Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2025/060

Newfoundland and Labrador Region

Status of Iceland Scallop (*Chlamys islandica)* in the Canada-France Transboundary Zone (CORE Area) of St. Pierre Bank (NAFO Subdivision 3Ps) in 2023

E. Coughlan, K.D. Baker and K. Charmley

Fisheries and Oceans Canada
Science Branch
80 East White Hills Road
P.O. Box 5667
St. John's, NL A1C 5X1

October 2025

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
DFO.CSAS-SCAS.MPO@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-78586-8 Cat. No. Fs70-5/2025-060E-PDF

Correct citation for this publication:

Coughlan, E., Baker, K.D., and Charmley, K. 2025. Status of Iceland Scallop (*Chlamys islandica)* in the Canada-France Transboundary Zone (CORE Area) of St. Pierre Bank (NAFO Subdivision 3Ps) in 2023. DFO Can. Sci. Advis. Sec. Res. Doc. 2025/060. iv + 31 p.

Aussi disponible en français :

*Coughlan, E., Baker, K.D. et Charmley, K. 2025. État des stocks de pétoncle d’Islande (*Chlamys islandica*) dans la zone transfrontalière franco-canadienne (boîte à pétoncles) du banc de Saint-Pierre (sous-division 3Ps de l’OPANO) en 2023. Secr. can. des avis sci. du MPO. Doc. de rech. 2025/060. iv + 32 p.*

TABLE OF CONTENTS

ABSTRACT

This research document summarizes the results from the Fisheries and Oceans Canada (DFO) February 23, 2024, regional peer review meeting “Assessment of Iceland Scallop in the Canada France Transboundary Zone of St. Pierre Bank (NAFO subdivision 3Ps)”. The last assessment for this resource prior to the 2024 meeting took place at a regional peer review for Iceland Scallop in February 2018 (Coughlan et al. 2021).

Directed fishing of Iceland Scallop on the St. Pierre Bank began in 1989 and peaked at 6,000 t in 1992. There was no directed fishing activity between 1997 and 2016, and fishing activity has been minimal since 2017. The total allowable catch has been 990 t in the trans-boundary zone shared by Canada and France, known as the CORE area, since 2018. Data collected during a Canadian resource assessment survey of the area in September 2023 estimated a minimum dredgeable biomass of 1,000 t, among the lowest in the survey time series. This represents a decrease of approximately 45% since 2017 and consists of only 8% of the average biomass observed in the early 1990s. The mean shell height was consistently higher in Canadian waters than in French waters, and the average meat count decreased slightly from 85 scallop/500 g in 2017 to 75 scallop/500 g in 2023. This remains near the survey time series high, indicating smaller-sized scallop meats. Natural mortality has sharply increased since the last survey in 2017, but remains far below the survey time series high. Biomass of predatory sea stars generally corresponds with natural mortality levels, and 2023 was the highest level in the survey time series since 2005.

INTRODUCTION

SPECIES BIOLOGY

Iceland scallop (*Chlamys islandica*) are widely distributed throughout the subarctic North Atlantic Ocean, with fishable aggregations occurring as far south as the coast of Massachusetts in the northeastern United States. Populations off of Newfoundland and Labrador (NL) are usually found at depths of 50−200 m, predominantly on hard substrates consisting of sand, gravel, shell fragments, and stones (DFO 2001, Naidu et al. 1983). Iceland Scallop are filter-feeders, consuming plankton and detritus, and are associated with areas of strong currents (Garcia 2006). To reside in such areas, scallops attach to the substrate with protein fibers known as byssal threads.

Iceland Scallop are dioecious (i.e., have separate sexes), become sexually mature at 3−6 years of age, and fully recruit to the commercial fishery at 60 mm shell height (approximate age of 9 years). Spawning in NL waters begins in April or May and is thought to be initiated by temperature. Eggs are externally fertilized, and larvae are planktonic for up to 10 weeks before settling to the bottom. During their planktonic phase, they may drift considerable distances from the spawning adults. Iceland Scallop frequently live more than 25 years but seldom exceed 100 mm in shell height (DFO 2010). Sea star species including *Leptasterias polaris*, *Crossaster papposus, and Solaster endeca* are the main predators known for Iceland Scallop.

THE FISHERY

The directed fishery for Iceland Scallop started in 1989 and peaked at 6,000 t in 1992 (Table 1, Figure 1). Prior to 1996, the entire catch was taken by Canada. In 1992, the decision by an International Court of Arbitration resulted in jurisdictional changes over the disputed waters to the south of Newfoundland and St. Pierre and Miquelon, France. Following the decision, an annual total allowable catch (TAC) was established to be shared between Canada and France in an area called the "Trans-boundary Zone" or simply the "CORE" (Figure 2). France and Canada are allocated fixed percentages of the TAC at 70% and 30%, respectively. The joint TAC was first established for the CORE in 1995 at 2,800 t (840 t allocated to Canada). The TAC was reduced to 100 t (30 t for Canada) in 1999–2000, then subsequently increased to 400 t (120 t in Canada) in 2001, 1,650 t (495 t in Canada) in 2006, and then decreased by 40% to 990 t in 2018 (297 t in Canada). However, less than 10% of the TAC was taken each year from 1995 to 1997. There was no fishing between 1997 and 2016, and there has been minimal fishing activity in the CORE area since 2017 (Figure 1, Table 1).

METHODOLOGY

THE FISHERY

The fishery landings data are based on dockside monitoring reports, commercial logbooks, and purchase slips from buyers. The harvesters report the daily catch for each week of the fishery.

RESEARCH VESSEL SURVEYS

Survey Design

Fisheries and Oceans Canada (DFO) conducted resource assessment surveys using various vessels over the following years: from 1990 to 1993 aboard the *MV Gadus Atlantica*; in 1996 and 1998 aboard the CCGS *Teleost*. In 2005 the CCGS *Wilfred Templeman* was used as part of a Canada–France joint survey (in collaboration with IFREMER – Department of Biological Resources and Environment, France). The survey in 2009 and 2017 was conducted aboard the CCGS *Alfred Needler*; and in 2023 again aboard the CCGS *Teleost*. Additionally, a resource assessment survey was conducted by IFREMER in 2011 using the *Marcel Angie*, a commercial vessel (see Table 3 in Coughlan et al. 2021 for biomass results).

In 1991, the survey area was reduced, and the strata were redrawn to focus on scallop aggregations in the north. The strata were revised again in 1993 to reflect the new Canada–France boundary. All subsequent surveys have used the 1993 stratification scheme (Figure 3).

All surveys used a stratified random sampling design, with strata based on area and depth, and sets were optimally allocated in proportion to stratum specific areas and variance of the previous survey catch rates. The number of sets allocated for the 2023 resource assessment survey was based on the variance in catch from the 2017 survey (Table 2). Sets were optimally allocated to minimize the variance of the mean for a fixed sample size in a stratified random sampling scheme according to Cochran (1977):

$$n_h = \frac{n \times A_h \times S_h}{\sum(A_i \times S_i)} \qquad \text{(Eq 1)}$$

Where n_h = number of sets in stratum 'h', n = total number of sets available, A_h = area of stratum 'h', S_h = variance in stratum 'h', A_i = area of each stratum, and S_i = variance in each stratum.

Fishing Methods

From 1990 to 1998, a 12-foot New Bedford scallop dredge equipped with 3-inch rings and a configuration of three top and four bottom interconnecting links was used during the surveys. Since 2005, an 8-foot dredge has been used, maintaining the same ring and link configuration. The standard tow length was one nautical mile with the 12-foot dredge and half a nautical mile with the 8-foot dredge. Towing speed was approximately 3 knots for both dredge types, with a warp (wire length) to depth ratio of 3:1.

For the Canadian resource assessment surveys, all catch results were standardized to the swept area of an 8-foot dredge to ensure comparability across the time series. Tows were generally conducted through the designated positions and followed the planned direction. However, if the position was too close to the stratum border or there was an obstruction, tow direction was modified so that the tow could be completed within the stratum or to avoid the obstruction.

Sampling

Upon completion of each tow, the total catch was sorted by species, counted, and weighed. Live scallops were bushelled and weighed in baskets. Depending on the volume of the catch and steam time to the next fishing station, either the whole catch or a randomly selected weighed subsample was set aside for individual shell height measurements to the nearest mm. Individual shell height and meat weight/yield information was also collected in each stratum. Cluckers (empty paired valves still attached at the hinge line) were separately sorted, weighed, counted, and measured. Clucker weights and the weight of residual debris (such as sand, broken shell fragments, and pebbles) were removed from sampled and total catch weights. Each station was only occupied after sampling from the previous set was completed. This prevented water loss, which can affect recorded weights and subsequently the biomass estimates of Iceland Scallop.

Predatory sea stars were sorted by species and sampled for individual weight and length. The length of each sea star was measured from the mouth to the end of the longest arm to the nearest mm.

BIOMASS AND ABUNDANCE ESTIMATES

In previous Iceland Scallop assessments, STRAP (Stratified Random Assessment Process; Smith and Somerton 1981) and/or Ogmap (Ogive Mapping; Evans 2000) was used to calculate Iceland Scallop minimum dredgeable biomass (MDB) and abundance indices. STRAP was also used to determine MDB for sea star species (Coughlan et al. 2021). STRAP is a spatial expansion method that uses survey catch rates to estimate biomass and abundance indices (Smith and Somerton 1981). The average weights and numbers sampled in each stratum are multiplied by the area of the stratum as an estimate for the total weight (biomass) and number (abundance) in that stratum. STRAP requires consistent sampling of at least two sets per stratum in each year of the survey to maintain a consistent time series and trend analysis. Ogmap is a spatial expansion method that includes correlation with depth (Evans 2000). It requires adequate annual sampling throughout the entire survey area, but there is no minimum sampling rate per stratum requirement. Ogmap is considered legacy software and is no longer maintained by DFO.

The spatial coverage of the Canadian resource assessment surveys has been inconsistent through time. For example, since 1993, stratum 10 has been sampled in 5 out of 7 surveys. In the last Iceland Scallop assessment (Coughlan et al. 2021), STRAP and Ogmap biomass estimates were calculated within the CORE area of interest for each year with available data, even though different strata were sampled throughout the time series (see Table 3 and 4 within Coughlan et al. 2021 for details). To alleviate issues related to inconsistent survey coverage and to improve current and future biomass estimation methodologies, we employed a spatiotemporal model to better predict consistent and reliable biomass and abundance indices for Iceland Scallop.

The spatiotemporal models were created for years with available Canadian resource assessment survey data using the R package '*sdmTMB'* (Anderson et al. 2024). This modelling technique was peer-reviewed and approved for species assessments by the International Council for the Exploration of the Sea (ICES 2022), Northwest Atlantic Fisheries Organization (NAFO 2022), and other DFO assessed species (e.g., NAFO Div. 3Ps orange-footed sea cucumber – *Cucumaria frondosa* and Shrimp Fishing Area 4 striped shrimp – *Pandalus montagui*). In addition, NAFO's Standing Committee on Research Coordination recommended this model technique be explored for species within the NAFO Regulatory Area (NAFO, 2022).

A stochastic partial differential equation mesh with a minimum distance edge of 3 km was constructed using integrated nested Laplace approximation (Figure 4). The mesh consisted of 116 vertices.

The package '*sdmTMB'* integrates a template model builder and the stochastic partial differential equation matrices (Anderson et al. 2024; Chopin 2009). Anisotropy (shared and estimated separately for model components), a depth covariate, and various distributions (i.e., Tweedie, delta-gamma, and delta log-normal) were considered within the model formulation. The best model was chosen based on the Akaike Information Criterion (Akaike, 1973), convergence diagnostics, and sanity function checks that assured the maximum gradient log-likelihood with respect to all fixed effects <0.001, a positive definite Hessian, and no random field marginal standard deviations less than 0.01. In addition, residuals were calculated using Markov Chain Monte Carlo (MCMC) sampling to estimate random and fixed effects at their maximum likelihood values within the R package '*sdmTMBextra*' (Anderson 2023). Model fit was examined using residual diagnostic plots (i.e., quantile-quantile plots and spatiotemporal mapping).

Biomass

The best model for estimating biomass was

$$Density_{BIO} = 0 + s\,(Depth) + 0 + as.factor(Year) \qquad \text{(Eq 2)}$$

Where $Density_{BIO}$ is the standardized biomass (kg / km^2) of Iceland Scallop in a set during the Canadian resource assessment survey, *Depth* is the average depth (m) during each set, and *Year* is the year of the survey, represented as a factor.

Spatial and spatiotemporal autocorrelation were included as Gaussian random fields to account for how unmeasured or latent habitat suitability metrics change spatially and temporally. The spatiotemporal random fields were assumed to be independent across years. The spatial random effect and the spatially-varying temporal dynamics were estimated by Delaunay triangulation over the mesh, assuming Gaussian Markov random fields (Rue and Held 2005). The best-fitting model used a Tweedie family distribution (family of probability distributions which include purely continuous normal, gamma, and inverse Gaussian distributions) with a log link. The inclusion of anisotropy (the structural property of non-uniformity in different directions) did not improve model fit.

The model was used to predict Iceland Scallop density (kg/km^2) annually across the surveyed CORE area (strata 10–12, and 21–25) on a 1 km^2 gridded surface, with depth estimated within each cell using General Bathymetric Chart of the Oceans bathymetry raster data (IOC et al., 2023). Annual biomass estimates were calculated within the whole area using the predicted density surface.

Abundance

The best model for predicting abundance was

$$Density_{ABUND} = s\,(Depth) + 0 + as.factor(Year) \qquad \text{(Eq 3)}$$

Where $Density_{ABUND}$ is the standardized number (# / km^2) of Iceland Scallop in a set during the Canadian resource assessment survey, *Depth* is the average depth (m) during each set, and *Year* is the year of the survey, represented as a factor. Spatial and spatiotemporal autocorrelation were included as Gaussian random fields to account for how unmeasured or latent habitat suitability metrics change spatially and temporally. The spatiotemporal random fields were assumed to be independent across years. The spatial random effect and the spatially varying temporal dynamics were estimated by Delaunay triangulation over the mesh, assuming Gaussian Markov random fields (Rue and Held 2005). The best model used a Tweedie (with log link) family distribution. Anisotropy was accounted for so that Matérn ranges varied by direction and were estimated independently for each model component (i.e., spatial and spatiotemporal random fields).

The model was used to predict Iceland Scallop abundance annually across the surveyed CORE area (strata 10–12, and 21–25) using the same approach as per biomass estimation.

Comparisons with STRAP and Ogmap

Model-derived MDB estimates were compared with the biomass and abundance estimates derived from STRAP and Ogmap. Since STRAP cannot be used with less than two sets per stratum, estimates could only be compared within a subset of consistently surveyed strata (11–12, 21–23).

MEAT YIELDS AND COUNTS

During the Canadian resource assessment surveys, Iceland Scallop were collected to determine biological meat yields (%), average meat weight (g), and meat counts (number of meats / 500 g) in representative strata that varied each year (Table 3).

