Northeast Fisheries Science Center Reference Document 10-06

Biological Reference Points for Spiny Dogfish

by PJ Rago and KA Sosebee

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Executive Summary

Biological reference points are a critical component for the stewardship of fishery resources. Appropriate target levels of biomass and harvest rates allow managers to set regulations consistent with maximum sustainable yield, or an appropriate proxy. The primary focus of this report is to revise the biomass reference points for spiny dogfish (*Squalus acanthias*), and to update the fishing mortality reference points using the most recent catch and survey information. Previous biomass reference points for spiny dogfish were based on a Ricker stock-recruitment model derived from Northeast Fishery Science Center trawl survey data. SSB_{max}, the biomass that results in the maximum projected recruitment, is the proxy for B_{MSY}. The revised biomass reference point incorporates additional information on the average size of the recruits as an important explanatory variable. A hierarchical AIC-based model building approach is used to identify the best model. Comparisons of maximum likelihood and robust nonlinear least squares regression models suggested that the robust estimator had the lowest AIC and highest precision for the estimate of SSB_{max}.

The revised target reference point, expressed in terms of average weight (kg) per tow of female spiny dogfish greater than 80 cm, is estimated as 30.343 kg/tow. Conversion of this metric to swept area biomass depends on the average swept area per tow, i.e., the trawl footprint. The nominal footprint of the R/V Albatross is 0.01 nm^2. Using this value, the swept area estimate of SSB_{max} is 189,553 mt. Using an alternative footprint more consistent with recent gear mensuration suggests that a footprint of 0.0119 nm^2 is more appropriate. The revised swept area biomass target (SSB_{max}) corresponding to this footprint is 159,288 mt. Applying the convention defined in the current control rule in the Spiny Dogfish Fishery Management Plan, the threshold biomass is one half of the target or 79,644 mt. It is important to note that conversion to swept area biomass is not necessary for determination of overfished or rebuilt status, as long as the survey and biomass reference points are expressed in the same units. Based on the revised biomass reference point and using the trawl footprint of 0.0119 nm^2, the US spiny dogfish resource was to be rebuilt in 2008 when the swept area female spawning stock biomass was 194,616 mt. Biomass in 2009 (163,256 mt) also exceeded the biomass reference point. Therefore, the stock is not overfished and it is rebuilt. Stochastic model estimates of female spawning stock biomass suggest a greater than 50% chance of exceeding the biomass target.

Conversion to swept area biomass is important for estimation of appropriate catch levels and the estimation of fishing mortality rates that can be compared with fishing mortality reference points. The updated fishing mortality reference point incorporates the most recent information on size composition of discards, landings and surveys. Collectively, these data update the estimated selectivity pattern of the fishery. The updated target and threshold fishing mortality rates are 0.207 and 0.325, respectively. Updated estimates of fishing mortality rates in 2008 were 0.110. Therefore the stock is not experiencing overfishing. Stochastic model estimates of fishing mortality rates suggest that the probability of exceeding either the target or threshold F is near zero.

Biomass and fishing mortality reference points are required for US management purposes. The US is currently working with Canada on a more comprehensive joint stock assessment that may lead to revisions in the biomass estimates and biological reference points. Canada does not have the same requirements for fishery resource management. At present, the utility of the revised reference points herein is restricted to management processes in the US only.

1.0 Background

This report summarizes analyses conducted after the Jan 25-29, 2010 meeting of the Transboundary Resource Assessment Committee (TRAC) for spiny dogfish. Despite major technical advances by both Canada and the US, the TRAC was unable to agree on a revised assessment model for spiny dogfish. The lack of an agreed-upon assessment meant that many of the Terms of Reference could not be met. In particular, a review of Biological Reference Points (BRP) could not be conducted. This posed a substantial problem for US management which requires biological reference points including an appropriate biomass reference point for a rebuilding program. BRPs are relevant for rebuilding purposes in the US management but are not relevant or binding for Canada. Current BRPs for the US fishery area have been controversial and no biomass target has been codified in the Mid Atlantic Fishery Management Council's (MAFMC) Spiny Dogfish Fishery Management Plan (FMP). Near the end of the meeting, some initial analyses of the current biomass reference points were conducted but there was insufficient time for the reviewers to consider them. This report follows up on and extends those earlier analyses. The TRAC agreed that the reviewers (Drs. Thomas Miller, Maurice Clarke, Robert Mohn, and Vincent Gallucci) would consider these updated analyses and provide comments. On April 9, 2010 the TRAC reconvened via an internet- based conference call to discuss the major findings of this report. Unabridged written comments from the reviewers on a draft April 6, 2010 report and the conference call meeting may be found in Appendix 2. Where possible, their comments have been incorporated into this report.

2.0 Current Biological Reference Points

In the current US management system, biological reference points for spiny dogfish are based on a life-history model to estimate appropriate fishing mortality rates, and a Ricker stock-recruitment model to estimate appropriate biomass targets. The assessment is based primarily on size- and sex-based swept area abundance indices derived from the NEFSC spring bottom trawl survey. A simple catch survey model (Rago and Sosebee, 2009) suggests that catchability is about 1.0 when the area swept per tow is based on the distance between the trawl wings. When the swept area is based on the area swept between the doors (twice as wide), the implied efficiency of the trawl is approximately 50%. The raw swept area indices (Table 1) provide useful measures of scale, but further experiments and/or a more formal analytical model are necessary to develop a more complete description of spiny dogfish dynamics. Nonetheless, the current assessment approach has proven to be useful for describing the important changes in the resource.

2.1 Effects of the 1989-2000 Fishery

The domestic directed fishery that commenced in 1989 removed more than 260,000 mt of landings and an estimated 163,000 mt via discards. Most of the landings occurred close to shore. Over 92% of the landings were females; female dogfish constituted about 76% of the estimated dead discards. The disproportionate removal of mature female dogfish led to a decline in indices of spawning stock biomass, reductions in average size of mature female spiny dogfish, and an increase in the sex ratio of mature male to female abundance. Recruitment indices between 1997 and 2003 were the lowest on record (Table 2). This stanza of low pup production resulted in a reduction of dogfish between 50 and 70 cm in subsequent years. Effects on population size structure are illustrated in Fig. 1 and 2.

Owing to their slow growth, longevity and sexual dimorphism, the changes in population structure induced by the fishery have long term implications for future harvesting. Those implications include a predicted oscillation in abundance as the maturation of the stanza of weak year classes reduces female SSB. The magnitude of future oscillations will vary depending on the intensity of the fishery (See Rago and Sosebee 2009, Fig 20, p. 362). As with year classes in any population, the influence of any single year class on stock dynamics is dampened as fishing mortality declines.

2.2 Reference Point for Fishing Mortality

The F_{msy} proxy for spiny dogfish is based on a length-based life history model that incorporates maturity, fecundity, expected number of female pups per female, a measure of population growth rate, and the contemporary selectivity pattern in the fishery. All of these attributes are expressed as functions of length. Details of the model are described in Rago et al. (1998) and Rago and Sosebee (2009, Appendix 2). This methodology underlying this biological reference point has been peer reviewed by the Stock Assessment Review Committee at SARCs 18 (NEFSC 1994), 26 (NEFSC 1998), 26 (NEFSC 2003) and most recently at SARC 43 (NEFSC 2006). The methodology for estimation of a biological reference point for fishing mortality was not updated as part of the present exercise. Therefore, the F_{msy} proxy is the rate of fishing mortality, given the prevailing selectivity pattern in the fishery, that ensures that the lifetime pup production of the average female will be sufficient for replacement.

The life history model for estimation of the F_{msy} proxy is strongly dependent on the selectivity pattern in the fishery. Beverton and Holt (1957) demonstrated long ago that when other factors are held constant, the force of mortality on a population declines as the size or age-at-entry into the fishery increases. The size selectivity of the current fishery was estimated using Millar's SELECT model by comparing the size frequencies in the survey and commercial catch (landings plus discards). The size selectivity estimates for males and females for the 2006-2008 fisheries are summarized in Appendix 1. This reflects an update from the last update at SARC 43 (NEFSC 2006).

The selectivity function for the 2008 fishery suggested an L50 of 90 cm and the estimated threshold F=0.325. This is similar to the estimate of 0.390 estimated in NEFSC (2006). In absolute terms these fishing mortality rates are high in comparison to the F provided for other elasmobranch studies. However, it must be remembered that the full force of mortality is applied to a relatively small fraction of the available size range owing to the shallow slope of the selectivity pattern (See Appendix 1). The target fishing mortality rate, that which allows 1.5 pups per recruit, is estimated as 0.207; the previous estimate of F_{target} in NEFSC 2006 was 0.284.

2.3 Scaling of Swept Area Estimates of Biomass

The primary objective of this exercise is a re-evaluation of the biomass reference point for spiny dogfish. One of the major sources of confusion in the current biomass estimates is the scaling to swept area biomass. This swept area biomass estimate depends on the size of the average survey footprint such that ***B=(A/a)(1/e)I*** where ***A*** is the area surveyed, ***a*** is the average swept per tow, ***e*** is the efficiency of the trawl, and ***I*** is the average weight per tow in kg. The nominal tow footprint of 0.01 nm^2 corresponds to a standard tow of 30 minutes at a speed of 3.5 knots. Fine-scale gear mensuration studies have subsequently revealed variation in the footprint associated with depth and the determination that average Albatross vessel speed was approximately 3.8 knots. Depending on the assumptions made about the variation in the haul back process with depth, the nominal footprint can range from 0.0112 to 0.0119 nm^2 per tow. Increases of 12 to 19% in the average survey footprint correspond to reductions in swept area biomass of 11 and 16% respectively. Hence a biomass reference point of 200,000 mt based on survey footprint of 0.01 nm^2 is equivalent to a biomass reference point of 168,067 mt using a footprint of 0.0119 nm^2. As a footnote, the Atlantic States Marine Fisheries Commission (ASMFC 2002) uses a biomass reference point of 167, 000 mt, representing a downward adjustment for the larger average survey footprint.

To reduce the potential confusion, all of the analyses of biomass reference points in this report are based on the original survey data, rather than the swept area adjusted values. Estimates of projected catch and F however, depend on the scaling factor. To facilitate comparisons with previously used biomass reference points, the results in Table 3 are re-expressed with the approximate scaling factors summarized below.

Summary of example expansion factors to compute swept area biomass estimates.

Survey Area (nm2)	Tow Speed (knots)	Tow Duration (minutes)	Distance between trawl wings (m)	Area Swept per tow (nm^2)	Expansion Factor from kg to mt
64207	3.50	30	10.7	0.010	6,350
64207	3.75	30	10.7	0.011	5,927
64207	3.75	33	10.7	0.012	5,388

As part of all assessments and annual updates conducted since 1998, the NEFSC has produced a summary of size- and sex- specific abundance indices from the spring bottom trawl survey. A standard nominal footprint of 0.01 nm^2 is used (Table 1).

3.0 Analyses of Stock-Recruitment Relationships

3.1 Background

A brief history of the biomass reference points provides a useful starting point for the analytical approaches used in this report. A Ricker stock recruitment function was first used for the US spiny dogfish assessment in 1999 at a joint meeting of the Science and Statistical Committees (SSCs) of the New England and Mid-Atlantic Fishery Management Councils. Recruits were defined as dogfish less than 36 cm TL; spawners were defined as females greater than 80 cm. The SSCs endorsed an exploratory analysis of the stock recruitment relationship and selected SSB_{max} equal to 200,000 mt as a biomass reference point proxy for B_{msy}. Owing to a variable rate of recruitment of juvenile spiny dogfish to the survey domain (juvenile are thought to be more pelagic than adults, and become more demersal with age), it was considered advisable to use the Ricker model primarily as a tool for estimating the stock size likely to produce maximum recruitment and, therefore, maximum potential yield. The original analyses were based on data from 1968 to 1996. SSB and recruitment estimates were smoothed in two-year stanzas as a way of reducing interannual variability and in part, to reflect the two-year gestation period for spiny dogfish. Comparisons with analyses that used the raw data (see Rago and Sosebee 2009, Table 5) suggested relatively minor effects of this approach on the estimated SSB_{max}. The basic analyses are recapitulated in Fig. 3 and summarized in Table 3 (Model 1). As a footnote, the SSBmax of 200,000 mt was not endorsed by the NEFMC; a lower alternative value proposed by NEFMC was not approved by NMFS.

At SARC 37 additional data through 2003 included 7 years of the lowest recruitments on record (See Table 2 for a complete summary of the data). The resulting estimate of SSB max increased from 200,000 mt to nearly 300,000 mt. The SARC review panel noted that this increase was an artifact of the low recruitment stanza and not a credible measure of stock productivity. Hence, the SARC could not recommend a new BRP; the stalemate was confirmed again at SARC 43 in 2006. That panel suggested that the BRP of 200,000 mt was not a useful target but that the threshold, (i.e., ½ the target) could be used for management. A $F_{rebuild}$ estimate was based on attaining a target value of 200,000 mt even though official reference point was in the federal plan. The Atlantic States Marine Fisheries Commission, however, did adopt a BRP corresponding to a rescaled estimate corresponding to 200,000 mt (i.e., the nominal footprint).

The use of a 2 yr moving average in previous analyses was noted earlier. Previous analyses also used imputed values of female SSB for 1968-1979. This was necessary at that time to account for the lack of sex information in the early years of the survey. The imputed estimate was based on the average sex ratio between 1980 and 1982. In view of the possible bias of this approach, we instead estimated SSB from actual survey data for 1968-1972, and dropped the imputed values for 1973-1979. A list of the original values, found in Table 5 of Rago and Sosebee (2009), can be compared with those summarized in Table 2 herein.

The retrospective effects of adding additional years of data can be seen in Fig. 3. Inclusion of data through 2003 increased the SSB_{max} by 37% (Fig. 3 middle). The updated estimate of SSB_{max} through 2009 (Fig. 3 bottom) was only about 23% greater than the original estimate from 1996, but it is clear that other sources of variation were influencing the lack of fit in the stock recruit relationship.

3.2 Incorporation of Covariates in the Ricker Model

The Ricker model assumes that the total female biomass is an adequate measure of spawning potential. Earlier results, described in NEFSC (2003), illustrated that the number and average size of pups per female decline with declines in maternal size. Declines in pup size in smaller females could provide a possible explanatory mechanism for the lower than expected pup production since 1997. Analyses of the residuals of a Ricker model, summarized in Rago and Sosebee (2009) revealed a cluster of negative residuals particularly when the spawning stock size was below 100,000 mt in the 1997–2003 period. Model residuals, plotted against mean maternal length (see Figure 21 bottom in Rago and Sosebee 2009), revealed a strong clustering when maternal size was below the 1968–2006 median of 87 cm. An odds ratio test suggested that the odds of having a negative residual were 4.5 times greater when the mean length of spawners was below 87 cm.

Three biological variables were considered as candidate explanatory variables in the Ricker model 1) average weight of mature females, 2) average weight of pups (<36 cm TL), and the 3) sex ratio of mature males to females. Each of these variables is related to general concepts of reproductive fitness, but they are correlated with each other (Fig. 4). An exploratory tree-based regression (Fig. 5) was used to gain further insights into the likely predictive utility of these variables. The regression tree model partitions the estimated log ratio of recruits per spawning stock biomass into groups using average weight of mature females, average weight of all pups and the mature male to mature female sex ratio as predictor variables. The model explained 35% of the variance in dependent variable. Highest average recruits per spawning stock biomass occurs when average weight of females exceeds 2.731 kg and average weight of pups exceeds 84 g.

A model based only on accumulated stock biomass may be inadequate to predict recruitment for a population currently: a) exhibiting a strongly truncated size distribution (Fig. 1 and 2); b) a reduced average size of mature females (Fig. 6); c) smaller-than-average size pups (Fig. 7); and d) a skewed sex ratio (Fig. 8). The implications of the current sex ratio, which is dominated by males, are more problematic since this is a long-term transient condition. It is not known if biological mechanisms alone are sufficient to shift the balance toward the sex ratio observed before 1992 (Fig. 8). Recent information in the literature (Sims et al. 2001, Daly-Engel et al. 2010) highlight potential negative effects of skewed sex ratios for elasmobranch reproduction.

To evaluate the utility of these candidate predictors , a reductionist model building approach was employed. The full model included all of the variables; the reduced models progressively tested all possible models (Table 3, Models 4-10, and Models 14-20). Two primary measure of model fit were employed. The first was a measure of AIC when maximum likelihood estimation was used. An approximation of AIC was used when robust estimation methods were employed (Burnham and Anderson 2002, p 63). The second primary measure of fit was associated the relative precision of the estimate of

SSB_{max}. Asymptotic standard errors of the SSB_{max} suggested wide confidence intervals when MLE methods were used. In many instances the confidence intervals included values less than zero and wide confidence intervals. The width of the confidence interval (High-Low) for the MLE based estimates were considered were considered unrealistic. (Table 3, Models 4-10)

As an alternative estimation method, a robust estimation method recommended by Chen et al. (2003) was employed. The robust method was based on a down weighting of residuals using a *t*-distribution with 30 degrees of freedom. The full and all reduced models were examined using this approach (Models 14-20). In addition, the effect of alternative degrees of freedom was examined over the range of 5 to 20 (Model 21-23).

3.3 Stock Recruitment Results

Comparison of the estimates based on MLE were not conclusive with respect to the "best" model. The best AIC was obtained when all three variables were included (Model 4) but the confidence interval width on SSB_{max} was more than 3-fold greater than the most precise estimate (Model 8). The lower bound of CI for SSB_{max} in the full model was less than zero. Model 7 included two factors and was next best in terms of AIC but less precise for SSB_{max}. Average pup weight was an improvement (lower AIC) over the average maternal weight, but the confidence interval was unacceptably wide.

Robust nonlinear regression methods gave much smaller confidence intervals and the minimum AIC model also had the narrowest confidence interval. Model 19 was selected as the "best" model for these reasons. A sensitivity analysis of the effect of varying the degrees of freedom for the t-distribution in the robust regression did not reveal any significant trend (Models 21-23).

An additional sensitivity analysis was conducted to evaluate the effects of measurement error in the regression estimate of SSB max (Table 4). Measurement error is particularly relevant for spiny dogfish because the input data for the analysis have not been filtered through a model. Moreover, variations in availability are likely to affect the number of recruits and SSB estimates similarly. To account for these effects, additional error was added to fitted estimates of R and the predictor variable SSB. This "errors-in-variables" like approach demonstrated that the estimate of SSB max increased consistently with additional measurement error. The percent bias increased for both correlated and uncorrelated error but was generally greater when correlation was equal to one. A similar trend of bias in parameter estimates was observed in Chen et al. (2003, especially their Fig. 6). Their work suggested that the bias was offset by robust regression methods.

The overall analyses of alternative models suggested that an appropriate measure of SSB_{max} was 30.343 kg/tow of mature female spiny dogfish. This model includes the average weight of pups as a covariate. This corresponds to a nominal swept area biomass estimate (0.01 nm^2 footprint) of 189,553 mt; and an estimate of 159,288 mt when using the 0.0119 footprint.

The overall model fit is summarized in Fig. 9 for varying levels of average pup weight. Model residuals suggest a reasonable degree of fit (Fig. 10) with no residual patterns. In other words, the inclusion of average pup weight seems to explain much of the variation. The exploratory tree-based regression (Fig. 5) suggested that exploration of a slightly more complex SR model that accounted for interactive effects might be useful for future research. Further exploration of the stock recruitment relation was conducted using lowess smoothing (Fig. 11). Results confirm that a simple Ricker model is insufficient to capture the changes in recruitment that occurred between 1997 and 2003. The smoothing algorithm supports the hypothesis that factors other than spawning stock biomass alone were responsible for the low recruitment. Interestingly, comparisons with the analytical model estimate of SSB_{max} and the lowess smooth are remarkably close (Fig. 11)

Model 19 (Table 3) can be expressed as a three dimensional surface wherein recruitment is a function of both female spawning stock size and average pup weight. An examination of this response surface (Fig. 12) reveals the improvements in prediction by the inclusion of average pup weight. The solid contour lines (ranging from 3 to 15 pups per tow) represent predicted recruitment as a function of spawning stock biomass and average pup weight. The dotted lines represent intermediate steps of 0.5 pups/tow. The "conventional" stock recruit relationship for any fixed value of average pup size can be obtained as the height of the contour line as SSB increases. Each observation is labeled with the recruitment year. The size of the circle is proportional to the magnitude of the standardized residual; solid circles are positive residuals and open circles are negative residuals. The overall goodness-of-fit appears appropriate but the 1985 (standardized residual >4) appears to have a strong influence. The improvements in AIC from the robust regression over the MLE may be associated its down weighting of this observation.

