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Maritimes Region | **Région des Maritimes**

Status of Smooth Skate (*Malacoraja senta*) and Thorny Skate (*Amblyraja radiata*) in the Maritimes Region

Situation de la raie à queue de velours (*Malacoraja senta*) et de la raie épineuse (*Amblyraja radiata*) dans la région des Maritimes

James E. Simon, Sherrylynn Rowe, and/et Adam Cook

Department of Fisheries and Oceans / Ministère des Pêches et des Océans
Population Ecology Division / Division de l'écologie des populations
Bedford Institute of Oceanography / Institut océanographique de Bedford
P.O. Box 1006, 1 Challenger Drive / C.P. 1006, 1, promenade Challenger
Dartmouth, Nova Scotia / Dartmouth (Nouvelle-Écosse)
B2Y 4A2

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ABSTRACT

The status of smooth and thorny skate within the Maritimes Region was reviewed by examining data from Department of Fisheries and Oceans (DFO) research vessel (RV) surveys, United States (US) RV surveys, Canadian industry science surveys, observer information from directed fisheries, and fisheries landings. These data suggest that smooth skate were broadly distributed throughout the Maritimes Region in the 1970s with persistent areas of concentration. In the 1980s and 1990s, abundance fell across the Scotian Shelf and has continued to decline in Divs. 4VW. In Div. 4X, abundance has increased in the 2000s, primarily driven by an increase in the number of juveniles. The decline in abundance over the whole Scotian Shelf was 80% for mature individuals while the decline when all lengths are considered was 58%. Smooth skate are uncommon on Georges Bank with only scattered reports on the edges of the northeast peak area of the Canadian Zone. Seasonal US RV surveys suggest that these observations are simply the southern edge of a population of smooth skate that are found throughout the Gulf of Maine. These seasonal US surveys provide contradictory evidence with slight decreases or increases in abundance depending on the survey. These data also suggest that thorny skate were widespread across the Scotian Shelf and Bay of Fundy with the highest concentration in Div. 4V and the Bay of Fundy prior to 1990. Since the 1990s, there has been a dramatic reduction in the distribution of thorny skate on the central Scotian Shelf and the concentrations in the east and west are much reduced. Industry Science surveys suggests that there is still significant connectivity between these areas. An examination of the length frequencies collected during the Summer RV Survey indicates a progressive loss of the largest individuals in the population so that there are very few fish greater than 53 cm caught by the survey. The decline in abundance across the shelf of mature fish is 96%, while the decline when all lengths are considered is 82%. While these declines have occurred, recruitment of fish less than 21 cm has remained steady since 1970. Thorny skate are distributed on Georges Bank primarily on the edges of the northeast peak of the bank and in the deeper waters north of the Great Southwest Channel. Their distribution is similar to that observed for smooth skate but they are also observed in slightly shallower waters as well. As for smooth skate, the US RV surveys suggest that thorny skate are found throughout the Gulf of Maine and that the distribution observed during the Canadian survey in this area simply reflects the southern edge of this population. These two surveys also indicate that there is no separation in the distribution between Brown's and Georges Bank**.** The decline in mature abundance for all three surveys is similar to that observed on the Scotian Shelf while overall abundance has declined between 67 to 92%. There are no directed fisheries for smooth or thorny skate on the Scotian Shelf: although these species are caught as bycatch in other fisheries. In Div. 4X, an examination of these other fisheries suggests that annual smooth and thorny skate bycatch was relatively stable at approximately 450 and 1,750 t respectively from 1970 to 1992. Bycatch estimates declined for both species in the 1990s as catches in the traditional cod, haddock, pollock, and flatfish fisheries were reduced. In the last decade, removals have been less than half of what had been taken previously. In Divs. 4VsW, bycatch of smooth skate prior to 1992 was approximately 450 t and declined subsequently to 20 t per year due to the closures of the cod and haddock fisheries as well as changes in the silver hake fishery. Thorny skate bycatch was in the order of 4,500 t and declined to approximately 170 t over the same period. The response by each species to

these levels of bycatch is not well understood. Collectively, these data suggest that in Divs. 4VW, smooth skate abundance is currently low but threats have been reduced to near zero and recruitment is increasing. In Div. 4X, smooth skate abundance has been increasing over the last 15 years at the same time that removals have decreased by about half. Recruitment to the population has been increasing over the same period on both the eastern and western Scotian Shelf. Although the reduction in abundance in Divs. 4VW has resulted in some fragmentation in the population distribution, there is no evidence to suggest that the Scotian Shelf may comprise more than one designatable unit. These data also suggest that thorny skate abundance, especially mature abundance, is currently very low on the Scotian Shelf and Georges Bank area. These declines are continuing on the eastern Scotian Shelf despite dramatic reductions in fishing effort and steady recruitment. The increase in the local grey seal population and its possible affect on the recovery of thorny skate or smooth skate have not been examined in this paper. In Div. 4X, thorny skate abundance has continued to decline despite the reduction in removals by greater than half and steady recruitment over the last 15 years. Industry surveys provide evidence that thorny skate continue to be distributed across the Scotian Shelf likely reflecting a single designatable unit.

RÉSUMÉ

La situation des raies à queue de velours et des raies épineuses dans la région des Maritimes a été évaluée en examinant les données issues des relevés de recherche du ministère des Pêches et des Océans (MPO), des relevés de navires de recherche américains, des relevés scientifiques de l'industrie canadienne, ainsi que des renseignements fournis par des observateurs des pêches dirigées et des débarquements de poissons. Ces données permettent de croire que les raies à queue de velours étaient très répandues dans l'ensemble de la région des Maritimes dans les années 1970, avec des concentrations permanentes. Dans les années 1980 et 1990, l'abondance a diminué sur le plateau néo-écossais, et son déclin s'est poursuivi dans la division 4VW. Durant les années 2000, l'abondance a augmenté dans cette division, essentiellement en raison d'une augmentation du nombre de juvéniles. Le déclin de l'abondance sur l'ensemble du plateau néo-écossais était de 80 % pour les poissons adultes, alors qu'il était de 58 % pour toutes les longueurs. Les raies à queue de velours sont rares sur le banc Georges, n'ayant été observées qu'ici et là à l'extrémité de la pointe nord-est de la zone canadienne. Les relevés saisonniers américains suggèrent que les individus observés ne correspondent qu'à la portion la plus au sud d'une population de raies à queue de velours répandue dans l'ensemble du golfe du Maine. Ces relevés fournissent des données contradictoires, certains indiquant une légère diminution de l'abondance, d'autres une augmentation, selon le cas. Ces données laissent également croire que les raies épineuses étaient très répandues sur le plateau néo-écossais et dans la baie de Fundy, la plus forte concentration se trouvant dans la division 4V et dans la baie de Fundy avant 1990. Depuis les années 1990, la répartition de raies épineuses au centre du plateau néo-écossais a connu une réduction spectaculaire, et les concentrations à l'est et à l'ouest ont fortement diminué. Selon les relevés scientifiques de l'industrie, il subsiste toujours une importante connexion entre ces zones. Un examen des fréquences de longueur recueillies dans le cadre du relevé estival révèle une disparition progressive des plus gros individus de la population. Ainsi, très peu de poissons de plus de 53 cm ont été recensés lors du relevé. Le déclin de l'abondance de poissons adultes sur l'ensemble du plateau est de 96 %, tandis qu'il est de 82 % pour toutes les longueurs. Durant la période au cours de laquelle ces déclins sont survenus, le recrutement de poissons de moins de 21 cm est demeuré stable depuis 1970. Les raies épineuses sont réparties sur le banc Georges, principalement à l'extrémité de la pointe nord-est du banc, ainsi que dans les eaux plus profondes au nord du Grand chenal Sud-Ouest. Leur répartition est semblable à celle des raies à queue de velours, mais elles ont également été observées dans des eaux un peu moins profondes. Comme dans le cas des raies à queue de velours, le relevé du navire de recherche américain suggère que les raies épineuses sont présentes dans l'ensemble du golfe du Maine et que la répartition observée lors du relevé canadien ne correspond qu'à la portion la plus au sud de cette population. D'après ces deux relevés, il n'existe aucune séparation de la répartition entre le banc Brown et le banc Georges. Le déclin de l'abondance des poissons adultes constaté lors des trois relevés est comparable à celui observé sur le plateau néo-écossais, tandis que l'abondance générale a connu un déclin de 67 % à 92 %. Il n'existe pas de pêches dirigées des raies à queue de velours et des raies épineuses sur le plateau néo-écossais. Ces espèces sont toutefois capturées accidentellement dans le cadre d'autres pêches. Dans la division 4X, un examen de ces autres pêches révèle que le nombre annuel de captures accessoires de raies à queue de velours et de raies épineuses était relativement stable de 1970 à 1992, se situant à environ 450 et 1 750 t, respectivement. Le nombre estimé de captures accessoires des deux espèces dans les années 1990 a diminué en raison de la réduction du nombre de prises de morues, d'aiglefins, de goberges et de poissons plats des pêcheries traditionnelles. Au cours des dix dernières années, le nombre de prélèvements a diminué de plus de la moitié. Dans la division 4VsW, la capture accessoire de raies à queue de velours était d'environ 450 t avant 1992. Elle a par la suite diminué à 20 t par année en raison

de la fermeture des pêches de morues et d'aiglefins, ainsi que des modifications apportées aux pêches de merlus argentés. Les captures accessoires de raies épineuses étaient évaluées à 4 500 t et ont diminué au cours de cette même période, atteignant environ 170 t. La réaction de chacune de ces espèces à ces niveaux de captures accessoires n'est pas bien comprise. Dans l'ensemble, ces données indiquent que, dans la division 4VW, l'abondance de raies à queue de velours est actuellement peu élevée, mais que les menaces ont presque complètement été éliminées, et que le recrutement est en pleine croissance. Dans la division 4X, l'abondance de raies à queue de velours a augmenté au cours des 15 dernières années, en même temps que les prélèvements ont diminué d'environ 50 %. Au cours de cette même période, dans les parties est et ouest du plateau néo-écossais, le recrutement de la population a augmenté. Bien que la réduction de l'abondance dans la division 4VW ait entraîné une certaine fragmentation de la population, rien n'indique que le plateau néo-écossais compte plus d'une unité désignable. En outre, ces données indiquent que l'abondance de raies épineuses, surtout celle des adultes, est actuellement très faible sur les zones du plateau néo-écossais et du banc Georges. Ces déclins se poursuivent dans la partie est du plateau, malgré de considérables réductions de l'effort de pêche et un recrutement stable. L'augmentation de la population locale de phoques gris et son incidence possible sur le rétablissement de la population de raies à queue de velours et de raies épineuses n'ont pas été étudiées dans le présent document. Dans la division 4X, l'abondance de raies épineuses a continué à diminuer malgré la réduction de plus de la moitié du nombre de prélèvements et un recrutement stable au cours des 15 dernières années. D'après les relevés de l'industrie, les raies épineuses sont toujours distribuées sur l'ensemble du plateau néo-écossais, ce qui signifie qu'il s'agit probablement d'une seule unité désignable.

INTRODUCTION

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has called for the evaluation of the status of smooth skate, *Malacoraja senta*, and thorny skate, *Amblyraja radiata*, in the western Atlantic within the Canadian Zone. As the department responsible for marine species, the Department of Fisheries and Oceans (DFO) is required to summarize available information on these two species.

In 2004, regional information on the status of thorny skate was presented at a National Assessment Process (NAP) held in Halifax, by DFO. No proceedings or research documents are available from this meeting, but the regional information was provided to the COSEWIC author who completed a draft assessment in 2006. This assessment was considered incomplete, was updated to address issues raised by DFO, and in the end was not accepted by COSEWIC.

In 2006, information on the status of smooth skate was reviewed in St. John's Newfoundland by DFO. This review summarized the information available in all regions, provided new information on the growth and maturity of the species in the Maritimes Region, and suggested potential Designatable Units (DUs) for the Canadian Atlantic (Kulka et al. 2006).

This report represents a re-examination of the DFO RV and industry surveys, extends the analysis to include USA RV surveys, and examines observer and commercial bycatch information within the Maritimes Region (Figure 1). Both species of skate are examined in detail with distributional plots, trends in abundance by immature and mature length categories, and area occupied presented where possible. In addition, the results of a comprehensive review of predation on smooth and thorny skate and their diets are presented in Appendix A.

Life History Characteristics

The reproductive and growth characteristics of smooth and thorny skate on the eastern Scotian Shelf were examined by McPhie and Campana (2009a, 2009b). Collectively, these papers suggested that 50% maturity for smooth skate was between 47.2 and 49.8 cm (female/male) with an age at 50% maturity of 10.1 - 11.7 years (female/male) with low variance in the estimates. Thorny skate matured between 53.4 cm and 62.6 cm (female/male) while age at 50% maturity was between 10.7 and 14.7 years. There was very high variability in the length at 50% maturity with females maturing as small as 39 cm and males at 51 cm while maximum length at maturity was 74.5 and 78 cm.

Simon and Frank (1996) had previously reported on a small sample (28) of female thorny skate that were examined for maturity in Divs. 4VsW. They observed a strong pattern in maturity, with almost all fish less than 50 cm immature and all fish greater than 50 cm were mature. That study was expanded from 1996 to 1998 to a larger sampling of female thorny skate (n=245) on the eastern Scotian Shelf which suggested that length at 50% maturity was 53.6 cm (Figure 2). Of note is a 33 cm thorny skate that was mature. McPhie and Campana (2009b) have observed a small subset of thorny skate that mature at a length much lower than the majority of fish observed in this area.

Sulikowski et al. (2006) examined 170 thorny skate from the western Gulf of Maine to determine the length and age of 50% maturity. They found that length at 50% maturity was 86.5 cm and 87.5 cm, while age at 50% maturity was 10.9 and 11 for males and females respectively.

Sulikowski et al. (2009) also examined smooth skate in the western Gulf of Maine and determined that length at 50% maturity was between 54 and 56 cm (female/male) with an age at 50% maturity of 9-10 years.

These data suggest that for smooth skate on the Scotian Shelf length at 50% maturity would be at least 47 cm with a corresponding age of 10 years. On the western Scotian Shelf and Georges Bank, it is possible that the estimates by Sulikowski (2009) might be more appropriate but for ease of comparison, the eastern Scotian Shelf estimates for females by McPhie and Campana (2009) were used (48 cm and 11 years).

Similarly, for thorny skate the maturity estimates for females by McPhie and Campana (2009a) were used (53 cm and 11 years) to separate the length frequency information into immature and mature categories. In the case of thorny skate, the output from DFO programs is summarized in 3 cm groupings and 54 cm was used to separate the immature and mature portions of the population.

A breeding program at the Montreal Biodome has maintained three species of skate (barndoor, winter, and thorny) in captivity since 1997 (Parent et al. 2008). Although the sample size (2) for thorny was very small, they observed that the two females laid 81 eggs over a one year period. These eggs were laid throughout the year and, of the 14 eggs that hatched, the mean length of time to hatching was 446 days. This length of time was higher than that observed for either winter skate (371 days) or barndoor skate (421 days).

METHODS

Overview of Canadian RV, Industry/Science, and USA Survey Information

DFO Research Vessel Surveys

Maritimes Region (Divs. 4VWX, 5Ze)

The DFO summer survey has been conducted annually on the Scotian Shelf (Divs. 4VWX) since 1970 using a stratified random design based on depth and geographic area (Table 1, Figure 3). In 1995, coverage was expanded into three deepwater strata (365-732 m) on the edge of the shelf. These strata have been included in the distribution maps, but they have not been included in the abundance analyses. From 1970 to 1981, the survey was conducted by the *A.T. Cameron* using a Yankee 36 trawl. In 1982, the *A.T. Cameron* was replaced by the *Lady Hammond* using the Western IIA as the new standard trawl. In 1983, the *Lady Hammond* was replaced by the *Alfred Needler* using the Western IIA trawl. In 2004, the *Alfred Needler* was replaced by the *Teleost* due to a fire on the *Alfred Needler*. The 2005 survey was conducted by both the *Teleost* and the *Alfred Needler* to investigate differences in catchability between the two vessels but this has not been investigated for skate. In 2006, the survey was conducted by the *Alfred Needler*. In 2007, the survey reverted back to the *Teleost* and in 2008, the sister ship of the *Alfred Needler*, the *Wilfred Templeman* conducted the survey. In 2009 and 2010, the survey was again conducted by the *Alfred Needler*.

The 4VWCOD (spring) survey has been conducted since 1986 on the eastern half of the Scotian Shelf (Divs. 4VsW) (Table 1). This survey uses a stratification scheme that was meant to optimize the abundance estimates of cod (Figure 3). No surveys were conducted in 1998 or 2004. The Alfred Needler has conducted the survey using the Western IIA trawl during 1986-2003, 2005-2006, and 2009-2010. The Templeman, using the same gear, conducted the 2007

survey and in 2008, the *Teleost* was the survey vessel. Deep-water strata (365-549 m) in the Laurentian Channel were added to this survey in 1993 and, although not included in abundance trend analysis, the catches in these strata are included in the distribution maps.

The February/March RV survey on Georges Bank (Div. 5Ze) commenced in 1986 using Western IIA trawl gear and a stratified random design (Table 1, Figure 4). The *Alfred Needler* has been the primary vessel except in 1993 and 2004 when its sister ship the *Wilfred Templeman* was used. The survey concentrates on the Canadian side of the bank (Subdiv. 5Zc) with additional sets on the USA side of the EEZ that cover the remainder of the bank as well as stations north of the bank.

Other surveys examined for the presence of smooth skate include the Spring (1978-1984) and Fall (1979-1984) RV surveys of the Scotian Shelf that were conducted by the *Lady Hammond* and the *Alfred Needler* (Table 1). These surveys used the same stratification scheme as the Summer RV Survey.

A dedicated Redfish RV survey was conducted in the fall from 1982 to 1988 primarily on the edges of the Scotian Shelf (Table 1). These surveys also used a stratified random design based on depth and geographic area. They utilized the regular survey strata and included deepwater strata that extended down to 900 m.

USA Research Vessel Surveys (Div. 4X, SubArea 56)

Research surveys of the east coast of the USA and the southern half of the Scotian Shelf have been conducted by the National Marine Fisheries Service (NMFS) each fall since 1963 and each spring since 1968 (Table 1). Both surveys use a stratified random design similar to the Canadian DFO Summer RV Survey (Figure 4). Two research vessels, the *Albatross IV* and the *Delaware II,* have been the primary survey vessels, with the *Atlantic Twin* surveying the inshore areas from autumn 1972 to spring 1975. Generally, a Yankee 36 has been the standard survey gear except a modified Yankee 41 was used during the spring survey from 1973 to 1981. In addition, there was a change in the trawl doors in 1985. In 2008, the *Henry B. Bigelow* using a more efficient 400x12 four-seam rockhopper trawl replaced the *Albatross IV*. Tow distance, duration, and towing speed were modified from those used prior to 2008. No conversion factors between the two vessels have been applied to the data in this section.

Canadian Industry/Science Surveys

Three industry/science surveys based in the Maritimes Region and conducted since the mid 1990s were also evaluated (Table 1) to address data gaps in the RV surveys. These surveys have standard sampling designs. The industry participants have undergone training for sampling methods and species identification and, in addition, trained observers have been deployed on a majority of the participating vessels.

The Individual Transferable Quota (ITQ) Fixed Station Industry Survey in Div. 4X began in the summer of 1995. This survey is conducted by four otter trawlers using a balloon trawl that has smaller diameter footgear than the RV survey gear and, therefore, potentially higher catchability of skate. The area sampled is similar to the RV survey in Div. 4X except an area inshore of the 50-fathom depth contour is also surveyed.

The Divs. 4VsW Sentinel Survey is a stratified random longline survey conducted by industry participants. The series began in fall 1995 and includes all areas surveyed by the RV survey in Divs. 4VsW as well as three additional inshore strata. In 2005, the survey was reduced to the

two western inshore strata as well as four core offshore strata that were thought to be the centre of distribution for haddock.

The Halibut Industry Survey began in 1998 using longline gear primarily on the Scotian Shelf with sets extending into the southern portion of the Grand Banks. An index fishery conducted by the same participants, fished in waters deeper than the regular survey, primarily in the slope waters of the Scotian Shelf and the Grand Banks. Details on location, gear type, time of year, duration, and sampling effort are described by Armsworthy et al. (2006).

Population Sizes and Trends

Estimates of minimum trawlable abundance were calculated for smooth and thorny skate by extrapolating RV survey catch per tow to the total number of trawlable units in a survey area. These estimates should be considered minimum estimates given that the catchability of the survey gear is much less than one. Minimum total population estimates were calculated from the research vessel surveys for Div. 5Z and Divs. 4VWX from the Canadian and USA surveys.

Trends in population abundance for smooth and thorny skate, for immature and mature categories, as well all length groups combined are presented. The mature component and all lengths combined were transformed using log transformation to determine whether there has been a decline or increase in the population using linear regression. Concern has been expressed regarding the use of this method when the data series is complex and non-linear. This appears to be the case for smooth skate but not for thorny skate. These trends are provided for each survey series, as the period of three generations is longer than the period of any of our series. A generation was estimated to be age at 50% maturity (11 years old) (McPhie and Campana, 2009), plus 1/M where M (natural mortality) was assumed to be 0.2 for both smooth and thorny skate. This would result in a three generations time period of 48 years.

Trends in abundance (numbers per tow) from the industry surveys are generally not available since the participants measured only weights per set. In the case where numbers were available, lengths were not consistently taken, thus limiting the utility of these surveys for these species.

Area Occupied

This section provides information on the trends in design weighted area of occupancy (DWAO) within the Maritimes Region (Divs. 4VWX and 5Z) based on the DFO annual bottom-trawl surveys in those areas.

Area of occupancy (A_t) was calculated for year *t* as follows:

$$A_t = \sum_{i=1}^{n} a_i I \quad \text{where } I = \begin{cases} 1 \text{if } Y_i > 0 \\ 0 \text{ otherwise} \end{cases}$$

where *n* is the number of tows in the survey in year *t*, Y_i is the number of smooth or thorny skate caught in tow *i*, and a_i is the area of the stratum fished by tow *i* divided by the number of sites fished in that stratum (Smedbol et al. 2002). In some DFO and industry surveys, relatively few sets captured smooth or thorny skate and the DWAO index was not calculated.

Habitat Associations

Ecosystem Considerations

Essential Habitat

Packer et al. (2003a, b) summarized the known information on geographic range, habitats, reproduction, food habits, size, age, growth, and maturity for smooth and thorny skate. Although the focus was on the species in US waters, information was also reported for the remainder of the range.

As stated in the introduction, predation and diet information for both species on the Scotian Shelf will be presented in the Appendix.

Cumulative stratified estimates of abundance of smooth and thorny skate were compared to cumulative stratified estimates of depth, temperature, and salinity from the Summer RV Survey.

Threats

An examination of observations by the International Observer Program (IOP) within the Maritimes Region from 1977 to 2010 was used to broadly examine the distribution of smooth and thorny skate. Examining data in this manner only provides information on the presence of smooth and thorny skate in the observed sets. Sets where these two species were not observed are not presented. The lack of observer coverage in some areas will also bias the observed distribution, but the observer data does provide additional information on the connectivity between areas that appear to be separate in the RV surveys. Another issue in using these data is that, prior to 1994, skate were not generally speciated and, over the entire time period, there have been problems with identification of skate. The two species most likely to be confused are winter and little skate. Large thorny skate have the potential to be misidentified as spinytail skate, but these are generally in waters deeper than DFO RV surveys. Smooth skate are quite distinctive and there should not be a problem identifying this species.

To estimate removals (bycatch and discards) of smooth and thorny skate, observer reports from a number of fisheries in Div. 4X and Divs. 4VsW were examined. Observer coverage in Div. 4Vn was very low and not included in this analysis. Landings in each division from fisheries where smooth and thorny skate were observed were summarized annually since 1970 using NAFO, ZIF and MARFIS landings statistics. Observer reports of the catch for each main species and the associated bycatch of all skate species were summarized from 1995 to 2008. The percentage of smooth and thorny skate observed of all speciated skate (average from 1995 to 2005) was applied to all skate removals and then bumped up by the ratio of observed main species catch and total landings. This percentage was applied to all landings from 1970 to 2009 except in some fisheries where observer coverage indicated that skate were a significant bycatch, but no species information was available. In these situations, the percentage of skate by species was calculated from the RV survey for that area and the percentage was applied to the reported skate. Given the problems with low and variable observer coverage, as well as problems with skate identification, caution should be used when considering removals from any single year or gear sector.

Gavaris et al. (2010) estimated total discards of skate by determining the observed bycatch of each species of skate in each gear category (i.e. otter trawl bottom (OTB)). Using this total, as well as the total landings of other species from this gear category, they were able to create bycatch estimates for each species of skate for each gear sector. These estimates were then

bumped up to the total landings in a subdivision. They used a window of 2002 to 2005 observer reports for their analysis and estimated total removals for each skate species, as well as a category called other skate. There was high interannual variability in the estimates of removals for each species and by using other skate as another species instead of trying to prorate the unspecified skates into the speciated skate, there was a possiblility of underestimating the removals of the speciated species. They noted that their methods should not be considered the best option for each species and provided alternative approaches. Their Approach C, which was not used, matches closely to what was used in this document.

A directed fishery for skate on the eastern Scotian Shelf was active from 1994 to 2005. The primary species caught in this fishery was winter skate with thorny skate estimated to comprise between 1.7 and 8.6% of the landings in 2000 (Simon and Frank, 2000). An average of 5% was used in this analysis. This fishery used otter trawl with a large mesh net, which resulted in the capture of fish between 45 and 80 cm with a peak at 60 - 65 cm (Simon and Frank 2000). Across the remainder of the shelf, small amounts of skate were landed as a bycatch in other fisheries. Again, these were primarily winter skate.

RESULTS

SMOOTH SKATE

Overview of Canadian RV Surveys

Maritimes Region/Scotian Shelf

Summer Survey of the Scotian Shelf (Divs. 4VWX)

The Summer RV Survey is the longest running survey in the Maritimes Region and has been conducted annually since 1970. Out of the 7,200 sets completed during 1970–2010, 1,489 sets or 20.7% captured smooth skate (Table 2). This compares with 25.8% as reported by Simon and Comeau (1994) for the Summer RV Survey from 1970-1992 when it was the 12th most common groundfish on the survey.

The composite distribution pattern revealed a number of areas of concentration, notably the eastern Scotian Shelf including Div. 4Vn, the Gully, south of Emerald Bank, an area north of Brown's Bank, and in the deep waters close to the US border (Figure 5). The distributional data were aggregated into approximately decadal periods (1970-79, 1980-89, 1990-99, and 2000-10) to examine the persistence of the these areas of concentration over time (Figure 6). By the 1980s, the concentration near Emerald Bank was much reduced and this continued into the 1990s. In the 1990s, the species was mostly concentrated in Div. 4Vn, the Gully, and the area near the US border with few fish outside these areas. During the 2000s, there has been further erosion of the concentration within the Gully and in Div. 4Vn (Figure 6). The length frequencies for these decadal periods are shown in Figure 7. The minimum, maximum, and peak lengths are similar for all four-time blocks (range 10-65 cm with a peak near 50 cm) but there was a decrease in the number of mature individuals in the 1970s and 1980s. In the recent time block, there has been some recovery in the number of fish greater than 50 cm.

Trends in abundance (number per tow with error bars) of smooth skate from the Summer RV Survey were examined separately for Div. 4X, Divs. 4VW, and for the entire survey area (Divs. 4VWX) (Figure 8). Note that in all cases, the deep-water strata that were sampled since 1995 have not been included in the abundance estimates, although they have been included in

the distribution maps. In Div 4X, the trend in abundance generally increased until 1976 when it peaked near 1.7 fish per tow. Subsequently, abundance declined to a series low in 1993 and has increased since then so that the 2009 and 2010 estimates are the third and sixth highest in the series (Figure 8). In Divs. 4VW, abundance was highest in 1971 near 1.3 fish per tow, declined to a low in 1984, rebounded to a peak near 0.8 fish per tow and has been below 0.5 fish per tow since 1998. Combined abundance for Divs. 4VWX has declined from a peak in the mid 1970s to a low in the early 1990s; there has been a slight recovery since then (Figure 8).

The composite distributional pattern was also separated into two length group categories (1-47 cm and >47 cm) representing immature and mature abundance. The patterns in distribution of the immature and mature individuals were similar (Figure 9). The trends in abundance for these two length groups were examined for the same three areas as the overall number per tow (Figure 10). In Div. 4X, mature abundance was generally higher than immature abundance until the mid 1990s when immature abundance was very low. By the mid 1990s, immature abundance was higher than mature abundance and was the highest observed in the series. Mature abundance has also increased but at a slower rate, with current mature abundance about half of that seen in the mid 1970s (Figure 10). In Divs. 4VW, mature abundance declined from the late 1970s to low levels in the mid 1980s where they remain. Immature abundance has been more variable and has been about the long-term mean since 2000. When considered together, the composite abundance of immature and mature abundance for Divs. 4VWX declined from the mid 1970s to a low for both length categories around 1990. Mature abundance has slowly increased since then but remains below the long-term mean. Immature abundance has increased sharply to estimates that are similar to those seen in the early part of the series (Figure 10).

Recruitment (age 0) was estimated for Div. 4X, Divs. 4VsW, and Divs. 4VWX by summing the abundance at length for each area of all fish less than 15 cm based on modes from RV length frequencies and the growth parameters estimated by McPhie and Campana (2009a). In Div. 4X, recruitment has averaged 83,000 individuals since 2000 while in Divs. 4VW, recruitment has been slightly lower at 74,000 individuals (Figure 11). Generally, recruitment has been increasing since the early 1990s (Figure 11).

The total number of individuals in the three divisional groupings was calculated as the catch rate times the number of trawlable units for the four decadal periods. The average number of individuals in these four time blocks revealed that in Div 4X the number of mature individuals has declined from an average of 0.9 million fish in the 1970s, to 0.5 million in the 1980s, to 0.2 million in the 1990s, and increased slightly to 0.3 million in the 2000s. The average of the total number of fish was 1.5, 0.7, 0.6, and 1.1 million fish for the same time blocks. In Divs. 4VW, the mature number of fish was 0.8, 0.4, 0.2, and 0.1 million fish per time block while the average of the total number of fish was 2.0, 0.9, 0.9, and 0.6 million fish per time block.

The log transformed catch rates of smooth skate are presented for the entire survey period for all sizes classes combined and for mature fish only in Div. 4X, Divs. 4VW, and Divs. 4VWX (Table 3, Figure 12). For the entire survey period (1970-2010, 41 years), the eastern and western Scotian Shelf exhibited similar trajectories during the survey series. In Div. 4X, there was a decline in the mature length group of 71%, while the decline when all length groups were considered was 33%. In Divs. 4VW, there was a decline in the mature group of 92% with a decline in the total numbers at length of 77%. When the Scotian Shelf is considered as a whole (Divs. 4VWX), the decline in the mature fish only was 80% with a decline of 58% for all length groups (Table 3, Figure 10). There are issues with using this procedure given the decline and subsequent increase in the series and any decline rate should be considered with caution.

March Survey of the Eastern Scotian Shelf (Divs. 4VsW)

A total of 2,022 sets have been completed since 1986 with 420 records of smooth skate, or 20.8% containing smooth skate (Table 2). The species is distributed primarily in the deep-water sets in the Laurentian Channel, in the Gully, and along the edges of the Scotian Shelf. They are also found to the west of Middle Bank (Figure 13). This distribution is similar to that observed during the Summer RV Survey except for the fish located in the Laurentian Channel. Total number of immature and mature fish for the core strata (401-411) (Figure 3) has varied without trend since the beginning of the series (Figure 14). In 1991, there were a number of large sets of smooth skate in the Gully that resulted in highest annual estimates for both the mature and immature groups. This year and the high interannual variability for both length groups make it difficult to come up with a reasonable decline rate for the series. The overall length frequency for the survey series had similar minimum and maximum length to that observed in the summer RV series for Divs. 4VW, but the peak in the length frequency was at 33 cm with a second peak near 50 cm (Figure 15).

Spring Survey of the Scotian Shelf (Divs. 4VWX)
Fall Survey of the Scotian Shelf (Divs. 4VWX)

These two surveys series were examined for the presence of smooth skate. In both surveys, the distribution of the species was similar to that observed in the Summer RV Survey. A total of 741 and 941 sets were completed during the spring and fall surveys, respectively, with 220 and 262 sets containing smooth skate. The percent occurrence of smooth skate was 29.7 and 27.8 %, respectively (Table 2).

Redfish Survey of the Scotian Shelf (Divs. 4VWX)

A total of 546 sets were completed between 1982 to 1988 with 101 or 18.4% containing smooth skate (Table 2). Smooth skate were primarily distributed in the Gully with the species occurring throughout the surveyed area east of 64^{o}W (Kulka et al., 2006).

Industry Surveys on the Scotian Shelf

The longline surveys on the Scotian Shelf were examined in 2006 (Kulka et al., 2006) for the presence of smooth skate. The 4VsW Sentinel Survey reported a few smooth skate in the Gully, Banquereau Bank, and Emerald Bank during 1995-2005 but this survey has been restricted in area since 2005 to locations where smooth skate have not been reported previously. Of 2,378 sets in the fixed survey portion of the halibut industry survey, no smooth skate were reported. This is likely due to the size of bait or hooks used to catch halibut.

A total of 2711 sets from the ITQ survey were examined for the presence of smooth skate. Smooth skate were caught in 113 or 4.2% of the sets during 1996- 2009. The distribution was similar to that observed during the Summer RV Survey but there were fish caught in the inshore area near Cape Sable Island (Figure 16).

<u>Maritimes Region/Georges Bank</u>

Winter Survey of Georges Bank (Div. 5Ze)

A total of 2,169 sets have been completed since 1986 with 87 or 4% containing smooth skate (Table 2). Smooth skate were primarily distributed north of the Great Southwest Channel, near

Cape Cod with a few fish located on the northern half of the Northeast peak of Georges Bank in the Canadian zone (Figure 17).

An examination of the stratified number per tow from the Canadian side of the bank revealed that smooth skate were caught in 18 of the 24 survey years. There was no trend in abundance with catch rates much lower than on the Scotian Shelf (Figure 18). No decline rate was calculated for this survey. The cumulative length frequency from this survey suggests that the pattern in lengths caught is similar to that observed on the Scotian Shelf (Figure 19).

Overview of USA RV Surveys, SubArea 56

A comparison of the seasonal surveys conducted by the USA revealed little difference between the spring and fall surveys (Figures 20 and 21). Smooth skate were distributed throughout the Gulf of Maine area and abundance was similar on either side of the Canada/US boundary. It is important to note that very few fish were caught in either survey southwest of the Southwest Channel indicating that this is near the southern extent of the distribution of the species (Figures 20 and 21).

The Spring RV Survey abundance was disaggregated into length groups greater than and less than or equal to 47 cm, which approximates the immature and mature length groups for the entire area surveyed (Figure 22). Both trends in abundance indicate a slow decline in abundance from the early 1970s to the mid 1990s. Subsequently, abundance appears to have rebounded to levels similar to those seen in the beginning of the series. In 2009, the number of smooth skate less than 48 cm was double that of any other year in the series but, as stated previously, the *Henry B Bigelow* conducted the surveys in 2008 and 2009 and these years' estimates not comparable to the remainder of the series (Figure 22).

The decline in the total number at length and the mature portion of the population was 35% and 57% respectively for 1968 to 2007 (40 years) (Figure 23 and Table 3).

The Fall RV Survey abundance trends were also disaggregated into similar length groups as the Spring RV Survey (Figure 24). Abundance was similar to that observed in the spring with little trend in either length group. In 2009, the abundance of both the immature and mature length groups was much higher than previously observed but, as has been noted, 2009 was conducted by the *Henry B Bigelow.*

Total and mature numbers at length increased from 1963 to 2007 (45 years) by 24% and 9%, respectively (Figure 25).

Area of Occupancy

The area of occupancy based on the Summer RV Survey from 1970 to 2010 was examined separately for the western Scotian Shelf (Div. X), the eastern Scotian Shelf (Divs. 4VW), and the entire survey area (Divs. 4VWX) (Figure 26). In Div. 4X, the area occupied was high from the mid 1970s to the mid 1980s. Area occupied declined sharply to a series low in 1989 and has slowly increased to above the long-term mean in the 2000s. In Div. 4VW, the area occupied has generally declined from greater than 40,000 km^2 to less than 10,000 km^2. When the entire survey area is considered, area occupied peaked in the late 1970s around 60,000 km^2 and declined in the mid 1980s to 30,000 km^2 where it has remained to present (Figure 26).

The area of occupancy based on the March RV survey has declined steadily from an average of 20,000 km^2 in the late 1980s to an average of less than 10,000 km^2 during the last seven survey years (Figure 27).

On the Canadian portion of Georges Bank (Subdiv. 5Zc), the area of occupancy has remained constant at approximately 400 km^2 for those years in which the species was caught (Figure 28).

Habitat Associations

Temperature and Depth Preferences

Cumulative stratified estimates of abundance of smooth skate were compared to cumulative stratified estimates of depth, temperature, and salinity from the Summer RV Survey (Figure 29). Smooth skate were found in waters deeper than normally sampled during the Summer RV Survey. The temperature range where the species occurred was 1-10 ^{o} C.

Temperature anomalies from Div. 4X (Lurcher Shoal) and Div. 4Vs (Misaine Bank) are shown in Figure 30 (linear loess model). In Div. 4X, the anomalies were positive from 1970 to 1986, below average until 1998 with no trend in the data subsequently. In Div. 4Vs, temperatures were above normal prior to the mid 1980s and much below normal from 1985 to 1998. Since 1998, the temperature anomalies were above normal for four year, followed by below normal for another four years. Since 2006, temperatures have been near normal.

Predator and Prey Preferences

Details of the diet analysis are contained in Appendix A. In summary, smooth skate have never been observed in the stomach contents of over 156,000 fish predators that were sampled primarily from the Scotian Shelf. Smooth skate's diet does not change appreciably between seasons or areas. The main constituents are shrimps, arthropods, oregoniids, euphausiids, and crustacean. Although cottids, osmerids, gadids, and macrourids were identified as prey items, they comprised a relatively small percentage of the diet

Threats

The recovery potential assessment on winter skate (Swain et al. 2006) identified skate purses as particularly vulnerable to various fishing activities, due to their long residency on the bottom. At that time, there was no information on the distribution of winter skate purses. Vladykov (1936) published a key to the skate purses, which was recently updated and modified by Simon (unpublished). Skate purses have been collected from a number of RV surveys on the Scotian Shelf since 1995. These purses were identified to species and their distributions are shown in Figure 31. Although sets occur across the shelf, almost all the skate purses were found on the eastern Scotian Shelf. Smooth skate were observed primarily on the edges of the Laurentian Channel with other purses scattered throughout the deeper waters of Divs. 4VsW. There were two reports of purses near Grand Manan (Figure 31).

The distribution of smooth skate since 1977, as suggested by the Observer Program in the Maritimes Region, is presented in Figure 32. No attempt has been made to address any possible species identification problems within this data set. Smooth skate have been reported throughout the Maritimes Region, primarily along the edges of the shelf and on Georges Bank (Figure 32). These data were examined in more detail on Georges Bank given the lack of smooth skate reported on the northeast peak by the Canadian and US RV surveys in this area

(Figure 33). The area north of 42^{o} N closely matches the reported distribution from the three RV surveys but the area of high concentration to the south is likely due to misidentification.

Removals of smooth skate in Div. 4X were estimated from the scallop, silver hake, white hake, cod/haddock/pollock (CHP), and flatfish fisheries by examining observer reports separately for each fishery (Table 4, Figure 34). The scallop fishery had limited observer coverage, which indicated that skate unspecified (ns) bycatch in this fishery was 10% of the total landings. The scallop fishery is conducted in areas that smooth skate are not usually distributed so this species was thought to be a small percentage (1%) of the total skate reported. Other fisheries considered used similar (but not identical methods) to determine bycatch. Usually the observed skate bycatch by species during 1995-2009 scaled up to account for the skate unspecified was applied to landings from 1970 to present. These years were varied where necessary to account for limited observer coverage or when the observed species compliment was considered suspect. Based on these methods, bycatch of smooth skate in the silver hake, white hake, CHP, flatfish, and redfish fisheries was estimated to be 0.025, 3.6, 0.3, 2.9, and 0.4%, respectively for each fishery. The reported landings in the skate fishery were separated into species using the Summer RV Survey from 1970-2010. The large reports of skate prior to 1977 were from foreign fisheries and there is great uncertainty in these estimates. The primary source of bycatch in Div. 4X was the CHP directed fishery followed by white hake and flatfish fisheries. Overall removals averaged approximately 400 t until the mid 1990s and have declined to less than 200 t since the mid 2000s (Table 4, Figure 34).

Similar methods were used to estimate removals from Divs. 4VsW (Table 5, Figure 34). The estimated bycatch of smooth skate from the silver hake (1977-2000), halibut, CHP, flatfish, and redfish fisheries were 0.1, 0.3, 0.5, 1.2, and 0.15% respectively. Removals of smooth skate from the reported skate fishery prior to 1994 were based on the Summer RV Survey for this period and area and were estimated to be 2.5% of the total biomass. Smooth skate removals from the directed skate fishery (1994-2005) were insignificant. The primary source of removals in Divs. 4VsW was the CHP fishery (Table 5, Figure 34) peaking over 400 t in the mid 1980s. Removals from the flatfish fishery have been generally less than 100t, while removals from the silver hake fishery averaged 60 t between 1977 and 1993. Overall removals ranged from 300 to 600 t prior to 1993 and the closure of the directed cod and haddock fisheries (Figure 34). Since the closure of the fisheries in 1994, removals have been less than 50 t.

Relative F (fishing mortality) was calculated by dividing the removals estimated for each division by the aerial expanded summer RV biomass in Div. 4X and Divs. 4VsW. In Div. 4X, relative F was low until 1985, increased to a high from the late 1980s to early 1990s, and subsequently fell to estimates observed at the beginning of the series. In Divs. 4VsW, relative F was moderate in the 1970s, increased sharply in the 1980s, and subsequently fell to very low levels where it has remained since 1994 (Figure 35).

THORNY SKATE

Overview of Canadian RV Surveys

Maritimes Region

Summer Survey of the Scotian Shelf (Divs. 4VWX)

The Summer RV Survey is the longest running survey in the Maritimes Region and has been conducted annually since 1970. Of the 7,200 sets completed during 1970–2010, 3,560 sets or 49.4% captured thorny skate (Table 2). This compares with 65.1% reported by Simon and

Comeau (1994) for the Summer RV Survey from 1970-1992 when it was the third most common groundfish in the survey.

The composite distribution pattern revealed that thorny skate are widespread across the entire Scotian Shelf and Bay of Fundy (Figure 36) with the highest concentrations in Div. 4V and the Bay of Fundy. The distributional data was aggregated into approximately decadal periods (1970-79, 1980-89, 1990-99, and 2000-10) to examine the persistence of these areas of concentration over time (Figure 37). By the 1980s, the abundance of thorny skate was much reduced over the central Scotian Shelf, a pattern that continues to present with the species now found in the Bay of Fundy and Div. 4V (Figure 37). The length frequencies for these decadal periods are shown in Figure 38. The peak in the length frequency has remained near 28 cm but the maximum length observed has been reduced from greater than 105 cm in the 1970s to less than 80 cm in the 2000s (Figure 38).

Trends in abundance (number per tow) of thorny skate from the Summer RV Survey were examined for Div. 4X and Divs. 4VW separately as well as for the entire survey area in Divs. 4VWX (Figure 39). Note that in all cases the deep-water strata that have been sampled since 1995 were not included in the abundance estimates, although they were included in the distribution maps. In Div. 4X, abundance was highest in 1975 when it peaked at five fish per tow. Abundance steadily declined until 1990 and subsequent estimates have been generally below one fish per tow. The 2010 estimate was the lowest in the series. In Divs. 4VW, abundance was highest in 1975 near 15 fish per tow and steadily declined to a series low in 2009. The 2010 estimate increased slightly but remains low. The abundance for Divs. 4VWX is similar to that observed in Divs. 4VW alone (Figure 39).

Abundance was also calculated for two length groups categories representing immature (1-53 cm) and mature (>53 cm) abundance for Div. 4X, Divs. 4VW and Divs. 4VWX combined. (Figure 40). In Div. 4X, abundance was similar for both the immature and mature groups until 1987 when mature abundance decreased sharply. Since 1988, mature abundance has continued to decrease slowly while immature abundance remained relatively constant until 2010 when the estimate fell sharply (Figure 40). In Divs. 4VW, mature abundance has slowly declined since the mid 1970s. Immature abundance was highest in the 1970s to mid 1980s. It declined until 2003 and has subsequently remained at a low level. The pattern for both immature and mature abundance observed in Divs. 4VWX is similar to that observed in Divs. 4VW alone (Figure 40).

