B: ASSESSMENT OF SPINY DOGFISH

Report of the Southern Demersal Subcommittee

and the

Atlantic States Marine Fisheries Commission
Spiny Dogfish Technical Committee

1.0 TERMS OF REFERENCE

1. Characterize the commercial and recreational catch including landings and discards.

2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.

3. Either update or re-estimate biological reference points (BRPs), as appropriate.

4. Evaluate current stock status with respect to the existing BRPs, as well as with respect to new or re-estimated BRPs (from TOR 3).

5. Perform sensitivity analyses to determine the impact of uncertainty in the recreational data on the assessment results.

6. Recommend what modeling approaches and data should be used for conducting single and multi-year stock projections, and for computing TACs or TALs.

7. If possible,

  a. provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and

  b. compare projected stock status to existing rebuilding or recovery schedules, as appropriate.

8. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC-reviewed assessments.

2.0 EXECUTIVE SUMMARY

TOR 1: *Characterize the commercial and recreational catch including landings and discards.*

The Working Group completed this term of reference. Discards were estimated with a new approach, mortality rates of discarded dogfish were updated, and the length and sex composition of the discards were estimated (see Dogfish Section 4.0).

TOR 2: *Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.*

The stochastic estimator of F and B, used in SARC 37 was updated to include uncertainty in recreational catch, and discards by gear type. This was the primary model used in the assessment. Full F on the female exploitable stock varied between 0.08 and 0.47 between 1990 and 2005. Even with the lower landings since 2001, fishing mortality rates on the fully recruited female stock component have remained above the rebuilding target (0.03). The current estimate of full F on dogfish in 2005 is 0.128 (0.09-0.174; 80% confidence interval). Female spawning stock size dropped to below 100,000 mt in 1997, declined to about 50,000 mt in 1998 and remained below 100,000 mt through 2004. The extremely high estimate in 2006 raised the 3-yr average female SSB estimate to 106,000 mt. The Working Group also developed an analytical model (LTM) to express survey indices of biomass in absolute scale and in turn to provide estimates of fishing mortality rates (see Dogfish Appendix B3).

TOR 3: *Either update or re-estimate biological reference points (BRPs), as appropriate.*

The Working Group estimated new biological reference points for spawning stock biomass based on the Ricker Stock-Recruitment model (Dogfish Section 8.0, Table 8.2). However, recent patterns of recruitment do not conform to the Ricker model, suggesting that more detailed consideration of reproductive biology may be necessary. Therefore, the Working Group recommended retaining the existing F and B reference points.

TOR 4: *Evaluate current stock status with respect to the existing BRPs, as well as with respect to new or re-estimated BRPs (from TOR 3).*

Based on the existing biomass threshold from SAW-37 (NEFSC 2003), the spiny dogfish stock is not currently overfished. The current estimated stock size of mature females (>80 cm) is 106,000 mt (72,000-140,000; 80% confidence interval), and this value exceeds $B_{threshold}$ (100,000 mt mature females, P=0.724). The biomass target in the spiny dogfish FMP (180,000 mt) was subsequently disapproved by NMFS; currently there is no approved biomass target in place.

The estimate for 2005 of F on fully recruited females is 0.128 (0.09-0.17; 80% confidence interval). This fishing mortality rate exceeds the existing overfishing threshold ($F_{threshold}$=0.11) and the existing rebuilding target ($F_{rebuild}$=0.03). However, the overfishing threshold was updated in the current assessment ($F_{threshold}$=0.39). Based on the updated estimate, overfishing is not occurring.

TOR 5: *Perform sensitivity analyses to determine the impact of uncertainty in the recreational data on the assessment results.*

Due to the small magnitude of recreational catch found it had little effect on the assessment. Moreover, the coefficient of variation of the discarded component of recreational landings is low (~10%) in recent years. Recreational removals are a minor source of uncertainty in the assessment.

TOR 6: *Recommend what modeling approaches and data should be used for conducting single and multi-year stock projections, and for computing TACs or TALs.*

The Working Group recommends using the approach from SAW37. (See Dogfish Section 10.0)

TOR 7: *If possible,*

c. provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and

d. compare projected stock status to existing rebuilding or recovery schedules, as appropriate.

Short term forecasts of spiny dogfish biomass (mt) are influenced by the current biomass and size structure of the population. Biomass of mature female spiny dogfish is expected to continue increasing through 2008 and 2009 as fish <80cm grow into mature size ranges (Figure B3). Subsequently, the biomass should decline due to the low number of recruits that were born during 1997-2003. If recruitment returns to levels consistent with expected size-specific reproduction, the biomass should begin to rebound again by 2015. (See Dogfish Section 10.0)

TOR 8: *Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC-reviewed assessments.*

This was addressed in Dogfish Section 11.

3.0 OVERVIEW

Spiny dogfish (*Squalus acanthias*) are distributed in Northwest Atlantic waters between Labrador and Florida, are considered to be a unit stock in NAFO Subareas 2-6, but are most abundant from Nova Scotia to Cape Hatteras. Seasonal migrations occur northward in the spring and summer and southward in the fall and winter and preferred temperatures range from 7.2° to 12.8°C (Jensen 1965). In the winter and spring, spiny dogfish are located primarily in Mid-Atlantic waters but also extending onto southern Georges Bank on the shelf break. In the summer, they are located further north in Canadian waters and move inshore into bays and estuaries. By autumn, dogfish have migrated north with high concentrations in Southern New England, on Georges Bank, and in the Gulf of Maine. They remain in northern waters throughout the autumn until water temperatures begin to cool and then return to the Mid-Atlantic.

Dogfish tend to school by size and, for large mature individuals, by sex. Dogfish prey on some commercially important species, mainly herring, Atlantic mackerel, and squid, and to a much lesser extent, on haddock and cod. Maximum reported ages for males and females in the Northwest Atlantic were estimated by Nammack (1982) to be 35 and 40 years, respectively, whereas ages as old as 70 years have been determined for spiny dogfish off British Columbia (McFarlane and Beamish 1987). In this paper, a maximum age of 50 years was assumed. Sexual maturity occurs at a length of about 60 cm (~8-10 yr) for males and 75 cm (~12-15 yr) for females (Jensen 1965). Reproduction occurs offshore in the winter (Bigelow and Schroeder 1953), and female dogfish bear live offspring. The gestation period ranges from 18 to 22 months with 2 to 15 pups (average of 6) produced. Females attain a greater size than males, reaching maximum lengths and weights up to 125 cm and 10 kg, respectively.

4.0 FISHERY-DEPENDENT INFORMATION

4.1 Commercial landings

Commercial landings data and biological information were obtained from the NEFSC commercial fisheries database. The sex of commercial landings was not recorded routinely until 1982. The commercial landings sampling program is described in Burns et al. (1983). Historical records dating back to 1931 indicate levels of US commercial landings of dogfish in Subareas 5 and 6 of less than 100 mt in most years prior to 1960 (NEFC 1990). Total landings of spiny dogfish in NAFO Subareas 2-6 by all fisheries climbed rapidly from the late 1960s to a peak of about 25,000 mt in 1974 (Table 4.1). Substantial harvests of dogfish by foreign trawling fleets began in 1966 in Subareas 5 and 6 and continued through 1977. Since 1978 landings by foreign fleets have been curtailed, and landings by US and Canadian vessels have increased markedly. A sharp intensification of the US commercial fishery began in 1990; estimated landings in 1996, in excess of 28,000 mt, were about five times greater than the 1980-1989 average. Landings between 1997 and 1999 averaged about 20,000 mt. Landings in 2001 and 2002 dropped dramatically with the large landings reductions imposed by federal and ASMFC management plans.

4.1.1 US landings

US commercial landings of dogfish from NAFO Subareas 2-6 were around 500 metric tons (mt) in the early 1960s (Table 4.1), dropped to levels as low as 70 mt during 1963-1975 while averaging about 90 mt, and remained below 1,000 mt until the late 1970s. Landings increased to about 4,800 mt in 1979 and remained fairly steady for the next ten years at an annual average of about 4,500 mt. Landings increased sharply to 14,900 mt in 1990, dropped slightly in 1991, but continued a rapid expansion from 18,987 mt in 1992 to over 28,000 mt in 1996. Landings in 1996 were the highest recorded since 1962, exceeding previous peak years during the early 1970's when the fishing fleet was dominated by foreign vessels (Fig. 4.1). Landings declined in 1997 and 1998 to around 20,000 mt. In 1999, the last full year unaffected by regulations, the landings declined to 14,860 mt. US landings dropped to about 2200 mt in 2001 and 2002 and then dropped further to around 1000 mt in response to quota restrictions.

4.1.2 Foreign landings

A substantial foreign harvest of dogfish occurred mainly during 1966-1977 in Subareas 5 and 6. Landings, the bulk of which were taken by the former USSR, averaged 13,000 mt per year and reached a peak of about 24,000 mt in 1972 and 1974 (Table 4.1). In addition to the former USSR, other countries which reported significant amounts of landings include Poland, the former German Democratic Republic, Japan, and Canada. Since 1978, landings have averaged only about 900 mt annually and, except for those taken by Japan and Poland, have come primarily from Subareas 4 and 3. Canadian landings, insignificant until 1979 when 1,300 mt were landed, have been sporadic, but again totaled about 1,300 mt in 1990. Canadian landings increased about nine-fold between 1996 and 2001 with landings of 3,755 mt in 2001. Landings in 2005 have not been finalized but should be around 1500 mt (Steve Campana, DFO personal comm.). and the other foreign landings were assumed to be the same as in 2004.

4.1.3 Gear types

The primary gear used by US fishermen to catch spiny dogfish has been otter trawls and sink gill nets (Table 4. 2, Fig. 4.2). The latter accounted for over 50% of the total US landings during the 1960s, while the former was the predominant gear through the 1970s and into the early 1980s. During the peak period of exploitation in the 1990s sink gill nets were the dominant gear. Landings in otter trawls ranged around 3000-5000 during this period. Both otter trawl and gill net landings decreased markedly in 2001, coincident with the rise in landings by hook gear. Landings of dogfish in drift gillnets peaked in 1998 with over 1300 mt but have since declined to near zero. Spiny dogfish taken by the distant water fleets were caught almost entirely by otter trawl. Recent Canadian landings have been mainly by gill nets and longlines.

4.1.4 Temporal and spatial distribution

The temporal and spatial pattern of dogfish landings are closely tied to the north-south migration patterns of the stock. Peak landings from May through October coincide with residency of dogfish along the southern flank of Georges Bank, the Gulf of Maine and the near shore waters around Massachusetts. At the population migrates to the south in late fall and early winter, landings increase in the southern states, especially North Carolina. US dogfish landings have been reported in all months of the year, but most have traditionally occurred from June through September (Table 4.3). During the peak years of the domestic fishery substantial quantities were also taken during autumn and winter months.

In most years since 1979, the bulk of the landings occurred in Massachusetts (Table 4.4). Other states with significant landings include New Jersey, Maryland, and Virginia. Landings in North Carolina peaked in 1996 at 6200 mt , about half of the Massachusetts landings, but dropped sharply to about 1300 mt between 1997 and 2000. North Carolina landings in 2001-02 were negligible. In 2001 and 2002, virtually all of the landings were taken north of Rhode Island.

