C. RED HAKE ASSESSMENT SUMMARY FOR 2010

State of Stock

Based on current biological reference points, the northern stock of red hake (*Urophycis chuss*) (Figure C1) is not overfished and overfishing is not occurring. The three year delta mean biomass index (Figure C2), based on the NEFSC fall bottom trawl survey for 2007-2009 (2.87 kg/tow), was above the management threshold level (1.6 kg/tow) and slightly below the target (3.1 kg/tow). The three year average exploitation index (landings divided by biomass index, Figure C3) for 2007-2009 (0.03) was below both the target (0.39) and the threshold (0.65).

Based on current biological reference points, the southern stock of red hake (Figure C1) is not overfished and overfishing status is unknown. The three year delta individual mean weight index (Figure C4), based on the NEFSC fall bottom trawl survey for 2007-2009 (0.10 kg/individual), is below the management threshold (0.12 kg/individual) but the three year average recruitment index (5.95 number/tow) is above the threshold value (4.72 number/tow).

Based on newly proposed biological reference points, the northern stock of red hake is not overfished and overfishing is not occurring. The three year arithmetic mean biomass index (Figure C5), based on the NEFSC spring bottom trawl survey for 2008-2010 (2.42 kg/tow), was above the proposed management threshold (1.27 kg/tow) and slightly below the target (2.53 kg/tow). The exploitation index (catch divided by biomass index, Figure C6) for 2009 (0.103 kt/kg) was below the threshold (0.163 kt/kg).

Based on newly proposed biological reference points, the southern stock of red hake is not overfished and overfishing is not occurring. The three year arithmetic mean biomass index (Figure C7), based on the NEFSC spring bottom trawl survey for 2008-2010 (0.95 kg/tow), was above the proposed management threshold (0.51 kg/tow) and slightly below the target (1.02 kg/tow). The exploitation index (catch divided by biomass index, Figure C8) for 2009 (1.150 kt/kg) was below the threshold (3.038 kt/kg).

Projections

Stochastic projections were not performed for this assessment. However, applying the threshold exploitation index F_{MSY} proxy to the three-year average biomass index (2008-2010) allows catches of 394 mt in the north and 2,897 mt in the south.

Catches

Nominal red hake commercial landings in the northern stock peaked at 15,000 mt in 1972 and 1973, followed by a sharp decline in 1977 corresponding to the departure of the distant water fleets (Figure C9). Landings then averaged 1,000 mt from 1977-1994, but declined to an average of only 100 mt through 2009. In the southern stock, nominal landings peaked at over 100,000 mt in 1965 with a second peak of 60,000 in 1972 (Figure C10). Landings then averaged 2,000 mt from 1977-1994, but declined to average 900 mt through 2009. Discards from the northern stock averaged 1300 mt in the early 1980s, declined to about 250 mt from 1995-2000 and have averaged 100 mt through 2009 (Figure C11). Discards from the southern stock averaged 4,000 mt in the 1980s, declined to about 1,000 mt from 1995-2000 and have averaged 700 mt through 2009 (Figure C12). Recreational landings have been relatively small with averages of 300 mt in

the south compared to less than 3 mt in the north (Figure C13).

Catch data are a major source of uncertainty for this assessment because of mixed reporting of landings of red and white hake and uncertain identification to species by observers. Therefore, a length-based model was developed to estimate the proportion of red hake in the total hake catch (red and white hake combined). The model estimates for the northern stock area were generally lower than the nominal and the large peak in landings in the 1970s is eliminated (Figure C9). The landings for the southern stock area were also lower but the trend was similar (Figure C10). The complete change in trend in the north was not considered acceptable, so the length-based split was not used, and the nominal catch was used in the assessment.

From 1994 to 2009, landings for bait in the north have averaged 50% of the reported landings and ranged from one percent of the reported landings early in the time series to five times the reported landings in more recent years. In some years, less than three vessels reported bait landings on VTRs. Therefore, bait landings cannot be tabulated separately.

Catch and Status Table (weights in mt): Red Hake

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Max[1]	Min[1]	Mean[1]
Nominal Landings[2]														
North														
US	197	222	275	210	103	96	96	69	52	85		3792	52	746
DWF[2]												14926	2	4704
Rec	0.06	0.48	0.28	0.13	0.02	0.02	0.05	0.21	0.22	0.43		30.89	0.00	3
Total	197	223	275	210	103	96	96	69	52	85		15290	52	2160
South														
US	1417	1469	663	623	588	356	375	470	580	575		32622	356	4054
DWF[3]												103937	50	21258
Rec	44	24	10	18	10	55	53	20	74	100		971	10	275
Total	1462	1492	673	641	599	411	429	489	653	674		108016	411	14533
Combined														
US	1614	1691	938	832	691	452	471	539	632	659		32910	452	4799
DWF[3]												108627	50	24198
Rec	44	24	11	18	10	55	54	20	74	100				
Total	1659	1715	949	850	701	507	524	559	706	760		113594	507	16693
Nominal Discards														
North	55	135	101	88	57	57	181	127	59	95		1460	55	552
South	250	138	327	345	616	1007	674	1545	814	869		6343	138	2265
Combined	3944	4045	3069	3476	3371	3519	855	1673	873	964		5752	855	3287
Catch Used in Assessment[4]														
Northern	252	358	376	297	160	153	277	197	112	180		15290	112	2480
Southern	1712	1630	1000	986	1214	1418	1103	2035	1467	1543		108016	986	15847
Combined	1963	1988	1376	1283	1374	1572	1380	2231	1579	1724		113594	1283	18326
North														
Fall Survey Delta Biomass	6.50	5.38	6.47	3.88	1.66	1.27	3.68	2.41	3.56	2.65		6.50	0.26	2.86
3-Year Average Fall Survey Delta Biomass	4.96	5.07	6.12	5.24	4.00	2.27	2.20	2.45	3.21	2.87		6.12	0.45	2.84
Landings/Fall Delta Biomass	0.02	0.03	0.03	0.04	0.04	0.06	0.04	0.04	0.01	0.03		5.00	0.01	0.81
South														
Individual Fall Mean Weight/Tow[5]	0.16	0.15	0.10	0.09	0.06	0.08	0.11	0.06	0.12	0.11		0.22	0.04	0.13
3-Year Average Ind. Mean Wt/Tow	0.12	0.11	0.13	0.11	0.08	0.08	0.09	0.09	0.10	0.10		0.21	0.08	0.13
Fall Recruitment[6]	0.50	10.18	5.71	4.45	4.78	7.60	5.63	10.33	3.14	4.38		29.86	0.50	5.14
3-Year Average Recruitment	4.67	7.72	5.46	6.78	4.98	5.61	6.00	7.85	6.37	5.95		11.82	1.11	5.26
Biomass (Spring Survey kg/tow)														
North	3.19	3.58	4.46	1.00	1.77	1.10	0.91	2.06	3.49	1.75	2.02	6.35	0.54	2.43
South	0.42	0.64	0.54	0.21	0.15	0.38	0.38	0.86	0.47	1.34	1.04	7.65	0.15	1.61
Combined	1.51	1.80	2.08	0.52	0.79	0.66	0.59	1.33	1.66	1.50	1.66	5.65	0.52	1.94
3-Year Average Biomass (Spring Survey kg/tow)														
North	2.68	3.03	3.74	3.01	2.41	1.29	1.26	1.36	2.15	2.43	2.42	4.12	0.61	2.48
South	0.36	0.51	0.54	0.46	0.30	0.25	0.30	0.54	0.57	0.89	0.95	5.09	0.25	1.64
Combined	1.27	1.50	1.80	1.47	1.13	0.66	0.68	0.86	1.19	1.50	1.61	4.21	0.66	1.97
Relative Exploitation Rate (Catch/Spring Biomass)														
North	0.079	0.100	0.084	0.298	0.090	0.140	0.303	0.096	0.032	0.103		9.631	0.032	1.198
South	4.047	2.540	1.846	4.794	7.865	3.772	2.902	2.373	3.099	1.150		49.360	0.841	6.930

