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# Distribution and Analysis of Canadian Greenland Shark (*Somniosus microcephalus*) bycatch in the NAFO Regulatory Area

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## ABSTRACT

Greenland Shark (*Somniosus microcephalus*) bycatch was investigated using the Canadian At-Sea Fisheries Observers data and Canadian research survey data. Greenland Sharks were bycaught in Canadian fisheries operating from Baffin Island-Subarea 0 south to Divs. 4X and 5Z (at the Canadian – United States Border). Temporally, the greatest observed bycatch of Greenland Shark occurred in the early 1990s, prior to the Northern Cod moratorium and the exclusion of foreign fleets from Canada's EEZ. However, it must be noted that patterns in the occurrence of Greenland Shark bycatch presented here depended on the type of fisheries being conducted (i.e., fishing area/ directed species/gear type) and the level of Canadian At-Sea Observer coverage of those fisheries. A number of Greenland Shark bycatch mitigation measures are also summarized.

## INTRODUCTION

Greenland Shark (*Somniosus microcephalus*) bycatch in NAFO-regulated fisheries recently became a concern of the Northwest Atlantic Fisheries Organization's Fisheries Commission (NAFO/FC Doc. 16/11). However, as with most shark species, accurate estimates of fishing mortality are unavailable, because bycatch and subsequent discarding of Greenland Sharks in unobserved fisheries are not recorded in catch statistics. Discard estimates are only available from ASOs aboard commercial vessels. Furthermore, post-release mortality of any live-released Greenland Shark bycatch remains unknown; although Canadian At-Sea Fisheries Observers (ASOs) have reported 100% mortality of larger, ram-breathing sharks caught by gillnets and otter bottom trawls (regardless of fishing depth). In addition, Campana *et al*. (2015) found that almost half of Porbeagle Sharks (*Lamna nasus*) bycaught with pelagic longlines were dead; although Blue Shark (*Prionace glauca*) live discards from that gear indicated low mortality (Campana *et al*. 2009). Grant *et al.* (2018*b*) found that Greenland Sharks can survive after being released from entanglement in longline gear, while Barkley *et al.* (2017) found increased physiological stress metabolites (blood lactate) in this species when hauled from deeper depths by commercial longlines. However, Greenland Sharks usually roll when caught on longlines; thus greatly entangling the fishing gear (especially around their caudal peduncle; Grant *et al.* 2018*b*).

This lack of data impedes any assessment of the potential impact of fisheries on Greenland Shark populations in the NAFO Regulatory Area (NRA), outside of Canada's exclusive economic zone (EEZ). NAFO Fisheries Commission has requested a review of available information on the life history and fishing mortality of Greenland Sharks in NAFO-regulated fisheries.

Previous analysis of Greenland Shark bycatch was conducted with Canadian At-Sea Observers data (2008-2011; July-November) from the Baffin Bay Greenland Halibut (*Reinhardtius hippoglossoides*) gillnet fishery (Cosandey-Godin *et al*. 2015). This study found that Greenland Shark bycatch in this fishery was highly variable from year to year, but spatially and temporally clustered. It should also be noted that some of the hotspots identified in that study are considered to be possible nursery areas (Cosandey-Godin *et al*. 2015). Overall, Cosandey-Godin *et al*. (2015) found that bycatch was reduced in deeper waters, and was higher in shallower waters. Another recent study on the abundance of Greenland Shark in Lancaster Sound (2015, 2016; July-September) found that density, while variable, was generally highest in deeper warm (>0$^{o}$C) water and lower in shallower sub-zero waters (Devine *et al*. 2018).

This paper provides an analysis of available Greenland Shark commercial bycatch and Canadian research survey data to investigate its spatial and temporal distributions, and summarizes a number of possible Greenland Shark bycatch mitigation measures.

## METHODS

The primary source of Greenland Shark commercial bycatch data was the Canadian At-Sea Fisheries Observer Program. Canadian ASO data are maintained by Fisheries and Oceans Canada in four regional databases originating from different geographic areas: Newfoundland and Labrador (NAFO Subareas 2+3); Maritimes (NAFO Divisions 4VXW+5); Gulf (Div. 4T); and Quebec (Divs. 4RS). ASO data from the Canadian North (Divs. 0AB) are maintained separately by both NL and Quebec Regions. In addition, data from Fisheries and Oceans Canada research surveys were also investigated for Greenland Shark catch.

## RESULTS AND DISCUSSION

### A. Canadian At-Sea Fisheries Observer Program

Greenland Shark bycatch appeared to be widespread in Canadian fisheries using several gear types targeting various fish species, according to 14 731 Canadian ASO records over 1985-2017 from Subarea 0 south to Div. 5Z). It must be noted that patterns in the occurrence of Greenland Shark bycatch presented in this paper depended on the type of fisheries being conducted (i.e., fishing area/directed species/gear type), and the level of Canadian At-Sea Observer coverage of those fisheries. Given that Greenland Shark bycatch and subsequent discarding in unobserved fisheries are not recorded in catch statistics, accurate estimates of fishing mortality for this species were unavailable.

On a temporal basis, bycatch of Greenland Sharks has varied widely, with peaks in 1988-1993 at an average of 1 293 observed sets (Table 1). Post-1994, potentially due to the Northern Cod moratorium and/or the exclusion of foreign fleets from Canada's EEZ, catches declined to only 75 observed sets with Greenland Sharks in 1998. Over 1999-2013, an average of 263 observed sets contained Greenland Sharks, and only 21 observed sets on average in 2015-17. It must be noted that the reporting of Greenland Shark bycatch in any particular year depends on the type of fisheries conducted and the level of ASO coverage of those fisheries.

