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Working Paper: Atlantic Wolffish (Main Report)
December 2, 2008

Atlantic Wolffish

NE Stocks Data Poor Working Group Meeting
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Executive Summary

Wolffish in the Gulf of Maine and Georges Bank region are on the southern edge of the species distribution. Analysis herein was limited to the stock within United States waters. There is currently no fishery management plan for the Atlantic wolffish in US waters. Wolfish are associated with rough topography. Catchability of wolffish is low in the trawl surveys due to this habitat preference. Wolffish are a long lived (22 years), late maturing, low fecund species. Males nest guard the eggs in the fall. Larger fish are caught in the spring survey compared to the fall which may be due to this nest guarding behavior. All surveys indices show a declining trend in abundance over the time series. The catch has also declined since 1983. However there is no indication of size truncation in the catch over the time series. A wolffish growth study from the 1980s in the Gulf of Maine and Georges Bank region was done by Nelson and Ross (1992). The DCAC, AIM, and simple exploitation ratios were examined for this assessment. A forward projection model (SCALE) that tunes to size and age data integrated information from trawl survey recruitment and adult indices, total catch, and catch size distributions along with information on overall growth (Appendix 1). The SCALE model has difficulty in estimating selectivity due to the overall lack of data. Two different selectivity regimes were chosen to determine its influence of stock status determination. Maturation of wolffish in U.S. waters is also uncertain. The sensitivity of non-parametric biological reference points were tested with a range of knife edges maturity cutoffs. Wolffish life history suggests that F50% may be a more appropriate proxy for Fmsy than F40%. All SCALE model results suggest the stock in 2007 is at a low biomass (26% to 45% of Bmsy). The overfishing status determination was more uncertain with F_{2007} to Fmsy ratios ranging from 56% to 158%.

Section 1. *Provide the current exact, legal definitions for overfished and overfishing given in the FMP (if the definition was revised with an official FMP amendment, then give that def.). (NEFSC staff should consult with appropriate RO and Council staff who are on the DPWG to get this info).*

NONE

Section 2. *List the current Biological Reference Points (parameters and values). (e.g., the proxy for Bmsy is the 3-yr average of survey catch per tow from years 19xx to 19yy. The estimate is zzz kg/tow). Include the targets and thresholds for both overfishing and overfished, if those definitions exist.*

NONE

Section 3. *Explain the logic/justification for why the current definitions were adopted.*

NA

Section 4. *Explain weaknesses with the current definitions (e.g., not easily measured, not logical, outdated, etc.). If they are OK, say so.*

NA

Section 5. *(If a change to the BRPs is being recommended by the WG:) Recommend biological reference points (BRPs) and measurable BRP and MSY proxies. Provide justification for the recommendation. Be as specific as possible. If something might be proposed that is not yet measurable, then make that clear and explain what is needed to make it measurable.*

A range of reference points are available to the DPWG via the forward projecting SCALE model under various model scenarios (Appendix 1). Non-parametric biological reference points (BRP) were developed for both the selectivity L_{50} = 90 run (run 1) and the slope = 0.15 run (run 2) within the SCALE model using F40% as a proxy from F_{msy}. A range of knife edge maturity values were used in estimating the BRPs. Maturity as 40+ cm, a 65+ cm and 75+ cm cutoffs were used as bounds taken from NEFSC survey results and literature. The DPWG suggested Run 3, F50%, may be a better proxy for a species which is long lived, late maturing and has low fecundity. F50% BRPs were then developed for the slope =0.15 scenario.

SCALE run	1			2			3		
Selectivity	L_{50} = 90			slope = 0.15			slope = 0.15		
Length of maturity	40	65	75	40	65	75	40	65	75
F_{MSY} proxy	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{40\%}$	$F_{50\%}$	$F_{50\%}$	$F_{50\%}$
F_{MSY}	0.70	0.51	0.39	0.35	0.25	0.20	0.195	0.154	0.128
F_{max}	> 0.8	> 0.8	> 0.8	0.60	0.60	0.60	0.60	0.60	0.60
YPR	0.871	0.841	0.809	0.854	0.829	0.788	0.783	0.728	0.678
SSB per Recruit	5.987	5.247	4.686	5.792	5.166	4.548	7.629	6.796	6.050
Initial Recruits (000s)	171	171	171	175	175	175	172	172	172
MSY (mt)	149	144	138	149	145	138	135	125	117
SSB_{MSY} (mt)	1,024	898	802	1,011	902	794	1,314	1,171	1,042
SSB_{07} (mt)	405	293	209	457	339	249	447	330	242
F_{07}	0.516	0.516	0.516	0.195	0.195	0.195	0.202	0.202	0.202
SSB_{07}/SSB_{MSY}	40%	33%	26%	45%	38%	31%	34%	28%	23%
F_{07}/F_{MSY}	74%	101%	132%	56%	78%	98%	104%	131%	158%

Section 6. *Provide supporting information for Section 5.*

Basic Biology and Ecology

Geographic Range

Atlantic wolffish (*Anarhichas lupus*) can be found in northern latitudes of the eastern and western North Atlantic Ocean (Figure 1). In the north and eastern Atlantic they range from eastern Greenland to Iceland, along northern Europe and the Scandinavian coast extending north and west to the Barents and White Sea's. In the northwest Atlantic they are found from Davis Straits off of western Greenland, along Newfoundland and Labrador and continue southward through the Canadian Maritime Provinces to Cape Cod, USA. They are found infrequently in southern New England to New Jersey (Collete and Klein-MacPhee 2002). Northeast Fishery Science Centers Bottom Trawl surveys have only encountered 1 fish southwest of Martha's Vineyard, Massachusetts since 1963.

Habitats

Atlantic wolffish are a demersal species which prefer complex habitats with large stones and rocks which provide shelter and nesting sites (Pavlov and Novikov 1993). They are occasionally seen in soft sediments such as sand or mud substrate and likely forage for food sources in these habitats (Collete and Klein-MacPhee 2002; Falk-Petersen and Hansen 1991). They are believed to be relatively sedentary and populations localized. Tagging studies from Newfoundland, Greenland and Iceland indicate that most individuals were recaptured within short distances, ~8km, of the original tagging sites (Templeman 1984; Riget and Messtorff 1988; Jonsson 1982). Three significantly longer migrations were reported in Newfoundland ranging from 338 – 853 km (Templeman 1984).

Atlantic wolffish occupy varying depth ranges across its geographic range. In the Gulf of Maine they inhabit depths of 40 – 240 m, in Greenland and Newfoundland 0 – 600 m, in Iceland 8 – 450 m and in Norway and the Barents Sea from 10 – 215 m (Riget and Messtorff 1988; Albikovskaya 1982; Templeman 1984; Jonsson 1982; Falk-Petersen and Hansen 1991). In U.S. waters, abundance appears to be highest in the southwestern portion of the Gulf of Maine, from Jefferies Ledge to the Great South Channel, corresponding to the 100 m depth contour (Nelson and Ross 1992). Similarly, abundance is highest in the Browns Bank, Scotian shelf and northeast peak of Georges Bank areas in the Canadian portion of the Gulf of Maine (Nelson and Ross 1992). Atlantic wolffish in Newfoundland and Icelandic waters were identified as most abundant in depths 101 – 350 m and 40 - 180 m, respectively (Albikovskaya 1982; Jonsson 1982).

Temperature ranges where Atlantic wolffish occurs also deviate slightly with geographic region. Historically in the Gulf of Maine they have been associated with temperatures ranging from 0 – 11.1°C (Bigelow and Schroeder 1953). Bottom temperatures collected from NEFSC bottom trawl surveys where wolffish were encountered range from 0 – 10°C in spring and 0 – 14.3°C in fall. In Newfoundland wolffish thermal habitat ranged from -1.9 – 11.0 °C, Norway from -1.3 - 11 °C and in Iceland and Northern Europe -1.3 – 10.2 °C (Collete and Klein-MacPhee 2002; Falk-Petersen and Hansen 1991; Jonsson 1982). Laboratory studies indicate wolffish can survive a wide span of temperatures -1.7 – 17.0°C and that feeding is negatively correlated with the higher temperature extremes (Hagen and Mann 1992; King et al. 1989).

Reproduction

In general Atlantic wolffish are solitary in habit, except during mating season when bonded pairs form in spring/summer depending on geographic location (Collete and Klein-MacPhee 2002; Keats et al. 1985; Pavlov and Novikov 1993). Spawning is believed to occur in September through October in the Gulf of Maine but is likely to depend on temperature and possibly photoperiod (Collete and Klein-MacPhee 2002; Pavlov and Moksness 1994). Spawning is reported to occur from August – September in Nova Scotia, during autumn in Newfoundland, September – October in Iceland, July – October in Norway, and late summer – early autumn in the White Sea (Keats et al. 1985; Templeman 1986; Jonsson 1982; Falk-Petersen and Hansen 1991; Pavlov and Novikov 1993). In the Gulf of Maine there is weak indication of a seasonal migration as wolffish may travel from shallow to deep in autumn and then deep to shallow in spring (Nelson and Ross 1992). Similar migrations occur in Iceland and the White Sea where wolffish migrate to colder temperatures before the spawning season (Pavlov and Novikov 1993; Jonsson 1982). Atlantic wolffish have the lowest fecundity compared to their relatives, the spotted wolffish (*Anarhichas minor*) and the northern wolffish (*Anarhichas denticulus*). Fecundity is related to fish size and body mass in this species and increases exponentially with length. Newfoundland mean fecundity estimates, combined from several NAFO statistical areas, range from 2,440 eggs at 40 cm to 35,320 eggs at 120 cm (Templeman 1986). In Norway a female at 60 cm produces approximately 5,000 eggs while a female 80-90 cm will lay 12,000 eggs (Falk-Petersen and Hansen 1991). Potential fecundity of wolffish in Iceland was measured between 400 and 16,000 eggs for fish at lengths of 25 and 83 cm respectively (Gunnarsson et al. 2006). Mature eggs are large measuring 5.5 – 6.8 mm in diameter (Colette and Klein-MacPhee 2002). Male Atlantic wolffish have small testes and produce small amounts of sperm peaking during late summer and autumn. These data along with morphological development of a papilla on the urogenital pore during spawning suggest internal fertilization (Pavlov and Novikov 1993; Pavlov and Moksness 1994, Johannessen et at. 1993). Males have been observed guarding egg clusters for several months but it is not certain if they continue until hatching (Keats et al. 1985; Collete and Klein-MacPhee 2002). Hatching may take 3 to 9 months depending on temperature (Collete and Klein-MacPhee 2002).

Food Habits

The diet of Gulf of Maine and Georges Bank wolffish consist primarily of bivalves, gastropods, decapods and echinoderms (Nelson and Ross 1992). Wolffish possess specialized teeth, including protruding canine tusks (hence its name) and large rounded molars, which allow for removal of organisms from the sea floor and crushing of hard shelled prey (Collete and Klein-MacPhee 2002). Due to diet teeth are replaced annually (Albikovskaya 1983; Collete and Klein-MacPhee 2002). Fish have also been reported as an important food source in other regions along with amphipods and euphausiid shrimp for smaller individuals, 1 – 10 cm (Collete and Klein-MacPhee 2002; Albikovskaya 1983; Bowman et al. 2000). Travel between shelters and feeding grounds occurs during feeding periods as evidenced by crushed shells and debris observed in the vicinity of occupied shelters (Collete and Klein-MacPhee 2002; Pavlov and Novikov 1993). Fasting does occur for several months while replacing teeth, spawning and nest guarding occurs (Collete and Klein-MacPhee 2002).

Size

In the Gulf of Maine and Georges Bank regions individuals may attain lengths of 150 cm and weights of 18 kg (Goode 1884; Idoine 1998). Northeast Fishery Science Center bottom trawl surveys have captured animals ranging in size from 3 – 137 cm in spring and 4 – 120 cm in fall and with a maximum weight of 11.77 kg.

Age and Growth

Mean length at age for Atlantic wolffish in the Gulf of Maine was determined to be 22 years at 98 cm and 0 years at 4 cm (Nelson and Ross 1992). Fish over 100 cm were not sampled extensively in this study, 10 fish from 100-118 cm. Ages in the Gulf of Maine are comparable to wolffish ages in other regions, such as 21 years in east Iceland and 23 years in Norway (Gunnarsson et al. 2006; Falk-Petersen and Hansen 1991). Age 0 fish grow quickly in Icelandic waters and may reach 10.5 cm in the first year (Jonsson 1982). Gulf of Maine wolffish have faster growth rates than fish in Iceland but grow fastest in the North Sea region (Nelson and Ross 1992; Liao and Lucas 2000). Growth in the Gulf of Maine for both male and female wolffish was best estimated using a Gompertz growth function, $L\infty = 98.9$ cm, $K = 0.22$ and $t_0 = 4.74$ (Nelson and Ross 1992). Female growth from Iceland has been modeled using a logistic growth function and coefficients estimated using non-linear optimization (Gauss-Newton method), results from the east and west regions were: $L\infty = 90.919$, $K = 0.230$ and $t_0 = 8.837$ and $L\infty = 70.046$, $K = 0.378$ and $t_0 = 4.691$, respectively (Gunnarsson et al. 2006). Von Bertalanffy growth parameters for the North Sea population of wolffish were $L\infty = 111.2$, $K = 0.12$ and $t_0 = -0.43$ and $L\infty = 115.1$, $K = 0.11$ and $t_0 = -0.39$, for males and females respectively (Liao and Lucas 2000).

Maturity

In the Gulf of Maine individuals are believed to reach maturity by age 5-6 when they reach approximately 47 cm total length (Nelson and Ross 1992; Templeman 1986). Size at fifty percent maturity (L_{50}) of females varies latitudinally which is likely due to the effects of temperature. Templeman (1986) showed that northern fish mature at smaller sizes than faster growing southern fish in Newfoundland. L_{50} was reported as 51.4 cm in the northern area, 61.0 cm in the intermediate region and 68.2 cm in the south. In a study somewhat contradictory to Templeman 1986, Atlantic wolffish in east Iceland, where water temperatures are colder, had larger L_{50} values than fish in the relatively warmer waters of east Iceland (Gunnarsson et al. 2006). Authors indicate that maturity may be difficult to determine using visual methods in females because of large eggs size in this species. Second generation eggs are visible in young, immature fish when the reach the cortical alveolus stage but they may not be able to spawn for several more years (Gunnarsson et al. 2006; Templeman 1986).

The US Fishery

Landings and Total Catch

NMFS Commercial Fishery Databases contain historical and current catch and effort information of Atlantic wolffish, 1963 - 2007. Data presented here are only from fishery statistical reporting areas that are completely or almost entirely within US territorial waters throughout the time series (Figure 2). The International Court of Justice in 1984 established the maritime boundary in the Gulf of Maine, known as the Hague Line, which divided US and Canadian Exclusive Economic Zones (ICJ 1984). In 1985 fishery statistical areas 523 and 524, which overlapped the US/Canada boundary in the Georges Bank region, were separated into distinct areas 551, 552, 561 and 562 Figure 2). Disaggregating United States and Canadian landings data in areas 523 and 524 prior to 1985 was not possible so they are not reported here. Also not reported are landings in the newly created areas in US waters because they do not span the entire time frame.

US landings increased until it peaking in 1983 at 498.1 metric tons (mt) and then decline steadily until 2007, the latest complete year available, where landings were 28.7 mt (Figure 3 and Table 1). In the US, Atlantic wolffish are taken primarily as bycatch in the otter trawl fishery. Over all years, percent commercial landings of wolffish were dominated by otter trawl gear (92.24%), followed by fixed gillnets (3.76%) and bottom tending longlines (2.83%) (Figure 4). However, otter trawls have decreased in importance over time as evidenced by increased reported landings of gillnets and longlines (Appendix 3). Otter trawl gear accounted for a minimum of 74% to a maximum of 99% of the wolffish landings from 1964 to 2007 (Appendix 3). Fixed gill nets and bottom tending longline fisheries account for the majority of remaining landings.

Reported US commercial wolffish landings come primarily from fishery statistical areas 513, 514, 515, 521 and 522 (Figure 5 and Table 2). Landings have fluctuated between statistical areas over time and spatial differences may be difficult to interpret due to management actions, such as permanent closures and rolling time closures, in the Gulf of Maine.

Commercial fishery discards from the Northeast Fisheries Observer Program database were estimated for the period 1989-2007 from US only statistical areas based on the Standardized Bycatch Reporting Methodology combined ratio estimation (Wigley et al 2007). Discards appear to be a small component of the overall catch of Atlantic wolffish (Figure 7 and Table 1).

The maximum estimated discards in any one year are 26.98 mt, 1989 (Table 3). Otter trawls account for 98.3% of the total discarded wolffish from all years. Discards appear to be increasing in the gillnet sector, which reported approximately 17% of the total wolffish discarded for 2007 (Table 3).

Recreational catch data was retrieved from the MRFSS database (Figure 6 and Table 4). Landings are reported in total number of fish and total weight per year. Landings include both A and B1 fish, these are fish permanently removed from the population. B2 fish are discarded live and are assumed to have survived. Adjusted landings were developed because average weight of an individual wolffish was highly variable. Average weight (kg) was calculated based on the reported numbers of landed fish (A + B1) divided by the reported landed weight (kg). A grand mean was calculated from average weights and used in the new adjusted landings values. Adjusted landing are less variable than the original reported values and are likely to describe the recreational portion of total catch. Recreational catches have become more significant in recent years as commercial landings have steadily declined (Figure 7 and Table 1). Recreational catch makes up 30% of the total catch and is almost half a large as commercial landings for 2007 (Table 1).

Total Catch is comprised of reported landings, estimates of commercial discards from the primary fishery sectors and recreational catch from US waters as previously described (Figure 7 and Table 1). Recreational catches begin in 1981 and discard estimates begin in 1989. Total US catch peaked in 1983 with 510.82 mt and has decreased steadily reaching a low of 42.43 mt in 2007.

Commercial Lengths Data and CPUE

Fishery observers collect length samples at sea opportunistically providing information on the size structure of the population. Observer lengths have been collected since 1989. Sample sizes from early in the time series are low but have exceeded 100 samples per year during 2003-2007 (Table 5). Median length has been variable over time but increased slightly during the 2003-2007 period indicating that larger fish are being harvested (Figure 8). Differences in length composition by commercial gear types were also plotted (Figure 9). Sample sizes are small in all gears except for otter trawl and gillnet, where size distributions and median values are similar (Table 6).

Commercial lengths from port samples have been taken irregularly during the span of the commercial fishery. A significant amount of samples were collected during 1982 – 1985 and have also been taken consistently since 2001. Commercial port sample length distributions were plotted by year (Figure 10). An increase in median length can be seen during the 2001 – 2007 time period. The median has increased from 75 cm in 2001 to 84 cm in 2007 (Table 7). This data suggests that size in the commercial fishery may be increasing as the 95% confidence intervals from the 2001-2003 period do not overlap with the 2004-2007 period. Differences were then examined to see if the increase could be explained by major gear type since longlines, and gill nets have become a larger component of the fishery (Figure11). Slight differences were observed in the size compositions of the various gears but this may be an artifact of low sample size of commercial gears other than otter trawls (Table 8). Commercial length samples were also plotted by statistical area to determine if any geographic trend in size could be seen (Figure 12). The primary fishery areas, 512-522, show similar length distributions. Areas 526 and 537 had anomalous length distributions but also had low sample sizes (Table 9).

Indices of catch per unit of effort (CPUE) were calculated from fishery observer trips and self reported Vessel Trip Reports (VTRs) in party and charter boat sectors for Atlantic wolffish. Observer CPUE was estimated for 1989-2007 in the longline, gillnet and otter trawl fisheries for US statistical areas 512-515, 521-522, 525-526 and 537 (Table 10). CPUE was calculated based on the ratio: sum of kept wolffish per year / sum of days fished per year. Observer CPUE has declined in the 3 fishing sectors reviewed (Figure 13). Atlantic wolffish CPUE for the longline fishery is plotted on the second y-axis as it is significantly higher than the otter trawl and gillnet sectors.

Party and Charter boat CPUE have also declined (Figure 14; Table 11). These indices were calculated from the number wolffish reported landed on VTRs and angler days fished. Angler days fished was estimated by number anglers * hours fished / 24 per year for all party and charter trips in areas 514 and 515.

Research Vessel Survey Data

Survey Length, Weight and Maturity

Atlantic wolffish catches were grouped by decade to reduce data gaps in length frequency plots. Distributions were plotted using proportion at length and number at length (Figures 15 and 16). The numbers at length graphs show an overall reduction in numbers by decade across the length range of Atlantic wolffish. The proportion at length graphs indicate that different size fish are available to the bottom trawl gear in spring and fall. In general, spring survey encounters larger individuals (>= 50 cm) and the fall survey captures smaller individuals ranging from 10-30 cm. The spring survey also captures a unique distribution of small individuals, less than or equal to 7 cm, and may be used as a juvenile index.

Length weight relationships were developed for Atlantic wolffish from NEFSC bottom trawl survey data. Spring and fall survey data were combined to create one relationship for both male and female fish as no differences were found between seasons or sexes (Figure 17). Linear regression of log transformed data provided a good fit, $R^2 = 0.996$.

A logistic maturity ogive was developed for female Atlantic wolffish based on spring and fall survey vessel data (Figure 18). L_{50} was estimated at approximately 35 cm from these data. This L_{50} for female wolffish is lower than estimates reported in Newfoundland and Iceland where females containing second generation eggs were considered immature (Templeman 1986; Gunnarsson et al. 2006). NEFSC maturity data is based on visual inspection of the reproductive organs. Fish are classified into 1 of 7 stages of maturity (Burnett et al 1989). Fish classifications for females include immature, developing, ripe, eyed (unique for redfish), ripe and running, spent and resting. This analysis considered fish that were in the developing through resting stages as a mature and immature were those fish that contained no visible eggs. Size at maturity may be difficult to interpret for wolffish from these data as they may have an additional developing stage, or a set of second generation eggs which may last for several years, where fish are reproductively immature (Gunnarsson et al. 2006). These immature fish would likely be classified as developing in NEFSC surveys and were considered mature in the ogive thereby reducing the size at 50% mature.

Biomass and Abundance

Atlantic wolffish are encountered infrequently on NEFSC bottom trawl surveys. Strata used in wolffish analyses were limited to offshore areas completely or almost completely within US waters (Figure 19). Some historically important strata were excluded from this analysis, specifically on the Canadian portion of Georges Bank, but due to the sedentary nature of this fish it is believed to have not affected the estimation of the indices or overall trends in US waters (Figures 20 &21). Sampling effort per survey stratum in the Gulf of Maine has remained relatively consistent over most of the time series (Figure 22). The timing of the surveys in the Gulf of Maine has also been consistent during the spring and fall. Inshore sampling did not commence until the mid 1970's and was therefore not used. Higher sampling intensity did occur in portions of the 1970's and 1980's in select survey stratum but elevated abundance and biomass are not likely due to increased sampling effort (Figure 23).

In general the NEFSC spring and fall bottom trawl survey indices show abundance and biomass of Atlantic wolffish has declined over the last two to three decades (Figure 24.). The spring survey typically encounters higher abundance and biomass than the fall survey and was considered by the Data Poor Working Group to be optimal for assessing resource trends (Table 1). Survey differences may be attributed to wolffish being less available to the sampling gear while nest guarding in the fall (Colette and Klein-MacPhee 2002). Inter-annual variability among both surveys is high.

The spring biomass index averaged 0.786 kg/tow and ranged between 0.38 and 1.44 kg/tow from 1968 to 1988. Since the mid to late 1980's the resource has steadily declined. The average spring biomass index for 1989-2007 was 0.143 kg/tow, only 18% of the 1968-1988 average, and ranged from 0.0 kg/tow to 0.42 kg/tow. The fall biomass index shows little trend over time and is relatively low over most of the time series (Figure 24). A large anomalous peak in biomass appears in 1982 but is not seen again in subsequent years. Since the mid 1990's wolffish biomass has fluctuated with a slightly declining trend.

