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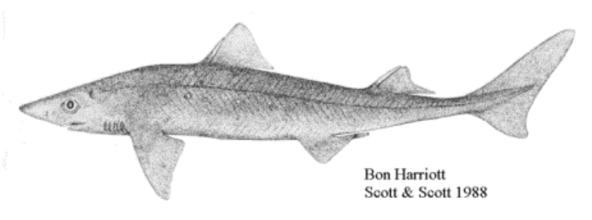
ASSESSMENT OF SPINY DOGFISH IN THE NORTHWEST ATLANTIC



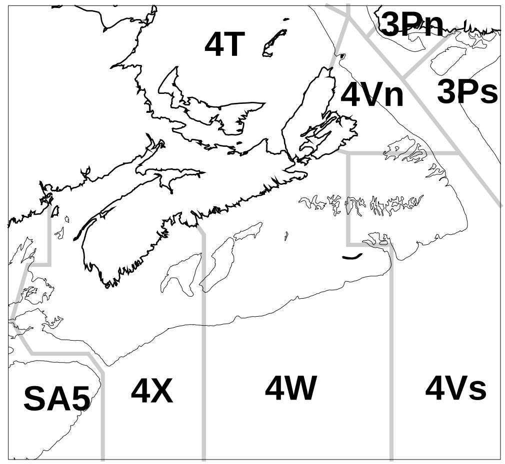


Figure 1. Spiny Dogfish assessment area.

Context:

Northwest Atlantic Spiny Dogfish (Squalus acanthias) is a small, cold-temperature shark found in waters throughout the Northwest Atlantic, with large numbers occurring between North Carolina and southern Newfoundland. Spiny Dogfish is a transboundary resource with significant catches in Canada and the United States of America (USA). Most Atlantic Canadian landings of Spiny Dogfish have historically been taken in longline and gillnet fisheries.

Canadian catches of Spiny Dogfish were unrestricted prior to 2002. Since 2002, total allowable catch (TAC) based on past catches has been in place for the Maritimes Region (Figure 1). The TAC since 2004 has been set at 2500 mt, but there has been no directed fishery since 2006. TACs have not been based on scientific advice, and there are no restrictions on discarding and bycatch in other fisheries. In 2003, an intensive 5-year research program on Canadian Spiny Dogfish was initiated by DFO, conducted in cooperation with the dogfish fishing industry through a Joint Project Agreement (JPA). The JPA provided for the collection of large numbers of at-sea and landed samples of Spiny Dogfish catches that were used in analyses of commercial catches and dogfish biology.

Although a joint Canada-USA Transboundary Resources Assessment Committee (TRAC) assessment framework (benchmark) review was held in early 2010, there was no consensus on an assessment model. Both USA and Canada have continued development of Spiny Dogfish stock and population models independently since 2010. This report presents the outcome of the most recent framework and assessment process for Canada.

This Science Advisory Report is from the January 20-21 and May 29, 2014, Northwest Atlantic Spiny Dogfish Framework and Assessment meetings. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Canadian landings averaged about 2500 mt annually between 2000 and 2008. The quota for Spiny Dogfish has been set at 2500 mt since 2004. Landings since 2008 have been markedly lower, dropping to only 5 mt in 2010 and have remained at very low levels since. There are no restrictions on discarding and bycatch in other fisheries.
- Population estimates indicate a dramatic increase in Spiny Dogfish abundance during the 1980s, peaking about 1992, and then declining. The updated model demonstrates increased abundance since 2009, especially of juveniles, with a total population abundance of 789.2 million Spiny Dogfish for 2013. Adult females have remained at relatively high abundance since 2006.
- Spiny Dogfish migrate seasonally, their distribution shifting between USA and Canadian waters as many migrate south in winter and north in summer, with the Gulf of Maine roughly corresponding to their centre of distribution in the Northwest Atlantic.
- Approximately half the population (53-56%, varying by sex and maturity stage) is estimated to be resident in Canadian waters during the summer. This varies considerably from year to year, with annual estimates ranging from 9% to 95%.
- Projections to evaluate the consequences of various catch levels suggest that a total catch (USA and Canada, landings and dead discards) of Spiny Dogfish in the vicinity of 47,350 mt (varies with assumed proportions of catch by region) would result in a 50% risk of decline in adult female biomass after 40 years.
- Abundance of adult females (SSN) and fishing mortality on adult females (Fssn) are used to evaluate stock status. Given the low productivity and associated recovery time of Spiny Dogfish, SSN_{msy} (32.8 million) is proposed as the USR and 65% of SSN_{MSY} (21.3 million) is proposed as a Lower Reference Point (LRP). $Fssn_{msy}$ is 0.072. Spiny Dogfish is currently above the USR, i.e., is in the healthy zone.
- Loss of trophic level competitors due to population declines of other fish species may have produced a non-equilibrium ecosystem in which Spiny Dogfish responded very positively, possibly exaggerating the estimate of carrying capacity as a long-term expectation.
- The current population model provides a reasonable basis for defining reference points and precautionary catch levels but cannot be rigorously updated without USA data.