Geographically, Greenland Sharks were bycaught in Canadian fisheries operating from Baffin Island-Subarea 0 south to Divs. 4X5Z (at the Canadian – United States Border; Fig. 1, Table 2). Overall, the majority of observed Greenland Shark bycatch occurred in Baffin Island-Subarea 0; although significant bycatch was also seen on the Newfoundland Shelf in Divs. 2GHJ3K. Fewer catches occurred on the Grand Banks (Divs. 3LNO), in southern Newfoundland waters (Div. 3P), on the Scotian Shelf (Divs. 4VWX), and in the Gulf of St. Lawrence (Divs. 4RST). As mentioned previously,, spatial patterns in these data are influenced by the type of fisheries conducted and ASO coverage levels in those fisheries. Consequently, the greater occurrence of Greenland Shark reported in northern areas is confounded by significantly higher levels of ASO coverage of several northern fisheries, relative to more southern areas. This pattern is exemplified by directed fisheries with the most Greenland Shark bycatch observed: ASO coverage of the shrimp trawl fishery in Shrimp Fishing Areas 2&3 is 100% (resulting in greater reported Greenland Shark bycatch); and the northern Greenland Halibut fishery usually has high coverage levels (20-30%). Conversely, low Greenland Shark bycatch recorded on the Grand Banks may be primarily due to very low (0-5%) ASO coverage of those groundfish fisheries. An exception is the Div. 3NO Yellowtail Flounder fishery, which had 100% observer coverage during the late 1990s, and has 25% ASO coverage since 2003. Similarly, observed Greenland Shark bycatch that is concentrated in shrimp trawls and otter trawls probably reflects higher ASO coverage in those gear sectors, relative to other observed gear types (e.g., gillnets, longlines; Table 3).

In relation to depth, bycatch of Greenland Shark varied by NAFO area (Figs. 2-5). Generally, the depth distribution of observed bycatch represented bathymetry of the area being fished (e.g., shallow-water fisheries in Div. 4T; deeper-water hauls in Divs. 4RS), and not depth preferences of this species. Typically, Greenland Sharks are thought to inhabit deep and cold waters (MacNeil *et al.* 2012); however, as indicated by Canadian ASO bycatch records, this species also occurs in shallower waters: including the St. Lawrence Estuary up to its confluence with the Saguenay River; near-surface around Baffin Island (Beck and Mansfield 1969); and Cumberland Sound, Nunavut (Idrobo 2008; Gallant *et al.* 2016).

When both number and weight of Greenland Shark bycatch were available (since 2008) in the Canadian ASO database, sizes of individual sharks were investigated. A couple of reported individual weights greater than 1 200 kg from Subdiv. 3Ps were deleted and assumed to be either misidentified Basking Shark (*Cetorhinus maximus*), or data-entry errors. No corrections were made on the lower end of this range of individual weights. Based on the remaining 430 records, most Greenland Sharks that were observed weighed between 200 and 400 kg (348 kg average); although the largest specimens recorded weighed 1 000-1 200 kg (Bigelow and Schroeder 1953; Fisk *et al.* 2002; MacNeil *et al.* 2012; Canadian ASOs, pers. comm.).

**B. Canadian Research Surveys**

In Canadian research vessel surveys, a total of 69 Greenland Sharks (Fig. 6) have been captured: 63 in surveys conducted by DFO-NL Region in southern Newfoundland and on St. Pierre Bank (Div. 3P), on the Grand Banks (Divs. 3LNO) and NL Shelf (Divs. 2GHJ3K); and 6 in surveys conducted by Quebec Region in the northern Gulf of St. Lawrence (Divs. 4RS). No sharks were caught in surveys of Div. 3P, the southern Gulf of St. Lawrence (Div. 4T), or on the Scotian Shelf (Divs. 4VWX); despite some catches being observed in commercial fisheries in all of these areas. Overall, this limited number of captures in research survey gear suggests that the bottom trawls used, coupled with a short tow duration (usually 15 minutes), are not effective in catching Greenland Sharks.

The average mass of 31 Greenland Sharks caught in DFO-NL fall surveys was 640 kg at an average depth of 540 m (range: 178-987 m), and an average bottom temperature of 3.6$^{o}$C (range: 0.9-5.1$^{o}$C). Average mass of 6 Greenland Sharks caught in DFO-NL spring surveys was 760 kg at an average depth of 436 m (range: 198-629 m), and an average bottom temperature of 2.6$^{o}$C (range: 0.1-3.9$^{o}$C).

**C. Conservation and Management**

Key to the reduction of Greenland Shark bycatch is greatly improving the reporting of bycatch through significantly more data collection and improved species identification. Through mandatory reporting of all shark bycatch by commercial and recreational fisheries, and increased coverage of relevant fisheries by adequately trained ASOs, the resultant greater knowledge of shark bycatch levels will lead to the development of efficacious bycatch mitigation policies and measures. Furthermore, effective monitoring and enforcement of the ban on shark finning and prohibition of the sale and possession of shark fins, in addition to training commercial fishers in safe handling and release practices for live shark bycatch, are all critical to reducing the mortality of sharks in commercial fisheries.

