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An Update on Harp Seal (*Pagophilus groenlandicus)* By-Catch Estimates in the Newfoundland Lumpfish Fishery

Mise à jour des estimations des prises accidentelles de phoques du Groenland (*Pagophilus groenlandicus*) dans le cadre de la pêche à la lompe à Terre-Neuve

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Abstract

By-catch of marine mammals in fishing gear occurs throughout the world's oceans and is a major conservation concern. While entrapment of cetaceans is increasingly well documented, less effort has gone into quantifying the by-catch of seals. This is certainly the case in Newfoundland waters where catch rates for many of these species are thought to be under-reported. This research provides estimates of the number of harp seals taken annually as by-catch in the Newfoundland lumpfish gill net fishery from 1970 to 2003. Data were obtained from a By-catch Monitoring Program that required lumpfish fishermen around the coast of Newfoundland to record fishing effort (roe landings) and the number of seals caught on a daily basis from 1989 to 2003. Prior to 1989, annual seal by-catches were estimated using historic roe landings and mean by-catch levels based on the fishermen's logbook data from 1989 to 1991. From the beginning of the lumpfish roe fishery in 1970 until 1985, the by-catch of harp seals remained below 5,000 animals. In 1987 catches increased to a high of about 13,100 seals and then declined to approximately 3,600 animals in 1990. The peak by-catch for the time series was 46,394 seals in 1994; catch levels remained higher than 18,000 animals until 1997. In more recent years annual catches declined and became increasingly variable. In 2002 and 2003 there was a major down-turn in the fishery and seal by-catch levels dropped to below 10,000 animals. These estimates of annual by-catch vary depending on several key assumptions; however, they do provide a long-term view of by-catch as a source of mortality for harp seals and can be used for population modeling initiatives.

Résumé

Les prises accidentelles de mammifères marins dans les engins de pêche surviennent dans l'ensemble des océans du monde et constituent une importante préoccupation sur le plan de la conservation. Tandis que les prises de cétacés sont de mieux en mieux documentées, moins d'efforts sont déployés pour quantifier les prises accidentelles de phoques. C'est certainement le cas dans les eaux de Terre-Neuve où l'on pense que les taux de capture sont sous-déclarés pour bon nombre de ces espèces. La présente recherche fournit des estimations du nombre de phoques du Groenland qui ont été capturés accidentellement chaque année dans le cadre de la pêche à la lompe pratiquée au filet maillant dans les eaux de Terre-Neuve entre 1970 et 2003. Les données proviennent d'un programme de surveillance des prises accidentelles dans le cadre duquel les pêcheurs de lompe des eaux côtières de Terre-Neuve devaient consigner leur effort de pêche (débarquements d'œufs de lompe) et le nombre de phoques capturés quotidiennement entre 1989 et 2003. Pour la période antérieure à 1989, les prises accidentelles annuelles de phoques ont été estimées à partir des débarquements historiques d'œufs de lompe et de la moyenne des prises accidentelles établi d'après les données des journaux de bord des pêcheurs de 1989 à 1991. Du début de la récolte d'œufs de lompe en 1970 jusqu'en 1985, les prises accidentelles de phoques du Groenland sont demeurées inférieures à 5000 animaux. En 1987, le nombre de prises a augmenté pour atteindre un maximum d'environ 13 100 phoques, puis a chuté à environ 3600 animaux en 1990. Le nombre de prises accidentelles record de la série chronologique était de 46 394 phoques en 1994; les niveaux de prises sont demeurés supérieurs à 18 000 animaux jusqu'en 1997. Depuis quelques années, les prises annuelles ont chuté et sont devenues de plus en plus variables. En 2002 et en 2003, on a observé un important renversement dans la pêche, et les niveaux de prises accidentelles de phoques ont chuté en dessous de 10 000 animaux. Les estimations du nombre de prises accidentelles annuelles varient en fonction de plusieurs hypothèses principales; cependant, elles donnent une perspective à long terme des prises accidentelles en tant que cause de mortalité chez les phoques du Groenland et peuvent être utilisées pour la modélisation des populations.

Introduction

By-catch is defined as the incidental entrapment or capture of non-target species during a fishing operation (Murawski 1995) and it has become a key conservation issue for numerous marine species around the world (e.g. Harwood 1983). Although the by-catch of marine mammals on a site or time specific basis may be rare, over an entire fishery or within a specific type of fishing gear, by-catch rates can be significant (Alverson 1999; West et al. 1999). Prior to the 1990s relatively little effort had gone into quantifying by-catch and few long-term studies had been conducted (Harwood 1983; Lien et al. 1988; Woodley and Lavigne 1991). Reports of incidental takes, for the most part, were sporadic, gathered opportunistically and tended to focus on endangered species or on a limited number of large cetaceans. Human attitudes and cultural perspectives towards small cetaceans and pinnipeds partially explain why by-catch issues involving these species have not been well studied (Fontaine et al. 1994; Hall-Arber 1995). Small cetaceans and seals are often viewed as being nuisances because they damage fishing gear and are perceived to compete with fishermen for a resource. When caught these species are often not reported because they cause less damage than large cetaceans and fishermen do not require assistance in removing them from their gear. Small cetaceans and seals that are caught incidentally may be dumped at sea or consumed as food (Lien et al. 1988; FAO 1995).

The Food and Agriculture Organization (FAO) of the United Nations (1995) reported that 36 of 45 pinniped species have been recorded as being involved in some form of interaction with fishing operations or fish farms. Most of these interactions have been detrimental to the seal species involved (FAO 1995). For example, a reported 724 northern stellar sea lions (*Eumetopias jubatus*), were taken annually in the foreign commercial trawl fishery near Kodiak Island and the Aleutian Islands between 1978 and 1981 (Loughlin et al. 1983). Another Otarid experiencing large incidental takes in trawl fisheries is the Cape fur seal (*Arctocephalis pusillus pusillus*), with an estimated 4,000 or more are killed annually off the coasts of Nambia and South Africa (Shaughnessy 1985). The extremely high levels of harp seal *(Pagophilus groenlandicus)* by-catches in Norwegian waters in 1986 and 1987 occurred on such a large scale that they have been termed harp seal 'invasions' (Woodley and Lavigne 1991). Nearly 60,000 harp seals were caught in gill nets, longlines and trawls between January and May of 1987 (ICES 1990).

All species of seals found in Newfoundland waters are incidentally taken in fishing gear. Seals are caught in active (e.g. trawls and purse seines) and passive gear types (e.g. hook and line and gill nets; Lien et al. 1988; Woodley and Lavigne 1991; Pemberton 1994; FAO 1995). In Newfoundland, harp seals are involved in the majority of entrapments and most animals are caught in monofilament gill nets that are set for cod (*Gadus morhua)*, flounder (*Pseudopleuronectes sp.)* and lumpfish (*Cyclopterus lumpus*) (Lien et al. 1987 and 1988; Piatt and Nettleship 1987). The existing data on seal by-catch in Newfoundland has been based on reports obtained from fishermen through phone interviews, in situ interviews and questionnaires as well as summer surveys conducted to examine incidental catches of marine mammals (Piatt and Nettleship 1987; Lien et al. 1994). Although most seal catches go unreported, anecdotal information from fishermen suggests that the level of annual harp seal by-catch in Newfoundland waters is notably high (Barker 1985; Rompkey 1985; Lien. 1987).