The utility of average pup weight is evinced in Fig. 7 where weight greater than 70 grams resulted in consistent increases in recruits per spawner. A plot of the slope of the SR curve at the regression (Fig. 13) suggests a sharp drop in slope with the onset of the directed fishery, but some suggestion in recent years that productivity may be improving.

4.0 Comparisons with Current Biomass with Revised Biomass Reference Points

Biological sampling of commercial landings and at-sea observer coverage have both improved in recent years. A summary of the biological samples and derived estimates of landings and discards by sex are given in Tables 5 and 6 respectively. Spiny dogfish are hardy fish and experimental evidence suggests that many survive capture. Estimated survival rates by gear type were applied to discards summarized in Table 6. Updated estimates of discards, landing and selectivity parameters were incorporated into a model to approximate the sampling distributions of swept area biomass and fishing mortality rates.

Stochastic estimates of fishing mortality (Table 7) incorporate measurement error in stock size and total catch by incorporating sampling variability of the trawl survey, variations in the footprint of the trawl, and uncertainty in the discard estimates for commercial fisheries and the landings and discards in the recreational fishery. The resulting variations in the fishing mortality rates are depicted in 2008 (Fig. 14). Box plots of the entire sampling series are shown in Fig. 15. The high rate of fishing mortality in 2004 (Fig. 15) is due primarily to a change in selectivity. It should be remembered that the F_{msy} proxy reference point also fluctuates annually in response to changes in selectivity. This is not necessarily a desirable feature of reference point estimation and comparisons of stock status. Future work will examine the multi-year selectivity patterns. The current modeling framework behaves similarly to a dynamic model with a random walk component for selectivity.

Estimated exploitable biomass by sex (Table 8) varies annually. In part this is due to changes in size composition due to growth and recruitment, and interannual variability in catchability. Additional variability arises due to changes in selectivity of the fishery. A composite selectivity function is estimated across fleets. Landings and discard size frequencies are pooled so that the mixture of discard and landings by fleet can induce large swings in the magnitude of exploitable biomass. Female spawning stock biomass has varied over about a 4 fold range since 1991 reaching a low in 2005. Since then biomass estimates have increased steadily (Fig. 16).

Comparisons of the newly defined biomass reference point with recent spawning stock biomass estimates (Fig. 16, 17, and 18) suggest that spiny dogfish exceeded the target biomass in 2008. The biomass estimate for 2008 is based on survey estimates for 2006-2008. There was about an 80% chance (Fig. 17) that the female spawning stock biomass exceeded the target of 30.343 kg per tow or equivalently, 159,288 mt based on the 0.0119 nm^2 footprint (Table 3). Estimated spawning stock biomass again exceeded the threshold in 2009 (i.e., 2007-2009 survey years) (Fig. 18). Comparison of the 1991 to 2009 time series of biomass estimates (Fig. 16) revealed that female biomass fell below the target level in 1995 and remained below the threshold level from 1999 to 2005. Since then the stock has climbed steadily owing to growth of immature female dogfish into the 80 cm+ size range, survival and growth of the extant mature individuals, and a change in availability. Previous projections of stock biomass (SARC 37, Fig. 10) suggested that the population would increase to median biomass levels of about 130, 000 mt by about 2007 if status quo fishing persisted. Estimates made in 2006 at SARC 43 suggested that the median population biomass should exceed 175,000 mt by 2009 (See Fig. 20 in Rago and Sosebee). Hence, the current status is consistent with model forecasts made 7 and 5 years ago.

Based on the revised biomass reference point and using the trawl footprint of 0.0119 nm^2, the US spiny dogfish resource was rebuilt in 2008, when the swept area female spawning stock biomass was 194,616 mt. Biomass in 2009 (163,256 mt) also exceeded the biomass reference point. Therefore, the stock is not overfished and it is rebuilt. Stochastic model estimates of female spawning stock biomass suggest a greater than 50% chance of exceeding the biomass target.

The updated target and threshold fishing mortality rates are 0.207 and 0.325, respectively. Updated estimates of fishing mortality rates in 2008 were 0.11. Therefore, the stock is not experiencing overfishing. Stochastic model estimates of fishing mortality rates suggest that the probability of exceeding either the target or threshold F is near zero.

5.0 Reviewer Comments

The unabridged comments of the reviewers on the initial draft of this are summarized in Appendix 2. All of the comments were constructive and many provide guidance of future areas of research. Their comments have been incorporated into this report to the extent possible. Three of the four reviewers considered the Ricker model with covariates as a useful way forward. Additional analyses, especially Fig. 11 and 12 were designed to address some of the concerns raised by the fourth reviewer. All of the reviewers suggested addition research on other factors that may have been responsible for the complex patterns of recruitment in the past 15 years.

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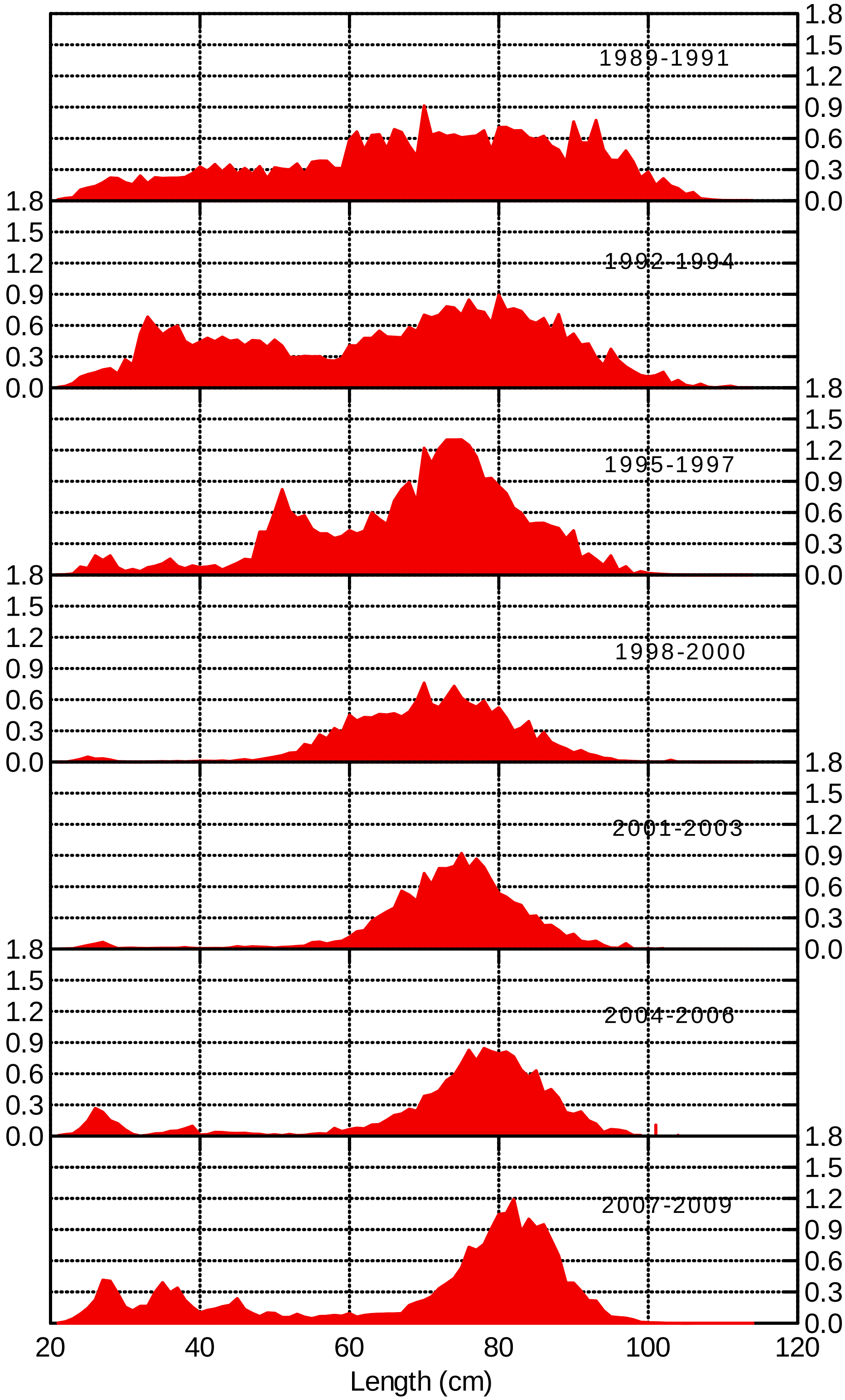


Fig. 1. Average number of female spiny dogfish per tow by 1 cm length class in NEFSC Spring Bottom Trawl Survey by 3-yr period, 1989-2009.

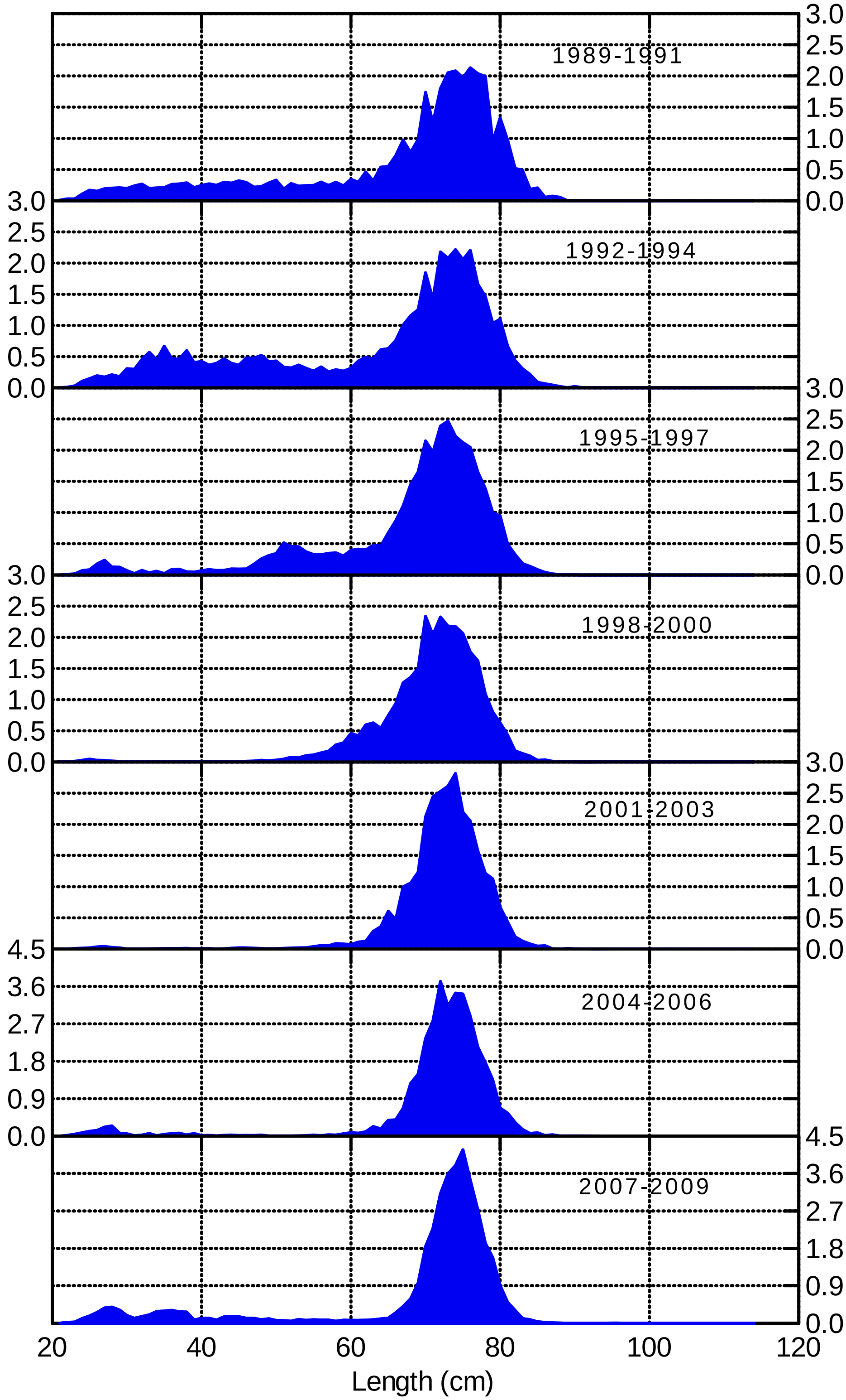


Fig. 2. Average number of male spiny dogfish per tow by 1 cm length class in NEFSC Spring Bottom Trawl Survey by 3-yr period, 1989-2009. Note the scale change for 2004-06 and 2007-2009.

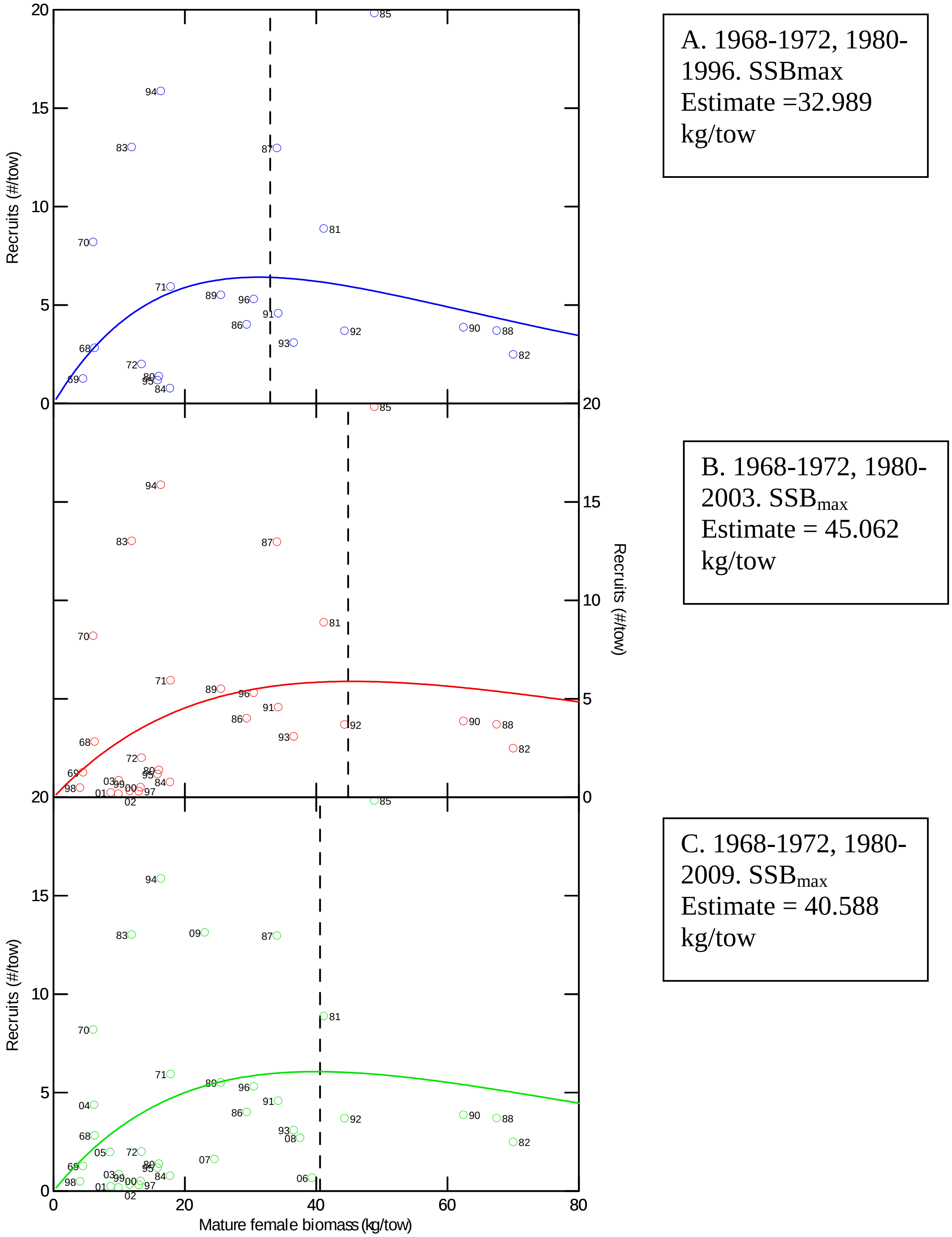


Figure 3. Summary of stock-recruitment relationships for spiny dogfish based on a Ricker stock-recruitment model for three periods. Year labels on data points refer to survey year for both mature females(weight of females > 80cm) and recruits (Number of dogfish < 36 cm). See Table 3 for additional details.

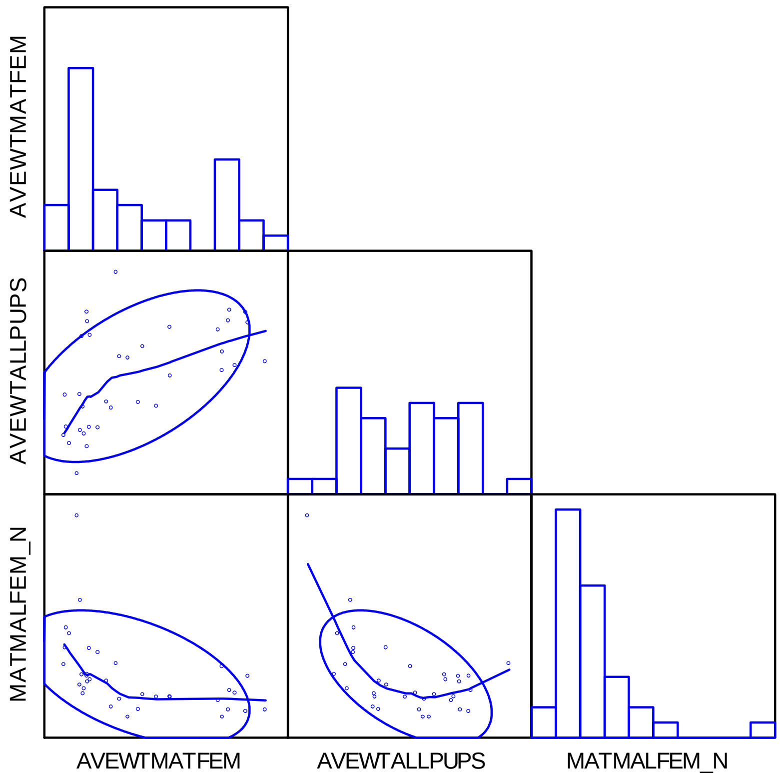
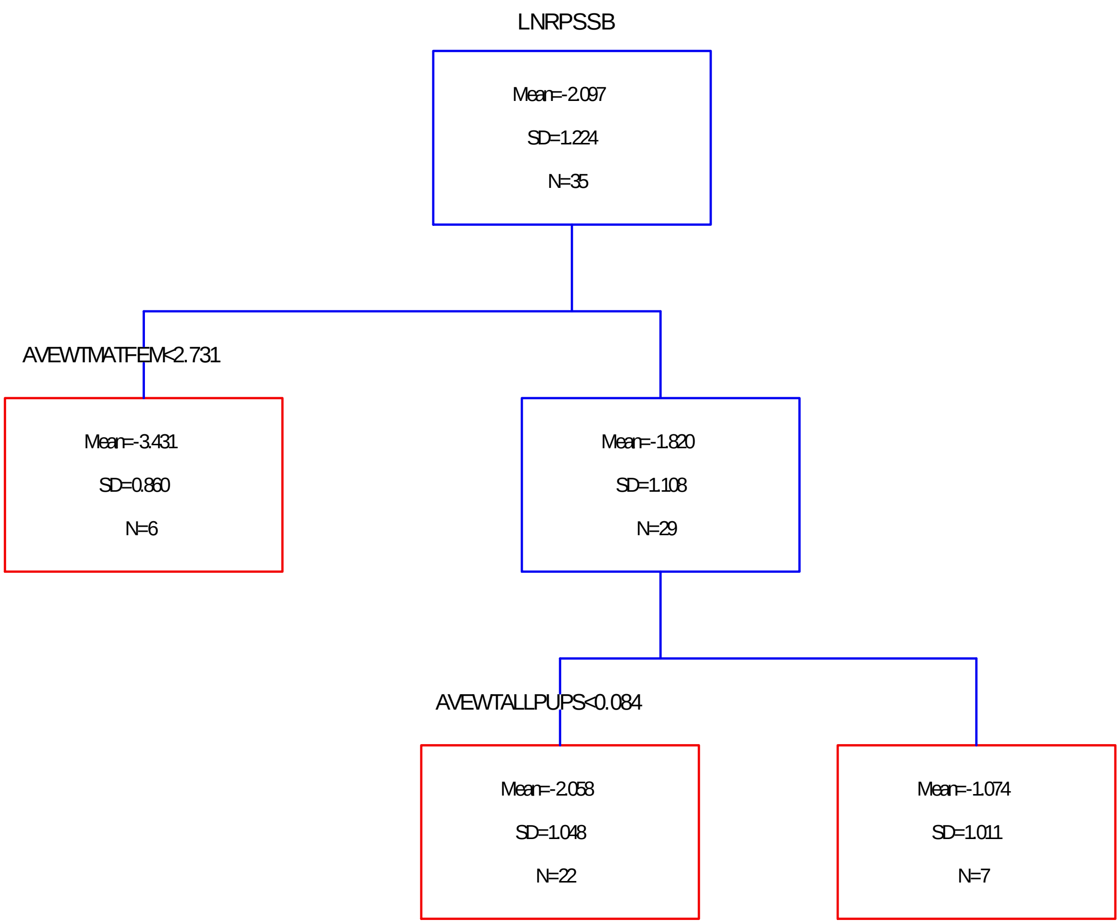


Fig 4. Scatterplot matrix of relationships between average weight of mature females (AVEWMATFEM), average weight of pups (AVEWTALLPUPS) and ratio of mature males to mature female spiny dogfish (MATMALFEM_N) in the NEFSC spring bottom trawl survey. Lowess smoothes are based on a span (tension) = 0.5.

