

B. Spiny Dogfish (*Squalus acanthias*)

1.0 Introduction

The Atlantic States Marine Fisheries Commission (ASMFC) Spiny Dogfish Stock Assessment Subcommittee and the Stock Assessment Review Committee (SARC) Southern Demersal Working Group meet jointly during May 12-14, 2003 at the NEFSC in Woods Hole, MA to develop the spiny dogfish stock assessment for 2003. The following scientists and managers participated in the meeting:

Jim Armstrong	Mid-Atlantic Fishery Management Council
Laurel Col	NMFS NEFSC
Eric Dolan	NMFS NERO
Megan Gamble	ASMFC
Joe Grist	North Carolina Division of Marine Fisheries
Ralph Mayo	NMFS NEFSC
Steve Murawski	NMFS NEFSC
Loretta O'Brien	NMFS NEFSC
Chris Powell	Rhode Island Division of Fish and Wildlife
Paul Rago	NMFS NEFSC
Jim Ruhle	Mid-Atlantic Fishery Management Council
Roger Rulifson	East Carolina University
Alexi Sharov	Maryland Department of Natural Resources
Katherine Sosebee	NMFS NEFSC
Mark Terceiro (chair)	NMFS NEFSC

2.0 Terms of Reference

The Terms of Reference for the assessment were as follows:

- 1) Characterize the commercial and recreational catch (landings and discards) for the entire stock (includes Canadian catch) and identify methods for improving the accuracy of discard and discard mortality estimates.
- 2) Estimate current and historic fishing mortality, spawning stock biomass, and total stock biomass and characterize the uncertainty of those estimates.
- 3) Update or re-estimate biological reference points (including rebuilding targets) as appropriate.
- 4) Estimate yield based on stock status and target mortality rate ($F = 0.08$) for fishing year 2004 (May, 2004 through April, 2005).
- 5) Provide short term projections (2-3 years) of stock status under a variety of TAC/F strategies

- 6) Evaluate existing and alternative rebuilding schedules based on current/projected stock status.
- 7) Provide estimates of juvenile recruitment and pupping rates. Characterize the uncertainty of these estimates.
- 8) Characterize the level of discards, bycatch rates, discard mortality rates, and length and sex data for spiny dogfish (per trip, per net, etc.) in directed and bycatch fisheries and how changes in regulations and fishing practices may have affected these rates.

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 extend 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 are major predators on some commercially important species, mainly herring, Atlantic mackerel, and squid, and to a much lesser extent, 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 for males and 75 cm 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 metric tons (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 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 (Figure 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 2,200 mt in 2001 and 2002 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 2002 have not been finalized but should range between 3,000 and 3,400 mt (Steve Campana, DFO personal comm.).

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, Figure 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 3,000 – 5,000 mt 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 1,300 mt landed 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. As 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 landings traditionally occur 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.

Landings by statistical area were not updated for this assessment. As reported in SARC 19 (NEFSC 1994) most landings during the 1980's originated from statistical area 514 (Massachusetts Bay). 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).

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 6,200 mt, about half of the Massachusetts landings, but dropped sharply to about 1,300 mt between 1997 and 2000. North Carolina landings in 2001-2002 were negligible. In 2001 and 2002, virtually all of the landings were taken north of Rhode Island.

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 methodology). 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 MRFSS 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 type 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, 100% discard mortality 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 1,500 mt to less than 400 mt in 1996. Landings by number (Figure 4.3) 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. As most of the recreational landings are discarded, with discarding unlikely to be size or sex selective, recreational landings were added to the total discard estimates in this assessment. This treatment of the data will be discussed more fully in Section 7.

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 4.5). Most samples were taken in June through November with much lower effort from January to May. In addition to the samples listed in Table 4.5, port samples obtained by MADMF in 2000 (15) and 2002(8) (provided by Brian Kelly, MADMF), were incorporated 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 marketplace, 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 4.6). 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 (Figure 4.4, top). The average size of males dropped about 5 cm between 1994 and 2000 (Figure 4.4 bottom). Reductions in average weight of females (Figure 4.5) 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 (Figure 4.5) 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 the research surveys (later section) suggest 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 (17,327 mt) were about equal to those in 1992 (17,687 mt) but the decrease in average weight resulted in the removal of almost twice as many dogfish (9.3 million fish versus 4.6 million fish). The relative increase in number killed as a function of average size can be evaluated by considering mean lengths of the landed fish (Figure 4.6 top). For example, a decline of average size from 95 cm to 70 cm in females would imply a 3-fold increase in the total numbers removed. A drop from 95 to 85 cm average size would result in a 50% increase. Switching to male dogfish would result in even more severe increases in numbers killed since the weight at length for males is less than for females of the same length (Figure 4.6). As an illustration, a switch from 85 cm females to 80 cm males would imply 50% more deaths of males for the same landings weight. The effects of selectivity will be characterized more fully in Section 7.3.2 when fishing mortality rates are considered.

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 are 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 analysis suggested that total discards were about the same order of magnitude at the commercial fishery. SARC 19 accepted provisional estimates of discard mortality of 0.75 in gillnets and 0.5 in otter trawls but noted the considerable uncertainty in these estimates. To our knowledge, no scientific studies of post-capture survival rates have been conducted for spiny dogfish. Ongoing tagging studies by Roger Rulifson (East Carolina State University, pers. comm.) may provide indirect evidence of these important parameters.

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.

The ratio-estimator concept was expanded in this study in several important ways. First, the target species were defined by first identifying 21 species groups or associations (Table 4.7).

These associations were determined via consultations with stock assessment scientists within NEFSC. Similarly, fisheries were grouped in to general gear types (Table 4.8) wherein minor differences among gears were ignored. The objective of the grouping by species and gear types was to increase the number of samples available for estimation of the discard ratios from the fishery observer program and to allow for estimation of variance estimates. Likely differences among areas were aliased by the choice of species groups. For example, the principal groundfish category encompasses most of the Gulf of Maine (GOM) and Georges Bank (GB) areas, where as the fluke-four spot flounder species group aliases the Mid-Atlantic flatfish fishery. The flatfish group (witch, yellowtail, plaice, winter, windowpane, southern, hogchoker), in general, aliases the GOM, GB and Southern New England (SNE) areas. Second, the primary species group was identified post hoc by the actual landings pattern within the observed trip. The primary species was identified as the most abundant species group (by weight) within the set of 21 possible species groups. Third, we tested the relationship between the discard rate and the primary species group landed. 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). Finally, we estimated the variance of the discard estimates using the approximate variance approach of Cochran (1963, see also Fogarty and Gabriel, 2003, unpublished report).

To test whether the species grouping method sufficiently characterized the total landings of the observed trip, the relationship between total landings and primary species was plotted for all gears and species groups (Figure 4.7), trawl gear (Figure 4.8) and gill nets (Figure 4.9). In all instances the post hoc identification of primary species group appears to characterize the overall landings from the trip. For trips with over 1,000 pounds of total landings, the primary species group generally comprised more than 75% of the total landings. In contrast, the second most abundant species group had a much weaker association with the total landings (bottom panels of Figures 4.7-4.9).

