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**Data Review and Assessment Framework of the Arctic Surf Clam
(*Mactromeris polynyma*) on Banquereau and the Grand Banks**

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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.

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ACRONYMS

AZMP – Atlantic Zonal Monitoring Program

B_{MSY} – Biomass at Maximum Sustainable Yield

CI – Confidence Interval

CLAM - DFO Offshore Clam Data Archival Database

CPUE – Catch Per Unit Effort

CSAS – Canadian Science Advisory Secretariat

DFO – Fisheries and Oceans Canada (federal Department of Fisheries and Oceans)

F – Fishery Mortality

FCI – Foot Condition Index

GM – Geometric Mean

GSI – Gonad Somatic Index

IFMP – Integrated Fishery Management Plan

LF – Length Frequency

LPUE – Landings Per Unit Effort

LRP – Limit Reference Point

M – Natural Mortality

MARFIS – Maritimes Fishery Information System

MLE - Maximum Likelihood Estimation

NAFO – Northwest Atlantic Fisheries Organization

RV – DFO Ecosystem Research Vessel trawl survey

SDM – Species Distribution Model

SE – Standard Error

SIR - Substrate-inhibitor Ratio

SPM – Spatial Production Model

TAC – Total Allowable Catch

USR – Upper Stock Reference

VMS – Vessel Monitoring System

Z – Total Mortality

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ABSTRACT

Arctic Surf Clam (*Mactromeris polynyma*) is a large, long-lived bivalve that supports two offshore fisheries in Atlantic Canada: Banquereau and the Grand Banks. A review of life-history characteristics, impacts of dredging, habitat suitability, survey data, and fishery data for Arctic Surf Clam on the two banks since 2016 was conducted in support of developing a model-based framework for assessment of the two stocks (Banquereau and the Grand Banks). There is no recent or continuous fishery independent data upon which to base biomass estimates, so fishery data is used. Since 2016, both banks have been fished consistently. Both banks have shown patterns of increasing catch rates with decreasing effort, illustrating an increasing efficiency of the fishery. When fishing data is examined spatially, either aggregated to an area or explicitly, patchiness of the resource and annual movement of the fishery between beds and areas is evident. Fishing behavior is rotational such that a concentration of clams may be fished heavily in one year and then not again for many years; this behaviour presents challenges for modelling the two stocks. To address this, a new approach and model are presented herein – named SpaceClam (model developed by co-author Ethan Lawler) – based on commercial data that incorporates habitat. The SpaceClam approach determines habitat using a model that takes into account environmental variables (or proxies) and fishing locations; the habitat is used as a covariate in determining population growth. The population is then modelled spatially in 1-squared kilometre (1 km²) grids on Banquereau and 2.5 km² grids on the Grand Banks. This approach mitigates some of the uncertainties inherent in the use of commercial data, as well as incorporates growth and habitat in a spatially-explicit way. Limit reference points for each bank, as well as other reference points used to guide management of the two fisheries (e.g., upper stock reference), were adopted. In addition, secondary indicators for the Arctic Surf Clam fishery initially developed to monitor changes in the two stocks between assessments and/or surveys were reviewed, with new indicators being adopted. The content of the research document reflects consensus-based decisions made at the Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) regional peer review process entitled [Framework Review for Arctic Surf Clam on Banquereau and Grand Banks](#) held on June 4–6, 2025, and on October 16, 2025. This research document outlines a new framework for the assessment of Arctic Surf Clam stocks on Banquereau and the Grand Banks.

INTRODUCTION

The objective of this research document is to compile, review, and document available science information and methods used to develop an updated stock assessment framework for Arctic Surf Clam (*Mactromeris polynyma*) stocks on Banquereau and the Grand Banks in Atlantic Canada (Figure 1). The research document reviews and analyzes available fishery, survey, biological, and ecological information up to the end of the 2023 fishing year. Information presented in previous assessment documents is reproduced sparingly. The content of the research document reflects consensus-based decisions made at the Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) regional peer review process entitled [Framework Review for Arctic Surf Clam on Banquereau and Grand Banks](#) held on June 4–6, 2025, and October 16, 2025.

MANAGEMENT OF THE FISHERY

Details regarding development of the fishery up to 1989 can be found in Roddick and Kenchington (1990). Hubley and Heaslip (2018) subsequently documented the fishery up to 2016. The [Integrated Fishery Management Plan \(IFMP\)](#) for the fishery went through a large update in 2020 (DFO 2020) and has been updated since that time, as needed. The offshore clam fishery currently has three vessels and three licences. These licences permit fishing on Banquereau, Grand Banks, and Sable Island Bank (Figure 1). Licence conditions permit directed fishing for Arctic Surf Clam and Ocean Quahog (*Arctica islandica*), as well as the retention of other molluscs that include Northern Propeller Clam (*Cyrtodaria siliqua*) and Greenland Cockle (*Serripes groenlandicus*). Arctic Surf Clam quota is transferable between licences, but not between banks. Fishing is conducted from large freezer processors using hydraulic dredges on sandy substrates located at 50 to 160 m water depth. The main management tools for the offshore clam fishery are limited entry licences, total allowable catch (TAC) divided into enterprise allocations, 100% industry-funded dockside monitoring, mandatory logbooks, and 100% vessel monitoring system (VMS) coverage. Observer requirements are one observed trip per bank per year.

SPECIES BIOLOGY

Arctic Surf Clam, also commonly known as Stimpson's Surf Clam, is a large (up to 160 mm), long-lived bivalve that can reach more than 60 years of age. It is found in deep water of both the northern North Pacific and the northwestern Atlantic oceans (Chamberlin and Stearns 1963). Commercial quantities of Arctic Surf Clam are found in the inshore areas off southwest Nova Scotia, in the Gulf of St. Lawrence, and in the offshore areas of the Eastern Scotian Shelf and Eastern Grand Banks (DFO 2012). They are often found on medium- to coarse-grained substrates (Chamberlin and Stearns 1963).

SIZE AND AGE AT SEXUAL MATURITY

Previous work estimated the size and age at 50% sexual maturity (i.e., 50% of individuals at that size or age that are expected to be sexually mature) to be 45.2 mm and 8.3 years on Banquereau (Roddick et al. 2012) and 39.9 mm and 5.3 years on the Grand Banks (Roddick et al. 2011).

SPAWNING

Arctic Surf Clam are dioecious broadcast spawners that reach reproductive maturity between 5 and 8 years of age. Larval development and growth are temperature dependent. Davis and Shumway (1996) induced spawning and larvae hatched after 24 hours in warmer water (15°C) and settled at 24 days (15°C). In colder water, they hatched after 96 hours (8.5°C) and settled after 42 days (10°C). The high dispersal potential of the pelagic larvae of Arctic Surf Clam likely results in high gene flow throughout their range. Genetic surveys in the Northwest Atlantic found little genetic structure, which supports this hypothesis (Cassista and Hart 2007).

GROWTH

Arctic Surf Clam on Banquereau reach a larger size and grow faster than Arctic Surf Clam on the Grand Banks, based on ageing work done on samples collected from Banquereau (Roddick et al. 2012) and the Grand Banks (Roddick et al. 2011) during surveys (Table 1). No new work has been completed on ageing or growth for these populations since that time. The growth parameters estimated on Banquereau and Grand Banks are within the range of growth parameter estimates for various Arctic Surf Clam beds in the Gulf of St. Lawrence (summarized in: Dore et al. 2021). The previous work on both Banquereau and the Grand Banks relied on traditional sclerochronology (i.e., visually reading the age from ageing structure). More recently, geochemical tools have successfully been used to determine the location of annual growth rings in Arctic Surf Clam, which remove some of the error introduced by traditional ageing methods (Dore et al. 2021).

MORTALITY

For the Banquereau and Grand Banks Arctic Surf Clam fisheries, it is assumed that the natural mortality rate (M) is equivalent to the total mortality rate (Z) minus the fishing mortality rate (F). Hubley and Heaslip (2018) summarized multiple methods that have been used to estimate M for the fisheries. For Banquereau, an M of 0.08 was suggested at the 2012 stock assessment as being reasonable; it was maintained for consistency with previous assessments (Roddick et al. 2012). For the Grand Banks, an M of 0.08 was suggested at the 2010 stock assessment as being reasonable (Roddick et al. 2011). There are no new analyses presented herein to support any change in the use of M of 0.08 for the fishery on both banks.

ECOSYSTEM CONSIDERATIONS AND DREDGING IMPACTS

CLIMATE

The vulnerability of Arctic Surf Clam to a changing climate has not been directly studied, although inferences have been made based on other bivalve species and/or ecosystem modelling. Hare et al. (2016) assessed bivalve species such as Ocean Quahog and Atlantic Surf Clam as having a very high climate vulnerability, including a high potential for a change in species distribution. Similarly, Boyce et al. (2024) assessed Arctic Surf Clam in Northwest Atlantic Fisheries Organization (NAFO) Divisions 3LNO as having moderate climate risk under high mitigation scenarios and a high risk under high emission scenarios. Arctic Surf Clam in the Gulf of St. Lawrence were assessed as having a high risk under either scenario in the same analysis (Boyce et al. 2024).

Arctic Surf Clam have limited ability to avoid adverse conditions. An ability to burrow may support avoidance over a very short term, but an ability to burrow itself may be impeded by environmental conditions outside preferred ranges (discussed further in the following section). There are some records of species in the same family (*Mactridae*) as Arctic Surf Clam that

describe individuals as ‘leaping’ to avoid predation (Ansell 1969). Leaping is a very slow movement primarily used to avoid similarly slow predators, although this behaviour is unlikely to aid in a migration of Arctic Surf Clam to more favorable conditions. As such, changing climatic/environmental conditions will likely affect all life stages and some physiological processes of Arctic Surf Clam, the extent of this and within what tolerances remains largely unknown. More directed study is needed to answer these questions.

BIOLOGICAL, CHEMICAL, AND PHYSICAL ENVIRONMENT

Arctic Surf Clam are filter feeders that have a macroalgal diet (e.g., dinoflagellate phytoplankton) (Christian et al 2010). For similar filter feeders (e.g., Atlantic Surf Clam, *Spisula solidissima*), it has been hypothesized that resuspended benthic production (e.g., detritus and benthic algae) are also an important component of their diet, since the high metabolic demands of large clams are unlikely to be met by pelagic food sources alone (Munroe et al. 2013).

The [Atlantic Zonal Monitoring Program \(AZMP\)](#), overseen by DFO, monitors chlorophyll-*a* in the upper ocean (0–100 m) as a proxy for the overall phytoplankton biomass. Annual chlorophyll-*a* inventories in 2023 were generally near to above normal on the Scotian Shelf and below normal on the Grand Banks (Galbraith et al. 2024). Nitrate represents the nutrient pool available for new primary production on the Scotian Shelf and the Grand Banks, since it tends to be the limiting nutrient for phytoplankton growth. The amount of nitrate contained in waters below the surface mixed layer (50–150 m depth) is called the “subsurface nitrate inventory”. Subsurface nitrate inventories have generally been low most years on the Scotian Shelf since 2016 and above normal over the past two years on the Grand Banks (Galbraith et al. 2024). Despite positive signals in 2023 (i.e., higher-than-normal bottom nitrate concentrations observed on Banquereau), increasing stratification on the Scotian Shelf could interact with nutrient availability and have future impacts on the productivity of the Scotian Shelf (Casault et al. 2025).

The impact of ocean acidification has been studied in a number of bivalve species, although not directly on Arctic Surf Clam. Ocean water that becomes more acidic is expected to become more corrosive to organisms that have calcium carbonate shells (Galbraith et al. 2024), but is also expected to cause physiological effects to such species. For Atlantic Surf Clam, exposure to high dissolved carbon dioxide concentrations in seawater during laboratory experiments was observed to induce reduced feeding rates and increased energy loss (Pousse et al. 2020). For other similar species, very high and very low pH values had negative effects on the larval metamorphosis, such as in geoduck clams (*Panopea japonica*; Huo et al. 2019). Geoduck clams also exhibited changes in burrowing with changes in pH, with burrowing ceasing at very high and very low pH levels (Huo et al. 2019). Huo et al. (2019) estimated the optimal pH range for geoduck clams to be 7.6–8.8 for hatching and 7.2–8.8 for burrowing. For razor clams (*Sinonovacula constricta*), decreased pH levels (pH 7.4–7.8) reduced burrowing depths, with the mechanism being an increased energy demand under acidification-induced stress that led to decreased physiological condition (Peng et al. 2017). For the manila clam (*Ruditapes philippinarum*), decreased pH levels were observed to increase foot contractions and burrowing time, while burrowing depth also decreased (Jiang et al. 2023).

Overall, the rate of surface ocean pH decrease in Atlantic Canadian waters (i.e., 0.03–0.04 per decade) are generally faster than the global surface ocean average (i.e., 0.017–0.027 per decade) (Galbraith et al. 2024). In 2023, bottom water on the Eastern Scotian Shelf and Grand Banks was slightly undersaturated for aragonite and saturated for calcite. Undersaturation suggests that the environment is potentially corrosive to carbonate shells, as carbonate-based shells become more prone to dissolution (Galbraith et al. 2024). Bottom water pH values on the Scotian Shelf and Newfoundland shelves ranged from 7.8 to above 8.0 during summer, although it exhibited spatial variability (Galbraith et al. 2024).

Deoxygenation is also of concern to many marine bivalves, as it may impede life functions and a resilience to other stressors (Kim et al. 2018, Kruft Welton et al. 2024). Deoxygenation is driven by increased ocean warming and stratification, as well as changes in ocean circulation and biogeochemistry (Galbraith et al. 2024). Dissolved oxygen saturation was generally high on the Scotian Shelf and the Grand Banks in 2023 (Galbraith et al. 2024).

The temperature tolerance of Arctic Surf Clam is poorly studied. Work on larval development demonstrates that settlement will occur in waters as warm as 15°C (Davis and Shumway 1996). The DFO Maritimes Summer Ecosystem Research Vessel (RV) trawl survey collects bottom temperature data that dates back to 1970. The DFO Newfoundland and Labrador RV trawl survey also collects bottom temperature data during spring (generally April to June) and fall (generally late-September to December) that date back to 1996. The long-term persistence of Arctic Surf Clam on Banquereau and Grand Banks suggest that tolerable bottom temperatures have persisted through time on both banks.

The DFO Maritimes RV trawl survey separates Banquereau into East (Strata 447) and West (Strata 448). The East strata averages five measurements per year (range 1–8) and the West strata averages six measurements per year (range 2–9). The minimum annual mean (± 1 standard error [SE]) temperature in the time series for both strata was $1.4 \pm 0.03^\circ\text{C}$ in the West in 1976 and the maximum annual mean temperature $6.5 \pm 0.2^\circ\text{C}$ in 2015 in the East (Figure 2). In contrast, most of the Arctic Surf Clam fishery on the Grand Banks occurs in NAFO Division 3N (Figure 3). The DFO Newfoundland and Labrador Spring RV survey has an average of 65 measurements per year (range 22–88) and the DFO Newfoundland and Labrador Fall RV survey has an average of 58 measurements per year (range 3–72). The minimum annual mean (± 1 SE) temperature observed was $1.6 \pm 0.08^\circ\text{C}$ in the fall of 2017. The maximum annual mean (± 1 SE) temperature observed was $6.1 \pm 0.5^\circ\text{C}$ in the fall of 2010. The temperatures in NAFO Division 3L tend to be colder than in NAFO Division 3N, while in NAFO Division 3O they tend to be warmer (Figures 4 and 5). These values are similar to the 1 to 9°C temperatures observed for Arctic Surf Clam beds in inshore Quebec waters (Lambert and Goudreau 1999; Belley and Sean 2022).

Low salinity (less than 29 ppt) was considered a range-limiting factor for Surf Clam in Alaska, where the clams were observed in greatest abundance at water depths of approximately 30 m and salinity of 29–32 ppt (Hughes and Bourne 1981). The DFO Maritimes Summer RV trawl survey collects salinity data that dates back to 1970. The minimum annual mean (± 1 SE) salinity observed was 31.7 ± 0.04 on Banquereau East in 1982 (Figure 6). The maximum annual mean (± 1 SE) salinity observed was 32.8 ± 0.1 on Banquereau West in 1971 and 32.8 ± 0.02 on Banquereau East in 2008 (Figure 6). On the Grand Banks, bottom salinity is measured by the AZMP program. In NAFO Divisions 3LNO, bottom salinity ranges between 32 to 35 ppt depending on the area and season (Cyr et al. 2024).

PREDATION

Known predators across the Arctic Surf Clam range include sea stars, such as *Leptasterias polaris* (Rochette et al. 1995, Himmelman and Hamel 1993) and *Asterias rubens* (Morissette and Himmelman 2000a). Other animals may feed on vulnerable clams that have already been dug-out and opened by sea stars or have been rendered vulnerable to scavengers that might not otherwise be a threat, such as the Atlantic Rock Crab (*Cancer irroratus*), Spider Crab (*Hyas araneus*; Morissette and Himmelman 2000b), and Waved Whelk (*Buccinum undatum*; Rochette et al. 1995). Sea stars are routinely noted by At-sea Observers in the offshore clam fishery, although not all have been identified to the species level. There is only one record of *L. polaris* (on Banquereau; see: Table A9) and no records of *A. rubens*. However, both species are found on the Grand Banks shelf (Murillo et al. 2016), while only *A. rubens* is found on the Eastern

Scotian Shelf (Murillo et al. 2024). Atlantic Rock Crab and Spider Crab are also routinely noted by the At-sea Observers on both banks (Appendix A).