Recruitment (age 0) was estimated for Div. 4X, Divs. 4VsW and Divs. 4VWX by summing the abundance at length for each area of all fish less the 21 cm. This length was based on modes from RV length frequencies and the growth parameters estimated by McPhie and Campana (2009a). In both Div. 4X and Divs. 4VW, recruitment has varied without trend over the last 25 years. Although abundance was higher in the 1970s than subsequent periods, the decline has been slight. Abundance in Div. 4X is about 10% that observed in Divs. 4VW with average number of fish less than 21 cm of 240,000 individuals in Div. 4X and 1.9 million in Divs. 4VW since 2000 (Figure 41).

The total number of individuals in the three divisional groupings was calculated as the catch rate times the number of trawlable units for each of the four decadal periods. The average number of mature individuals for these four time blocks in Div. 4X has declined from an average of 2.2 million fish in the 1970s, to 1.5 million in the 1980s, 0.4 million in the 1990s and 0.2 million in the 2000s. The average number of all individuals was 14.8, 3.3, 1.7, and 1.2 million for the same time blocks. In Divs. 4VW, the number of mature fish was 5.3, 1.8, 0.6, and 0.6 million per

time block while the average number of all individuals was 22.1, 22.0, 11.3, and 6.5 million per time block.

The log transformed catch rates of smooth skate are presented for the entire survey period for all sizes classes combined and for mature fish only in Div. 4X, Divs. 4VW, and Divs. 4VWX (Table 3 and Figure 42). For the entire survey period (1970-2010, 41 years), the eastern and western halves of the Scotian Shelf exhibited almost identical trajectories. In Div. 4X, there was a decline in the mature length group of 97% while the decline when all length groups were considered was 83%. In Divs. 4VW, there was a decline in the mature group of 95% with a decline in all length groups combined of 82%. When the Scotian Shelf is considered as a whole (Divs. 4VWX), the decline in the mature fish only was 96% with a decline of 82% for all length groups (Table 3, Figure 42).

March Survey of the Eastern Scotian Shelf (Divs. 4VsW)

A total of 2,022 sets have been completed since 1986 with 928 records or 45.9% containing thorny skate (Table 2). The species was observed primarily in the deep-water sets in the Laurentian Channel, in the Gully, and along the edges of the Scotian Shelf. They were also found to the west of Middle Bank (Figure 43). The distribution was similar to that observed during the Summer RV Survey except for the fish located in the Laurentian Channel. The trends in total number of immature and mature fish for the core strata (401-411) only have varied without trend since the beginning of the series (Figure 44). The high interannual variability for both length groups and the large number of missing years makes it difficult to determine a reasonable decline rate for the series. The overall length frequency for the survey series had similar minimum and maximum lengths to those observed in the summer RV series for Divs. 4VW with a peak in the length frequency of 31 cm (Figure 45).

Spring RV Survey (Divs. 4VWX)
Fall RV Survey (Divs. 4VWX)

These two survey series were also examined for the presence of thorny skate. In both series, the distribution was similar to that observed in the Summer RV Survey (Figure 46). The Spring RV Survey, which ran during 1979-84, had 741 sets with 526 sets or 69.6% containing thorny skate. The Fall RV Survey, which ran from 1978-84, had a total of 941 sets with 660 or 70.1% containing thorny skate.

Redfish RV Survey

A total of 546 sets were completed between 1982-88 with 248 or 45.4% containing thorny skate (Table 2). Thorny skate occurred throughout the surveyed area except in the Laurentian Fan (Figure 47). They were found in greater than 49% of the sets to a depth of 300 fm. They were found in approximately 11% of the sets between 301-500 fm. The deepest occurrence was in 648 fm.

Industry Surveys on the Scotian Shelf

A total of 2,711 sets were completed during the ITQ survey during 1996-2010 and 455 or 16.8% of the sets contained thorny skate. The distribution was similar to that observed during the Summer RV Survey but fish were caught in the inshore area near German Bank (Figure 48). The catch rate averaged approximately 0.75 kg per tow during 1996-2006 with less than 0.3 kg/tow during the last three years (Figure 49).

The 4VsW Sentinel Survey was examined for the presence of thorny skate using data only from 1996-2003. Of the 1,713 sets examined, 796 or 46.5% caught thorny skate. The distribution of thorny skate was similar to that observed in the Summer RV Survey in Div. 4V but they were also concentrated in the area of the Haddock Closed Area (Figure 1) in Div. 4W and in the inshore area near Halifax (Figure 50).

The fixed stations from the Halibut Industry Survey were also examined for thorny skate. From 1998 to 2010, 912 of 2,595 sets or 35.1% contained thorny skate (Table 2). The survey indicated that thorny skate were scattered across the shelf and they were recorded from the fan of the Laurentian Channel (Figure 51). The stratified numbers per length from the survey indicates that the survey begins to catch fish around 40 cm, peaking near 58 cm with a maximum length near 118 cm (Figure 52). Thorny skate observed in the halibut survey were much larger than any of the other surveys examined.

Maritimes Region/Georges Bank

Winter Survey of Georges Bank (Div. 5Ze)

A total of 2,169 sets have been completed since 1986 with 332 sets or 15.3% containing thorny skate (Table 2). Thorny skate were primarily distributed north of the Great Southwest Channel, close to Cape Cod with fish located on the edges of the Northeast peak of Georges Bank in the Canadian zone (Figure 53).

An examination of the stratified number per tow from the Canadian side of the bank since 1987 revealed that thorny skate abundance was above 1.5 fish per tow during the late 1980s, declined to less than 1 fish per tow in 1992 and has varied without trend near 0.5 fish per tow since 1993 (Figure 54). Fish ranged in length from a minimum of 10 cm to a maximum of 91 cm. There was little difference in the number at length between 16 and 79 cm (Figure 55). The annual estimates of total number of thorny skate were also disaggregated into greater and less than 53 cm, corresponding to the maturity of thorny skate on the Scotian Shelf (McPhie and Campana 2009b). There appears to have been a decrease in the abundance of large thorny skate in this area while the number of small fish has remained relatively stable (Figure 56). The decline in large fish since 1986 was 98% while the decline for all sizes of fish combined was 67% (Figure 57, Table 3). The average total number of fish from 1986-2010 was 130,000 of which 46,000 were mature.

Overview of USA RV Surveys, SubArea 56

A comparison of the seasonal surveys conducted by the USA revealed little difference between the spring and fall surveys (Figures 58 and 59). Thorny skate were distributed evenly throughout the Gulf of Maine, northeast peak of Georges Bank extending south along its southern flank, and Browns Bank. It is important to note that very few fish were caught in either survey southwest of the Southwest Channel indicating that this is near the southern extent of the species range (Figures 58 and 59).

The Spring RV Survey abundance was aggregated into length groups greater than and less than or equal to 53 cm, which approximates the immature and mature length groups for the Scotian Shelf (Figure 60). Both trends in abundance indicate a slow decline from the early 1970s to the mid 2000s. There may have been a slight increase in the number of fish < 54 cm in 2007, but it remains well below the long term mean (Figure 60). The trend in the log transformed data for each length group from 1968 to 2007 indicates that the decline in the numbers of mature individuals is 94% while the decline rate for all lengths combined was 88% (Figure 61).

The Fall RV Survey data were aggregated into similar length groups and the trend in abundance was similar to that observed in the Spring RV Survey with declines noted for both length groups (Figure 62). The log transformed data had a decline rate of 96% for the >53 cm group and 94% when all length groups were considered (Figure 63).

Area of Occupancy

Based on the Summer RV Survey, the area of occupancy from 1970 to 2010 was examined separately for the western Scotian Shelf (Div. 4X), the east (Divs. 4VW), and the entire survey area (Divs. 4VWX) (Figure 64). In Div. 4X, the area occupied steadily declined from a high of 55,000 km^2 in the mid 1970s to series low near 9,000 km^2 in 2010. In Divs. 4VW, the area occupied has declined from approximately 94,000 km^2 to less than 30,000 km^2 in 2000 and has subsequently remained low. When the entire survey area was considered, area occupied peaked in the late 1970s around 150,000 km^2 and declined to approximately 50,000 km^2 by 2000 where it has remained (Figure 64).

The area of occupancy, based on the March RV survey has declined steadily from 60,000 km^2 in 1987 to an average of 20,000 km^2 during the last 10 years surveyed (Figure 65).

On the Canadian portion of Georges Bank (Subdiv. 5Zc), the area of occupancy has declined from 2,400 km^2 to approximately 1500 km^2 but there has been high interannual variability (Figure 66).

Habitat Associations

Temperature and Depth Preferences

Cumulative stratified estimates of abundance of thorny skate were compared to the cumulative stratified estimates of depth, temperature, and salinity from the Summer RV Survey (Figure 67). Thorny skate were found in slightly shallower depths than the average sampled during the survey. They were also found in much cooler and less saline waters than the survey average. The temperature range where thorny skate were normally found was usually less than 5 ^{o} C but the species has been found in waters up to 10 ^{o} C (Figure 67).

Predator and Prey Preferences

Details of the diet analysis are contained in Appendix A. In summary, predation on thorny skate is negligible although Atlantic halibut, sea raven, American plaice, Atlantic cod, and porbeagle sharks have been observed to have consumed them. Thorny skates consume a number of invertebrate groups including shrimps, arthropods, oregoniids, and gammarid amphipods. As thorny skate increase in size, their diet includes increasing amounts of fish including ammodytes, scombrids, clupeids and merlucciids in Divs. 4VW while in Div. 4X the diet include zoarcids, gadids, and scorpaenids.

Threats

The distribution of thorny skate purses on the Scotian Shelf was examined in a similar manner as smooth skate. Thorny skate was the most commonly captured skate purse on the eastern Scotian shelf with the highest concentrations located just east of the Gully and north east of Banquereau Bank. They were scattered reports of thorny skate purses located throughout the

remainder of Div. 4Vs, Div. 4Vn, and on the eastern half of Div. 4W. There were only three reports of thorny skate purses west of 61^{o}W (Figure 31).

The distribution of thorny skate since 1977, as suggested by the Observer Program in the Maritimes Region, is presented in Figure 68. No attempt has been made to address any possible species identification problems within this data set. Thorny skate have been reported throughout the Maritimes Region with the highest concentrations on Banquereau Bank, the edges of the Scotian Shelf, and on Georges Bank (Figure 68). As with the smooth skate information, the data on Georges Bank should be considered suspect.

Removals of thorny skate in Div. 4X were estimated from the scallop, silver hake, white hake, cod/haddock/pollock (CHP), and flatfish fisheries by examining observer reports separately for each fishery (Table 6). The scallop fishery had limited observer coverage which indicated that skates unspecified bycatch in this fishery was 10% of the total landings. The scallop fishery is conducted in areas that thorny skate are estimated to be approximately 10% of the total skate reported resulting in a thorny skate bycatch in the scallop fishery of 1% of total landings. The other fisheries considered used similar but not identical methods to determine bycatch. Usually, the observed skate bycatch by species from 1995 to 2009, bumped up to account for the unspecified skate was applied to landings from 1970 to present. These years were varied where necessary to account for limited observer coverage or when the observed species complement was considered suspect. Based on these methods, bycatch of thorny skate was estimated to be 0.17, 2.1, 1.8, 9.0, and 0.5% for each of the silver hake, white hake, CHP, flatfish, and redfish fisheries. The reported landings in the skate fishery were separated into species using the Summer RV Survey during 1970-2010. The large reports of skate prior to 1977 were from foreign fisheries and there is great uncertainty in these estimates. The primary source of bycatch in Div. 4X was the CHP directed fishery followed by the flatfish and scallop fisheries. Overall removals averaged approximately 1,500 t until the mid 1990s and have declined to approximately 500 t since the mid 2000s (Table 6 and Figure 69).

Similar methods were used to estimate thorny skate removals from Divs. 4VsW (Table 7). Foreign reports of skate landings were estimated to be 77% thorny skate based on Summer RV Survey catches. The estimated bycatch of thorny skate from the silver hake (1977-2000), halibut, CHP, flatfish, and redfish fisheries were 0.4, 4.6, 5.1, 14.7, and 2.3% respectively. The estimated removals from the reported skate fishery prior to 1994 were based on the Summer RV Survey for this period and area and were 70%. Thorny skate removals from the directed skate fishery were estimated from observer reports and commercial length frequency information to be 5% of the total skate landings. The primary source of removals in Divs. 4VsW prior to 1977 was the foreign skate landings but these reports were considered suspect by R. Halliday (pers comm.). If these reports are discounted, the largest removals were by the CHP fishery (Table 7, Figure 69) peaking over 4000 t in the mid 1980s. Removals from the flatfish fishery peaked above 1,000 t in the 1970s and were about 500 t in the 1980s. Removals by the silver hake fishery averaged about 300 t from the 1970s to the early 1990s. Overall removals from 1977 to 1993 averaged 4,500 t. Since 1993, removals have declined to approximately 100 t per year (Figure 69).

Relative F was calculated by dividing the removals estimated for each division by the aerial expanded summer RV biomass in Div. 4X and Divs. 4VsW. In Div. 4X, relative F remained low throughout the 1970s, increased steadily until the early 2000s, and has subsequently declined. The estimate in 2010 was primarily due to the very low catch of immature fish in the RV survey (Figure 70). In Divs. 4VsW, relative F was moderate in the 1970s except for 1971 which was driven primarily by the extremely high estimated removals by foreign fisheries that are

considered suspect. Relative F generally increased until the early 1990s. Since the closure of the groundfish fisheries in 1994, relative F has been very low (Figure 70).

DISCUSSION

Based on the Summer RV Survey, smooth skate were broadly distributed throughout the Maritimes Region in the 1970s with persistent concentrations in Div. 4Vn, the Gully, south of Emerald Bank, an area north of Browns Bank and in the deeper waters adjacent to the US border in Div. 4X. Since the 1990s the concentrations located on the central Scotian Shelf have become much reduced so that smooth skate are now primarily located in the western half of Div. 4X, in Div. 4Vn, and with a remnant concentration near the Gully. Trends in abundance differ between the eastern and western halves of the shelf. In the east, abundance has declined from the highs observed during the 1970s to relatively low estimates throughout the 2000s. On the other hand, in Div. 4X, abundance was high in the mid 1970s, declined to very low values in the early 1990s, and has rebounded in the 2000s to above average estimates. This rebound has been driven primarily by an increase in the abundance of immature fish less than 47 cm.

A subset of these immature fish (6-14cm) was defined as recruitment. In both Div. 4X and Divs. 4VW, recruitment to the population was highest in the 2000s and, when the Scotian Shelf was considered as a whole, recruitment has been increasing sharply since the mid 1990s. An examination of the distribution of skate purses suggests that smooth skate purses are located primarily in Divs. 4VW with very few in Div. 4X. This does not match the observed increase in recruitment on both the eastern and western halves of the shelf. This dichotomy suggests that smooth skate purses are in locations where the summer survey does not fish or the young are migrating into the area from adjoining locations.

The log transformed total abundance of mature smooth skate has declined 80% since 1970 over the whole Scotian Shelf. The decline when all lengths are considered is 58%. The decline rate for all length groups as well as for mature lengths only is much greater in Divs. 4VW than in Div. 4X.

There had been previous suggestions that, based on the concentrations observed during the Summer RV Survey, there might be more than one DU on the Scotian Shelf (Kulka et al. 2006). An examination of other DFO and industry surveys on the Scotian Shelf suggests that there continues to be connectivity between these areas.

The Canadian Survey of Georges Bank suggested that smooth skate are uncommon on the bank itself with scattered reports on the edges of the northeast peak area of the Canadian Zone. In addition, smooth skate were observed north of the Southwest Channel area of this survey. The US RV surveys both suggest that smooth skate are found throughout the Gulf of Maine and that the Canadian observations in this area are simply the southern edge of the population. The abundance trends from the US spring and fall RV surveys provide contradictory evidence of slight decreases and increases in abundance, respectively.

To estimate threats to the population, observer reports from a number of directed fisheries in Div. 4X and Divs. 4VsW were examined in detail. These suggest that in Div. 4X, removals of smooth skate averaged approximately 450 t annually from 1970 to 1992. Total removals declined in the 1990s due primarily to restrictions in the cod/haddock/pollock and flatfish fisheries so that during 1998 to 2009, removals were in the order of 190 t annually. In Divs. 4VsW, removals by other fisheries during 1970 to 1991 were similar to those observed in

Div. 4X. The closures of the cod and haddock fisheries, as well as changes in the silver hake fishery, resulted in removals declining to approximately 20 t per year.

Collectively, these data suggest that in Divs. 4VW, smooth skate abundance is currently low but threats from other fisheries have been almost eliminated, and recruitment is increasing. In Div. 4X, smooth skate abundance has been increasing over the last 15 years at the same time that removals have decreased by about half. Recruitment to the population has been increasing over the same period in both the eastern and western Scotian Shelf. Although the reduction in abundance in Divs. 4VW has resulted in some fragmentation in the population distribution, there is no evidence to indicate that the Scotian Shelf comprises more than one designatable unit.

The Summer RV Survey indicates that prior to 1990, thorny skate were the third most commonly caught species on the Scotian Shelf. The species was widespread across the entire shelf and Bay of Fundy with the highest concentrations in Div. 4V and the Bay of Fundy. Since 1990, there has been a dramatic reduction in the distribution of thorny skate on the central Scotian Shelf and the concentrations in Div. 4V and the Bay of Fundy are much reduced. An examination of the length frequencies collected during the Summer RV Survey indicates a progressive loss of the largest individuals from the population. The maximum length observed has been reduced from 105 cm to 80 cm and very few fish greater than 53 cm are caught by the survey at present.

Although the number of immature fish (<54 cm) has declined during the Summer RV Survey recruitment of thorny skate (9 to 20 cm) has remained steady. In Divs. 4VW, the 2007, 2008, and 2010 estimates of recruitment were above the long-term mean at a time when the number of mature animals was very low. In Div. 4X, the 2008 and 2009 estimates were also above average while mature abundance was very low. As with smooth skate, thorny skate purses were primarily located in Divs. 4VW with very few in Div. 4X. The continuing strength in recruitment in Div. 4X with few observations of skate purses again suggests that thorny skate purses are located in areas where the summer survey does not fish (inshore or deeper water) or the young are migrating into the area from adjoining locations.

Across the Scotian Shelf the log transformed abundance of thorny skate has declined 82% since 1970 for all length groups while the decline rate has been 96% when only mature fish are considered.

Although the Summer RV Survey indicates that the concentrations of thorny skate on the eastern and western halves of the Scotian Shelf are widely separated, the 4VsW Sentinel, ITQ, and halibut surveys all indicate that thorny skate are also distributed on the central Scotian Shelf and there continues to be significant connectivity between these areas.

The Canadian Survey of Georges Bank suggests that thorny skate distribution is similar to smooth skate but that they are observed in slightly shallower waters. They are primarily distributed on the edges of the northeast peak of the bank and in the deeper waters north of the Great southwest Channel. The US RV surveys both suggest that thorny skate are found throughout the Gulf of Maine and that the Canadian observations in this area are simply the southern edge of the distribution. These two surveys also indicate that there is no separation in the distribution between Brown's and Georges Bank**.** The decline in mature abundance for all three surveys is similar to that observed on the Scotian Shelf, while overall abundance has declined 67 - 92 percent.

To estimate threats to the thorny skate population, observer reports were examined in a manner similar to that previously described for smooth skate. The Summer RV Survey indicates that

thorny skate are much more common in both Div. 4X and Divs. 4VW which is reflected in the observer reports. In Div. 4X, removals of thorny skate from 1970 to 1992 averaged approximately 1,750 t. Total removals declined in the 1990s due primarily to restrictions in the cod/haddock/pollock and flatfish fisheries so that during 1998-2009 removals were in the order of 750 t annually. Removals of thorny skate from the primary fisheries in Div. 4VsW were estimated to be 4,500 t annually from 1977 to 1991, which was substantially higher than that observed in Div. 4X. The closures of the cod and haddock fisheries, as well as changes in the silver hake fishery, resulted in removals declining to less than 200 t per year.

These data suggest that thorny skate abundance, especially mature abundance, is currently very low on the Scotian Shelf and Georges Bank area. These declines are continuing on the eastern Scotian Shelf despite dramatic reductions in fishing effort and steady recruitment. The increase in the local grey seal population (DFO, 2011) and its possible affect on the recovery of thorny skate or smooth skate have not been examined in this paper. In Div. 4X, thorny skate abundance has continued to decline despite substantial reductions in bycatch and steady recruitment over the last 15 years. Industry surveys continue to provide evidence that thorny skate are distributed across the Scotian Shelf suggesting that thorny skate on the Scotian Shelf are one Designatable Unit.

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Table 1. Temporal and spatial extent of data used in examining the distribution, abundance, and threats of skate in the Maritimes Region.

	Canadian RV Surveys						Canadian Industry Surveys					US RV Survey	
Identifier NAFO AREA	Georges Bank 5Z	4VWCOD 4VsW	Summer 4VWX5Y	Spring 4VWX	Fall 4VWX	Redfish 4VWX	Sentinel (LL) 4VsW	Halibut (LL) 3NOP4VWX5	ITQ (OT) 4X	Observer Subarea 02345	Commerical 4VWX	Spring 4X5	Fall 4X5
1963											x		x
1964											x		x
1965											x		x
1966											x		x
1967											x		x
1968											x	x	x
1969											x	x	x
1970			x								x	x	x
1971			x								x	x	x
1972			x								x	x	x
1973			x								x	x	x
1974			x								x	x	x
1975			x								x	x	x
1976			x								x	x	x
1977			x							x	x	x	x
1978			x		x					x	x	x	x
1979			x	x	x					x	x	x	x
1980			x	x	x					x	x	x	x
1981			x	x	x					x	x	x	x
1982			x	x	x	x				x	x	x	x
1983			x	x	x	x				x	x	x	x
1984			x	x	x	x				x	x	x	x
1985			x			x				x	x	x	x
1986	x	x	x			x				x	x	x	x
1987	x	x	x			x				x	x	x	x
1988	x	x	x			x				x	x	x	x
1989	x	x	x							x	x	x	x
1990	x	x	x							x	x	x	x
1991	x	x	x							x	x	x	x
1992	x	x	x							x	x	x	x
1993	x	x	x							x	x	x	x
1994	x	x	x							x	x	x	x
1995	x	x	x						x	x	x	x	x
1996	x	x	x				x		x	x	x	x	x
1997	x	x	x				x		x	x	x	x	x
1998	x		x				x	x	x	x	x	x	x
1999	x	x	x				x	x	x	x	x	x	x
2000	x	x	x				x	x	x	x	x	x	x
2001	x	x	x				x	x	x	x	x	x	x
2002	x	x	x				x	x	x	x	x	x	x
2003	x	x	x				x	x	x	x	x	x	x
2004	x		x				x	x	x	x	x	x	x
2005	x	x	x				x	x	x	x	x	x	x
2006	x	x	x				x	x	x	x	x	x	x
2007	x	x	x				x	x	x	x	x	x	x
2008	x	x	x				x	x	x	x	x	x	x
2009	x	x	x				x	x	x	x	x	x	x
2010	x	x	x										

Table 2. Details of the individual surveys series examined in this document showing gear, sampling effort and percent occurrence of smooth (top panel) and thorny skate (bottom panel).

	Identifier	NAFO AREA	Years	Gear	Total Number of sets examined	Number of Sets with smooth skate	Percent Occurrence
Canadian RV Surveys	Georges Bank	5Z	1987-2010	OT	2169	87	4
	4VWCOD	4VsW	1986-2010	OT	2022	420	20.8
	Summer	4VWX5Y	1970-2010	OT	7200	1489	20.7
	Spring	4VWX	1979-1984	OT	741	220	29.7
	Fall	4VWX	1978-1984	OT	941	262	27.8
	Redfish	4VWX	1982-1988	OT	546	101	18.4
Canadian Industry Surveys	Sentinel	4VsW	1996-2009	LL	1812	21	1.2
	Halibut	3NOP4VWX5	1998-2009	LL	2378	0	0
	ITQ	4X	1995-2009	OT	2711	113	4.2
US RV Survey	Spring	4X5	1968-2009	OT	8220	1077	13.1
	Fall	4X5	1963-2009	OT	9428	1181	12.5

	Identifier	NAFO AREA	Years	Gear	Total Number of sets examined	Number of Sets with thorny skate	Percent Occurrence
Canadian RV Surveys	Georges Bank	5Z	1986-2010	OT	2169	332	15.3
	4VWCOD	4VsW	1986-2010	OT	2022	928	45.9
	Summer	4VWX5Y	1970-2010	OT	7200	3560	49.4
	Spring	4VWX	1979-1984	OT	741	516	69.6
	Fall	4VWX	1978-1984	OT	941	660	70.1
	Redfish	4VWX	1982-1988	OT	546	248	45.4
Canadian Industry Surveys	Sentinel	4VsW	1996-2009	LL	1713	796	46.5
	Halibut (Fixed)	3NOP4VWX5	1998-2009	LL	2595	912	35.1
	ITQ	4X	1995-2009	OT	2711	455	16.8
US RV Survey	Spring	4X5	1968-2009	OT	8220	2142	26.1
	Fall	4X5	1963-2009	OT	9428	2770	29.4

Table 3. Summary of percent change in abundance for smooth and thorny skate from the research surveys conducted within the Maritimes Region. Trends are reported for both individuals of all sizes and those representing mature individuals (>47 cm for smooth and >53 cm for thorny skate). Trends in abundance were not calculated for surveys where abundance was too low or sporadic.

Smooth skate

Survey	Years	Area	Abundance Trend	
			All lengths	Mature lengths
Summer RV	1970-2010	4X	-33	-71
	(41 years)	4VW	-77	-92
		4VWX	-58	-80
4VWCOD	1986-2010	4VsW	NA	NA
	(25 years)			
Georges Bank	1986-2010	5Z, Cdn	NA	NA
	(25 years)			
US Fall	1963-2007	4X5YZ	+24	+9
	(45 years)			
US Spring	1968-2007			
	(40 years)	4X5YZ	-35	-57

Thorny skate

Survey	Years	Area	Abundance Trend	
			All lengths	Mature lengths
Summer RV	1970-2010	4X	-83	-97
	(41 years)	4VW	-82	-95
		4VWX	-82	-96
4VWCOD	1986-2010	4VsW	-61	-12
	(25 years)			
Georges Bank	1986-2010	5Z, Cdn	-67	-98
	(25 years)			
US Fall	1963-2007	4X5YZ	-92	-96
	(45 years)			
US Spring	1968-2007			
	(40 years)	4X5YZ	-88	-94

Table 4. Estimates of total removals (tonnes) of smooth skate from selected fisheries in Div. 4X based on observer reports and the Summer RV Survey.

Year	Cdn Scallop[1] (used 0.1%)	Cdn silver hake [2] 0.025%	Cdn white hake [3] 3.6%	Cdn CHP [4] 0.3%	Cdn Flatfish [5] 2.9%	Cdn Redfish [6] 0.39%	Cdn Reported skate [7] 7.3%	Total Removals [8]
1970	3	0	72	134	87	14	0	310
1971	2	0	105	147	82	29	11	376
1972	2	0	142	156	77	10	2	388
1973	1	0	138	176	64	4	60	443
1974	1	0	144	161	68	5	40	420
1975	1	0	104	172	63	4	154	497
1976	9	0	78	166	56	4	28	340
1977	6	0	71	179	87	4	11	358
1978	5	0	91	206	85	3	3	392
1979	10	0	78	230	100	3	2	422
1980	22	0	92	256	122	6	3	501
1981	17	0	79	257	117	7	0	477
1982	19	0	122	244	114	11	1	512
1983	15	0	85	222	122	12	2	458
1984	10	0	114	196	106	12	4	442
1985	8	0	110	200	110	17	0	445
1986	5	0	169	185	158	21	1	541
1987	8	0	184	186	119	19	2	518
1988	28	0	141	176	133	12	1	492
1989	40	0	114	158	96	8	1	417
1990	28	0	128	170	175	8	1	509
1991	21	2	102	201	167	6	3	502
1992	24	1	120	184	170	8	1	508
1993	27	3	129	117	117	19	2	413
1994	36	0	114	87	94	19	7	356
1995	35	0	152	68	74	18	10	357
1996	15	1	99	74	71	14	5	279
1997	11	1	92	88	56	21	5	274
1998	14	0	49	85	45	21	3	218
1999	16	1	49	56	41	16	2	181
2000	20	1	66	53	48	18	1	206
2001	26	2	65	59	38	16	2	209
2002	36	1	72	60	35	18	1	223
2003	36	0	52	65	41	12	1	207
2004	42	0	54	56	40	8	2	201
2005	25	0	57	48	34	12	3	178
2006	24	0	39	36	35	10	2	145
2007	25	0	31	48	43	11	2	160
2008	16	0	42	44	36	14	1	153
2009	12	1	37	42	36	17	1	145

Notes: Prior to 1994 observers coded skate primarily as species unknown.

[1] Limited observer coverage estimated that skate,ns are 10% bycatch in scallop fishery,

[1] Smooth skate have limited overlap with scallop grounds so estimated to be 1% of skate,ns

[2] Based on observer reports that 10% of all skate reported in 4X from the silver hake fishery (1995-2005) were smooth skate.

[3] Based on observer reports that 49% of all skate reported in 4X from the white hake fishery (1991-2006) were smooth skate.

[4] Based on observer reports that 9% of all skate reported in 4X from the CHP fishery (1995-2009) were smooth skate.

[5] Based on observer reports that 23% of all skate reported in 4X from the flatfish fishery (1995-2008) were smooth skate.

[6] Based on observer reports that 32% of all skate reported in 4X from the redfish fishery (1995-2008) were smooth skate.

[7] Based on the percentage of smooth skate of the total skate catch from the 1970-2010 summer RV survey in 4X.

[8] Other fisheries did not have sufficient information to make even broad estimates of discarding.

Table 5. Estimates of total removals (tonnes) of smooth skate from selected fisheries in Divs. 4VsW based on observer reports and the Summer RV Survey.

Year	Foreign All fisheries [1] 2%	Foreign silver hake [2] 0.1%	Cdn halibut [3] 0.3%	Cdn CHP [4] 0.5%	Cdn Flatfish [5] 1.2%	Cdn Redfish [6] 0.15%	Cdn Reported skate [7] 2.5%	Total Removals
1970	77		1	101	73	11	1	265
1971	350		1	142	107	24	0	624
1972	105		1	125	105	23	0	358
1973	134		1	116	84	13	0	348
1974	169		1	76	94	12	2	352
1975	323		1	81	83	13	0	500
1976	157		1	69	62	10	19	318
1977		30	1	104	84	13	11	242
1978		44	1	194	82	14	3	339
1979		49	2	265	79	10	2	406
1980		36	2	382	101	12	2	535
1981		39	2	470	94	14	0	620
1982		58	2	430	78	8	0	576
1983		33	3	368	77	8	0	488
1984		71	3	367	81	5	0	528
1985		72	3	419	49	8	0	552
1986		79	3	428	36	4	0	551
1987		59	2	329	57	6	1	454
1988		52	2	281	37	5	0	376
1989		84	2	288	49	9	0	432
1990		96	2	266	55	9	0	428
1991		139	2	251	32	13	0	437
1992		34	2	236	40	4	0	315
1993		45	1	39	36	2	2	126
1994		1	1	11	26	9		49
1995		10	1	9	19	7		46
1996		16	1	11	14	4		46
1997		6	1	8	13	4		32
1998		4	1	11	10	1		27
1999		3	1	12	11	4		31
2000		0	1	4	7	3		14
2001		0	1	4	4	6		15
2002		0	1	2	4	4		11
2003		0	1	1	4	3		9
2004		0	1	1	2	3		8
2005		0	1	1	2	3		7
2006		0	1	1	4	4		10
2007		0	1	4	2	3		10
2008		0	1	3	1	2		7
2009		0	1	1	1	4		7

Notes: Prior to 1994, observers coded skate primarily as species unknown.

[1] Based on the percentage of smooth skate of the total skate catch from the 1970-76 summer RV survey in 4VsW.

[2] Based on observer reports that % of all skate reported in 4VsW from the silver hake fishery (1995-2005) were smooth skate.

[3] Based on observer reports that 48.6% of all skate reported in 4VsW from the halibut fishery (1995-2005) were thorny skate.

[4] Based on observer reports that 56.2% of all skate reported in 4VsW from the CHP fishery (1995-2005) were thorny skate.

[5] Based on observer reports that 75% of all skate reported in 4VsW from the flatfish fishery (1995-2005) were thorny skate.

[6] Based on observer reports that 38.5% of all skate reported in 4VsW from the refish fishery (1995-2005) were thorny skate.

[7] Based on the percentage of winter skate of the total skate catch from the 1970-93 summer RV survey in 4VsW.

[8] Percentage based on approximate estimates from DFO commercial samples.

[9] Other fisheries did not have sufficient information to make even broad estimates of discarding.

Table 6. Estimates of total removals (tonnes) of thorny skate from selected fisheries in Div. 4X based on observer reports and the Summer RV Survey.

Year	Cdn Scallop[1] (used 1%)	Cdn silver hake [2] 0.17%	Cdn white hake [3] 2.1%	Cdn CHP [4] 1.8%	Cdn Flatfish [5] 9.0%	Cdn Redfish [6] 0.5%	Cdn Reported skate [7] 62.3%	Total Removals
1970	25	0	41	768	271	18	4	1128
1971	20	0	60	839	254	36	95	1304
1972	24	0	80	889	240	12	14	1259
1973	14	0	78	1003	199	5	512	1812
1974	6	0	81	922	212	7	345	1573
1975	11	0	59	980	195	5	1310	2560
1976	87	0	44	947	174	5	236	1493
1977	60	0	40	1023	271	5	95	1493
1978	50	0	51	1174	265	3	27	1571
1979	95	0	44	1312	310	4	17	1782
1980	221	0	52	1463	380	7	22	2147
1981	173	0	45	1471	364	8	1	2061
1982	188	0	69	1396	355	13	11	2034
1983	152	0	48	1268	379	15	20	1882
1984	99	0	64	1119	331	15	36	1664
1985	76	0	62	1141	342	22	1	1644
1986	52	0	96	1058	493	27	11	1737
1987	79	0	104	1063	372	24	17	1659
1988	284	0	80	1006	414	16	9	1808
1989	404	0	65	904	297	10	10	1689
1990	277	0	73	972	544	10	9	1884
1991	209	15	58	1151	519	8	23	1982
1992	242	9	68	1049	529	10	8	1915
1993	267	18	73	669	364	24	17	1432
1994	356	0	64	496	293	25	59	1293
1995	347	1	86	391	229	23	85	1162
1996	151	5	56	421	220	18	46	917
1997	108	6	52	502	175	27	44	914
1998	141	1	28	484	141	27	27	849
1999	156	8	28	322	128	20	18	679
2000	199	8	37	302	150	22	8	725
2001	263	15	37	336	119	20	18	808
2002	358	5	41	345	109	23	13	893
2003	362	1	30	370	127	15	12	918
2004	415	2	30	317	125	10	21	921
2005	247	1	32	276	105	15	24	701
2006	237	0	22	206	107	13	14	600
2007	246	3	17	277	135	14	15	707
2008	160	2	24	250	113	17	5	570
2009	118	4	21	240	112	22	7	524

Notes: Prior to 1994, observers coded skate primarily as species unknown.

[1] Limited observer coverage estimated that skate,ns are 10% bycatch in scallop fishery,

[1] Thorny skate estimated to be 10% of skate,ns

[2] Based on observer reports that 77% of all skate reported in 4X from the silver hake fishery (1995-2005) were thorny skate.

[3] Based on observer reports that 28% of all skate reported in 4X from the white hake fishery (1991-2006) were thorny skate.

[4] Based on observer reports that 51% of all skate reported in 4X from the CHP fishery (1995-2009) were thorny skate.

[5] Based on observer reports that 73% of all skate reported in 4X from the flatfish fishery (1995-2008) were thorny skate.

[6] Based on observer reports that 41% of all skate reported in 4X from the redfish fishery (1995-2008) were thorny skate.

[7] Based on the percentage of thorny skate of the total skate catch from the 1970-2010 summer RV survey in 4X.

[8] Other fisheries did not have sufficient information to make even broad estimates of discarding.

Table 7. Estimates of total removals (tonnes) of thorny skate from selected fisheries in Divs. 4VsW based on observer reports and the Summer RV Survey.

Year	Foreign l fisheries [1] 77%	Foreign silver hake [2] 0.4%	Cdn halibut [3] 4.6%	Cdn CHP [4] 5.1%	Cdn Flatfish [5] 14.7%	Cdn Redfish [6] 2.3%	Cdn Reported skate [7] 69.9%	Cdn Skate Fishery [8] 5%	Total Removals
1970	2963		20	993	920	174	18		5088
1971	13399		24	1396	1342	361	9		16531
1972	4009		16	1225	1312	344	1		6906
1973	5125		17	1145	1055	196	3		7540
1974	6457		11	744	1178	175	43		8607
1975	12386		12	793	1036	192	1		14420
1976	6030		13	680	773	152	533		8181
1977		114	11	1019	1050	196	303		2695
1978		171	23	1905	1030	207	94		3430
1979		187	26	2606	988	154	62		4023
1980		140	32	3757	1263	178	50		5419
1981		152	28	4622	1179	215	6		6202
1982		222	37	4230	982	116	0		5586
1983		127	43	3620	960	118	6		4875
1984		274	47	3607	1014	81	11		5034
1985		278	54	4124	610	120	5		5192
1986		304	49	4209	456	62	8		5089
1987		228	29	3232	718	94	31		4331
1988		199	28	2762	463	76	5		3533
1989		324	31	2834	611	131	7		3938
1990		367	27	2619	690	141	1		3845
1991		536	27	2465	405	197	9		3640
1992		130	27	2316	496	61	1		3031
1993		174	22	385	449	34	50		1114
1994		3	22	112	331	138		108	713
1995		38	15	89	242	105		77	565
1996		60	15	106	177	62		83	503
1997		23	17	76	158	67		52	392
1998		15	16	107	130	19		26	313
1999		10	16	116	142	64		31	379
2000		0	14	37	84	39		19	193
2001		0	21	35	51	98		12	217
2002		0	20	17	49	59		15	159
2003		0	22	7	56	41		2	129
2004		0	23	13	29	40		12	117
2005		0	19	12	24	46		1	101
2006		0	18	14	48	56		1	137
2007		0	20	42	21	44		0	128
2008		0	21	30	14	26		0	91
2009		0	24	15	10	55		0	103

Notes: Prior to 1994, observers coded skate primarily as species unknown.

[1] Based on the percentage of thorny skate of the total skate catch from the 1970-76 summer RV survey in 4VsW.

[2] Based on observer reports that 22.3% of all skate reported in 4VsW from the silver hake fishery (1995-2005) were thorny skate.

[3] Based on observer reports that 48.6% of all skate reported in 4VsW from the halibut fishery (1995-2005) were thorny skate.

[4] Based on observer reports that 56.2% of all skate reported in 4VsW from the CHP fishery (1995-2005) were thorny skate.

[5] Based on observer reports that 75% of all skate reported in 4VsW from the flatfish fishery (1995-2005) were thorny skate.

[6] Based on observer reports that 38.5% of all skate reported in 4VsW from the refish fishery (1995-2005) were thorny skate.

[7] Based on the percentage of winter skate of the total skate catch from the 1970-93 summer RV survey in 4VsW.

[8] Percentage based on approximate estimates from DFO commercial samples.

[9] Other fisheries did not have sufficient information to make even broad estimates of discarding.

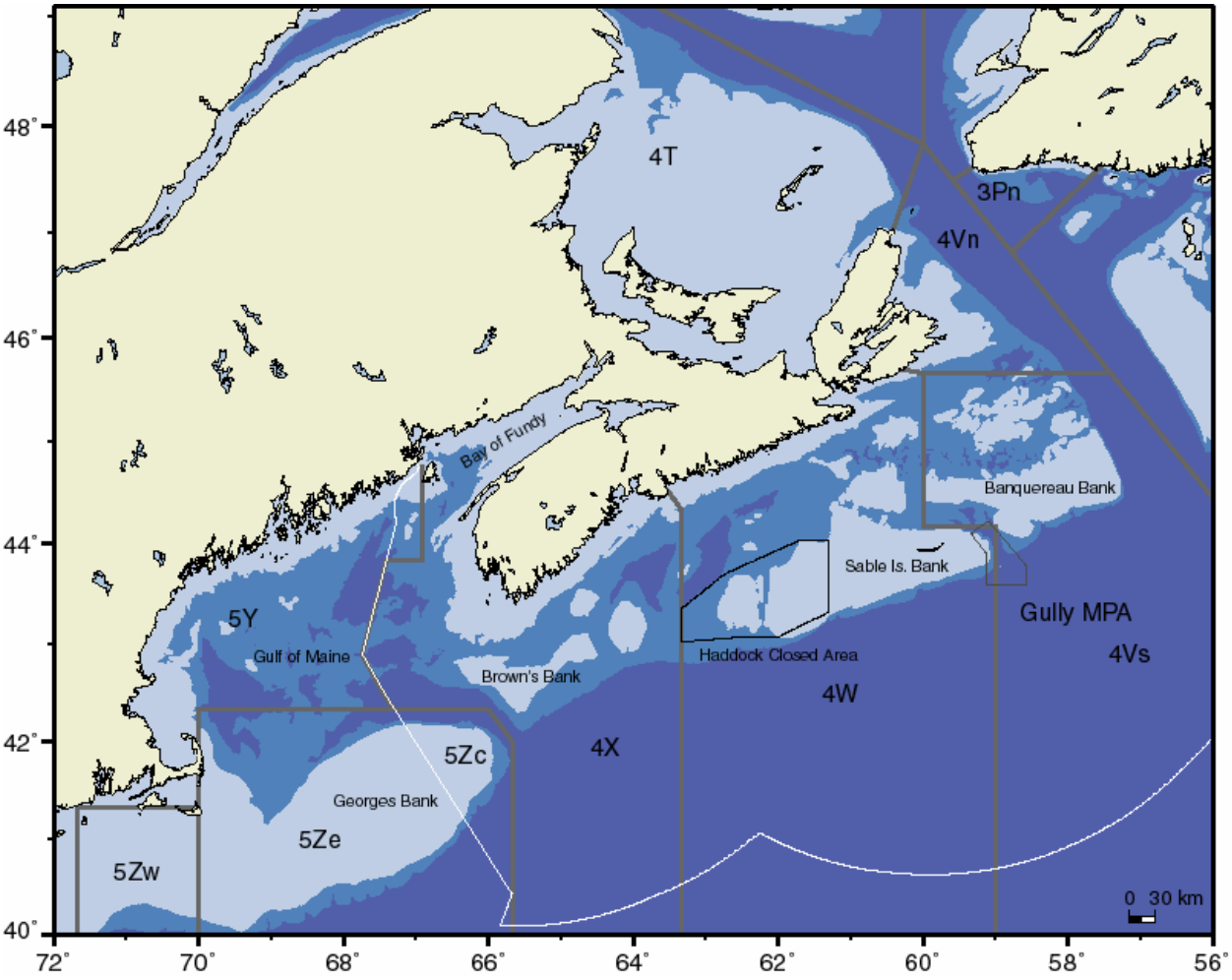

Figure 1. Geographic display of NAFO Divisions and principle areas described in this document.