BACKGROUND

Biology

Spiny Dogfish (*Squalus acanthias*) are small squaloid sharks that exhibit both demersal and pelagic habits. Dogfish populations are known to be present in the waters off of Europe, Argentina, New Zealand and Japan, as well as in the Northeast Pacific and Northwest Atlantic. In the Northwest Atlantic, dogfish are common from North Carolina to southern Newfoundland, and can be found further to the south and north. In the Northwest Atlantic, Spiny Dogfish occur at water temperatures from 0-12°C (preferred temperature of 6-11°C) and depths of 0-350 m (preferred depths of 50-200 m).

Spiny Dogfish migrate seasonally, their distribution shifting between USA and Canadian waters as many migrate south in winter and north in summer, with the Gulf of Maine roughly corresponding to a centre of distribution in the Northwest Atlantic.

As part of an intensive study of Spiny Dogfish conducted in cooperation with the commercial dogfish fishery via a dogfish Joint Project Agreement (JPA), the sexual maturation and growth of dogfish in Atlantic Canada were studied. Sexually mature and pregnant females were found to be distributed throughout the waters of southwest Nova Scotia during the summer and fall, but they moved offshore to deeper waters in the winter.

Pupping grounds have not been observed in either Canadian or USA waters. However, large aggregations of mature females occur in deep warm waters off the edge of the continental shelf and in the deep basins of the central shelf throughout their range in the winter. Based on the presumed birth months in late winter, pupping occurs in these deep offshore areas. Small juveniles are seldom collected in Canadian research surveys, but those that are collected are found in the areas where mature females are found in winter. It appears likely that the small juveniles pursue a largely pelagic existence before moving onto the continental shelf. Based on the presence of mature females and young juveniles in offshore waters each winter, most of the pupping probably occurs in USA waters.

The accuracy of Spiny Dogfish age interpretations using spine growth bands has been confirmed using bomb radiocarbon dating (Campana et al. 2006). Males and females grow at similar rates until the size and age of male maturity, after which male growth rate slows considerably. Maximum observed age in this study was 31 years, although USA sampling and aging extends this to 40 years (35 for males). Northwest Atlantic Spiny Dogfish appear to grow more quickly, mature at a younger age, and die at a younger age than Northeast Pacific Spiny Dogfish. Thus, the Atlantic population is more productive than the Northwest Pacific population.

A long-lived, slow-growing, low-fecundity ovoviviparous species, Spiny Dogfish are characterized by low productivity. Females usually do not mature until they are 14 (11-17) years of age, so only a small proportion of females live to maturity.

Fishery

The first significant exploitation of dogfish was a USA government-subsidized World War II vitamin A fishery that was conducted primarily during 1940-1941. Industrial (or trash) fishing between the mid-1950s and mid-1960s represented the largest directed fishery conducted on dogfish to that time, but it declined as the Peruvian anchovy fishery grew in the 1960s. Commercial interest in dogfish continued with the arrival of foreign fishing fleets in the Northwest Atlantic, which caught appreciable numbers of dogfish between 1966 and 1977. Reported landings prior to extension of jurisdiction in 1977 were dominated by USSR (Russia) and other European countries, and peaked at about 25,000 mt annually (Figure 2). Domestic fleets supplanted the foreign fishery after 1977, but at lower exploitation levels until the 1990s. Since 1977, USA commercial landings have accounted for most of the reported catch, peaking at more than 27,000 mt annually. The 2014 USA quota was 18,960 mt. Canadian landings were a relatively small proportion of the total catch until 2000, at which point the introduction of quotas in the USA made Canadian landings a significant portion of the total.

Canadian landings averaged about 2500 mt annually between 2000 and 2008, with the majority being directed catch by longline, followed by gillnets. Landings since 2008 have been markedly lower, dropping to only 5 mt in 2010 and have remained at very low levels since, apparently due to demands by the European market for “green-certified” products. Reported landings in 2013 were also 5 mt. Almost all of the Spiny Dogfish were caught in the Bay of Fundy, Southwest Nova Scotia or off Halifax during the summer. Catches were unrestricted prior to 2002. From 2002 onwards, precautionary directed catch quotas based on past catches were put in place. The quota for Spiny Dogfish has been set at 2500 mt since 2004. Quotas to this point have not been based on scientific advice. There are no restrictions on discarding and bycatch in other fisheries.