The problem of harp seal by-catch in the Newfoundland lumpfish fishery is not a new issue. The commercial lumpfish fishery began in 1968 and was initially conducted on the northeast coast of Newfoundland. It is mainly an inshore activity conducted by fishermen during the months of April-July with at least 90% of the landings reported from small boats less than 45 ft (Blackwood 1983; Stansbury 1996). The fishery quickly expanded from the northeast coast to other areas of the province and since 1977 the Department of Fisheries and Oceans (DFO) has been promoting the industry. It is likely that some by-catch of harp seals has occurred since the start of the lumpfish fishery; however, official reports on how serious the problem had become did not arise until 1985. Fishermen at the time stated that there was an increase in the number of young seals interfering and sometimes damaging their gill nets (Barker 1985; Rompkey 1985). In a preliminary study of the issue it was estimated, from fishermen's logbooks, that the number of seals caught incidentally in the Newfoundland lumpfish fishery varied from 4,000 to 20,000 per annum between 1989 and 1993 (Sjare and Stenson unpublished data).

Lumpfish are short (30–60 cm), stout fish that are found on both sides of the North Atlantic Ocean. In Newfoundland, the species occurs along all coasts (Goulet et al*.* 1986) and there are also major concentrations on the St. Pierre Bank (Gavaris 1985). The fish migrate from deep, cool offshore waters into coastal waters in late April or early May to spawn (Stevenson and Baird 1988). The lumpfish fishery uses monofilament gill nets with a mesh size of 25-27 cm that are usually set in 3-33 m of water (Stevenson and Baird 1988). Fishermen typically use between 20 and 100 nets that are set in series of long strings. These nets are left to fish for approximately 2 or 3 days before they are hauled and when storm conditions arise the nets may be left fishing for up to 10 days before contents are removed. In almost all cases the lumpfish are alive when the nets are hauled as they are caught by the rough tubercles surrounding their robust body as opposed to their gills. The males and immature females are then released, pre-spawning mature females are cut ventrally and the roe is scooped out and retained. The lumpfish fishery concentrates on the larger females as a source of roe for the caviar market. The majority of lumpfish roe is exported to Germany and Denmark, with smaller quantities going to Belgium, France, Sweden, Japan and the United States where it is used primarily in the restaurant industry (Department of Industry 1971).

The type of gear used and the timing of the lumpfish fishery in Newfoundland are key factors influencing the level of harp seal by-catch. Large mesh monofilament gill nets used in the fishery pose a significant barrier to the seals, possibly by being invisible to them when they are clean or perhaps attracting them when they become full of fish. In certain areas of the province, seal migration routes overlap with fishing activities. Young harp seals born in late February to mid-March migrate out of the southern Gulf of St. Lawrence in April and May. Births off the northeast coast of Newfoundland occur about five days later and following their first moult the young harps disperse and move northward (Lavigne and Kovacs 1988). Adult harp seals move from their spring breeding and moulting concentrations in the Gulf of St. Lawrence and the northeast coast of Newfoundland during May and June and migrate north into Arctic waters to feed during summer and fall (Sergeant 1991; Lavigne and Kovacs 1988). During spring migration, harp seals of all age classes may travel individually or in groups (sculls) along inshore areas of Newfoundland and it is these animals (particularly the inexperienced young seals) that encounter lumpfish gill nets.

Preliminary estimates of harp seal by-catch in the Newfoundland lumpfish fishery from 1970 to 1998 were reported by Walsh et al*.* (2000). The objectives of this manuscript

are to update the estimates to 2003 and to present a revised approach to data analyses. The study represents the first long-term analysis of seal by-catch in Newfoundland and the results will provide an opportunity to examine by-catch as a source of harp seal mortality.

Methods

DFO has conducted a By-catch Monitoring Program since 1989. Several near-shore gill net fisheries (cod, flounder, lumpfish, capelin, salmon) were monitored for seal by-catch. However, due to the general down-turn in many Newfoundland fisheries in the early 1990s, seal by-catch information from most of these fisheries was sparse except for lumpfish. This fishery is thought to be one of the most important in terms of high seal by-catch levels and there is now a good time series of information available from the Program.

Fishermen from around the island portion of the Province were requested to take part based on recommendations from DFO conservation officers, local fishermen's committees or based on previous work experience with DFO science personnel. An effort was made to select participants from all regions of Newfoundland in order to provide the best geographical coverage of the lumpfish fishery as possible. The number of fishermen involved in the Program on a yearly basis varied from a minimum of 4 to a maximum of 27 (Table 1). Participants were asked to record the weight of lumpfish roe landed (kg), the number of netdays fished (i.e. number of nets fishing x soak time), and the number as well as species of seals caught on a per net haul basis. Although all species of seals found in Newfoundland waters have been reported as by-catch, this manuscript deals only with harp seals. To determine the age composition of the harp seal catch, fishermen were requested to record the age class of the animal as a beater (3 weeks – 1 year old), a bedlamer (1-4 years old) or an old harp (at least 4 years old). Additional information requested included fishing location, the depth fished, daily water and weather conditions, vessel size, crew size, other species that were taken incidentally on a per haul basis, and a description of the type of fishing gear used. A small honorarium was given to fishermen once they had returned all completed logbooks at the end of the season.

Historic and recent roe landings for Newfoundland from 1970 to 2003 were obtained from DFO Statistics Branch, St. John's. The commercial lumpfish fishery began in 1968, however, there were no records kept of roe landings until 1970. Information from 1970 to 1975 is considered complete, but can not be cross validated with other data sources such as purchase slips or hail reports. The inshore landings taken by vessels <45 ft. were considered for this analysis since they were responsible for greater than 95% of the annual lumpfish roe catch (DFO Statistics Branch).

To obtain regional seal by-catch information that reflected both the current lumpfish fishing industry and the ecology of coastal areas within the province, fishermen were designated as coming from one of the three following regions: the northeast coast (NAFO Divisions 3K and 3L (except for area 3Lq), the south coast (3Pn, 3Ps and 3Lq) or the west coast (4R; Fig. 1). NAFO area 3Lq was considered to be part of the south coast because the characteristics and scale of fishing operations were more consistent with that region as compared to the northeast coast. To derive estimates of harp seal by-catch rates based on logbook data, the weight of lumpfish roe landed and the number of harp seals caught per fishing trip by each participating fisherman in a region were used to calculate trip catch rates which were then bootstrapped (1000 iterations) using Excel's Resample Program (n=4,109 fishing trips from 1989 to 2003). The total number of harp seals caught annually in a region

was estimated using the bootstrapped mean number of seals caught/tonne of roe from the By-catch Monitoring Program and then extrapolating to the total weight of roe (tonnes) taken in the entire region. Newfoundland estimates of harp seal by-catch were calculated by summing the data across regions. Several high trip by-catch estimates of >1000 seals/tonne of roe (n=11) were not included in the analysis because they require further validation.