Groundfish have been observed to prey on Arctic Surf Clam. Samples from Banquereau in 1989 found Surf Clam in the stomachs of an Atlantic Cod of 87 cm length, but not in smaller Cod (less than 56 cm) or Haddock (46–56 cm length). It was thought that Cod were eating whole clams, not just scavenging in dredged areas for damaged clams (Roddick and Lemon 1992). Ongoing sampling of stomach contents for fish caught in the annual DFO Maritimes RV Ecosystem trawl survey is conducted by the DFO Food Habits Program. The data is stored in a DFO Maritimes Food Habits Database, which currently includes information up to 2020. It can be difficult to identify stomach contents to species, but the database has records of Arctic Surf Clam found in the stomach of Cod, Haddock, American Plaice, and Longhorn Sculpin that were caught in NAFO Subdivision 4Vs (Table 2). In the samples, Arctic Surf Clam made up 2–65% of the stomach contents by weight (which is only comprised of seven stomachs). The fish preying on Arctic Surf Clam ranged in average size from 11 to 56 mm in length and of average weight that ranged from 5 to 1,758 g. It is more common for clams to be unidentifiable, with 13 species having non-specified clams making up 11–70% of their stomach contents by weight (comprising 158 stomachs in those samples) (Table 3). American Plaice was the predator that exhibited the most clams by weight in stomach contents, followed by Daubed Shanny and Atlantic Cod. Predators with non-specified clams in stomach contents ranged in average size from 5 to 53 cm in length and in average weight from 5 to 1,981 g.

The abundances of some of the species known to prey on Arctic Surf Clam are monitored by DFO. The Atlantic Cod stocks are below short-and long-term indicators in NAFO Divisions 4VsW (DFO 2024a), and under moratorium or in the cautious zone in NAFO Divisions 3NO (NAFO 2021) and 2J3KL (DFO 2024b). Similarly, Haddock in NAFO Divisions 4VW are below the long term mean (DFO 2024a), and under moratorium in NAFO Divisions 3LNO (DFO 2018). While no information is available on Longhorn Sculpin in NAFO Divisions 3LNO, the stock is below the has long-term indicator in NAFO Divisions 4VW (DFO 2024a). The impact of groundfish predation on Surf Clam has not been quantified. It is unlikely that there is currently a large impact from predation, given observed predator abundances. As direct predation is size-dependent commercial sizes of Arctic Surf Clam will be less vulnerable to groundfish predation, and their burrowing behaviour also offers protection from predation. Clams in fished areas are more vulnerable to predation, since clams that are dislodged to the sediment surface after an area is dredged may be damaged and unable to borrow or are slow to burrow (e.g., Nunez et al. 2014).

HABITAT

The previous Arctic Surf Clam stock assessment framework used VMS data to define habitat (see: Hubley and Heaslip 2018). This was based on an assumption that fishing activity would correlate with habitat suitability (Brown et al. 2012). In contrast, recent Species Distribution Modelling (SDM) results have shown that the most important variables determining the presence of Arctic Surf Clam on Banquereau were depth, rugosity, and direction of slope (Haar 2024). Arctic Surf Clam that were generally found at depths of 28 to 72 m (weighted average) were less likely to be found in topographically-complex areas and less likely to be found on slopes facing directly north or south (Haar 2024). The area south of the Eastern Shoal on Banquereau was predicted to be highly-suitable for Arctic Surf Clam, whereas the central region of the bank exhibited greater uncertainty in habitat suitability and the southwestern and eastern edges of bank were deemed unsuitable.

Haar (2024) cautioned against interpreting anything other than simplistic inference from these results, given the lack of ground truthing in areas not historically fished. Even still, the general

pattern of species presence agreed with VMS maps of fishery footprint that have been used as habitat proxies, which also show an extensive suitable habitat southeast of Eastern Shoal and more patchy areas of less suitable habitat elsewhere on Banquereau (Figure 7). The analyses of Hubley and Heaslip (2018) and Haar (2024) both used commercial data in a presence-only capacity, although more extensive analysis with differing time periods and additional data was completed for the SDM (Haar 2024). Results of the important SDM variables for Banquereau are proxies influenced by the hydrodynamics on and around the bank; however, it is unlikely that they can translate directly to the Grand Banks.

DREDGING IMPACTS

The clam fishery is the only bottom contact dredge fishery on Banquereau, which allows for the study of bottom contact gear impacts associated with the fishery. Previous studies on dredging impacts have been conducted on Banquereau for gear type used in the clam fishery (Gilkinson et al. 2003, 2005, 2015). The studies found that physical seabed recovery could occur within a 10-year time span post-fishing, although impacts on the benthic communities persisted beyond this time. Building on this work, Haar (2024) studied broad scale habitat and benthic community recovery 2-, 5-, and 8-years post-fishing using a replicated control-impact design in areas that were representative of the fishery (i.e., not too deep or of poor habitat). Results demonstrated spatial and temporal variability in the recovery of bottom sediment post-dredging. One area showed no evidence of dredge tracks, although it was only surveyed with side scan sonar. In contrast, two other areas were surveyed with multibeam echosounders. For one of the areas, it was the deepest site that had the greatest extent of visible tracks, whereas they were absent or minimal in other treatments. In contrast, a third study site had similar, visible tracks of varying extent in all treatments. Based on these observations, Haar (2024) concluded that time was not the only factor in filling in dredge tracks and that a track that has been filled in is not the same as a return to a pre-dredging state, as subsurface impacts can persist beyond surficial sediment recovery times.

Haar (2024) also observed spatial variability in epifaunal (animals that live on the surface of the seabed) and infaunal (animals that live within the sediments of the seabed) communities post-dredging. While epifauna diversity was impacted by fishing, there was no temporal trend and there were likely confounding effects within the study area. In contrast, infauna species diversity showed no effect from fishing. There was more consistency and similarity in infauna community structure among study areas and treatments, suggesting a greater resilience to dredging (Haar 2024). In addition to physical and community composition impacts, dredging also exhibited impacts through mortality and damage to animals that interacted with gear, whether they were retained or retained and discarded. There has been no study on discard mortality in the Banquereau or the Grand Banks Arctic Surf Clam fisheries. In contrast, Bargione et al. (2024) studied the damage and mortality of discards in the hydraulic fishery for Striped Venus Clam (*Chamelea gallina*) in Italian waters. They observed that 61% of the catch in the study was undamaged and 19.2% was severely damaged. They further observed an overall discard mortality rate of 22.9%, with taxa-specific mortality ranging as high as 96% for the echinoderm species *Echinocardium cordatum* and 20–36% for thin-shelled clam species *Macra stultorum* and *Polititapes aureus*.

SURVEY AND ASSESSMENT HISTORY

Fishery independent surveys on Banquereau were conducted and used for assessments in 2004 (Roddick et al. 2007a) and 2010 (Roddick et al. 2012). A fishery independent survey on the Grand Banks was conducted in 2006, 2008, and 2009 and used for an assessment in 2010 (Roddick et al. 2011). Hubley and Heaslip (2018) summarized the surveys, survey data, and

analytical methods. The last framework for Banquereau Arctic Surf Clam was held in 2016 (Hubley and Heaslip 2018) with an assessment held in 2017 (DFO 2017, Hubley et al. 2020). Updates have been provided annually from 2018 to 2024 (DFO 2024c) using the stock framework assessment methods described in Hubley and Heaslip (2018). The 2016 framework changed the stock definition of Banquereau from the entire bank to the area directly under exploitation. Five spatial assessment areas were used to divide Banquereau (Figure 8). In these areas, the fished areas were determined using VMS data, which is used as a proxy for Arctic Surf Clam habitat (Figure 7). For each of the five assessment areas, a surplus production model was then fit to a time series of catch per unit effort (CPUE) data. Areal expansion of Arctic Surf Clam density (g/m^2) was limited to the fished area.

Biomass-based reference points have been developed for Banquereau based on the default 0.4 and 0.8 biomass at maximum sustainable yield (B_{MSY}), which are often used to define the limit reference point (LRP) and upper stock reference (USR) (Hubley et al. 2020) (Table 4). These biomass reference points are based on the fished area biomass and not the entire bank. It also proposed that the stock status also be assessed against a reference value (i.e., CPUE_{70}) that was based on the previously-established CPUE threshold level of $70 \text{ g}/\text{m}^2$ (Hubley et al. 2020). The removal reference of $F = 0.5 F_{\text{MSY}}$ has been used on Banquereau since the Framework.

Biomass-based reference points for the Grand Banks were developed based on an estimate of B_{MSY} from the survey data and using the default 40% and 80% for the LRP and USR, respectively (Roddick 2013). With no new information on which to base a biomass estimate, these reference points have not been used to assess stock status since they were developed. The removal reference of $F = 0.33 M$ has been used for Grand Banks in the past. This was based on a Maximum Constant Yield approach (Annala 1993; DFO 2007) and intended for a larger, less productive stock area.

In 2013, secondary indicators were developed for the Arctic Surf Clam fishery to monitor changes in the stock between assessments and/or surveys (Roddick 2013) (Table 5). Application of the indicators continued within the 2016 recent framework of Hubley and Heaslip (2018), although they were not updated at that time to reflect the fishery footprint approach adopted from biomass modelling; that is, the secondary indicators continued to apply to the entire bank. Three secondary indicators have been used to date to assess the two stocks. Catch per Unit Effort is a biomass indicator, with the threshold being $70 \text{ g}/\text{m}^2$ for Banquereau and $50 \text{ g}/\text{m}^2$ for the Grand Banks. Fishery footprint is an indicator of the spatial extent of the fishery and stock density. As densities decline the footprint will increase as more area is fished, to maintain landings or as the fishery searches for new high-density areas. Fishery footprint is calculated as the sum of the area dredged, with no adjustment for overlapping tows. The footprint thresholds are 250 km^2 for Banquereau and 125 km^2 for Grand Banks. Last, the size composition indicator is the relative abundance of old, large clams. This maintains older age classes in the stocks. Large changes in the size composition indicator between years could be a function of fishing location, as the size composition of the stock can vary across the banks. The size composition indicator is 1% of the unsorted catch being greater than 120 mm on Banquereau and 0.5% being greater than 105 mm on the Grand Banks.

DATA REVIEW

BIOLOGICAL DATA

Gonad Somatic Index and Spawning

Sampling of Arctic Surf Clam on Banquereau for the purposes of studying spawning timing began in 2019. Similar sampling on the Grand Banks began in 2022. For each sampling event, 25 live Surf Clam are measured and dissected, with the foot and gonad preserved in formaldehyde. Once the tissue is fixed, a small amount of gonad is removed and sent to the Atlantic Veterinary College Diagnostic Services Department at the University of Prince Edward Island for histological analysis. Gonad sections are classified into five maturity stages in order of development: early-active; late-active; ripe; partially-spawned; and spent (Ropes 1968, Rowell et al. 1990).

In some cases (14 clams) an intermediary stage was noted by the histologist (e.g., “late active/ripe”). For these, the most advanced gonad stage of the two was assigned to that clam. Clams identified as non-differentiated (n=9) were considered to be early-active, as they were all above the size at 50% sexual maturity. The sampling coverage goals are three (3) samples for each calendar month for Banquereau and two (2) samples for each calendar month for the Grand Banks. Given the opportunistic nature of the sampling (i.e., dependency on the fishing schedule), it is not possible to sample every month within a single year. Data presented herein are preliminary, as sampling is ongoing at the time of this publication.

In addition, DFO Science maintains a large dataset of morphological measurement data from frozen clams that date back to 1999, including samples as recent as 2022 (Table 6). Gonad condition is difficult to determine from a visual assessment of tissue that has been frozen, but the tissue sampling allows for the calculation of a gonad somatic index (GSI). GSI is calculated as:

$$\text{GSI (\%)} = \frac{\text{wet gonad weight}}{\text{wet tissue weight}}$$

It is assumed that GSI increases as animals are preparing to spawn and decreases as a result of spawning.

Banquereau

The pre-2009 clams used for GSI analysis on Banquereau ranged from 31.7 to 156.9 mm and 4 to 52 years (when ages were known); there are no samples between 2009 and 2019. Post-2019, the clams ranged in size from 50.9 to 131.8 mm, although exact ages are unknown. The data do not have obvious peaks in GSI in every year, although declines in GSI of varying magnitude were seen as early as April (2006, 2007), May (2000, 2004), and June (1999, 2019, 2021). Subsequent declines in GSI were seen in some months for some years; for instance, in July (2007) and August (2004). It is hard to know if these are separate spawning events or are part of a protracted spawning over the April to September period (as seen in 2006 for example; see: Figures 9 and 10).

At the time of drafting this document in 2025, the spawning sampling program on Banquereau was almost complete. Three samples have been collected from all but two months. Clams sampled ranged from 55.4 to 141.1 mm, with 57% of clams being male. Preliminary results showed that ripe Arctic Surf Clam were observed in every month (Figure 11). From January to April, ripe clams are 2–19% of the samples, increasing to 39% in May. In June, there is the highest proportion of ripe clams seen in the series (64%), with ripe clams dominant in July and August. Partially-spawned clams are seen from June to November, with the highest proportions

being in July (21%) and September (23%). Spent clams are seen in March and then again from June to September and December. Spent clams are at the highest in the series in June (10%). There is intra-annual variation in the samples within months, which is not captured in the composite.

Grand Banks

The pre-2009 clams used for GSI analysis on the Grand Banks ranged from 51.4 to 135.5 mm and 10 to 51 years (when ages were known); there are no samples between 2009 and 2019. Post-2019, clams ranged in size from 74.6 to 127.3 mm, although exact ages are not known. Peaks in GSI on the Grand Banks were seen as early as May (e.g., 2004) and June (e.g., 2001, 2003). The Grand Banks also showed some fall declines in GSI, which was not seen on Banquereau: in September (2002, 2021), October (2005), and November (2001) (Figures 9 and 10).

At the time of drafting this document in 2025 the spawning sampling program on the Grand Banks was only 25% complete (Figure 12). Clams sampled ranged from 55.4 to 141.1 mm, with 51% of clams being male. Preliminary results showed that ripe Arctic Surf Clam are present from May to September, dominating in June (64%). No spent clams have been observed in the Grand Banks samples to date, although partially-spawned clams were seen in August, so spawning is possibly occurring in that time period.

Condition

The relationship between weight and size is commonly referred to as ‘condition’. For bivalves, condition is used to evaluate growth and survival, spatio-temporal changes of resources, effects of stressors, reproduction status, and meat yield and quality (Zeng and Yang 2021). There is no consistent approach to calculate condition for bivalves. A review by Zeng and Yang (2021) identified 19 different methods used to calculate bivalve condition. Generally, condition expresses the meat weight of the animal relative to its size in length or shell volume. Herein, meat yield (foot) is of interest, with Foot Condition Index (FCI) being calculated as:

$$FCI = \frac{\text{Dry Gutted Foot Weight}}{\text{Shell Length}}$$

FCI is expressed in g/mm, where dry gutted foot weight is the weight of the foot, with digestive gland and gonads removed, placed in a drying oven at 60°C for up to 24 hours. These indices are often multiplied by 100 or 1000 to avoid working with very small numbers, although this was not done herein. The relationship between FCI and length was then modelled, with year as a random effect. The resulting relationships were:

$$\text{Banquereau FCI} = 3.18 \times 10^{-6} * \text{Length}^{2.08}$$

$$\text{Grand Banks FCI} = 4.04 \times 10^{-6} * \text{Length}^{2.00}$$

These represent the bank-wide average relationship (Figures 13 and 14). Deviation from these relationships was examined using the residuals between the actual FCI and the predicted FCI based on a whole area regression for each clam (Marzec et al. 2010).

As a different approach, the annual variation in the dry foot-length relationship was used to predict dry foot weight for a single length, to standardize comparisons within a bank. For this, 90 mm was used for Banquereau and 80 mm for the Grand Banks. This approach is similar to one used for scallop fisheries in the DFO Maritimes Region, where condition is expressed as a predicted weight at a standard size (e.g., Hubley et al. 2011). For this analysis, the resulting average bank-wide relationships were (Figures 15 and 16):

Banquereau Dry Foot Weight = $4.09 \times 10^{-6} * \text{Length}^{3.03}$

Grand Banks Dry Foot Weight = $4.04 \times 10^{-6} * \text{Length}^{3.00}$

This approach has the benefit of being easier to interpret. If this is an index that is considered valuable, it can potentially be improved upon by a deeper examination of other factors that affect the relationship between dry foot weight and length (e.g., depth and location). A standard length could also be used for both banks to allow more direct comparison. More work, however, would need to be done to determine how many samples would be needed each year to maintain an annual index. As is, the index provides useful, retrospective context for fishery trends, but cannot be used to provide advice.

Banquereau

FCI tracks the monthly GSI trends (Figures 17 and 18). On Banquereau, the mean annual FCI ranged from 0.042 to 0.053 g/mm, with the time series high being observed in 2005 (Figure 19). The FCI was less than expected at the start of the time series, but slightly more than expected in recent years (Figure 20). The highest positive residuals were in Area 4 in 2021, the greatest negative residuals were in Area 1 in 2002 (Figure 20). The predicted dry foot weight for a clam of 90 mm (Figure 21, top panel) ranged from 2.95 (2007) to 3.93 g (2004). The trends in predicted weight are similar to the annual FCI residuals, with the exception of 2001 (Figure 21, bottom panel). There was no relationship between bank-wide CPUE and the predicted weight of a clam at 90 mm (Figure 22).