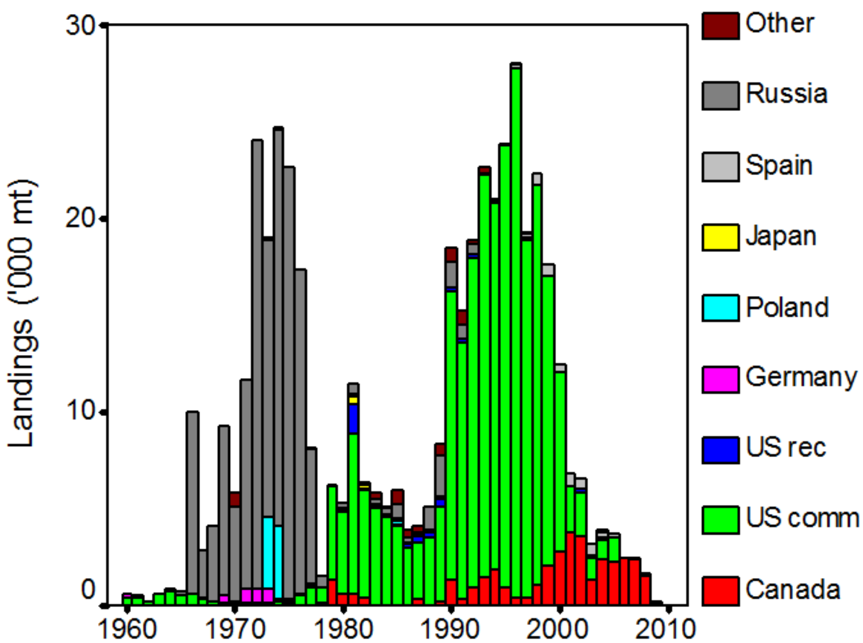


Figure 2. Landings of Spiny Dogfish reported to NAFO by country and year in NAFO Areas 2-6. No USA data available from NAFO since 2005.

Since the mid-1950s, bycatch of Spiny Dogfish in longline, otter trawl, and gillnet fisheries on other species has been the largest source of fishing mortality. Bycatch has declined with the downturns in directed groundfish fisheries since 1992 (Table 1).

Table 1. Landings, dead discards and Canadian total allowable catch (TAC) (thousands mt) of Northwest Atlantic (4VWX5YZ6ABC) Spiny Dogfish. Dashes indicate that no TAC was set during these years USA landings and discards for 2011-2013 were derived from the most recent USA assessment (2013) and Fisheries Management Plan (2014). NA = not available.

	Year	1922-1939	1940-1955	1956-1970	1971-1980	1981-1990	1991-2001	2002	2003	2004
Canada	TAC	-	-	-	-	-	-	-	-	2.5
	Landings	0.0	0.0	0.4	3.9	0.5	1.1	3.4	1.3	2.3
	Dead Discards	0.0	0.8	1.3	1.3	1.9	1.0	0.7	0.7	0.7
USA	Landings	0.0	0.1	2.5	13.8	6.1	17.4	3.0	2.1	1.4
	Dead Discards	3.6	10.3	33.3	16.6	19.6	8.5	5.9	4.4	6.5

	Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Canada	TAC	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	Landings	2.3	2.4	2.4	1.5	0.2	0.0	0.1	0.1	0.0
	Dead Discards	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
USA	Landings	1.6	1.8	3.6	3.9	5.2	5.8	10.2	12.7	NA
	Dead Discards	5.7	6.2	6.9	5.1	5.8	5.2	NA	NA	NA

Catch composition (catch proportions by sex and maturity stage) varies over time, and varies between Canada and the USA (Table 2).

Table 2. Proportion of Spiny Dogfish in the USA and Canadian catch, separated into male juveniles (Mj), male adults (Ma), female juveniles (Fj), and female adults (Fa) from 1990 to 2010. Dashes indicate no catch composition information for the Canadian fishery during 1990-1997 and 2007-2010.

	USA				CANADA			
Year	Mj	Ma	Fj	Fa	Mj	Ma	Fj	Fa
1990	0.15	0.27	0.36	0.23	-	-	-	-
1991	0.10	0.27	0.32	0.31	-	-	-	-
1992	0.12	0.27	0.35	0.25	-	-	-	-
1993	0.11	0.18	0.34	0.37	-	-	-	-
1994	0.11	0.15	0.34	0.40	-	-	-	-
1995	0.16	0.23	0.33	0.28	-	-	-	-
1996	0.19	0.09	0.42	0.30	-	-	-	-
1997	0.17	0.17	0.34	0.32	-	-	-	-
1998	0.24	0.16	0.39	0.22	0.08	0.37	0.42	0.14
1999	0.24	0.10	0.40	0.25	0.02	0.12	0.56	0.30
2000	0.26	0.05	0.46	0.23	0.02	0.10	0.59	0.29
2001	0.36	0.06	0.45	0.13	0.09	0.30	0.37	0.24
2002	0.32	0.06	0.44	0.18	0.02	0.17	0.38	0.43
2003	0.38	0.06	0.47	0.09	0.03	0.24	0.39	0.34
2004	0.29	0.13	0.42	0.16	0.04	0.30	0.37	0.28
2005	0.29	0.14	0.41	0.16	0.03	0.28	0.36	0.33
2006	0.09	0.26	0.28	0.37	0.04	0.29	0.36	0.31
2007	0.07	0.26	0.24	0.43	-	-	-	-
2008	0.17	0.19	0.32	0.32	-	-	-	-
2009	0.22	0.12	0.33	0.34	-	-	-	-
2010	0.16	0.21	0.28	0.35	-	-	-	-

