980.

	YEAR																										
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	0	1	2	3	4	5	6
CATCHES																											
Landings																											
Unspecified Skate (PacFIN)		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OR (longnose skate)																■	■	■	■	■	■	■	■	■	■	■	■
WA (longnose skate)																									■	■	■
CA (longnose skate)																											
Discard																											
OR							■	■									■	■	■							■	
WA							■	■																		■	
CA																										■	
BIOLOGICAL DATA																											
Length																											
OR																■	■	■	■	■	■	■	■	■	■	■	■
WA																									■	■	■
CA																											
Sex																											
OR																■	■	■	■	■	■	■	■	■	■	■	■
WA																									■	■	■
CA																											
Age																											
OR																								■	■		
WA																											
CA																											

Table 2. Summary of fishery-independent data used in the assessment by source and year.

	YEAR																										
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	0	1	2	3	4	5	6
BIOMASS																											
NWFSC Slope																				■	■	■	■				
NWFSC Shelf-Slope																								■	■	■	■
AFSC Shelf Triennial	■			■			■			■			■			■			■			■			■		
AFSC Slope																		■		■	■	■					
BIOLOGICAL DATA																											
Length																											
NWFSC Slope																											
NWFSC Shelf-Slope																								■	■	■	■
AFSC Shelf Triennial																						■			■		
AFSC Slope																		■		■	■	■					
Age																											
NWFSC Slope																											
NWFSC Shelf-Slope																								■			
AFSC Shelf Triennial																											
AFSC Slope																											

Table 3. Estimated percentage of longnose skate in combined-skate landings by state and year (for the pre-1981, percentage of longnose skate in combined-skate landings is assumed as 62%).

Year	CA	OR	WA	Average
1981	50	79	64	64
1982	54	75	54	61
1983	58	71	44	58
1984	56	66	51	58
1985	55	60	58	57
1986	54	54	64	57
1987	49	60	65	58
1988	44	67	66	59
1989	40	73	67	60
1990	33	63	63	53
1991	26	53	60	46
1992	19	43	57	39
1993	30	57	64	50
1994	41	71	71	61
1995	52	78	78	69
1996	55	81	78	71
1997	58	88	78	74
1998	60	92	78	77
1999	60	95	78	78
2000	60	100	77	79
2001	59	69	77	68
2002	59	25	78	54
2003	58	67	78	68
2004	58	53	52	55
2005	58	76	34	56
2006	58	74	48	60

Table 4. Surveys used in the assessment by year, latitudinal and depth ranges.

Survey	Year	Latitudes	Depths (fm)
NWFSC slope	1999	35° 00'- 48° 10'	100-700
	2000	35° 00'- 48° 07'	100-700
	2001	35° 00'- 48° 08'	100-700
	2002	35° 51'- 48° 07'	100-700
NWFSC shelf-slope	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
AFSC Shelf (triennial)	1977	34° 00'- 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'- Border	30-275
AFSC Slope	1988	44° 05'- 45° 30'	100-700
	1990	40° 30'- 43° 00'	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'- Border	100-700
	1997	34° 30'- Border	100-700
	1999	34° 30'- Border	100-700
	2000	34° 30'- Border	100-700
	2001	34° 30'- Border	100-700

Table 5. Survey biomass indices (mt) and standard deviation of log (index), calculated as $\sqrt{\ln\left(1+CV^2\right)}$.

	NWFS shelf-slope survey		NWFS slope survey		AFSC triennial survey		AFSC slope survey	
Year	**Biomass (mt)**	**s**	**Biomass (mt)**	**s**	**Biomass (mt)**	**s**	**Biomass (mt)**	**s**
1980					968.00	0.22		
1983					1453.00	0.15		
1986					1552.00	0.16		
1989					3049.00	0.18		
1992					1672.00	0.16		
1995					1635.00	0.16		
1997							17226.00	0.12
1998					3733.00	0.16		
1999			28431.14	0.13			14199.00	0.11
2000			24002.33	0.17			13748.00	0.13
2001			24150.44	0.14	3180.00	0.08	14278.00	0.12
2002			27022.31	0.10				
2003	50768.03	0.08						
2004	55648.34	0.07			7827.00	0.09		
2005	50762.13	0.06						
2006	55267.93	0.08						

Table 6. Sample size for size composition data (both sexes combined) by source.

Year	Fishery	NWFSC shelf-slope survey	AFSC shelf triennial survey	AFSC slope survey
1995	53			
1996	99			
1997	459			764
1998	84			
1999	311			731
2000	299			743
2001	457		796	681
2002	235			
2003	518	2675		
2004	149	2647	794	
2005	248	3326		
2006	603	3325		

Table 7. Sample size for age data (both sexes combined) by source.

Year	Fishery	NWFSC shelf-slope survey
2003	38	
2004	102	258

Table 8. Von Bertalanffy growth model parameters estimated in different studies (both sexes combined).

Lead author	Year of study	Area of study	*K*	L_{inf} (cm)
Thompson	2006	US West Coast	0.047	194
Gburski	2007	Gulf of Alaska	0.046	202
McFarlane	2006	British Columbia	0.065	135
Zeiner	1993	California	0.2	102

Table 9. Parameters used for the base model.

PARAMETER	VALUE	MIN	MAX	FIXED	ESTIMATED (PHASE)
Natural Mortality	0.2			x	
Growth					
Size (cm) at age 1	18.7	15	40		x (4)
Size (cm) at age 17	105.9	70	130		x (4)
K	0.064	0.05	0.15		x (4)
CV in size at age 1	0.14			x	
CV in size at age 17	-0.71			x	
Biologi parameters					
Coeffient to convert L(cm) to W(kg)	4.28E-06			x	
Exponent in female L-W conversion	3.05975			x	
Maturity logistic inflection	120.753			x	
Maturity slope	-0.09859			x	
eggs/gm intercept	0.5			x	
eggs/gmslope	0			x	
Weight at length					
Coefficient	4.28E-06			x	
Exponent	3.05975			x	
Stock-Recruitment					
Log of virgin recruiment level	9.65	5	15		x (1)
Steepness of stock-recruiemnt curve	0.4			x	
Survey catchability as Log (Q)					
NWFSC shelf slope survey	-0.19			x	
NWFSC slope survey	-0.87	-7	0		x (1)
AFSC triennial lope survey	-3.14	-7	0		x (1)
AFSC slope survey	-1.45	-7	0		x (1)
Size selectivity parameters Fishery					
Peak	93.5	80	100		x (2)
Top	0.55	-6	4		x (2)
Ascendin slope	5.73	-1	9		x (2)
Descenfin slope	8.3			x	
Selectivity at fist bin	-5			x	
Selectivity at last bin	2.05	-5	9		x (2)
Size selectivity parameters NWFSC shelf-slope survey					
Peak	80	20	80		x (2)
Top	-2.95	-6	4		x (2)
Ascendin slope	8.09	-1	9		x (2)
Descenfin slope	6			x	
Selectivity at fist bin	-4.8			x	
Selectivity at last bin	9			x	
Size selectivity parameters NWFSC shelf-slope survey					
First size bin (mirror)	1			x	
Last size bin (mirror)	27			x	
Size selectivity parameters AFSC triennial shelf survey					
Peak	75	50	75		x (2)
Top	-0.07	-6	4		x (2)
Ascendin slope	7.69	-1	9		x (2)
Descenfin slope	-0.008	-1	9		x (2)
Selectivity at fist bin	-5			x	
Selectivity at last bin	-0.71	-5	9		x (2)
Size selectivity parameters AFSC slope survey					
Peak	55	50	60		x (2)
Top	-0.87	-6	4		x (2)
Ascendin slope	6.06	-1	9		x (2)
Descenfin slope	7.7			x	
Selectivity at fist bin	-4			x	
Selectivity at last bin	9			x	

Table 10. Minimum, maximum and mid-point values of different factors affecting survey catchability used to estimate prior of NWFSC shelf-slope survey log (Q).

	minimum	**maximum**	**mid-point**
Depth availability	0.95	1	0.975
Latitudinal availability	1	1	1
Vertical availability	0.75	0.95	0.85
Probability of capture	0.75	1.5	1
Product of all factors	0.53	1.43	**0.83**

Table 11. The summary of likelihood components for the base model.

LIKELIHOOD	1055.67
indices	17.0821
discard	0
length_comps	595.302
age_comps	23.2279
size-at-age	420.056
mean_body_wt	0
Equil_catch	0
catch	0
Recruitment	0
Parm_priors	0
Parm_devs	0
penalties	0
Forecast_Recruitment	0

Fleet	surv_lambda	surv_like	disc_lambda	disc_like	length_lambda	length_like	age_lambda	age_like	sizeage_lambda	sizeage_like
1	0	0	1	0	1	269.514	1	0	1	389.397
2	1	0.938181	1	0	1	183.105	1	23.2279	1	30.6588
3	1	0.463396	1	0	1	0	1	0	1	0
4	1	14.8925	1	0	1	47.3419	1	0	1	0
5	1	0.788065	1	0	1	95.3409	1	0	1	0

Fleet1=fishery
Fleet 2=NWFSC shelf-slope survey
Fleet 3=NWFSC slope survey
Fleet 4=AFSC shelf (triennial) survey
Fleet 5=AFSC slope survey

Table 12. Estimated time-series for total, summary and spawning biomass, recruitment harvest rate and depletion (continued on the next page).

year	Total biomass	Summary biomass	Spawning biomass	Recruitment	Harvest rate	Depletion
1915	91,855	90,955	7,034	15,454	0.00%	100%
1916	91,855	90,955	7,034	15,454	0.04%	100%
1917	91,837	90,937	7,032	15,452	0.07%	100%
1918	91,803	90,904	7,027	15,449	0.11%	100%
1919	91,755	90,855	7,020	15,443	0.14%	100%
1920	91,693	90,794	7,011	15,435	0.18%	100%
1921	91,619	90,721	7,000	15,426	0.21%	100%
1922	91,535	90,637	6,987	15,415	0.25%	99%
1923	91,440	90,543	6,972	15,403	0.28%	99%
1924	91,335	90,439	6,956	15,389	0.32%	99%
1925	91,221	90,326	6,938	15,374	0.36%	99%
1926	91,098	90,204	6,918	15,358	0.39%	98%
1927	90,967	90,073	6,898	15,340	0.43%	98%
1928	90,826	89,934	6,876	15,322	0.47%	98%
1929	90,678	89,786	6,854	15,303	0.50%	97%
1930	90,521	89,631	6,830	15,283	0.54%	97%
1931	90,356	89,467	6,806	15,262	0.58%	97%
1932	90,183	89,295	6,782	15,241	0.62%	96%
1933	90,003	89,116	6,756	15,219	0.65%	96%
1934	89,815	88,929	6,730	15,197	0.69%	96%
1935	89,619	88,735	6,704	15,174	0.73%	95%
1936	89,417	88,534	6,677	15,150	0.77%	95%
1937	89,207	88,326	6,650	15,126	0.81%	95%
1938	88,992	88,112	6,622	15,101	0.85%	94%
1939	88,770	87,891	6,593	15,076	0.89%	94%
1940	88,541	87,665	6,564	15,050	0.93%	93%
1941	88,307	87,432	6,534	15,023	0.97%	93%
1942	88,068	87,194	6,503	14,995	1.01%	92%
1943	87,823	86,951	6,472	14,967	1.05%	92%
1944	87,573	86,703	6,441	14,938	1.09%	92%
1945	87,318	86,449	6,409	14,909	1.13%	91%
1946	87,058	86,191	6,376	14,878	1.17%	91%
1947	86,794	85,928	6,343	14,848	1.21%	90%
1948	86,525	85,661	6,310	14,816	1.26%	90%
1949	86,251	85,389	6,276	14,784	1.30%	89%
1950	85,973	85,113	6,241	14,751	0.72%	89%
1951	85,982	85,123	6,244	14,754	0.52%	89%
1952	86,070	85,211	6,259	14,769	0.58%	89%
1953	86,105	85,245	6,272	14,781	1.78%	89%
1954	85,562	84,703	6,213	14,724	0.65%	88%
1955	85,589	84,732	6,223	14,734	1.86%	88%
1956	85,043	84,187	6,161	14,674	0.83%	88%
1957	85,022	84,168	6,162	14,675	0.72%	88%
1958	85,048	84,194	6,169	14,682	0.75%	88%
1959	85,050	84,195	6,175	14,687	1.02%	88%
1960	84,918	84,063	6,164	14,677	0.62%	88%
1961	84,976	84,121	6,177	14,689	3.10%	88%

Table 12 (continuation). Estimated time-series for total, summary and spawning biomass, recruitment harvest rate and depletion.

year	Total biomass	Summary biomass	Spawning biomass	Recruitment	Harvest rate	Depletion
1962	83,878	83,027	6,042	14,558	1.77%	86%
1963	83,511	82,665	5,990	14,506	2.01%	85%
1964	83,068	82,226	5,927	14,442	1.98%	84%
1965	82,682	81,843	5,868	14,382	1.14%	83%
1966	82,705	81,868	5,860	14,374	1.40%	83%
1967	82,595	81,759	5,840	14,353	1.39%	83%
1968	82,482	81,647	5,823	14,336	2.45%	83%
1969	81,892	81,060	5,749	14,259	1.60%	82%
1970	81,723	80,894	5,727	14,236	0.89%	81%
1971	81,866	81,037	5,747	14,257	0.39%	82%
1972	82,197	81,365	5,797	14,309	0.59%	82%
1973	82,385	81,551	5,836	14,349	0.60%	83%
1974	82,534	81,698	5,875	14,389	0.59%	84%
1975	82,662	81,824	5,913	14,429	0.66%	84%
1976	82,736	81,895	5,946	14,462	1.81%	85%
1977	82,283	81,442	5,910	14,425	1.83%	84%
1978	81,870	81,031	5,871	14,386	2.99%	83%
1979	80,995	80,160	5,766	14,276	3.23%	82%
1980	80,129	79,301	5,649	14,153	2.13%	80%
1981	79,848	79,026	5,596	14,095	6.88%	80%
1982	77,574	76,763	5,289	13,752	4.85%	75%
1983	76,465	75,670	5,111	13,543	3.84%	73%
1984	75,891	75,106	4,997	13,404	2.00%	71%
1985	76,082	75,303	4,982	13,386	2.86%	71%
1986	75,865	75,088	4,933	13,326	2.36%	70%
1987	75,811	75,036	4,917	13,306	2.70%	70%
1988	75,567	74,793	4,893	13,276	1.74%	70%
1989	75,668	74,894	4,922	13,312	1.91%	70%
1990	75,634	74,858	4,949	13,345	1.50%	70%
1991	75,717	74,939	4,998	13,406	1.27%	71%
1992	75,842	75,060	5,060	13,482	0.75%	72%
1993	76,136	75,348	5,147	13,586	1.16%	73%
1994	76,211	75,418	5,209	13,660	1.63%	74%
1995	76,076	75,280	5,243	13,699	0.82%	75%
1996	76,292	75,492	5,311	13,778	3.26%	76%
1997	75,487	74,687	5,245	13,701	6.05%	75%
1998	73,668	72,877	5,032	13,448	2.85%	72%
1999	73,380	72,599	4,982	13,386	4.33%	71%
2000	72,577	71,802	4,858	13,232	5.07%	69%
2001	71,608	70,844	4,703	13,032	3.30%	67%
2002	71,427	70,671	4,638	12,945	1.21%	66%
2003	72,026	71,272	4,671	12,989	3.23%	66%
2004	71,781	71,027	4,617	12,918	1.42%	66%
2005	72,198	71,445	4,651	12,963	2.32%	66%
2006	72,194	71,439	4,650	12,962	2.79%	66%
2007	71,971	71,217	4,634	12,941	2.16%	66%

Table 13. Numbers of longnose skate at age, estimated by the base model (continued on the next page).

	Age (years)																								
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1915	15454	12653	10359	8481	6944	5685	4655	3811	3120	2555	2092	1712	1402	1148	940	769	630	516	422	346	283	232	190	155	702
1916	15454	12653	10359	8481	6944	5685	4655	3811	3120	2555	2092	1712	1402	1148	940	769	630	516	422	346	283	232	190	155	702
1917	15452	12653	10359	8481	6944	5685	4655	3811	3120	2554	2091	1712	1402	1148	939	769	630	516	422	346	283	232	190	155	701
1918	15449	12651	10359	8481	6944	5685	4655	3811	3120	2554	2091	1712	1401	1147	939	769	629	515	422	345	283	232	190	155	701
1919	15443	12648	10358	8481	6944	5685	4655	3811	3120	2554	2091	1711	1400	1146	938	768	629	515	421	345	282	231	189	155	700
1920	15435	12644	10355	8480	6944	5685	4655	3811	3120	2554	2090	1710	1400	1145	937	767	628	514	421	345	282	231	189	155	699
1921	15426	12637	10352	8478	6943	5685	4655	3811	3120	2553	2090	1710	1399	1144	936	766	627	513	420	344	282	231	189	155	698
1922	15415	12630	10346	8475	6941	5684	4654	3811	3119	2553	2089	1709	1398	1143	935	765	626	512	419	343	281	230	188	154	696
1923	15403	12621	10340	8471	6939	5683	4654	3810	3119	2553	2089	1708	1397	1142	934	764	625	511	418	342	280	229	188	154	695
1924	15389	12611	10333	8466	6935	5681	4653	3810	3119	2553	2088	1708	1396	1141	933	763	624	510	417	342	280	229	187	153	693
1925	15374	12600	10325	8460	6931	5678	4651	3809	3118	2552	2088	1707	1395	1140	932	762	622	509	416	341	279	228	187	153	691
1926	15358	12587	10315	8453	6926	5674	4648	3807	3118	2552	2087	1706	1394	1139	931	760	621	508	415	340	278	227	186	152	688
1927	15340	12574	10305	8445	6920	5670	4646	3805	3116	2551	2087	1706	1394	1138	930	759	620	507	414	339	277	227	185	152	685
1928	15322	12560	10294	8437	6914	5666	4642	3803	3115	2549	2086	1705	1393	1137	928	758	619	506	413	338	276	226	185	151	683
1929	15303	12545	10283	8428	6907	5661	4638	3800	3112	2548	2084	1704	1392	1136	927	757	618	504	412	337	275	225	184	151	679
1930	15283	12529	10270	8418	6900	5655	4634	3797	3110	2546	2083	1702	1390	1135	926	756	617	503	411	336	274	224	183	150	676
1931	15262	12513	10258	8408	6892	5649	4630	3794	3107	2544	2081	1701	1389	1134	925	754	615	502	410	335	273	223	183	149	673
1932	15241	12496	10244	8398	6884	5643	4625	3790	3104	2542	2079	1699	1387	1132	923	753	614	501	409	334	272	222	182	149	669
1933	15219	12478	10230	8387	6875	5636	4619	3786	3101	2539	2077	1697	1386	1130	922	752	613	500	408	333	271	222	181	148	665
1934	15197	12461	10216	8375	6866	5629	4614	3781	3098	2536	2075	1695	1384	1129	920	750	611	499	406	332	271	221	180	147	661
1935	15174	12442	10201	8364	6857	5621	4608	3777	3094	2533	2072	1693	1382	1127	919	749	610	497	405	331	270	220	180	147	658
1936	15150	12423	10186	8352	6847	5614	4602	3772	3090	2530	2069	1691	1380	1125	917	747	609	496	404	329	269	219	179	146	654
1937	15126	12404	10171	8339	6837	5606	4596	3767	3086	2527	2067	1688	1377	1123	915	745	607	494	403	328	268	218	178	145	650
1938	15101	12384	10155	8327	6827	5598	4589	3762	3082	2523	2064	1685	1375	1121	913	743	605	493	402	327	267	217	177	145	645
1939	15076	12364	10139	8314	6817	5589	4583	3756	3078	2520	2060	1683	1372	1118	911	741	604	491	400	326	266	216	176	144	641
1940	15050	12343	10122	8300	6806	5581	4576	3751	3073	2516	2057	1680	1370	1116	908	739	602	490	399	325	265	216	176	143	637
1941	15023	12322	10105	8287	6795	5572	4569	3745	3069	2512	2054	1677	1367	1113	906	737	600	488	397	323	263	215	175	142	633
1942	14995	12300	10087	8273	6784	5563	4562	3739	3064	2508	2051	1674	1365	1111	904	735	598	486	396	322	262	214	174	142	629
1943	14967	12277	10069	8258	6773	5554	4554	3733	3059	2504	2047	1671	1362	1108	902	733	596	485	394	321	261	213	173	141	625
1944	14938	12254	10051	8243	6761	5545	4547	3727	3054	2500	2044	1668	1359	1106	899	731	594	483	393	319	260	212	172	140	620
1945	14909	12230	10032	8228	6749	5535	4539	3721	3049	2496	2040	1665	1356	1103	897	729	592	481	391	318	259	210	171	139	616
1946	14878	12206	10013	8213	6736	5525	4531	3715	3044	2492	2036	1661	1353	1100	894	726	590	479	390	317	257	209	170	139	612
1947	14848	12181	9993	8197	6724	5515	4523	3708	3039	2487	2033	1658	1350	1098	892	724	588	477	388	315	256	208	169	138	607
1948	14816	12156	9972	8181	6711	5504	4514	3702	3033	2483	2029	1654	1347	1095	889	722	586	476	386	314	255	207	168	137	603
1949	14784	12130	9952	8164	6697	5494	4506	3695	3028	2478	2025	1651	1344	1092	886	719	584	474	384	312	254	206	168	136	598
1950	14751	12104	9931	8147	6684	5483	4497	3688	3022	2473	2021	1647	1340	1089	884	717	581	472	383	311	252	205	167	135	593
1951	14754	12077	9910	8130	6670	5472	4488	3681	3017	2471	2020	1649	1343	1091	886	719	583	473	383	311	253	205	167	135	592
1952	14769	12079	9888	8113	6656	5461	4480	3674	3013	2468	2020	1650	1345	1095	889	722	585	475	385	312	253	206	167	136	593
1953	14781	12092	9889	8095	6642	5449	4471	3667	3007	2464	2017	1649	1346	1097	892	724	588	477	386	313	254	206	167	136	593
1954	14724	12101	9899	8096	6627	5437	4461	3658	2998	2454	2006	1638	1335	1087	884	718	583	473	383	311	252	204	166	135	586
1955	14734	12055	9907	8104	6628	5425	4451	3651	2993	2452	2005	1637	1335	1087	885	719	584	474	384	312	253	205	166	135	586
1956	14674	12063	9869	8110	6634	5426	4441	3642	2985	2443	1996	1627	1325	1077	876	712	578	469	381	309	251	203	165	134	580
1957	14675	12014	9876	8079	6640	5431	4442	3635	2980	2440	1995	1628	1325	1078	876	711	578	469	381	309	251	203	165	134	579
1958	14682	12015	9836	8085	6614	5436	4446	3636	2974	2437	1994	1628	1326	1079	877	712	578	470	382	310	251	204	165	134	579
1959	14687	12021	9836	8053	6619	5415	4450	3639	2975	2432	1991	1626	1326	1080	878	713	579	470	382	310	252	204	166	134	580
1960	14677	12025	9841	8053	6592	5419	4433	3642	2977	2431	1985	1622	1323	1077	876	712	578	469	381	309	251	204	166	134	579
1961	14689	12017	9845	8057	6593	5397	4436	3629	2981	2435	1987	1620	1323	1078	877	713	579	470	382	310	252	204	166	135	580

Table 13 (continuation). Numbers of longnose skate at age, estimated by the base model.

	Age (years)																								
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1962	14558	12027	9836	8059	6595	5396	4417	3629	2964	2427	1975	1603	1300	1057	858	697	566	460	373	303	246	200	162	132	567
1963	14506	11919	9845	8052	6597	5399	4417	3614	2967	2419	1976	1603	1297	1050	852	691	561	455	370	300	243	198	161	130	562
1964	14442	11877	9757	8060	6592	5400	4419	3614	2954	2421	1968	1603	1296	1046	844	684	555	450	365	297	241	195	159	129	556
1965	14382	11824	9723	7987	6598	5396	4420	3616	2954	2411	1970	1596	1296	1044	841	678	549	445	361	293	238	193	157	127	549
1966	14374	11775	9680	7960	6539	5401	4417	3618	2958	2414	1967	1604	1297	1051	846	681	549	445	360	292	237	193	156	127	548
1967	14353	11769	9640	7925	6516	5353	4421	3615	2959	2416	1968	1600	1301	1051	850	684	550	444	359	291	236	192	155	126	545
1968	14336	11752	9634	7892	6488	5334	4382	3618	2956	2417	1969	1601	1298	1054	850	687	552	444	358	290	235	191	155	126	542
1969	14259	11737	9620	7887	6460	5311	4366	3585	2957	2410	1964	1594	1290	1042	844	680	549	441	355	286	231	188	152	124	533
1970	14236	11674	9608	7875	6456	5288	4347	3573	2931	2414	1964	1595	1291	1043	841	681	548	442	356	286	230	186	151	123	529
1971	14257	11655	9557	7866	6447	5286	4329	3558	2923	2396	1971	1601	1299	1050	847	683	553	445	359	288	232	187	151	123	529
1972	14309	11673	9542	7825	6440	5278	4327	3544	2912	2392	1960	1611	1307	1060	857	691	557	451	363	293	235	189	152	123	531
1973	14349	11715	9556	7812	6406	5273	4321	3542	2900	2382	1955	1600	1314	1066	863	697	563	454	367	295	238	191	154	124	533
1974	14389	11748	9591	7824	6396	5245	4316	3537	2899	2372	1946	1596	1305	1071	868	703	568	458	369	299	240	194	156	125	535
1975	14429	11781	9618	7852	6405	5236	4294	3533	2895	2371	1939	1589	1302	1063	872	707	572	462	373	300	243	195	158	127	537
1976	14462	11813	9645	7874	6429	5244	4287	3515	2891	2367	1937	1582	1296	1060	866	710	575	465	376	303	244	198	159	128	540
1977	14425	11840	9671	7896	6446	5263	4292	3508	2873	2360	1927	1572	1280	1046	854	697	571	462	374	302	244	196	159	128	537
1978	14386	11811	9693	7917	6464	5277	4308	3512	2868	2345	1921	1564	1272	1033	842	687	560	459	371	301	243	196	158	128	535
1979	14276	11778	9668	7934	6480	5291	4319	3524	2869	2336	1902	1551	1256	1017	824	670	546	445	364	295	239	193	156	125	526
1980	14153	11688	9641	7914	6494	5304	4330	3532	2877	2336	1893	1534	1243	1003	809	654	532	433	353	289	234	189	153	123	516
1981	14095	11587	9568	7892	6478	5316	4342	3543	2887	2347	1900	1534	1238	1001	806	649	524	426	347	283	231	187	152	122	513
1982	13752	11540	9482	7830	6459	5301	4349	3547	2885	2336	1881	1505	1201	960	770	617	496	400	325	265	215	176	143	116	484
1983	13543	11260	9445	7761	6409	5286	4337	3555	2893	2342	1884	1504	1194	946	752	602	481	387	312	253	206	168	137	111	467
1984	13404	11088	9216	7731	6352	5245	4326	3547	2902	2353	1895	1514	1201	948	749	594	474	379	304	245	199	162	132	108	456
1985	13386	10975	9077	7545	6329	5200	4294	3539	2899	2368	1914	1537	1224	968	763	601	477	381	304	244	197	160	130	106	453
1986	13326	10960	8983	7430	6176	5181	4256	3512	2891	2362	1921	1546	1235	980	773	608	479	379	303	242	194	157	127	104	444
1987	13306	10910	8971	7354	6082	5055	4240	3482	2870	2357	1920	1555	1247	993	785	619	486	383	303	242	193	155	125	102	438
1988	13276	10894	8931	7344	6020	4979	4138	3469	2845	2339	1914	1552	1251	999	793	627	493	387	305	241	193	154	124	100	430
1989	13312	10869	8918	7311	6012	4928	4075	3386	2836	2322	1905	1554	1256	1011	806	639	504	397	312	245	194	155	124	100	426
1990	13345	10899	8898	7301	5985	4921	4034	3335	2768	2314	1890	1545	1257	1013	814	648	513	405	319	250	197	156	125	100	422
1991	13406	10926	8923	7284	5977	4900	4029	3301	2727	2260	1886	1536	1253	1017	819	657	523	414	327	257	202	159	126	100	421
1992	13482	10976	8945	7305	5963	4893	4011	3297	2700	2228	1843	1535	1248	1016	823	662	531	422	335	264	208	163	128	102	421
1993	13586	11038	8986	7323	5980	4882	4005	3283	2698	2208	1820	1504	1251	1015	826	669	538	432	343	272	215	169	133	104	425
1994	13660	11123	9036	7357	5995	4896	3997	3278	2685	2204	1801	1482	1222	1015	823	669	542	436	349	278	220	174	137	107	428
1995	13699	11184	9106	7398	6022	4908	4007	3270	2681	2192	1796	1463	1200	988	819	663	539	436	351	281	224	177	140	110	432
1996	13778	11216	9156	7455	6056	4930	4018	3280	2676	2192	1791	1464	1192	977	803	665	539	438	354	285	228	182	144	114	440
1997	13701	11280	9181	7495	6102	4957	4035	3286	2679	2179	1776	1443	1174	951	777	637	527	427	347	281	226	181	144	114	438
1998	13448	11218	9232	7514	6134	4994	4056	3297	2677	2170	1750	1412	1136	916	737	600	491	406	329	267	216	174	139	111	425
1999	13386	11010	9183	7557	6150	5021	4087	3317	2694	2181	1761	1414	1135	909	731	587	477	391	323	261	212	172	138	111	426
2000	13232	10960	9012	7516	6185	5034	4108	3342	2707	2189	1762	1412	1125	898	716	574	461	374	306	253	205	166	135	108	421
2001	13032	10833	8970	7376	6151	5062	4119	3358	2725	2197	1764	1408	1119	885	703	558	447	358	291	238	197	159	129	105	411
2002	12945	10670	8867	7342	6037	5035	4143	3369	2742	2218	1780	1422	1128	892	703	557	442	354	284	230	188	156	126	102	408
2003	12989	10599	8735	7259	6011	4943	4122	3391	2755	2241	1809	1449	1155	915	723	569	451	358	286	229	186	152	126	102	413
2004	12918	10635	8676	7150	5942	4920	4045	3371	2769	2243	1816	1459	1162	922	728	574	452	357	284	227	182	148	121	100	408
2005	12963	10577	8706	7102	5853	4865	4028	3310	2757	2261	1829	1477	1183	941	745	588	463	364	288	229	183	147	119	97	410
2006	12962	10614	8658	7127	5814	4792	3982	3295	2705	2248	1838	1481	1191	951	755	597	471	371	292	231	183	146	117	95	406
2007	12941	10612	8688	7087	5834	4759	3922	3257	2692	2204	1825	1485	1191	954	760	602	475	375	295	232	184	146	117	93	399

Table 14. Summary of recent trends in longnose skate exploitation and estimated population levels.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Landings (mt)	782	1,177	1,351	860	313	848	373	615	742	*576
Estimated Discards (mt)	438	659	757	482	175	475	209	344	415	323
Estimated Total Catch (mt)	1,220	1,835	2,108	1,342	488	1,323	582	959	1,157	*899
ABC (mt)										
OY * (if different from ABC) (mt)										
SPR	74.28%	64.22%	59.83%	71.03%	87.96%	71.56%	85.99%	78.42%	74.81%	79.65%
Exploitation Rate (total catch/summary bi	1.66%	2.50%	2.90%	1.87%	0.68%	1.84%	0.81%	1.33%	1.60%	1.25%
Summary Age 2+ Biomass (B) (mt)	72,877	72,599	71,802	70,844	70,671	71,272	71,027	71,445	71,439	71,217
Spawning Stock Biomass (*SB*) (mt)	5,032	4,982	4,858	4,703	4,638	4,671	4,617	4,651	4,650	4,634
Uncertainty in Spawning Stock Biomass estimate	4,582-5,483	4,532-5,432	4,411-5,305	4,260-5,147	4,196-5,079	4,229-5,113	4,177-5,057	4,211-5,091	4,211-5,090	4,196-5,073
Recruitment at age 0	13,448	13,386	13,232	13,032	12,945	12,989	12,918	12,963	12,962	12,941
Uncertainty in Recruitment estimate	12,414-14,482	12,351-14,421	12,195-14,267	11,995-14,069	11,908-13,982	11,951-14,027	11,880-13,956	11,926-14,000	11,925-13,999	11,905-13,978
Depletion (SB/SB0)	71.54%	70.82%	69.06%	66.86%	65.93%	66.40%	65.64%	66.12%	66.13%	66.44%
Uncertainty in Depletion estimate									64.15%-68.11%	64.46%-68.41%

* indicates values calculated as the average for the last three years (2004-2006)

Table 15. Longnose skate proportion, discard and discard mortality rates used to reconstruct alternative catch histories.