Abundance indices in both surveys show a decline in stratified mean number per tow since the mid 1990's. 3 year centered moving average plots of abundance and biomass removes the inter-annual variability within the indices and depicts an overall declining trend in the resource (Figure 25).

Spring and fall percent positive Atlantic wolffish catch was plotted by year (Figure 26). This type of index for species rarely captured can be a good indicator of how frequently rare events occur over time. These indices indicate that the number of survey tows catching at least one wolffish has decreased with time in both the spring and fall. The spring index shows an almost continuous declining trend since the late 1970's/early 1980's, averaging around 12% and dropping to approximately 2%. The fall index appears relatively stable from the mid 1960's through the early 1990's, fluctuating around 6 %. It then declines quickly from 1993 to 1996 and becomes relatively stable again near 2 % until 2007 where it reaches zero.

The spatial distribution of Atlantic wolffish has contracted according to the spring and fall bottom trawl surveys. Data were grouped by decade and survey catch in numbers were displayed using GIS (Figures 27 and 28). The spring survey shows high catch along Jefferies Ledge, Stellwagen Bank National Marine Sanctuary and off outer Cape Cod through the Great South Channel during the 1970's and 1980's. Catches in the 1990's extend across a similar area but appear with less abundance and frequency. Highest catches during the 2000's are limited to Stellwagen Bank region. A similar pattern emerges from fall survey catches and the resource appears to be more concentrated within the Jefferies Ledge and Stellwagen Bank regions. During the 1990's and 2000's catches are smaller and appear less frequently in the fall.

Modeling Results

SCALE Model
See appendices 1 and 2

DCAC Model

The DCAC model input consists of summed annual catch, an estimate of M, an estimate of the F_{MSY} to M ratio, the ratio of catch depletion over time and the number of years being analyzed (Appendix 4). It calculates a sustainable yield of a population after accounting for the "windfall" which occurs at the beginning of a fishery. When natural mortality is high, the DCAC model is the same as calculating the average landings. We conducted a sensitivity analysis of the delta depletion parameter over several time blocks to look at potential sustainable yields (Figure 30; Table 12). All of the time blocks cover the majority of the fishery and include high, moderate and low catch levels. The depletion-corrected average catch was significantly lower than the uncorrected average catch in each time block. Time block did not affect the DCAC but the delta depletion ratio has strong influence. DCAC results ranged from 138.8 mt to 176.6 mt are comparable to MSY values derived from the SCALE model.

Exploitation Ratios

Exploitation indices were created from reported wolffish catch and spring and fall biomass estimates (Figures 29; Table 1). Exploitation appears to have increased and could indicate this species is being over harvested even at low level commercial catches. Due to low survey catches some values cannot be shown on the chart. The spring exploitation index peaks at a value of 2135.2 in 2004 and fall exploitation index contains 2 high points at approximately 20.1 in 1998 and 35.2 in 2006.

AIM – An Index Method

The relationship between total catch of Atlantic wolffish and the spring biomass was explored using the An Index Method (AIM) model (NEFSC 2002). Both catch and the survey index have been declining over time with little response of the spring index to declining catches (Figure 31). The linear regression between the $\log_e$ replacement ratio and $\log_e$ relative F was not significant in a randomization test, critical value -0.385 and a significance level of 0.134 (Figure 32).

Section 7. *Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.*

Major sources of uncertainty include:

1. Life history – size at maturity, age composition, $L\infty$ within the Gulf of Maine
2. Catchability in NEFSC bottom trawl surveys
3. Commercial length compositions and impacts to SCALE Model
4. Interpretation of 0 catches in recent years – modeling implications
5. Discard information from commercial fisheries
6. Habitat association is poorly known

Section 8. *If applicable, consider developing BRPs for species groups*

NA

Section 9. *Comment on what can be done to improve the information, proxies or assessments for each species.*

Much work could be done to improve information on the basic biology of Atlantic wolffish in the Gulf of Maine. Age and growth data from both commercial and fishery independent sources needs to be collected to improve life history information, specifically L infinity. Conduct a maturity study based on egg size or first generation eggs in female wolffish to improve size at maturity estimates. Estimate fecundity for Gulf of Maine wolffish. Conduct tagging studies to confirm populations are sedentary and localized. Collect fishery observer data from more fishery sectors including the offshore lobster fishery. Comparative studies on wolffish catchability in multiple habitats, including complex rock habitat, with NEFSC survey gear and commercial gear types. A fishery independent index for wolffish should be developed for assessing potential biomass located in rocky habitats.

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Table 1. Summary table of total catch, commercial landings, recreational catch, discards and NEFSC survey indices.

YEAR	MRFSS (mt)	CFDBS (mt) US Only	Discard OT LL GN (mt) US Only	Total Catch (mt) US Only	Total Catch (1000 mt) US Only	Spring Biomass Index (kg/tow) US Only	Spring Exploitation Index US Only	Fall Biomass Index (kg/tow) US Only	Fall Exploitation Index US Only	Spring Abundance Index US only	Fall Abundance Index US only
1963	--	--	--	--	--	--	--	0.00	0.00	--	0.03
1964	--	51.86	--	51.86	0.05	--	--	0.18	0.28	--	0.09
1965	--	75.53	--	75.53	0.08	--	--	0.30	0.25	--	0.31
1966	--	79.12	--	79.12	0.08	--	--	0.17	0.47	--	0.33
1967	--	67.85	--	67.85	0.07	--	--	0.23	0.29	--	0.09
1968	--	52.72	--	52.72	0.05	0.38	0.14	0.41	0.13	0.07	0.15
1969	--	74.06	--	74.06	0.07	1.11	0.07	0.03	2.19	0.15	0.01
1970	--	70.23	--	70.23	0.07	1.12	0.06	0.36	0.20	0.18	0.08
1971	--	78.38	--	78.38	0.08	0.60	0.13	0.16	0.49	0.14	0.12
1972	--	110.65	--	110.65	0.11	0.51	0.22	0.16	0.69	0.34	0.13
1973	--	110.06	--	110.06	0.11	0.87	0.13	0.13	0.83	0.14	0.34
1974	--	160.02	--	160.02	0.16	1.11	0.14	0.10	1.66	0.53	0.23
1975	--	142.03	--	142.03	0.14	0.92	0.15	0.03	4.39	0.14	0.04
1976	--	182.31	--	182.31	0.18	0.53	0.34	0.05	3.94	0.10	0.07
1977	--	178.61	--	178.61	0.18	0.62	0.29	0.08	2.10	0.22	0.04
1978	--	274.53	--	274.53	0.27	1.17	0.23	0.54	0.51	0.30	0.47
1979	--	297.78	--	297.78	0.30	0.71	0.42	0.10	2.91	0.21	0.05
1980	--	374.88	--	374.88	0.37	0.70	0.54	0.18	2.08	0.30	0.14
1981	0.81	304.64	--	305.44	0.31	0.63	0.49	1.14	0.27	0.31	0.26
1982	23.12	344.91	--	368.03	0.37	0.68	0.54	0.19	1.92	0.19	0.05
1983	11.90	498.92	--	510.82	0.51	0.74	0.69	0.33	1.53	0.13	0.25
1984	13.18	424.25	--	437.44	0.44	0.47	0.92	0.07	6.13	0.12	0.04
1985	15.95	399.14	--	415.10	0.42	0.74	0.56	0.32	1.30	0.28	0.19
1986	7.24	358.24	--	365.49	0.37	1.44	0.25	0.37	0.99	0.24	0.10
1987	37.71	301.70	--	339.40	0.34	0.91	0.37	0.06	5.36	0.25	0.04
1988	9.03	229.33	--	238.36	0.24	0.54	0.44	0.10	2.37	0.20	0.11
1989	20.49	211.76	26.98	259.23	0.26	0.40	0.64	0.11	2.43	0.27	0.14
1990	29.17	171.53	2.63	203.32	0.20	0.17	1.22	0.21	0.95	0.06	0.11
1991	16.86	202.56	1.95	221.37	0.22	0.36	0.61	0.30	0.75	0.05	0.13
1992	10.73	195.46	19.18	225.37	0.23	0.11	1.96	0.18	1.23	0.14	0.13
1993	20.11	211.93	13.38	245.41	0.25	0.42	0.58	0.41	0.60	0.13	0.19
1994	18.54	206.56	0.11	225.21	0.23	0.14	1.62	0.28	0.81	0.21	0.11
1995	20.45	204.03	5.77	230.25	0.23	0.20	1.17	0.27	0.86	0.12	0.15
1996	12.33	157.84	4.53	174.70	0.17	0.17	1.05	0.01	12.40	0.11	0.01
1997	20.21	136.88	7.82	164.91	0.16	0.04	4.01	0.21	0.79	0.05	0.07
1998	16.84	130.11	2.25	149.19	0.15	0.10	1.43	0.01	20.79	0.04	0.01
1999	8.54	110.11	0.35	119.00	0.12	0.06	2.00	0.19	0.64	0.04	0.05
2000	12.40	86.79	0.54	99.74	0.10	0.21	0.48	0.03	3.99	0.03	0.01
2001	16.67	107.05	6.47	130.19	0.13	0.06	2.07	0.12	1.06	0.03	0.04
2002	9.82	66.03	13.10	88.96	0.09	0.08	1.06	0.07	1.24	0.06	0.03
2003	24.23	55.82	3.82	83.87	0.08	0.18	0.46	0.08	0.99	0.09	0.08
2004	12.45	53.05	1.58	67.08	0.07	0.00	2135.24	0.02	3.25	0.02	0.01
2005	10.73	51.73	1.31	63.76	0.06	0.00	0.00	0.02	3.28	0.00	0.05
2006	17.86	36.31	1.45	55.62	0.06	0.00	0.00	0.00	35.23	0.00	0.04
2007	12.87	28.72	0.84	42.43	0.04	0.01	4.58	0.00	--	0.02	0.00
2008	--	--	--	--	--	--	--	--	--	--	--

Table 2. Percent US Commercial Landings of Atlantic wolffish by Statistical Area and Year

YEAR	512	513	514	515	521	522	525	526	537	Grand Total
1964	3.12	4.04	37.04	3.23	27.92	19.68	4.20	0.76	0.00	100
1965	8.06	3.35	29.81	0.92	29.43	25.04	0.72	2.64	0.04	100
1966	1.04	5.00	40.12	0.98	30.95	16.79	1.47	3.60	0.05	100
1967	1.45	17.26	35.79	1.27	29.84	13.21	0.49	0.70	0.00	100
1968	1.72	10.96	32.65	0.55	37.79	12.71	2.55	0.97	0.10	100
1969	0.86	12.90	43.91	1.74	24.19	14.83	1.31	0.26	0.01	100
1970	1.12	11.05	41.51	1.25	31.19	13.03	0.19	0.63	0.03	100
1971	1.85	8.22	42.60	1.63	26.38	16.63	0.85	1.11	0.73	100
1972	1.07	8.43	33.74	0.31	32.11	17.62	2.50	3.95	0.28	100
1973	0.74	10.16	42.75	0.80	33.97	8.85	1.32	1.41	0.00	100
1974	0.74	8.16	37.03	0.21	37.61	12.80	1.21	2.21	0.02	100
1975	1.36	10.36	41.55	2.50	33.34	9.56	0.60	0.50	0.23	100
1976	1.70	12.99	34.29	1.53	32.27	13.75	1.06	2.40	0.00	100
1977	1.34	10.35	37.32	2.02	41.23	6.41	0.58	0.69	0.06	100
1978	3.71	14.34	35.40	2.37	34.21	8.93	0.36	0.53	0.15	100
1979	3.10	17.30	28.31	3.09	36.66	10.77	0.16	0.61	0.00	100
1980	2.94	21.78	21.63	7.24	33.58	11.75	0.49	0.57	0.00	100
1981	3.99	22.82	24.83	6.61	28.63	11.73	0.39	0.80	0.21	100
1982	7.88	22.65	23.83	10.27	26.92	7.67	0.35	0.19	0.24	100
1983	4.65	25.89	28.51	13.92	19.84	6.35	0.22	0.57	0.06	100
1984	4.46	28.29	16.08	16.53	23.95	9.41	0.70	0.49	0.09	100
1985	6.17	25.18	14.83	19.47	26.63	7.09	0.21	0.35	0.05	100
1986	8.92	25.29	14.59	18.43	24.31	7.10	0.78	0.52	0.06	100
1987	5.90	25.25	17.55	18.22	25.56	6.91	0.18	0.42	0.01	100
1988	5.82	26.08	15.75	9.69	32.96	8.31	0.26	1.11	0.00	100
1989	6.39	22.29	11.78	8.76	41.19	8.01	0.10	1.37	0.13	100
1990	7.90	29.96	15.65	8.59	29.71	5.05	0.83	2.02	0.30	100
1991	6.08	24.30	16.41	16.68	25.59	9.10	0.33	1.22	0.29	100
1992	5.74	24.38	15.56	18.10	23.29	10.64	0.49	1.25	0.55	100
1993	3.73	20.35	15.56	20.61	19.51	17.49	0.83	1.49	0.42	100
1994	4.32	18.85	15.44	15.27	28.65	15.68	0.39	1.20	0.19	100
1995	2.26	14.92	20.65	17.80	28.26	14.39	0.29	1.04	0.39	100
1996	2.16	15.06	25.96	13.82	28.98	12.18	0.63	0.97	0.24	100
1997	1.82	13.48	24.10	11.09	33.59	13.72	0.54	0.43	1.23	100
1998	1.87	9.25	35.34	10.08	29.92	11.24	0.44	1.58	0.28	100
1999	1.18	9.34	18.35	7.91	41.27	17.39	0.83	2.66	1.06	100
2000	1.53	13.68	29.21	8.72	29.39	14.38	0.90	0.59	1.61	100
2001	0.96	9.84	18.99	5.81	34.47	26.30	0.83	0.60	2.21	100
2002	1.36	11.77	28.52	6.17	35.49	14.24	1.05	0.28	1.13	100
2003	1.91	14.05	35.62	5.81	29.78	7.93	1.18	0.25	3.47	100
2004	3.91	16.86	39.49	6.92	24.22	5.78	0.18	0.18	2.46	100
2005	2.58	20.06	40.80	12.93	16.14	6.22	0.61	0.64	0.03	100
2006	2.56	16.84	42.28	8.33	20.32	8.85	0.31	0.10	0.41	100
2007	3.29	14.39	39.78	10.08	23.84	7.30	0.85	0.34	0.12	100
Grand Total	4.11	19.26	24.64	10.28	29.20	10.70	0.59	0.94	0.27	100

Table 3. Commercial Discard Estimates for Atlantic wolffish US waters only

	Metric Tons				Percent		
YEAR	**LL**	**OT**	**GN**	**Grand Total**	**LL**	**OT**	**GN**
1989	0.00	26.98	0.00	26.98	0.00	100.00	0.00
1990	0.00	2.63	0.00	2.63	0.00	100.00	0.00
1991	0.00	1.95	0.00	1.95	0.00	100.00	0.00
1992	0.51	18.67	0.00	19.18	2.66	97.34	0.00
1993	0.00	13.38	0.00	13.38	0.00	100.00	0.00
1994	0.00	0.11	0.00	0.11	0.00	100.00	0.00
1995	0.00	5.77	0.00	5.77	0.00	100.00	0.00
1996	0.00	4.53	0.00	4.53	0.00	100.00	0.00
1997	0.00	7.11	0.71	7.82	0.00	90.91	9.09
1998	0.00	2.25	0.00	2.25	0.00	100.00	0.00
1999	0.00	0.35	0.00	0.35	0.00	100.00	0.00
2000	0.00	0.49	0.06	0.54	0.00	89.28	10.72
2001	0.00	6.47	0.00	6.47	0.00	100.00	0.00
2002	0.00	13.10	0.00	13.10	0.00	100.00	0.00
2003	0.00	3.67	0.15	3.82	0.00	96.01	3.99
2004	0.00	1.34	0.23	1.58	0.00	85.28	14.72
2005	0.00	1.22	0.09	1.31	0.00	93.37	6.63
2006	0.03	1.42	0.00	1.45	1.90	98.10	0.00
2007	0.01	0.69	0.14	0.84	0.65	82.16	17.19
Grand Total	0.54	112.13	1.39	114.06	0.48	98.31	1.21

Table 4. Atlantic wolffish recreational catch summary from MRFSS database, 1981-2007.

Year	Landed # (A + B1)	Discarded # (live) (B2)	Landed kg (A + B1)	Landed MT	Ave Wt kg	Adjusted Landed kg	Adj Landed MT
1981	334	0	unk	unk		806.38	0.81
1982	9,576	2,789	4,952	4.952	0.52	23,119.43	23.12
1983	4,930	88	16,776	16.776	3.40	11,902.54	11.90
1984	5,461	366	12,740	12.74	2.33	13,184.54	13.18
1985	6,607	0	14,428	14.428	2.18	15,951.34	15.95
1986	3,000	0	unk	unk		7,242.93	7.24
1987	15,618	691	31,733	31.733	2.03	37,706.68	37.71
1988	3,740	574	3,748	3.748	1.00	9,029.52	9.03
1989	8,486	6,956	21,415	21.415	2.52	20,487.83	20.49
1990	12,081	386	9,628	9.628	0.80	29,167.27	29.17
1991	6,984	7,180	14,250	14.25	2.04	16,861.54	16.86
1992	4,446	213	4,985	4.985	1.12	10,734.02	10.73
1993	8,329	1,544	11,969	11.969	1.44	20,108.78	20.11
1994	7,681	820	10,526	10.526	1.37	18,544.31	18.54
1995	8,470	2,027	32,287	32.287	3.81	20,449.20	20.45
1996	5,105	5,841	10,391	10.391	2.04	12,325.05	12.33
1997	8,369	833	37,474	37.474	4.48	20,205.35	20.21
1998	6,974	5,029	19,760	19.76	2.83	16,837.39	16.84
1999	3,538	2,389	4,741	4.741	1.34	8,541.83	8.54
2000	5,138	4,463	11,592	11.592	2.26	12,404.72	12.40
2001	6,905	4,841	15,628	15.628	2.26	16,670.81	16.67
2002	4,069	1,953	17,996	17.996	4.42	9,823.82	9.82
2003	10,035	1,204	42,207	42.207	4.21	24,227.59	24.23
2004	5,158	6,237	9,573	9.573	1.86	12,453.01	12.45
2005	4,445	481	14,955	14.955	3.36	10,731.60	10.73
2006	7,397	9,513	28,614	28.614	3.87	17,858.65	17.86
2007	5,329	8,678	15,253	15.253	2.86	12,865.85	12.87
2008							

Grand Mean Average Weight (kg) = **2.41**

Table 5. Summary Statistics of Commercial Observer Length Samples by Year, 1989-2007.

YEAR	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
1989	72	74.25	5.91	4	70 - 83
1991	77	81.89	13.25	9	70 - 114
1992	45.5	49.14	10.93	70	39 - 80
1993	61.5	64.58	11.01	24	49 - 86
1994	73	72.80	10.36	25	45 - 95
1995	62.5	62.00	18.08	20	21 - 102
1996	75	72.76	10.96	25	42 - 94
1997	81	78.38	12.52	13	47 - 92
1998	89	85.58	9.89	19	67 - 99
1999	83	82.14	11.28	7	65 - 94
2000	77	77.30	7.19	50	60 - 89
2001	76	75.69	10.86	74	52 - 96
2002	82	81.75	10.64	53	63 - 110
2003	77	73.78	13.41	186	31 - 113
2004	75	74.35	12.40	253	41 - 115
2005	81	80.23	11.38	264	29 - 107
2006	82	82.34	12.04	163	54 - 111
2007	83	81.59	12.48	129	44 - 105

Table 6. Summary Statistics of Commercial Observer Length Samples by major gear type.

Gear Type	Gear Code	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
Longline Bottom	10	73.5	71.91	14.04	22	71-96
Otter Trawl Fish	50	78.0	76.21	14.75	1000	21-115
Gillnet Fixed	100	77.0	76.32	11.82	335	36-114
Gillnet Drift	117	78.5	77.71	9.90	14	64-99
Scallop Dredge	132	69.0	67.64	14.66	11	46-94
Offshore Lobster	200	71	66.17	13.83	6	42-79

Table 7. Commercial Port Sample Summary Statistics by Year, 1982-1985 and 2001-2007.

YEAR	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
1982	69	71.71	15.35	354	45-114
1983	78	78.25	14.46	1349	42-128
1984	76	76.10	12.76	445	51-130
1985	77	76.98	11.86	729	47-119
2001	75	76.59	10.11	176	59-110
2002	76	76.34	10.30	297	38-104
2003	76	76.88	11.07	473	52-109
2004	81	80.83	10.72	1159	48-115
2005	82	81.40	9.95	500	54-110
2006	83	83.03	10.36	894	37-111
2007	84	83.55	10.01	800	51-108

Table 8. Commercial Port Samples Summary Statistics by Gear Type

Gear Type	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
Longline	71	71.08	8.84	134	45-92
Handline	80	79.41	10.90	29	62-99
Otter Trawl Fish	80	80.04	12.63	7041	37-130
Gill Net	76	76.36	11.68	211	51-109

Table 9. Commercial Port Samples Summary Statistics by Fishery Statistical Areas

Statistical Area	Median Length (cm)	Mean Length (cm)	Std Dev.	Total N	Min-Max Range (cm)
0	83	83.27	6.13	11	75 - 95
512	83	82.16	10.76	421	37 - 108
513	80	79.70	10.99	1745	46 - 110
514	77	77.69	12.04	1357	42 - 130
515	79	78.50	11.67	1956	44 - 112
521	78	79.19	12.53	894	38 - 119
522	77	77.88	12.39	478	50 - 115
525	82	82.70	9.30	47	57 - 102
526	112	110.72	9.67	79	79 - 128
537	68	68.00	15.43	10	48 - 101

Table 10. Observer based CPUE (sum of kept wolffish per year / sum of days fished per year) for Atlantic wolffish, 1989-2007.

	CPUE Gear Type		
YEAR	**LLB**	**OTF**	**GNF**
1989		2.56	0.58
1990		0.71	2.90
1991	8.80	1.40	1.57
1992	8.52	2.90	1.76
1993	45.65	3.05	2.15
1994		3.89	2.61
1995		1.29	6.03
1996		1.22	3.81
1997		1.82	1.84
1998		1.26	2.08
1999		1.30	1.49
2000		1.32	1.90
2001		1.59	2.04
2002	11.79	1.05	1.79
2003	5.14	0.86	3.03
2004	1.19	0.61	1.72
2005	2.48	0.36	1.88
2006	1.56	0.37	1.70
2007	1.28	0.39	0.95
Grand Total	2.59	0.71	1.98

Table 11. Party and Charter Boat CPUE (number of wolffish / angler days fished) from VTR data for Atlantic wolffish, 1994-2007.

YEAR	CPUE Charter Boats	CPUE Party Boats
1994	0.072	0.015
1995	0.077	0.009
1996	0.068	0.011
1997	0.082	0.013
1998	0.139	0.013
1999	0.039	0.008
2000	0.017	0.005
2001	0.047	0.007
2002	0.019	0.008
2003	0.031	0.006
2004	0.018	0.006
2005	0.015	0.006
2006	0.019	0.004
2007	0.013	0.003

Table 12. Sensitivity analysis of the delta depletion parameter in the Depletion-Corrected Average Catch model (DCAC) over time.