[1]Nominal Landings data based on 1960-2009 (mt). Length-Based Model Estimated Landings based on 1964-2009. Commercial fishery discard means from 1981-2009. Fall survey north data based on 1963-2009. Fall survey south data based on 1967-2009. Spring survey data based on 1968-2010. Relative exploitation rate (catch/spring biomass) based on 1980-2009.

[2]Nominal landings from 1994-2009 include landings sold as bait.

[3]Foreign landings are for NAFO Areas 5 and 6.

[4]Catch is nominal landings plus nominal discards.

[5] Mean weight of an individual fish from the NEFSC fall survey.

[6] Number of fish < 25 cm from the NEFSC fall survey.

Stock Distribution and Identification
Red hake is a demersal gadoid species distributed from the Gulf of St. Lawrence to North Carolina, and is most abundant from the western Gulf of Maine through Southern New England waters (Bigelow and Schroeder 1953). Red hake are separated into northern and southern stocks for management purposes. The northern stock extends from the Gulf of Maine to Northern Georges Bank region, while the southern stock extends from the Southern Georges Bank to Mid-Atlantic Bight region. Red hake stock structure was determined by considering distribution, homogeneous maturity, and differences in growth. There was no strong biological evidence to support either a separate or combined assessment. Analysis of otoliths from red hake captured in the northwestern and eastern part of the Bay of Fundy (Gulf of Maine) varied from the otolith morphology for red hake captured elsewhere and had intermediate characteristics with white hake, suggesting the possible existence of hybridization in that area (Penttila and Dery 1988).

Data and Assessment
Information used in the 2010 assessment include data from the NEFSC surveys, as well as commercial fishery data from vessel trip reports, dealer landings records and on-board fishery observers through 2009. The NEFSC bottom trawl survey switched from the FRV *Albatross IV* to the FSV *Bigelow* in spring 2009. Survey data given here are in "*Albatross IV"* units.

Although some statistical catch at length models (SCALE and SS3) were applied, model diagnostics were not adequate for stock status determination or for the provision of fishery management advice. Therefore, the assessment is based on the spring survey indices and exploitation indices from each area.

Examination of the effect of using the delta transformation on the variability of red hake survey indices indicated that the transformation did not reduce the variance. The delta transform and was very sensitive to the treatment of zero weight tows which occurred when the weight of fish was less than 0.1 kg prior to 2001. Therefore, the arithmetic mean is considered a better option for assessment purposes.

Biological Reference Points
The current overfishing definition for northern red hake reads as follows:

> *The northern stock of red hake is overfished when the three-year moving average of stock biomass, derived from the fall survey, is below* ***1.6 kg/tow****. If an analytical assessment is available for northern red hake, then the three-year moving average will be replaced with the terminal year biomass estimate and compared with the biomass reference points.*
>
> *Overfishing occurs when the ratio between catch and survey biomass exceeds* ***0.65****, the proxy for* F_{MSY}*. When biomass is less than 3.1 kg/tow (the biomass target), the stock is overfished when fishing mortality is above a rate that declines linearly to zero when biomass equals the minimum biomass threshold (1.6 kg/tow).*

The current overfishing definition for southern red hake reads as follows:

The southern stock of red hake is in an overfished condition when the three-year moving average weight per individual in the fall survey falls below the 25th percentile of the average weight per individual from the fall survey time series 1963-1997 (0.12) AND when the three-year moving average of the abundance of immature fish less than 25 cm falls below the median value of the 1963-1997 fall survey abundance of fish less than 25 cm (4.72).

In previous SAFE Reports, the Whiting Monitoring Committee (WMC) noted problems associated with the overfishing definition for southern red hake. Although the current definition is intended to identify overfished (i.e. low biomass) stock conditions, it is a better indication of overfishing (high exploitation rate). The WMC recommended that the overfishing definition for the southern stock of red hake be revisited.

New proposed BRPs for both northern and southern red hake stocks are as follows:

> *Red hake is overfished when the three-year moving arithmetic average of the spring survey weight per tow (i.e., the biomass threshold) is less than one half of the B_{MSY} proxy, where the B_{MSY} proxy is defined as the average observed from 1980 – 2010. The current estimates of $B_{THRESHOLD}$ for the northern and southern stocks are 1.27 kg/tow and 0.51 kg/tow, respectively.*
>
> *Overfishing occurs when the ratio between catch and spring survey biomass exceeds 0.163 kt/kg and 3.038 kt/kg, respectively, derived from AIM analyses from 1980-2009.*

Applying the F_{MSY} proxy to the B_{MSY} proxy allows for an MSY of 412 mt for the northern stock and 3,086 mt for the southern stocks. Catch per tow is in "Albatross" units (see Data and Assessment section).

The 80% confidence interval around the F_{MSY} proxy for the north is 0.062 - 0.240 kt/kg/tow (Figure C14), and for the south is 2.240 - 3.700 kt/kg/tow (Figure C15).

Fishing Mortality

For the northern stock, exploitation indices were derived for two time series. The fall survey shows very high exploitation in the 1960s and early 1970s, followed by a drop to low values from 1977 through the rest of the time series (Figure C3). This coincides with the departure of the distant water fleet. The second time series for exploitation was derived using the spring survey and shows a similar trend (Figure C6).

There is only one time series for the southern stock and it is based on the spring survey. The same peak is evident in the 1960s-1970s followed by a decline (Figure C7). However, exploitation generally increased from the late 1970s through 2005 (Figure C8). Exploitation declined since 2005.

Recruitment
Recruitment estimates from the southern stock have been variable with increased recruitment in the last decade (Figure C4).

Stock Biomass
For the northern stock, total biomass indices were derived for two time series. The fall survey increased from 1970 through 2002 followed by a decline through 2005 (Figure C2). The spring survey increased from 1970 through 1980, but declined through 1990, increased again through 2002 and then was consistent with the fall survey (Figure C5).

For the southern stock, the spring survey increased from 1970 through 1980, but declined through 2005, with a slight increase through 2009 (Figure C7).