Grand Banks

FCI tracks the monthly GSI trends (Figures 17 and 18). In all sampled years, the Grand Banks had a lower mean annual FCI compared to Banquereau. On the Grand Banks, the FCI ranged from 0.034 to 0.043 g/mm, with the time series maximum being observed in 2021 (Figure 19). On the Grand Banks, the southern portion had higher FCI while the northern portion generally had lower FCI. The greatest negative residual was in the northern portion in 2000, and the greatest positive residual was in the southern portion in 2002 (Figure 23). The predicted weight was compared to the annual residuals (Figure 24). The predicted dry foot weight for a clam of 80 mm ranged from 1.86 g (2000) to 2.24 g (2002). The trends in predicted weight are similar to the annual FCI residuals. There was no relationship between bank-wide CPUE and the predicted weight of a clam at 80 mm (Figure 25).

FISHERY DATA

There is no minimum legal size for Arctic Surf Clam. A previous commercial dredge selectivity study of hydraulic gear conducted on Banquereau found the size at 50% retention is 85.6 mm (Roddick et al. 2007a) and estimated age at 50% retention is 22.9 years (Roddick et al. 2011). The spacing on the commercial dredge bars used in the current fishery is 25 to 30 mm (C. Boyd, personal communication 2025). Active discarding of Arctic Surf Clam is not occurring in the offshore fishery and it is assumed that landings equal catch, with the two terms 'landings and catch' often being used interchangeably herein.

In the course of this data review, inconsistencies in the fishery effort measures being used were identified. Tows can be measured from the time the gear leaves the vessel to when it returns to the vessel (shoot-to-haul), or the time when it touches the sea floor to when it lifts off the sea floor (bottom contact). The CLAM database contained both measures when it should have been only bottom contact. To more accurately represent the towed area, data from 2014 to 2023 was corrected to be measures of bottom contact effort only. This changed some time series trends from what has been shown in previous documents.

Fishery Data Management

Commercial data used in the stock assessment framework described herein are stored in the DFO Offshore Clam Data Archival (CLAM) database. Fishing data is supplied to DFO Science directly from Industry and loaded into the CLAM database. Before and during data loading, raw data is validated against data integrity checks (e.g., expected ranges for certain values, expected unit types, etc.) and potential errors are discussed with Industry, and corrected if required, before storage in the CLAM database. Since 2017, the data review process has been extensive, so for fishing years since 2017 it is unlikely that any data outliers are errors. The CLAM database is separate from other DFO databases used for quota monitoring, including the DFO Maritimes Region Maritimes Fishery Information System (MARFIS) 1.0 and 2.0 database and the DFO Newfoundland and Labrador Region Catch and Effort database. For certainty, unless otherwise noted in this research document, data used herein are from the CLAM database.

Fishery Conversion and Component Factors

Landings in the offshore clam fishery are in the form of products (Table 7). The weight of the product types is converted to round weights (i.e., whole animal weight) using conversion factors. Not all landed product types (e.g., mantle) count against the TAC because the product is already accounted for in the conversion of foot product to round weight.

The fishery creates three mixed-species products:

1. C-grade;
2. recovery; and
3. mantle mix.

C-grade is a mixed product that can contain Arctic Surf Clam foot, but also parts of other clam species. A component factor for the C-grade product was developed and used starting in the 2019 fishing year and subsequently reviewed and updated in 2020 (Table 7). The C-grade component factor was reviewed in 2023 and did not change. The C-grade component factor is based on an analysis of C-grade component data provided to DFO by Industry. It is assumed to reflect current fishing practices and species mix; as such, C-grade component factor changes are prospective and do not apply retroactively to the time series. Other mixed species products (i.e., recovery and mantle mix) in the fishery do not contain Arctic Surf Clam foot, so do not have component factors nor count against the quota. However, C-grade landings do count against the TAC for quota monitoring purposes and are included in landing calculations in this research document.

Other commonly-retained species in the offshore clam fishery are also landed as products and converted to a round weight for monitoring (Table 8). Conversion factors for Northern Propeller Clam were previously based on a Statistical Coordinating Committee for the Atlantic Coast report (STACAC 1984), but were revised for the start of the 2023 fishery (DFO 2024a). This change in conversion factor was applied retroactively to the time series on both banks. Work is ongoing to confirm or revise the Greenland Cockle and Ocean Quahog conversion factors; until then, the STACAC (1984) values will continue to be used. In 2021, component factors for the Greenland Cockle portion of the C-grade product were developed for Banquereau and the Grand Banks (DFO 2022). The Northern Propeller Clam portion of the C-grade was found to be negligible (less than 0.13%), so a component factor is not used for this species (DFO 2022).

Fishing Time Period

This fishery operates under a fishing year that corresponds to a calendar year. To avoid including early exploratory fishing years in the time series, a fishery start year of 1987 for Banquereau and 1989 for the Grand Banks were chosen. Shorter time series are used in cases when data is not available for the entire time series. For the purposes of the stock assessment framework discussed herein, the 2023 fishing year was chosen as the terminal year for both banks.

Banquereau Fishery Data

Landings

The TAC on Banquereau has been 20,943 t from 2018 to 2023 and has not changed since the last stock assessment framework of Hubley and Heaslip (2018). In that time period, landings ranged from a minimum of 17,377 t in 2018 to a maximum of 21,969 t in 2022 (Figure 26). C-grade product makes up a small proportion of the landings, from less than 0.01% to 2.3 % (Table 9). The fishery is rotational in nature and moves around the bank, which is reflected in the landings by assessment area (Figure 27). Landings from some areas are consistent and relatively low (e.g., Areas 3 and 4) in recent years. Other areas are more productive and account for greater landings (e.g., Areas 1 and 5). Although in any given year a majority of the catch can come out of one Area (e.g., 2019 Area 1, Figure 27), since 1987, Areas 1, 2, 3, and 5 have each accounted for 19% to 30% of the catch, with Area 4 accounting for only 8.8% (Table 10). Spatial distributions of the catch in five-year increments are illustrated in Figure 28.

Effort

Effort in the fishery is measured in towed area (in km²). Bank-wide effort declined 36% between 2014 and 2020 (Table 9; Figure 26). Since 2020, effort has fluctuated. As with landings, effort varies among the assessment areas as the fishery moves around (Figure 29). Since 1987, Areas 1, 2, and 3 have each accounted for 20 to 30% of the effort, with Area 5 accounting for 18% and Area 4 accounting for only 8.7% of effort (Table 10). The spatial distribution of effort shows expansions and contractions of effort over time in the assessment areas (Figure 30).

Catch Per Unit Effort

CPUE is calculated as the sum of catch over the sum of effort in each year, aggregated either at the bank-level or assessment area-level. Bank-wide CPUE increased 44% from 2018 to 2022, exhibiting a time series high of 176 g/m² in 2022 (Table 9; Figure 26). That time period was marked by increasing catch rates with decreasing or only small fluctuations in effort. The first change to this trend occurred in 2023, when a 18% decline in CPUE corresponded with an 11% increase in effort. That change was driven by Area 3, in which a 169% increase in effort kept CPUE at a level similar to the previous year, as well as in Area 5 where similar effort to the previous year resulted in a 30% decline in CPUE (Figure 31). The spatial distribution of CPUE shows high catch rates across the bank, with some consistency in areas of highest catch rates (Figure 32).

Size Composition

Size composition data comes from onboard sampling of unsorted catch conducted during fishing operations by Industry. The protocol until the end of the 2021 fishing season was to take a length frequency sample every second day or when moving to a new area. A sample should consist of 100 measurements. In practice, samples were generally collected every three days, although there was no way to track if samples were collected when the vessel moved to a new area. Starting with the 2022 fishing year, the protocol changed to a target of at least eight length

frequency (LF) samples from each trip. When possible, the samples are spatially separated to reflect areas fished on the trip. This change was made to allow for the increase in LF sampling of the other retained species in the fishery. Since 1999, 2,736 samples have been collected on Banquereau. The average number of samples per trip in a given year ranges from 1.6 to 10.9 (Table 11).

LF for Banquereau from 2010 to 2023 are presented in Figures 33 and 34; LF by assessment areas from 2017 to 2023 are presented in Figures 35 to 39. The mode of the bank-wide LF from 2010 to 2015 was 85–90 mm, or flat (2012, 2013). The mode in 2016 was 80–90 mm. From 2017 to 2022, the mode was 90–95 mm, which increased again in 2023 to 95–100 mm. The area LFs differ slightly in some years, but generally have modes within the range seen bank-wide (i.e., 85–100 mm). Area 4 had the highest modes, more frequently greater than 100 mm, and a greater abundance of clams greater than 120 mm.

Depth

Depth is reported as the average depth fished over a six-hour watch. Since 1987, the annual mean of the average watch depth has ranged from 50 to 59 m. Histograms of fishing depths from 2012 to 2023 are presented in Figures 40 and 41. Figure 42 shows an example of the different depth-based fishing profiles across the areas.

Grand Banks Fishery Data

Assessment Areas

There is no spatial division of Grand Banks into areas that are used to assess the stock at a smaller scale. The surveys used the 45° latitude as a separation between the northern and southern portions of the bank. The fishing locations and VMS data suggest that this line bisects an aggregation of clams. A division line that was slightly north of this was adopted, in order to ensure the entirety of the aggregate is captured in one area (Figure 43).

Landings

The TAC on the Grand Banks is set at 14,756 t and has not changed since 2011. Up to 2016, landings were far less than the TAC; however, since 2016 landings have ranged from 77% to 102% of the TAC. A complete timeseries of catch is presented in Table 12 and Figure 44. C-grade product generally makes up a small proportion of the landings, from 1% to 3.6 %, with the exception being 21.5% in 2013 that was a low effort/low catch year (Table 12). The fishery occurred entirely on the southern portion of the bank until 1995, after which fishing started to occur on the northern portion of the bank (Figure 45). The southern portion of the bank is the larger contributor to total landings, ranging from 19% (1998) to 100% (multiple years) of the landings over the time series, exhibiting an average of 78% (Table 13). The northern portion of the bank contributes a smaller proportion of total landings, ranging from 0% (multiple years) to 81% (1998), exhibiting an average of 22% over the time series (Table 13). The spatial distribution of the catch in five fishing year aggregations show some consistency in areas fished over the long term, but also some beds that contributed more in some years than others (e.g., northern patch in 2001–05; see: Figure 46).

Effort

Effort in the fishery is measured in towed area (in km²). Bank-wide effort was low (3.6–9.3 km²) or nil (i.e., no fishing) from 2007 to 2015. Effort increased 1,149% from 2015 to 2016. Effort then trended slightly upward over the next four years, before declining 25% in 2020. While the 2020 decline in effort was in part due to external factors, effort after 2020 did not increase to pre-2020 levels, rather remained lower and has generally declined in the last few years (Table 12;

Figure 44). As with catch, most of the effort is on the southern portion of the bank (Figure 47). The southern portion is the larger contributor to total effort, ranging from 3% (2011) to 100% (multiple years) of the effort over the time series, exhibiting an average of 75% (Table 13). The northern portion of the bank contributes a smaller proportion of effort, ranging from 0% (multiple years) to 97% (2011), exhibiting an average of 25% over the time series (Table 13). At the aggregate level, there is some consistency in the spatial distribution of effort after 2006 (Figure 48).

Catch Per Unit Effort

CPUE is calculated as the sum of catch over the sum of effort in each year, aggregated either at the bank-level or assessment area-level. Since 2019, there has been a pattern of increasing bank-wide CPUE with decreasing effort, similar to the 2018–22 time period on Banquereau (Figure 44). The CPUE in 2023 (226 g/m²) was the highest since 1990 (Table 12; Figure 44.) CPUE is generally greater on the southern portion of the bank, although some years it was greater on the northern portion (e.g., 1997, 2005; see: Figure 49). The time series median CPUE for the southern portion is 113.1 g/m² and for the northern portion is 87.1 g/m². Increases in CPUE over the last five years were observed on both areas of the bank (Figure 50).

Size Composition

Since 2000, 751 LF samples have been collected on the Grand Banks. The average number of samples per trip in a year ranges from 1.8 to 8.5 (Table 14). LF for the Grand Banks from 2017 to 2023 are presented in Figure 51 and by area presented in Figures 52 and 53. The mode of the bank-wide LF from 2017 to 2023 is not consistent. In 2017, it was 95–100 mm and in subsequent years was 85–90 mm, or flat, and then was 80–85 mm in 2023. The area LFs differ in that the southern portion of the bank has a larger mode (95–100 mm in some years) and a greater abundance of the larger sizes, while the northern portion of the bank has smaller modes (75–80 mm in some years) and low abundance of the larger sizes (greater than 105 mm).

Depth

Depth is reported as the average depth fished over a six hour watch. The annual mean of the average watch depth on the Grand Banks has a wider range than on Banquereau, from 56 m to 73 m since 1987. Histograms of fishing depths since 2012 are shown in Figures 54 and 55. Generally, fishing occurs at greater depths on the northern portion of the bank than on the southern portion (Figure 56).

At-sea Observer Program

At-sea Observer program data prior to 2017 is summarized in Hubley et al. (2020) and Hubley and Heaslip (2018). Collecting Observer data onboard commercial clam fishing vessels is complicated and time intensive. In 2017, the protocols were revised with input from DFO Science staff. Protocols prior to this time are not well known and any documentation remains sparse. Generally, protocols aim to collect estimated weights of Arctic Surf Clam and all other species encountered, as well as to collect LF data on Arctic Surf Clam, Northern Propeller Clams, Greenland Cockles, Ocean Quahog, and other species encountered (as time permits). The large volume of catch in a single tow necessitates sub-sampling. A sub-sample of the tow consists of five bushel baskets of catch, collected before onboard automated sorting procedures take place.

To determine the total catch weight from the sub-sample catch weight, the relationship between the total volume and weight of the five bushel baskets and the volume of the dredge is used. Dredges are not always full, so an estimate of dredge fullness is used to account for any difference. Given that the dredge fullness and dredge volume can contribute to an

over-estimation of catch, extensive work was done to determine an accurate dredge volume estimate, as well as to standardize dredge fullness estimates. Protocols to incorporate these values and methods going forward were piloted in 2023, with Observer feedback being incorporated. The protocols were fully implemented at the start of the 2024 fishing year. They are applied retroactively to the raw Observer data for the analysis presented in this research document. Additional work is ongoing to reduce other sources of error; for example, in the collection of weights onboard.

The current IFMP Observer requirement is one observed trip per bank per year (DFO 2020). DFO Science does not direct the timing of the Observer trip, but does request that Observed trips not span the calendar/fishing year (i.e., a trip departure in December and a landing in January). It is assumed that Observed trips are representative of the fishery in a given year on a given bank. The Observer can only observe approximately half the watches per trip. To get an estimate for the entire trip, the observed watch data is scaled to the entire trip using effort (Gavaris et al. 2010):

$$\text{Estimated trip discards} = \text{trip effort} * \left(\frac{\text{discards observed}}{\text{effort observed}} \right)$$

There is no discarding of Arctic Surf Clam, so looking at Arctic Surf Clam landings as documented in the DFO CLAM database against the trip-scaled estimates of catch are a useful check on how representative of the catch the Observer data really is. It is difficult to identify the source of overestimation (when occurring). It is likely a cumulative effect of error being introduced at many steps in the process. Future protocol work will focus on reducing any errors to the greatest extent possible.

Shell LF data has not been collected consistently across the fishing time period or the data was collected but not entered into the DFO CLAM database. It does not appear that Observer LF data has been published in previous DFO reports, so all available data is shown herein.

Banquereau

From 2018 to 2023, there were nine fishing trips observed on Banquereau across all months except May, June, and July (Table 15). One of these fishing trips spanned the calendar year and is separated into two observed trips, given the Observer trips are counted by calendar year (Table 15). The proportion of trip effort observed on these trips ranged from 0.42 to 0.52. The proportion of Arctic Surf Clam catch observed ranged from 0.41 to 1.35 (Table 15). The situation where more catch was observed than landed is due to an over-estimation of observed catch. The observer data generally over-estimates the catch of Arctic Surf Clam by an average of 67%, ranging from an under-estimate of 22% to an over-estimate of 196% in the Banquereau trips (Figure 57).

As a proportion of total trip catch, Arctic Surf Clam, shells, stones and rocks, Northern Propeller Clam, and Sand Dollars tend to dominate, although the percentages change over trips (see: Appendix A1–A10). When catch is expressed as a percentage of Arctic Surf Clam catch, similar taxa/objects have dominated, with the proportions varying among the trips (Table 16). LF data from 1999 and earlier is variable from year-to-year, with modes as large as 115–120 mm and as small as 95–100 mm (Figures 58 and 59). In the data since 2018, 90–100 mm tends to be the mode (Figure 60). Observer data tends to have more small clams than seen in the onboard sampling (Figures 33 to 39).

Grand Banks

From 2018 to 2023, there were five fishing trips observed on the Grand Banks across half the months, excluding June to October (Table 17). One of these fishing trips spanned the calendar

year and is separated into two observed trips, given the Observer trips are counted by calendar year (Table 17). The proportion of trip effort observed on these trips ranged from 0.39 to 0.71. The proportion of Arctic Surf Clam catch observed ranged from 0.42 to 0.77. The observer data will both over- and under-estimate the catch of Arctic Surf Clam by an average of 19%, ranging from an under-estimate of 19% to an over-estimate of 97% in the Grand Banks trips (Figure 61).