To estimate a seal by-catch rate for the period 1970-88 which pre-dates the By-catch Monitoring Program, the mean number of harp seals caught/tonne of roe based on pooled landings from 1989 to 1991 of the Program were bootstrapped by region and used for hind-casting purposes. These years were used for hind casting because they preceded the Newfoundland groundfish moratorium and reflected the level of seal by-catch that experienced fishermen considered to be most similar to the 1970s and 1980s.

Results

The commercial lumpfish fishery in Newfoundland developed slowly until 1977, roe landings increased into the 500–1,200 tonne range during the early 1980s, peaked at 3,500 tonnes in 1987, and then fell to 1,300 tonnes by 1990 (Fig. 2). From 1991 to1993 roe landing remained relatively high at approximately 2,200 tonnes and then dropped back to 1,300 tonnes by 1995. From 1996 to 2000 landings varied considerably but generally recovered to levels seen in the early 1990s. In 2001, landings again fell significantly to less than 800 tonnes; the 2002 catch was the lowest in the time series since 1976. The lumpfish fishery was initially concentrated on the northeast coast of the Island, but after 1977 it became established on the west and south coast (Fig. 2). Landings from the northeast and south coasts tended to dominate the lumpfish industry during the 1980s and 1990s with a growth in the fishery on the west coast in the mid-1990s. Table 2 summarizes the percentage of landed roe that was monitored for seal by-catch in each region by fishermen in the By-catch Program. On average, only 0.9%(SD=0.37, n=15) of the northeast coast was monitored while 2.3% (SD=1.22, n=14) and 10.2% (SD=6.55, n=15) of the south and west coast were covered respectively.

Bootstrapped estimates of the mean number of harp seals caught/ tonne of roe in each region from 1989 to 2003 were highly variable (Table 3). For the northeast coast estimates ranged from 1.7–51.5 seals, for the south coast 1.9–53.1 seals, and for the west coast 2.2–94.7 seals/tonne of roe. Table 3 also presents the 95% CI interval for the bootstrapped means in each region form 1989 to 2003. For hind-casting prior to 1989, the estimated mean number of seals caught/tonne of roe in each region was based on pooled data from 1989 to 1990; for the northeast coast it was 3.03 seals/tonne, for the south coast 5.21 seals/tonne and for the west coast 3.97 seals/tonne (Table 3).

Although a significant proportion of the seal by-catch in the lumpfish fishery was beaters (i.e. harp seals <1 year of age), there was considerable variation among regions and years (Table 4). On the Northeast Coast the proportion of beaters in the catch ranged from 0.16-0.90, with a mean of 0.58 (SD=0.21, n=12). The south and west coast had similar proportions ranging from 0.56–1.00, with means of 0.88 (SD=0.12, n=12) and 0.88 (SD=0.11, n=12) respectively. From 2001 to 2003, the proportions of beaters caught along the northeast, south and west coasts were estimated to be 0.51, 0.84 and 0.85 respectively. For the years 1970–88, the proportion of beaters caught along the northeast coast was 0.77 while along the south and west coast proportions were 0.92 and 0.93 respectively. The 2001-2003 estimates are a mean of the last five years of the time series and the 1970-88 estimates are a mean of the first three years of the series.

Estimates of the total number of harp seals taken as by-catch in the Newfoundland lumpfish fishery are presented in Fig. 2 and Table 5. Estimates remained below 5,000 seals until 1985 and then increased significantly to approximately 13,100 in 1987. By 1990 the by-catch had dropped to below 4,000 but then increased dramatically to reach a time series high of approximately 46,400 seals in 1994. From 1995 to 1997 by-catches remained at levels higher than 18,500 animals. However, in more recent years by-catch levels have declined and become increasing variable from year to year with a major down-turn in the industry in 2002 and 2003. Both the northeast and south coasts contributed significantly to the high levels of total by-catch in 1987, while a peak in seal catches along the south coast in 1994 contributed to the overall high level during that year. Estimated harp seal catches on the west coast appeared consistently low in the 1970s and 1980s and then increased noticeably following the 1992 Newfoundland cod moratorium. The relatively high west coast by-catch in 2001 contributed significantly to the increased catches in that year.

Discussion

Fishery observer programs and observations from fishermen are both useful methods of monitoring by-catch within a fishery. Well designed and properly managed observer programs can provide relatively unbiased information that is often higher quality and more reliable than the latter approach (Northridge 1996; Cox et al. 1998). However, logbook reports and observations of by-catch from fishermen are useful monitoring tools in certain types of fisheries and yield results that can be verified if the program is well designed (Lien, et al.1994). The Newfoundland commercial lumpfish fishery engages fishermen who often fish sporadically from small boats (i.e. in between other fishing seasons). Placing observers on the small boats that prosecute this fishery would be economically unfeasible, labor intensive, and in many cases, physically impossible in terms of space requirements. The estimates of harp seal by-catch in the lumpfish fishery, based on logbook data from fishermen, represents one of the first attempts at providing a long-term view of by-catch as a source of mortality for a pinniped species. The database resulting from the By-catch Monitoring Program represents the most complete time series of information on marine mammal by-catches in Newfoundland waters.

There are several data gaps and assumptions that influence the accuracy of the by-catch estimates presented here including a lack of fishing effort data at the provincial level, limited fisherman participation in the program, hind-casting to fill in historical data gaps, seal identification problems and the importance of storms and other environmental factors that affect net soak time. A major obstacle in attempting to estimate the number of harp seals taken in the lumpfish fishery stems from the fact that there are no standardized data on fishing effort (i.e. number of trips, number of nets fished, or estimates of netdays) for the industry throughout Newfoundland. Therefore, roe landings were used as an index of fishing effort for this study. More detailed analyses on the relationships between roe landings, seal by-catch and netdays are needed to evaluate how appropriate this index is. For fishermen participating in the logbook program a record of netdays, which is a measure of the number of nets in the water and soak times, is a more direct index of fishing effort. A preliminary comparison of roe landings, seal catches and netdays for fishermen in the program from 1989 to 1993 suggested that the increasing number of seals taken was primarily the result of increased fishing effort (Sjare and Stenson unpublished).

Estimates of seal catches per tonne of roe are highly variable due to the limited number of fishermen in the By-catch Monitoring Program and their unequal geographic coverage. Future efforts to improve the quality of data collected should focus on increasing the number of participants in the program. It is also important to replace fishermen who drop out of the program with another individual from the same fishing area. Increasing the number of fishermen participating in the Program along the south and northeast coasts is critical given the low percentage of roe monitored for seal by-catch in these areas. Presently it is not known if the low coverage has introduced a bias into the estimates; however, participating fishermen from these areas did have operations that generally reflected the character and scale of other operations in their areas. More detailed analyses will improve the extrapolation procedures as well as develop better methods to estimate the variance associated with roe landings and with the number of seals caught/ tonne of roe based on data provided by a limited number of fishermen.

