# Length and sex-specific associations between spiny dogfish (*Squalus acanthias*) and hydrographic variables in the Bay of Fundy and Scotian Shelf

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## ABSTRACT

The associations between spiny dogfish (*Squalus acanthias*) and hydrographic variables (temperature, salinity and depth) were examined in the Bay of Fundy and Scotian Shelf from 1970 to 1998. Data were obtained from standard groundfish bottom trawl surveys. Dogfish sex affected habitat associations. Males were found to occupy bottom water of significantly higher salinities and depths than that occupied by females. Length also significantly affected habitat associations. Smaller dogfish occupied relatively deep, high salinity bottom water compared with larger dogfish. Overall, the occupied temperatures, salinities and depths were significantly different from those which were available. Dogfish occupied warmer temperatures along a narrow range (6.62–9.19°C) compared with those which were available (1.57–9.35°C). Occupied salinity (32.70–34.43 ppt) and occupied depth (88.62–184.66 m) were also distributed along a narrower range than available salinity (32.16–34.79 ppt) and available depth (55.00–218.10 m). Sex-specific, length-specific and overall environmental preference by dogfish may bias traditional 'offshore' groundfish surveys while large scale changes in hydrographic parameters may alter dogfish distribution and their interactions with other marine fauna.

**Key words:** Bay of Fundy, environmental preference, fisheries oceanography, habitat preference, Scotian Shelf, spiny dogfish, *Squalus acanthias*

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## INTRODUCTION

Distributions of fish populations are often aligned along physical environmental gradients (Scott, 1982). These distributions may reflect a preference for a certain range or value along the gradient. This preference has been defined for temperature as the temperature around which all individuals of a given species will distribute (Fry, 1947). More commonly, a descriptive measure of preference has been defined by the range bounded by the 95% confidence intervals of the distribution of fish along an environmental gradient (Scott, 1982).

Environmental preference had been shown to vary with age (Swain and Kramer, 1995; Smith and Page, 1996; Ottersen *et al*., 1998), season (Clark and Green, 1991; Swain *et al*., 1998) and geographical location (Smith and Page, 1996). Because of these variations, Clark and Green (1991) argued that a single value may not be a valid measure of environmental preference. Other studies have shown habitat preference to be related to changes in food supply, i.e. fish occupy habitats of lower energetic cost (e.g. lower temperatures) when food available per individual is low (Swain and Kramer, 1995).

The most common physical factor examined in environmental preference studies is temperature. Temperature would be expected to affect distribution as it is key to physiological processes such as growth (Fry, 1971). As well, preferred temperature has been found to match the theoretical optimal temperature for physiological activity in some fishes (Crawshaw, 1977). Depth is also known to affect fish distribution. While it may often not directly affect fish, it may serve as a proxy for sediment type (Scott, 1982). Sediment may be especially important for fish which prey on benthic fauna where prey types may only be found in or on certain sediment types. Less obvious is the importance of salinity to the distribution of marine fish. Salinity is often indicative of a particular water mass. For example, in the north-west Atlantic, the cold intermediate layer is associated with salinities within the range of 32–33.5 psu (practical salinity units). Smith and Page

(1996) found that cod, *Gadus morhua*, were most often associated with this water mass on the Scotian Shelf.

Spatial and temporal arrangements of environmental gradients are dynamic. For example, the amount of bottom water that exhibits preferred characteristics for a given species can fluctuate over time (Smith and Page, 1996). These fluctuations are believed to affect the catchability of some marine fish species which can skew bottom trawl survey assessments. A greater understanding of how fish catchability covaries with changes in the environment may lead to more accurate fish stocks assessments (Smith, 1990). Changes in environmental gradients, such as temperature, have also been shown to affect large-scale distributions of fish populations (Rose *et al.*, 1994; Swain and Kramer, 1995; Ottersen *et al.*, 1998). Thus, knowledge of environmental preference of fish may help explain changes in fish distribution.

Spiny dogfish, *Squalus acanthias*, are distributed in the north-west Atlantic Ocean along the continental shelf from Florida, USA to Labrador, Canada. This population is highly migratory and undertakes northward migrations in the spring and summer and southward in the fall and winter (McRuer and Hurlbut, 1996). Spiny dogfish distribution has undergone considerable change recently, characterized by increased abundance in the Gulf of St Lawrence and on the Grand Banks (McRuer and Hurlbut, 1996). This fish has not traditionally been considered commercially important by Canadian and American fisheries organizations. However, declines in abundances of many heavily exploited groundfish have recently caused the spiny dogfish to emerge as a commercially viable species. Growth of the dogfish fishery has led to substantial increases in catches since the mid-1980s (McRuer and Hurlbut, 1996). This increase in exploitation of dogfish off the east coast of North America has spawned a need of an understanding of the ecology of this population so that meaningful stock assessments may be performed. Changes in dogfish distribution and abundance, coinciding with declines in abundance of many north-west Atlantic groundfish species, has provoked research into the interactions between dogfish and commercially important groundfish (Salsbury, 1986), and dogfish and fishing gear (Hurley *et al.*, 1987). However, studies on the interactions between dogfish and the environment are lacking.

In this study, the environmental preference (temperature, salinity and depth) of spiny dogfish is characterized within North-west Atlantic Fisheries Organization (NAFO) divisions 4VWX (Bay of Fundy and Scotian Shelf, Canada) from 1970 to 1998. These preferences are further analysed by examining length-specific and sex-specific environmental preferences. Results of this analysis are expected to aid in understanding the basic ecology of the spiny dogfish, changes in its distribution, and provide a foundation for models of how dogfish catchability changes under various environmental conditions.