DCAC model - DCAC Average Catch (mt)
Sensitivity Analysis of % reduction on Several Time Periods

	Delta Depletion Ratio										
	50%		**75%**		**90%**		**95%**		Total	Uncorrected	
Base Years	mean	median	mean	median	mean	median	mean	median	Catch	Catch	N Years
1970-1990	175.1	178.5	152.0	154.0	141.1	142.4	137.8	138.8	5422	258.2	21
1970-2000	176.6	180.2	158.0	160.9	148.9	151.4	146.1	148.4	7277.0	234.7	31
1970-2005	166.5	169.9	150.6	153.6	142.7	145.3	140.2	142.7	7711.0	214.2	36
	Confidence Intervals										
	5%	95%	5%	95%	5%	95%	5%	95%			
1970-1990	118.5	220.0	94.9	202.6	84.6	193.5	81.7	190.7			
1970-2000	130.5	210.1	108.4	197.9	98.2	191.4	95.3	189.4			
1970-2005	126.9	194.5	106.9	184.6	97.5	179.2	94.7	177.6			

assumptions:
M = 0.15 std dev = 0.5
Fmsy to M = 1.0 std dev = 0.2
delta depl std dev = 0.1

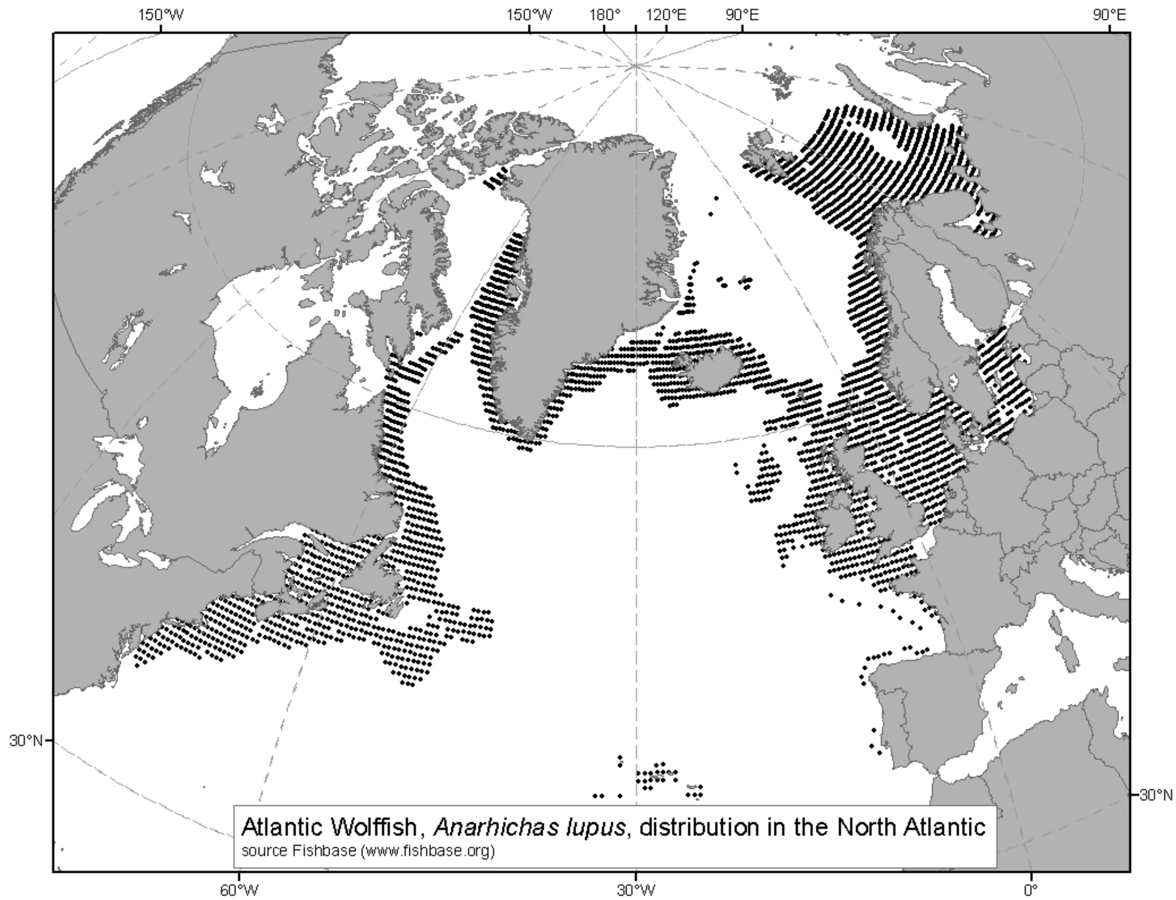


Figure 1. Atlantic wolffish distribution in the North Atlantic Ocean. US is the southern extent of the geographic range.

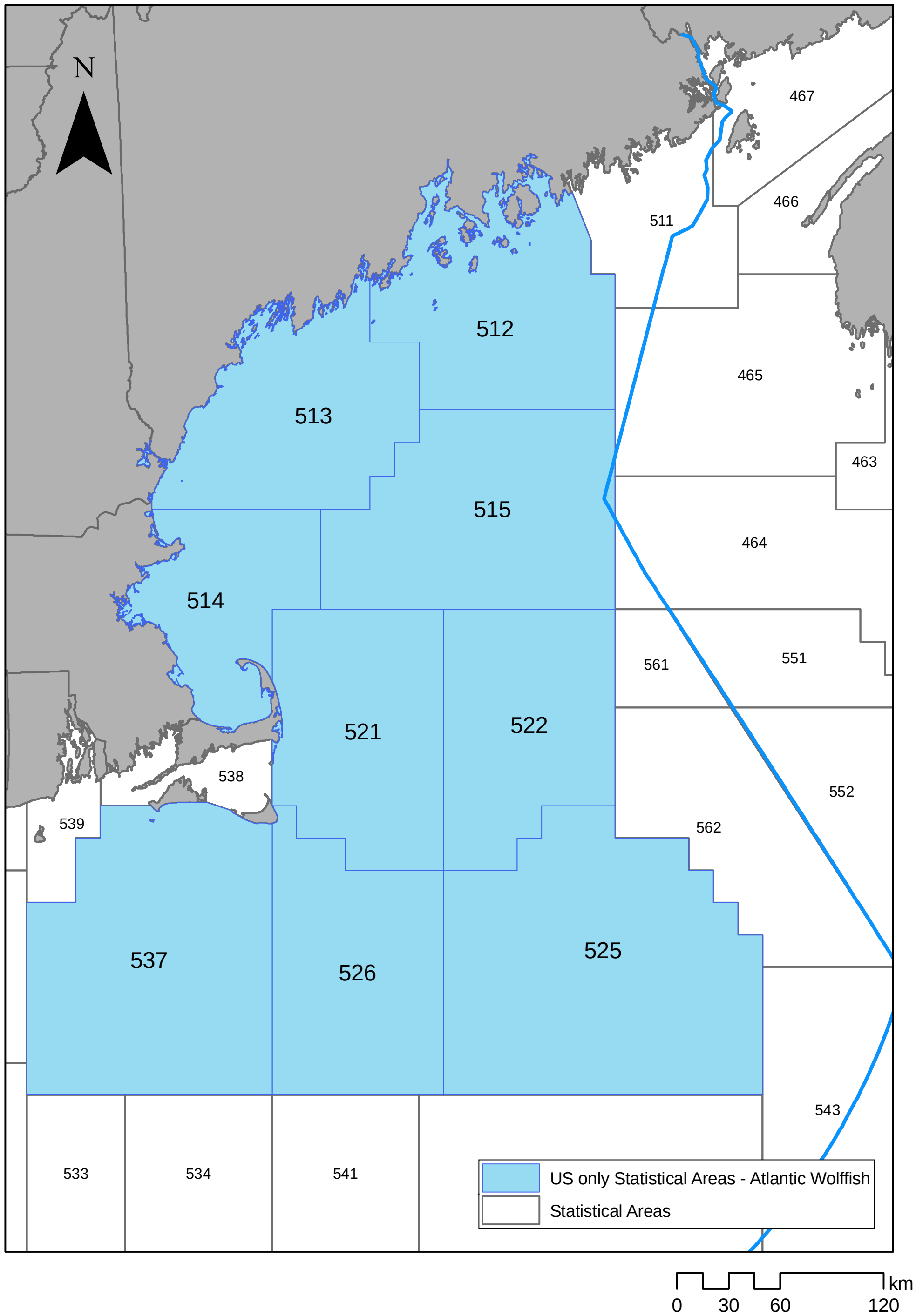


Figure 2. Fishery statistical areas used for Atlantic wolffish landings, catch and discard estimates.

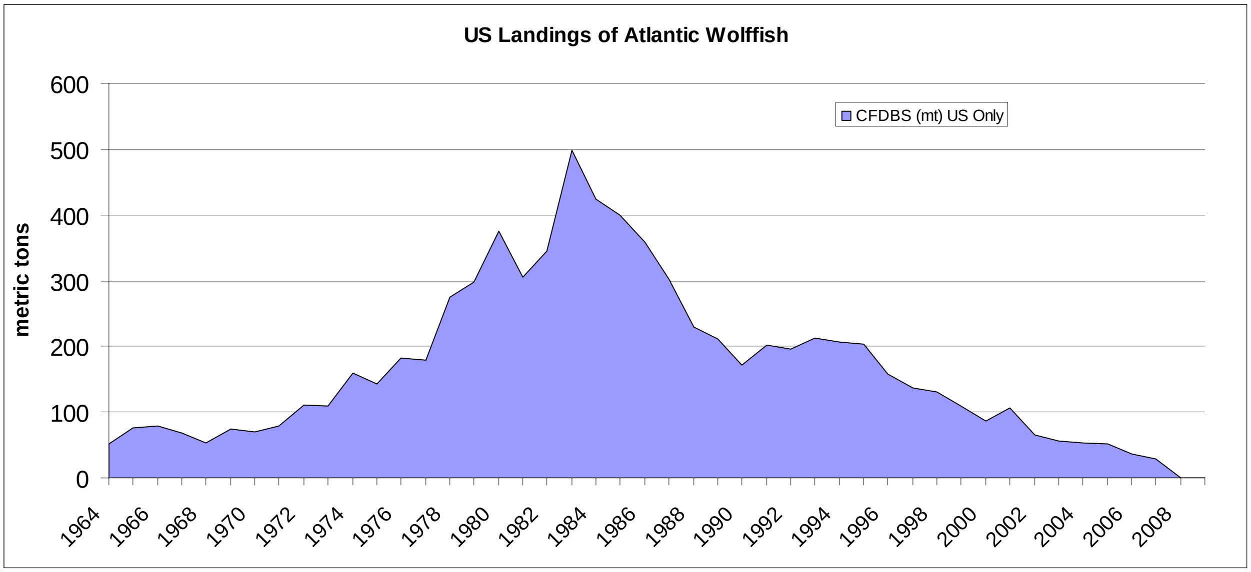


Figure 3. Reported landings of Atlantic wolffish in fishery statistical areas 512-515, 521-522, 525-526 and 537.

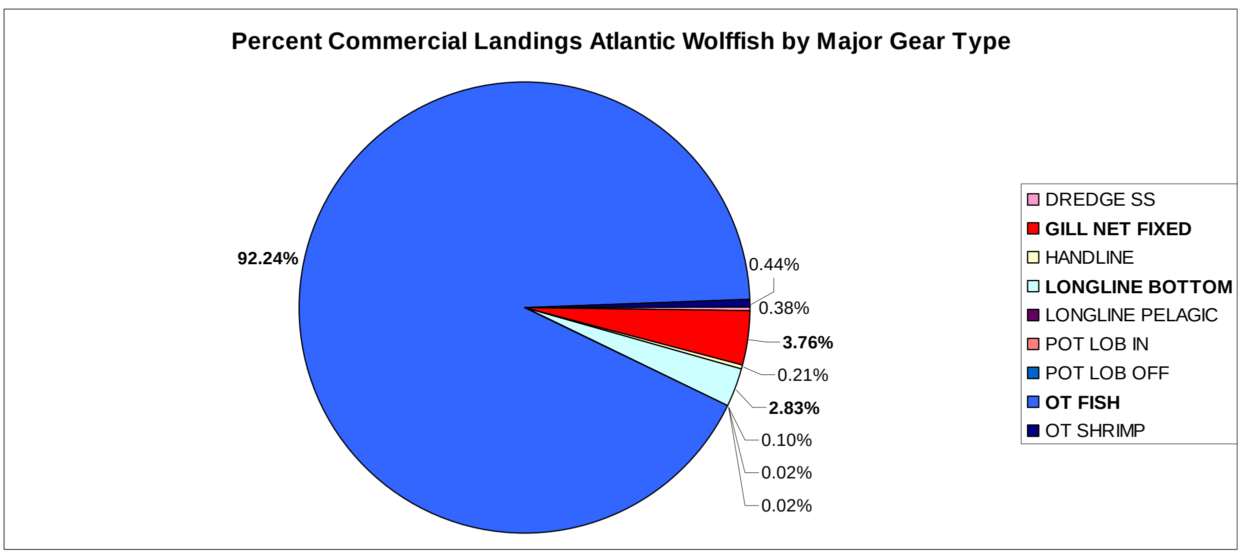


Figure 4. Atlantic wolffish landings by gear type for all years, 1964-2007.

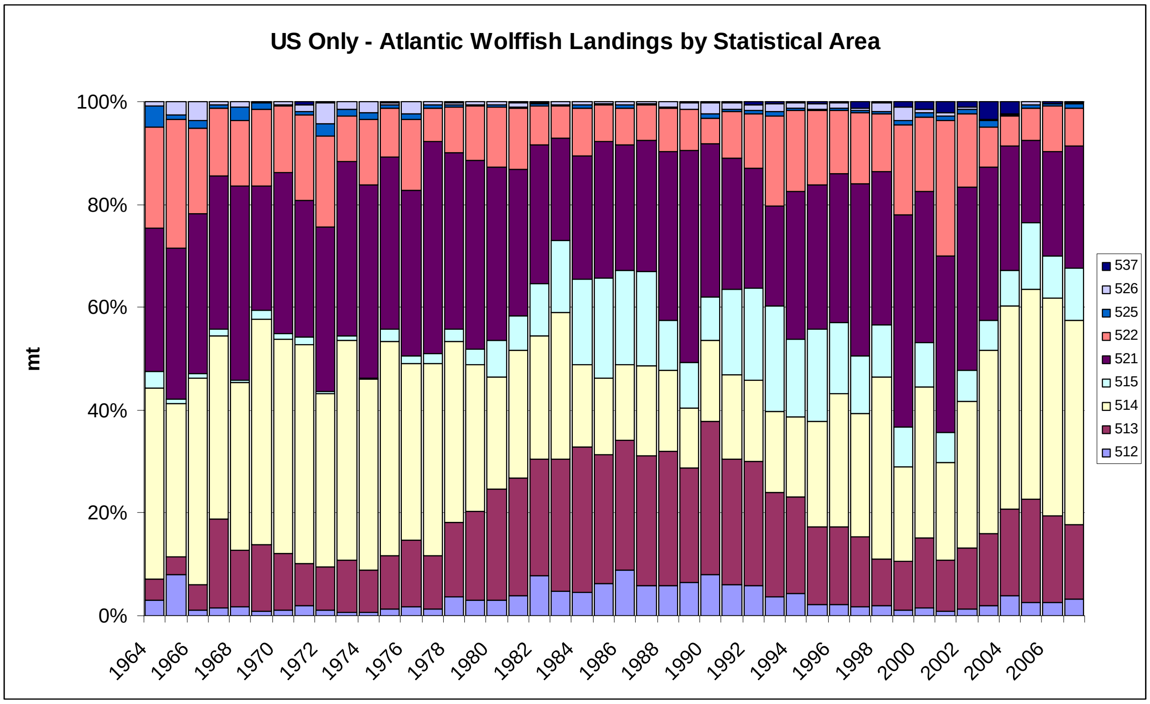


Figure 5. Reported wolffish landings by fishery statistical area in US waters.

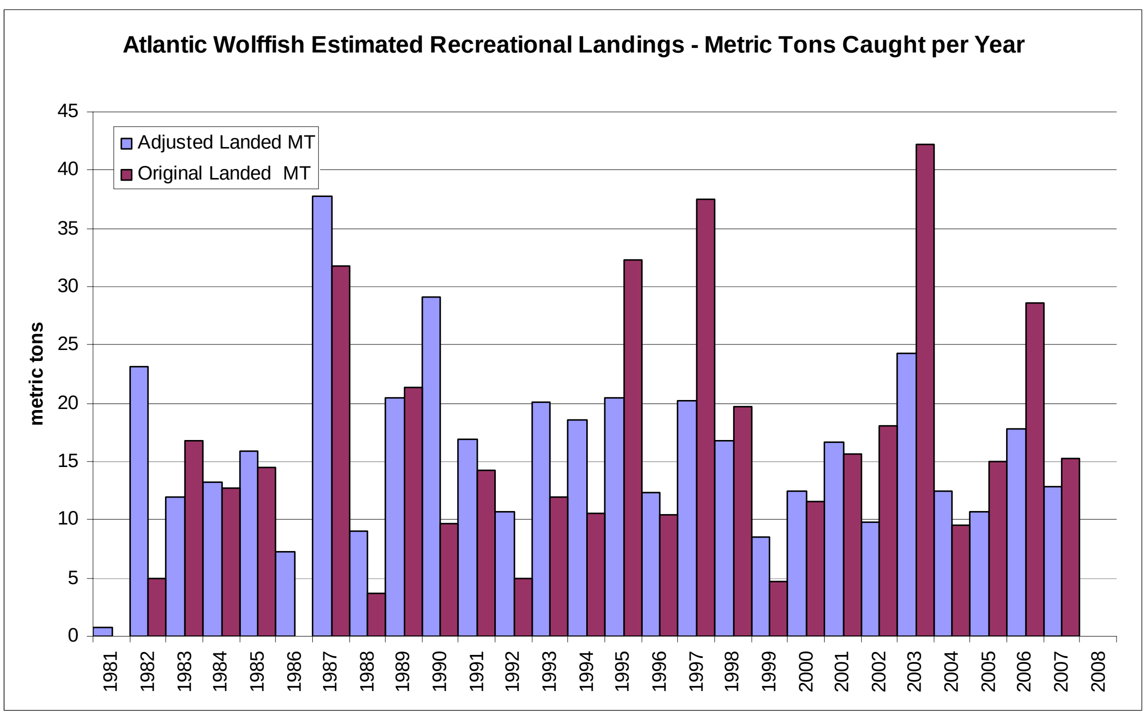


Figure 6. Reported and adjusted recreational landings by year from MRFSS database, 1981-2007.

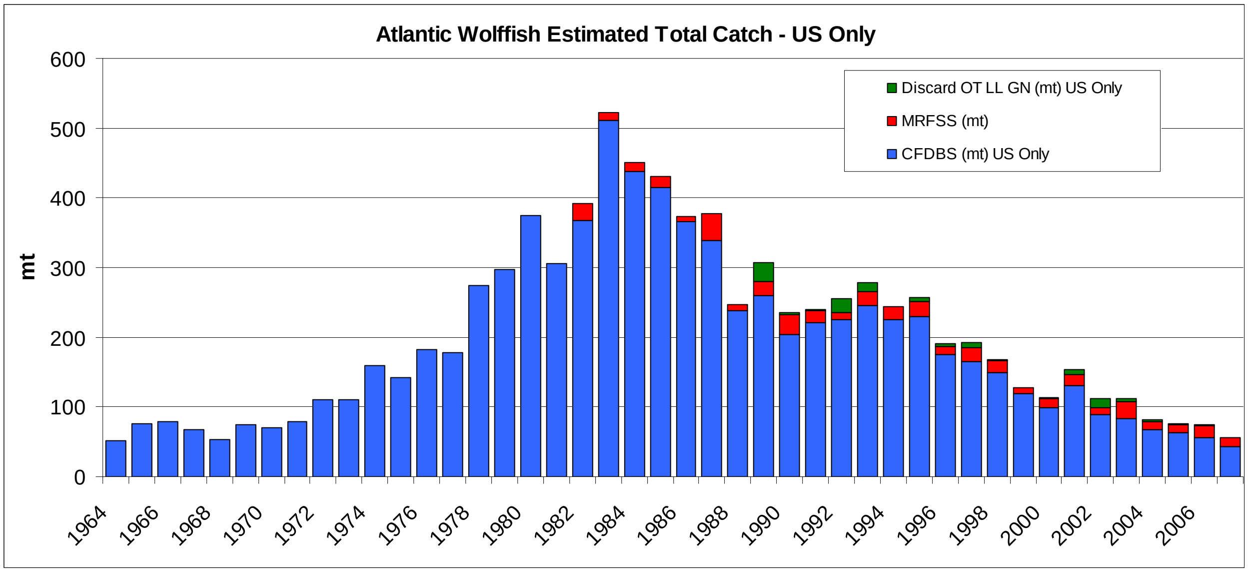


Figure 7. Total catch from reported commercial landings, estimated discards and recreational landings for US only 1964-2007.

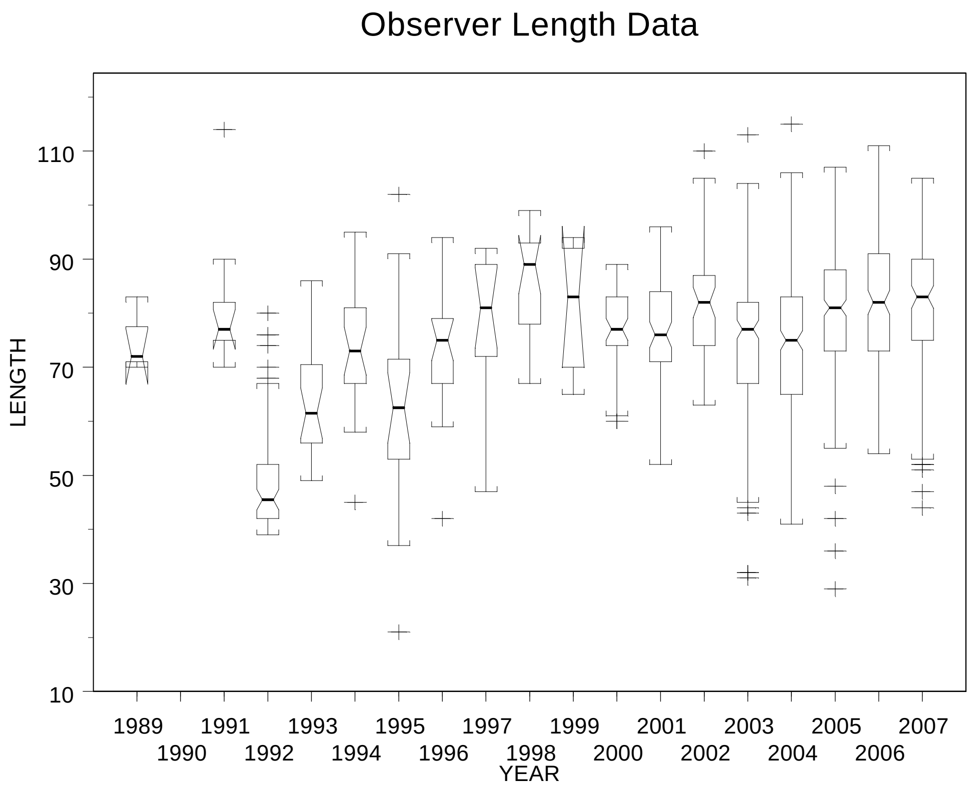


Figure 8. Fishery observer length distribution by year, 1989-2007.