Given the difficulties in estimating the number of seals caught/tonne of roe when the By-catch Program was in operation, estimating by-catch levels prior to 1989 must be considered as exploratory. Estimating the true level of by-catch mortality in any fishery retroactively is known to be difficult because of critical uncertainties regarding fishing practices and the distribution and/or availability of the species involved (Forney 1999). In this preliminary analysis of the historical database, the average bootstrapped estimates for the years 1989-91 were used because they preceded the 1992 cod moratorium in Newfoundland and are considered by experienced fishermen to be most similar to the earlier years in terms of seal by-catch levels. Although using one estimate per region for the entire time frame (1970-88) could be problematic, considering that reports of higher seal by-catches did not occur until the mid 1980s, this is likely not a significant issue from a population modeling perspective. Seal by-catch estimates from the early portion of the time series may be further refined based on interviews with fishermen who were involved in the lumpfish fishery since the early days of the industry and when more is known about the relationship between roe landings and seal by-catch rates.

Over the duration of the By-catch Monitoring Program some fishermen did not specify the species or age class of seal they caught, making it difficult or sometimes impossible to determine the species and age composition of their catch. Lack of specifying seal species and age class could be explained by a combination of several factors: 1) fishermen being unable to identify or remember the name of a particular seal species; 2) seals falling out the nets before being brought onboard the vessel, and 3) seals being scavenged or decomposed beyond species recognition. The majority of fishermen along the northeast coast can reliably identify seals; however, some fishermen along the south and west coasts can not because not all of these areas are traditional seal hunting grounds and therefore residents may not be familiar with identifying seal species. Through follow-up interviews it was possible to correct the ‘unknown seal’ problem, to some extent, by showing fishermen photographs of several seal species and getting them to identify which species they referred to as being an ‘unknown’. Some of the fishermen who submitted by-catch information were also apart of DFO’s Seal Sampling Program and had sent in biological samples (jaw bones, stomachs, reproductive organs) from some of the seals caught in their lumpfish nets for analysis. This information was used to verify the species and age composition of the seals recorded by fishermen as by-catch in their logbooks whenever possible. Any changes to the logbook forms in the future should include more detailed instructions for fishermen to identify the species of seal caught.

Finally, a better knowledge of weather and ice conditions during peak fishing periods may be useful in explaining some of the variability associated with roe landings and seal by-catch estimates. Several fishermen within the logbook program have stated that their nets have been left to fish for extended periods of time due to adverse weather. Lumpfish rarely die during such events, but if deaths do occur, the roe is still marketable for a considerable amount of time. So, from this perspective extended soak times due to the inability of fishermen to access their nets in bad weather is not as problematic from an analysis perspective as previously thought. However, storms may cause nets to become full of seaweed and not capable of catching significant numbers of lumpfish but do continue to catch seals, biasing the estimate of seals caught/tonne of roe upward. Other important environmental factors noted by fishermen that may influence seal by-catch levels include the influence of tides and currents, water temperatures and depths, and coastal bathymetry.

Preliminary harp seal by-catch estimates for the Newfoundland lumpfish fishery from 1970 to 1998 were presented by Walsh et al. (2000). In that analysis, the total number of seals caught on an annual basis in the fishery was higher for the first half of the times series than presented here, while in the more recent time periods, the two data-sets were generally comparable. The updated estimates presented here differ from the earlier analyses in several respects. Follow-up interviews with fishermen participating in the Monitoring Program in 2002 indicated that the estimates of by-catch used for hind-casting by Walsh et al. (2000) were likely to high. All fishermen noted that by-catch levels in the 1970s and 1980s were more similar to the late 1980s and early1990s than to a mean of the whole time series (which was used in the earlier analyses). This adjustment in the estimates used for hind-casting accounts for most of the observed differences.

Differences in the more recent portion of the series from 1989 to 2000 can be explained by two factors. In Walsh et al. (2000) seal catches and roe landings were tabulated by fisherman (i.e. the fisherman's 'season' was the sample unit) and the seal by-catch rate was then extrapolated to the region based on total roe landings in that region; no bootstrapping analyses were conducted. To better reflect the variation in by-catch among individual trips and to alleviate some of the limitations due to the small number of fishermen participating in each region, in the current analyses, seal by-catch rates were calculated based on the 'fishing trip' as the sample unit and used a standard bootstrapping technique. These changes in analysis approach and technique were likely responsible for a relatively minor component of the differences observed in the estimated seal by-catch rate for each fishing region.

The other difference in the two analyses relates to the boundary designation for the south coast fishing region. In Walsh et al. (2000), NAFO area 4Rd was considered as part of the south coast region based on the characteristics (i.e. number of nets in the water, the amount of roe landed, and the level of seal by-catch) and intensity (i.e. frequency of net hauls, length of season, crew size) of the fishing operations in the area. However, additional interviews with fishermen, conservation officers and residents indicated that the seasonal pattern of roe landings and seal by-catches were more variable and pulsed along the west coast as compared to the south coast. From this perspective, the fishing operations in 4Rd were more representative of the west coast so the area was included in that region for the current analyses. This change appears to be responsible for much of the difference in the total number of seals taken as by-catch during the lumpfish fishery on a regional and provincial basis. Currently there has been no new information to suggest that area 3Lq should not be designated as part of the south coast.

The estimated seal by-catch rates and total numbers of seals caught in the Newfoundland lumpfish fishery reported here are difficult to compare directly with other by-catch studies because of differing methodologies and research scope. Most published reports analyze by-catch from a more limited geographic and/or temporal perspective. With few exceptions, (e.g. Vinther 1999: by-catch of harbour porpoise in Danish set-net fisheries) there has been little information published on the by-catch of any species in the lumpfish fishery. Iceland has a notable seal by-catch problem within the lumpfish fishery, however, the scope of the problem has yet to be examined (Aevar Peterson, personal communication).

The studies that have been conducted on seal by-catch in Newfoundland waters are generally supportive with the findings of this manuscript. Incidental catches of marine mammals for the south and east coasts of Newfoundland during the summers of 1981 to 1984 were reported by Piatt and Nettleship (1987). Accounts were based on direct observations by the authors as well as documented information from fishermen that listed numbers of species caught along with the type of areas and depths fished. An estimated 746 harp seals were taken annually from 1981 - 1984 in relatively deep-set cod and flounder gill nets set up to 100 km from shore in the vicinity of three major bird colonies. Most harp seals were taken in May and June and 91% of the catches consisted of immature harps (2-3 years old).