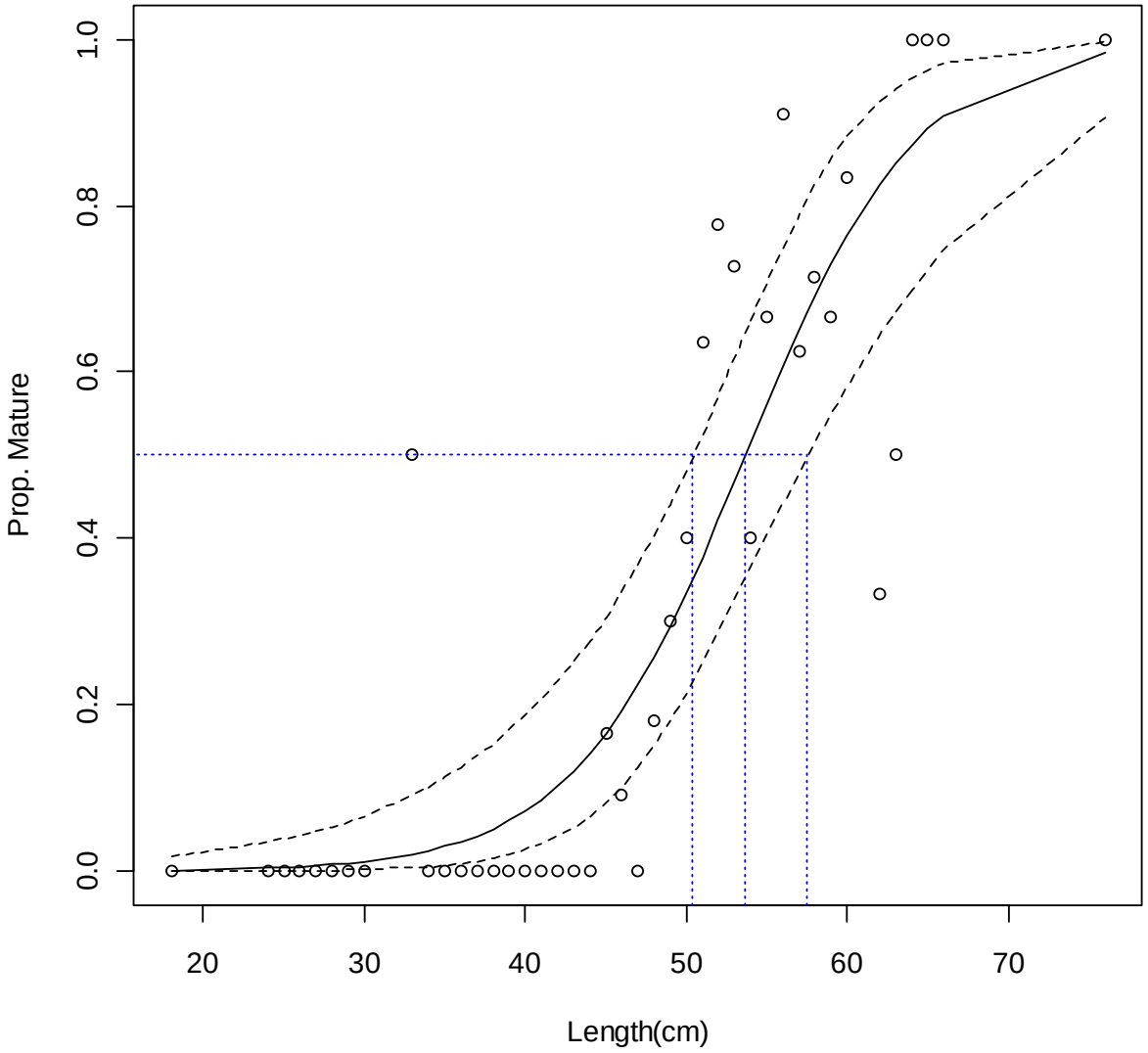

Figure 2. Logistics plot of percent mature female thorny skate on the eastern Scotian Shelf from 1996-1998 with 95% confidence intervals. Length at 50% maturity is 53.6 cm with 95% CI ranging from 50.5 to 57.5cm.

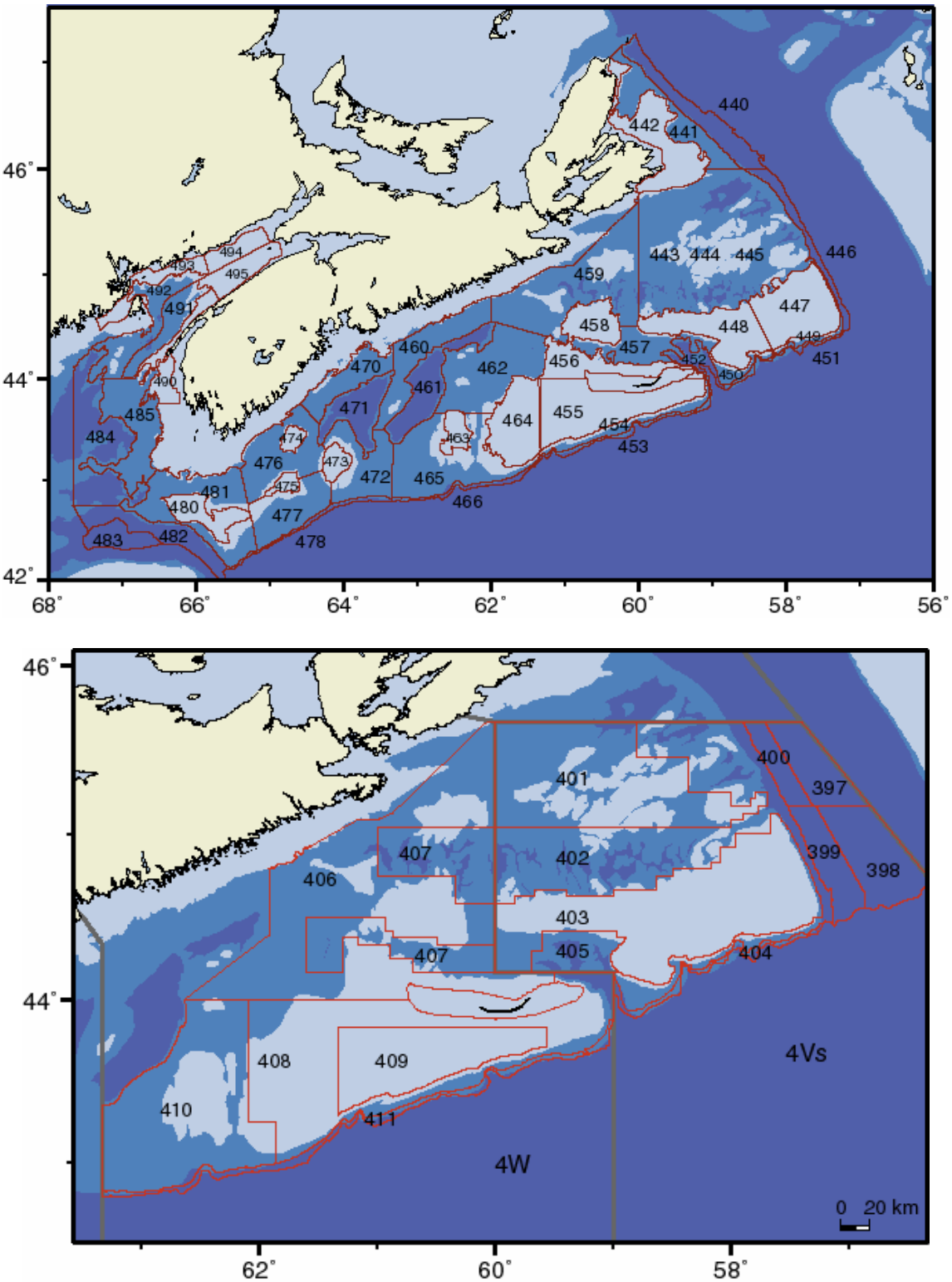

Figure 3. Canadian research survey strata used in the analysis of the Scotian Shelf during the Summer RV Survey (top panel) and the 4VWCOD (Spring) RV Survey (bottom panel). The deepwater strata added in 1995 to the Summer RV Survey are not displayed.

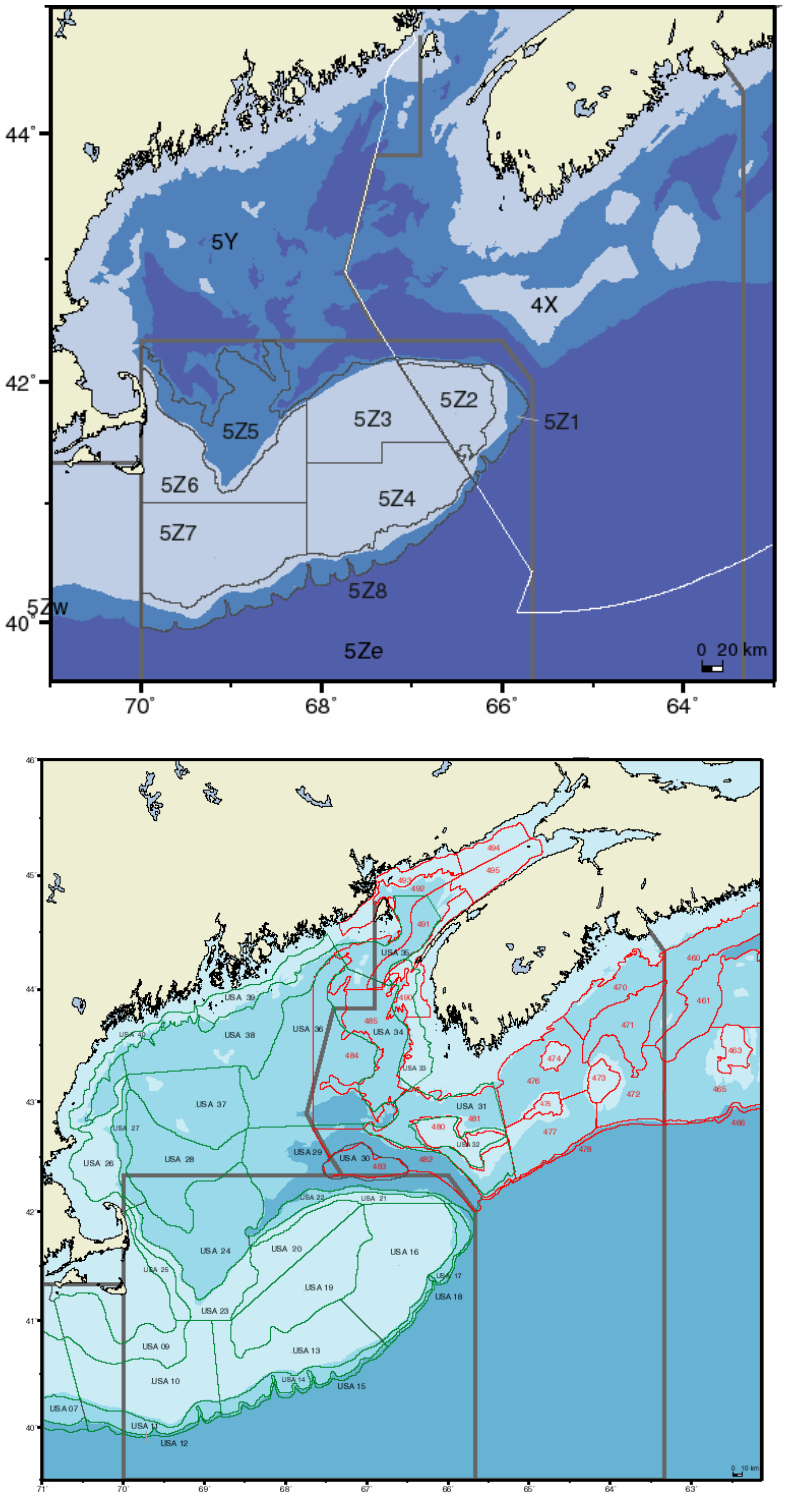

Figure 4. Research survey strata used in the analysis of the Canadian RV survey on Georges Bank (top panel) as well as the stratification of Georges Bank and the Gulf of Maine used during the USA Spring and Fall RV surveys (bottom panel). The Canada/USA boundary is indicated in white in the top panel, except on the bank where it is grey.

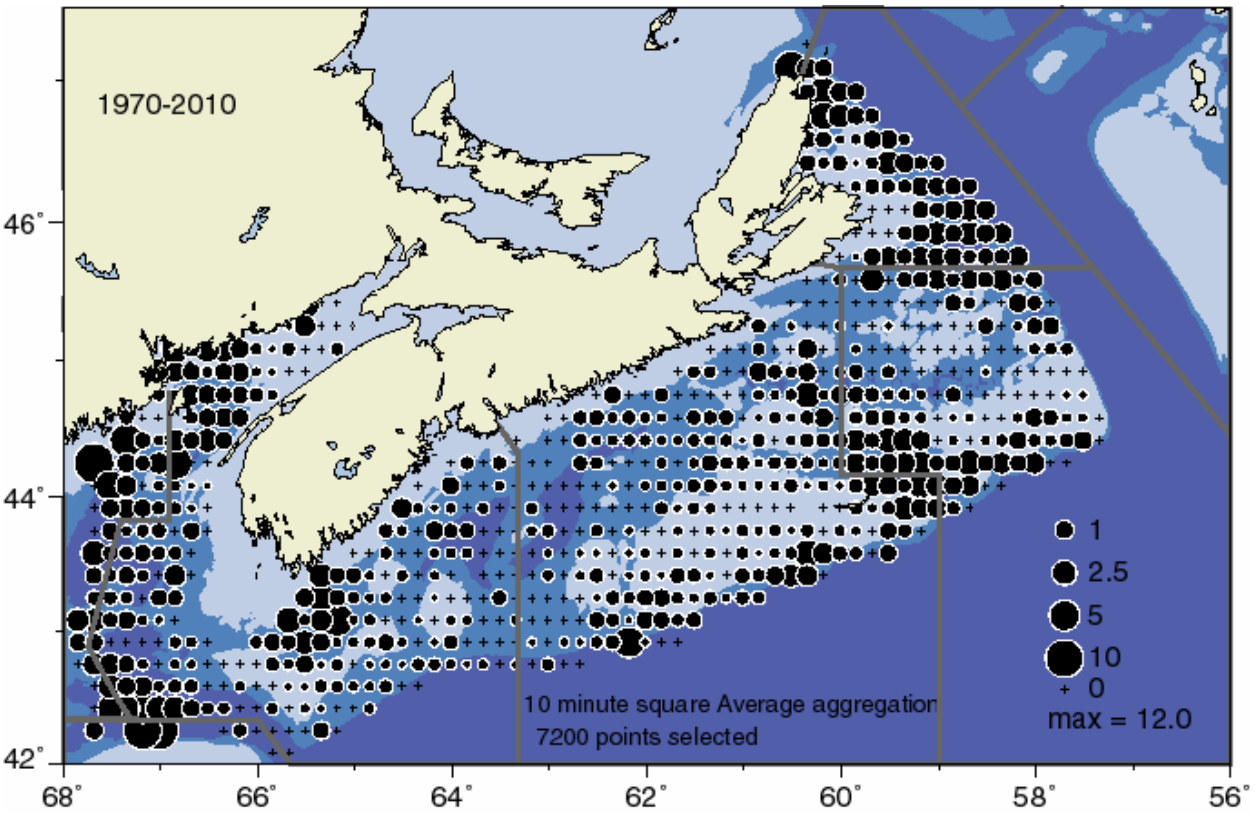

Figure 5. Distribution of smooth skate as indicated by the Summer RV Survey on the Scotian Shelf, 1970-2010.

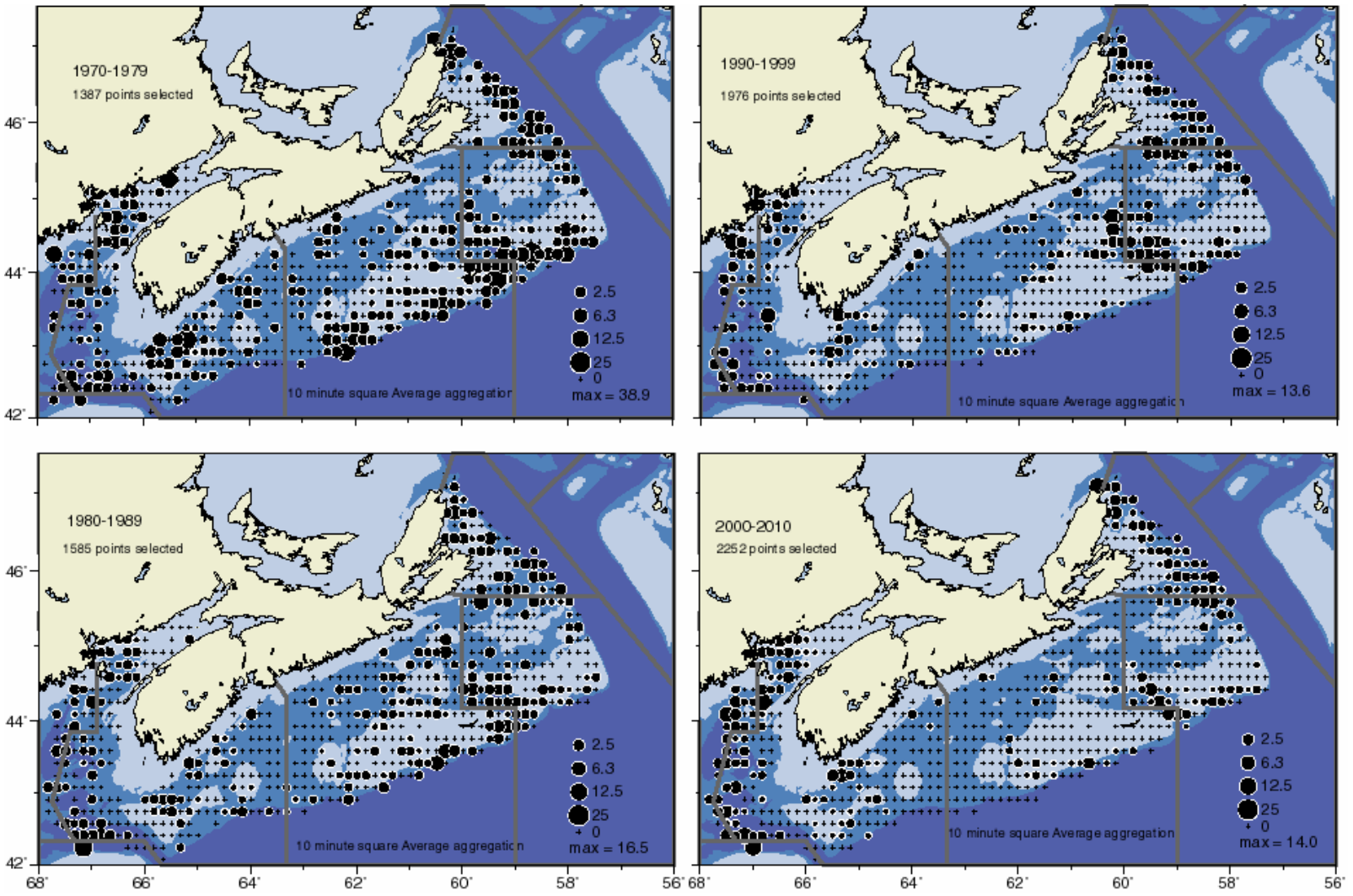

Figure 6. Distribution of smooth skate, summarized by decadal period, as indicated by the Summer RV Survey, 1970-2010.

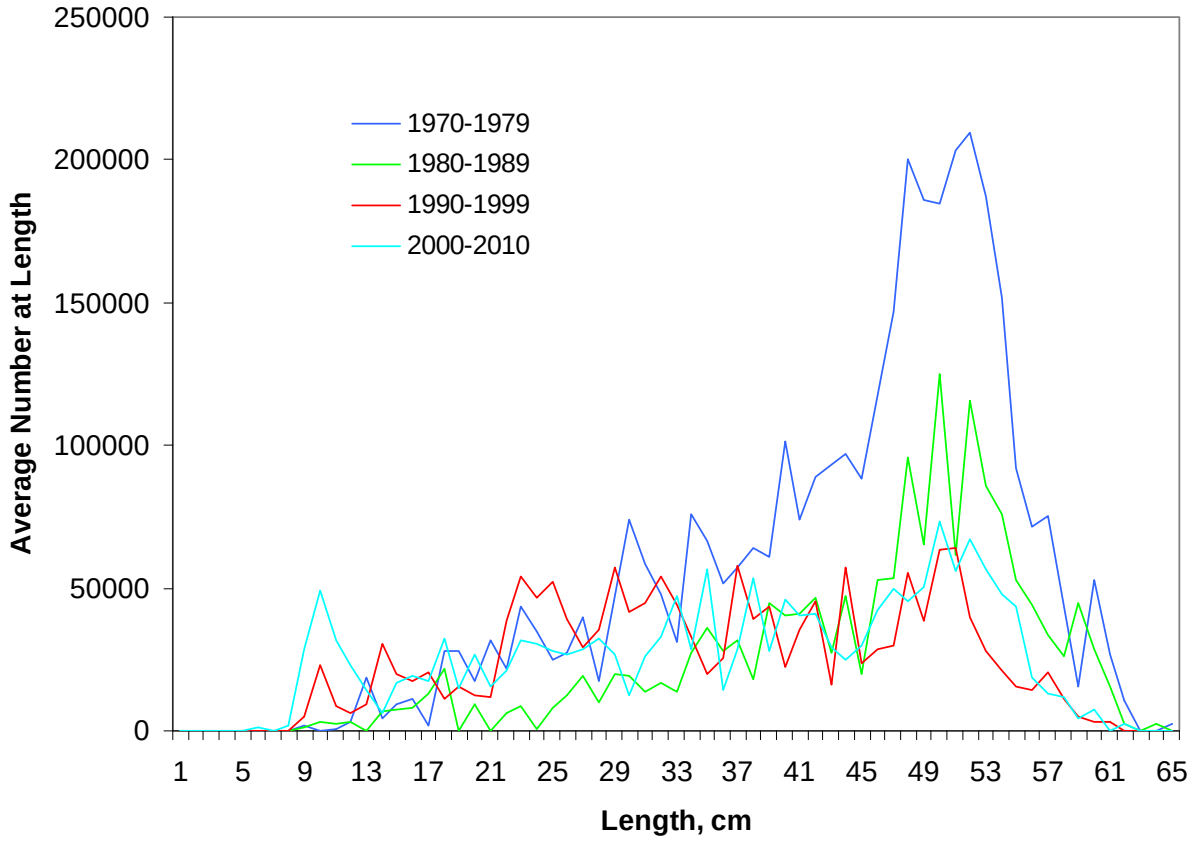

Figure 7. Length frequencies of smooth skate averaged by decadal period derived from the Summer RV Survey for Divs. 4VWX.

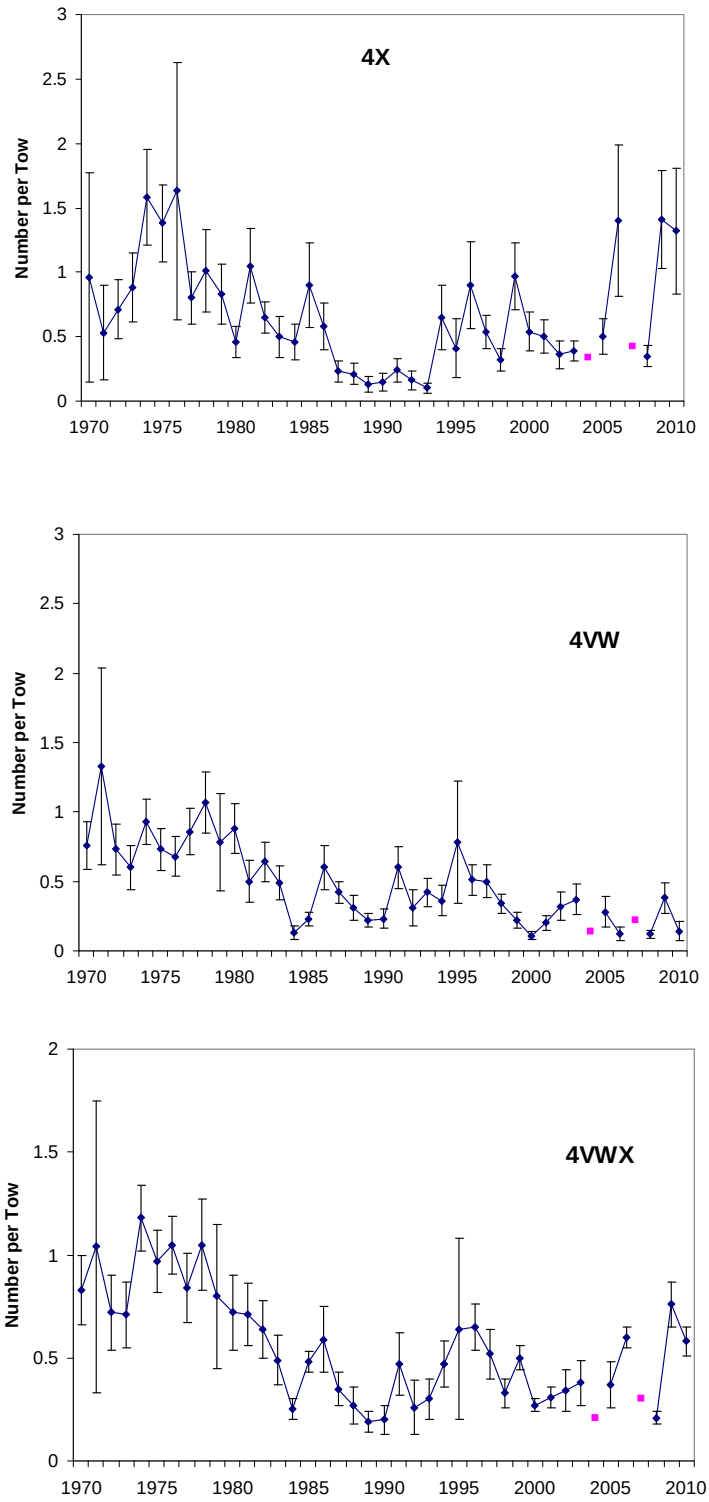

Figure 8. Trends in abundance (number per tow with error bars) of smooth skate caught during the Summer RV Survey, 1970-2010 from NAFO Div. 4X, Divs. 4VW, and Divs. 4VWX. The 2004 and 2007 data points were conducted by the MV Teleost.

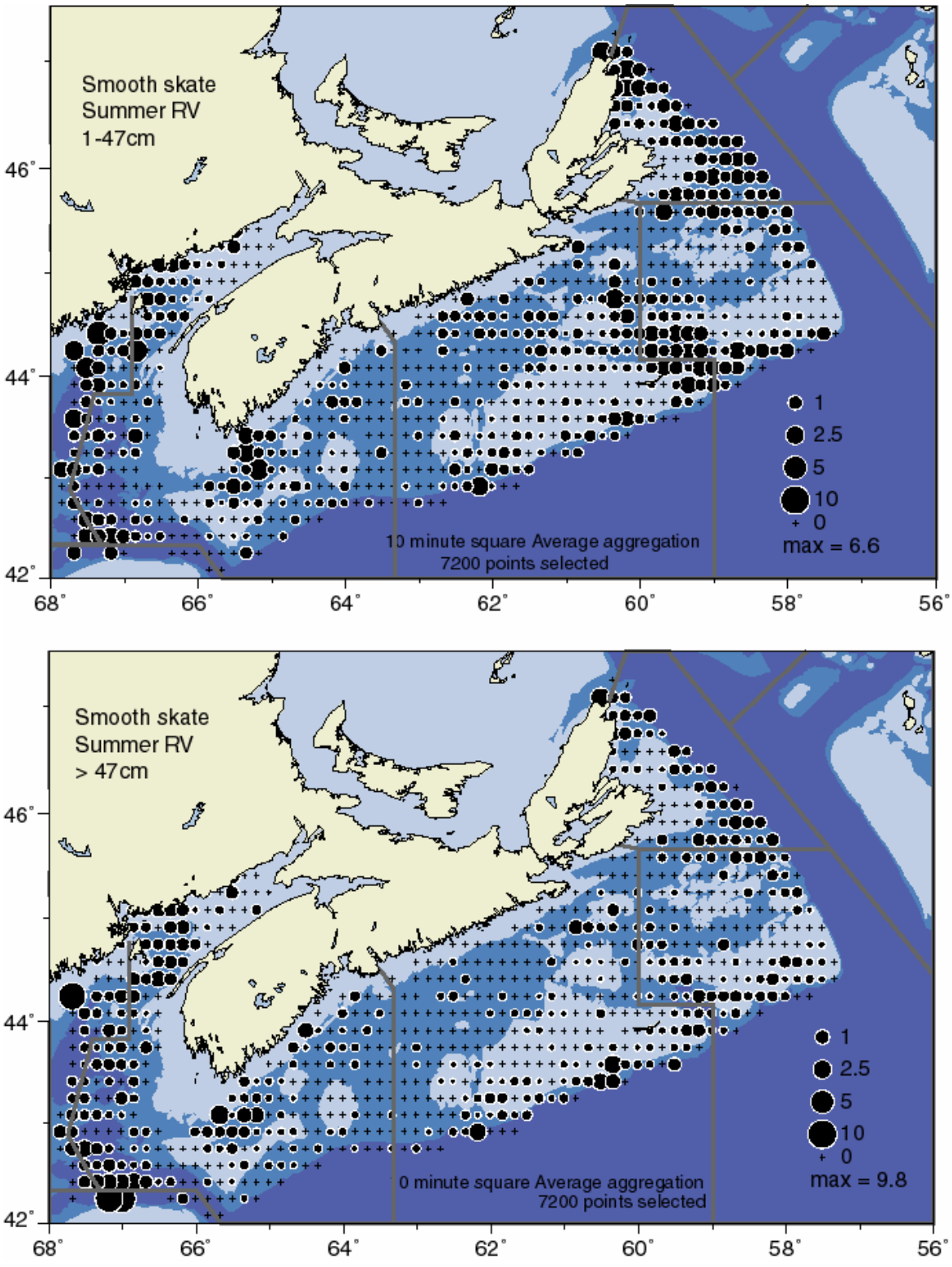

Figure 9. Distribution of smooth skate by length group, as indicated by the Summer RV Survey, 1970-2010. This figure does not include the deep-water sets on the edge of the Scotian Shelf.

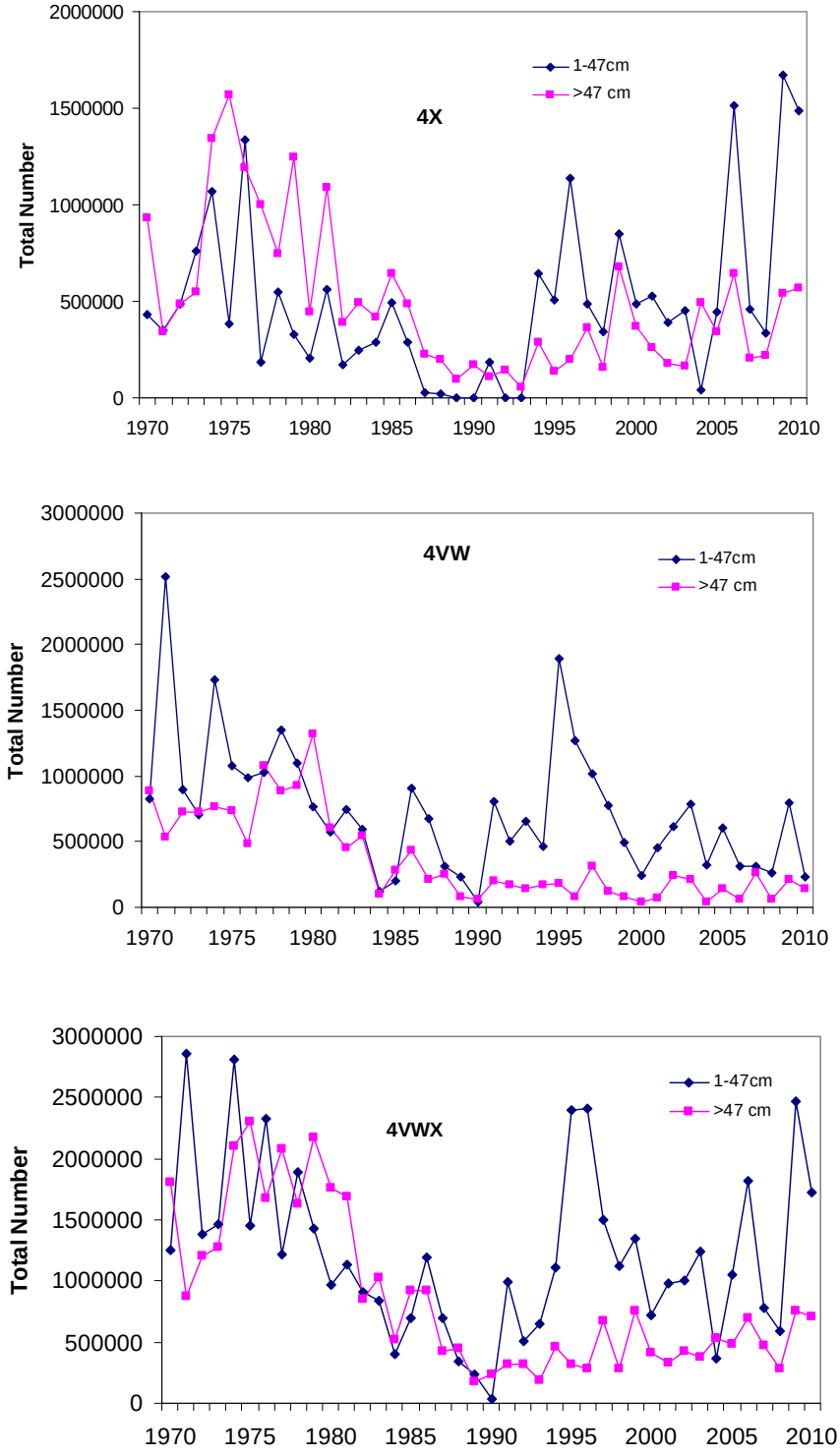

Figure 10. Abundance of smooth skate, summarized by length groups 1-47 cm and greater than 47 cm, as indicated by the Summer RV Survey from Div. 4X, Divs. 4VW, and Divs. 4VWX.

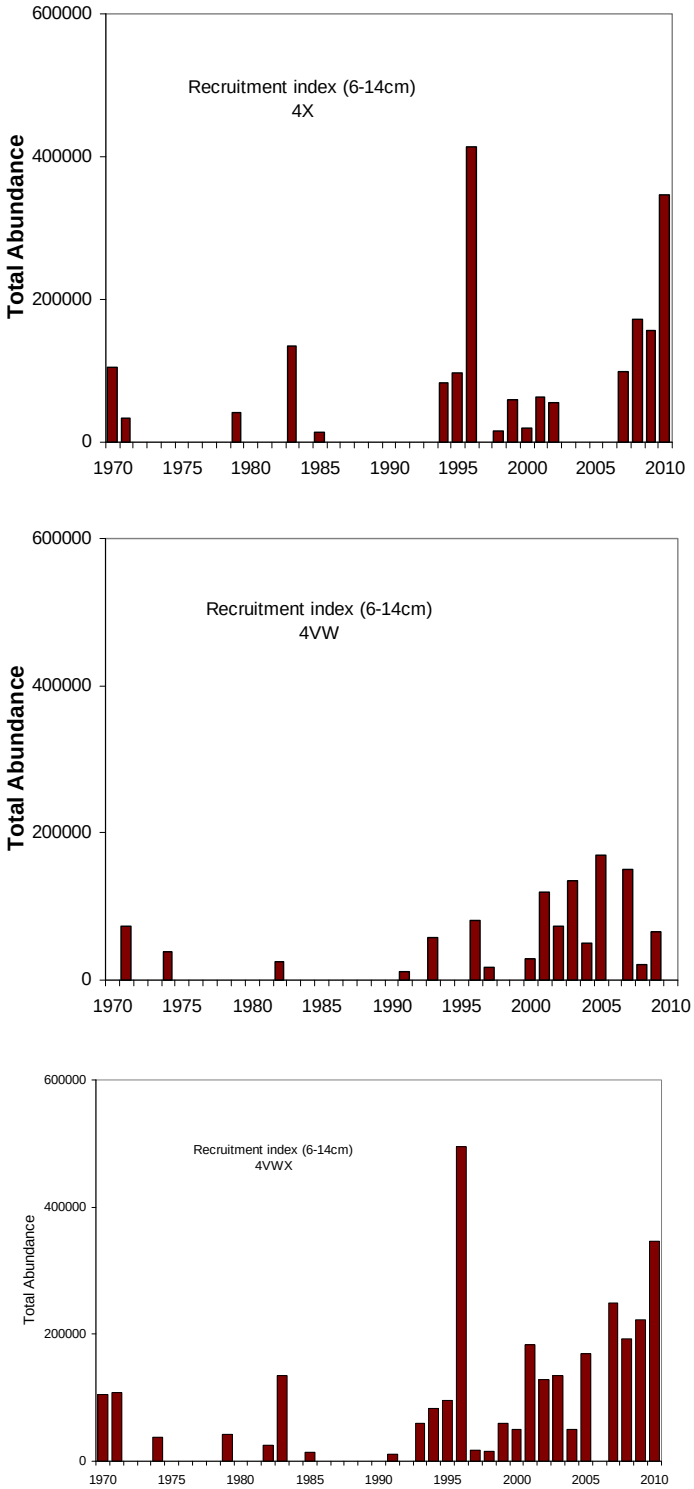

Figure 11. Recruitment index (abundance of individuals measuring 6-14 cm in length) of smooth skate in Div. 4X, Divs. 4VW, and Divs. 4VWX, as indicated by the Summer RV Survey.

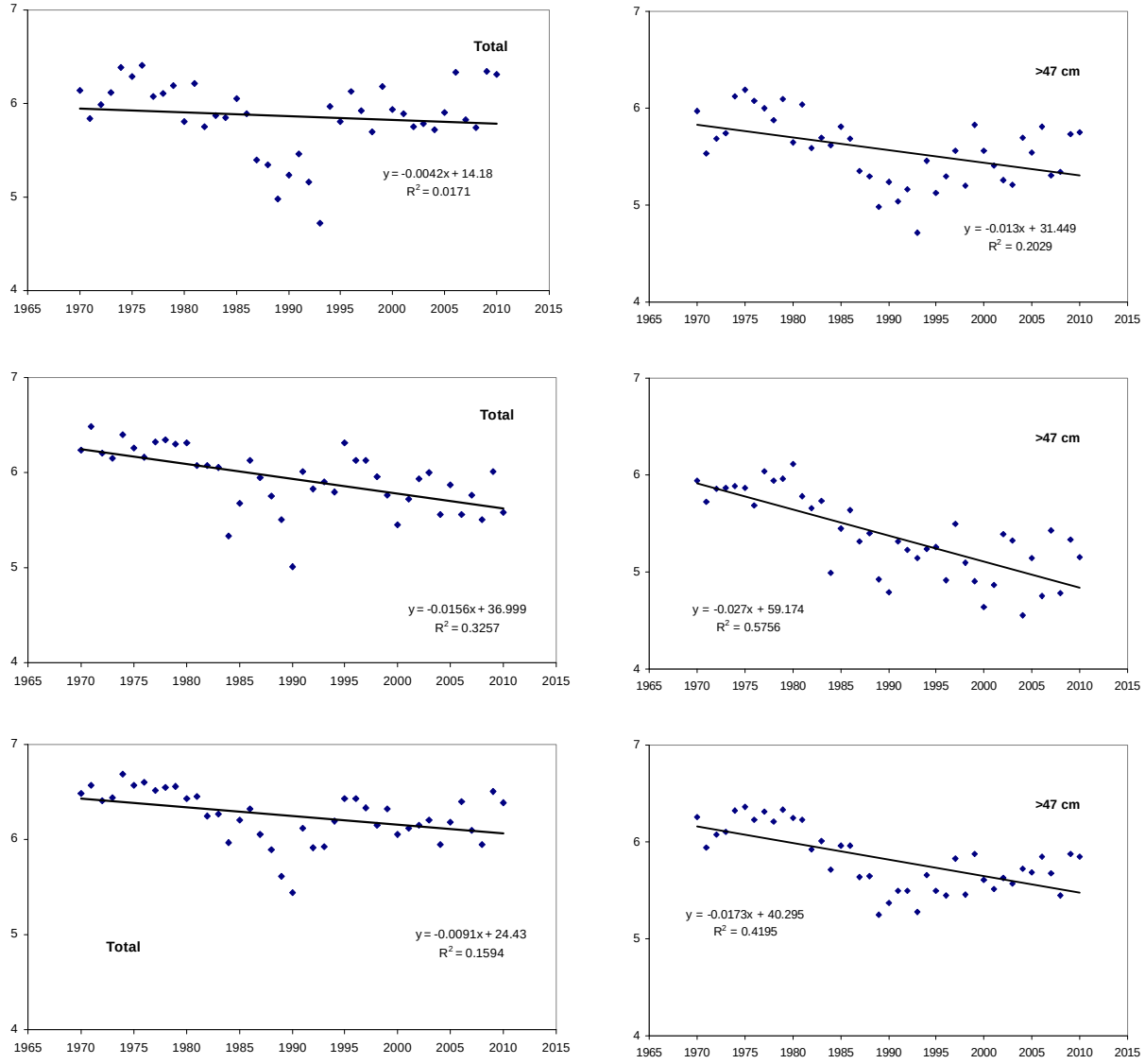

Figure 12. Log transformed total abundance of smooth skate (all length groups and mature length groups only) caught during the Summer RV Survey, 1970-2010 from NAFO Div. 4X (top panels), 4VW (middle panels), and 4VWX (bottom panels).

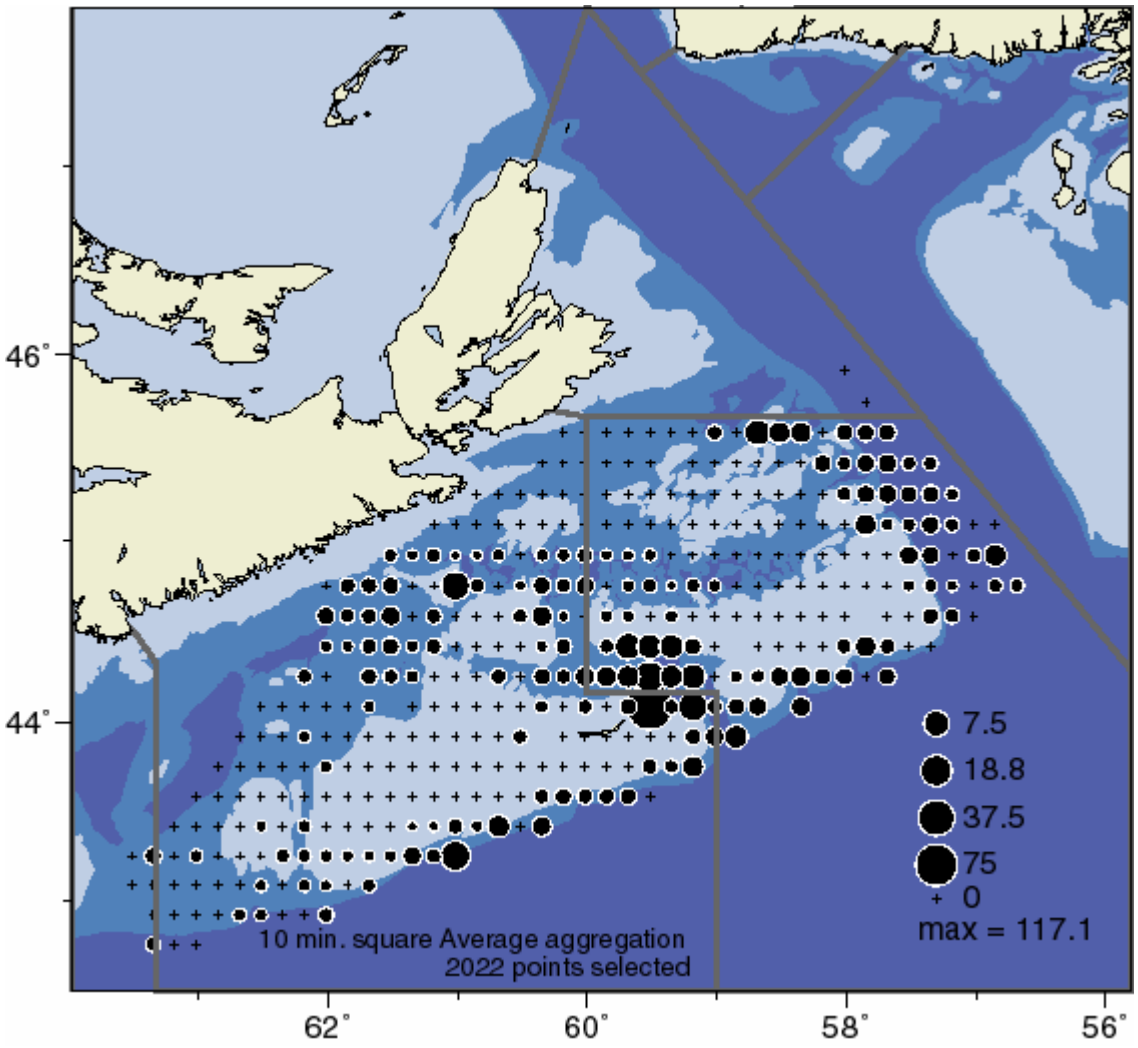

Figure 13. Distribution of smooth skate as indicated by the March RV survey on the eastern Scotian Shelf, 1986-2010. Note that during some of the survey years coverage was incomplete and the years 1998 and 2004 are missing.