## MATERIALS AND METHODS

### *Data source*

Length- and sex-specific spiny dogfish catch and hydrographic data sets were obtained from the standard groundfish bottom trawl surveys of the Scotian Shelf and Bay of Fundy (NAFO divisions 4VWX; Fig. 1) conducted in July since 1970 by the Canadian Department of Fisheries and Oceans (DFO). The data set used in this study encompassed the years 1970–98 (Table 1). The surveys use a stratified random sampling design in which strata are primarily based on depth ranges of 0–91 m, 92–183 m and 184–366 m. Further delineations of strata reflect species/stock distributions (Doubleday, 1981; Halliday and Koeller, 1981). Stratified random sampling designs divide the sample area *a priori* into relatively homogeneous sampling strata, from which samples are randomly drawn, in order to reduce the variance of population estimates (Cochran, 1977). The sample area includes 13 strata in division 4V, 14 strata in division 4W, and 21 strata in division 4X.

A sample unit (tow) for the survey was defined as the area over the bottom covered by a trawl 12.5 m wide towed at 3.5 knots for a distance of 1.75 nautical miles. Sample units are intended to sample continental shelf areas and thus are limited to depths of approximately 20–366 m. The number of sample units allocated to each strata annually is roughly proportional to strata area (1–12 samples per stratum). The location of sample units within each strata were randomly selected before each survey cruise.

Bottom water hydrographic data were collected immediately following each tow of the trawl over the bottom. Samples were taken by vertical casts of water sample bottles from 1970 to 1989, and afterwards by a Sea-Bird (Sea Bird Electronics, WA, USA) model 19 or model 25 CTD (conductivity, temperature and depth) profiler. It should be noted that sampling the hydrography in this way cannot detect environmental preference of groundfish on scales finer than the area of the sample unit.

In order to account for variation in tow distance during sampling, weights of dogfish caught were normalized to the standard tow distance of 1.75 nautical miles. Data were then aggregated by sex and into four

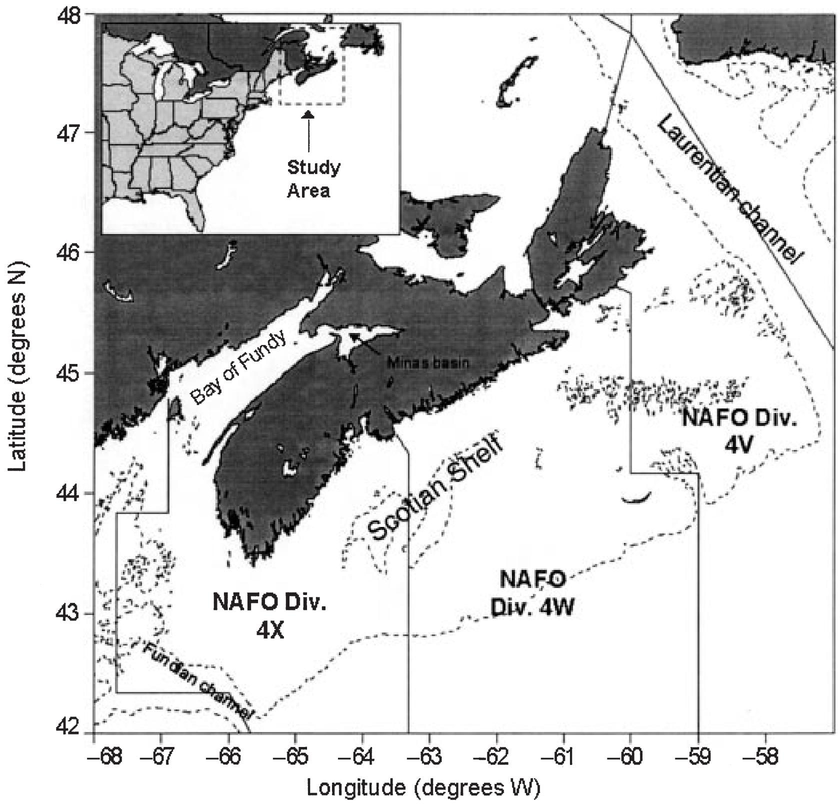



**Figure 1.** Map of Bay of Fundy and Scotian Shelf showing north-west Atlantic Fisheries Organization (NAFO) divisions 4VWX. See inset for geographical location of study area.

length-classes (total length): < 41 cm, 41–60 cm, 61–80 cm and > 80 cm. These groupings were chosen based on the nature of the data set and the fact that lengths of 60 and 80 cm roughly coincide with male and female maturity, respectively (Nammack *et al.*, 1985). Stratified mean abundance of dogfish, and stratified mean temperature, salinity and depth were calculated using standard formulations for stratified random sampling designs (Cochran, 1977).

*Environmental preference*

In order to identify environmental preference of spiny dogfish, cumulative distribution frequencies (cdf) were used (Smith, 1990; Perry and Smith, 1994). This method is a two step process. First, the general frequency distribution of the hydrographic variable (temperature, salinity or depth) is characterized by constructing its empirical cdf curve

$$f(t_j) = \sum_h \sum_i \frac{W_h}{n_h} I(x_{hij}) \tag{1}$$

where

$$I(x_{hij}) = \begin{cases} 1, & \text{if } x_{hij} \le t_j; \\ 0, & \text{otherwise} \end{cases}$$

and

$n_h$ = the number of tows in stratum $h$ ($h = 1,\ldots, L$),
$N_h$ = the total number of possible tows in stratum $h$ (stratum area ÷ tow area),
$N = \sum_{h=1}^{L} N_h$,
$W_h = \frac{N_h}{N}$,
$x_{hij}$ = the measurement for hydrographic variable $j$ in set $i$ of straum $h$,
$t_j$ = the ordered observations from lowest to highest of hydrographic variable $j$.