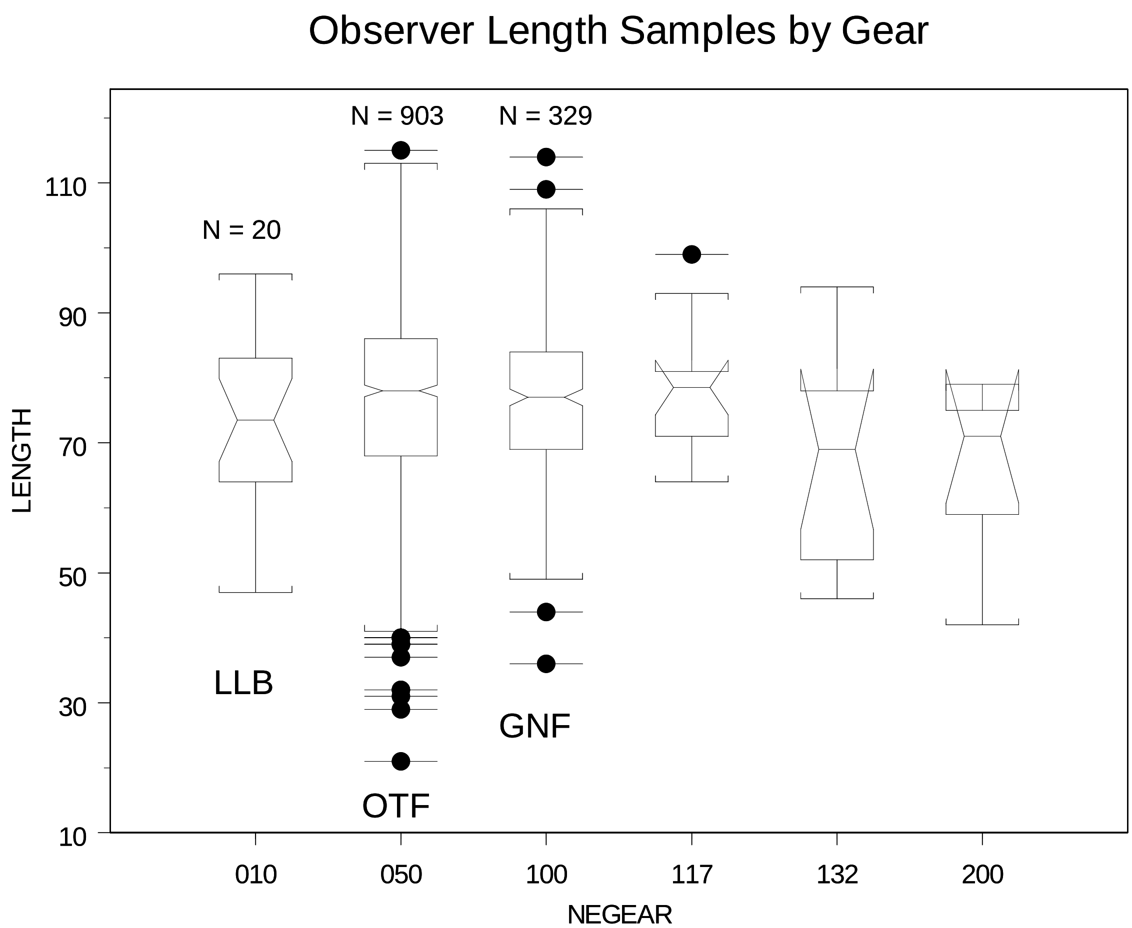


Figure 9. Fishery observer length distribution by major gear type.

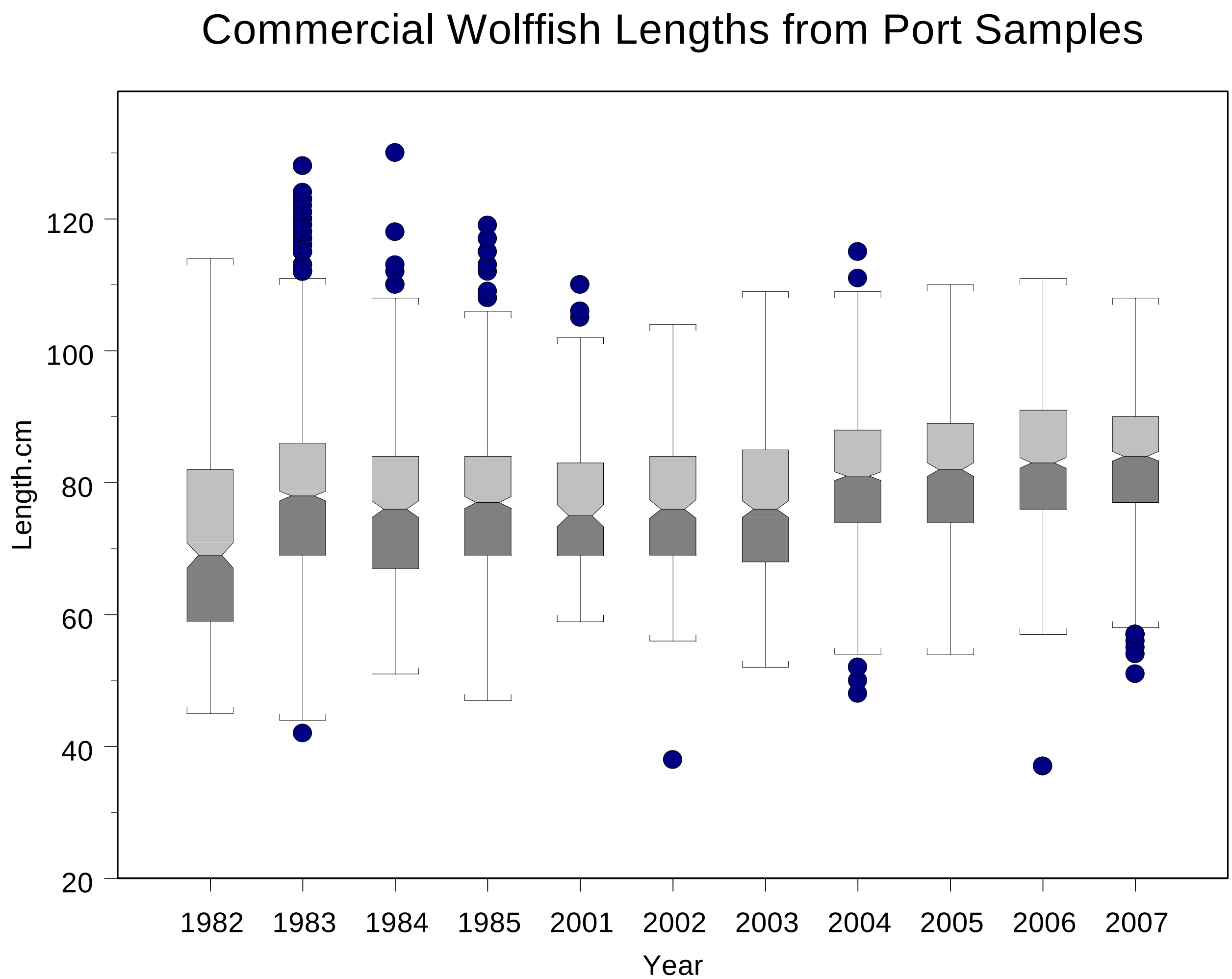


Figure 10. Atlantic wolffish commercial length distributions by year from port samples, 1982-1985 and 2001-2007.

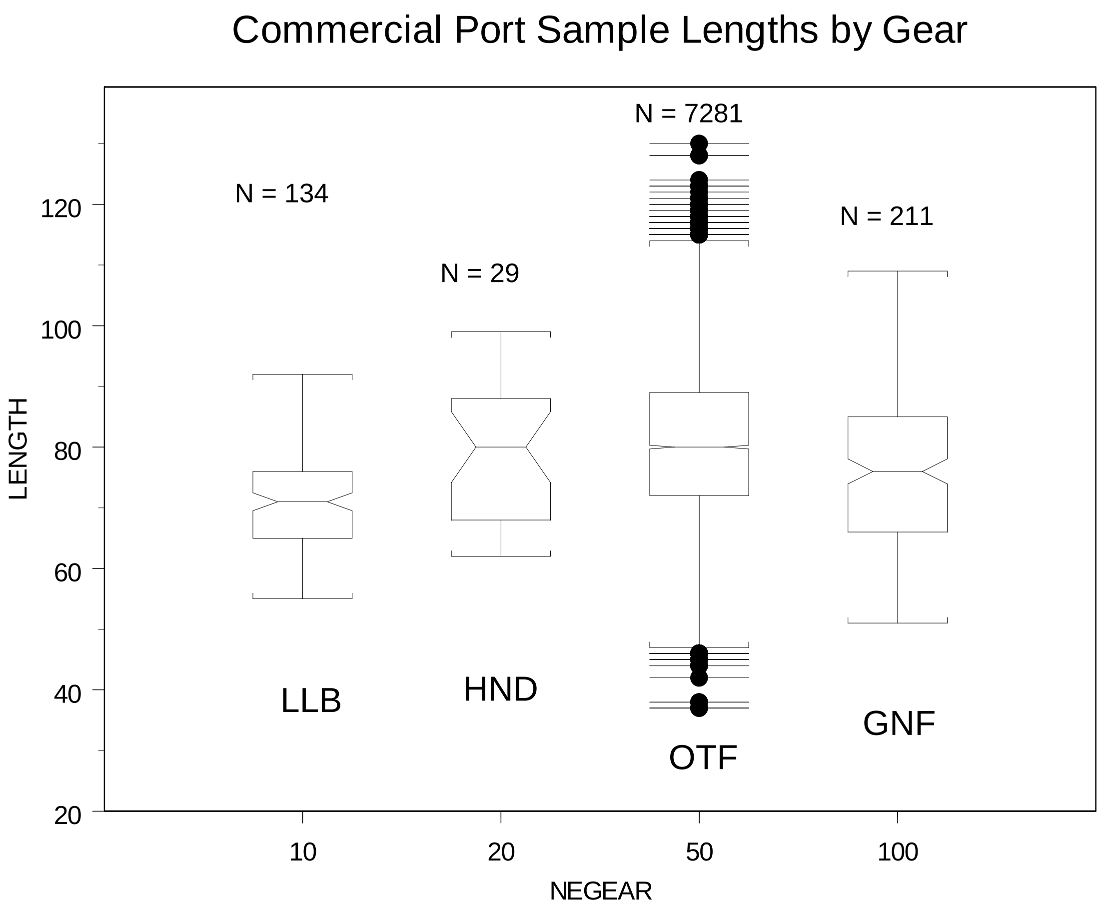


Figure 11. Commercial port sample length distributions by major gear type, all years combined (1982-1985 & 2001-2007).

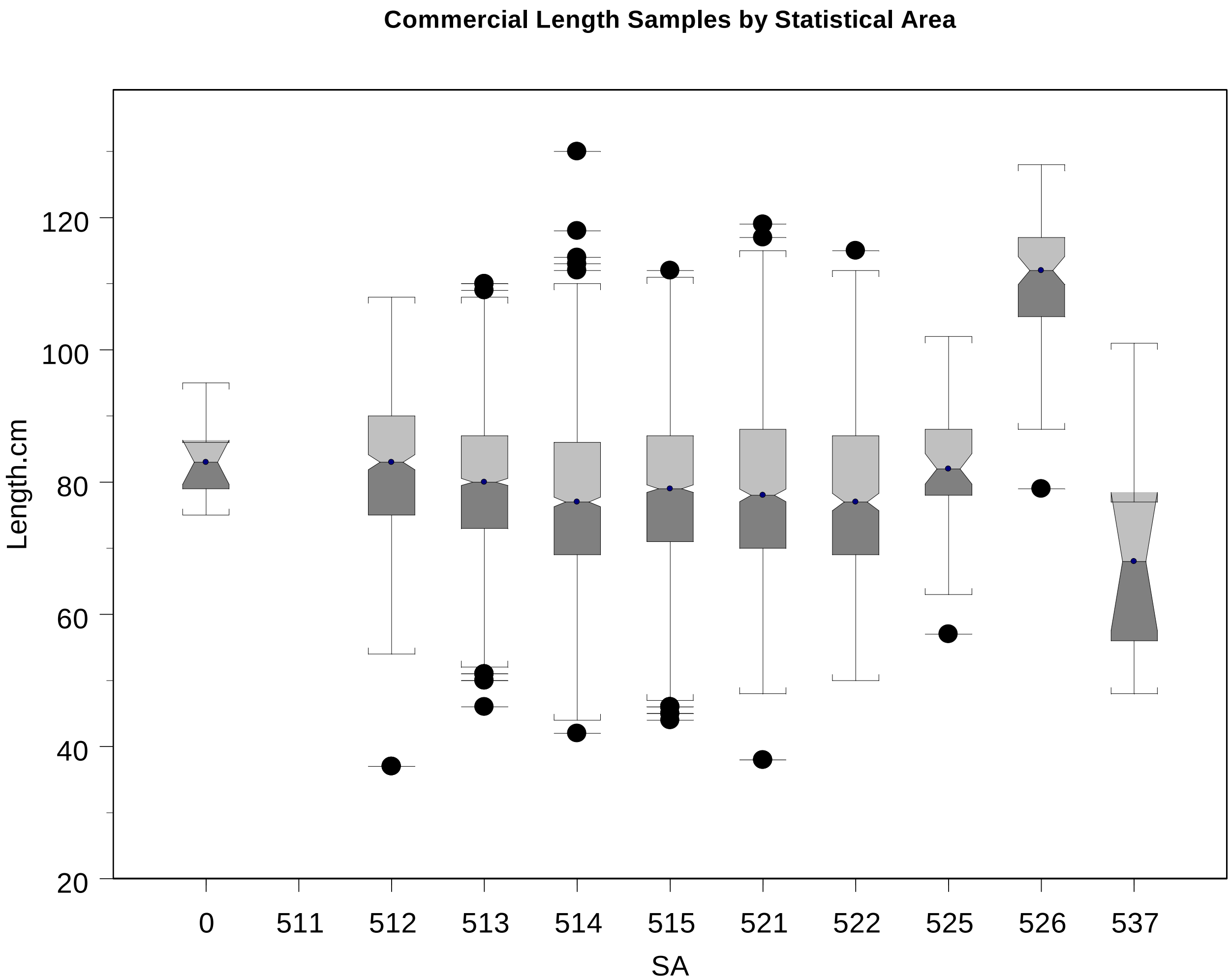


Figure 12. Commercial port sample length distributions by fishery statistical area in US waters, all years combined (1982-1985 & 2001-2007).

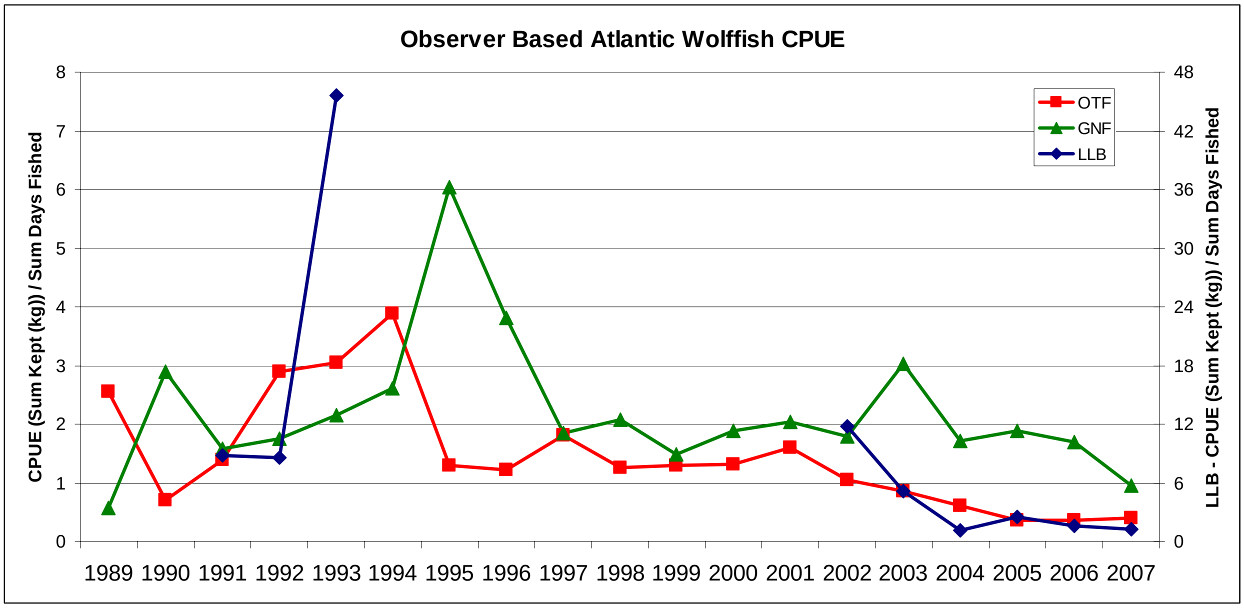


Figure 13. Catch per unit effort of Atlantic wolffish based on observer data in the otter trawl, gillnet and longline fisheries.

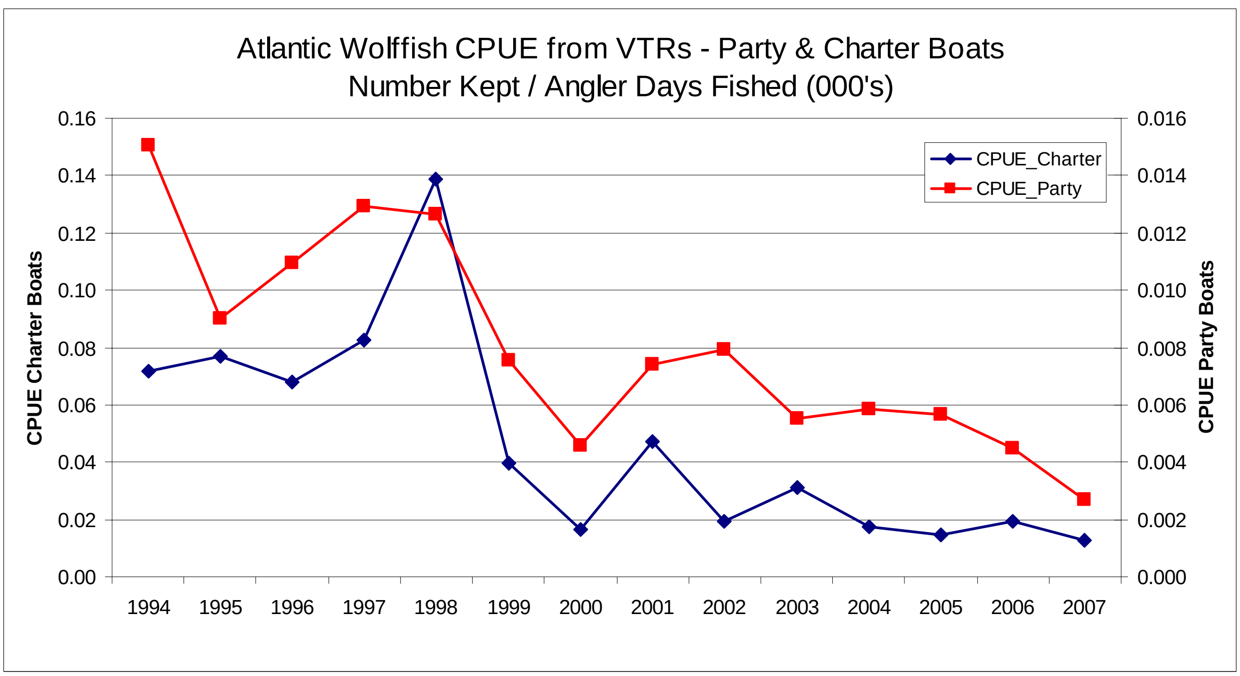


Figure 14. Catch per unit effort of Atlantic wolffish based on VTR data in the party and charter boat sectors.

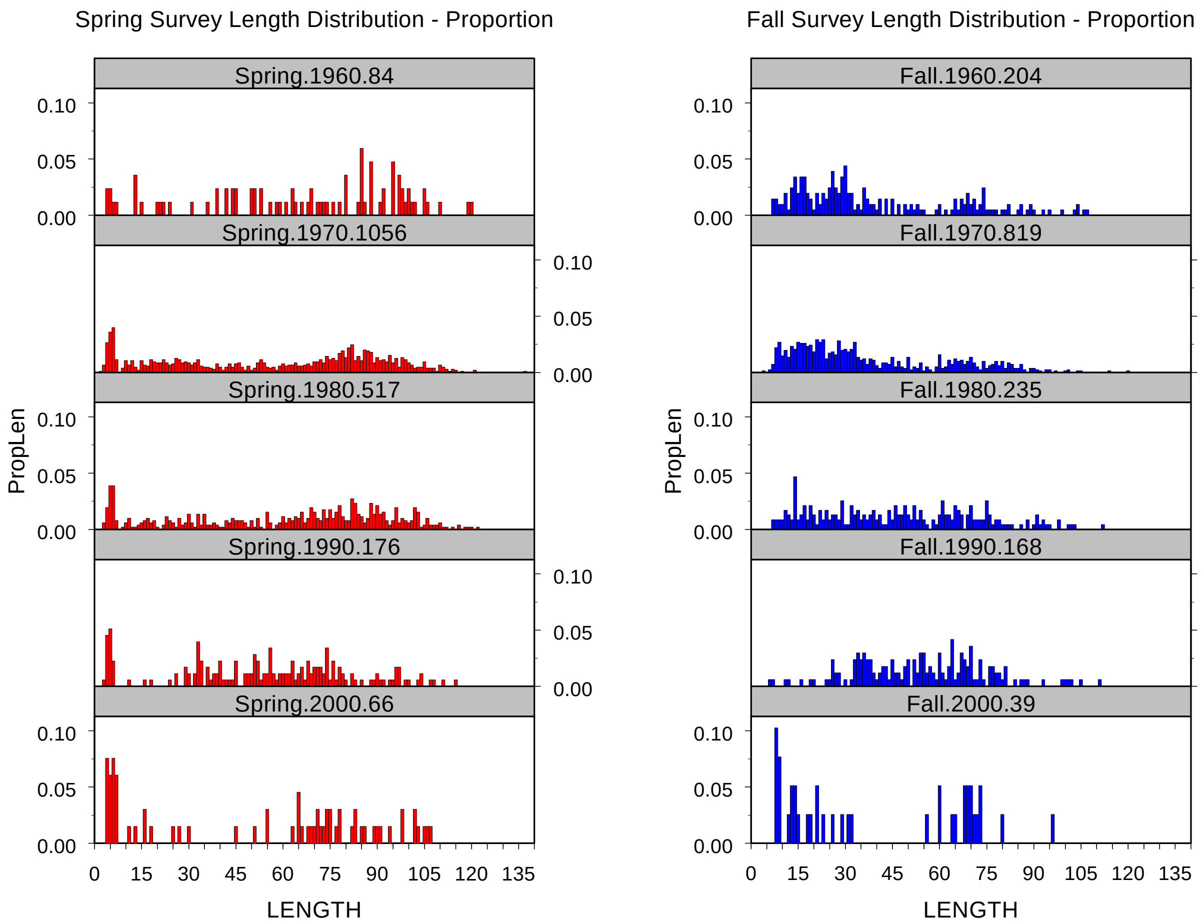


Figure 15. Spring and fall proportional length distributions grouped by decade from NEFSC bottom trawl surveys. Spring and fall time series 1968-2007 and 1963-2007 respectively.