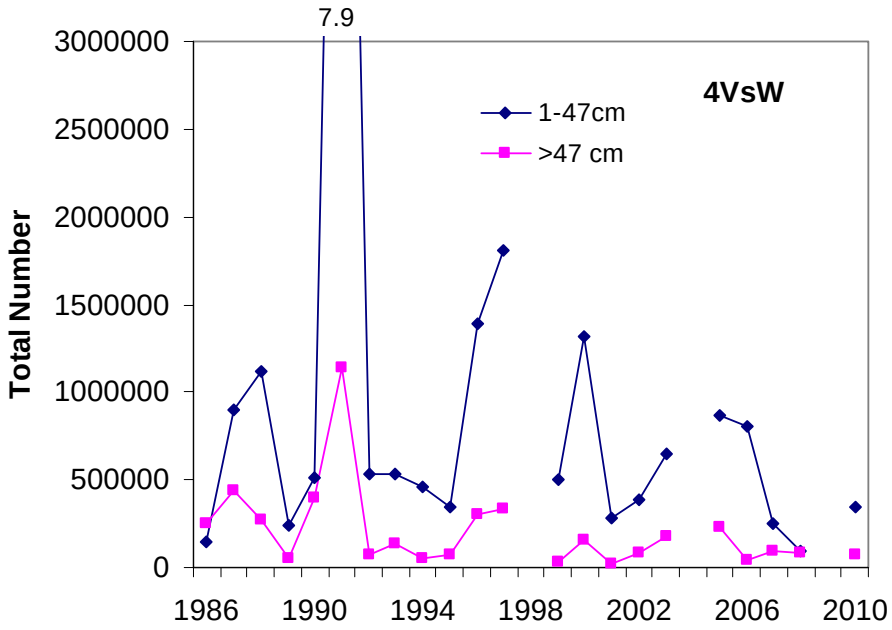

Figure 14. Abundance of smooth skate caught during the 4VWCOD RV survey, 1986-2010. Note that the 1998, 2004, and 2009 surveys are missing or incomplete.

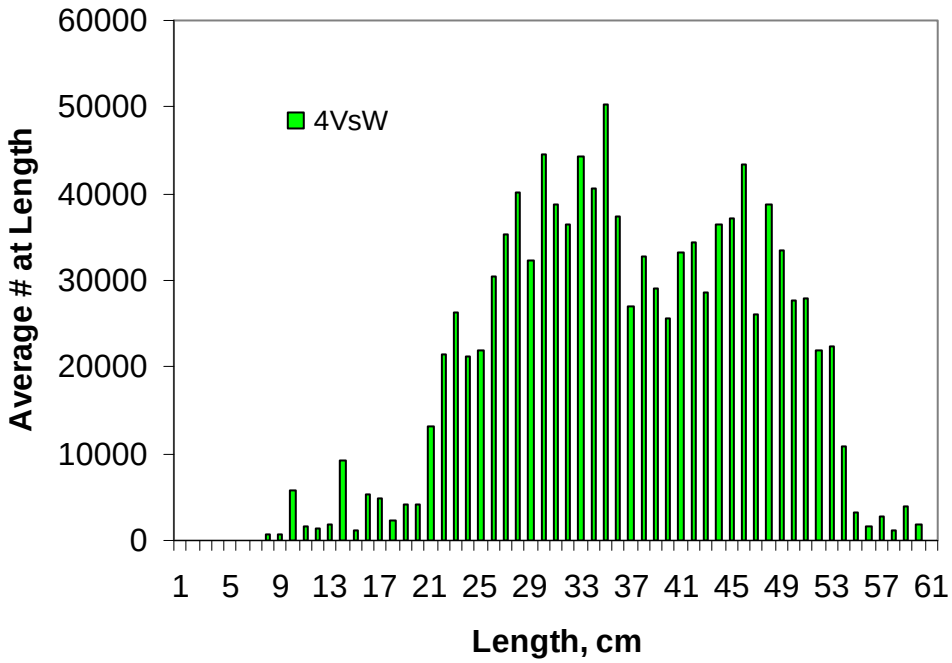

Figure 15. Average number at length (cm) of smooth skate from the 4VWCOD RV survey in Divs. 4VsW, 1986-2010.

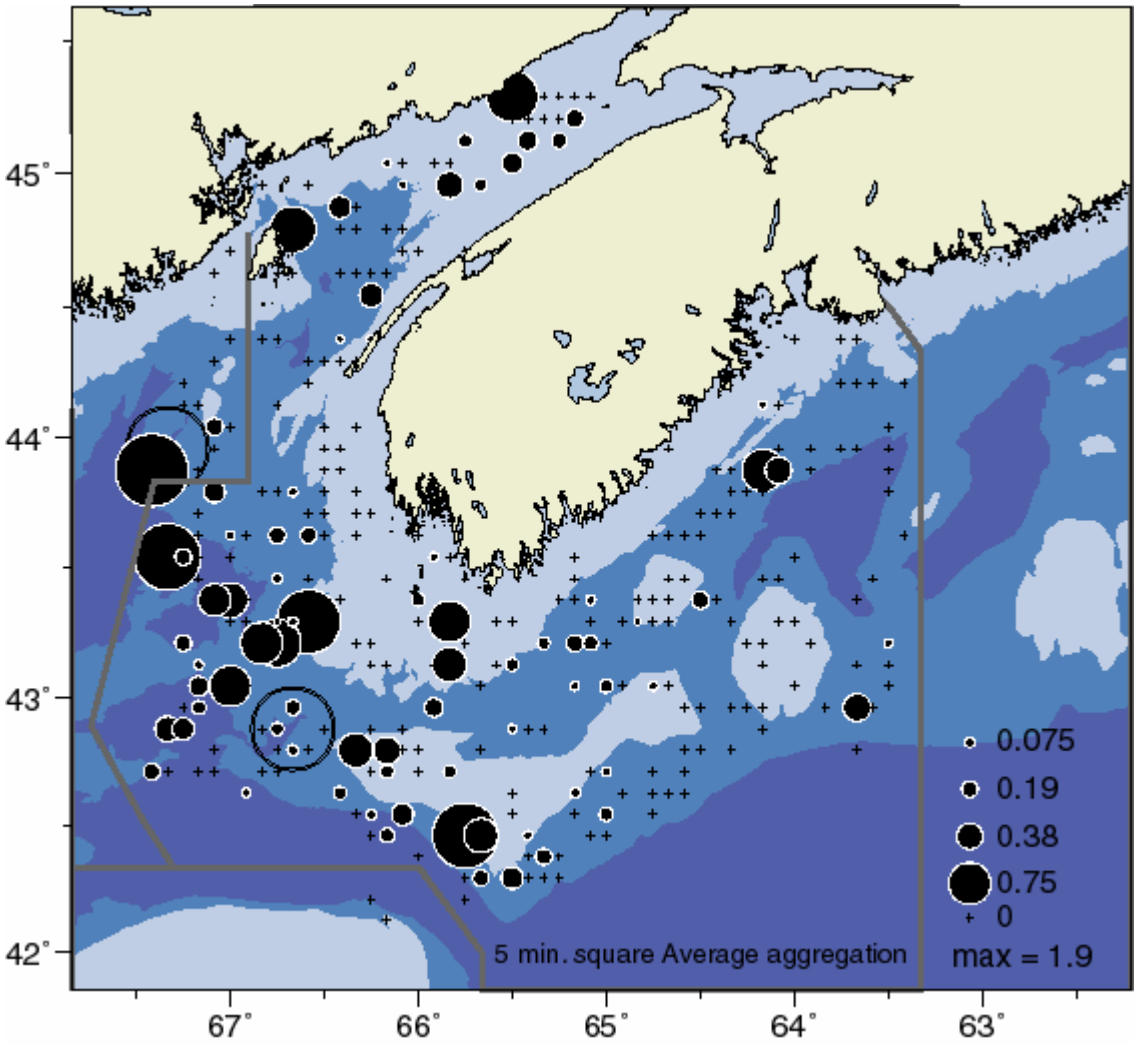

Figure 16. Distribution of smooth skate as indicated by the ITQ industry OT survey, 1996-2009.

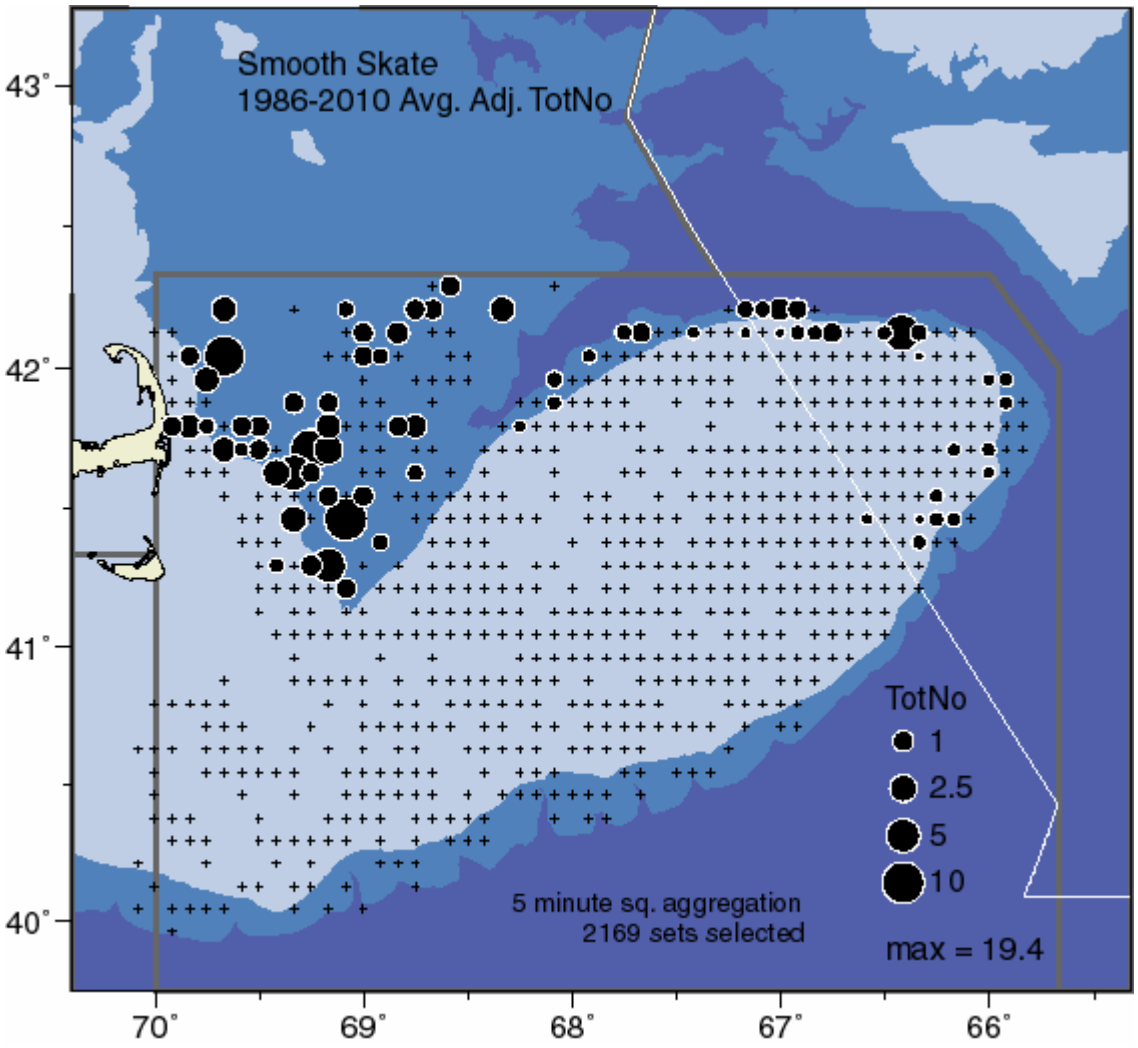

Figure 17. Distribution of smooth skate as indicated by the Georges Bank RV Survey, 1986-2010.

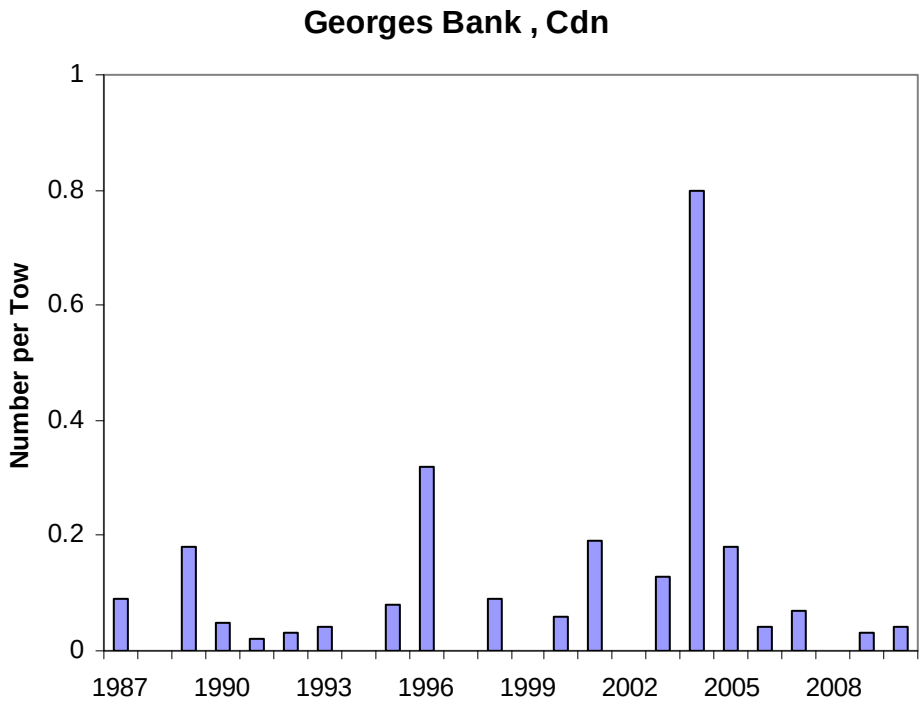

Figure 18. Number per tow of smooth skate from the Canadian strata of the Georges Bank RV survey in Div. 5Z.

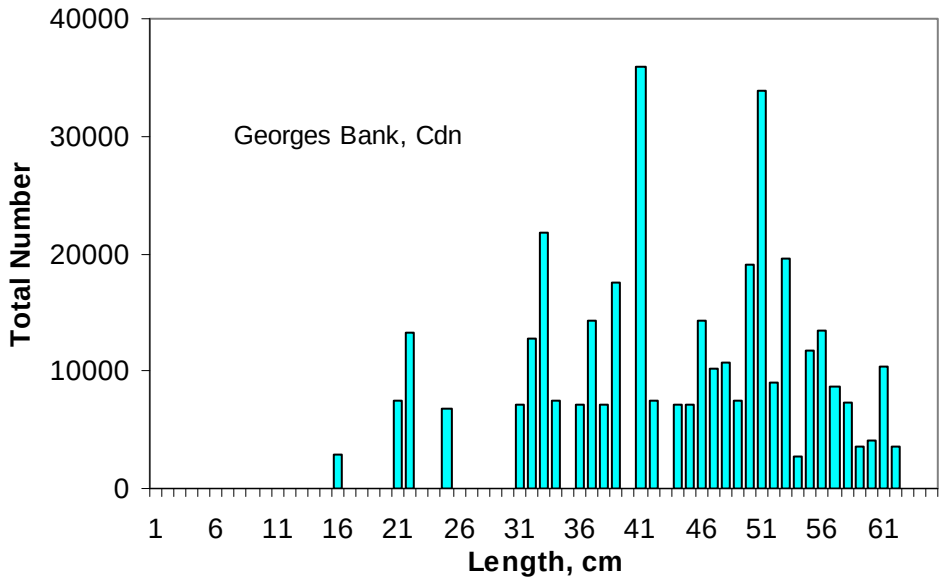

Figure 19. Total number at length (cm) of smooth skate from the Georges Bank RV survey in Subdiv. 5Zc, 1986-2010.

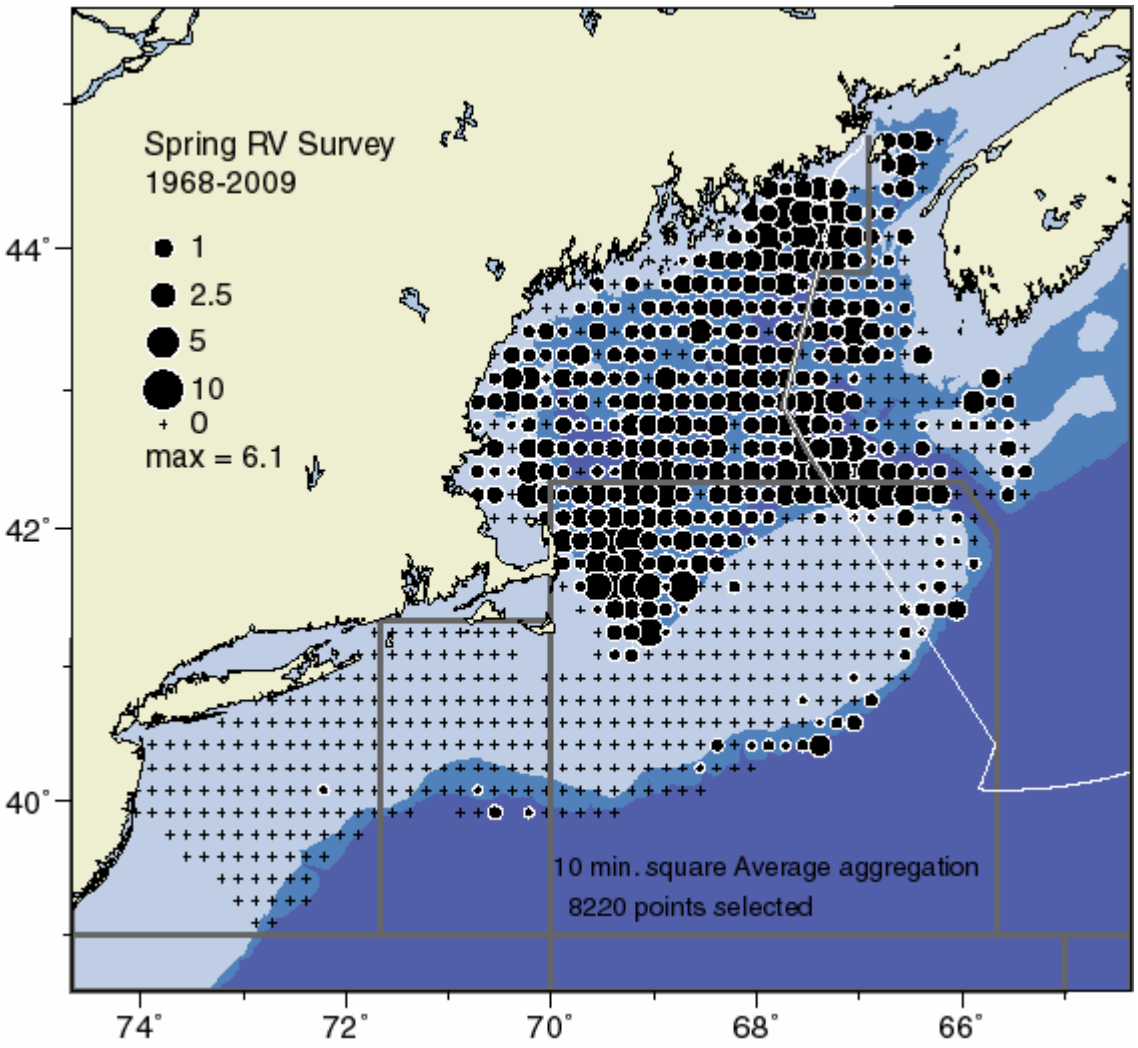

Figure 20. Distribution of smooth skate as indicated by the US Spring RV Survey, 1968-2009.

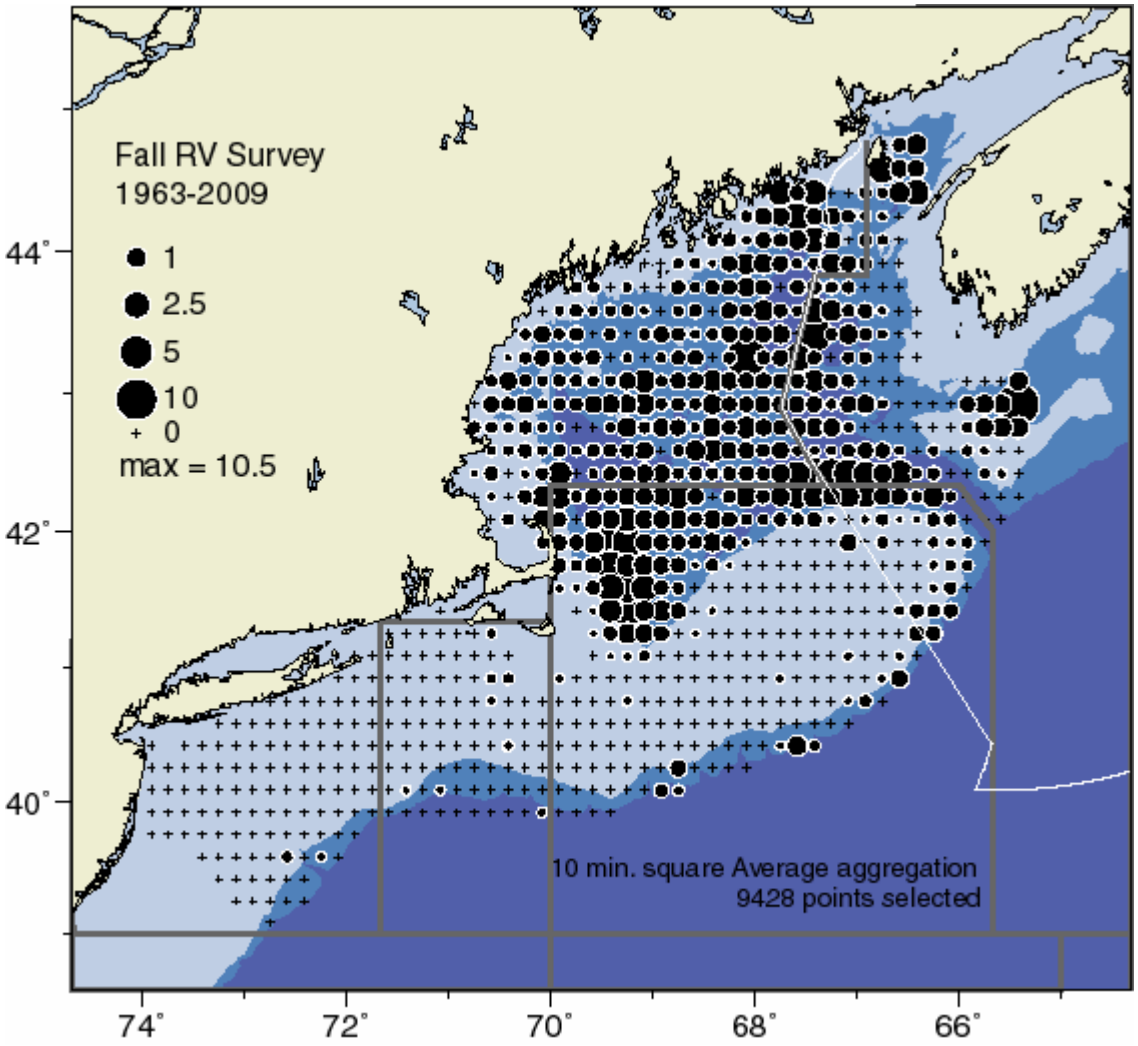

Figure 21. Distribution of smooth skate as indicated by the US Fall RV Survey, 1963-2009.

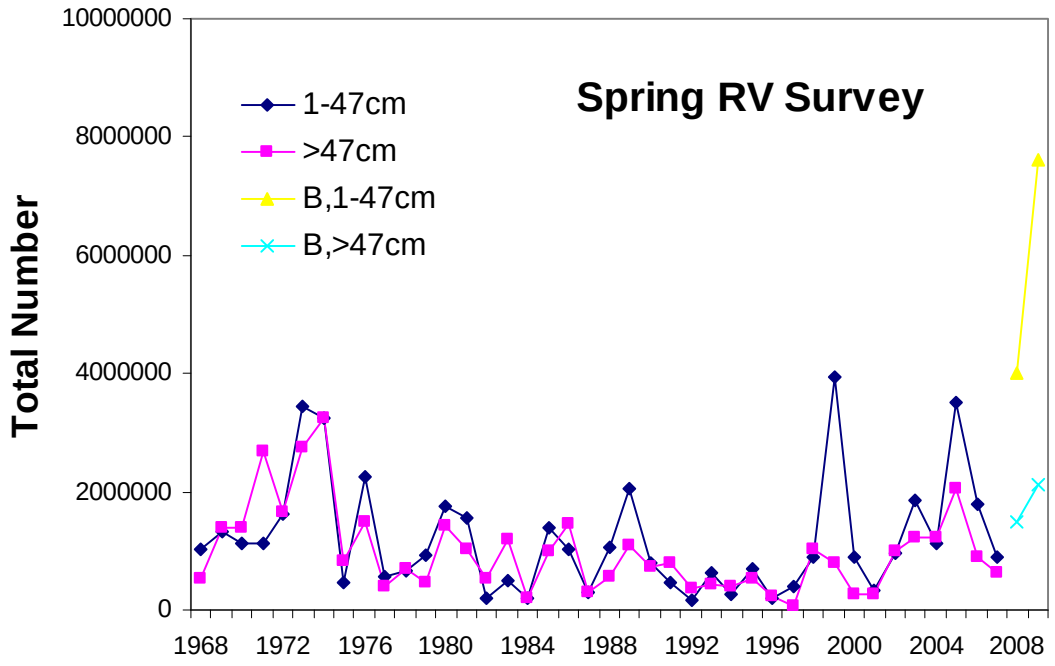

Figure 22. Abundance of smooth skate summarized by length groups representing immature (1-47 cm) and mature (>47 cm) categories as indicated by the US Spring RV Survey. In the figure legend the B, 1-47 cm refers to the vessel Bigelow, 1-47 cm length category.

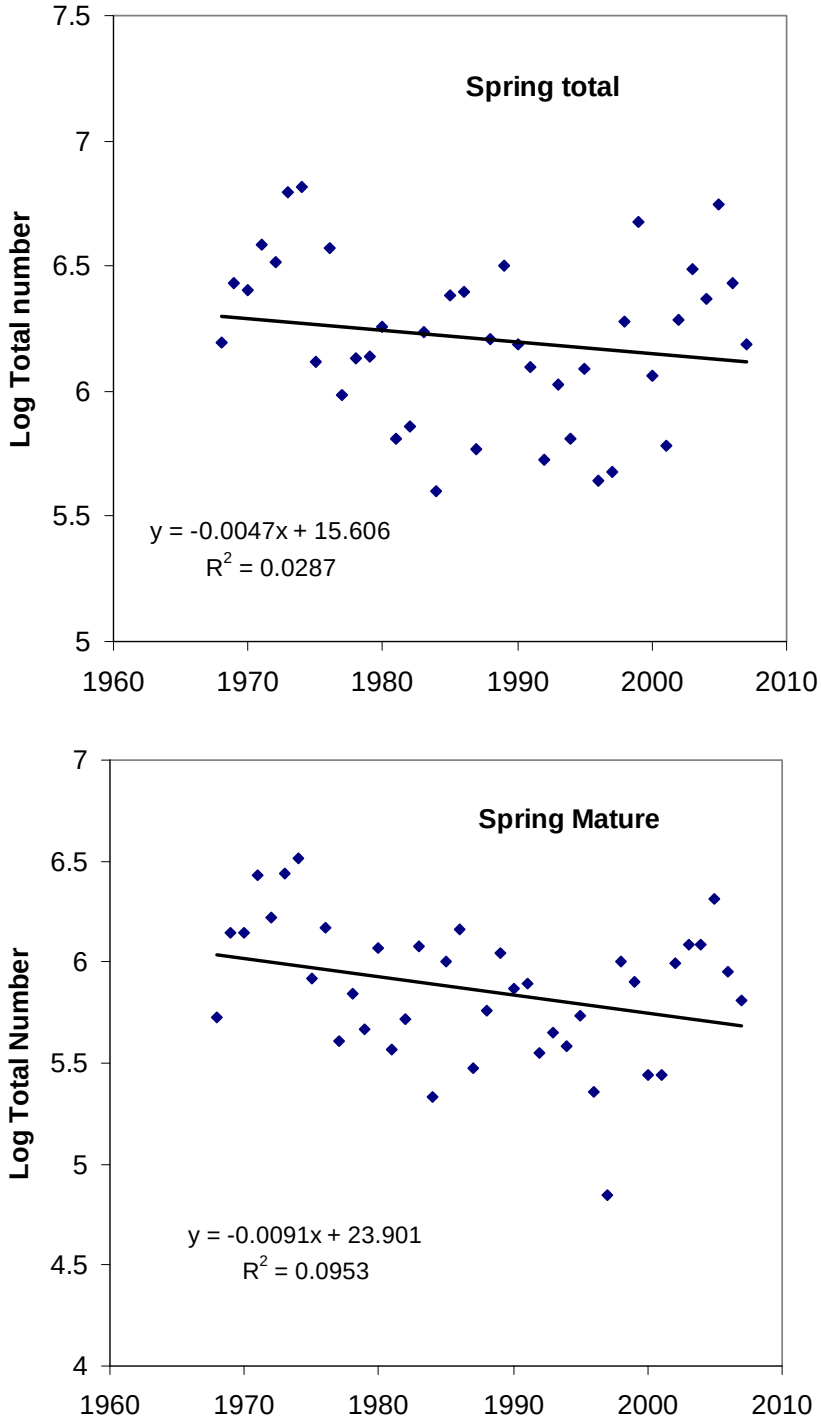

Figure 23. Log transformed total abundance of smooth skate (top panel: all length groups; bottom panel: mature length groups only (>47 cm)) from all strata of the US Spring RV Survey, 1968-2007. Note that the 2008 and 2009 surveys were conducted using different tow protocols, gears, and vessels and were not included in the analysis.

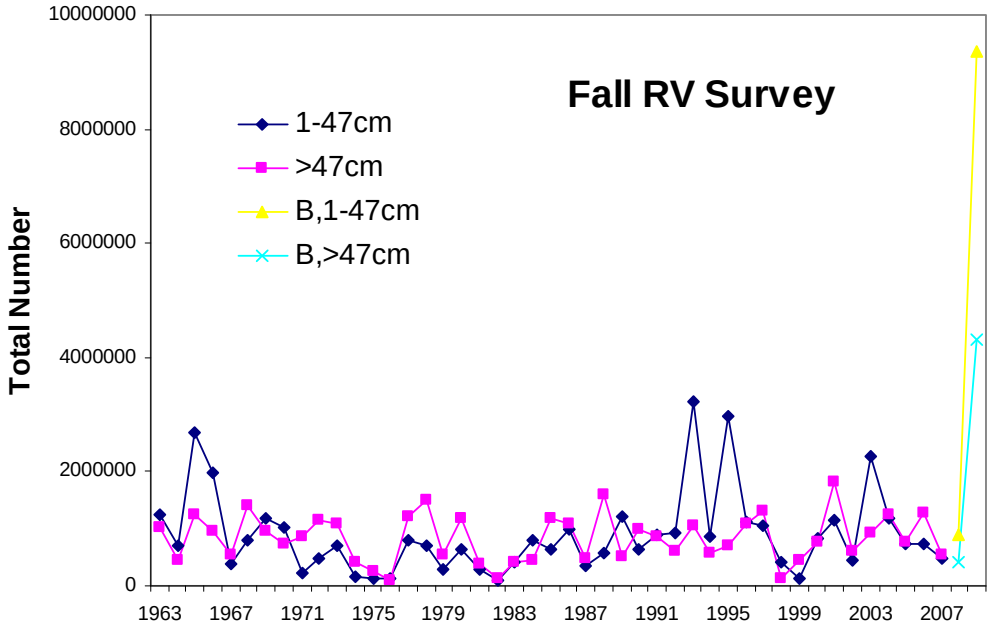

Figure 24. Abundance of smooth skate summarized by length groups representing immature (1-47 cm) and mature (>47 cm) categories as indicated by the US Fall RV Survey. In the figure legend the B, 1-47 cm refers to the vessel Bigelow, 1-47 cm length category.

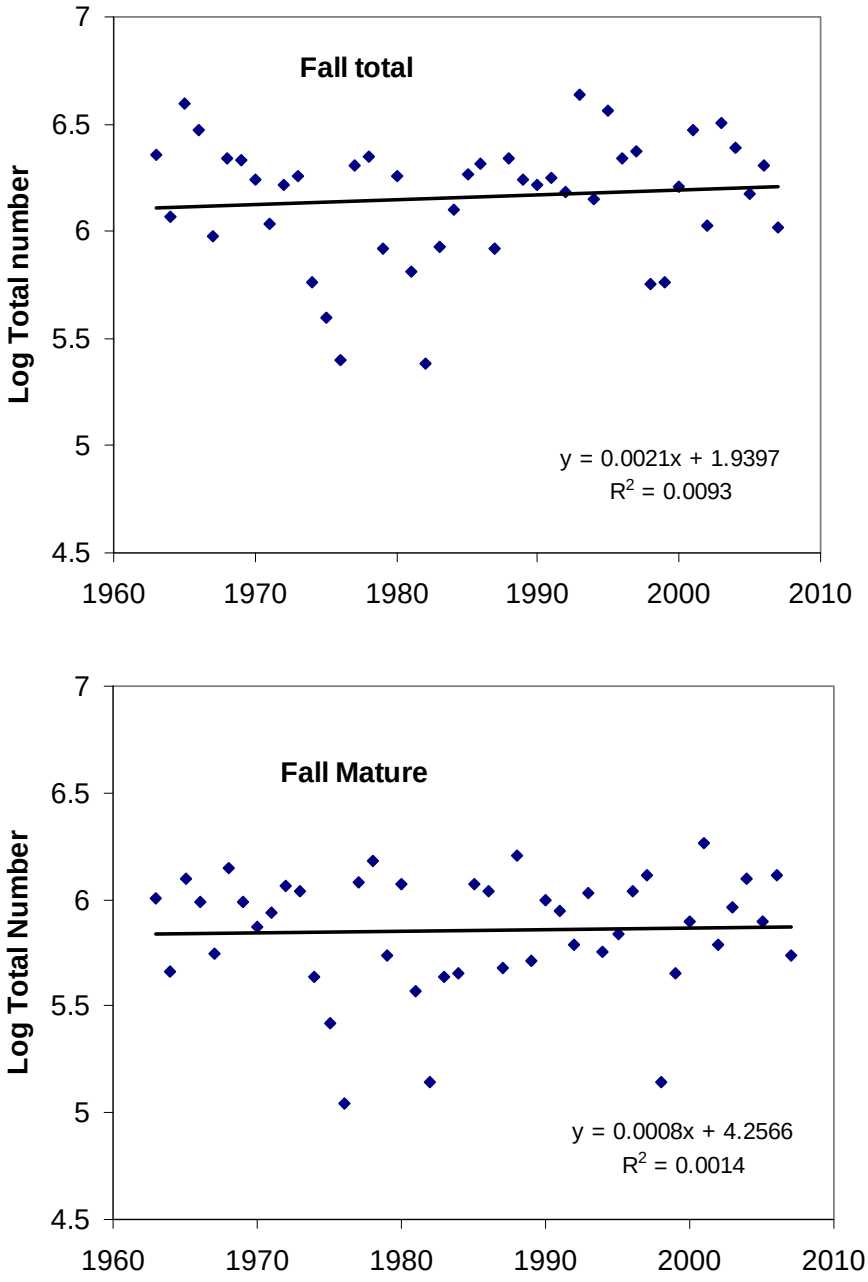

Figure 25. Log transformed total abundance of smooth skate (all lengths groups (total) and Mature length groups only (>47 cm)) from all strata of the US Fall RV Survey, 1963-2007. Note that the 2008 and 2009 surveys were conducted using different tow protocols, gears, and vessels and were not included in the analysis.

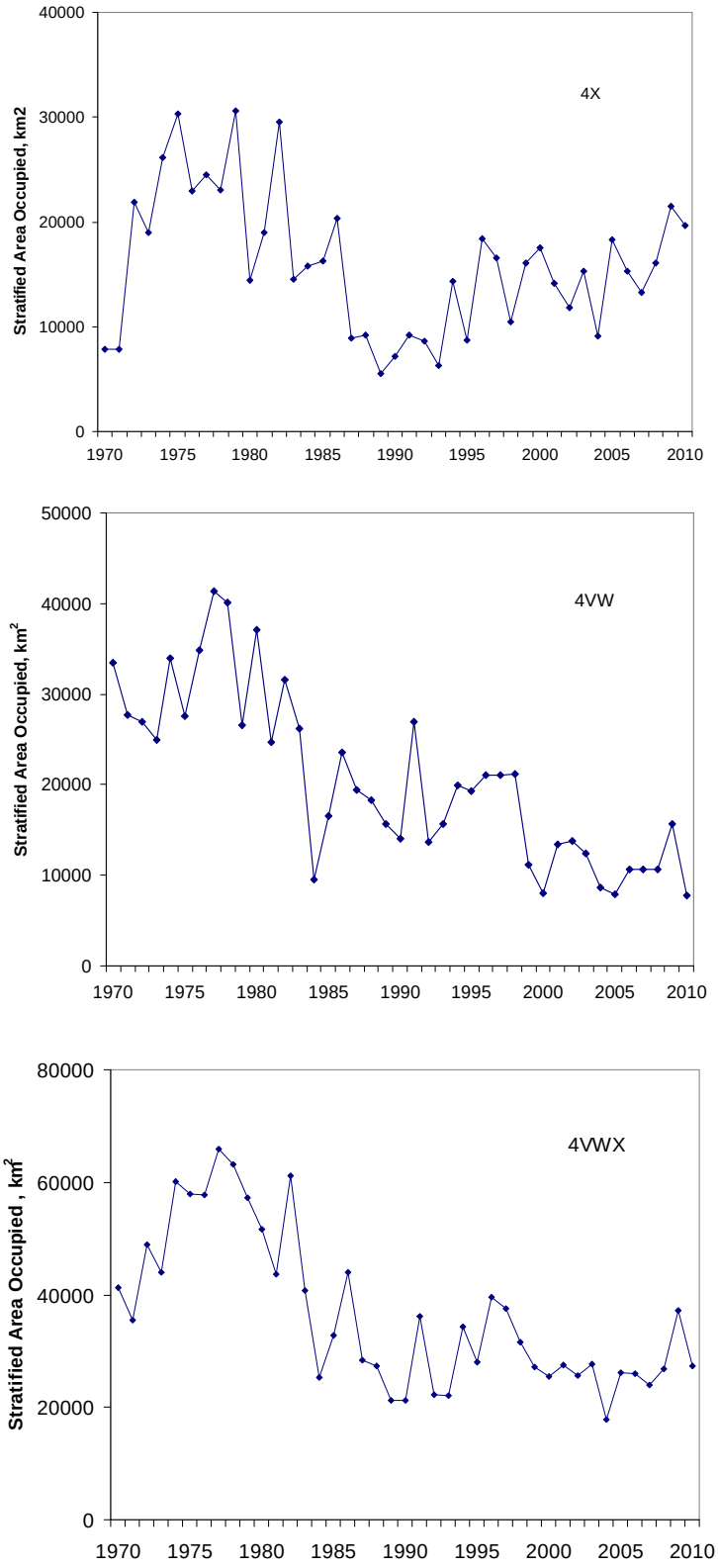

Figure 26. Design weighted area occupied (DWAO, km^2) for smooth skate in Div. 4X, 4VW and 4VWX combined as indicated by the Summer RV Survey.

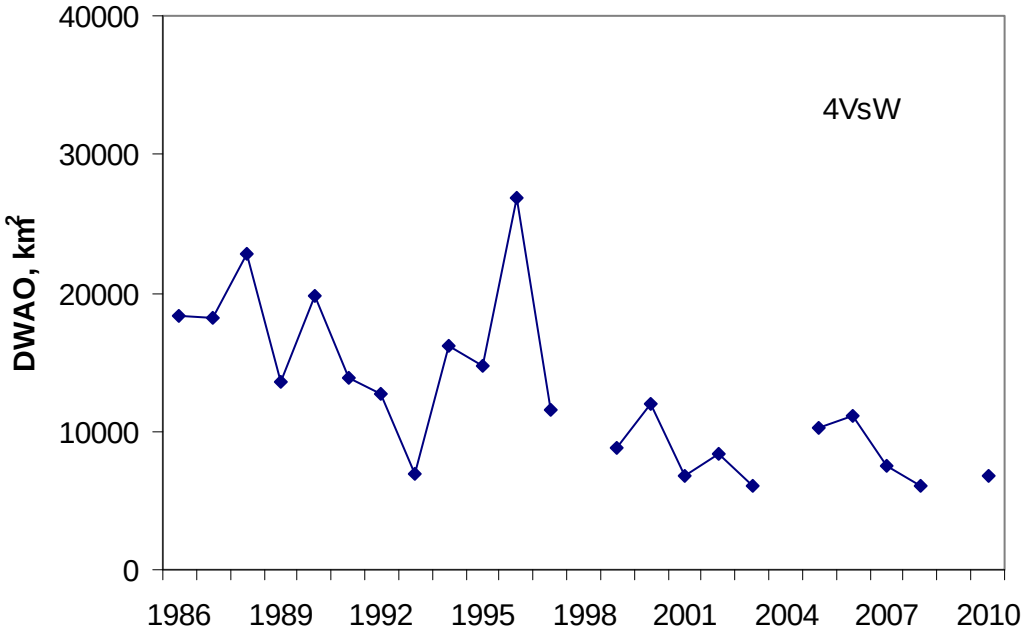

Figure 27. Design weighted area occupied (DWAO, km^2) for smooth skate caught during the 4VWCOD RV Survey, 1986-2010. Note that the 1998, 2004, and 2009 surveys are missing or incomplete.

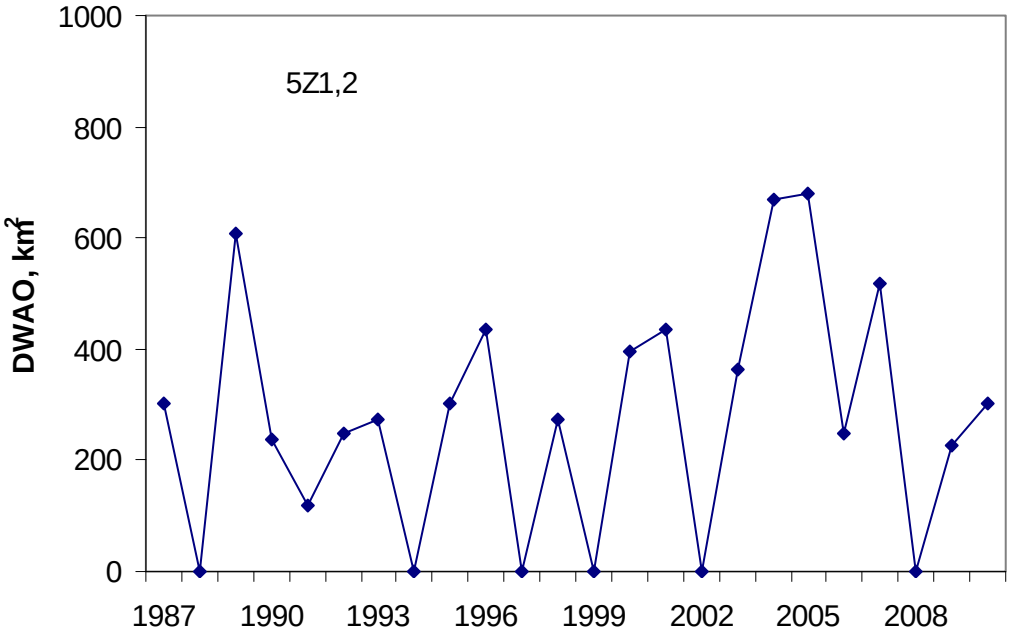

Figure 28. Design weighted area occupied (DWAO, km^2) for smooth skate on the Canadian side of the Georges Bank RV Survey.