Landings by statistical area (Fig 4.3) were updated for this assessment. As reported in SARC 19 (NEFSC 1994) most landings during the 1980's originated from statistical area 514 (Massachusetts Bay) and continue to occur in this statistical area (Table 4.5). Following the intensification of the fishery in 1990, statistical areas 537 (Southern New England) and 621 (off Delmarva and southern New Jersey) produced substantial quantities. In 1992 and 1993, large landings were reported from statistical areas 631 and 635 (North Carolina). However, in recent years, these have declined.

4.2 Recreational landings

Estimates of recreational catch of dogfish were obtained from the NMFS Marine Recreational Fishery Statistics Survey MRFSS (see Van Voorhees et al. 1992 for details). Recreational catch data have been collected consistently since 1979 but sex is not recorded. Methodological differences between the current survey and intermittent surveys before 1979 preclude the use of the earlier data. The MRFSS consists of two complementary surveys of anglers via on-site interviews and households via telephone. The angler-intercept survey provides catch data and biological samples, while the telephone survey provides a measure of overall effort. Surveys are stratified by state, type of fishing (mode), and sequential two-month periods (waves). For the purposes of this paper, annual catches pooled over all waves and modes and grouped by subregion (ME to CT, NY to VA, and NC to FL) were examined.

The MFRSS estimates are partitioned into three categories of numbers caught and landed: A, B1, and B2. Type A catches represent landed fish enumerated by the interviewer, while B1 are landed catches reported by the angler. Type B2 catches are those fish caught and returned to the water. Inasmuch as dogfish are generally caught with live bait and are often mishandled by anglers, the higher end of the estimated finfish discard mortality rates of 20% was assumed. The MRFSS provides estimates of landings in terms of numbers of fish. Biological information on dogfish is generally scanty, resulting in wide annual fluctuations in mean weights. To compute total catch in mt, an average weight of 2.5 kg per fish was assumed for all years.

Total recreational catches increased from an average of about 350 mt per year in 1979-1980 to about 1,700 mt in 1989-1991 (Table 4.1). Since 1991 recreational landings have decreased continuously from nearly 1500 mt to less than 400 mt in 1996. Landings by number (Fig. 4.4) suggest a similar but less pronounced decline. During the 1990s recreational landings represented a small fraction of the total fishing mortality on spiny dogfish. Even if all of the Type B2 catch died after release, recreational catches have comprised only about 8% of the total landings during this period. In 2001 and 2002 estimated B2 catches increased sharply. Total recreational catches represent about 25% of the landings in those years. In recent years, the precision of the discard estimates in the recreational fishery have been about 10% (Fig. 4.5). Precision of the estimates for the much smaller landed component has average about 28% over the 1981 to 2005 period.

As most of the recreational landings are discarded and is unlikely to be size or sex selective, recreational landings were added to the total discard estimates in this assessment. Average size composition of the recreational catch was assumed to be similar to the size compositions derived from at-sea observers in the otter trawl fishery. Size frequencies from a 2005 survey of recreational charter boat vessels (Fig. 4.6) was similar to the size composition of the NMFS trawl survey and the commercial fishery.

4.3 Size and sex composition of commercial landings

The seasonal distribution of biological sampling of the landings generally coincided with the seasonal pattern of landings (Table 4.6). Most samples were taken in June through November with much lower effort from January to May. In addition to the samples listed in Table 4.6, port samples obtained by MADMF in 2000 (15) and 2002(8), (provided by Brian Kelly, MADMF) were incorporated in into the analyses. These samples provided a substantial increase to the total number of measured fish in these years. The biological characteristics of the landings are driven primarily by the market place, particularly the acceptance of small dogfish. The major increase of small males in the 1996 landings probably reflects their acceptance by export markets as well as the availability of processing equipment for smaller dogfish. The estimated size and sex composition of the landings are based on pooled samples over the entire year.

From 1982 to 1995, over 95% of the sampled landings of spiny dogfish were females greater than 84 cm. Males comprised a small fraction of the landings and were rarely observed above 90 cm in length. In 1996 landings of male dogfish increased dramatically, both in numbers and total weight (Table 4.7). The increased fraction of male dogfish in the landings continued through 1999 but dropped markedly from 2000 through 2002. Presumably the drop in total quota resulted in a return to the remaining large females in the population.

Shifts in length frequencies toward smaller sizes reflect the marked increase in landings since 1989. The average size of landed females appears to have decreased by more than 15 cm since 1988 (Fig. 4.7, top). The average size of males dropped about 5 cm between1994 and 2000 (Fig. 4.8 top). Reductions in average weight of females (Fig. 4.7 bottom) are dramatic with a decline of average individual weight greater than 2 kg per fish since 1992. Again, the decline for males in 1996 is evident (Fig. 4.8 bottom) but the drop is about 25% for males in contrast to the 50% decrease for females. Decreases in average size are consistent with increased fishing mortality, but could also be due to changes in the mix of otter trawl and sink gill net catches.

Corroboration of these trends in observer program (Fig. 4.9) and in the research surveys (later section) suggests that these trends are the result of increased fishing mortality.

Mean sizes in the commercial fishery have declined to the extent that the increase in total landings of 14,731 mt in 1990 to 27, 241 mt in 1996 (an increase of 85%) was accompanied by a 311% increase in numbers landed. Percentage of males in the landed jumped dramatically in 1996 to 17% by weight and 25% by numbers. Commercial landings by weight in 1999 (17327 mt) were about equal to those in 1992 (17687 mt) but the decrease in average weight resulted in the removal of almost twice as many dogfish (9.3 M vs 4.6 M).

4.4 Discards

Methods

Owing to their ubiquitous distribution, dogfish are caught in a wide variety of fisheries. Owing to their low price per pound and need for special handling procedures onboard, dogfish is often discarded if more valuable species are present. Hence, high rates of dogfish bycatch and discards are expected. Previous assessments of spiny dogfish in the Northeast US have emphasized the need to estimate discard rates in other fisheries. In NEFSC (1994), preliminary estimates suggested that total discards were about the same order of magnitude at the commercial fishery. SARC 19 accepted provisional estimates of discard morality rates of 0.75 in gillnets and 0.5 in otter trawls but noted considerable uncertainty in these estimates. Preliminary information from discard mortality studies (Roger Rulifson, East Carolina State University, pers. comm.; Marianne Farrington and John Mandelman, New England Aquarium, pers. comm..) indicates that the mortality from gillnets may be much lower than previously assumed so an estimate of 0.3 was assumed in this assessment. The information from otter trawls also indicated a much lower mortality. However, the dogfish in various unpublished studies were all captured in relatively small tows. It was decided by the Working Group that these may not be representative of the otter trawl fishery in all areas, especially when very large tows are encountered. Therefore, the value of 50% was retained for otter trawls.

The primary database for discard estimates in the Northeast began in 1989 with the advent of a large-scale fisheries observer program for commercial vessels (Murawski et al. 1995, Anderson 1992). Species catch, effort, and associated biological and fishery data are collected for each trip. Previous estimates of dogfish discards used a ratio estimator to expand the sample discard rates to the total population. A primary component of this expansion was the reliance on the skipper's characterization of "primary species sought". Total estimates of dogfish discards were expanded by multiplying the discard/ton ratio by the total tonnage of landings of the target species. Previous estimates of dogfish discards were hampered by low sample sizes in major gear/area/target species cells.

A modified ratio estimator for discards developed for SARC 37 resulted in improved estimates of total discards and relative precision. The estimator relied on a post stratification of the observed data set into a groups defined by a primary species group landed. Instead of relying on a discard to kept (d/k) ratio based on a single species or effort, the method developed for SARC 37 was a more precise estimator of the d/k ratio. However, the method was subsequently shown to generate biased estimates of total discards. The difficulty arose because the expansion factor used to estimate total discards was based on the total landings of the primary species group. Since the total landings of the primary species groups also occurred in fishing trips where the not the dominant catch, the method could lead to extreme overestimates of dogfish discards in poorly sampled fisheries.

The ratio-estimator used in this assessment is based on the methodology described in Rago et al. (2005). It relies on a d/k ratio where the kept component is defined as the total landings of all species within a “fishery”. A fishery is defined as a homogeneous group of vessels with respect to gear type, mesh, season, and geographic region. Each of these attributes is an observable property and easily defined within existing data bases. Moreover, it is not dependent on ambiguous properties such as “target species” or imprecise self-reported attributes such as area fished.

The discard ratio for spiny dogfish in stratum h is the sum of discard weight over all trips divided by sum of kept weights over all trips:

$$\hat{R}_h = \frac{\sum_{i=1}^{n_h} d_{ih}}{\sum_{i=1}^{n_h} k_{ih}} \qquad (1)$$

where d_{ih} is the discards for dogfish within trip i in stratum h and k_{ih} is the kept component of the catch for all species. R_h is the discard rate in stratum h. The stratum weighted discard to kept ratio is obtained by weighted sum of discard ratios over all strata:

$$\hat{R} = \sum_{h=1}^{H} \left(\frac{N_h}{\sum_{h=1}^{H} N_h} \right) \hat{R}_h \qquad (2)$$

The total discard within a strata is simply the product of the estimate discard ratio R and the total landings for the fishery defined as stratum h, i.e., $D_h=R_hK_h$

The approximate variance of the estimate of R_{jh} is obtained from a first order Taylor series expansion about the mean (Cochran 1963):

$$V\left(\hat{R}_{jh}\right)=\frac{1}{(n_{jh}-1)n_{jh}\bar{k}_{jh}^2}\left[\left(\sum_{i=1}^{n_{jh}}d_{ijh}\right)^2+\hat{R}_{jh}^2\left(\sum_{i=1}^{n_{jh}}k_{ijh}\right)^2-2\hat{R}_{jh}\left(\sum_{i=1}^{n_{jh}}d_{ijh}\right)\left(\sum_{i=1}^{n_{jh}}k_{ijh}\right)\right] \tag{3}$$

where d_{ih} is the total discard weight of dog fish in trip i within stratum h, k_{ih} is the total kept weight of species in trip i within stratum h, n_h is the sample size (number of trips) in stratum h, and k_h bar is the sum of kept landings of all species within stratum h. Note that in this formulation of the variance, the finite population correction factor (fpc), i.e., one minus the sampling fraction within the stratum, has been omitted. This has been done to improve readability. The fpc is included however, in Eq. 4 for the total variance of the d/k ratio.

The variance of the d/k ratio for species group j over the entire set of strata is estimated using standard sampling theory methodology for a stratified random design as

$$V\left(\hat{R}_j\right)=\sum_{h=1}^{H}\left(\frac{N_h-n_{jh}}{N_h}\right)\left(\frac{N_h}{\sum_{h=1}^{H}N_h}\right)^2 V\left(\hat{R}_{jh}\right) \tag{4}$$

The overall coefficient of variation for the discard/kept ratio is defined as

$$CV_j=\frac{\sqrt{V(\hat{R}_j)}}{\hat{R}_j} \tag{5}$$

Under the assumption that the landings (K_h) are measured without error, the variance of the total discard estimate can be written as a linear combination of the stratum specific variances of d/k.