Adequate knowledge of the impact of fishing mortality on Greenland Sharks will allow the design, implementation, and monitoring of various management measures (see Table 2 *in* Cosandey-Godin and Morgan 2011): temporal and/or spatial closures to fishing (e.g., of shark "hot spots" such as seasonal nurseries or mating areas); gear restrictions (e.g., number of longline hooks, gillnet mesh size) or modifications (e.g., longline circle hooks, increased gillnet tensioning, otter trawl marine turtle excluder devices [TEDs], magnetic or chemical repellents); restrictions on bait type (e.g., switch from squid to using fish); shark bycatch limits (e.g., reduced bycatch-to-target species ratio, illegal possession/landings/sales of particular shark species); or reductions in fishing effort (e.g., shortening durations for trawling, reducing soak times for gillnets and longlines, restricting the number and size of vessels allowed in a fishery). For example, Treble and Stewart (2009) found that longline gear posed fewer ecosystem impacts (including reduced Greenland Shark bycatch) than gillnet fisheries for Greenland Halibut in Subarea 0. In addition, Woll *et al.* (2001) found that circle hooks, which also reduced gut-hooking in sharks, outperformed EZ-hooks in capturing the target species (Greenland Halibut) in this fishery. Another potentially effective gear modification involved reducing longline (gangion) breaking strength, which adequately released Greenland Shark bycatch after hooking while remaining intact with the target species (Greenland Halibut; based on the significant size differential between both species) (Grant *et al.* 2018*b*). However, a few experimental gear modifications, such as selective magnetic and repellent-treated (SMART) hooks, did not appear to reduce Greenland Shark bycatch (Grant *et al.* 2018*a*).

In otter trawl fisheries, rigid excluder devices (e.g., TEDs) that allow marine turtles and large sharks to escape upwards through the net significantly reduce shark bycatch (Brewer *et al.* 2006), and should be mandated for use in trawl fisheries that are known for capturing many sharks incidentally. In the Canadian northern shrimp fishery, mandatory excluder devices (e.g., the Nordmore size-separator grate) significantly reduce bycatch of groundfish by directing them upwards towards an exit "window" in the upper panel of the shrimp trawl. However, an inadequately-sized exit window in the net will not allow a large shark to escape capture; nor will an ineffective orientation to the net window upon capture (e.g., the shark's body is perpendicular to that exit). In addition, when a "flexible" groundfish excluder is used, it does not maintain enough rigidity to direct a large shark to the exit window; instead, this type of excluder caves inwards under the pressure of the shark's mass with the continual forward motion of the trawl, and is thus rendered out-of-alignment with the exit window for the remainder of the tow (Canadian ASOs, pers. comm.).

Greenland Shark bycatch mitigation measures must also consider its diel vertical movements (Gallant 2016): fisheries conducted in deep water during the day or in shallow water at night have a much higher risk of encountering this species, and thus should avoid its natural depth distributions by altering fishing practices.

Another bycatch mitigation measure was proposed by Davis *et al.* (2013), who mentioned that Inuit communities consider Greenland Sharks as a "nuisance species", and of no cultural, social, or economic importance. These authors highly recommended that information on the important role of this large apex predator in the Arctic ecosystem be offered to Arctic Indigenous peoples, followed by training in safe handling and release practices for live bycatch of this species. However, it must be noted that they are subsistence fishers, and do not fish on an industrial scale.

**D. Conclusion**

The Canadian At-Sea Observer database is the sole source of Greenland Shark bycatch data within Canada's EEZ. It has been noted that any patterns of occurrence of Greenland Shark bycatch presented in this paper depended on the type of fisheries being conducted (i.e., fishing area/directed species/gear type), and the level of Canadian ASO coverage of those fisheries. Therefore, although the Canadian ASO database is limited for comparing Greenland Shark bycatch between fisheries due to predominantly low levels of Observer coverage, details within these commercial data are useful for monitoring the occurrence and distribution of such bycatch (e.g., Cosandey-Godin *et al*. 2015). Lack of information on discarding in unobserved fisheries, which is not recorded in any catch statistics, is the most serious impediment to the accurate estimation of fishing mortality for this or any other shark species. Key to the reduction of Greenland Shark bycatch is greatly improving the reporting of bycatch through increased coverage of relevant fisheries by adequately trained ASOs. The resultant greater knowledge of shark bycatch levels will lead to the development of efficacious bycatch mitigation policies and measures. Furthermore, effective monitoring and enforcement of the ban on shark finning and prohibition of the sale and possession of shark fins, in addition to training commercial fishers in safe handling and release practices for live shark bycatch, are all critical to reducing the mortality of sharks in commercial fisheries. Given that climate change is rapidly increasing access to Arctic fish stocks by decreasing sea-ice cover, industrialized fisheries (e.g., Greenland Halibut, Northern Shrimp) are moving north; thereby greatly increasing the risk of bycatch and fishing mortality of this unprotected apex predator on a large scale (Davis *et al.* 2013).