In random sampling designs, the probability associated with each observation in a cdf is 1/n. However, the stratified random sampling design results in a probability of $1/n_h$ within each strata. This statistical method was designed to incorporate the stratified random sampling design of the surveys into the construction of the cdf (Perry and Smith, 1994).

The second step of this statistical method is to characterize the association between the dogfish and each hydrographic variable by a catch-weighted cdf

$$g(t) = \sum_h \sum_i \frac{W_h}{n_h} \frac{y_{hi}}{\bar{y}_{st}} I(x_{hij}) \tag{2}$$

**Table 1.** Dates and number of samples taken during the Department of Fisheries and Oceans annual July groundfish survey conducted in the Bay of Fundy and on the Scotian Shelf.

| Year | Start date | End date | Samples |
|---|---|---|---|
| 1970 | July 06 | July 30 | 133 |
| 1971 | June 29 | July 21 | 106 |
| 1972 | June 23 | July 19 | 144 |
| 1973 | July 09 | August 02 | 129 |
| 1974 | July 09 | August 03 | 152 |
| 1975 | July 15 | August 06 | 142 |
| 1976 | July 12 | August 05 | 135 |
| 1977 | July 09 | July 30 | 143 |
| 1978 | July 09 | July 31 | 139 |
| 1979 | July 06 | July 27 | 144 |
| 1980 | July 07 | July 26 | 141 |
| 1981 | July 04 | July 25 | 137 |
| 1982 | July 10 | July 30 | 150 |
| 1983 | July 05 | July 27 | 141 |
| 1984 | July 10 | August 02 | 141 |
| 1985 | July 04 | July 25 | 114 |
| 1986 | July 07 | July 29 | 168 |
| 1987 | June 29 | August 06 | 183 |
| 1988 | July 04 | July 27 | 175 |
| 1989 | July 05 | July 27 | 167 |
| 1990 | July 03 | July 31 | 211 |
| 1991 | July 04 | July 28 | 187 |
| 1992 | June 23 | July 17 | 191 |
| 1993 | July 05 | August 01 | 181 |
| 1994 | July 04 | July 28 | 177 |
| 1995 | June 25 | July 20 | 192 |
| 1996 | July 04 | July 31 | 185 |
| 1997 | July 02 | July 31 | 191 |
| 1998 | July 06 | July 30 | 171 |

where

$y_{hi}$ = the number of fish of a particular group caught in tow $i$ and stratum $h$,

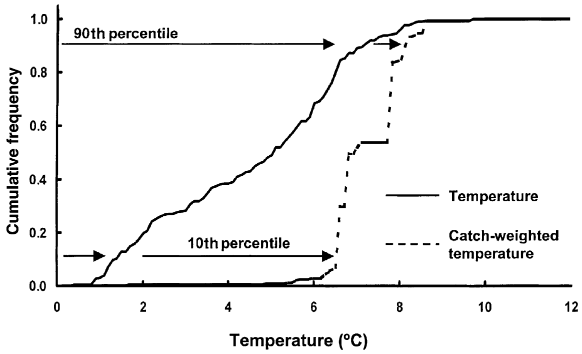
$\bar{y}_{st}$ = the estimated stratified mean abundance for a particular group of fish.

Using this method, catches larger than the stratified mean would indicate hydrographic conditions with a stronger association for the group of fish in question than conditions where catches were smaller than the stratified mean. From the resulting cdf's, percentiles are easily calculated (Zar, 1996) which can than be used in further statistical analysis. As an example of this method, the available temperature cdf and catch-weighted temperature cdf were plotted for the 1998 data. The 10th percentiles and 90th percentiles of each distribution can be easily determined from this plot (Fig. 2).

Cumulative distribution functions were generated annually for temperature, salinity and depth using Eqn 1. Cumulative distribution functions were also generated for all spiny dogfish and each sex for each year using Eqn 2. For length, annual data were first aggregated to four groups which corresponded to a gradient of oceanographic conditions. This was necessary as certain length classes were not represented in many years. The 40-cm length class (< 41 cm) was excluded from this analysis because of very few observations of dogfish less than 41 cm total length. The 10th, 50th (median) and 90th percentile of each cdf were calculated. Differences in environmental preference between sexes were evaluated by performing a series of two-tailed, two-sample $t$-tests (Zar, 1996) on the 10th, 50th and 90th percentiles of the cdf's (catch-weighted temperature, salinity and depth) across sexes, while differences in environmental preference between length class were evaluated using a series of single factor analysis of variances (ANOVA) (Zar, 1996) on the 10th, 50th and 90th percentiles of the cdf's (catch-weighted temperature, salinity and depth) across length classes.

In order to test if dogfish associated with hydrographic conditions that were different than those which were available, the 10th, 50th and 90th percentiles of each hydrographic variable cdf and its

**Figure 2.** Example of environmental and catch-weighted environmental cumulative distribution functions (cdf). Data used for example is cdf's for temperature and catch-weighted temperature for spiny dogfish, *Squalus acanthias*, in NAFO divisions 4VWX in 1998.




corresponding catch-weighted cdf for all spiny dogfish were compared. This was carried out using a series of paired *t*-tests (Zar, 1996). Paired *t*-tests were chosen to account for variability in hydrographic variables between years. Probability values derived from such a test would be identical to those obtained using a series of two-way, fixed effects ANOVAs including year and the cdf type (e.g. observed temperature vs. catch-weighted temperature) as factors. However, the objective of this study was not to examine interannual variation in environmental preference of dogfish so the ANOVA method was not used.