Given an acceptable predictive ability to define the primary species group, the second critical requirement is that the dogfish discard level should be proportional to the landings of the primary species group. This assumption is tested by plotting observed dogfish discards versus the observed primary species group landings for all gears, years, and species groups (Figure 4.10), all years and species groups in observed trawl gear trips (Figure 4.11 top), and all years and species groups in observed gill net gear trips (Figure 4.11 bottom). The associations between discards and landings were positive, as expected, but the magnitude of the variation suggested that some species groups might have weaker associations. Examination of individual species groups plots (not shown in this report) suggested that certain species groups were only weakly related to dogfish discards. For example, no further consideration was given to discards in the large pelagic, mollusk, other sharks, other fish categories (Table 4.7).

The ratio of dogfish discards to primary species landed is multiplied by the total landings of the species group within the gear group. In order for this estimator to be reliable, it is important to consider the relationship between the observed landings and the total landings reported in the dealer records. The ratio of these two quantities can be considered the

sampling ratio. The inverse of this quantity is the expansion factor that will be applied to the total observed dogfish discards. For example, a sampling rate of 0.001 would imply an expansion factor of 1000 and a concomitant increase in the sampling variability. Plots of the sampling rates for the primary species groups versus year suggest an overall sampling rate of about 0.01 since 1990 (Figure 4.12). For trawl gear (Figure 4.13) the sampling rate is about 0.05, but for gill nets, the sampling rate seems to be clustered around 0.03 to 0.05 (Figure 4.14). The lower panels of Figures 4.12-4.14 show the degree of association between the total landing of the species groups from the dealer records (x axis) and the total landings observed during sea-sampling trips. Again, the relationship appears stronger for the gill net gear than for trawls, but both groups' relationships seem acceptable.

Collectively, the results presented in Figures 4.7 to 4.14 were considered sufficient to proceed with the computation of discard rates based on landings within the trawl and gill net gear groups, and the following species groups: Atlantic herring, crustaceans, dogfish, flatfish, fluke- four spot, mackerel, menhaden, monkfish, principal groundfish, scup-sea bass, skates, small-mesh groundfish, and squid-butterfish. A completely parallel set of analyses were conducted using a trip-based ratio estimator. These analyses gave similar results to the catch-based ratio estimator but appeared to be more variable. The subcommittee considered both sets of information and recommended the use of the catch-based estimator. Of particular concern was the lack of consideration of trip duration, and variations in vessel power. More detailed analyses, perhaps using GLM or Generalized Additive Models (GAM) could be used to more precisely identify the association between effort and discards.

Means and variances of the discard estimates were computed using standard formula for ratio estimators per Cochran (1963). For completeness, these estimators are summarized below.

$D_{G,S,T}$ = Observed discards of dogfish in gear G for target species S and trip T

$L_{G,S,T}$ = Landings of target species S in gear G and trip T

$L_{G,S}$ = Landings of species S in gear G

$$D_{TOT} = \sum_G \sum_S \left(\frac{\sum_T D_{G,S,T}}{\sum_T L_{G,S,T}} \right) L_{G,S}$$

The approximate variance is estimated by assuming that the dealer records of landings are measured with negligible reporting error and that most of the error obtains from the variance of the discard ratio R.

Let

$$\hat{R}_{G,S} = \left(\frac{\sum_T D_{G,S,T}}{\sum_T L_{G,S,T}} \right)$$

$$V(D_{G,S}) = V(\hat{R}_{G,S}) L^2_{G,S}$$

Where

$$V(\hat{R}_{G,S}) = \frac{(\hat{\sigma}_{D,G,S}^2 + \hat{R}_{G,S}^2 \hat{\sigma}_{L,G,S}^2 - 2\hat{R}_{G,S} \text{cov}(\hat{\sigma}_{L,G,S}, \hat{\sigma}_{D,G,S}))}{\left(\sum_T \bar{L}_{G,S,T} / N \right)^2}$$

It is important to note that the variance of R is obtained by substituting the sample variances and co-variances for the population estimates.

Results

A composite table of dogfish discard estimates and variances are summarized by primary species groups for trawl, gill net and hook gear groups for 1989 to 2002 in Table 4.9. The discard estimates are based on a fishing year, defined as May 1 to April 30. Hence, the sampling in January-April 1989 sea sampling trips are labeled as the 1988 fishing year. Sampling frequency for hook gear was very low but this gear group was considered important for contemporary fishing practices under the federal and ASMFC management plans. Of the 13,637 trips analyzed, over 80% of the observer trips were on vessels using gillnets. Since 2000, the number of trips on trawling vessel has increased, with the number of trips exceeding 250 in each year. It should be noted that all of the standard MADMF observer trips are recorded in the NMFS observer database. Ancillary sea-sampling trips (~20 trips) conducted by MADMF in 2000 and 2002 on targeted dogfish trips will be summarized and compared with the current estimates in a later report.

Total discard estimates by year ranged from a high of nearly 90,000 mt in 1989 and 1990. The large estimates are driven by a limited number of trips in the trawl fishery. For example, the 55,000 mt estimate in the 1988 fishing year is based on one trawl trip in which mackerel were the primary species. Estimates of dogfish discards in later years consistently had discard rates an order of magnitude less, even though the number of trips per year approached 15 in many years (Table 4.9). Similarly high rates were observed in a few scup-sea bass group trips in 1990 (36,016 mt) and squid-butterfish trips in 1991 (29,532 mt). In both instances, the CV of the estimate exceeded 75%, suggesting that the numbers were highly imprecise. In contrast, the results from 1992 onward suggested much more stable estimates, with relatively few outliers.

To avoid complications of arbitrarily deleting species groups across years, a consistent set of species group was used to generate annual estimates of discard rates by year and gear category (Table 4.10). After 1993 the discard estimates decline steadily, and the variance of the estimates decreases as well (Figure 4.15, top panel). By coincidence, the estimated discards for 1993 fishing year of 24,188 mt agrees well with an alternative estimator summarized in NEFSC (1994) and published in Rago et. al (1998). In general, the coefficients of variation for the annual totals were on the order of 25%. Higher CV values were typically associated with large discard estimates in the trawl fishery. Standard errors of the total discard estimates were generally proportional to the total discard estimate for all species groups for both trawls and gill nets (Figure 4.16). The projected number of dead discards was estimated by multiplying the discards in each gear group by an assumed level of discard mortality (Table 4.11). Discards mortality rates in the gill net, trawl, and hook gear categories were 0.75, 0.5 and 0.25, respectively.

As noted above, an analogous set of computations were conducted using a trip-based ratio estimator (Table 4.12). Although the numbers will not be used in the assessment, the numbers for the sum of the trawl and gill net gear groups agree well with the rates derived from the catch based estimator (Fig. 4.15, 4.17). The number of trips by gear groups is very large (Table 4.13) implying large expansion factors. Together with the indeterminacy of what constitutes a standard “trip”, additional work is necessary before such estimates could be useful for assessments.

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) 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.