Ecosystem Considerations
Estimates of minimum annual consumption of red hake by a subset of 12 finfish predators were computed using data from NEFSC spring and fall surveys during 1977-2009. Consumption was approximately 5 thousand mt per year during the late 1970s to late 1990s. These removals have averaged approximately 10 thousand mt in the 2000s (Figure C16). Estimates of red hake consumed by the subset of fish predators in this study were compared to total catch (Figure C16). Catch and minimum estimates of consumption were approximately equal for the early part of the time series. More recently, consumption has been the dominant source of removals, averaging approximately five times the fishery catch (Figure C17).

Special Comments
Some juvenile red hake inhabit shells of dead sea scallops. Abundance of scallop shells might have had an impact on the abundance of red hake. Prior to the recovery of the scallop stock, there may not have been enough available habitat to protect juvenile red hake (Steiner *et al* 1992). This is more related to the southern stock because the northern stock is likely to be able to find shelter in the rocky habitat of the Gulf of Maine. The recovery of scallops may have contributed to recent red hakes increases in the south, and scallop shell availability is probably not currently limiting.

The scientific information available on red hake stock structure included distribution, maturity, and growth rate. There was no strong biological evidence to support either a separate or combined red hake assessment.

Both the fall and spring surveys were examined, and the spring survey had more consistency in the AIM analysis. The confidence intervals for the relative exploitation indices were also smaller. Therefore, the spring survey data were used for reference point estimation.

References

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildl. Serv., Fish. Bull. 74: 223-230 p.

NEFC (Northeast Fisheries Center). 1986. Report of second NEFSC stock assessment workshop (Second SAW) Woods Hole Lab. Ref. Doc. 86-09, 114 p.

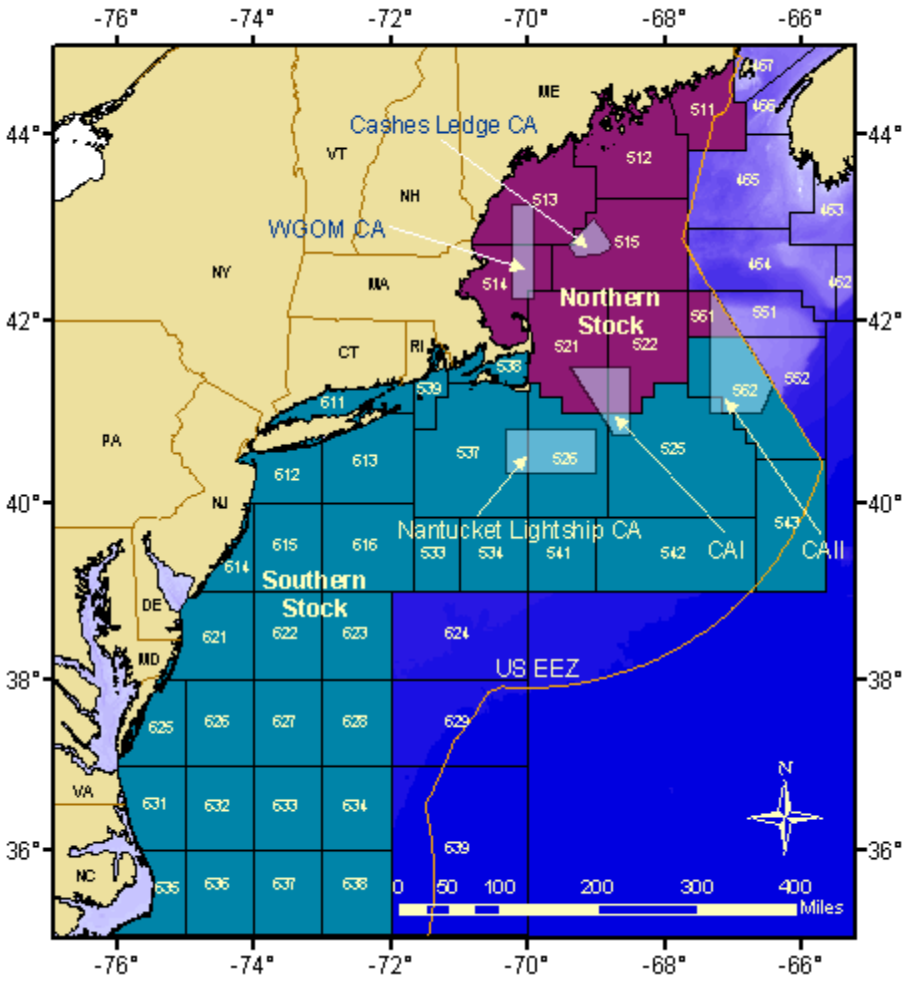
NEFMC (Northeast Fisheries Management Council). 2000. Amendment 12 to the Northeast Multispecies Fishery Management Plan. http://www.nefmc.org/mesh/index.html

NEFMC (Northeast Fisheries Management Council. 2003. Stock Assessment and Fish Evaluation Report (SAFE). http://www.nefmc.org/mesh/index.html

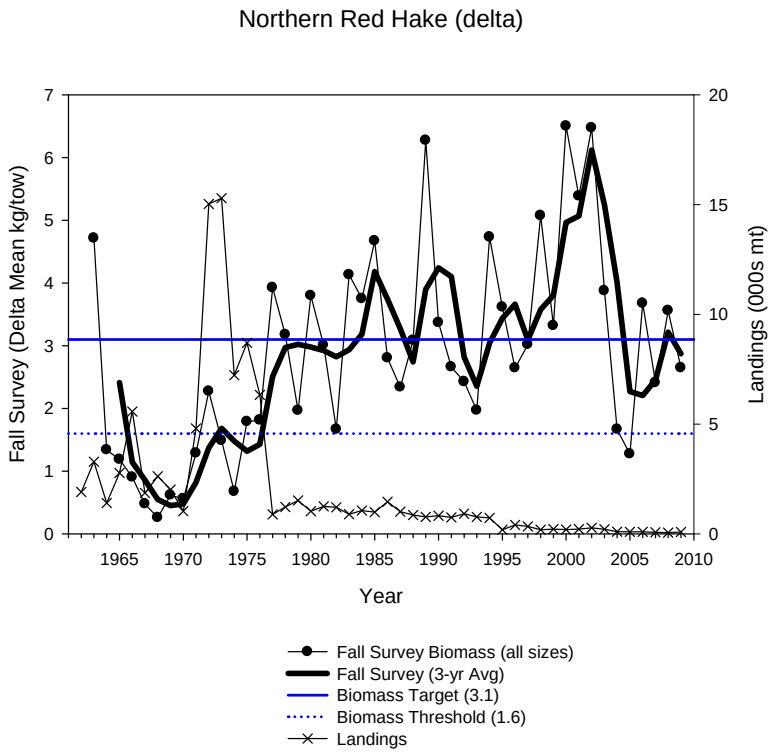
NEFSC (Northeast Fisheries Center). 1990. Report of the Eleventh NEFC Stock Assessment Workshop (11th SAW), fall 1990. Northeast Fish. Cent. Ref. Doc. 90-09. 121 p.

Penttila, Judy and Louise M. Dery. 1988. Age Determination Methods for Northwest Atlantic Species. NOAA Tech. Rpt. 72, 132 pp.