As a proportion of total trip catch, Arctic Surf Clam, shells, sea cucumber (non-specified), Northern Propeller Clam, and Sand Dollars tend to dominate, although the percentages change over the trips (see: Appendix A11–A16). When catch is expressed as a percentage of Arctic Surf Clam catch, similar taxa/objects have dominated, with the proportions varying among the trips (Table 18). Shell LF data from 1989 and 1990 shows modes at 90–100 mm (Figure 62). In the data collected since 2018, there is more variability, with modes as large as 100–105 mm and as small as 75–80 mm (Figure 63). As with Banquereau, observer data tends to have more small clams than seen in the onboard sampling (Figures 51 to 53).

Other Retained Species

The fishery IFMP (DFO 2020) allows for the retention of other clam species. There are no limits on the bycatch of Northern Propeller Clam or Greenland Cockle. Ocean Quahog catch is limited on the Grand Banks to 10% of the Arctic Surf Clam catch, up to a maximum TAC of 500 t. On Banquereau there is an Ocean Quahog TAC of 800 t. In August 2021, the fishery switched from a policy of partial retention to one of 100% retention for Greenland Cockle and Northern Propeller Clam. Comparison of data before and after this time should take this into consideration. Fishery discards are not recorded, so true catch (landings plus discards) prior to 2021 is unknown.

The size at 50% sexual maturity has been studied for these species. Greenland Cockle is hermaphroditic. The size at 50% sexual maturity for male tissue is 27.9 mm and for female tissue is 37.2 mm (Kilada et al. 2007). These values are from pooled Banquereau and Grand Banks samples. Northern Propeller Clam has been studied on Banquereau, with the size at 50% sexual maturity being 28.6 mm (Kilada et al. 2009). Ocean Quahog from Sable Bank exhibit a size at 50% sexual maturity of 30.96 mm (Roddick et al. 2007b).

Banquereau

Greenland Cockle

The time series high for Greenland Cockle occurred in 2013. Since then, landings declined to 2016 and increased slowly to 2022 before a large decline in 2023 (Figure 64). It was hypothesized that this decline was likely a function of the patchy distribution of the species and the areas fished in 2023, not an underlying decline in biomass (DFO 2024a). Onboard length sampling from 2004 shows a mode of 75–80 mm, with a smaller mode (and smaller sample size) in 2005 at 65–70 mm (Figure 65). More recent onboard sampling shows modes at 70–75 in 2022 and 60–65 mm in 2023 (Figure 66). Recent Observer LF data also show modes of 60–65 mm (Figure 67). Cockles below the size at 50% sexual maturity were seen in the onboard sampling in 2022 and 2023 (Figure 66) and the observer data (Figure 67).

Northern Propeller Clam

Landings of Northern Propeller Clam have been increasing on Banquereau, with some fluctuation since 2010. The catch in 2023 represented a time series high (Figure 68). LF from the onboard sampling in the 2000s (Figure 69) show modes at the 75–80 mm and 80–85 mm sizes, which is similar to the modes in the most recent years (Figure 70). The older (Figure 71) and more recent (Figure 72) Observer LF data have similar modes. Clams below the size at

sexual maturity were not seen in the onboard sampling data, but they were seen in the observer data (Figures 71 and 72).

Ocean Quahog

Ocean Quahog have not been landed on Banquereau since 2007 (Figure 73). LF data from observed trips in the 1980s show modes as large as 90–95 mm and small as 70–75 mm (Figure 74). More recent Observer LF data from 2023 show a large range of size classes (12–99 mm; see: Figure 75). The small Quahog (less than 30 mm) in the 2023 observer samples were seen in most areas on Banquereau, with the exception of Area 3.

Grand Banks

Greenland Cockle

On the Grand Banks, Cockle landings increased from 2015 to a time series high in 2019. Since then, landings have fluctuated and remained within the range seen in recent years (Figure 76). In the onboard LF data, the largest mode was seen in 2000 at 90–95 mm (Figure 77), but in the recent years sampled (Figure 78) it has been smaller around 70–85 mm. The Observer LF data generally shows modes at 80–85 mm (Figure 79). In some years, there may be bimodality in the distribution, with smaller modes at 45–50 mm and 60–65 mm, but this was only seen in 2018 and 2019 (Figure 79). Cockles below the size at 50% sexual maturity were seen in the observer data in 2019 (Figure 79), but not in the recent onboard sampling (Figure 78).

Northern Propeller Clam

On the Grand Banks, landings of Northern Propeller Clam have increased, with fluctuation, from 2017 to a time series high in 2022, then decreased in 2023 (Figure 80). Onboard LF sampling shows modes as large as 90–95 mm in 2005 (Figure 81), but with a small sample size in that case, and as small as 65–70 mm in 2023 (Figure 82). Clams below the size at 50% sexual maturity were seen in the onboard sampling in 2023. There has been no Observer LF sampling of Northern Propeller Clam on the Grand Banks.

Ocean Quahog

Ocean Quahog have not been landed from the Grand Banks since 2019 (Figure 83). LF data from the onboard sampling from one trip in 2001 shows a mode 70–75 mm (Figure 84). An observed trip in 2019 shows a large mode of 80–85 mm (Figure 85).

SURVEY DATA

The last survey on Banquereau was conducted in 2010, with the results described in Roddick et al. (2012) and updated analyses described in Hubley and Heaslip (2018). A survey on the Grand Banks was conducted in 2006, 2008, and 2009 (Roddick et al. 2011). Only new analyses are shown herein to supplement what has already been published previously.

Length-Weight Relationship

A linear mixed-effects model was applied to the length and weight data from the surveys. Weight data described herein is the round animal weight. Data was log-transformed and tow was used as a random effect.

Banquereau

The length-weight relationship from Banquereau survey data is presented in Figure 86. The overall relationship is described as:

$$\text{Round Weight} = 5.40 \times 10^{-5} \times \text{Length}^{3.16}$$

Grand Banks

The length-weight relationship from the Grand Banks survey data is presented in Figure 87. The overall relationship is described as:

$$\text{Round Weight} = 6.02 \times 10^{-5} \times \text{Length}^{3.14}$$

Biomass Distribution

Grand Banks

For the Grand Banks, as part of the survey design, a north/south divide was drawn at 45°. At the time, the division was not used to stratify the survey or develop separate biomass estimates (Roddick et al. 2011). In the survey results, it was noted that the concentrations of Arctic Surf Clam differ in that on the southern portion of bank they tended to be closer to the shelf edge and on the northern portion of the bank they were more centrally dispersed. That survey showed that 51% of the biomass was in areas with densities less than 75 g/m² (Figure 88). The estimate of biomass at the time was 1,140,682 t for a survey area of 49,473 km². This estimate assumed 100% dredge efficiency. Of the three years of the survey (i.e., 2006, 2008, and 2009), only two also had fishing occurring (i.e., 2006 and 2009; see: Table 12). There was no overlap between fishing locations and survey locations in 2009. In contrast, in 2006 five survey tow locations did overlap with fishing in that year (Figure 89). Those tows tend to indicate higher densities than were seen in the fishery, but not a lot can be concluded from such a small sample size. The 2005 survey is generally considered by Industry as not being representative of the stock.

SPACECLAM SPATIO-TEMPORAL ASSESSMENT MODEL

OVERVIEW

Two modelling approaches applied to both banks were considered for the stock assessment framework described herein. Based on peer review, a new high resolution spatio-temporal model, entitled SpaceClam, was adopted for the framework moving forward. A Spatial Production Model (SPM) previously used for Banquereau, and applied to the Grand Banks for the first time in this framework for consideration, is described in Appendix B. SPM did not receive consensus-support for application to stock assessment, so is only documented herein for comparison with the accepted SpaceClam model.

BANQUEREAU

Habitat Suitability

Habitat suitability is used to define areas of Banquereau that are suitable for fishing and is a combined proxy of environmental conditions that lead to a high density of Arctic Surf Clam biomass, as well as conditions that are compatible with the fishing gear used on the commercial fleet. Habitat suitability at a location is defined as the expected proportion of fishing time near that location compared to total fishing time by the fleet. Since fishing effort on Banquereau has been consistent and has covered a high percentage of the total area of the bank, it is assumed herein that the spatial footprint of the fishery up to the present is an accurate measurement of ideal fishing grounds across the entire bank.

Data Description

The primary data used to estimate habitat suitability are the reported locations of commercial fishing vessels on a per-minute basis only if the fishing gear is actively deployed (not shown for

data privacy reasons). The fishing vessels continuously fish as they move across the bank, so even if a vessel is in a location with a low density of clams the location will still be reported and included in the model. However, if a location has a low density of clams, or is incompatible with the gear, it is less likely to be targeted for fishing and will be visited less often than areas with high density or areas that are compatible with the gear.

Covariates in the model, shown in Figure 90, include two proxies for seafloor characteristics and bathymetry. The two proxies for seafloor characteristics are types of acoustic data. The first is called *RoxAnn*, which sends a single beam of acoustics from a vessel to the seafloor. The beam then bounces between the seafloor and a receiver on a surface vessel, which records the intensity of the first (e1) and second (e2) reflections of the acoustic signal off of the seafloor relative to the intensity of the original signal. A higher intensity return generally corresponds to a more reflective substrate such as hard rock, while a lower intensity return generally corresponds to a less reflective substrate such as silt or sand. Because *RoxAnn* sends down a single beam, measurements from *RoxAnn* need to be interpolated by statistical algorithms to generate a map of the e1 and e2 values across the whole bank.

The second type of acoustic data is a more modern counterpart to *RoxAnn* called multibeam echosounder (MBES) backscatter. MBES works by sending a wide fan of acoustic beams instead of the single acoustic beam sent by *RoxAnn*, but otherwise works on a similar principle. Because MBES sends a wide fan of acoustic beams, measurements do not need to be interpolated but do need a pre-processing step to standardize the spatial resolution of the measurements. Bathymetry was measured from MBES data where available and taken from the General Bathymetric Chart of the Oceans (GEBCO) where MBES data was not available (GEBCO Compilation Group 2024).

Model Description

A standard point process model was used, where the local intensity depends on additive smooth functions of *RoxAnn* e1, *RoxAnn* e2, MBES backscatter, and bathymetry.

$$\Pr[S_i = s] = \frac{\pi(s)}{\int \pi(s) ds}$$

$$\pi(s) = \sum_{i=1}^4 f_i(x_i(s))$$

Here, $\pi(s)$ is the relative habitat suitability of a given location. The probability that an observed fishing location is in that location is proportional to $\pi(s)$. The smooth functions f_i are functions of the four covariates. By construction, the average effect of each covariate is zero and when a covariate is missing the effect of that covariate is assumed to be the average effect of zero.

Results

Predicted habitat suitability (Figure 91) showed significant variability on Banquereau, with four main areas of high suitability: western tail of the bank, eastern patch, and two areas in the centre-north and centre-south of the bank. Outside of these four areas, suitability on the bank is typically low, with small, isolated patches of medium suitability.

All four of the covariates had a significant effect on habitat suitability (Figure 92). Habitat suitability increases with bathymetry, as depth increases from 0 m to approximately 40 m, and stays relevantly constant at deeper levels. The relationship with MBES backscatter is more complicated, although the main feature is a sharp decline in habitat suitability at high backscatter values and a return to typical habitat suitability at the highest backscatter levels. This suggests that hard, reflective substrate is not suitable for Arctic Surf Clam, which agrees

with a known preference of the species for sandy seafloor. The reason for high suitability at the highest backscatter values remains unknown; however, one plausible theory is that the backscatter is reflecting off of shell hash from dead clams. The relationship between habitat suitability and *RoxAnn* is also fairly uncertain, with the estimated relationship for the strength of the first return (e1) being roughly quadratic with higher habitat suitability at extreme values and lower habitat suitability at intermediate values. The estimated relationship for the strength of the second return (e2) is nearly constant, but with very low habitat suitability at the lowest e2 values.

Size Composition and Individual Growth

Data Description

The 2010 survey on Banquereau included morphometric measurements on a sample of clams (Figure 93). The weight of each clam was measured and a further subset of clams was aged. The location where the clam was caught was also recorded as part of the survey database. For the analysis herein, the weight of each clam was classified into one of seven size classes shown in Table 19. The minimum size in each class was provided by Clearwater Seafoods Inc. to reflect the class composition recorded onboard the commercial vessel during fishing operations used later in the SpaceClam model (details in Model Description Section below). The average weight was taken to be the average weight of clams in each size from the survey data. Survey selectivity and commercial selectivity were converted from the length selectivity curve to the values shown in the Table 19 by taking the average selectivity-at-length of clams within each size class.

Model Description

The model used to estimate size class composition across the bank is a compositional regression model that uses continuation ratio logits with probabilities that depend on both habitat suitability and a spatially correlated random field. Habitat suitability, as estimated in the Banquereau Habitat Suitability section above, is used as a proxy for environmental condition. The random fields are independent between size classes. Continuation ratio logits model the probability π_c that a clam is in a size class c given that the clam is in class c or larger. These can be transformed into marginal probabilities through simple probability rules, where the probability that a given clam is in size class c is p_c . The compositional regression model is:

$$\begin{aligned} \Pr[w_i = c] &= p_{c, s_i} \\ p_{c, s} &= \pi_{c, s} \cdot \prod_{j=1}^{c-1} (1 - \pi_{j, s}) \\ \pi_{c, s} &= \logit(\mu_c + \beta_c \cdot x_s + f_c(s)) \end{aligned}$$

where c is the recorded size class of clam i , μ_c is a class-specific intercept, β_c is a class-specific slope for the effect of habitat suitability x , and $f(s)$ is a class-specific spatial random field. All clams that have a recorded size class are used as data for this component of the model.

An additional component of the model estimates how composition changes as a function of age. Clams at age 1 are all assumed to be in the smallest size class, the composition at age a and location s is given by the vector $WA_{\cdot, a, s}$. Transitions between size classes are governed by a probability transition matrix Γ_s where $WA_{\cdot, a+1, s} = \Gamma_s \cdot WA_{\cdot, a, s}$. Γ_s is modeled as the result of the matrix exponential $Exp_m[r_s \cdot L]$, where r_s is a spatially varying growth rate multiplier and L is a spatially constant growth rate matrix:

$$\begin{vmatrix} -1 & & & & & \\ 1 & -l_2 & & & & \\ & l_2 & \ddots & & & \\ & & \ddots & -l_6 & & \\ & & & l_6 & 0 & \end{vmatrix}$$

where each l is greater than zero and each empty cell is zero. The form of L ensures that the transition matrix Γ_s respects the sequential nature of growth from one size class to the next. For clams that have both a size class and an age recorded, the probability of size class at age is modeled with:

$$\begin{aligned} \Pr[c_i = c \mid a_i = a] &= WA_{c_i, a_i, s_i} \\ WA_{c, a, s} &= \text{Exp}[r_s \cdot L] \cdot WA_{\cdot, a, s} \\ r_s &= \text{Exp}[f(s)] \end{aligned}$$

where $f(s)$ is a spatially-correlated random field.

The growth rate r_s estimated in model is a compositional growth rate that describes how fast clams grow between the size classes. A more useful metric is the biomass growth rate. To estimate this derived quantity, a matrix W whose (i, j) th entry is the average weight of class i over the average weight of class j is first created, giving the expected change in biomass as a ratio when transitioning from class j to class i . Taking $G_s = W \cdot M_s$, using component-wise multiplication, gives the biomass transition matrix. For clarity, if $B_{a, s}$ is the vector of biomass within each size class at location s , then $G_s \cdot B_{a, s}$ gives the expected biomass within each size class after growing for one year. To estimate the population average biomass growth rate, $G_s \cdot P_s$ is taken, where P_s is the vector of size classes estimated in size class composition model.

The assessment model treats the SSS size class as a Small class and all other size classes as a single Large class, so a conversion of selectivity and growth from the seven classes here to the Small and Large assessment classes are needed. Small selectivity is the same as SSS selectivity, while Large selectivity is a weighted average of SS through XLL selectivity. The weights are given by the relative composition of SS through XLL clams normalized to sum to 1. Since the composition of clams changes with location, the Large selectivity also changes with location. The biomass transition matrix is reclassified to the Small and Large clams by taking:

$$G'_s = V G_s P_s V^T (V P_s V^T)^{-1}$$

where P_s is the diagonal matrix with entries equal to the SSS through XLL class compositions and V is the selector matrix

$$\begin{vmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 1 \end{vmatrix}$$

Results

The composition of clams across Banquereau (Figure 94) is overwhelmingly made up of the smallest size class (SSS), although the area just to the northwest of the Eastern Shoal is predicted to have nearly 40% in the largest size class. This area only had survey data along its

outer edge, so the total area that is home to the largest clams is uncertain. Estimates of population average biomass growth rate (Figure 95) range from 2% per year to 15% per year, with most locations demonstrating average growth rates between 6% and 10% per year. Uncertainty in the estimates of growth rate is generally low; however, the area to the northwest of the shoal has much higher uncertainty due to a lack of survey coverage in that area.