	Longnose proportion, *b* **(≤ 1980)**	Discard rate, *d* **(≤ 1980)**	Discard rate, *d* **(1981-1994)**	Discard mortality rate, *m* **(all years)**
Base	0.62	0.93	0.93	0.5
"Low" catch history	0.5	0.85	0.91	0.3
"High" catch history	0.75	0.97	0.95	0.7

Table 16. Summary of reference points for the longnose skate.

	Point estimate	95% confidence interval
Unfished Spawning Stock Biomass (SB_0) (mt)	7,034	6,521-7,548
Unfished Summary Age 2+ Biomass (B_0) (mt)	90,955	
Unfished Recruitment (R_0) at age 0	15,454	14,403-16,505
Reference points based on SB $_{40\%}$		
MSY Proxy Spawning Stock Biomass ($SB_{40\%}$)	2,814	2,608-3,019
SPR resulting in $SB_{40\%}$ ($SPR_{SB40\%}$)	62.50%	62.4999%-62.500059%
Exploitation rate resulting in $SB_{40\%}$	2.57%	N/A
Yield with $SPR_{SB40\%}$ at $SB_{40\%}$ (mt)	1,264	1,194-1,334
Reference points based on SPR proxy for MSY		
Spawning Stock Biomass at SPR (SB_{SPR})(mt)	844	782-906
$SPR_{MSY\text{-}proxy}$	45%	
Exploitation rate corresponding to SPR	4.26%	N/A
Yield with $SPR_{MSY\text{-}proxy}$ at SB_{SPR} (mt)	787	744-831
Reference points based on estimated MSY values		
Spawning Stock Biomass at MSY (SB_{MSY}) (mt)	2,626	2,433-2,819
SPR_{MSY}	60.84%	60.80%-60.86%
Exploitation Rate corresponding to SPR_{MSY}	2.71%	N/A
MSY (mt)	1,268	1,198-1,338

Table 17. 10-year forecast of longnose skate catch, summary biomass, spawning biomass and stock depletion estimated based on current rate of fishing mortality.

Year	Total catch (mt)	Summary biomass (mt)	Spawning Biomass (mt)	Depletion
2009	901	71,184	4,673	66%
2010	902	71,129	4,697	67%
2011	902	71,060	4,721	67%
2012	902	70,986	4,743	67%
2013	900	70,914	4,763	68%
2014	899	70,848	4,778	68%
2015	897	70,794	4,789	68%
2016	895	70,754	4,795	68%
2017	894	70,727	4,797	68%
2018	892	70,714	4,794	68%

Table 18. 10-year forecast of longnose skate catch, summary biomass, spawning biomass and stock depletion estimated based on F45%.

Year	Total catch (mt)	Summary biomass (mt)	Spawning Biomass (mt)	Depletion
2009	3,428	71,184	4,673	66%
2010	3,269	68,833	4,424	63%
2011	3,128	66,836	4,195	60%
2012	3,006	65,135	3,985	57%
2013	2,902	63,676	3,794	54%
2014	2,816	62,403	3,621	51%
2015	2,745	61,264	3,465	49%
2016	2,686	60,211	3,327	47%
2017	2,638	59,208	3,206	46%
2018	2,598	58,226	3,100	44%

Table 19. Decision table based on alternative states of nature, defined based on alternative catch histories and different levels of NWFSC shelf-slope survey catchability *Q*.

		Low Q (Q=0.654) Low historical catch			Q=0.83 BASE			High Q (Q=1.046) High historical catch		
Forecast	Year	Total catch (mt) (landings and discard mortality)	SSB (mt)	Depletion	Total catch (mt) (landings and discard mortality)	SSB (mt)	Depletion	Total catch (mt) (landings and discard mortality)	SSB (mt)	Depletion
F45% for base scanario 40-10	2009	3,428	5,855	80%	3,428	4,673	66%	3,428	4,021	41%
	2010	3,269	5,577	76%	3,269	4,424	63%	3,269	3,854	39%
	2011	3,128	5,321	72%	3,128	4,195	60%	3,128	3,699	37%
	2012	3,006	5,087	69%	3,006	3,985	57%	3,006	3,555	36%
	2013	2,902	4,874	66%	2,902	3,794	54%	2,902	3,422	35%
	2014	2,816	4,681	64%	2,816	3,621	51%	2,816	3,298	33%
	2015	2,745	4,508	61%	2,745	3,465	49%	2,745	3,185	32%
	2016	2,686	4,353	59%	2,686	3,327	47%	2,686	3,085	31%
	2017	2,638	4,217	57%	2,638	3,206	46%	2,638	2,997	30%
	2018	2,598	4,098	56%	2,598	3,100	44%	2,598	2,923	30%
Average landings and discard mortality for base scanario 2004-2006	2009	899	5,855	80%	899	4,673	66%	899	4,021	41%
	2010	899	5,850	80%	899	4,697	67%	899	4,125	42%
	2011	899	5,845	80%	899	4,721	67%	899	4,228	43%
	2012	899	5,840	80%	899	4,744	67%	899	4,327	44%
	2013	899	5,832	79%	899	4,764	68%	899	4,418	45%
	2014	899	5,823	79%	899	4,779	68%	899	4,500	46%
	2015	899	5,810	79%	899	4,790	68%	899	4,571	46%
	2016	899	5,795	79%	899	4,796	68%	899	4,630	47%
	2017	899	5,777	79%	899	4,797	68%	899	4,679	47%
	2018	899	5,757	78%	899	4,794	68%	899	4,720	48%
50% increase in average landings and discard mortality for base scanario 2004-2006	2009	1,349	5,855	80%	1,349	4,673	66%	1,349	4,021	41%
	2010	1,349	5,801	79%	1,349	4,649	66%	1,349	4,077	41%
	2011	1,349	5,749	78%	1,349	4,624	66%	1,349	4,130	42%
	2012	1,349	5,696	78%	1,349	4,599	65%	1,349	4,179	42%
	2013	1,349	5,643	77%	1,349	4,572	65%	1,349	4,220	43%
	2014	1,349	5,590	76%	1,349	4,542	65%	1,349	4,253	43%
	2015	1,349	5,536	75%	1,349	4,509	64%	1,349	4,277	43%
	2016	1,349	5,482	75%	1,349	4,475	64%	1,349	4,292	43%
	2017	1,349	5,429	74%	1,349	4,439	63%	1,349	4,300	44%
	2018	1,349	5,377	73%	1,349	4,402	63%	1,349	4,303	44%

LIST OF FIGURES:

FIGURES

Figure1. Photograph of longnose skate, *Raja rhina* (photo provided by Duane Stevenson, AFSC).

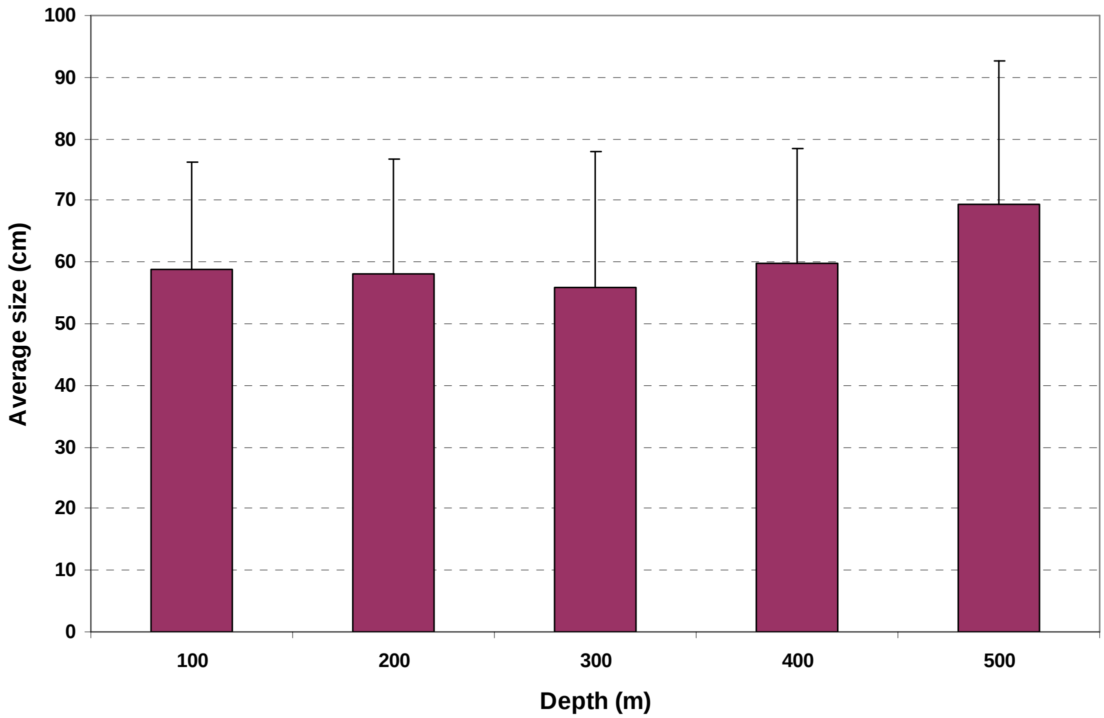

Figure 2. Size distribution of longnose skate by depth, calculated from AFSC triennial survey (1980-2004) (x-axis represents upper threshold values of 100 m depth intervals).

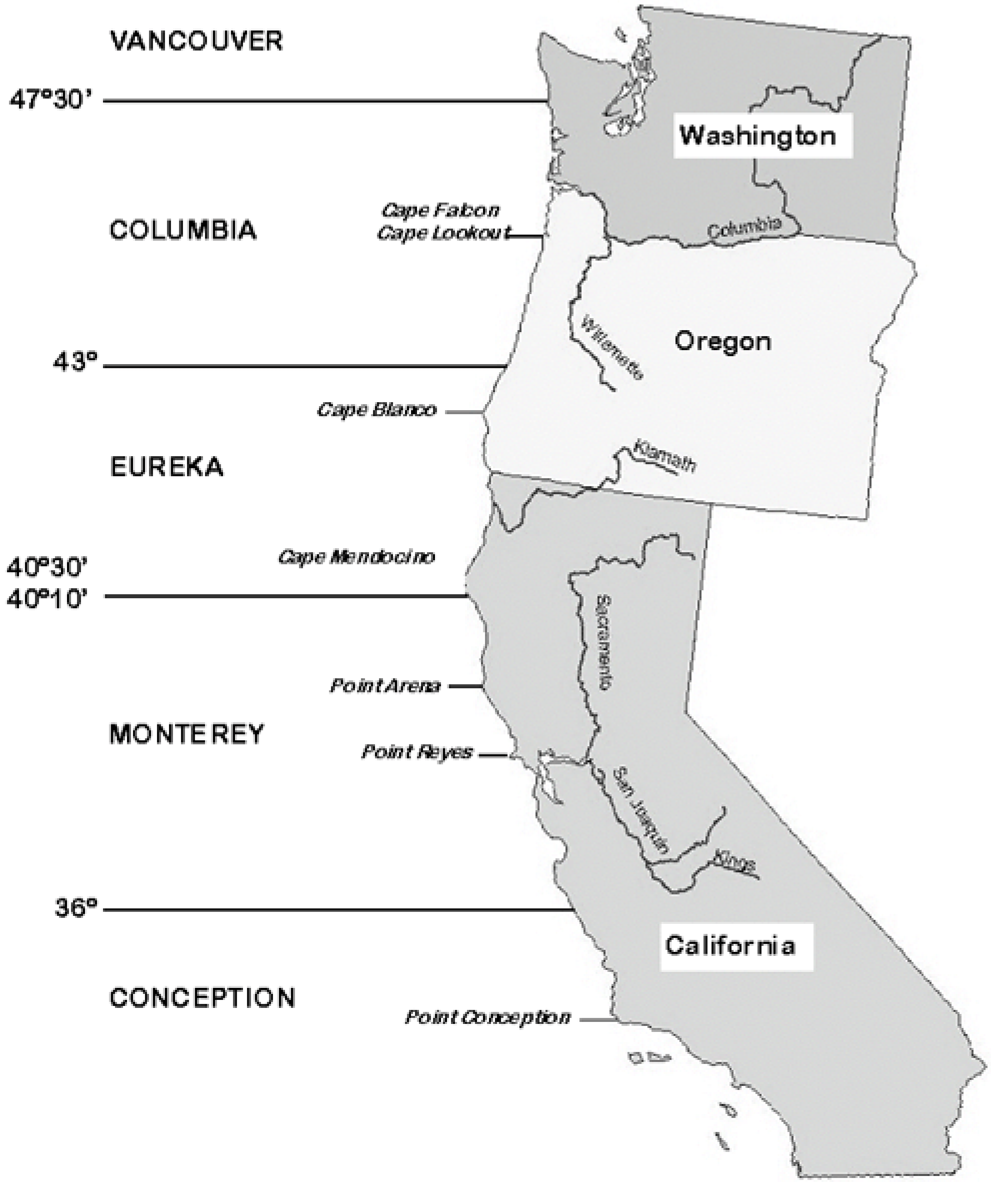

Figure 3. Area map for longnose skate assessment that includes International Northern Pacific Fisheries Council (INPFC) fisheries management regions defined by latitude.

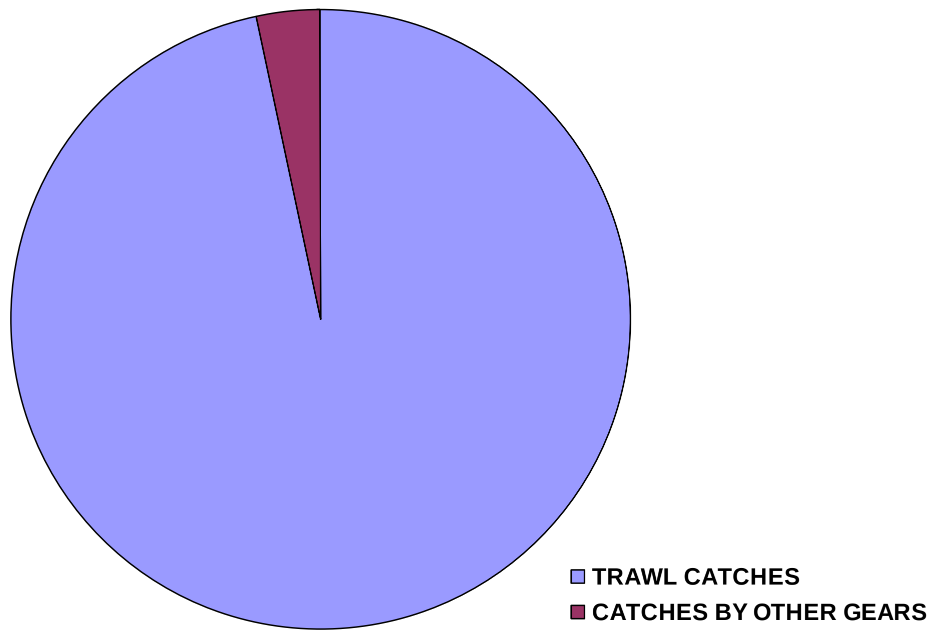

Figure 4. PacFIN skate landings by gear averaged for the last 25 years, indicating that 97% of landed catch was brought by trawl fishery.

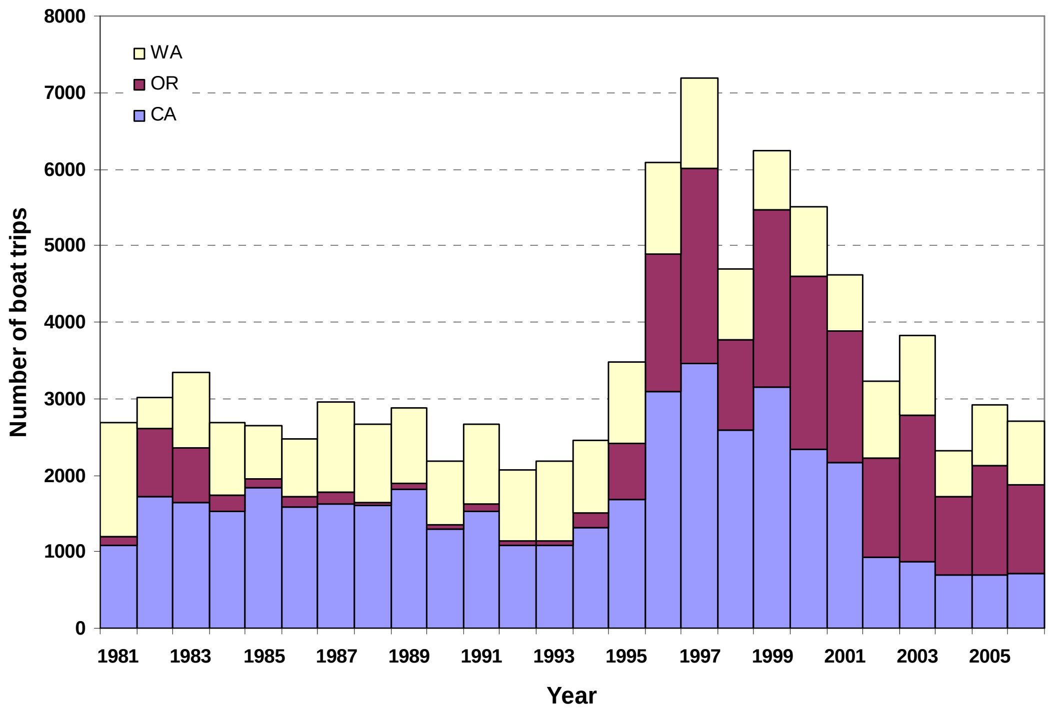

Figure 5. The number of boat trips when skates were landed by state and by year.

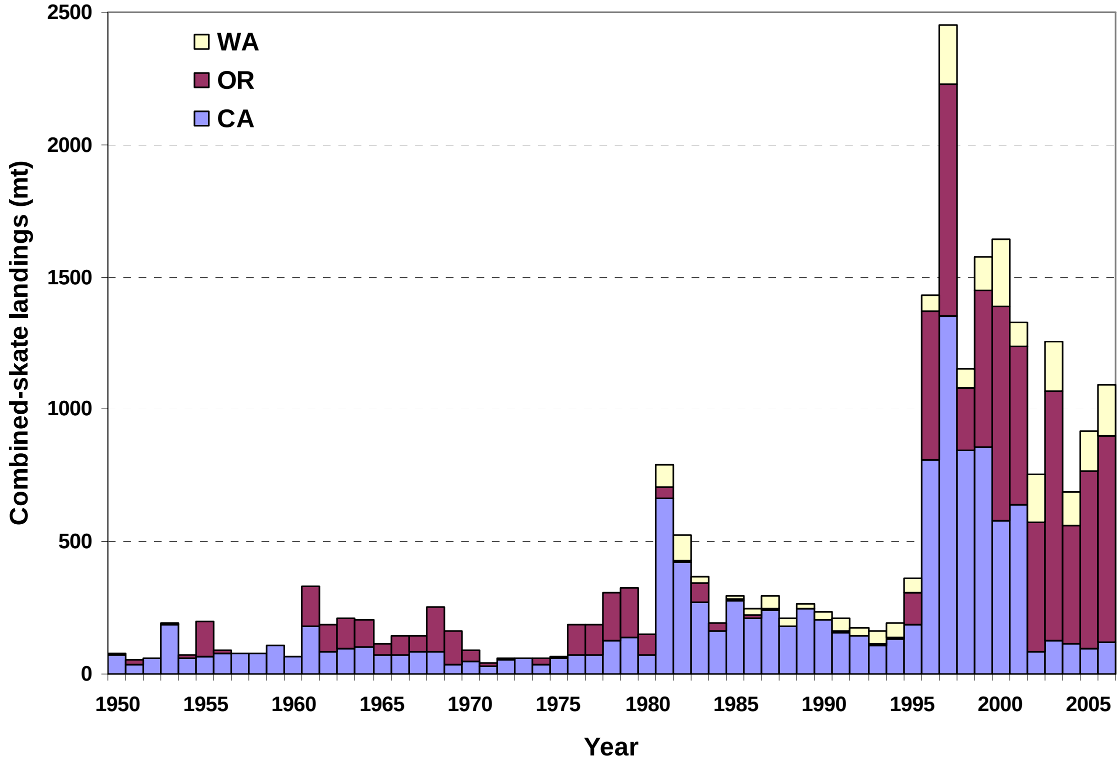

Figure 6. Time-series of combined-skate landings by year and state.

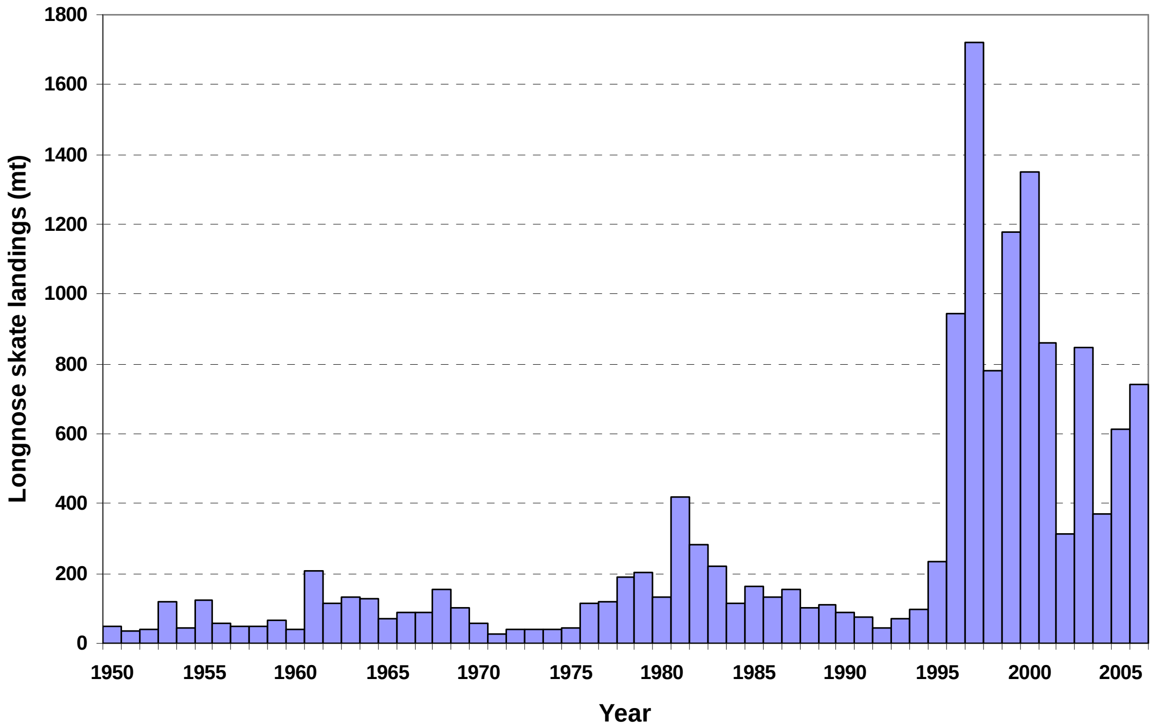

Figure 7. Estimated longnose skate landings by year.

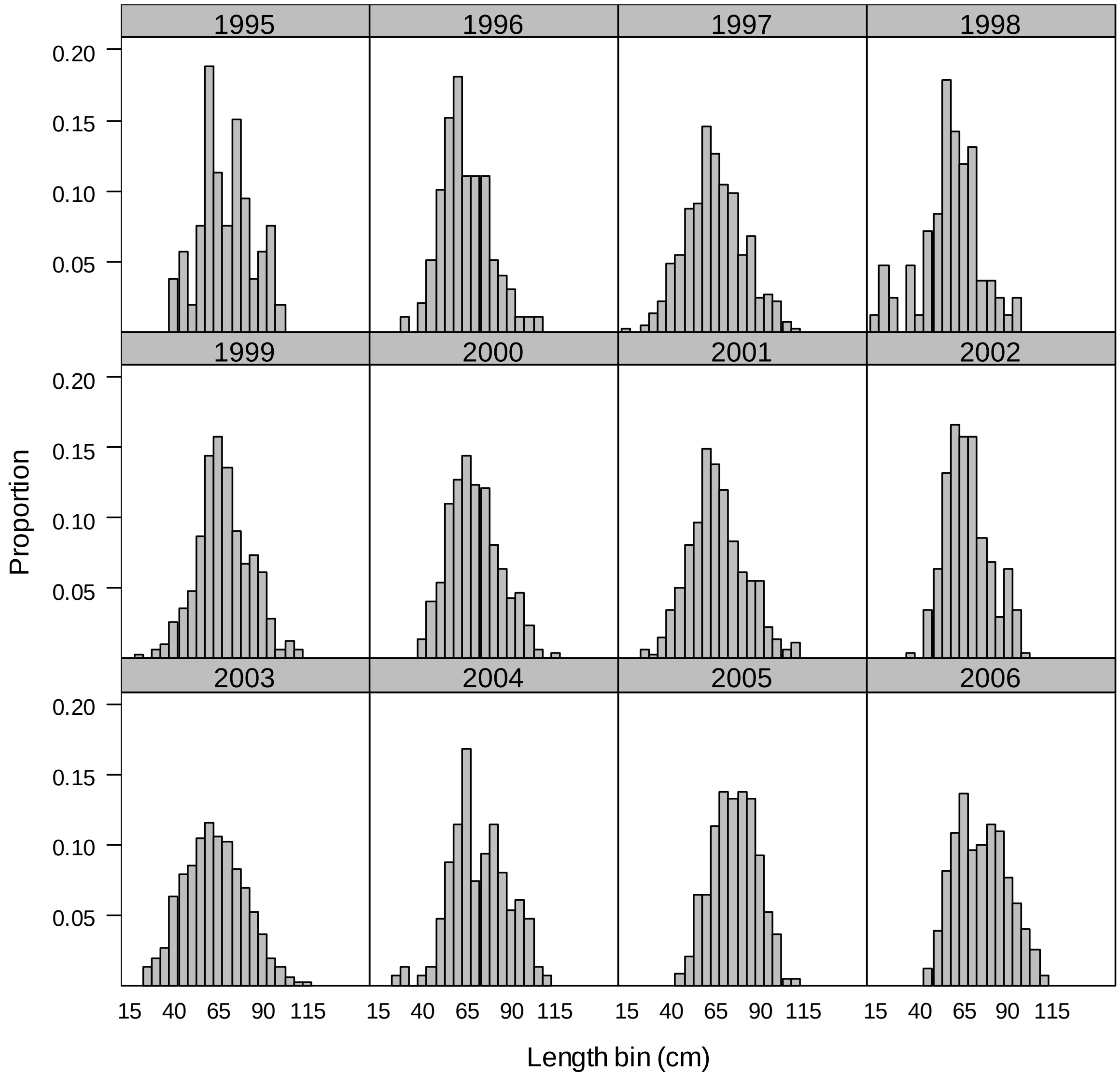

Figure 8. Length composition of longnose skate (both sexes combined) caught in fishery.

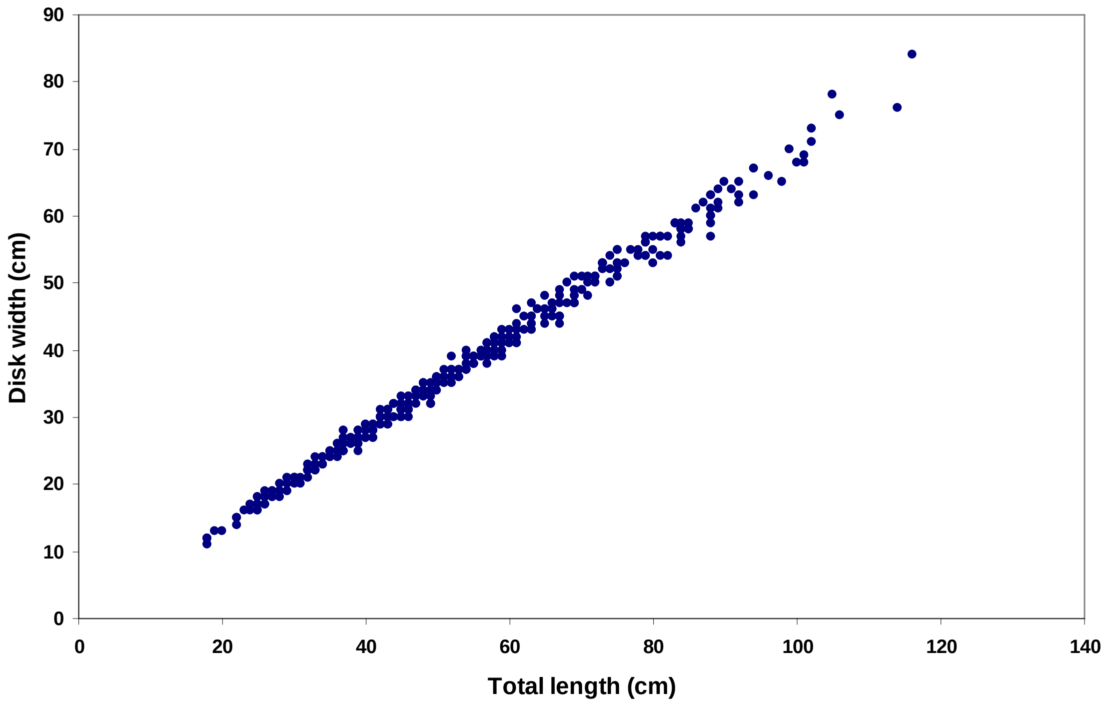

Figure 9. Relationship between total length (TL) and disk width (DW) for the longnose skate received from 1999 AFSC slope survey ($TL = 7.36 + 1.41 \cdot DW$).