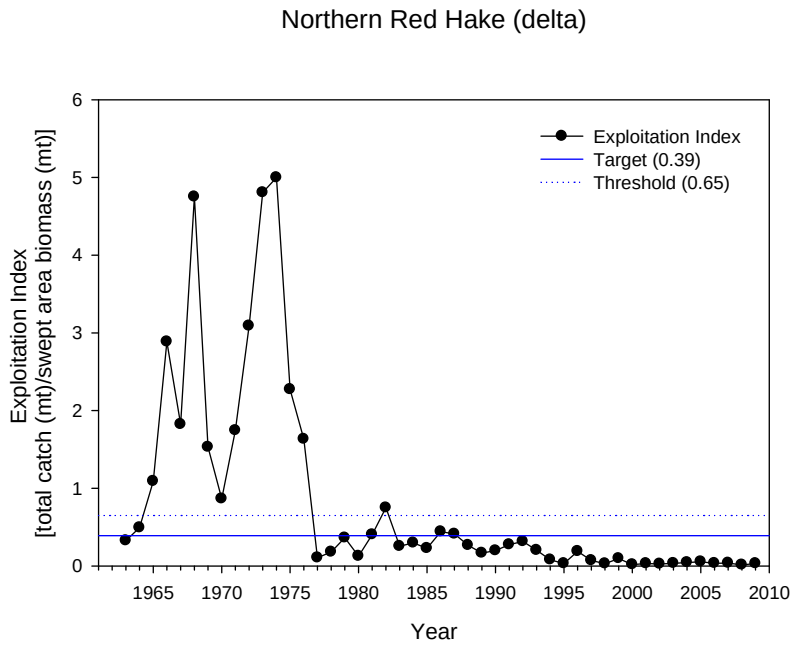
Steiner, W.W., J.J. Luczkovich, and B.L. Olla. 1982. Activity, shelter usage, growth and recruitment of juvenile red hake *Urophycis chuss*. Mar. Ecol. Prog. Ser. 7:125-135.



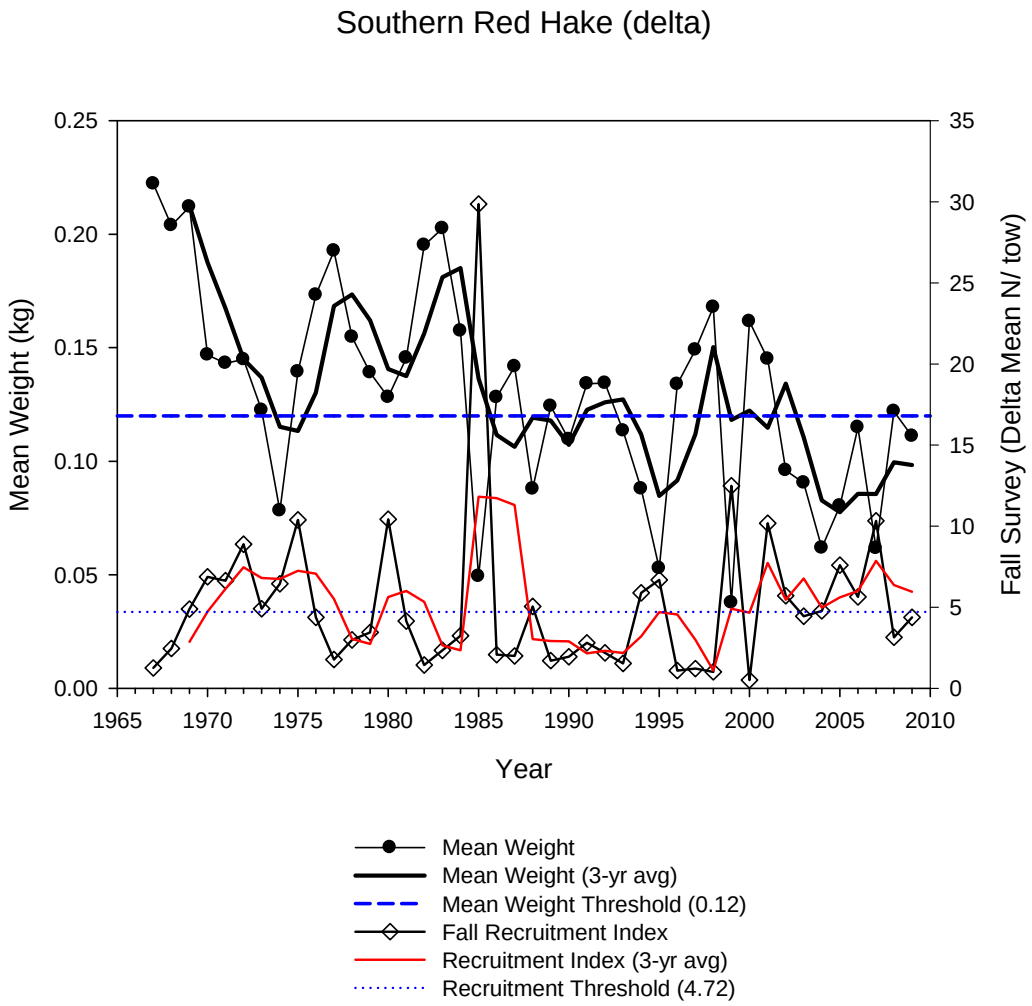
C1. Statistical areas used to define the northern and southern red hake stocks. Areas 464 and 465 are also included in the northern stock.



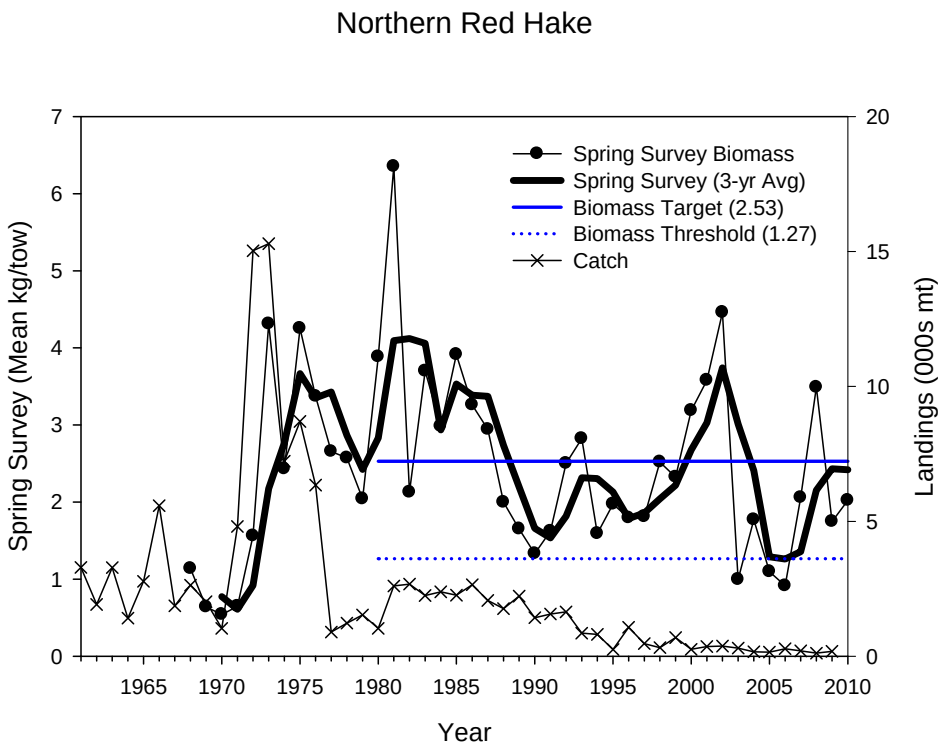
C2. Fall survey biomass (delta transformation) and current BRPs (as opposed to "proposed" BRPs) for the **northern** stock of red hake.