ASSESSMENT

Research Surveys

Both the DFO summer Research Vessel (RV) survey and the USA National Marine Fisheries Service (NMFS) spring RV survey trends in biomass are highly variable but generally depict a period of low abundance at the start of the time series rising to high levels of abundance in the 1980s (Figure 3). A decline in abundance between 1990 and 2005 was followed by a subsequent increase in more recent years.

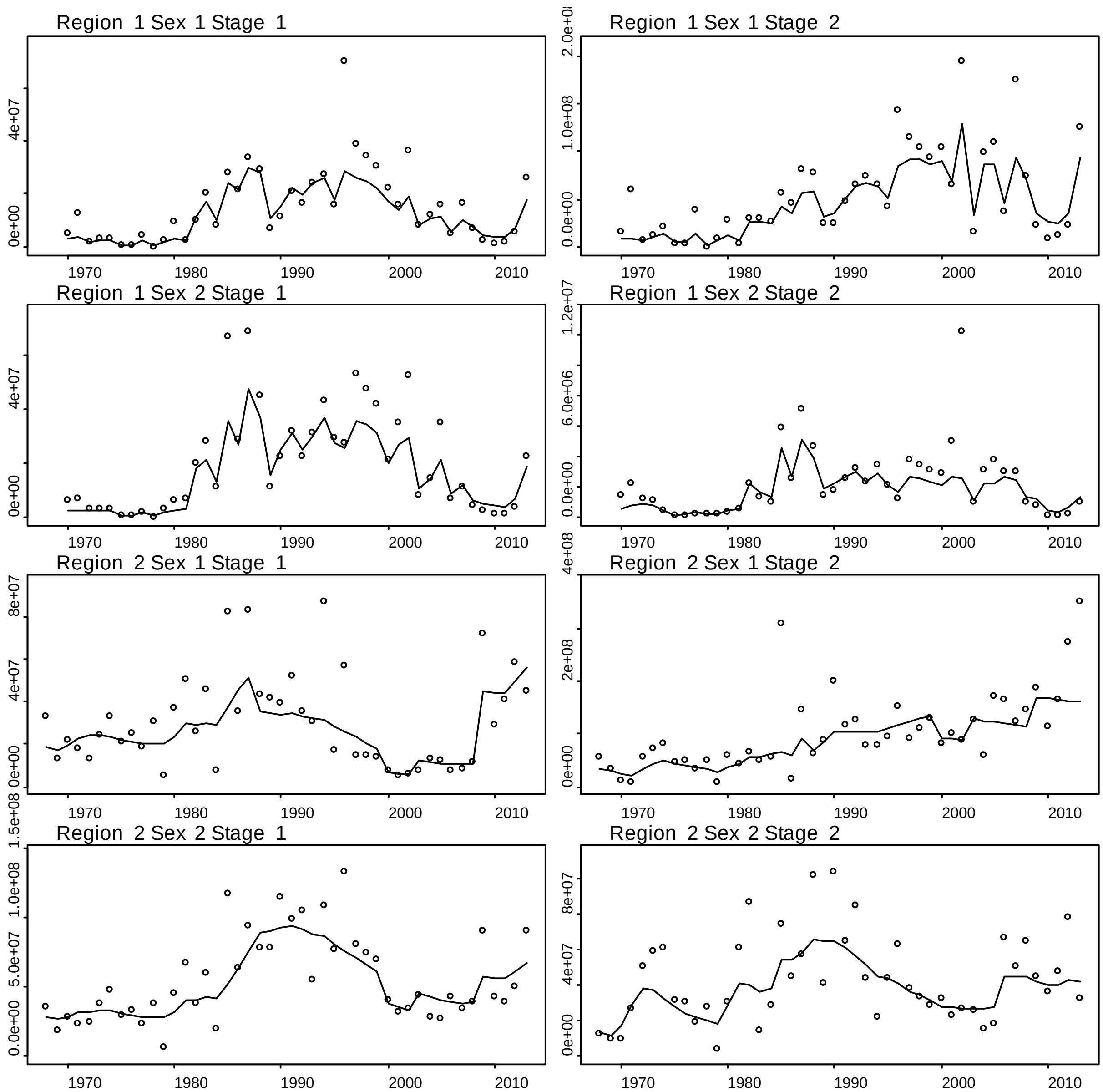


Figure 3. Fits (solid lines) to observed stratified survey abundance estimates (dots) of the stage-based population model updated through 2013. Region 1 = Canada, 2 = USA. Sex 1 = Males, 2 = Females. Stage of maturity 1 = Juveniles, 2 = Adults.