Biological meat yield is given by the formula:

$$x = \frac{meat\ weight\ (g)}{round\ weight\ (g)}\ X\ 100 \qquad \text{(Eq. 4)}$$

Meat count is given by the formula:

$$x = \frac{500\ (g)}{meat\ weight\ (g)}\ X\ sample\ (n) \qquad \text{(Eq. 5)}$$

SIZE STRUCTURE

The shell height data from the Canadian resource assessment surveys in 1998, 2005, 2009, and 2017 were used to determine the abundance at length in 1-mm groups determined with STRAP analysis for each stratum within the Canadian and French zones; and to generate length frequency distributions of the catches. STRAP and sdmTMB abundance trends were considered comparable and therefore STRAP was used.

The shell height data were also used to calculate the average of mean shell height (mm) for all strata within the CORE area combined, as well as for the strata within Canadian, and French zones, respectively. These results were presented in line plots to compare trends.

NATURAL MORTALITY

Natural mortality of Iceland Scallop was computed over the survey time series directly from the occurrence of cluckers (Dickie 1955):

$$M = 1 - e\left(\frac{c}{t}\right)\left(\frac{1}{L}\right) * 365 \qquad \text{(Eq. 6)}$$

where M = annual mortality rate, C = number of cluckers in a sample adjusted to account for tow-induced disarticulation (number of cluckers*1.211; Naidu 1988), L = number of live scallops in a sample, and t = average time in days (210.8) required for natural clucker disarticulation (Mercer 1974).

RESULTS

THE FISHERY

There was no fishing between 1997 and 2016, with minimal fishing activity in the CORE area since 2017 (Table 1, Figure 1). The total TAC in the CORE area decreased by 40% in 2018 from 1,650 t to 990 t (297 t in Canada, 693t in France).

BIOMASS AND ABUNDANCE INDICES

Biomass

The best model used to predict MDB throughout the area of interest showed no concerning patterns in the diagnostic plots of the MCMC-derived residuals (Figures 5, 6). The model incorporated both spatial (Figure 7) and spatiotemporal (Figure 8) random fields. The spatial random field showed negative effects in stratum 23, stratum 10, the southeast corner of stratum

25, and the eastern corner of stratum 12. Spatial random fields represented latent effects that do not vary with time (e.g., sediment patterns), whereas the spatiotemporal random fields represented latent effects that vary both spatially and temporally (e.g., temperature or current patterns). Model specifics (e.g. Matérn range) are provided in Table 4. The highest density of Iceland Scallop were predicted in depths of approximately 70 m within the CORE area of interest (Figure 9).

The MDB density spatial patterns (Figure 10) consistently illustrated that the density of Iceland Scallop was higher in the early 1990s, particularly in strata 11, 21, 22, and 23. However in recent surveys, scallop biomass was low throughout the surveyed area. Unsurprisingly, the largest uncertainty in the prediction surface of biomass occurred within the areas most poorly surveyed throughout the time series (i.e., strata 10 and 25), and in years with the fewest survey sets (e.g., 2017 and 2023) (Figure 11).

The model-derived MDB index was comparable to those estimated using STRAP and Ogmap in the main commercial strata and where data were consistently available throughout the survey time series (strata 11–12, 21–23) (Figure 12, Table 5), particularly in most recent years. In survey years from 1990 to 1998, the model-derived MDB estimates were larger than the MDB estimates derived from both STRAP and Ogmap. However, the confidence intervals always overlapped, with the exception of 1993, and the general trend in the time series remained consistent among methods.

The 2023 model-derived MDB estimate of 1,000 t for the total CORE area (including 10–12, 21–25) is among the lowest in the survey time series, and reveals a decrease of approximately 45% from 1800 t in 2017 (Table 6, Figure 13). This decrease was driven by a drop in MDB estimates in both the Canadian and French zones with a 45-50% decrease since the last survey in 2017 (Figures 13 and 14). Throughout the survey time series, the MDB was highest in the early 1990s and decreased to a low of 1300 t in 1998 and then increased in 2005 and 2009, due mainly to an increase in MDB in the Canadian zone (Table 6, Figure 13). The main commercial strata (11–12, 21–23) (Figure 3) account for 80-90% of the entire Iceland Scallop MDB in the CORE area. The MDB in the main commercial strata declined from 1,570 t in 2017 to 800 t in 2023 (Table 6, Figures 12 and 14).

Abundance

The best-fitting model predicting abundance of Iceland Scallop in the area of interest showed no concerning patterns in the MCMC derived residuals (Figures 15, 16). The model incorporated anisotropy, with Matérn range estimated separately for both spatial (Figure 17) and spatiotemporal (Figure 18) random fields (Figure 19, Table 4). The spatial random field showed negative effects in the northern and western edge of stratum 23, southeast corner of stratum 25, and stratum 10. The conditional effect plot of depth highlights that the largest abundance of Iceland Scallop are predicted in depths of approximately 70 m within the CORE area of interest (Figure 20). Similar to the MDB model, the largest uncertainty in the prediction surface of abundance was found within the areas most poorly surveyed (i.e., strata 10 and 25), and in years with the fewest survey sets (e.g., 2017 and 2023; Figure 21).

The abundance indices derived from STRAP, Ogmap and the model were comparable and had overlapping confidence intervals, with the exception of 1993. In this year, the model-derived estimate of abundance was substantially larger than the STRAP-derived and Ogmap-derived estimates (Figure 22).

The abundance trends throughout the survey time series are similar to MDB trends with the highest numbers in the early 1990s, a decrease in 1998, and then an increase in 2005 and 2009. Since then, the abundance of Iceland Scallop has declined to the lowest level in the survey time series in 2023. This decrease is driven by a decline in abundance in both the Canadian and French zones, with a decrease of 45% since 2017 (Figure 23).

MEAT YIELDS AND COUNTS

Biological meat yields were estimated for samples collected in strata 11, 12, 22, and 25 in the 2023 resource assessment survey. Overall, the meat yield showed little change over the last few surveys with 11.5% in 2009, 11.2% in 2017, and 10.8 in 2023 (Figure 24, Table 3).

The meat count based on the Canadian surveys increased from 68 meats/500 g in 2009 to 85 meats/500 g in 2017 then decreased to 75 meats/500 g in 2023 (Figure 25). The slight decrease in the meat count in 2023 compared to 2017 indicates little change in the meat yield, with little change in scallop size within the designated areas.

SIZE STRUCTURE

The length frequency distributions (shell height) for the strata combined within the Canadian (strata 10–12) and French (strata 22–25) zones showed little apparent change, with a mean shell height consistently close to 80 mm throughout the survey time series (Figure 26, Table 7). Scallop in the Canadian zone were larger than scallop observed in the French zone, where the mean shell height was close to 70 mm in 2017 and 2023 (Figure 27, Table 7).

The abundance at length was highest in 2005 and 2009, and the abundance of small Iceland Scallop in the French zone was higher than the abundance of small scallop in the Canadian zone in 2009, 2017, and 2023 (Figure 27). It was also evident that the overall abundance has decreased throughout the size range in both zones.

NATURAL MORTALITY

The overall natural mortality index (computed as the proportion of cluckers to live scallops) (Naidu 1988) gradually increased between 1992 and 1996 from 0.19 to 0.52 and then peaked at a high of 0.88 in 1998. Since then, the mortality index has decreased to 0.12 and 0.07 in 2009 and 2017, respectively and then increased to 0.18 in 2023 (Figure 28, Table 8). This increase in natural mortality is likely associated with the increase in MDB of predatory sea stars.

PREDATION

In the early to mid-1990s, a high abundance of predatory sea stars contributed to significant mortality in Iceland Scallop in the CORE Area (Lawrence et al. 1997; Naidu et al. 2001). Biomass of all sea star species increased to a high of 1,600 t (MDB) in 1998, when Iceland Scallop biomass was at its lowest (Figure 29). In the CORE Area, biomass of predatory sea star species (*Leptasterias polaris*, *Crossaster papposus, and Solaster endeca)* increased from 1993 to 1998, then decreased to the lowest level in the survey time series in 2017 to 315 t, and since has increased by more than 50% (to 686 t) in 2023.

ECOSYSTEM CONSIDERATIONS

Marine ecosystem conditions indicated overall limited productivity of the fish and shellfish community in NAFO Subdivision 3Ps. The ecosystem has undergone structural changes, with increased dominance of warm water species starting in 2010. In recent years (2019–22), ecosystem indicators have suggested that conditions could be improving.

Sea surface temperature in 2023 in NAFO Subdivision 3Ps was at the second warmest level on record (2022 being the record). Bottom temperatures were back to normal after being at record-warm levels in 2021 and 2022. This warmer climate corresponded with improved conditions observed at the lower trophic levels, including increased concentrations of chlorophyll-a, earlier spring blooms, and increased zooplankton abundance and biomass.

CONCLUSIONS

The 2023 MDB estimate of 1,000 t is among the lowest in the survey time series, a decrease of approximately 45% since 2017 and is 8% of the average in the early 1990s. The number of scallop meats per 500 g (i.e., average meat count) remains near the survey time series high, which indicates smaller-sized scallop meats. Natural mortality has sharply increased since the last survey in 2017, but remains far below the survey time series high. Biomass of predatory sea stars generally corresponds with natural mortality levels with an increasing trend.

Currently, there are no established reference points by which to determine stock status in relation to a precautionary approach framework. For this resource monitoring is limited with no annual resource assessment survey with time gaps (3–4 years) in between surveys, therefore data is limited to assess this resource, or estimate reference points for a precautionary approach framework.

REFERENCES CITED

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. *In*: Second International Symposium on Information Theory. Akademiai Kiado, Budapest. pp. 267–281.

Anderson, S.C. 2023. sdmTMBextra: Extra functions for working with 'sdmTMB' models. R package version 0.0.1.

Anderson, S.C., Ward, E.J., English, P.A, Barnett, L.A.K., and Thorson, J.T. 2024. sdmTMB: An R Package for Fast, Flexible, and User-Friendly Generalized Linear Mixed Effects Models with Spatial and Spatiotemporal Random Fields. bioRxiv: 2022–03.

Chopin, N. 2009. Approximate Bayesian Inference for Latent Gaussian Models by using Integrated Nested Laplace Approximations. J. Royal Stat. Soc. Ser. B: Stat. Method. 71(2): 319–392.

Cochran, W.G. 1977. Sampling Techniques. Third Edition. John Wiley & Sons, Toronto, 428 p.

Coughlan, E., Hynick, E., and Skanes, K. 2021. The Status of Iceland Scallop (*Chlamys Islandica*) in the Canada-France Transboundary Zone (Core area) of St. Pierre Bank in 2017. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/071. iv + 17 p.

DFO. 2001. Iceland Scallop in Newfoundland and Labrador. DFO Sci. Stock Status Rep. C2-07(2001).

DFO. 2010. Assessment of Iceland Scallop in the Canada-France Transboundary Zone of St. Pierre Bank. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/054.

Dickie, L.M. 1955. Fluctuations in Abundance of the Giant Scallop, *Placopecten magellanicus* (Gmelin), in the Digby Area of the Bay of Fundy. J. Fish. Res. Board Can. 12(6): 707–856.

Evans, G.T. 2000. Local estimation of probability distribution and how it depends on covariates. DFO Can. Stock Asses. Sec. Res. Doc. 2000/120. 11 p.

Garcia, E.G. 2006. The Fishery for Iceland Scallop (*Chlamys islandica*) in the Northeast Atlantic. Adv. Mar. Biol. 51: 1–55.

ICES. 2022. Benchmark workshop on *Pandalus* stocks (WKPRAWN). ICES Sci. Rep.

IOC, IHO, BODC. 2023. The GEBCO_2023 Grid.

Lawrence, J.H., Naidu K.S., and Mahé J.C. 1997. The development of a plague of *Crossaster papposus* and *Leptasterias polaris* (Echinodermata: Asteroidea) on the St. Pierre Bank, Grand Banks of Newfoundland (1989-96) and its effects on the Iceland Scallop. Abstract only. 4th Intnl. Temperate Reef Symposium, 1997.

Mercer, M.C. 1974. Natural mortality of the Iceland scallop (*Chlamys islandica*) in the Gulf of St. Lawrence. ICES C.M. 1974/K7: 11 p.

NAFO. 2022. Report of the Scientific Council Meeting. NAFO Scientific Council Studies. Serial No. N7322(22/18).

Naidu, K.S., F.M. Cahill, and D.B. Lewis. 1983. Scallop Survey in NAFO Division 3Ps (including Green, St. Pierre and Burgeo Banks). CAFSAC Res. Doc. 83/4. 27 p.

Naidu, K.S. 1988. Estimating Mortality Rates in the Iceland Scallop, (*Chlamys islandica* O.F. Muller). J. Shellfish Res. 7(1): 61–71.

Naidu, K.S., F.M. Cahill, and E.M. Seward. 2001. The Scallop Fishery in Newfoundland and Labrador Becomes Beleaguered. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/064. 55 p.

Rue, H., and Held, L. 2005. Gaussian Markov Random Fields: Theory and Applications. J. Royal Stat. Soc. Ser. A: Stat. Soc. 170(3): 858.

Smith, S.J. and G.D. Somerton. 1981. STRAP: A user-oriented computer analysis system for groundfish research trawl survey data. Can. Tech. Rep. Fish. Aquat. Sci. 1030: iv + 66 p.

TABLES

Table 1. Total allowable catch (TAC) and removals for Iceland Scallop in the northern portion of St. Pierre Bank (NAFO subdivision 3Ps). Note 2017 and 2018 were not presented as the Rule of Five guidelines applies for this particular year.

		TAC (t, round)			Removals (t, round)		Non-CORE
	Canada	France	Total	Canada	France	Total	Removals
	No distinction between			36	0	36	0
	Canadian or French zones			507	0	507	0
	Boundary dispute before			755	0	755	0
	an international court.			5,967	0	5967	0
International boundary decision June, 1992							
1993	-	-	-	0	0	0	667
1994	-	-	-	0	0	0	440
1995	840	1960	2800	230	0	230	831
1996	975	2275	3250	158	148	306	302
1997	630	1470	2100	4	118	122	5245
1998	630	1470	2100	0	0	0	2792
1999	30	70	100	0	0	0	1198
2000	30	70	100	0	0	0	1148
2001	120	280	400	0	0	0	498
2002	120	280	400	0	0	0	478
2003	120	280	400	0	0	0	87
2004	120	280	400	0	0	0	38
2005	120	280	400	0	0	0	1992
2006	495	1155	1650	0	0	0	136
2007	495	1155	1650	0	0	0	6
2008	495	1155	1650	0	0	0	3
2009	495	1155	1650	0	0	0	2
2010	495	1155	1650	0	0	0	-
2011	495	1155	1650	0	0	0	-
2012	495	1155	1650	0	0	0	-
2013	495	1155	1650	0	0	0	-
2014	495	1155	1650	0	0	0	-
2015	495	1155	1650	0	0	0	-
2016	495	1155	1650	0	0	0	-
2017	495	1155	1650		0	0	-
2018	297	693	990	-	-	-	-
2019	297	693	990	0	-	-	-
2020	297	693	990	0	-	-	-
2021	297	693	990	0	-	-	-
2022	297	693	990	0	-	-	-
2023	297	693	990	0	-	-	-

Table 2. Distribution of survey sets by strata, areas, and intensity of coverage in the 2023 resource assessment survey for Iceland Scallop in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps).