All traditional statistical tests were performed using the statistical analysis software SAS v6.12 (SAS Institute, Cary, NC, USA). Levels of $\alpha$ for all tests were set at 0.05. All data were tested to determine whether they met the assumptions of parametric tests (normality and homogeneity of variances; Zar, 1996). Any departures from the assumptions of both the *t*-test and ANOVA were found to be minor. These tests are robust to minor violations of normality and homogeneity of variances, especially when sample sizes are equal (Zar, 1996) which was the case in this study. Because of this, no attempt was made to correct data which showed minor departures from normality or homogeneity of variances.

## RESULTS

The entire 28-years series consisted of 4591 individual groundfish survey tows which captured a total of 1130 metric tonnes (approximately 800 000 individuals) of spiny dogfish. The mean weight of dogfish captured was 1.40 kg individual$^{-1}$. The average weight of female dogfish (1.36 kg) was less than that of males (1.42 kg). The mean total length of female dogfish (66.0 cm) was also found to be less than that of males (69.9 cm).

After historical lows in the mid-1970s of less than 2 kg tow$^{-1}$, dogfish abundance increased greatly to levels over 60 kg tow$^{-1}$ in the 1980s (Fig. 3). At the same time, the relative proportion of females comprising this population increased from less than 5% in 1977 to over 50% in 1981. After 1988, dogfish abundance declined through 1989–90 to less than 20 kg tow$^{-1}$. Throughout the 1990s, until 1997, dogfish appeared relatively plentiful, reaching historic highs of slightly less than 80 kg tow$^{-1}$ in 1996. However, in 1998 the abundance index for dogfish dropped to approximately 12 kg tow$^{-1}$, the lowest since 1981.

The 80-cm-length class consistently comprised approximately 80% of the reported abundances (Table 2). This was followed by the 60-cm- and 120-cm-length classes which comprised 15 and 4% of dogfish abundance, respectively. The 40-cm length class typically contributed very little to the abundance index. During periods of low abundance in the 1970s, the 80-cm-length class was strong while the 60-cm-length class was weak. A similar trend can be seen developing since 1994 where the proportion of dogfish in the 80-cm-length class has increased from 78 to 87% of the population while the strength of the 60-cm-length class has decreased from 17 to 9% of the population.

From 1970 to 1998, spiny dogfish were concentrated within the Bay of Fundy and southern Scotian Shelf (NAFO division 4X; Figs 4 and 5). Along the eastern Scotian Shelf, dogfish were more sparsely distributed (NAFO divisions 4VW). Within 4VW, significant dogfish concentrations were found along the edge of the Laurentian Channel, the edge of the Scotian Shelf and along the edges of deeper gullies and

**Figure 3.** Canadian groundfish survey abundance index trend for both male and female spiny dogfish, *Squalus acanthias*, from 1970 to 1998 in NAFO divisions 4VWX.

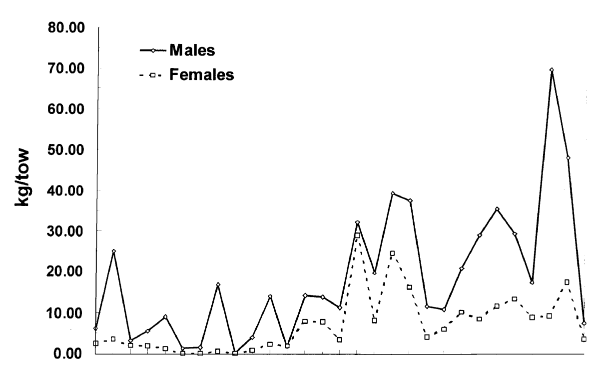


**Table 2.** Proportion of four length classes comprising spiny dogfish, *Squalus acanthias*, abundance in NAFO divisions 4VWX July groundfish surveys from 1970 to 1998.

| | Length class | | | |
|---|---|---|---|---|
| Year | 120 cm* | 80 cm† | 60 cm‡ | 40 cm§ |
| 1970 | 0.09 | 0.71 | 0.20 | 0.00 |
| 1971 | 0.04 | 0.87 | 0.10 | 0.00 |
| 1972 | 0.13 | 0.78 | 0.09 | 0.00 |
| 1973 | 0.08 | 0.86 | 0.06 | 0.00 |
| 1974 | 0.03 | 0.95 | 0.02 | 0.00 |
| 1975 | 0.02 | 0.95 | 0.03 | 0.00 |
| 1976 | 0.03 | 0.97 | 0.00 | 0.00 |
| 1977 | 0.02 | 0.94 | 0.04 | 0.00 |
| 1978 | 0.29 | 0.53 | 0.15 | 0.04 |
| 1979 | 0.06 | 0.75 | 0.19 | 0.00 |
| 1980 | 0.04 | 0.74 | 0.22 | 0.00 |
| 1981 | 0.05 | 0.60 | 0.33 | 0.01 |
| 1982 | 0.06 | 0.81 | 0.13 | 0.00 |
| 1983 | 0.03 | 0.63 | 0.35 | 0.00 |
| 1984 | 0.08 | 0.75 | 0.17 | 0.00 |
| 1985 | 0.04 | 0.81 | 0.15 | 0.00 |
| 1986 | 0.05 | 0.74 | 0.21 | 0.00 |
| 1987 | 0.05 | 0.81 | 0.12 | 0.02 |
| 1988 | 0.04 | 0.83 | 0.13 | 0.00 |
| 1989 | 0.07 | 0.83 | 0.10 | 0.00 |
| 1990 | 0.04 | 0.84 | 0.11 | 0.00 |
| 1991 | 0.03 | 0.72 | 0.21 | 0.03 |
| 1992 | 0.07 | 0.82 | 0.11 | 0.00 |
| 1993 | 0.03 | 0.82 | 0.15 | 0.00 |
| 1994 | 0.05 | 0.78 | 0.17 | 0.00 |
| 1995 | 0.03 | 0.79 | 0.15 | 0.03 |
| 1996 | 0.04 | 0.80 | 0.16 | 0.01 |
| 1997 | 0.03 | 0.85 | 0.12 | 0.00 |
| 1998 | 0.04 | 0.87 | 0.08 | 0.00 |
| Mean | 0.04 | 0.80 | 0.15 | 0.01 |
| Min | 0.02 | 0.53 | 0.00 | 0.00 |
| Max | 0.29 | 0.97 | 0.35 | 0.04 |