Reclassifying the results into the Small and Large classes used in the assessment model does not show any significantly-different patterns in either composition (Figure 96) or growth (Figure 97) compared to the original classes. Transitions from the Small class to the Large class occur for roughly 5 to 10% of the Small population each year, although due to the increased growth rate in the area northwest of the shoal, roughly 50% of Small clams transition to Large clams each year. Within the Large clam population, biomass growth ranges from approximately 2 to 7% for most of the bank and up to 12% in the area northwest of the shoal.

Validation

Model validation was performed using residual analysis to check model validity and simulation tests to quantify bias and confidence interval coverage.

Since the response variable in both the composition and composition-at-age models are discrete, taking only a finite number of possible values, randomized quantile residuals were used. If F is the distribution function for a discrete response y then the randomized quantile residual for an observation is $r_i = \Phi^{-1}(u_i)$, where Φ^{-1} is the inverse distribution function for a standard Gaussian variable and u_i is a uniform random variable on the interval $[F(y_i - 1), F(y_i)]$. If the estimated model accurately reflects the true data-generating mechanism than these residuals will have a standard Gaussian distribution. Observations within the same category will have similar residual values since the corresponding interval for their respective u_i values will be similar. The residuals for the real data were compared with residuals from three simulated examples to check that the real residuals do not look different from the simulated residuals.

Bias and confidence coverage were investigated using simulation studies to measure the expected systematic error in estimates and predictions, and the calibration of the estimates of uncertainty around estimated and predictions. For each model, 100 new datasets were simulated, refitted the model to each new dataset, and compared the parameter estimates with the true values. Bias is the average difference between the true and simulated values. Confidence interval coverage is the percentage of simulations whose true value is within the confidence interval.

Validation results for the composition model do not show any major concerns. The residuals (Figure 98) for the real data do not look different from the residuals from the simulated data and are normally distributed, as expected. Bias, both spatially (Figure 99) and averaged across the bank (Table 20), is very low. Coverage both spatially (Figure 100) and averaged across the bank (Table 20) is just under the nominal coverage of 0.9, which suggests that the confidence intervals are slightly narrower than they should be.

Validation for the composition-at-age model focused on the class transition matrix since that is the main quantity of interest. Results generally look acceptable despite a few minor concerns. The residuals (Figure 101) suggest that the model struggles to accurately reflect the data-generating mechanism for the youngest and smallest clams. Based on the residuals for the youngest age classes being negative, the residual analysis suggests that the model over-estimates the rate of growth out of the smallest size class at young ages. The estimates of bias, both spatially (Figure 102) and averaged across the bank (Table 21), show that the model tends to under-estimate growth rates, with a small positive bias for the probabilities of staying within

each class and a small negative bias for the probabilities of transitioning into a larger class. Coverage, both spatially (Figure 103) and averaged across the bank (Table 22), is just under the nominal coverage of 0.9, which suggests that the confidence intervals are slightly narrower than they should be.

SpaceClam: High Spatial Resolution Delay-Difference Model

Data Description

Primary data used for the SpaceClam assessment model is data provided by Clearwater Seafoods Inc.. The data consists of records of fishing locations, catch weight, and catch size class composition aggregated to watches lasting six hours (not shown for data privacy reasons). The fishing locations are aggregated as the percent area of each raster cell that was towed by the watch. Data for the analysis ranged from the beginning of December 2014 to the end of December 2023, which represents the entirety of fishing effort on Banquereau during that time period. Additional inputs into the model are the selectivity by weight class and individual growth estimates, as described in the previous section.

Model Description

The SpaceClam model is purpose-built for estimating biomass of sessile species, such as Arctic Surf Clam, at a high spatial resolution and for multiple size classes. The high spatial resolution is achieved by splitting the study region into many smaller regions within which biomass density and other biological and environmental processes are assumed constant. For this model, Banquereau is split into raster cells with an area of 7.5 km². Application of the model uses two size classes, a Small size class consisting of all clams with at most 12 g tongue weight (approximately 78 g round weight) and a Large size class consisting of all other clams.

The raster cells are large enough to assume that movement of Arctic Surf Clam between raster cells is negligible. Therefore, changes in biomass within a given raster cell can only be attributed to individual growth, natural mortality, removals due to fishing, and recruitment. Estimates of individual growth were obtained from survey data, as described in previous section, and vary spatially depending on the local size class composition and the local growth rate. Natural mortality is considered constant across space and time, although each size class has its own natural mortality estimates. Fishing removals are assumed known with no error; however, catch is reported on a per-watch basis where each watch may cover an area associated with multiple raster cells. A central feature of the model is an explicit accounting of the raster cells from which the fishing removals should be taken.

Recruitment to the fishery is difficult to model for two reasons. First, since Arctic Surf Clam are broadcast spawners, recruitment for a given area will be influenced by the spatial distribution of sexually mature clams across the whole bank, and possibly further, as well as environmental factors such as ocean currents. Modelling such non-local effects can be achieved in theory through an integrodifference equation; however, these models are too computationally intensive to be considered herein. Second, clams are generally recruited to the fishery at ages between 5 and 8 years old. Given the relatively short time span of the data used for this analysis, 10 years of data, there is unlikely to be enough to estimate a relationship between the mature biomass and recruits. A very rudimentary parameter is included in the model to allow for recruits, but most of the recruitment in the model is identified through random error that is not separated from other sources of uncertainty in the biomass dynamics.

The biomass dynamics for a single raster cell are modeled using a modified delay-difference model that accounts for the two size classes, the previously estimated individual growth rates, and the fishing removals on a per-cell basis.

$$B_{\cdot,s,y+1} = [e^{-M} \cdot G_s \cdot B_{\cdot,s,y} - C_{\cdot,s,y}] \cdot e^{\varepsilon_{\cdot,s,y}}$$

In this equation $B_{\cdot,s,y}$ is the vector of Small and Large biomass in raster cell s and year y , M is natural mortality, G_s is the 2x2 growth matrix estimated from the survey data and the class-at-age model, $C_{\cdot,s,y}$ is the vector of total Small and Large removals from raster cell s in year y , and $\varepsilon_{\cdot,s,y}$ is a vector of spatially-correlated process error for Small and Large biomass. The growth matrix G_s is a lower triangular matrix, although an additional parameter $G_{1,2}$ is estimated for a simple proportional relationship between Large biomass and recruits Small biomass.

The fishing dynamics are more complicated because a single fishing watch may cover multiple raster cells and it is not directly observed what percentage of the catch for that watch comes from each raster cell. Conditional on the biomass B within each raster cell s , the fished biomass for watch i and size class c is:

$$fB_{i,c,s} = q\phi_{c,s}A_{i,s}B_{c,s,y_i}$$

where q is the estimated dredge catchability, $\phi_{c,s}$ is size selectivity, and $A_{i,s}$ is the proportion of the area of raster cell s that was dredged during the watch. Selectivity depends on location because the selectivity for the Large class is a weighted average of the size classes used in the compositional analysis.

Given the fished biomass, the reported catch for each size class is assumed to follow a Tweedie distribution:

$$C_{i,c} \sim \text{Tweedie}(\mu = \widehat{C}_{i,c}, \sigma^2 = \phi_c \widehat{C}_{i,c}^{p_c})$$

$$\widehat{C}_{i,c} = \sum_{s=1}^S fB_{i,c,s}$$

where $\phi_c > 0$ and $1 < p_c < 2$ are variance parameters to be estimated. The Tweedie distribution allows for measurement error due to deviations from the average catchability and selectivity, as well as accounting for biomass not being uniformly distributed within each raster cell.

The remaining step in the model is connecting the reported catch $C_{i,c}$ of each watch with the yearly total removal from each raster cell $C_{\cdot,s,y}$. For each watch, the proportion of the catch attributed to each raster cell is assumed proportional to the fished biomass of that raster cell. Summing the catch from each watch in a year gives:

$$C_{\cdot,s,y} = \sum_{i;y_i=y} C_i \cdot \frac{fB_{i,c,s}}{1^T fB_{i,c,\cdot}}$$

where $fB_{i,c,\cdot}$ is the vector of fished biomass from all raster cells.

A note on the computation of confidence intervals for predicted bank-wide biomass: since the estimators of biomass in adjacent raster cells are highly correlated in complicated ways, the confidence intervals for bank-wide biomass need to be computed carefully. Simulation techniques are used to sample realizations of the spatial biomass that is coherent with the data, find the bank-wide biomass for each of those realizations, then for each year the 5% and 95% quantiles of the biomass are taken in that year from the simulated realizations. Specifically, as part of fitting the model, the maximum likelihood estimate $\hat{\theta}$ for the model parameters and random effects and the joint covariance matrix Σ of the maximum likelihood estimators at $\hat{\theta}$ are obtained. Assuming the maximum likelihood estimation (MLE) is approximately normal, 100

realizations of the parameters are sampled and random effects from a normal distribution with mean $\hat{\theta}$ and covariance Σ . Sampling parameters and random effects in this way, computing derived statistics, and taking empirical confidence intervals of the derived quantities, gives accurate confidence intervals for the derived quantities as long as the MLEs are approximately normal. The accuracy of the confidence intervals holds even if the relationship between the sampled parameters and the derived statistics is highly non-linear; however, accuracy is dependent on the number of samples taken. A relatively small number of realizations are used due to computational constraints and to calculate 90% confidence intervals instead of 95% confidence intervals to accommodate the small simulation sample size.

Results

The estimated 2018 Small and Large biomass with a 90% confidence interval for each cell is shown in Figure 104. This is used to highlight general spatial trends in biomass and to discuss uncertainty in the spatial distribution of clams. The eastern patch of the bank is a highly productive area with high estimated biomass for both Small and Large clams. Another important area for Large clams is the western tail of the bank, with this area predicted to have relatively little Small biomass. The uncertainty within any given raster cell is generally large; for example, the 90% confidence interval for Large biomass in a typical cell in the eastern patch of the bank ranges from approximately 0.4 kilotonnes (kt) to approximately 1.2 kt, with a point estimate of approximately 0.7 kt. This amounts to a percent change of -43% for the lower endpoint of the confidence interval and +71% for the upper endpoint of the confidence interval.

This high amount of local uncertainty is due in large part to each watch being recorded over multiple raster cells and not being able to precisely identify which raster cells contribute how much biomass to each watch. The confidence intervals are expected to drastically decrease in width (in terms of percent change) if the biomass is aggregated over larger areas, particularly if the size of the area approaches the size of the typical area towed during a fishing watch. See for example bank-wide biomass in Figure 111, where the percent change compared to the point estimate is 16% for the lower endpoint of the 2018 Large confidence interval and +20% for the upper endpoint.

Large biomass exhibited significant differences in both space and time (Figure 105). The harvest data in 2014 only included December, which was not enough information to inform the spatial distribution of biomass in that year. The productive eastern patch of the bank reached a peak estimated biomass density of 1.0–1.2 kt per km² in 2020, with densities much higher compared to the rest of the bank. The western tail of the bank also has generally higher biomass compared to the rest of the bank, but does not demonstrate a large peak in biomass in any year. The rest of the bank consists of a relatively homogeneous distribution of low to intermediate biomass that ranges from 0.2 kt to 0.5 kt per km².

Exploitation of the fishery typically occurs by a commercial vessel fishing in a relatively small area very intensely in a year and then not returning to that area for multiple years in the style of an opportunistic rotational harvesting strategy (Figure 106). Because of this fishing strategy, local exploitation rates for areas targeted by the fishery can be as high as 40% in any given year. However, areas that have such a high exploitation rate in one year are unlikely to be fished again in the near future, which gives the local population time to recover. Outside of the areas of extremely high fishing intensity local exploitation rates are typically between 5% and 20% if the area is fished.

The structural component of the model estimates a bank-wide average for biomass dynamics. The local growth rate accounts for some spatial variation in the biomass dynamics, although there is expected to be some additional variability due to temporal difference in growth rate and

spatio-temporal difference in mortality. These sources of additional variability contribute to the estimated random error shown in Figure 107. Areas in green are areas that have a higher biomass than expected given the previous years biomass and the bank-wide average model, while areas in purple have a lower biomass than expected (Figure 107).

Estimates of Small biomass follow similar patterns to estimates of Large biomass; however, Small biomass is typically less than Large biomass (Figure 108). The eastern patch of the bank exhibits a high density concentration of Small clams in 2015 that slowly decreases until 2018, as those clams are both fished and grow into the Large class. The local exploitation rate for Small clams mirrors the pattern of local exploitation rate for Large clams since exploitation is driven by fishing effort (Figure 109). Local exploitation for Small clams reaches up to 15% in some areas with targeted fishing but is typically closer to 1–3%. Random variability in Small biomass shows significant spatio-temporal difference, especially on the eastern patch in 2018 (Figure 110). This area of much higher than expected Small biomass has a high percent change from what is expected from the model, but given the expected Small biomass in that region is extremely small the absolute difference between Small biomass and expected biomass is also fairly small.

Bank-wide estimates of Small and Large biomass and exploitation rates are shown in Figure 111, with tabular versions of biomass estimates given in Table 23 and Table 24. There is little evidence that the bank-wide biomass changes substantially during the years considered herein; however, may have slightly declined between 2016 and 2018. Estimated Large biomass ranges from 1,304.0 kt in 2018 to 2,082.1 kt in 2014. Bank-wide exploitation rate of Large clams is consistently close to 0.85% per year. Estimated Small biomass ranges from 619.4 kt in 2020 to 1368.9 kt in 2014. Bank-wide exploitation rate of Small clams is around 0.3% for all years, but may have been slightly higher in 2015 and 2016.

Parameter estimates for the model are given in Table 25. The model estimates dredge catchability to be about 60%, with a 90% confidence interval ranging from 43% to 75%. This estimate of q is larger than previously reported, but is based on the current fisheries data and gear. Natural mortality of Small clams is estimated to be 0.097, with a 90% confidence interval ranging from 0.058 to 0.163. Natural mortality of Large clams is estimated to be 0.148, with a 90% confidence interval ranging from 0.117 to 0.187. These estimates of natural mortality are slightly higher than estimates previously reported. The model also estimates that recruitment per year is equal to 1.8% of the Large biomass, with a 90% confidence interval of 1.0% to 3.2% per year.

Validation

Predictions of total biomass on Banquereau using three model settings were compared. The first and main model used a resolution of approximately 7.5 km² per spatial polygon and freely estimated catchability, the second used a fixed value of catchability equal to that estimated value, and the third model used a fixed value of catchability and a resolution of approximately 3.7 km² per spatial polygon. When a fixed value of catchability is used, the only change in predicted biomass is the width of the confidence interval. Neither using a fixed value of catchability nor increasing the spatial resolution changed the point estimates of total biomass (Figure 112).

A retrospective analysis was performed to investigate the predictive performance of the model. The model was re-estimated four times each using a shorter time series of data by removing the final year of data. The re-estimated models were used to predict biomass one year ahead and compared to the biomass estimated using all the data. To prevent different estimates of catchability affecting the results, catchability was fixed to the estimated value when running the retrospective analysis. The retrospective patterns for bank-wide biomass (Figure 113) demonstrate that one-year-ahead predictions are generally accurate for Large biomass, with a

slight positive bias. One-year-ahead predictions for Small biomass are unreliable, with a negative bias.

A simulation study was also performed with 100 simulated datasets to investigate possible bias of the model and to check the confidence interval coverage. Bias for total biomass shows a small positive bias in nearly all years, while coverage for total biomass is slightly under the nominal 90% coverage expected Small clams and slightly over that for Large clams (Table 26). Spatial bias for Large clam density shows a few small, isolated patches with large negative bias on the edge of the eastern shoal, while the remainder of the bank has very low bias in either direction (Figure 114). Large biomass coverage (Figure 115) shows most locations have coverage within 10% of the nominal coverage, with no spatial patterns present. Small bias (Figure 116) and coverage (Figure 117) are similar to bias and coverage for Large clam, except that small bias does not have the area of large negative bias.

GRAND BANK

Habitat Suitability

Since fishing effort on the Grand Bank has been limited, the fishing locations may not accurately reflect the habitat most suitable for fishing. Habitat suitability is predicted by taking the estimate environmental covariate effects from Banquereau and applying them to the environmental covariates on the Grand Banks. The Grand Banks has very limited backscatter data, so these predictions are based entirely on *RoxAnn* and bathymetry (Figure 118). Predicted habitat suitability is shown in Figure 119, with a large patch of high habitat suitability on the southern portion of the bank and a smaller patch of high habitat suitability on the northern portion of the bank.

Size Composition and Individual Growth

The models used for composition and composition-at-age on the Grand Banks are the same as the models used for Banquereau, but are estimated using Grand Banks data (Figure 120). As with Banquereau, the composition of clams across the Grand Banks (Figure 121) is overwhelmingly made up of the smallest size class (SSS). Estimates of population average biomass growth rate (Figure 122) range from close to 0% per year in the northern portion of the bank up to 10% per year in some parts of the southern portion of the bank.

Uncertainty in the estimates of growth rate is generally low; however, the area with the largest estimated growth rate also has a large amount of uncertainty. Reclassifying the results into the Small and Large classes used in the assessment model shows that the southern portion of the bank may have more Large clams than Small clams (Figure 123), but does not have significantly higher growth (Figure 124) compared to the northern portion of the bank. Residuals for both the composition model (Figure 125) and composition-at-age model (Figure 126) do not show any concerning patterns that would indicate the model does not reflect the data.