Stratum	Mean Depth (m)	Area(nmi^2)	No. of Sets completed	No. of sets/nmi^2
10	67.3	17.9	3	0.17
11	72.2	51.6	18	0.35
12	50.9	38.6	13	0.34
21	78.6	13.6	4	0.22
22	50.2	60.0	19	0.32
23	81.0	23.8	10	0.42
24	72.2	17.0	4	0.24
25	55.1	46.6	10	0.19
Total	70.3	269.1	81	0.50

Table 3. Biological meat yields, average meat weights, and meat counts of Iceland Scallop in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps) over the survey timeseries (1996–2023).

Year	Stratum	Number Sampled	Whole wt. (kg)	Meat wt (g)	Yield %	Avg. meat wt. (g)	Meat Count (#/500g)
1996	11	310	20.87	2,407	11.53	7.8	64.4
	22	504	33.75	4,520	13.39	9	55.8
	25	79	7.3	1,022	14	12.9	38.6
	Total	893	61.92	7,949	12.84	8.9	56.2
2005	11	118	8.44	1,172	13.9	9.9	50.3
2009	11	250	18.13	1,814	10.01	7.26	69
	12	50	3.59	490	13.8	9.8	51
	22	100	5.91	706	11.9	7.06	71
	23	50	2.09	304	14.6	6.08	82
	Total	800	29.72	3,314	11.2	7.36	68
2017	12	30	1.94	216	11	7.1	69
	22	50	2.56	252	9.8	5.0	99
	23	145	6.93	850	12	5.7	85
	Total	225	11.43	1,318	11.5	5.9	85.4
2023	11	134	9.7	985.2	10.2	7.35	68
	12	80	7.1	799.5	11.3	9.99	50
	22	184	8.12	922.6	11.4	5.01	99.7
	25	94	5.26	557.6	10.6	5.93	84.3
	Total	492	30.18	3264.9	10.8	6.64	75.3

Table 4. Outputs of Iceland Scallop in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps) spatiotemporal generalized additive mixed models.

Parameters	Biomass model	Abundance model
Matérn range (km)	8.3	Spatial: 5.9–20.3 @ 154° Spatiotemporal: 3.0–10.5 @ 154°
Tweedie p	1.70	1.67
Spatial SD	1.63	1.80
Spatiotemporal SD	1.46	1.66

Table 5. Minimum dredgeable biomass (MDB) estimates derived from sdmTMB (model), Ogmap and STRAP analysis for the main commercial strata/consistently sampled strata (11,12, 21, 22, 23) in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps). (based on Canadian resource assessment survey data; including joint Canada- France survey in 2005). Note: CI_Low (Lower Confidence Interval- 95%): CI_Upper (Upper Confidence Interval- 95%).

	Main Commercial Strata (11, 12, 21, 22, 23)								
	sdmTMB Model			Ogmap			STRAP		
Year	**MDB-Biomass Estimate (t, 1000s)**	**CI Low**	**CI Upper**	**MDB-Biomass Estimate (t, 1000s)**	**CI Low**	**CI Upper**	**MDB-Biomass Estimate (t, 1000s)**	**CI Low**	**CI Upper**
1990	9.61	6.98	13.23	7.24	5.61	10.3	9.77	6.36	13.18
1991	11.19	8.29	15.10	8.01	5.95	10.1	8.78	6.234	11.32
1992	13.01	9.87	17.15	8.17	5.94	10.7	9.58	7.05	12.112
1993	8.34	6.53	10.66	5.08	3.71	6.27	4.67	3.637	5.696
1996	2.99	2.03	4.38	1.92	1.24	2.68	2.62	1.831	3.41
1998	1.21	0.75	1.94	0.606	0.33	0.832	0.92	0.594	1.25
2005	1.93	1.48	2.52	2.21	1.64	2.81	2.05	1.13	2.975
2009	2.20	1.64	2.95	2.24	1.34	2.87	2.73	1.694	3.758
2017	1.57	0.83	2.98	0.891	0.56	1.34	1.13	1.838	4.151
2023	0.80	0.49	1.31	0.489	0.35	0.671	0.6	0.305	0.886

Table 6. Minimum dredgeable biomass (MDB) estimates derived from spatiotemporal model, for all strata in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps) (including strata 10, 11,12, 21, 22, 23, 24, 25) and main commercial strata (based on Canadian resource assessment survey data, including joint Canada- France survey in 2005).Note: CI_Low (Lower Confidence Interval- 95%): CI_Upper (Upper Confidence Internal- 95%).

	sdmTMB Model						
	CORE Area (Strata 10-12; 21-25)			Main Commercial Strata (Strata 11-12; 21-23)			
Year	**MDB-Biomass Estimate (t, 1000s)**	**CI_ Low**	**CI_ Upper**	**MDB-Biomass Estimate (t, 1000s)**	**CI_ Low**	**CI_ Upper**	**Commercial Strata % of Total MDB**
1990	10.53	7.75	14.31	9.61	6.98	13.23	91
1991	12.83	9.41	17.51	11.19	8.29	15.10	87
1992	14.93	11.31	19.69	13.01	9.87	17.15	87
1993	10.26	7.99	13.18	8.34	6.53	10.66	81
1996	3.20	2.21	4.63	2.99	2.03	4.38	93
1998	1.33	0.84	2.10	1.21	0.75	1.94	91
2005	2.20	1.69	2.85	1.93	1.48	2.52	88
2009	2.45	1.84	3.25	2.20	1.64	2.95	90
2017	1.84	1.02	3.30	1.57	0.83	2.98	86
2023	1.00	0.64	1.57	0.80	0.49	1.31	80

Table 7. Shell height (mm) for Iceland Scallop over the survey timeseries (1998, 2005, 2009, 2017, and 2023) in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps) (in respective Canada and France zones) with 95% Confidence intervals.

Area/Zone	Year	Number sampled	Mean Shell Height	Maximum Shell Height	Minimum Shell Height	Upper CI	Lower CI
Canada	1998	383	74.51	75.34	73.68	0.83	0.83
	2005	905	79.63	80.16	79.11	0.52	0.52
	2009	836	79.31	79.84	78.79	0.52	0.52
	2017	281	79.26	80.34	78.18	1.08	1.08
	2023	353	81.26	82.31	80.22	1.04	1.04
France	1998	824	71.16	72.06	70.25	0.91	0.91
	2005	271	73.61	75.09	72.12	1.49	1.49
	2009	958	65.33	66.13	64.54	0.80	0.80
	2017	254	69.61	70.70	68.53	1.09	1.09
	2023	428	71.40	72.39	70.41	0.99	0.99

Table 8. Stratum-specific natural mortality estimates for Iceland Scallop in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps), calculated from the ratio of cluckers to live scallops. Clucker numbers are adjusted by a factor of 1.221 to allow for tow-induced disarticulation.

Stratum	1996	1998	2005	2009	2017	2023
10	0.02	0.00	0.00	-	-	-
11	0.16	0.22	0.14	0.14	0.06	0.08
12	0.00	0.00	0.19	0.18	0.21	0.30
-	-	-	-	-	-	-
21	0.34	0.00	0.00	0.19	0.00	0.24
22	0.59	0.97	0.49	0.10	0.15	0.26
23	0.00	0.45	0.31	0.04	0.02	0.23
24	0.99	0.98	0.00	0.00	0.00	0.00
25	0.89	1.00	0.15	0.11	0.09	0.23
Overall	0.50	0.88	0.21	0.12	0.07	0.1834

FIGURES

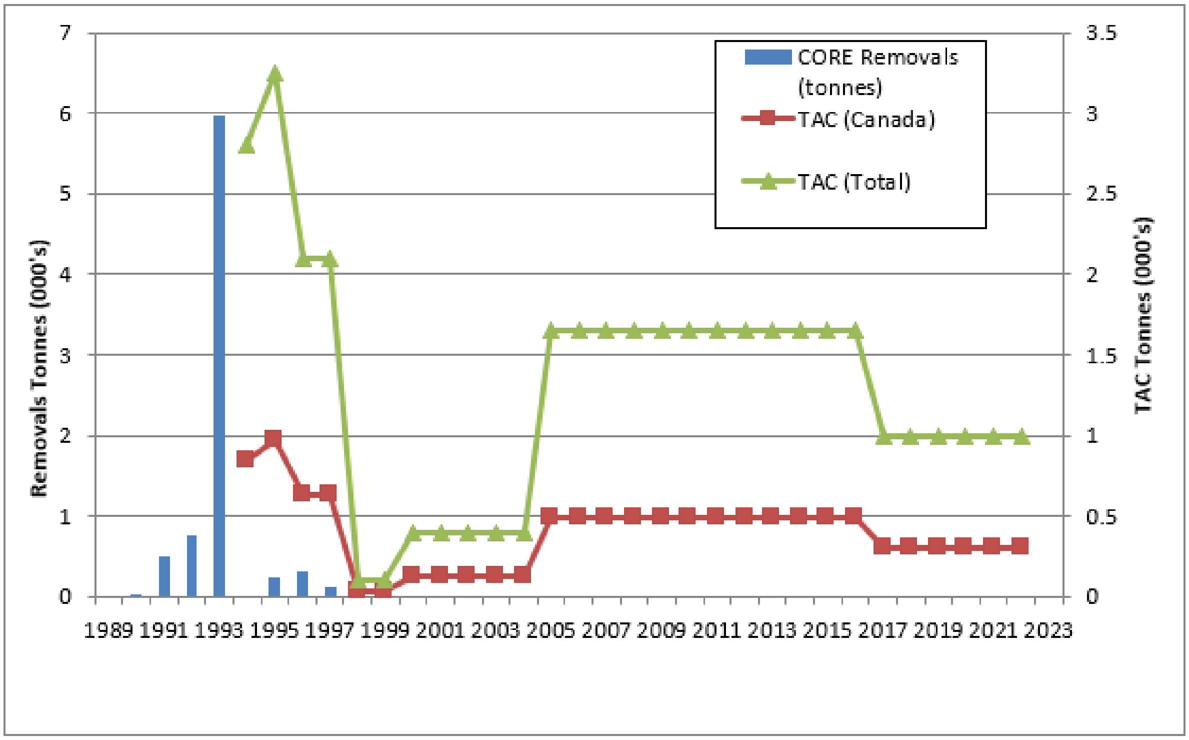

Figure 1. Total TACs, Canadian TACs and total removals for Iceland Scallop in the northern portion (Canada-France Transboundary (CORE) Zone) of St. Pierre Bank (NAFO subdivision 3Ps).

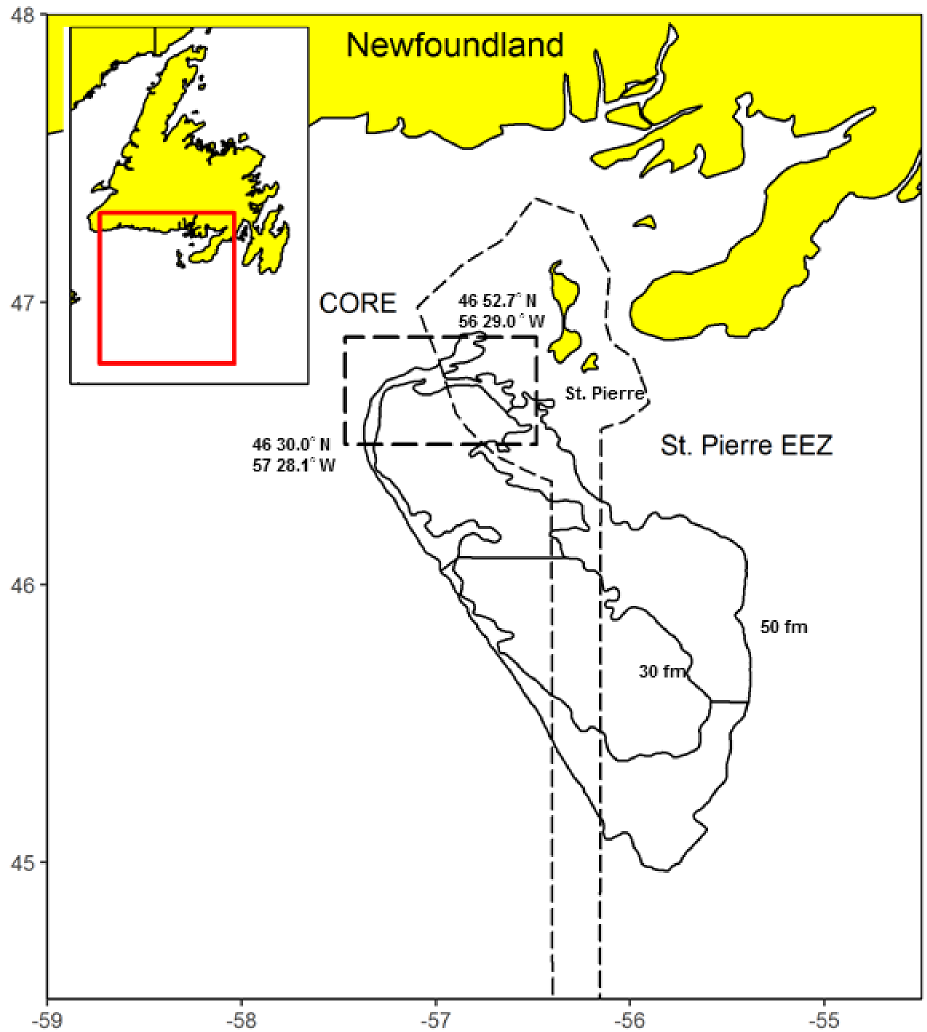

Figure 2. Northern St. Pierre Bank (NAFO subdivision 3Ps) showing the Canada-France Transboundary (CORE) Zone and French Economic Exclusive Zone (EEZ).