One of the key assumptions of ratio estimators is that the predictor variable (i.e., primary species group) should be positively correlated with the dependent variable (i.e., dogfish discards). In the gill net fishery, the correlation between dogfish discard and total landings was 0.851 (Fig. 4.10). In the otter trawl fishery, the correlation was 0.321 (Fig. 4.11) and statistically significant. For other fisheries examined (e.g., the scallop dredge fishery, Fig. 4.12) it was not possible to develop a statistically reliable estimator due to a lack of historical observer coverage. Precision of discard estimates decreases as one move toward inferences at finer temporal or spatial scales. This occurs no only because the reduction in sample size within strata but also because the estimate of the variance itself becomes less precise. The variability of the d/k ratio at a quarterly level is about twice as high as the derived annual estimate (Fig. 4.10-4.12).

Annual estimated discards for gill net and trawl fisheries for 1989-2005 are summarized in Table 4.8. Total discards peaked in 1990 with about estimates of about 40,000 mt. Most of this came from the otter trawl fishery. Relative precision of the estimates overall was reasonable, with highest levels of about 25% corresponding low numbers of observed trips. The overall effect of increased observer coverage can be seen in Fig. 4.13-4.15. Levels of observer coverage in past 2 years appear to be sufficient to generate annual discard estimates with CV<15% for all regions combined. Precision at finer spatial or temporal scales is much lower as shown in Fig. 4.10-4.12. A much greater source of uncertainty is the fate of the discarded dogfish, as discussed below.

Dogfish appear to be hardy animals and have a high post capture survival rate. Many factors influence this rate but one common feature appears to be the size of the total catch. Survival in very large tows appears to be low owing to compression, wounding, and delays in processing large catches. As noted above, the Subcommittee endorsed retaining the previously used survival rate of 0.50 for dogfish taken in trawl fisheries. Application of these survival rates to the total discard estimates by gear type and year are summarized in Tables 4.9 and 4.10. Discard estimates in fisheries other than otter trawls and gill nets appear to be an order of magnitude lower. Historical coverage for many of these fisheries has been sporadic and instances of high discard mortality cannot be denied or confirmed. In 2004 and 2005, when coverage has been high, estimated dead discards in scallop dredge, hook gear, midwater trawls and shrimp trawls appears to less than 5% of the total discard mortality (Table 4.10) .

Estimates of dead discards, using the method described above, compare favorably to values obtained at SARC 37 (Fig. 4.16) for 1992 onward. The very high levels in 1989-1991 in the previous report (e.g., greater than 45,000 mt) may have been a manifestation of the potential bias of the “primary species group” approach used at SARC 37.

In contrast to the previous assessment, the discard information on size and sex of retained and kept spiny dogfish was analyzed. Estimates of total discard weight by sex were obtained by multiplying the total discard weight by the ratio of sampled weights of males or females to the total sampled weight of discarded dogfish. Analyses of the size composition of the discarded dogfish could then be used to obtain a mean weight of the discarded dogfish. Dividing this value into the estimated total discards by sex allows for an estimate of total numbers discarded (Tables 4.11 and 4.12). Finally, the discard estimates by size can be estimated by redistributing the total numbers over the proportions at size from the observer data. Between 1989 and 2005 over 250,000 spiny dogfish were measured, with over 100,000 of these in the last 3 years.

Changes in size composition in the kept fraction of the catch on observed trips (Fig. 4.9) mirror the changes in median sizes found by port agents (Fig. 4.7). More detailed examination of the trends for males and female dogfish by gill net and trawl fisheries over time reveal a general decline in average size landed for females (Fig. 4.17 top). Large male dogfish appeared to decline quickly in the trawl fishery (Fig. 4.18 top) but there was no apparent change in average size of males retained in the gill net fishery. The effect of management measures on the discarded dogfish can be seen in Fig. 4.17 (bottom) where the average size has increased steadily since 2000 for both trawl and gill nets. No changes in average size of discarded male dogfish are evident for either gill nets or trawl (Fig. 4.18).

Estimates of discards for the 1981 to 1988 period were based on hindcast approach that relied on the observed ratio of discarded dogfish to landings of all species in 1989. For the otter trawl fishery this ratio was 0.21; for gill nets 0.28. Discards for 1981 to 1988 were estimated as the product of these ratios and the total landings within these fisheries (Table 4.13). Estimates of the size and sex composition of for this 1981 to 1990 period required another layer of imputation. Biological attributes of dogfish were irregularly collected in the early years of the at-sea observer program. Samples from 1991 to 1994 were pooled to obtain sufficient samples for a suitable size frequency distribution for discards. The composite sex and size frequency information was applied to actual total discard estimates for 1989 and 1990, and to the imputed discards for the period 1981-1989. As a consequence, the discard estimates for the1981-1990 are considerably less precise than those since then. The resulting composite size frequencies for female spiny dogfish landings and dead discards by year are presented in Fig. 4.19 to 4.21. The strong mode at about 70 cm reflects the assumptions associated with the use of the pooled biological attributes from 1991-1994.

5.0 FISHERY-INDEPENDENT DATA

5.1 Research vessel abundance indices

5.1.1 NEFSC surveys

The Northeast Fisheries Science Center (NEFSC) has conducted both spring and autumn trawl surveys of the USA continental shelf annually since 1968. The surveys extend from the Gulf of Maine to Cape Hatteras. Details on the stratified random survey design and biological sampling methodology may be found in Grosslein (1969), Azarovitz (1981) and NEFSC (1995). Sex of spiny dogfish was not entered into the database until 1980.

Indices of relative stock biomass and abundance for spiny dogfish were calculated from NEFSC spring and autumn bottom trawl survey data. Overall indices were determined using only the offshore strata (1-30, 33-40, and 61-76) (Fig. 5.1) in order to obtain longer time series (i.e., 1967-1993 for the autumn survey and 1968-1994 for the spring survey). The autumn survey could not be extended back to 1963 because sampling of the Mid-Atlantic strata (61-76) did not begin until 1967. Estimates of dogfish density in inshore strata (Fig. 5.2) were also computed.

In both the spring and the autumn surveys, there was considerable variability in the indices (Table 5.1 ,5.2, Fig. 5.3). Both sets of indices indicate an overall increase in abundance and biomass from the early 1970s through the early 90s. Since that time, total index biomass has begun to decline, with greatest change occurring with females in the spring survey. The rate of change in the autumn survey has generally been less than observed for spring. At SARC 18 it was determined that the higher variability in the fall survey is attributable to variable fraction of the population present in Canadian waters during the NEFSC fall survey. The NEFSC winter survey utilizes a flat net without the large rock-hopper rollers present on Yankee 36 trawl used in the spring survey. Average catches in the winter survey are generally 3 to 5 times greater than the other NEFSC surveys (Table 5.3)

5.1.2 Canada R/V survey

The Canadian Department of Fisheries and Oceans conducts a survey from the Bay of Fundy eastward to Georges Bank and northeast to the boundary of the Laurentian Channel in NAFO Divisions 4VWX. Average station densities for the 1980-2001 period (Fig. 5.4) reveal the distribution of dogfish to be low east of 62.5 deg W. Male dogfish are much more abundant than female dogfish in Canadian waters in the summer. Over the entire time series estimated male dogfish biomasses were 2.8 times greater than female biomass.

5.1.3 State surveys

Abundance indices for spiny dogfish from Massachusetts spring and autumn inshore bottom trawl surveys in 1978-2005 reveal two different facets of dogfish abundance. The spring survey usually occurs before the major influx of dogfish to Massachusetts waters. Catches are low but variable. In the fall, catches tend to be an order of magnitude larger, as much of the dogfish stock is concentrated near the Massachusetts coast (Table 5.4, 5.5, Fig. 5.5). Wide variations in availability result in highly variable survey indices. High variability in this survey is also a reflection of the seasonal use by dogfish of the area surveyed by the State of Massachusetts.

5.2 Size and sex compositions

Size frequency distributions of spiny dogfish (sexes combined) from the spring and autumn NEFSC surveys were examined (Fig. 5.6 a-d). The spring survey length frequencies have three modes corresponding to new recruits (≤40 cm), mature males (70-80 cm), and mature females 95 cm. Large numbers of recruits have appeared periodically in the time series, especially in the early 1970s. The length frequency patterns in the autumn survey catches are much less consistent and there is no apparent tracking of modal lengths over time. Since 1997 both the spring and fall surveys are characterized by a single mode (Fig. 5.6d). NEFSC spring survey indices increased sharply in 2006 (Fig. 5.6d), and catches are shown in maps (Fig. 5.6 e-f).

Male and female size frequencies distributions are summarized by year for the spring (Fig. 5.7 a-c) and fall surveys (Fig. 5.8a-c). Male length frequencies are strongly skewed with an accumulation near the asymptotic size limit.

Qualitatively similar size frequency patterns for both sexes combined can be seen in the Massachusetts survey data (Fig. 5.9 a-c) autumn survey.

Further insight into the changes in abundance and size composition may be obtained by examining the average size frequency compositions over multi-year periods (Fig. 5.10). The size composition changed as the fishery progressed. The 1988-90 length frequencies approximate the expected female size composition in a stable population under a low rate of fishing mortality. A large number of adults greater than 80 cm are present with a peak near the asymptotic size. Concomitantly, a relatively large number of juveniles less than 35 cm are also present. Reductions in maximum sizes occurred rapidly such that by 1996 the population of mature females had been reduced roughly by half. Beginning in 1997 incidence of pups in the survey was almost non existent, a pattern that has continued until 2006. A slight increase in pup production was observed in 2004 but not since. The absence of pups during this period is similarly confirmed in the 1997-2005 fall survey (Fig. 5.6c-d)

The cumulative effects of reductions in the spawning stocks and the near absence of pups in the surveys since 1997 are evident in the size frequency of both male and female spiny dogfish. The progressive loss of smaller dogfish less than 70 cm is evident and is consistent with the expected growth of dogfish. These reductions support the hypothesis that the absence of recruits beginning in 1997 is real, since dogfish in this size range are expected to be about 4-7 years old. While the reduction in dogfish size groups below 70 cm is consistent for both males and females, no truncation of male dogfish is evident for males. This observation is again consistent with the observed low rates of landings of males.

Size frequencies of male and female dogfish in the DFO summer survey (Fig. 5.11) do not show major reductions in either large females or immature males or females during the period of the intense size selective fishery on female dogfish in the US. The apparent absence of these smaller dogfish over the entire time series suggests that pups are not present in 4VWX in appreciable numbers. This would support the argument that the adults present in Canadian waters of the Gulf of Maine and Scotian shelf are born elsewhere.

Changes in average size of mature female dogfish is a consistent property of NEFSC spring, fall, and winter surveys, the Massachusetts Division of Marine Fisheries survey, and the ASMFC shrimp survey (Fig. 5.11a). All of these surveys have shown declines in average size of 10 cm or more between 1990 and 2000. A SeaMap Survey (not shown) conducted off North Carolina has a similar current average size for mature females. The average average length of mature females in the DFO survey is about a cm smaller than in the US (Fig. 5.11b). While the average size of female dogfish has also declined about 10 cm, the decline commenced slightly earlier (~1980) than in the US.

Spiny dogfish are known to school by size and sex and a viable hypothesis for the scarcity of pups in the 1997 to 2006 period is that the surveys “missed” the few tows that define a peak. Due to intracluster correlation, (Pennington et al. 2002) the effective sample size of a trawl tows is close to one. To examine these hypotheses, each tow of the 24,000+ tows taken in the NMFS spring and fall surveys since 1982 were assigned a value related to the fraction of females present (0-1) and average size of individuals in the tow. A bivariate bubble plot of these variables was used to illustrate the effect of tows on the derivation of changes in size and sex composition of the population structure. Bivariate nonparametric kernel densities were used to define the loci of nearly pure male and female schools and the mixed schools of immature fish. It is hypothesized that the all male and all female schools represent sexually mature fish while the mixed schools are immature fish. Marginal kernel distributions in each plot reveal the overall sex ratios and size frequencies.