SpaceClam: High Spatial Resolution Delay-Difference Model

The model used for biomass on the Grand Banks is the same model used for biomass on Banquereau, but is estimated using Grand Banks data. When applied to Grand Banks, the model struggled to estimate catchability, so a fixed catchability of 0.6, equal to the catchability estimated on Banquereau, was used. The model also had convergence issues due to eight fishing watches with extremely high biomass caught per square kilometre fished (greater than 2 kt per km²), so these watches were removed from the analysis. Given the sparse nature of fishing effort on the Grand Banks, the modelled area was constrained to be only locations that

have been fished, which are along the eastern edge of the bank. As more data become available this area should be expanded to encompass all fished areas.

Estimated Large biomass density (Figure 127) is very low on the northern portion of the bank, with less than 0.2 kt per km², but is significant in the southern portion of the bank with approximately 0.8 kt per km². There is very little variability between years. A single modeled polygon has an estimated Large density greater than 2 kt per km² in 2019 and onwards. Exploitation of Large clams is concentrated in the southern portion of the bank and in 2016 through 2018 (Figure 128). The peak exploitation occurred in 2016 and 2017 with a concentrated area with exploitation rates of 20% or more, although typical local exploitation is closer to 5–10% if an area is fished. Estimated random error for Large clam density shows large positive deviations in the southern portion of the bank in 2015 and the northern portion of the bank in 2019, but otherwise shows patterns expected of the spatial random error (Figure 129).

Estimated Small biomass density is high on the northern portion of the bank, with up to 3 kt per km², and more typically 1.5 kt per km², but is relatively low on the southern portion of the bank with average densities near 1 kt per km² (Figure 130). Exploitation for Small clams follows similar spatial patterns to Large exploitation, but is limited to peaks of 6% exploitation rates and on average 2% exploitation if an area is fished (Figure 131). Estimated random error for Small clam density shows a few isolated areas, with lower than expected density, but exhibits almost exclusively higher than expected density (Figure 132). This suggests that the structural component model on the Grand Banks consistently under-estimates the amount of Small density.

Total biomass and exploitation estimates suggest that biomass of both Large and Small clams has been increasing since 2015, although the estimates are very uncertain (Figure 133; Tables 27 and 28). Estimated exploitation of Large clams peaked in 2016 at 0.45% and has steadily declined to 0.15% in 2023. Estimated exploitation of Small clams has been steady at 0.7% since 2016. Parameter estimates for the model suggest that there is currently not enough data to fully inform the model (Table 29). The estimate of natural mortality for Small clams is 0.002; however, the 90% confidence interval around this estimate include virtually all possible values. Natural mortality for Large clams is estimated at 0.06, with a 90% confidence interval ranging from 0.016 to 0.233 indicating a fairly uncertain estimate for Large clam mortality as well.

Validation was not performed for the Grand Banks model, as there was not enough data to fully fit the model. If more fishing is done on the Grand Banks, and more data become available to inform the model, then model validation can be performed at that time.

MODEL COMPARISON

Both SpaceClam and the previous SPM of Hubley and Heaslip (2018) estimate habitat suitability (see: Appendix B). The extent of the habitat and locations of high suitability habitat from the two different approaches are similar for Banquereau. The habitat model on the Grand Banks encompasses more area in the SpaceClam model than the VMS-derived version used in SPM. The SpaceClam area is based on predicted habitat, using known relationships from Banquereau; it is not based solely on fishing locations. Further, the SpaceClam model incorporates fishery independent information through the survey data morphology and selectivity analyses, as well as uses new data in the form of the meat size class data to estimate recruitment. In contrast, the SPM aggregates biomass into one unit regardless of meat size and has no measure of recruitment.

To compare biomass estimates from SpaceClam to SPM, the SpaceClam modeled area was used in SPM instead of the VMS-derived habitat map. The results of the SPM model were then

adjusted for q and compared to the vulnerable biomass (small and large combined) from the SpaceClam model (adjusted for q and selectivity). Results were then expressed as a density. On Banquereau, the two models had good agreement in the first three years of overlap, although the SpaceClam model did not track CPUE as closely as SPM did (Figure 134). In the latter years, SpaceClam shows a decline in density with small fluctuations in the last few years. On the Grand Banks, the SpaceClam model and the SPM show the same trend, with the SpaceClam estimating lower densities (Figure 135).

A known bias of SPM is that high catch rates could drive biomass estimates, especially in cases where catch rates were high in a concentrated area (although the biomass estimate was expanded to the entire area by the suitable habitat). This is seen in the SPM results on the Grand Banks. The SpaceClam model mitigates this issue somewhat by modelling at a higher resolution, so that the effect of high catch rates only informs the biomass estimate in the immediate area of high catch rates; thus, is not applied to a larger area.

REFERENCE POINTS

OVERVIEW

The [DFO Precautionary Approach \(PA\) Policy \(2009\)](#) defines the LRP as the stock status below which serious harm is occurring to the stock and where there may also be impacts to the ecosystem, associated species, and a long-term loss of fishing opportunities (DFO 2009). The PA Policy defines the USR as the stock status below which removals must be progressively reduced in order to avoid reaching the LRP. The USR can also serve as a target reference point, based on productivity objectives for the stock, and broader biological, social, and economic objectives for the fishery. The PA Policy default LRP and USR of 0.4 and 0.8 B_{MSY} , respectively, were used previously to guide advice for the Arctic Surf Clam stocks (Table 4).

LIMIT REFERENCE POINT AND UPPER STOCK REFERENCE

The vulnerable biomass density was chosen as the stock status indicator. On Banquereau, the density has been consistent at approximately 10 t/km² over the modeled time period. The mean of the vulnerable density over the timeseries was 102 t/km². This value is considered to be a proxy for B_{MSY} , making the default LRP 40 t/km². A proxy for B_0 (the mean long-term equilibrium biomass of the stock in the absence of fishing) was also explored. For this, the sum of the time series maximum vulnerable biomass for each raster cell was used. This value was 672 t/km² on Banquereau. An LRP based on B_0 is generally 20%, resulting in an LRP of 134 t/km². This is greater than the value derived from the other proxy and was not thought to be relevant for the stock. The LRP based on the B_{MSY} proxy of 40 t/km² was chosen for both banks; it represents a density below which biological harm to the stock would be expected.

The PA Policy default approach to defining USR is to double the LRP, which in this case would be 80 t/km². It is unlikely that the stocks will experience large changes in biomass from year-to-year due to their low productivity, so a USR that is double the LRP would result in a longer response time in the cautious zone than may be needed for more productive or dynamic stocks. In contrast, another USR candidate that was considered is the CPUE secondary indicator value of 70 g/m² (i.e., 70 t/km²). This value has been used previously for the stock, in addition to B_{MSY} -based reference points (Table 4) and, although lower than 80% B_{MSY} , would still provide time for management response.

REMOVAL REFERENCE

To date, there has not been large changes in biomass at the fishing rates the two banks have experienced. This suggests that fishing has been occurring at a sustainable level and that keeping exploitation within the levels observed would be precautionary. The average F from 2014–23 was agreed upon as a removal reference (e.g., Figures 111 and 133). This value would result in only a small proportion of the stock being exploited in a given year, but remains appropriate given uncertainty in the models, low productivity of the stocks, and unknowns of both recruitment and recovery time of the species.

SECONDARY INDICATORS

ECOSYSTEM INDICATORS

Secondary ecosystem indicators were considered for ongoing monitoring of both stocks based on review of an Ecosystem Summary Report for NAFO Division 4Vs (Tam 2025). Based on discussions, annual near-bottom temperature anomalies and annual near-bottom measurements of acidification (i.e., pH, aragonite and calcite saturation, and substrate-inhibitor ratio) were selected as the most relevant ecosystem indicators to help track species well-being. AZMP uses a critical threshold of 0.1 mol/ μ mol for the substrate-inhibitor ratio (SIR), which is defined as the ratio of the substrate (bicarbonate ions) to the waste product (hydrogen ions). The SIR is a metric used to assess the influence of changing carbonate chemistry on biocalcification (Galbraith et al. 2025). Below the SIR threshold, it is expected that calcification in certain marine organisms may decline. For aragonite and calcite saturation, a threshold of less than 1 is used to indicate conditions that favour dissolution of structures composed of those materials, while conditions less than 1.5 may favour onset of physiological effects (Galbraith et al. 2025). All of these variables are measured and published in reports by AZMP in the DFO Maritimes Region and DFO Newfoundland and Labrador Region.

Banquereau

The near-bottom temperature anomaly for 2023 in NAFO Division 4Vs was in the normal range (Figure 31b in Hebert et al. 2024). Measures of ocean acidification in the Scotia-Fundy bioregion show that overall, there is a trend of normal to increasing acidification conditions in near-bottom waters (Figure 17 in Galbraith et al. 2025).

Grand Banks

In NAFO Divisions 3LNO, spring bottom temperatures in 2023 were in the normal range after a period of warmer years (Figure 33 in Cyr et al. 2024). As with Banquereau, measures of ocean acidification on the Grand Banks show a trend of normal to increasing acidification conditions in near-bottom waters (Figure 17 in Galbraith et al. 2025).

STOCK INDICATORS

Secondary stock indicators were considered for ongoing monitoring of the stocks, with such indicators originally intended to track status of the stocks between surveys (Roddick 2013) (Table 5). In recent years, the secondary stock indicators have been reviewed annually. Secondary stock indicators can provide useful context for the fishery and the stock, but are less informative about localized changes since the information is averaged across an entire bank. The indicators were reviewed at the assessment area level, in addition to the bank level, to see if increased resolution offered any benefit. In all cases, the indicator levels were intended to trigger a closer look at the stock, but not trigger any immediate management action(s). A “closer

look” could entail an exploration of CPUE trends in smaller spatial areas to determine if there is any evidence of stock depletion, plotting shell LF, and exploration of the spatial distribution of LF samples among years.

Banquereau

CPUE Indicator

The CPUE indicator was set at a recent time series low, at which the stock still remained commercially viable and at which the CPUE increased with no management intervention (Roddick 2013). The CPUE indicator on Banquereau is set at 70 g/m². The bank-wide threshold was set based on a low value in 2001. The indicator threshold has not been surpassed since development (Figure 26, middle panel).

Footprint Indicator

The fishery footprint indicator was set at historic highs (Roddick 2013). Values above this threshold could be an indication of the fishery searching for new beds, as other beds are depleted, which would warrant a closer look at the stock. The footprint was set at the 1999 value of 250 km², at which time there were three active vessels in the fishery. The indicator threshold has not been surpassed since development. The effort in 2015 came closest to approaching the line at 242 km² (Figure 26, bottom panel).

Length Indicator 1

The first length indicator was developed to monitor abundance of older clams in the population. Size values were chosen to represent the upper tail of the size distribution. The threshold was based approximately on time series lows of percentage of that larger size class in the catch (Roddick 2013). The Length Indicator 1 is 1% of clams in the unsorted commercial catch being above 120 mm. This value was chosen visually to represent the tail end of the distribution and is greater than L_{inf} of 111.7 mm (Table 1). The indicator threshold has not been surpassed since development (Table 30).

New Length Indicators

Additional length monitoring is to be achieved using two new secondary stock indicators. The first new length indicator is the percent of the unsorted catch below the size at 50% sexual maturity, with the percent threshold set based on a maximum in the time period used for the original length indicator. This indicator uses an existing data source, so no additional sampling is required. Although the gear tends to exclude small clams due to the size of gaps in the dredges, small clams can still be retained if they are unable to pass through the grate due to it being blocked by other catch.

The second new length indicator is L_{max} , which is the mean total length of the largest n number of individuals caught. This indicator is based on $L_{max5\%}$ (Probst et al. 2013a) and can be a measure of the truncation of the length distribution. This indicator has been shown to be positively related to population biomass, exhibiting significant correlation in simulations (Probst et al. 2013b). It is considered an appropriate stock indicator to consider for slow growing species (Kell et al. 2022). For this indicator, a threshold of $0.8L_{inf}$ is often used (Kell et al. 2022), so this is applied here. This indicator uses two existing data sources (onboard sampling and observer sampling), so no additional sampling is required. In contrast, use of $L_{max5\%}$ was also considered, but not adopted given challenges presented by small sample sizes in some years. Instead, fixed values were adopted for the indicator. In this case, 100 for bank-wide (L_{max100} , the mean length of the largest 100 individuals in the sample) and 50 for individual areas, when applicable (L_{max50} ; the mean length of the largest 50 individuals in the sample).

Length Indicator 2 ($L_{\max}$)

The threshold for the $L_{\max}$ indicator is 80% of $L_{\inf}$ (Table 1), which is set at 89 mm (Figure 136). The indicator threshold has not been surpassed since the start of the data series that began in 1987. The Observer $L_{\max}$ values are consistently lower than the onboard sampling data. This is likely a function of spatial distribution. The observer data comes from one or a small number of trips, with only half the watches in those trips.

Length Indicator 3 (45.2 mm)

The percent of unsorted catch below size at 50% sexual maturity dating back to 1999 is shown in Table 31. An indicator threshold of 0.5% was derived from the time series high of 0.49% in 2004. This indicator threshold has not been surpassed since the start of the data series that began in 1999 (Table 31).

Bank-wide Versus Assessment Area

For Banquereau, separate assessment area indicators were examined and compared to the bank-wide value applied to each area. These area-based indicators were not adopted and the bank-wide indicator remains unchanged.

Grand Banks

CPUE Indicator

The CPUE indicator was set at a recent time series low, at which the stock still remained commercially viable and at which the CPUE increased with no management intervention (Roddick 2013). The CPUE indicator on the Grand Banks is set at 50 g/m². The bank-wide threshold was set based on a time series low in 2002. Indicators by assessment area set at 2002 levels were also examined and compared to the bank-wide value applied to each area. Values were rounded to the nearest whole number. The corresponding values for a CPUE indicator by assessment area based on this approach are in Table 32 and Figure 137. They were not very different from the bank-wide indicator. The area-specific indicator is slightly higher in the northern portion and slightly lower in the southern portion of the bank when compared to the bank-wide indicator. Use of these indicators would have triggered further examination of the data in the northern portion in 2018. Effort in 2018 was only a little lower than the effort in 2019 that resulted in better catch rates. When the areas of overlap in 2019 were examined, 2018 was more spread out, and in 2019, the fishing was more focused and had greater catch from less effort. This could be evidence of exploration in 2018 benefiting the catch in 2019.

Footprint Indicator

The fishery footprint indicator was set at historic highs. Values above this threshold could be an indication of the fishery searching for new beds, as other beds are depleted, which would warrant a closer look at the stock (Roddick 2013). The footprint indicator on the Grand Banks is set at 125 km². The bank-wide threshold is based on a time series high in 1995. The effort that year was driven by effort in the southern portion of the bank (95%) and at the start of fishing in the northern portion of the bank. The value from 2003 was chosen as a timeseries high close to the timeseries of the original indicator, instead of 1995. The corresponding values for a footprint indicator by assessment area based on that approach is in Table 32 and Figure 138. Use of these indicators would not have triggered further examination of the data.

Length Indicator 1

The first length indicator was developed to monitor abundance of older clams in the population. Length values were chosen to represent the upper tail of the size distribution. The threshold was

based approximately on time series lows of percentage of that larger size class in the catch (Roddick 2013). The indicator is 0.5% of clams in the unsorted commercial catch being above 105 mm. This value was chosen visually to represent the tail end of the distribution and is smaller than L_{inf} for the stock of 111.7 mm (Table 1). A standardized approach using the size at the 95th percentile in the survey data has been proposed for other species in the fishery (DFO 2022). The corresponding values for Length Indicator 1 by assessment area based on that approach is outlined in Table 33. The range is from 99 mm to 116 mm. In the northern portion of the bank, the indicator threshold was not met in 2018 and 2021. Both years have similar modes to years before and after (Figure 52), and both years have some geographic overlap to other years, so the differences are not solely a function of sample location. In the southern portion of the bank, the indicator threshold was not met in 2023. In 2023, the mode was slightly smaller and there was a suggestion of bimodality in the LF (Figure 53). In this case, there was little overlap with sample locations in 2021 and 2022, with the 2023 samples being more spatially concentrated. Samples in 2021 and 2022 ranged over approximately 1.7 degrees latitude, with the 2023 samples ranging over 0.12 degrees latitude.

New Length Indicators

New length indicators were developed as described in the Banquereau section above. For Grand Banks, the L_{max} indicators use 100 for bank-wide (L_{max100} , the mean length of the largest 100 individuals in the sample) and 50 for the individual areas (L_{max50} ; the mean length of the largest 50 individuals in the sample).

Length Indicator 2 (L_{max})

The threshold for the L_{max} indicators is 80% of L_{inf} (Table 1), which is set at 78 mm (Figure 139). Bank-wide, the indicator was above the threshold for the time series. For the individual areas, the indicator was above the threshold, but close to it in 2010 in the northern portion of the bank based on the observer data.

Small Size Indicator

The percent of unsorted catch below size at 50% sexual maturity dating back to 2000 is shown in Table 34. An indicator threshold of 0.5% was derived from the time series high of 0.45% in 2006. This threshold has not been surpassed to date, either at a bank-wide or individual level.

Bank-wide Versus Assessment Area

The separation of data by assessment area does improve the indicators for the Grand Banks. In the early years of the fishery, and as recently as 2017, only one assessment area would be fished in a given year. In such instances, the bank-wide indicator is made up of only one portion of the bank, although the separate indicators by assessment area account for this.