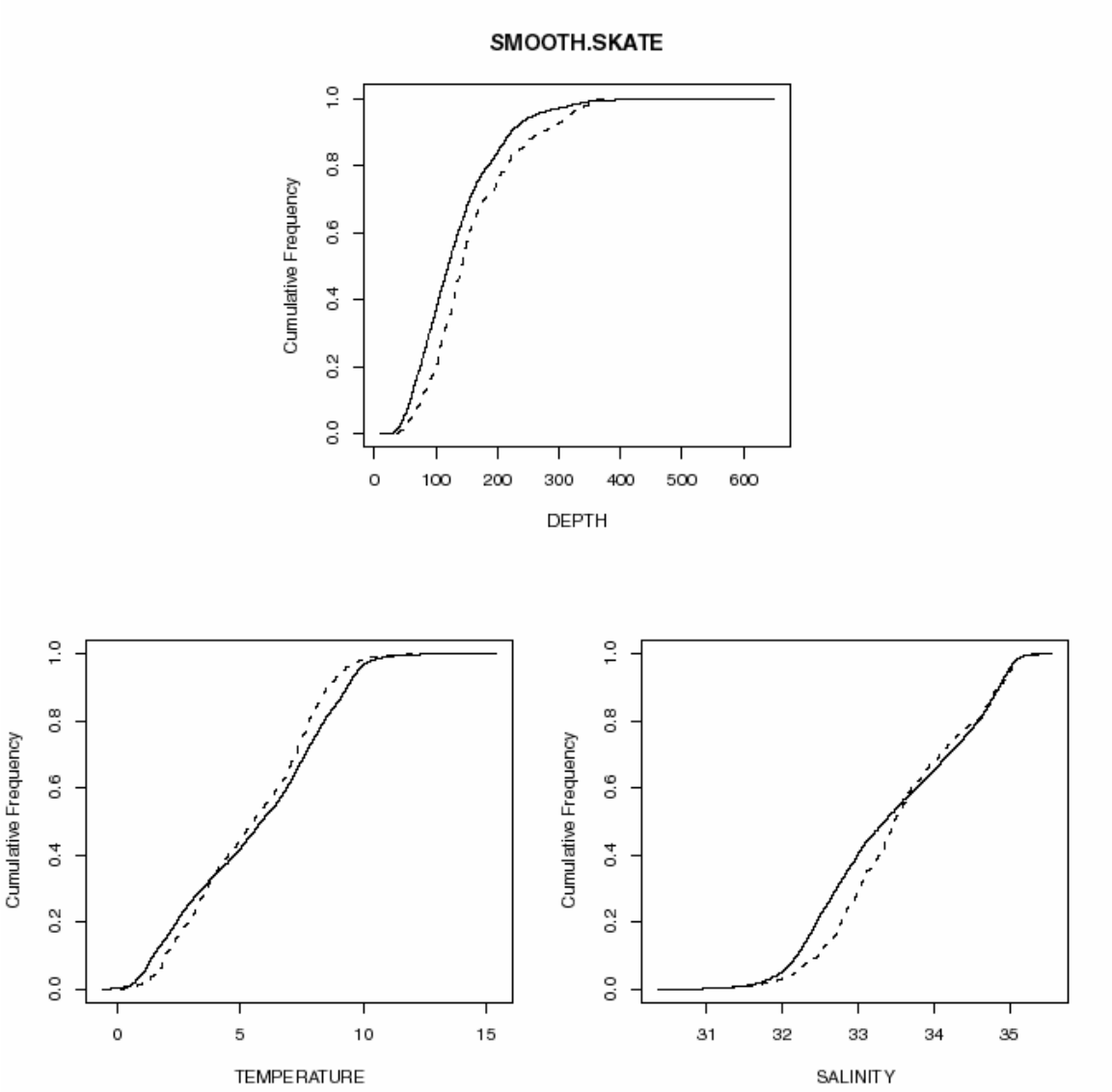

Figure 29. Cumulative stratified abundance of smooth skate compared to the cumulative stratified depth, temperature, and salinity from the Summer RV Survey. The solid line is the survey estimate while the dashed line is the estimate for smooth skate.

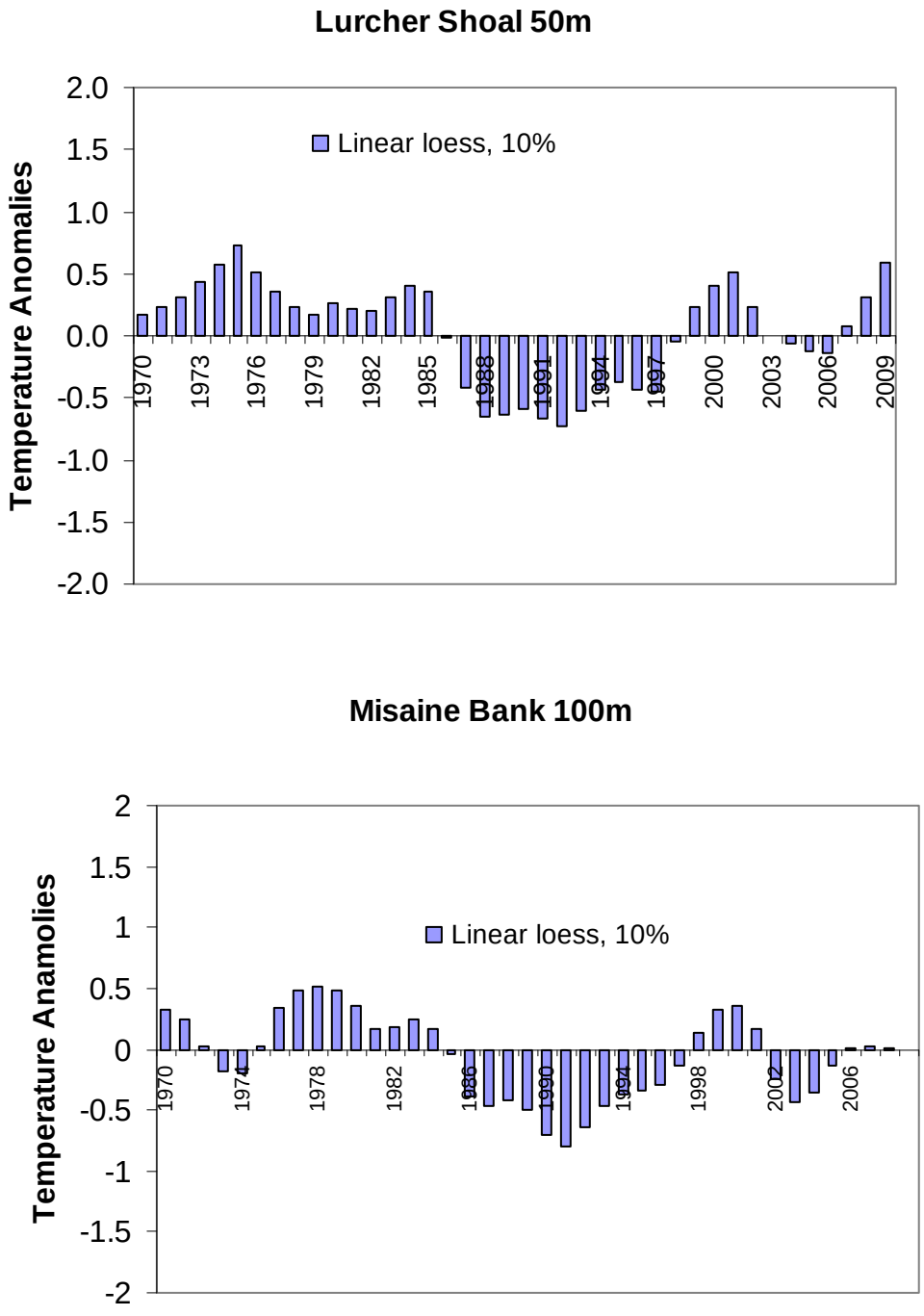

Figure 30. Temperature anomalies in Div. 4X (top panel) and Divs. 4VsW (bottom panel) using a linear loess (10%) model.

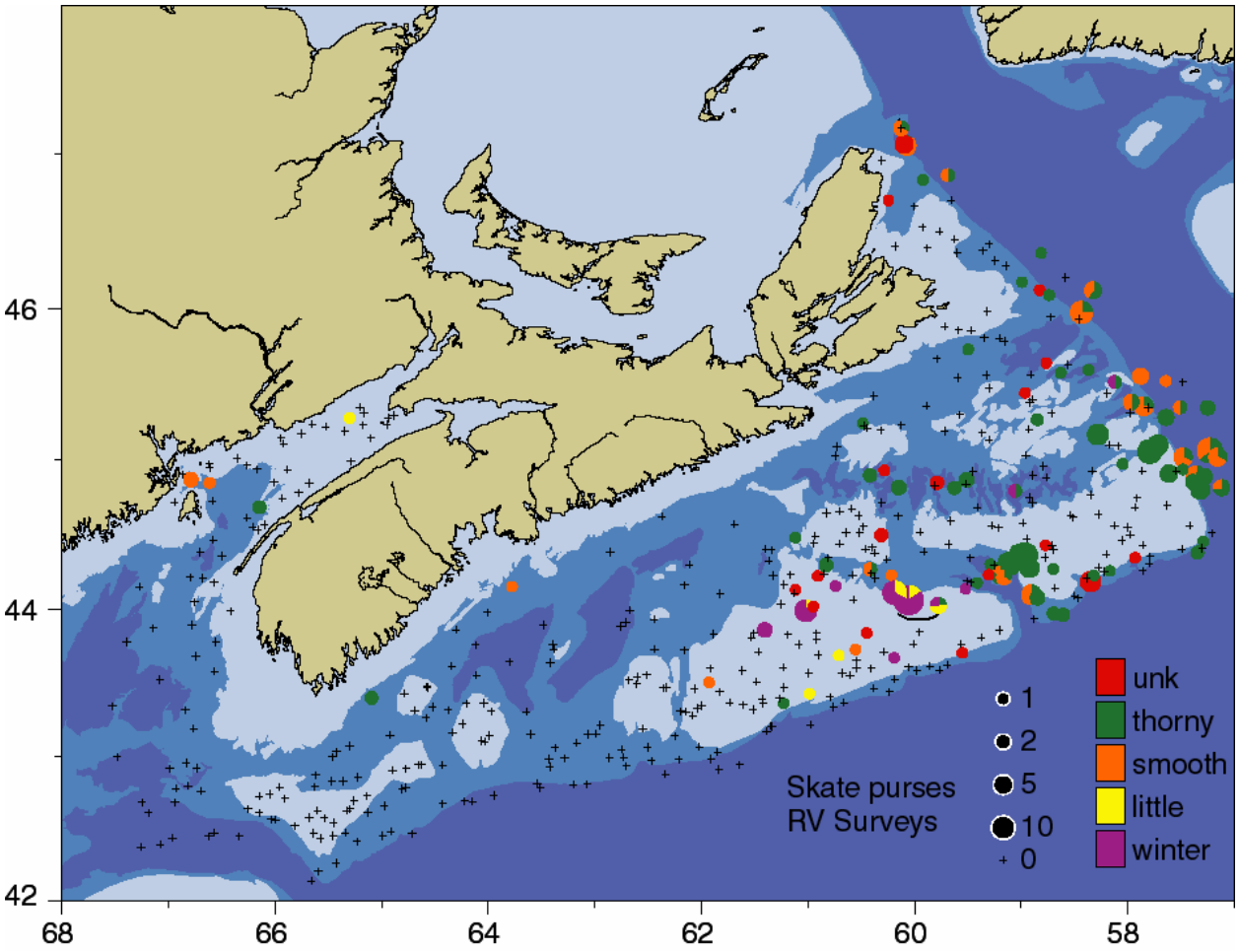

Figure 31. Distribution of skate purses by species from 4VWCOD and Summer RV Surveys on the Scotian Shelf in 2006 and 2007. Sets with no skate purses are indicated by a cross.

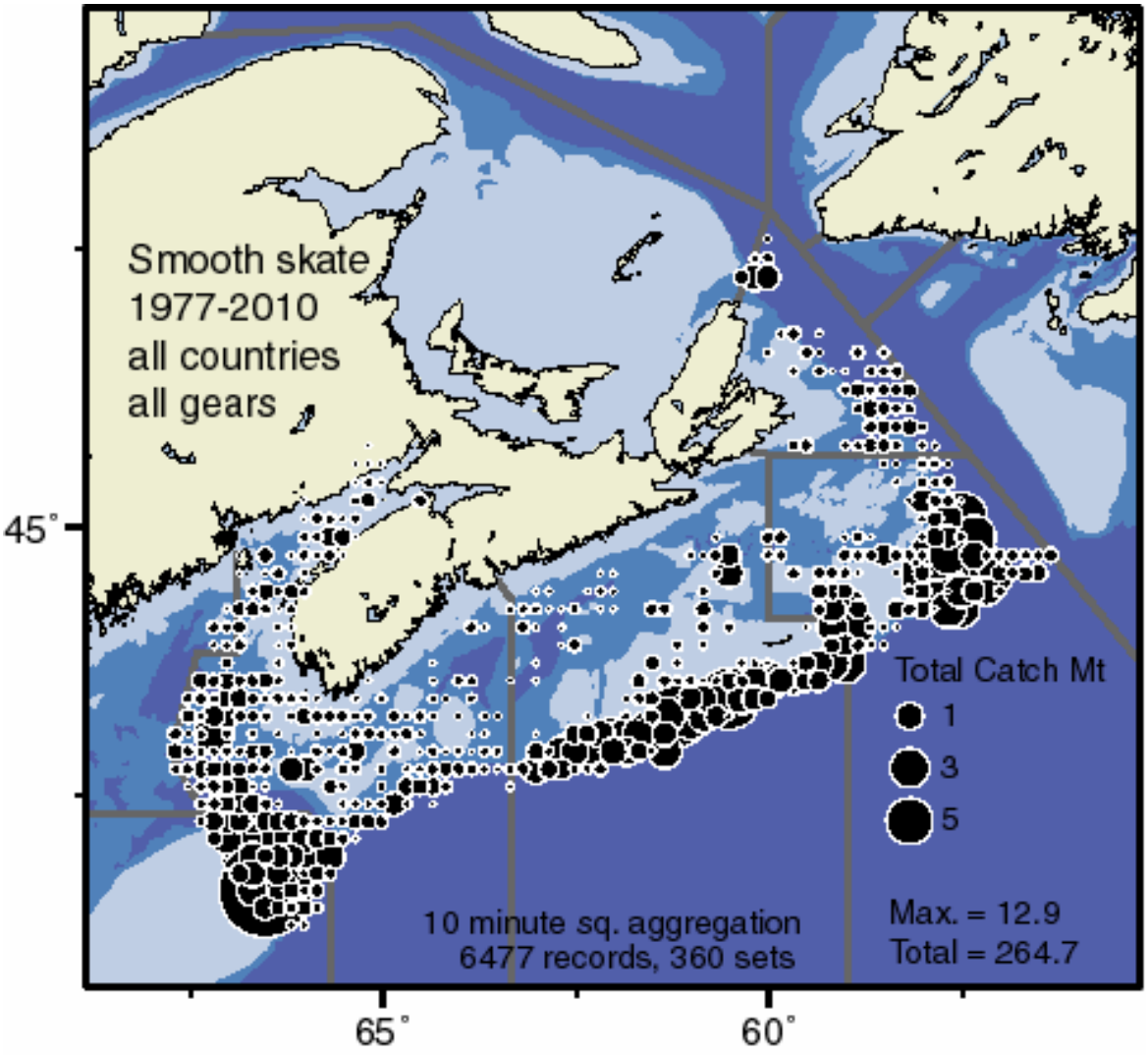

Figure 32. Reported locations of smooth skate from the Maritimes Observer Program, 1978-2010.

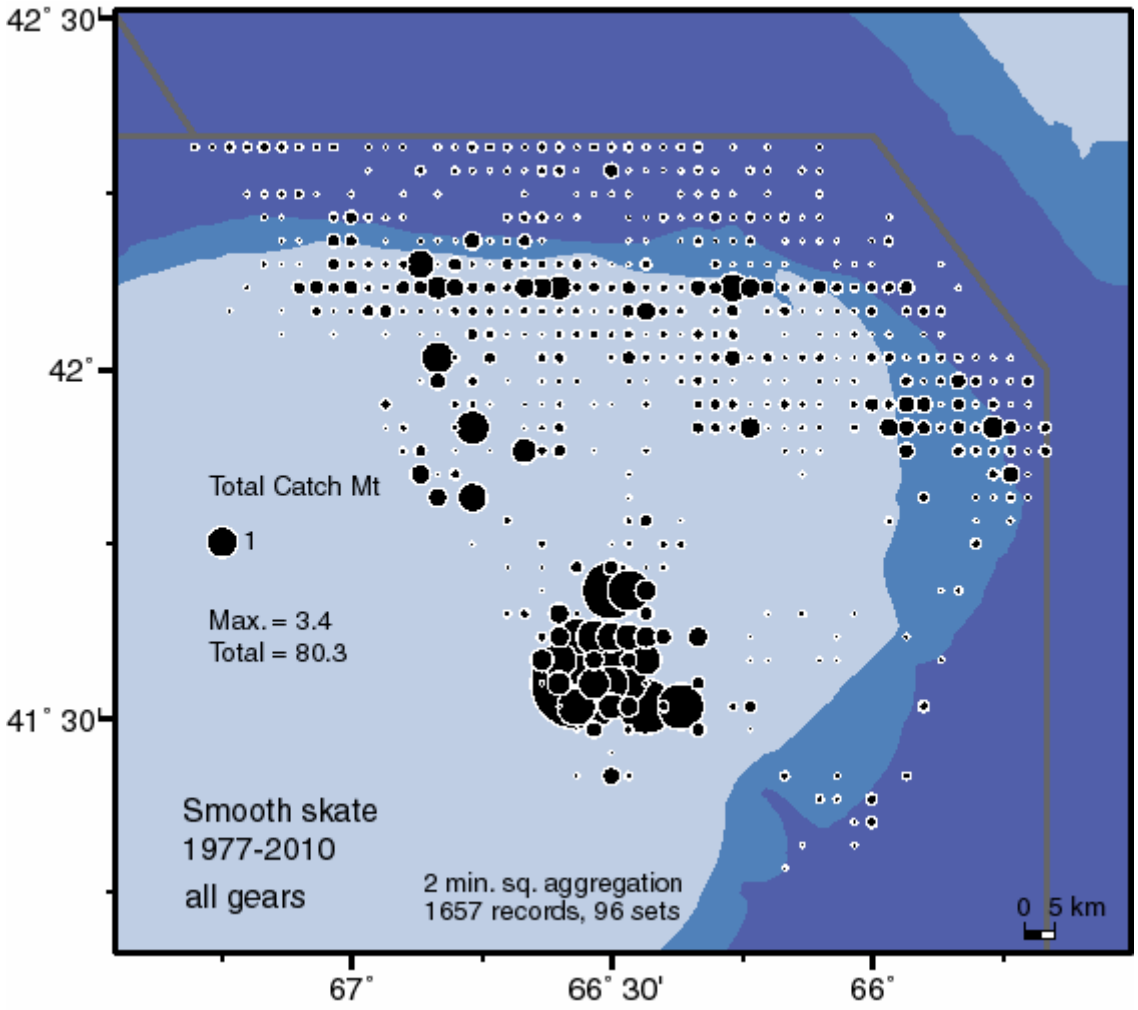

Figure 33. Reports of smooth skate on Georges Bank as indicated by Maritimes Observer Program. This figure is a representation of the same data as presented in the previous figure but at a finer spatial scale.

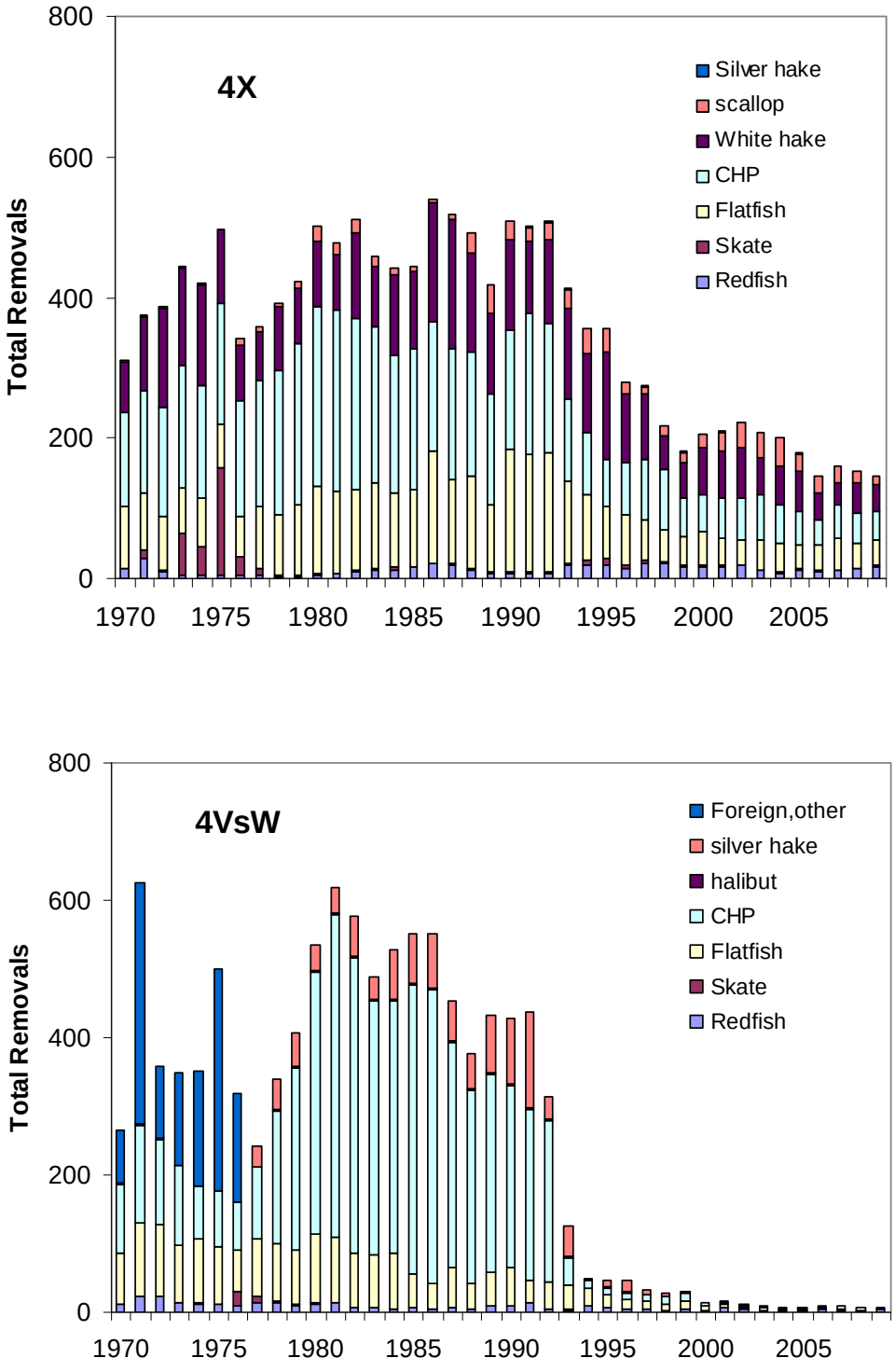

Figure 34. Estimated removals, t of smooth skate from selected directed fisheries in Div. 4X and Divs. 4VsW as derived from observer reports. Observer coverage in other fisheries was insufficient to estimate removals or there were no significant amounts of smooth skate reported as bycatch.

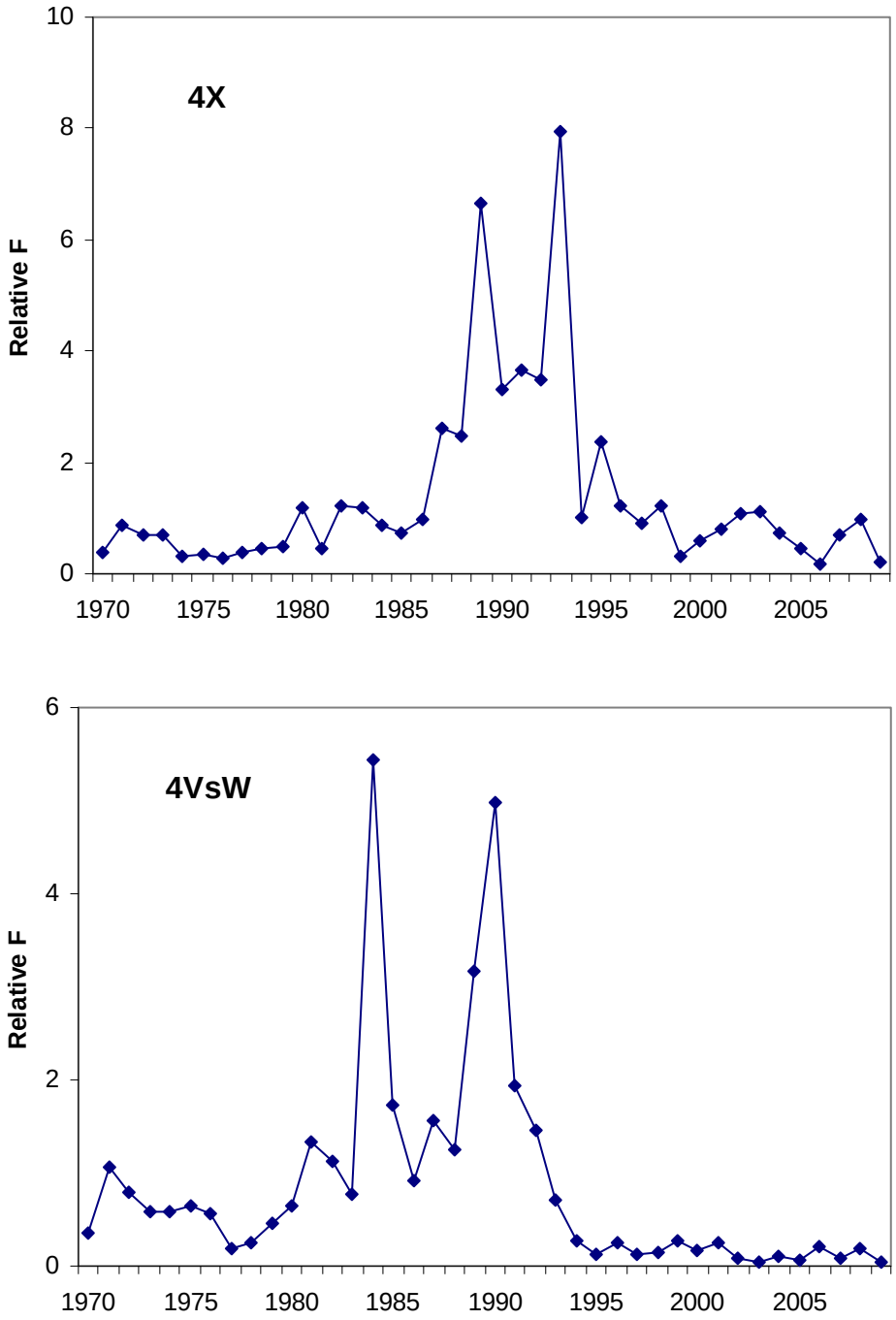

Figure 35. Relative F (fishing mortality) derived from the estimated removals of smooth skate and Summer RV biomass for Div. 4X and Divs. 4VsW.

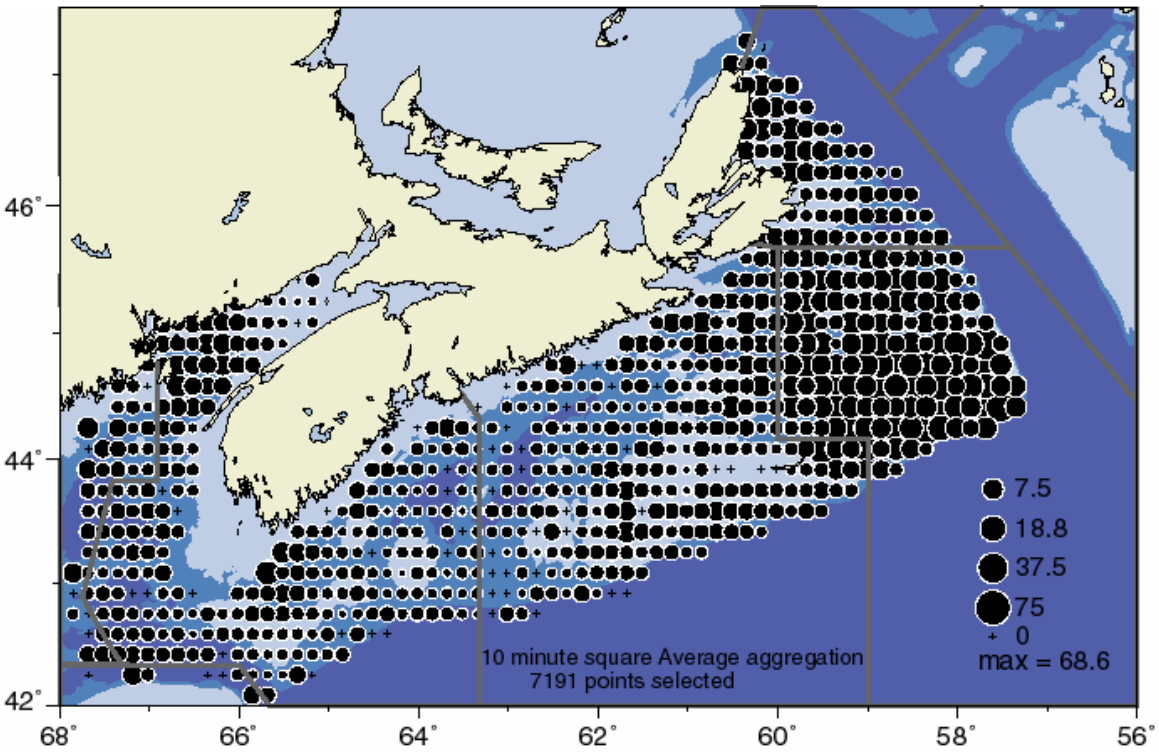

Figure 36. Distribution of thorny skate as indicated by the Summer RV Survey, 1970-2010.

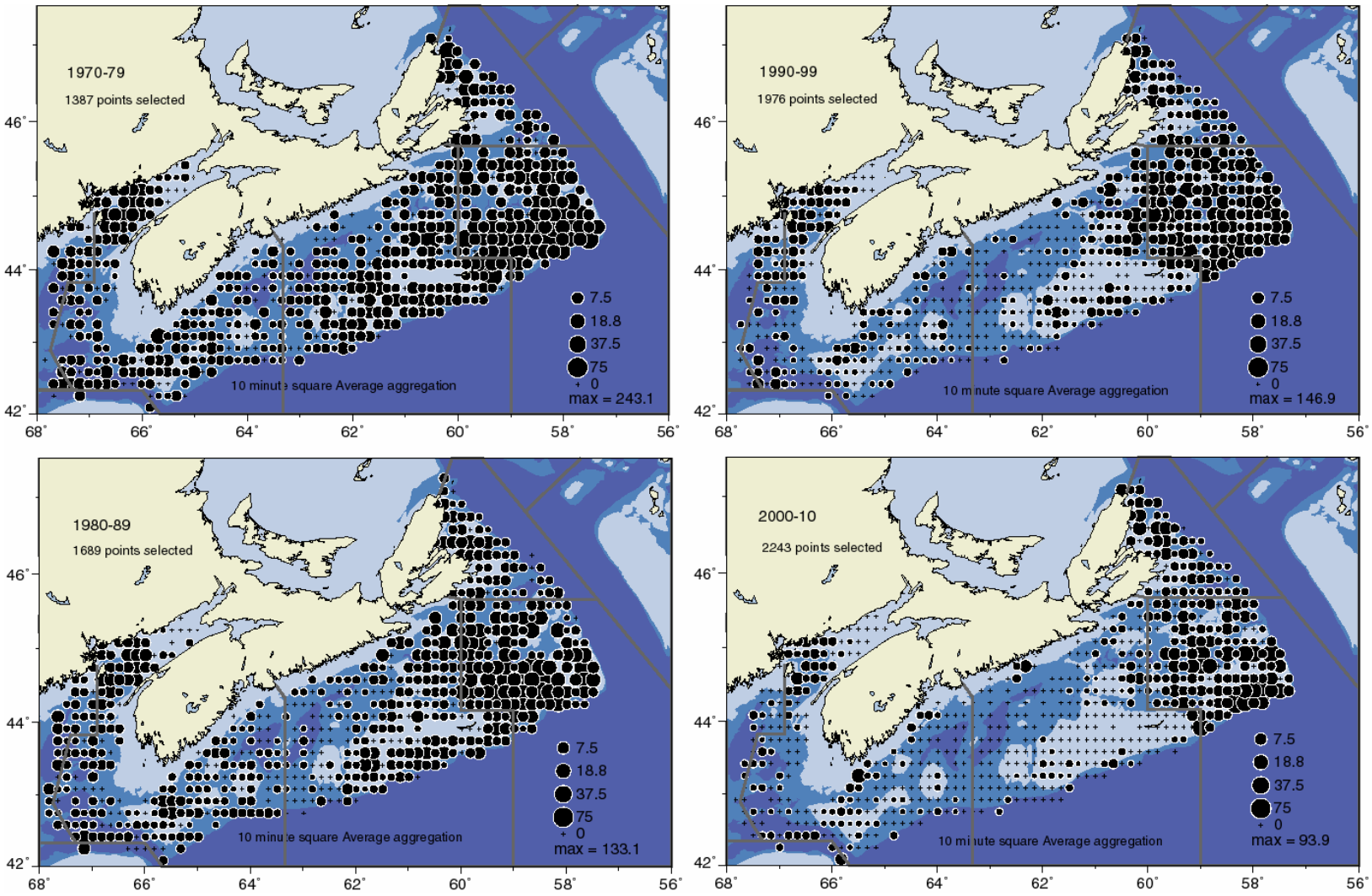

Figure 37. Distribution of thorny skate by decadal period as indicated by the Summer RV Survey.

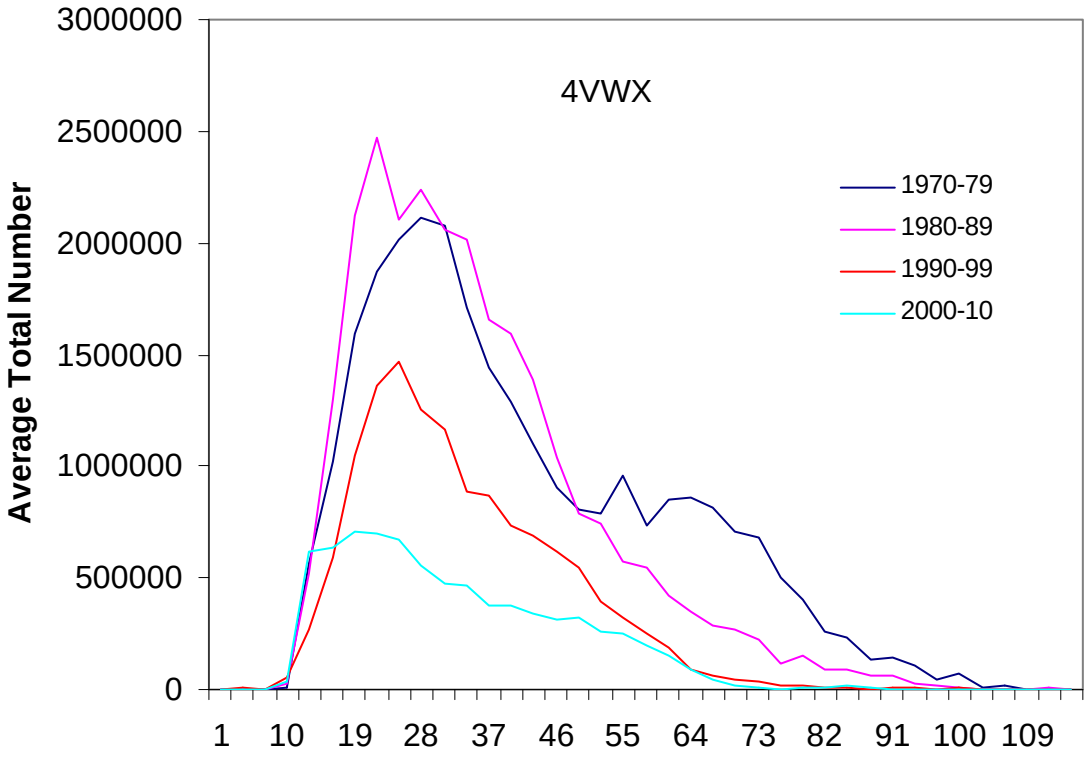

Figure 38. Average decadal abundance by length for Divs. 4VWX from the Summer RV Survey.

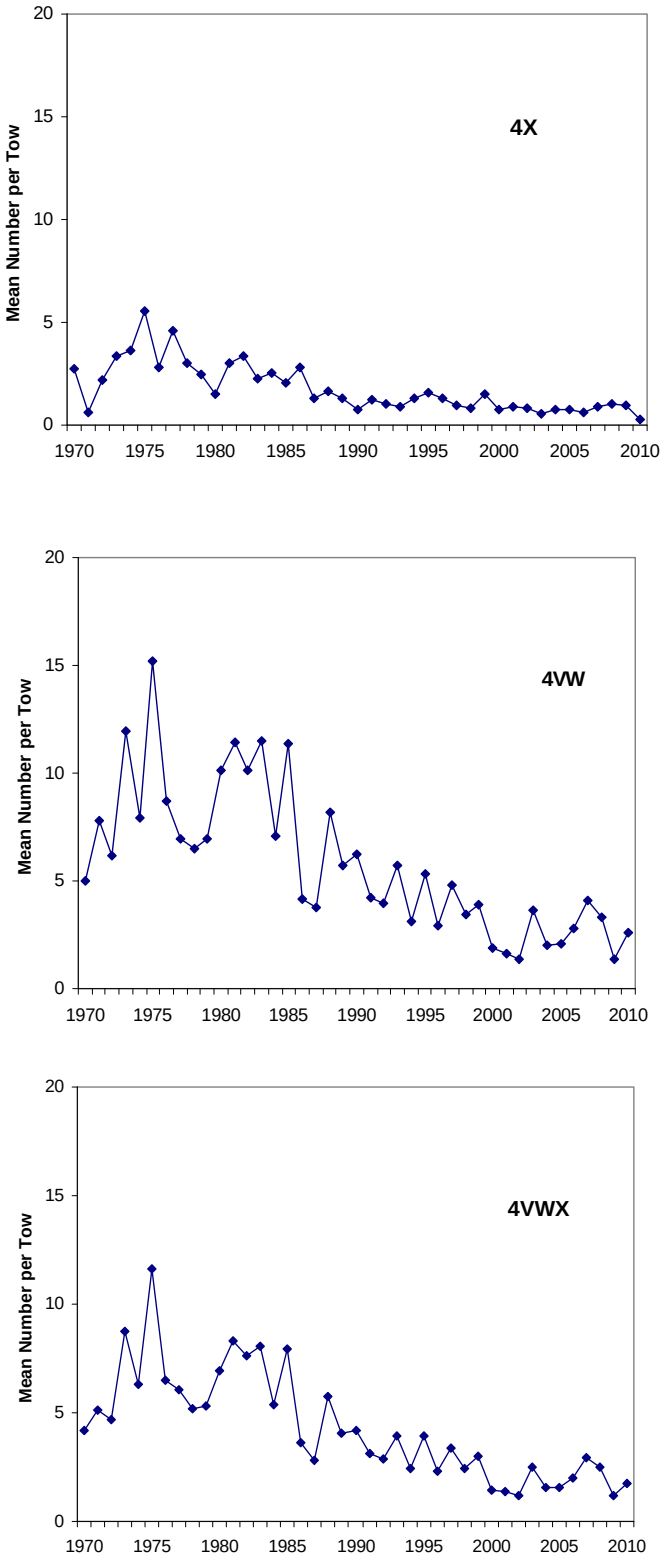

Figure 39. Number per tow of thorny skate caught during the Summer RV Survey, 1970-2010, from NAFO Div. 4X, 4VW, and 4VWX combined.

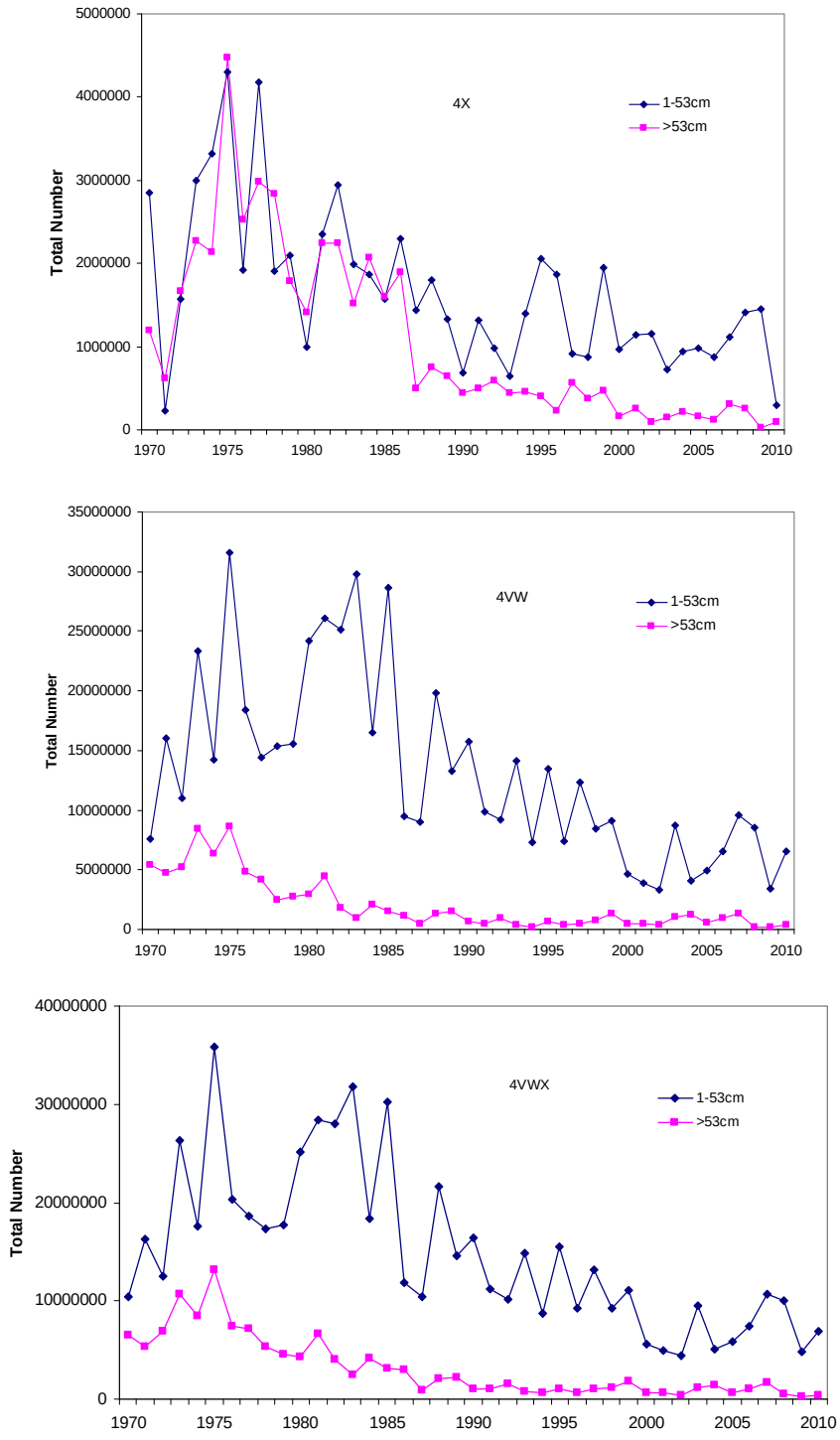

Figure 40. Total abundance of immature (1-53 cm) and mature (>53 cm) of thorny skate as indicated by the Summer RV Survey from Div. 4X, Divs. 4VW, and Divs. 4VWX combined.