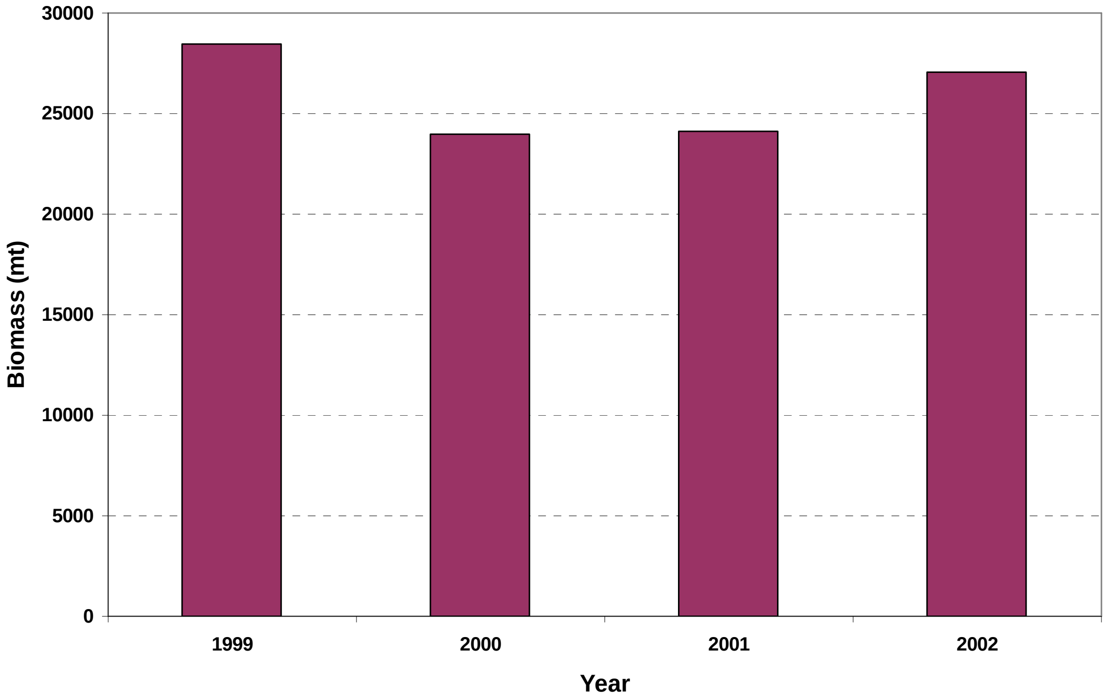

Figure 10. Estimated biomass of the longnose skate from NWFSC slope survey.

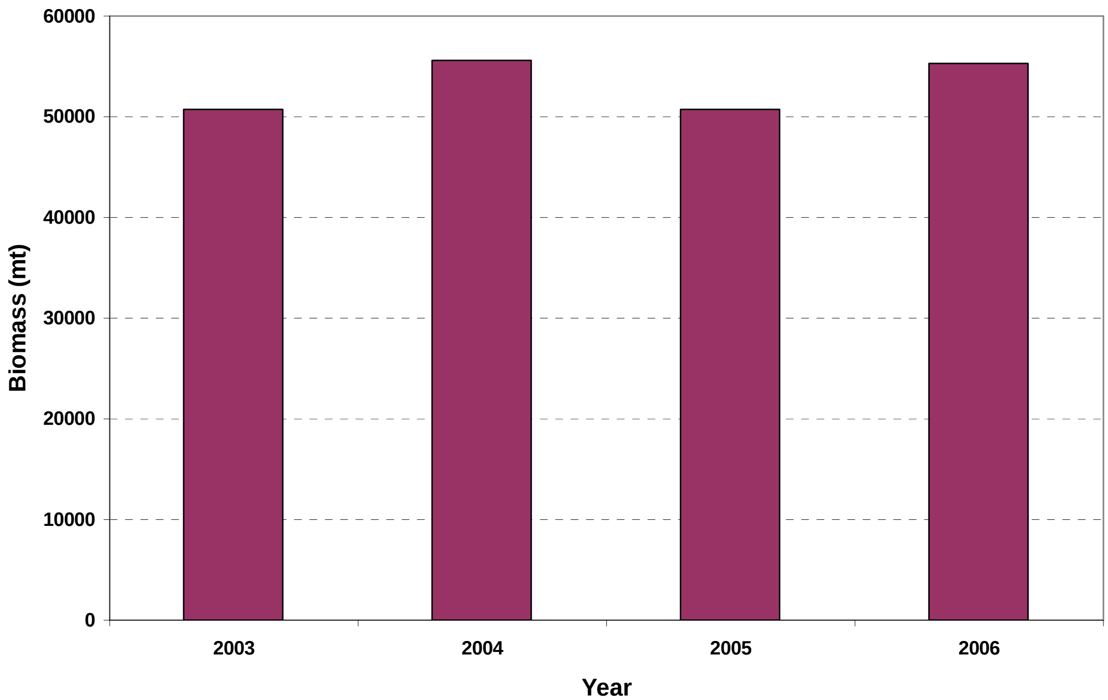

Figure 11. Estimated biomass of the longnose skate from NWFSC shelf-slope survey.

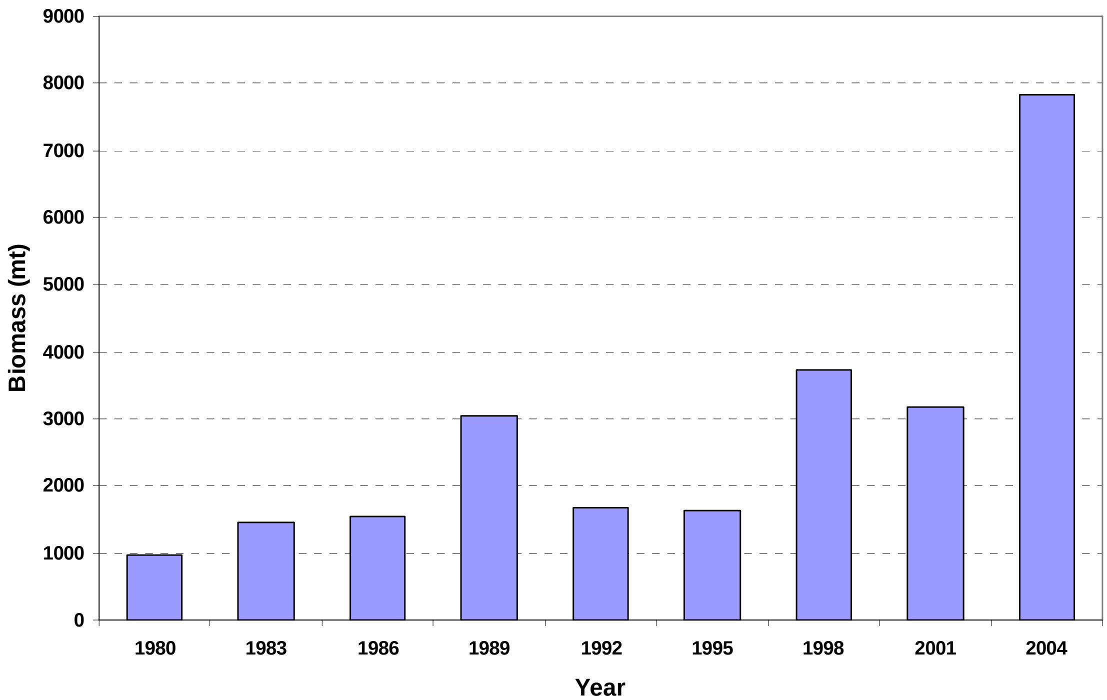

Figure 12. Estimated biomass of the longnose skate from AFSC shelf (triennial) survey.

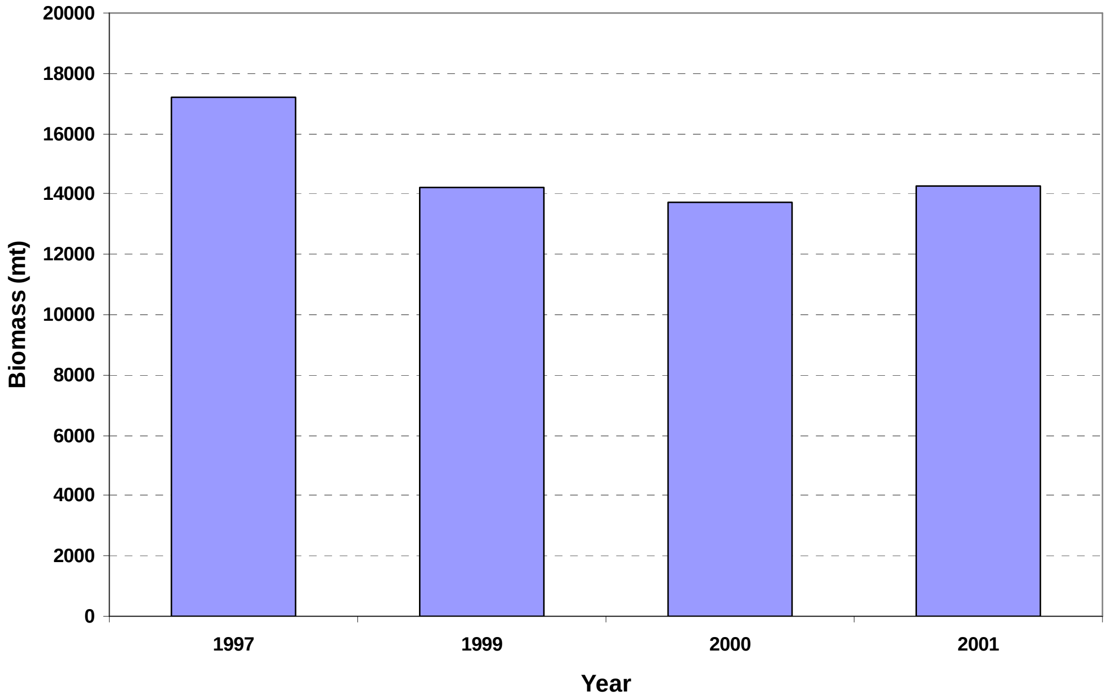

Figure 13. Estimated biomass of the longnose skate from AFSC slope survey.

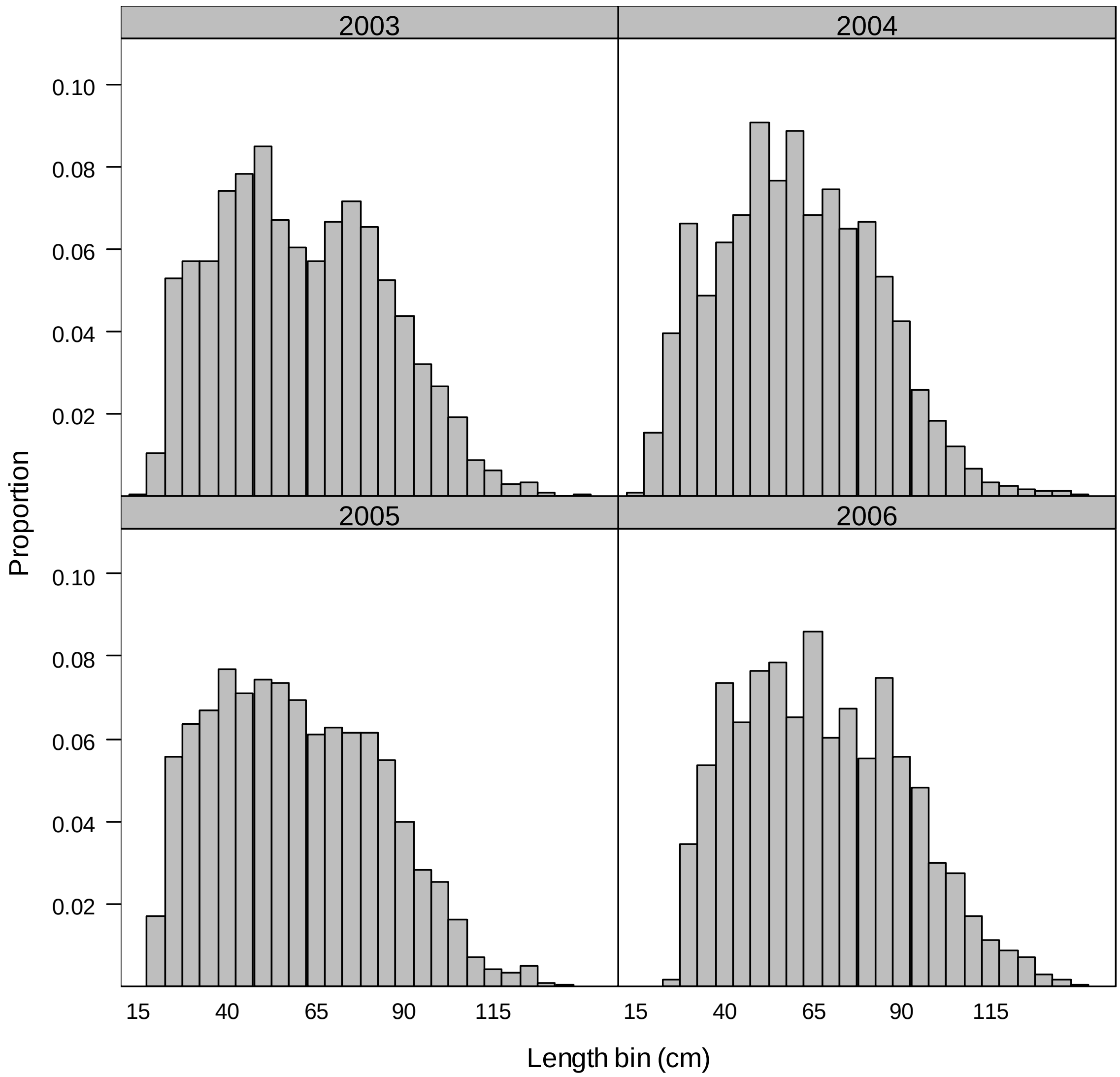

Figure 14. Length composition of longnose skate (both sexes combined) caught in the NWFSC shelf-slope survey.

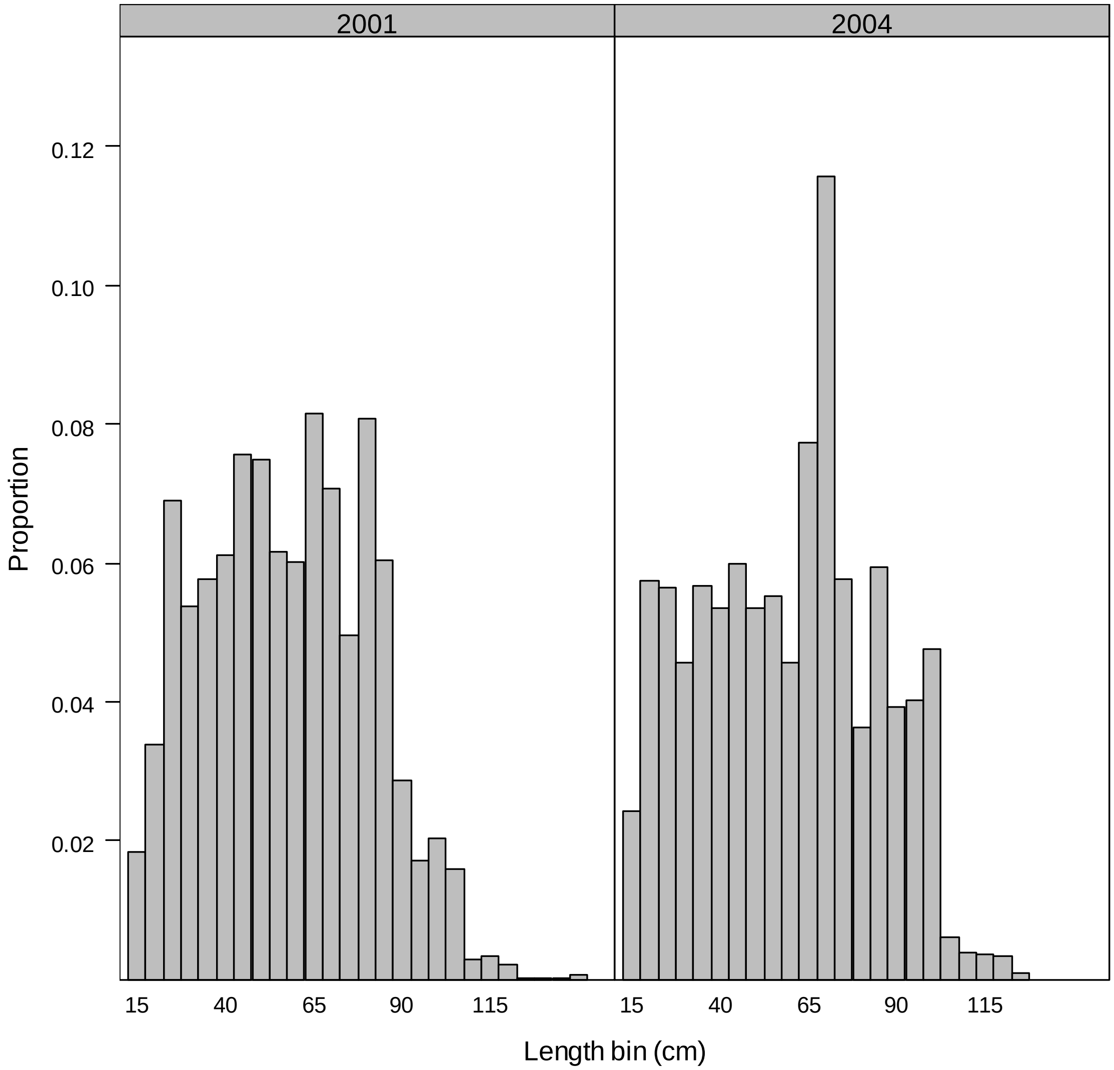

Figure 15. Length composition of longnose skate (both sexes combined) caught in the AFSC shelf (triennial) survey.

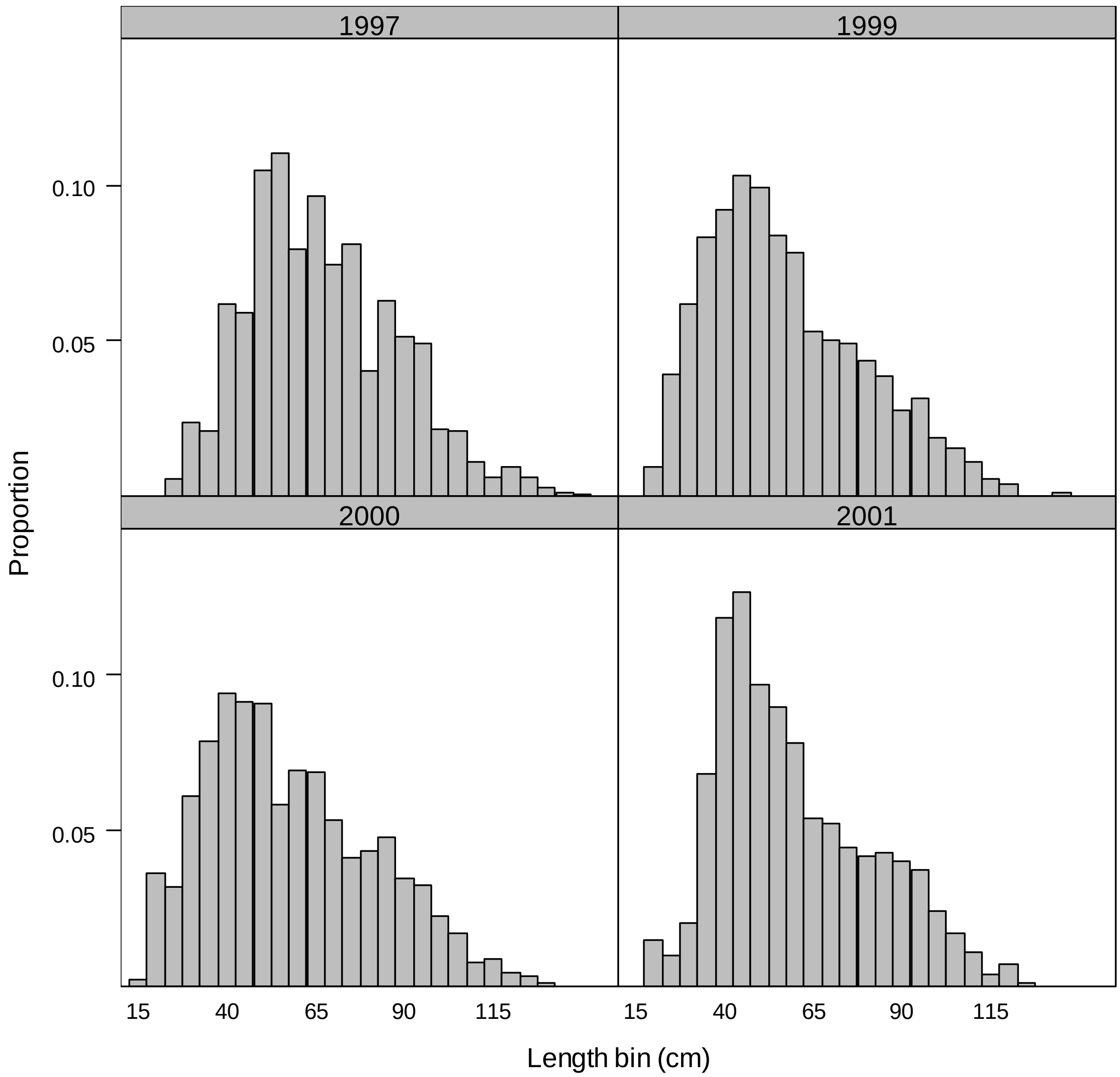

Figure 16. Length composition of longnose skate (both sexes combined) caught in the AFSC slope survey.

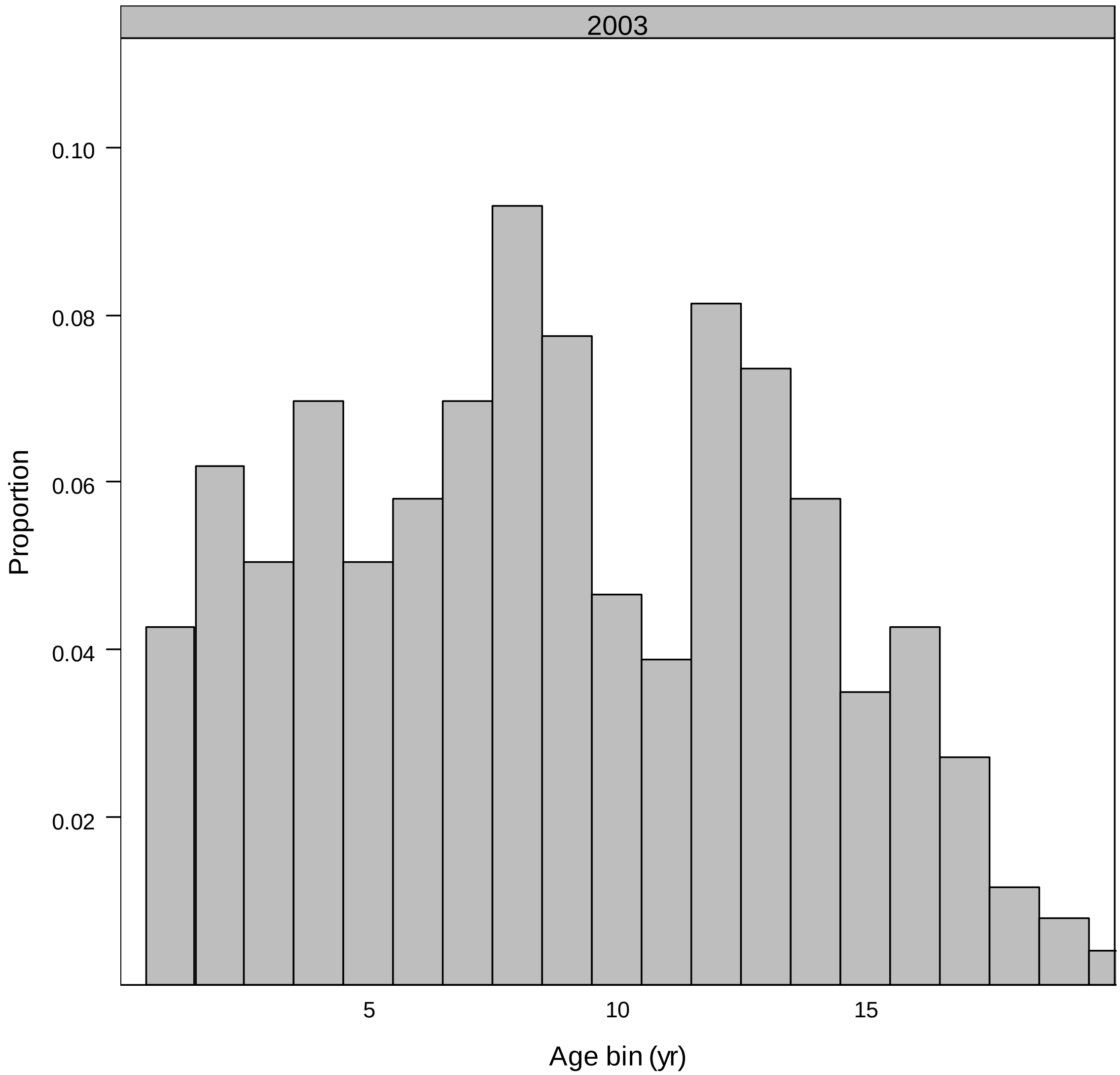

Figure 17. Age composition of longnose skate (both sexes combined) caught in the NWFSC shelf-slope survey (2003).

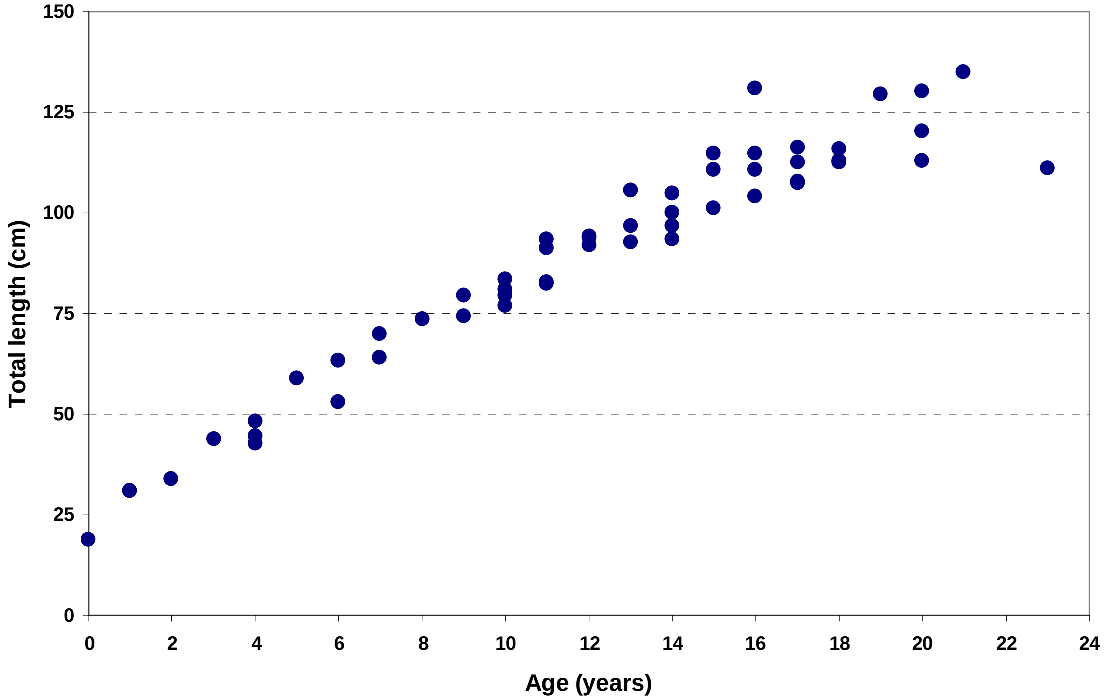

Figure 18. Size-at-age data of longnose skate (both sexes combined) caught in fishery.

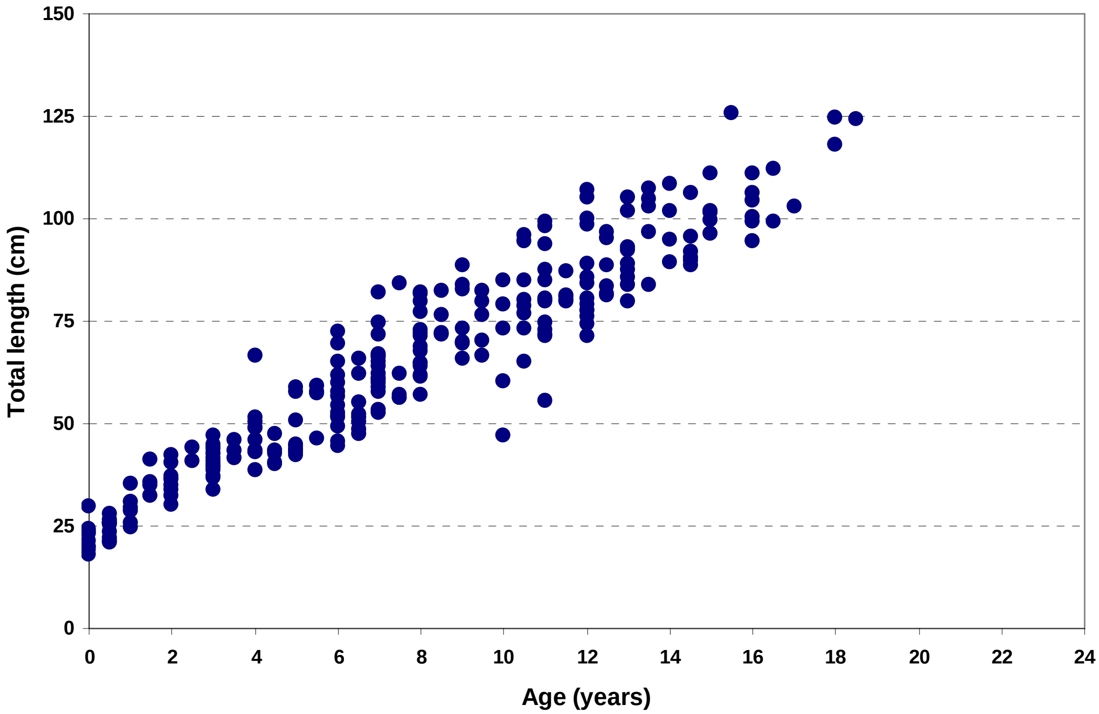

Figure 19. Size-at-age data of longnose skate (both sexes combined) collected in the NWFSC shelf-slope survey.