* 120–81 cm, † 80–61 cm, ‡ 60–41 cm, § < 41 cm.

basins. The distribution of both males and females were similar within the sampled area (Fig. 4). However, females did appear to occur more frequently in the farther offshore samples along the Scotian Shelf than did males. The 80-cm-length class distribution was similar to that of the overall distribution (Fig. 5). While the distribution of the 120-cm- and 60-cm-length classes approximated the distribution of the 80-cm-length class, they were generally less abundant along the edge of the Laurentian Channel. The distribution of the 40-cm-length class was distinct in that the majority of the catches were within Fundian Channel rather than within the Bay of Fundy and across the southern Scotian Shelf.

Stratified mean temperature of bottom water in NAFO divisions 4VWX from 1970 to 1998 varied from a minimum of 4.56°C in 1998 to a maximum of 6.83°C in 1984 (Fig. 6). Throughout the 1970s and into the mid 1980s, the bottom water temperatures were relatively warm as compared with the 1970–98 mean (5.58°C). After 1986, bottom water temperatures decreased to levels below the long-term mean. From 1987 to 1992, temperatures were approximately 5°C. After a period of relatively normal temperatures from 1993 to 1995, bottom water temperatures once again decreased reaching a sample low in 1998. The large decreases in temperature seen in 1998 were mainly manifest in those strata on the Scotian Shelf while very little change was seen within the Bay of Fundy. Bottom water through the majority of the 1970s was characterized by high salinities while the 1990s were characterized by low salinity water relative to the long-term mean of 33.46 ppt (Fig. 6).