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**Table 1.** Total number of sets in the Canadian At-sea Observer database reporting Greenland Shark bycatch by year.

| Year | Number of Observed Sets |
|---|---|
| 1985 | 341 |
| 1986 | 453 |
| 1987 | 569 |
| 1988 | 978 |
| 1989 | 1673 |
| 1990 | 1676 |
| 1991 | 1504 |
| 1992 | 1138 |
| 1993 | 790 |
| 1994 | 413 |
| 1995 | 297 |
| 1996 | 249 |
| 1997 | 148 |
| 1998 | 75 |
| 1999 | 173 |
| 2000 | 139 |
| 2001 | 283 |
| 2002 | 343 |
| 2003 | 381 |
| 2004 | 309 |
| 2005 | 361 |
| 2006 | 355 |
| 2007 | 488 |
| 2008 | 317 |
| 2009 | 207 |
| 2010 | 217 |
| 2011 | 189 |
| 2012 | 81 |
| 2013 | 106 |
| 2014 | 53 |
| 2015 | 9 |
| 2016 | 11 |
| 2017 | 42 |

**Table 2.** Total number of sets in the Canadian At-sea Observer database reporting Greenland Shark bycatch by NAFO division.

| NAFO | Number of Observed Sets |
|---|---|
| 0A | 408 |
| 0B | 582 |
| 2G | 594 |
| 2H | 1136 |
| 2J | 1786 |
| 3K | 969 |
| 3L | 356 |
| 3M | 15 |
| 3N | 59 |
| 3O | 151 |
| 3Pn | 3 |
| 3Ps | 117 |
| 4R | 7 |
| 4S | 11 |
| 4T | 8 |
| 4V | 20 |
| 4Vs | 6 |
| 4W | 37 |
| 4X | 31 |
| 5Z | 26 |
| Baffin Island | 8311 |
| Hudson Strait | 23 |
| Ungava Bay | 11 |

**Table 3.** Total number of sets in the Canadian At-sea Observer database reporting Greenland Shark bycatch by fishing gear type.

| Fishing Gear | Number of Observed Sets |
|---|---|
| Crab Pots | 2 |
| Drift Lines (drifting Longlines) | 1 |
| Gillnets | 623 |
| Longlines | 303 |
| Midwater Trawls | 14 |
| Otter Bottom Trawls | 4936 |
| Purse Seines | 1 |
| Set Lines (bottom or near bottom) | 109 |
| Shrimp Trawls | 8742 |

**Table 4.** Total number of sets in the Canadian At-sea Observer database reporting Greenland Shark bycatch by directed species.

| Directed Species | Number of Observed Sets |
|---|---|
| American Plaice (*Hippoglossoides platessoides*) | 13 |
| Atlantic Halibut (*Hippoglossus hippoglossus*) | 158 |
| Atlantic Cod (*Gadus morhua*) | 566 |
| Atlantic Cod, Haddock (*Melanogrammus aeglefinus*), Pollock (*Pollachius pollachius*) | 247 |
| Flatfish (unspecified) | 2 |
| Greenland Halibut (*Reinhardtius hippoglossoides*) | 5821 |
| Herring (*Clupea harengus*) | 1 |
| Monkfish (*Lophius americanus*) | 7 |
| OTHER | 12 |
| Porbeagle Shark (*Lamna nasus*) | 1 |
| Redfish (unspecified) | 198 |
| Roundnose Grenadier (*Coryphaenoides rupestris*) | 205 |
| Shrimp | 7378 |
| Silver Hake (*Merluccius bilinearis*) | 1 |
| Skate (unspecified) | 3 |
| Snow Crab (*Chionoecetes opilio*) | 2 |
| Squid | 1 |
| Swordfish (*Xiphias gladius*) | 1 |
| White Hake (*Urophycis tenuis*) | 3 |
| Witch Flounder (*Glyptocephalus cynoglossus*) | 103 |
| Yellowtail Flounder (*Pleuronectes ferruginea*) | 8 |