A minimum of 10,700 harp seals were taken along the south and west coasts of Newfoundland (primarily between St. Anthony and Port aux Basques) in gill nets during spring 1988 (Lien et al. 1988). These data were derived from a monitoring program conducted by the DFO and Memorial University of Newfoundland from 1978-1988. Most information came from interviews with fishery officers and fishermen who reported that grey, harbour, harp and hooded seals are caught incidentally in monofilament gill nets set for cod and lumpfish. However the majority of entrapments involved young harp seals that were caught in May and June along the west and south coasts of Newfoundland, a period when the animals are migrating northward to their Arctic feeding grounds (Lien et al. 1988). Based on comments by fishermen in the Bonne Bay area, Lien et al. (1987) reported that there is an extensive harp seal catch in groundfish gill nets, estimates were from 8-15 young harps caught per 60-70 nets per day.

The majority of harp seal by-catch in gill nets consists of animals aged one year or younger; this finding is consistent with other published reports (Rompkey 1985; Piatt and Nettleship 1987; Lien et al. 1988). In a letter to the Royal Commission on Seals and the Sealing Industry, Rompkey (1985) stated that increased numbers of young seals caught in fishing nets had occurred because of declines in the sealing industry, particularly reduced activity associated with the whitecoat hunt. In 1983 the European Economic Community (EEC) banned the importation of products from harp seal pups, which resulted in the closure of the large vessel hunt (Lavigne and Kovacs 1988). This fact, along with increases in the seal population (Stenson et al. 2005) and changes in the marine environment during the late 1980s and 1990s may partially explain why there has been an increase in the number of harp seals taken in lumpfish nets around Newfoundland in recent years (Drinkwater 1996, 2000; Lilley and Carscadden 2002).

In summary, these results represent the first long-term direct assessment of harp seal by-catch in the Newfoundland lumpfish fishery and provide a basis for future by-catch research, population modeling initiatives as well as the development of sustainable management plans. Further interactions between harp seals and this fishery should be

monitored, especially if groundfish closures continue in Newfoundland and more economic emphasis is placed on the lumpfish industry.

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References

Alverson, D.L. 1999. Some observations on the science of bycatch. Mar. Tech. Soc. J. 33: 6-12.

Barker, A. 1985. Testimony before the Royal Commission on Seals and the Sealing Industry in Canada. On behalf of the Bonavista South Development Corporation, St. John's, May 23, 1985. Vol. 3: 561-676.

Blackwood, G. 1983. Lumpfish roe fishery development in Newfoundland, 1982-83. Industry Support Services Development Report No. 31. Government of Newfoundland and Labrador.

Lilly, G.R., and Carscadden, J.E. 2002. Predicting the future of marine fish and fisheries off Labrador and eastern Newfoundland under scenarios of climate change; information and thoughts for the Arctic Climate Impact Assessment (ACIA). DFO Can. Sci. Advis. Sec. Res. Doc. 2002/111. 35 p.

Cox, T.M., Read, A.J., Barco, S., Evans, J., Gannon, D.P., Koopman, H.N., McLellan, W.A., Murray, K., Nicolas, J., Pabst, D.A., Potter, C.W., Swingle, W.M., Thayer, V.G., Touhey, K.M., and Westgate. A.J. 1998. Documenting the bycatch of harbor porpoises, *Phocoena phocoena*, in coastal gillnet fisheries from stranded carcasses. Fish. Bull. 96: 727-734.

Department of Industry. 1971. A report on world trade in lumpfish roe. Department of Industry, Ottawa, Ontario.

Drinkwater, K.F. 1996. Atmospheric and oceanic variability in the Northwest Atlantic during the 1980s and early 1990s. J. Northw. Atl. Fish. Sci., 18: 77-97.

Drinkwater, KF. 2000. Changes in ocean climate and its general effect on fisheries: examples from the north-west Atlantic, p. 116-136. *In* D. Mills [ed.] The ocean life of Atlantic salmon: environmental and biological factors influencing survival. Fishing News Books, Oxford. 228 p.

FAO. 1995. A review of operational interactions between pinnipeds and fisheries. FAO Fisheries Technical Paper 346. Rome, Italy.

Fontaine, P.M., Barrette, C., Hammill, M.O., and Kingsley, M.C.S. 1994. Incidental catches of harbour porpoise (*Phocoena phocoena*) in the Gulf of St. Lawrence and the Gulf of St.

Lawrence River Estuary, Quebec, Canada. Rep. Int. Whal. Commn. Special Issue 15: 159-163.

Forney, K.A. 1999. Managing marine mammal by-catch in dynamic habitats: lessons from a California gillnet fishery. 13th Biennial Conference on the Biology of Marine Mammals, Abstract. Maui, Hawaii November 28 – Dec. 3, 1999.

Garavis, S. 1985. Lumpfish. *Underwater World*. Department of Fisheries and Oceans, St. John's, Newfoundland: 4pp.

Goulet, D., Green, J.M., and Shears, T.H. 1986. Courtship, spawning, and parental care behavior of the lumpfish, *Cyclopterus lumpus L*., in Newfoundland. Can. J. Zool. 64: 1320-1325.

Hall-Arber, M. 1995. Bane or boon: taste, finances, and anthropomorphizing affect beliefs about bycatch. pp.45-48. *In*: Proceedings of the East Coast Bycatch Conference. Newport, Rode Island, April 7-8, 1995.

Harwood, J. 1983. Interactions between marine mammals and fisheries. Adv. App. Biol. 8: 189-214.

Hofman, R.J. 1995. The changing focus of marine mammal conservation. TREE 10: 462-465.

ICES. 1990. Report of the working group on harp and hooded seals. International Council for the Exploration of the Sea, Bergen, 16-19 October 1989. C.M. 1990 I Assess: 8. 25pp.

Lavigne, D.M., and Kovacs, K. 1988. Harps and Hoods. University of Waterloo Press, Waterloo, Canada.

Lien, J., Papineau, J., and Dugan, L. 1987. Incidental entrapments of cetaceans, sharks and marine turtles in inshore fishing gear reported during 1987 in Newfoundland and Labrador. Report to Fisheries and Oceans Canada, Nfld. Region, 10 Oct, 22p.

Lien, J., Stenson, G.B., and Ni, I.H. 1988. A review of incidental entrapment of seabirds, seals and whales in inshore fishing gear in Newfoundland and Labrador: a problem for fishermen and fishing designers. pp. 67-71. *In*: The Proceedings of the World Symposium on Fishing Gear and Fishing Vessel Design. Marine Institute, St. John's, Newfoundland, Canada.

Lien, J., Stenson, G.B., Carver, S., and Chardine, J. 1994. How many did you catch? The effect of methodology on by-catch reports obtained from fishermen. Paper SC/090/G50 presented to the IWC Workshop on Mortality of Cetaceans in Passive Fishing Nets and Traps, La Jolla, CA, October 22-25, 1994. 14pp.

Loughlin, T.R., Consiglieri, L., Delong, R.L., and Actor, A.T. 1983. Incidental catch of marine mammals by foreign fishing vessels, 1971-81. Mar. Fish. Rev. 45: 44-49.