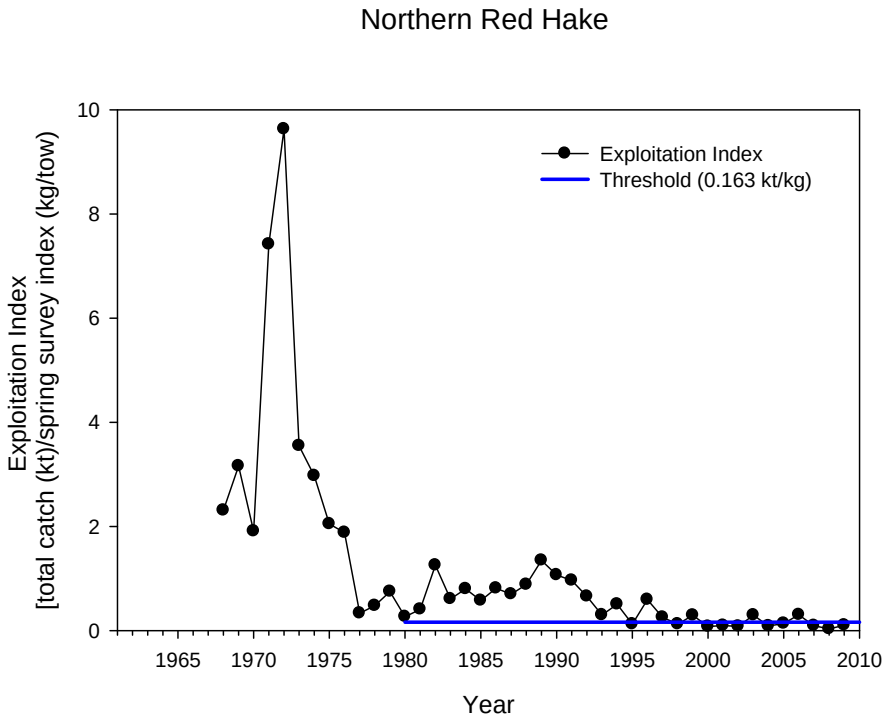
C3. Exploitation Indices (delta transformation of fall survey) and current BRPs (as opposed to "proposed" BRPs) for the **northern** stock of red hake.



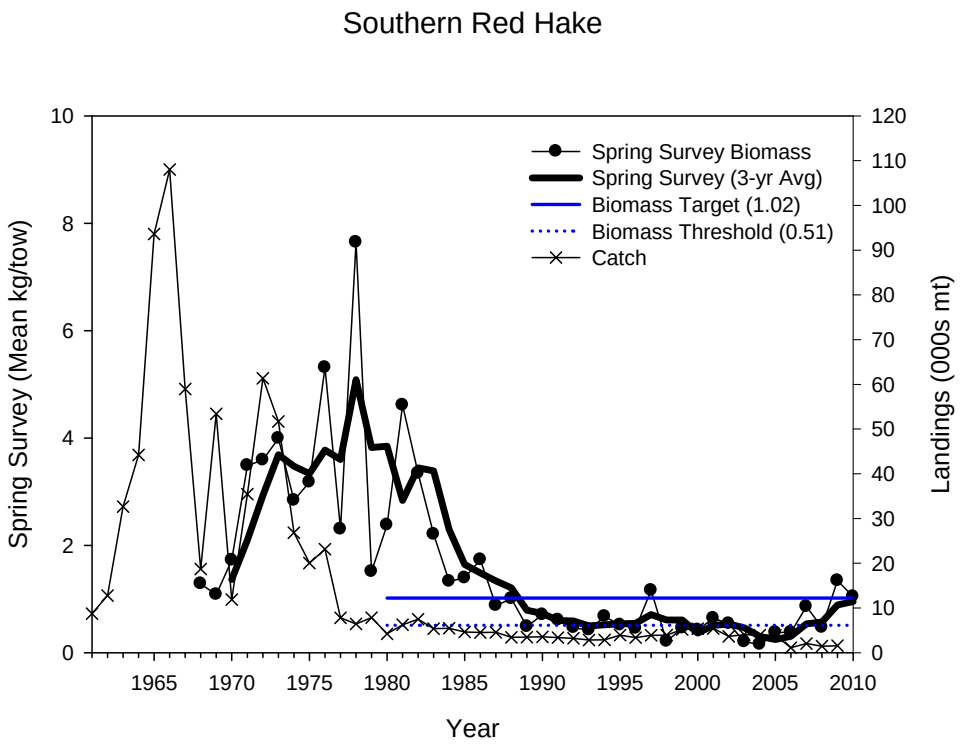
C4. Mean Individual weight (kg)/tow and recruitment index (Number of fish <25cm) from the NEFSC fall survey for the **southern** stock of red hake. Also shown are current BRP (as opposed to "proposed" BRP) thresholds.



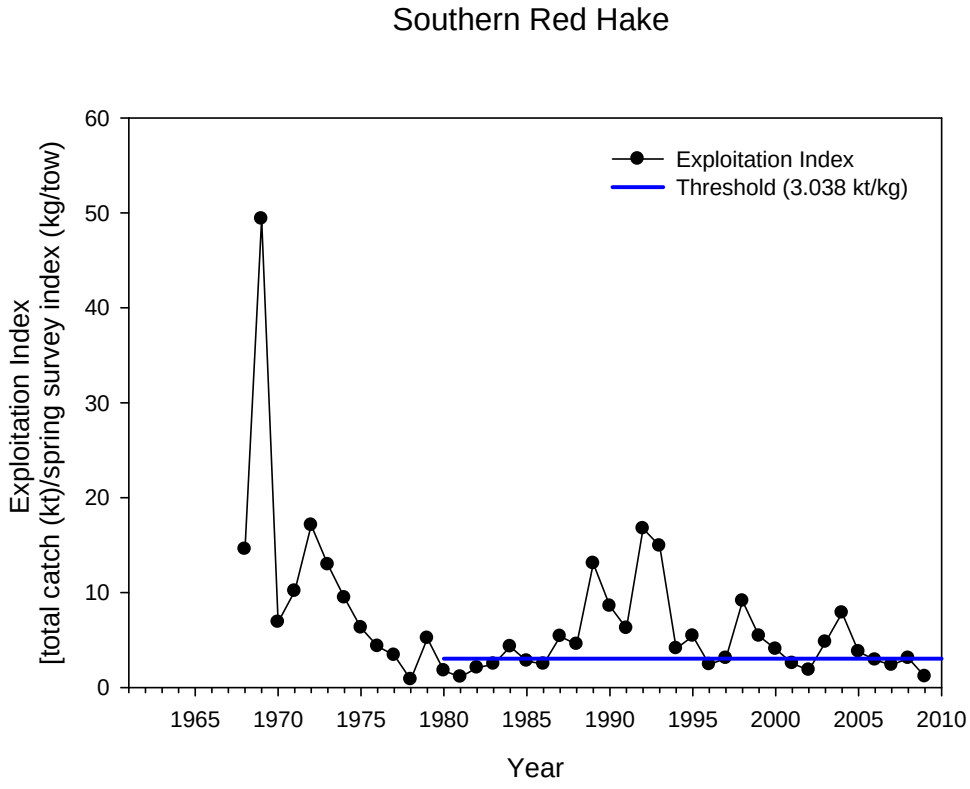
C5. Spring survey biomass and newly proposed BRPs for the **northern** stock of red hake.