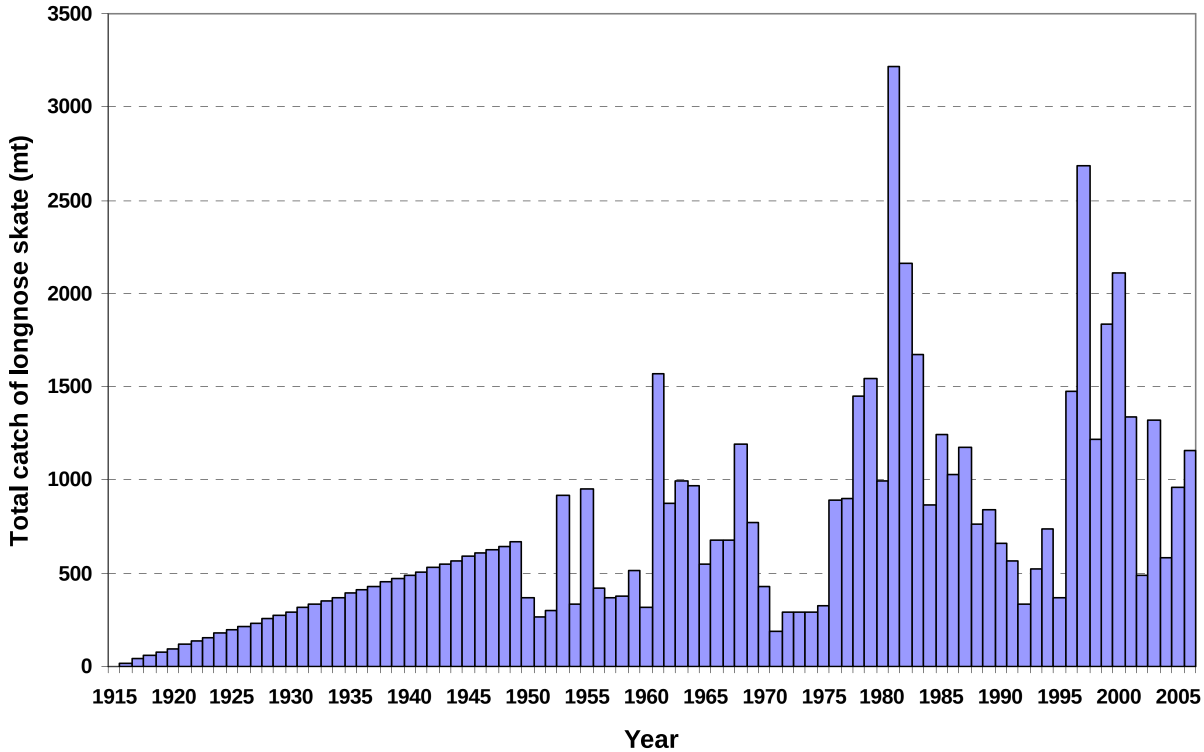

Figure 20. Time-series of estimated longnose skate total catch.

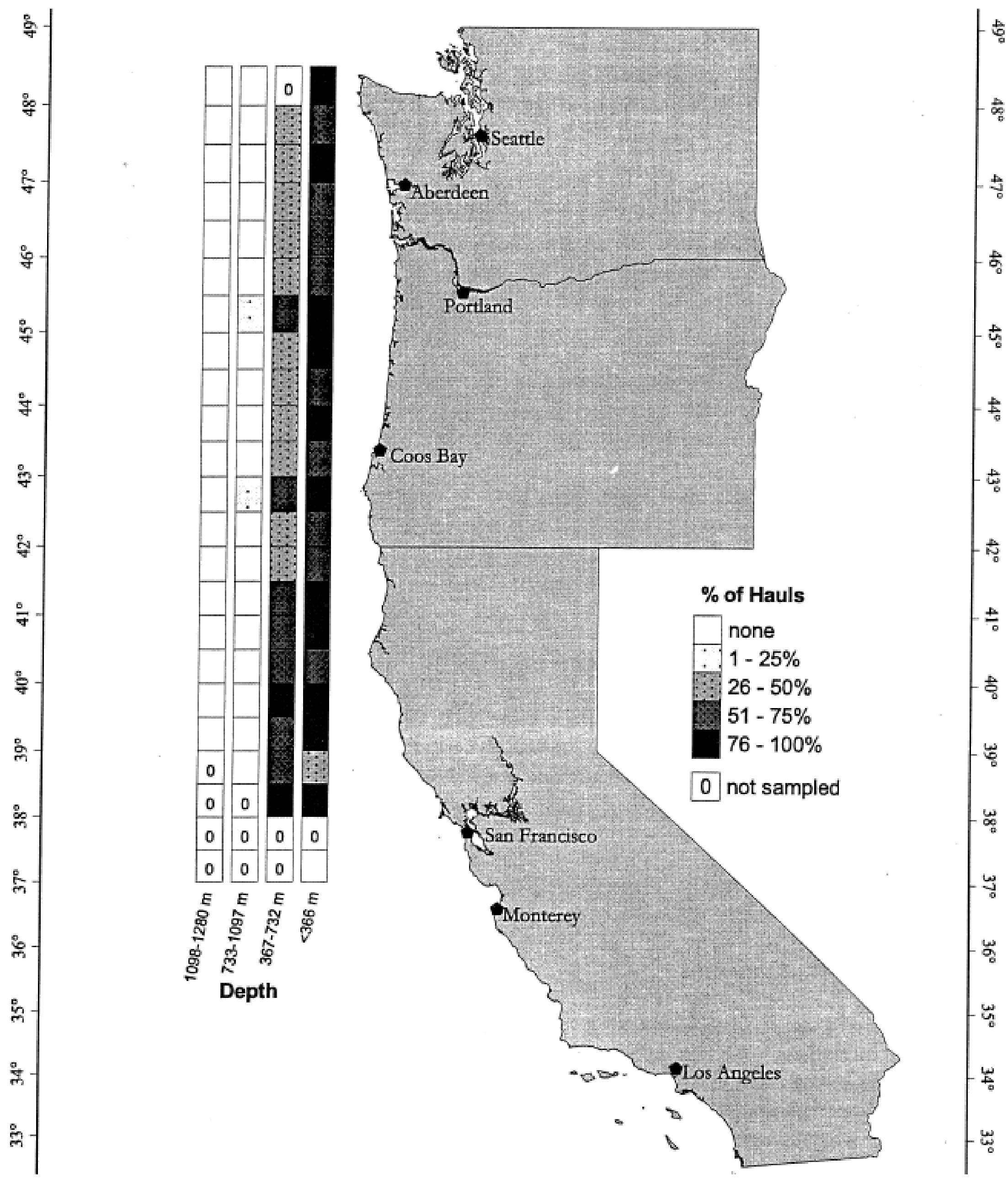

Figure 21. Longnose skate frequency of occurrence in AFSC slope survey by depth (1984-1996).

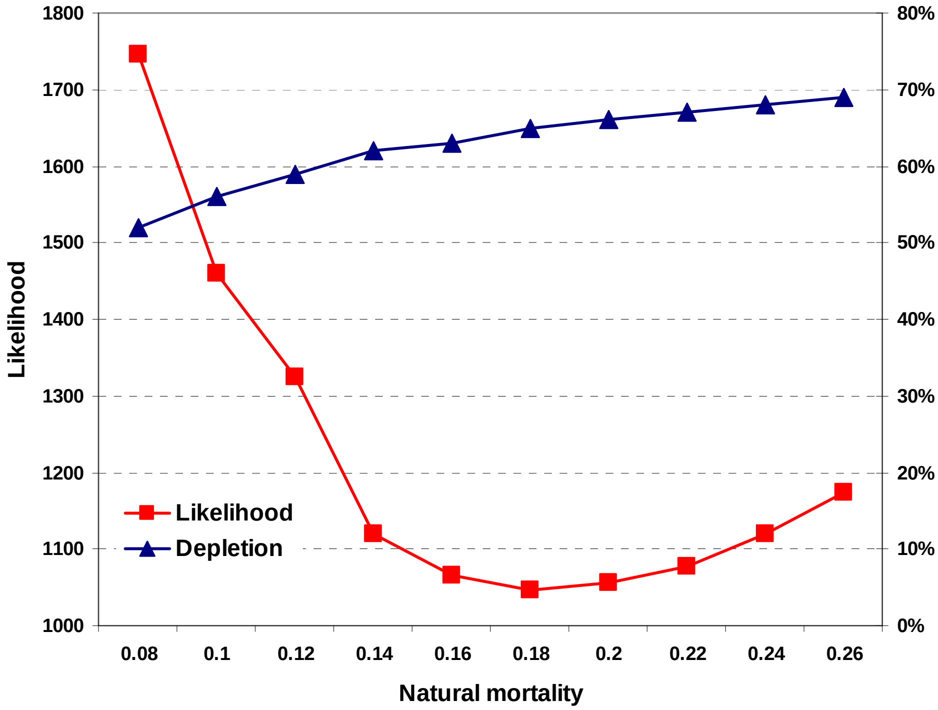

Figure 22. Likelihood profile analysis for natural mortality

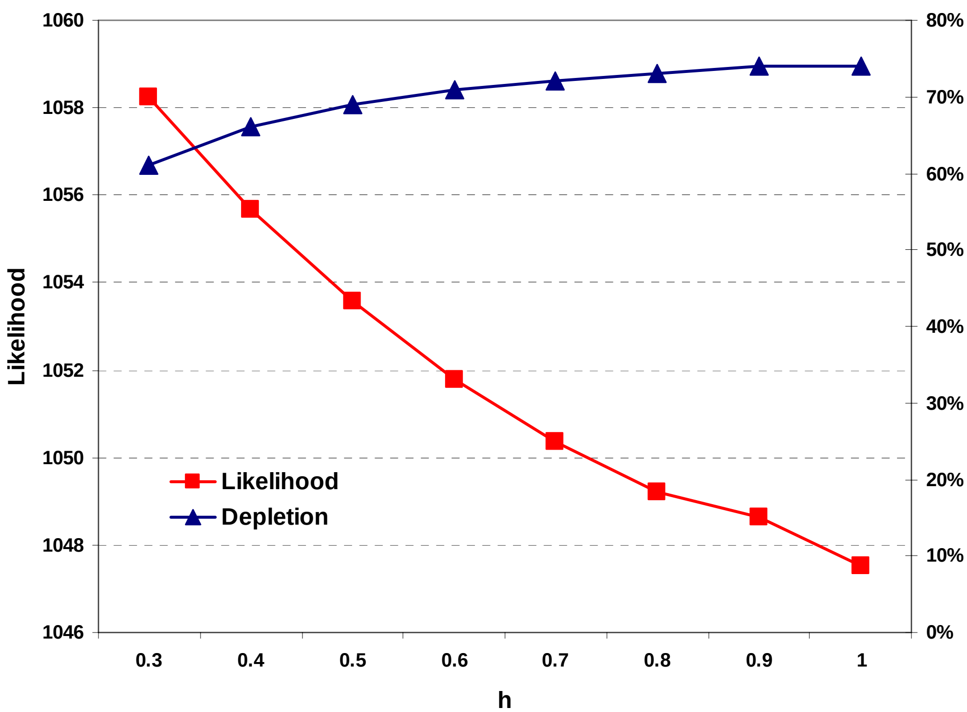

Figure 23. Likelihood profile analysis for stock-recruitment curve steepness *h*.

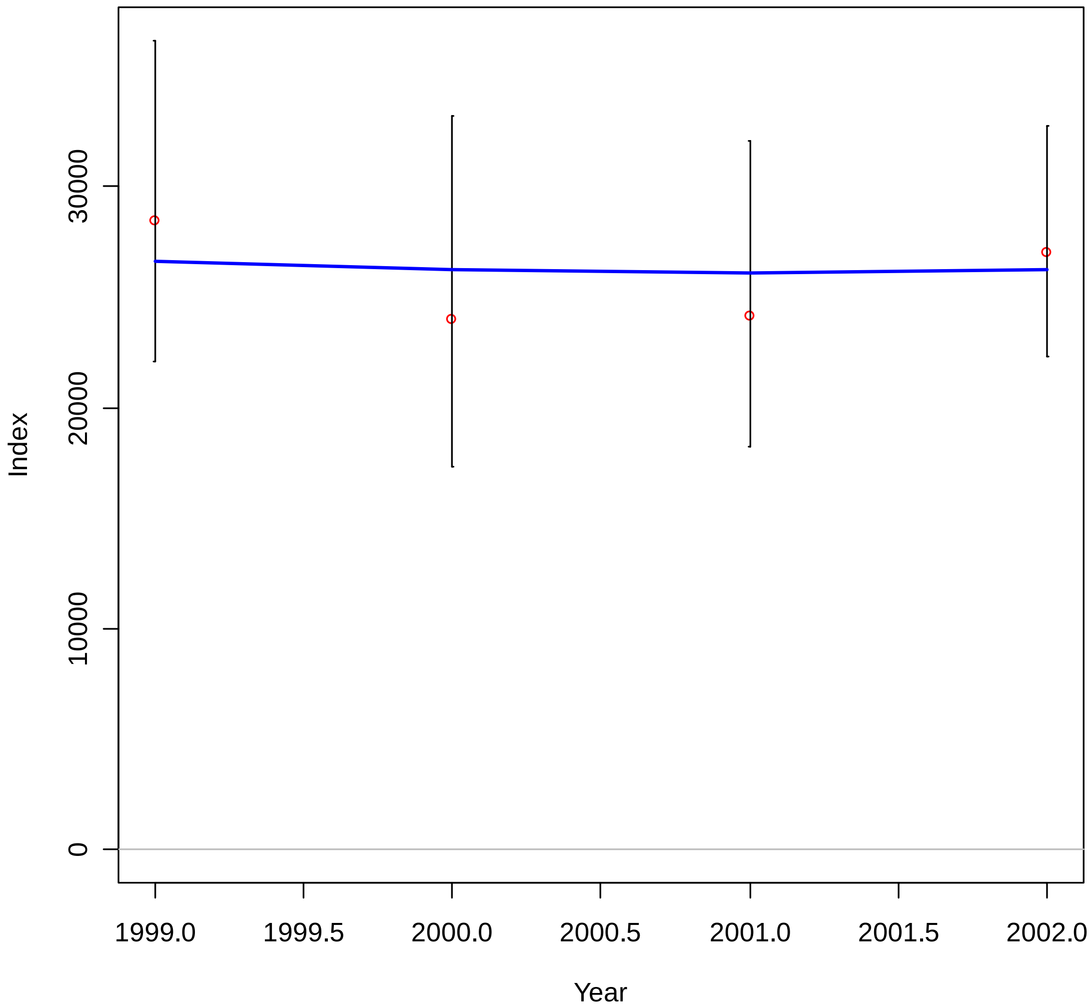

Figure 24. Observed and expected values of biomass index (mt) for the NWFSC shelf-slope survey.

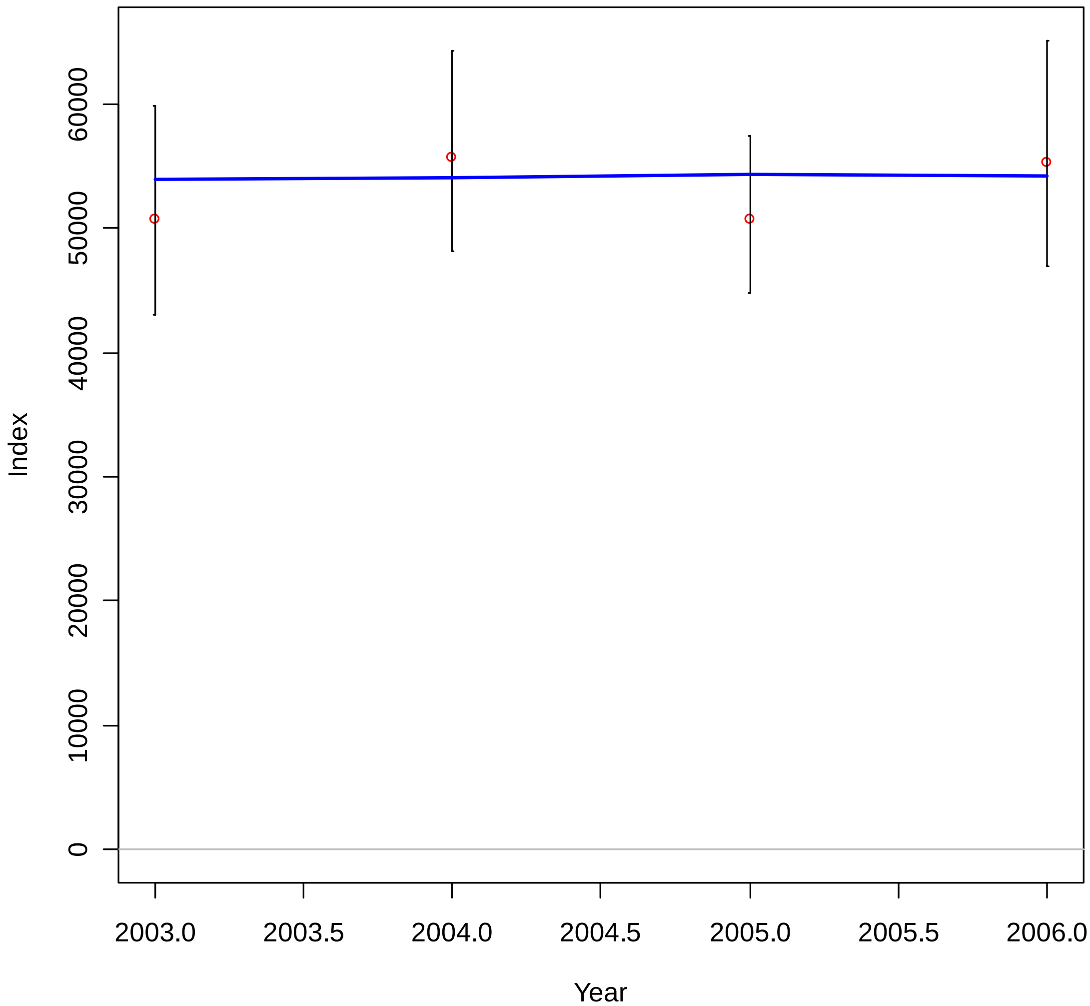

Figure 25. Observed and expected values of biomass index (mt) for the NWFSC slope survey.

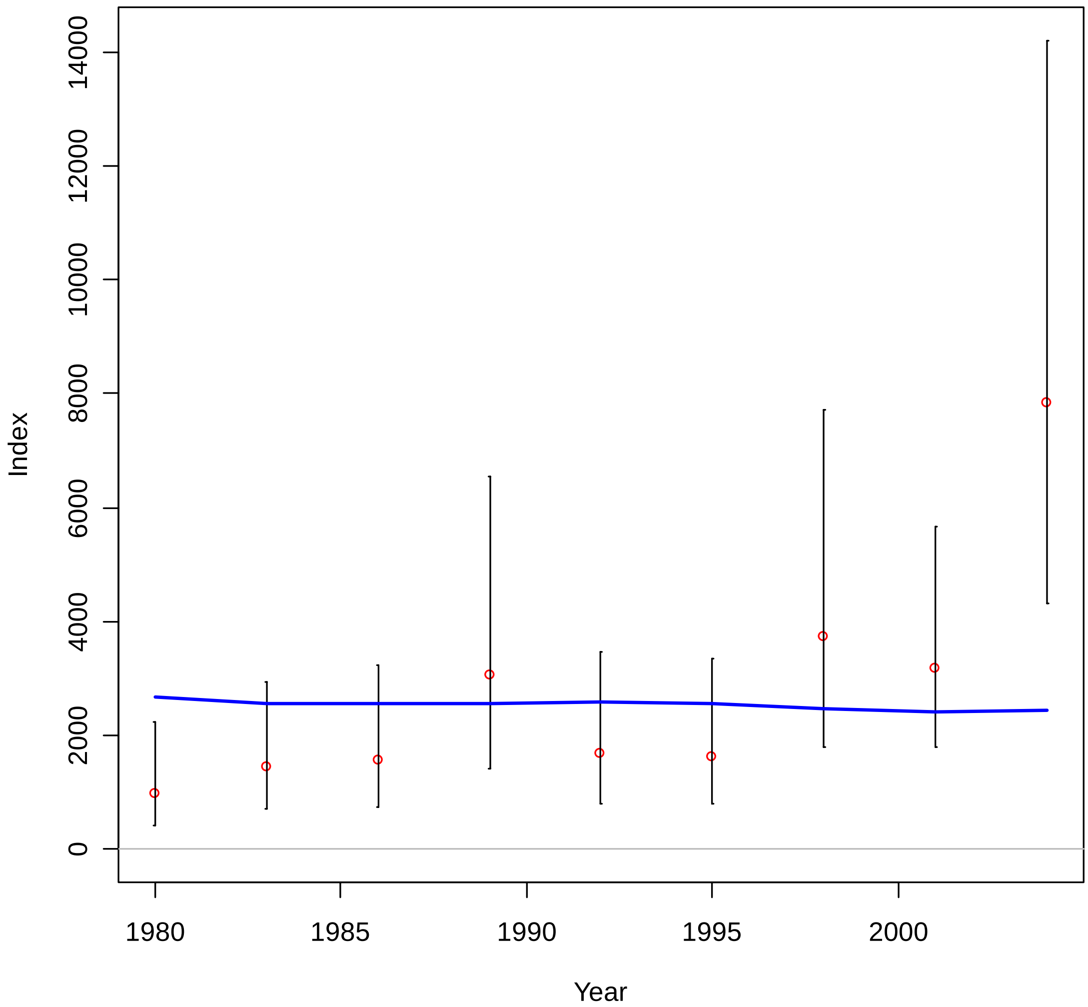

Figure 26. Observed and expected values of biomass index (mt) for the AFSC shelf (triennial) survey.

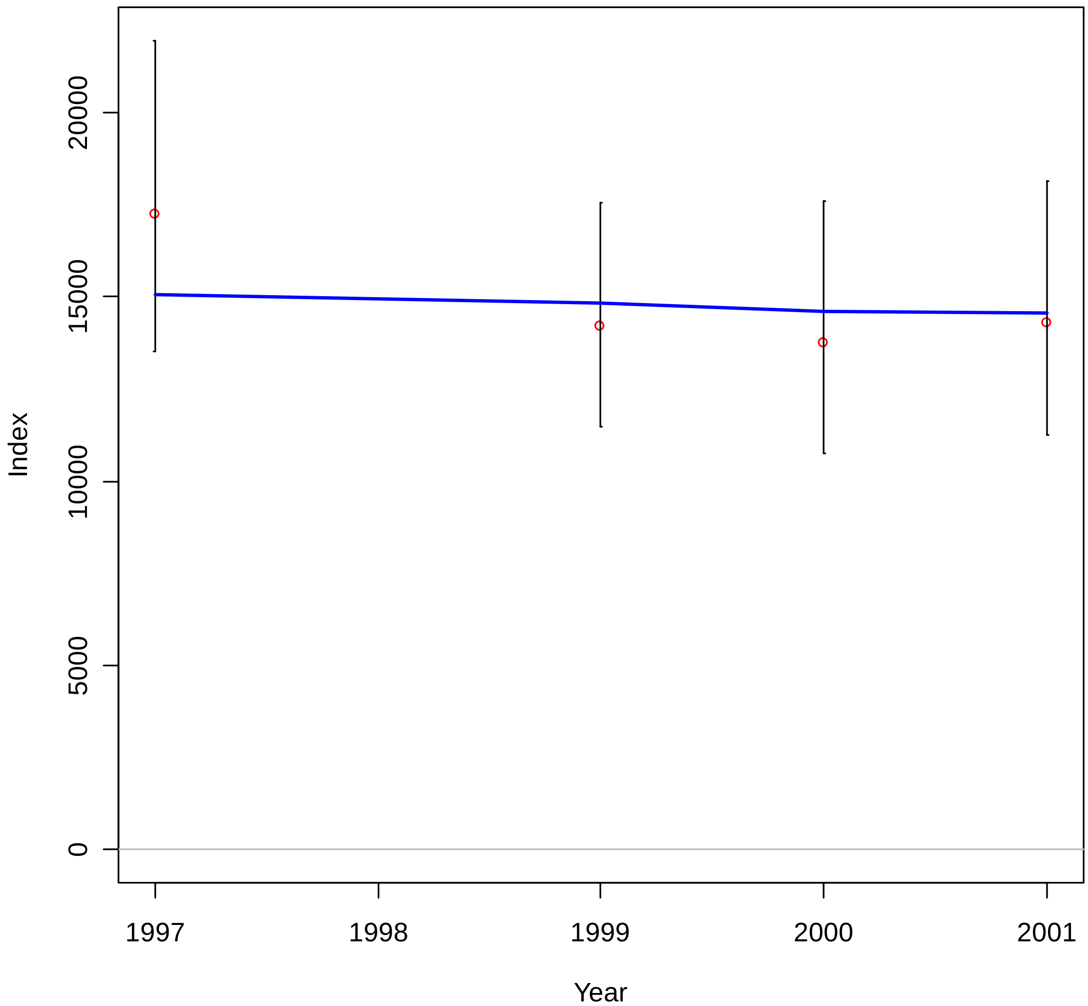

Figure 27. Observed and expected biomass index (mt) for the AFSC slope survey.

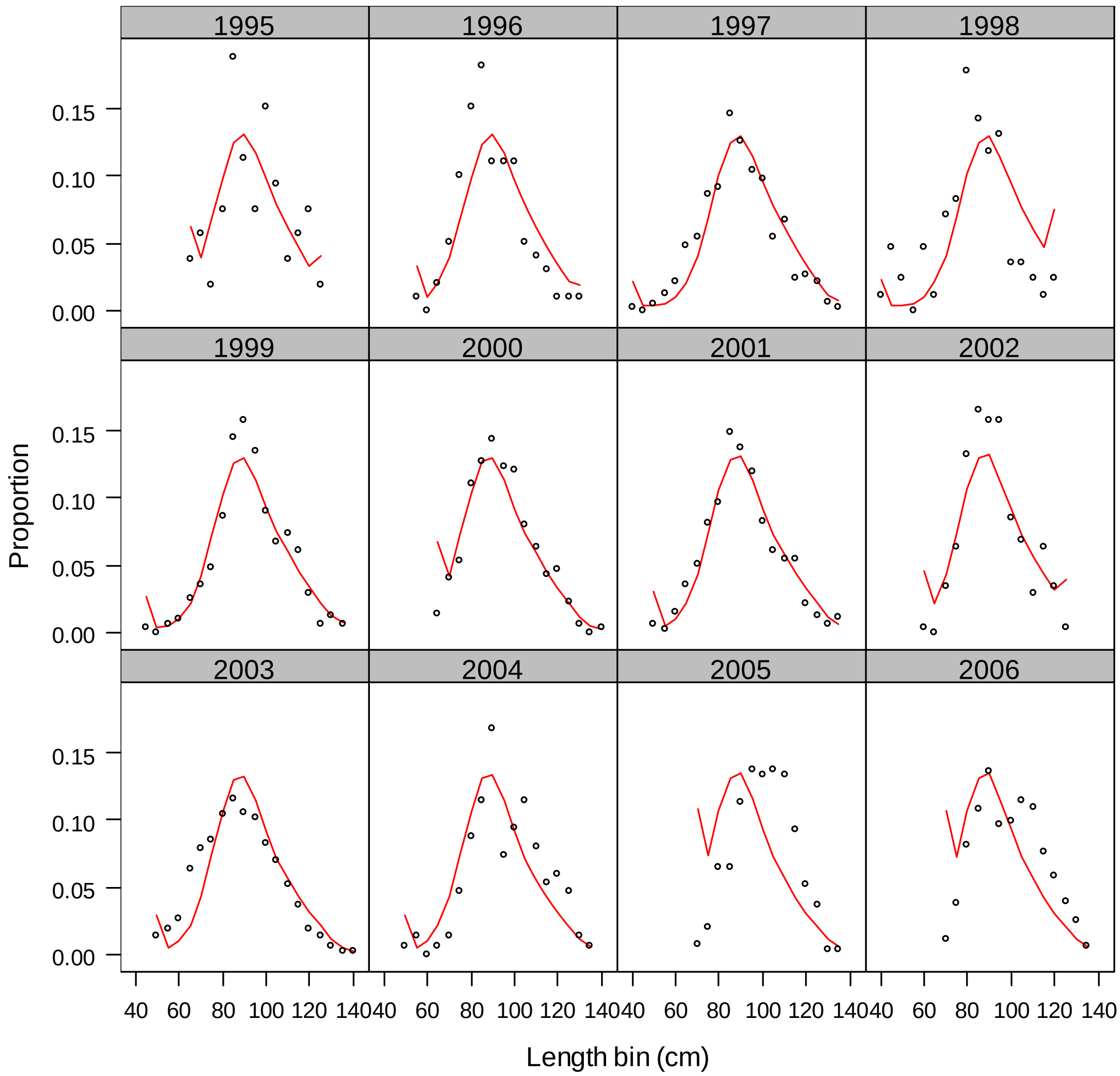

Figure 28. Fit to fishery length frequency of longnose skate (both sexes combined).