In both the spring and the autumn surveys, there was considerable variability in the indices (Table 5.1, 5.2, Figure 5.1). 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) Overall catches exhibit a slight downward trend but higher average catch rates are typically associated with higher SE of the estimates. An analysis of the relationship between the standard deviation of stratum estimates and its mean (Figure 5.2) illustrates the strong association linear relation between the SD and mean of each stratum. The proportionality suggests that a log transformed catch rate might lead to more stable estimates, although an initial examination of this relationship for the spring survey (Figure 5.3) revealed comparable levels of interannual variation.

5.1.2 State surveys

Abundance indices for spiny dogfish from Massachusetts spring and autumn inshore bottom trawl surveys in 1978-2002 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, Figure 5.4). Wide variations in availability results 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.

5.1.3 Canadian surveys

Indices of relative abundance for 1970-1993 from the Canadian summer bottom trawl survey conducted in NAFO Divisions 4VWX (Campana, pers. comm.) are depicted graphically in Figure 5.5. Overall dogfish abundance increased along with the rise the US spring survey. In contrast to the US surveys, male dogfish are more abundant than females. Additional work is necessary to understand differences between abundance patterns in US and Canada surveys.

5.2 Size and Sex Compositions

Size frequency distributions of spiny dogfish (sexes combined) from the spring and autumn NEFSC surveys were examined (Figure 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 (Figure 5.6d).

Male and female size frequencies distributions are summarized by year for the spring (Figure 5.7 a-c) and fall surveys (Figure 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 (Figure 5.9 a-c) autumn survey.

Further insight into the changes in abundance and size composition may be obtained by examining the averaging size frequency compositions over multi-year periods (Figure 5.10). Three stanzas are considered. The first, 1985-88, illustrates the expected female size composition in a stable population. 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. The second stanza can be considered the state of the resource during the peak of the fishery, 1995-1997. The numbers of adults has declined substantially and pups are much less abundant. Finally, the most recent stanza, 2001-2003, illustrates the cumulative effects of reductions in the spawning stocks and the near absence of pups in the surveys in the last 7 years. The reduction in abundance of the dogfish in the 50-60 cm range provides support for 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. Changes in the total biomass at length (Figure 5.10 lower) illustrate the progressive removal of spawning stock over the three stanzas.

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. We then consider changes in the average size of mature females, the average size of pups, and demonstrate the relationship among maternal size, numbers of pups and average size of pups.

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 mi²) and divided by the average area swept by a 30-minute trawl haul (0.01 n mi²). Three size categories were defined (≤ 35 cm, 36-79 cm, and ≥ 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, Survey Branch, NEFSC) on variations in vessel speed and the increased contact time during haulback suggest that the effective area swept is greater than the nominal footprint. Additional details on this are provided in section 7. To illustrate the effect of this factor, the swept area biomass estimates are also computed with a nominal footprint of 0.012 n mi² (Table 6.2).

Swept area biomass estimates, using the 0.012 n mi² footprint were partitioned into size groups <36 cm, 36-79 cm, and ≥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 (Figure 6.1). The changes in total biomass mask significant changes that have occurred within size and sex groups. Most of the change since 1992 has occurred in the 80+ cm male and female spawners stock where abundance has declined from about 250 k mt to about 50 k mt in 2003 (Figure 6.2, top). The pool of male and female dogfish between 36 and 79 cm has remained relatively stable over the past decade (Figure 6.2, 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 6.3 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 (Figure 6.4, top) as the fishery has continued to accept smaller sized dogfish. No change is apparent in male 36-79 cm dogfish since the early 1990's (Figure 6.4, bottom).

The biomass of dogfish less than 36 cm represents individuals less than one year old at the time of the survey and are considered 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 (Figure 6.5). The numbers of recruits in the last 7 years, however, are the 7 lowest in the 36 year series. Coincident with the change in abundance, the average size of dogfish in this size range has also declined about 3 cm (Figure 6.6). The trend in abundance of recruits is consistent with the reduction in spawning stock, but the magnitude of the change is unexpected. In the following sections we explore possible reasons for the decline in pup abundance and introduce new biological information on dogfish reproduction.

6.2 Changes in Mean Size of Mature Females

In recent years, considerable attention has been paid to the impacts of demographic variation on reproductive output (Murawski et al. 2001). In general evidence for many fish populations suggests lower reproductive output from younger spawners, and these differences are greater than simple reductions in number of eggs produced. To examine the reduction in average size of mature female dogfish, the average length of mature dogfish (80+ cm) was computed for the NEFSC fall (1980-2002), winter (1992-2003), and spring (1980-2003) surveys, the MADMF spring (1980-2002) and fall (1980-2002) surveys, and the NC SeaMap (1997-2003) surveys. The trends in average size of mature females show a remarkable consistency across all surveys (Fig. 6.7). Average size has declined from about

95 cm to 85 cm over this period, with consistent rates of change among surveys . Even the much shorter time series of the NC SeaMap survey shows a size range of mature dogfish consistent with the observations of the 5 other surveys (Figure 6.8). From these data, there is no evidence that a population of large-sized females is present in the Northeast US. The Canadian summer survey typically captures a much smaller sized female than the US surveys (S. Campana, DFO, per comm.). Additional analyses of Canadian data are warranted.

6.3 Potential Reasons for Reduced Pup Production 1997-2003

6.3.1 Fecundity and Pup Size in Relation to Maternal Size

In 1997 the SARC 26 noted the first year of low pup production and commented that it may be related to the reduction in spawning stock. A substantial amount of additional information on the reproductive biology of dogfish has been collected since the last assessment. Here we provide additional information on the factors that may underlie these changes in dogfish abundance.

Spiny dogfish females 65 cm or greater in total length (10 cm below the previously estimated size at first maturity) were examined during the bottom trawl surveys conducted by the NEFSC from 1998-2002. The trawl surveys are conducted in three seasons: winter (February), spring (March-April), and autumn (September-October) (Azarovitz 1982). The spring and autumn surveys cover the region from Cape Hatteras, NC, through the Gulf of Maine. The winter survey covers the region from Cape Hatteras, NC, to Georges Bank. A summary of the sampling by year and survey is provided in Table 6.3.

Each female was examined for the presence of free embryos, fertilized uterine eggs (candled embryos), and ovarian eggs. Immature females were classified as those with small ovaries containing either no eggs or small, non-developing eggs. A female was determined to be mature if large, well-developed eggs were present in the ovaries or if embryos were present in the uterus. If free embryos were present and time permitted, the embryos were counted for fecundity analysis. Candled embryos and ovarian eggs were not used in the fecundity analyses because they were prone to rupture.

The relationships between pup weight and average pup weight with maternal length (Figure 6.9) show a consistent increase with maternal length. All of the data in Figure 6.9 represent near-term free embryos at least 18 months old. A 100-cm female produces a pup that is 5 cm longer and about 50% heavier than an 80 cm female. The number of pups produced also increased with maternal length (Figure 6.10, top) but females with more than 6 pups were uncommon for dogfish less than 95 cm. The number of fertilized eggs and free embryos did not appear to change with gestational month (Figure 6.10 bottom). Such changes might be expected if capture stress or other factors were decreasing the number of fertilized eggs within the females. Larger numbers of near-term free embryos also corresponded to larger average sizes (Figure 6.11). Thus, larger females produce larger clutches of eggs and larger average-sized pups. Collectively, these factors suggest, but do not confirm, that larger females produce a more fit offspring, potentially subject to a smaller spectrum of predators.