Figure 5. Exploratory regression tree model of stock recruitment that partitions the estimated log ratio of recruits per spawning stock biomass using average weight of mature females, average weight of all pups and the mature male to mature female sex ratio as predictor variables. The model explained 35% of the variance in dependent variable. Highest average recruits per spawning stock biomass occurs when average weight of females exceeds 2.731 kg and average weight of pups exceeds 84 g.



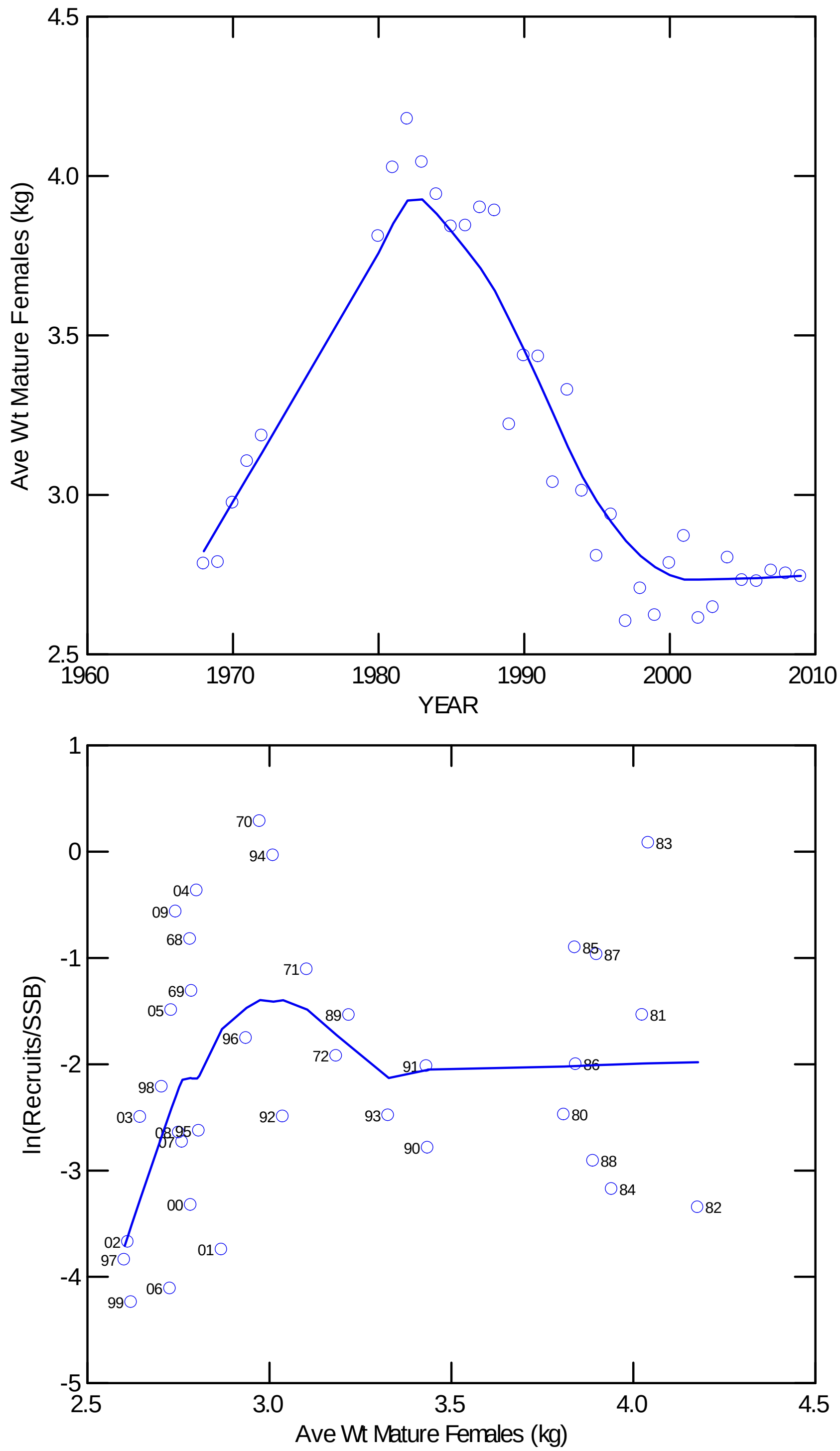


Figure 6. Changes in the average weight (kg) of mature female spiny dogfish (≥80 cm) for the period 1968-1972, 1980-2009 (top) and the relationship between average weight and the log of number of recruits per spawner (#/tow) / (kg/tow) for the NEFSC spring bottom trawl survey. Lowess smoothes are based on a span (tension) = 0.5.

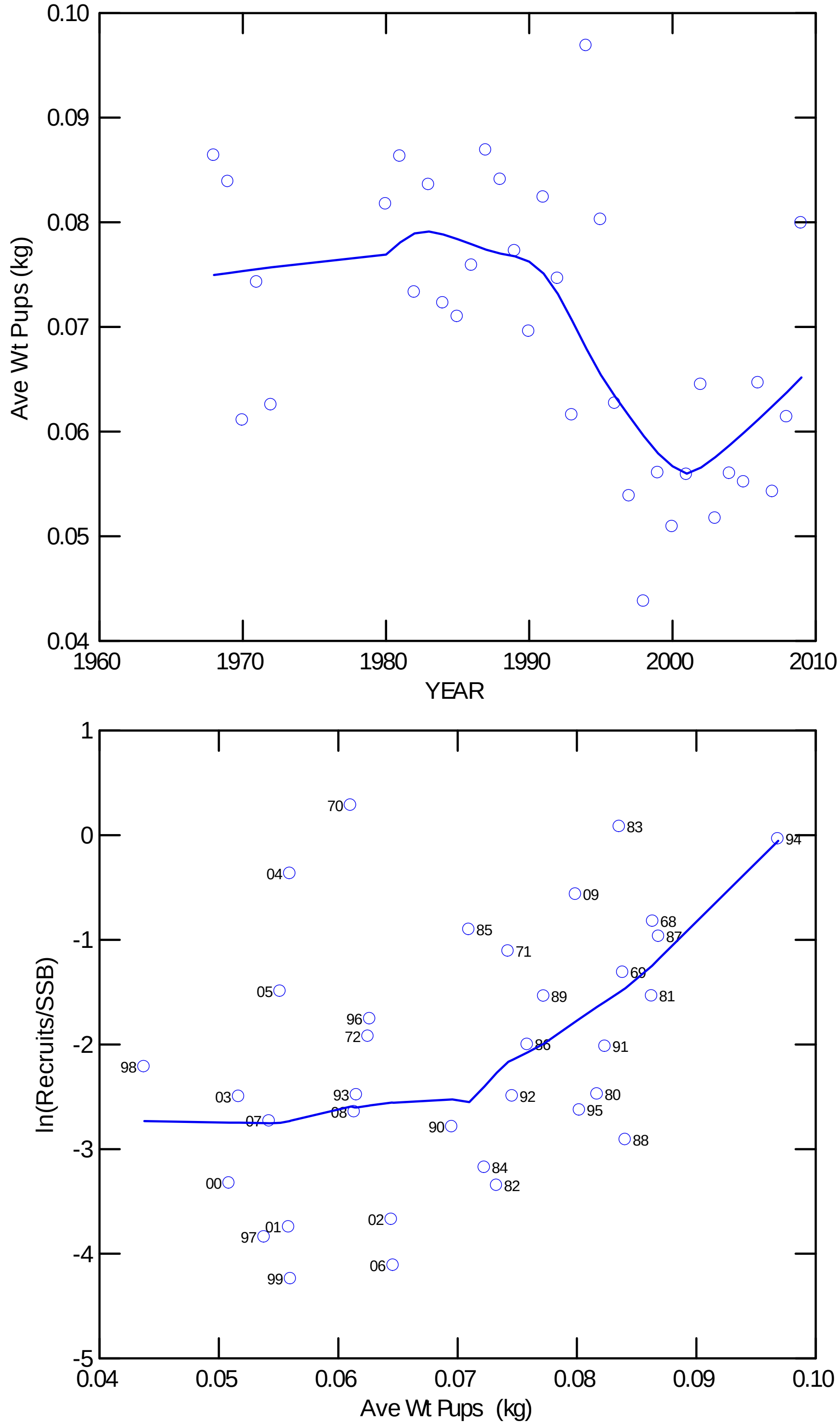


Figure 7. Changes in the average weight (kg) of juvenile spiny dogfish (≥36 cm) for the period 1968-1972, 1980-2009 (top) and the relationship between average weight and the log of number of recruits per spawner (#/tow) / (kg/tow) for the NEFSC spring bottom trawl survey. Lowess smoothes are based on a span (tension) = 0.5.

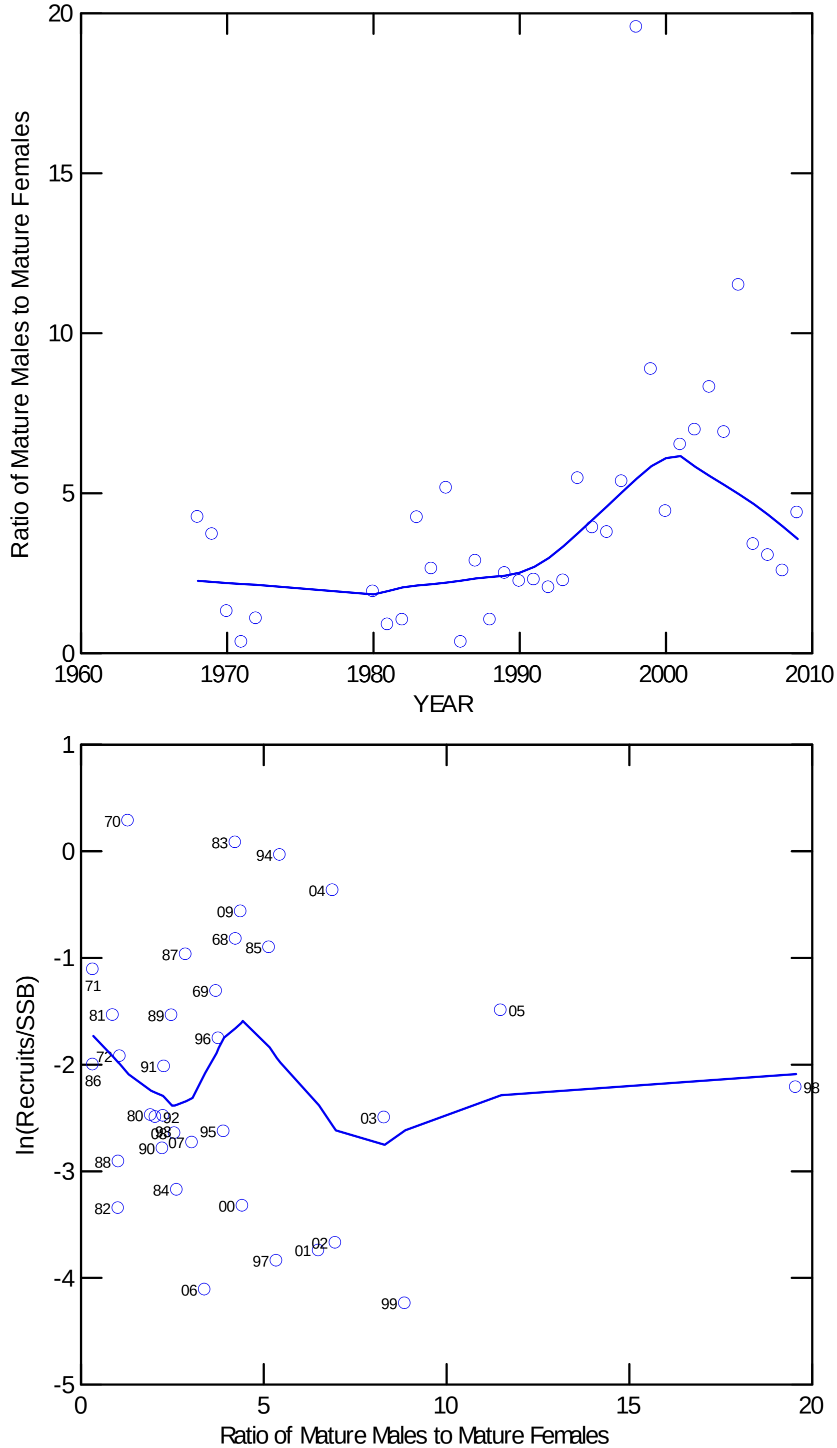


Figure 8. Changes in the ratio of numbers of mature male (≥60 cm) to mature female (≥80 cm) for the period 1968-1972, 1980-2009 (top) and the relationship between sex ratio and the log of number of recruits per spawner (#/tow) / (kg/tow) for the NEFSC spring bottom trawl survey. Lowess smoothes are based on a span (tension) = 0.5.

Predicted R vs SSB for 10th (red), 90th (greeen) %ile and maximum (black) ave pup wt

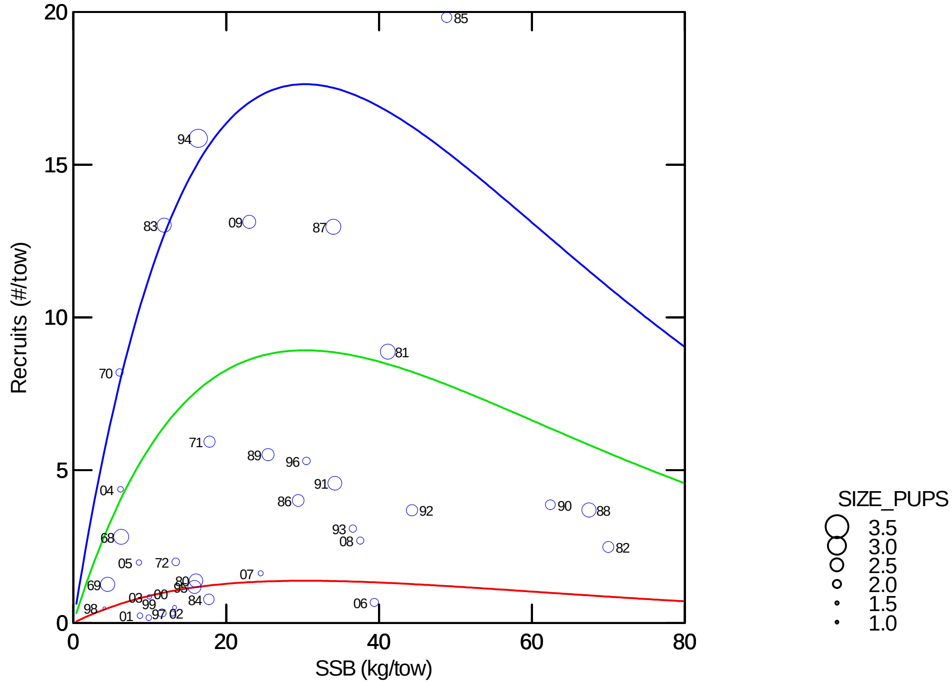


Figure 9. Summary of Ricker stock recruitment relationship fits for Model 19, Table 3 where R=0.005 SSB exp(-0.033 SSB + 59.437 Ave Pup Wt). Symbol size is proportional to average weight of pups. Lowest S-R curve corresponds to predicted recruitment at 10%ile of average pup weight or 0.054 kg. Middle line corresponds to predicted recruitment at 90%ile of pup weight = 0.085 kg. Top line depicts predicted recruitment at the maximum observed pup weight of 0.097 kg (1994).

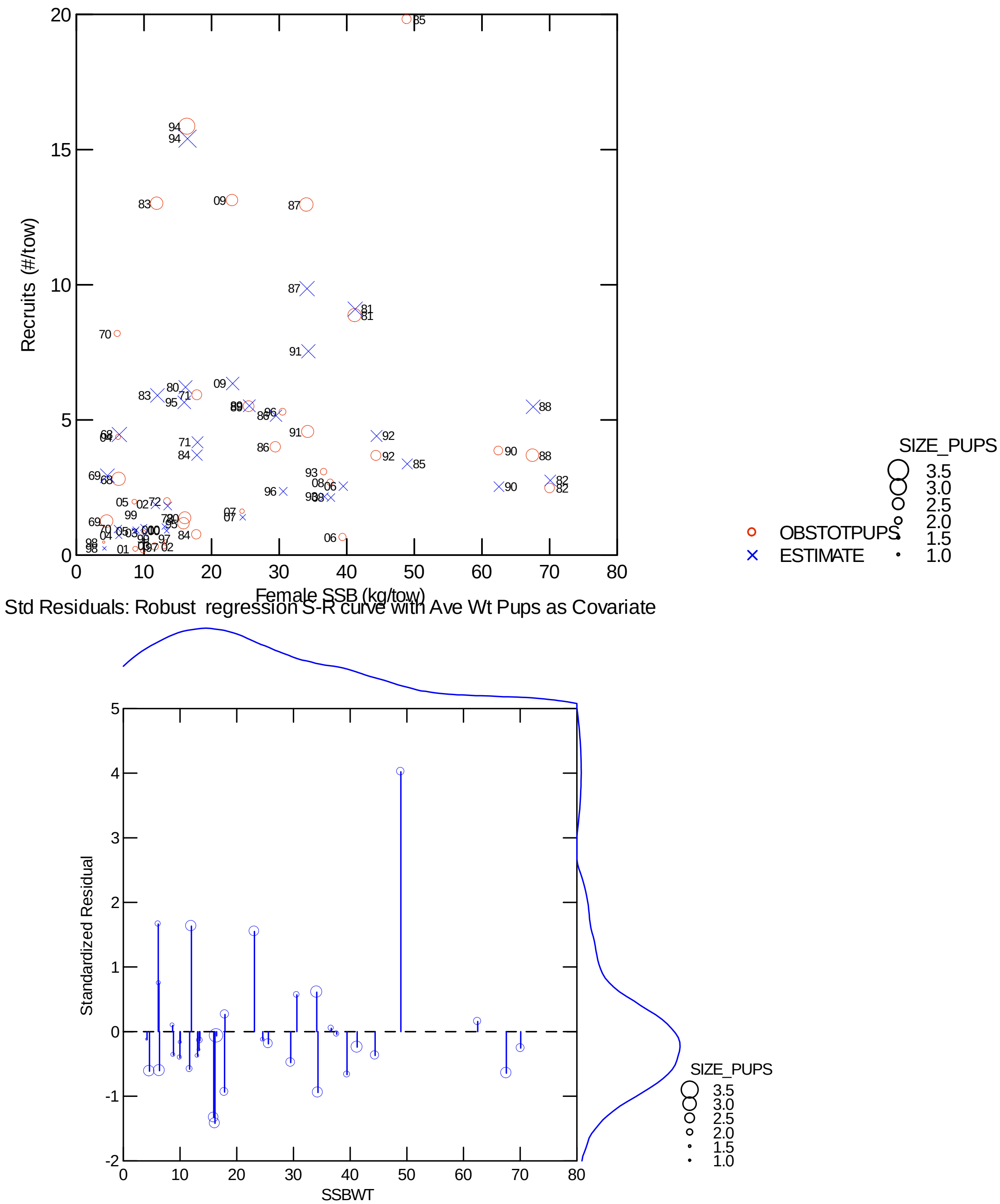


Figure 10. Comparison of observed (circle) vs predicted (X) recruitments by year (top) for Model 19 (Table 3) and standardized residuals vs SSB weight (bottom). Symbol size is proportional to average weight of pups. Nonparametric kernel of the residuals suggest a slightly skewed normal distribution.