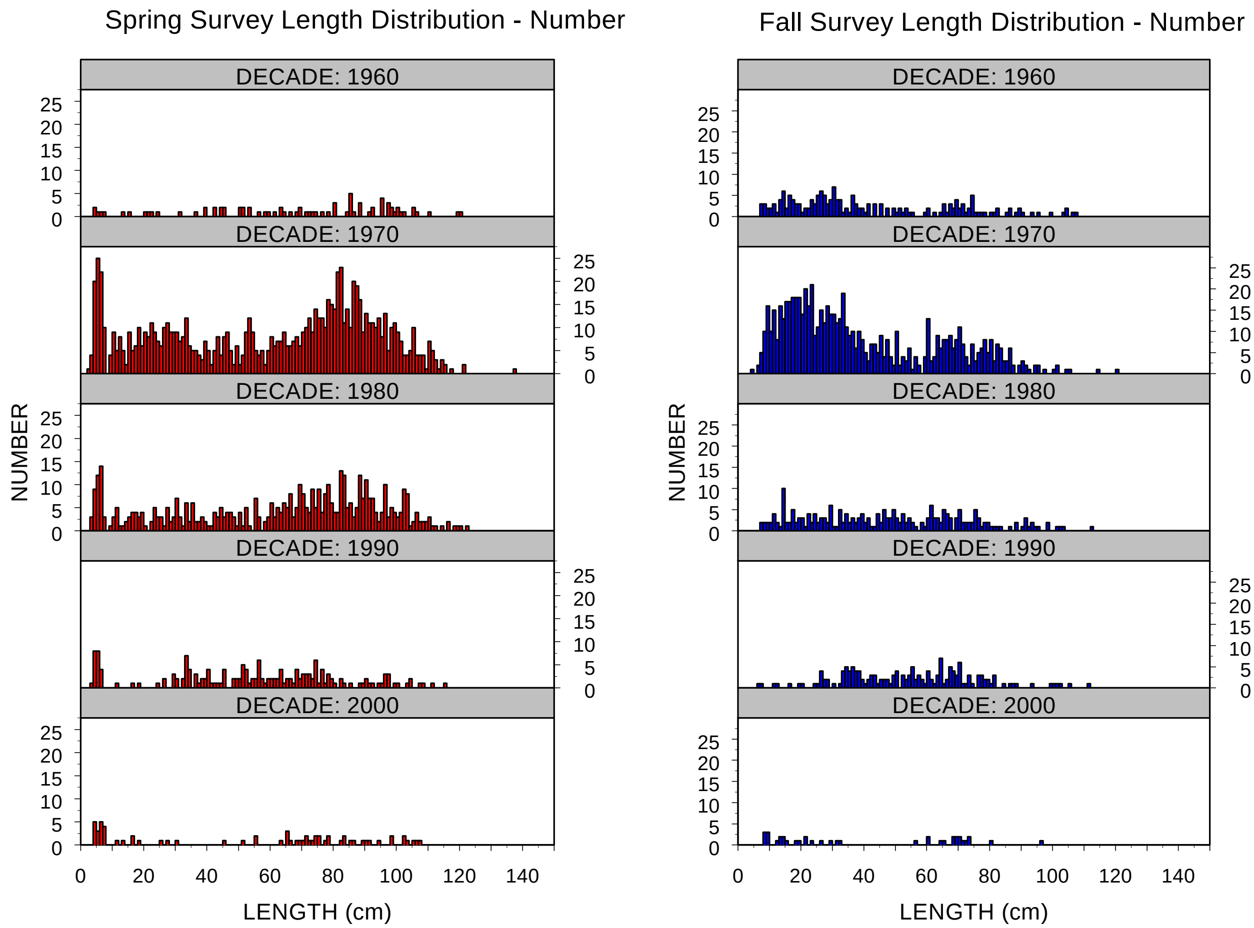


Figure 16. Spring and fall number at length histograms grouped by decade from NEFSC bottom trawl surveys. Spring and fall time series 1968-2007 and 1963-2007 respectively.

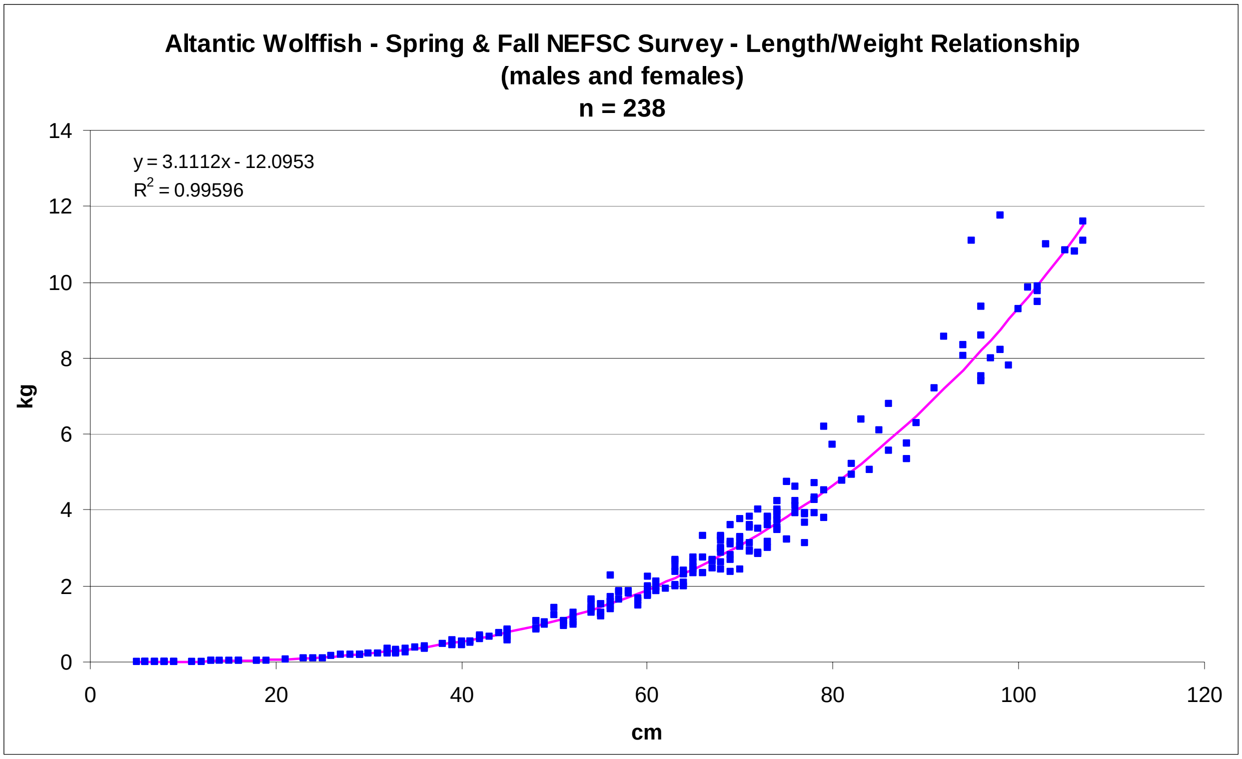


Figure 17. A combined male and female length weight relationship for Atlantic wolffish from NEFSC spring and fall bottom trawl surveys, all years.

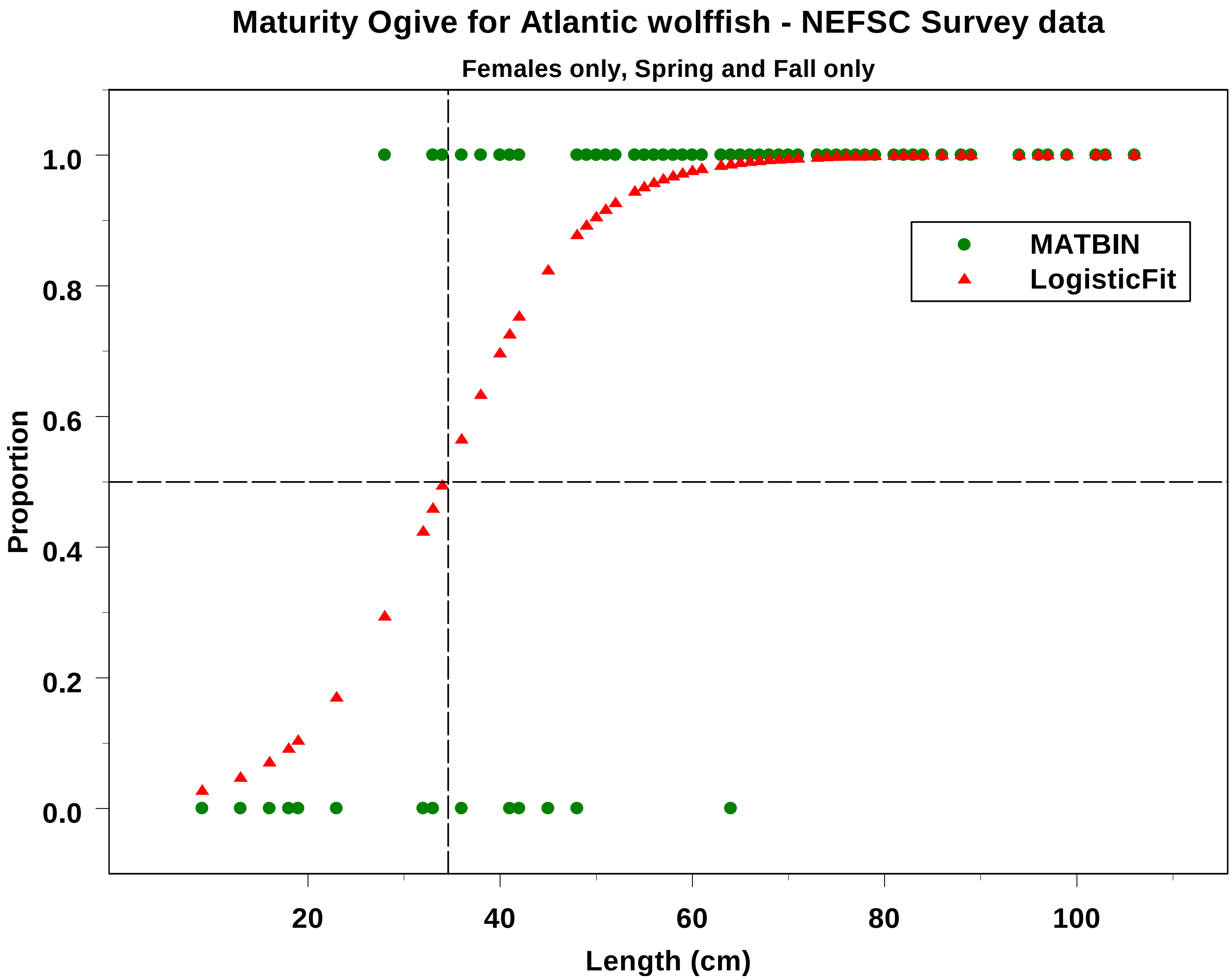


Figure 18. Maturity ogive for female Atlantic wolffish from NEFSC spring and fall data, all years.

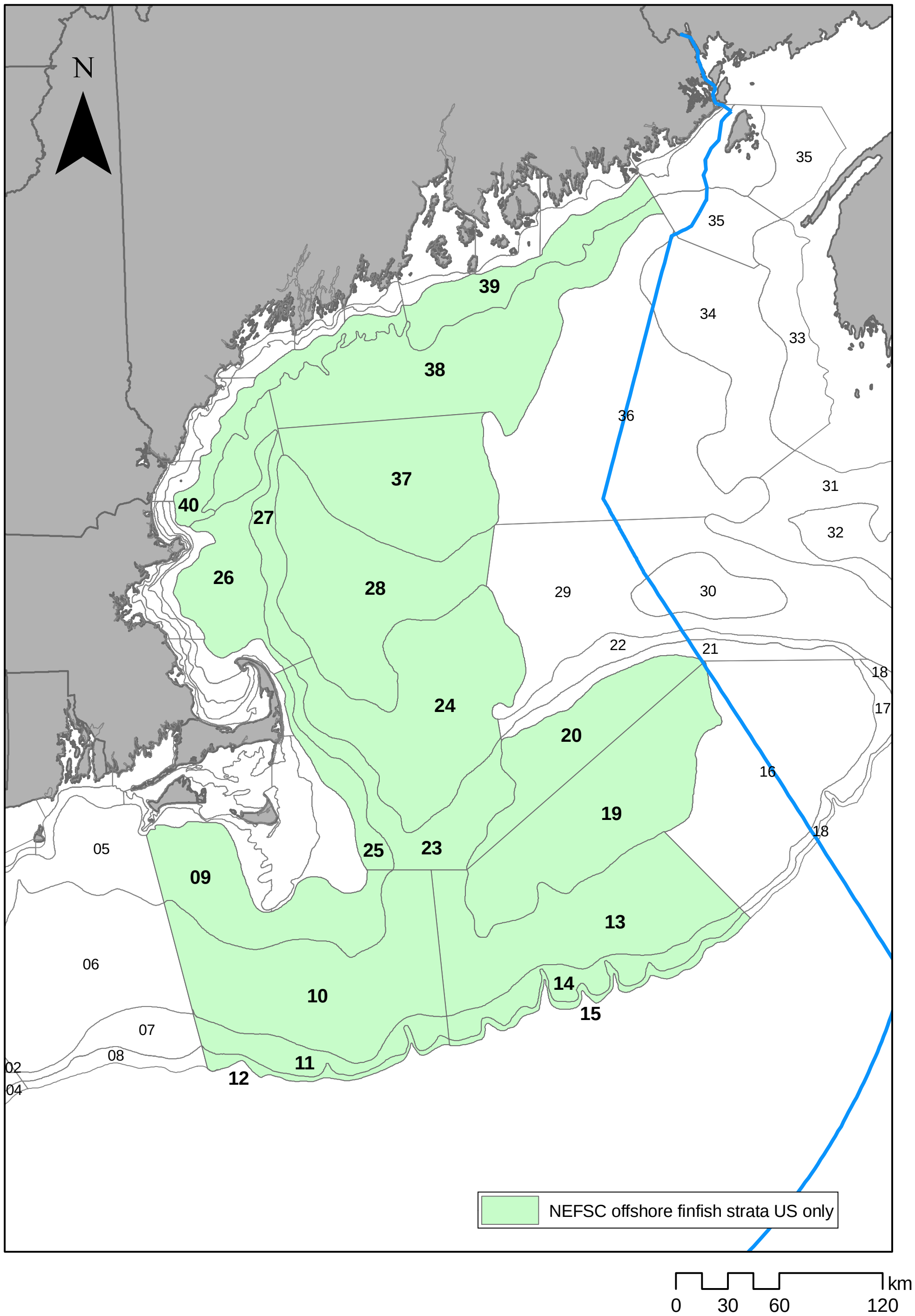


Figure 19. NEFSC survey strata used for Atlantic wolffish abundance and biomass indices.

NEFSC Spring Bottom Trawl Survey 1968-2007

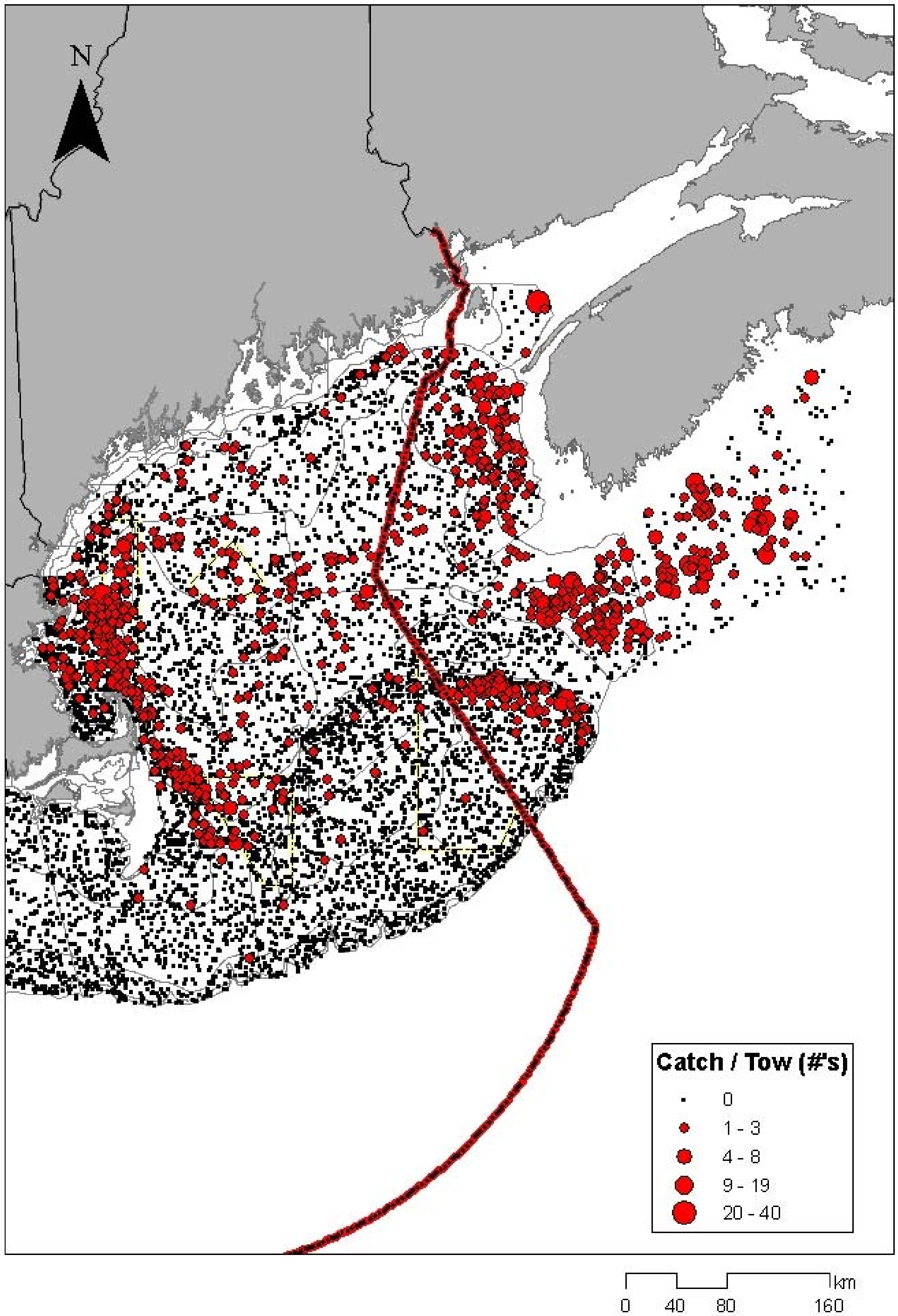


Figure 20. NEFSC spring bottom trawl survey wolffish catches, 1968-2007. Regions east of the Hague line were not included in abundance and biomass estimates.

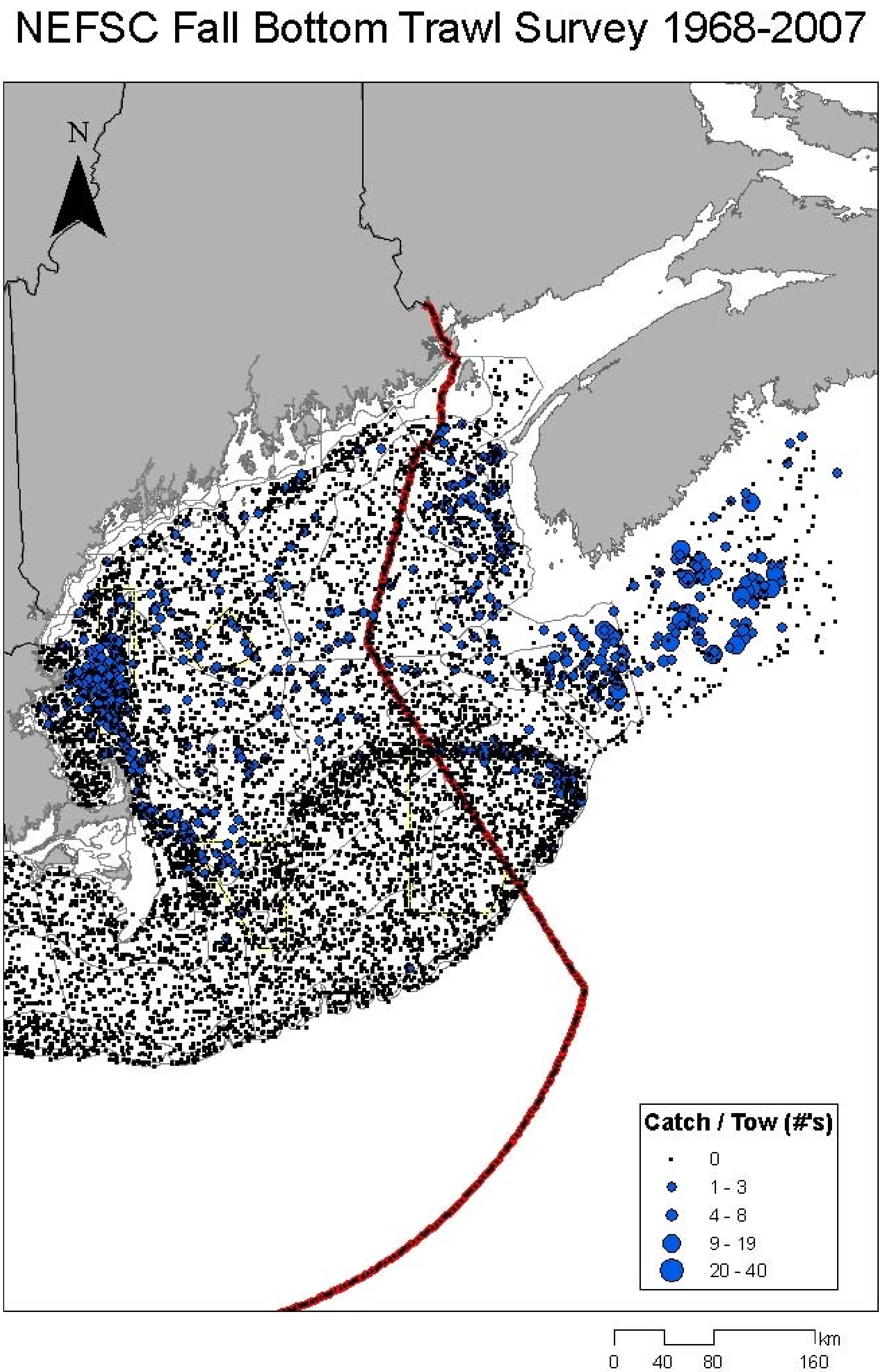


Figure 21. NEFSC fall bottom trawl survey wolffish catches, 1963-2007. Regions east of the Hague line were not included in abundance and biomass estimates.

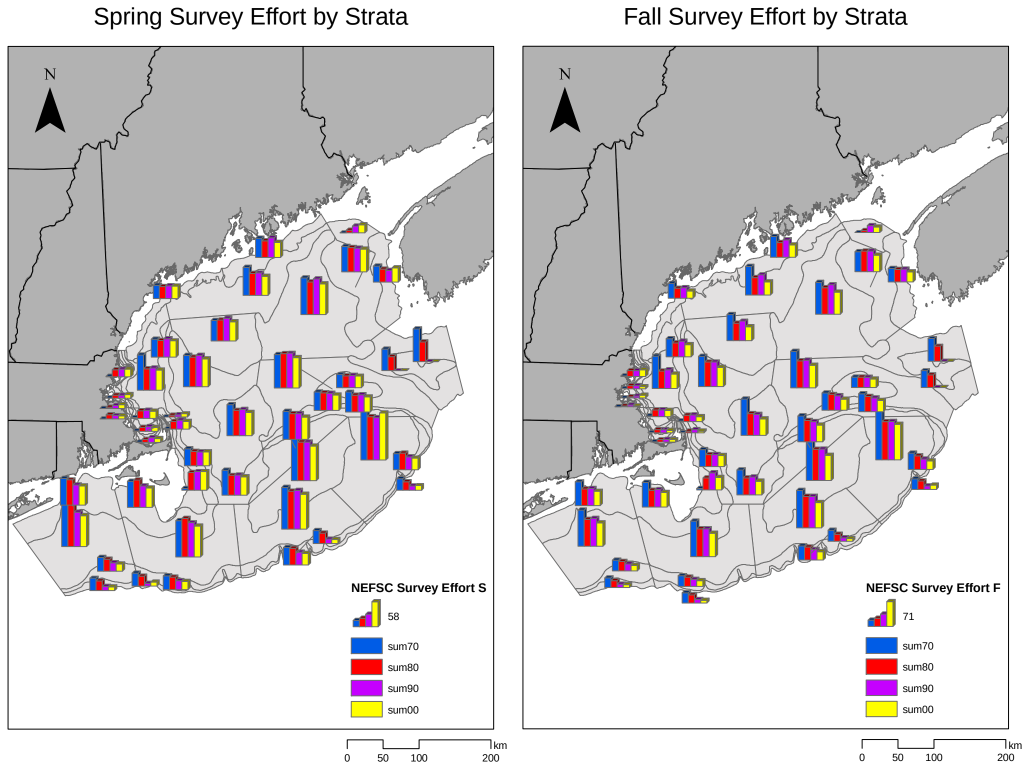


Figure 22. NEFSC spring and fall bottom trawl survey effort by decade per strata. Bars indicate number of stations per strata.