A simple test of this hypothesis was conducted by examining the relationship between the predicted pup production from the spring survey and the observed numbers in the survey. Using a 3-yr average size composition of females, the predicted number of pups in year t was estimated at the sum product of the number at length and the average pups per 1-cm length group. The total pup production from this computation is multiplied by the first year survival rate (Section 8.0) = 0.68. No other statistical adjustments to the data were computed. The relationship between the observed and predicted numbers of pups (Figure 6.12) reveals good agreement in terms of scale. Moreover, the differences between the observed and predicted pup production shows that predicted number of pups are consistently negative from 1997 onward. Thus, the number of pups actually produced are lower than expected even when accounting for the reduced abundance of mature females. Figure 6.13 provides additional support for this hypothesis, showing the decrease in numbers and average size of mature females (top) and the clustering of negative residuals by year (bottom). These results suggest that population projections that rely on a constant first year survival rate (Section 9.0) may be overly optimistic with respect to population recovery.

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 were $K=0.1128$, $L_{\max}=105$ cm. Fishing mortality rate is obtained at 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 6,000 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) (Figures 7.1, 7.2). 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

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 $p_s(\ell)$ represent the proportion at length ℓ in the survey and let $p_c(\ell)$ 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.

Additional data on the size selectivity of the dogfish fishery are can be obtained by examining detailed discard size composition data provided by the Massachusetts Division of Marine Fisheries for 2000-2002. The fraction retained by size interval was fit to a logistic function by year (Fig. 4.18). Model results suggest that the median size of retained dogfish in Massachusetts fisheries declined from 77 cm in 2000 to 70 cm in 2001 and further decreased to 65 cm in 2002.

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. (In VPA speak, this is the biomass-weighted F). In terms of evaluating the fishing mortality rate with respect to a biological reference point, we are interested in a metric commensurate with the pup-per-recruit analyses (Section 8.0).

Define

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

$F_2 = F$ generated by total discards plus recreational catch, acting on the total biomass of male and female dogfish.

$F_{\text{bar}} =$ Biomass-weighted average F derived from F_1 and F_2

$F_3 =$ Fishing mortality rate on female dogfish, estimated as the ratio of female dogfish landings divided by exploitable biomass of female dogfish

$F_4 =$ Fishing mortality rate on male dogfish, estimated as the ratio of male dogfish landings divided by 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 male dogfish in USA plus Canadian commercial landings

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

$B_f(\ell) =$ Total biomass(mt) of female dogfish at length ℓ .

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

$B(\ell) = B_f(\ell) + B_m(\ell)$

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

$B_{\text{fxpl},f}(\ell) =$ Exploitable biomass(mt) of female dogfish at length ℓ .

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

$B_{\text{expl}}(\ell) = B_{\text{expl,f}}(\ell) + B_{\text{expl,m}}(\ell)$

D = Total discards (mt)

$N(\ell)$ = 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

$\text{sel}_f(\ell)$ = Selectivity fraction for females of length ℓ .

$\text{sel}_m(\ell)$ = 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).

\bar{X}_{t} = Average number of dogfish caught per tow in NMFS spring survey in year t .

S_t^2 = Estimated variance of mean catch per tow in NMFS spring survey in year t .

$$L_f + L_m = \sum_{l=l_{\min}}^{l_{\max}} F_1 (\text{sel}_f(l)B_f(l) + \text{sel}_m(l)B_m(l))$$

$$D = \sum_{l=l_{\min}}^{l_{\max}} F_2 B(l)$$

$$L_m + L_f + D = \sum_{l=l_{\min}}^{l_{\max}} F_{\text{bar}} B(l)$$

$$L_f = \sum_{l=l_{\min}}^{l_{\max}} F_3 \text{sel}_f(l)B_f(l)$$

$$L_m = \sum_{l=l_{\min}}^{l_{\max}} F_4 \text{sel}_m(l)B_m(l)$$

The estimates of F can be obtained by rearranging Eq. 1 to 5, 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.

$$B(l) = B_f(l) + B_m(l)$$

where,

$$B_f(l) = N_f(l)W(l) = I_f(l)\left(\frac{A}{a}\right)W_f(l)$$

$$B_m(l) = N_m(l)W(l) = I_m(l)\left(\frac{A}{a}\right)W_m(l)$$

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

$$I_f(l) = \bar{X}_f p(l)$$

$$I_m(l) = \bar{X}_m p(l)$$

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 3 yr 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

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

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

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 α_{\min} and α_{\max} , over equal probability intervals.

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

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 $a \sim N(\mu_a, \sigma_a^2)$ and the discard estimate $D \sim N(\mu_D, \sigma_D^2)$. 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. As each parameter was evaluated over 500 equal probability intervals, there is reasonable assurance that the sampling distributions of the Fs will be appropriately estimated. The computer program for evaluating the distributions of F is provided in Appendix 2.

7.3.2 Results

Biomass Estimates

Stochastic estimates of exploitable biomass, total biomass and spawning stock biomass are summarized in Table 7.3 (minimum footprint assumption) and Table 7.4 (maximum footprint assumption) for 1990 to 2002. Trends in total biomass and SSB biomass are comparable to results presented in Tables 6.1-6.2. Incorporation of the uncertainty in the survey mean numbers per tow and footprint variation (within the two alternatives, i.e., min versus max footprint) suggests relatively precise estimates. The exploitable biomass quantities vary as a function of the selectivity functions derived in Section 7.2. 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 various biomass estimates are depicted graphically in Figures 7.3 to 7.6. As the selectivity of the fishery shifted toward smaller individuals the distributions of total and exploitable biomass exhibited a greater degree of overlap (Figures 7.3 and 7.5). The decline in SSB between 1990 and 2002 is evident in Figures 7.4 and 7.6, and notably, the reduced variation is also evident. By 2002, the stochastic SSB estimates were coincident with the exploitable biomass estimates. This suggests that the fishery is selecting individuals over the entire range of sizes within the exploitable stock.

Fishing Mortality Estimates

Stochastic estimates of F attributable to removals, the total exploitable biomass, discards, and exploitable biomass by sex are summarized in Table 7.5 (minimum footprint assumption) and Table 7.6 (maximum footprint assumption) for 1990 to 2002. The fishing mortality on the total biomass peaked in 1996 at 0.09 and has decreased since then to about 0.03 (Table 7.5). Under the assumption of the maximum footprint, the fishing mortality on total biomass is on the order of 0.07 (Table 7.6). Discard mortality, as it acts over the entire population, has generally been low, ranging under 0.03 over the last 10 years (Table 7.5). For the maximum footprint assumption, the discard F has generally been less than 0.06 (Table 7.6).