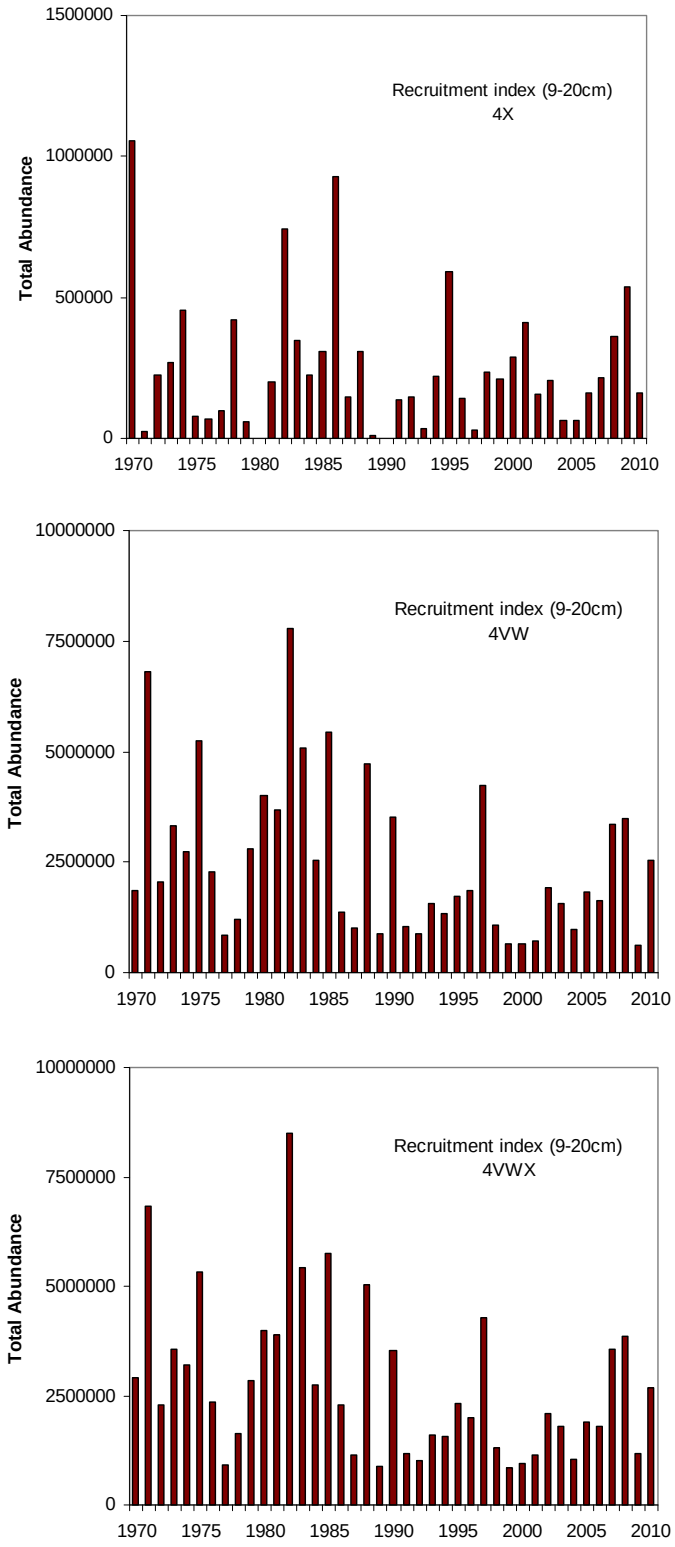

Figure 41. Recruitment index (abundance of individuals measuring 9-20cm in length) of thorny skate in Div. 4X, Divs. 4VW and Divs. 4VWX, as indicated by the Summer RV Survey.

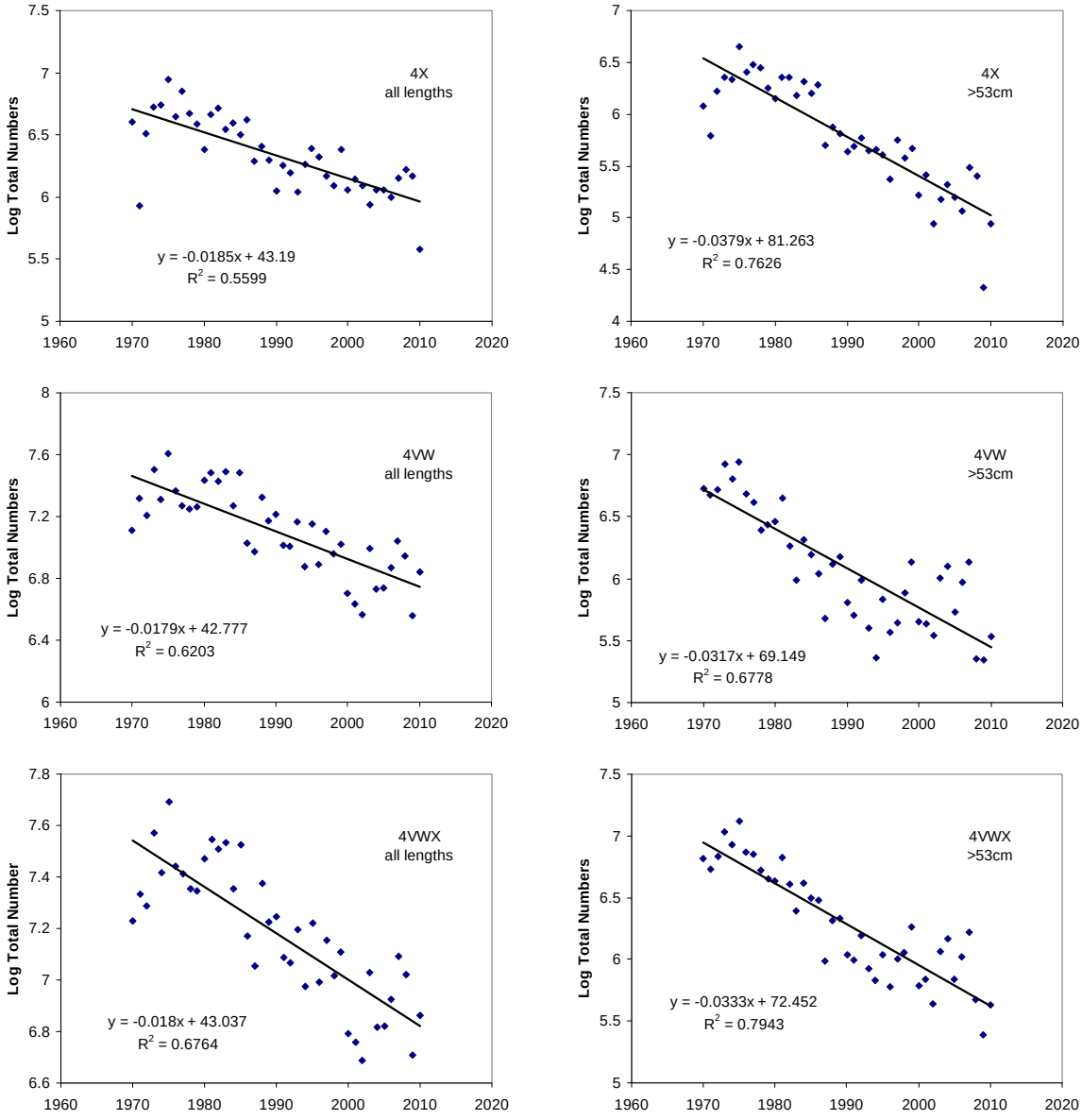

Figure 42. Log transformed total abundance of thorny skate (all length groups and mature length groups only) caught during the Summer RV Survey, 1970-2010 from NAFO Div. 4X, 4VW, and 4VWX.

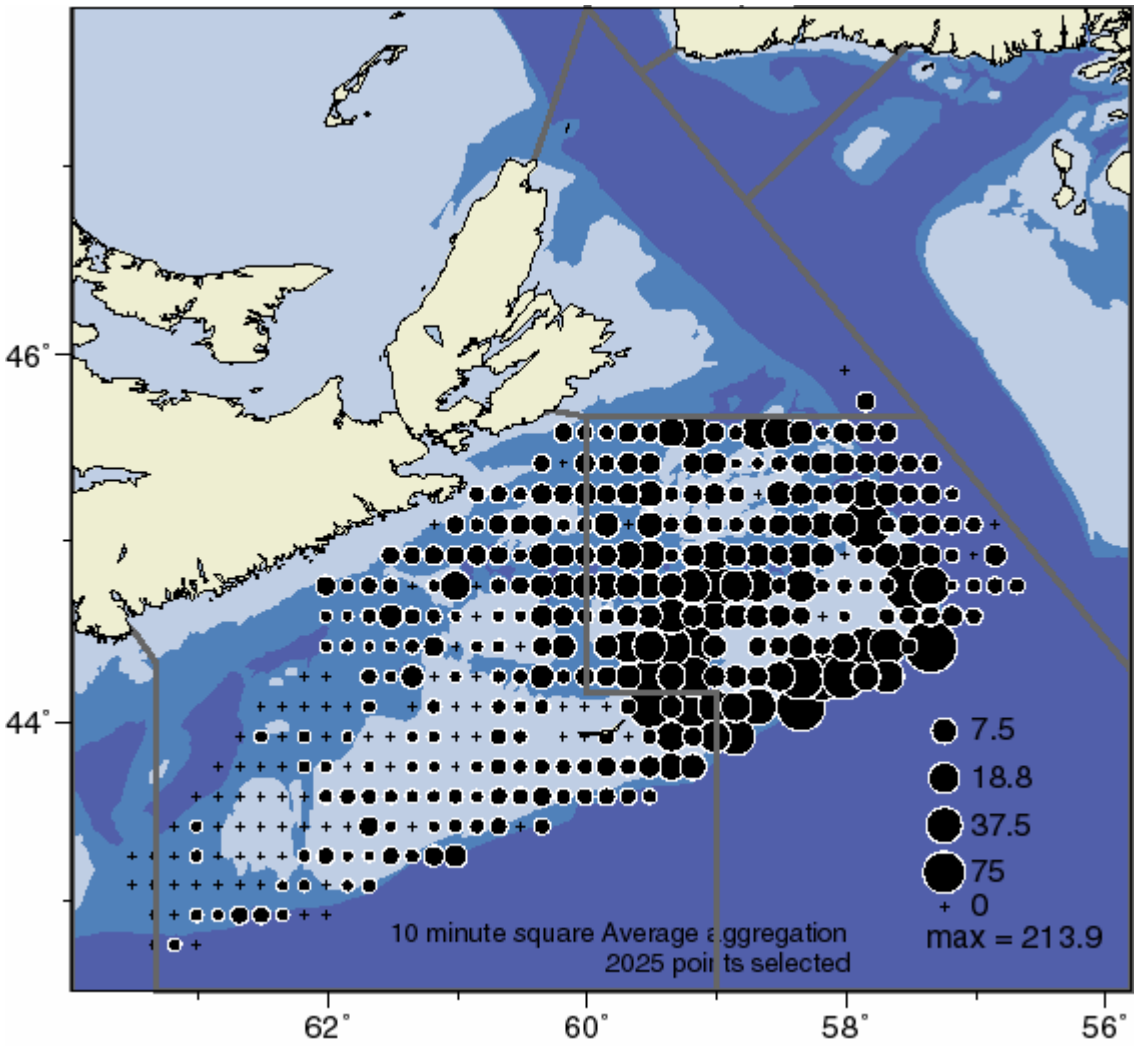

Figure 43. Distribution of thorny skate from the March 4VsW RV survey on the eastern Scotian Shelf, during 1986-2010. Note that during some of the years coverage was incomplete and the years 1998 and 2004 are missing.

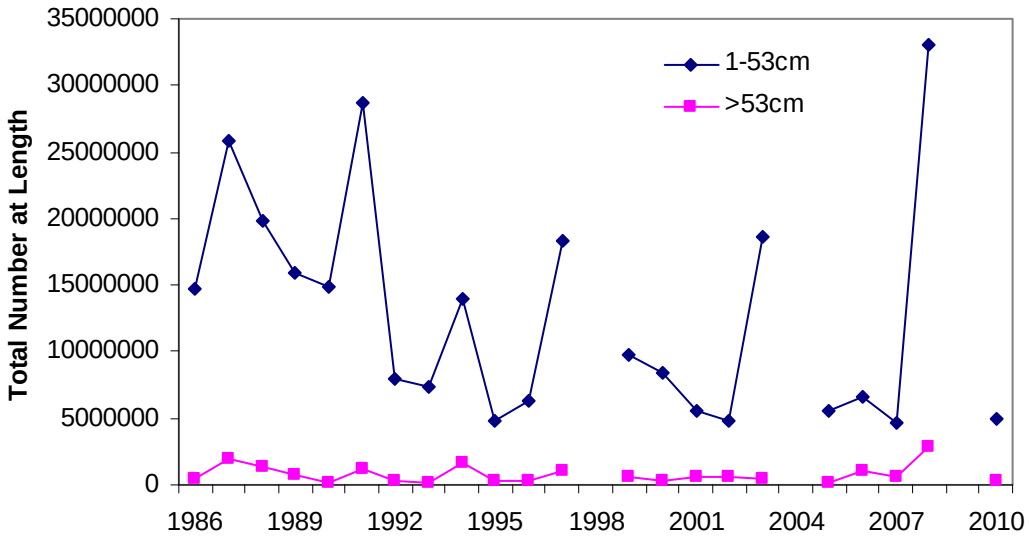

Figure 44. Abundance of immature (1-53 cm) and mature (>53 cm) thorny skate caught during the March 4VsW RV survey, 1986-2010. Note that the 1998, 2004, and 2009 surveys are missing or incomplete.

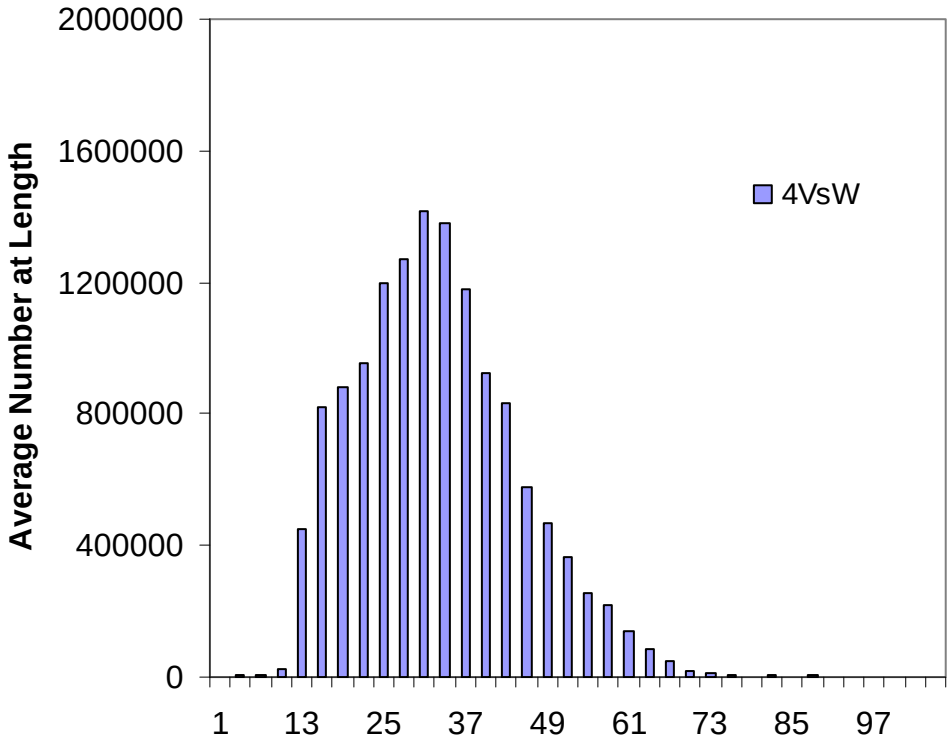

Figure 45. Abundance at length (cm) of thorny skate from the 4VWCOD RV survey, 1986-2010.

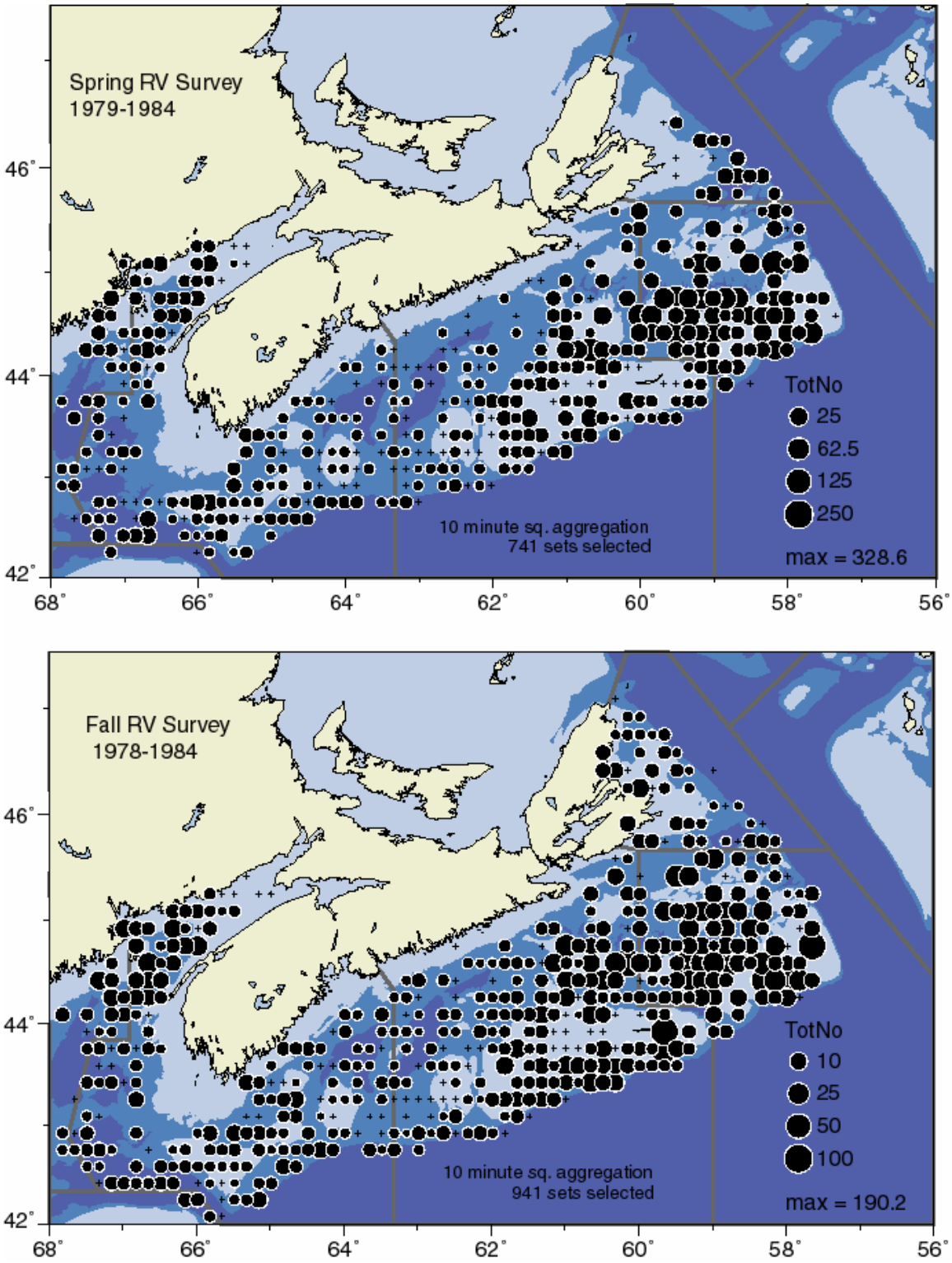

Figure 46. Distribution of thorny skate as indicated by the 4VWCOD and Fall RV Surveys of the Scotian Shelf.

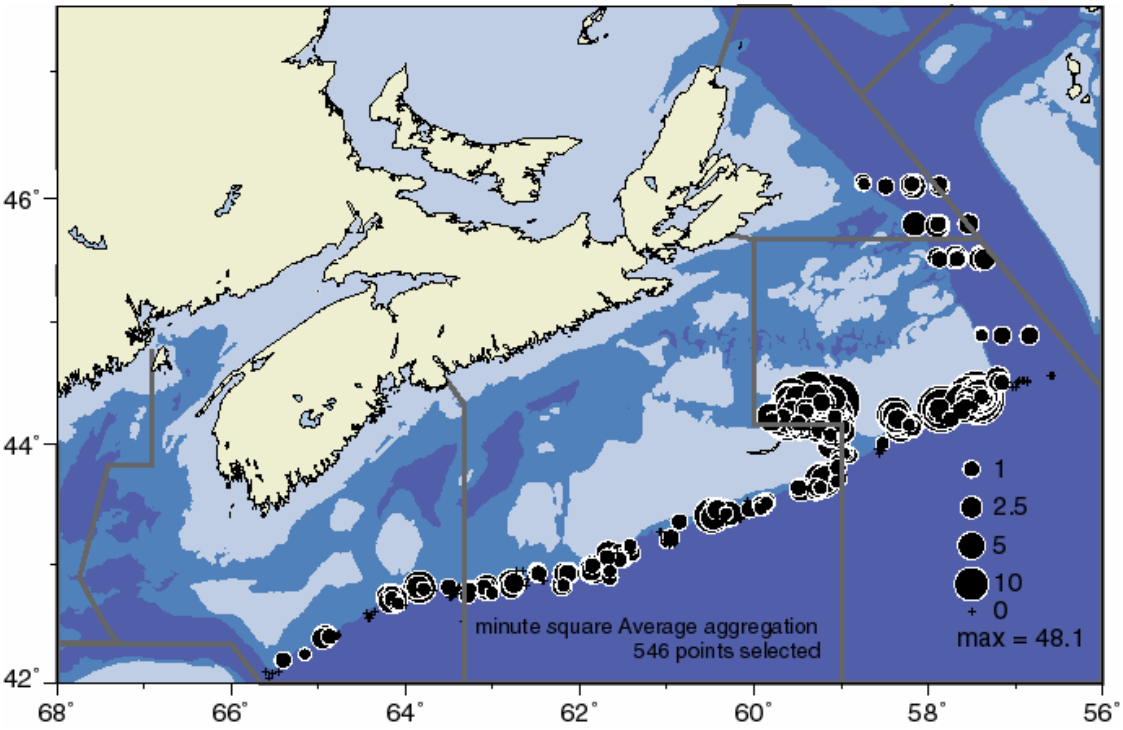

Figure 47. Distribution of thorny skate as indicated by the Redfish RV survey, 1982-88.

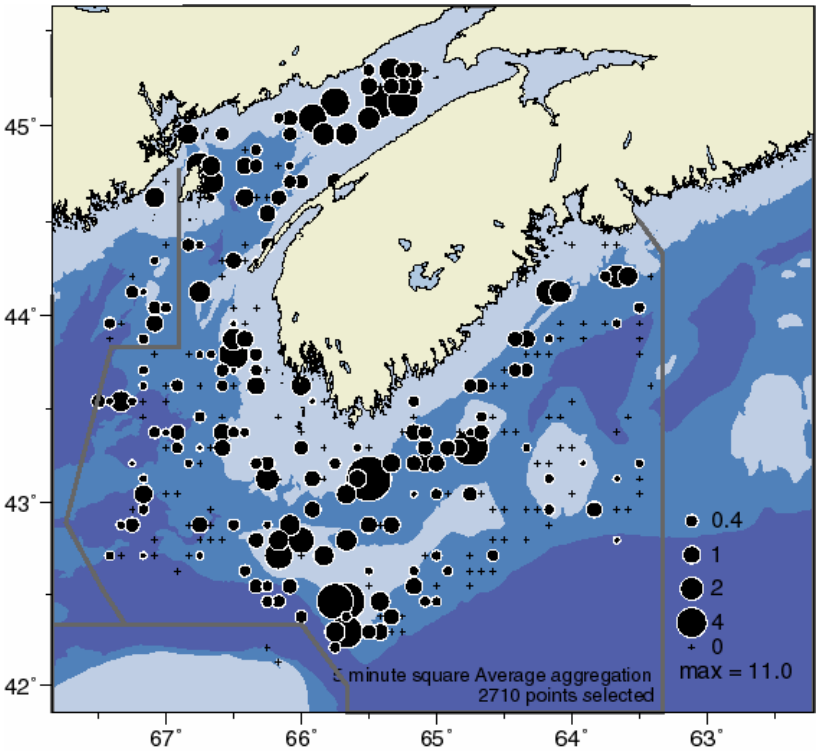

Figure 48. Distribution of thorny skate (kg per tow) as indicated by the ITQ industry OT survey, 1996-2010.

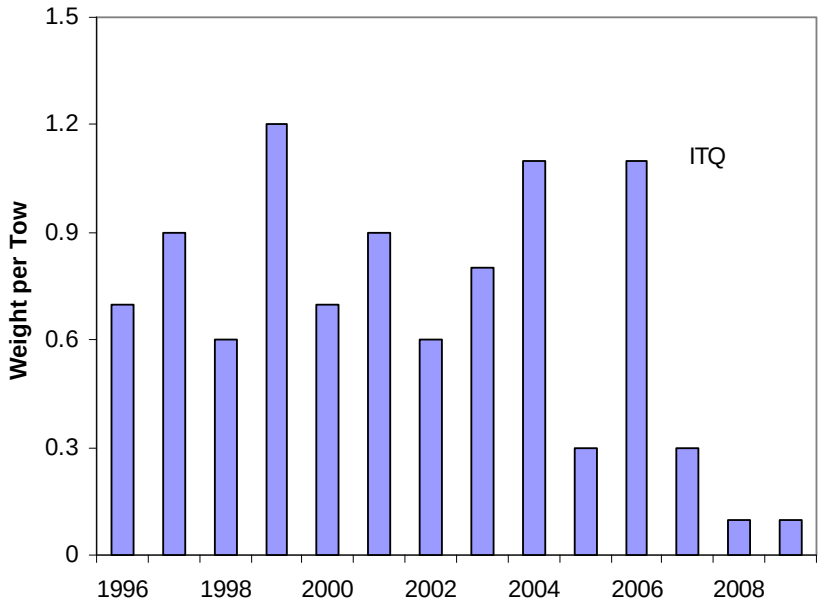

Figure 49. Weight (kg) per tow of thorny skate as indicated by the ITQ survey.

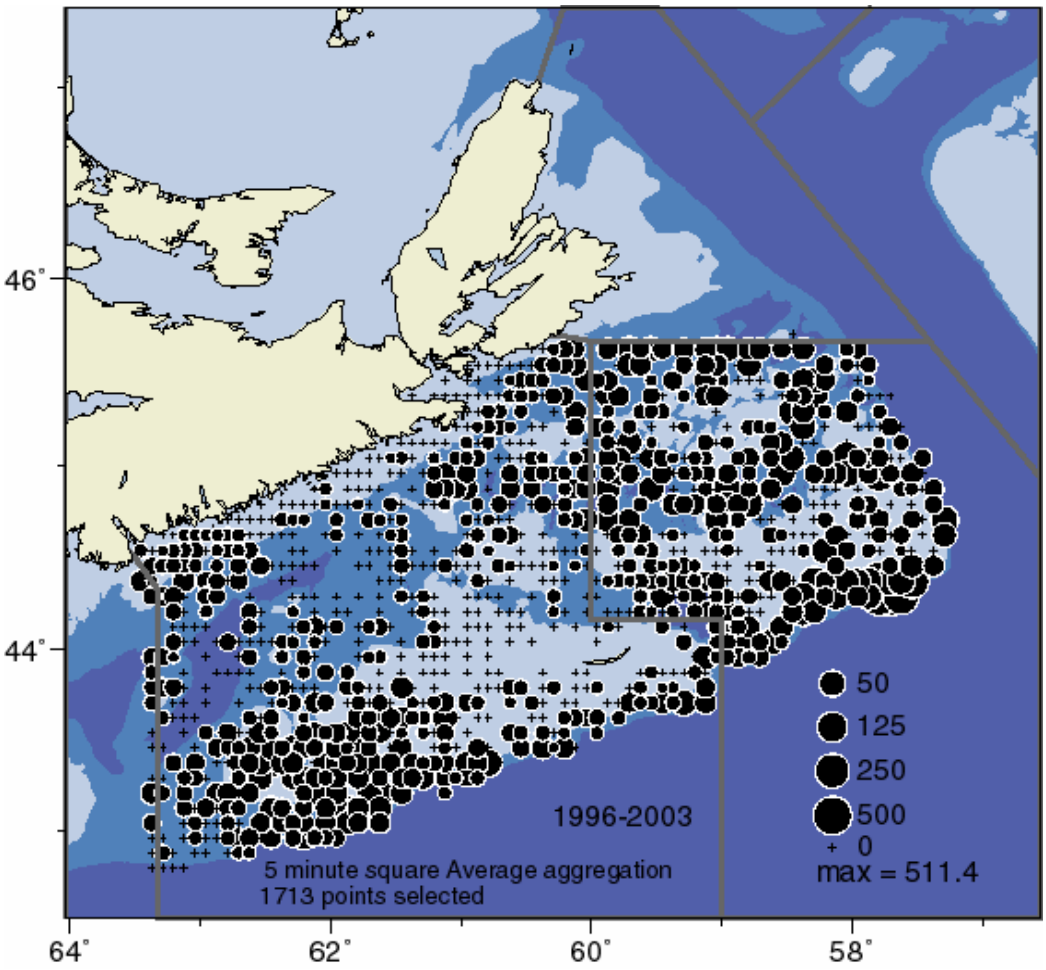

Figure 50. Distribution of thorny skate as indicated by the 4VsW Sentinel Survey, 1996-2003.

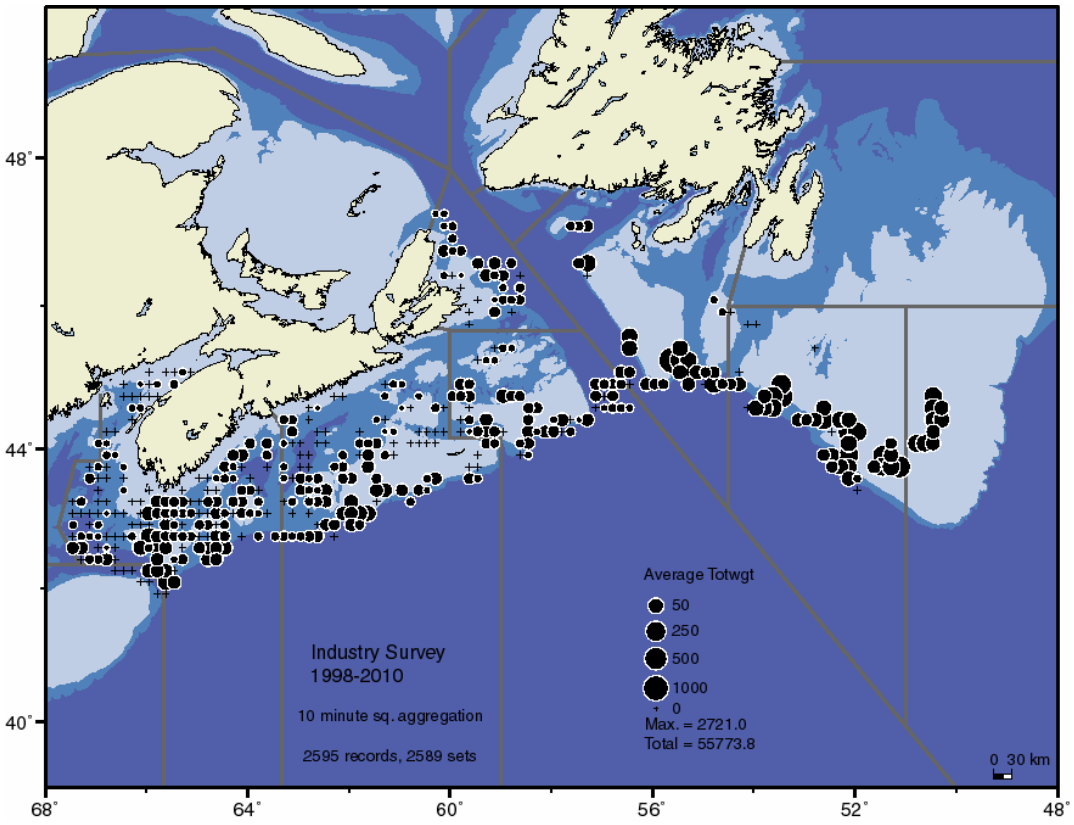

Figure 51. Distribution of thorny skate as indicated by the fixed survey sets of the Halibut Industry Survey, 1998-2010.

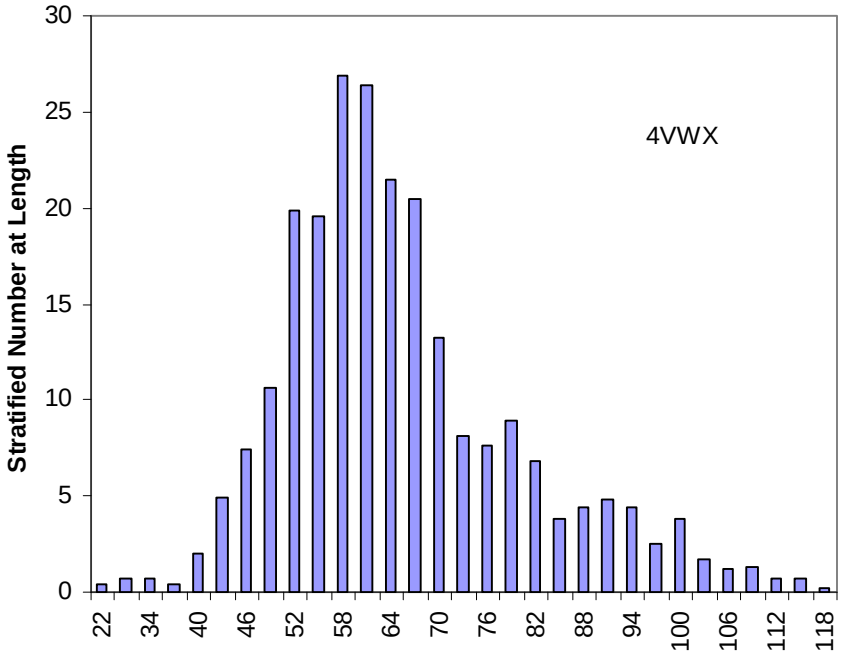

Figure 52. Length frequency of thorny skate in Divs. 4VWX as indicated by the fixed stations of the Halibut Industry Survey.

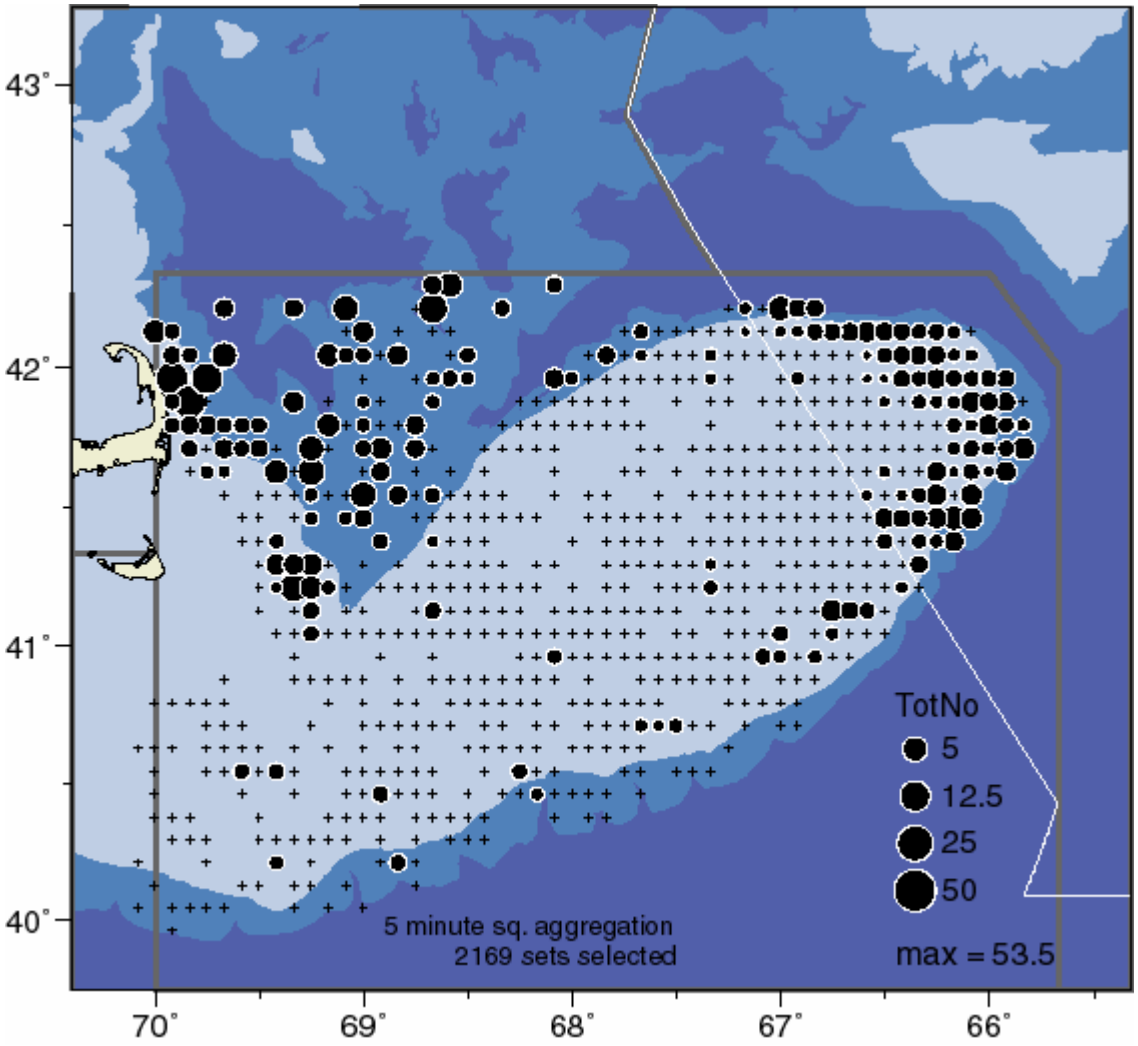

Figure 53. Distribution of thorny skate as indicated by the Georges Bank RV Survey, 1986-2010.

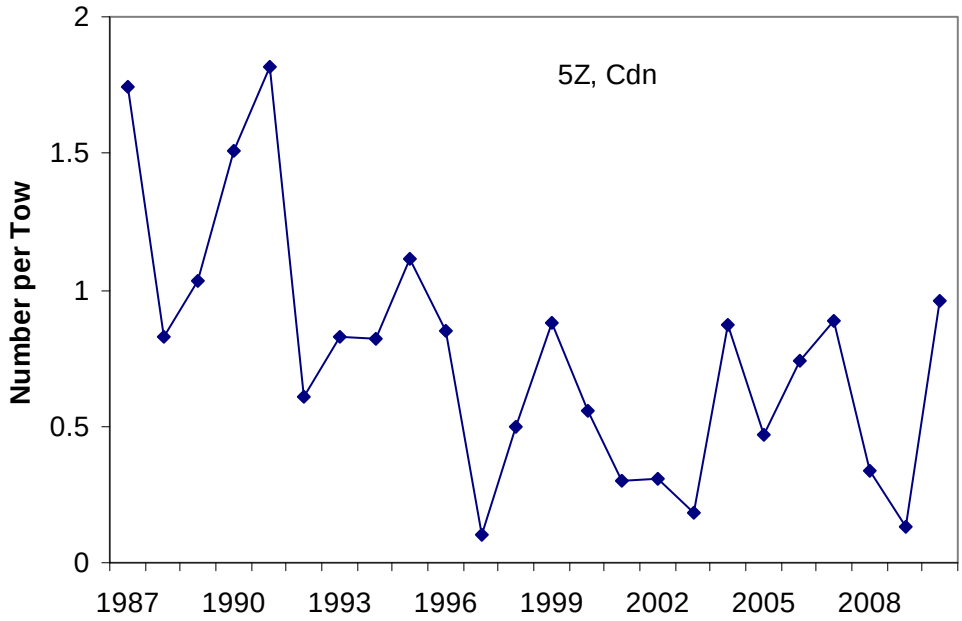

Figure 54. Number per tow of thorny skate from the Canadian strata of the Georges Bank RV survey in Div. 5Z.

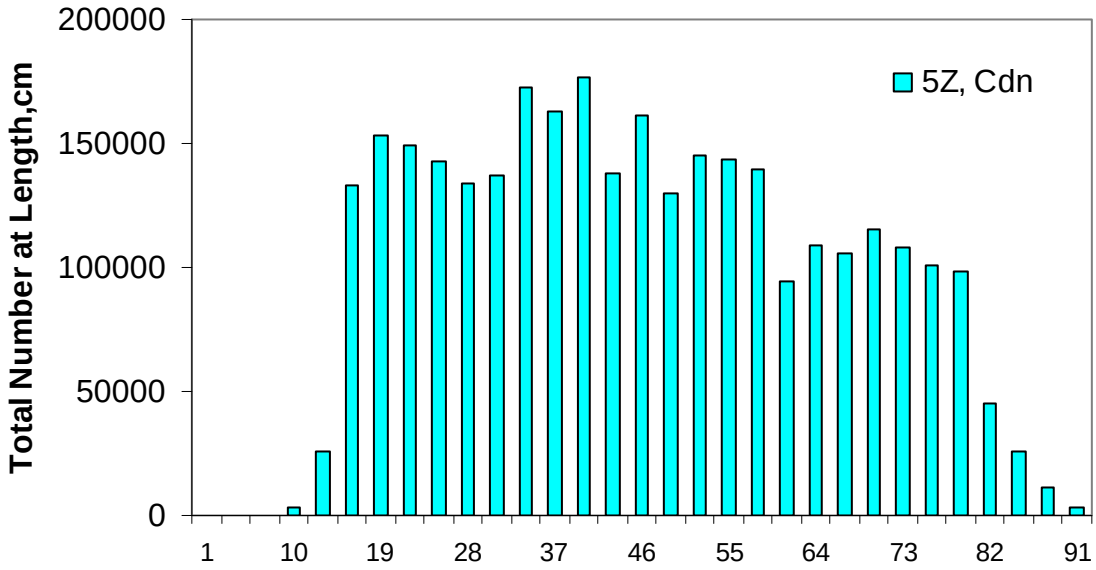

Figure 55. Abundance at length (cm) of thorny skate from the Georges Bank RV survey in Div. 5Z, 1987-2010.

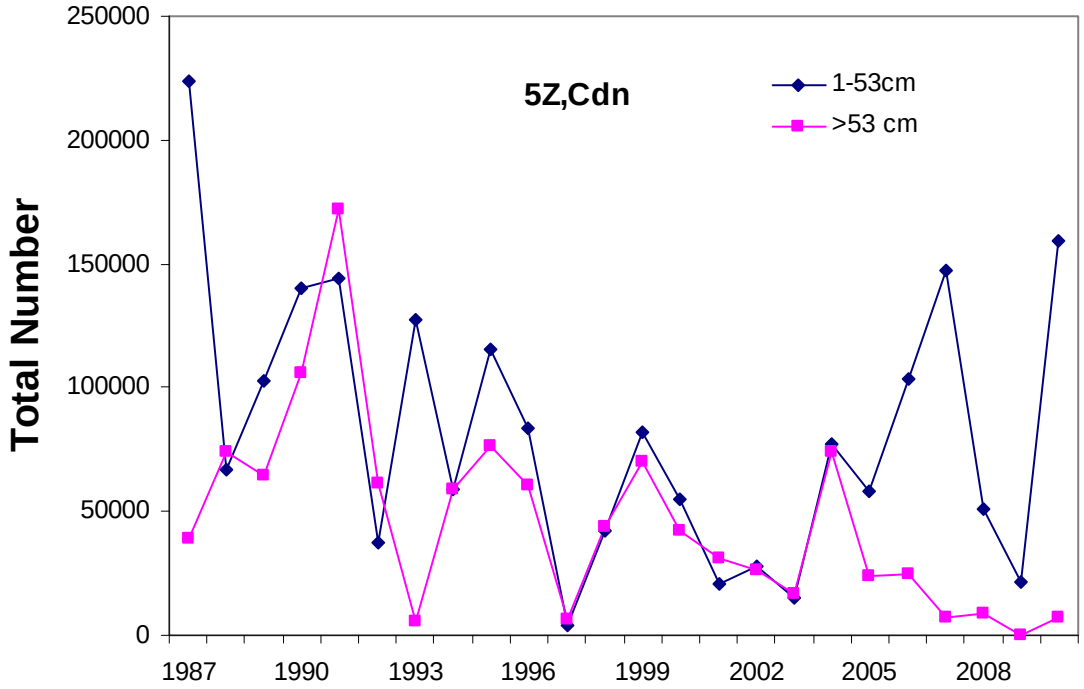

Figure 56. Abundance of immature (1-53 cm) and mature (>53 cm) thorny skate caught during the Georges Bank RV survey, 1987-2010 in the Canadian Zone (Strata 5Z1 and 5Z2).