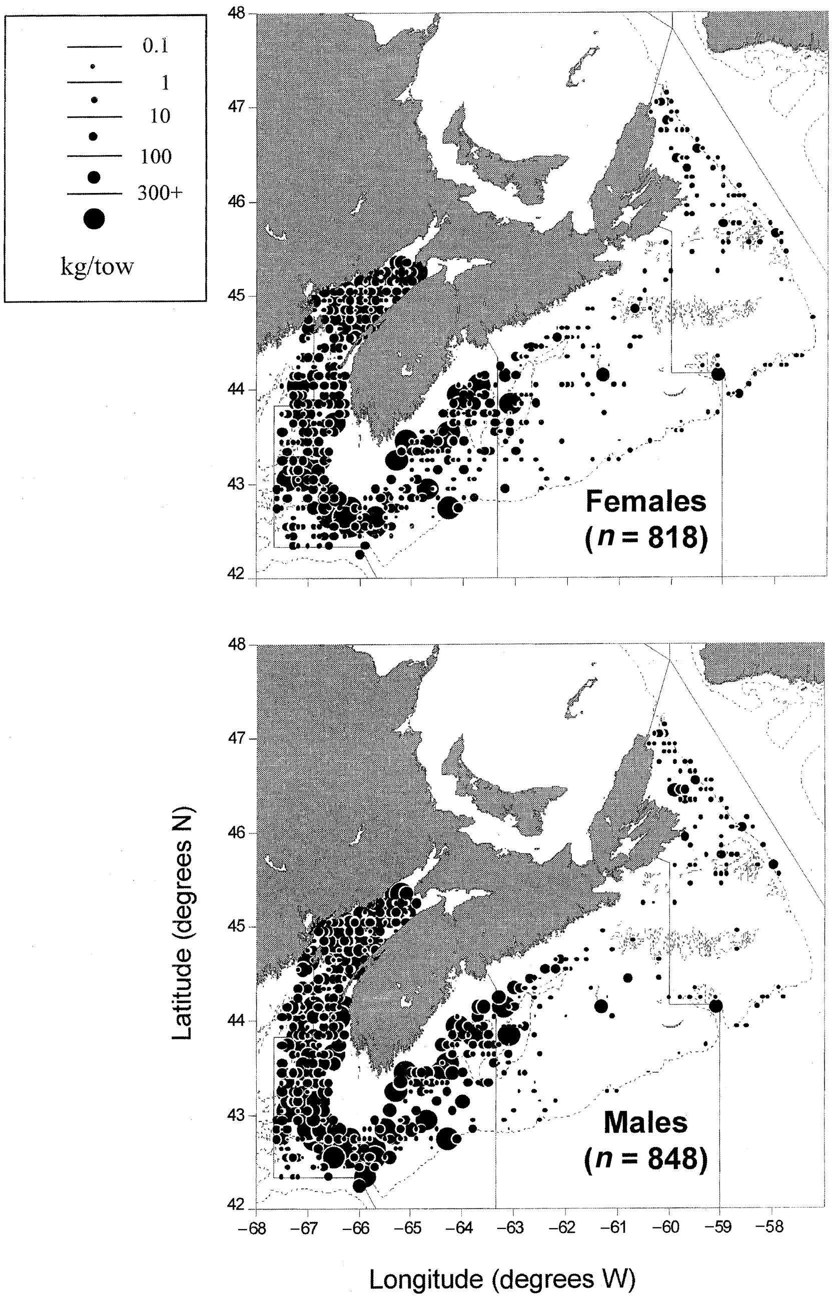
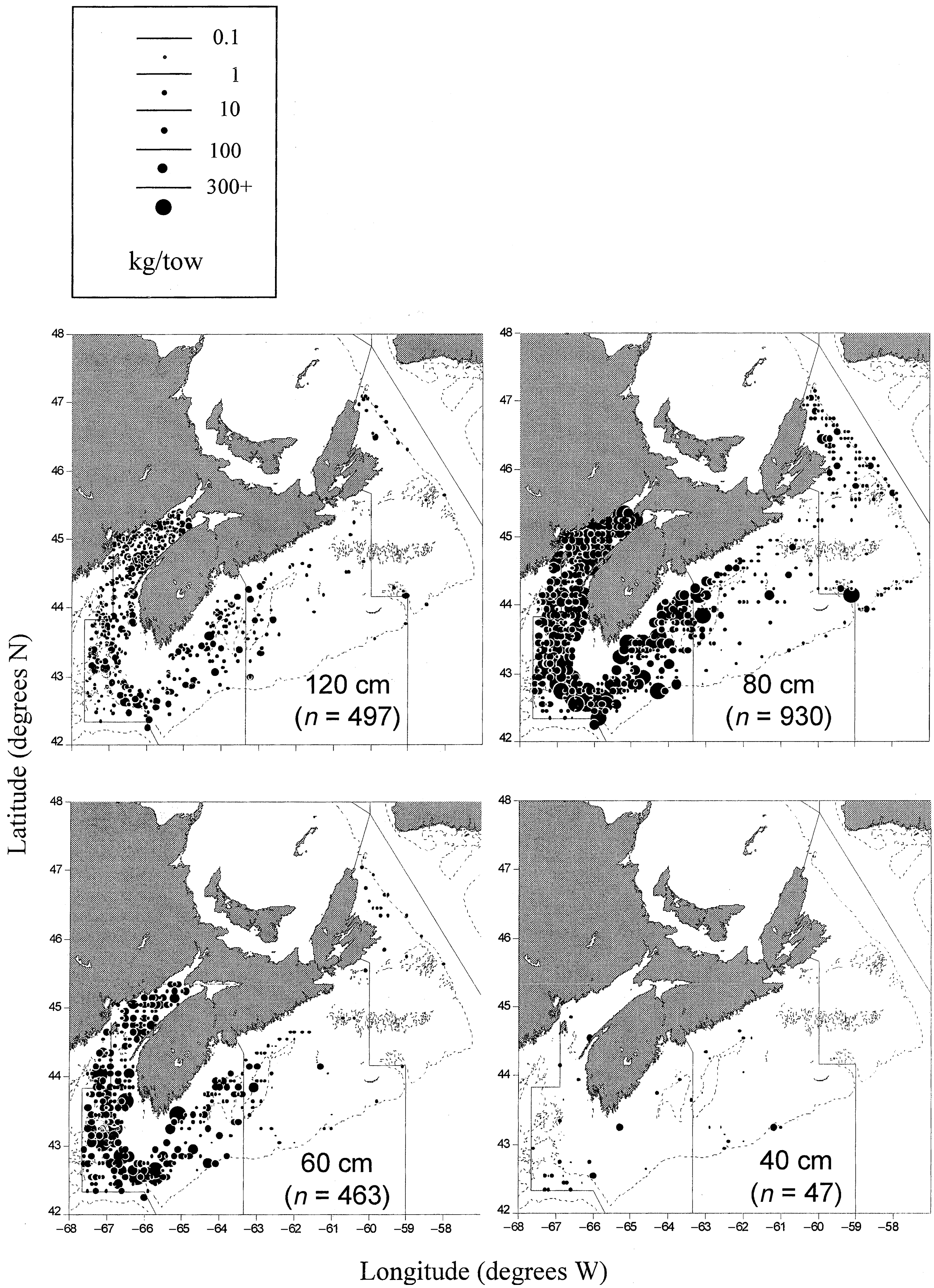



**Figure 4.** Sex specific distribution of spiny dogfish, *Squalus acanthias*, catches in NAFO divisions 4VWX from 1970 to 1998. A total of 4570 samples were taken during this time period. The number of catches where each sex was present is shown on the corresponding panel.

*Environmental preference*

Temperature preferences of male and female dogfish were not significantly different from each other (Table 3). Significant differences in environmental preference between the sexes was found for median (50th percentile), salinity ($P = 0.033$) and depth ($P = 0.009$). In these cases, male dogfish preferred bottom water which was of higher salinity and greater depth than that preferred by female dogfish. A similar trend was seen for the 10th percentile of salinity ($P = 0.101$) and depth ($P = 0.106$) distributions; however, these differences were not significant using $\alpha = 0.05$.

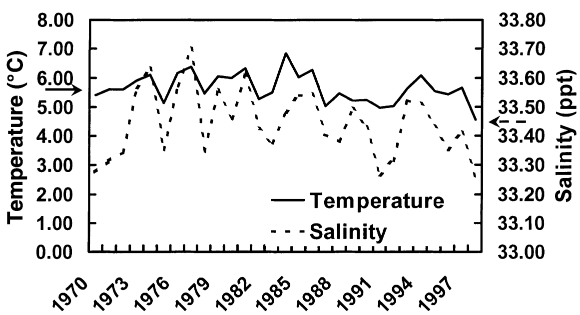
**Figure 5.** Length specific distribution of spiny dogfish, *Squalus acanthias*, catches in NAFO divisions 4VWX from 1970 to 1998. A total of 4570 samples were taken during this time period. The number of catches where each length-class was present is shown on the corresponding panel.