The changes in size and sex composition since 1982 are marked and consistent for both the spring and fall surveys (Fig. 5.12 and 5.13). The frequency of large female schools decreased between 1982 and 2006 concomitant with a reduction in average length of fish in the schools. Densities of mixed schools with average sizes less than 60 cm declined markedly as the abundance of large female dominated schools dropped. For both the fall and spring surveys, the bivariate distribution of average size vs sex ratio that resembled a “Y” in 1982-1986 had been transformed to a long “dash”, with little distinction in average size.

Marked changes in the ratio of numbers of mature male spiny dogfish to female spiny dogfish have occurred since 1980. Sex ratios of mature males (>60 cm) to mature females (i.e. >80 cm) averaged about 2:1 before 1992 but increased rapidly to about 7:1 in 2001 (Fig.5.13a). Since then it has been varied about the 7:1 ratio. The importance of the sex ratio for successful reproduction of spiny dogfish is unknown. Spatial segregation of shark populations by sex has been reported in the lesser spotted dogfish, *Scyliorhinus canicula* by Sims et al. (2001) and appears to be a general behavior of sharks (Springer 1967, cited by Sims et al.). Sims et al. hypothesized that the spatial segregation may be related to a “need for females to conserve energy by limiting multiple matings during a time when mating coincides with a peak in egg production and laying.” Parturition and fertilization in spiny dogfish (*Squalus acanthias*) overlap in time (~October-January, Jones and Ugland, 2001). Therefore, a similar behavioral mechanism for spatial segregation by school may be present in spiny dogfish.

5.3 Analysis of survey variability

Wide swings in spiny dogfish abundance are common in all of the survey indices for spiny dogfish. In most instances the variations are greater than expected or possible for a slowly growing, low fecundity species like spiny dogfish. Much of the variation can be attributed to the schooling behavior of dogfish and a hypothesized herding response to trawl doors. Many teleost species herd (Ramm and Xiao 1995), a process which increases the effective footprint of the trawl. When herding occurs, but not accounted for, population sizes will be overestimated and fishing mortality will be underestimated. Schooling and herding effects both contribute to the overdispersion of catch data. Exploratory analyses of the relationship between the mean and variance of each stratum reveal that the standard deviation of stratum numbers per tow increases linearly with the mean in both the spring (Fig 5.14) and fall (Fig. 5.15) surveys. This property is consistent with the variances increasing with the square of the mean, an expected property of the negative binomial distribution where $\sigma^2=\mu+\mu^2/k$. Since the variance is increasing faster than the mean, the ability to detect moderate true changes will decrease as population size increases (and vice versa). Thus the variability of a single realization of a sampling program is also expected to increase with overall density. This property manifested itself in the 2006 NEFSC spring survey wherein average weight per tow increased by two fold, after more than a decade of consistent declines or no appreciable increases (Fig. 5.3). This change, and its implications for stock rebuilding, mandated a more intensive investigation of the variability of the survey data and a consideration of alternative hypotheses. The remainder of this section and section 5.3 are devoted to this line of investigation.

The sampling properties of finfish surveys have been investigated by many authors (see Smith 1997 as a starting point). It has been noted that the variability induced by availability to the survey area and changes in gear efficiency can exceed variations associated with sample selection within a stratified design. Analyses were conducted to address the following questions:

- Is the current stratified sampling design an improvement over simple random sampling for dogfish?
- Has the proportion of positive tows or excessively large tows masked true changes in abundance?
- Does the use of an untransformed response variable (numbers or weight) an appropriate measure of central tendency and dispersion?
- Has the population changed its distributional patterns?
- If distributional changes have occurred, can they be associated with an environmental change?

The design efficiency was evaluated using the methodology of Gavaris and Smith (1987) and Cochran (1963) and using Splus software written by Stephen Smith, DFO, Halifax. Design efficiency can be decomposed into components associated with stratification and allocation of samples to strata. Stratification effects alone are always neutral or positive, i.e., they will always improve the precision of an estimate relative to a simple random sample or leave it unchanged. Allocation effects can be positive or negative such that a stratified design can have lower precision than a simple random sample. Analyses of the spring and fall surveys, using female weight per tow as the response variable, suggests a small positive effect (~ 10%) due to stratification (Fig. 5.16) and a small, usually negative allocation effect. Effects of stratification and allocation appear to be less variable for the spring survey than the fall survey. Neither survey represents a significant improvement over a simple random sample for spiny dogfish. This conclusion however cannot be generalized since the survey stratification is designed to accommodate many species. A theoretical analysis of optimal allocation of sampling effort for these surveys suggested that sampling effort would have to be redirected almost entirely to the strata with the highest densities. Since the strata with highest concentrations of dogfish can change over time, an allocation strategy based on the previous year's distribution could be seriously in error, especially since it would diminish sampling effort in strata important for other species.

The fraction of positive tows in the spring survey for decreased from about 50 to 30% between 1970 and 1980 and has fluctuated at about 40% since then (Fig. 5.17). An arbitrary total catch weight of 1000 kg was used to define "large" tows. "Large" tows have increased in the fall survey to about 2.5% of the tows. These tows represent about 50% of the total dogfish catch taken by the survey in a given year (Fig. 5.17 bottom, Table 5.6). In the spring survey (Fig. 5.18, Table 5.7) the fraction of positive tows exhibited no trend, nor has the fraction tows with "large" catches. The contribution of large tows to the spring survey appears to fluctuate about 30% of the total survey catch. Thus the fall survey is more variable over time and thought to be less useful as a measure of the closed population.

A variety of method have been proposed to deal with overdispersed catch data including transformations (Pennington 1996), trimming (Kappenman 1999), and bootstrapping (Smith 1997). Bootstrap methods per Smith (1997) were used to examine the sampling distribution of the survey estimates of mean density. Bootstrap estimates of mean weight per tow for female and male dogfish in the spring survey are reported in Fig. 5.19. Bootstrap confidence intervals increase in length as density increases. With respect to the 2006 value however, little overlap with the 2005 estimate is evident. Confidence regions for 2006 do appear to overlap with survey values in 2002. The length of the nominal confidence interval (=upper percentile value – lower percentile) is generally smaller for the bootstrap method than the parametric method (Fig. 5.20). It appears that the bootstrap interval is an improvement over the conventional parametric confidence intervals, especially since it ensures that the lower bound predicted confidence interval will always exceed zero and it does not require the uncertain implications of the back transformation to the arithmetic scale.

The 2006 spring survey index for mature females of 39.4 kg/tow was the 5th highest in the 39 year time series. The swept area estimate of spawning stock was 4.5 times greater than that observed in 2005. A map of the survey catches in 2006 did not reveal any extraordinary outliers (Fig. 5.20.1). Two major concentrations were evident from in a band directly east of Gloucester into the Gulf of Maine, and in the Mid Atlantic south of Long Island. Relatively lower concentrations were found in along the shelf break from Southern New England to the southern flank of Georges Bank. Over the entire time series, this zone was generally in the upper quintile of densities. The high concentration in the central Gulf of Maine is anomalous with the long term patterns of use for this region (lower 40% of station densities) but appears consistent with patterns in the last 5 years (2001-2005). A comparison of the mean variance relationship for 2006 with the 1993-2005 period suggested a newly equivalent relationship (Fig. 5.20.2) .

5.4 Analysis of environmental factors

Over the past few years, numerous fishermen have complained about the increased densities of dogfish in the inshore waters, particularly in the fall. A comparison of swept area estimates for the inshore and offshore strata in spring and fall supports these claims (Fig. 5.21, Table 5.8). In the fall survey the inshore strata constituted about 10% of the population; in the last 5 years this fraction has been greater than 30%. The spring survey typically indicates about 1-2% in the inshore strata, but since 2001 this has been about 5%.

The movement toward shore was quantified by computing the distance to shore for each station and computing catch weighted average distances. Catch-weighted distances were compared to the average distance from shore for sample stations. This approach is similar to that used by Perry and Smith 1994 to identify important environmental factors. In the present context, we are simply using this approach to describe trends. This methodology was applied to a number of other factors including latitude, longitude, bottom temperature, average depth, and salinity. (Fig. 5.22 to 5.27) Computations were performed for each year by sex for both spring and fall surveys.

Analyses of distance to shore reveal a striking inshore movement by males (fall survey) of nearly 60 km between the mid 1980s and the last decade (Fig. 5.22). Females also moved closer to shore, from 60 km offshore to 40 km. In the spring survey, males moved about 50 km closer to shore but females showed no consistent trend. Historically, the locus of male abundance was about150 km offshore. Currently the locus for males is about 100 km offshore and more coincident with the distribution of females. This increased overlap during this period immediately after dogfish have released their pups may be important ecologically.

Survey catches from 2006 are mapped in Fig. 5.6 e-f. Stock size of mature females increased nearly five-fold compared to the previous years. Such rapid changes in the true abundance of dogfish are implausible owing to the slow growth rate of the species. Changes in distribution and availability of dogfish to the Spring survey in 2006 can partly explain the major change in the survey index. The high index in 2006 was not due to one or two exceptionally large tows. Rather, the dogfish distribution shifted into large strata with higher weighting factors. In 2006, five strata had average survey catches that were the highest since 1980. Strata 65 and 66, east of Delmarva, had female catch rates that ranked second and first, respectively over their time series. Stratum 73, off New Jersey, also recorded its highest ever female dogfish survey catch. The high average in stratum 73 was attributable to a large catch on the boundary with stratum 74, a much smaller stratum.

Changes in catch-weighted latitude (Fig. 5.23) and longitudes (Fig. 5.24) suggest that dogfish are north of the average station in the fall survey and south of the average station in the spring. In particular, the locus for male dogfish is almost 2 degrees farther south than during the 1990's. Males in the spring have moved farther west (~ 2 degrees).

Analyses of temperature (Fig. 5.25), average depth (Fig. 5.26) and salinity (Fig. 5.27) did not appear to have any significant trends. However, males and females are found at cooler temperatures in the fall (~10 deg) than the standard survey station and higher temperatures in the spring. In the fall these temperatures are found in more shallow depths whereas in the spring males are found at deeper depths than the average over all tows.

6.0 ANALYSIS OF INDEX TRENDS

In this section we further examine the changes in the survey indices and consider changes in swept area biomass for various size groups by sex. A summary of the research on changes in the average size of mature females and interrelationships with numbers and average size of pups may be found in NEFSC (2003, SARC 37)

6.1 Swept-area biomass estimates

Estimates of minimum stock biomass were determined from the NEFSC spring survey catches. Mean numbers per tow by sex and 1-cm length class were converted to average weights using a length-weight regression (females: $W = \exp(-15.0251) * L^{3.606935}$; males: $W = \exp(-13.002) * L^{3.097787}$). These average weights were then multiplied by the total survey area (64,207 n mi^2) and divided by the average area swept by a 30-minute trawl haul (0.01 n mi^2). Three size categories were defined ($\leq$35 cm, 36-79 cm, and $\geq$80 cm) which approximately correspond to new recruits, males and immature females, and mature females, respectively (Table 6.1).