Murawski, S.A. 1995. Biological Implications of Bycatch. pp. 31-36. *In*: Proceedings of the East Coast Bycatch Conference. Newport, Rode Island, April 7-8, 1995.

Northridge, S.P. 1996. JNCC Report. A review of marine mammal bycatch observer schemes with recommendations for best practice. Joint Nature Conservation Committee, Aberdeen, U.K. 42pp.

Pemberton, D., Merdsoy, B., Gales, R., and Renouf, D. 1994. The interaction between offshore cod trawlers and harp *Phoca groenlandica* and hooded *Cystophore cristata* seals off Newfoundland, Canada. Biol. Cons. 68: 123-127.

Piatt, J.F., and Nettleship, D.N. 1987. Incidental catches of marine birds and mammals in fishing nets off Newfoundland, Canada. Mar. Pollut. Bull. 18 : 344-349.

Rompkey, W.R. 1985. Brief to the Royal Commission on Seals and the Sealing Industry in Canada, May 22, 1985: 6-7.

Sergeant, D.E. 1991. Harp seals, man and ice. Can. Spec. Publ. Fish. Aquat. Sci. 114: 153pp.

Shaughnessy, P.D. 1985. Interactions between fisheries and Cape fur seals in southern Africa. *In*: Beddington, J.R., R.J.H. Beverton and D.M. Lavigne (eds). Marine Mammals and Fisheries. George Allen & Unwin; London: 119-134.

Stansbury, D. 1996. Lumpfish in divisions 3K, 3L and 3Ps. DFO Can. Sci. Advis. Sec. Stock Status Rep. 96/87.

Stenson, G.B., Hammill, M.O., Lawson, J., Gosselin, J.F., and Haug, T. 2005. 2004 Pup production of harp seals *Pagophilus groenlandicus*, the Northwest Atlantic. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/037. Available at www.dfo-mpo.gc.ca/csas/

Stevenson, S.C., and Baird, J.W. 1988. The fishery for lumpfish (*Cyclopterus lumpus*) in Newfoundland waters. Can. Tech. Rep. Fish. and Aqua. Sci. No. 1595.

Walsh, D., Sjare, B., and Stenson, G.B. 2000. Preliminary estimates of harp seal by-catch in the Newfoundland lumpfish fishery. DFO Can. Stock. Assess. Sec. Res. Doc. 2000/078. Available at www.dfo-mpo.gc.ca/csas/

West, I.F., Molloy, J., Donoghue, M.F., and Pugsley, C. 1999. Seabird and marine mammal bycatch reduction through fishing industry funded research: The New Zealand Conservation Services Levy Program. Mar. Tech. Soc. J. 33: 13-18.

Woodley, T.H., and Lavigne, D. 1991. Incidental capture of pinnipeds in commercial fishinggear. Internat. Mar. Mamm. Assoc., Tech.l Rep. No. 91-01. 1-51.

Vinther, M. 1999. Bycatches of harbour porpoises (*Phocoena phocoena* L.) in Danish set-net fisheries. J. Cetacean Res. Manage. 1: 123-135.

Table 1: Number of fishermen involved in the By-catch Monitoring Program from 1989 to 2003.

Year	Number of Fishermen
1989	4
1990	11
1991	17
1992	24
1993	27
1994	25
1995	19
1996	26
1997	21
1998	10
1999	13
2000	12
2001	26
2002	20
2003	16

Table 2: Percentage of the total amount of landed roe that was monitored for seal by-catch in the northeast, south and west coast regions of Newfoundland from 1989 to 2003.

Year	NE Coast	S Coast	W Coast
1989	0.15	NA	2.30
1990	0.39	4.18	2.14
1991	0.92	3.84	19.33
1992	1.18	4.66	21.37
1993	0.91	2.60	19.13
1994	0.74	2.32	17.81
1995	0.30	2.30	4.72
1996	1.36	1.36	3.97
1997	0.53	1.44	7.68
1998	0.51	1.50	6.40
1999	0.45	0.34	10.64
2000	0.99	1.09	10.55
2001	2.08	1.78	7.25
2002	1.76	1.98	14.03
2003	1.20	2.18	6.35

Table 3: Bootstrapped estimates of the mean (95% CI) number of harp seals caught/tonne of landed roe along the northeast, south and west coasts of Newfoundland from1989 to 2003. The pre-1989 estimates used for hind-casting to 1970 are also shown.

Year	NE Coast		S Coast		W Coast	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
Pre 1989	**3.03** (187)*	(1.50 - 4.99)	**5.21** (296)	(3.54 - 7.03)	**3.97** (133)	(2.14 - 6.33)
1989	**3.71** (57)	(0.88 - 7.80)	**3.71**	(0.88 - 7.80)	**3.71**	(0.88 - 7.80)
1990	**1.69** (50)	(0.15 - 3.63)	**4.04** (91)	(1.66 - 6.94)	**6.59** (36)	(1.90 - 12.61)
1991	**2.63** (114)	(0.85 - 5.09)	**5.70** (205)	(3.61 - 8.08)	**4.06** (64)	(1.23 - 7.74)
1992	**12.72** (224)	(8.35 - 17.04)	**9.34** (207)	(6.12 - 13.25)	**11.75** (97)	(5.48 - 19.79)
1993	**15.91** (187)	(9.99 - 23.35)	**4.34** (238)	(2.80 - 6.09)	**35.67** (146)	(19.04 - 55.59)
1994	**34.26** (108)	(22.16 - 49.66)	**22.04** (213)	(13.84 - 32.33)	**94.70** (78)	(60.32 -132.29)
1995	**32.47** (57)	(13.45 - 55.15)	**10.14** (201)	(5.77 - 15.10)	**28.80** (57)	(17.16 - 41.24)
1996	**40.61** (132)	(25.55 - 56.06)	**12.35** (160)	(6.84 - 18.39)	**15.14** (98)	(10.33 - 20.64)
1997	**21.23** (58)	(13.55 - 30.08)	**3.59** (142)	(1.98 - 5.41)	**10.28** (72)	(6.00 - 15.52)
1998	**2.90** (105)	(1.52 - 4.74)	**2.90**	(1.52 - 4.74)	**2.90**	(1.52 - 4.74)
1999	**18.30** (36)	(9.60 - 29.68)	**1.86** (67)	(0.46 - 4.03)	**4.67** (59)	(1.94 - 7.85)
2000	**8.96** (47)	(4.39 - 14.72)	**2.62** (33)	(1.26 - 4.44)	**5.07** (51)	(2.27 - 8.53)
2001	**11.50** (110)	(7.05 - 16.97)	**22.85** (46)	(15.03 - 31.52)	**61.62** (86)	(36.45 - 88.53)
2002	**51.54** (69)	(29.35 - 80.60)	**53.14** (13)	(11.48 -102.61)	**69.24** (130)	(25.17 -129.44)
2003	**20.75** (51)	(1.32 - 54.90)	**6.03** (64)	(2.23 - 10.83)	**2.20** (50)	(0 - 5.70)

* equals the number of fishing trips in each region/year. Note that pre-1989 estimates of harps seals taken/tonne of roe were based on pooled landings from 1989 to 1991 and that all trips were pooled across regions for 1989 and 1998 due to small sample sizes.