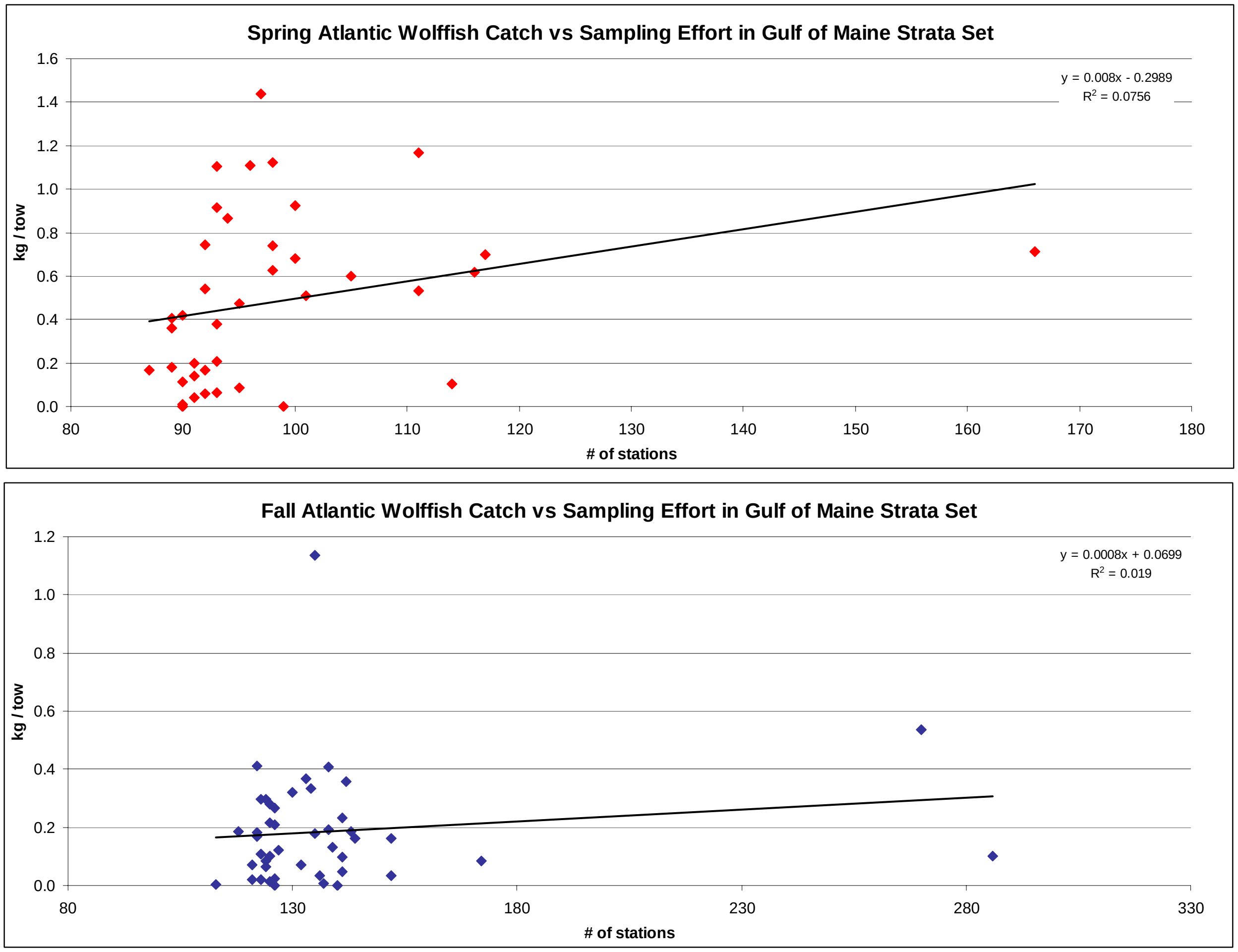
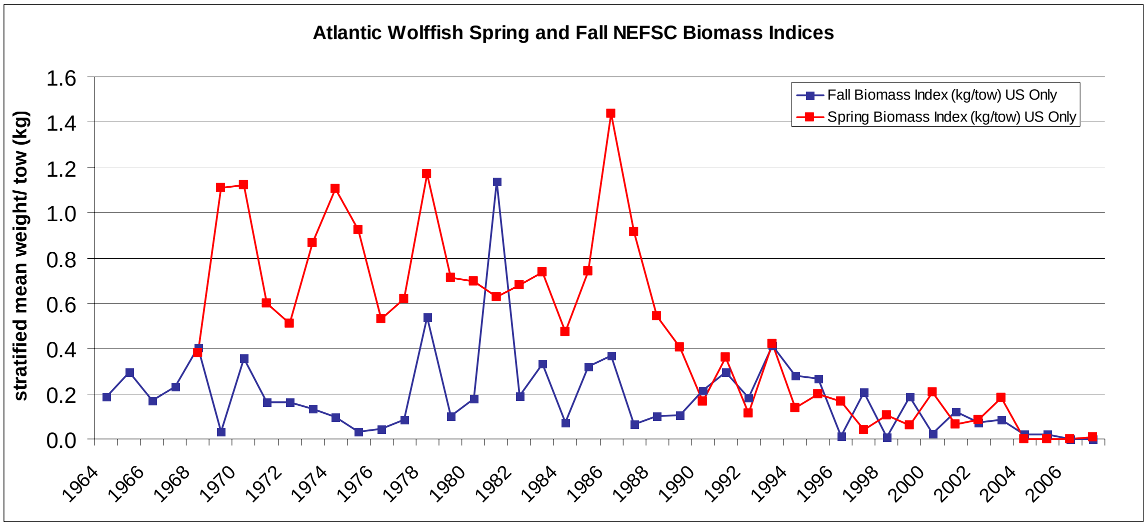


Figure 23. NEFSC sampling effort and biomass of Atlantic wolffish captured.



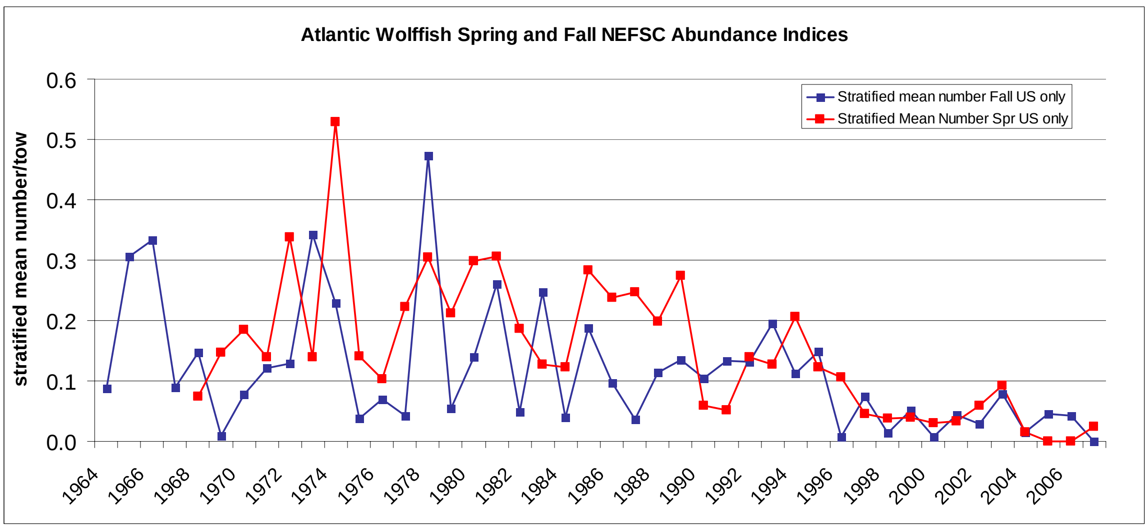
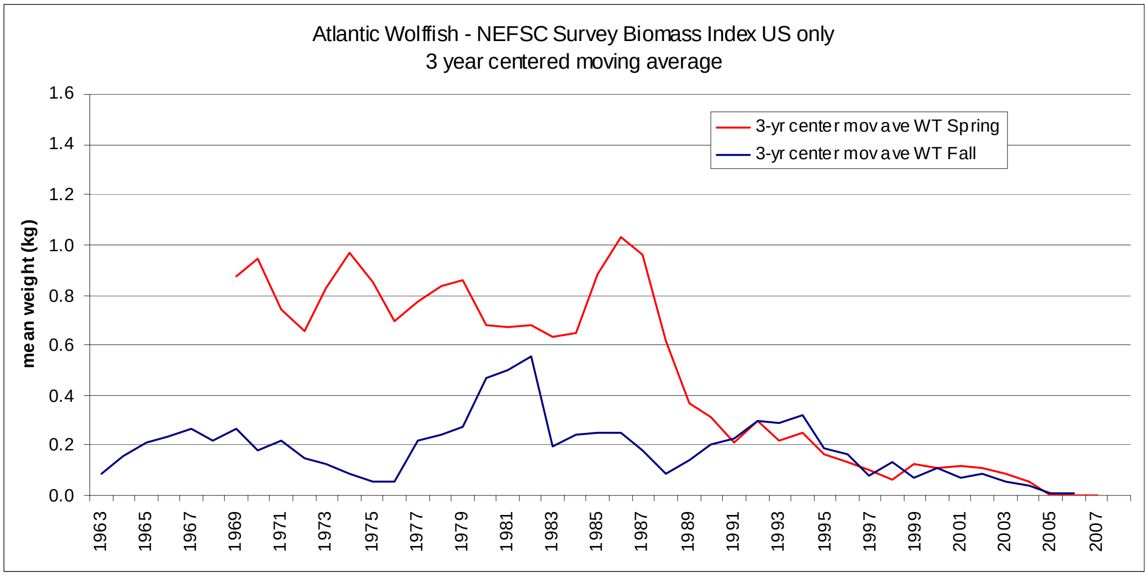


Figure 24. Spring and fall biomass and abundance indices for US only survey strata, 1964-2007.



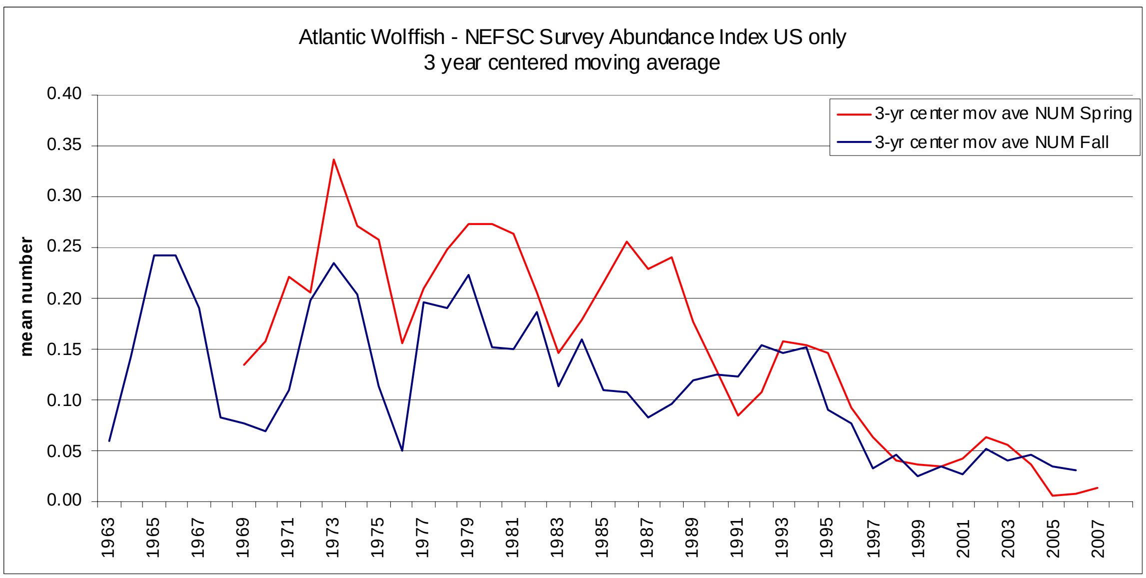
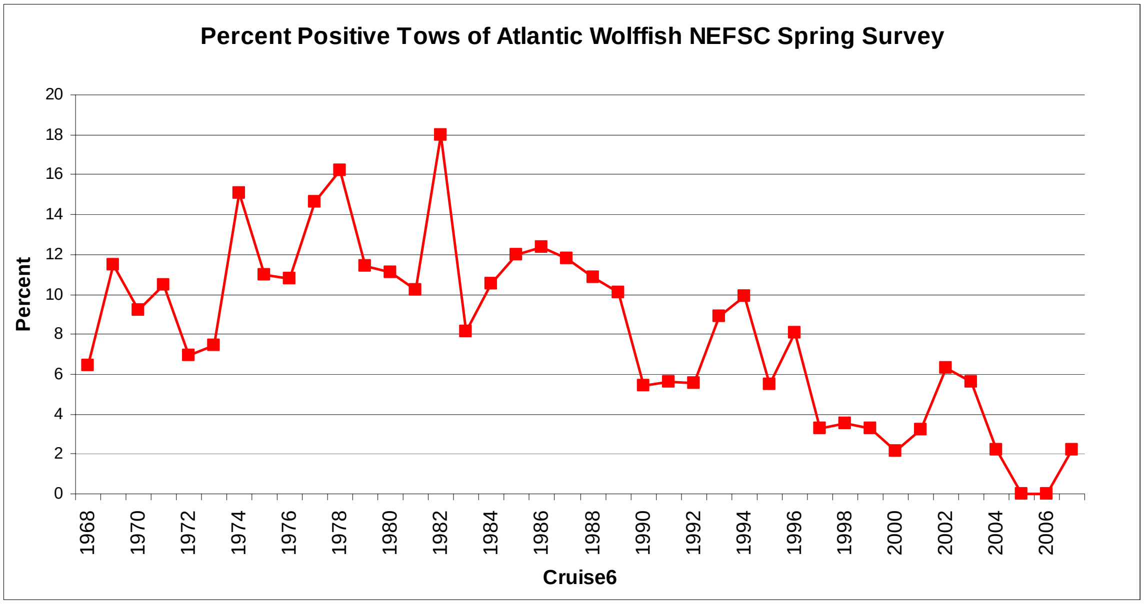


Figure 25. 3 year moving average for NEFSC spring and fall biomass and abundance indices.



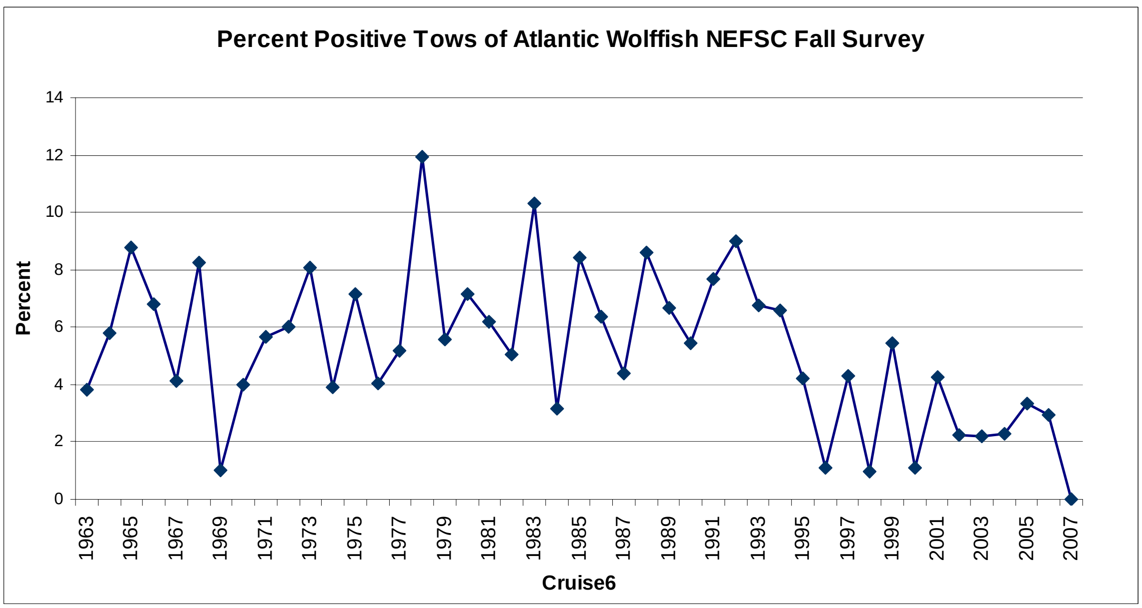


Figure 26. Percent positive Atlantic wolffish catches by year from NEFSC spring and fall bottom trawl surveys.

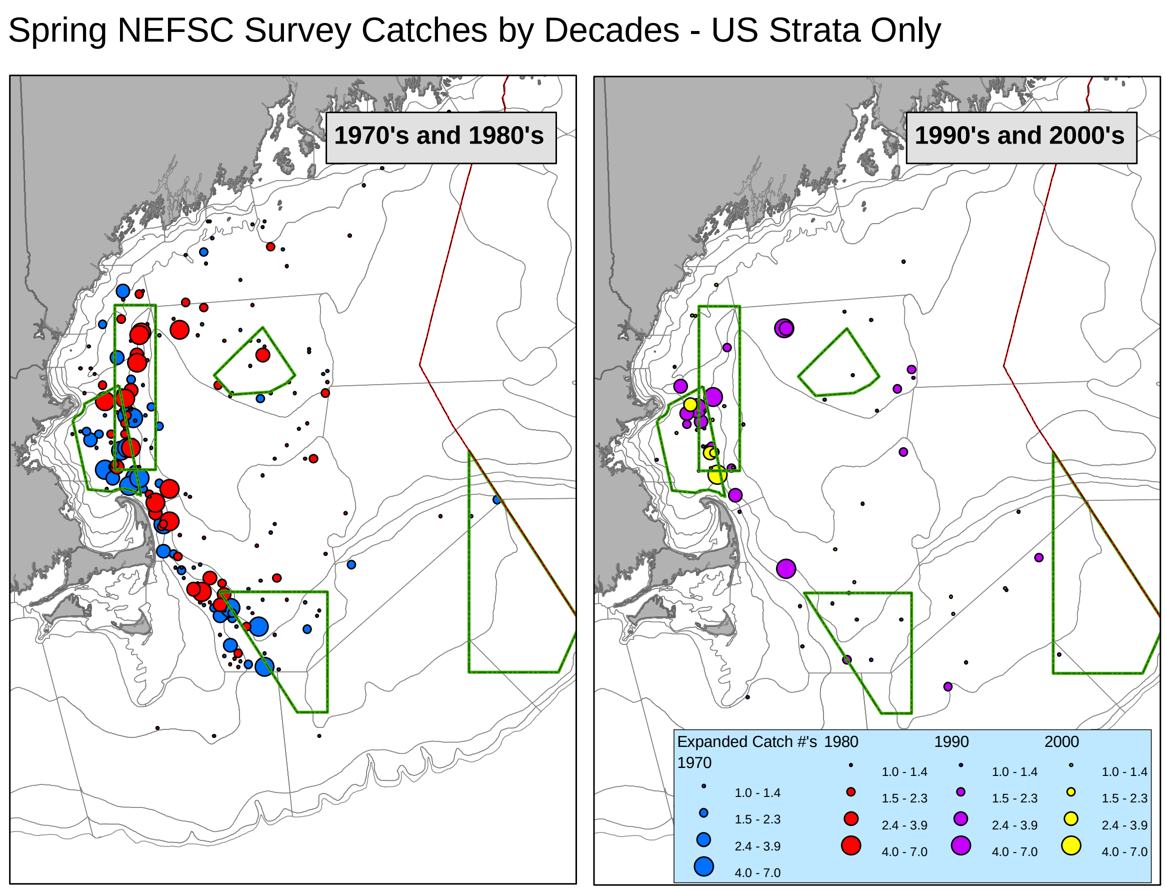


Figure 27. NEFSC spring survey catches by decade.

Fall NEFSC Survey Catches by Decades - US Strata Only

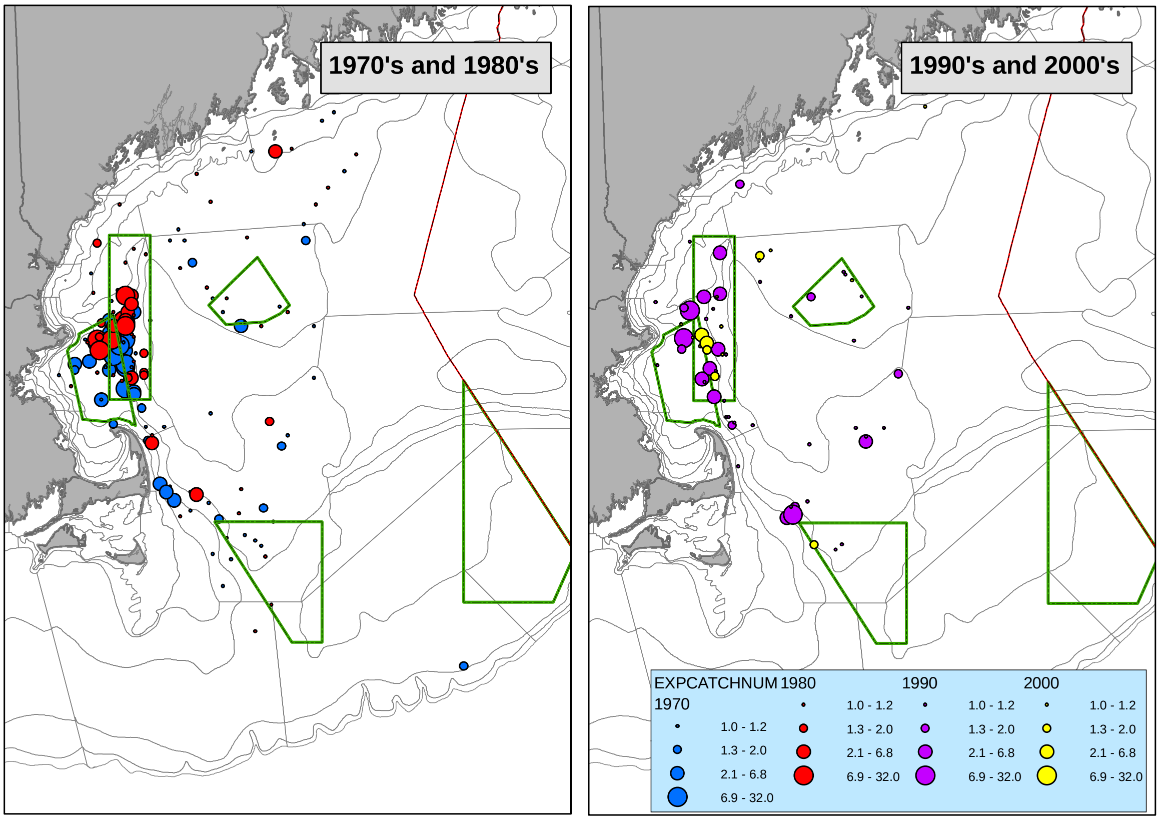
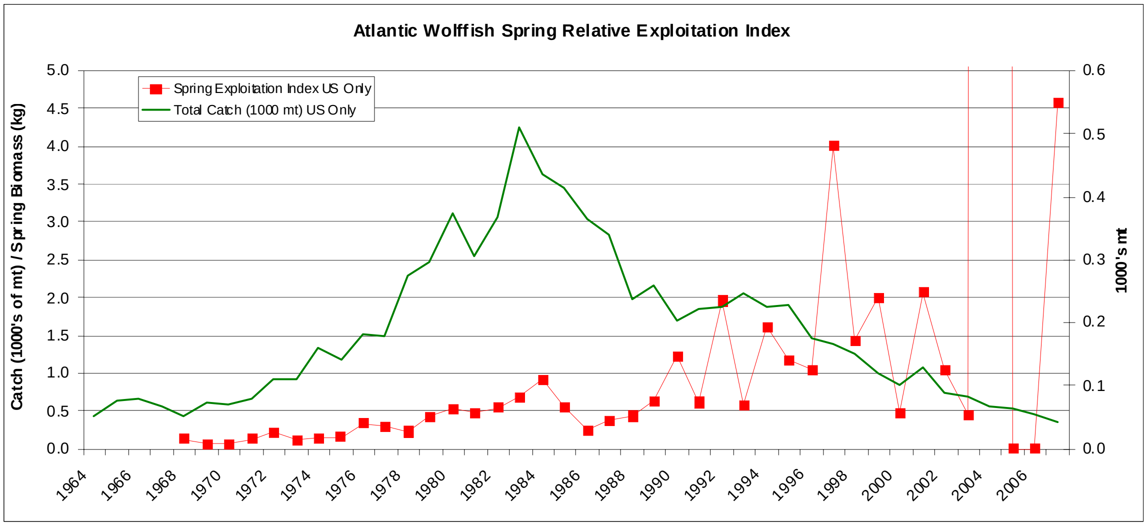


Figure 28. NEFSC fall survey catches by decade.