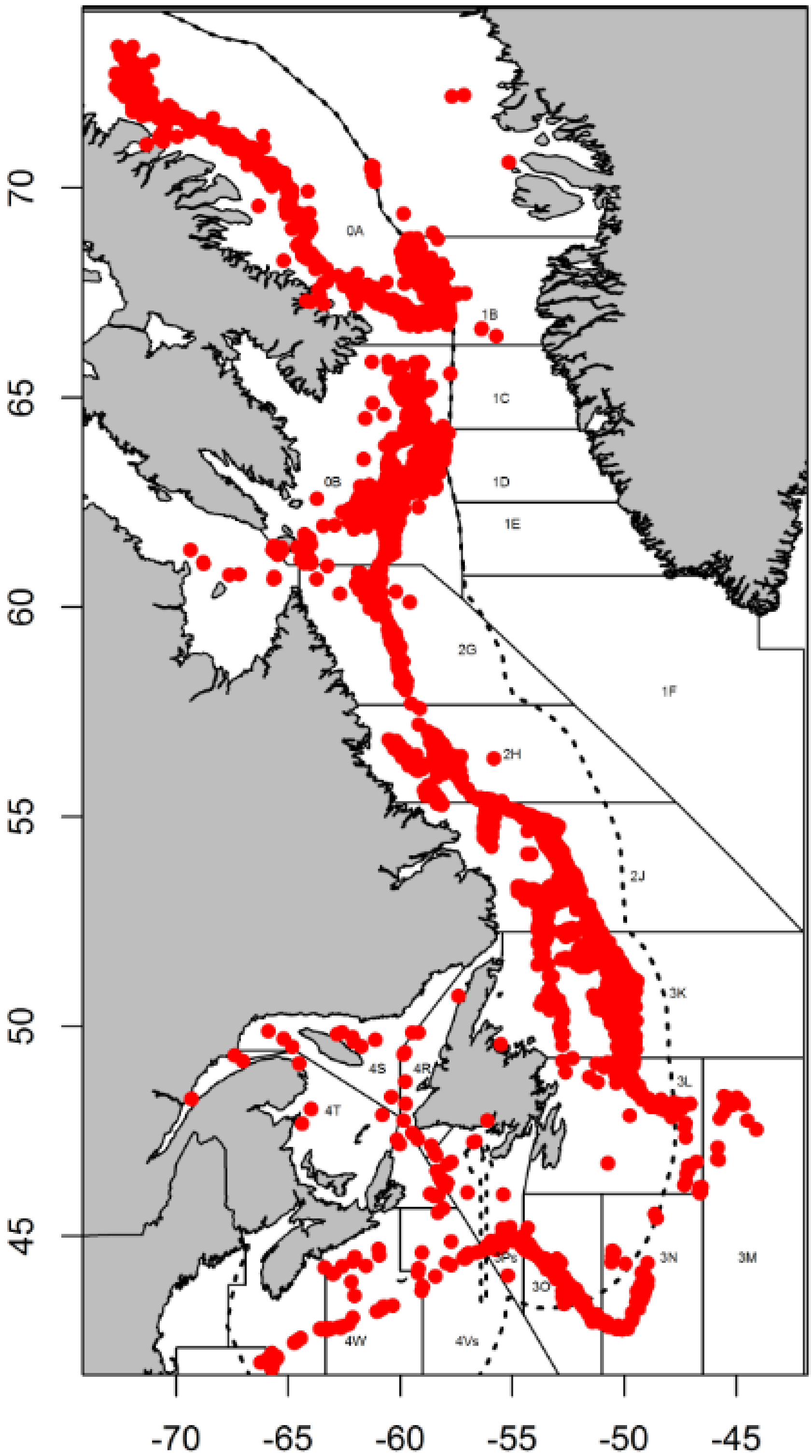


**Fig. 1.** Greenland Shark catch distribution from Canadian At-Sea Fisheries Observer data, 1985-2017. Note data for 2017 are incomplete.