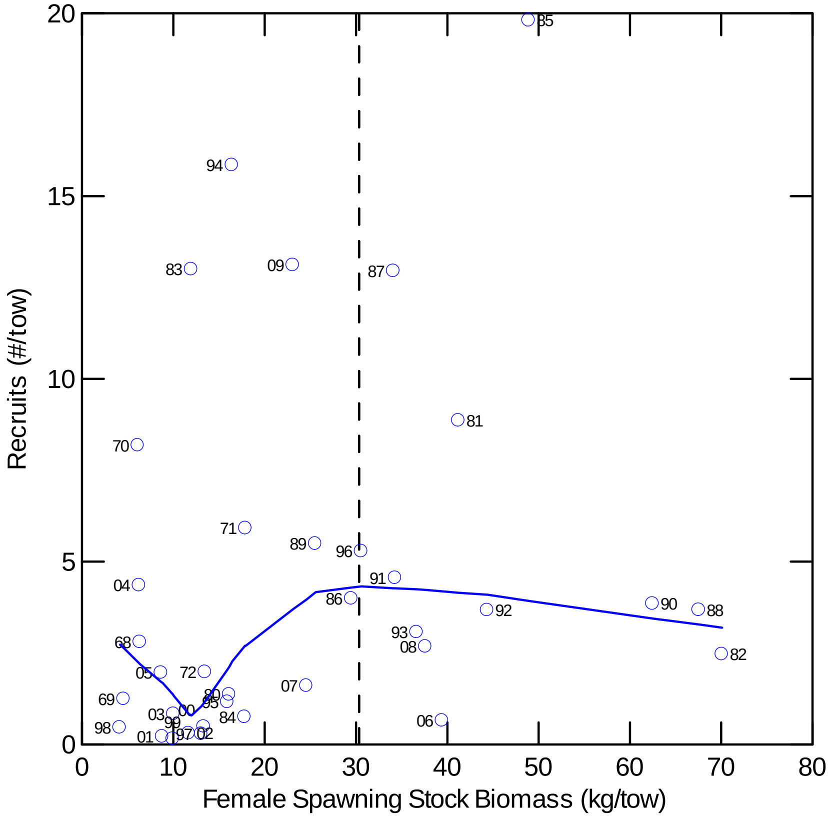


Figure 11. Comparison of lowess smooth of stock recruitment data with the derived estimate of female spawning stock biomass from model 19, Table 3. Vertical dashed line is estimate of SSB_{max} =30.3 kg/tow. Lowess smooth is based on a span (tension) = 0.5.

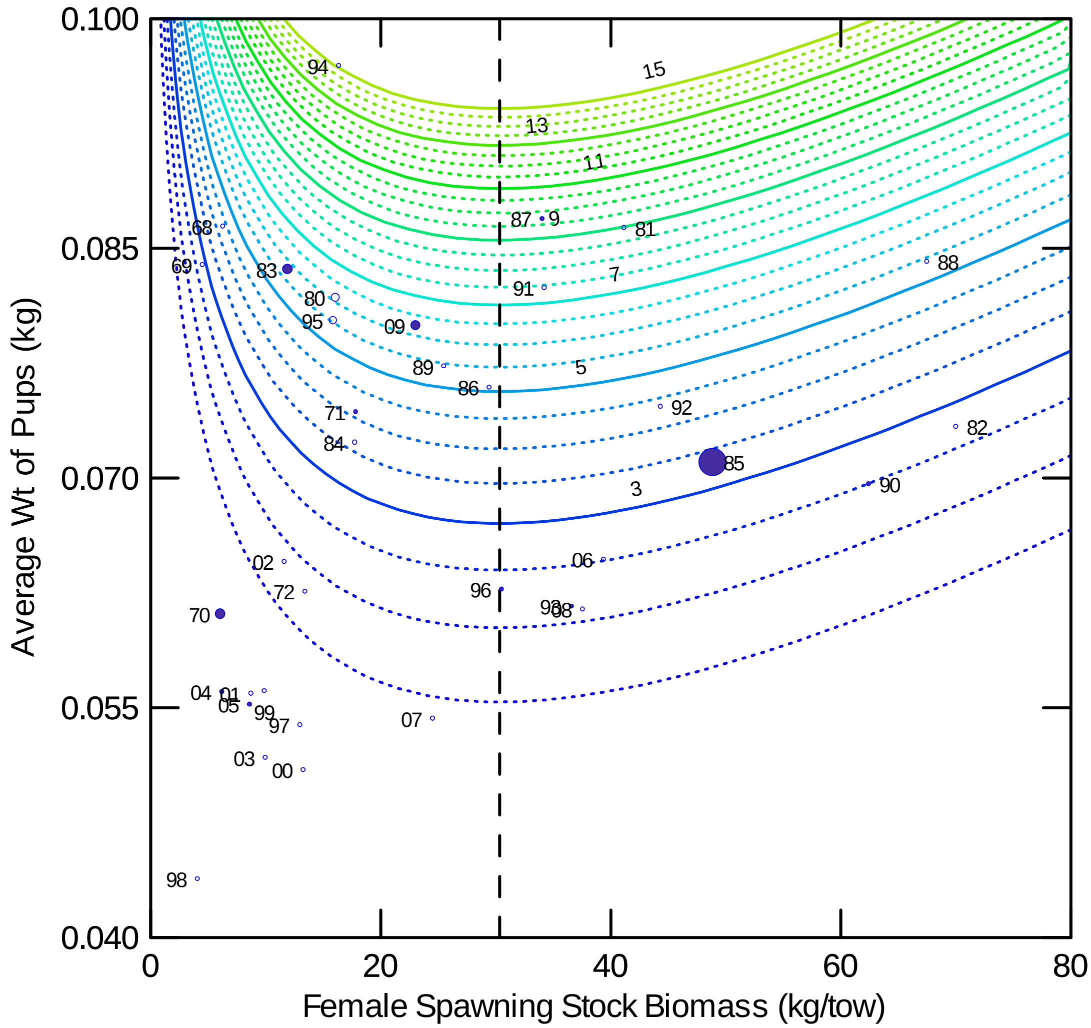


Figure 12. Alternative depiction of stock recruitment relationship for spiny dogfish (Model 19, Table 3). Dashed vertical align represents estimate of SSB_{max}. Curved contour lines represent predicted recruitment. Each data point is labeled by year with the size of the dot proportional to the standardized residual of the model fit. Open circles are negative residuals; filled circles are positive residuals. Note the small residuals when female SSB is less than 25 kg/tow and average pup weight is less than 0.06 kg.

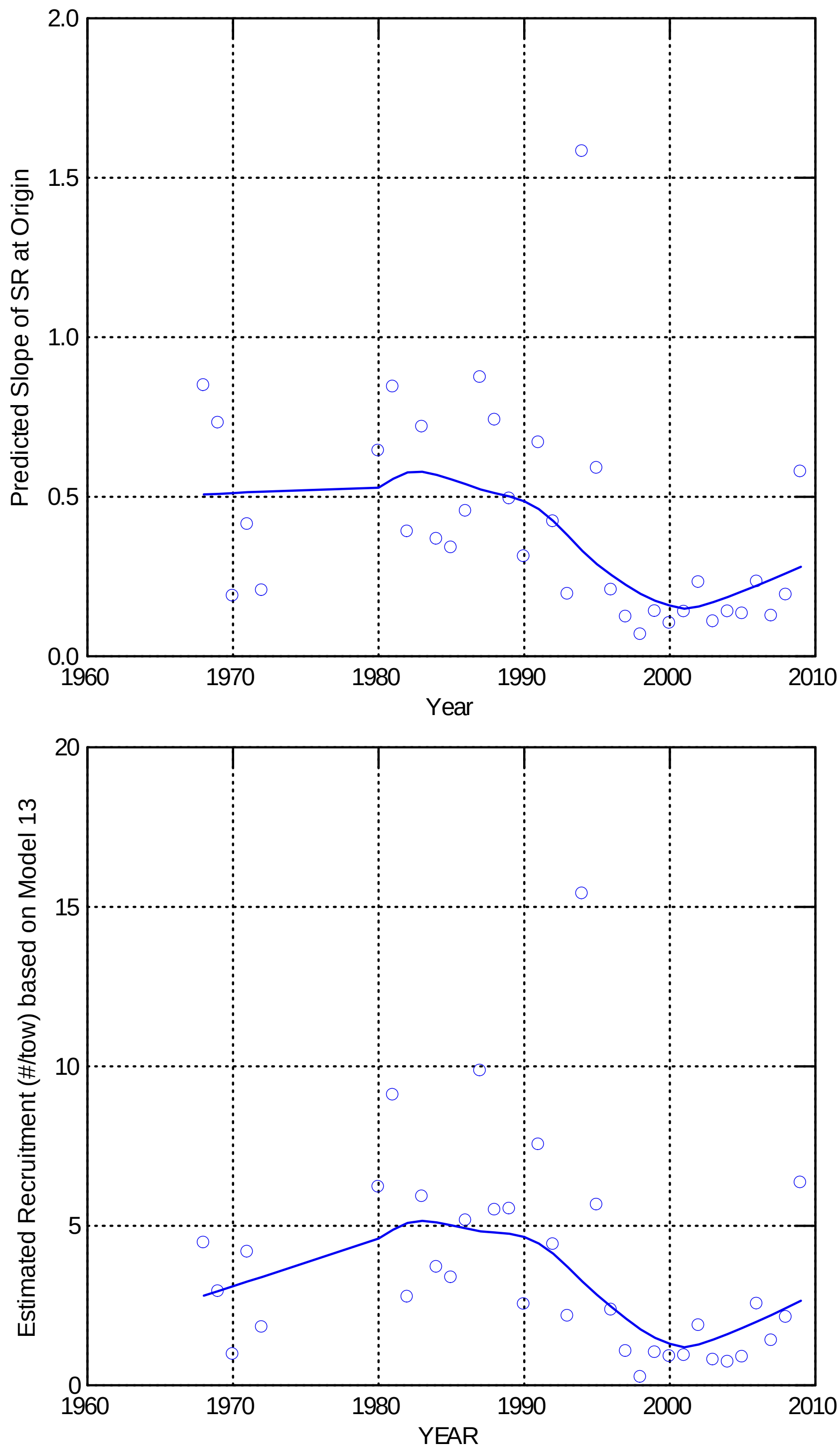
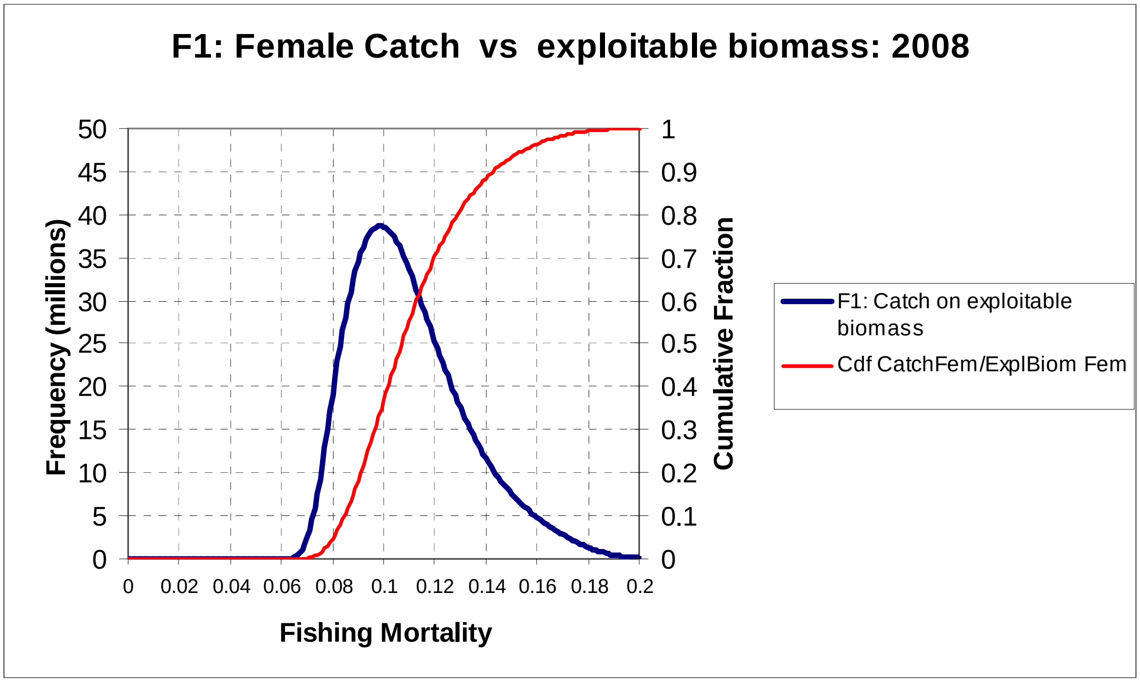


Figure 13. Year specific predictions of slope at the origin and predicted numbers of pups. This is based on estimated model alpha adjusted for average weight of pups in each year. See Model 19 in Table 3. The slope at the origin is equal to 0.005 * exp(59.437 * Ave Pup Wt in year t). Lowess smoothes are based on a span (tension) = 0.5.



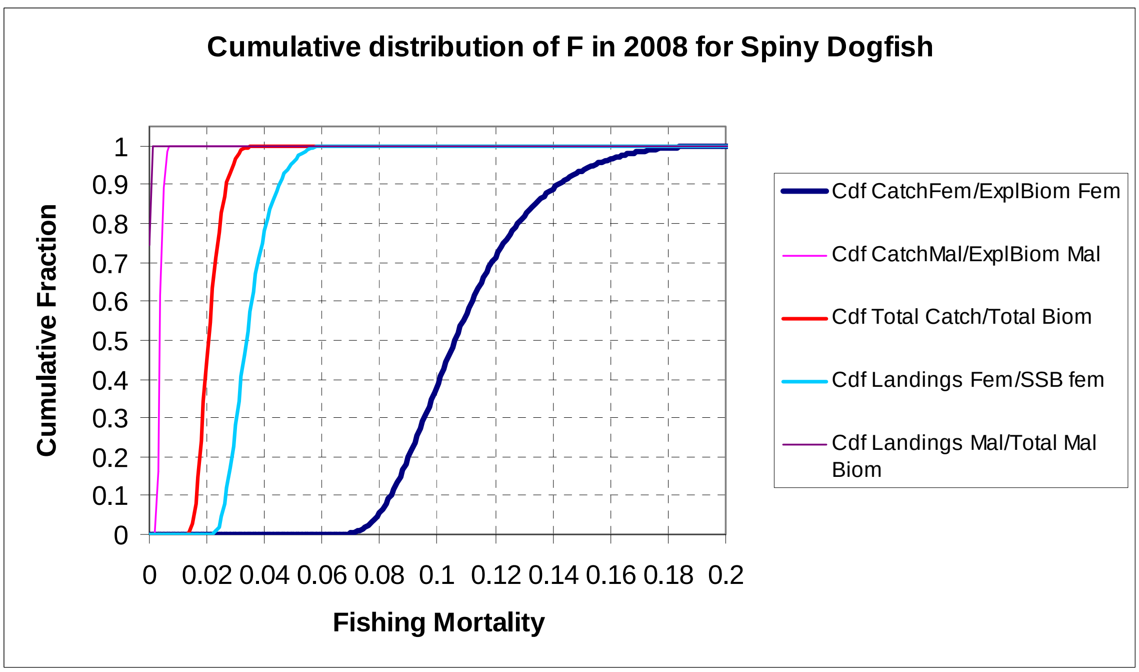


Figure 14. Estimated sampling distributions of stochastic estimates of fishing mortality rates on spiny dogfish based on catches (landing plus dead discards) in calendar year 2008.

Stochastic Estimate of F on exploitable Female Biomass

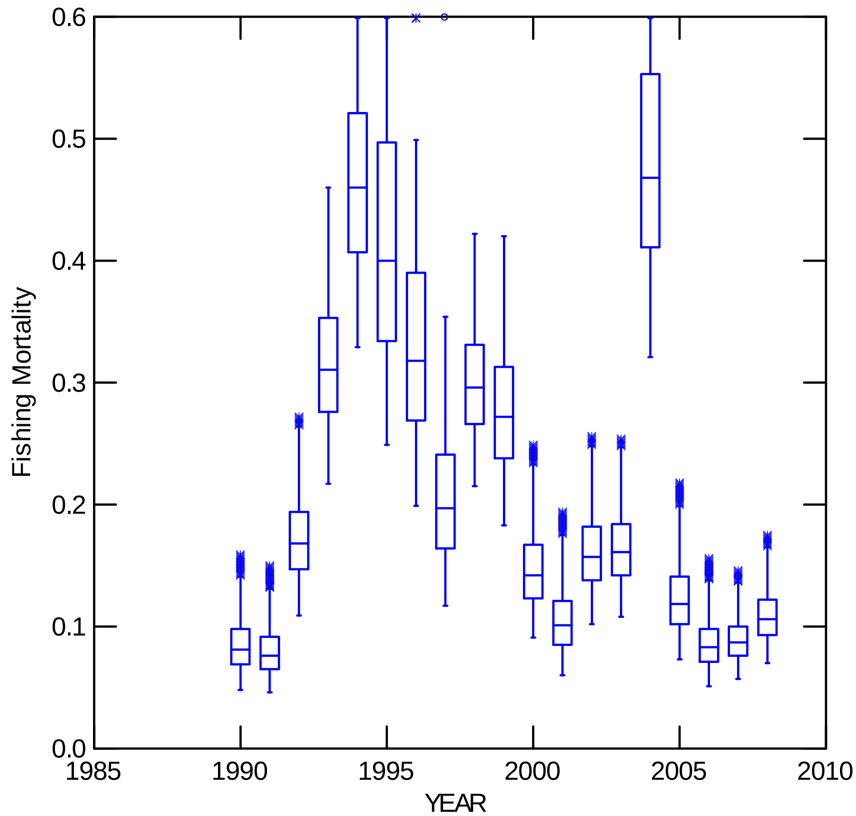


Figure 15. Box plots of estimated fishing mortality rates on exploitable female biomass (mt) based on stochastic estimation model. Center line of box represents median; upper and lower bounds represent interquartile range. Year on X-axis identifies the calendar year of the catch. Dashed lines represent the target and threshold fishing mortality rates associated with the selectivity pattern estimated in 2008.