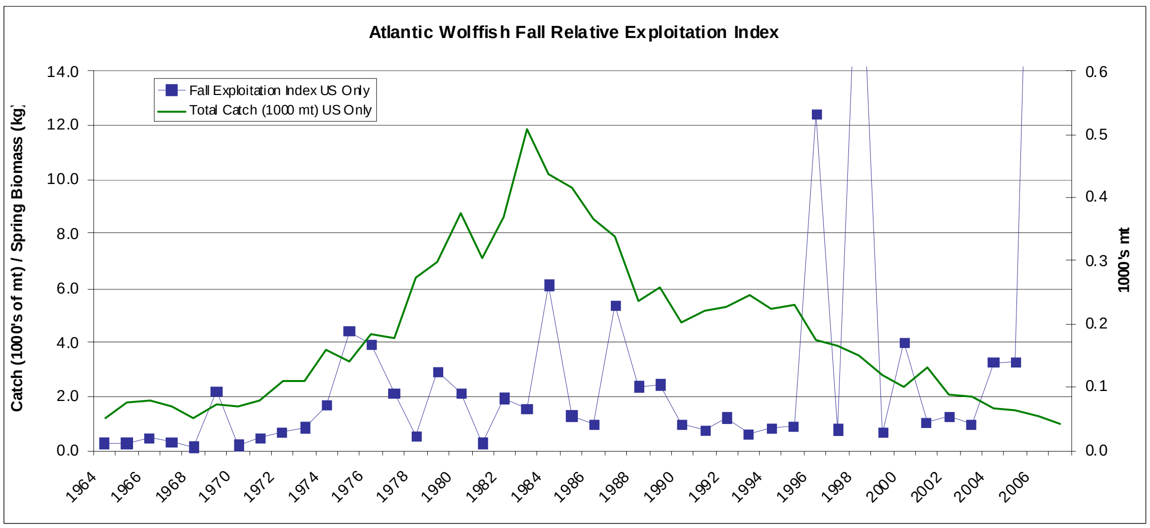


Figure 29. Spring and fall exploitation indices with total catch of Atlantic wolffish.

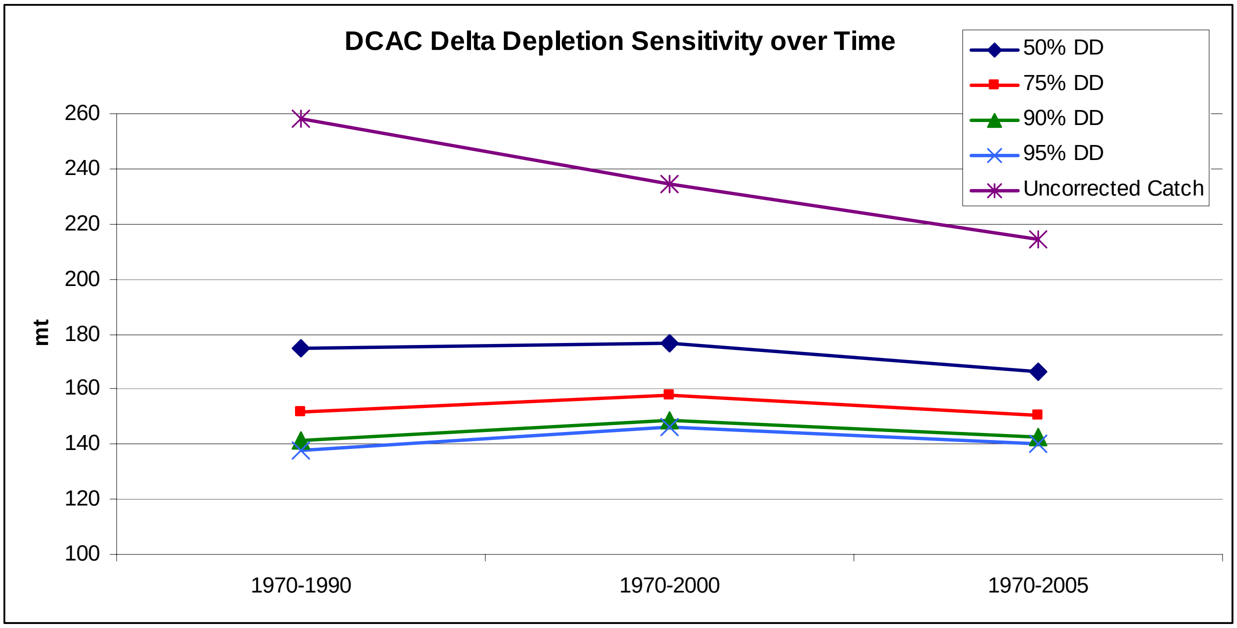


Figure 30. Results of a sensitivity analysis of the depletion ratio from the Depletion-Corrected Average Catch model (DCAC) over time.

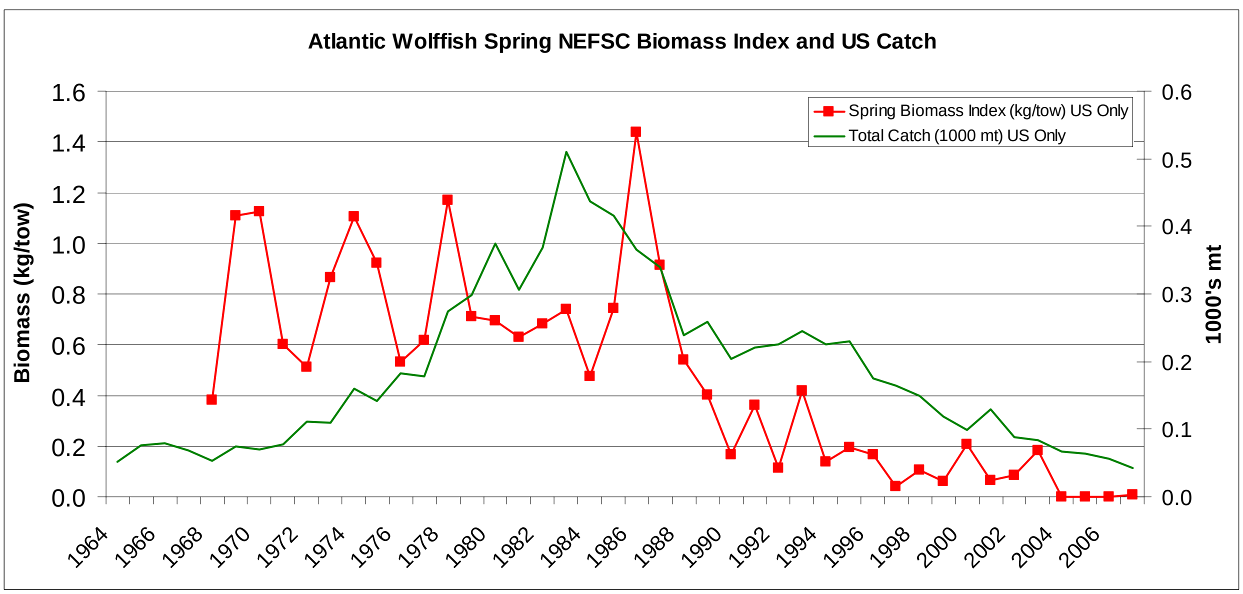
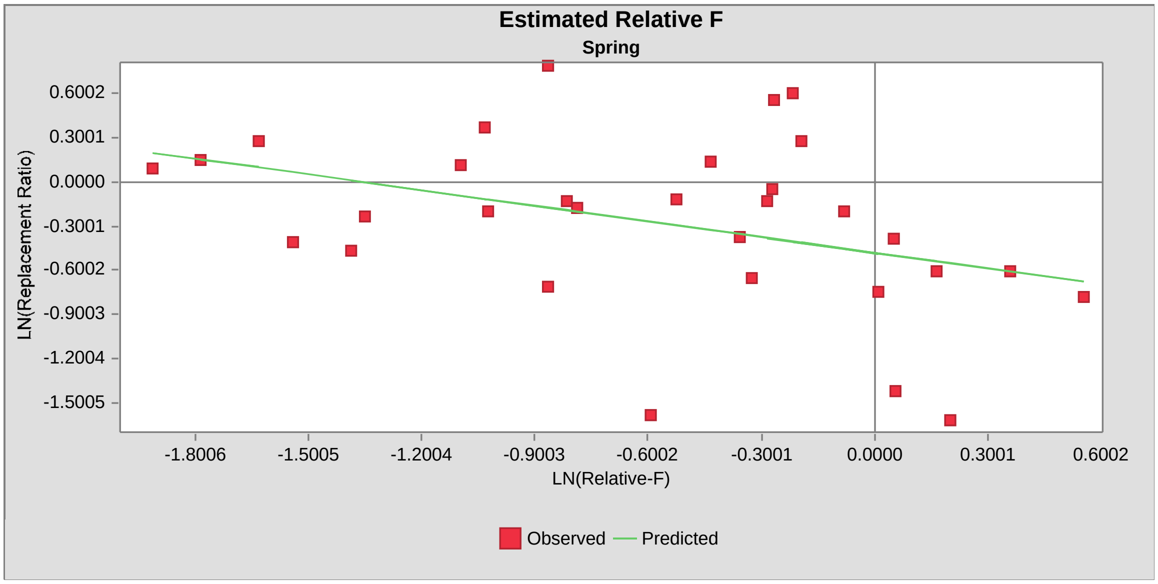


Figure 31. NEFSC spring biomass index and total US catch of Atlantic wolffish used in the AIM (An Index Method) model.



Randomization Test	
	Spring
Critical Value	-0.384824
Significance Level	0.134000

Figure 32. Linear regression of log replacement ratio and log relative F and statistical test results from the AIM model.

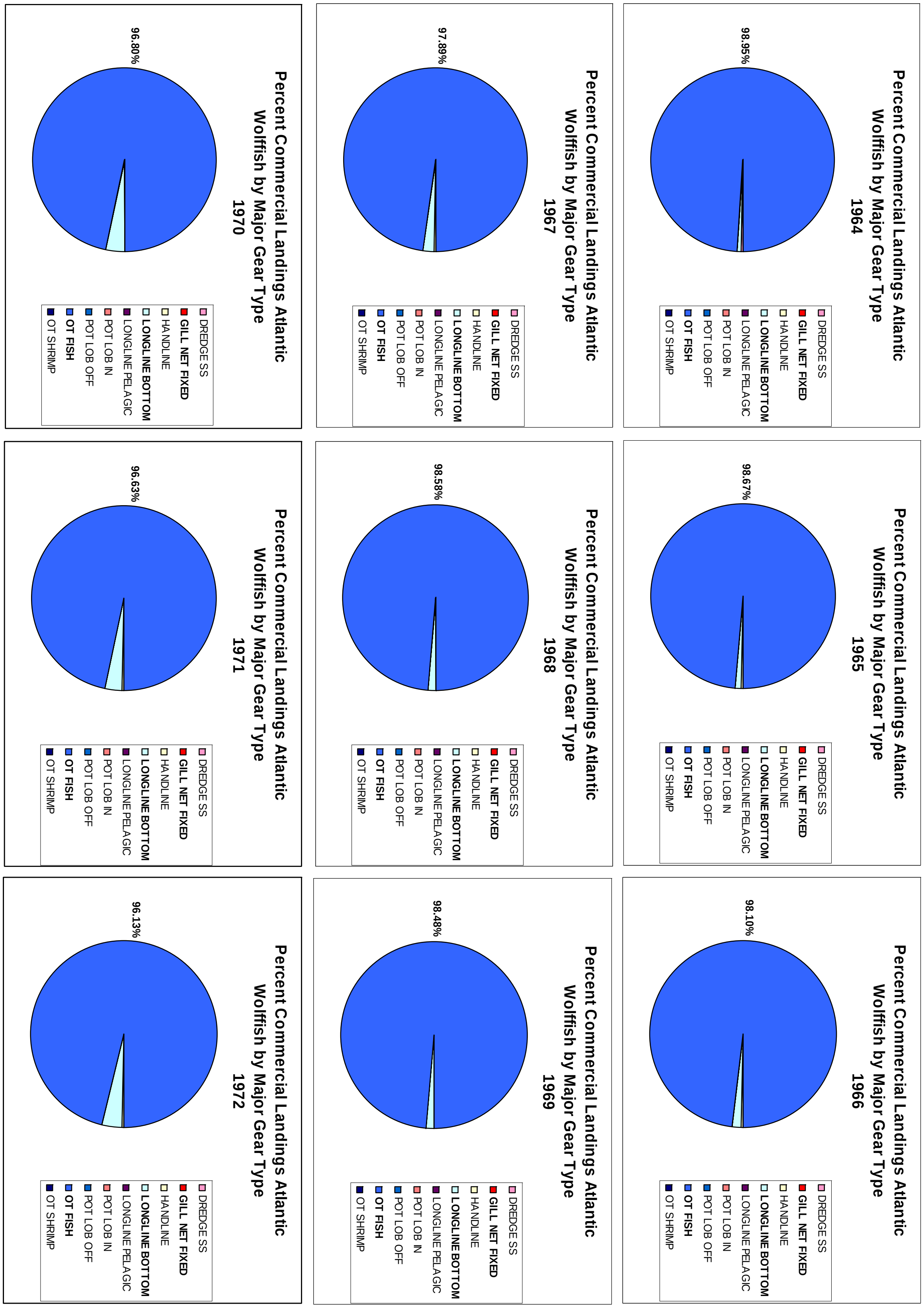
Appendix 1.
SCALE Model

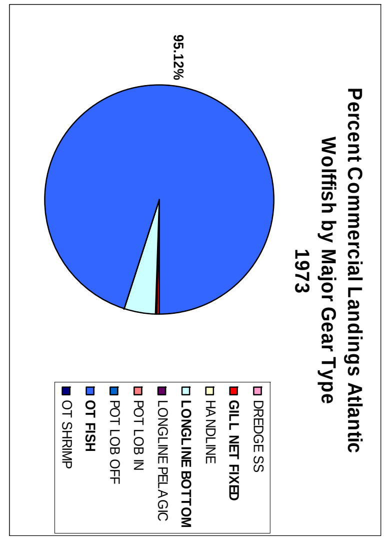
(This is a separate WP)

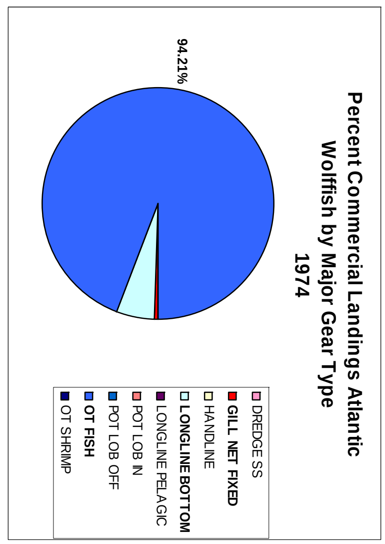
Appendix 2.
SCALE run 3 results

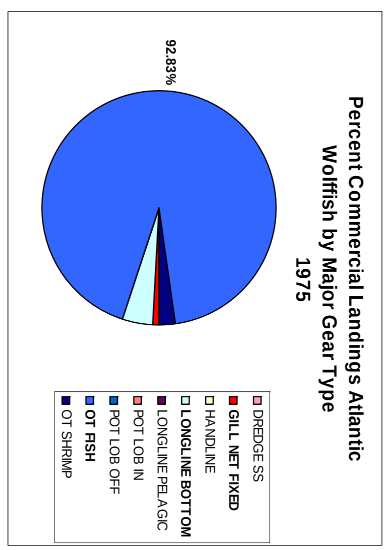
(This is a separate WP)

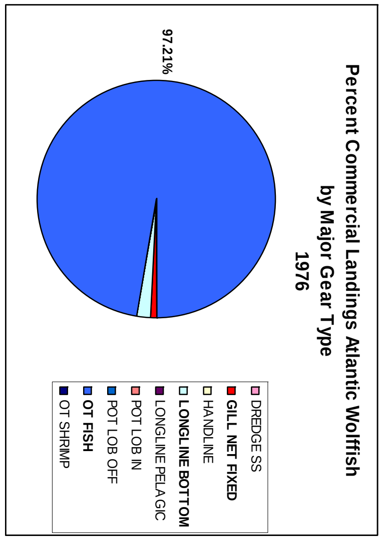
Appendix 3. Commercial landings of Atlantic wolffish by gear, 1964-2007.

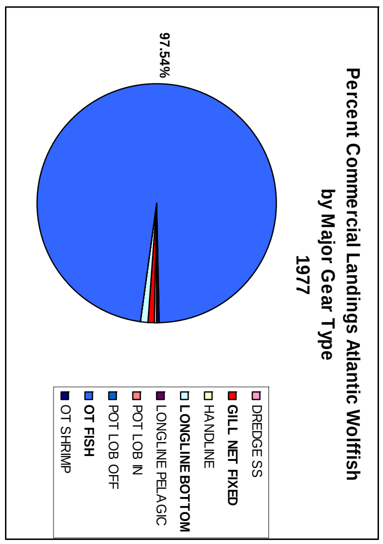


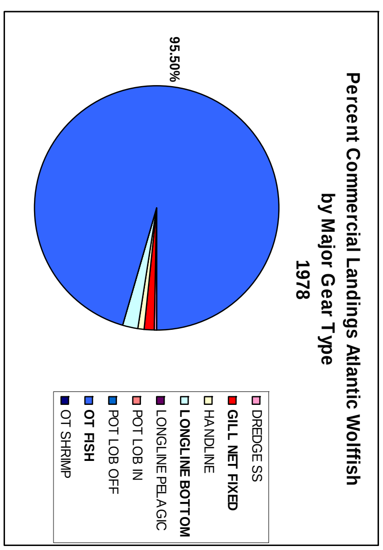

Percent Commercial Landings Atlantic
Wolffish by Major Gear Type
1973
95.12%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

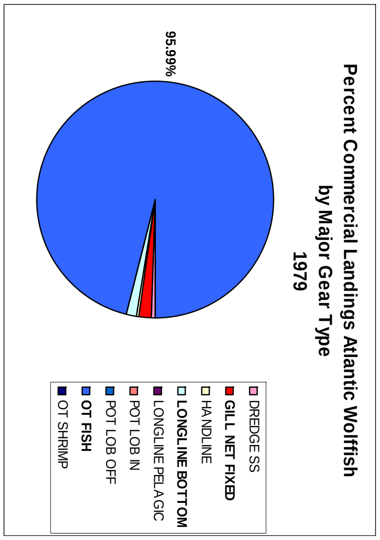

Percent Commercial Landings Atlantic
Wolffish by Major Gear Type
1974
94.21%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

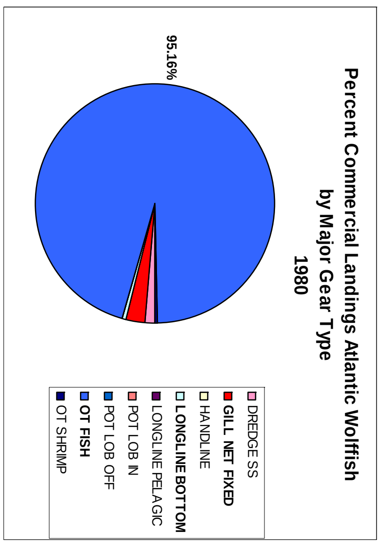

Percent Commercial Landings Atlantic
Wolffish by Major Gear Type
1975
92.83%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

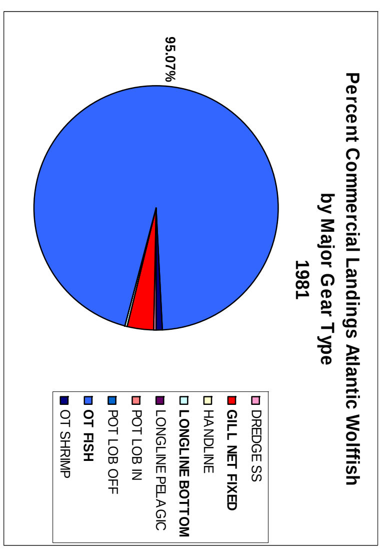

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1976
97.21%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

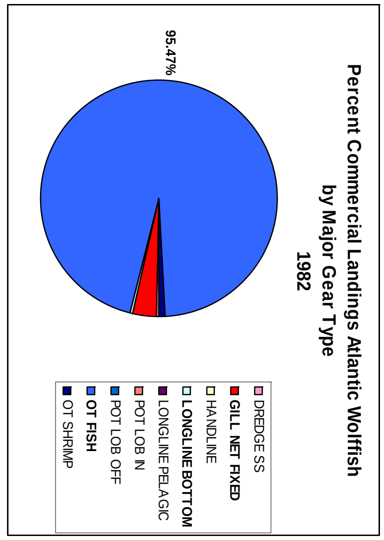

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1977
97.54%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

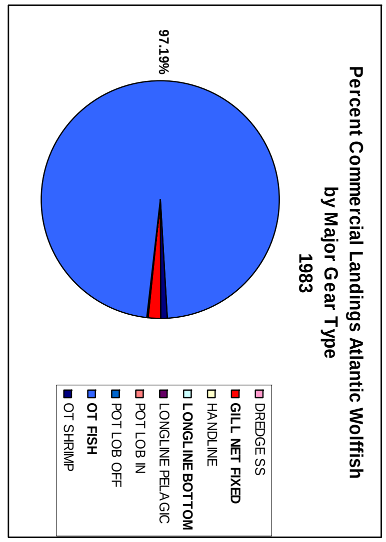

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1978
95.50%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

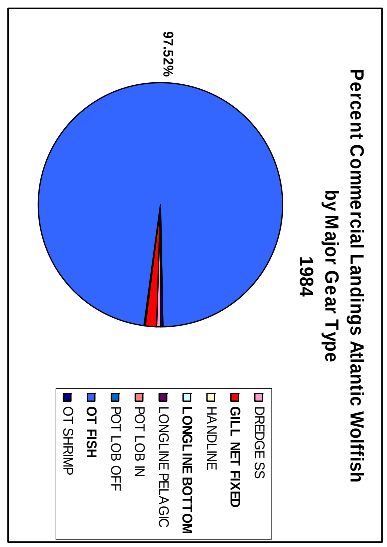

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1979
95.99%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

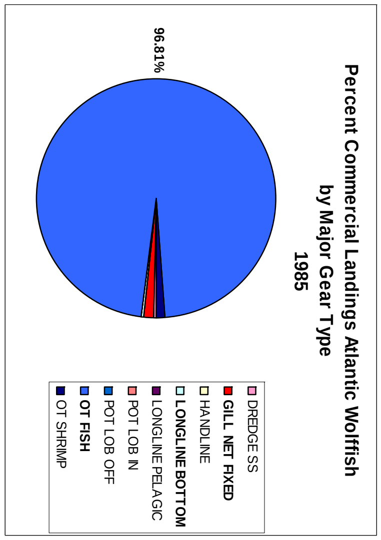

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1980
95.16%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