From the standpoint of the stock assessment, the most relevant quantity is the fishing mortality rate on the exploitable female biomass. As noted above, this quantity is now equivalent to the total spawning stock. The fishing mortality rate on the exploitable stock is denoted as F_3 in Tables 7.5 and 7.6. Under the assumption of the minimum footprint, the F on the exploitable female biomass is 0.094. Note that the fishing mortality biological reference points are 0.08 for the target and 0.11 for the threshold. Note also that the target F for rebuilding of the stock is intended to be 0.03. The implications of these rates of fishing mortality for population recovery are treated more fully in Section 9.

The derived empirical distributions of F estimates on the exploitable biomass by sex and the discard mortality rate are shown in Figures 7.7 (min footprint) and 7.8 (max footprint). Despite the wide variation in the range of discard estimates, the overall rate remains relatively low except in the early 1990s. The distribution of F on females has been greatly reduced by the management measures in the US but these have been offset by concomitant increases in landings in Canada.

Comparison with Beverton-Holt Estimates

An overall comparison of the stochastic mean estimates of F on the exploitable female population and the Beverton-Holt estimates is provided in Figure 7.9. The range of stochastic Fs derived under the alternative footprint values generally envelope the quantities derived from the BH estimates. The lack of agreement is greatest in the last 3 years, consistent with the hypothesis that the BH estimator would be more strongly influenced by the transient population condition. It is also interesting to note the substantial degree of agreement among the estimates during the period when the fishery was growing rapidly through the mid 1990s.

8.0. Life History Model

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 was reviewed jointly by the New England and Mid-Atlantic Fishery Management Councils' Statistical and Scientific Committees 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 ($\sim 64,207 \text{ nm}^2$) 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%. More specifically, 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 than the nominal footprint. Increasing the footprint reduces the swept area biomass estimate, leading to an alternative estimate of the SSB_{max} of 167,000 (i.e., $200,000 \text{ mt} \cdot (0.01/0.12) = 166,667 \text{ mt}$).

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 2003 illustrates another important property of the SSB_{max} estimate. Recruitments since 1997 represent the seven lowest values in the 1968-2003 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 37% to 294,000 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 SSB_{max} slightly less than 200,000 mt (using the 0.01nm² footprint).

Discussion of the scaling problems at the SARC 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 Section 6.3, the reproductive output of dogfish declines with maternal size with decreases in 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 SARC requested additional exploration of this mechanism, the results of which are summarized below.

An alternative measure of reproductive potential can be obtained considering the reproductive potential as a function of the maternal size distribution and numbers of pups per female at size. For this analysis, no smoothing of abundance indices was performed. Observed pups were computed as the sum of densities (number per tow) for all catches between 20 and 35 cm. Predicted pups were computed as product of mature female densities at length, predicted numbers of pups per length class and estimated survival rate. The estimated survival rate is computed under two models: a) no maternal effect, b) survival as function of maternal length. Under model (a) the survival function is estimated as $S_o(L) = 1/(1+\exp(0.5389)) = 0.368$ with a MSE of 0.234 and $R^2 = 0.456$ (Fig. 8.2). Under model (b) wherein maternal size is assumed to affect pup survival, the resulting function $S_o(L) = 1/(1+\exp(28.123-0.305*L))$ reduces MSE to 0.196 and increases R^2 to 0.564. Both of these models appear to be superior to the Ricker SR model for predicting recruitment. The limitation of the demographic model is that it does not provide a simple method for defining the optimum level of SSB corresponding to R_{max} . Instead, the demographic model is unbounded with respect to SSB_{max} . The results of the demographic recruitment model are incorporated into the stochastic projection scenarios in the following section.

9.0 Stochastic projection model

9.1 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

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

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

where

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

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

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

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

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

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

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

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

P_{up} = 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 \mathbf{X} denote a matrix with $k \times k$ elements, and \mathbf{Y} denote a vector with k elements. Then \mathbf{XY} would define the matrix multiplication of the vector \mathbf{Y} by matrix \mathbf{X} yielding a vector quantity, say \mathbf{Z} . Similarly, $\mathbf{Y}^T\mathbf{Y}$, read as \mathbf{Y} transpose \mathbf{Y} , represents the dot product of the elements of \mathbf{Y} with itself, yielding a scalar quantity. Scalar multiplication of a vector is denoted as $c\mathbf{Y}$ 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 \mathbf{X} and $Y(i)$ represents the i^{th} element of the vector \mathbf{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.

9.2 Processes

9.2.1 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. 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.

9.2.2 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 $S_{f,z,t}$ and $S_{m,z,t}$ 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-Raphson 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.

9.2.3 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

$$\begin{aligned} N_{f,t+\Delta t} &= S_{D,t} N_{f,t} \\ N_{m,t+\Delta t} &= S_{D,t} N_{m,t} \end{aligned}$$

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

$$\begin{aligned} D_{f,t} &= N_{f,t} - N_{f,t+\Delta t} \\ D_{m,t} &= N_{m,t} - N_{m,t+\Delta t} \end{aligned}$$

9.2.4 Reproduction

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

$$\begin{aligned} \text{female pups} &= \phi Pup_{TOT,t} R_f^o \\ \text{male pups} &= (1 - \phi) Pup_{TOT,t} R_m^o \end{aligned}$$

The \mathbf{R}_f and \mathbf{R}_m vectors representing the proportions by length class consist of $(\ell_{\max} - \ell_{\min} + 1)$ 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.

9.2.5 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

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

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

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:

$$Y_{f,t} = C_{f,t}^T W_f$$

$$Y_{m,t} = C_{m,t}^T W_m$$

and

$$Y_t = Y_{f,t} + Y_{m,t}$$

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

$$D_{B,f,t} = D_{f,t}^T W_f$$

$$D_{B,m,t} = D_{m,t}^T W_m$$

and

$$D_{B,t} = D_{B,f,t} + D_{B,m,t}$$

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.

$$B_{f,t} = N_{f,t}^T W_f$$

$$B_{m,t} = N_{m,t}^T W_m$$

and

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

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 as 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

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

9.3 Initial conditions

The initial condition of the population was defined as the 3-yr average (2001-2003) 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.

Following the recommendation of the subcommittee, all projections were computed using the minimum footprint size. Use of the minimum footprint increases the biomass estimate and decreases the fishing mortality estimate, relative to the alternative maximum footprint.

9.4 Scenarios

A large number of scenarios are possible. Terms of Reference 4 through 6 requested

4) Estimate yield based on stock status and target mortality rate ($F = 0.08$) for fishing year 2004 (May, 2004 through April, 2005).

5) Provide short term projections (2-3 years) of stock status under a variety of TAC/F strategies

6) Evaluate existing and alternative rebuilding schedules based on current/projected stock status.

Items 5 and 6 are closely related but indefinite. To help bound the problem, six projection scenarios were defined. Each was based on previously specified scenarios that have been previously analyzed in committee preparations for the joint MAFMC and NEFSC dogfish management plan for federal waters and/or the ASMFC plan for state waters. Three scenarios utilize an F-based strategy with constant fishing mortality rates over a 30 year projection period. The other three scenarios utilize a fixed quota over a 30 period.