Assessment Results

The model developed for assessment of Northwest Atlantic Spiny Dogfish in Canada is a forward-projecting stage-based (juveniles and adults, males and females), spatially explicit (two regions – Canada and USA) population dynamics model, with two time steps (November-April and May-October) in each year. The accepted framework model used data to 2010. For the current assessment, this model was updated with data to 2013. There were no substantive changes to parameter estimates or temporal patterns in abundance estimates when the 2010 framework model was updated to 2013, and the fit remained reasonable (Figure 4).

Population estimates from the model indicate a dramatic increase in abundance during the 1980s, peaking about 1992, and then declining, with recent increases since 2009, especially of juveniles, with a total population abundance of 789.2 million Spiny Dogfish for 2013. Adult females have remained at relatively high abundance since 2006. There is low confidence in estimates prior to the mid-1950s due to model constraints.

Low exploitation since 1977 would be expected to result in population increase, although the rapidity and magnitude of the increase is greater than would be expected with current understanding of Spiny Dogfish biology (pupping rates, maturation rates, natural mortality). As the period of increase coincides with the period of decline of formerly dominant populations of other species that share the same habitat and trophic level with dogfish (e.g., Atlantic Cod, Haddock, Pollock), the decline of these competitors may have altered the usual biological parameters for dogfish (more food, enhanced productivity, lower natural mortality). The subsequent decline might be attributable to changes in the ecosystem (as suggested for several examples of non-recovery groundfish stocks) or density-dependent mechanisms.

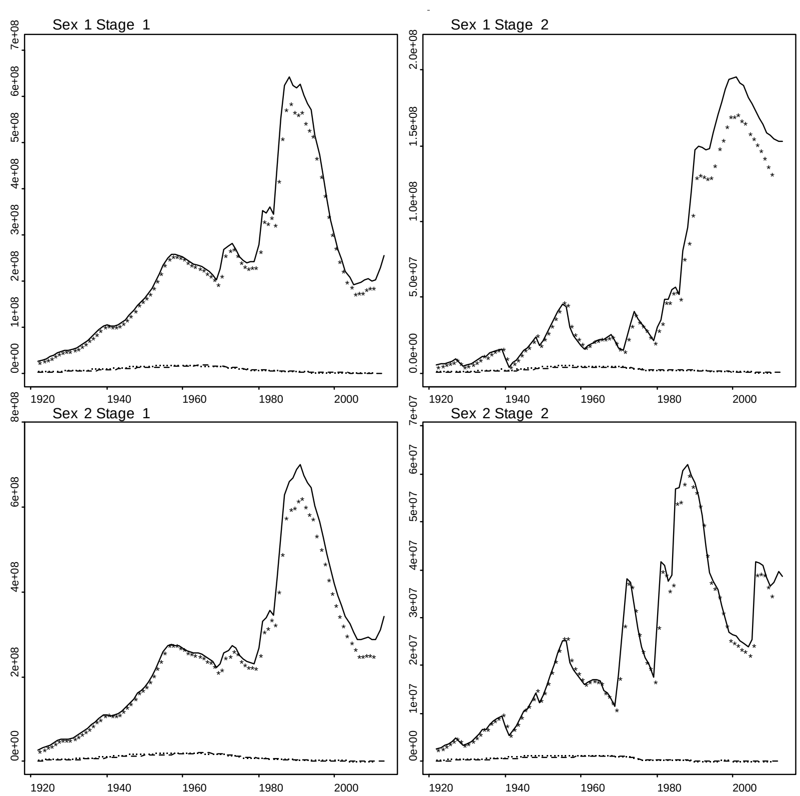


Figure 4. Abundance estimates (end of March) of population components from the updated 2013 model (straight line for USA, dashed line for Canada) overlaid on estimates from the 2010 model (points for both regions).

Increased female abundance since 2006 caused increased recruitment, which was predicted by the 2010 model and observed in the 2011-2013 survey estimates. The update preserved the original model trends in population components, and the 2011-2013 survey results, portraying increased abundance of the remaining components, are compatible with previous model predictions. However, the rate and magnitude of the increase is higher than previously predicted, and this scales juvenile and adult male abundances up relative to the 2010 model, raising maximum population size (by 4.5%) and, thus, assumed carrying capacity (K). This increase in K also occurred in the 2013 USA assessment model (Rago[1] and Sosebee 2013).