One of the critical assumptions of the swept area computation is the size of the trawl footprint. The nominal footprint is based on the area swept by the net traveling at an average speed of 3.5 knots for 30 minutes. The effective capture zone is the distance between the wings of the net. Recent information (unpublished net mensuration data, Ecosystem Survey Branch, NEFSC) on variations in vessel speed and the increased contact time during haulback suggest that the effective area swept is expected area swept is greater than the nominal footprint. Additional details on this are provided in section 7 of this report. To illustrate the effect of this factor, the swept area biomass estimates are computed with a nominal footprint of 0.012 n mi^2 (Table 6.2).

Swept area biomass estimates, using the 0.01 n mi^2 footprint were partitioned into size groups <36 cm, 36-79 cm, and $\geq$80 cm. For females, these size ranges roughly correspond to dogfish less than one year old, immature individuals and mature adults, respectively. For males, the intermediate size range represents both adolescent and mature individuals. Male dogfish >80 cm are mature, but relatively uncommon as the average asymptotic size is about 80 cm.

Swept-area estimates of stock biomass exhibit annual variation that exceeds biologically realistic changes for such a long-lived species. Therefore, LOWESS smoothed (tension=0.5) estimates of biomass were considered to be better measures of population trends. Overall biomass estimates increased steadily from 1968 through 1992 to about 600 k mt but have declined to about 400 k mt, about the same level as observed in 1985 (Fig. 6.1). The changes in total biomass mask significant changes that have occurred within size and sex groups. The pool of male and female dogfish between 36 and 79 cm has remained relatively stable over the past decade (Fig. 6.1 bottom) at about 350 k mt. From 1980 onward dogfish sex was recorded in the NEFSC database, allowing examination of the trends by sex as well. Figure 6.2 reveals the marked change in female spawner biomass (top) and evidence of reductions in the large males as well (bottom). Biomass changes in the intermediate size range of females are now evident (Fig. 6.3 top) as the fishery has continued to accept smaller sized dogfish. Male 36-79 cm dogfish biomass has increased steadily since the early 1980's (Fig. 6.3 bottom). The effects of the increased catch rates for the 2006 survey do not seem to have much influence on the predicted abundance in the terminal year.

Dogfish less than 36 cm represent individuals less than one year old at the time of the survey and are considered as recruits to the population. Recruitment generally has been stable through most of the time series with a number of strong year classes in the 1980's (Fig. 6.4). Number of recruits between 1997 and 2003 were the 7 lowest in the 41 year series. Coincident with the change in abundance, the average size of dogfish in this size range has also declined by about 3 cm (Fig. 6.5). The trend in abundance of recruits is consistent with the reduction in spawning stock but the magnitude of the change is unexpected. The decline in the average size of mature females appears to have attenuated in the last 3 years. Average pup size has stabilized and may have increased by about 1 cm. No additional work on this topic was reviewed by the Subcommittee. See Section 6.2 of NEFSC (2003) for a summary of previous work.

7.0 FISHING MORTALITY AND BIOMASS ESTIMATION

7.1 Beverton-Holt estimator

Instantaneous total mortality rates (Z) for female dogfish were estimated using the length based method of Beverton and Holt (1956)

$$Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L'}$$

where K and L∞ are from the von Bertalanffy growth model and L is the stratified mean length of individuals in the spring survey greater than the critical length L'. L' is the 25%-ile of length in the commercial landings. Parameters for female growth were K=0.1128, Lmax=105 cm. Fishing mortality rate is obtained as the difference between Z and natural mortality M. The Beverton-Holt estimator was evaluated over a range of sizes at entry to the fishery and natural mortality rates (M=0.092; 50-yr lifespan, M=0.06; 100-yr lifespan) to explore the sensitivity to these assumptions.

Mortality rates averaged about 0.06 during 1980's when landings averaged about 6000 mt. Landings nearly tripled between 1989 and 1990, increased since then to over 28,000 mt in 1997 and have subsequently decreased (Table 4.1). The increase in fishing mortality rates reflects the increase in landings to levels above 0.4 in the late 1990's. Regardless of the underlying parameter assumptions, the estimates of F exceed the biological reference points of 0.08 (target) and 0.11 (threshold) (Fig. 7.1). The Beverton-Holt estimator is expected to lag the true rate of fishing mortality when fishing mortality is increasing. Conversely, since it is dependent on the growth and assumes an equilibrium size structure, it is subject to transient conditions. Thus the mortality estimates for the female population in the last 3 years, when fishing mortality rates have declined are likely to reflect the history of the fishery rather than the contemporary status. During the course of various meetings related to the development of the federal and ASMFC management plans, it was noted that additional analyses would be required to assess contemporary fishing mortality rates. Those analyses are presented below.

7.2. Selectivity of fishery: landings and discards

The changes in average size of dogfish are consistent with the targeted removal of large females. However, the changes in size selectivity over time also have important implications for the total force of fishing mortality on the population. High rates of mortality over a broad range of size groups have greater biological implications than an equivalent fishing mortality rate over a narrow range of size classes. The magnitude of these changes is important for estimation of fishing mortality, for evaluation of reference points and for population projections under various management scenarios. The first step in developing an estimator of F which incorporates both landings and survey information is to estimate a size specific selectivity function.

The selectivity of the fishery was approximated by assuming that proportion of stock available to the commercial fishery could be expressed as a logistic function of the size frequency distribution of the survey. Let $p_s(l)$ represent the proportion at length l in the survey and let $p_c(l)$ represent the proportion at length l in the commercial landings. The statistical model to relate these quantities can be written as

$$p_c(\ell) = \frac{p_s(\ell)\left(\frac{1}{1+e^{a+b\ell}}\right)}{\sum_{\ell=50}^{L_\infty} p_s(\ell)\left(\frac{1}{1+e^{a+b\ell}}\right)}$$

where a and b represent the parameters to be estimated. In general this model fit the data very well. Details on the application of this model to data from 1990-2002 by sex are provided in Appendix 1. Appendix 1 deals with the selectivity of the commercial fishery, in the absence of data on the discarded length classes. Appendix 2 examines the derived selectivity function for composite size frequencies in Fig. 4.19-4.21. The selectivity model tends to fit the composite landed + discard data more poorly. Owing to the mixture of component fleets constituting this composite size frequency distribution, and the extreme uncertainty of the size compositions for 1994 and earlier, a more complicated selection function may be warranted.

7.3 Stochastic estimation of fishing mortality and biomass

7.3.1 Methods

A stochastic estimator of fishing mortality was developed to improve the estimation of contemporary estimates of fishing mortality. The estimator developed below incorporates a greater degree of mechanistic detail and uncertainty in the data. Several different measures of fishing mortality are of interest. First we are interested in the total rate of mortality on the exploitable stock of male and female dogfish (F_1).

Second, we are interested in the mortality generated by the removals of discards (F_2). This quantity is differentiated from F_1 because it acts non-selectively over the entire stock, not just the exploitable stock. The weighted average of F_1 and F_2, called F_{bar}, represents the force of mortality acting on the entire stock. (i.e., a biomass-weighted F). In terms of evaluating the fishing mortality rate with respect to a biological reference point, we are interested in have a metric commensurate with the pup-per-recruit analyses (Section 8.0).

Define

F_1 = F generated by female landings and discards acting on the exploitable biomass of female dogfish
F_2 = F generated by male landings and discards acting on the exploitable biomass of male dogfish

F_3 = F generated by female landings acting on the spawning biomass of female dogfish (>80 cm)

F_4 = F generated by male landings acting on the exploitable biomass of male dogfish

Using the catch equation, it is possible to define the various F metrics as follows

Variable Definitions

L = Total landings (mt) of USA plus Canadian commercial landings
L_f = Landings (mt) of female dogfish in USA plus Canadian commercial landings
L_m = Landings (mt) of female dogfish in USA plus Canadian commercial landings

$B(\ell)$ = Total biomass(mt) of male plus female dogfish at length ℓ. $B(\ell)=B_f(\ell) + B_m(\ell)$
$B_f(\ell)$ = Total biomass(mt) of female dogfish at length ℓ.

$B_m(\ell)$ = Total biomass(mt) of male dogfish at length ℓ.

$B_{expl}(\ell)$ =Exploitable biomass(mt) of male plus female dogfish at length ℓ.
$B_{expl}(\ell)=B_{expl,f}(\ell) + B_{expl,m}(\ell)$
$B_{expl,f}(\ell)$ = Exploitable biomass(mt) of female dogfish at length ℓ.
$B_{expl,m}(\ell)$ = Exploitable biomass(mt) of male dogfish at length ℓ.

D = Total discards (mt)

D_{G_f} = Dead discards of females in the gill net fishery
D_{T_f} =Dead discards of females in the otter trawl fishery
D_{R_f} = Discards of females in the recreational fishery

D_{G_m} = Dead discards of males in the gill net fishery
D_{T_m} =Dead discards of males in the otter trawl fishery
D_{R_m} = Discards of males in the recreational fishery

$N(\ell)$ = Number of dogfish in population at length ℓ.
$I(\ell)$ = Index number of dogfish in population at length ℓ.
$p(\ell)$= proportion of dogfish in population of length class ℓ

$sel_f(\ell)$ = Selectivity fraction for females of length ℓ.
$sel_m(\ell)$ = Selectivity fraction for males of length ℓ.

$W_f(\ell)$ = Average weight (kg) of females of length ℓ.
$W_m(\ell)$ = Average weight (kg) of males of length ℓ.

A= Total domain of offshore survey strata (nm^2)
a= Area swept by standard trawl tow (nm^2).

Xbar,t = Average number of dogfish caught per tow in NMFS spring survey in year t.
S^2_t = Estimated variance of mean catch per tow in NMFS spring survey in year t.

$$L_f + D_{Gf} + D_{Tf} + D_{Rf} = \sum_{l=l_{\min}}^{l_{\max}} F_1\left(sel_f(l)B_f(l)\right) \qquad 1)$$

$$L_m + D_{Gm} + D_{Tm} + D_{Rm} = \sum_{l=l_{\min}}^{l_{\max}} F_2\left(sel_m(l)B_m(l)\right) \qquad (2)$$

$$L_f = \sum_{l=80}^{l_{\max}} F_3 B_f(l) \qquad (3)$$

$$L_m = \sum_{l=l_{\min}}^{l_{\max}} F_4 sel_f(l) B_m(l) \qquad (4)$$

The estimates of F can be obtained by rearranging Eq. 1 to 4, simply dividing the left hand side by the non-F terms on the right hand side equation.

The biomass variables can be written as the product of survey numbers at length and average weight at length and a scaling factor equal to the ratio of the total survey area divided by the footprint of the average tow.

$$\begin{aligned}
&B(l) = B_f(l) + B_m(l) \\
&\mathit{where,} \\
&B_f(l) = N_f(l)W(l) = I_f(l)\left(\frac{A}{a}\right)W_f(l) \\
&B_m(l) = N_m(l)W(l) = I_m(l)\left(\frac{A}{a}\right)W_m(l)
\end{aligned}$$

The index number at length by sex can be further generalized to express it as the average number per tow X_{bar} times the fraction of the population at length p(ℓ). The proportion at length is derived from the survey.

$$\begin{aligned}
&I_f(l) = \overline{X}_f p(l) \\
&I_m(l) = \overline{X}_m p(l)
\end{aligned}$$

All of the quantities in Eq.1 to 5 are measured with error but for this assessment it is assumed that the errors in the estimates of landings by sex and length class are negligible. Much greater variation is likely for survey abundance measures and total discards. To capture the effects of these sources of variation, stochastic versions of Eq. 1 to 5 were computed by convolving distributions of survey abundance, discards and trawl footprints.