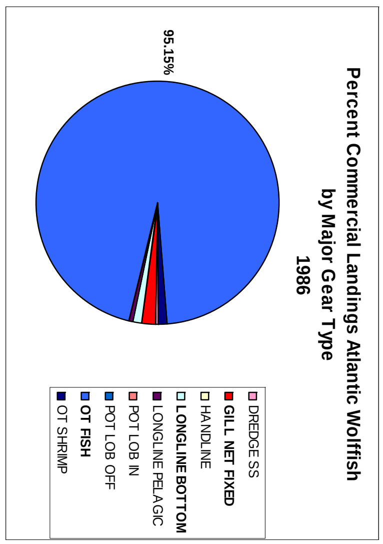

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1981
95.07%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1982
95.47%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1983
97.19%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1984
97.52%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1985
96.81%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1986
95.15%
DREDGE SS
GILL NET FIXED
HANDLINE
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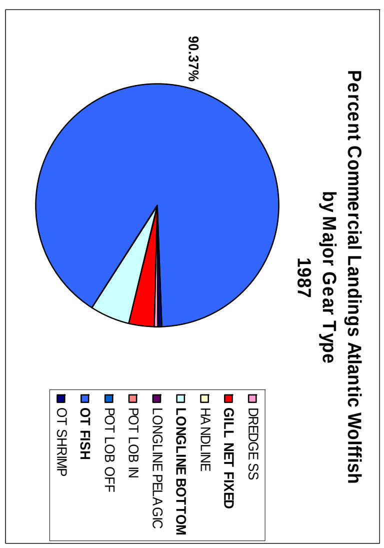
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1987
90.37%
DREDGE SS
GILL NET FIXED
HANDLINE
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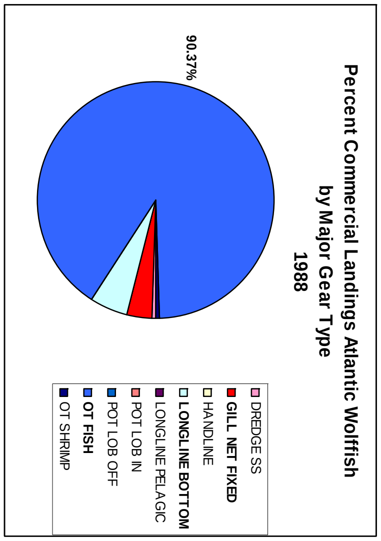
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1988
90.37%
DREDGE SS
GILL NET FIXED
HANDLINE
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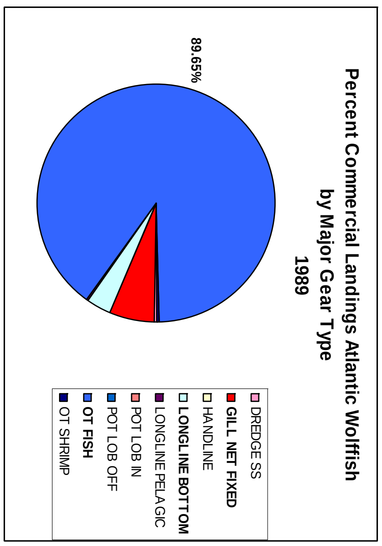
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1989
89.65%
DREDGE SS
GILL NET FIXED
HANDLINE
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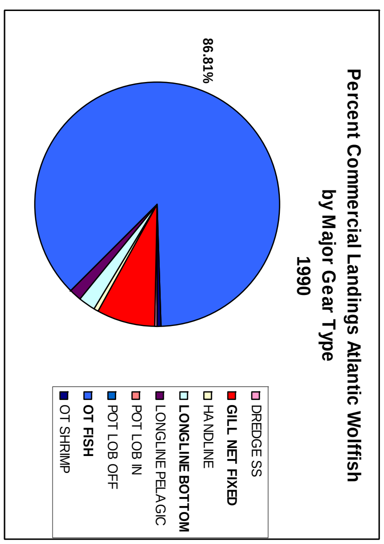
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1990
86.81%
DREDGE SS
GILL NET FIXED
HANDLINE
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POT LOB IN
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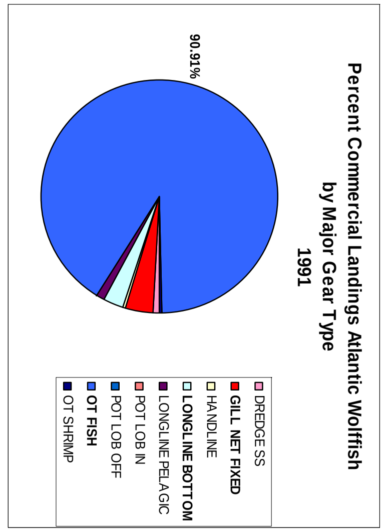
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1991
90.91%
DREDGE SS
GILL NET FIXED
HANDLINE
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POT LOB IN
POT LOB OFF
OT FISH
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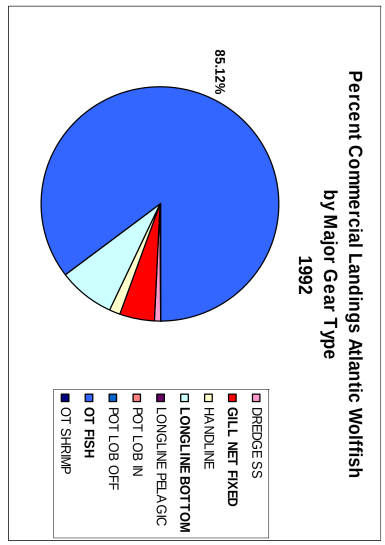
Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1992
85.12%
DREDGE SS
GILL NET FIXED
HANDLINE
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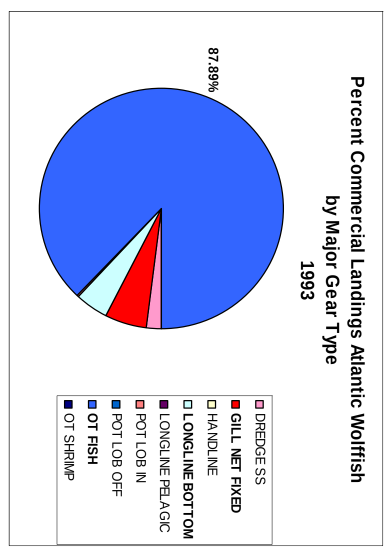
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1993
87.89%
DREDGE SS
GILL NET FIXED
HANDLINE
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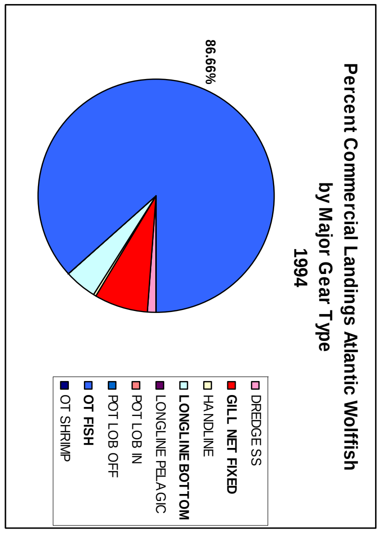
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1994
86.66%
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HANDLINE
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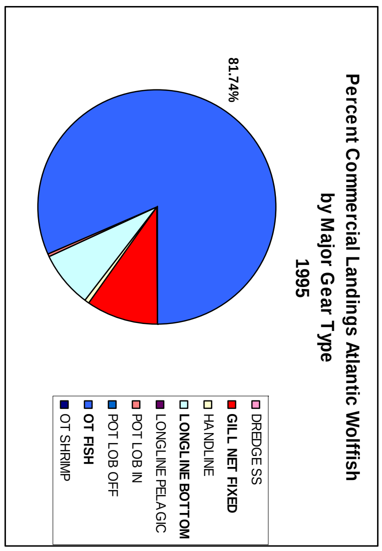
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1995
81.74%
DREDGE SS
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HANDLINE
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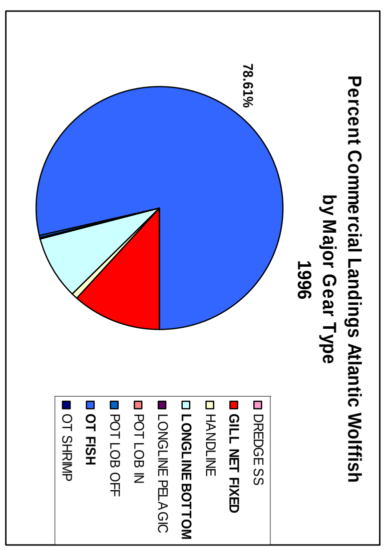
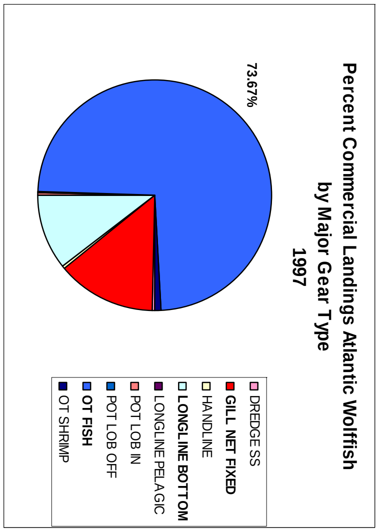
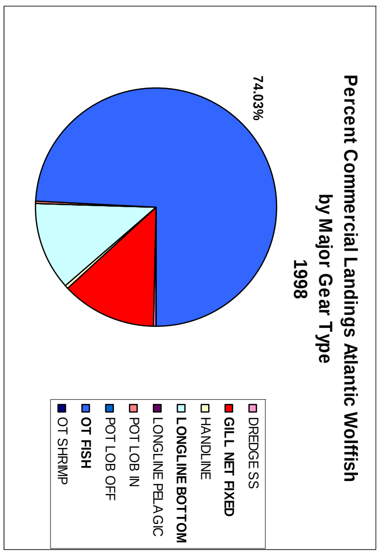
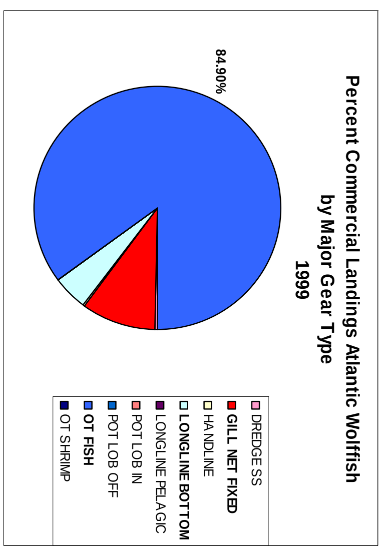
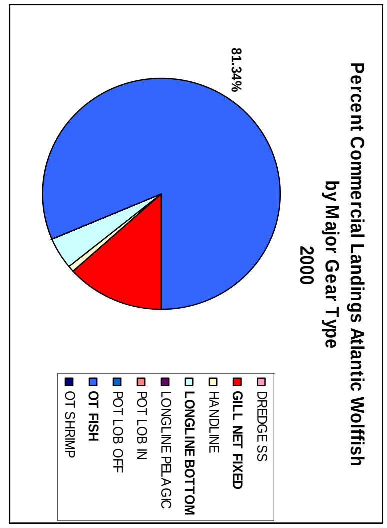
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

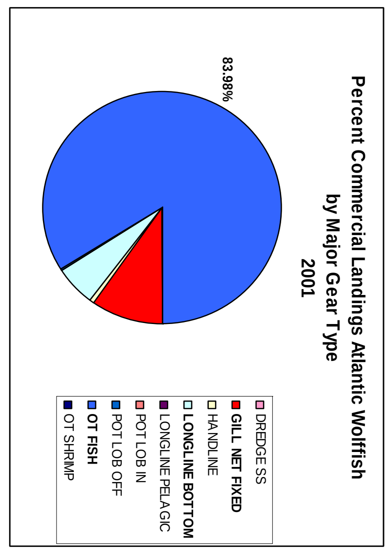

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1996
78.61%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

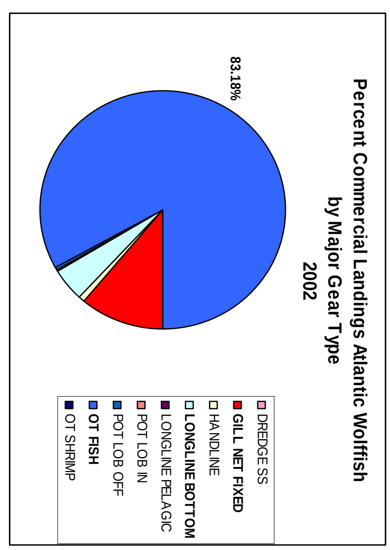

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1997
73.67%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

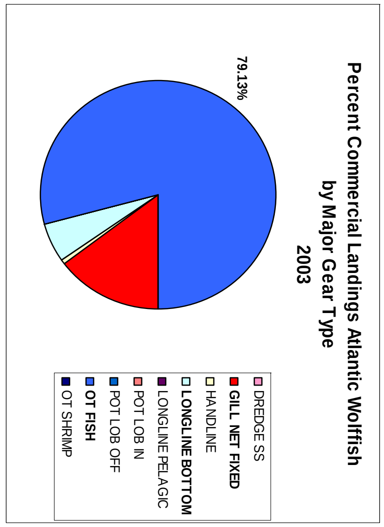

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1998
74.03%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

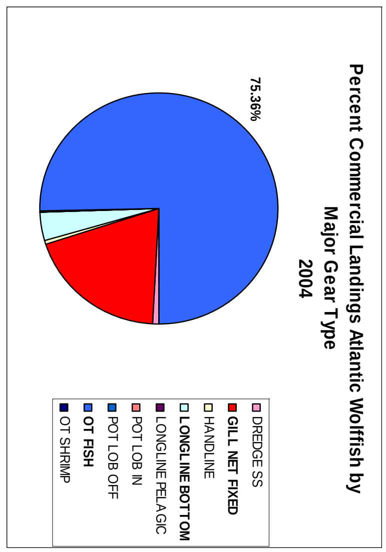

Percent Commercial Landings Atlantic Wolffish
by Major Gear Type
1999
84.90%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

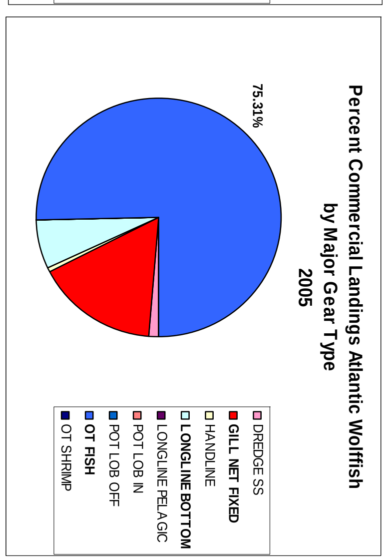

Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2000
81.34%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

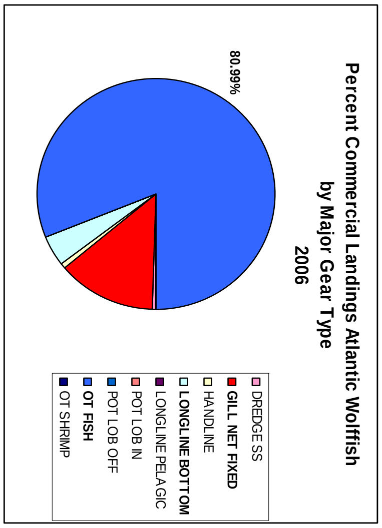

Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2001
83.98%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

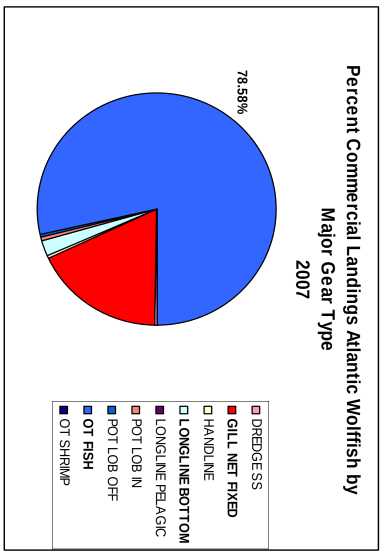

Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2002
83.18%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2003
79.13%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2004
75.36%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2005
75.31%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2006
80.99%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP


Percent Commercial Landings Atlantic Wolffish by Major Gear Type 2007
78.58%
DREDGE SS
GILL NET FIXED
HANDLINE
LONGLINE BOTTOM
LONGLINE PELAGIC
POT LOB IN
POT LOB OFF
OT FISH
OT SHRIMP

Appendix 4.

Depletion-Adjusted Average Catch Model

Alec MacCall, NMFS/SWFSC/FED (draft 9/6/07)

Unlike the classic fishery problem of estimating MSY, data-poor fishery analysis must be content simply to estimate a yield that is likely to be sustainable. While absurdly low yield estimates would have this property, they are of little practical use. Here, the problem is to identify a moderately high yield that is sustainable, while having a low chance that the estimated yield level greatly exceeds MSY and therefore is a dangerous overestimate that could inadvertently cause overfishing and potentially lead to resource depletion before the error can be detected in the course of fishery monitoring and management.
Perhaps the most direct evidence for a sustainable yield would be a prolonged period over which that yield has been taken without indication of a reduction in resource abundance. The estimate of sustainable yield would be nothing more than the long-term average annual catch over that period. However, it is rare that a resource is exploited without some change in underlying abundance. If the resource declines in abundance (which is necessarily the case for newly-developed fisheries), a portion of the associated catch stream is derived from that one-time decline, and does not represent potential future yield supported by sustainable production. If that non-sustainable portion is mistakenly included in the averaging procedure, the average will tend to overestimate the sustainable yield. This error has been frequently made in fishery management. Based on these concepts, we present a simple method for estimating sustainable catch levels when the data available are little more than a time series of catches. The method needs extensive testing, both on simulated data and on cases where reliable assessments exist for comparison. So far, test cases indicate that it may be a robust calculation.

The Windfall/Sustainable Yield Ratio

The old potential yield formula Ypot = 0.5*M*Bunfished (Alverson and Pereyra,1969; Gulland, 1970) is based on combining two approximations: 1) that Bmsy occurs at 0.5*Bunfished, and 2) that Fmsy = M. In this and the following calculations fishing mortality rate (F) and exploitation rate are treated as roughly equivalent. However, it is possible to take the potential yield rationale one step farther, and calculate the ratio of the one-time "windfall" harvest (W) due to reducing the abundance from Bunfished to the assumed Bmsy level. After that reduction in biomass has occurred, a tentatively sustainable annual yield Y is given by the potential yield formula. So we have the following simple relationships:
Y = 0.5*M*Bunfished, and
W = 0.5*Bunfished.

Under the potential yield assumptions, the ratio of one-time windfall yield to sustainable yield is the windfall/sustainable yield ratio (or simply the "windfall ratio") W/Y = 1/M. For example, if M = 0.1, the windfall is equal to 10 units of annual sustainable yield.

An Update
The assumptions underlying the potential yield formula are out-of-date, and merit reconsideration. Most stock-recruitment relationships indicate that MSY of fishes occurs somewhat below the level of 0.5*Bunfished. We replace the value of 0.5 with a value of 0.4 as a better approximation of common stock-recruitment relationships.
The Fmsy = M assumption also requires revision, as fishery experience has shown it tends to be too high, and should be replaced by a Fmsy = c*M assumption (Deriso, 1982; Walters and Martell, 2004). Walters and Martell suggest that coefficient c is commonly around 0.8, but may be 0.6 or less for vulnerable stocks. Figure 1 shows the distribution of c values for West Coast groundfish stocks assessed in 2005. The average of c for those West Coast species is 0.62, but there is a substantial density of lower values. Because the risk is asymmetrical (ACLs are specifically intended to prevent overfishing), use of the average value is risk-prone.
Consequently, we have used a value of c=0.5 in the following calculations.

The yield that is potentially sustainable under these revised assumptions is

Y = 0.4* Bunfished *c*M,

or for c = 0.5,

Y = 0.2* Bunfished *M.

The windfall is based on the reduction in abundance from the beginning of the catch time series to the end of the series,

W = Bbegin - Bend = DELTA*Bunfished,

where DELTA is the fractional reduction in biomass from the beginning to the end of the time series, relative to unfished biomass. The analogous case to the potential yield formula is Bbegin = Bunfished, and Bend = 0.4*Bunfished, in which case DELTA = 0.6. In practice, Bbegin is rarely Bunfished, and DELTA is unlikely to be known explicitly. Although data may be insufficient for use of conventional stock assessment methods, an estimate (or range) of DELTA based on expert opinion is sufficient for this calculation. The windfall ratio is now

W/Y = DELTA/(0.4*c*M),

or in the case of c=0.5,

W/Y = DELTA/(0.2*M).

For example, in the case of fishing down from Bunfished to near Bmsy where DELTA=0.6, if c = 0.5, W/Y = 3/M. Thus the revised calculation gives a much larger estimate of the windfall ratio. For the previous example of M = 0.1, the windfall ratio is now estimated at 30 units of sustainable annual yield.

A Sustainable Yield Calculation

Assume that in addition to the windfall associated with reduction in stock size, each year produces one unit of annual sustainable yield. The cumulative number of annual sustainable yield units harvested from the beginning to the end of the time series is n + W/Y, where n is the length of the series. In this calculation it should not matter when the reduction in abundance actually occurs in the time series because assumed production is not a function of biomass. Of course, in view of the probable domed shape of the true production curve, the temporal pattern of exploitation may influence the approximation.

The estimate of annual sustainable yield (Ysust) is

Ysust = sum(C)/(n + W/Y).

In the special case of no change in biomass, DELTA = 0, W/Y = 0, and Ysust is the historical average catch. If abundance increases, DELTA is negative, W/Y is negative, and Ysust will be larger than the historical average catch.

Examples

The widow rockfish fishery began harvesting a nearly unexploited stock in 1981 and for the first three years, fishing was nearly unrestricted (Table 1). Reliable estimates of sustainable yield based on conventional stock assessments were not available for many years afterward. By the mid-1990s, stock assessments were producing estimates of sustainable yield ca. 5000 mtons, with indications that abundance had fallen to 20-33% of Bunfished.

Application of depletion-corrected catch averaging indicates good performance of the method within a few years of the beginning of the fishery. Two alternative calculations are given in Table 1. The first calculation assumes M = 0.15, c = 0.5, and that biomass was near Bmsy at the end of the time period, so that DELTA = 0.6. The second calculation is closer to the most recent stock assessment (He et al., 2007) and assumes M = 0.125, c = 0.5, DELTA = 0.75 (ending biomass in year 2000 is about 25% of Bunfished).

Other examples would be worth exploring, especially were they can be compared with "ground truth" from a corresponding formal stock assessment.

Low biomasses

The yields given by these calculations can only be sustained if the biomass is at or above Bmsy. If the resource has fallen below Bmsy, the currently sustainable yield (Ycurrent) is necessarily smaller. A possible approximation would be based on the ratio of Bcurrent to Bmsy,

Ycurrent = Ysust*(Bcurrent/Bmsy) if Bcurrent<Bmsy

Implementation

This method is most useful for species with low natural mortality rates; stocks with low mortality rates tend to pose the most serious difficulties in rebuilding from an overfished condition. As natural mortality rate increases (M > 0.2), the windfall ratio becomes relatively small, and the depletion correction has little effect on the calculation.

The relationship between Fmsy and M may vary among taxonomic groups of fishes, and among geographic regions, and would be a good candidate for meta-analysis. Uncertainty in parameter values can be represented by probability distributions. A Monte Carlo sampling system such as WinBUGS can easily estimate the output probability distribution resulting from specified distributions of the inputs.

With minor modifications, this method could also be applied to marine mammal populations. Although estimation of sustainable yields is not a central issue for marine mammals nowadays, the method would be especially well suited to analysis of historical whaling data, for example.

References

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Gulland, J. 1970. Preface. In: J. Gulland (ed.) The fish resources of the oceans. FAO Fish. Tech. Pap. 97, p.1-4.

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