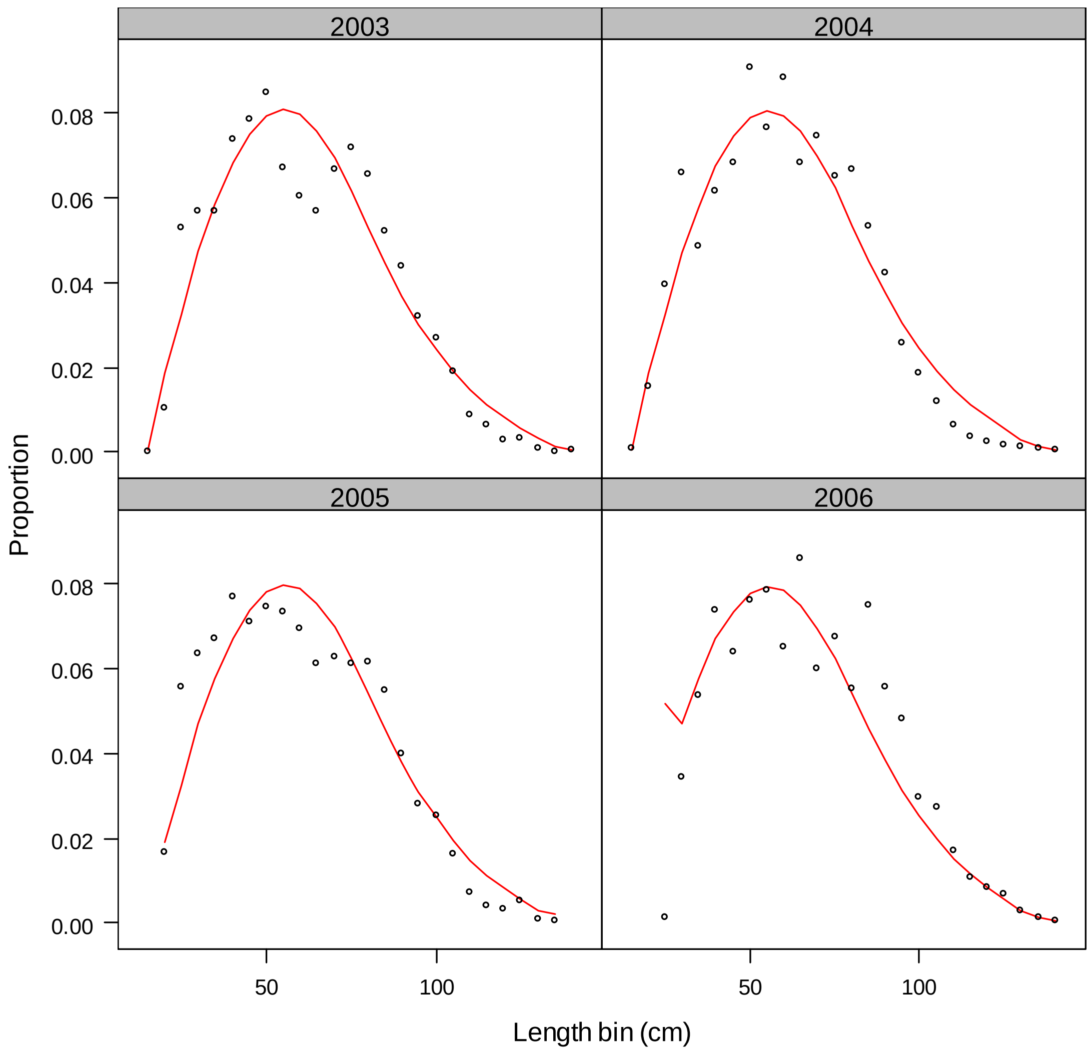

Figure 29. Fit to length frequency of longnose skate (both sexes combined) for NWFSC shelf-slope survey.

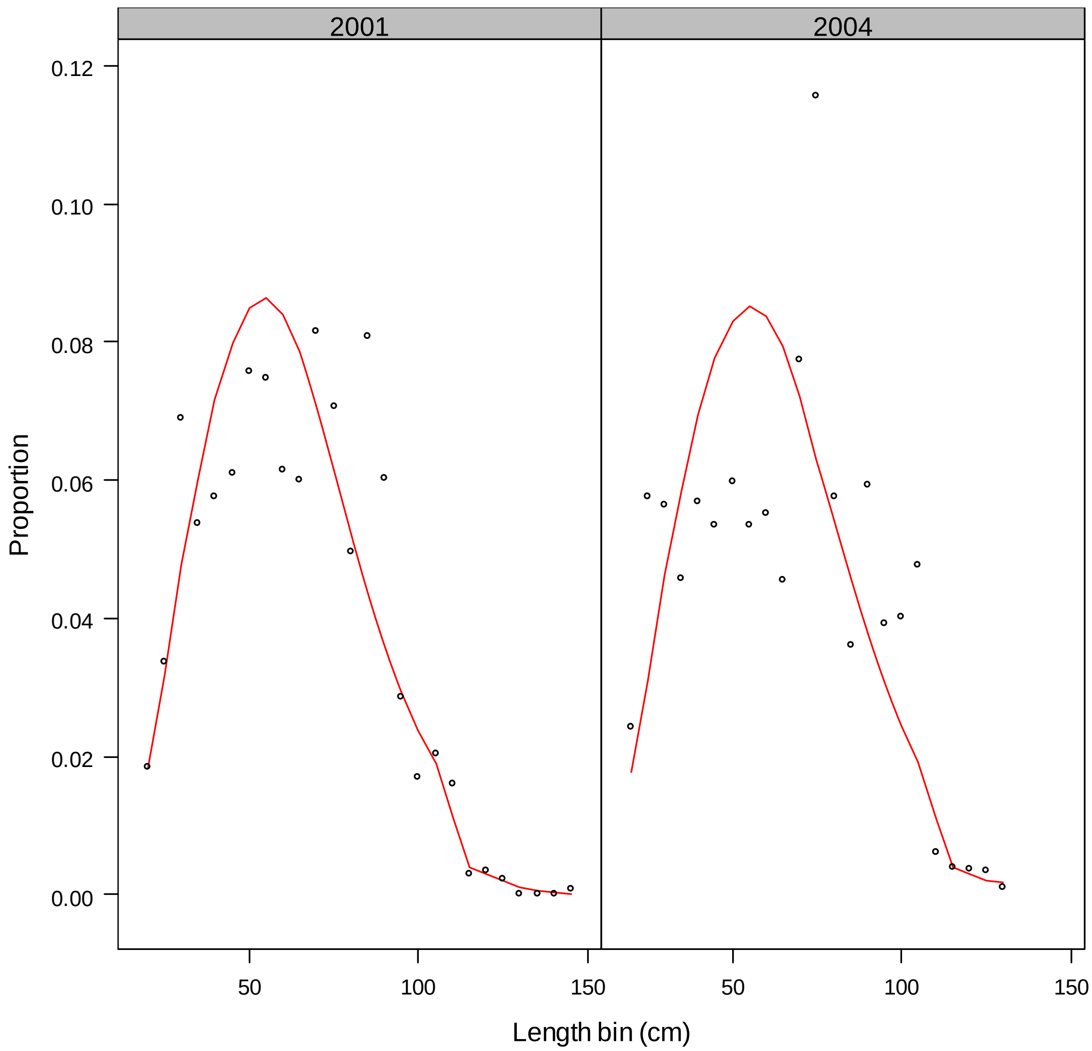

Figure 30. Fit to length frequency of longnose skate (both sexes combined) for AFSC shelf (triennial) survey.

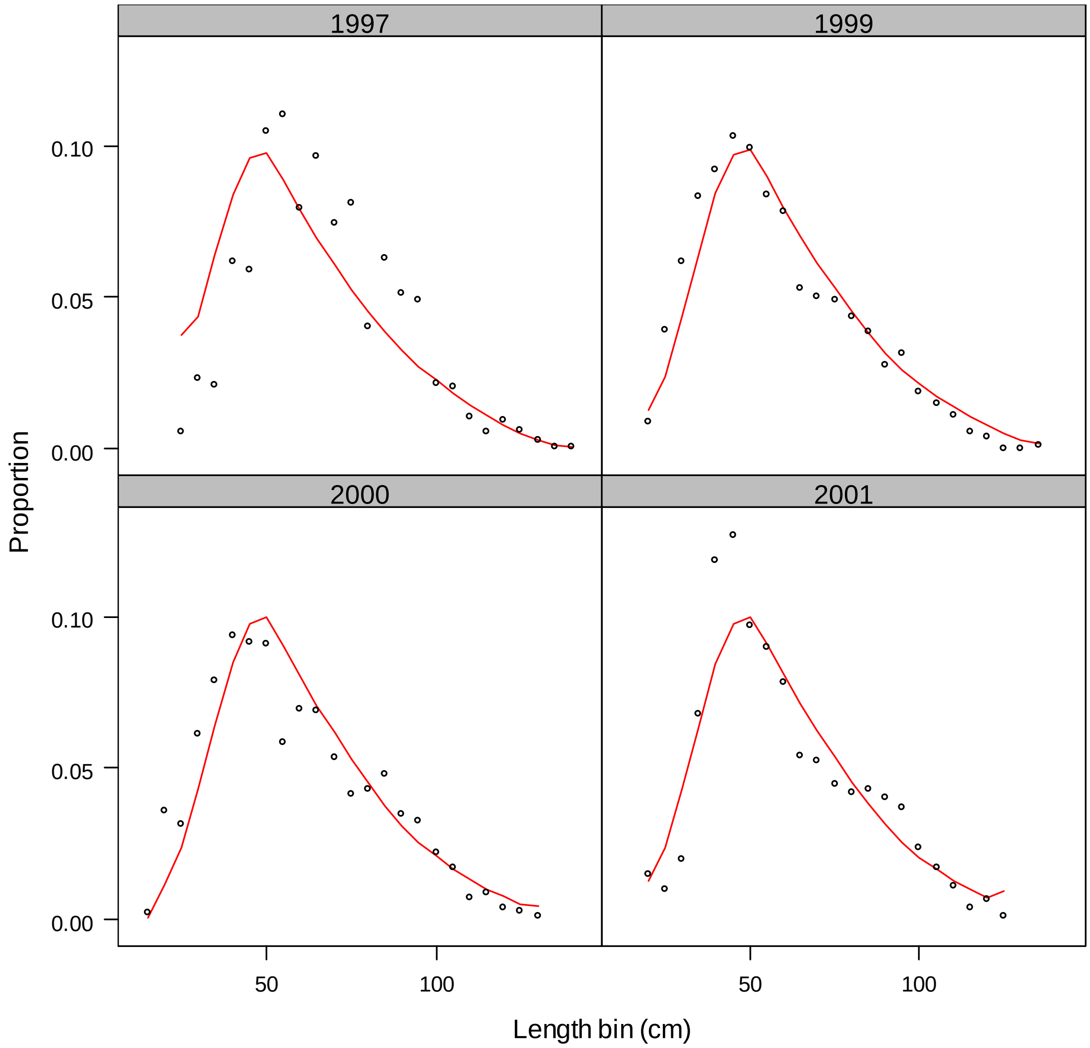

Figure 31. Fit to length frequency of longnose skate (both sexes combined) for AFSC slope survey.

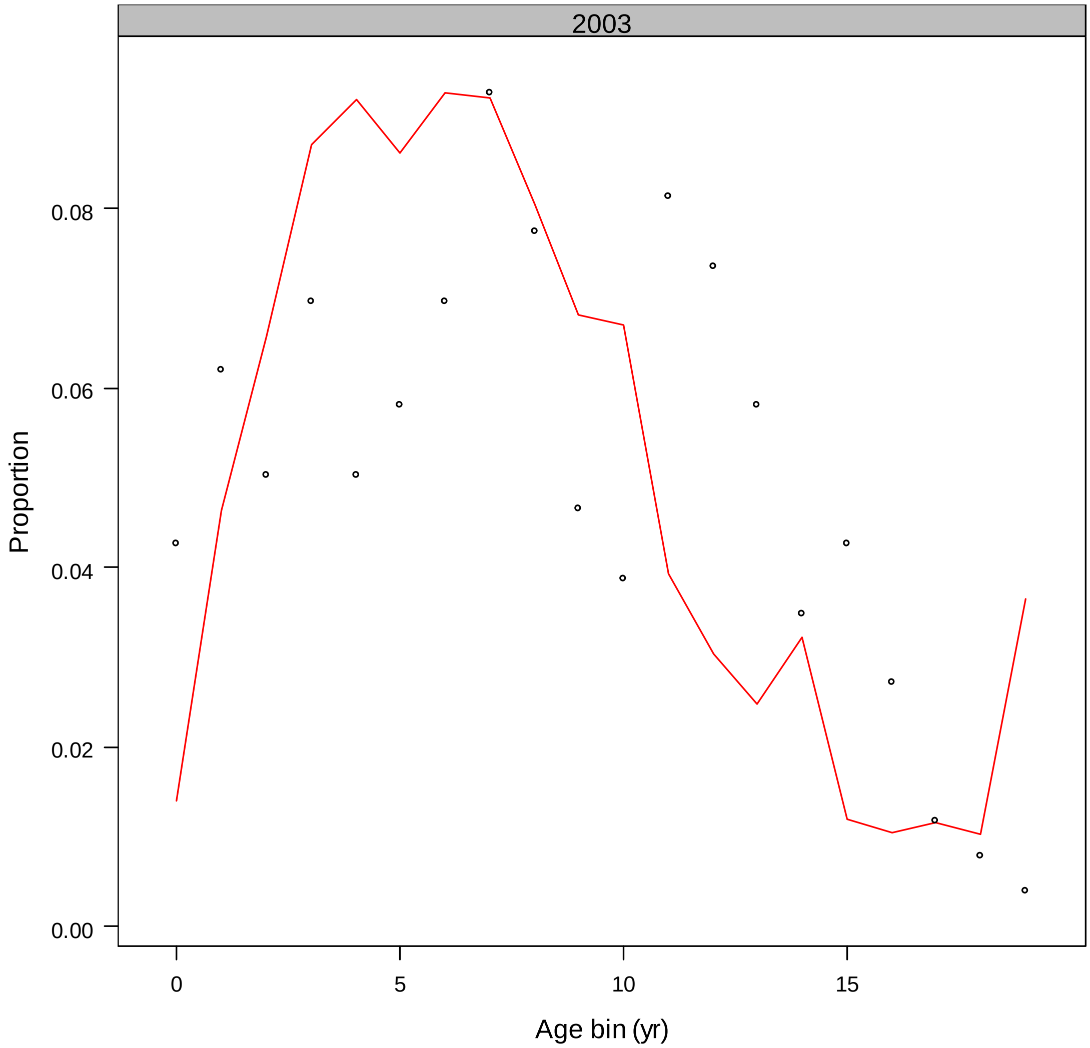

Figure 32. Fit to age frequency of longnose skate (both sexes combined) for NWFSC shelf-slope survey.

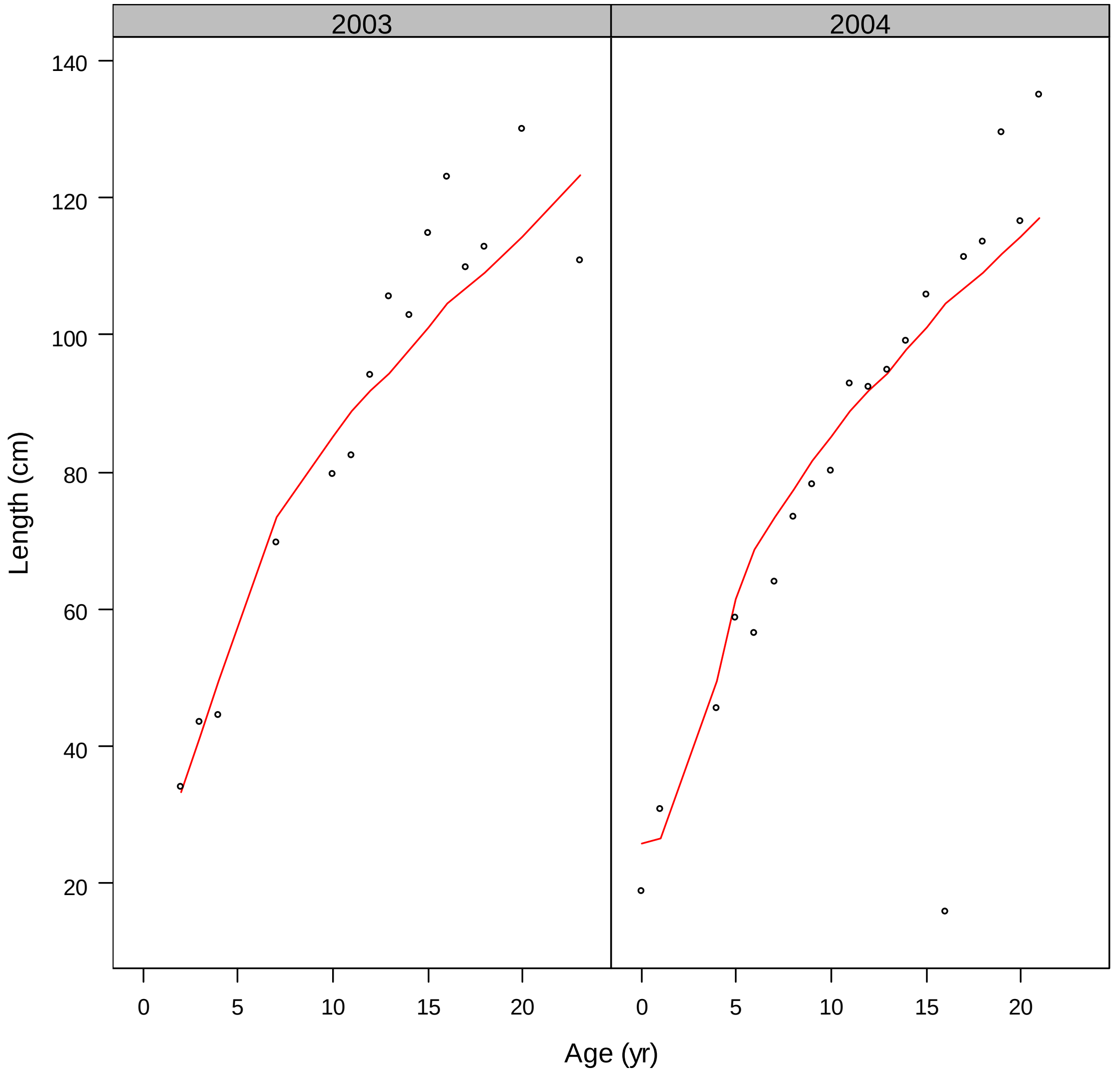

Figure 33.Fit to size-at-age data of longnose skate caught in fishery.

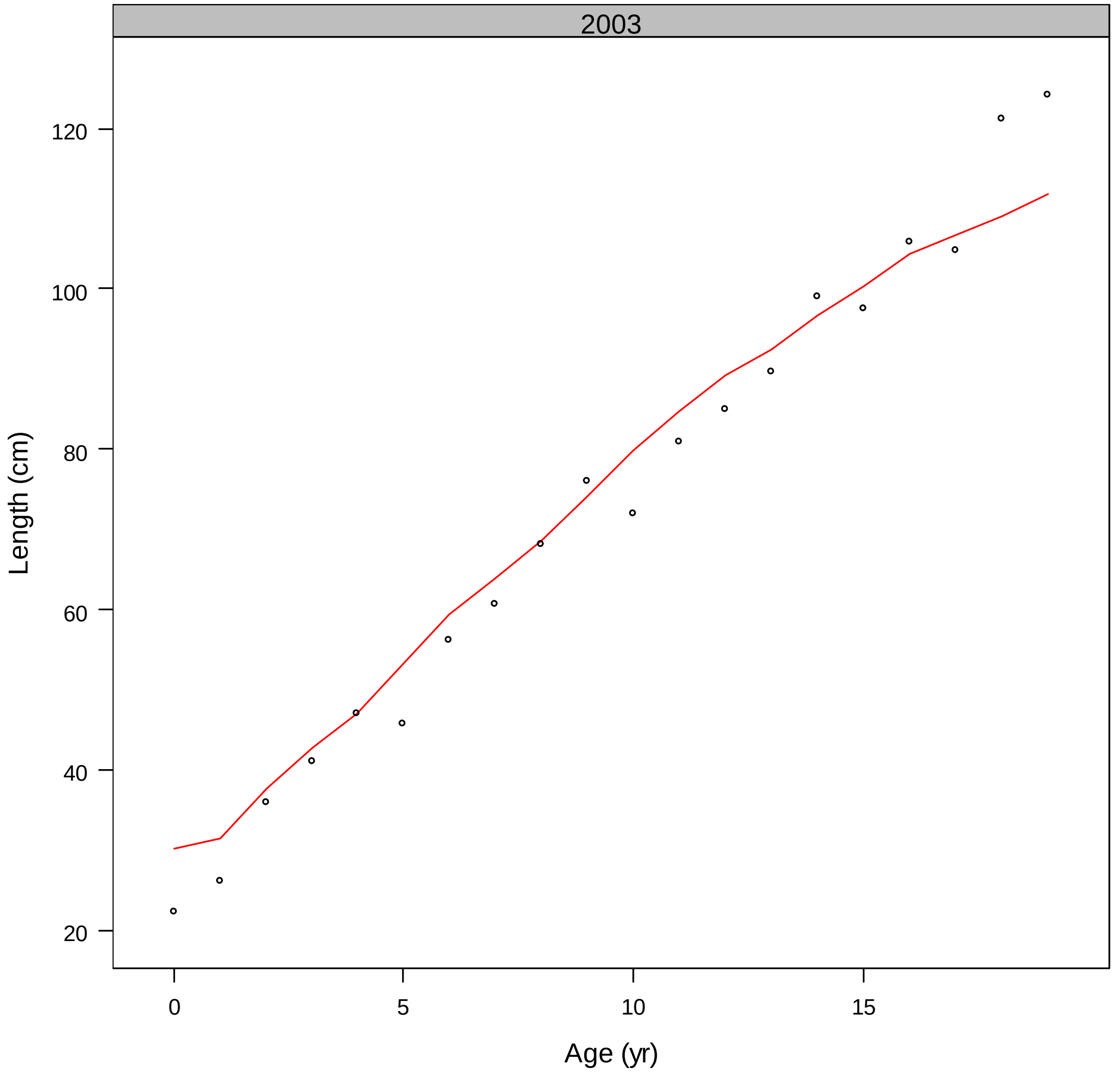

Figure 34. Fit to size-at-age data of longnose skate caught in NWFSC shelf-slope survey.

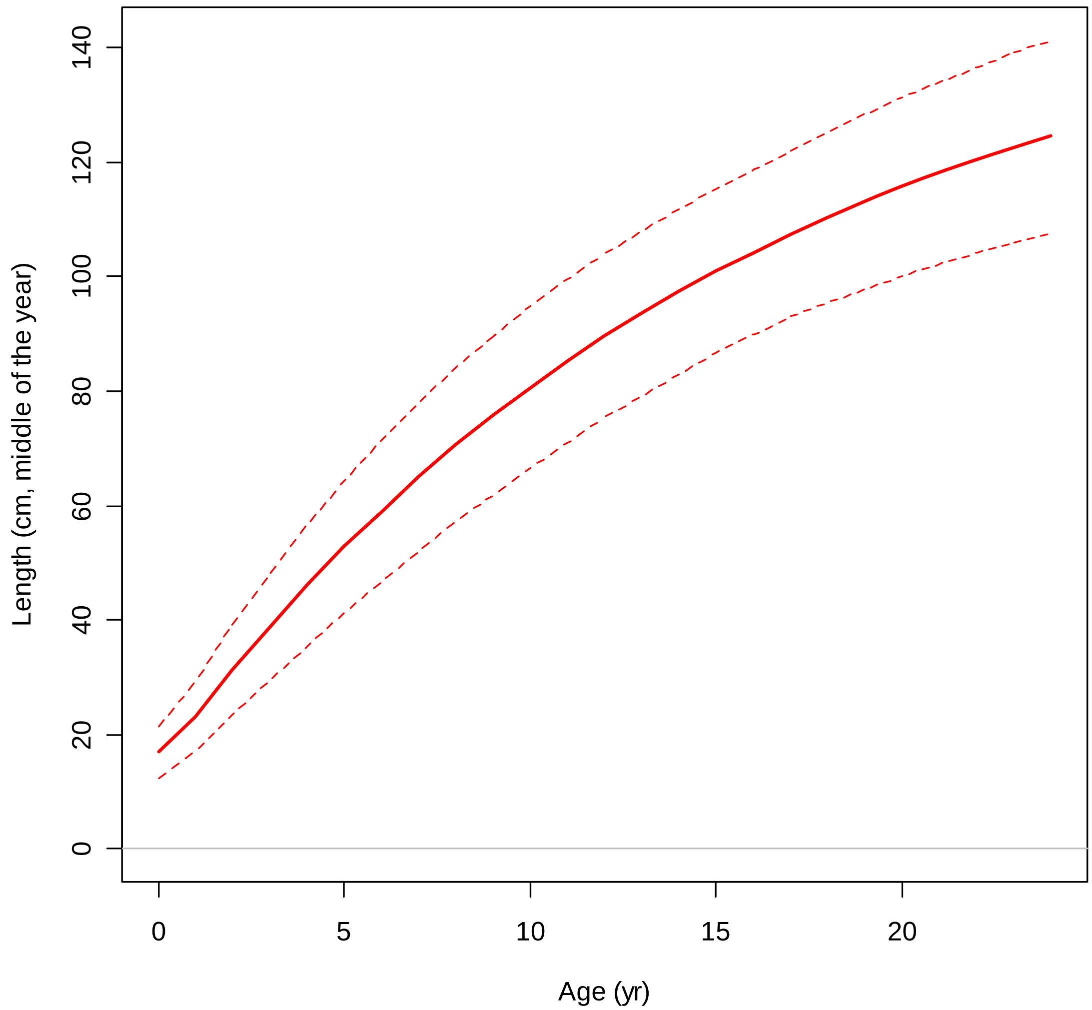

Figure 35. Growth curve of longnose skate (both sexes combined) estimated by the base model.

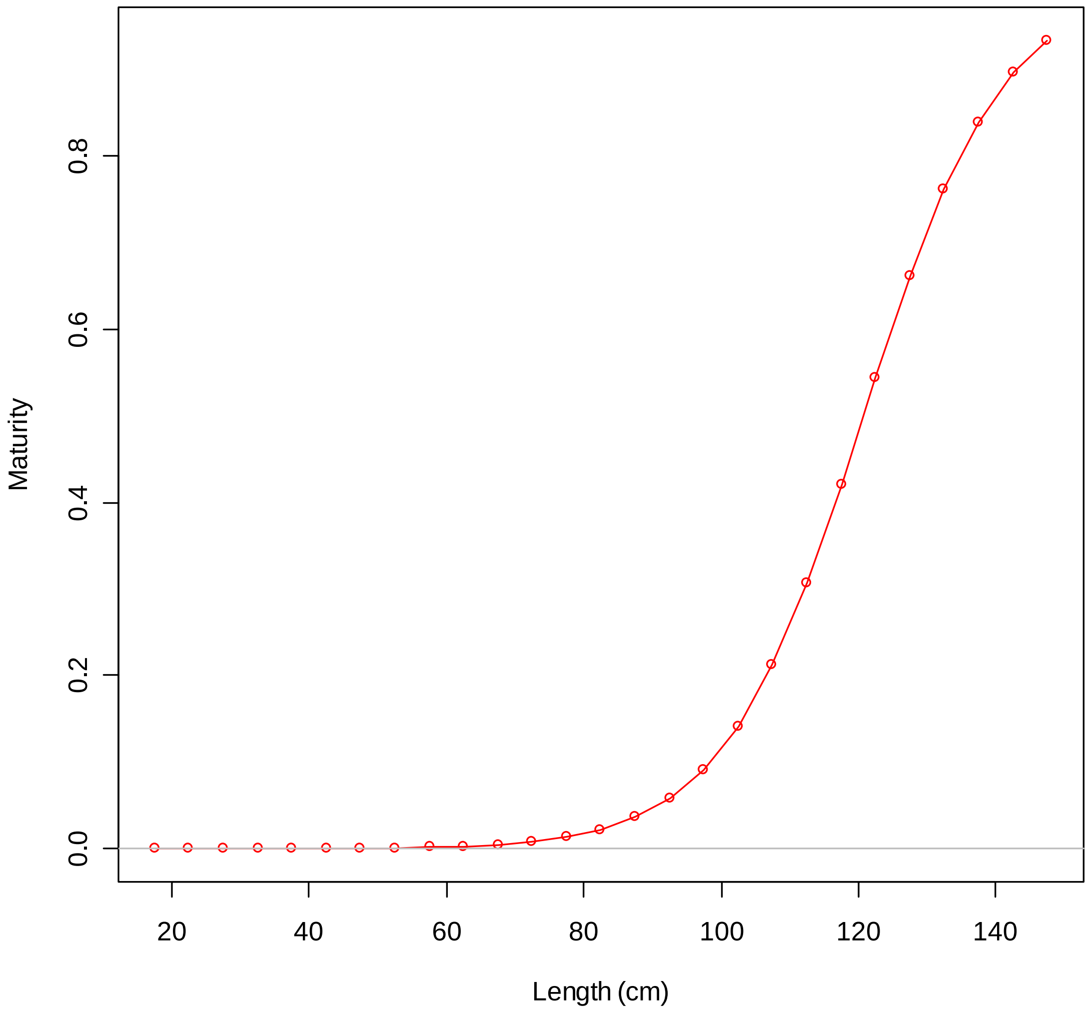

Figure 36. Maturity curve of female longnose skate estimated by the base model.

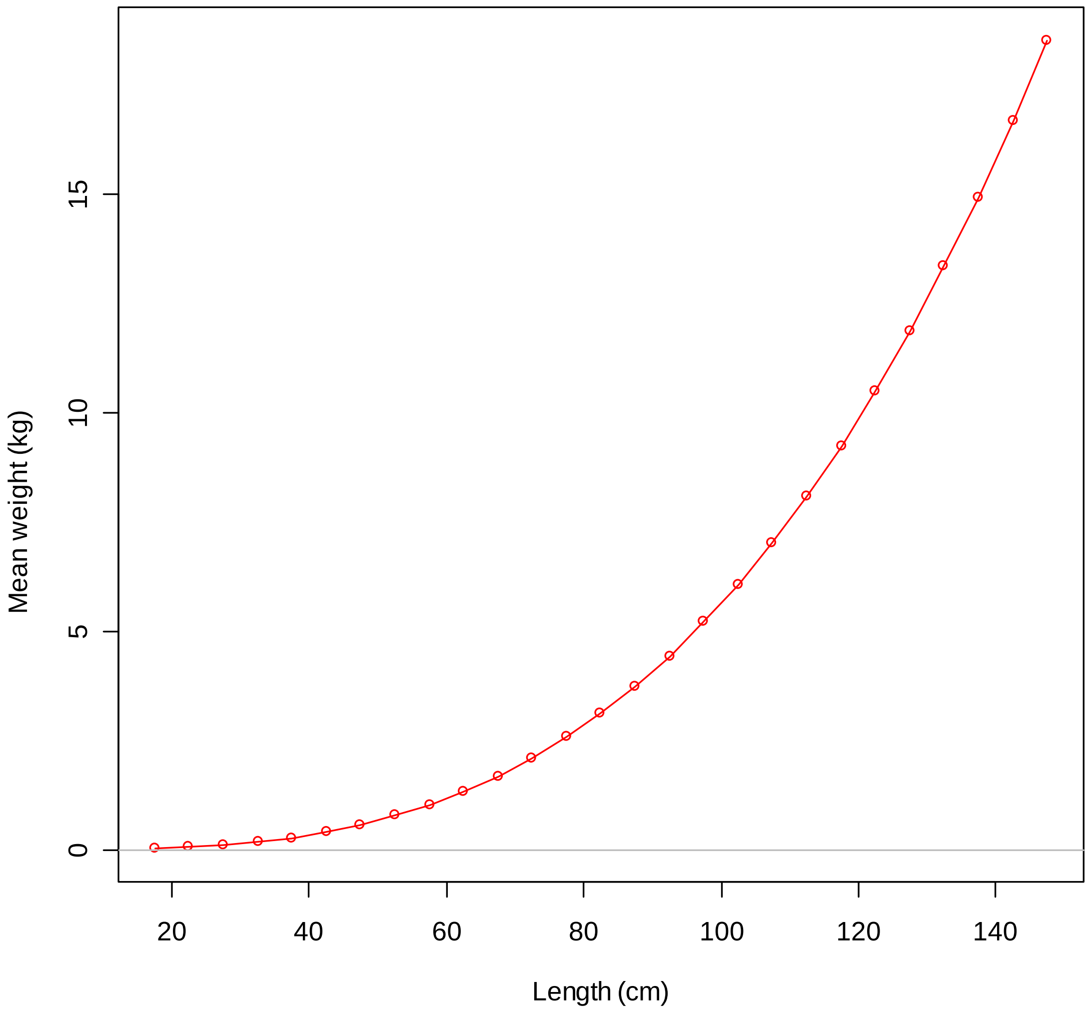

Figure 37. Length-weight relationship for longnose skate estimated by the base model.