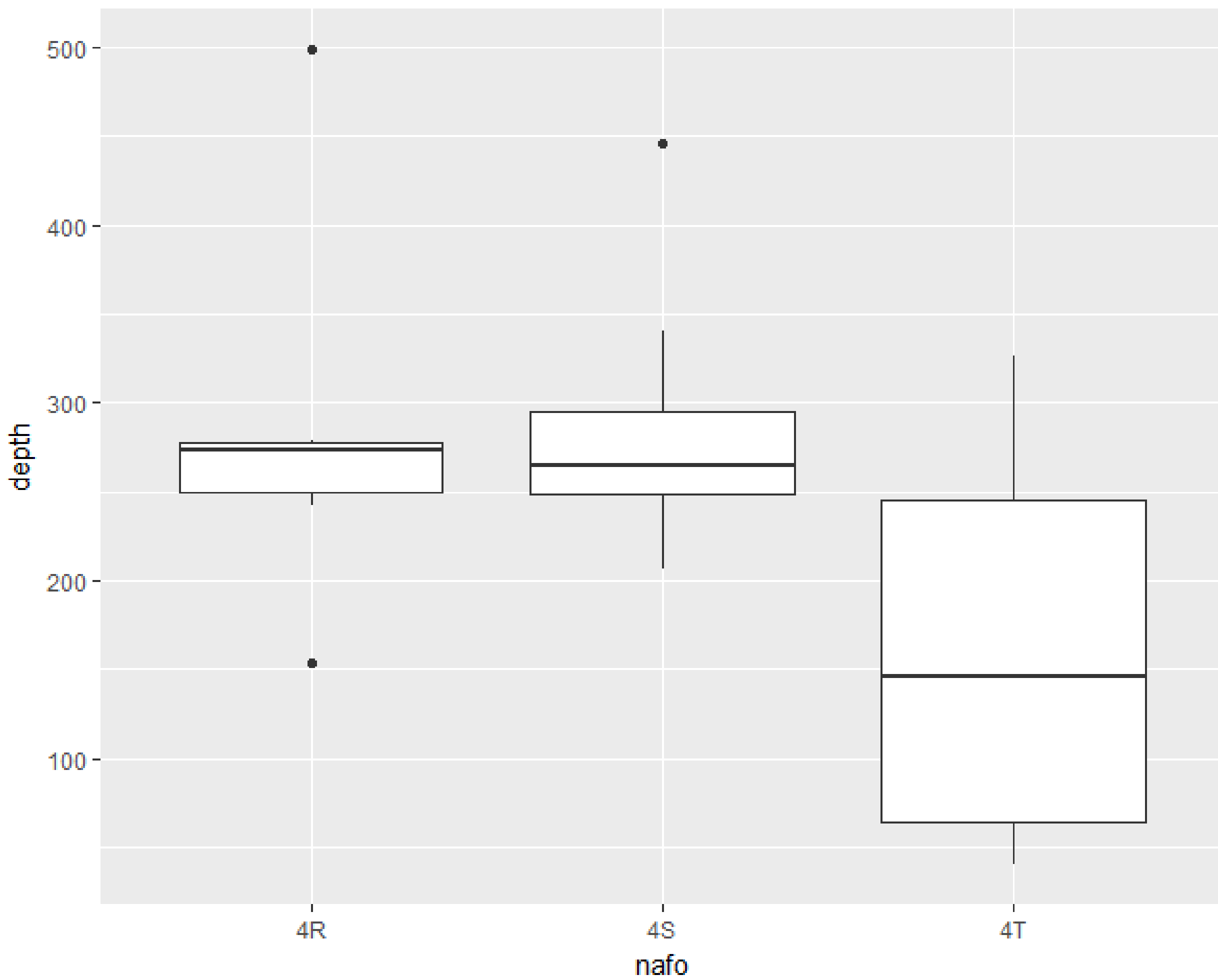


**Fig. 2.** Depth range of fishing sets that captured Greenland Sharks in Divs. 4R, 4S, and 4T.

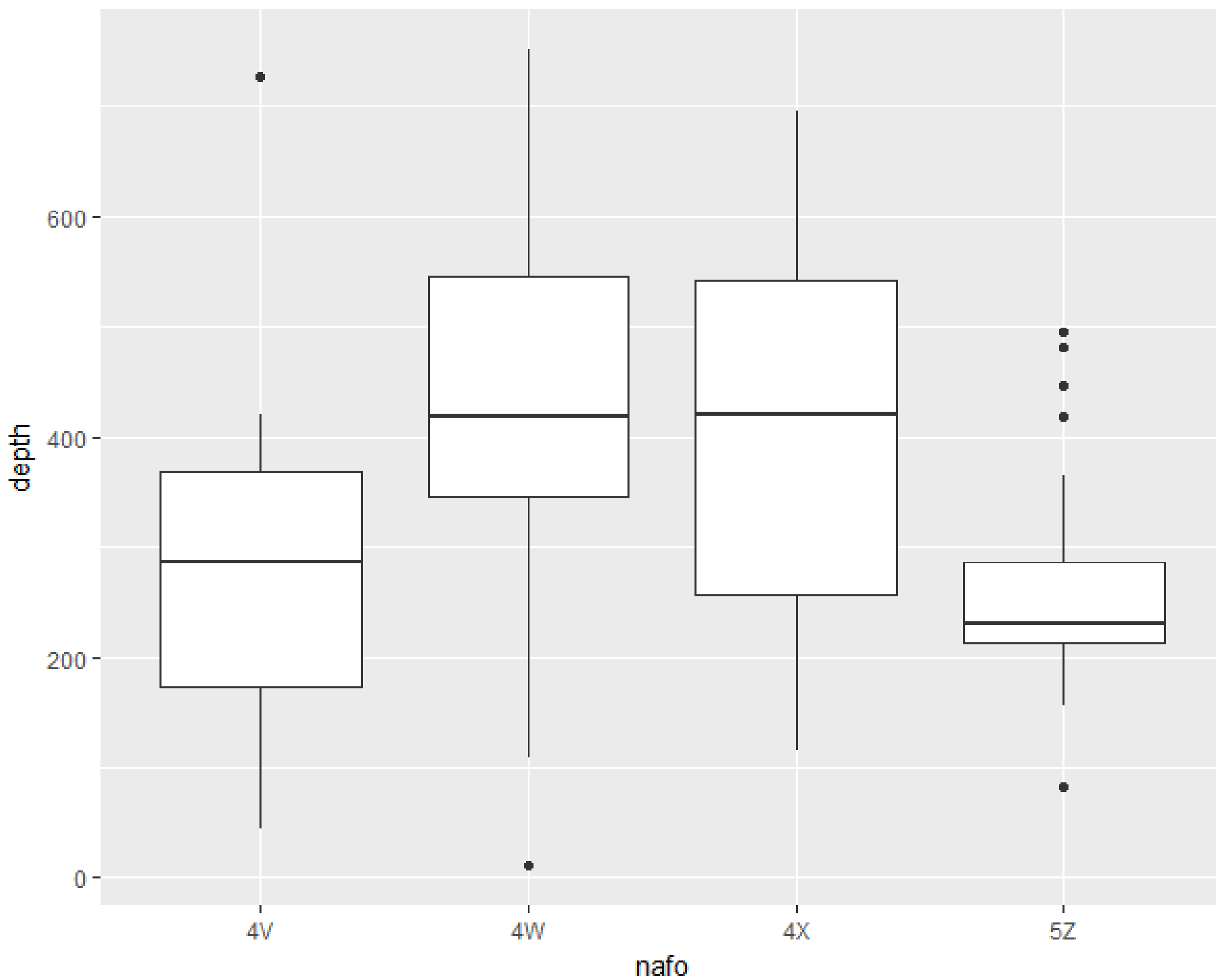


**Fig. 3.** Depth range of fishing sets that captured Greenland Sharks in Divs. 4V, 4W, 4X, and 5Z.