The status quo F scenario assumes that the fishing mortality rate estimate in 2002 would continue through from 2003 to 2032. No assumptions about the relative allocation of yield between the US and Canada are made but the current rate of F is based on the summation of landings from both countries. The rebuilding level of F is based on projection results from an earlier version of the model. Given the initial conditions of the resource in 1997 and the model formulation, a fixed level of $F = 0.03$ was determined to be adequate to rebuild the stock within the 10-year rebuilding period specified by the Sustainable Fisheries Act (SFA). Finally, an implausible scenario of zero fishing mortality was employed to evaluate the minimum possible rebuilding time. The utility of this scenario is that it provides a benchmark to compare alternative scenarios.

Three quota-based scenarios were also evaluated. In each of these scenarios it was assumed that the future level of landings in Canada would remain near its current value of about 3,400 mt. It was further assumed that landings from the US would be additive. The base quota scenario assumes that US commercial fisheries extract a target quota of 4 M lb (1,814 mt) and Canadian landings remain at 3,400 mt. The “alternative” quota evaluates the effects of an 8.8 M lb (3,992 mt) US commercial landings and 3,400 mt in Canada. Finally, the “No Commercial Quota” scenario assumes that no dogfish would be landed in US fisheries.

The scenarios are designed to evaluate the relative merits of possible alternatives, rather than to accentuate allocation issues. The “status quo F”, “base quota”, “alternative quota” and “No US Commercial Quota” scenarios provide feedback on what might be accomplished under US regulatory measures. The “zero F” and “rebuild F” scenarios would require joint management by the US and Canada.

For all scenarios, it was assumed that the current rate of discard mortality would prevail for the projection period. Moreover, recreational fishery was assumed to consist mainly of discard mortality with no targeted effect of discarding.

The relative merits of each alternative scenario can be evaluated with respect to the magnitude of landings and the attainment of biological reference points. For each year in a scenario, 500 realizations of F and biomass are computed. Each of these is compared to threshold and target F and biomass levels. In addition, each simulated value of F was compared to an F_{rebuild} level = 0.03 per the various management plans. The number of times that the F reference points were exceeded divided by the number of bootstrap intervals (500) represents a measure of the probability of exceeding the reference value. Similarly, the count

of Biomass levels above the target level represents probability of restoring the population. Count of biomass above the threshold level could be interpreted as the shift in status from the “overfished” condition.

The projection model output was condensed to provide rapid comparison among alternatives. First, box plots were used to summarize the projected range of model outputs for key management variables {1)Yield (mt total, female, male), 2) Discards (mt), 3) SSB (mt), 4) F, 5) Fraction of the SSB target and 6) Total biomass (mt)}. To further reduce the information, these quantities were tabulated as averages on a decadal time scale (Table 9.1) and as a series of 10 year waypoints (Table 9.2). It should be noted that the current non-equilibrium status of the population induces transient oscillations in abundance. These oscillations should be kept in mind when evaluating the tabulated waypoint data. In particular, it is expected that some scenarios will rapidly attain restoration followed by a decline in abundance at the effects of recent low levels of recruitment feed into the adult stock. The input files and probability output files are included in Appendix 4. The following sections provide additional details on the results of the simulation model.

9.4.1 Status quo F

Under the status quo F scenario, the population exhibits wide variation in SSB and yield. (Figure 9.1). Both of these oscillations are induced by the non equilibrium size structure of the population. The population does not achieve rebuilt status but does stabilize at about 100 k mt of SSB supporting about 8,000 mt of yield. The stabilization occurs because the joint effect of the current fishing mortality rate and discard rate closely approximate the predicted equilibrium threshold F of about 0.11. As a result, population stability is achieved by about 2020.

9.4.2 Rebuild F

The rebuild F option is based on recommended fishing mortality rates specified in the federal FMP. The target rate of $F=0.03$ is based on an earlier version of the model presented herein. Under this option, the population rebuilds rapidly but then oscillates as the effects of the paucity of 36-79 cm initial population is felt about 10 years into the simulation (Figure 9.2). The effects occur in both the yield and SSB trajectories. Population rebuilding occurs in 2020. The model uses a constant F but presumably a more liberal fishing mortality rate could be applied at that time.

9.4.3 Zero F

The zero F option is designed to benchmark the minimum possible rebuilding time. Under this assumed option the population is predicted to have a 50% of exceeding the target biomass level in 2017 (Figure 9.3)

9.4.4 Base Quota

The baseline quota option represents continuation of the current level of total landings in the US and Canada. The current quota level results in a gradual increase in population size allowing rebuilding by about 2026 (Figure 9.4).

9.4.5 Alternative Quota

The alternative quota option (Figure 9.5) fails to achieve rebuilding over the 30-yr period of the simulation.

9.4.6 No Commercial Quota

This option results in a rebuilding of the population by 2020 (Figure 9.6). The model results suggest that a quota of about 3,400 mt, however allocated, could be harvested without severely delaying the rebuilding time that would occur under the zero F option.

9.4.7 F=0.08 in 2004 and later

This scenario corresponds to the target fishing mortality rate specified in the federal FMP. Yield under this scenario fluctuates around 9,000 mt, but the population never rebuilds over the 30 year horizon.

9.4.8. Status Quo F and Maternal Effect on first year Survival

Projection model simulation results under the assumption that the status quo F continues and first year pup survival is expressed as a function of maternal size (Figure 8.2) are provided in Figure 9.8. This scenario suggests that the population will neither rebuild nor stabilize under the status quo F.

9.4.9 Summary

No density dependent factors associated with high densities are included. This is appropriate for dogfish in view of the low present state of the female spawner biomass and limited range for compensation in terms of growth and pup production. The absence of density-dependent regulation is justified also by the steepness of the SR function at the origin. This projection model is considered adequate for describing the dynamics of the resource up to the point of restoration, i.e., attainment of the biological reference point for biomass.

Important caveats apply to ALL of the above simulations. No assumptions are made about possible size dependent decreases in pup viability. It is assumed that pup survival is constant for pups produced by all females, regardless of maternal size. If the size-dependent decreases in initial survival rates are real, then all of the scenarios would be considered optimistic with respect to rebuilding the populations. Further, it is assumed that the current discard pattern persists into the future. Another important factor is that the minimum footprint is assumed to apply. While the exact expansion factor (A/a) is unknown, the true value is likely to be between the min and max footprint assumptions. If so, appropriate caution should be applied when considering long-term quota options. Earlier projections of stock biomass under the max footprint assumption suggested that the range of quota levels that gave increasing versus decreasing populations was fairly narrow.

10.0 Simple Mass Balance Models

The SARC 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. The SARC 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. The following analyses were conducted during the SARC and are intended to provide an initial exploration of the utility of model-based methods of estimating abundance. 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.

As in all analyses of survey data for spiny dogfish, data are averaged across years to provide a better estimate of abundance. This tends to dampen interannual changes.