RECOMMENDED TIMING OF STOCK ASSESSMENT AND UPDATE

It is recommended that a stock framework review occur in five years (i.e., 2030). However, a framework review could be triggered sooner if there are substantial improvements to the assessment model, if there are issues associated with the modeled outputs, or concern about stock status. Interim stock updates can be provided upon request by DFO Resource Management and supported by DFO Science. Interim stock updates could include update on key stock information, including time series of catch, effort, footprint, CPUE, secondary indicators, other retained species, bycatch, and results of the SpaceClam model, including stock status and TAC at the removal reference.

Triggers to consider a new framework or full stock assessment of either bank before the next framework review in 2030 include:

1. issues that may arise with the SpaceClam model (e.g., model non-convergence);
2. a stock status indicator(s) (e.g., vulnerable biomass) has a greater than 50% chance of being in the cautious zone;
3. an unexplained 30% increase in the annual fishery footprint indicator;
4. the CPUE indicator falls below the threshold; and/or
5. if the modeled fished area on the Grand Banks increases by 50% from the 2023 modeled fished area, as this would indicate a large expansion of the fishery that should be examined in more detail.

These conditions will be evaluated within the context of all other indicators, to determine what process is best suited to address these situations.

SOURCES OF UNCERTAINTY

There are no recent fishery independent data sources available to estimate biomass, stock indicators, or to ground-truth modeled results. Additionally, the stock-recruit relationship is unknown for the stocks. Although recruitment can be estimated from SpaceClam, the relationship between the stock and recruits cannot be determined from the model. There is also a lag in reporting of catch and effort for the fishery. Due to processing timelines, catch reported in one watch could be from the effort of a previous watch. Further, the fishery is increasing its catch efficiency, which is evident in the relationship between CPUE and effort, and is also of the opinion of Industry members. Efficiencies have been gained in vessel capacity and in an improved use of technology to locate, sort, and process catch. Such increases in efficiency and catchability can obscure actual biomass trends. There is a risk that catch rates may remain high as beds are depleted (i.e., hyperstability), with any improved ability for Industry to maximize catchability not being accounted for in the SpaceClam approach.

FUTURE RESEARCH RECOMMENDATIONS

The Canadian Biogenome Project has sequenced chromosome-level reference genomes for three of the clams in the fishery: Arctic Surf Clam (GenBank reference GCA_032209605.1); Northern Propeller Clam (GCA_037043455.1); and Greenland Cockle (GCA_031761405.1). The genomes are freely-available and provide a new basis for research on these populations. Research that has previously been recommended for the stocks include investigating patterns of connectivity within and between fishing banks for Arctic Surf Clam and co-occurring species in the fishery. Other avenues of genetic research include direct investigation of the environmentally-driven local adaptations for each species in the fishery.

The response of Arctic Surf Clam to a changing climate should also be investigated through different means. This could include laboratory experiments to investigate range tolerances for environmental conditions or targeted surveys to monitor for range expansion or contraction. The relationship between Arctic Surf Clam productivity and environmental and oceanographic conditions should be further explored, with a goal to incorporate them into future assessment models.

The linkage between temperature and the spawning timing should be examined, as well as any spatial variation in GSI and spawning timing. The condition factor index can be revised by

exploring the impact of depth and/or location on the relationship between length and foot weight, as well as exploring the factors affecting the relationship of shell height to foot weight.

The stock-recruit relationship is an unknown for the fishery and a gap that, if addressed, would improve the models and application of biological reference points. Revised mortality estimates in general could be beneficial; the SpaceClam estimate of mortality for Grand Banks has large uncertainty for both size classes. The use of SpaceClam to investigate clam bed recovery time and factors that might contribute to recovery could be explored.

Conversion factors for Arctic Surf Clam have not been updated since 2012. These values are a crucial link between what is landed and the biomass estimates in the models. Additional research should be pursued to evaluate more up to date values, including updating in the assessment if necessary.

It is known that the Arctic Surf Clam growth rate on the Grand Banks is slower than on Banquereau. Exploration of length indicators in this research document suggest that there may be further north/south growth differences on the Grand Banks. A closer examination of the potential differences would inform more meaningful indicator thresholds for the Grand Banks stock.

Updated dredge selectivity experiments could be undertaken to refine modeled parameters.

More research needs to be done to understand the impact of changing fishery efficiency over time and the impact this may have on CPUE.

Last, a fishery independent research survey would provide a reference and comparison for modeled results, as well as information on clams in areas of the banks that are not fished.

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TABLES

Table 1. von Bertalanffy growth curve fit parameters weighted to population numbers for Arctic Surf Clam on Banquereau (from: Roddick et al. 2012) and Grand Banks (from: Roddick et al. 2011). L_{inf} is the asymptotic length; k is a growth coefficient; and t_0 is the theoretical age at zero length.

Bank	L_{inf} (mm)	k	t_0
Banquereau	111.7	0.084	-2.512
Grand Banks	98.1	0.082	-2.223

Table 2. Summary of fish with Arctic Surf Clam in their stomach contents from fish caught in the DFO Maritimes Ecosystems Research Vessel trawl survey in Northwest Atlantic Fisheries Organization Subdivision 4Vs from 1999 to 2020. Data is from the DFO Maritimes Food Habits Database.

Predator Species	Number of Stomachs	Average Fish Length (cm)	Average Fish Weight (g)	Portion of Stomach Contents by Weight (%)
Longhorn Sculpin	3	36	615	65
Atlantic Cod	2	51	1,216	48
American Plaice	1	11	5	17
Haddock	1	56	1,758	2

Table 3. Summary of fish with non-specified clams in their stomach contents from fish caught in the DFO Maritimes Ecosystems Research Vessel trawl survey in Northwest Atlantic Fisheries Organization Subdivision 4Vs from 1999 to 2020. Data is from the DFO Maritimes Food Habits Database.

Predator Species	Number of Stomachs	Average Fish Length (cm)	Average Fish Weight (g)	Portion of Stomach Contents by Weight (%)
American Plaice	20	23	106	70
Daubed Shanny	3	12	5	59
Atlantic Cod	5	53	1,560	49
Thorny Skate	6	46	961	37
Redfish Unseparated	1	20	104	33
Vahl Eelpout	6	32	129	32
Sea Raven	2	31	293	24
Longhorn Sculpin	1	49	1,981	22
Witch Flounder	62	38	660	16
Snake Blenny	22	29	174	14
Yellowtail Flounder	11	32	27	14
Haddock	17	21	96	12
Laval's Eelpout	1	40	731	11

Table 4. Upper stock reference (USR), limit reference points (LRP) and catch per unit effort level of 70 g/m² (CPUE₇₀) reference values for assessment areas 1–5 on Banquereau (Hubley et al. 2020).

Area	USR	LRP	CPUE ₇₀
1	18,195	36,389	59,339
2	28,377	56,753	92,619
3	26,513	53,026	86,514
4	12,101	24,202	39,479
5	11,720	23,441	38,226
All Areas	96,906	193,811	316,178

Table 5. Secondary Stock Indicators for Banquereau and Grand Banks stocks used up until 2023. For length, the Banquereau indicator is 1% of clams in the unsorted commercial catch being above 120 mm. The Grand Banks indicators is 0.5% of clams in the unsorted commercial catch being above 105 mm. > indicates greater than.

Indicator	Banquereau	Grand Banks
Catch Per Unit Effort (g/m ²)	70	50
Footprint (km ²)	250	125
Length Indicator (mm)	1 % >120	0.5% >105

Table 6. Summary of individual frozen Arctic Surf Clams sampled from each year. Dashes (—) indicate no samples.

Year	Banquereau	Grand Banks
1999	910	—
2000	1,033	224
2001	461	446
2002	1,320	684
2003	759	991
2004	1,208	586
2005	1,153	550
2006	921	253
2007	609	47
2008	642	—
2019	756	—
2020	63	—
2021	545	177
2022	184	—

Table 7. The component and conversion factors applied to product type for Arctic Surf Clam product types landed in the offshore clam fishery. N/A indicates no conversion factor is required for that product because it does not count against the total allowable catch.

Product Type	Conversion Factor and Component (%)
Blanched foot (tongue)	6.51
Blanched mantle	N/A
C-grade (mixed species product; 2019–20)	80% × 6.51
C-grade (mixed species product; 2021–present)	86% × 6.51

Table 8. The component and conversion factors applied to other retained species product types landed in the offshore clam fishery (%; when applicable) applied to the product types.

Other Retained Species	Product Type	Conversion Factor and Component (%)
Greenland Cockle	Blanched foot (tongue)	5.5
Greenland Cockle	Raw foot (tongue)	5.5
Greenland Cockle (Banquereau)	C-grade (mixed species product)	5.5 x 12%
Greenland Cockle (Grand Banks)	C-grade (mixed species product)	5.5 x 8.8%
Northern Propeller Clam	Blanched siphon	3.84
Ocean Quahog	Foot (tongue)	6.0

Table 9. Landings, effort, and catch per unit effort (CPUE) for Banquereau. C-grade is presented as a proportion of total landings. TAC is total allowable catch. Dashes (—) indicate no data. Data from the DFO CLAM database.

Year	Landings (t)	Effort (km ²)	CPUE (g/m ²)	C-grade in Landings (%)	TAC (t)
1987	1,210	16	75	—	30,000
1988	2,474	25	101	—	30,000
1989	9,159	85	108	—	30,000
1990	6,158	68	90	—	30,000
1991	714	10	74	—	30,000
1992	0	0	0	—	30,000
1993	64	2	29	—	30,000
1994	5,313	40	133	—	30,000
1995	11,425	84	136	—	30,000
1996	19,262	156	123	—	30,000
1997	19,517	157	124	—	30,000
1998	24,456	237	103	—	30,000
1999	24,138	254	95	—	30,000
2000	20,248	233	87	—	30,000
2001	11,014	159	69	—	30,000
2002	12,506	149	84	—	24,000
2003	16,960	147	115	—	24,000
2004	16,493	150	110	—	24,000
2005	14,327	142	101	—	24,000
2006	1,5932	117	137	—	24,000
2007	17,931	115	155	—	24,000
2008	19,301	131	148	—	24,000
2009	24,158	181	134	—	24,000
2010	22,450	160	140	—	24,000
2011	20,608	128	161	<0.001	24,000
2012	20,909	144	145	<0.001	24,000
2013	19,343	151	128	1.3	24,000
2014	23,786	193	123	1.6	24,000
2015	23,833	156	153	1.6	24,000
2016	24,793	165	151	1.2	24,000
2017	22,038	148	149	2.3	24,000
2018	17,377	142	122	0.9	20,943
2019	21,169	144	147	1.6	20,943
2020	18,405	123	149	2.2	20,943
2021	20,938	137	153	2.3	20,943
2022	21,969	125	176	2.3	20,943
2023	20,106	139	144	2.3	20,943

Table 10. Contribution to landings and effort from each assessment area on Banquereau. VMS is vessel monitoring system. Data from the DFO CLAM database.

Area	VMS Habitat	Portion of Total Area (%)	Portion of Mean Landings Since 1987 (%)	Portion of Mean Effort Since 1987 (%)	Portion of Maximum Landings (%)	Portion of Maximum Effort (%)
1	315	19.7	19.4	20.3	71 (2019)	69.1 (2019)
2	436	27.3	23.4	26.1	76.7 (1994)	78.5 (1994)
3	442	27.7	29.8	30.0	88.8 (1988)	90.5 (1988)
4	220	13.8	8.8	8.7	50.9 (2002)	40.6 (2002)
5	185	11.6	22.03	18.0	85.5 (1989)	74.3 (1989)

Table 11. Summary of length frequency samples from Banquereau collected from onboard sampling by Industry.

Year	Number of Samples	Average Number of Samples per Trip	Minimum Samples in a Trip	Maximum Samples in a Trip
1999	71	6.5	3	14
2000	62	4.8	2	10
2001	21	3.0	1	5
2002	36	3.3	1	6
2003	28	2.2	1	4
2004	44	2.9	1	6
2005	16	2.7	1	5
2006	6	3.0	2	4
2007	8	1.6	1	3
2008	87	10.9	3	17
2009	233	10.6	1	17
2010	222	10.6	1	15
2011	158	9.9	3	14
2012	162	10.8	6	14
2013	19	4.8	1	11
2014	196	10.3	1	15
2015	151	8.4	2	14
2016	196	9.8	1	15
2017	170	9.4	3	15
2018	167	7.3	1	13
2019	148	7.0	1	10
2020	134	7.4	1	12
2021	145	6.3	1	10
2022	135	6.8	2	10
2023	121	5.5	1	9

Table 12. Landings, effort, and catch per unit effort (CPUE) for Grand Banks. C-grade is presented as a proportion of total landings. TAC is total allowable catch. Dashes (—) indicate no data. Data from the DFO CLAM database.

Year	Landings (t)	Effort (km ²)	CPUE (g/m ²)	C-grade in Landings (%)	TAC (t)
1989	373	3	110	—	20,000
1990	6,049	24	256	—	20,000
1991	2,094	11	185	—	20,000
1992	5,161	27	190	—	20,000
1993	13,100	93	141	—	20,000
1994	10,979	95	115	—	20,000
1995	14,907	128	116	—	20,000
1996	5,772	54	108	—	20,000
1997	7,492	80	94	—	20,000
1998	931	11	82	—	20,000
1999	1,472	19	79	—	20,000
2000	3,289	46	72	—	20,000
2001	8,026	110	73	—	20,000
2002	6,077	120	51	—	20,000
2003	8,727	121	72	—	20,000
2004	6,437	67	96	—	20,000
2005	3,967	52	77	—	20,000
2006	4,990	75	66	—	20,000
2007	215	8	29	—	20,000
2008	—	—	—	—	20,000
2009	437	8	58	—	20,000
2010	296	9	32	—	20,000
2011	55	4	15	—	14,756
2012	—	—	—	—	14,756
2013	239	6	39	21.5	14,756
2014	—	—	—	—	14,756
2015	737	6	123	3.6	14,756
2016	14,443	74	195	3.2	14,756
2017	14,580	75	196	2.4	14,756
2018	13,962	80	176	1.1	14,756
2019	15,029	91	166	2.0	14,756
2020	11,334	68	168	1.3	14,756
2021	14,761	78	189	1.0	14,756
2022	14,764	71	210	1.6	14,756
2023	14,773	65	226	1.9	14,756

Table 13. Contribution of each assessment area on the Grand Banks to landings and effort since 1987, from the CLAM database.

Area	Portion of Landings Since 1989 (%)	Portion of Effort Since 1989 (%)	Maximum Landings (%)	Maximum Effort (%)
1 (North)	22.1	24.6	81 (1998)	97 (2011)
2 (South)	77.9	75.4	100 (multiple years)	100 (multiple years)

Table 14. Summary of length frequency samples from Grand Banks collected from onboard sampling by Industry. Years with no fishing are not shown.

Year	Number of Samples	Average Number of Samples per Trip	Minimum Samples in a trip	Maximum Samples in a Trip
2000	14	4.7	3	6
2001	17	4.3	4	5
2002	14	2.8	2	3
2003	15	3.0	2	4
2004	25	3.6	2	5
2005	7	1.8	1	2
2006	23	3.3	1	6
2007	0	0	0	0
2009	0	0	0	0
2010	4	2.0	1	3
2011	8	8.0	8	8
2013	0	0	0	0
2015	6	6	6	6
2016	90	3.0	3	11
2017	76	6.0	3	10
2018	80	6.9	2	12
2019	93	6.9	7	10
2020	70	6.7	3	9
2021	75	8.5	1	10
2022	73	6.4	4	9
2023	63	5.4	2	8

Table 15. Summary of fishing trips on Banquereau with At-sea Observers on board. An asterisk (*) indicates a year that an observed fishing trip spanned a change in calendar year, resulting in two observed trips.

Year	Number of Observed Trips	Month	Proportion of Trip Effort Observed	Proportion of Arctic Surf Clam Catch Observed	Trip Catch Difference (%)
2018	1	Feb/Mar	0.46	1.35	196
2019	1	Mar/Apr	0.48	0.55	15
2020	1	Mar/Apr	0.51	0.72	42
2021	1	Feb	0.48	1.11	130
2021	2	Feb/Mar	0.45	0.54	21
2021	3	Aug/Sep	0.42	1.25	194
2022*	1	Dec	0.47	0.55	16
2023*	1	Jan	0.52	0.41	-22
2023	2	Mar/Apr	0.50	0.68	35
2023	3	Nov/Oct	0.48	0.69	43

Table 16. Comparison of observed catch as a percentage of Arctic Surf Clam catch on Banquereau. Catch estimates for the calculation are based on effort-expanded trip totals. Only the last five trips are shown, with more details on these years and others outlined in Appendix A. The observed trip number is indicated after the year. Species sorted from highest to lowest percentage based on the most recent trip in the table. An asterisk (*) indicates a single fishing trip that spanned a change in calendar year resulting in two observed trips. Dashes (—) indicate the taxa/object was not observed on that trip. < indicates less than.