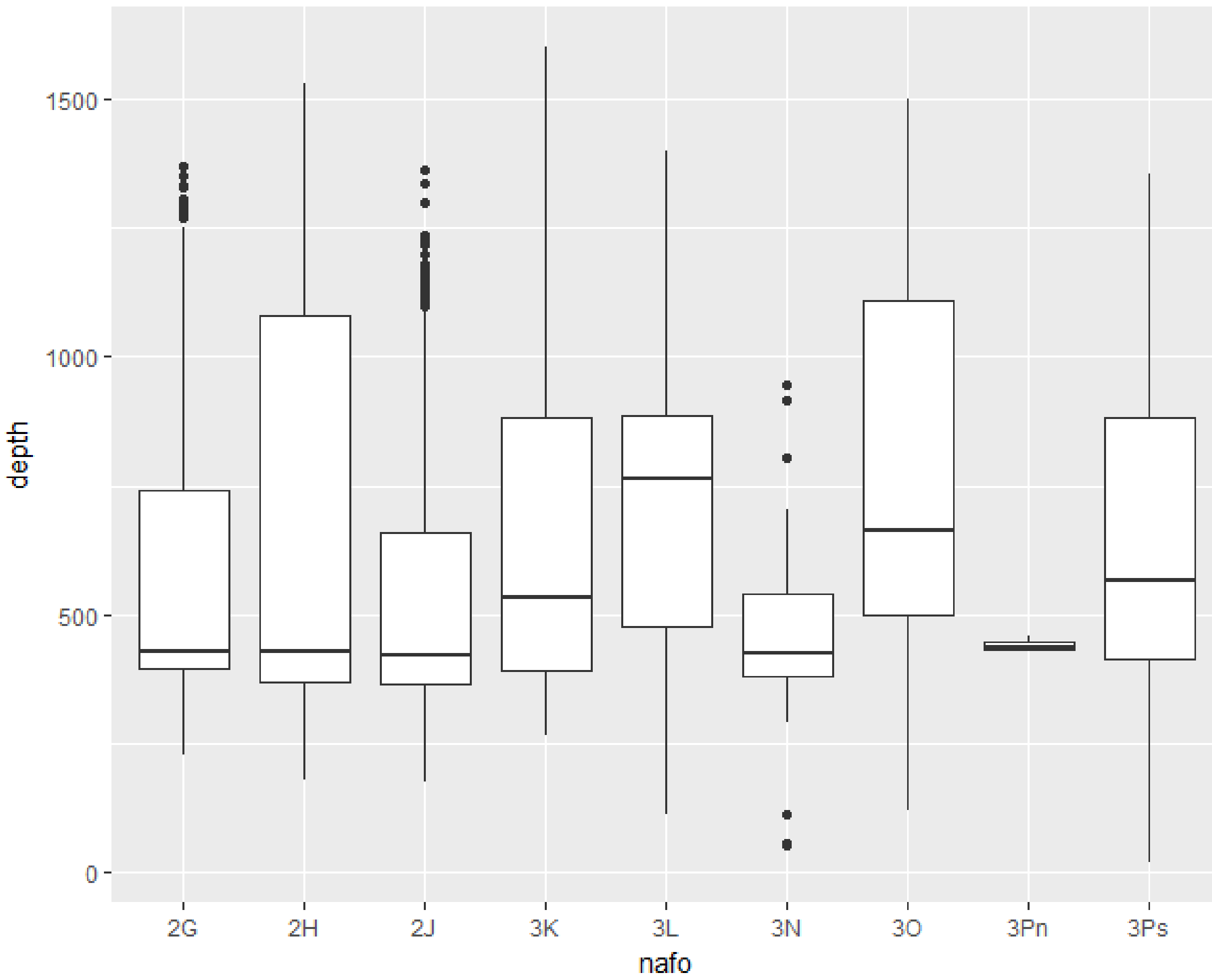


**Fig. 4.** Depth range of fishing sets that captured Greenland Sharks in Divs. 2GHJ, 3KLNO, Subdiv. 3Pn and 3Ps.

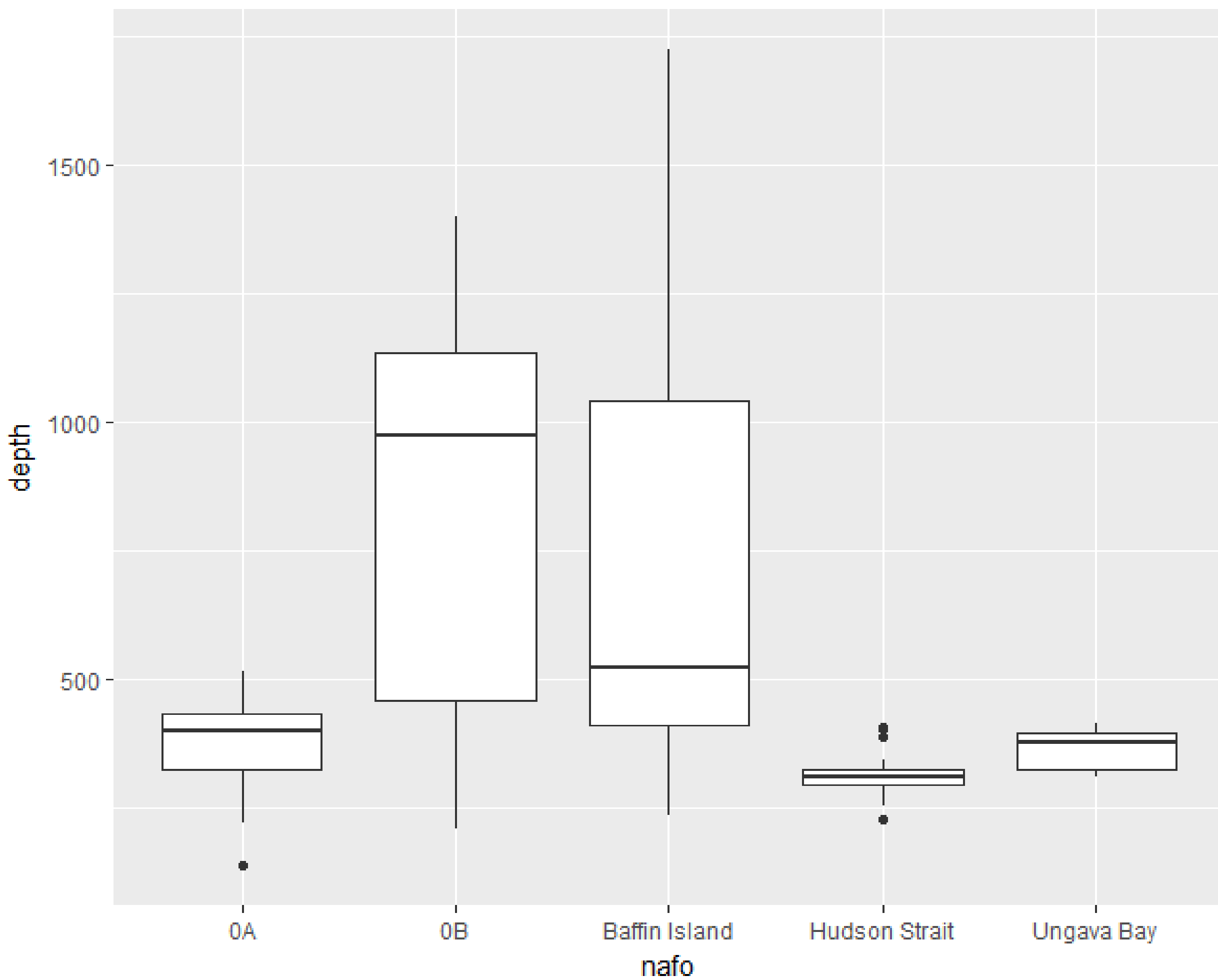


**Fig. 5.** Depth range of fishing sets that captured Greenland