Table 4: Estimates of the proportion of harp seal by-catch that consisted of animals one year of age or younger (beaters) from the northeast, south and west coast regions of Newfoundland from 1989 to 2000.

Year	NE Coast	S Coast	W Coast
Pre 1989*	0.77	0.92	0.93
1989	0.90	0.95	0.95
1990	0.60	0.83	0.85
1991	0.80	0.99	0.99
1992	0.66	0.96	0.92
1993	0.60	0.77	0.90
1994	0.48	0.95	0.90
1995	0.38	0.93	0.79
1996	0.16	0.56	0.62
1997	0.47	0.92	0.92
1998	0.73	0.82	0.73
1999	0.41	0.90	0.97
2000	0.79	1.00	1.00
2001-03*	0.51	0.84	0.85

* The pre 1989 estimate is the mean of the first three years of the times series in each region and the estimate for 2001-03 is the mean of the last five years.

Table 5: Total by-catch estimates for harp seals taken in the Newfoundland lumpfish fishery from 1970 to 2003 based on the current analyses and from Walsh et al. (2000) for comparison.

Year	Beaters	Total Harps	Total Harps Walsh et al. (2000)
1970	53	68	239
1971	391	490	1,706
1972	480	621	2,184
1973	358	465	1,637
1974	141	182	642
1975	219	285	1,001
1976	923	1,092	3,746
1977	1,281	1,577	5,618
1978	2,381	2,919	7,991
1979	2,799	3,310	7,426
1980	2,454	2,717	3,345
1981	3,539	3,921	5,340
1982	3,442	3,785	5,152
1983	4,504	4,962	6,928
1984	3,683	4,108	6,545
1985	4,225	4,857	9,206
1986	7,136	8,178	16,751
1987	11,118	13,096	29,693
1988	7,154	8,545	21,563
1989	9,457	10,256	6,847
1990	2,700	3,621	2,481
1991	9,074	9,689	9,655
1992	18,969	25,476	16,077
1993	18,876	26,472	29,040
1994	35,881	46,394	35,531
1995	13,641	19,701	16,946
1996	10,765	29,112	23,400
1997	13,541	18,600	17,531
1998	3,571	4,546	15,571
1999	9,750	16,030	
2000	9,715	11,323	
2001	14,572	19,400	
2002	5,492	9,329	
2003	3,486	5,367	

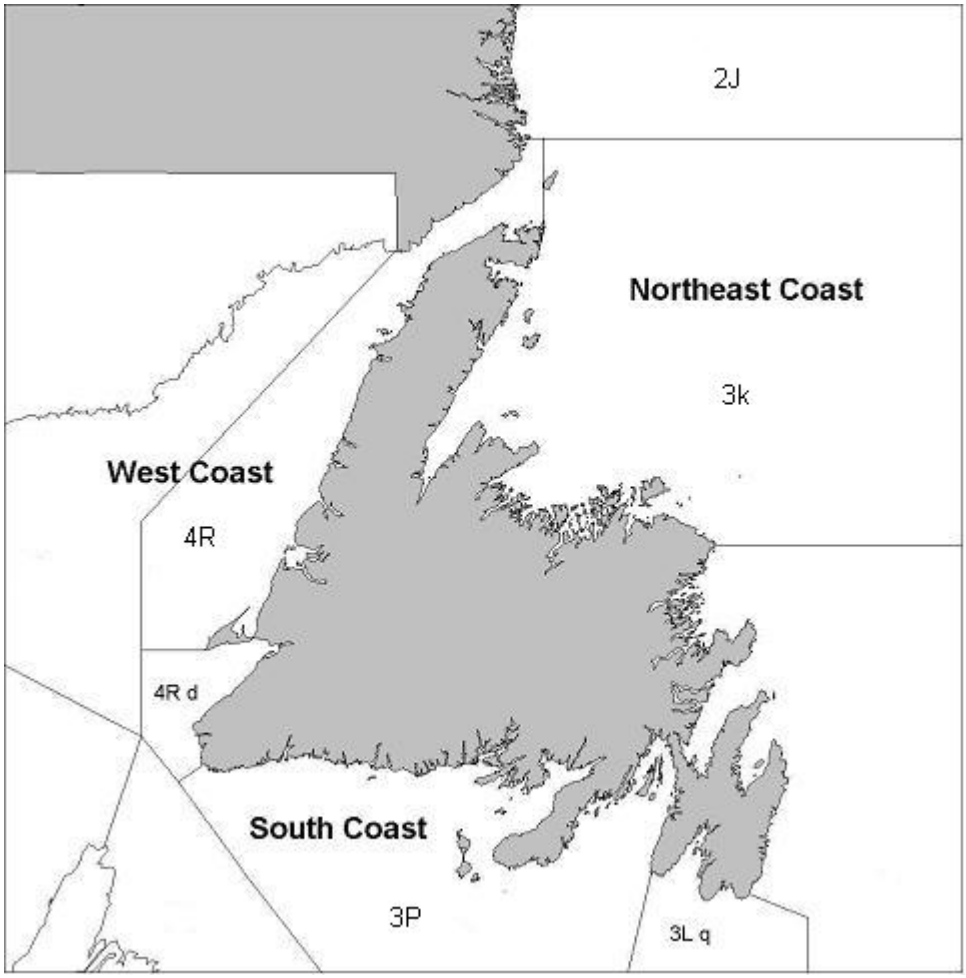

Figure 1. Map of study area showing NAFO Divisions and areas.