Stochastic Estimate of Female Spawning Stock Biomass

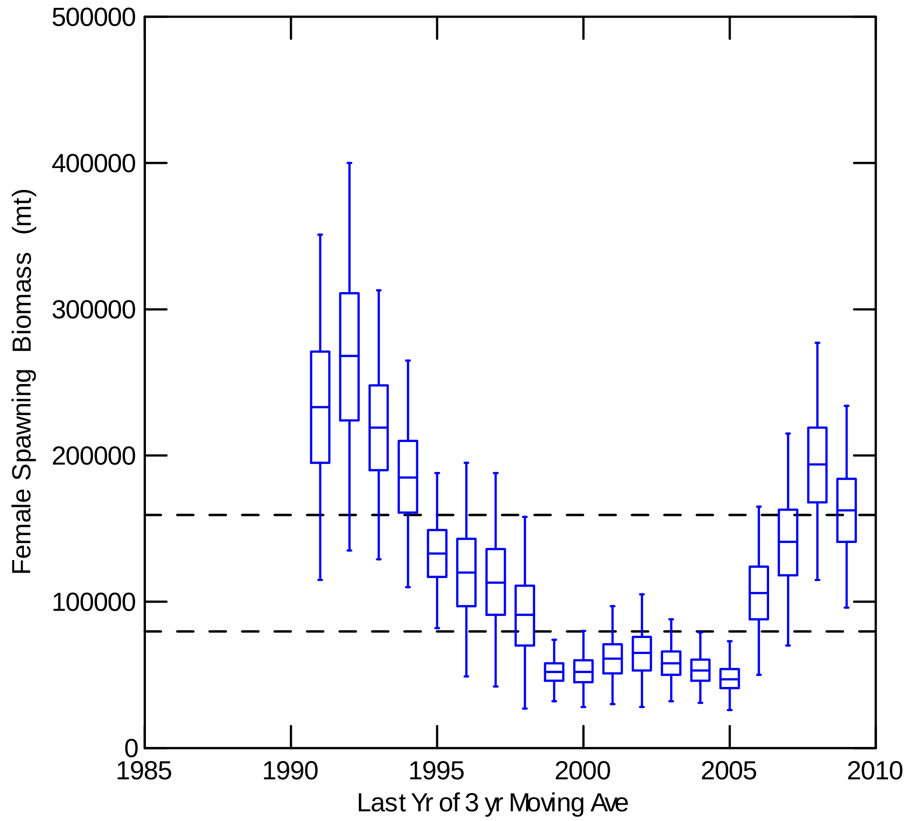


Figure 16. Box plots of estimated female spawning stock biomass (mt) based on stochastic estimation model (mt). Horizontal dashed lines represent female SSB target of 159,288 mt and threshold of 79,644 mt based on Ricker Stock-Recruitment model (Model 19, Table 3). Center line of box represents median; upper and lower bounds represent interquartile range. Year on X-axis identifies the last year of a 3-year moving average, e.g., 2009 is last year of 2007-2009. Threshold biomass target is assumed to be ½ target biomass.

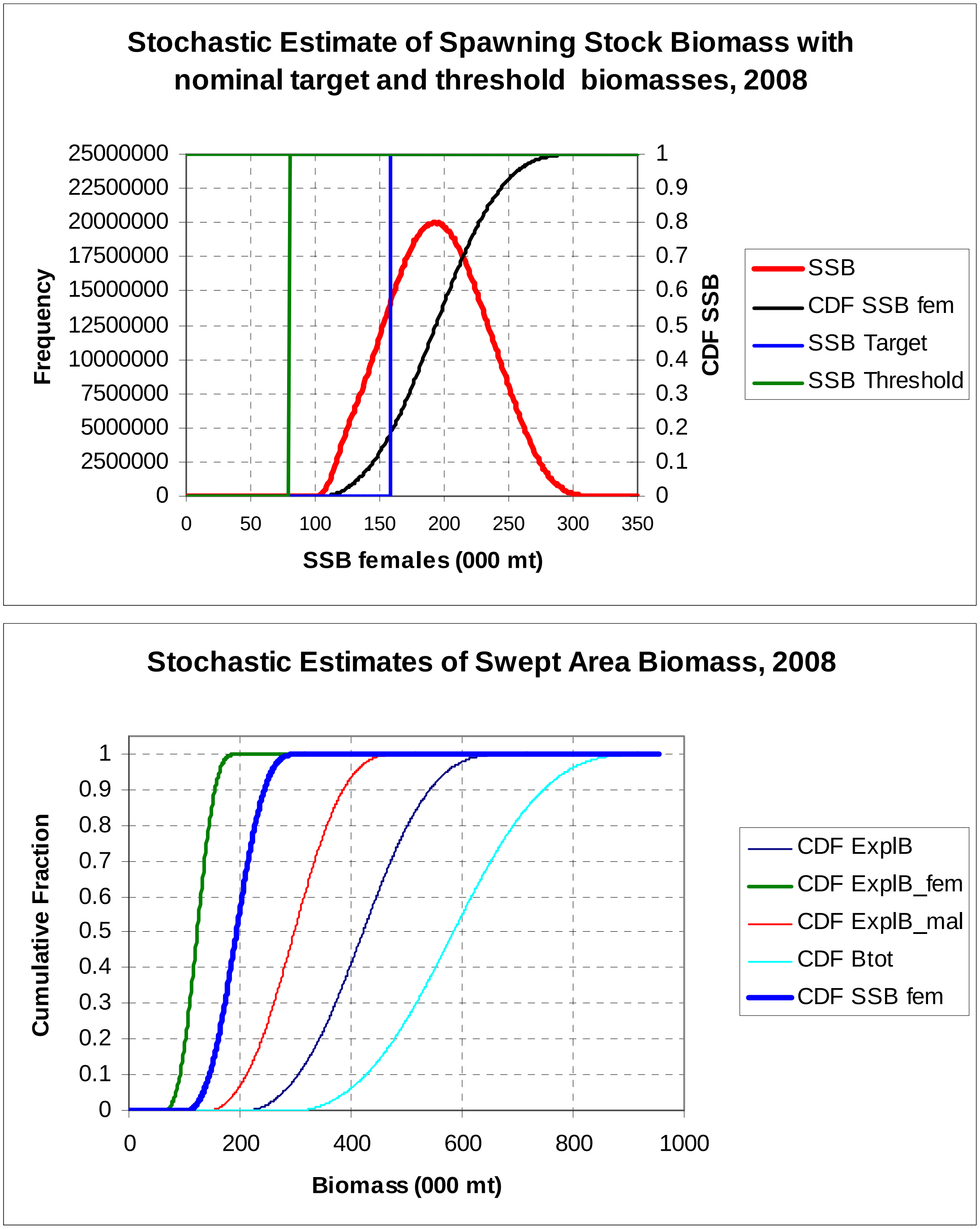
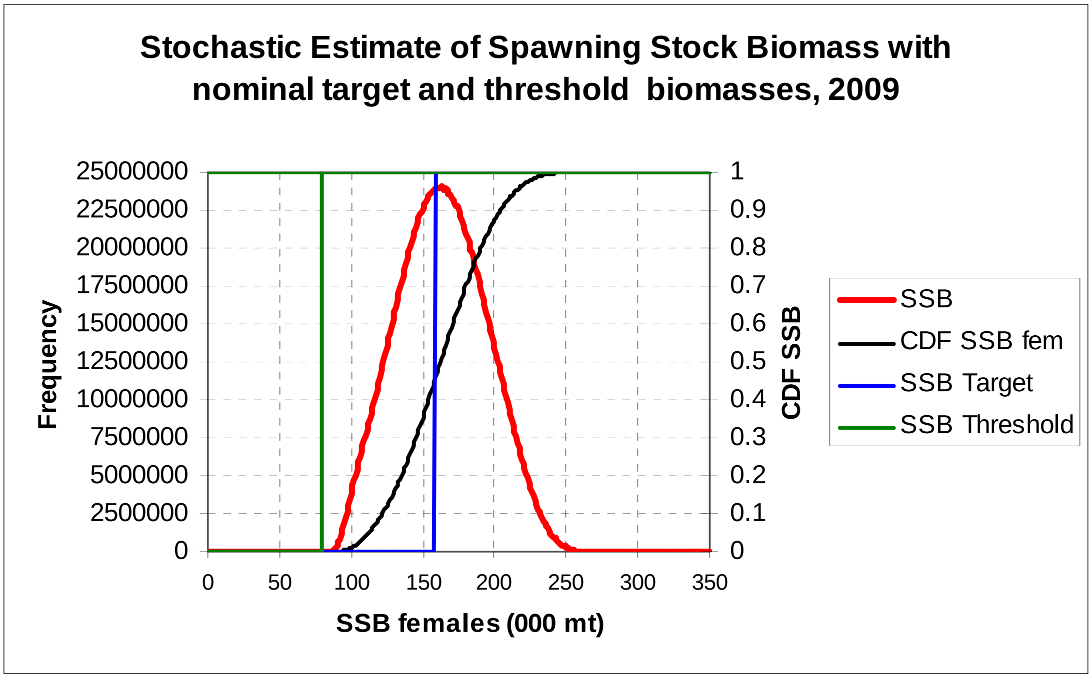


Figure 17. Sampling distribution of female spawning stock biomass (top) and cumulative distribution functions for exploitable male and female spiny dogfish for the 2006-2008 survey period. Female SSB target is defined by Model 19, Table 3 based on a survey footprint of 0.0119 nm^2. Using this biomass reference point, the stock would be considered rebuilt in 2008.



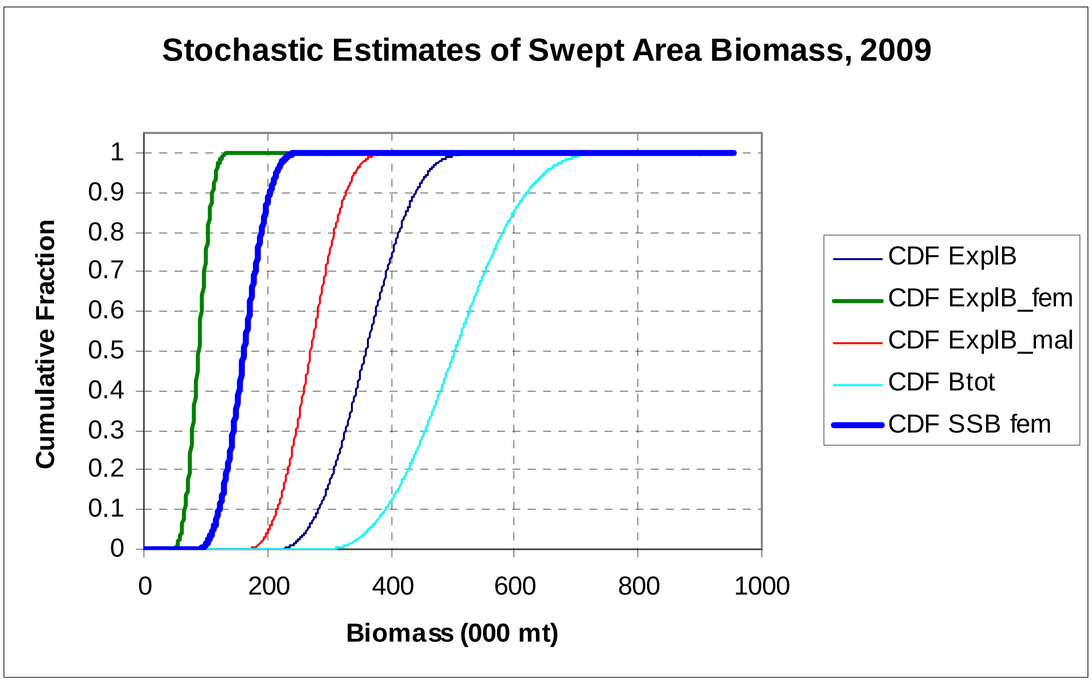


Figure 18. Sampling distribution of female spawning stock biomass (top) and cumulative distribution functions for exploitable male and female spiny dogfish for the 2007-2009 survey period. Female SSB target is defined by Model 19, Table 3 based on a survey footprint of 0.0119 nm^2. Using this biomass reference point, the stock would be considered rebuilt in 2009, i.e. greater than 50% chance of exceeding the biomass reference point.

Table 1. Biomass estimates for spiny dogfish (thousands of metric tons) based on area swept by NEFSC trawl surveys, 1968-2009 . Estimates for 1968-2008 are based on nominal survey trawl footprint of 0.01 nm^2 for the R/V Albatross. Estimates for 2009 are based on FSV Bigelow survey adjusted to an R/V Albatross equivalent by the calibration coefficient of 1.1468. A simple 3-yr moving average is used to estimate female SSB.

Year	Lengths >= 80 cm			Lengths 36 to 79 cm			Length <= 35 cm			All Lengths	3-pt average Fem SSB
	Females	Males	Total	Females	Males	Total	Females	Males	Total		
1968			41.4			110.4			1.52	153.3	
1969			27.4			69.3			0.66	97.3	
1970			36.7			33.0			3.19	72.9	
1971			103.8			27.6			2.76	134.2	
1972			126.6			145.9			1.55	274.1	
1973			178.7			165.3			2.58	346.5	
1974			221.9			179.6			2.66	404.1	
1975			105.1			125.0			3.97	234.0	
1976			96.3			120.8			1.20	218.3	
1977			77.3			68.0			0.53	145.9	
1978			87.4			131.2			1.24	219.8	
1979			52.3			18.6			1.82	72.7	
1980	104.7	15.3	168.1	16.8	72.2	123.5	0.32	0.39	0.84	292.4	104.7
1981	266.5	24.4	293.8	25.5	75.1	100.6	2.14	2.80	5.06	399.5	185.6
1982	454.0	34.6	488.6	61.6	143.3	204.9	0.48	0.69	1.17	694.6	275.1
1983	77.7	30.1	107.8	36.7	98.5	135.3	3.09	3.95	7.03	250.1	266.1
1984	115.6	27.5	143.1	33.4	88.0	121.4	0.14	0.21	0.35	264.9	215.8
1985	317.0	125.5	442.6	102.5	502.5	605.0	4.01	5.10	9.10	1056.7	170.1
1986	191.3	3.5	194.8	51.9	29.6	81.5	0.84	1.11	1.96	278.2	208.0
1987	219.1	90.5	309.6	61.5	171.7	233.1	2.46	4.76	7.22	550.0	242.5
1988	433.1	26.2	459.4	93.3	153.6	247.0	0.89	1.09	1.98	708.4	281.2
1989	162.1	40.5	202.6	100.4	158.2	258.6	1.14	1.54	2.68	463.9	271.5
1990	400.3	70.7	471.0	163.5	303.1	466.6	0.68	1.03	1.71	939.3	331.8
1991	220.4	30.0	250.3	108.4	186.3	294.7	0.98	1.43	2.41	547.4	260.9
1992	280.5	41.9	322.4	179.9	231.9	411.8	0.73	1.00	1.73	735.9	300.4
1993	234.6	27.8	262.5	104.1	198.5	302.6	0.55	0.65	1.21	566.3	245.2
1994	105.3	37.1	142.4	108.3	254.2	362.5	4.28	5.54	9.82	514.8	206.8
1995	102.4	29.5	131.9	154.0	174.5	328.5	0.25	0.35	0.59	460.9	147.5
1996	196.5	33.4	229.9	201.7	334.8	536.4	0.98	1.14	2.12	768.5	134.7
1997	83.7	17.5	101.2	205.2	209.1	414.3	0.05	0.05	0.10	515.5	127.5
1998	26.7	22.9	49.7	69.0	236.4	305.4	0.05	0.08	0.13	355.2	102.3
1999	62.7	20.4	83.1	140.8	256.4	397.2	0.02	0.03	0.05	480.4	57.7
2000	85.8	11.7	97.5	91.5	166.2	257.7	0.07	0.09	0.16	355.4	58.4
2001	56.7	16.7	73.4	71.4	160.5	231.9	0.04	0.03	0.07	305.4	68.4
2002	75.2	19.0	94.2	131.5	246.3	377.8	0.06	0.06	0.12	472.1	72.5
2003	64.5	22.5	87.1	125.5	256.3	381.8	0.13	0.14	0.27	469.1	65.5
2004	40.4	10.0	50.3	46.9	126.2	173.1	0.66	0.91	1.56	225.0	60.0
2005	55.8	30.8	86.6	59.8	294.7	354.5	0.28	0.42	0.69	441.9	53.6
2006	253.4	29.0	282.5	141.6	406.5	548.1	0.10	0.17	0.27	830.8	116.6
2007	158.0	18.9	176.9	73.6	227.6	301.1	0.23	0.32	0.56	478.6	155.8
2008	241.7	29.6	271.4	91.2	293.7	385.0	0.47	0.59	1.05	657.4	217.7
2009*	***148.3***	***21.9***	***170.2***	***54.9***	***326.1***	***381.0***	***2.95***	***3.76***	***6.71***	***557.9***	***182.7***

Notes: Total equals sum of males and females plus unsexed dogfish. Data for dogfish prior to 1980 are currently not available by sex.

Data 2009 have been adjusted to AL IV equivalents using preliminary HB Bigelow calibration coefficients.

Table 2. Summary of input data for stock-recruitment analyses. Survey data are from NEFSC Spring Bottom Trawl Surveys, 1968-1972, 1980-2009. Sex data on spiny dogfish from 1973-1979 are not available.