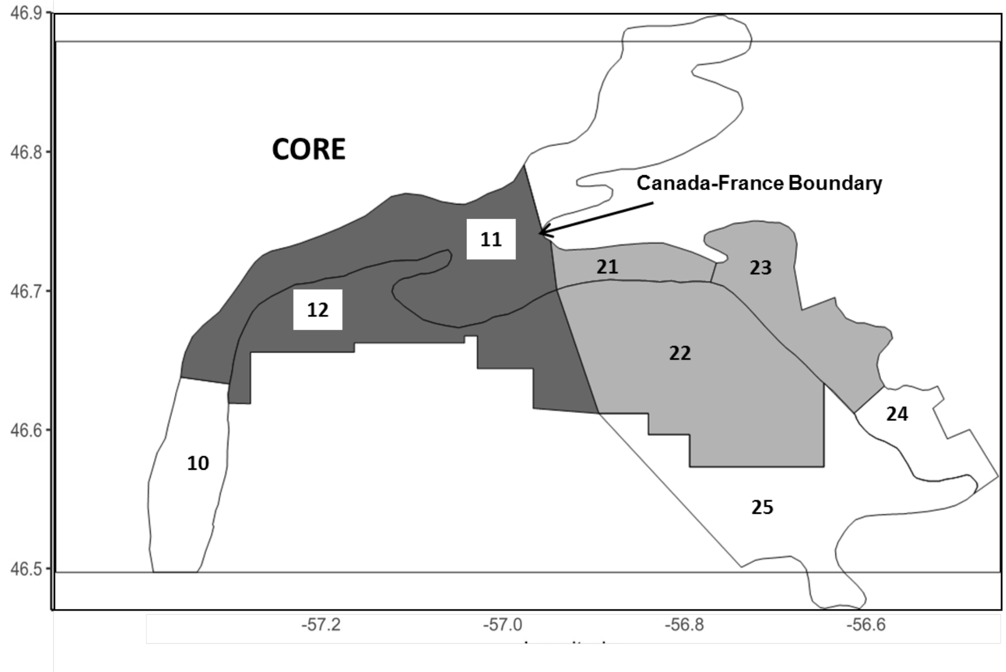

Figure 3. Map of strata on the Northern St. Pierre Bank, highlighting the main "commercial" strata for Iceland Scallop in the Canadian zone (strata 11, 12) and the French zone (strata 21, 22, 23) with shading of the Canada-France Transboundary (CORE) Zone of St. Pierre Bank (NAFO subdivision 3Ps). Note will add axis titles.

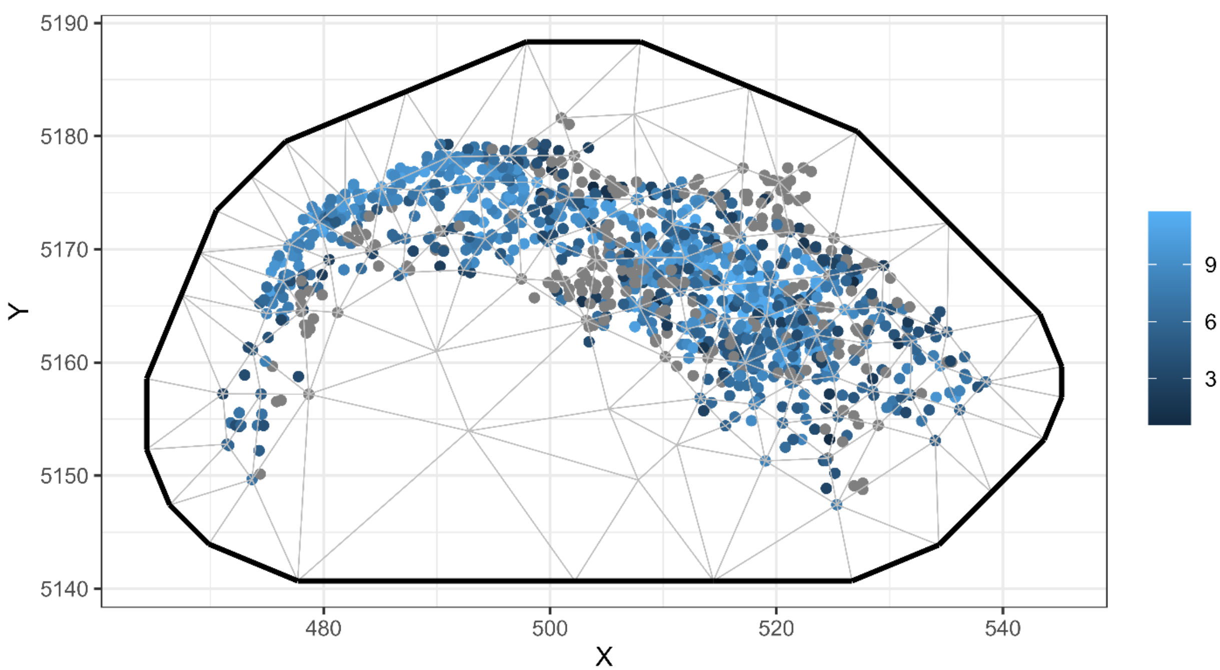

Figure 4. SPDE mesh used in fitting the spatiotemporal model. Points represent logged catch rates (kg/km^2) of Iceland Scallop during the Canadian resource assessment survey.

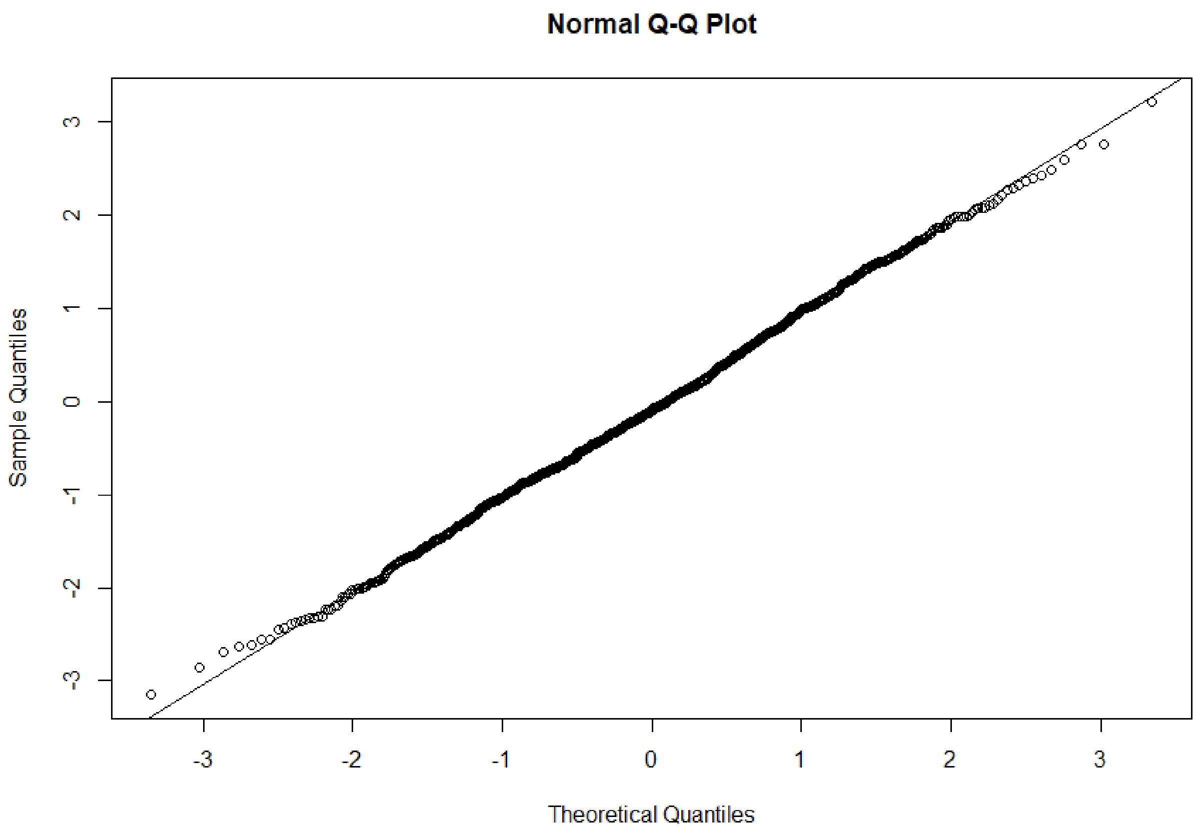

Figure 5. Quantile-quantile (Q-Q) plot of Iceland Scallop MDB spatiotemporal model.

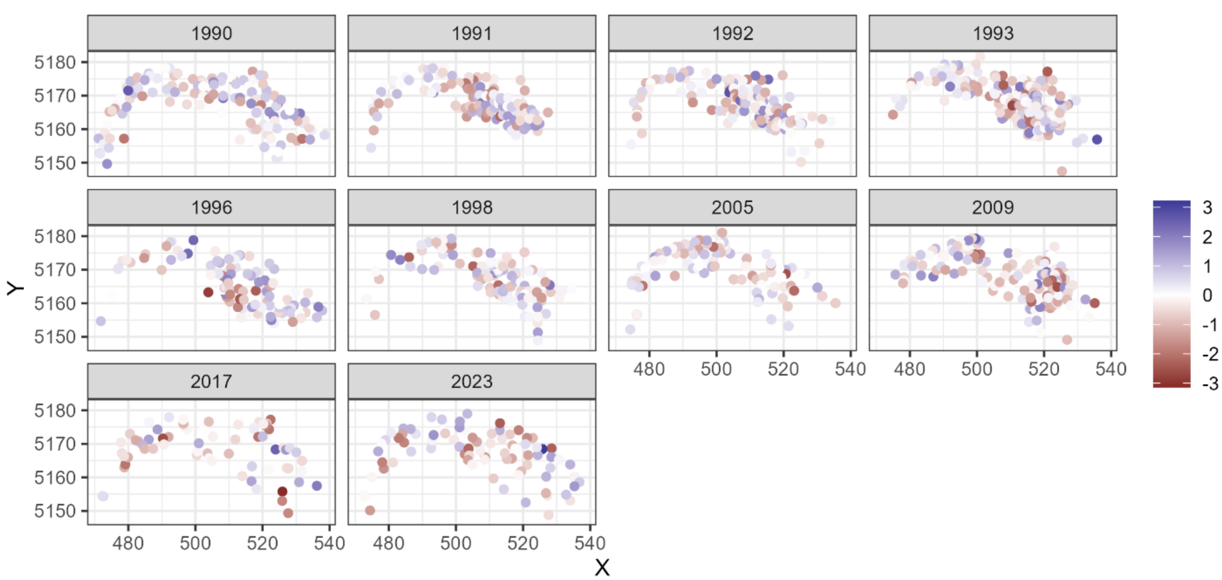

Figure 6. The annual spatial pattern of residuals based on the Iceland Scallop MDB spatiotemporal model.

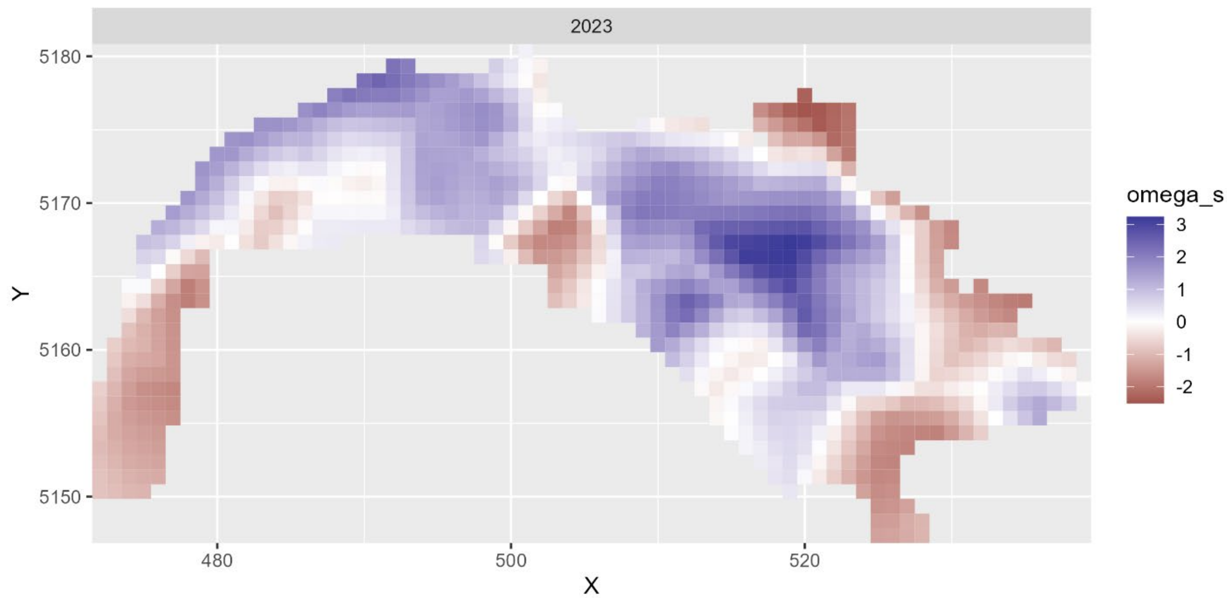

Figure 7. Spatial random effects of the spatiotemporal biomass model for Iceland Scallop in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps). Spatial random effects do not vary by year, so a single year (2023) is depicted.

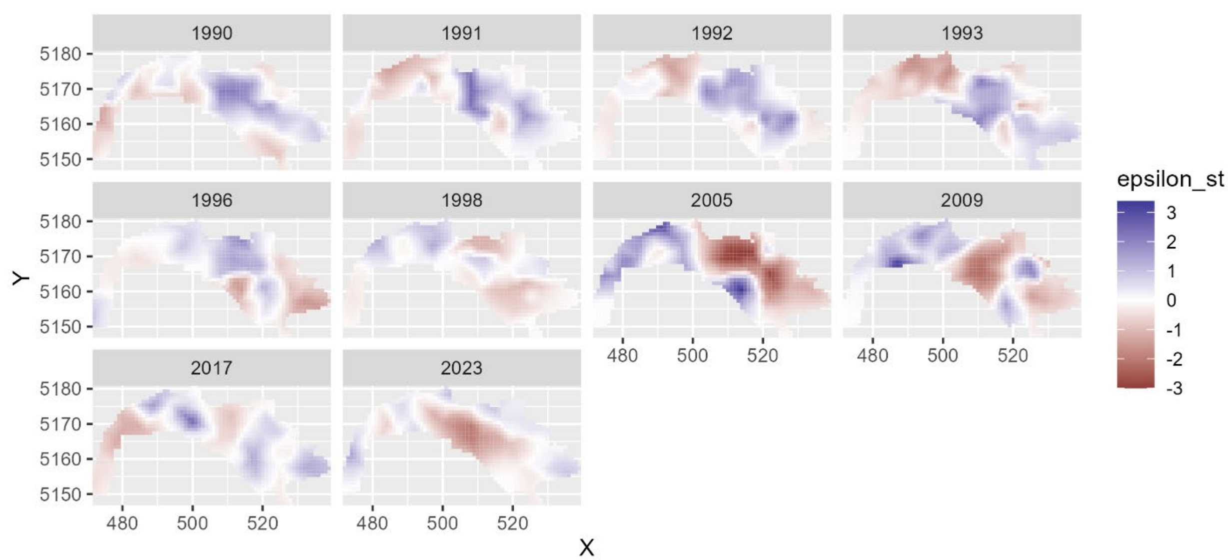

Figure 8. Spatiotemporal random effects of the spatiotemporal MDB model for Iceland Scallop.