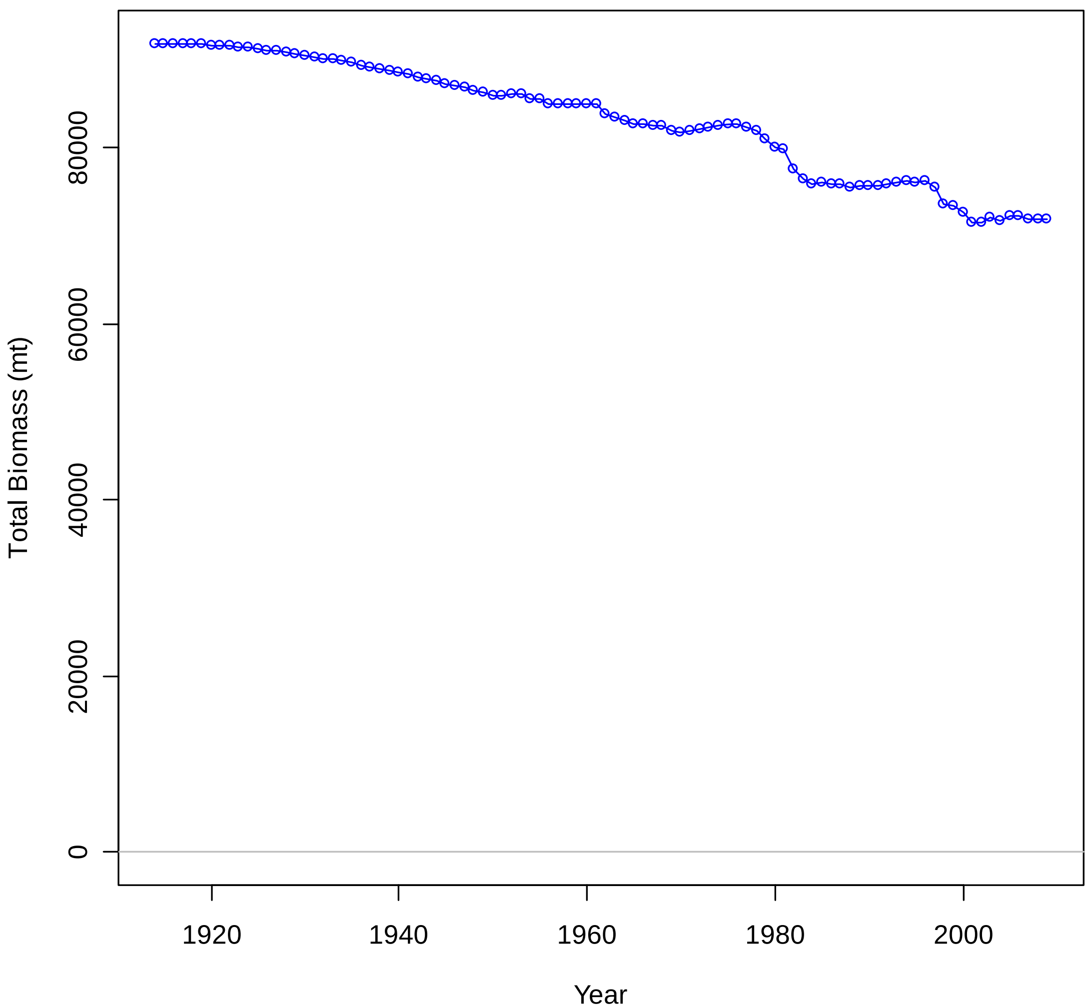

Figure 38. Time-series of total biomass, estimated by the base-run model.

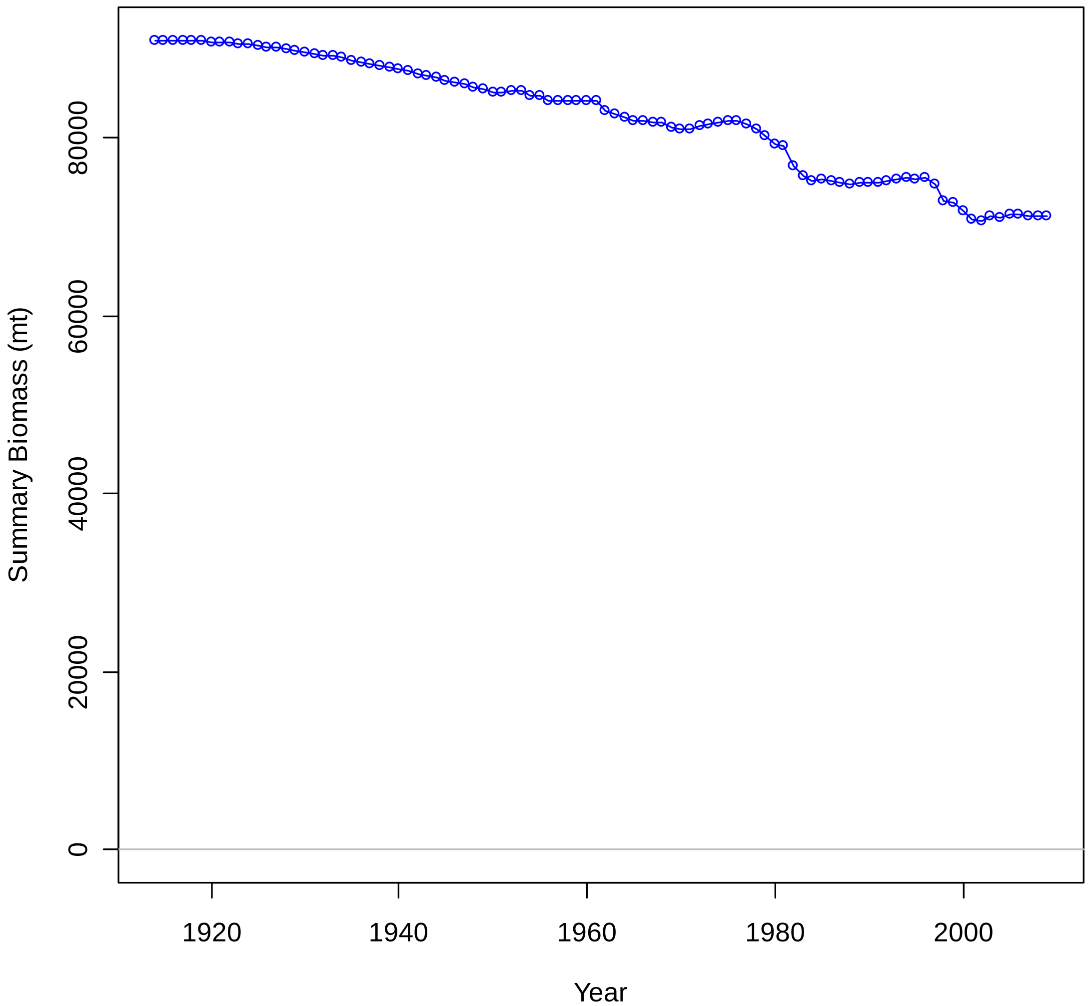

Figure 39. Time-series of summary biomass, estimated by the base-run model.

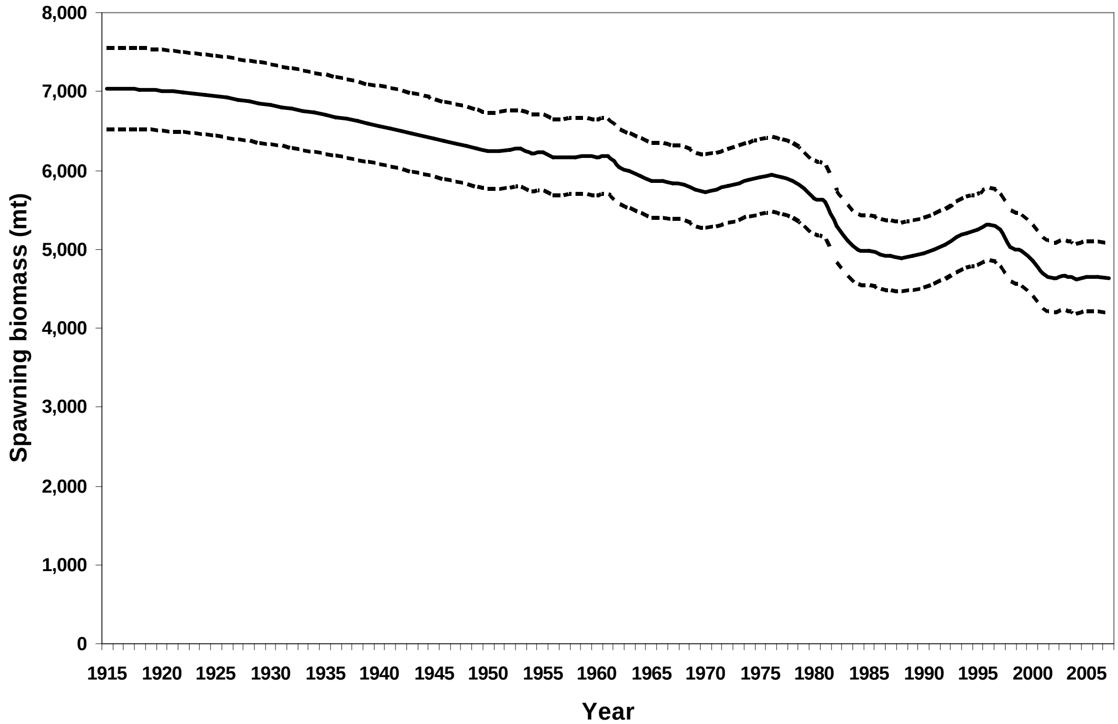

Figure 40. Time-series of spawning biomass with 95% Confidence Interval, estimated by the base-run model.

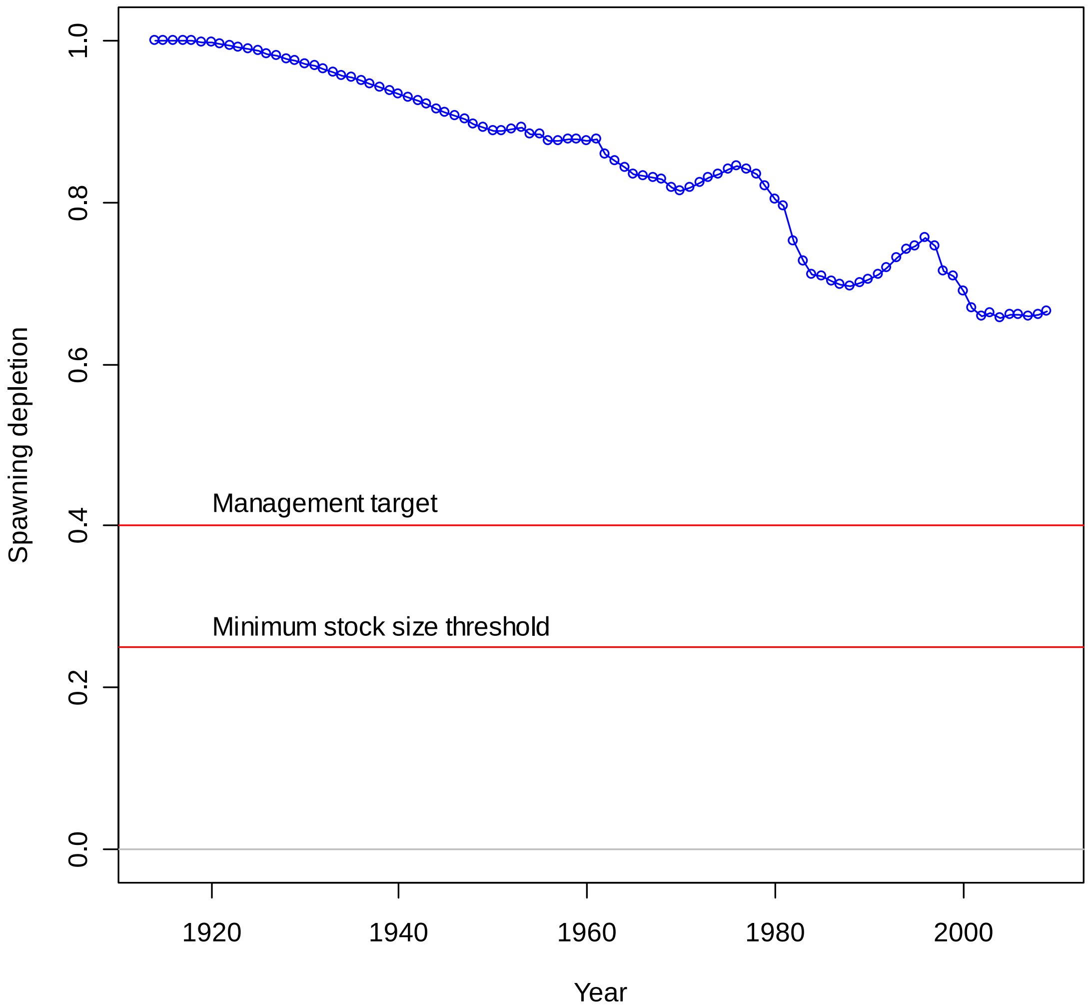

Figure 41. Time-series of spawning depletion, estimated by the base-run model.

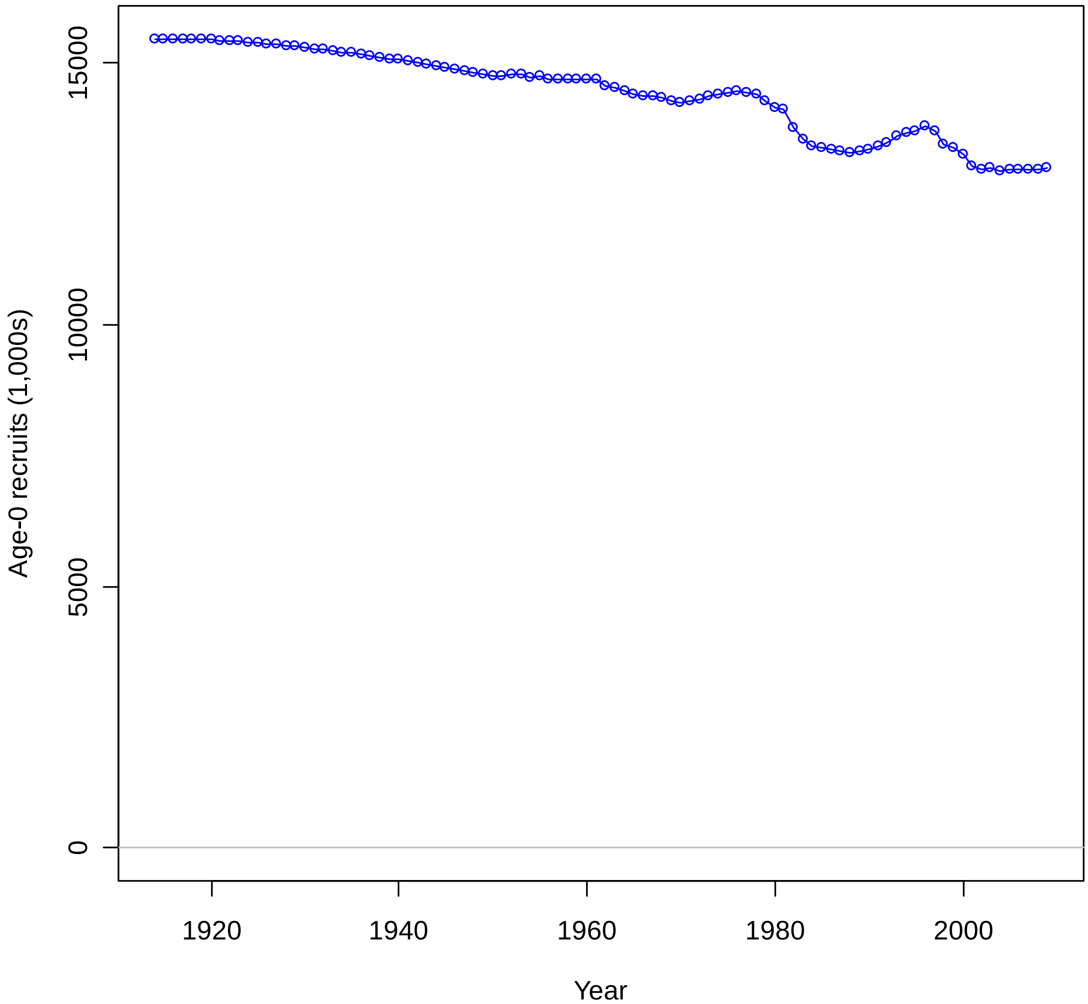

Figure 42. Time-series of recruitment, estimated by the base-run model.

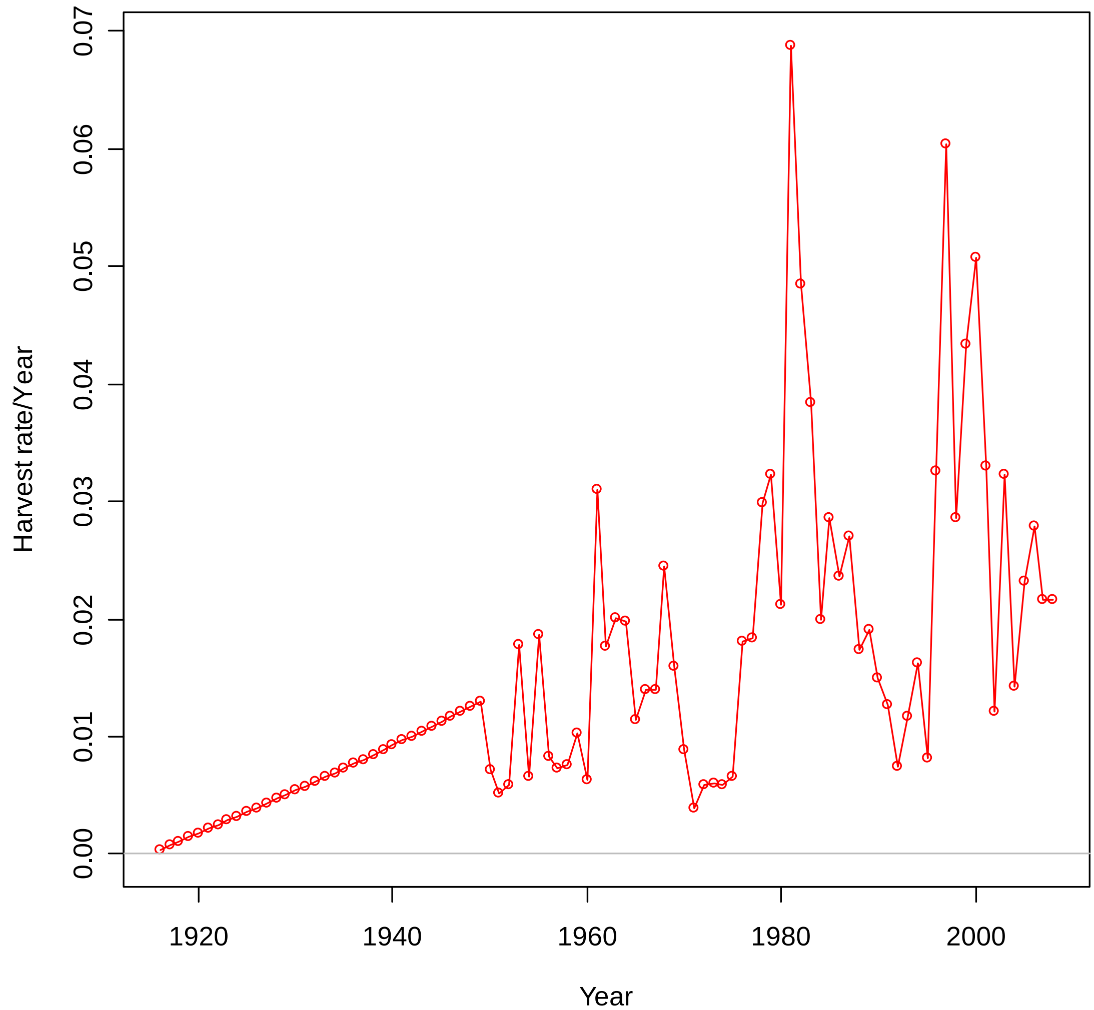

Figure 43. Time-series of harvest rate, estimated by the base-run model.

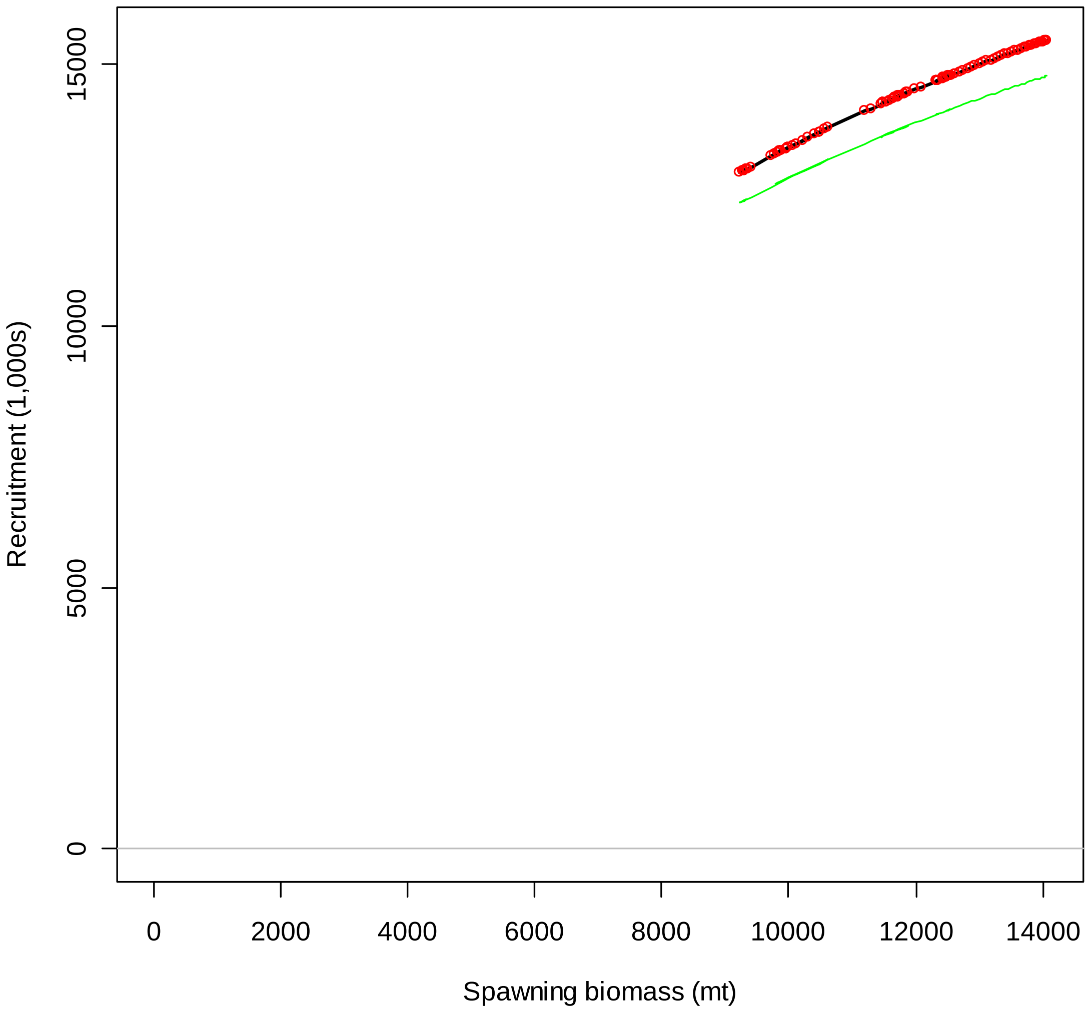

Figure 44. Stock recruitment relationship, estimated by the base-run model.

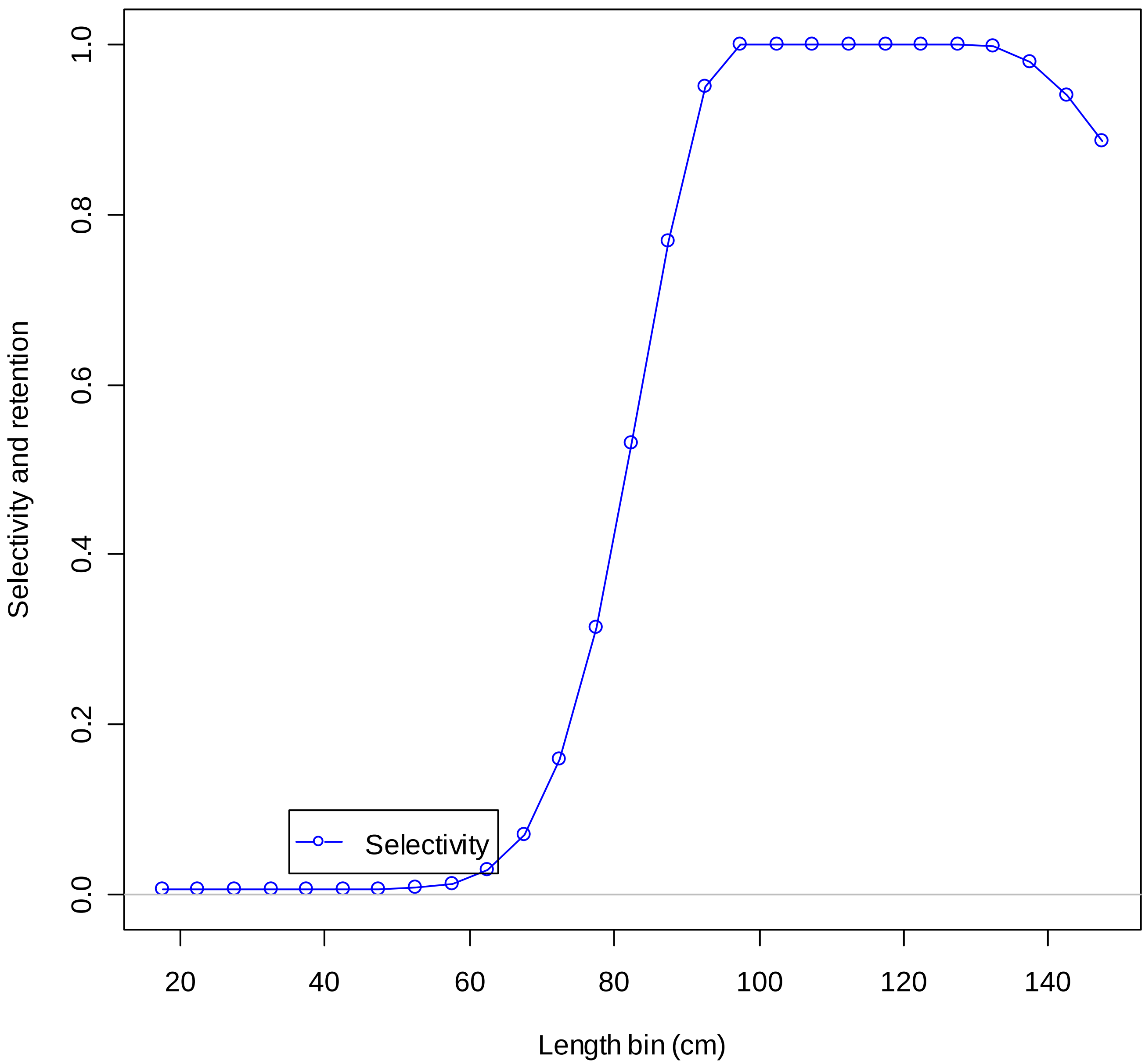

Figure 45. Fishery selectivity, estimated by the base-run model.

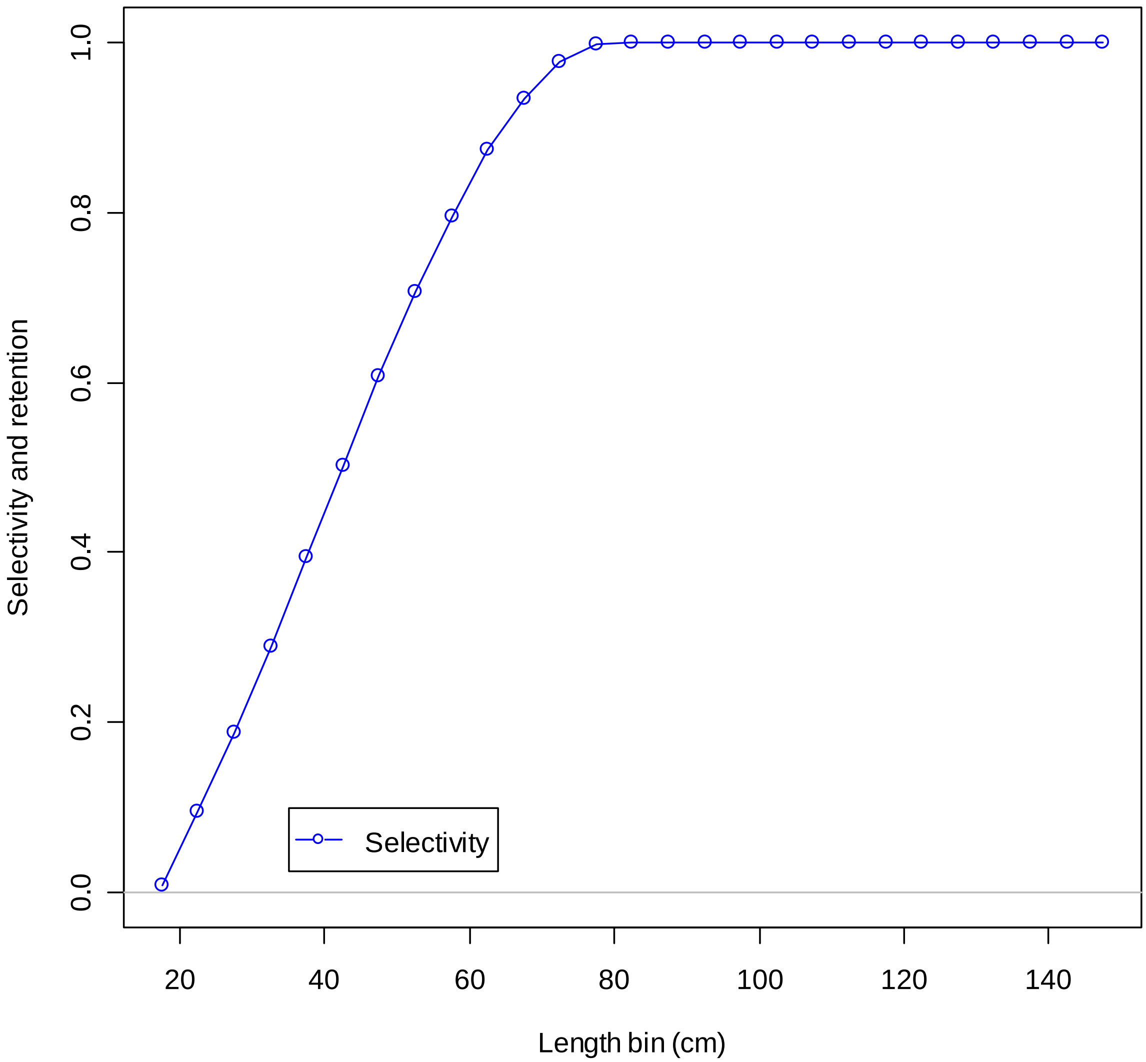

Figure 46. Selectivity for NWFSC shelf-slope survey, estimated by the base-run model.