If we consider the reduction of female dogfish abundance since 1989 as a simple depletion experiment wherein the slow growth of dogfish above 80 cm, and low mortality combine to result in low recruitment and biomass production, a Leslie-Davis model is a plausible approach. Under this assumption the change in abundance could be viewed as a simple depletion experiment. If the index data are scaled to the nominal footprint, the slope of the Leslie Davis regression is a measure of the efficiency of the trawl. Results of the Leslie Davis application are provided in Figure 10.1. The slope estimate of 1.23 is consistent with an effective footprint approximately equal to the increased contact time of the trawl. As a very rough approximation, the efficiency of the trawl for dogfish should be on the order of $0.0123/0.0239 \sim 50\%$. (Note: the value of 0.0239 nm^2 corresponds to a trawl footprint defined as the distance between the trawl doors. This indirect measure of trawl efficiency further assumes that dogfish herd in between the doors.)

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 more complicated mass balance model was devised. The model is similar to that proposed by Collie and Sissenwine, 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 -0.061 which corresponds well with the assumed natural mortality rate of 0.092 and a very slow adult growth rate. Results of the model fit are summarized in Figure 10.2. 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. (Figure 10.2 bottom panel).

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.

11.0 Spiny Dogfish Research Recommendations

New

- 1) Attempt to allocate landings to statistical area (i.e. attempt proration) using Vessel Trip Report data for 1994 and later years.
- 2) Evaluate the utility of length frequency for spiny dogfish sampled in the NEFSC Observer Program in the most recent years (2001 and later).
- 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.
- 4) Conduct tagging and genetic studies of spiny dogfish in U.S. and Canadian waters to clarify current assumptions about stock structure.
- 5) Conduct discard mortality studies for spiny dogfish, with consideration of the differences in mortality rates among seasons, areas, and gear types.
- 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.
- 7) Investigate the distribution of spiny dogfish beyond the depth range of current NEFSC trawl surveys, possibly using experimental research or supplemental surveys.
- 8) Initiate ageing 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 development.
- 9) Explore an alternative assessment which uses a standard statistical fisheries modeling approach (i.e., data inputs not smoothed before fitting the model, and trawl biomass used as relative indices with a selectivity pattern estimated within the model).

Old: Pending

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

Old: In Progress

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

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

Old: Completed

1) The SARC recommended continued work on the change-in-ratio estimators for mortality rates and suggested several options for analyses.

The change-in-ratio estimator approach was not successful, and has been dropped from the assessment.

2) The SARC noted the absence of projections for this species and recommended the development of a projection model.

Projections are now included in the assessment.

3) The SARC recommended additional analyses of sea sampling data since 1994. Further analyses of the commercial fishery is also warranted, especially with respect to the effects of gear types, mesh sizes, and market acceptability on the mean size of landed dogfish.

Discard estimates based on sea sampling (observer) data are now included in the assessment.

4) The SARC noted the potential importance of dogfish predation in the ecosystem and recommended further work on the diet composition.

See Link et al, 2002 (N. Am. J. Fish. Mgmt. 22:550-562).

12.0 SARC Comments

12.1. Discussion on Life History, Discard Estimation and Survey Trends

The Stock Assessment Review Committee (SARC) discussed the different longevity estimates for the east and west coast. The east coast assumes spiny dogfish live for fifty years, whereas on the west coast it is assumed that dogfish live for 100 years. There is some evidence that the west coast ageing consistently doubles the ages assigned to the rings on the second dorsal spine resulting in a life span twice as long as the east coast. There does not appear to be any evolutionary reason for the Pacific spiny dogfish to live twice as long as the Atlantic spiny dogfish. While there is a need for more ageing work, the SARC determined that a life span of fifty years is the based best available information at this time.

The stock assessment assumes 100% of the spiny dogfish discarded in the recreational fishery are discarded dead. Estimates of discard mortality in the recreational fishery are based on the treatment of dogfish on charter boats. The SARC discussed the appropriateness of the assumed discard mortality rates in the assessment because the commercial hook and line fishery has an assumed discard mortality rate of 25%. Information on discard mortality rates in the spiny dogfish recreational and commercial fisheries is lacking.

Due to recent management decisions to employ a different quota determination methodology to estimate the annual commercial quota, some members of the Committee felt that the SAW/SARC process would have been an appropriate venue to review the new quota determination model. While fishery managers are responsible for selecting the fishery's quota, the SARC could have provided some advice on the potential implications on the stock. The SARC felt it should conduct a technical review of the models used to estimate annual quotas.

Observed patterns from the NEFSC trawl survey show that the number of pups in a litter has changed over time, from 5–15 to 2-10. Litters over ten pups are a rare occurrence. There is some variability in the number of pups in a litter, but, generally, the number of pups in a litter increases with the length of the female.

Biological sampling of spiny dogfish has been sporadic because the species does not have a high priority. Massachusetts Division of Marine Fisheries does perform some port and sea sampling for spiny dogfish, although the timing of commercial landings has challenged the ability to obtain biological samples. Commercial landings come in over a short period of time because of the current management scheme and the low quota.

The Committee discussed the use of inshore surveys, such as the Maine and New Jersey surveys. These surveys would complement the current catch rate information from the NEFSC trawl survey, but would not supplement the information collected on the biological attributes of the resource (e.g. length and sex), which are critical to the stock assessment.

It was suggested that the discard estimates should have confidence intervals, derived from a more robust method such as bootstrapping.

Catch per unit effort should be incorporated into the discard estimation, but defining a standardized unit of effort between the different gear types would be difficult. Much of the data are for short trips, so the definition of a trip for a small gillnet vessel will be different to that of bigger trawl vessels. Future work on estimating discards could include GLM or other models using catch per unit effort, vessel classification and other covariates.

The assessment uses information collected from the NOAA Fisheries Observer Program to determine an estimation of the level of discards associated with different gear types. The catch-based discard estimation focused on three different gear type predominantly used when targeting spiny dogfish; gillnets, hook and line, and trawls. The estimation included only trips where spiny dogfish was not the primary target species, and therefore assumed to be bycatch.

At a previous SARC, the winter, fall, and spring surveys were reviewed to determine the most appropriate survey to characterize the stock. During the time of year that the spring survey is conducted, about 90% of the spiny dogfish population inhabits the same area covered by the survey. This earlier SARC review also revealed that when the abundance dropped in the fall survey, the absent portion of the resource appeared in the Canadian survey. This implies that the US fall survey and the Canadian survey combined may track abundance of the entire population, but NEFSC spring survey alone provided the best representative sample of the entire population.

The assessment did not review the NEFSC trawl survey to determine if there was a spatial trend associated with the characteristics of mean size of females and pups.

The Committee discussed the influence of environmental variation creating a size dependent response. The length frequencies in the survey reveal that the mature females over 80 cm have not been captured by the survey over the last six or seven years. The same evidence is seen in the commercial landings. At one point, it was common for the fishery to harvest females over 100 cm. The males are commonly found along the continental shelf, whereas the females tend to be found inshore. The spatial movements of the sexes might be a reason for the biological characteristics seen in the survey.