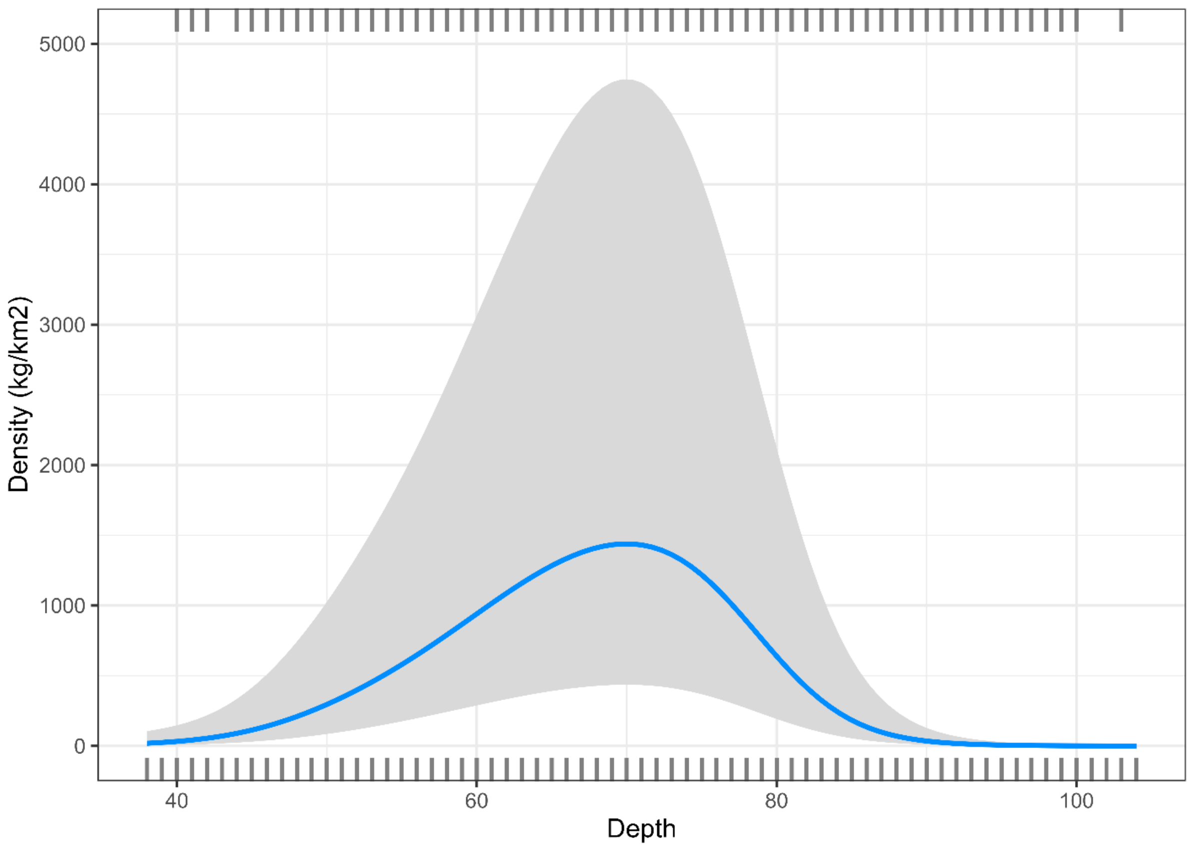

Figure 9. Conditional effect plot of depth and the density (kg/km^2) of Iceland Scallop based on the spatiotemporal MDB model. The shaded confidence interval includes the uncertainty associated with the intercept.

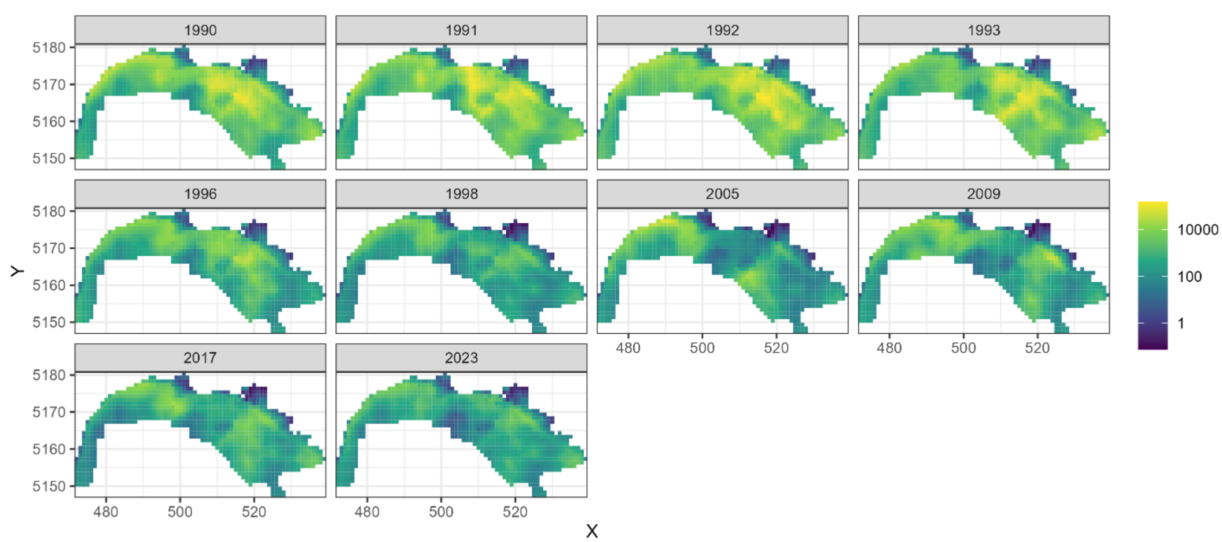

Figure 10. Predicted density (kg/km^2) of Iceland Scallop throughout the CORE area (St. Pierre Bank, NAFO subdivision 3Ps) of interest based on spatiotemporal MDB model.

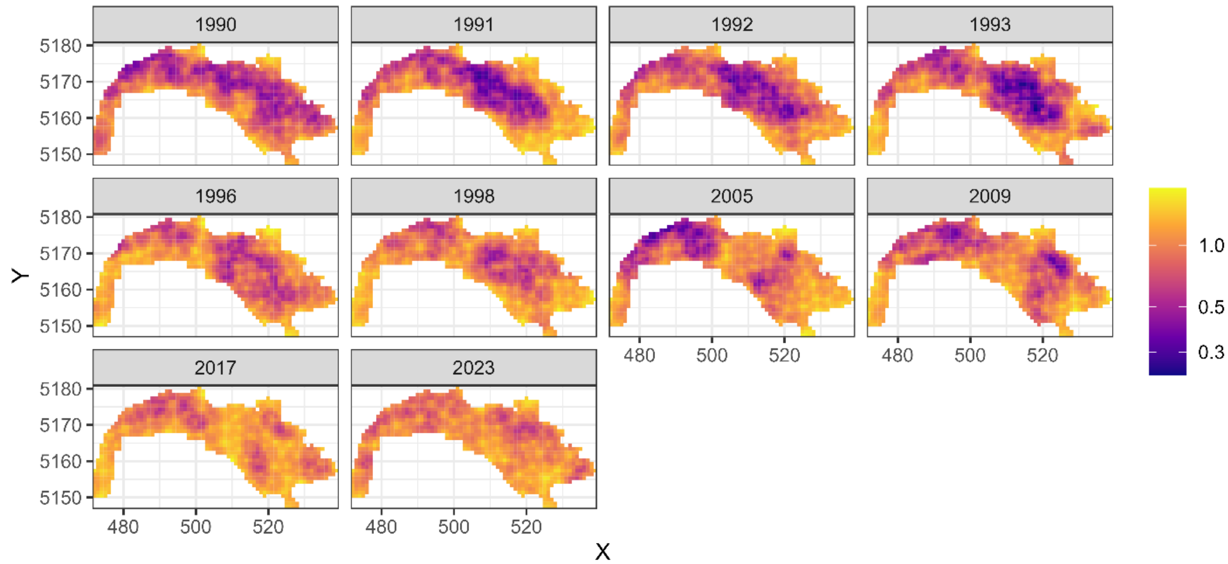

Figure 11. Spatial patterns of standard error associated with the spatiotemporal biomass model predictions for Iceland scallop.

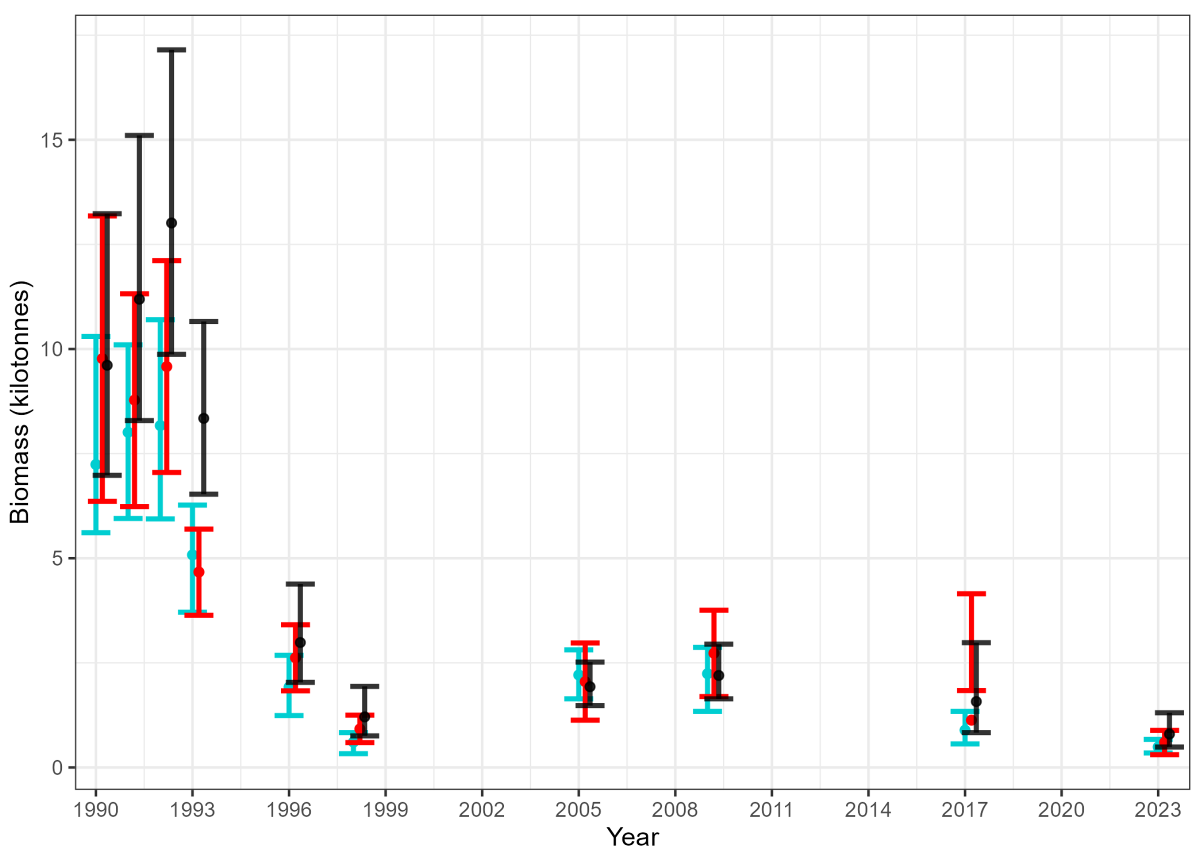

Figure 12. Comparison of model-derived (black), STRAP-derived (red), and Ogmap-derived (turquoise) minimum dredgeable biomass (MDB) estimates of Iceland Scallop in consistently sampled and main commercial strata (11–12, 21–23) with 95% confidence intervals. This data source is based on Canadian resource assessment surveys that took place between 1990 and 2023.

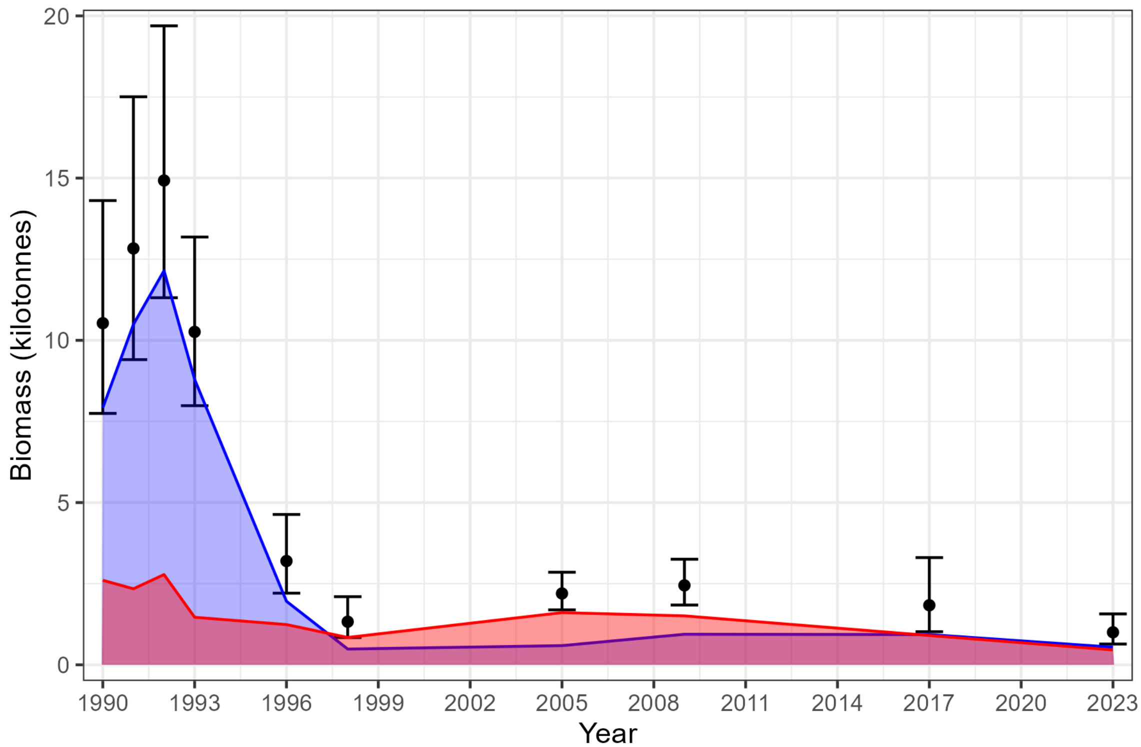

Figure 13. Model-derived Iceland Scallop MDB (kt) indices within the CORE area (strata 10–12, 21–25). Points represent predicted biomass estimates whole area of interest and bars represent 95% confidence limits around those estimates. The blue shaded area represents biomass estimates in French waters (strata 21-25), while the red shaded area represents biomass estimates within Canadian waters (strata 10-12). Although the shaded areas are filled throughout the timeseries, there are no biomass estimates within non-surveyed years (e.g.,1999–2004).