0.1
1
10
100
300+
kg/tow
120 cm
(n = 497)
80 cm
(n = 930)
60 cm
(n = 463)
40 cm
(n = 47)
Latitude (degrees N)
Longitude (degrees W)

Temperature preference of dogfish did not vary among length classes (Table 4). The 10th percentile of salinity ($P = 0.007$) and depth ($P = 0.010$) distributions did vary between length classes. The 10th percentile of these distributions were increasingly saline and deeper as length decreased.

Spiny dogfish preferred bottom water habitats which were significantly warmer than those which were available (Table 5). Both the 10th ($P = 0.001$) and 50th ($P = 0.001$) percentiles of the temperature distributions were significantly different. Dogfish also preferred bottom water more saline and deeper than those available (Table 5). As well, dogfish were distributed along narrower salinity and depth ranges than were available in the habitat.

**Figure 6.** Stratified mean temperature and salinity of bottom water in NAFO divisions 4VWX from 1970 to 1998. Solid grey line and dotted grey line indicate stratified mean temperature and salinity of bottom water averaged over the entire 1970–98 time series, respectively.




## DISCUSSION

### *Spiny dogfish abundance*

Interpretation of the observed variation in the abundance index of dogfish is complicated by a number of factors. The spiny dogfish is a highly migratory fish (Bigelow and Schroeder, 1953), and timing of fish migrations may be cued by environmental factors such as temperature (Konstantinov, 1965). If the relative timing between dogfish migrations into, out of, or within NAFO divisions 4VWX, and annual DFO July groundfish survey show interannual variation, then the calculated abundance index reported could be affected.

The decline in spiny dogfish abundance in 1998 may have been partially the result of a northward migration later than usual. In the summer of 1998, commercial fishers reported little or no dogfish on the southern Scotian Shelf where they are often abundant. However, commercial dogfish catches in the same area increased substantially in the fall of 1998 (D. Clark, DFO, St Andrews, N.B., pers. comm.). This problem has been previously identified for 4VWX dogfish assessments (Annand, 1985). McRuer and Hurlbut (1996) recommended that US and Canadian survey data on spiny dogfish be combined into one data set which may reduce variation in abundance indices caused by changes in timing between migrations and surveys.

The high proportion of males in the spiny dogfish sample is similar to findings of other studies based on groundfish survey data from the Gulf of St Lawrence (Hurlbut *et al.*, 1995). The relatively low number of females in the survey may be indicative of sex selective

**Table 3.** Summary of sex specific, environmental preference data for spiny dogfish, *Squalus acanthias*, in NAFO divisions 4VWX from 1970 to 1998. Data are taken from annual catch-weighted cumulative distribution functions for each sex.

| | | Occupied habitat | | |
|---|---|---|---|---|
| | | Males | Females | |
| Variable | Percentile | Mean ± SE | Mean ± SE | Sex effect (*P*) |
| Temperature (°C) | 10th | 6.50 ± 0.32 | 6.08 ± 0.35 | 0.264 |
| | 50th | 7.68 ± 0.20 | 7.66 ± 0.19 | 0.801 |
| | 90th | 9.10 ± 0.39 | 9.16 ± 0.18 | 0.864 |
| Salinity (ppt) | 10th | 32.72 ± 0.15 | 32.41 ± 0.15 | 0.101 |
| | 50th | 33.76 ± 0.14 | 33.53 ± 0.18 | 0.033 |
| | 90th | 34.40 ± 0.11 | 34.43 ± 0.12 | 0.572 |
| Depth (m) | 10th | 90.34 ± 6.67 | 79.48 ± 5.96 | 0.106 |
| | 50th | 142.07 ± 7.05 | 128.79 ± 7.28 | 0.009 |
| | 90th | 185.52 ± 5.40 | 189.48 ± 6.00 | 0.258 |

SE = Standard error.

**Table 4.** Summary of length specific, environmental preference data for spiny dogfish, *Squalus acanthias*, in NAFO divisions 4VWX from 1970 to 1998. Data are taken from annual catch-weighted cumulative distribution functions for each length class.

| | | Occupied habitat | | | |
|---|---|---|---|---|---|
| | | 41–60 cm | 81–120 cm | 61–80 cm | |
| Variable | Percentile | Mean ± SE | Mean ± SE | Mean ± SE | Size effect (*P*) |
| Temperature (°C) | 10th | 5.93 ± 0.40 | 6.08 ± 0.25 | 6.10 ± 0.33 | 0.923 |
| | 50th | 8.18 ± 0.16 | 7.85 ± 0.19 | 7.95 ± 0.21 | 0.489 |
| | 90th | 9.28 ± 0.21 | 9.10 ± 0.20 | 9.10 ± 0.18 | 0.773 |
| Salinity (ppt) | 10th | 31.78 ± 0.13 | 32.33 ± 0.14 | 32.63 ± 0.16 | 0.007 |
| | 50th | 33.73 ± 0.19 | 33.88 ± 0.15 | 33.93 ± 0.15 | 0.684 |
| | 90th | 34.78 ± 0.02 | 34.70 ± 0.04 | 34.78 ± 0.05 | 0.338 |
| Depth (m) | 10th | 57.50 ± 5.95 | 76.25 ± 5.15 | 82.50 ± 1.44 | 0.010 |
| | 50th | 123.75 ± 13.75 | 122.50 ± 4.33 | 151.25 ± 10.87 | 0.143 |
| | 90th | 192.50 ± 5.95 | 193.75 ± 8.00 | 191.25 ± 8.00 | 0.972 |

SE = Standard error.