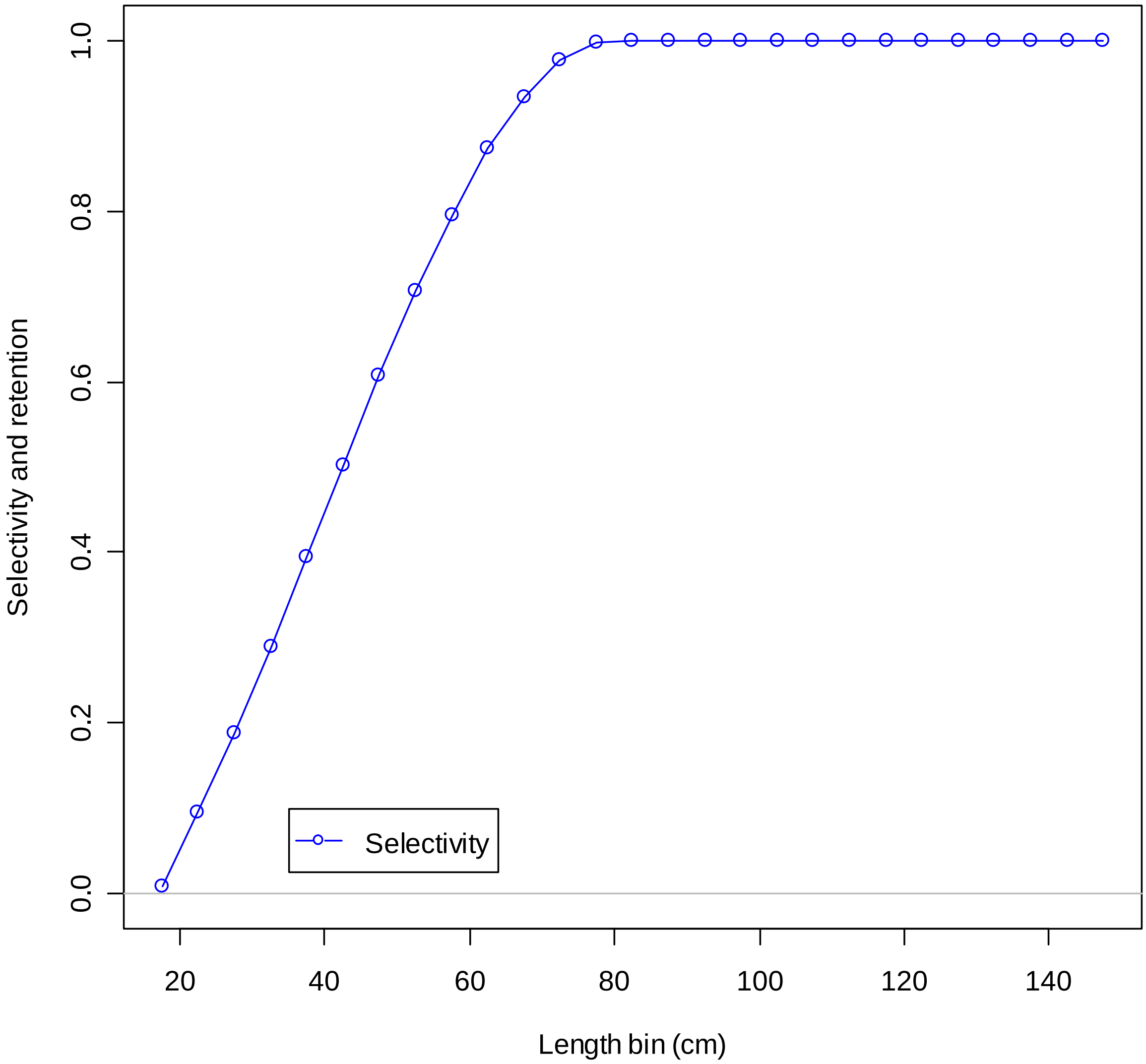

Figure 47. Selectivity for NWFSC slope survey (mirrored to NWFSC shelf-slope survey).

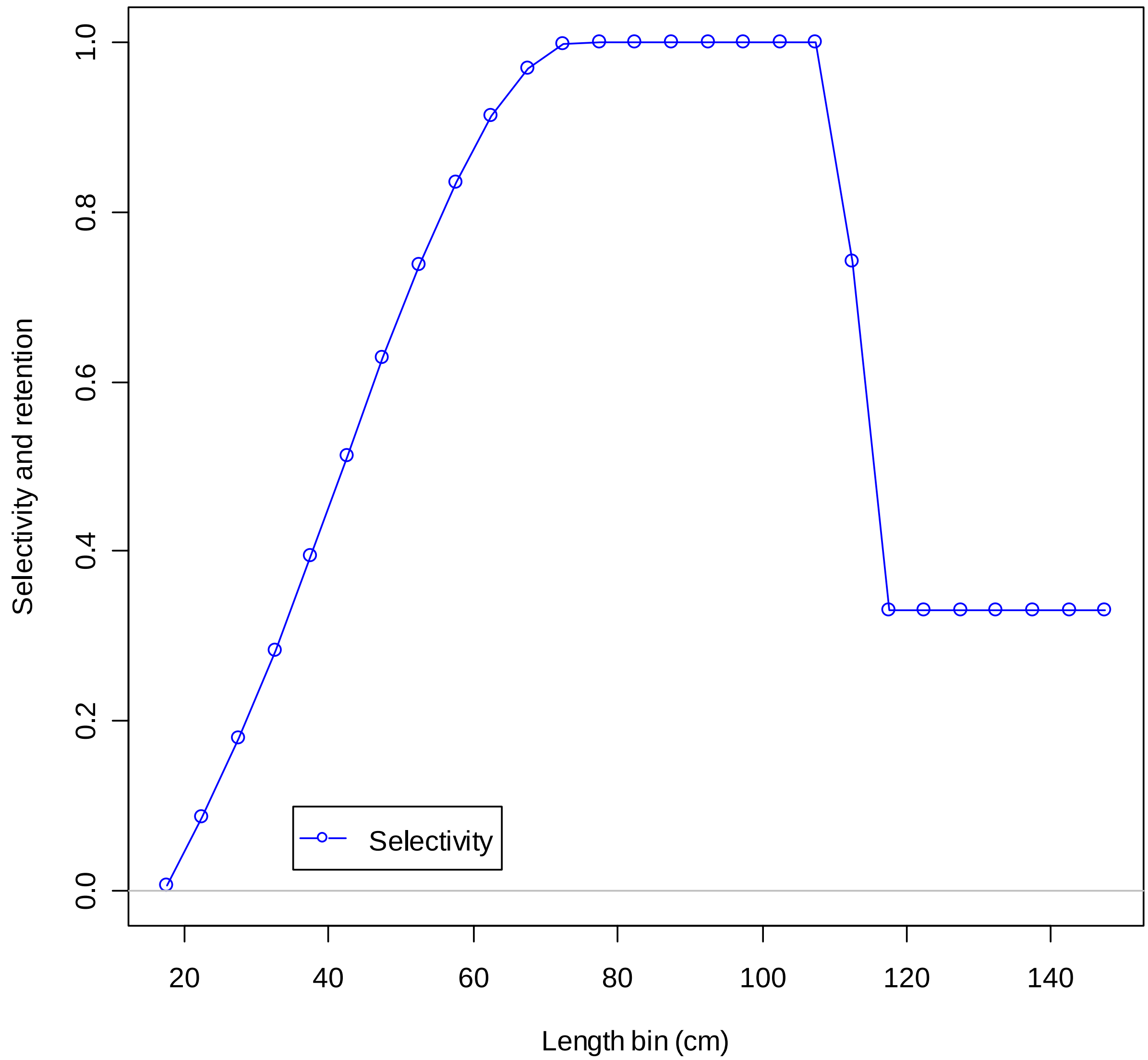

Figure 48. Selectivity for AFSC triennial shelf survey, estimated by the base model.

l

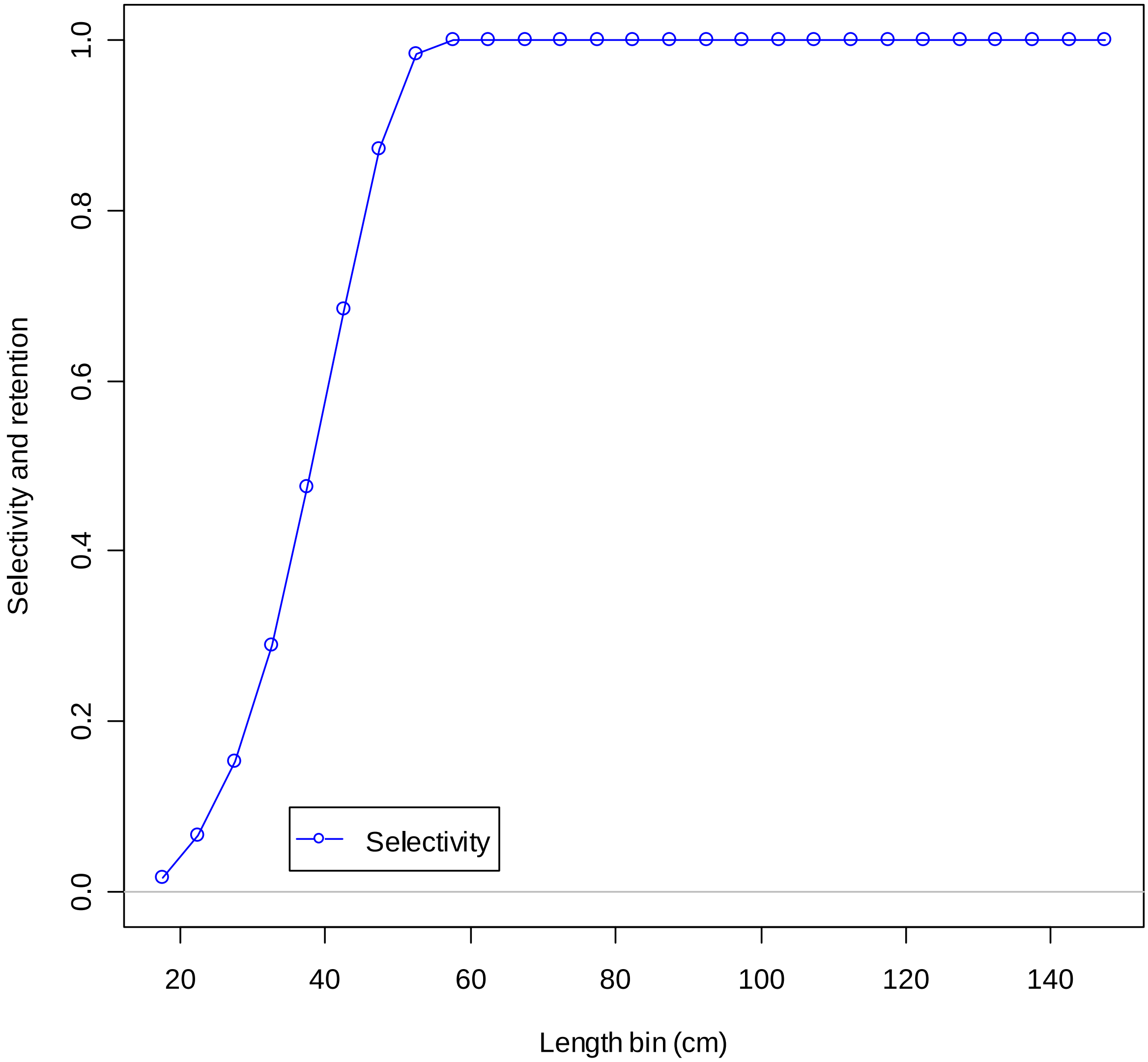

Figure 49. Selectivity estimates for AFSC slope survey.

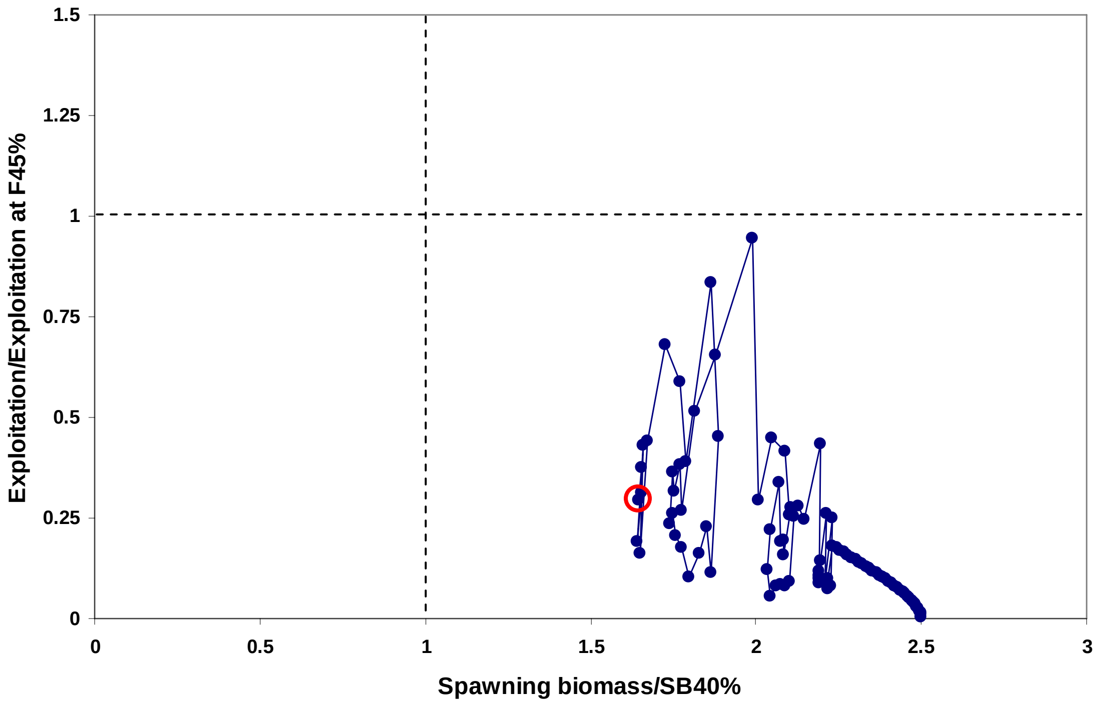

Figure 50. Exploitation rate and spawning biomass relative to their target values (circle indicates the point that corresponds to 2007).

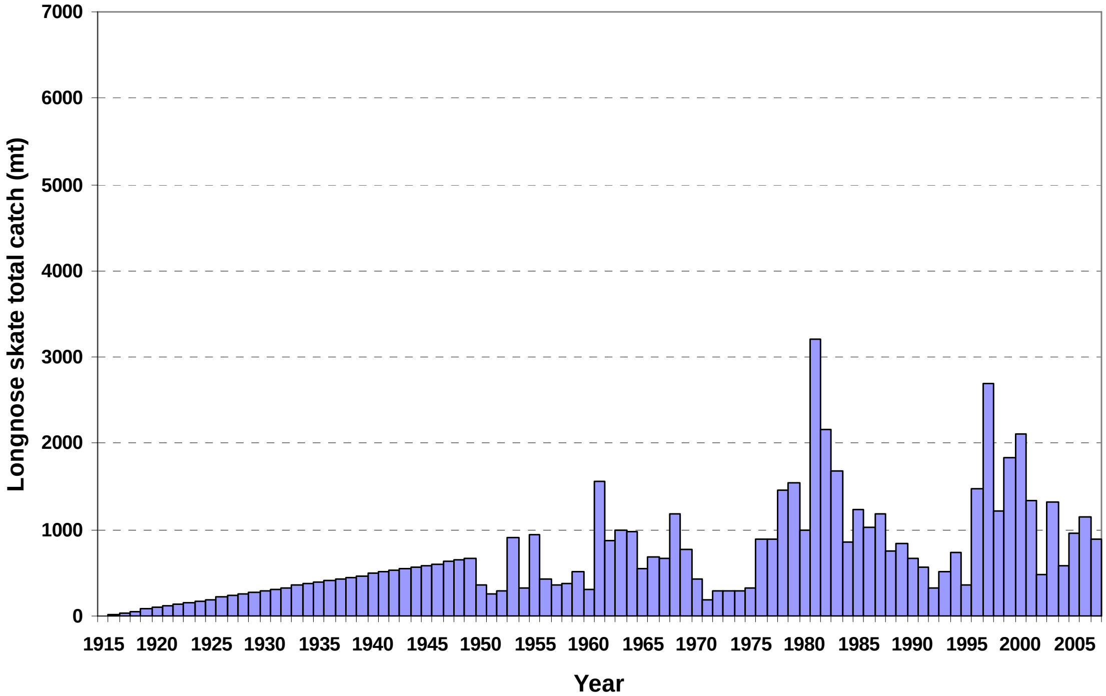

Figure 51. Base catch history for longnose skate, reconstructed based on the best information about longnose skate catch available.

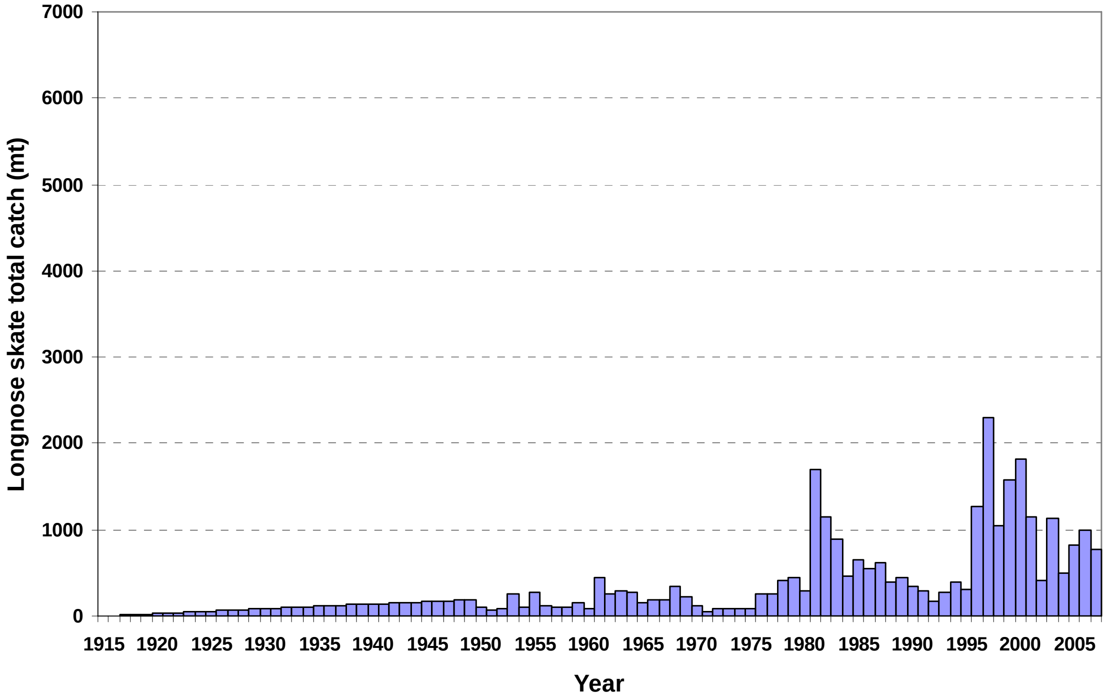

Figure 52. “Low” catch history for longnose skate (see section Uncertainty and sensitivity analysis and Table 15 for values used for proportion of longnose skate in combined-skate catches, discard and discard mortality rates).

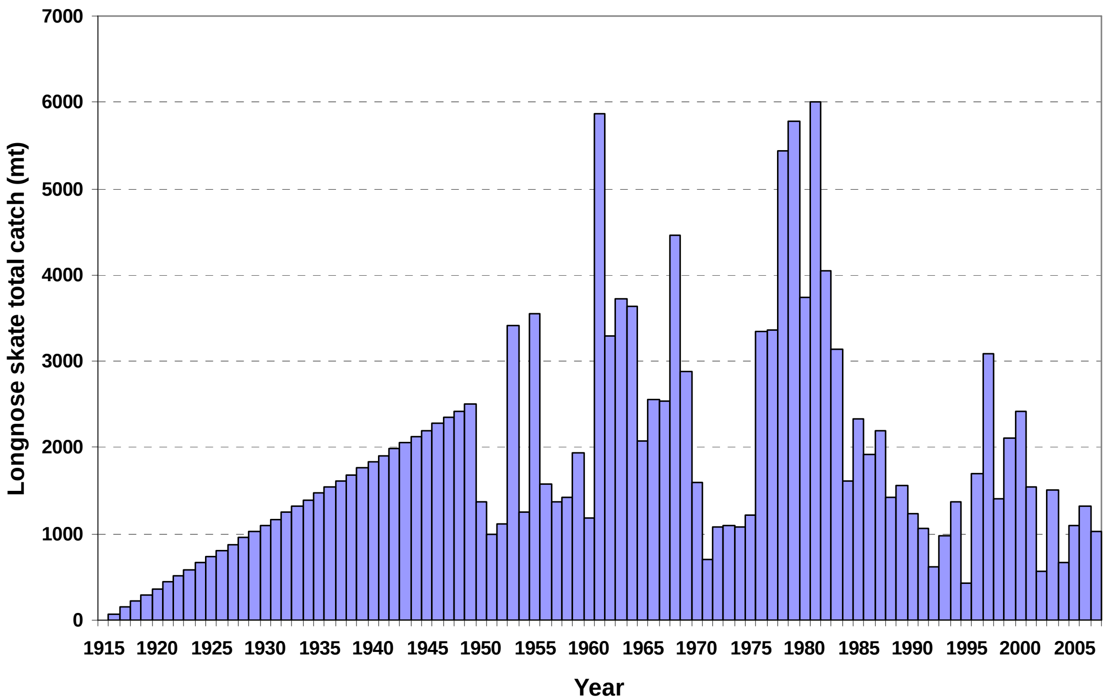

Figure 53. “High” catch history for longnose skate (see section Uncertainty and sensitivity analysis and Table 15 for values used for proportion of longnose skate in combined-skate catches, discard and discard mortality rates).

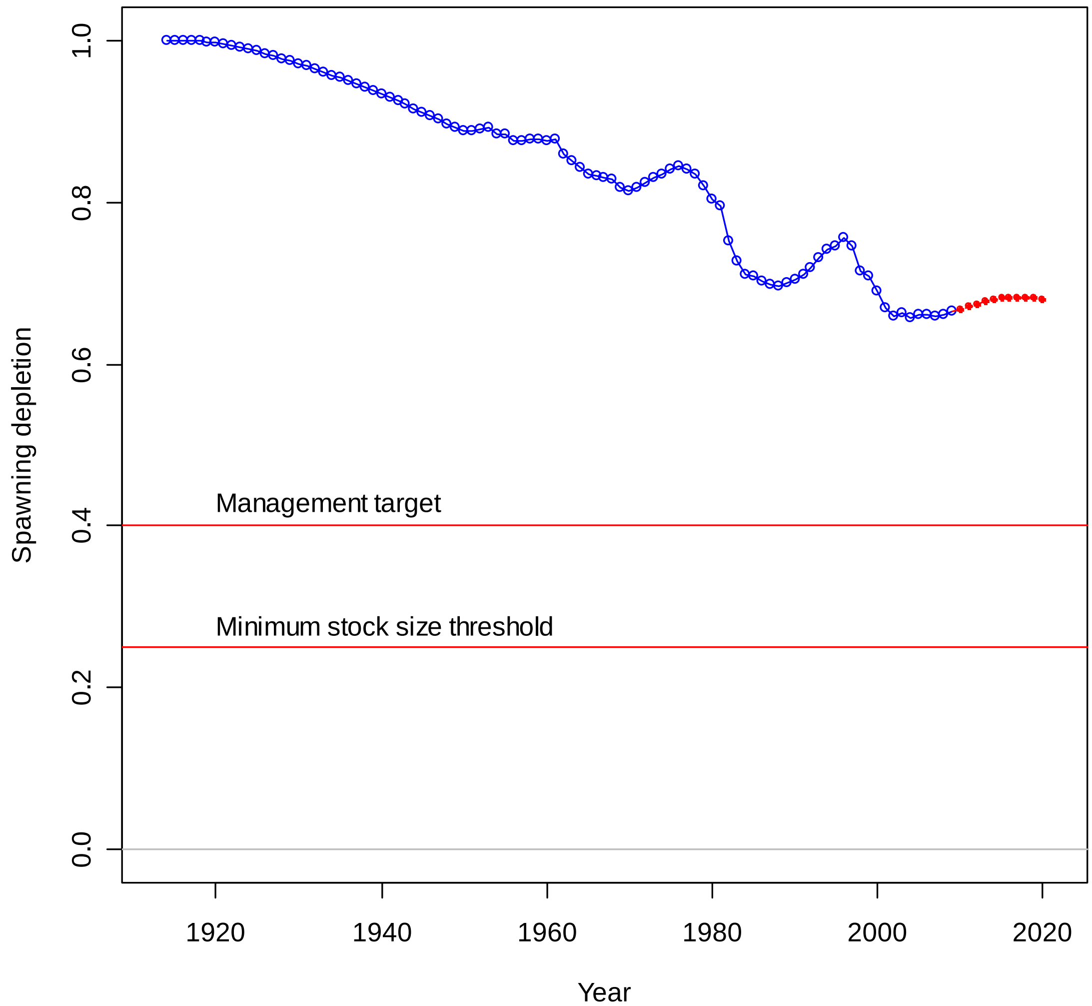

Figure 54. Spawning depletion of longnose skate with future projection calculated under current fishing mortality rate.

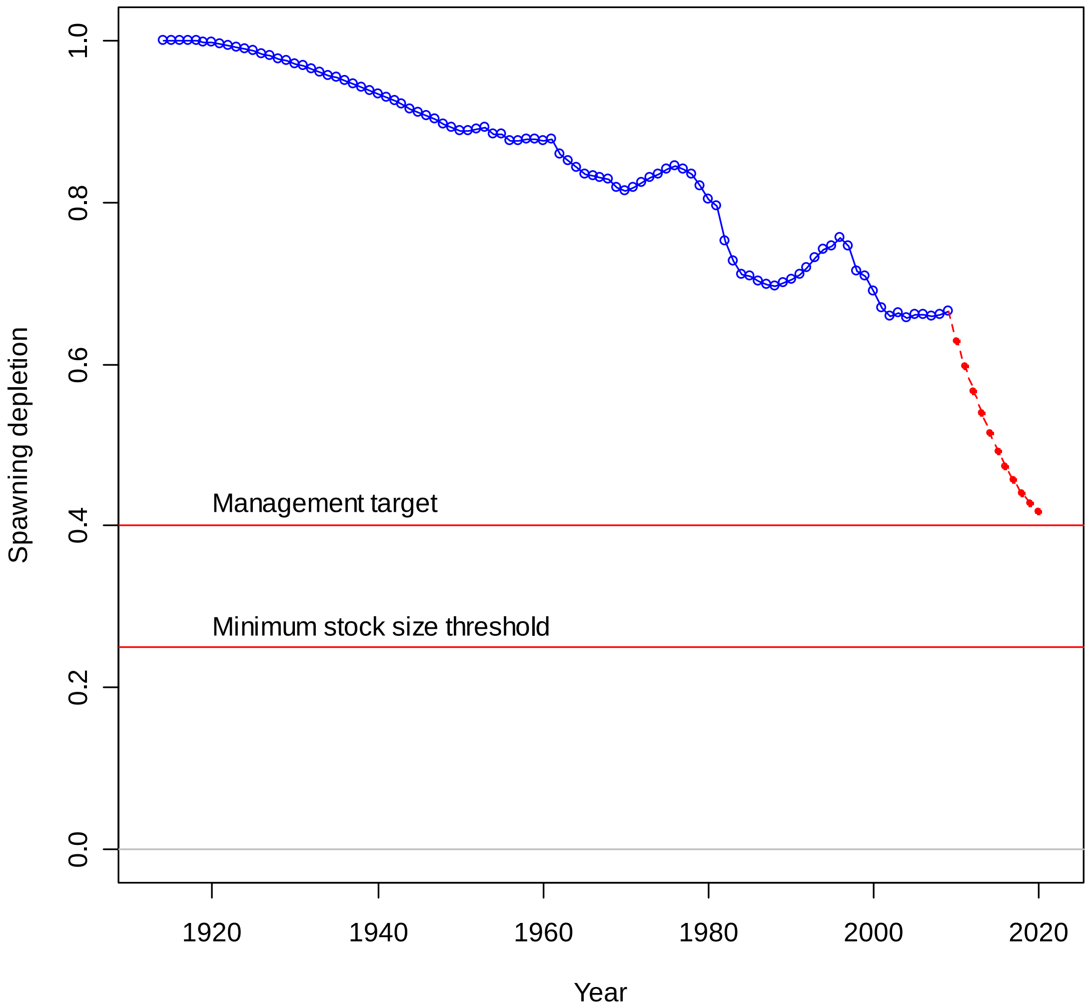

Figure 55. Spawning depletion of longnose skate with future projection calculated under F 45%.

APPENDIX 1: List of STAR Panel requests

During the STAR Panel review of the assessment, analysis and evaluation of the base model were performed. These analyses and evaluations caused changes in the base model specifications. These changes significantly improved the assessment model. This appendix provides an overview of changes to the base model that were implemented during the STAR panel review, as well as requests by the STAR Panel for additional model runs that were conducted during the review.

Prior to the STAR Panel, the base model had the following characteristics:

- The model began in 1980 and assumed non-zero equilibrium catch in 1979;
- Landed and discarded catch were entered separately in the SS2 data file;
- Historical landed catch records (1951-1980) were used only to estimate initial equilibrium catch;
- Model included two sexes;
- Natural mortality *M* was fixed at 0.1
- Two out of three parameters of von Bertalanffy growth model (L_1 and L_2) were estimated, while the third parameter (*K*) was fixed;
- From1984 forward, the model treated recruits stochastically and recruitment deviations were estimated;
- NWFSC slope-shelf survey *Q* was fixed at 1;
- Selectivities of slope surveys were not fixed asymptotic;
- The model used a “data point” approach for iterative re-weighting.