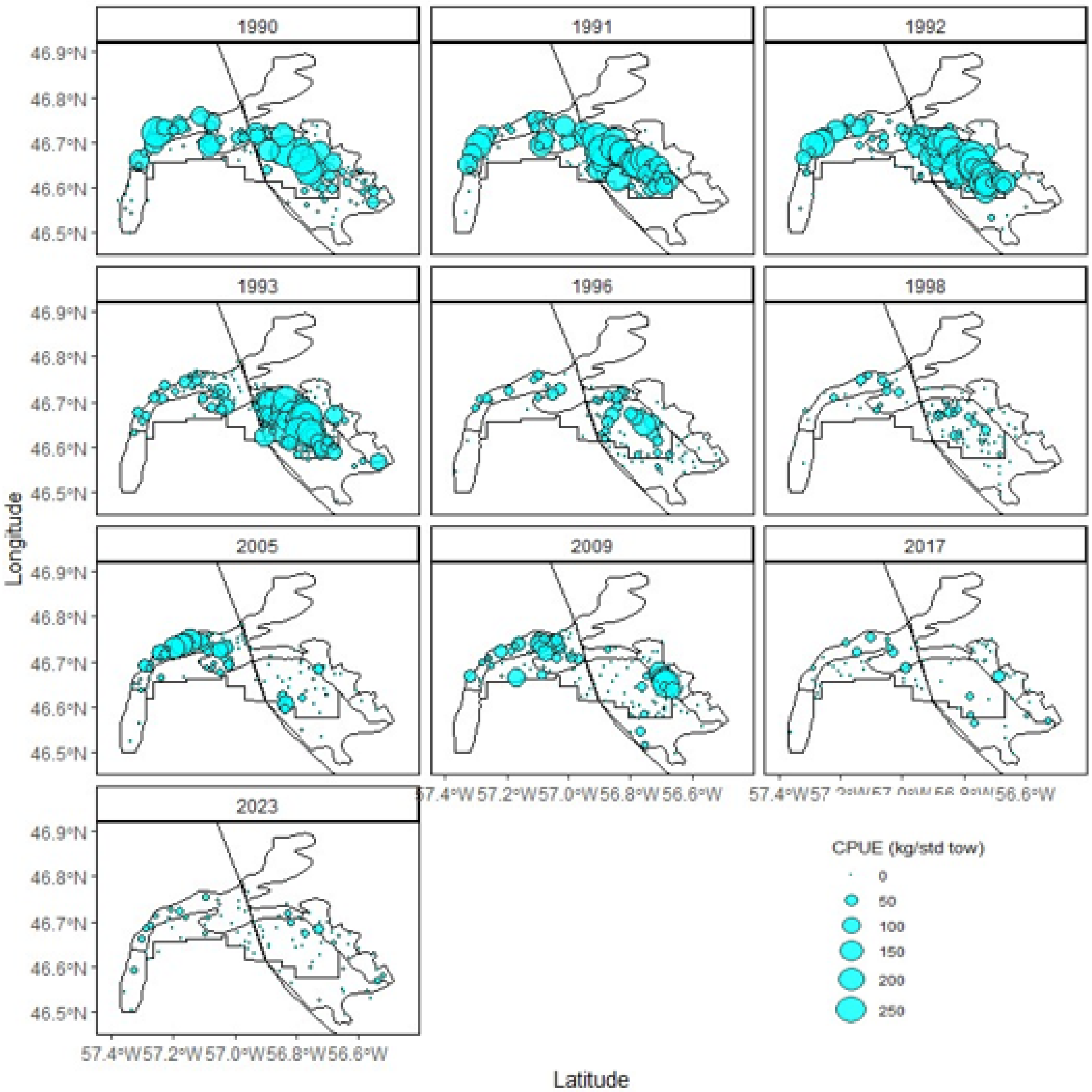

Figure 14. The location of Iceland Scallop catch rates (kg/std tow) in the Canada-France Transboundary (CORE) Area of St. Pierre Bank (NAFO subdivision 3Ps) based on Canadian resource assessment surveys from 1990 to 1993, 1996, 1998, 2005, 2009, 2017 and 2023. Black line represents the France Economic Exclusive Zone (EEZ).

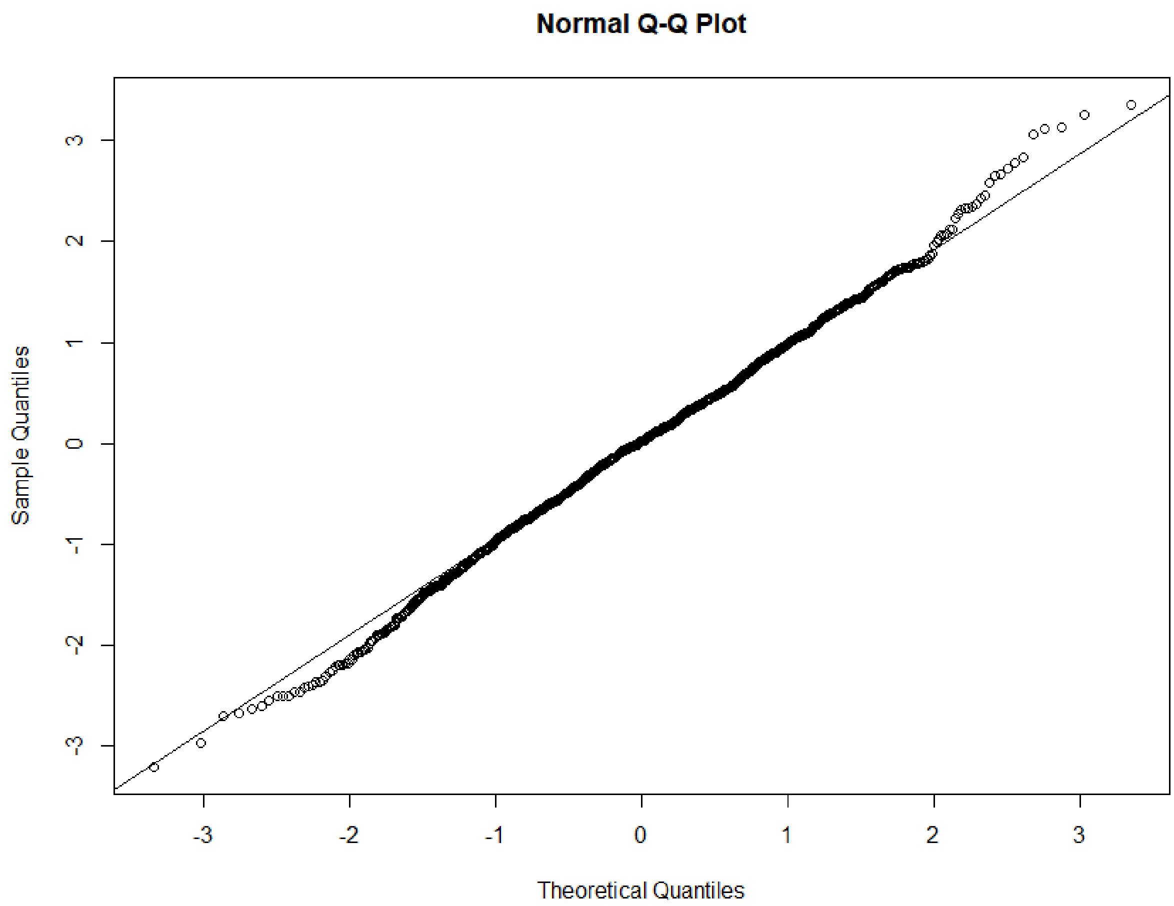

Figure 15. Quantile-quantile (Q-Q) plot of Iceland Scallop abundance spatiotemporal model.

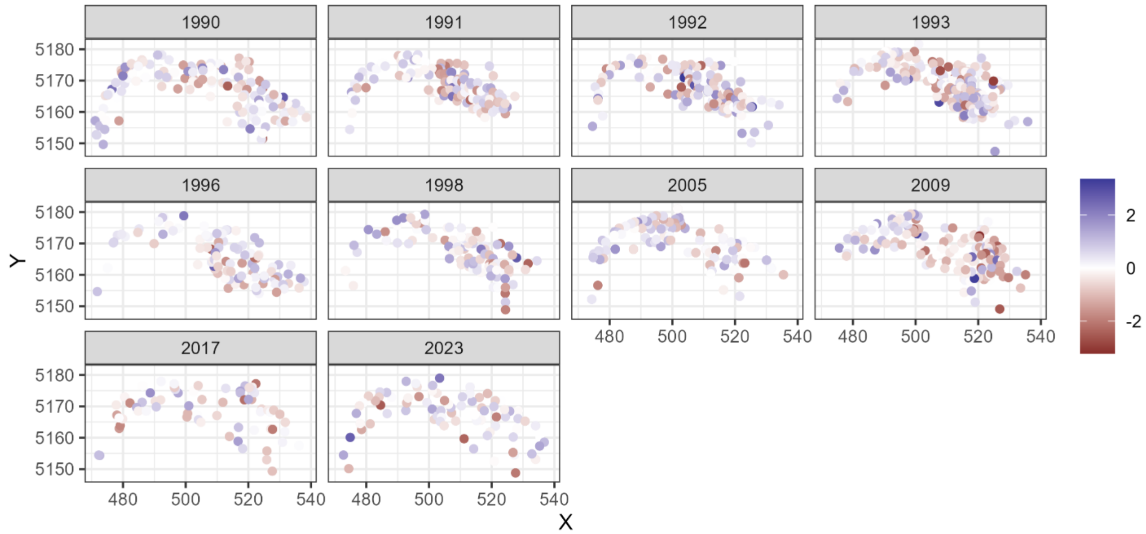

Figure 16. The annual spatial pattern of residuals based on the Iceland Scallop abundance spatiotemporal model.

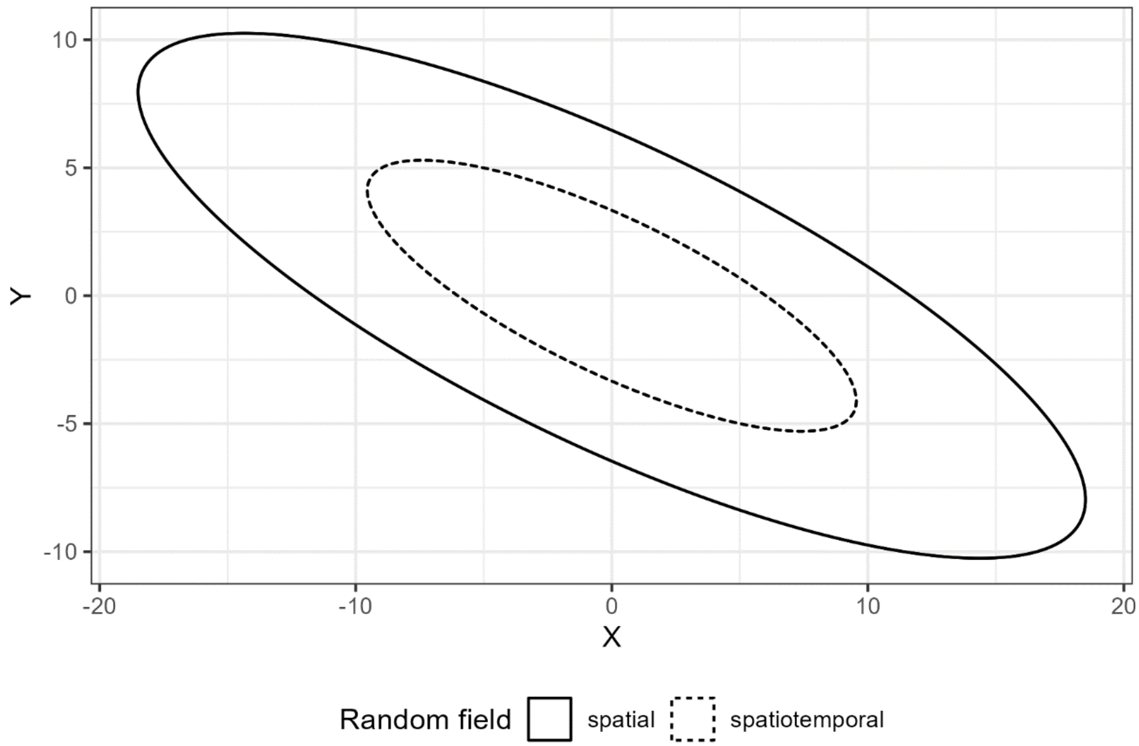

Figure 17. Anisotropy of the spatial and spatiotemporal random fields in the spatiotemporal abundance model of Iceland Scallop.

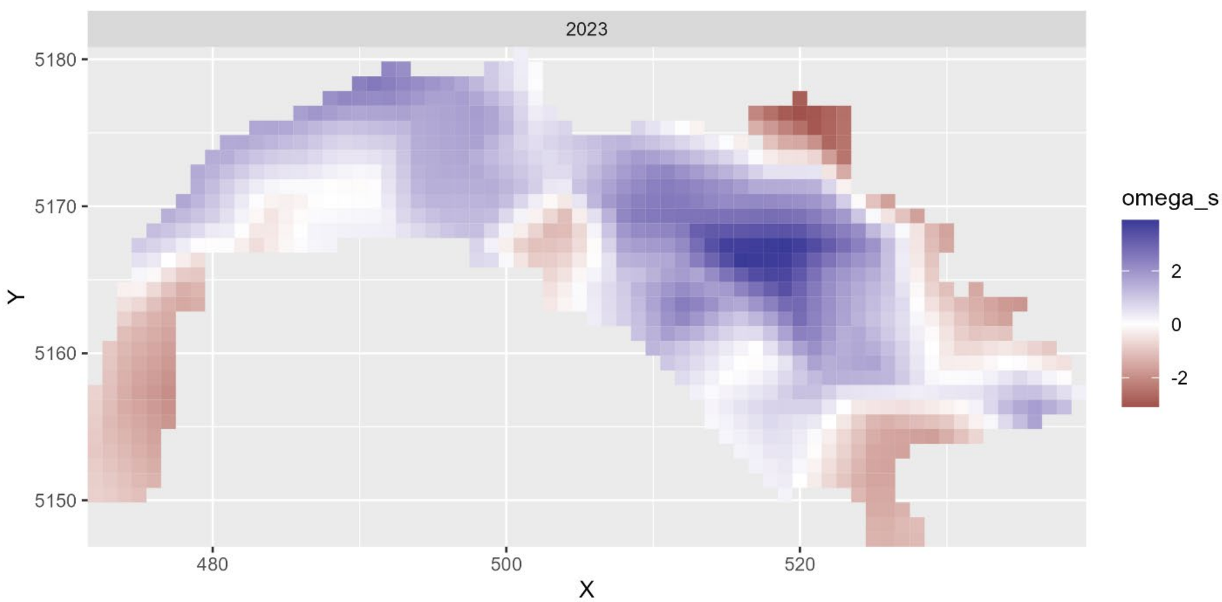

Figure 18. Spatial random effects of the spatiotemporal abundance model for Iceland Scallop. Spatial random effects do not vary by year, so a single year (2023) is depicted.