**Table 5.** Summary of overall environmental preference data for spiny dogfish, *Squalus acanthias*, in NAFO divisions 4VWX from 1970 to 1998. Data are taken from annual environmental cumulative distribution functions and annual catch-weighted cumulative distribution functions.

| | | Available habitat | Occupied habitat | |
|---|---|---|---|---|
| Variable | Percentile | Mean ± SE | Mean ± SE | Habitat effect (*P*) |
| Temperature (°C) | 10th | 1.57 ± 0.12 | 6.62 ± 0.27 | 0.001 |
| | 50th | 5.96 ± 0.13 | 7.70 ± 0.21 | 0.001 |
| | 90th | 9.35 ± 0.27 | 9.19 ± 0.37 | 0.754 |
| Salinity (ppt) | 10th | 32.16 ± 0.02 | 32.70 ± 0.17 | 0.002 |
| | 50th | 33.36 ± 0.07 | 33.68 ± 0.14 | 0.045 |
| | 90th | 34.79 ± 0.02 | 34.43 ± 0.11 | 0.003 |
| Depth (m) | 10th | 55.00 ± 0.66 | 88.62 ± 6.57 | 0.001 |
| | 50th | 115.34 ± 1.33 | 136.21 ± 6.68 | 0.003 |
| | 90th | 218.10 ± 2.86 | 184.66 ± 5.49 | 0.001 |

SE = Standard error.

fishing mortality. The current dogfish fishery targets mature females while discarding males and immature females (McRuer and Hurlbut, 1996). Since 1992, 95% of all sampled US commercial spiny dogfish landings have been females larger than 84 cm (Hurlbut *et al.*, 1995). It is also possible that a high proportion of female dogfish were distributed outside the sampled area leading to their under-representation in the abundance indices. Annual DFO groundfish surveys sample only 'offshore' areas, i.e. depths greater than ≈ 20 m. Moore (1998) sampled the Minas Basin, Nova Scotia, an area which is not sampled in the DFO surveys, and found a female-to-male ratio of 99 : 1.0. She suggested the Minas Basin may be used as a pupping ground by dogfish.

*Environmental preference*

Temperature and salinity conditions of bottom water in NAFO divisions 4VWX are influenced by the cold Labrador current and the warm Gulf Stream. The relative influences of these two water masses account for much of the variation in hydrographic conditions of bottom water (Houghton *et al.*, 1978). The cold water observed in 1998 may be because of anomalously high influence of the Labrador current (Drinkwater, 1999). Decreases in water temperature on the Scotian Shelf causes spiny dogfish to expand their migrations farther south, thus possibly affecting the timing of the subsequent the northward migration (Frank *et al.*, 1988).

Habitats exploited by spiny dogfish varied between sexes and length classes. Female spiny dogfish are believed to seek out warmer waters in order to maximize growth rate of internal embryos (Moore, 1998). This study found no difference in temperature preference between male and female dogfish, although females were found in shallower waters. This may indicate their tendency to move farther inshore where summer water temperatures are relatively warm. This may also explain why females occupied habitats of relatively low salinity, because inshore waters would be fresher due to greater influence of river outflows.

Mature dogfish tend to remain more inshore than immature dogfish (Nammack *et al.*, 1985; Hurlbut *et al.*, 1995). While the age structure of the dogfish sampled in this study was not available, length may serve as a proxy for age. In that sense, results of this study support the results of others, since the smaller fish were generally found in deeper waters. The reason for these differences in depth preference is unknown but may relate to differences in diet or it may serve as a method by which to partition resources between ages within the population. The significance of differences in preferred salinities between length classes may be more closely linked to differences in depth preference, and the fact that salinity is often correlated with depth, rather than any biological phenomenon.

No other studies could be found that reported salinity or depth preferences of spiny dogfish. The study of Jensen (1966), which included US waters, reported that dogfish were primarily found at depths less than 360 m. The temperature preference of dogfish found in this study is similar to that reported by Jensen (1966) who found that spiny dogfish occur mainly in waters from 7 to 13°C. The discrepancy between the upper limit found in this study of slightly more than 9°C and the 13°C limit reported by Jensen (1966) is likely the result of the ranges of temperatures sampled in this study (annual mean range of 0.6–11.8°C). The lower limit of 6–7°C of temperature preference was much greater than the lower limit of the sampled area (1.6°C) and thus may indicate an important variable limiting the distribution of dogfish. Thus, changes in the temperature of continental shelf water would likely affect dogfish distribution where warming would produce a northward expansion of their distribution.

Changes in the distribution of such a large population would likely have major ecological implications. Spiny dogfish are opportunistic feeders which prey on pelagic fish, demersal fish and benthic invertebrates (Garrison, 2000). An environmentally forced change in their spatial distribution would then be expected to change the degree to which they interact with prey populations in a given space. The distributions of some species of groundfish, such as yellowtail flounder (*Pleuronectes ferrugineus*), have been shown to be relatively insensitive to wide variations in temperature. They instead tend to distribute around a preferred depth or bottom type (Murawski and Finn, 1988). Large-scale changes in water temperature would then be expected to have much less effect on yellowtail flounder distribution than on spiny dogfish distribution. Yellowtail flounder prey on many benthic invertebrates common to the diet of spiny dogfish which have been identified as a major predator of yellowtail flounder (NMFS, 1999). Because the distribution of these two species would react differently to temperature changes, the degree to which they interact (competition and predation) in space may be affected. This suggests changes in predation and competition caused by interspecies differences in environmental preference may represent an important factor in fisheries ecology and warrants further study.

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