Substantial variation in survey based estimates of dogfish abundance occurs across years. For some years the variation exceeds what would be expected in terms of possible biological changes. To accommodate such variation, we use a simple 3yr moving average smooth of the overall abundance estimates. The composite averages by sex are estimated as

$$\bar{\bar{X}}_{f,t} = \frac{\sum_{j=t-1}^{j=t+1} \bar{X}_{f,j}}{3}$$

$$\bar{\bar{X}}_{m,t} = \frac{\sum_{j=t-1}^{j=t+1} \bar{X}_{m,j}}{3}$$

The associated variances are estimated as

$$\bar{S}^2_{f,t} = \frac{\sum_{j=t-1}^{j=t+1} \bar{S}^2_{f,j}}{3}$$

$$\bar{S}^2_{m,t} = \frac{\sum_{j=t-1}^{j=t+1} \bar{S}^2_{m,j}}{3}$$

Sampling theory suggests that the survey mean should be asymptotically normal. We exploit this feature to simplify the estimation of the stochastic distribution of the Fs. A summary of the 3-yr moving average and its composite variation is provided in Table 7.1.

The survey footprint is also measured with error. One source of error is the magnitude of variation in the length of the tow. The effective time on the bottom can exceed the nominal tow duration owing to delays in lifting the net off the bottom during haulback. As the net is moving forward with the combined forward velocity of the vessel plus the forward speed of the cable, the effective area swept will exceed the nominal target. To account for this variation in footprint size, preliminary data collected aboard the R/V Albatross IV in 2002 were used to estimate the possible variation in tow lengths. See Table 7.2

Variation in discards was estimated using the method described in Section 4.4.

Evaluation Method

Let Φ = Normal cumulative distribution function. The inverse of Φ, denoted as Φ^{-1} allows the evaluation of a set of values over a specified range, say $\alpha_{\min}$ and $\alpha_{\max}$, over equal probability intervals.

$$X'_{t,\alpha} = \Phi^{-1}(\alpha \mid \bar{\bar{X}}, \bar{S}_t^2)$$

The step size between successive values of α was set as 1/500 (0.975-0.025), where α_{min} =0.025 and α_{max}=0.975. An equivalent approach was used for evaluation of the footprint parameter a where a~N(μ_a , σ_a^2) and the discard estimate D~N(μ_D , σ_D^2). Discard means and variances were estimated for each gear and sex and incorporated into Eq. 1 and 2. For both of these parameters the sample mean and variance estimates were used to estimate the normal distribution parameters.

The sampling distribution of each of the Fs described above was evaluated by integrating over each of the normal distributions for X, a, and D_G, D_T, and D_R. The density X and footprint a parameters were evaluated over 500 equal probability intervals, while the sampling distribution D_G , D_T, and D_R were evaluated over 20 intervals. This brute force approach to the multidimensional integration provides reasonable assurance that the sampling distributions of the Fs will be appropriately estimated.

7.3.2 Results

Biomass Estimates

Stochastic estimates of total, exploitable, and female spawning stock biomass are summarized in Fig. 7.2. Trends in SSB are comparable to Tables 6.1 and 6.2. Incorporation of the uncertainty in the survey mean numbers per tow and footprint variation suggests relatively precise estimates. The exploitable biomass quantities vary as a function of the selectivity functions derived in Section 7.2 (Appendix 2). These quantities are more erratic as they reflect the joint action of a temporally varying selectivity pattern and changes in underlying total biomass. The derived sampling distributions of the exploitable male and female biomasses and spawning stock biomass estimates are depicted in Fig. 7.3a-b. Estimates of male biomass are much less precise than those for females.

Swept area (minimum footprint) spawning stock biomass in for the 3 yr average 2004-2006 was estimated to be 106, 000 mt (Fig. 7.2). This estimate rose sharply from 2003-2005 owing to the large increase in the point estimate for 2006 spring survey (Fig. 5.19, Table 6.1). The sampling distribution of SSB for 2004-06 was much broader than the 2003-05 distribution (Fig. 7.3b). The sampling distributions of SSB suggest that the probability of SSB exceeding 200,000 mt was about 65-80% in 1990-1992 but rapidly declined to zero by 1997 and has remained there since.

Estimates of exploitable biomass for males and females are driven by the size selective pattern of the fishery and the size distribution of the dead discards. These components have varied greatly in the past 15 years. As a consequence the estimates of exploitable biomass have different bases across years (Fig. 7.3a-b).

Fishing Mortality Estimates

Stochastic estimates of the fully recruited F for exploitable female and SSB are presented Fig. 7.4 (with table). Estimated F on the exploitable female stock peaked in 1994 at 0.465, remained high through 1999, and has declined to about 0.13 in recent years. The ratio of landings to SSB showed a rapid rise from 0.06 to more than 0.4 by 1998. Since then however, it has declined sharply (Fig. 7.4).

The sampling distribution of fully recruited F (Fig. 7.5a-b) shows the progression of fishing mortality on the exploitable male and female biomasses and on female SSB. Estimates of higher rates of F tend to be much less precise. Estimated F's on males, even when discarding was included, was well below 0.05 during the 1990-2005 period. The ratio of female landings to SSB (F_3, Eq. 3) was much greater than the F on the fully exploited female stock (F_1 Eq. 1).

The incorporation of the size frequency of discards into the estimate of total mortality alters the force of mortality on the population such that the various estimates of F given in Eq. 1 to 4 are difficult to interpret. The patterns of increasing F from 1990 to 1999 and a decline since then are consistent with patterns observed in SARC 37. For this assessment (SARC 43) the force of mortality is distributed over a greater range of length classes such that the full Fs are not strictly comparable among year or with the biological reference points for target F (0.08), threshold F (0.11) and rebuild F (0.03).

The changing force of mortality on the female spiny dogfish motivated a need for a more synthetic approach. The varying force of mortality can be expressed as its net effect on reproductive value. This concept was employed in Rago et al. (1998) as pups per recruit (see their Eq. 8) and more recently by Gallucci et al (2006). Both approaches are measures of net reproductive rate and express an integration of the force of mortality on the expected reproductive output. If net reproductive value is expressed as number of female offspring per female spawner, then values below one imply a declining population; values above one imply that the population has the ability to increase.

Pups per recuit were modeled as a function of length specific growth, maturation and fecundity. The average duration Δt (yrs) of a length interval ΔL was computed by inverting the von Bertalanffy growth model

$$\Delta t_j = t_{j+1} - t_j$$

where

$$t_{j+1} = \frac{-\ln\left(1 - \frac{L_j}{L_\infty}\right)}{K} + t_o$$

$$t_j = \frac{-\ln\left(1 - \frac{L_{j+1}}{L_\infty}\right)}{K} + t_o$$

$$L_{j+1} = L_{j+1} + \Delta L$$

The von Bertalanffy parameters used for spiny dogfish were K=0.1128, t_o=-2.552, and L_∞=110 cm.

Reproduction at length class j (R_j) is computed as the expected annual number of female pups per female by length class. It is necessary to consider the fraction of the population mature, the average gestation period, the number of pups per female and the expected fraction of pups that are female as follows:

$$R_j = \left(\frac{f_{mature,L_j}}{t_{gestation}}\right) f_{female,L_j} \; x \; Pups_{L_j}$$

Size specific survival was modeled as a function of size specific selectivity, full F and natural mortality as

$$S_j = e^{-\left(Sel_{L_j} F + M\right)\Delta t_j}$$

The expected pups per recruit is given as

$$PPR = S_o\left(R_1 + \sum_{j=2}^{J}\prod_{i=1}^{j-1}\frac{S_i R_j}{\lambda^{T_j}}\right)$$

$$where$$

$$T_j = \sum_{i=1}^{j} t_i \qquad (5)$$

The variable S_o defined as the first year survival rate of pups (0.72) , was derived by Rago et al. (1998) for the finite rate of increase λ =1.09.

Evaluation of Eq. 5 vs F for the selectivity functions in Appendix 2 demonstrated that the full F cannot be easily interpreted across years (Fig. 7.6). A full F corresponding to a PPR=1 (i.e., equilibrium) can vary between 0.11 when selectivity occurs over the entire length structure to 0.6 when the full F only applies to the largest size class.

The frequency distributions of full F in Fig. 7.5a-b were mapped to frequency distributions of Pups per recruit in Fig. 7.7a-b using the selectivity functions defined in Fig. 7.5.

8.0. LIFE HISTORY MODEL AND STOCK RECRUITMENT

The life history model used to estimate biological F reference points for spiny dogfish are summarized in Rago et al. (1998) and in SARC 26. No additional work on this particular aspect of the assessment has been conducted.

The application of the Ricker stock-recruitment relationship to spiny dogfish has been reviewed the Joint Statistical and Scientific Committee of the New England and Mid-Atlantic Fishery Management Councils in 1999. On the basis of these meetings an estimate of the SSB necessary to produce the maximum recruitment, denoted as SSB_{max} , was set at 200,000 mt. It should be noted that the estimate of 200,000 mt “roughly” corresponds to a swept area biomass estimate based on a nominal trawl footprint of 0.01 nm^2. The modifier “roughly” is used because the estimate was taken from a graph of the Ricker function plot. The stock and recruitment data for spiny dogfish are summarized in Table 8.1. The actual point estimate corresponding to the peak value of the Ricker function for the 1968-1996 data is 215,024 mt. The data used in this relationship were two year averages of recruitment, and SSB.

It is important to note that the estimate of SSB_{max} scales directly with the NEFSC spring research trawl survey. The abundance index, in kg/tow, for female dogfish greater than 80 cm is converted to total biomass by multiplying the average by the ratio of the total survey area (~64207 nm^2) and the footprint of the trawl. Evidence presented in section 6.3 suggests that the actual footprint exceeds the nominal footprint of 0.01 nm^2

by about 10 to 20%. For example, since SARC 26 updated information on vessel speed and contact time suggested that the average footprint corresponded to a contact time of 33 minutes (rather than 30) and a vessel speed of 3.8 knots (rather than 3.5). These changes increase the nominal footprint to 0.012206 nm^2 or about 20% greater. Increasing the footprint reduces the swept area biomass estimate, leading to an alternative estimate of the SSB_{max} of 167,000 (i.e., 200,000 mt *(0.01/0.12) = 166,667 mt).

The important conclusion from this example is that the trawl footprint simply scales the abundance index for both recruitment and SSB. The underlying relationship between recruits and SSB is unaffected, such that estimates can be derived from analyses of the survey data alone (recruits expressed in numbers per tow, SSB expressed in kg/tow). The results of alternative model formulations are summarized in Table 8.2. The estimate of SSB_{max} of 214,024 mt corresponds to an average weight per tow of 33.2 kg. If unsmoothed data, rather than a 2 point moving average, are used, the estimate of SSB_{max} becomes 35.9 kg but its variance increases significantly.