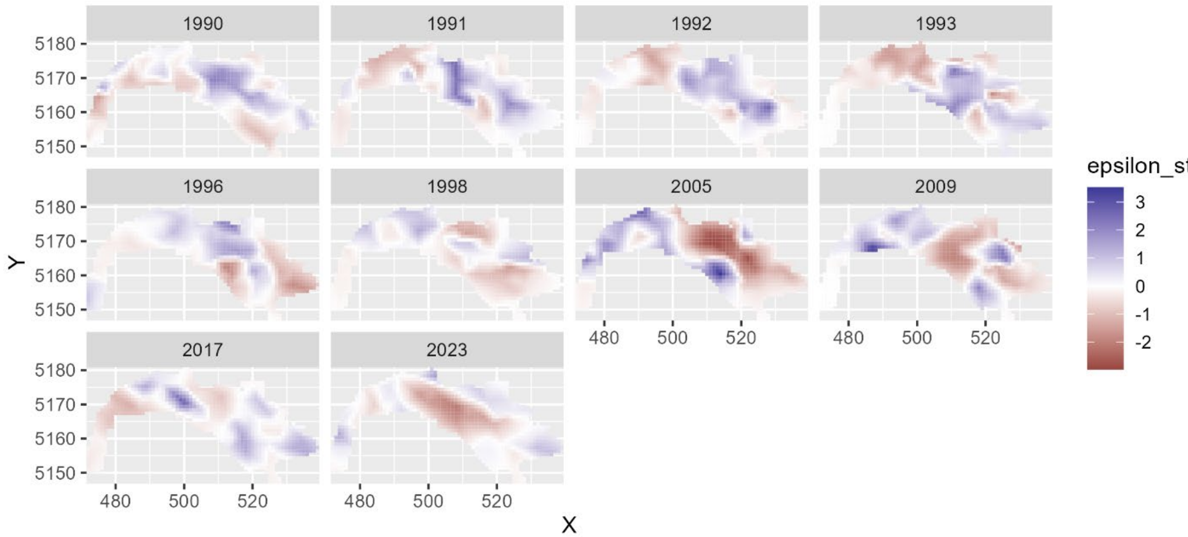

Figure 19. Spatiotemporal random effects of the spatiotemporal abundance model for Iceland Scallop.

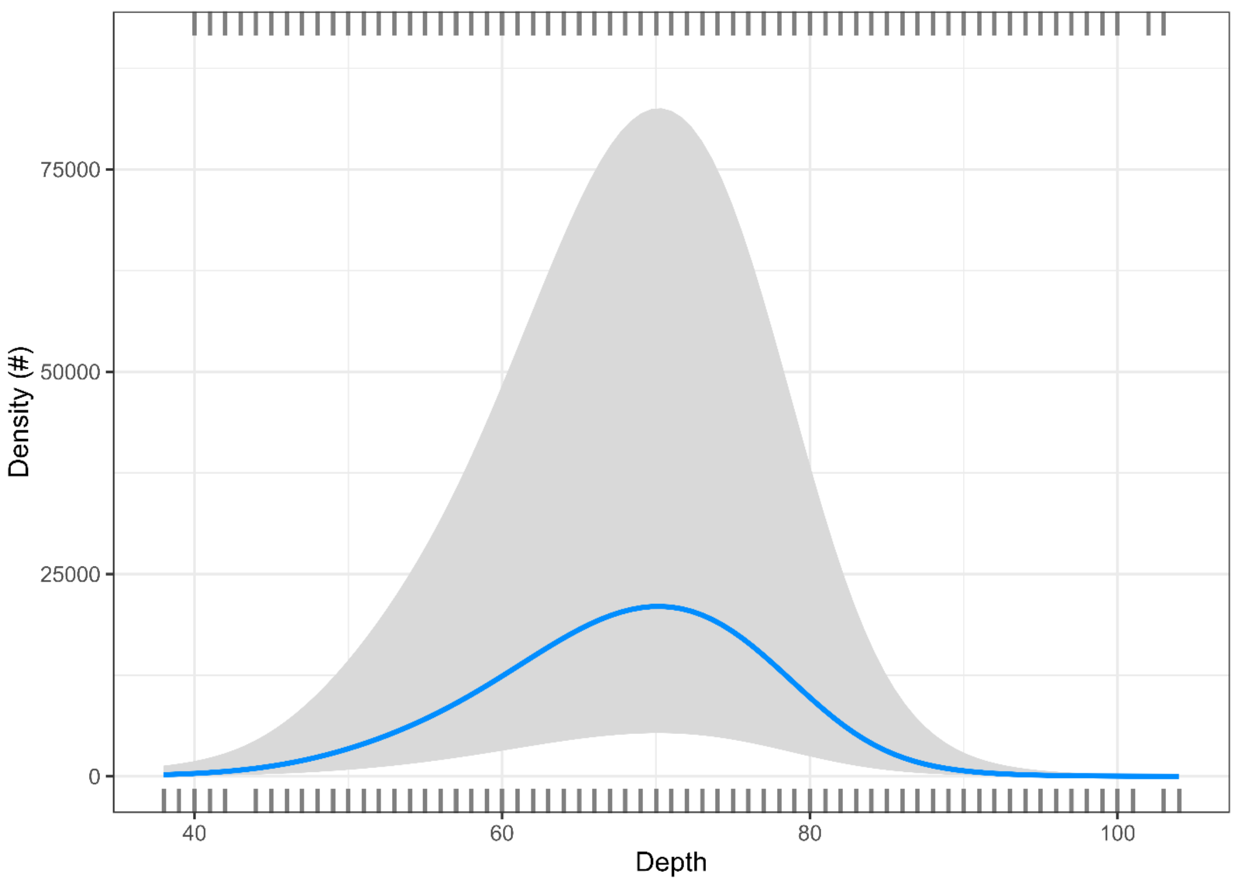

Figure 20. Conditional effect plot of depth and the density (number) of Iceland Scallop based on the spatiotemporal abundance model. The shaded confidence interval includes the estimated uncertainty associated with the intercept.

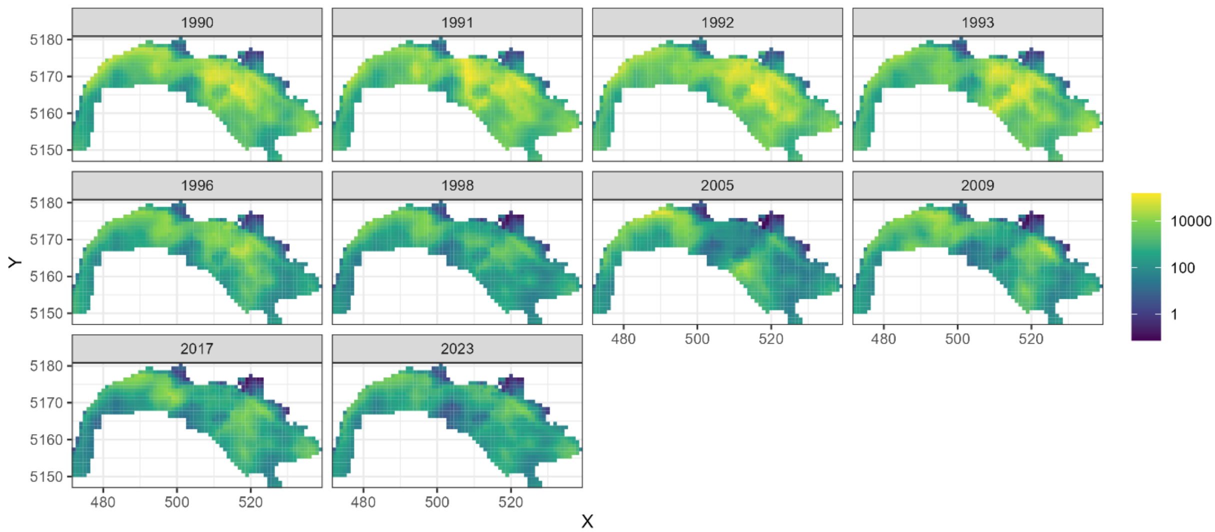

Figure 21. Predicted abundance of Iceland Scallop throughout the CORE area of St. Pierre Bank (NAFO subdivision 3Ps) of interest based on spatiotemporal abundance model.

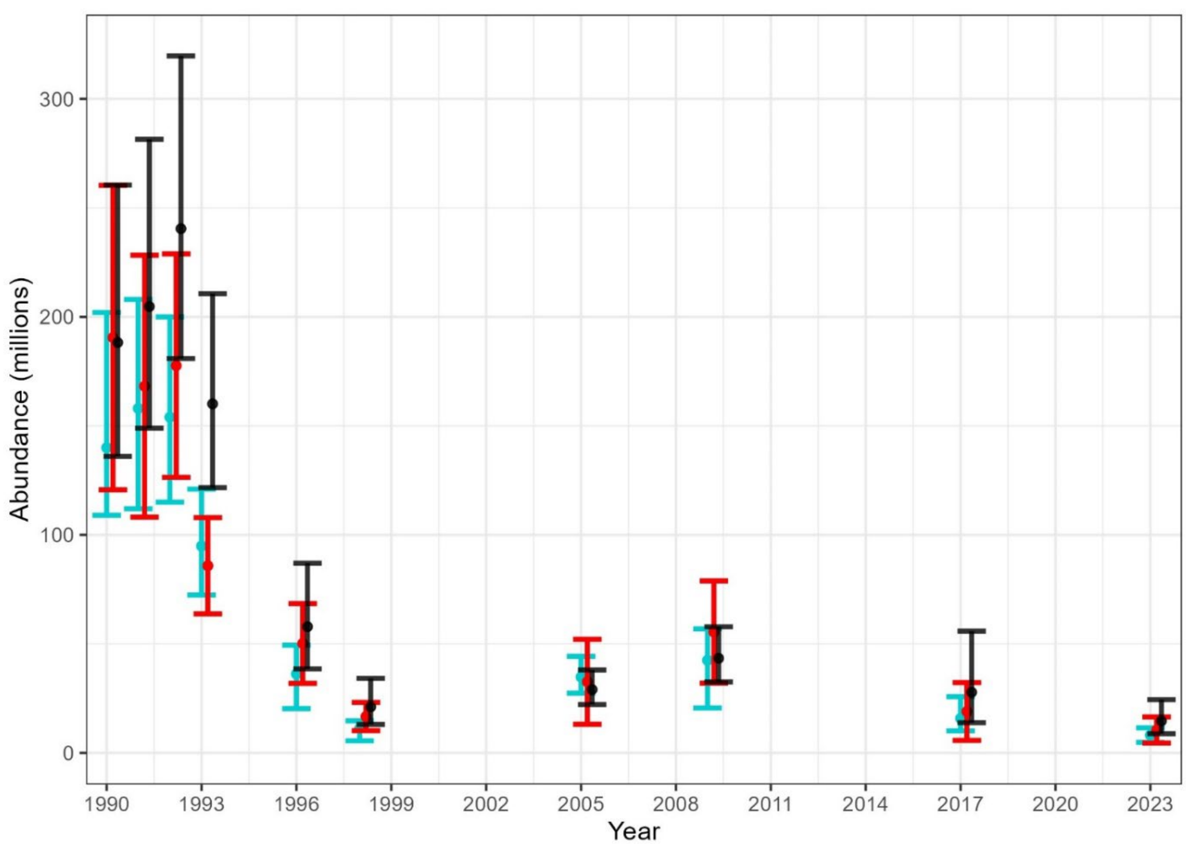

Figure 22. Comparison of annual model-derived (black), Ogmap- derived (turquoise) and STRAP-derived (red) abundance estimates of Iceland Scallop in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps) in consistently sampled strata (11–12, 21–23) with 95% confidence intervals. This data source is based on Canadian resource assessment surveys that took place between 1990 and 2023.

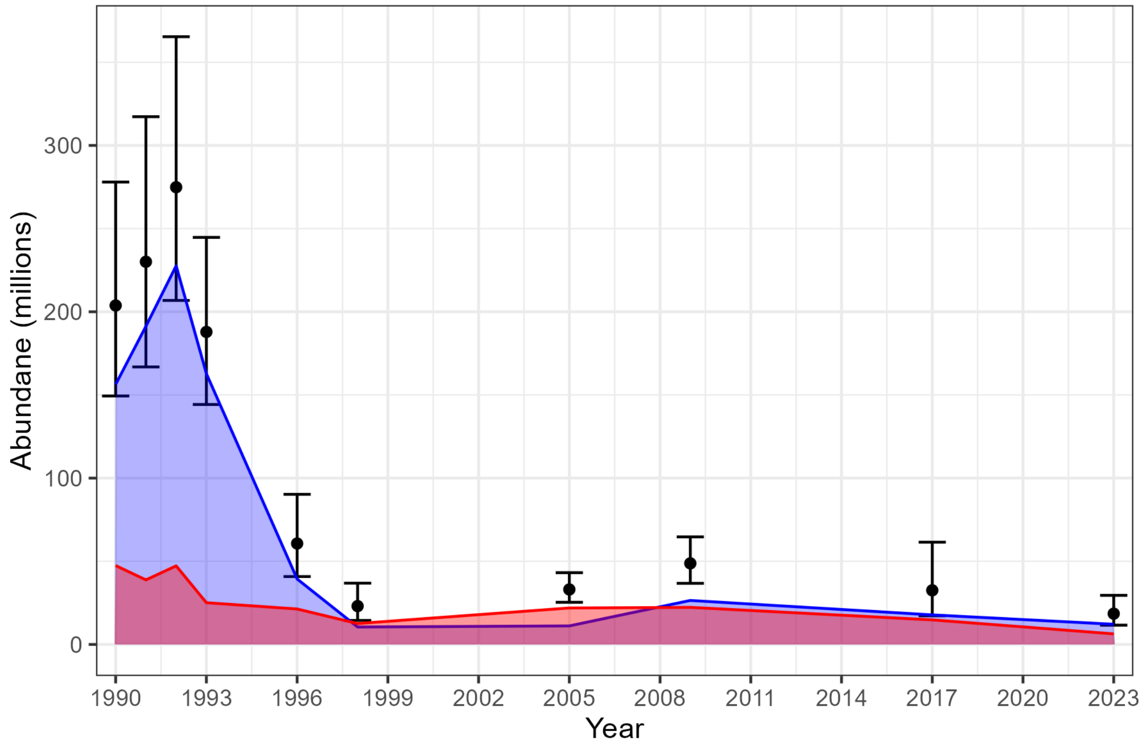

Figure 23. Model-derived Iceland Scallop abundance (millions) indices within the CORE area (in St. Pierre Bank (NAFO subdivision 3Ps) of interest (strata 10–12, 21–25). Points represent predicted abundance within the whole area of interest and bars represent 95% confidence limits around those estimates. The blue shaded area represents abundance estimates in France waters (strata 21–25) while the red shaded area represents abundance estimates within Canadian waters (strata 10–12). Although the shaded areas are filled throughout the timeseries, there are no abundance estimates within non-surveyed years (e.g.,1999–2004).