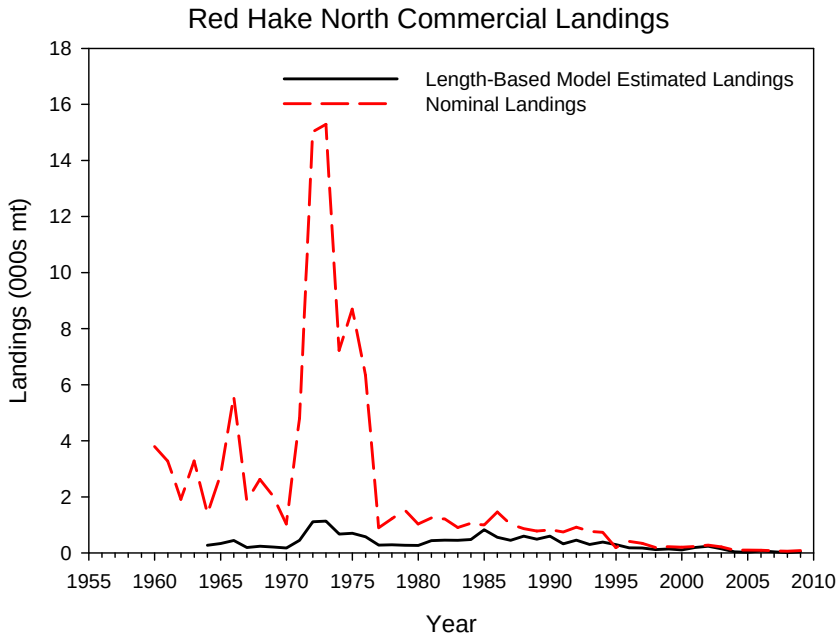
C6. Exploitation indices (spring survey) and newly proposed BRPs for the **northern** stock of red hake.



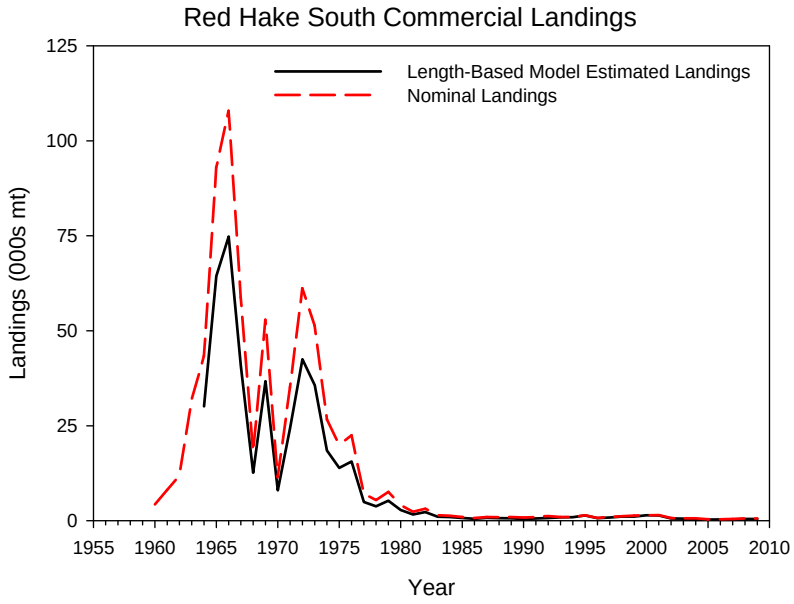
C7. Spring survey biomass and newly proposed BRPs for the **southern** stock of red hake.



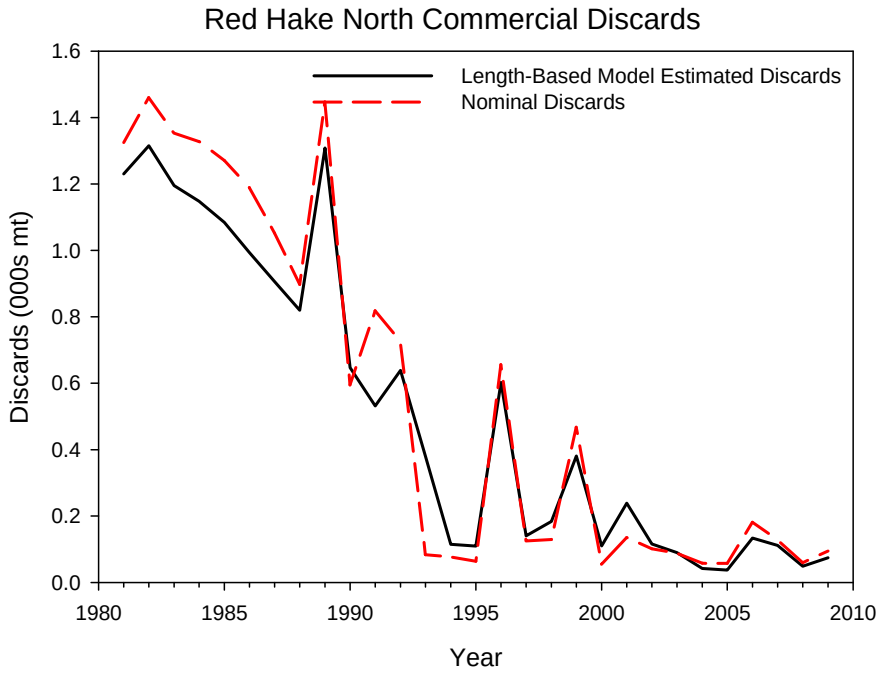
C8. Exploitation indices (spring survey) and newly proposed BRPs for the **southern** stock of red hake.