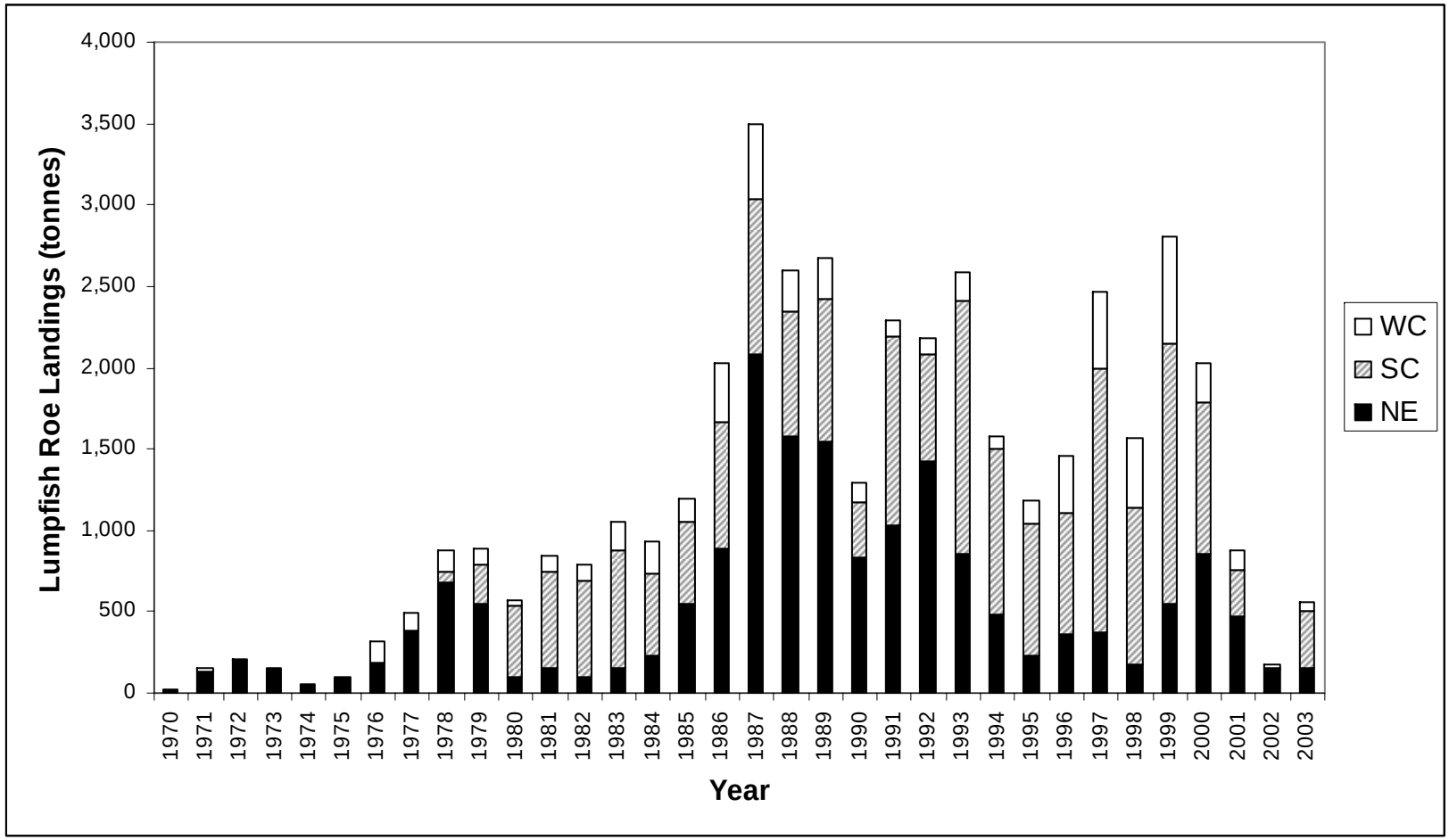

Figure 2. Newfoundland lumpfish roe landings by vessels less than 45ft. fishing along the northeast (NE), south coast (SC) and west coast (WC) from 1970 to 2003.

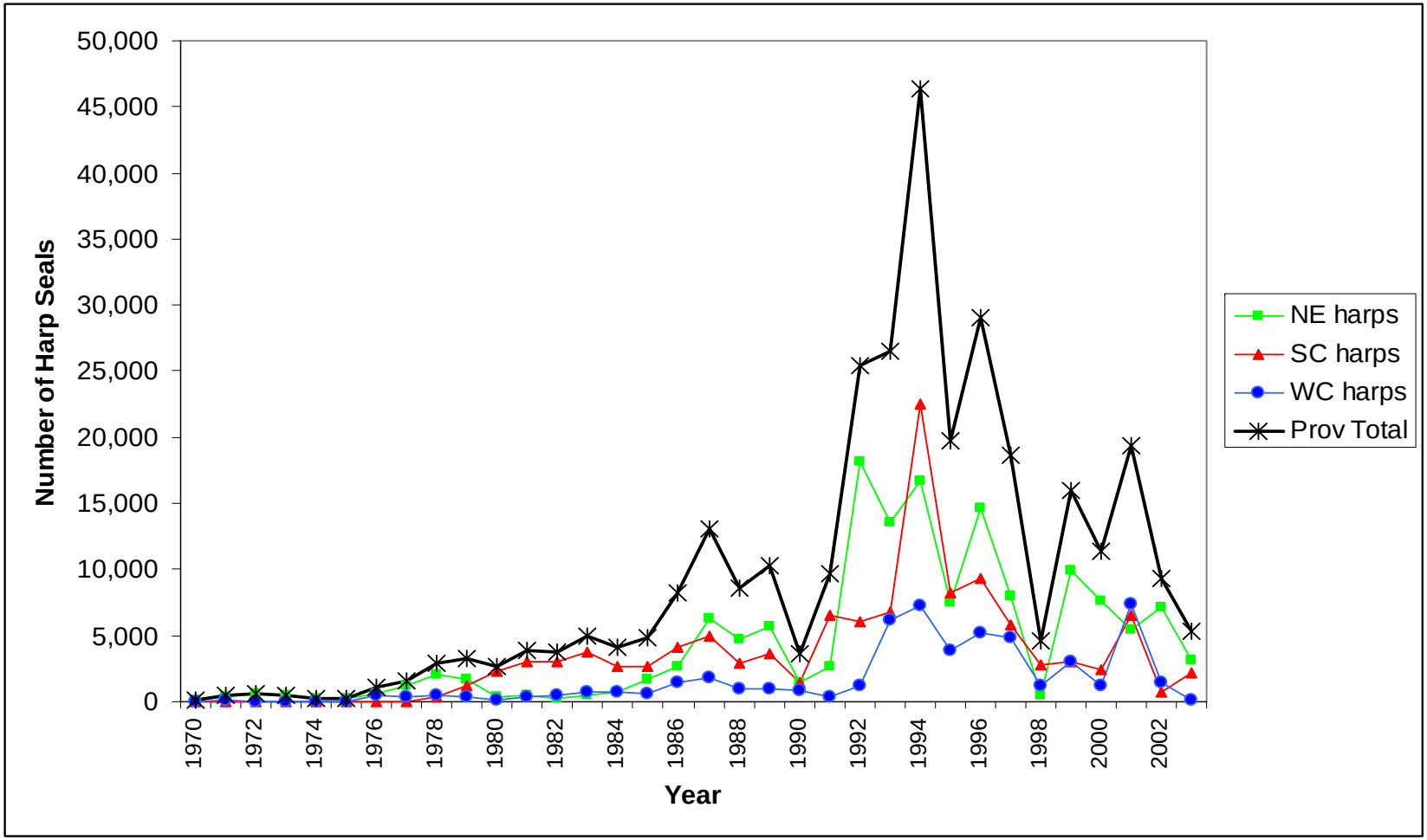

Figure 3. Estimated harp seal by-catch levels along the northeast coast (NE), south coast (SC) and west coast (WC) during the Newfoundland lumpfish fishery from 1970 to 2003. The total by-catch estimate for Newfoundland (Prov Total) was derived by summing across regions.