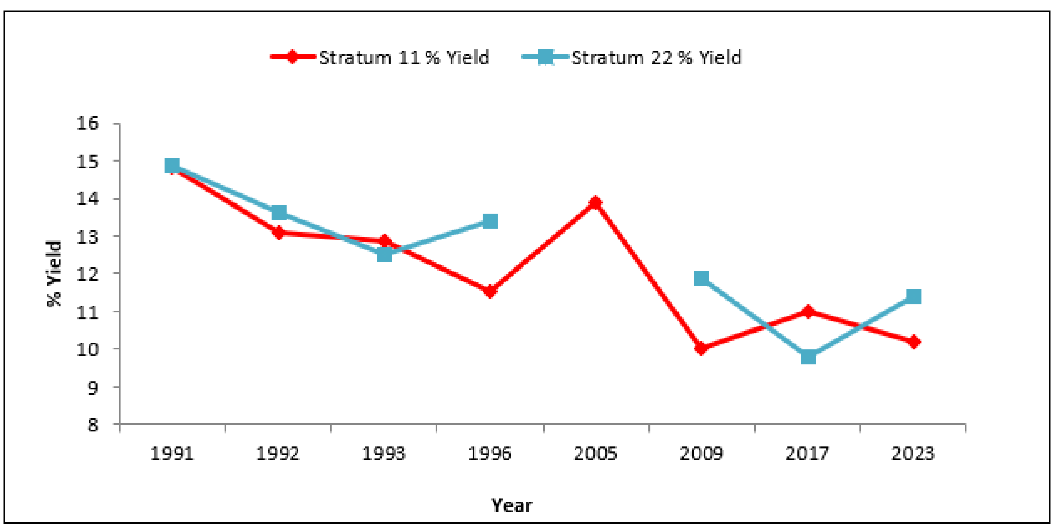

Figure 24. Biological meat yields (% yield) in strata 11 and 22 (reference stratum) based on Canadian resource assessment surveys in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps) that took place within the survey timeseries between 1991 and 2023.

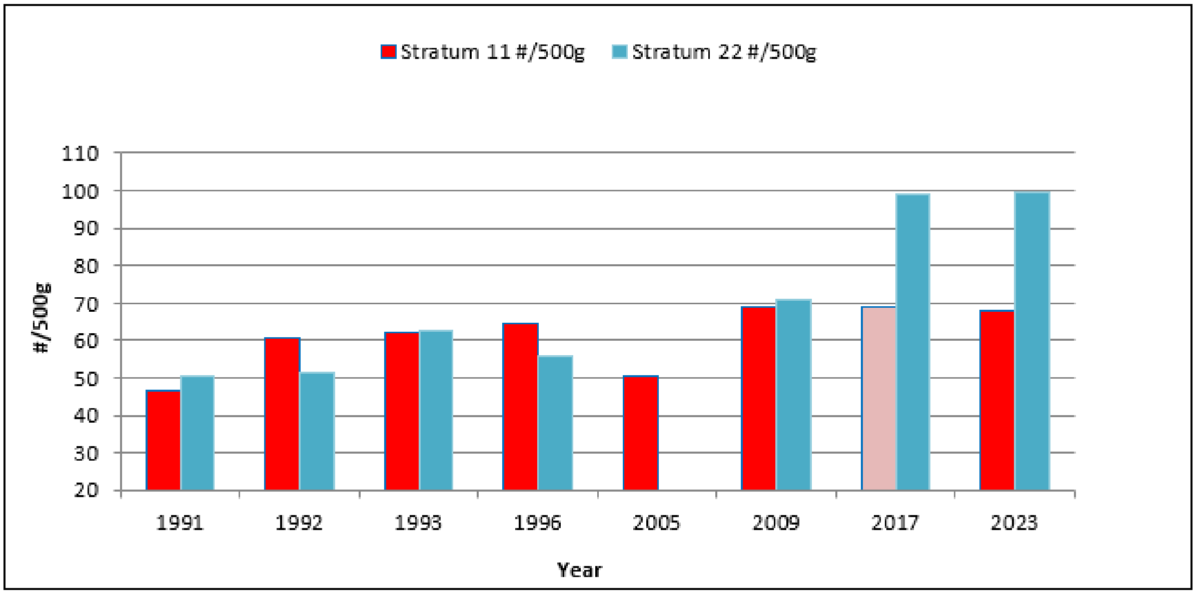

Figure 25. Meat counts (# of meats per 500 g) in strata 11 and 22 (reference strata) based on Canadian resource assessment surveys in the Canada-France Transboundary (CORE) Area of St. Pierre Bank (NAFO subdivision 3Ps) that took place between 1991 and 2023. Note in 2017 meat yield samples were collected in stratum 12 (lighter shade bar) instead of stratum 11.

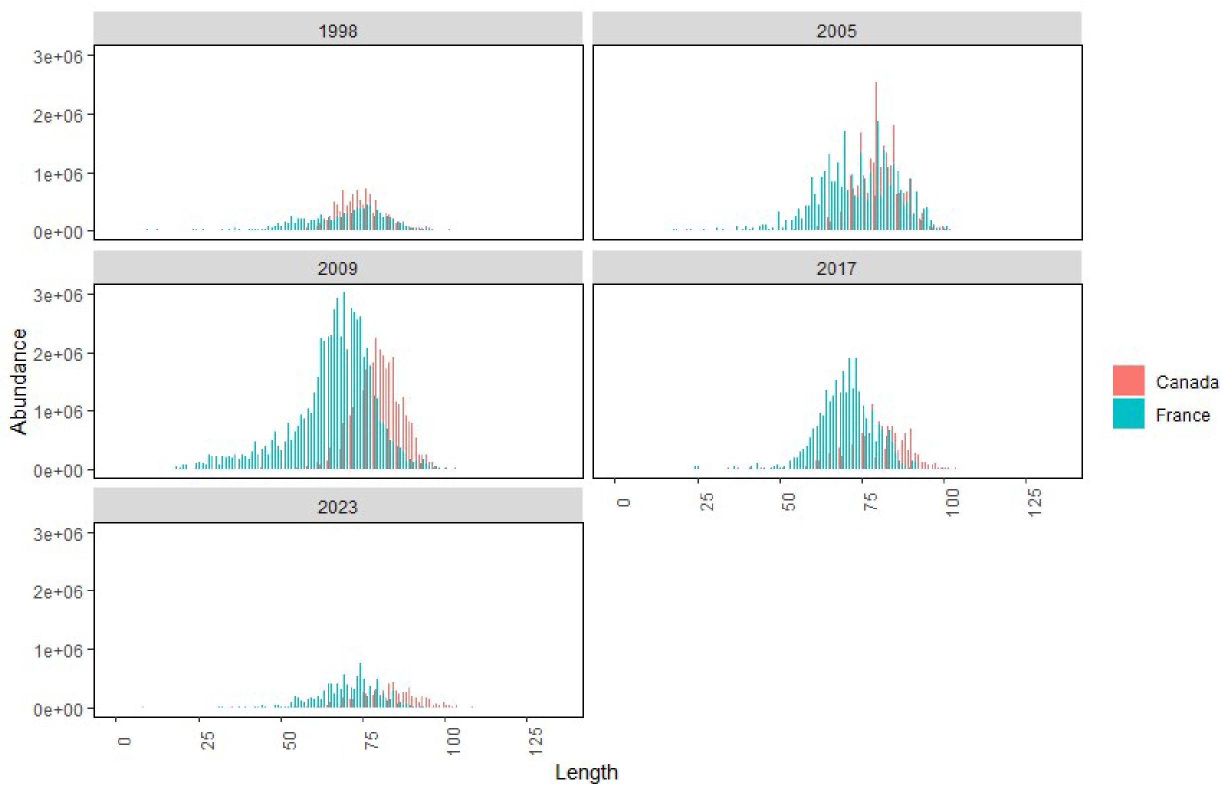

Figure 26. Abundance at length (shell height) during Canadian conducted resource surveys (1998, 2005, 2009, 2017 and 2023) in Canadian (strata 11-12) and French (strata 21-25) zones in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps).

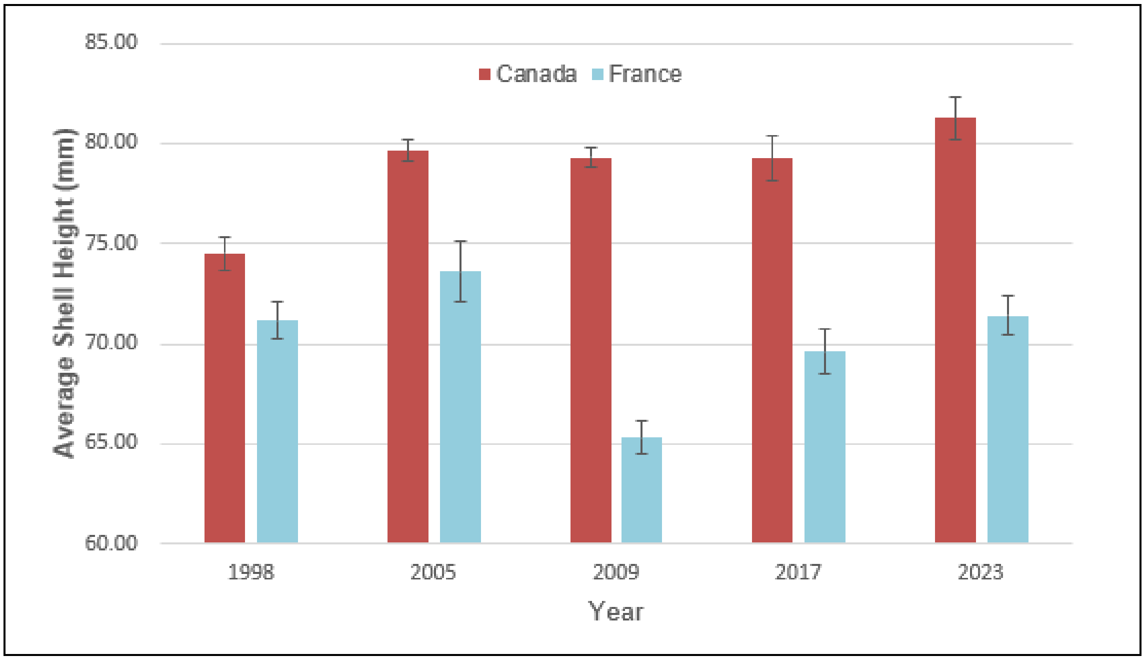

Figure 27. Average shell height (mm) of Iceland Scallop in the Canada-France Transboundary (CORE) Area (Canadian and France zones) of St. Pierre Bank (NAFO subdivision 3Ps) based on Canadian resource assessment that took place between 1998 and 2023.

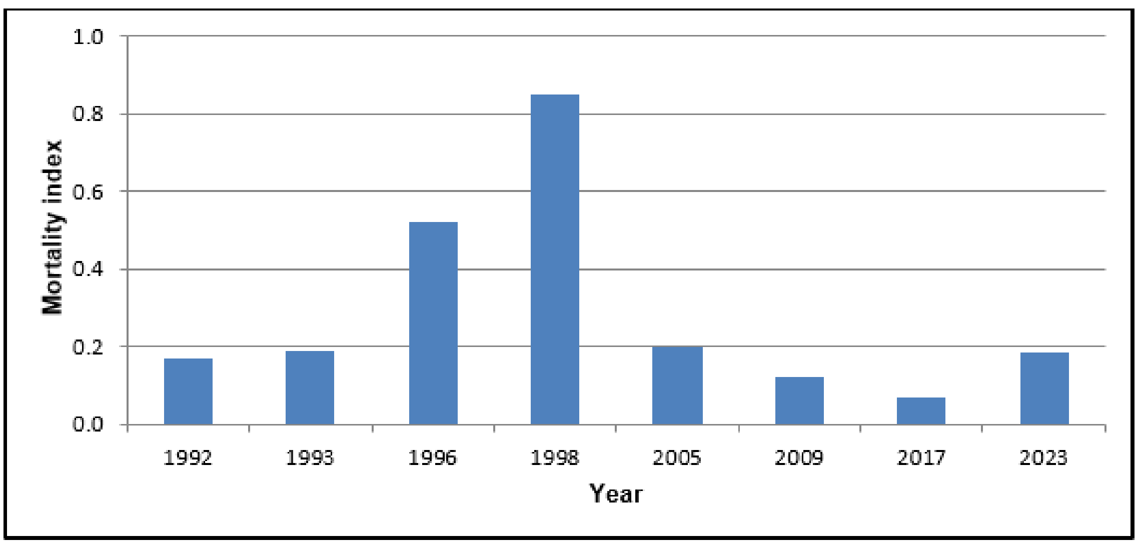

Figure 28. Mortality index for Iceland Scallop the Canada-France Transboundary (CORE) Area of St. Pierre Bank (NAFO subdivision 3Ps), based on Canadian resource assessment surveys that took place between 1992 and 2023.

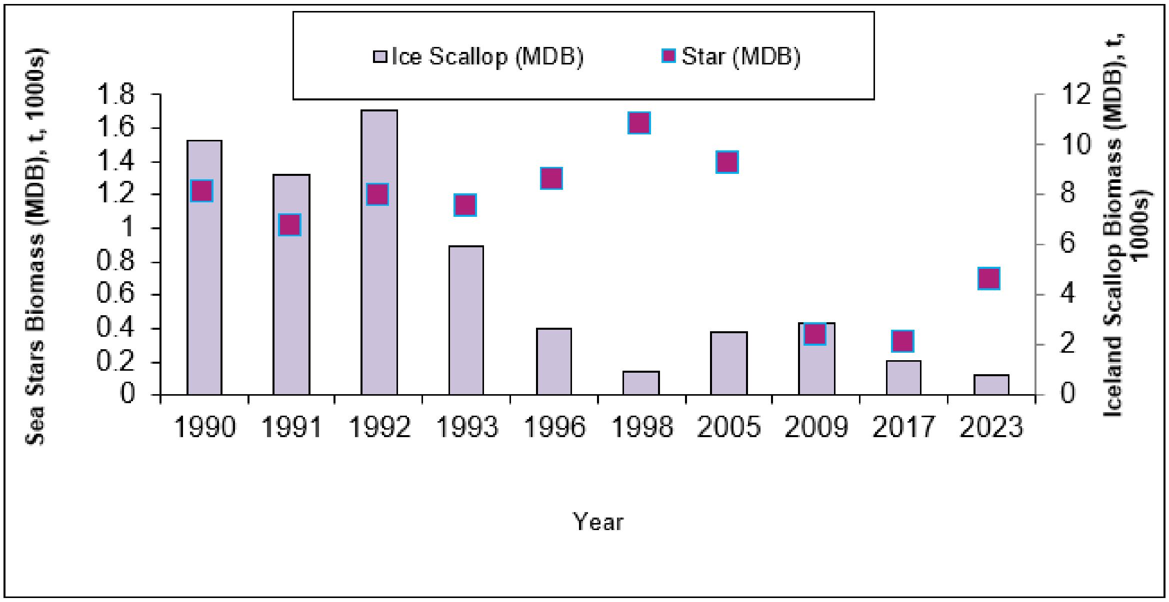

Figure 29. Iceland Scallop and sea star (Leptasterias polaris, Crossaster papposus and Solaster endeca) minimum dredgeable biomass (MDB) estimates based on Canadian resource assessment surveys that took place in the CORE area of St. Pierre Bank (NAFO subdivision 3Ps) (in strata 10,11,12,21,22,23,24 and 25) between 1990 and 2023. Both MDB estimates within this figure are derived from STRAP analysis.