Inclusion of the data from 1997 to 2006 illustrates another important property of the SSB_{max} estimate. Recruitments since 1997-2003 represented the seven lowest values in the 1968-2006 time series. Incorporation of these values into the Ricker model estimate has no effect on the R_{max} estimate, but the estimate of SSB_{max} increases by 41% to 304,000 mt (Table 8.2). A Lowess smooth of the SR data (Fig. 8.1) is much less sensitive to the additional years of data with an approximate SSBmax slightly less than 200,000 mt (using the 0.01nm^2 footprint). Discussion of the scaling problems at the SARC 37 led to the general recommendation that the smoothed estimate for the entire data series would be a more appropriate measure of SSB_{max}, if an empirical model of the SR function were used to provide a biomass reference point.

The Ricker model assumes that the total female biomass is an adequate measure of spawning potential. As described in NEFSC (2003 Section 6.3) the reproductive output of dogfish declines with maternal size. Declines in maternal size decrease both numbers and size of pups. The information on decline in pup size in smaller females is an important conclusion in this assessment as it provides a possible explanatory mechanism for the lower than expected pup production since 1997. The temporal trajectory of recruits and SSB in Fig 8.2 illustrates that most of the negative residuals have occurred since 1989. Notably, a dense cluster of negative residuals has occurred when the spawning stock size has been below 100,000 mt in the 1997-2003 period. Model residuals, plotted against mean maternal length (Fig. 8.3), 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 fell below 87 cm. The clustering of negative residuals is also consistent with the increase in male to female ratio (Fig. 5.13a).

Our analyses of the Ricker model suggest that additional biological processes may be necessary to explain the lack of fit in recent years. Clearly, a model based only on accumulated stock biomass may be inadequate to predict recruitment for a population which is currently experiencing a strongly truncated size distribution (Fig. 5.10), reduced average size of females (Fig.5.11a and 6.5), smaller than average size pups (Fig. 6.5), and a skewed sex ratio (Fig.5.13a). Some consideration might be given to a proxy value for B_{MSY} that would be based on the product of average recruitment and the biomass per recruit wherein the force of mortality was sufficient to ensure that pups per recruit exceeded 1.0. The current sex ratio dominated by males is more problematic because 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. 5.13a).

9.0 SIMPLE MASS BALANCE MODELS

SARC37 expressed concerns regarding the utility of the nominal footprint (0.01 nm^2) analyses of survey data as an adequate measure of true stock abundance. It was suggested that model- based approaches would be an alternative means of estimating the likely magnitude of q and therefore, efficiency, defined as the probability of capture given encounter. To test this concept two alternative mass balance models were applied. A simple Leslie-Davis model, based on a closed population was applied, primarily as a means of circumscribing the possible value of q. The second model was based on a simplified catch survey analysis, similar to the process model of Collie and Sissenwine.

Swept area estimates of mature female dogfish, based on a footprint of 0.012 (Table 6.2) were used as an index of abundance and compared with cumulative landings of females (Table 4.7). A 3-yr moving average of swept area biomass was used . This tends to dampen interannual changes, and is consistent with time-series approaches (e.g. Pennington 1986) for estimating abundance from surveys.

Leslie-Davis model results (Fig. 9.1) suggest that the initial SSB size in 1989, prior to the start of the fishery, was ~250,000 mt (R^2=0.91) and that the q was 0.943. This would imply that the effective footprint for the tow would be 0.943* 0.012 nm^2 = 0.011 nm^2. In terms of the capture process, this could occur if, on the average, spiny dogfish were herded by the trawl doors (footprint ~ 0.02325, Table 7.2) and 48.6% of these were caught by the trawl. Since the 3-yr average measures of CPUE are autocorrelated, the Leslie-Davis model was refit to a reduced number of points, such that the CPUE terms were not used twice (i.e, 1988-1991, 1992-1994, etc was regressed against cumulative landings. Results for this model suggested an initial abundance of 238,000 mt and a q=0.837. Under this model the effective footprint is 0.837 * 0.012=0.01, which is equivalent to the nominal footprint of the survey and implies an efficiency of 0.432 for the area swept by the doors. These results are consistent with Harley and Myers (2001) who reported rapidly increasing catchabilities for a variety of fish exceeding 80 cm.

The Leslie Davis model makes strong, and perhaps untenable, assumptions about constancy of recruitment and offsetting effects of growth and natural mortality. To address these concerns a (slightly) more complicated mass balance model was devised. The model is similar to that proposed by Collie and Sissenwine (1983), except in this instance, it was assumed that all of the error is process error, rather than observation error. Thus the model boils down to one parameter as follows.

Define recruits R_t as the biomass of dogfish in the 79 cm range that will grow into the 80 cm range in the next time step. The biomass of 80+ cm dogfish will change between time steps in response to the growth of individuals (G), losses through natural mortality (M), and biomass removals by the fishery C_t. Basing the expanded values of B and R on a nominal footprint of 0.01, the model can thus be defined as

$$B_{t+1} = B_t\, e^{G-M} + R_t - C_t$$

The G and M parameters are not separably estimable but their difference can be estimated as a single parameter, say ϕ. The model estimate of ϕ was -0.06 which corresponds well with the assumed natural mortality rate of 0.092 and a very slow adult growth rate (Fig. 9.2) Results of the model fit are summarized in Fig. 9.2. The model fits well with no aberrant residual patterns. The model now adequately tracks the recent change in abundance, a small upturn in the last 3 yrs. This appears to be due to a decrease landings, since the difference between the recruitment and the landings becomes positive in 2001 and 2002. (Fig. 9.2, bottom panel). An independent estimate of the average G parameter for 1980-2006 suggests a continuous increase since 1980 as the population size structure has been truncated. Since 1995 the average G, defined as follows:

$$G = \ln\left(\sum_L \hat{W}_{L+\Delta L,t+1} N_{L+\Delta L,t+1}\right) - \left(\sum_L W_{L,t} N_{L,t}\right)$$

where the predicted value of weight in time t+1 is based on the von Bertalanffy growth model.

The fit of mass balance model declined slightly when the model was used to describe the population back to 1980 (Fig. 9.3). Model fit declined precipitously when unsmoothed data were used (Fig. 9.4). All three applications of the model suggest that landings exceeded recruitment to the spawning biomass between 1990 and 2001.

Both the Leslie-Davis and simple mass-balance models support the concept that the nominal footprint assumption adequately characterizes the true size of the population. The rapid change in the size-structure, and paucity of pups in recent years also provide evidence that the removals in the directed fishery were sufficient to exert a relative large mortality on the adult stock.

10.0 STOCHASTIC PROJECTION MODEL

This section describes the stochastic projection model for spiny dogfish. Examples are provided with initial conditions based on the 2004 -2006 population size structure.

10.1 Overview

A length-based stochastic projection model was developed to evaluate effects of alternative fishing mortality scenarios. The model incorporates sex specific rates of growth and fishing mortality. Discard mortality is assumed to act equally all size ranges of both sexes. Reproduction in the model is assumed to be proportional to stock abundance. The basic model can be written in terms of two matrix equations as

$$N_{f,t+1} = S_{f,Z,t} P_f S_{D,t} N_{f,t} + S_{D,t} N_{f,t}^T Pup\, S_o \varphi R_f^o$$

$$N_{m,t+1} = S_{m,Z,t} P_m S_{D,t} N_{m,t} + S_{D,t} N_{f,t}^T Pup\, S_o (1-\varphi) R_m^o$$

where

$\mathbf{N_{f,t}}$= Vector of female population abundance at length. Dimension = (ℓ_{max}- ℓ_{min}+1)

$\mathbf{N_{m,t}}$= Vector of male population abundance at length. Dimension = (ℓ_{max}- ℓ_{min}+1)

$\mathbf{S_{D,t}}$= Diagonal matrix of discard survival rates at time t. Dimensions = (ℓ_{max}- ℓ_{min}+1, ℓ_{max}- ℓ_{min}+1)

$\mathbf{S_{f,Z,t}}$=Diagonal matrix of composite survival from instantaneous fishing and natural mortality rates for females at time t. Dimensions = (ℓ_{max}- ℓ_{min}+1, ℓ_{max}- ℓ_{min}+1)

$\mathbf{S_{m,Z,t}}$=Diagonal matrix of composite survival from instantaneous fishing and natural mortality rates for males at time t. Dimensions = (ℓ_{max}- ℓ_{min}+1, ℓ_{max}- ℓ_{min}+1)

$\mathbf{R^o}$=Vector of proportions at length of new recruits. Dimension = (ℓ_{max}- ℓ_{min}+1)

$\mathbf{P_f}$= Growth projection matrix for females. Dimensions = (ℓ_{max}- ℓ_{min}+1, ℓ_{max}- ℓ_{min}+1)

$\mathbf{P_m}$= Growth projection matrix for males. Dimensions = (ℓ_{max}- ℓ_{min}+1, ℓ_{max}- ℓ_{min}+1)

Pup= Vector of length specific pup production rates for mature females. Dimension = (ℓ_{max}- ℓ_{min}+1)

S_o= Scalar first year survival rate of newborn pups. Derived from analysis of life history model

T = Transpose operator

φ = proportion of female pups at birth; 0.5 implies an equal sex ratio.

Note that the projection equation for males is a function of the numbers of recruits. produced by females.

Notation Footnote
Vector quantities and operations will be denoted in bold font. As examples, let **X** denote a matrix with k x k elements, and **Y** denote a vector with k elements. Then **XY** would define the matrix multiplication of the vector **Y** by matrix **X** yielding a vector quantity, say **Z**. Similarly, $\mathbf{Y}^\mathbf{T}\mathbf{Y}$, read as **Y** *transpose* **Y,** represents the dot product of the elements of **Y** with itself, yielding a scalar quantity. Scalar multiplication of a vector is denoted as c**Y** where c is an arbitrary constant. By convention, matrix operators proceed from left to right and in general, operations are not commutable.
The elements of a matrix are denoted by appending the appropriate number of identifiers within parentheses following the variable name. Thus, X(i,j) represents the scalar quantity in the i^{th} row and j^{th} column of the matrix **X** and Y(i) represents the i^{th} element of the vector **Y**.

The component processes of the matrix model and quantities derived from the population states are described below. The Fortran computer code used to implement the model is provided in Appendix 3.

10.2 Processes

10.2.1 Growth

Growth in length at age is modeled by the von Bertalanffy equation applied separately to each sex. The model parameters are taken from Nammack et al. (1985). The projection matrices, $\mathbf{P_f}$ and $\mathbf{P_m}$ for females and males, respectively are defined as square matrices consisting of 0, 1 elements. The non-zero elements in cell i, j indicate the growth of individuals from cell i to cell j. The growth of individual dogfish from length i to length j is modeled by first inverting the von Bertalanffy equation to obtain the age of individuals of length i to obtain age_i. The projected length at age_{i+1} is then obtained substituting age_i+1 back into the von Bertalanffy equation to obtain length j. The projection matrix algorithm for females can be summarized as follows:

$$Step\ 1.\ Find\ age\ for\ L_i$$

$$a_{f,i} = \frac{\log\left(1 - \frac{L_{f,i}}{L_{f,\infty}}\right)}{K_f} + t_{f,o}$$

$$Step\ 2. Compute\ L\ in\ next\ time\ step$$

$$L_{f,j} = L_{f,\infty}(1 - e^{-K_f(a_{f,i}+1-t_{f,o})})$$

$$Step\ 3.\quad Compute\ element\ of\ \ projection\ matrix$$

$$P_f(\text{int}(L_{f,j}), \text{int}(L_{f,i})) = 1$$

The same algorithm is defined for males by substituting the m for f in the subscript terms of the above equation.