Year	Female SSB (kg/tow)	Total Recruits (#/tow)	AveWt Mature Females (kg)	Ave Wt Pups (<36 cm) in kg	Mature Male to Mature Female Sex Ratio	ln(R/SSB)	R/SSB	SSB/R	3 yr Moving average of female SSB (kg)
1968	6.373	2.793	2.783	0.086	4.245227	-0.825	0.438	2.282	
1969	4.595	1.235	2.788	0.084	3.708974	-1.314	0.269	3.721	
1970	6.157	8.172	2.974	0.061	1.299573	0.283	1.327	0.753	5.709
1971	17.931	5.906	3.104	0.074	0.340913	-1.111	0.329	3.036	9.561
1972	13.513	1.971	3.185	0.063	1.076171	-1.925	0.146	6.857	
1980	16.159	1.356	3.810	0.082	1.920072	-2.478	0.084	11.915	
1981	41.252	8.853	4.026	0.086	0.884929	-1.539	0.215	4.660	
1982	70.094	2.459	4.178	0.073	1.032874	-3.350	0.035	28.506	42.502
1983	11.998	12.990	4.042	0.084	4.236328	0.079	1.083	0.924	41.115
1984	17.844	0.744	3.941	0.072	2.633139	-3.178	0.042	23.991	33.312
1985	48.946	19.799	3.840	0.071	5.158537	-0.905	0.405	2.472	26.263
1986	29.528	3.982	3.843	0.076	0.34122	-2.004	0.135	7.415	32.106
1987	34.130	12.942	3.900	0.087	2.877858	-0.970	0.379	2.637	37.535
1988	67.571	3.671	3.890	0.084	1.03694	-2.913	0.054	18.408	43.743
1989	25.586	5.482	3.220	0.077	2.49234	-1.541	0.214	4.667	42.429
1990	62.511	3.841	3.436	0.070	2.242335	-2.790	0.061	16.275	51.889
1991	34.319	4.548	3.433	0.082	2.288966	-2.021	0.133	7.546	40.806
1992	44.407	3.663	3.038	0.075	2.046817	-2.495	0.082	12.124	47.079
1993	36.678	3.060	3.328	0.062	2.26248	-2.484	0.083	11.985	38.468
1994	16.448	15.840	3.011	0.097	5.455118	-0.038	0.963	1.038	32.511
1995	15.953	1.151	2.807	0.080	3.914834	-2.629	0.072	13.857	23.026
1996	30.603	5.276	2.937	0.063	3.772397	-1.758	0.172	5.800	21.001
1997	13.088	0.281	2.603	0.054	5.360178	-3.843	0.021	46.644	19.881
1998	4.164	0.454	2.706	0.044	19.55955	-2.216	0.109	9.169	15.952
1999	9.978	0.143	2.621	0.056	8.869291	-4.242	0.014	69.576	9.077
2000	13.364	0.479	2.785	0.051	4.427263	-3.328	0.036	27.873	9.168
2001	8.825	0.208	2.870	0.056	6.510849	-3.747	0.024	42.397	10.722
2002	11.709	0.297	2.613	0.064	6.972351	-3.674	0.025	39.427	11.299
2003	10.052	0.825	2.646	0.052	8.307197	-2.500	0.082	12.186	10.195
2004	6.288	4.346	2.802	0.056	6.896326	-0.370	0.691	1.447	9.350
2005	8.698	1.951	2.731	0.055	11.49529	-1.495	0.224	4.459	8.346
2006	39.472	0.645	2.728	0.065	3.397613	-4.113	0.016	61.160	18.153
2007	24.610	1.597	2.761	0.054	3.051354	-2.735	0.065	15.406	24.260
2008	37.648	2.670	2.752	0.061	2.57258	-2.646	0.071	14.102	33.910
2009	23.122	13.106	2.744	0.080	4.382755	-0.568	0.567	1.764	28.460

Statistic	Female SSB (kg/tow)	Total Recruits (#/tow)	AveWt Mature Females (kg)	Ave Wt Pups (<36 cm) in kg	Mature Male to Mature Female Sex Ratio	ln(R/SSB)	R/SSB	SSB/R	3 yr Moving average of female SSB (kg)
Average	24.675	4.478	3.168	0.070	4.202	-2.097	0.248	15.328	25.928
Std Dev	18.120	4.946	0.512	0.013	3.695	1.224	0.320	17.366	14.003
ave '07-09	28.460	5.791	2.753	0.065	3.336	-1.983	0.234	10.424	
min	4.164	0.143	2.603	0.044	0.341	-4.242	0.014	0.753	5.709
max	70.094	19.799	4.178	0.097	19.560	0.283	1.327	69.576	51.889
median	17.844	2.793	2.974	0.071	3.398	-2.216	0.109	9.169	25.262
25%ile	10.880	0.988	2.757	0.059	2.145	-2.851	0.058	3.379	10.867
75%ile	35.499	5.379	3.623	0.081	5.259	-1.212	0.299	17.341	38.235
90%ile	47.131	12.971	3.925	0.085	7.773	-0.449	0.641	41.209	42.626
10%ile	6.322	0.360	2.670	0.054	1.035	-3.718	0.024	1.574	9.159

Table 3. Summary of model building exercise for stock-recruitment relationship in spiny dogfish. Response variable is observed total number of pups per tow in year t. Dependent variables include total weight (kg) per tow of mature female dogfish (>80 cm), average weight of pups (kg/tow) (individuals <36 cm TL), average weight (kg) of mature females (≥80 cm), and mature male to mature female sex ratio. All variables are based on NEFSC spring bottom trawl survey, 1968-1972, 1980-2009.

			Additional Model Factors						Asymptotic Confidence Interval (kg/tow)					
Estimation Method	Model ID	Model Description	Ave Wt of Mature Females	Ave Wt of Pups (<36 cm)	Mat Male to Mat Female Ratio by number	Negative Log Likelihood	AIC	SSB_max (kg/tow)	Lower 2.5% CI	Upper 97.5% CI	Length of Conficence Interval	Swept Area Equivalent (mt) using 0.01 nm^2 NOMINAL	Swept Area Equivalent (mt) using 0.0112 nm^2	Swept Area Equivalent (mt) using 0.0119 nm^2
	1	Base Model 1 (1968-72, 1980-1996)				66.55	139.11	32.989	-33.144	99.122	132.266	206,082	184,002	173,178
	2	Base Model 2 (1968-72, 1980-2003)				85.75	177.49	45.062	-49.505	139.629	189.134	281,502	251,341	236,557
	3	Base Model 3 (1968-72, 1980-2009)				103.40	212.79	40.588	-40.749	121.926	162.675	253,553	226,387	213,070
	4	Full Model (1968-72, 1980-2009)	●	●	●	91.66	195.32	47.936	-48.12	143.992	192.112	299,456	267,372	251,644
Maximum Likelihood		*Two Factor Models*												
	5	Base Model 3 + Mat Fem + Pup Wt	●	●		96.78	203.57	31.035	-14.543	76.613	91.156	193,876	173,103	162,921
	6	Base Model 3 + Mat Fem + Sex Ratio	●		●	99.53	209.05	36.593	-19.272	92.458	111.73	228,596	204,104	192,098
	7	Base Model 3 + Pup Wt + Sex Ratio		●	●	93.70	197.41	67.543	-126.485	261.571	388.056	421,941	376,733	354,572
	8	Base Model 3 + Mat Fem	●			101.47	210.94	30.768	13.309	74.844	61.535	192,208	171,614	161,519
	9	Base Model 3 + Pup Wt		●		96.86	201.71	32.913	-10.267	76.094	86.361	205,608	183,578	172,779
	10	Base Model 3 + Sex Ratio			●	103.14	214.28	50.809	-102.648	204.266	306.914	317,404	283,396	266,726
						SSE	approx AIC							
	11	Base Model 1 (1968-72, 1980-1996)				554.866	102.72	31.413	4.213	58.612	54.399	196,237	175,212	164,905
	12	Base Model 2 (1968-72, 1980-2003)				638.677	107.64	44.845	-2.387	92.076	94.463	280,147	250,131	235,417
	13	Base Model 3 (1968-72, 1980-2009)				768.47	114.12	39.881	1.038	78.724	77.686	249,137	222,443	209,358
Robust Non linear Least Squares with T function, df=30	14	Full Model (1968-72, 1980-2009)	●	●	●	did not converge								
		Two Factor Models												
	15	Base Model 3 + Mat Fem + Pup Wt	●	●		532.17	105.26	28.098	8.103	48.093	39.99	175,528	156,722	147,503
	16	Base Model 3 + Mat Fem + Sex Ratio	●		●	616.70	110.42	33.396	10.221	56.572	46.351	208,625	186,272	175,315
	17	Base Model 3 + Pup Wt + Sex Ratio		●	●	did not converge								
	18	Base Model 3 + Mat Fem	●			692.88	112.49	28.29	8.71	47.871	39.161	176,728	157,793	148,511
	19	Base Model 3 + Pup Wt		●		536.91	103.57	30.343	10.98	49.706	38.726	189,553	169,244	159,288
	20	Base Model 3 + Sex Ratio			●	765.72	115.99	41.197	-6.62	89.015	95.635	257,358	229,784	216,267
Robust with variable T df	21	Base Model 3 + Pup Wt {T df=20}		●		703.16	113.01	27.958	7.588	48.628	41.04	174,654	155,941	146,768
	22	Base Model 3 + Pup Wt {T df=10}		●		723.50	114.01	28.662	4.588	52.737	48.149	179,052	159,867	150,463
	23	Base Model 3 + Pup Wt {T df=5}		●		557.867	104.91	31.339	8.36	54.319	45.959	195,775	174,799	164,517

Table 4. Summary of simple Monte Carlo experiment to estimate the variation and bias induced in estimate of SSBmax when errors in variables are introduced into SSB and R. Both SSB and R were assumed to have lognormal distributions. Results are based on 500 simulations. The true underlying estimate of SSBmax was 32.913 kg in all simulations.

		Estimates of SSBmax based on 500 simulations			
Measurement Error Assumption	Input Coefficient of Variation in SSB and R	Mean	Standard Deviation of Mean	CV of SSBmax Est	Percent Bias from True value
Uncorrelated. Variation in SSB and R is independent	0.01	32.96	0.36	0.01	0.1
	0.1	37.94	5.38	0.14	15.3
	0.15	44.96	12.55	0.28	36.6
	0.2	55.16	22.35	0.41	67.6
	0.25	70.86	43.72	0.62	115.3
	0.3	88.73	62.99	0.71	169.6
Correlation =100%. Deviations in SSB and R are perfectly correlated.	0.01	33.00	0.42	0.01	0.3
	0.1	41.44	6.58	0.16	25.9
	0.15	52.73	14.66	0.28	60.2
	0.2	69.97	31.10	0.44	112.6
	0.25	94.82	63.77	0.67	188.1
	0.3	119.55	100.09	0.84	263.2

Table 5. Summary of estimated landings of US, Canadian and foreign commercial fisheries by sex.

Table 1. Summary of estimated landings of US, Canadian and foreign commercial fisheries by sex. US recreational landings included. Port samples from NMFS and MADMF were pooled. Estimated total weights based on summation of estimated weights from sampled length frequency distributions. Estimated weights computed from length-weight regressions. Females W =exp(-15.025)*L ^3.606935, Males W=exp(-13.002)*L^3.097787 with weight in kg, length in cm. "Samples"= number of measured dogfish.

	Composite (NMFS and MADMF) Biological Samples from Ports							Commercial Landings			Prorated Landings By Sex				
year	Total Samples Males	Est Tot Wt (kg) Males	Ave Wt (kg) Males	Total Samples (females)	EstTot Wt (kg) females	Est Avg Wt (kg) females	Fraction Females by weight	US Commercial + Recreational Landings (mt)	Canada and Foreign Landings (mt)	Total Landings (mt)	Est Landings (mt) of Males	Est. Landings (mt) of females	Number of Males Landed (000)	Number of Females Landed (000)	Total Numbers Landed (000)
1982	24	52.0	2.167	680	3015.7	4.435	0.9830	5481	753	6234	106	6128	49	1382	1431
1983				610	2513.9	4.121	1.0000	4964	464	5428	0	5428	0	1317	1317
1984	9	15.8	1.760	1478	6448.9	4.363	0.9976	4542	393	4935	12	4923	7	1128	1135
1985	21	35.2	1.678	1657	6799.2	4.103	0.9948	4117	1025	5142	27	5116	16	1247	1263
1986	64	104.1	1.626	1152	4666.0	4.050	0.9782	2930	388	3318	72	3246	45	801	846
1987	31	52.7	1.700	1999	7542.1	3.773	0.9931	3009	420	3429	24	3406	14	903	917
1988	7	14.8	2.114	1764	7560.7	4.286	0.9980	3464	648	4112	8	4104	4	957	961
1989	35	67.5	1.927	1375	5528.0	4.020	0.9879	4910	423	5333	64	5269	33	1311	1344
1990	19	33.7	1.772	2228	8898.3	3.994	0.9962	14909	1702	16611	63	16548	35	4143	4179
1991	148	379.1	2.562	1518	5923.9	3.902	0.9399	13307	541	13848	833	13016	325	3335	3660
1992	12	22.3	1.861	3187	12180.6	3.822	0.9982	17073	935	18008	33	17975	18	4703	4721
1993	42	78.4	1.866	2773	9927.5	3.580	0.9922	20763	1462	22225	174	22051	93	6159	6253
1994	47	86.6	1.843	2091	6618.8	3.165	0.9871	18952	1822	20774	268	20506	146	6478	6624
1995	25	38.9	1.555	2266	6676.6	2.946	0.9942	22645	970	23615	137	23479	88	7969	8056
1996	569	886.7	1.558	1644	4397.6	2.675	0.8322	27160	667	27827	4669	23158	2996	8657	11654
1997	303	449.1	1.482	382	780.9	2.044	0.6349	18418	660	19078	6966	12112	4700	5925	10625
1998	68	85.4	1.257	683	1434.5	2.100	0.9438	20667	1662	22329	1255	21073	999	10034	11033
1999	93	130.3	1.401	311	625.5	2.011	0.8276	14907	2645	17552	3026	14527	2160	7223	9382
2000	405	561.2	1.386	5144	12168.1	2.365	0.9559	9262	3143	12405	547	11858	395	5013	5407
2001	12	17.1	1.422	215	456.5	2.123	0.9640	2322	4497	6819	246	6573	173	3096	3269
2002	65	97.6	1.501	1893	5065.7	2.676	0.9811	2404	4058	6462	122	6340	81	2369	2450
2003	34	48.3	1.421	966	2338.4	2.421	0.9798	1210	1945	3155	64	3091	45	1277	1322
2004	15	23.9	1.593	1180	3296.9	2.794	0.9928	1086	2692	3778	27	3751	17	1343	1360
2005	745	1018.7	1.367	2065	5196.0	2.516	0.8361	1192	2600	3792	622	3171	455	1260	1715
2006	646	924.4	1.431	4211	10382.9	2.466	0.9182	2343	2439	4782	391	4391	273	1781	2054
2007	507	720.7	1.421	2863	7514.8	2.625	0.9125	3587	2384	5971	523	5449	368	2076	2444
2008	236	342.0	1.449	2925	7973.8	2.726	0.9589	4322	1572	5894	242	5652	167	2073	2240
formula	*A*	*B*	*C=B/A*	*D*	*E*	*F=E/D*	*G=E/(E+B)*	*H*	*I*	*J=H+I*	*K=(1-G)*J*	*L=G*J*	*M=K/C*	*N=L/F*	*O=M+N*

Table 6. Summary of estimated dead discards of US commercial fishery by sex.

Table 2. Summary of estimated dead Discards of US commercial fisheries by sex. Port samples from NMFS and MADMF were pooled. Estimated total weights based on summation of estimated weights from sampled length frequency distributions. Estimated weights computed from length-weight regressions. Females W =exp(-15.025)*L ^3.606935, Males W=exp(-13.002)*L^3.097787 with weight in kg, length in cm. "Samples"= number of measured dogfish.

	Composite (NMFS and MADMF) Biological Samples from Observers							Landings and Discards (mt)			Prorated Dead Discards By Sex				
year	Total Samples Males	Est Tot Wt (kg) Males	Ave Wt (kg) Males	Total Samples (females)	EstTot Wt (kg) females	Est Avg Wt (kg) females	Fraction Females by weight	Total Landings	Total Discards	Total Dead Discards (mt)	Est Discards (mt) of Males	Est.Discards (mt) of females	Number of MalesDiscarded (000)	Number of Females Discarded (000)	Total Numbers Discarded (000)
1989								5333	34990	16020					
1990								16611	41474	19174					
1991	372	461	1.240	891	2349	2.636	0.836	13848	31831	13274	2179	11095	1757	4209	5966
1992	446	503	1.129	630	1089	1.729	0.684	18008	41066	18983	6001	12982	5317	7510	12827
1993	57	62	1.087	130	414	3.184	0.870	22225	28461	11969	1559	10410	1434	3270	4704
1994	204	206	1.010	742	1395	1.881	0.871	20774	18486	8556	1101	7455	1090	3964	5054
1995	2152	2331	1.083	2290	3038	1.327	0.566	23615	24760	10932	4747	6185	4382	4663	9044
1996	1400	1810	1.293	1185	2002	1.689	0.525	27827	13742	6025	2861	3164	2213	1873	4086
1997	1170	1353	1.157	1265	2044	1.616	0.602	19078	10065	4366	1739	2627	1504	1626	3129
1998	1231	1302	1.058	1372	1920	1.400	0.596	22329	7963	3435	1388	2047	1312	1463	2775
1999	370	426	1.151	800	1797	2.246	0.808	17552	10263	4581	878	3703	762	1649	2411
2000	390	562	1.441	1351	3171	2.347	0.849	12405	8111	2917	439	2478	305	1056	1360
2001	633	839	1.326	2973	7359	2.475	0.898	6819	14252	5063	518	4544	391	1836	2227
2002	1288	1818	1.411	5874	13897	2.366	0.884	6462	16283	5049	584	4465	414	1887	2301
2003	4596	5349	1.164	12675	27190	2.145	0.836	3155	12358	4225	695	3531	597	1646	2243
2004	10735	14456	1.347	28266	64731	2.290	0.817	3778	16370	6146	1122	5024	833	2194	3027
2005	7051	9360	1.327	12378	28483	2.301	0.753	3792	15552	5589	1382	4207	1041	1828	2870
2006	4101	5395	1.316	6115	14487	2.369	0.729	4782	15126	5688	1544	4145	1173	1750	2923
2007	3893	5169	1.328	9738	24600	2.526	0.826	5971	17681	6510	1130	5380	851	2130	2981
2008	3039	3959	1.303	6083	14848	2.441	0.789	5894	14080	5088	1071	4017	822	1646	2468
formula	*A*	*B*	*C=B/A*	*D*	*E*	*F=E/D*	*G=E/(E+B)*	*H*	*I*	*J*	*K=(1-G)*J*	*L=G*J*	*M=K/C*	*N=L/F*	*O=M+N*

Table 7. Summary of fishing mortality rates expressed as the full F on the exploitable biomass of female and male spiny dogfish. Year represents the year of the catch (landings plus dead discards).

Year	F1: Female Catch on exploitable female biomass	F2: Male Catch on exploitable male biomass
1990	0.088	0.044
1991	0.082	0.026
1992	0.177	0.040
1993	0.327	0.021
1994	0.465	0.018
1995	0.418	0.014
1996	0.355	0.031
1997	0.234	0.038
1998	0.306	0.025
1999	0.289	0.043
2000	0.152	0.007
2001	0.109	0.005
2002	0.165	0.003
2003	0.168	0.004
2004	0.474	0.008
2005	0.128	0.007
2006	0.088	0.012
2007	0.090	0.005
2008	0.110	0.004

Table 8. Summary of swept area biomass estimates (mt) based on stochastic population estimator. Exploitable biomasses are based on year-specific selectivity functions based on 3 year moving averages. Female spawning stock biomass is base on sum of female spiny dogfish above 80 cm TL. The target spawning stock biomass based on Model 19 is 30.343 kg/tow or 159,288 mt (using the 0.0119 nm^2 trawl footprint).

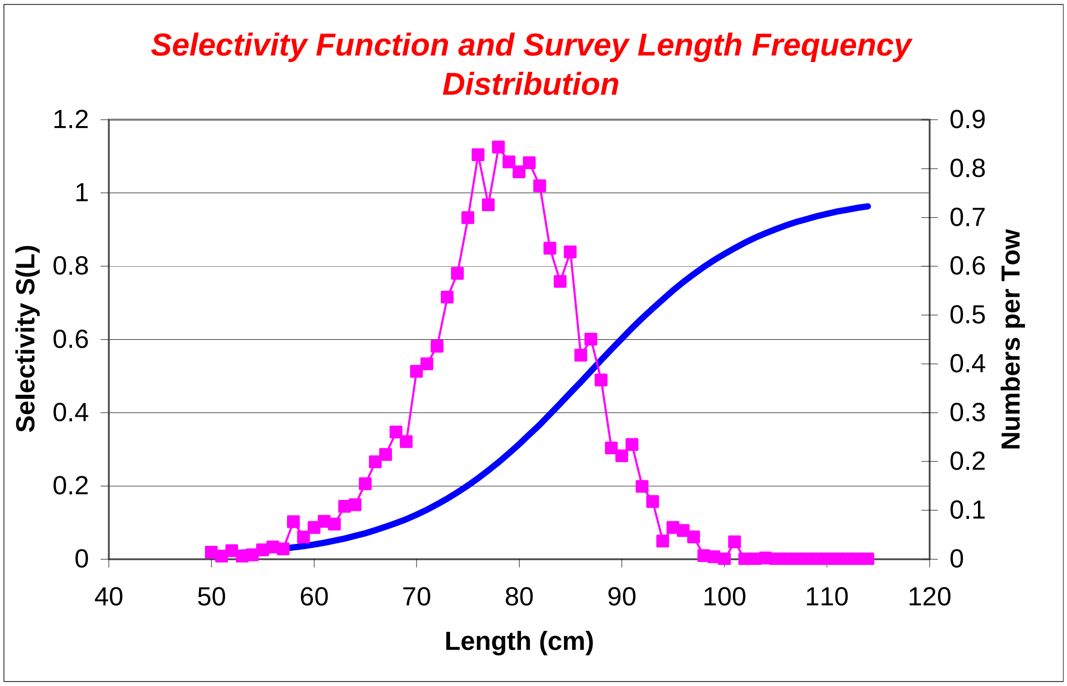
Terminal Year	Mid Year	Total Exploitable Biomass	Exploitable Female Biomass	Exploitable Male Biomass	Tot Biomass	Female Spawning Stock Biomass
1991	1990	570,113	339,405	230,208	582,274	234,229
1992	1991	532,641	278,419	253,722	664,850	269,624
1993	1992	379,501	169,227	209,773	553,731	220,002
1994	1993	322,345	93,716	228,128	544,415	186,132
1995	1994	261,387	55,102	205,785	460,932	133,264
1996	1995	329,048	77,600	250,948	519,920	120,664
1997	1996	316,075	81,413	234,162	520,782	114,091
1998	1997	319,828	69,005	250,323	489,233	91,458
1999	1998	185,468	77,142	107,825	406,287	51,821
2000	1999	167,483	66,023	100,960	358,185	52,562
2001	2000	286,458	96,233	189,725	343,602	61,552
2002	2001	291,695	107,026	184,169	337,686	64,844
2003	2002	278,283	63,794	213,989	371,200	58,376
2004	2003	241,697	39,745	201,452	347,176	53,625
2005	2004	237,536	17,432	219,604	338,170	47,719
2006	2005	327,077	54,587	271,991	453,881	106,180
2007	2006	233,662	90,651	142,511	524,205	141,351
2008	2007	423,273	123,742	299,031	586,413	194,616
2009	2008	361,040	89,151	271,390	505,116	163,256

Appendix 1. Comparison of size composition of commercial catch (landings + Discards) for male and female spiny dogfish with the NEFSC spring survey for 2006-2008. Both catch and survey frequencies represent 3-yr moving averages. Summary of estimated selectivity pattern for male and female spiny dogfish. Selectivity at length L is modeled as sel(L)=1/(1+exp(a + b L)) where sel(F) is the fraction of the spiny dogfish population vulnerable to the commercial fishery (both landings and discards). Size composition of the commercial fishery is based on analyses of port sampling and at-sea observer sampling, 1989-2008. Selectivity blocks are based on a 3-yr moving average, eg. 2006-2008.