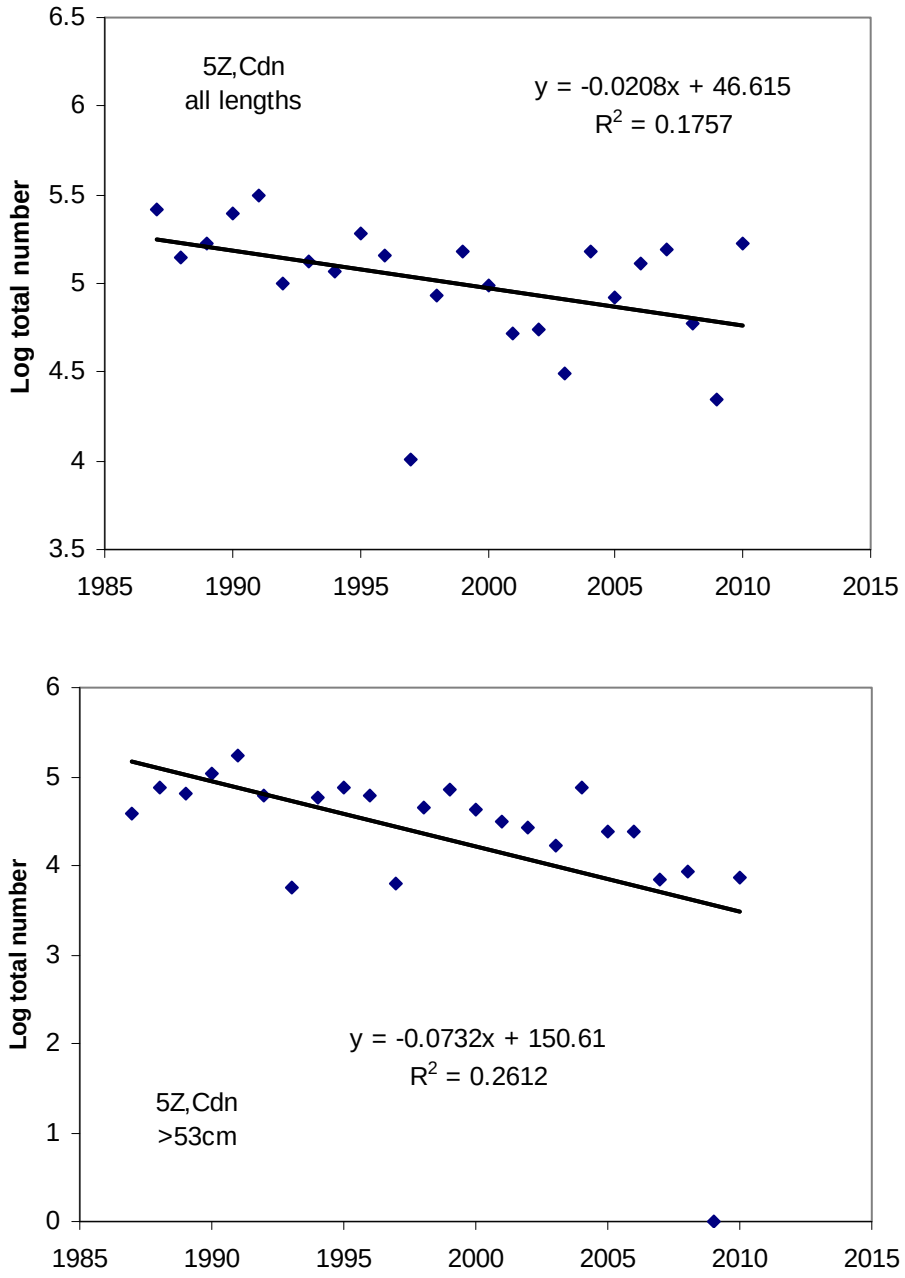

Figure 57. Log transformed abundance for all sizes of thorny skate (top panel) and those measuring >53cm (bottom panel) from the Georges Bank RV Survey for the Canadian strata only.

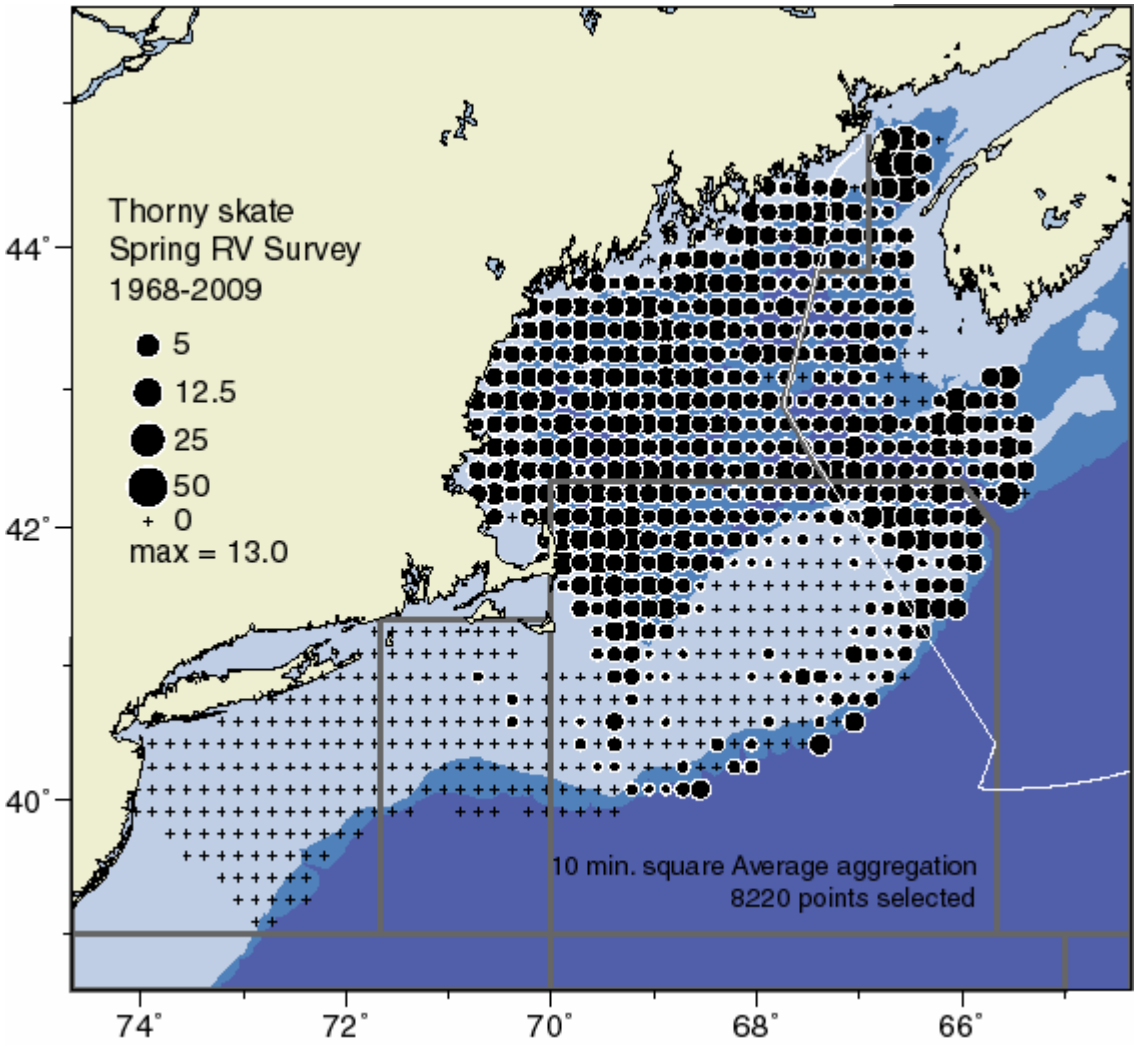

Figure 58. Distribution of thorny skate as indicated by the US Spring RV Survey, 1968-2009.

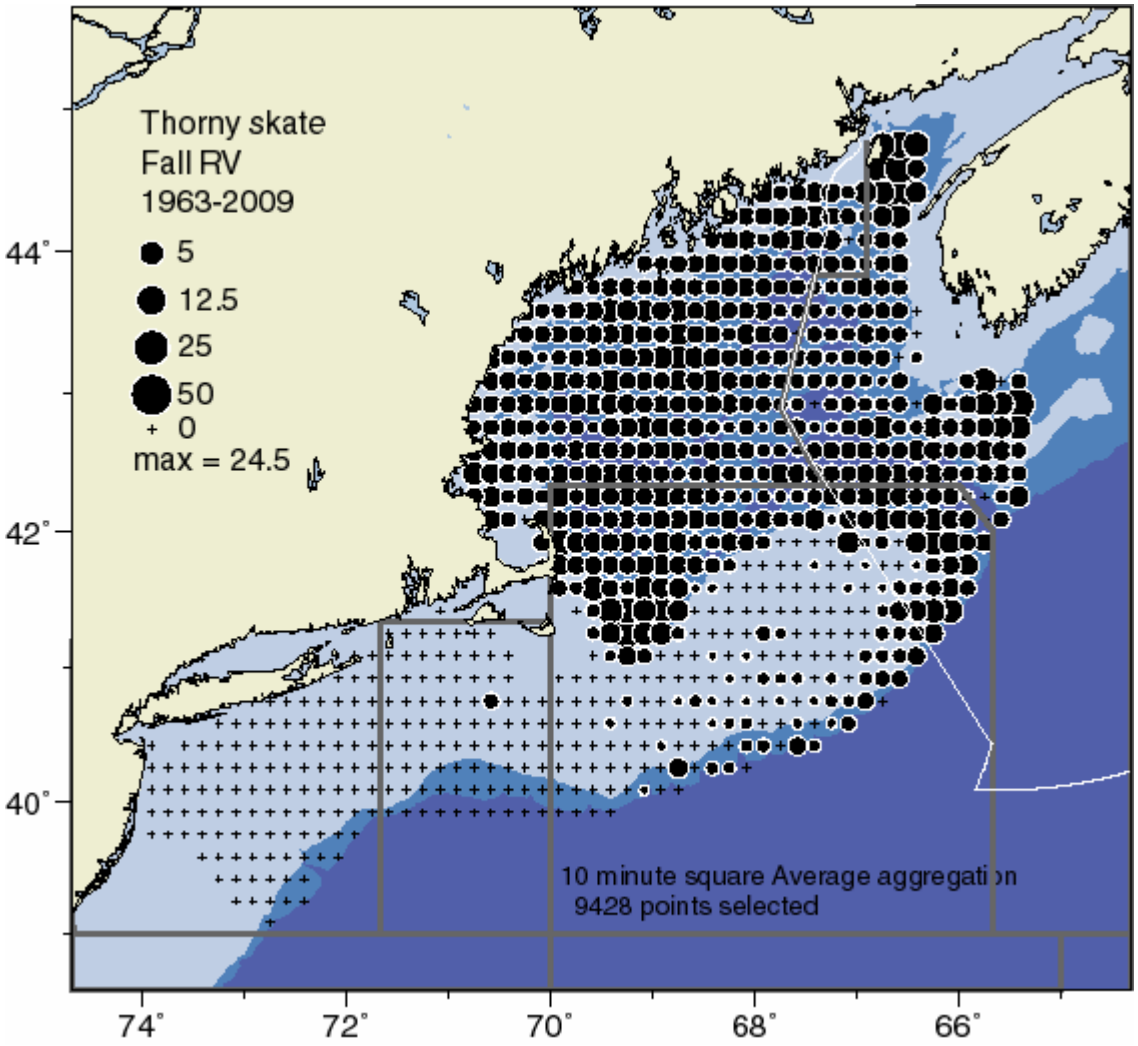

Figure 59. Distribution of thorny skate as indicated by the US Fall RV Survey, 1963-2009.

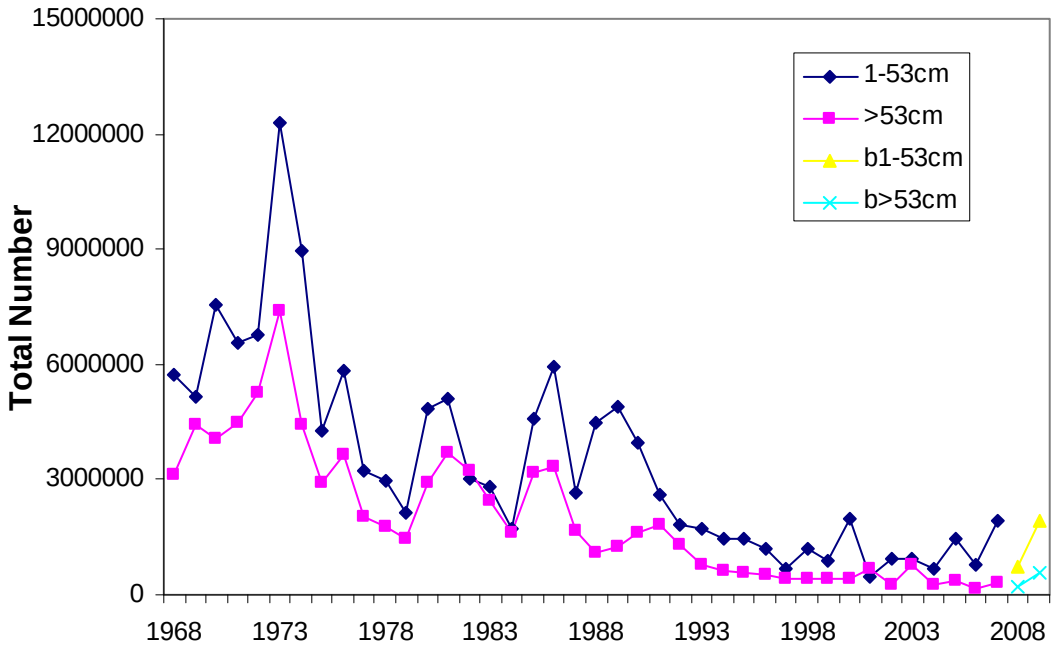

Figure 60. Abundance of thorny skate from the US Spring RV Survey aggregated into length groups greater and less than 53 cm. The 2008 and 2009 surveys were conducted by a different vessel (Bigelow) using a different tow protocol and gear (plotted separately on the figure (i.e. b1-53 cm in the legend)).

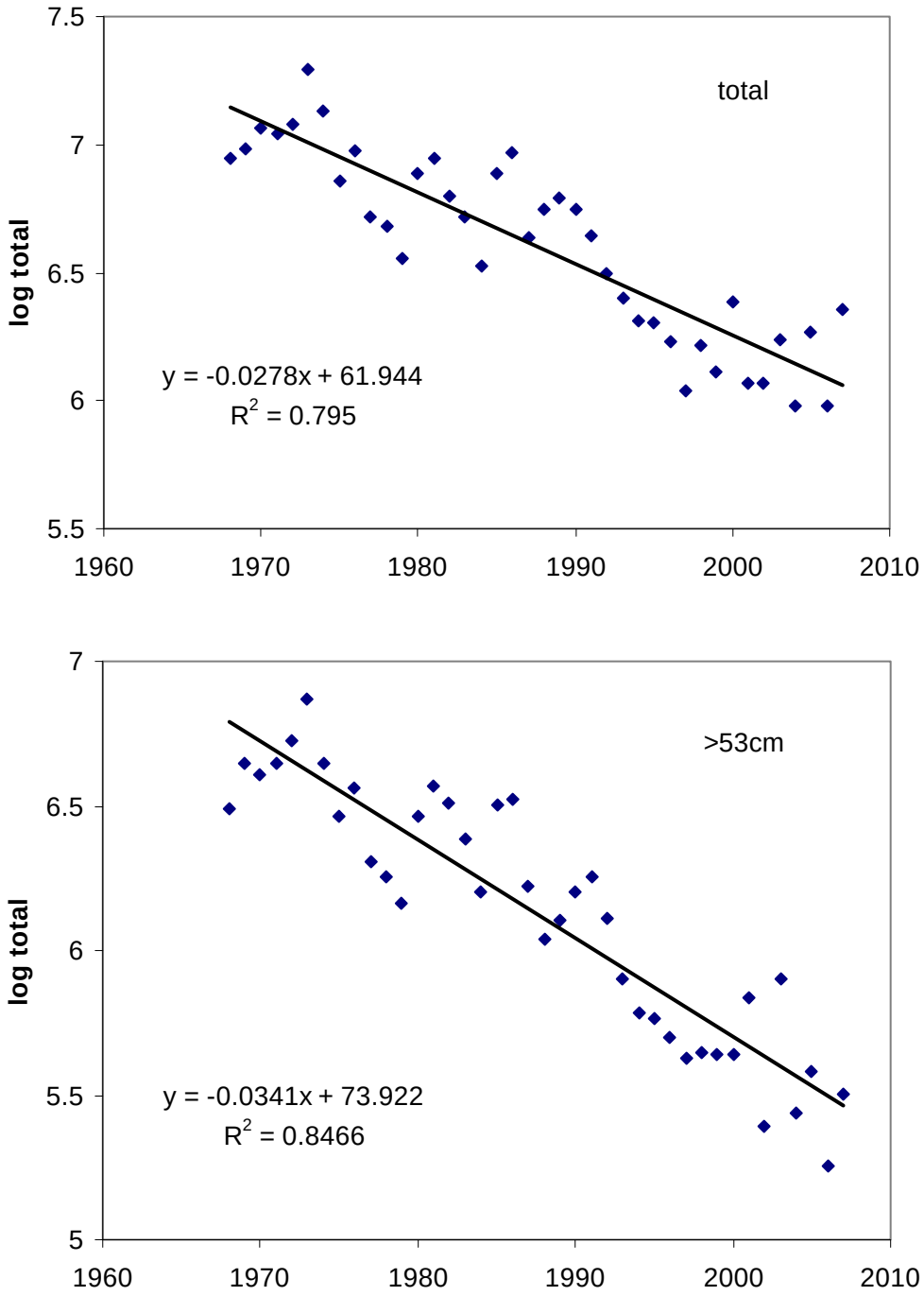

Figure 61. Log transformed total abundance of thorny skate (length groups (total and >53cm)) from all strata of the US Spring RV Survey, 1968-2007. Note that the 2008 and 2009 surveys were conducted using different tow protocols, gear, and vessel and were not included.

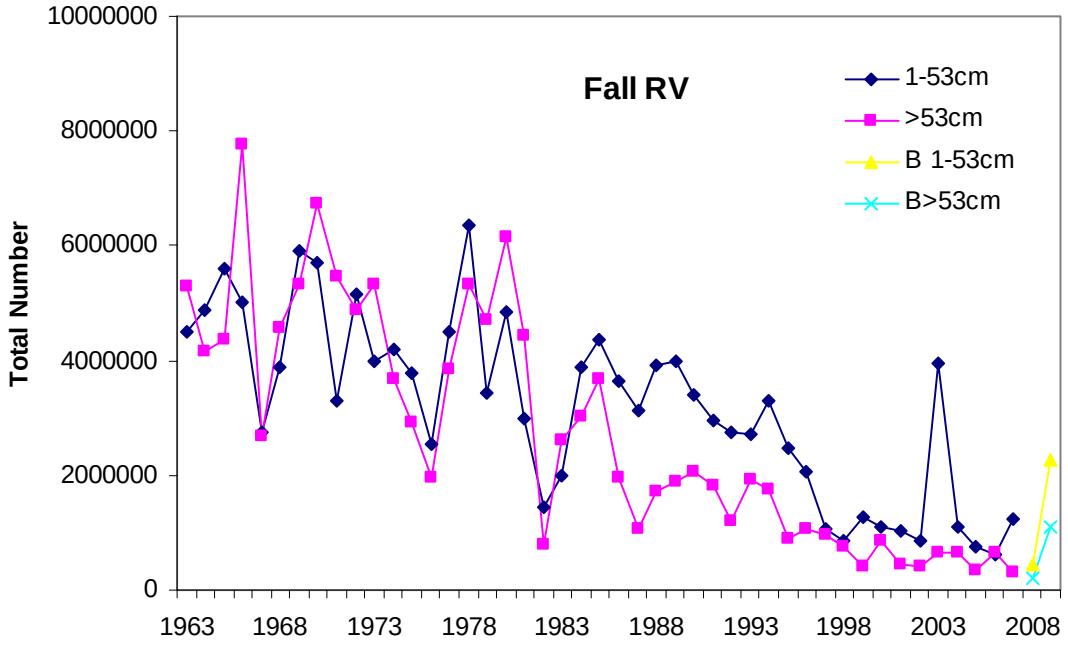

Figure 62. Abundance of thorny skate from the US Fall RV Survey aggregated into length groups greater and less than 53 cm. The 2008 and 2009 surveys were conducted by a different vessel (Bigelow) using a different tow protocol and gear (plotted separately on the figure (i.e. B1-53 cm in the legend)).

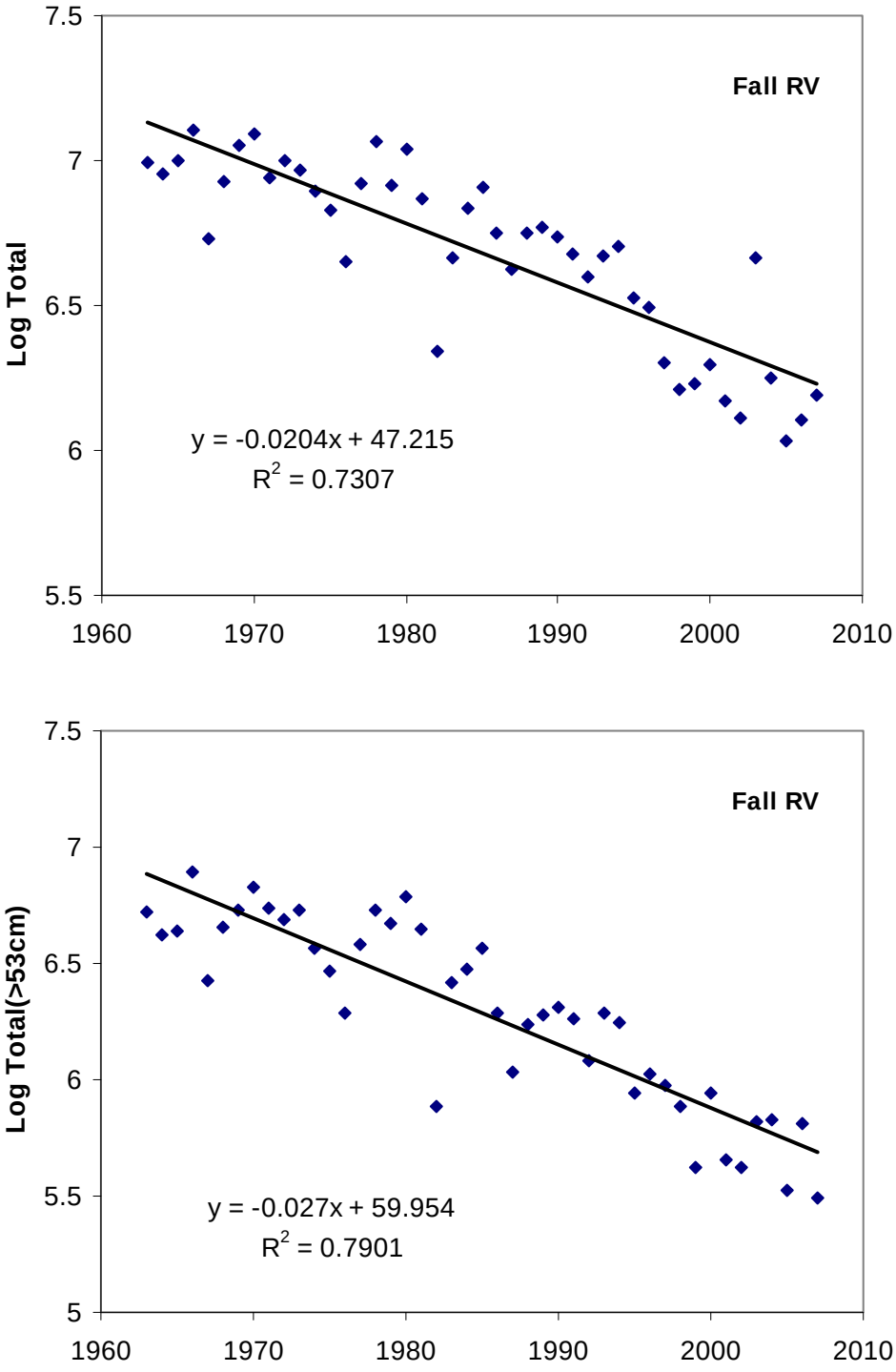

Figure 63. Log transformed total abundance of thorny skate (all lengths groups (top panel) and >53cm (bottom panel)) from the all strata of the US Fall RV Survey, 1963-2007. The 2008 and 2009 surveys were conducted using a different tow protocol, gear, and vessel and were not included.

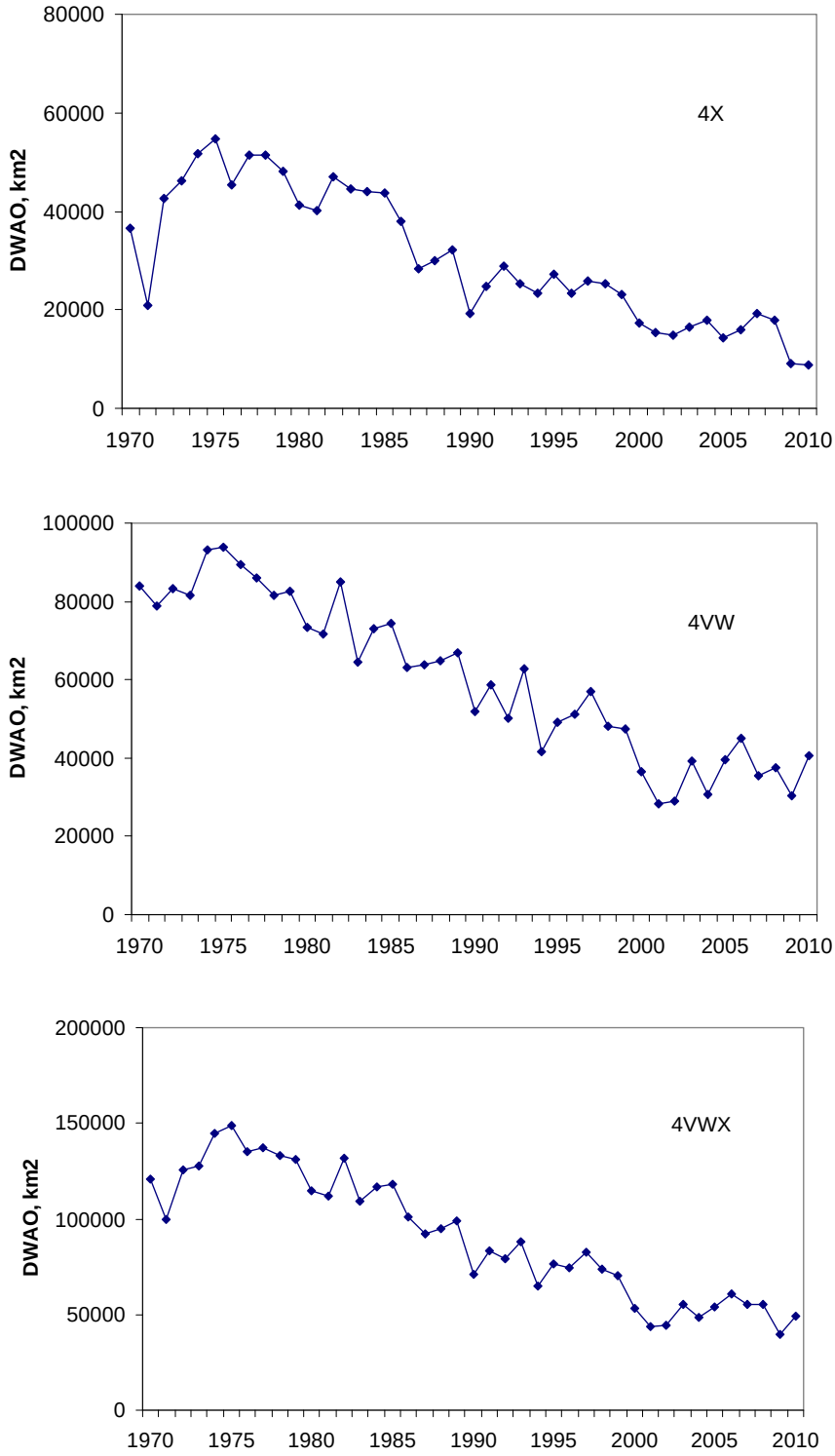

Figure 64. Design weighted area occupied (DWAO, km^2) of thorny skate as indicated by the Summer RV Survey.

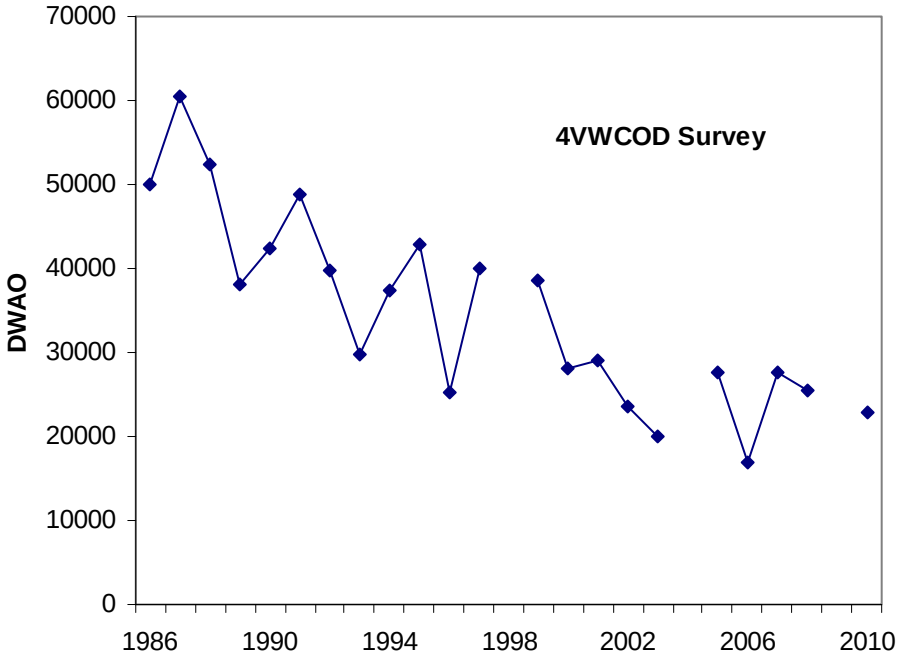

Figure 65. Design weighted area occupied (DWAO, km^2) of thorny skate as indicated by the 4VWCOD RV Survey, 1986-2010. Note that the 1998, 2004, and 2009 surveys are missing or incomplete.

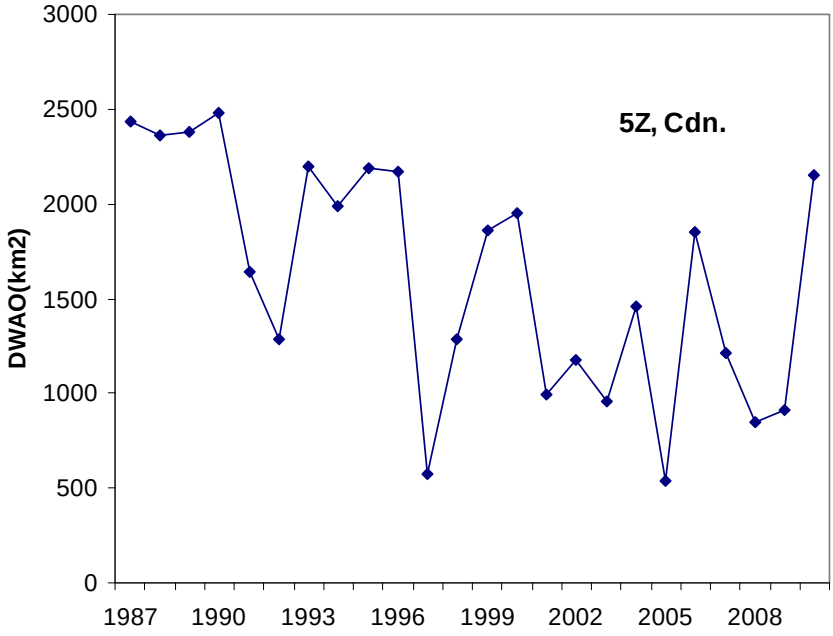

Figure 66. Design weighted area occupied (DWAO, km^2) of thorny skate as indicated by the Georges Bank RV survey.

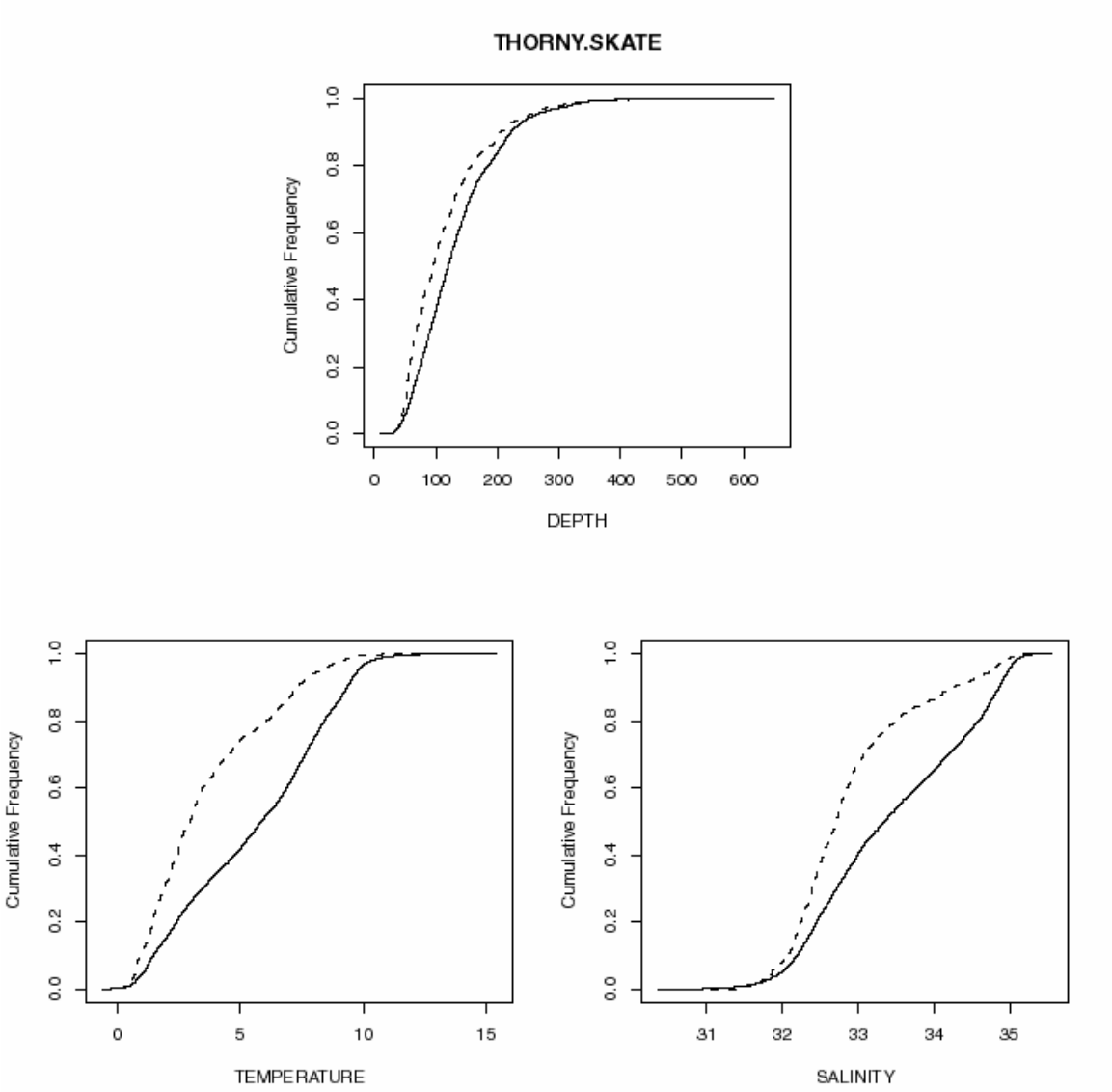

Figure 67. Cumulative stratified abundance of thorny skate compared to the cumulative stratified depth, temperature, and salinity from the Summer RV Survey. The solid line is the survey estimate while the dashed line is the estimate for thorny skate.

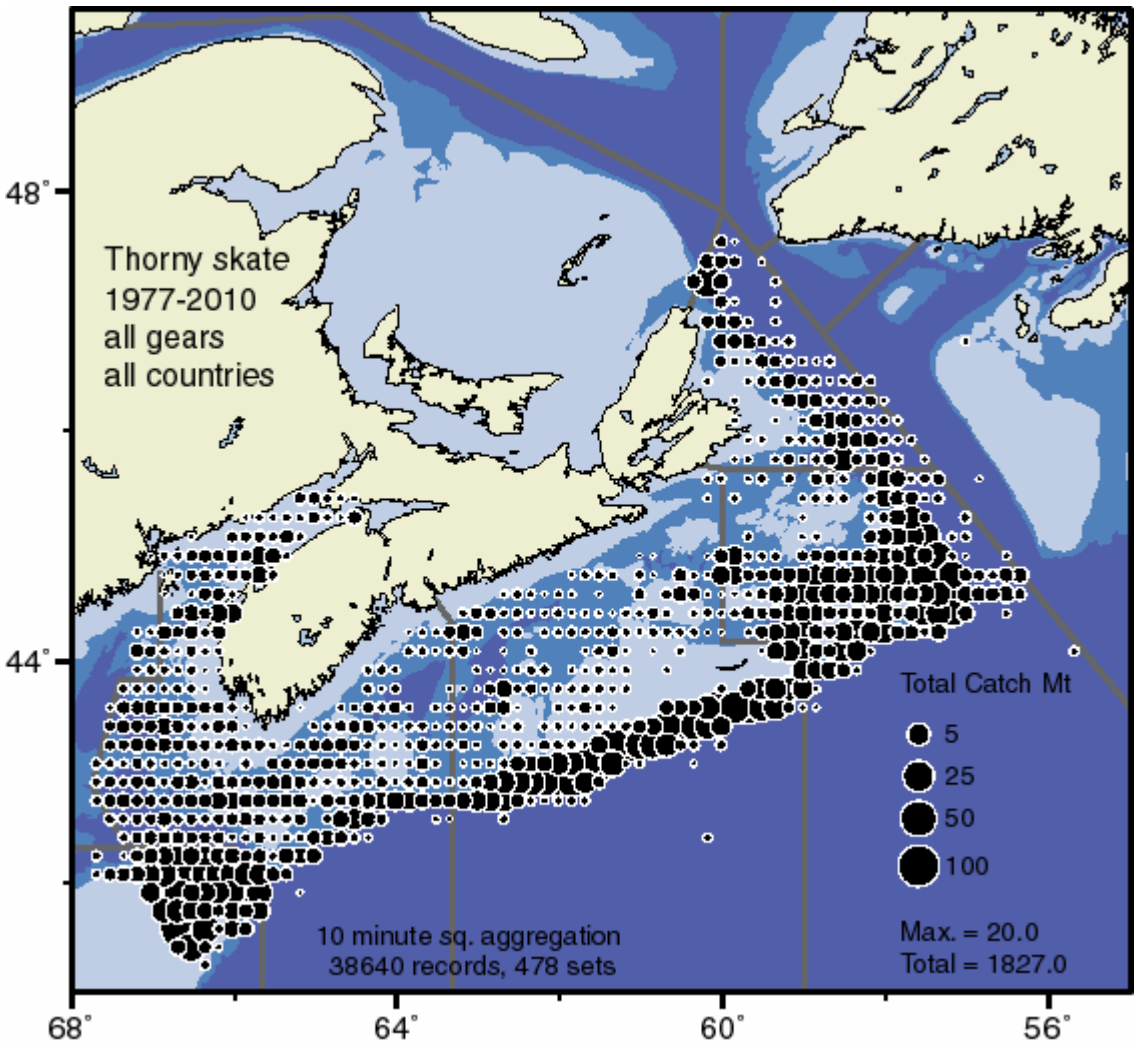

Figure 68. Reported locations of thorny skate from the Maritimes Observer Program from 1977-2010.

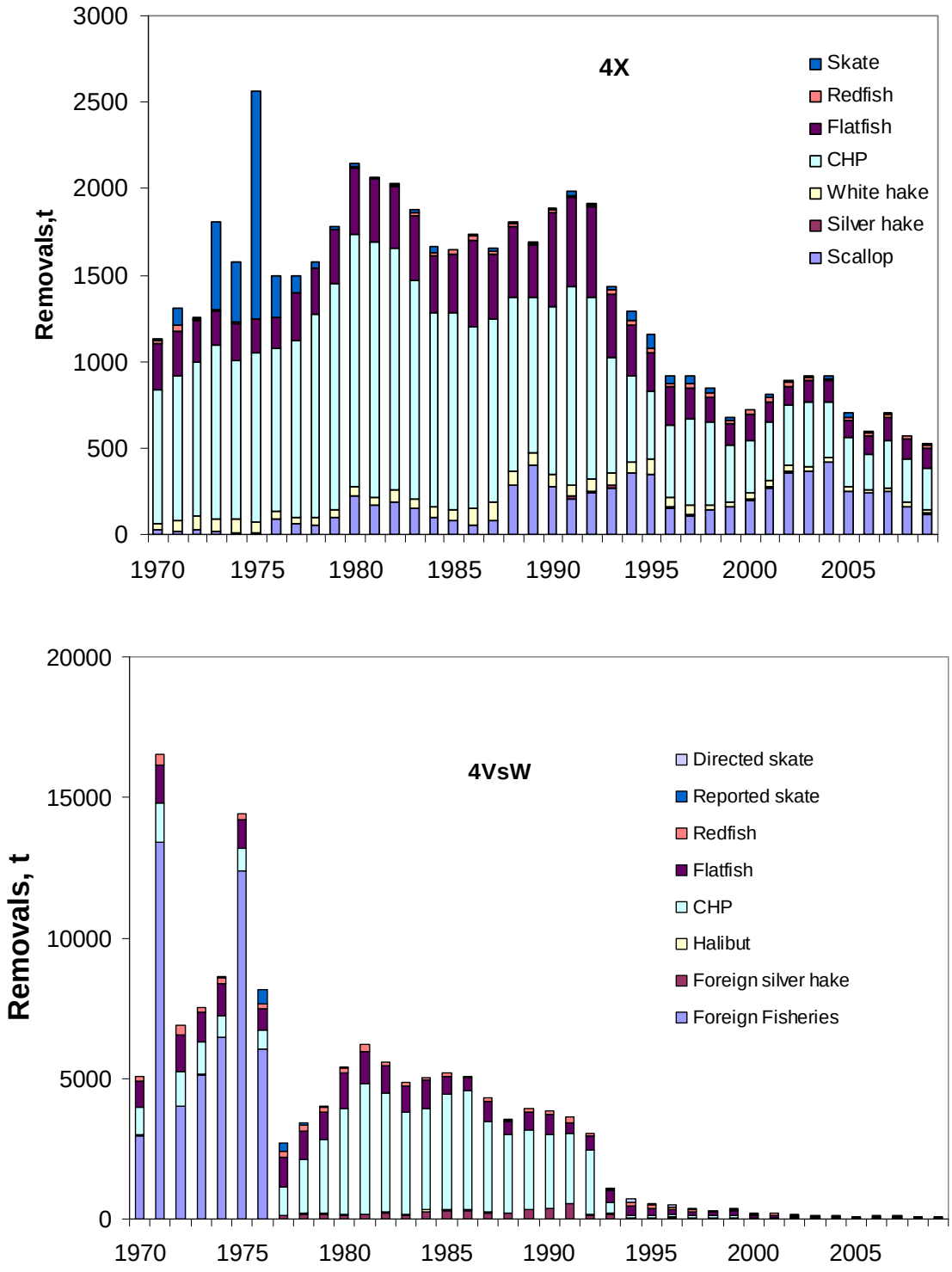

Figure 69. Estimated removals, t of thorny skate from selected directed fisheries in Div. 4X and Divs. 4VsW as derived from observer reports. Observer coverage in other fisheries was insufficient to estimate removals or thorny skate was not reported as bycatch.