After the STAR Panel, the base model for the longnose skate has the following features:

- The model begins in 1916 and assumes unfished equilibrium in 1915;
- Landed catch and discard mortality are combined in the data file as total catch, estimated outside of SS2;
- Historical records (1951-1980) are used to reconstruct time-series of longnose skate catches, with a linear increase in catches from 1916 to 1951;
- Model includes one sex;
- Natural mortality *M* is fixed at 0.2;
- All three parameters of von Bertalanffy growth parameters (L_1, L_2 and *K*) are estimated;
- Recruits are treated deterministically, and are taken from the estimated stock-recruit curve;
- NWFSC slope-shelf survey *Q* is fixed at 0.83;
- Selectivities of slope surveys are fixed asymptotic;
- Iterative re-weighting was conducted by applying the same adjustment to all points in each data series..

The STAR Panel requested model changes in five series. All of the STAR Panel requests were reflected in new base model and current assessment report.

STAR panel requests for longnose skate analyses (Series 1)

Modify base case (from current formulation):
- One sex model
- No recruitment deviations
- Use F45% proxy for MSY
- Do not assume discards on historical catch estimates, rather adjust the catch series to account for discarding, proportion of longnose skate in skate catch, discard mortality, etc.

A. Do fits using the base case formulation as adjusted above, with the equilibrium non-zero catch initialization (in 1980) to:
   1. The "best" historical catch (same as current)
   2. The low historical catch (see below)
   3. The high historical catch (see below)

   For these three series we are interested to see the biomass trajectories and a summary of the likelihood components.

B. Do a fit initializing the population at equilibrium conditions in 1915, with catches ramping up from 0 to the high historical catch between 1915 and 1950 and constant at the high historical level from 1951 to 1980. Show a comparison of the estimated 1980 age structure from this run and from run A3 above. This run is formulated the same as the runs "A" above, other than in how the population is initialized.

C. Based on run A1 above: Modify selectivity for the two slope surveys to be asymptotic. Do a profile on *q*.

D. AFSC triennial survey data. Jim Hastie is getting summary information so that potential bias in catchability in the 2004 survey can be investigated.

STAR panel requests for longnose skate analyses (Series 2)

The updated base case continues from changes made under the Series 1 requested changes (One sex model, no recruitment deviations). Additional changes to the new update base case will include:
- Washington State 1950-1979 catches will be removed
- *M*=0.2 (subject to evaluating basis for this)
- Population to be initialized at equilibrium in 1916
- Re-do the iterative re-weighting of fishery sample sizes using the output from SS2 (i.e., rescale a series, rather than individual samples)
- Slope surveys selectivity parameters; asymptotic selectivity, estimate peak parameter, and no estimation of descending width parameters (because it had no influence on the fits)

For this new base case:

A. Fit to the "best" catch data series

B. Separate fits to the "low catch" and "high catch" series
C. Profile on *q* (NWFSC shelf-slope survey) for the "best" catch series run
D. Do a fit using the B.C. estimates of maturity at length ("best" catch series)
E. Provide supporting information for *M*=0.2
F. For one run (e.g., base case with "best" catch series) try different techniques to see if you find alternative minima (jittering or other method to begin with different initial parameter estimates and different phases for the parameters).

STAR panel requests for longnose skate analyses (Series 3)

New base case:

- fix one parameter (descending limb) of fishery selectivity
- add priors for *q* and *M*
- finish iterative re-weighting for sample sizes
- keep the Thompson estimates of maturity for base case
- add extra error to AFSC shelf survey (so that the RMSEs are similar to SEs)

1) Run base case scenario with "best" catch series. Produce R graphics for this run.
2) Run base case formulation with low catch series
3) Run base case formulation with high catch series
4) Run model with B.C. maturity estimates (otherwise same formulation as base case)

STAR panel requests for longnose skate analyses (Series 4)

Base case as defined in previous request:

1) Run base case formulation using the low catch series but fixing the shelf-slope survey *q* at the value estimated for the base case run (using the "best" catch series)
2) Run base case formulation using the high catch series but fixing the shelf-slope survey *q* at the value estimated for the base case run (using the "best" catch series)

STAR panel requests for longnose skate analyses (Series 5)

Base case as defined in previous request, except that M is fixed 0.2 and the NWFSC shelf-slope survey *q* is fixed at 0.83. Three runs:

1) Low *q* (0.654) and low catch history
2) Mid *q* (0.83) and mid catch history
3) High *q* (1.046) and high catch history

APPENDIX 2: Codes for the longnose skate assessment model

SS2 data file

```
1916  #_styr
2008  #_endyr
1      #_nseas
12     #_months/season
1      #_spawn_seas
1      #_Nfleet
4      #_Nsurv

fishery1%survey1_NWFSC_shelf_slope%survey2_NWFSC_slope%survey3_Triennial%Survey4_AFSC_Slope
0.5 0.5 0.66 0.66 0.9 #_surveytiming_in_season
1      #_Ngenders
24     #_Nages
       #_catch_biomass(mtons):_columns_are_fisheries,_rows_are_year*season"

       0             #_init_equil_catch_for_each_fishery (1915)
       19.62103302   #1916
       39.24206604  #1917
       58.86309906  #1918
       78.48413208  #1919
       98.1051651   #1920
       117.7261981  #1921
       137.3472311  #1922
       156.9682642  #1923
       176.5892972  #1924
       196.2103302  #1925
       215.8313632  #1926
       235.4523962  #1927
       255.0734293  #1928
       274.6944623  #1929
       294.3154953  #1930
       313.9365283  #1931
       333.5575613  #1932
       353.1785944  #1933
       372.7996274  #1934
       392.4206604  #1935
       412.0416934  #1936
       431.6627264  #1937
       451.2837595  #1938
       470.9047925  #1939
```

490.5258255	#1940
510.1468585	#1941
529.7678915	#1942
549.3889245	#1943
569.0099576	#1944
588.6309906	#1945
608.2520236	#1946
627.8730566	#1947
647.4940896	#1948
667.1151227	#1949
367.57568	#1950
264.31344	#1951
298.89208	#1952
913.72872	#1953
333.47072	#1954
948.78104	#1955
422.04888	#1956
365.20728	#1957
379.89136	#1958
517.25856	#1959
315.94456	#1960
1568.35448	#1961
878.6764	#1962
994.728	#1963
972.46504	#1964
553.25824	#1965
681.62552	#1966
677.3624	#1967
1191.77888	#1968
771.62472	#1969
428.20672	#1970
186.62992	#1971
287.99744	#1972
294.15528	#1973
287.52376	#1974
325.41816	#1975
891.93944	#1976
898.09728	#1977
1453.72392	#1978
1542.77576	#1979
998.51744	#1980
3212.684566	#1981

```
        2165.499881   #1982
        1676.587936   #1983
        862.63616     #1984
        1242.938008   #1985
        1026.139441   #1986
        1177.537321   #1987
        759.7376229   #1988
        838.3027082   #1989
        661.0358749   #1990
        563.9250269   #1991
        334.0527082   #1992
        523.0623677   #1993
        735.481455    #1994
        367.3896881   #1995
        1474.014567   #1996
        2685.460845   #1997
        1220.16021    #1998
        1835.376757   #1999
        2108.321244   #2000
        1342.347064   #2001
        487.5559279   #2002
        1323.043348   #2003
        581.5133621   #2004
        959.0928615   #2005
        1157.063834   #2006
        899.2233525   #2007
        899.2233525   #2008

21 #_N_cpue_and_surveyabundance_observations #(2-NWFSC_shelf_slope,3-NWFSC_slope,4-Triennnial,5-AFSC_Slope)
#_year  seas        index        obs                 se(log)
#NWFS Slope_shelf survey (30-700 fm)
2003    1           2            50768.03368         0.084145859   #_orig_obs:
2004    1           2            55648.33897         0.073307751   #_orig_obs:
2005    1           2            50762.1337          0.063176781   #_orig_obs:
2006    1           2            55267.92954         0.083718657   #_orig_obs:
#NWFS Slope survey (100-700 fm)
1999    1           3            28431.13646         0.128927013   #_orig_obs:
2000    1           3            24002.32992         0.165365711   #_orig_obs:
2001    1           3            24150.43873         0.143851631   #_orig_obs:
2002    1           3            27022.31278         0.097986123   #_orig_obs:
#Triennial (30-200 fm)
1980      1         4            968                 0.218        #_orig_obs:
```

```
1983    1           4             1453                0.149        #_orig_obs:
1986    1           4             1552                0.162        #_orig_obs:
1989    1           4             3049                0.179        #_orig_obs:
1992    1           4             1672                0.162        #_orig_obs:
1995    1           4             1635                0.156        #_orig_obs:
1998    1           4             3733                0.159        #_orig_obs:
2001    1           4             3180                0.084        #_orig_obs:
2004    1           4             7827                0.093        #_orig_obs:
#AFSC Slope (100-700 fm)
1997    1           5             17226               0.12389778   #_orig_obs:
1999    1           5             14199               0.108038426  #_orig_obs:
2000    1           5             13748               0.12580153   #_orig_obs:
2001    1           5             14278               0.122041609  #_orig_obs:

2 #_discard_type(1=biomass;_2=fraction)
0 #_N_discard_obs

0 #_N_meanbodywt_obs
#Yr    Seas   Type   Part   Value    CV
#2006  1       1      1      2.58    0.95

0.0001  #_comp_tail_compression
0.0001  #_add_to_comp

#_N_LengthBins
27
15  20  25  30  35  40  45  50  55  60  65  70  75  80  85  90  95  100 105 110 115 120 125 130 135 140 145

22 #_N_Length_obs
#Yr    Seas   Flt/Svy Gender  Part  Nsamp datavector(female-male)
#Fishery
1995   1      1      0      0      53           0            0            0            0            0
       0            0            0            0            0            0.037735849  0.056603774  0.018867925
       0.075471698  0.188679245  0.113207547  0.075471698  0.150943396  0.094339623  0.037735849  0.056603774
       0.075471698  0.018867925  0            0            0            0
1996   1      1      0      0      99           0            0            0            0            0
       0            0            0            0.01010101                0            0.02020202   0.050505051
       0.101010101  0.151515152  0.181818182  0.111111111  0.111111111  0.111111111  0.050505051  0.04040404
       0.03030303   0.01010101   0.01010101   0.01010101   0                         0            0
1997   1      1      0      0      459          0            0            0            0            0
       0.002178649  0            0.004357298  0.013071895  0.021786492  0.047930283  0.054466231  0.087145969
```

```
        0.091503268  0.145969499  0.126361656  0.104575163  0.098039216  0.054466231  0.067538126  0.023965142
        0.026143791  0.021786492  0.006535948  0.002178649  0            0
1998    1      1     0      0     84           0            0            0            0            0
        0.011904762  0.047619048  0.023809524  0            0.047619048  0.011904762  0.071428571  0.083333333
        0.178571429  0.142857143  0.119047619  0.130952381  0.035714286  0.035714286  0.023809524  0.011904762
        0.023809524  0      0     0                         0            0
1999    1      1     0      0     311          0            0            0            0            0
        0            0.003215434  0            0.006430868  0.009646302  0.025723473  0.035369775  0.048231511
        0.08681672   0.144694534  0.15755627   0.135048232  0.090032154  0.067524116  0.073954984  0.061093248
        0.028938907  0.006430868  0.012861736  0.006430868  0            0
2000    1      1     0      0     299          0            0            0            0            0
        0            0            0            0            0            0.013377926  0.040133779  0.053511706
        0.110367893  0.127090301  0.143812709  0.123745819  0.120401338  0.080267559  0.063545151  0.043478261
        0.046822742  0.023411371  0.006688963  0            0.003344482               0
2001    1      1     0      0     457          0            0            0            0            0
        0            0            0.006564551  0.002188184  0.015317287  0.035010941  0.050328228  0.080962801
        0.096280088  0.148796499  0.13785558   0.120350109  0.083150985  0.061269147  0.054704595  0.054704595
        0.021881838  0.013129103  0.006564551  0.010940919  0            0
2002    1      1     0      0     235          0            0            0            0            0
        0            0            0            0            0.004255319  0            0.034042553  0.063829787
        0.131914894  0.165957447  0.157446809  0.157446809  0.085106383  0.068085106  0.029787234  0.063829787
        0.034042553  0.004255319  0            0            0            0
2003    1      1     0      0     518          0            0            0            0            0
        0            0            0.013513514  0.019305019  0.027027027  0.063706564  0.079150579  0.084942085
        0.104247104  0.115830116  0.106177606  0.102316602  0.083011583  0.069498069  0.052123552  0.036679537
        0.019305019  0.013513514  0.005791506  0.001930502  0.001930502  0
2004    1      1     0      0     149          0            0            0            0            0
        0            0            0.006711409  0.013422819  0            0.006711409  0.013422819  0.046979866
        0.087248322  0.11409396   0.167785235  0.073825503  0.093959732  0.11409396   0.080536913  0.053691275
        0.060402685  0.046979866  0.013422819  0.006711409               0            0
2005    1      1     0      0     248          0            0            0            0            0
        0            0            0            0            0            0            0.008064516  0.02016129
        0.064516129  0.064516129  0.112903226  0.137096774  0.133064516  0.137096774  0.133064516  0.092741935
        0.052419355  0.036290323  0.004032258  0.004032258  0            0
2006    1      1     0      0     603          0            0            0            0            0
        0            0            0            0            0            0            0.011608624  0.03814262
        0.081260365  0.107794362  0.135986733  0.096185738  0.099502488  0.114427861  0.109452736  0.07628524
        0.058043118  0.039800995  0.024875622  0.006633499  0            0

#NWFS Shelf_slope survey
2003    1     2       0       0   2675         0.000153143  0.010446371  0.052865857  0.057020155  0.056969682
        0.074003282  0.078485036  0.08485576   0.067196025  0.060574022  0.057080145  0.066755707  0.071773516
```

```
      0.065475447  0.052347076  0.043758763  0.031927664  0.02670609   0.019021869  0.008626458  0.006355062
      0.00300481   0.003249119  0.000818884  0            0.00053006   0
2004  1     2     0     0      2647         0.000749611  0.015337003  0.039522762  0.066109916  0.048693229
      0.061780396  0.068493942  0.090977691  0.076685202  0.088616396  0.06833257   0.074510142  0.065118796
      0.066820305  0.053379229  0.042423605  0.025787787  0.018419471  0.011893947  0.006418267  0.003456819
      0.002238862  0.001775282  0.001106247  0.001015137  0.000337386  0
2005  1     2     0     0      3326         0            0.016755488  0.055840771  0.063564351  0.067027308
      0.077055281  0.070944638  0.074542922  0.073580392  0.069575534  0.061129744  0.062941288  0.061324177
      0.061409618  0.054730843  0.039891822  0.028213688  0.025276804  0.016186173  0.006979488  0.003907415
      0.003051025  0.005005446  0.000759643  0.000306139  0            0
2006  1     2     0     0      3325         0            0            0.001416816  0.034348927  0.053760622
      0.073713285  0.063959501  0.076317292  0.078679747  0.065346917  0.08617749   0.060220398  0.067448639
      0.055182885  0.075019689  0.055820984  0.0480657    0.029674178  0.027260659  0.016960297  0.010884979
      0.008460468  0.006897071  0.002685534  0.001302793  0.000395129  0

#Triennial
2001  1     4     0     0      796          0            0.018280364  0.033732258  0.069089355  0.053676643
      0.05767752   0.061090051  0.075796257  0.074982001  0.0616435    0.060193756  0.081533398  0.070666441
      0.049609647  0.080940154  0.060433135  0.028598769  0.016980002  0.020290904  0.015977181  0.002819286
      0.003242945  0.002098088  0            0            0            0.000648344
2004  1     4     0     0      794          0            0.024273252  0.057540289  0.056475451  0.045736376
      0.056825564  0.053425147  0.059794931  0.053619976  0.055329675  0.045571338  0.077470615  0.115810859
      0.057692936  0.036163376  0.059355181  0.039309118  0.040189936  0.047703914  0.006091645  0.003863367
      0.003663002  0.003261743  0.000832309  0            0            0

#AFSC Slope
1997  1     5     0     0      764          0            0            0.005347784  0.023488466  0.021111317
      0.061647608  0.059301493  0.104640293  0.110245197  0.079598263  0.096338749  0.07456304   0.081054704
      0.04050164   0.063165014  0.051421584  0.049336808  0.021410921  0.02075607   0.010713947  0.005848062
      0.009237117  0.006154195  0.002582645  0.000865769  0.000669314  0

1999  1     5     0     0      731          0            0.009117414  0.039426599  0.061591825  0.083621386
      0.092257061  0.103421937  0.099310388  0.083754789  0.078494886  0.052785373  0.050162803  0.049083344
      0.043815061  0.038659965  0.027462902  0.031536278  0.018952251  0.015220695  0.010861494  0.005361119
      0.003958062  0            0            0.001144365  0            0
2000  1     5     0     0      743          0.00211345   0.036186922  0.031756364  0.061243376  0.07867173
      0.093999265  0.091674939  0.090969654  0.058462173  0.069604189  0.068993455  0.053546347  0.041490576
      0.043178906  0.047777876  0.034642343  0.032378887  0.022268755  0.016922877  0.007506844  0.008654331
      0.004020956  0.002950818  0.000984969  0            0            0
2001  1     5     0     0      681          0            0.014688929  0.009970098  0.019972499  0.068060303
      0.118687433  0.127096269  0.096840372  0.089846499  0.078159363  0.054172957  0.052361879  0.044467393
```

```
      0.041932806  0.043032848  0.040156899  0.03721173   0.023845346  0.016927802  0.011086603  0.003751119
      0.006711379  0.001019472  0      0      0            0

#_N_AgeBins
24
0 1 2 3 4 5 6 7 8 9 10  11  12  13  14  15  16  17  18  19  20  21  22  23
1 #_N_ageerror_definitions
0.5   1.5   2.5    3.5  4.5   5.5   6.5   7.5   8.5   9.5   10.5  11.5  12.5  13.5  14.5  15.5  16.5
      17.5  18.5  19.5  20.5  21.5  22.5  23.5  25.5

0.3669 0.594088526  1.060660172  1.097517861  1.011299794  1.744739994  0.963624112  1.030776406  0.9397724035
      0.866025404  0.564076075  1.026436276  1.064120736  1.095445115  0.353553391  1.541103501  1.620185175
      1            1.111788648  1.111788648  1.111788648  3.16227766   1.111788648  1.1          1.1
#_N_Agecomp_obs
1
#Yr Seas  Flt/Svy Gender Part Ageerr Lbin_lo Lbin_hi Nsamp datavector
2003  1     2       0      0    1      -1      -1      258  0.042635659  0.062015504  0.050387597  0.069767442
      0.050387597  0.058139535  0.069767442  0.093023256  0.07751938   0.046511628  0.03875969   0.081395349
      0.073643411  0.058139535  0.034883721  0.042635659  0.027131783  0.011627907  0.007751938  0.003875969
      0            0            0            0
#_N_MeanSize-at-Age_obs
3
#Yr Seas  Flt/Svy Gender  Part  Ageerr  Ignore  datavector
#samplesize
2003  1     2       0       0     1       10   22.32727273  26.21875     35.99230769  41           46.99230769
      45.76666667  56.26666667  60.6625      68.1         76.02727273  72.01        80.92857143  85.00526316
      89.62666667  98.93333333  97.53636364  105.9285714  104.7666667  121.2        124.2        0
      0     0     0
      11    16    13    18    13    15    18    24    20    12    10    21    19    15    9     11
      7     3     2     0     0     0     0
2003  1     1      0      0     1       10        0     0     34    43.6  44.6  0     0     69.7  0
      0     79.6  82.5  94.05 105.5 102.9166667  114.8 122.9 109.925     112.75 0    130   0     0
      110.9  0    0     1     1     1     0     0     1     0     0     5     5     2     4     6
      2     2     4     2     0     1     0     0     1
2004  1     1     0     0     1     10    18.8  30.9  0     0     45.4  58.65 56.5        64.06666667
      73.425      78.075 80.21818182  92.775 92.26666667  94.9  99.2  105.8625    15.91666667  111.3111111
      113.5666667  129.5  116.5  135  0     0     2     3     3     4     8     11    4     15    9
      5     8     6     9     3     1     2     1     0     0
0 #_N_environ_variables
0 #_N_environ_obs
999
```

SS2 control file

```
 1           #_N_Growth_Patterns
 1           #_N_submorphs
 1           #_N_areas
 1 1 1 1 1   #_area_assignments_for_each_fishery_and_survey
 1           #_recruit_design_(G_Pattern_x_birthseas_x_area)_X_(0/1_flag)
 0           #_recr_distr_interaction
 0           #_Do_migration
 0 0 0       #_movement_pattern_(season_x_source_x_destination)_x_(0/1_flag)_minage_maxage
 0           #_Nblock_Designs
 0.5         #_fracfemale
 1           #_submorph_between/within
-1           #vector_submorphdist_(-1_first_val_for_normal_approx)
 1           #_natM_amin
 3           #_natM_amax
 1           #_Growth_Age-at-L1
 17          #_Growth_Age-at-L2
 0           #_SD_add_to_LAA
 0           #_CV_Growth_Pattern
 1           #_maturity_option
 8           #_First_Mature_Age
 3           #_parameter_offset_approach
 1           # new flag For selection of env and block adjustment method
-1           #_MGparm_Dev_Phase

#_growth_parms
#_LO     HI    NIT          PRIOR  PR_type SD   PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
 0.01    0.8   0.2           0.2          0     0.04   -3     0 0 0 0 0.5 0 0#_Gpattern:_1
-3       3     0             0           -1     99     -3     0 0 0 0 0.5 0 0#M1_natM_old_as
 15      40    26.958        26.958      -1     99      4     0 0 0 0 0.5 0 0#M1_Lmin
 70      130   109.74        109.74      -1     99      4     0 0 0 0 0.5 0 0#M1_Lmax
 0.05    0.15  0.047         0.047       -1     99      4     0 0 0 0 0.5 0 0#M1_VBK
 0.1     0.5   0.1394        0.1394      -1     99     -3     0 0 0 0 0.5 0 0#M1_CV-young
-1       1    -0.708        -0.708       -1     99     -3     0 0 0 0 0.5 0 0#M1_CV-old
-3       3     4.28e-006     4.28e-006   -1     99     -3     0 0 0 0 0.5 0 0#_wt-len&maturity
 2       4     3.05975       3.05975     -1     99     -3     0 0 0 0 0.5 0 0#Female wt-len-2
 10      140   120.753       120.753     -1     99     -3     0 0 0 0 0.5 0 0#Female mat-len-1
-0.09   -0.05 -0.0985876    -0.0985876   -1     99     -3     0 0 0 0 0.5 0 0#Female mat-len-2
-3       3     0.5           1           -1     99     -3     0 0 0 0 0.5 0 0#Female eggs/gm intercept
-3       3     0             0           -1     99     -3     0 0 0 0 0.5 0 0#Female eggs/gm slope
-4       4     0             0           -1     99     -3     0 0 0 0 0.5 0 0#_recrdistribution_by_growth_pattern
```

```
-4      4    0            0           -1     99     -3     0 0 0 0 0.5 0 0#_recrdistribution_by_area1
-4      4    4            0           -1     99     -3     0 0 0 0 0.5 0 0#_recrdistribution_by_season 1
 1      1    1            1           -1     99     -3     0 0 0 0 0.5 0 0#_cohort_growth_deviation

0 #_custom_MG-env_setup
0 #_custom_MG-block_setup

#_Spawner-Recruitment
1 #_SR_function: 1=Beverton-Holt
#_LO   HI     INIT   PRIOR  PR_type SD   PHASE
 5     15     13     11.1   -1     10     1     #Ln(R0)
 0.2   1      0.4    0.6    -1     0.2   -1     #steepness
 0     0.4    0.3    0.3    -1     0.8   -3     #SD_recruitments
 0     0      0      0      -1     99    -3     #Env_link
-2     2      0      0      -1     99    -1     #init_eq
 0     0      0       0     -1     0     -99    #  new parameter Line reserved For future use as autocorrelation

0 #_SR_env_link
3 #_SR_env_target_1=devs;_2=R0;_3=steepness
0 #do_recr_dev:  0=none; 1=devvector; 2=simple deviations
1984   2008   -15    15     3 #_recr_devs
1492 #_first_yr_fullbias_adj_in_MPD

#_initial_F_parms
#_LO   HI     INIT   PRIOR PR_type SD    PHASE
 0     1      0      0.03   -1     99     -1

#_Q_setup
# A=do power, B=env-var, C=extra SD, D=devtype(<0=mirror, 0/1=none, 2=cons, 3=rand, 4=randwalk); E=0=num/1=bio, F=err_type
#_A  B  C  D  E  F
       0  0  0  0  1  0    #Fishery
       0  0  0  2  1  0    #Survey1_NWFSC_shelf_slope
       0  0  0  2  1  0    #Survey2_NWFSC_slope
       0  0  0  2  1  0    #Survey3_Trieannial
       0  0  0  2  1  0    #Survey4_AFSC_Slope
#_Q_parms(if_any)
# LO         HI           INIT   PRIOR        PR_type      SD           PHASE
 -7          5            -0.19  -0.19        0             0.187       -1
 -7          0            -0.6   0            0             99           1
 -7          0            -0.6   0            0             99           1
 -7          0            -0.6   0            0             99           1
```

```
#_size_selex_types
#_Pattern                Discard             Male          Special
      24                 0                   0             0 # 1
      24                 0                   0             0 # 2
      5                  0                   0             2 # 3
      24                 0                   0             0 # 4
      24                 0                   0             0 # 5
#_age_selex_types
#_Pattern                Discard             Male          Special
      10                 0                   0             0 # 1
      10                 0                   0             0 # 2
      10                 0                   0             0 # 3
      10                 0                   0             0 # 4
      10                 0                   0             0 # 5
#_selex_parms
#_LO HI INIT PRIOR  PR_type  SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
#_size_sel: 1_fishery
  80   100     85     85    0      99      2     0 0 0 0 0.5 0 0 # PEAK
 -6    4      -6     -6     0      99      2     0 0 0 0 0.5 0 0 # TOP:_width of plateau
 -1    9       5.8    5.8   0      99      2     0 0 0 0 0.5 0 0 # Asc_width
 -1    9       8.3    6.7   0      99     -2     0 0 0 0 0.5 00 # Desc_width
 -5    9      -5     -5     0      99     -2     0 0 0 0 0.5 0 0 # INIT:_selectivity_at_fist_bin
 -5    9       9      9     0      99      2     0 0 0 0 0.5 0 0 # FINAL:_selectivity_at_last_bin
#_size_sel: 2_NWFSC_shelf_slope
  20   80      50    50     0      99     2      0 0 0 0 0.5 0 0 # PEAK
 -6    4      -1.5  -1.5    0      99     2      0 0 0 0 0.5 0 0 # TOP:_width of plateau
 -1    9       9     9      0      99     2      0 0 0 0 0.5 0 0 # Asc_width
 -1    9       6     6      0      99    -2      0 0 0 0 0.5 0  0 # Desc_width
 -5    9      -4.8  -4.8    0      99    -2      0 0 0 0 0.5 0 0 # INIT:_selectivity_at_fist_bin
 -5    9       9     9      0      99    -2      0 0 0 0 0.5 0 0 # FINAL:_selectivity_at_last_bin
#_size_sel: 3_NWFSC_slope
 -2    1      -1     1      0      99    -2      0 0 0 0 0.5 0 0 # Min Bin Number in Survey 2
 -2    27     -1     27     0      99    -2      0 0 0 0 0.5 0 0 # Max Bin Number in Survey 2
#_size_sel: 4_Triennial
  50   75      75    75     0      99      2     0 0 0 0 0.5 0 0 # PEAK
 -6    4      -2.8  -2.8    0      99      2     0 0 0 0 0.5 0 0 # TOP:_width of plateau
 -1    9       9     9      0      99      2     0 0 0 0 0.5 0 0 # Asc_width
 -1    9       7.2   7.2    0      99      2     0 0 0 0 0.5 0  0 # Desc_width
 -5    9      -5    -5      0      99     -2     0 0 0 0 0.5 0 0 # INIT:_selectivity_at_fist_bin
 -5    9       9     9      0      99      2     0 0 0 0 0.5 0 0 # FINAL:_selectivity_at_last_bin
#_size_sel: 5_Slope
  50   60    45       45    0      99      2     0 0 0 0 0.5 0 0 # PEAK
```

```
 -6    4    -5.5     -5.5   0      99      2     0 0 0 0 0.5 0 0 # TOP:_width of plateau
 -1    9     5        5     0      99      2     0 0 0 0 0.5 0 0 # Asc_width
 -1    9     7.7      7.7   0      99     -2     0 0 0 0 0.5 0  0 # Desc_width
 -5    9    -4       -4     0      99     -2     0 0 0 0 0.5 0 0 # INIT:_selectivity_at_fist_bin
 -5    9     9        9     0      99     -2     0 0 0 0 0.5 0 0 # FINAL:_selectivity_at_last_bin

1 #_new flag For environment and block adjustment method
0 #_custom_sel-env_setup
0 #_custom_sel-block_setup

-1 #_selparmdev-phase

#_Variance_adjustments_to_input_values
#_1 2 3 4 5
0           0           0      0.211025     0            #_add_to_survey_CV
0           0           0      0            0            #_add_to_discard_CV
0           0           0      0            0            #_add_to_bodywt_CV
0.783545    0.408719    0      0.460038     0.645069     #_mult_by_lencomp_N
0           0.534747    0      0            0            #_mult_by_agecomp_N
1           1           1      1            1            #_mult_by_size-at-age_N
30 #_DF_for_discard_like
30 #_DF_for_meanbodywt_like

1 #_maxlambdaphase
0 #_sd_offset
#_lambdas_(columns_for_phases)
0 #_CPUE/survey:_1
1 #_CPUE/survey:_2
1 #_CPUE/survey:_3
1 #_CPUE/survey:_4
1 #_CPUE/survey:_5
1 #_discard:_1
1 #_discard:_2
1 #_discard:_3
1 #_discard:_4
1 #_discard:_5
1 #_meanbodyweight
1 #_lencomp:_1
1 #_lencomp:_2
1 #_lencomp:_3
1 #_lencomp:_4
1 #_lencomp:_5
```

```
1 #_agecomp:_1
1 #_agecomp:_2
1 #_agecomp:_3
1 #_agecomp:_4
1 #_agecomp:_5
1 #_size-age:_1
1 #_size-age:_2
1 #_size-age:_3
1 #_size-age:_4
1 #_size-age:_5
1 #_init_equ_catch
1 #_recruitments
0 #_parameter-priors
1 #_parameter-dev-vectors
100 #_crashPenLambda
0.7 #_maximum allowed harvest rate
999
```