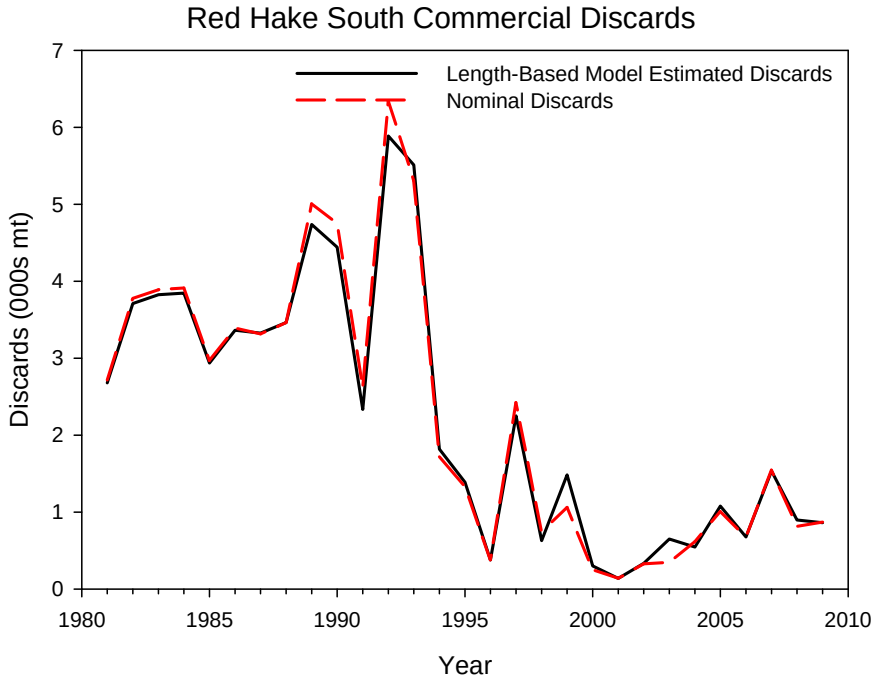
C9. Comparison of nominal landings with length-based model estimated landings of red hake from the **northern** stock. (Length-based estimates were not used in the assessment.)



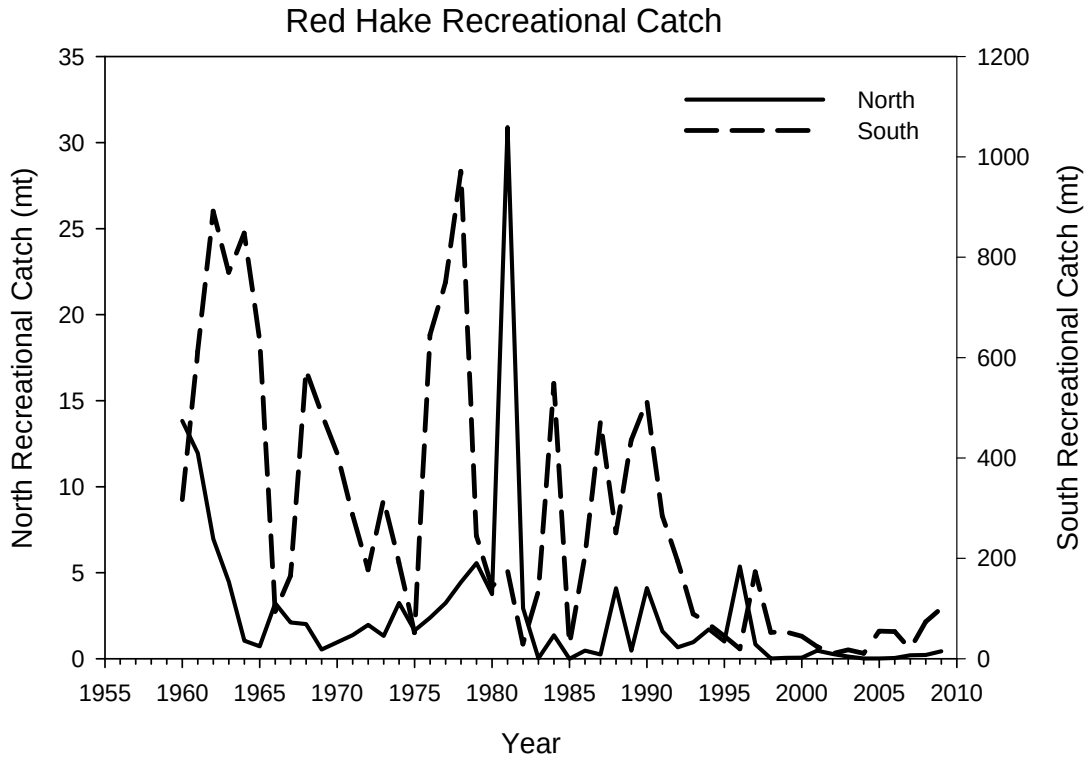
C10. Comparison of nominal landings with length-based model estimated landings of red hake from the **southern** stock. (Length-based estimates were not used in the assessment.)



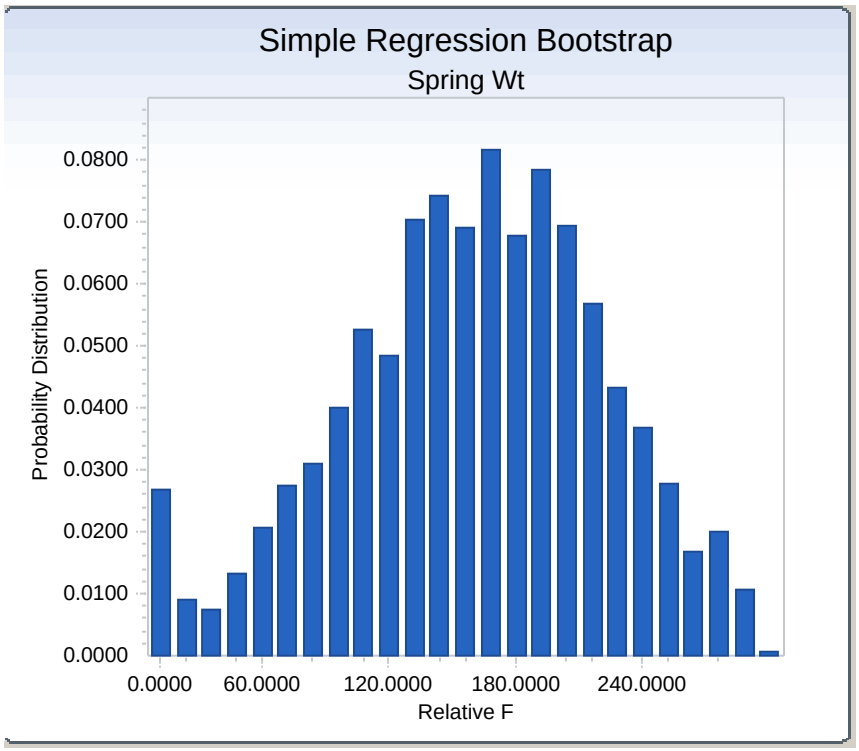
C11. Comparison of nominal discards with length-based model estimated discards of red hake from the **northern** stock. (Length-based estimates were not used in the assessment.)