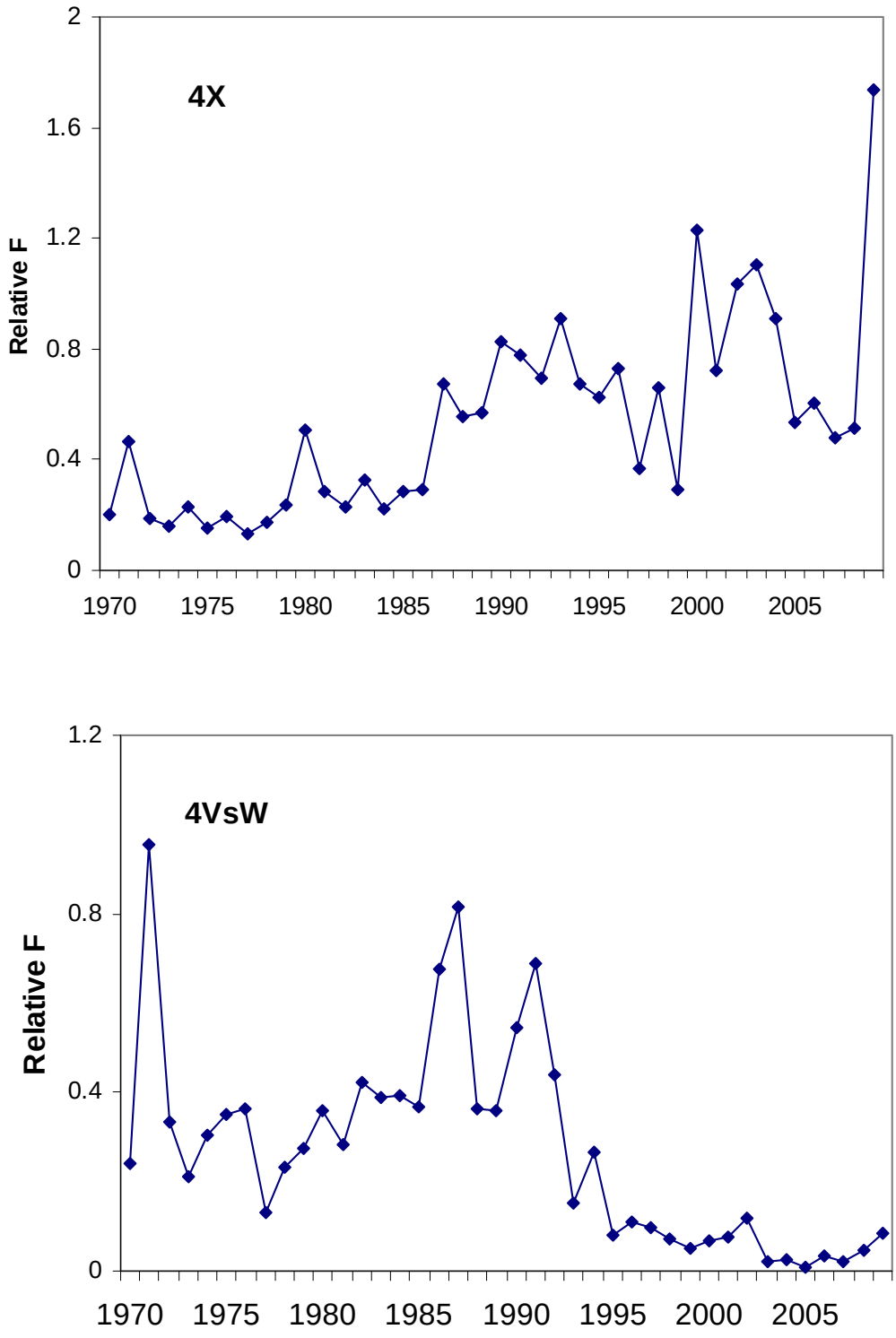

Figure 70. Relative F (fishing mortality) derived from the estimated removals of thorny skate and summer RV biomass for Div. 4X and Divs. 4VsW.

APPENDIX A

METHODS

Predation

Observed predation of smooth and thorny skate was complied by querying DFO Maritimes Region Population Ecology Division's stomach database (Cook and Bundy 2010). This database consists of >156,000 stomachs for 68 predator species from 21 data sources focused on NAFO Divs. 4VWX, but does include limited information from NAFO Divs. 3OP, 4T and 5YZ. Data spans four decades (1958-1969; 1981-1990, 1991-1998 and 1999-2008).

Diets

Data Source

Food habits data was collected during winter (February-April) and summer (July-August) DFO research vessel surveys between 1999 and 2008. Both surveys use a stratified random design and stomach contents are obtained from a length stratified sample of the catch. The Summer RV Survey is conducted across NAFO Divs. 4VWX whereas the winter survey is performed in 4VsW. Stomachs were excised and either processed at sea or frozen and analyzed in the lab. Full details on stomach sampling protocols are given in Cook and Bundy (2010). Data was separated into Div. 4X and Divs. 4VW as well as two seasons winter and summer for diet comparisons.

Data Analysis

Species Accumulation Curves

We used species accumulation curves (SAC) to determine the adequacy of information to characterize the diets. The SAC plot compares the number of species observed against the measure of sampling effort, or in this instance, the number of prey items observed against the number of stomachs examined. The rate of 'new' prey items identified is the largest for the first several stomachs examined, which declines as more stomachs are examined since the incidence of unique prey items decreases. Eventually, this relationship reaches an asymptote. This indicates a low probability that novel prey items will be identified with the examination of additional stomachs and that the prey breath has been adequately defined. In cases where prey items are only identified to broad taxonomic levels, an asymptote may be reached at a low sample size, indicating that more effort needs to be directed toward prey identification for these groups. SACs were generated in the R-project package vegan (Oksanen et al. 2010; R development core team 2009), using the random ordering method with 100 permutations. The plots produced depict the SAC and the confidence interval polygons. A family (FAM) prey grouping was selected to ensure consistency in describing the diet across predators since prey items are recorded at different levels of resolution. For example, fish are usually identified to the species level, whereas some invertebrates are only recorded at the family level.

Diet Summary

We developed mean stomach content weights of prey items for both smooth and thorny skate for each season and area. These estimates incorporate the survey design and the catch rates as suggested in Warren et al. (1994). Overall means and variances were obtained from the annual mean diet estimates. Additionally, the frequencies of occurrence of prey items were

determined. Mean frequency of occurrence was obtained from the annual estimates and variances were obtained by bootstrapping (Efron and Tibshirani 1993).

RESULTS

Predation on thorny skate by fish predators was negligible although Atlantic halibut, sea raven, American plaice, Atlantic cod and porbeagle sharks have all been observed with thorny skate in their stomach contents. Smooth skate has never been observed in the stomach contents of any fish predator in our database (Table A1).

Sample sizes of feeding thorny and smooth skate ranged between 134 – 527 and 58 – 94 respectively, for each region and season (Table A2). Species accumulation curves indicated that diets are approaching their asymptote, particularly for thorny skate; however, more sampling is required to fully depict diets (Figure A1, A2). The length of thorny and smooth skate examined range from 8 -102 cm and 8 – 60 cm respectively and varied little between season and region (Figure A3, A4). The proportion of feeding fish decreased in the winter months for both thorny and smooth skate (Table A2).

The frequency of occurrence of thorny skate prey items changed little between areas and seasons with identified items including arthropods, gammarid amphipods, shrimps, euphausiids, oregoniids and annelids (Figure A5). Weight based descriptions of diet show an increase in the proportion of large items in the diet; however, shrimps, oregoniids, arthropods and gammarid amphipods are still important components of thorny skate weight based diets (Figure A6). The largest weight of fish consumed in Divs. 4VW includes Ammodytes, Scombrids, Clupeids, and Merlucciids, whereas Div. 4X includes Zoarcids, Gadids, and Scorpaenids (Figure A6, Table A3). Of the Oregoniidae species consumed by thorny skate, 10% were *Chionoecetes opilio*.

Smooth skate's diet does not change appreciably between seasons or areas (Figure A7, A8; Table A3). The main constituents for the diet for smooth skate are shrimps, arthropods, oregoniids, euphausiids and crustacean. Overall, they consume less fish than do thorny skate; however, Cottids, Osmerids, Gadid, and Macrourids were identified as prey items (Table A4). Of the Oregoniidae species consumed by smooth skate, 12% were *Chionoecetes opilio*.

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Table A1: Instances of observed predation recorded in the food habits database.

Predator	N Stomachs Examined	Thorny Skate (n)	Smooth Skate (n)
American plaice	13627	1	0
Atlantic cod	32153	1	0
Atlantic halibut	1337	3	0
Porbeagle shark	1452	1	0
Sea raven	1175	2	0

Table A2: Sample sizes of thorny and smooth skate stomachs examined, numbers feeding and the proportion feeding separated by region and season.

		Thorny Skate			Smooth Skate		
Region	Season	Total Examined	Feeding	Prop.	Total Examined	Feeding	Prop.
4X	Summer	207	134	0.65	121	58	0.48
4VW	Summer	917	527	0.57	149	88	0.59
4VW	Winter	1454	447	0.31	318	94	0.30

Table A3: Thorny skate diet separated by region and season.

	4X Summer		4VW Summer		4VW Winter	
	Wt	Freq	Wt	Freq	Wt	Freq
Agonidae	.	.	0.000	0.002	.	.
Ammodytidae	0.097	0.029	1.915	0.070	0.164	0.018
Annelida	0.869	0.465	0.093	0.135	0.483	0.203
Aphroditidae	0.343	0.122	0.024	0.025	0.006	0.007
Arthropoda	0.156	0.203	0.321	0.306	0.143	0.142
Ascidia	.	.	0.038	0.002	.	.
Bivalvia	.	.	0.012	0.007	0.004	0.007
Cancridae	0.202	0.022	0.020	0.006	.	.
Caprellidae	.	.	0.002	0.015	0.013	0.008
Cephalpoda	0.159	0.035	.	.	0.018	0.007
Cnideria	.	.	0.000	0.002	0.000	0.002
Copepoda	.	.	.	.	0.000	0.015
Crangonidae	.	.	0.033	0.010	.	.
Cumacea	0.000	0.007	0.000	0.002	0.002	0.015
Shrimps	0.369	0.262	1.242	0.243	0.505	0.146
Echinodermata	0.029	0.015	0.011	0.004	.	.
Euphausiidae	0.157	0.149	0.105	0.056	0.004	0.024
Fish Eggs and Larvae	.	.	0.000	0.002	0.009	0.007
Gadidae	0.173	0.007	0.002	0.002	.	.
Galatheidae	.	.	.	.	0.013	0.002
Gammaridae	0.413	0.277	0.283	0.241	0.025	0.166
Gastropoda	.	.	0.042	0.006	.	.
Hippolytidae	.	.	0.000	0.002	.	.
Hyperiidae	0.001	0.009	0.026	0.035	0.014	0.011
Isopoda	0.081	0.075	0.007	0.023	0.006	0.008
Merlucciidae	.	.	.	.	0.163	0.002
Mollucsa	.	.	.	.	0.004	0.002
Myctophidae	0.029	0.007	.	.	.	.
Mysidae	0.003	0.015	0.004	0.012	.	.
Nereidae	0.023	0.007	.	.	.	.
Nuculanidae	.	.	0.000	0.002	.	.
Ommastrephidae	0.259	0.020	0.163	0.002	0.015	0.003
Ophiuroids	.	.	0.006	0.012	.	.
Oregoniidae	1.896	0.062	0.468	0.074	0.205	0.026
Osmeridae	.	.	0.012	0.002	0.001	0.003
Unid Remains	2.611	0.618	1.864	0.536	1.103	0.604
Unid Fish	0.448	0.063	0.840	0.075	0.606	0.068
Paguridae	0.216	0.029	0.014	0.009	0.004	0.003
Pandalidae	0.072	0.037	0.280	0.029	0.085	0.009
Parasites	0.019	0.104	0.009	0.077	0.026	0.028
Pasiphaeidae	0.212	0.041	.	.	.	.
Phyllodocidae	0.004	0.008	0.003	0.006	.	.
Pleuronectidae	.	.	0.041	0.005	0.013	0.005
Polynoidae	.	.	0.000	0.007	.	.
Priapulidae	0.007	0.007	.	.	.	.
Pycnogonia	.	.	.	.	0.000	0.002
Scombridae	.	.	0.212	0.002	.	.
Scorpaenidae	0.037	0.009	.	.	.	.
Macrophytes	0.000	0.007	0.001	0.009	.	.
Sepiolodae	.	.	0.015	0.002	.	.
Stichaeidae	.	.	0.069	0.008	.	.
Thalassinidae	0.167	0.029	.	.	.	.
Tunicata	.	.	0.000	0.002	.	.
Crustacea	0.043	0.028	0.046	0.042	0.003	0.006
Zoarcidae	0.433	0.017	.	.	.	.

Table A4: Smooth skate diet by weight and frequency of occurrence separated by season and area.

	4X Summer		4VW Summer		4VW Winter	
	Wt	**Freq**	**Wt**	**Freq**	**Wt**	**Freq**
Agonidae	0.009	0.016	.	.	0.005	0.021
Ammodytidae	0.188	0.028	0.346	0.012	.	.
Annelida	0.024	0.046	.	.	0.045	0.047
Aphroditidae	.	.	0.008	0.013	0.011	0.022
Arthropoda	0.024	0.083	0.139	0.178	0.163	0.152
Bivalvia	.	.	0.000	0.013	.	.
Cancridae	0.141	0.014	.	.	.	.
Caprellidae	0.005	0.026	.	.	0.008	0.021
Cottidae	.	.	0.012	0.033	.	.
Crangonidae	.	.	0.012	0.013	.	.
Shrimps	1.115	0.529	1.209	0.346	0.862	0.478
Euphausiidae	0.110	0.092	0.128	0.099	0.050	0.084
Fish larvae	0.010	0.016	.	.	.	.
Gadidae	.	.	.	.	0.015	0.011
Gammaridae	0.091	0.134	0.170	0.098	0.132	0.021
Hippolytidae	0.002	0.014	.	.	.	.
Hyperiidae	0.000	0.014	0.033	0.077	.	.
Isopoda	0.001	0.013	0.038	0.013	.	.
Lithodidae	0.047	0.033	.	.	.	.
Macrouridae	.	.	.	.	0.180	0.012
Mollusca	0.001	0.013	.	.	.	.
Mysidae	0.030	0.016	0.007	0.013	.	.
Oregoniidae	0.247	0.030	0.650	0.172	0.068	0.114
Osmeridae	.	.	0.188	0.012	0.556	0.509
Unid Remains	0.928	0.483	1.280	0.514	0.038	0.033
Unid Fish	0.002	0.014	0.173	0.048	0.005	0.012
Paguridae	0.019	0.030	0.055	0.048	0.141	0.023
Pandalidae	0.094	0.067	0.337	0.122	.	.
Parasites	0.015	0.026	.	.	.	.
Pasiphaeidae	0.014	0.017	.	.	0.001	0.012
Macrophytes	0.027	0.053	.	.	.	.
Tunicata	0.001	0.013	.	.	.	.
Crustacea	0.210	0.095	0.249	0.110	.	.

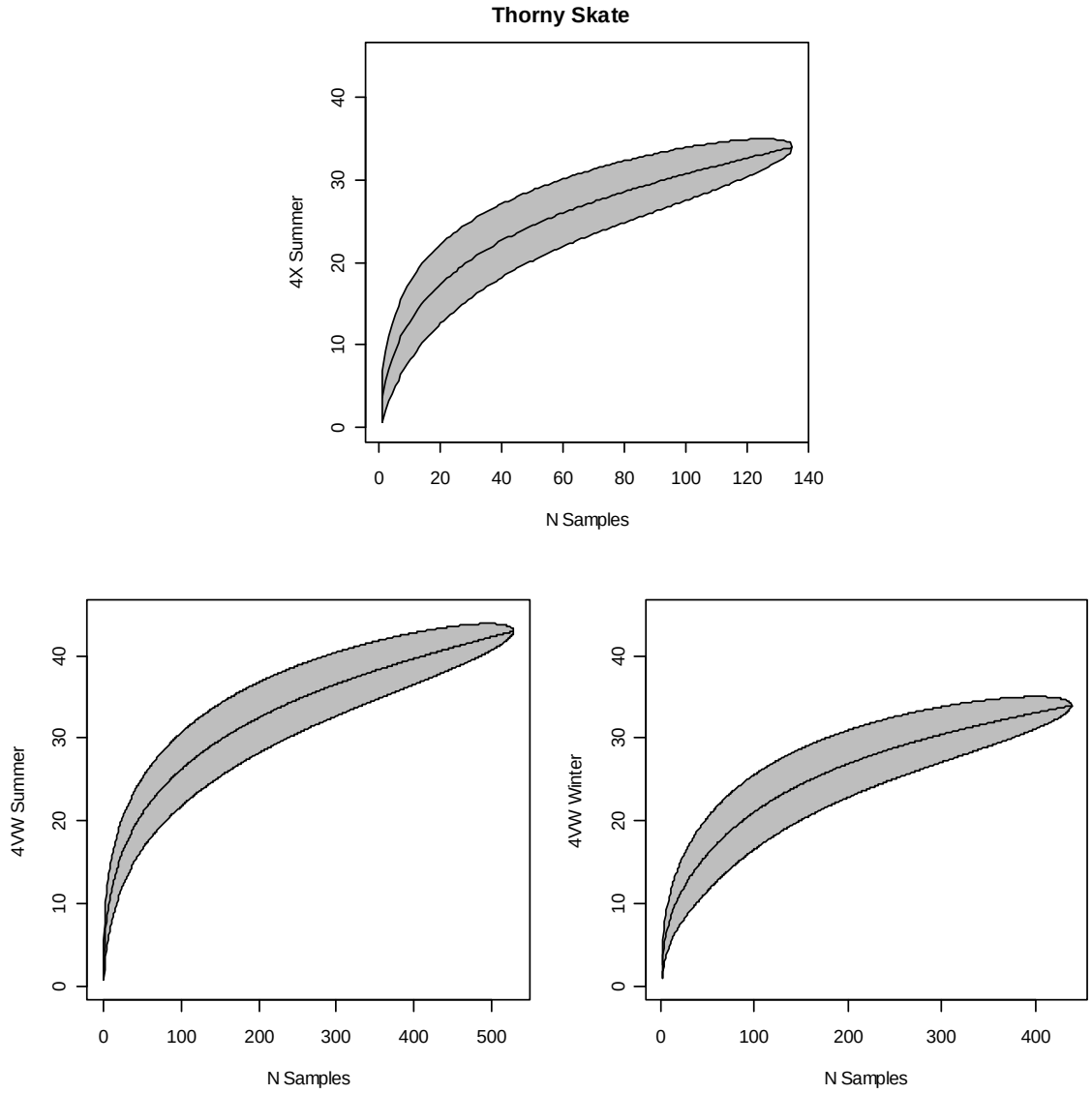

Figure A1: Species accumulation curves for thorny skate sampled in RV surveys between 1999 and 2008 across two regions and seasons.

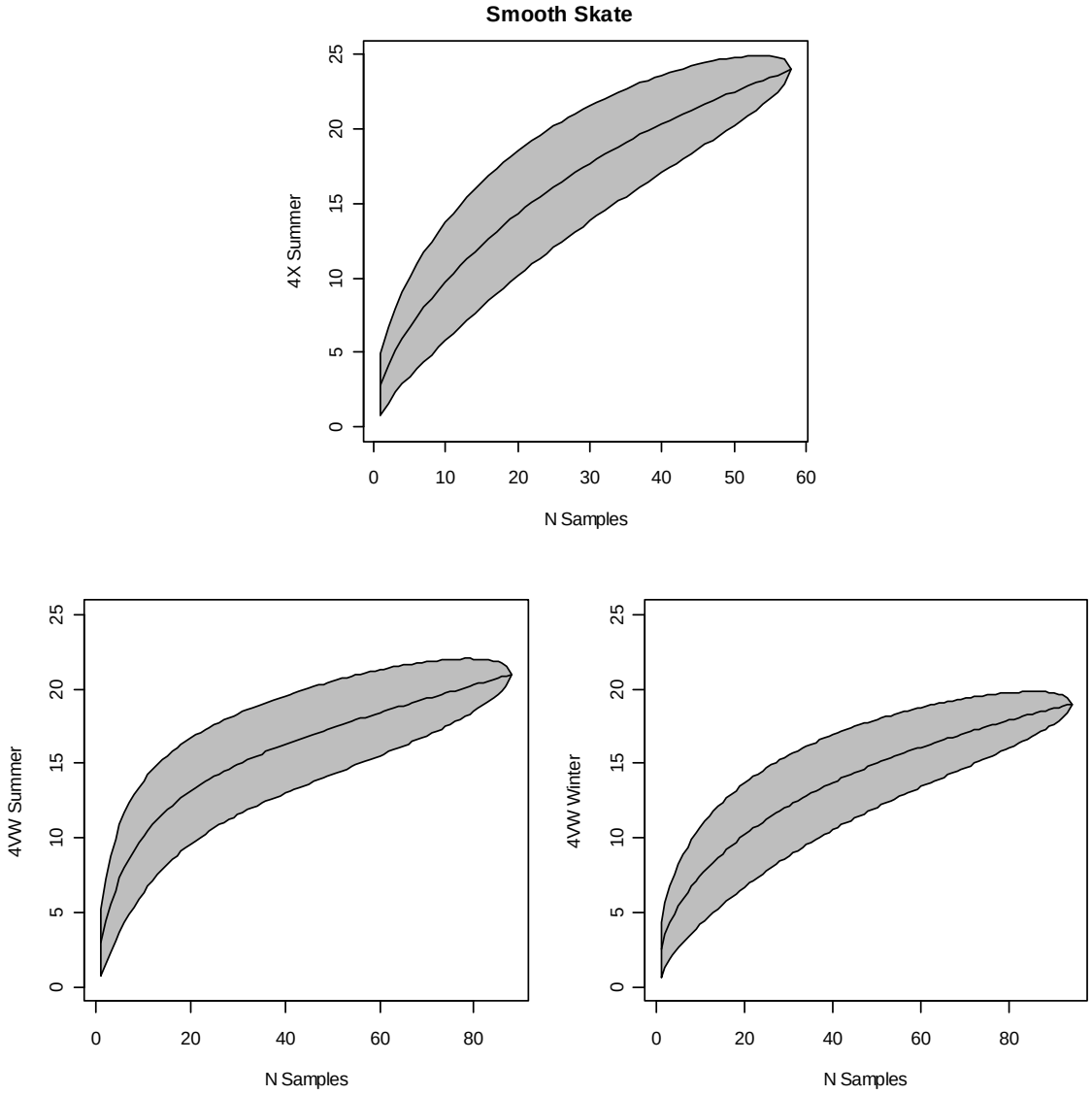

Figure A2: Species accumulation curves for smooth skate sampled in RV surveys between 1999 and 2008 across two regions and seasons.

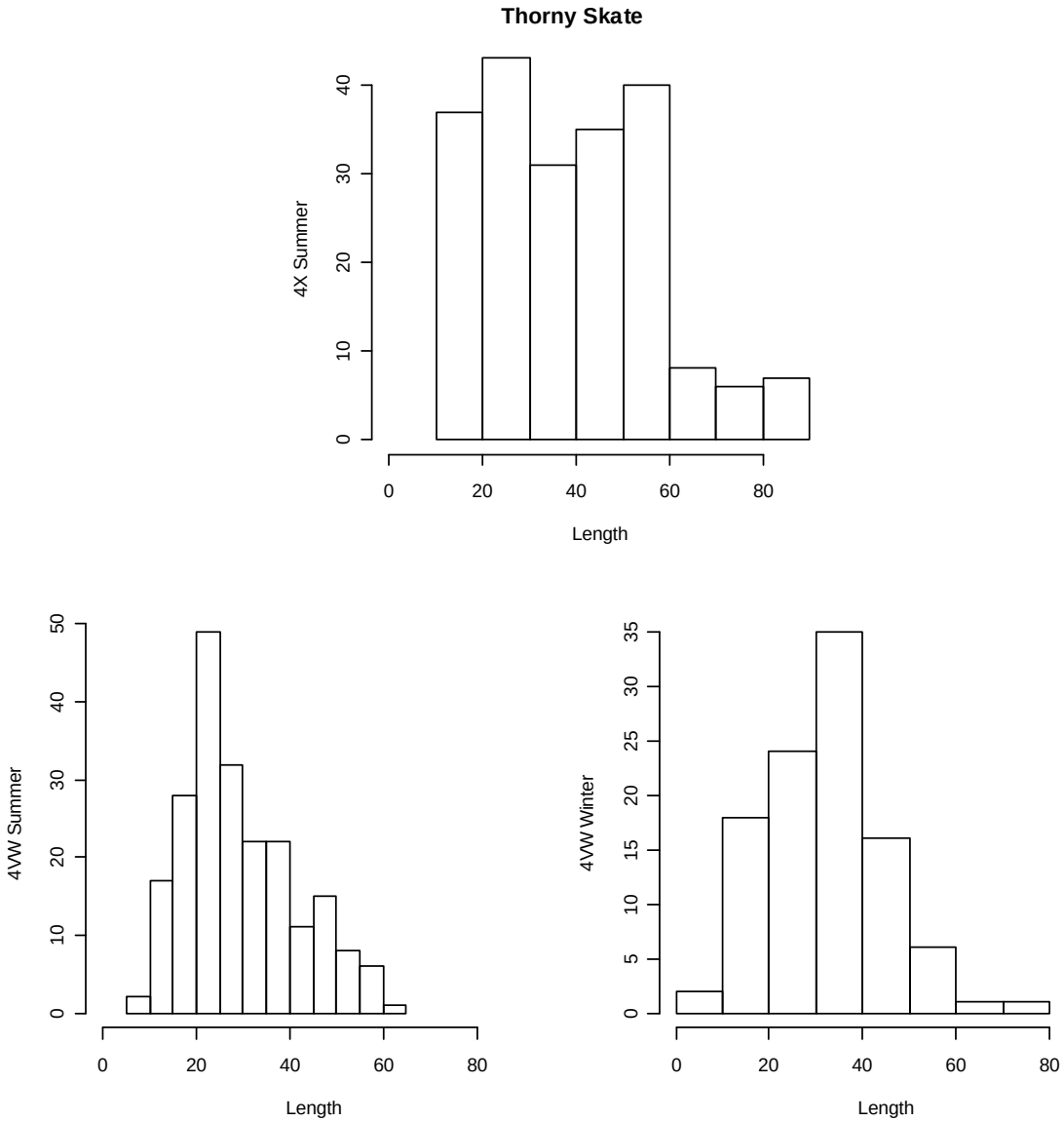

Figure A3: Length histograms of thorny skate sampled for stomach contents across regions and seasons.

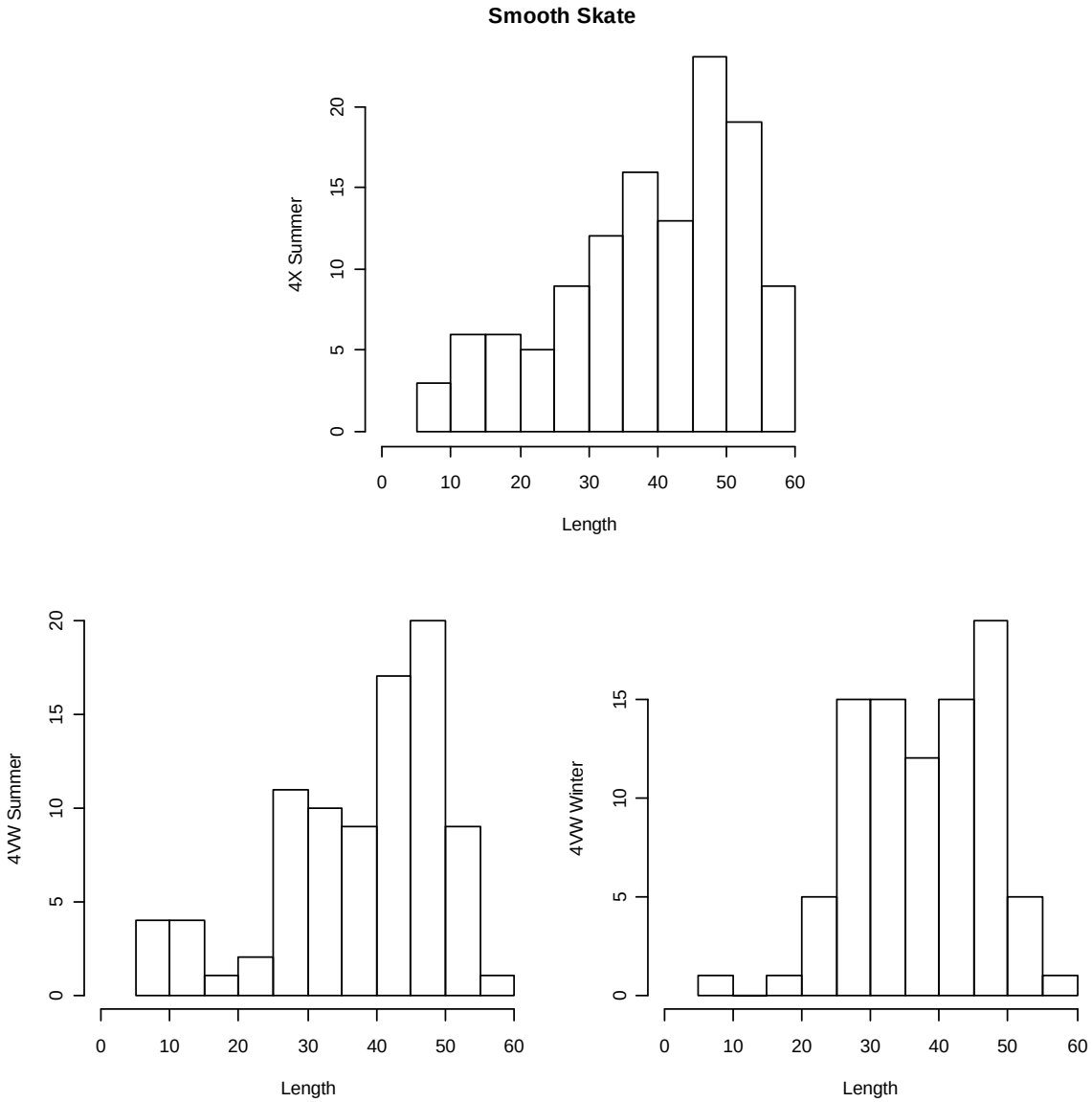

Figure A4: Length histograms of smooth skate sampled for stomach contents across regions and seasons.

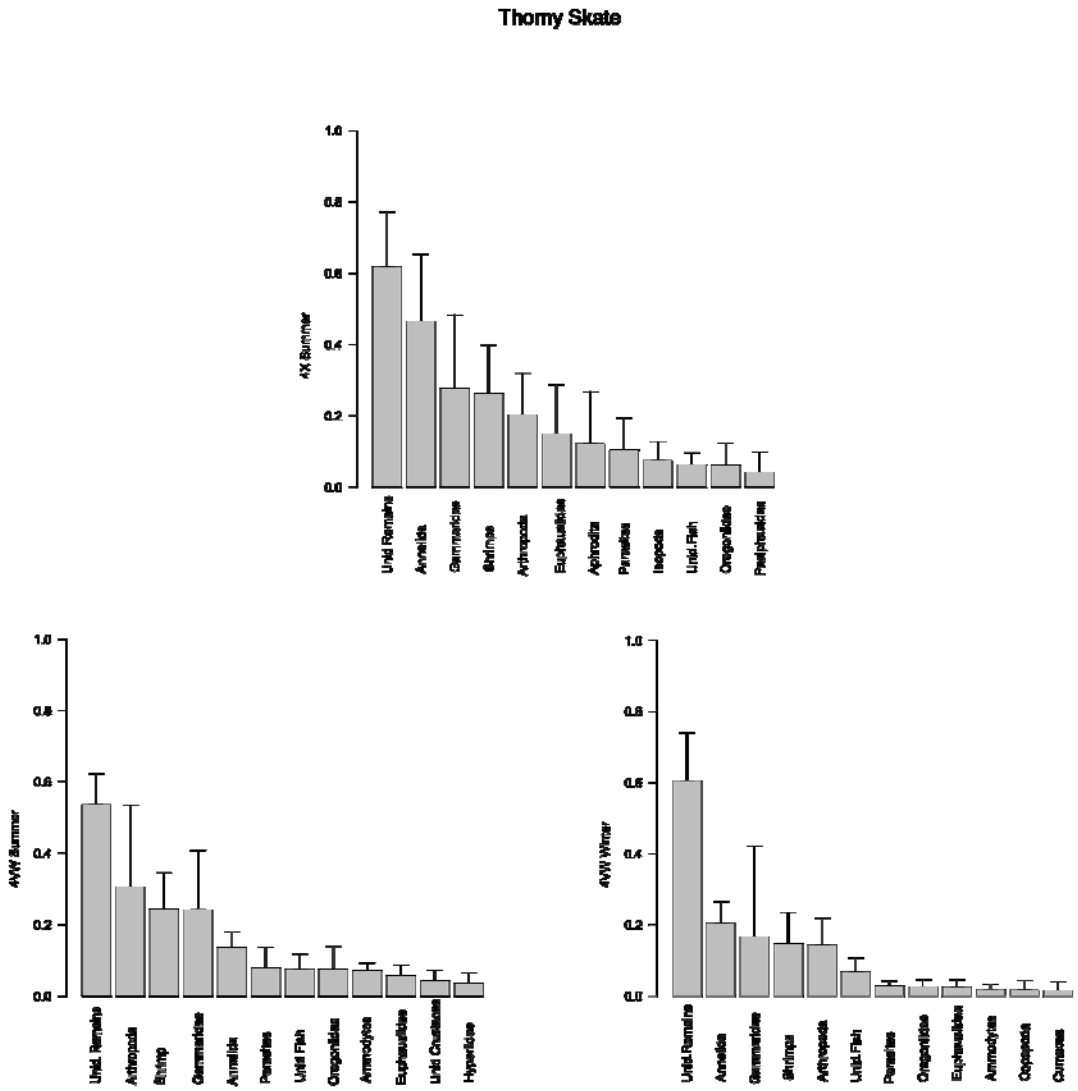

Figure A5: Frequency of occurrence of thorny skate's top twelve prey items across regions and seasons.

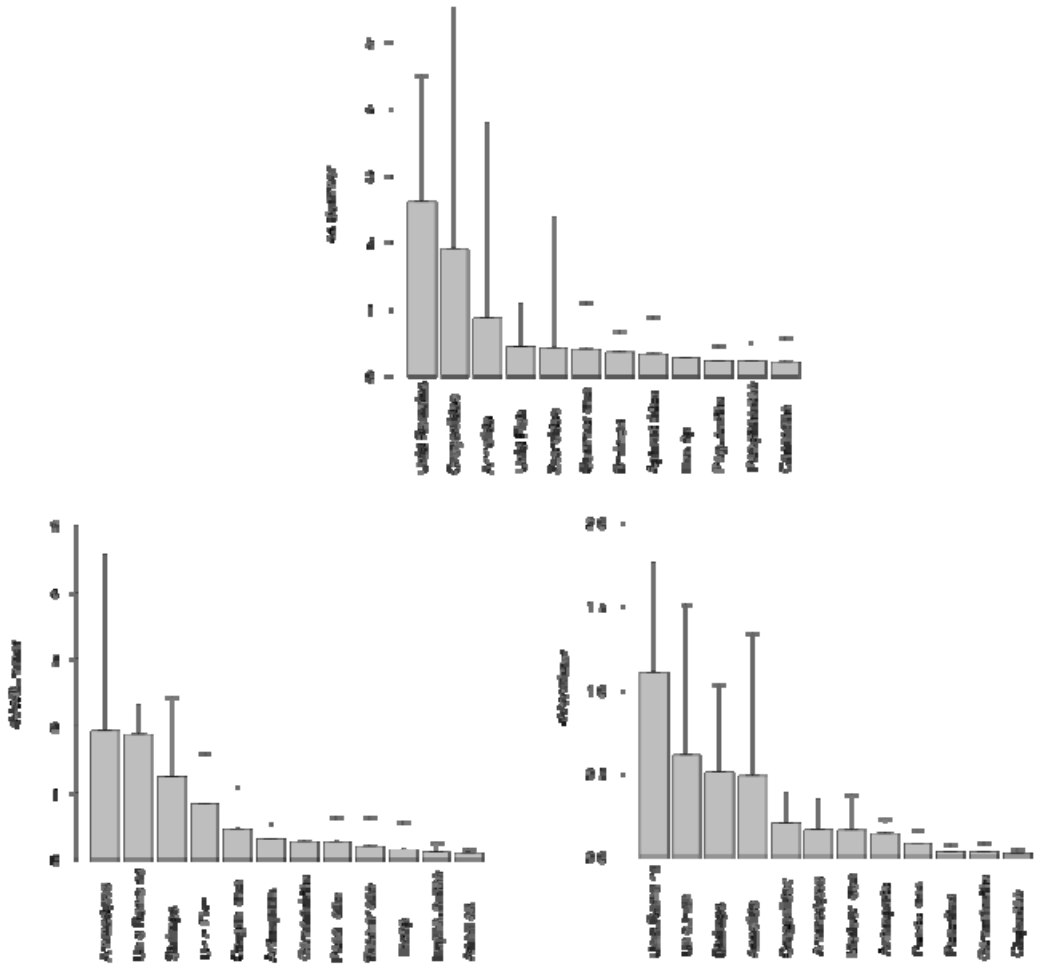

Figure A6: Diet composition of most abundant prey items by weight (g) in thorny skate diets by area and season.

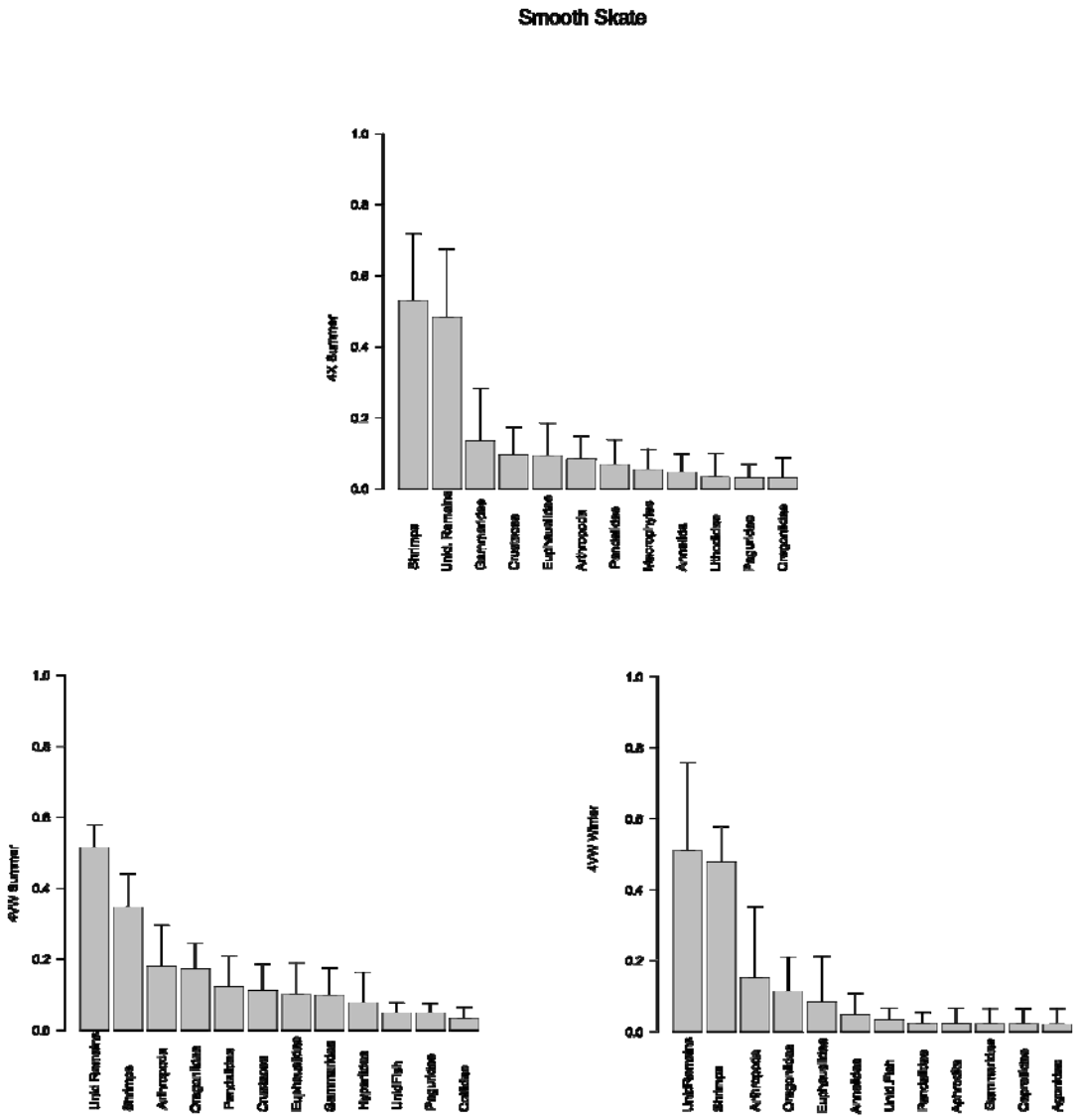

Figure A7: Frequency of occurrence of smooth skate's top twelve prey items across regions and seasons.

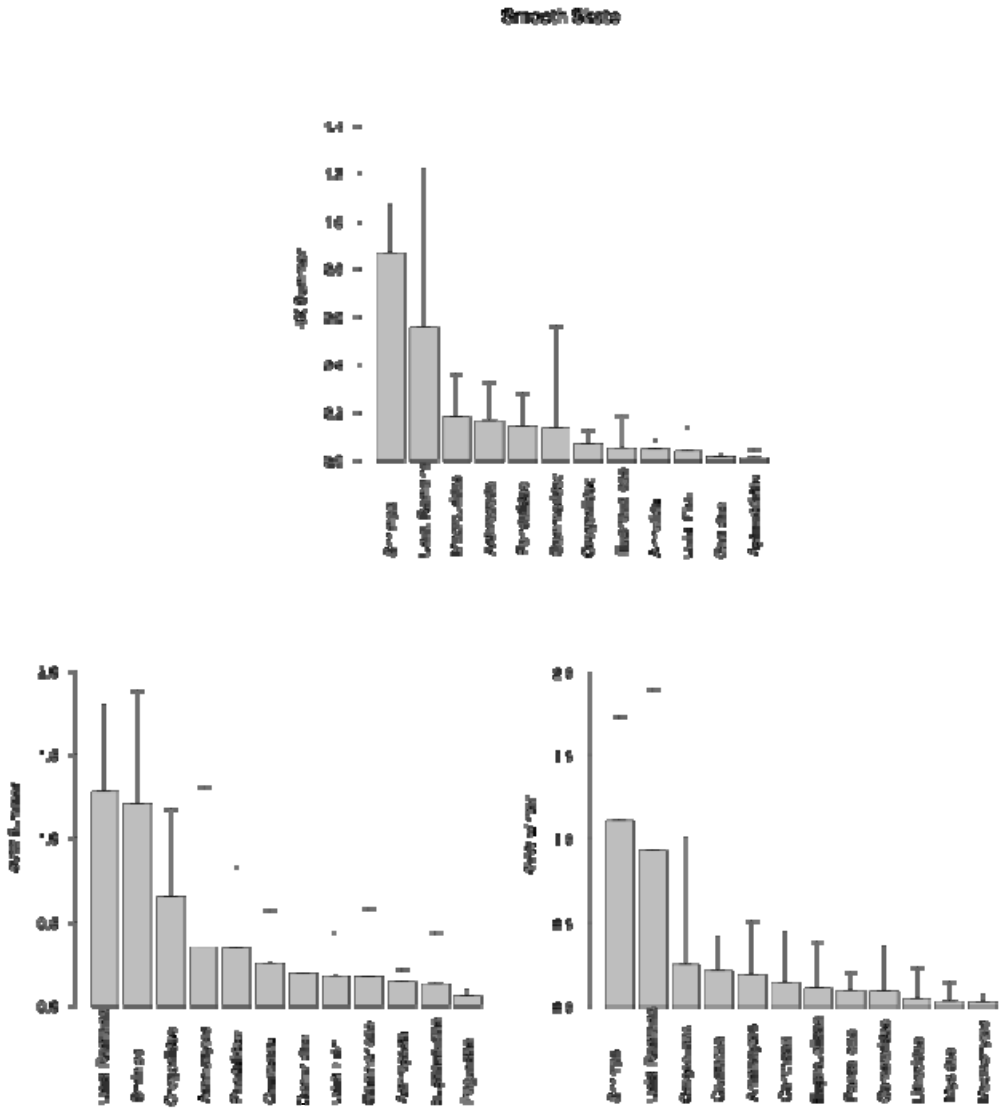

Figure A8: Diet composition of most abundant prey items by weight (g) in smooth skate diets by area and season.