FEMALES, 3-yr Average, w/Discard 2006

model: S(L) = 1/(1+exp(alpha+beta * L))

alpha	beta	L50%ile
10.35	-0.12	86.523



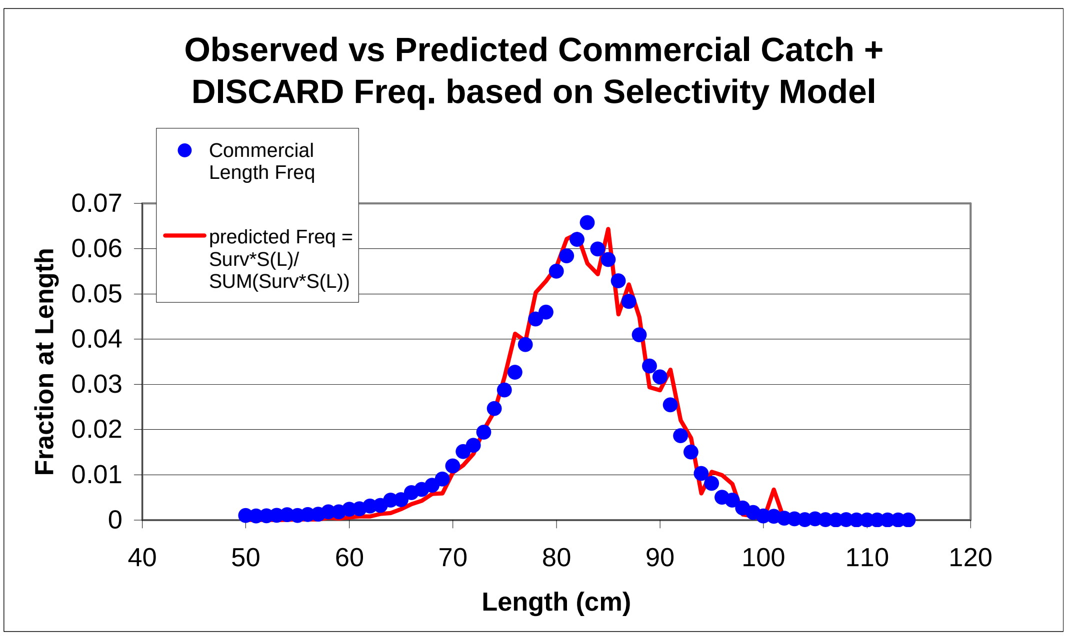
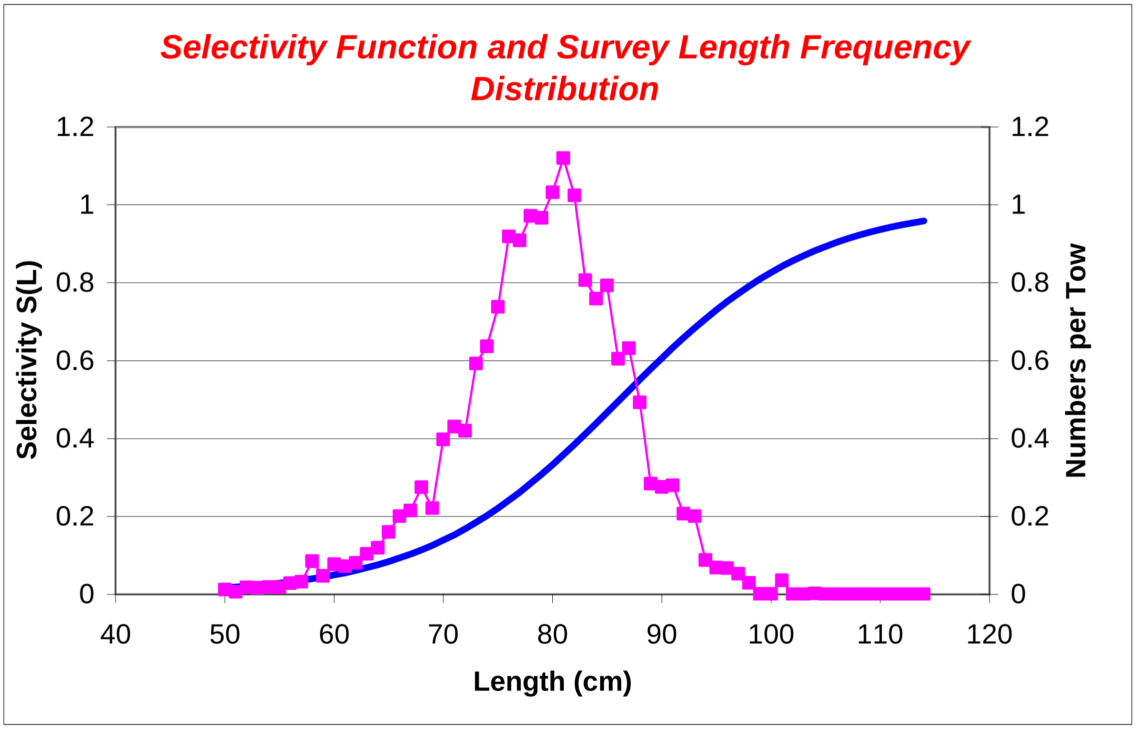


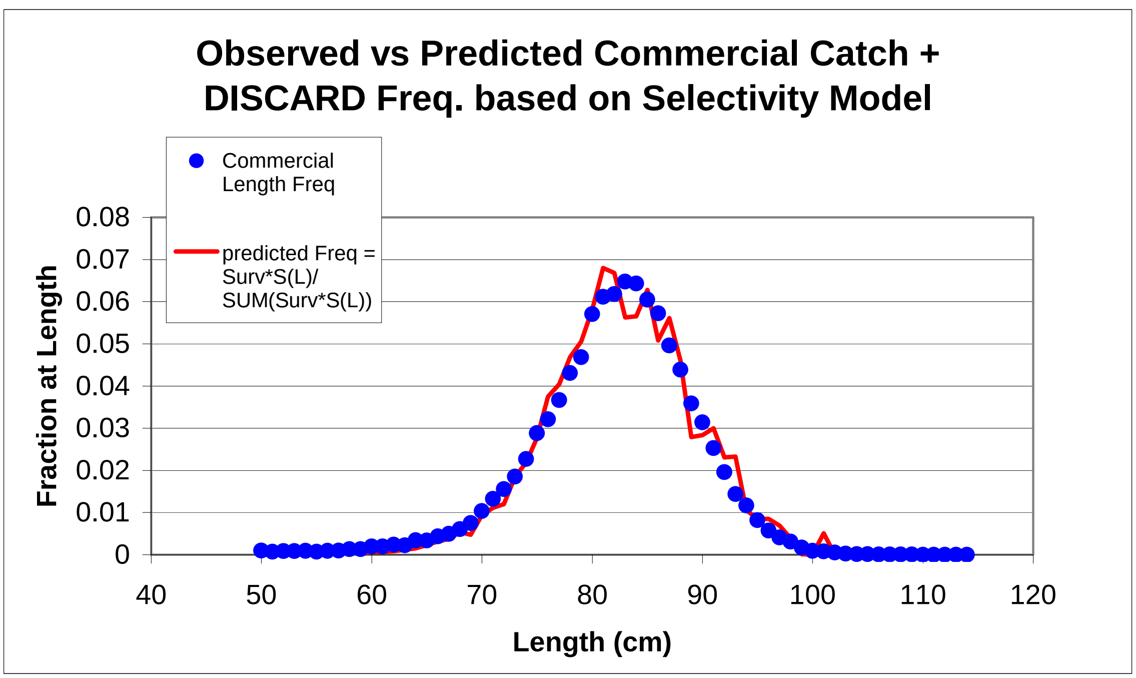
Fig Y

FEMALES, 3-yr Average, w/Discard 2007

model: S(L) = 1/(1+exp(alpha+beta * L))

alpha	beta	L50%ile
9.722	-0.113	86.169

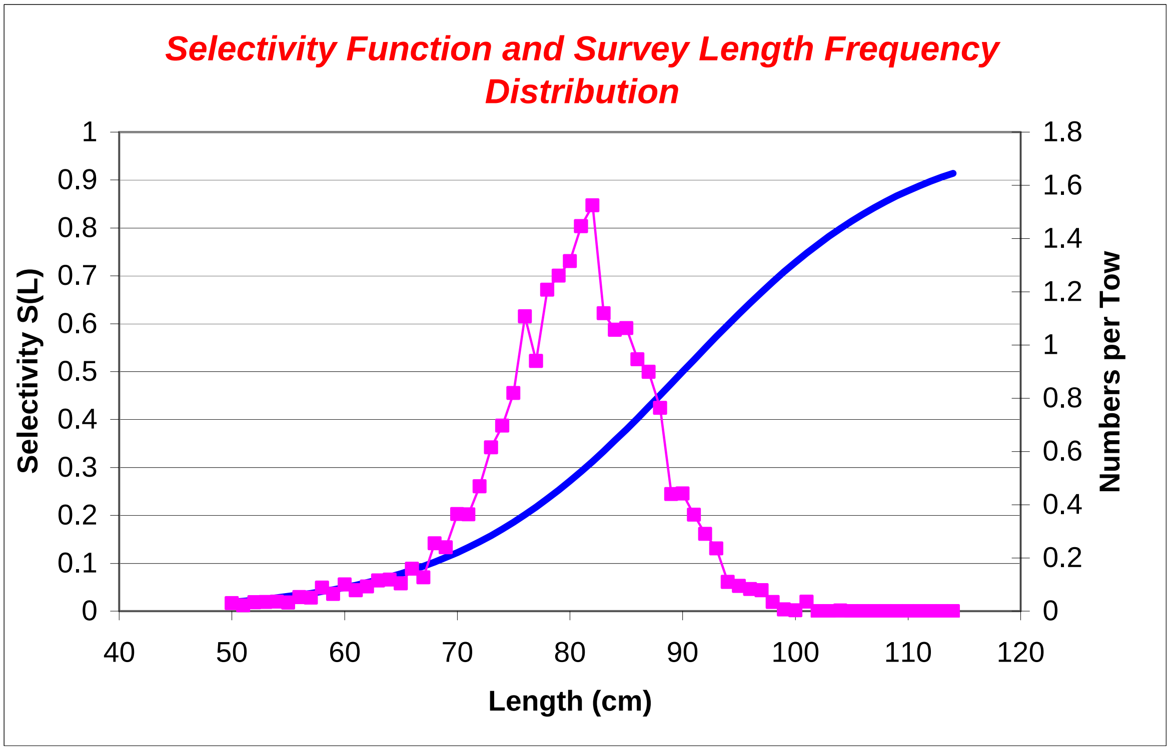


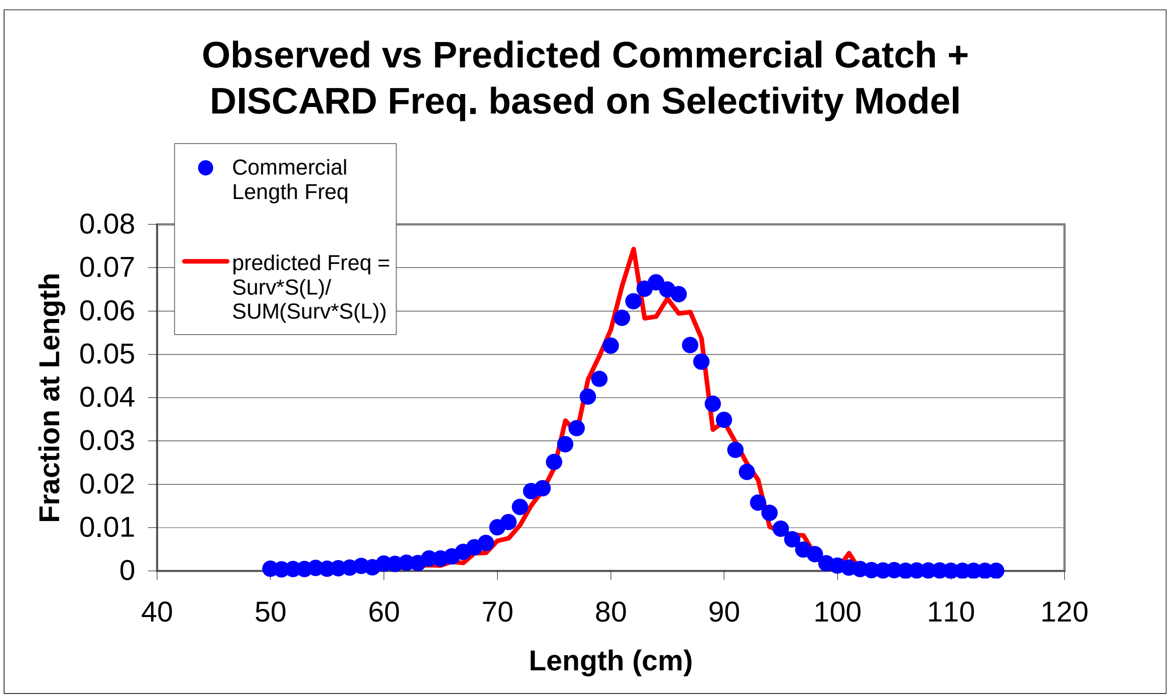


FEMALES, 3-yr Average, w/Discard 2008

model: S(L) = 1/(1+exp(alpha+beta * L))

alpha	beta	L50%ile
8.867	-0.099	90



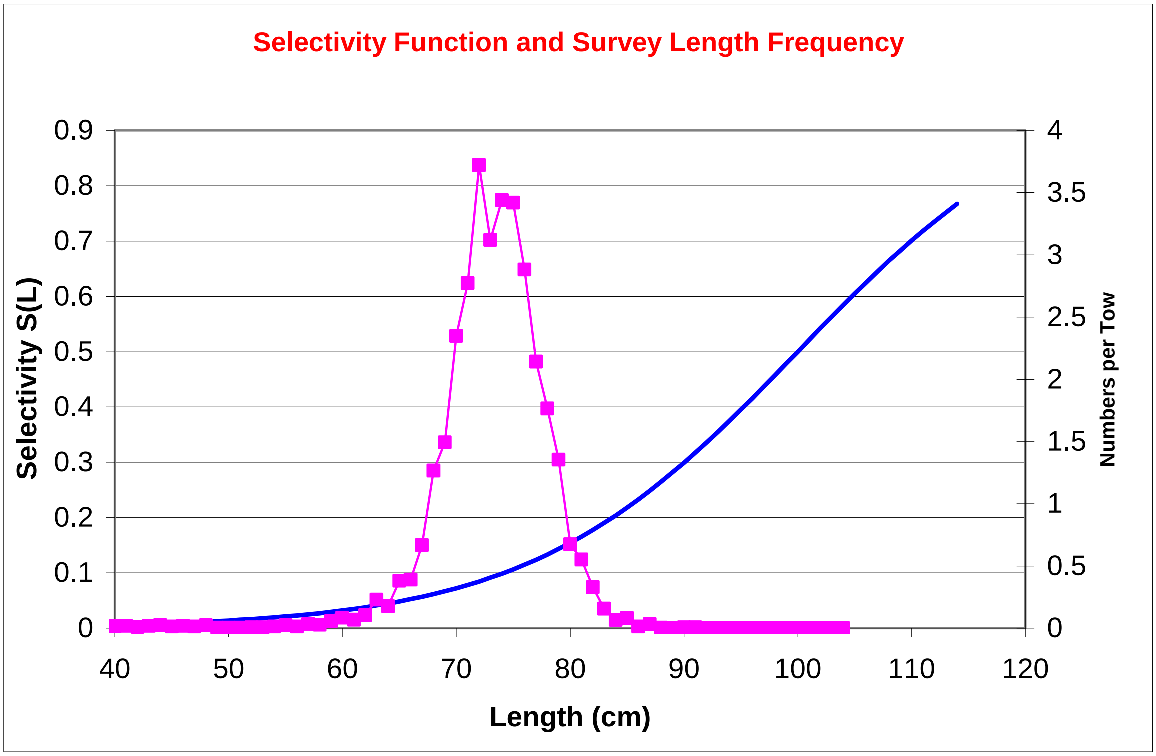


Fix ccc

MALES, 3-yr Average, 2006

model: S(L) = 1/(1+exp(alpha+beta * L))