10.2.2. Fishing and natural mortality

Natural mortality is assumed equal to 0.092 and to be constant over all length classes. Fishing mortality in year t, defined as F_t , is multiplied by sex-specific selectivity functions (Sec. 7) to estimate the sex- and length-specific fishing mortality rates. The diagonal matrices that decrement the populations for fishing and natural mortality are defined as $\mathbf{S}_{\mathbf{f,Z,t}}$ and $\mathbf{S}_{\mathbf{m,Z,t}}$ with elements defined by

$$S_{f,Z,t}(\ell,\ell) = e^{-(sel_f(\ell)F_t + M)}$$

$$S_{m,Z,t}(\ell,\ell) = e^{-(sel_m(\ell)F_t + M)}$$

In some scenarios it is desirable to evaluate the effects of a quota rather than a fishing mortality rate. For these scenarios it is necessary to iteratively solve for F_t sufficient to generate a quota of magnitude Q_t. A Newton-Ralphson algorithm (function rtsafe, p 359 in Press et al. 1992) was used to find the value of F. The application to this length-based model is patterned after the approach used in Brodziak et al. 1998. When a quota was too large for the estimated exploitable biomass to support, a default F=3.0 was set as an upper bound.

10.2.3 Discard mortality

Instantaneous discard mortality rates for the entire population were estimated using methodology described in Section 7.. The discard matrix in Eq. 9.1 is a diagonal matrix with principal diagonal elements estimated as

$$S_{D,t}(\ell,\ell) = e^{F_{discard,t}}$$

For all scenarios considered in this report, the discard rate was set equal to the estimate for 2002 (i.e. $F_{discard} \sim 0.02$). Note that the discard rate is assumed to be equal for all length classes. In the model, it is assumed that discard acts as a Ricker Type I Fishery in which the discard is assumed to occur before the fishing and natural mortality. This approximation results in a small overestimate of the numbers discarded. Assuming a discard rate of 0.02, the effect on discard numbers would be 4% higher when F=0 and 8% when F=0.11 when comparing a type I and II fishery.

The survivors, after discard mortality has occurred, is written as

$$N_{f,t+\Delta t} = S_{D,t} N_{f,t}$$
$$N_{m,t+\Delta t} = S_{D,t} N_{m,t}$$

The numbers of discards at length by sex, $\mathbf{D}_{\mathbf{f,t}}$ and $\mathbf{D}_{\mathbf{m,t}}$, for females and males, respectively, is defined as

$$D_{f,t} = N_{f,t} - N_{f,t+\Delta t}$$
$$D_{m,t} = N_{m,t} - N_{m,t+\Delta t}$$

10.2.4 Reproduction

The total number of pups produced is written at the product of the length-specific pup production rates and the number of females alive in year t.

$$Pup_{TOT,t} = S_o N_{f,t+\Delta t}^T Pup$$

The numbers of pups produced by length and size category are estimated by splitting the total pup number by sex and multiplying by the observed proportion of dogfish at length for lengths assumed to be less than one year old at the time of the survey. The resulting numbers of pups produced is written as:

$$female\ pups = \varphi Pup_{TOT,t} R_f^o$$
$$male\ pups = (1-\varphi) Pup_{TOT,t} R_m^o$$

The $\mathbf{R_f}$ and $\mathbf{R_m}$ vectors representing the proportions by length class consist of (ℓ_{max}- ℓ_{min}+1) elements of which only elements 1 to k are non-zero. The male and female vectors have equivalent proportions but differ with respect to vector length, owing to the larger maximum size attained by females.

10.2.5 Biomass outputs: yield, discards SSB, exploitable biomass, total biomass

Yield is estimated by applying the catch equation to the number of individuals alive after discarding has occurred. The catch at length by sex is estimated as

$$C_{f,t}(\ell) = \left(\frac{F_t sel_f(\ell)}{F_t sel_f(\ell) + M} \right) \left[1 - e^{-\left(F_t sel_f(\ell) + M\right)} \right] N_{f,t+\Delta t}(\ell)$$

$$C_{m,t}(\ell) = \left(\frac{F_t sel_m(\ell)}{F_t sel_m(\ell) + M} \right) \left[1 - e^{-\left(F_t sel_m(\ell) + M\right)} \right] N_{m,t+\Delta t}(\ell)$$

The total yield by sex is computed as the sum of the products of the numbers caught and their average weight . In matrix notation this is written as:

$$\begin{aligned} Y_{f,t} &= C_{f,t}^T W_f \\ Y_{m,t} &= C_{m,t}^T W_m \\ &and \\ Y_t &= Y_{f,t} + Y_{m,t} \end{aligned}$$

Discards in weight, $D_{B,t}$ are estimated in a similar fashion such that:

$$\begin{aligned} D_{B,f,t} &= D_{f,t}^T W_f \\ D_{B,m,t} &= D_{m,t}^T W_m \\ &and \\ D_{B,t} &= D_{B,f,t} + D_{B,m,t} \end{aligned}$$

The total biomass of the population by sex $B_{f,t}$ and $B_{m,t}$, is estimated as the total number alive at the start of the year multiplied by the average weight at length.

$$\begin{aligned} B_{f,t} &= N_{f,t}^T W_f \\ B_{m,t} &= N_{m,t}^T W_m \\ &and \\ B_t &= B_{f,t} + B_{m,t} \end{aligned}$$

Exploitable biomass is defined as the fraction of the population biomass available to the fishery given the prevailing selectivity pattern. The commercial selectivity pattern by sex is defined in Section 7.2. Exploitable biomass will always be less than total biomass and is computed as follows:

$$B_{Expl,f,t} = \sum_{j=\ell_{\min}}^{\ell_{\max}} sel_f(j) N_{f,t}(j) W_f(j)$$

$$B_{Expl,m,t} = \sum_{j=\ell_{\min}}^{\ell_{\max}} sel_m(j) N_{m,t}(j) W_m(j)$$

and

$$B_{Expl,t} = B_{Expl,f,t} + B_{Expl,m,t}$$

Finally, the spawning stock biomass is expressed in terms of female biomass only and is defined at the sum of mature females. In the projection model, females are assumed to be mature at 80 cm such that the spawning stock biomass can be written as

$$SSB_t = \sum_{j=80}^{\ell_{\max}} N_{f,t}(j) W_f(j)$$

10.3. Initial conditions

The initial condition of the population was defined as the 3-yr average (2004-2006) of dogfish abundance in the NEFSC spring R/V trawl survey. Unlike the stochastic estimator of fishing mortality and biomass, the projection model does not incorporate uncertainty in the estimates of discard mortality or the footprint of the survey. Instead, the projection model incorporates the variation in abundance defined by survey abundance. Variation in mean abundance is used to scale the index numbers at length by generating values of mean abundance over 500 equally-spaced probability intervals.

10.4 Scenarios

A projection based on the 2004-06 initial condition and the 2004-2006 selectivity parameters is shown in Table 10.1 and in Figure 10.1. Short term forecasts of spiny dogfish biomass (mt) are influenced by the current biomass and size structure of the population. Biomass of mature female spiny dogfish is expected to continue increasing through 2008 and 2009 as fish <80cm grow into mature size range. Subsequently, the biomass should decline due to the low number of recruits that were born during 1997-2003. If recruitment returns to levels consistent with expected size-specific reproduction, the biomass should begin to rebound again by 2015. These oscillations are expected to occur whether or not there is fishing (Figure 10.1). With the “rebuild F” strategy (F=0.03), female SSB will rise through 2010, then decrease slightly through 2015, and then rise to approximately 200,000 mt in 2018. Higher levels of fishing mortality will increase the amplitude of the oscillation and take longer to reach 200,000 mt. Potential negative influences of low birth weight and male-dominated sex ratio are not included in these projections.

11.0 SPINY DOGFISH RESEARCH RECOMMENDATIONS

1) Attempt to allocate landings to statistical area (i.e. attempt proration) using Vessel Trip Report data for 1994 and later years.

The Working group successfully completed work to address this RR.

2) Evaluate the utility of length frequency for spiny dogfish sampled in the NEFSC Observer Program in the most recent years (2001 and later).

The Working group successfully completed work to address this RR.

3) Ensure the inclusion of recent (2000 and later) MADMF Observer sample data for spiny dogfish in the NEFSC database, for more efficient use in future assessments.

The Working group successfully completed work to address this RR.

4) Conduct tagging and genetic studies of spiny dogfish in U.S. and Canadian waters to clarify current assumptions about stock structure.

The Working Group reviewed an ongoing streamer tag project conducted by East Carolina University.

5) Conduct discard mortality studies for spiny dogfish, with consideration of the differences in mortality rates among seasons, areas, and gear types.

The Working Group reviewed a discard mortality study in North Carolina near-shore trawl and gillnet fisheries conducted by East Carolina University, and took these results into consideration in updating assumed discard mortality rates for the coast-wide trawl, gillnet, and hook fisheries.

6) Conduct experimental work on NEFSC trawl survey gear performance, with focus on video work to study the fish herding properties of the gear for species like dogfish and other demersal roundfish.

The Working Group made no progress on this RR.

7) Investigate the distribution of spiny dogfish beyond the depth range of current NEFSC trawl surveys, possibly using experimental research or supplemental surveys.

The Working Group made no progress on this RR.

8) Initiate aging studies for spiny dogfish age structures (e.g., fin spines) obtained from NEFSC trawl surveys and other sampling programs. These studies should include additional age validation and age structure exchanges. The WG notes that other aging methodologies (e.g., Canadian studies on radiometry) are also in dev*elopment.*

The Working Group reviewed preliminary results of NEFSC aging work for spiny dogfish. Preliminary results agree more with validated ages for Pacific dogfish, then with current estimates used for Northwest Atlantic dogfish.

9) Additional analyses of the effects of environmental conditions on survey catch rates should be conducted.

The Working Group investigated the associations of temperature and depth with trawl survey densities. Examination of dogfish distributions in trawl surveys indicates greater concentrations closer to shore over the last five years.

10) Additional work on the stock-recruitment relationship should also be conducted with an eye toward estimation of the intrinsic rate of population increase.

The Working Group used the results from a new analytical model (LTM) to estimate parameters of a stock-recruitment relationship.

11) The SARC noted that the increased biological sampling of dogfish should be conducted and research trawl surveys. Maturation and fecundity estimates by length class will be particularly important to update. Additional work on the survey database to recover and encode information on the sex composition prior to 1980.

The Working group notes that a sampling program to collect aging structures (2003) and maturity data (1998) for dogfish has been implemented on NEFSC surveys. The WG examined sex composition data from NEFSC spring and fall surveys from 1968 to 1972, and this historical information has been included in this assessment.

New:

1) Incorporate Canadian commercial fishery sample data into the assessment when it is made available (expected in 2007).

2) Conduct an aging workshop for spiny dogfish, encouraging participation by NEFSC, NCDMF, Canada DFO, other interested state agencies, academia, and other international investigators with an interest in dogfish aging (US and Canada Pacific Coast, ICES).

3) Examine observer data to calculate a weighted average discard mortality rate based on an assumption that the rate increases with catch size.

4) Develop experimental estimates of discard mortality in the New England and Mid-Atlantic commercial fisheries.

5) Develop experimental estimates of discard mortality in the New England and Mid-Atlantic recreational fisheries.

6) Conduct a coast-wide tagging study for spiny dogfish to explore stock structure, migration patterns, and mixing rates.

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