A permanently resident (non-migrating) Canadian subpopulation is estimated as 6-9% of the total population by the population model. However, attempting to represent the population as discrete USA and Canadian components, as opposed to a single migrating population, is not worthwhile because it is unlikely these are discrete components.

Approximately half the population (53-56%, varying by sex and maturity stage) is estimated to be resident in Canadian waters during the summer. This varies considerably from year to year, with annual estimates from the model ranging from 9% to 95%.

Estimates of Maximum Sustainable Yield (MSY) are primarily informed by the highest peak in abundance (observed or predicted) of Spiny Dogfish. As the rate of population growth producing that peak is higher than would be expected of this species in Canadian waters based on our knowledge of Spiny Dogfish biology from sampling within the stock area, this might produce an unreasonable high estimate of carrying capacity and, therefore, K is constrained in the context of estimates of MSY. This may be the carrying capacity for the trophic level occupied by Spiny Dogfish with reduced abundances of competitors (i.e., representing an unbalanced ecosystem). Decline in dogfish abundance since 1992 is also a concern, as it cannot be attributed to fishing mortality. This might reflect enhanced natural mortality (a low productivity regime), as suggested for some collapsed stocks that have failed to show signs of recovery. However, it is also what would be expected if a population reached or exceeded its carrying capacity. For the model, rather than estimate K, K is assumed to be the maximum predicted abundance of the population during the observed period (1,640 million fish). Estimates of MSY for this carrying capacity would vary with growth rate (r), which was estimated to be approximately 0.042 based on simulations using the available biological data. However, there are concerns that the data may not constitute a representative sample, and, thus, MSY is derived for a series of r assumptions (0.017-0.062) based on a literature review (Table 3). The literature review generally favoured estimates in the 0.042 to 0.062 range.

Table 3. Estimates of K, Bmsy and MSY in millions of fish, as well as Fmsy, over a range of growth rates (r). The shape parameter (s) is held constant at 2.0.

r	s	K	Bmsy	MSY	Fmsy	MSY in Tons
0.017	2	1639	820	7	0.0085	9,415
0.022	2	1639	820	9	0.011	12,184
0.027	2	1639	820	11	0.0135	14,953
0.032	2	1639	820	13	0.016	17,722
0.037	2	1639	820	15	0.0185	20,491
0.042	2	1639	820	17	0.021	23,260
0.047	2	1639	820	19	0.0235	26,029
0.052	2	1639	820	21	0.026	28,799
0.057	2	1639	820	23	0.0285	31,568
0.062	2	1639	820	25	0.031	34,337

[1] Rago, P., and Sosebee, K. 2013. Update on the Status of Spiny Dogfish in 2013 and Projected Harvests at the Fmsy Proxy and Pstar of 40%. (unpublished manuscript)

A series of projections were used to simulate how long it would take for the stock to recover to Bmsy if fished down to a given percent of Bmsy (Table 4).

Table 4. Projected time for a population to recover to Bmsy if fished down to a given percent of Bmsy.

Fished Down to Percentage of Bmsy	Years to Recover to Bmsy
40	24
50	18
60	15
70	13
80	8

Long recovery times, reaching up to 24 years at 40% of Bmsy, are largely due to early loss of adult females. Adult females are knocked out well before the population as a whole reaches any appreciable percent of Bmsy. Thus, there may be no recruitment occurring for several years before reaching a given percent of Bmsy and, subsequently, juvenile females must then mature to create new recruits. The estimate of the likeliest age of maturity (historical mean A50) for a female Spiny Dogish is 14 years. This is how long it would take to recover to Bmsy if fished down to 65% of Bmsy.

Given the characteristics of this species (demographics) and the fishery, use of the abundance females as the indicator of stock status was considered to be a more appropriate (and sensitive) measure than total biomass. Abundance of adult females (SSN) and fishing mortality on adult females (Fssn) are used to gauge the consequences of exploitation, historically and when projecting future catch levels.

Given long expectations for recovery and low productivity of Spiny Dogfish, SSN at maximum sustainable yield (SSN_{msy}) (32.8 million) is proposed as the USR, and 65% of SSN_{msy} (21.3 million) is proposed as a Lower Reference Point (LRP) in the Harvest Control Rule (HCR). Fssn at maximum sustainable yield ($Fssn_{msy}$) is 0.072, and this is suggested as a fishing mortality reference point (Fref).

A Harvest Control Rule using the proposed LRP, USR and Fref is shown in Figure 5. This shows known periods of high exploitation during the industrial and foreign fishery years (most years between 1956-1977) resulting in a cluster of SSN values below the LRP (in the critical zone). During periods of lower exploitation, such as in recent years (2006-2013), the HCR shows that Spiny Dogfish is above the USR, i.e., is in the healthy zone.