alpha	beta	L50%ile
8.513	-0.085	100



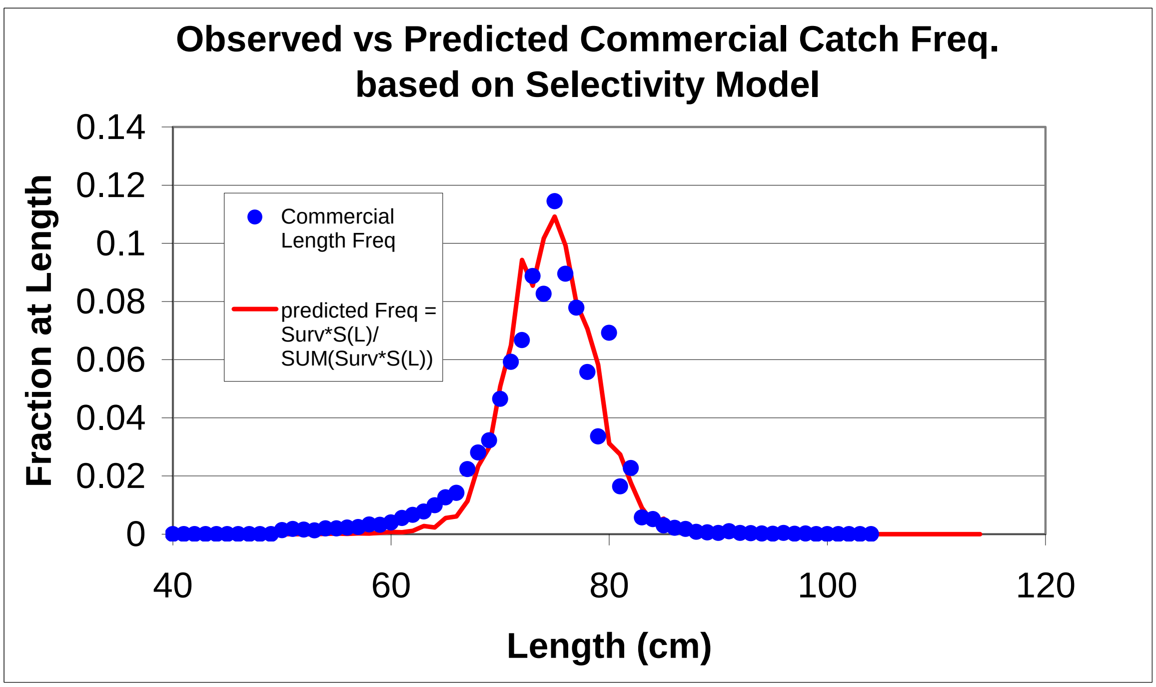
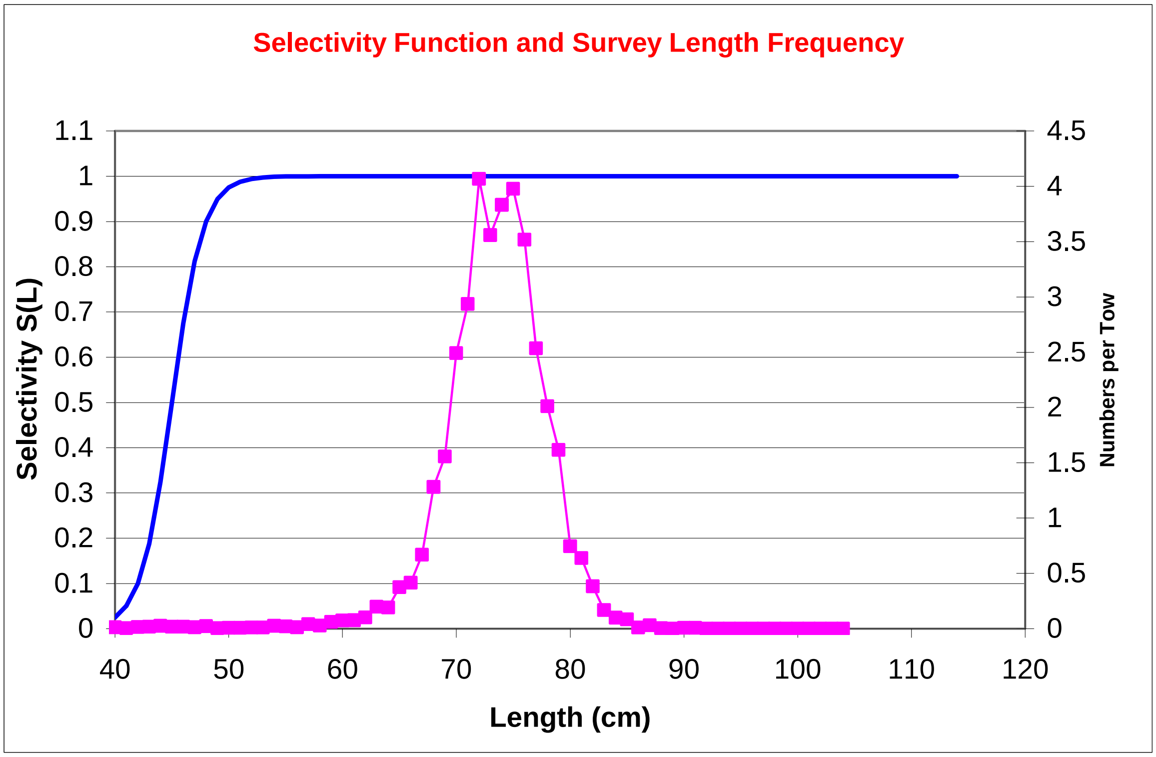


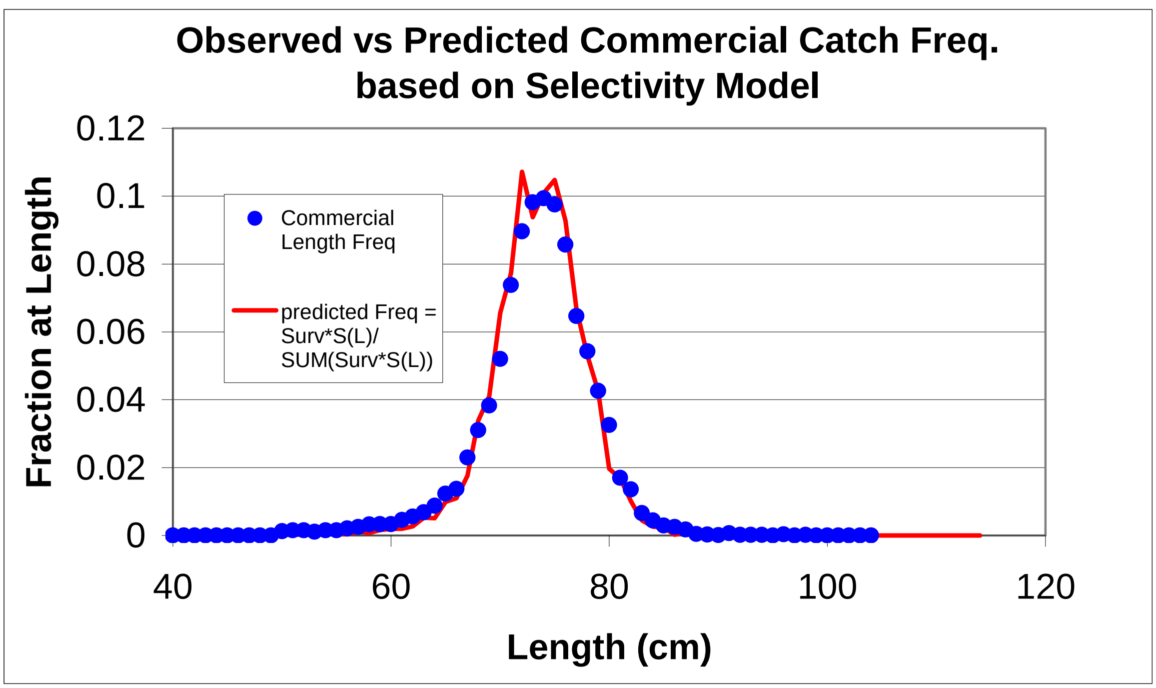
Fig ddd

MALES, 3-yr Average, 2007

model: S(L) = 1/(1+exp(alpha+beta * L))

alpha	beta	L50%ile
32.97	-0.733	45

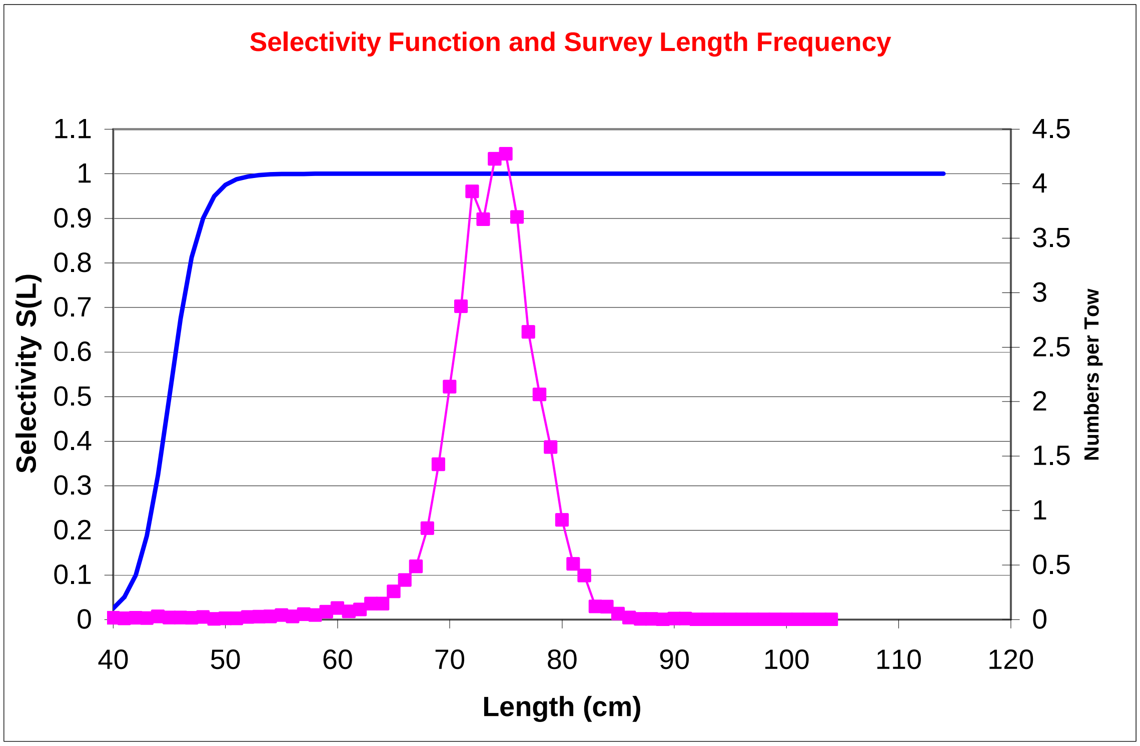


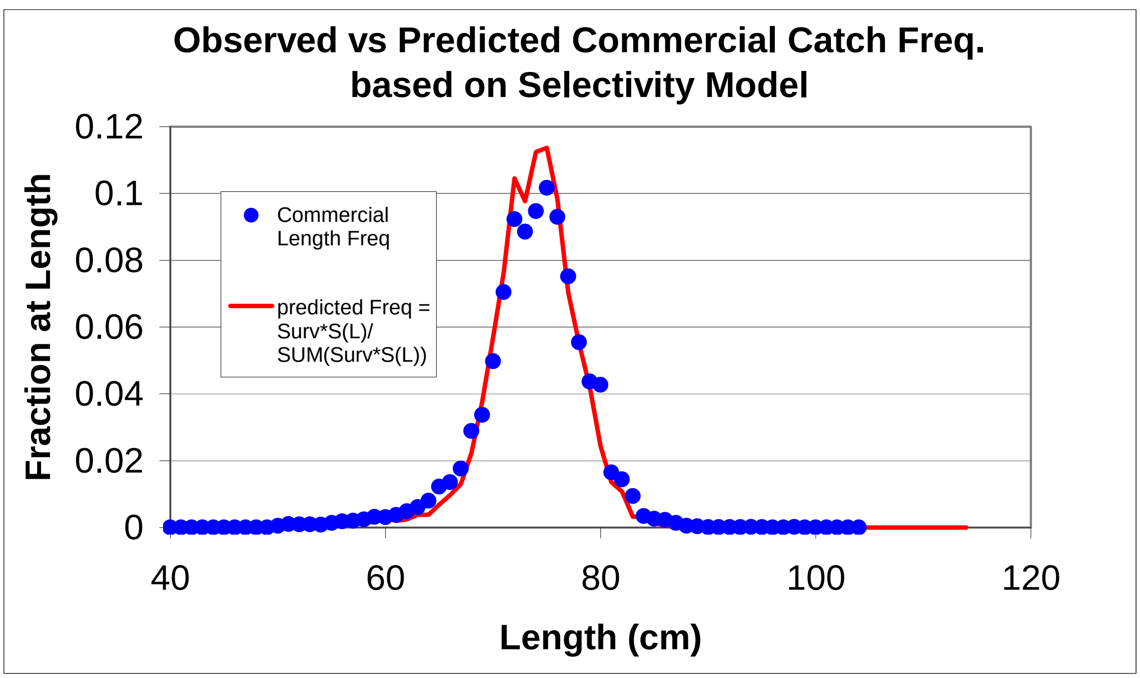


MALES, 3-yr Average, 2008

model: S(L) = 1/(1+exp(alpha+beta * L))

alpha	beta	L50%ile
32.97	-0.733	45





Appendix 2---Summary of Reviewer Comments. All comments are unedited. Reviewer comments are in alphabetical order.

Reviewer #1:

Review of Biological reference points for spiny dogfish 2010, by Rago and Sosebee

Review by Maurice Clarke

Date: 20th April 2010.

I reviewed the paper "Biomass Reference Points for Spiny Dogfish" by Rago and Sosebee. I was not able to participate in the conference call. Based on my reading of the documents, I accept the work as a basis for setting the biomass reference point for this stock.

The approach uses a stock recruit function derived from observations of SSB (larger dogfish) and recruits (small dogfish) from the NMFS groundfish survey. The method is not without its difficulties, being based on the NMFS trawl survey observations.

The Ricker model seems plausible in this case. It seems reasonable that total female biomass is a measure of spawning potential. The Ricker model fit seems adequate.
The raw data do seem to indicate low recruitment at high stock size.

Error in the stock recruitment data are due to their coming from trawl survey observations in a given year. The recruits as defined, span several age groups. The recruit data do not match up with the SSB that produced those recruits. In addition recruits are more pelagic in their habits, indicating poorer selection to the survey. Both these factors introduce extra error into the stock recruitment relationship. Is the relationship as modeled sensitive to differing time lags, and smoothers in recruitment vs. stock? This could be explored in future work.

Future work could consider other possible stock recruit models too, including segmented regression, where we assume an SSB level at which recruitment impairment takes place, but does not consider density dependency at high stock size. Underlying biases and errors in the trawl survey could be further explored and documented.

Reviewer #2

Date: 13 April, 2010
To: Paul Rago and Loretta O'Brien
From: Vincent Gallucci
Re: Commentary on the 9 April phone telephone review.

Dear Paul and Loretta,

GENERAL COMMENTS

I have reviewed again the material we were sent in preparation for the 9 April 2010 telephone and Webex meeting. I feel that even right after that meeting that there was consensus on the material, viz., that it laid out reasonable analyses of biomass reference points (BRPs) for spiny dogfish and that the model # 19 found in Table 3 was the most appropriate of the models for estimation. My additional reading of this material confirms that opinion.

The utility of the document entitled *BRPs for Spiny Dogfish* is, in my opinion, certainly adequate as a foundation for further analyses. Further, it is a practical document for making management decisions at the present time.

Nevertheless, projecting into the future, I recommend that an alternative BRP other than, or supplementing, spawning stock biomass SSB be sought. Choosing an F that maximizes SSB is in my opinion excellent for herring or cod, but insensitive to many of the demographic changes that occur with dogfish sharks.

SOME SPECIFIC COMMENTS

1. I think that the new work on estimates of area swept are an improvement from what I recall from the January meeting.
2. The choice of the Ricker model to make these model based estimates is a good step forward. It is biologically logical to include pup weight as a covariate as well as being the most statistically efficient covariate. Considering the average weight of pups as a plausible predictor of recruitment may, however, be a bit too easy.
   While the literature probably suggests that pup weight is correlated with health of the mother (is size the measure?) and size of the mother correlated with larger offspring, there are alternative interpretations to consider. Maternal size does correlate with number of offspring but there is a tradeoff between size of off spring and number of offspring. The fitness argument likely can go both ways.
   I am not sure how this connects biologically to be a "plausible predictor of recruitment'. I would like to see a tighter argument than I can construct now.
3. I understand the need for biological reference points in this country. And, I know that spawning stock biomass is an important indicator. However, I think that will be better for herring or cod than dogfish since it will be insensitive to many of the demographic characteristics of dogfish sharks. Thus the recommendation in the general comments.

SINCE YOU NEED TO GO FORTH THIS MORNING WITH COMMENTS I WILL STOP HERE.

Reviewer #3

Memorandum

To: Paul Rago and Loretta O'Brien (NEFSC)
From: Tom Miller (CBL)
Date: April 11, 2010
Re: Review comments on proposed BRPs for Spiny dogfish

I have reviewed the Rago and Sosebee document "Biomass Reference Points for Spiny Dogfish" and participated in the recent TRAC-sponsored conference call. Based on my review and on the discussions held during the conference call, I find that the reference point recommended by Rago and Sosebee to serve as a proxy for the spiny dogfish stock biomass at maximum sustainable yield represents the best scientific information available and should be used as a basis for management decisions.

The assessment of the spiny dogfish stock has proved challenging. The recent spiny dogfish TRAC, held in Woods Hole in January 2010, failed to produce an accepted dynamic model of the stock from which reference points could be developed. Accordingly at that meeting, NMFS staff from the NEFSC committed to proposing management reference points to serve US management needs and to submit these proposals to the independent peer-reviewers who had evaluated the TRAC models. These proposed reference points were provided in an April 6, 2010 document prepared by Paul Rago and Kathy Sosebee. Subsequently, the proposed reference points were presented to and discussed by the TRAC reviewers during a conference call held on April 9, 2010.

The biomass predicted to result in maximum recruitment (SSB_{max}) was proposed as a proxy for the stock biomass at maximum sustainable yield (B_{MSY}). SSB_{max} was calculated from an analysis of stock and recruitment that used pup weight measured in the NEFSC survey as a covariate. This model resulted in an acceptable model fit and had parameter values with low uncertainty. Alternative configurations of stock-recruitment models were presented and explored, including one that had no covariate (simple model) and ones that had combinations of pup weight, female weight and the male:female sex ratio as covariates. In general the addition of covariates to the simple model improved model fit, by helping to account for negative residuals in the simple model during periods of low recruitment in the 1990s. Residuals in the accepted model, that included pup weight as a covariate, were generally well-behaved and did not exhibit pathological behavior. The inclusion of pup weight into the stock-recruitment model represents a reasonable scientific hypothesis regarding regulation of recruitment in this stock. However, although I find the proposed SSB_{max} reference point to be a justified and reasonable basis for current management needs, I strongly encourage NEFSC scientists to continue develop of a dynamic population model of spiny dogfish. A dynamic population model will integrate the full range of potential regulatory factors into management reference points and projections of stock status. As an intermediate measure, I would also encourage NEFSC scientists to evaluate more fully the correlation structure among potential covariates – particularly with respect to their temporal responses. For example, it is clear from the material presented that although female weight and pup biomass are correlated, their temporal responses differ substantially. A fuller understanding of the reasons behind this apparent uncoupling of female weight, pup weight and stock dynamics would be helpful.

Conversion of the SSB_{max} reference point into an absolute estimate of stock abundance is not without challenges. There are several plausible conversion factors that account for both the behavior of spiny dogfish when caught in trawls and the duration of the trawl itself. These alternative but plausible parameterizations introduce uncertainty into the estimate of SSB_{max} accepted by the review panel. I strongly encourage NEFSC scientists to bring forward estimates of the uncertainty in the SSB_{max} reference point to the relevant regional councils and SSCs. It is important for these bodies to have a full understanding of the uncertainty in **both** the current stock status and the reference point when evaluating risk

Reviewer #4

Review of:

Biomass Reference Points for Spiny Dogfish. MS 2010. Paul Rago and Katherine Sosebee.

I reviewed this ms as a result of unfinished work left over from the spiny dogfish TRAC. An earlier version of the work was presented but there was not sufficient time to review it adequately.

The document develops BRPs using survey based information of stock and recruitment. No errors were found during the review, but all analyses were taken as presented. (I did not play with any of the data in tables). Most of my technical concerns were addressed during the Conference call on April 9. I will list a couple of them here again:

> 1) To better display the quantified uncertainty, Figure 15 and 16 should show the respective reference levels with a representation of their uncertainty.
>
> 2) Is a Ricker stock recruitment a reasonable description of production for this stock? All of the BRPs are derived from a fitting a Ricker curve and then using the B that gives maximum recruitment as approximation the BMSY. The strong and correlated (in time) residuals suggest that something else is going on. The authors tried a couple of covariates, but a more extensive investigation is warranted. The influence of the covariate of choice (pup weight) seemed very large as was evidenced by to the affect adjacent years (1983 and 84) in Figure 10. Also, in a plot of a spline (at least I think it was) through the stock and recruit data a rather complex pattern was shown. If one were to look at this in an ad hoc way and ask where production was compromised the result may be quite different from the model based estimates.

While it is not my mandate to comment on process, I do not think that this important initiative and its documentation received the degree of review it warrants.

Robert Mohn

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