Sharks in Divs. 0A, 0B, Baffin Island Subarea 0, Hudson Strait, and Ungava Bay.

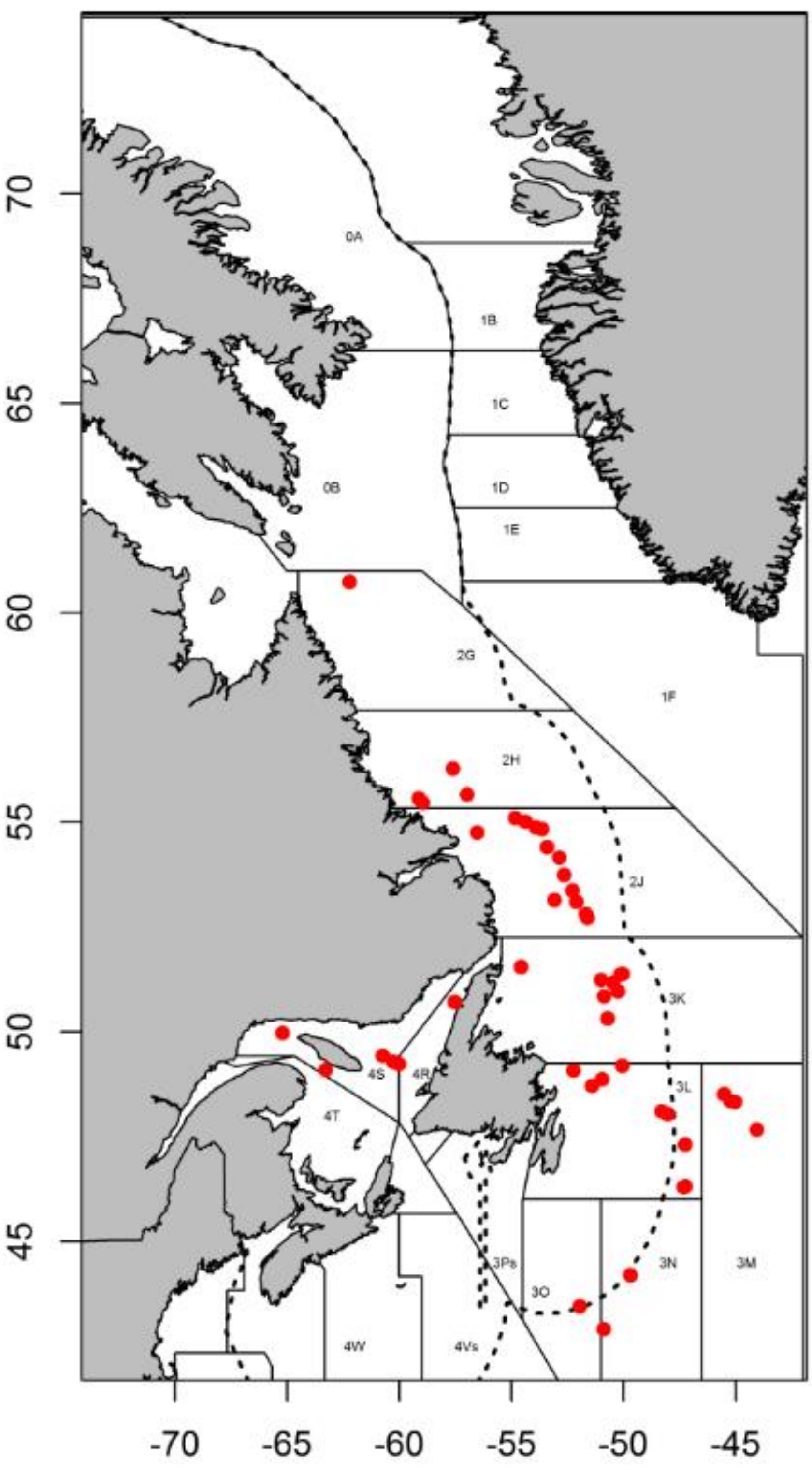


**Fig. 6.** All captures of Greenland Sharks from Fisheries and Oceans Canada research surveys conducted by the NL, Quebec, Gulf, and Maritimes Regions.