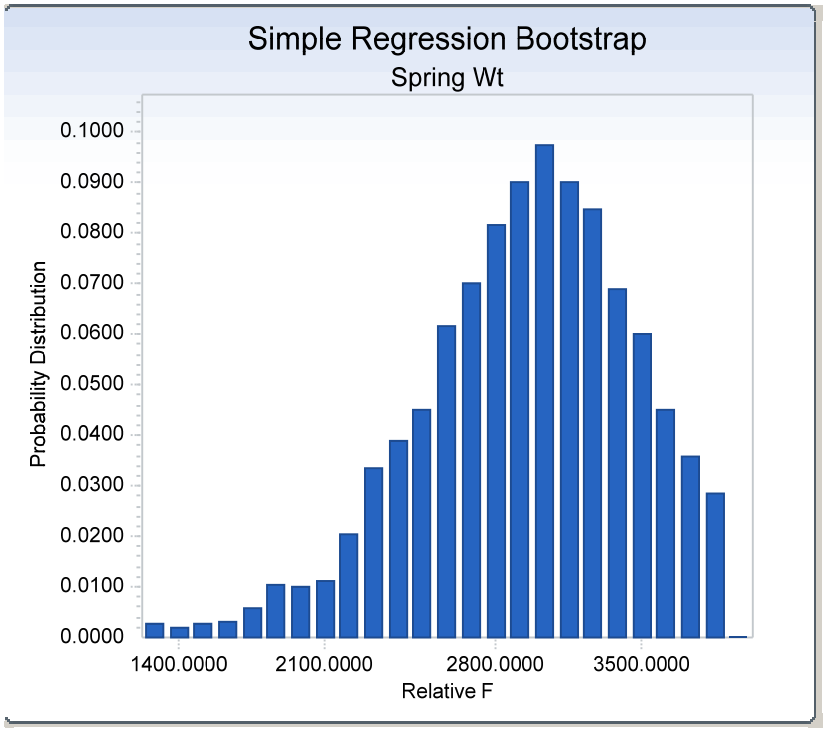
C12. Comparison of nominal discards with length-based model estimated discards of red hake from the **southern** stock. (Length-based estimates were not used in the assessment.)



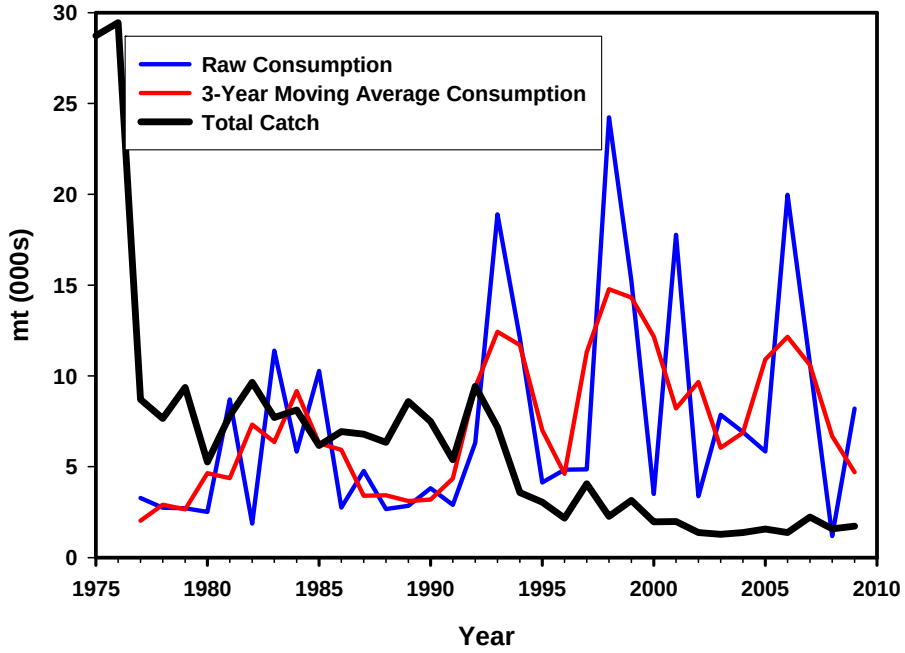
C13. Recreational catch of red hake by area.



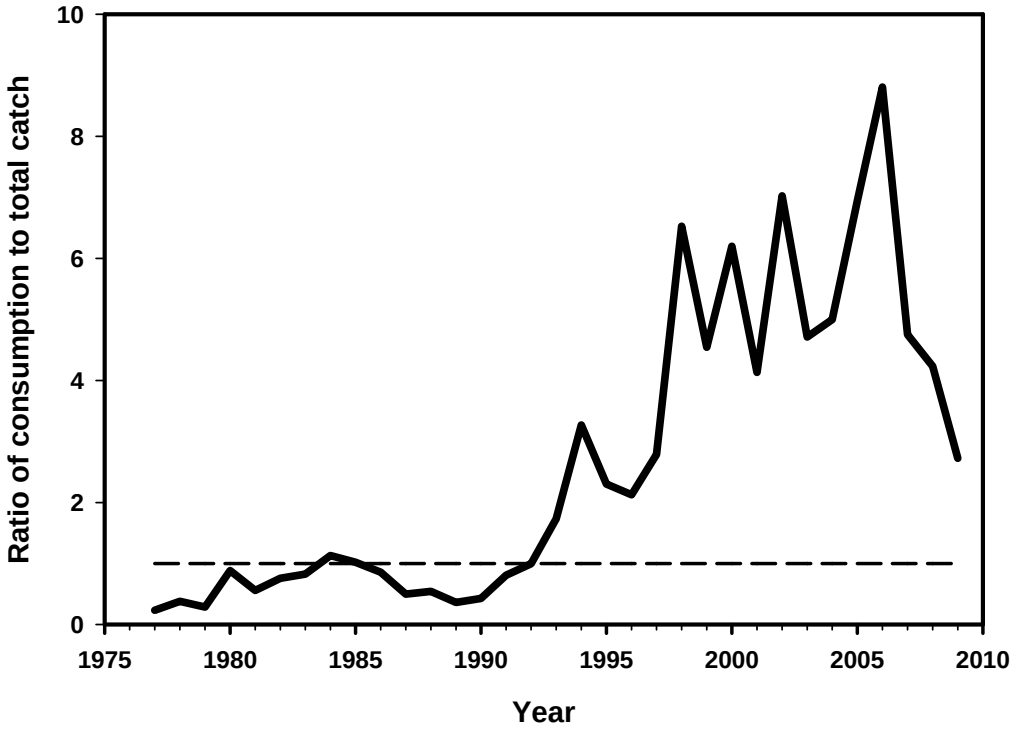
C14. Sampling distribution, from bootstraps, of relative F ([mt catch]/[kg/tow in survey]). Analysis considers replacement ratio and relative F for spring survey indices for **northern** red hake.



C15. Sampling distribution, from bootstraps, of relative F ([mt catch]/[kg/tow in survey]). Analysis considers replacement ratio and relative F for spring survey indices for **southern** red hake.



C16. Minimal estimates of total red hake biomass removed by consumption by major fish predators compared to total catch.



C17. Ratio of consumption to total catch of red hake over the time series. The constant line represents a ratio of unity.