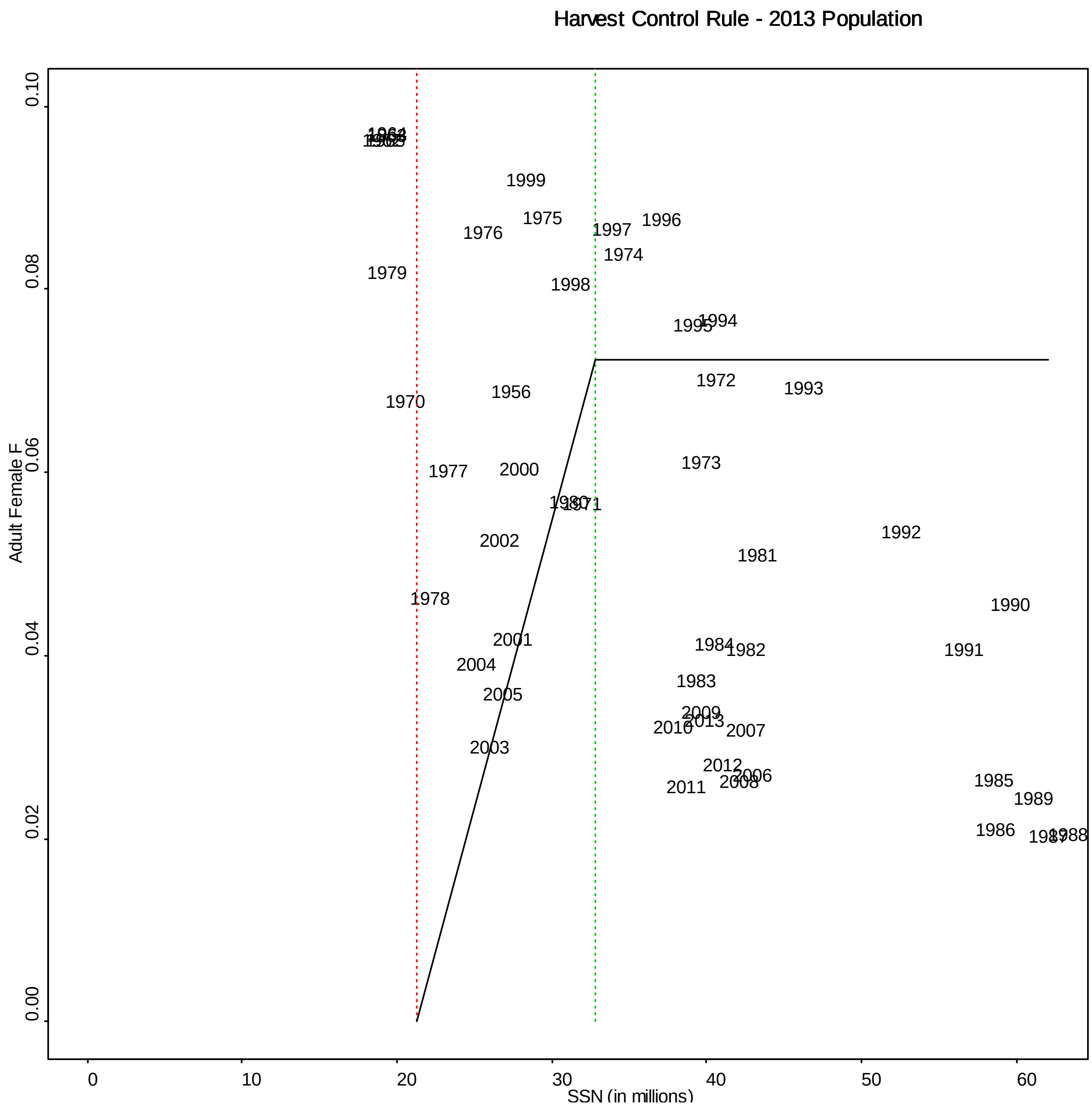


Figure 5. The Harvest Control Rule plot for SSN and Fssn from the updated Spiny Dogfish population model. The Lower Reference Point (LRP) is proposed as 65% of SSNmsy (dotted red line) and the Upper Stock Reference (USR) as SSNmsy (dotted green line). $Fssn_{msy}$ is proposed as Fref.

Projections were run to determine the annual total catch (including USA and Canada landings and dead discards) that would result in a 25%, 50% or 75% probability of decline in SSN at 40 years (Figure 6). This analysis used the 1998-2006 Canadian and 2010 USA catch compositions, and assumed that Canadian discards would be proportional to landings while USA discards would remain at the mean of 2002-2010. This analysis indicates that a catch of about 47,350 mt (varies with assumed proportions of catch by region) has a 50% chance of resulting in a decline in SSN after 40 years. The 2014 USA quota, if adjusted for discards, would be about 45,081 mt (based on the discard assumptions in the 2013 USA Fisheries Management Plan).