Future work on the assessment should include a review of the environmental variables associated with the encounter of spiny dogfish during the NEFSC trawl spring, like temperature and depth. The survey area should be stratified by temperature to determine if the temperature drives the dogfish to a different geographical location each year. Also, if the survey is partitioned into three or four strata, the data may reveal whether the biological characteristics are different in each area.

It was noted that the assessment may overestimate the spawning stock biomass if the pup viability is not taken into account in management decisions.

12.2. East Carolina University Spiny Dogfish Tagging Data

The North Carolina spiny dogfish fishery typically encounters more females than males. The fishery also takes place during the winter when the dogfish have migrated south. The weather during the winter prohibits fishermen from fishing out on the continental shelf. Data from the NEFSC trawl survey shows that the males tend to be in the deep waters off North Carolina at about 200 m.

The majority of the tag returns were in the US; only one or two were captured in Canadian waters. A possible explanation for the low return rate in Canada is the difference in effort. For the time period covered by the study, the US effort was about four to five times the Canadian landings. To determine the migrational patterns in the northern range of the species, tagging studies need to be conducted off Cape Cod, Massachusetts.

The tagging study should consider the associated handling mortality. It is assumed to be low because the dogfish are released soon after they are captured. The condition of the spiny dogfish should be assessed and recorded prior to releasing the fish. There was some concern that recapture of fish released from gillnets was much lower than those released from trawl, which may be due to tag induced mortality.

The tagging study is encountering a considerable number of dogfish that may not be caught by the fishery. The study should determine if there is a difference in size between the fish caught by the different gear types (e.g. trawls versus gillnets).

The population estimate derived from the tagging study is three times the estimate derived from the swept area estimate. The tagging study should factor in the possibility that dogfish are double tagged and tag shedding rates.

The tagging study used two different reward levels. Every tenth tag released was a \$50 reward; all of the remaining tags offer a \$10 reward. The different reward levels did not influence the reporting rate.

The biomass estimates derived from the gillnet study should factor in the probability of being captured associated with the distance from the gillnet.

The tagging work in North Carolina should be combined with the gillnet study to provide a better population estimate.

12.3. Discussion on Biological Reference Points and Projections

The Committee discussed the catchability associated with the trawl survey. The catchability may be influenced by a significant amount of herding in front of the doors.

The current target biomass uses the female spawning stock biomass. The target biomass was selected based on the number of pups that will survive to replace the mature female in the population so that the population remains stable. The Committee suggested using fecundity

as an alternative target to spawning stock biomass. The spawning stock biomass may not be the best target due to the uncertainty associated with the survey area-swept method. The assessment derived a predicted number of pups in the population based on the abundance and length frequencies of the mature females. The predicted number of pups in the population was overestimated compared to the observed number of pups in the survey.

Stochastic Biomass Estimates

The stock assessment introduces a new method for estimating biomass to replace the Beverton - Holt method used in previous assessments. The stochastic biomass estimator requires a set of assumptions. The biomass encountered by the NEFSC trawl survey is representative of the entire population and the availability of the resource is assumed to be equal over the entire survey area. The survey biomass also represents the size composition of the population, so all lengths are equally selected by the trawl survey. The length composition of the survey biomass is averaged over 3 years to reduce the survey variability.

It was questioned whether using swept area without taking into account vulnerability (i.e. assuming vulnerability = 1) could be used to obtain realistic biomass estimates. The three components of catchability are vertical availability, area availability and vulnerability to the survey gear. Vertical availability was assumed to be high as dogfish tend not to move far from the sea floor and area availability is already considered in the assessment. The biomass estimates derived in the survey produces a lower and upper bound on the biomass based on the area availability. The spring survey is assumed to encounter about 90% or more of the population.

A range of biomass estimates are produced in the assessment because of the uncertainty associated with the area swept by the survey. The minimum footprint of the survey is based on the area swept between the wings of the net. The minimum footprint translates into the maximum biomass estimate. The maximum footprint uses the area between the doors of the net and is the basis for the minimum biomass estimate. The doors may be creating a herding effect making the effective footprint the area swept between the doors. The Committee suggested the use of underwater video equipment on the net to determine if herding does occur, and, more generally, vulnerability to the gear.

The NEFSC spring survey is assumed to be the best indicator of the overall stock structure. Commercial landings are used to determine the size frequency and commercial selectivity. The assumption is that the commercial gear is fishing in a smaller size range than the entire population. The selectivity in the fishery exists because of market demand for a certain size range of dogfish.

The stochastic biomass estimator shows an increase in exploitable biomass in 1995 and 1996, which coincides with the increase in commercial landings. At this time, a large portion of the landings was male, so the force of mortality was over a greater portion of the entire population, influencing the selectivity for the fishery.

The biomass estimates are being used as absolute abundance estimates, when the estimates are probably relative abundance. It was pointed out that trawl surveys are not usually used to estimate absolute biomass. However, absolute biomass estimates are needed to derive the annual quota and no alternative is currently available. It was suggested that the assessment moved towards a fully age or size structured model and use the trawl survey as an index of relative abundance.

Additional research on ageing spiny dogfish is needed to resolve the ageing discrepancy between the east and west coast. Age information will reduce some of the uncertainties introduced by converting length frequencies to age classes.

It appears that spiny dogfish is a possible candidate for a biomass dynamics model, but the estimates derived in 1994 were poor and the model was not pursued further.

In recent years, the stochastic biomass estimator shows a convergence of the exploitable and spawning stock biomass. Variation in growth rates between individuals in the population should and can be introduced into the model. The current assessment assumes that there is no variation in growth rates. The model also assumes that the population is at equilibrium, although, it is clear that the population has not reached equilibrium.

Projections

The projection model should be configured so that the recruits to the population are a function of the population size. This will more accurately model the current condition of recruitment and implication of improved recruitment as the population.

The number of pups in a litter is proportional to the length of the female. An estimate of predicted pups can be derived based on the length frequencies of the females in the population. The pup survival rate is dependent on the average size of pups. The pups produced by smaller females are generally smaller in size, and therefore have a lower survival rate than the pups produced by larger females. Evidence of recruitment failure over the past seven years appears in the declining abundance of the immature dogfish between 50 cm and 60 cm.

The stochastic biomass estimator relies on the catchability of the survey to derive estimates of biomass and fishing mortality. In the interim, a connection should be made between the target female spawning stock biomass and an index of fecundity that could be used in future management decisions. The Committee suggested using pup production per tow or the number of mature females per tow multiplied by the number of pups that can be produced at sizes encountered in the tow.

Uncertainty in the F target has not been explicitly considered. Uncertainty in the target biomass could be characterized using bootstraps or other methods. It was suggested a full risk analysis could be conducted.

The Committee has more confidence in the relative abundance estimates. The relative abundance estimates should be used in the fishery management plans, but it would be acceptable to use both the upper and lower bounds of the absolute biomass estimates. The footprint of the trawl survey creates a lot of uncertainty in the absolute abundance estimates. Further exploration into the use of a fecundity index needs to be conducted and would be a recommended index for a biomass rebuilding target.

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