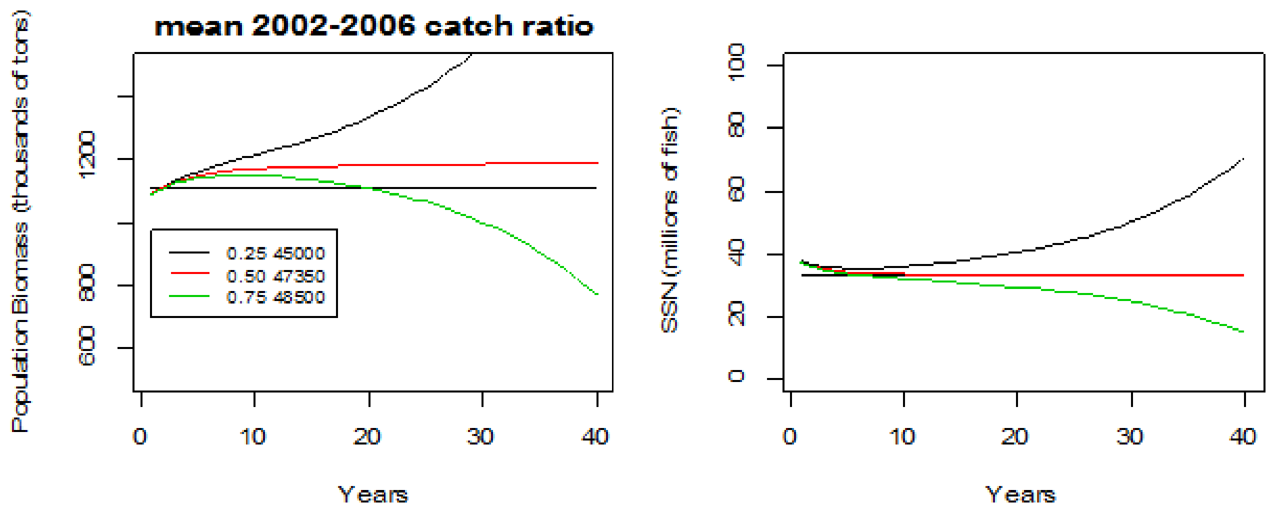


Figure 6. Projection results for regional catch levels according to a historical catch ratio. Catch levels were obtained for 25%, 50% and 75% likelihoods of crossing an indicator threshold in year 40. The black horizontal lines represent Bmsy on biomass graphs and SSNmsy on SSN graphs (overlapped by red line on SSN graph).

Ecosystem Considerations

Loss of trophic level competitors due to population declines of other fish species may have produced a non-equilibrium ecosystem in which Spiny Dogfish responded very positively, possibly exaggerating the estimate of carrying capacity as a long-term expectation.

Species caught as incidental catch in the Canadian Spiny Dogfish fishery from 2002-2008 included Atlantic Cod, Cusk, Haddock, White Hake, Atlantic Halibut, Monkfish, and Pollock. None of these were more than 2% of the Spiny Dogfish catch, and only Atlantic Cod and White Hake were more than 1% of Spiny Dogfish catch.

Sources of Uncertainty

Sources of uncertainty in this assessment include:

- Catch composition assumptions used in projections,
- Discard assumptions used in projections,
- Natural mortality assumptions, especially since 1983,
- Historical discard assumptions,
- Discard mortality assumptions,
- Catch composition assumptions before the 1980s, and
- Summer survey tracking of adult females.

The carrying capacity of Spiny Dogfish may overlap (i.e., is shared with) that of reduced populations of other fish species (e.g., Atlantic cod, Haddock, Pollock).

CONCLUSIONS AND ADVICE

The current population model for Spiny Dogfish provides a reasonable basis for defining reference points and precautionary catch levels but cannot be rigorously updated without USA data. It is anticipated that Spiny Dogfish would be assessed every 5 years, with annual stock status updates that take current catch composition into account. Assumptions about carrying capacity and catch composition will need to be re-evaluated in subsequent assessments. Within an update, it is expected that status will be evaluated in relation to reference points and some form of projection that indicates which direction SSN is going under current catch composition and discard assumptions (within an acceptable risk tolerance). Using Fssn and catch composition, probability of decline can be reported.

SOURCES OF INFORMATION

This Science Advisory Report is from the January 20-21 and May 29, 2014, Northwest Atlantic Spiny Dogfish Framework and Assessment meetings. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Campana, S.E., C. Jones, G.A. McFarlane, and S. Myklevoll. 2006. Bomb Dating and Age Validation Using the Spines of Spiny Dogfish (*Squalus acanthias*). Envir. Biol. Fish. 77: 327-336.

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