Taxa/Object	2021.3 (%)	2022.1* (%)	2023.1* (%)	2023.2 (%)	2023.3 (%)
Shells	53.45	110.81	260.31	53.53	236.16
Northern Propeller Clam	60.72	14.89	4.66	44.03	48.13
Stones and Rocks	10.02	5.28	13.31	2.64	46.06
Sand Dollar	27.71	26.11	31.06	13.85	45.43
Ocean Quahog	0.57	7.76	0.24	1.43	5.04
Buccinidae F.	8.60	1.67	0.95	2.16	2.69
Greenland Cockle	8.20	0.11	0.12	0.93	1.57
Asteroidea S.C.	0.56	0.14	0.40	0.06	1.02
Sea Cucumber NS	2.60	0.14	—	0.26	0.87
Skate NS	0.24	—	—	0.02	0.74
Hermit Crab	2.15	0.23	0.02	0.17	0.73
Sea Urchin	5.52	0.36	0.18	0.20	0.65
Sea Scallop	0.19	—	—	0.31	0.52
Sea Mouse	3.44	0.78	—	0.86	0.48
Sand Lance	3.31	0.18	—	0.06	0.29
Icelandic Scallop	1.63	—	—	0.11	0.29
Silver Hake	0.26	0.03	—	—	0.15
Razor Shell Clam	—	0.13	0.04	0.08	0.14
Mussels NS	—	0.64	0.02	0.36	0.14
Acanthocephala P.	1.09	0.04	0.14	0.01	0.13
Sea Anemone	0.17	0.09	—	0.06	0.12
Snow Crab	0.24	0.02	—	0.01	0.12
<i>Hyas araneus</i>	—	—	—	0.02	0.11
Seasnail NS	0.15	—	—	0.02	0.09
Yellowtail Flounder	0.42	—	—	0.21	0.08
<i>Psolus phantapus</i> (SC)	—	—	—	—	0.07
Sculpin NS	—	—	—	—	0.06
Sun Star	0.23	—	—	0.00	0.05
Moon snail	—	—	—	—	0.04
Debris/Foreign Material	0.16	—	—	0.04	0.04
Thorny Skate	3.36	0.18	—	0.32	0.02
Jonah Crab	—	0.06	—	—	0.02
Brittle star	0.88	0.01	—	0.27	0.02
Shorthorn sculpin	—	—	—	—	0.02
Cod	—	—	—	—	0.01
Coral NS	0.09	—	—	0.03	<0.01
Skate Egg Case	0.10	0.17	—	<0.01	<0.01
Seaweed	0.05	—	—	<0.01	<0.01
Red hake	—	—	—	<0.01	<0.01
Sea Sponge	0.08	—	—	0.13	—
Winter Skate	—	—	—	0.09	—
Mud	—	—	—	0.04	—
American Plaice	0.55	—	—	0.01	—
Smooth Scallop	—	—	—	0.01	—
Scallop NS	0.68	0.10	—	<0.01	—
<i>Leptasterias polaris</i>	—	—	—	<0.01	—

Taxa/Object	2021.3 (%)	2022.1*	2023.1*	2023.2 (%)	2023.3 (%)
Eggs Nonspecified	—	—	—	<0.01	—
Atlantic Rock Crab	0.14	0.07	—	—	—
Longhorn Sculpin	0.26	0.04	—	—	—
Sand	1.87	—	—	—	—
Tunicata	0.93	—	—	—	—
Witch Flounder	0.83	—	—	—	—
Smooth Skate	0.43	—	—	—	—
<i>Hyas Coarctatus</i>	0.10	—	—	—	—
Lumpfish	0.03	—	—	—	—

Table 17. Summary of fishing trips on the Grand Banks with At-sea Observers on board. An asterisk (*) indicates a year that an observed fishing trip spanned a change in calendar year, resulting in two observed trips. There were no observed trips in 2023.

Year	Number of Observed Trips	Month	Proportion of Trip Effort Observed	Proportion of Arctic Surf Clam Catch Observed	Trip Catch Difference (%)
2018	1	Mar/Apr	0.71	0.6	-15
2018	2	Apr/May	0.70	0.58	-19
2019	1	Nov/Dec	0.47	0.72	53
2020*	1	Dec	0.47	0.42	-9
2021*	1	Jan	0.48	0.52	8
2022	1	Feb/Mar	0.39	0.77	97

Table 18. Comparison of observed catch as a percentage of Arctic Surf Clam catch on the Grand Banks. Catch estimates for the calculation are based on effort-expanded trip totals. Only the last five trips are shown, with more details on these years and others outlined in Appendix A. The observed trip number is indicated after the year. Species sorted from highest to lowest percentage based on the most recent trip in the table. An asterisk (*) indicates a single fishing trip that spanned a change in calendar year resulting in two observed trips. NS means non-specified. Dashes (—) indicate the taxa/object was not observed on that trip. > indicates greater than.

Taxa/Object	2018.2 (%)	2019.1 (%)	2020.1* (%)	2021.1 (%)	2022.1 (%)
Shells	207.45	95.34	92.92	25.92	79.28
Northern Propeller Clam	5.84	28.21	14.47	38.18	53.08
Greenland Cockle	2.89	6.10	18.07	27.70	23.04
Sand Dollar	18.29	22.06	139.72	125.10	15.90
Whelk	1.64	1.54	0.03	—	4.37
Sea Cucumber (NS)	56.63	21.97	—	—	2.90
Asteroidea S.C.	1.08	0.38	0.64	0.82	2.44
Yellowtail Flounder	0.38	0.06	0.05	0.12	0.71
Stones and Rocks	24.07	7.79	11.49	2.40	0.65
Eggs (NS)	—	—	—	—	0.24
Sea Mouse	2.60	0.60	—	—	0.22
Hermit Crab	0.74	0.16	0.05	0.01	0.11
Thorny Skate	0.06	0.13	—	0.14	0.10
Sand Lance	0.08	0.04	1.25	0.75	0.04
Ocean Quahog	1.28	0.79	—	—	0.04
Snow Crab	—	0.03	0.84	0.47	0.02
Atlantic Rock Crab	—	—	—	—	0.01
Seasnail (NS)	—	—	0.44	0.26	>0.01
Skate Egg Case	—	—	—	—	>0.01

Taxa/Object	2018.2 (%)	2019.1 (%)	2020.1* (%)	2021.1 (%)	2022.1 (%)
Scallop Pectinidae F.	—	—	0.19	0.01	—
Sea Urchin	0.60	0.16	0.13	0.05	—
Acanthocephala P.	—	0.09	0.08	0.05	—
Eel	—	—	0.02	—	—
Clam (NS)	1.42	0.59	—	—	—
Mussel (NS)	—	0.07	—	—	—
American Plaice	0.71	0.05	—	—	—
Sea Anemone	—	0.03	—	—	—
<i>Hyas araneus</i>	—	0.03	—	—	—
Tunicata	—	0.02	—	—	—
<i>Hyas coarctatus</i>	0.10	0.01	—	—	—
Sea Potato	0.01	>0.01	—	—	—
Mussel (NS)	0.21	—	—	—	—
Spider Crab (NS)	0.16	—	—	—	—
Sea Weed	0.03	—	—	—	—

Table 19. Definition of size classes used to estimate size composition and individual growth for the SpaceClam model. Weight is measured in grams (g) round weight.

Size Class	Minimum Weight (g)	Average Weight (g)	Avg. Length (mm)	Avg. Age (years)	Survey Selectivity	Commercial Selectivity
SSS	0	46.2	64.3	12.2	0.16	0.24
SS	78	91.1	86.1	21.1	0.45	0.49
S	104	113.9	92.5	25.7	0.59	0.58
M	124	136.1	98.4	27.9	0.70	0.65
L	150	168.0	104.8	32.3	0.81	0.72
LL	189	212.9	111.5	37.9	0.89	0.79
XLL	241	316.4	121.6	40.4	0.95	0.87

Table 20. Composition model bias and coverage averaged over Banquereau.

Size Class	Mean Bias	Mean Coverage
SSS	0.0095	0.874
SS	-0.0061	0.874
S	-0.0045	0.874
M	-0.0050	0.873
L	-0.0050	0.875
LL	-0.0047	0.871
XLL	-0.0027	0.871

Table 21. Composition-at-age model transition matrix bias (spatially averaged). Dashes (—) indicate no comparison possible.

Size Class	SSS	SS	S	M	L	LL
SSS	0.0016	—	—	—	—	—
SS	-0.0005	0.0037	—	—	—	—
S	-0.0004	-0.0003	0.0047	—	—	—
M	-0.0003	-0.0017	-0.0013	0.0031	—	—
L	-0.0002	-0.0010	-0.0021	-0.0010	0.0029	—
LL	-0.0001	-0.0005	-0.0010	-0.0016	-0.0018	0.0021
XLL	0.0000	-0.0001	-0.003	-0.0005	-0.0011	-0.0021

Table 22. Composition-at-age model transition matrix coverage (spatially averaged). Dashes (—) indicate no comparison possible.

Size Class	SSS	SS	S	M	L	LL
SSS	0.8755	—	—	—	—	—
SS	0.8757	0.8742	—	—	—	—
S	0.8755	0.8753	0.8758	—	—	—
M	0.9750	0.8733	0.8739	0.8759	—	—
L	0.8759	0.8756	0.8772	0.8759	0.8722	—

Size Class	SSS	SS	S	M	L	LL
LL	0.8758	0.8750	0.8760	0.8747	0.8716	0.8738
XLL	0.8758	0.8751	0.8758	0.8752	0.8745	0.8738

Table 23. Estimated bank-wide Large biomass in kilotonnes (kt) for SpaceClam on Banquereau.

Year	5% Quantile	Estimate	95% Quantile
2014	1591.9	2082.1	2670.8
2015	1582.6	2030.5	2490.5
2016	1546.2	1994.2	2450.0
2017	1142.0	1478.4	1799.0
2018	1031.6	1304.0	1588.1
2019	1177.7	1538.6	1902.5
2020	1353.8	1716.2	2123.4
2021	1191.7	1560.0	1925.8
2022	1150.1	1414.9	1778.2
2023	1072.2	1333.4	1692.0

Table 24. Estimated bank-wide Small biomass in kilotonnes (kt) for SpaceClam on Banquereau.

Year	5% Quantile	Estimate	95% Quantile
2014	1054.2	1368.9	1758.1
2015	1009.4	1348.8	1642.2
2016	1156.4	1497.5	1811.3
2017	799.9	1072.7	1292.4
2018	573.9	762.3	931.5
2019	505.9	677.5	840.5
2020	478.3	619.6	776.0
2021	502.0	661.4	884.1
2022	555.4	735.1	949.5

Year	5% Quantile	Estimate	95% Quantile
2023	583.9	782.0	990.2

Table 25. Parameter estimates for SpaceClam on Banquereau. CI refers to confidence interval.

Parameter	Estimate (90% CI)
ϕ_{Small}	0.419 (0.412–0.427)
p_{Small}	1.477 (1.467–1.488)
ϕ_{Large}	0.869 (0.846–0.893)
p_{Large}	1.144 (1.133–1.157)
q	0.60 (0.43–0.75)
M_{Small}	0.097 (0.058–0.163)
M_{Large}	0.148 (0.117–0.187)
$G_{1,2}$	0.018 (0.010–0.032)

Table 26. Bias and 90% confidence interval coverage for total biomass on Banquereau.

Year	Small Bias (kt)	Large bias (kt)	Small Coverage	Large Coverage
2014	1.3	43.8	0.90	0.93
2015	16.6	40.5	0.88	0.90
2016	13.2	41.1	0.87	0.89
2017	9.7	35.8	0.88	0.89
2018	14.1	36.8	0.86	0.89
2019	15.3	33.0	0.89	0.89
2020	17.5	56.9	0.88	0.90
2021	17.6	33.8	0.88	0.90
2022	21.3	25.2	0.88	0.85
2023	20.1	35.9	0.88	0.89
2024	18.5	52.1	0.89	0.85

Table 27. Estimated bank-wide large biomass from SpaceClam in kilotonnes (kt) on the Grand Banks.

Year	5% Quantile	Estimate	95% Quantile
2015	1643.1	2142.4	2886.8
2016	2264.3	2700.7	3292.1
2017	2304.5	2740.3	3432.8
2018	2507.6	3014.0	3921.1
2019	2924.0	3542.8	4417.5
2020	2867.4	3472.3	5514.7
2021	2985.4	4035.9	6417.9
2022	3380.4	4782.4	7605.1
2023	3519.6	5713.9	9638.7

Table 28. Estimated bank-wide small biomass from SpaceClam in kilotonnes (kt) on the Grand Banks.

Year	5% Quantile	Estimate	95% Quantile
2015	2022.9	2782.7	3933.2
2016	2899.7	3463.4	4419.1
2017	2865.3	3876.1	4841.7
2018	3222.1	4112.9	5362.6
2019	3927.3	4905.0	6323.7
2020	3779.0	4982.6	7132.7
2021	4035.2	5514.4	7992.6
2022	4003.0	5637.1	8083.5
2023	4027.2	6318.9	9385.8

Table 29. Parameter estimates for SpaceClam on the Grand Banks. CI refers to confidence interval.

Parameter	Estimate (90% CI)
ϕ Small	0.581 (0.568–0.595)
pSmall	1.444 (1.433–1.455)
ϕ Large	0.568 (0.551–0.586)
pLarge	1.445 (1.432–1.458)
q	0.6* (held fixed)
MSmall	0.002 (standard error failed)
MLarge	0.060 (0.016–0.233)
G1,2	0.033 (0.017–0.064)

Table 30. Bank-wide Length Indicator 1 on Banquereau expressed as the percent of the sampled catch greater than the size indicated with on the last 10 years of data shown. The sample size is in brackets. The threshold for this indicator is 1%. > indicates greater than.

Year	>120 mm (%)
2014	1.6 (14,327)
2015	1.4 (15,137)
2016	2.3 (19,567)
2017	2.5 (16,995)
2018	1.2 (16,695)
2019	2.6 (14,799)
2020	3.9 (13,298)
2021	2.2 (14,491)
2022	1.1 (12,785)
2023	4.6 (11,943)

Table 31. Bank-wide Length Indicator 3 for Banquereau expressed as percent of the sampled catch below 45.2 mm. The sample size is in brackets. The threshold for this indicator is 0.5%. < indicates less than.

Year	<45.2 mm (%)
1999	0.14 (6,997)
2000	0.34 (5,343)
2001	0.13 (1,517)
2002	0.19 (2,597)
2003	0.36 (2,533)
2004	0.49 (3,233)
2005	0.12 (828)
2006	0 (528)
2007	0 (703)
2008	0.2 (7,416)
2009	0.08 (18,082)

Year	<45.2 mm (%)
2010	0.26 (16,683)
2011	0.32 (10,841)
2012	0.17 (12,090)
2013	0.49 (21,301)
2014	0.06 (1,4327)
2015	0.01 (15,137)
2016	0 (19,567)
2017	0.01 (16,995)
2018	0 (16,695)
2019	0 (14,799)
2020	0.14 (13,298)
2021	0.01 (14,491)
2022	0 (12,785)
2023	0.02 (11,943)

Table 32. Area-specific and bank-wide indicator thresholds for Grand Banks based on minimum catch per unit effort (CPUE) and maximum footprint in the year indicated in the table.

Area	CPUE 2002 (g/m²)	Footprint (km²)	Length Indicator 1 95th Percentile (mm)
North	55	65 (2003)	99
South	46	122 (1995)	116
Bank-wide	50	125 (1995)	105

Table 33. Area-specific and bank-wide values for Length Indicator 1 for Grand Banks expressed as the percent of the sampled catch greater than the size indicated. The sample size in brackets. The threshold for this indicator is 0.5%. Dashes (—) indicate no data.

Year	North Greater than 99 mm (%)	South Greater than 116 mm (%)	Bank-wide Greater than 105 mm (%)
2015	33.00 (100)	6.60 (500)	19.17 (600)
2016	0.00 (100)	3.35 (8,900)	16.97 (9,000)
2017	—	1.91 (7,598)	15.95 (7,598)
2018	0.17 (1,800)	2.26 (6,200)	11.35 (8,000)
2019	0.78 (3,200)	1.56 (6,100)	9.72 (9,300)
2020	2.15 (1,300)	8.04 (5,598)	17.25 (6,998)
2021	0.38 (1,299)	1.21 (6,194)	10.9 (7,493)
2022	2.5 (2,000)	1.06 (5,293)	11.12 (7,293)
2023	1.41 (2,700)	0.03 (3,598)	1.67 (6,298)

Table 34. Area-specific and bank-wide Length Indicator 3 for Grand Banks expressed as the percent of the sampled catch below 39.9 mm. The sample size in brackets. The threshold for this indicator is 0.5%. Years without samples are not included. Dashes (—) indicate no data.

Year	Bank-wide (%)	North (%)	South (%)
2000	0 (1,393)	0 (894)	0 (499)
2001	0 (1,697)	0 (688)	0 (1,009)
2002	0 (714)	—	0 (714)
2003	0 (621)	—	0 (621)
2004	0.08 (1,243)	0 (910)	0.3 (333)
2005	0 (172)	—	0 (172)
2006	0.45 (662)	—	0.45 (662)
2010	0 (224)	0 (152)	0 (72)
2011	0 (203)	0 (203)	—
2013	0 (159)	—	0 (59)
2015	0 (600)	0 (100)	0 (500)
2016	0 (9,000)	0 (100)	0 (8,900)
2017	0 (7,598)	—	0 (7,598)
2018	0 (8,000)	0 (1,800)	0 (6,200)
2019	0 (9,300)	0 (3,200)	0 (6,100)
2020	0 (6,998)	0 (1,300)	0 (5,598)
2021	0 (7,493)	0 (1,299)	0 (6,194)
2022	0 (7,293)	0 (2,000)	0 (5,293)
2023	0 (6,298)	0 (2,700)	0 (3,598)

FIGURES

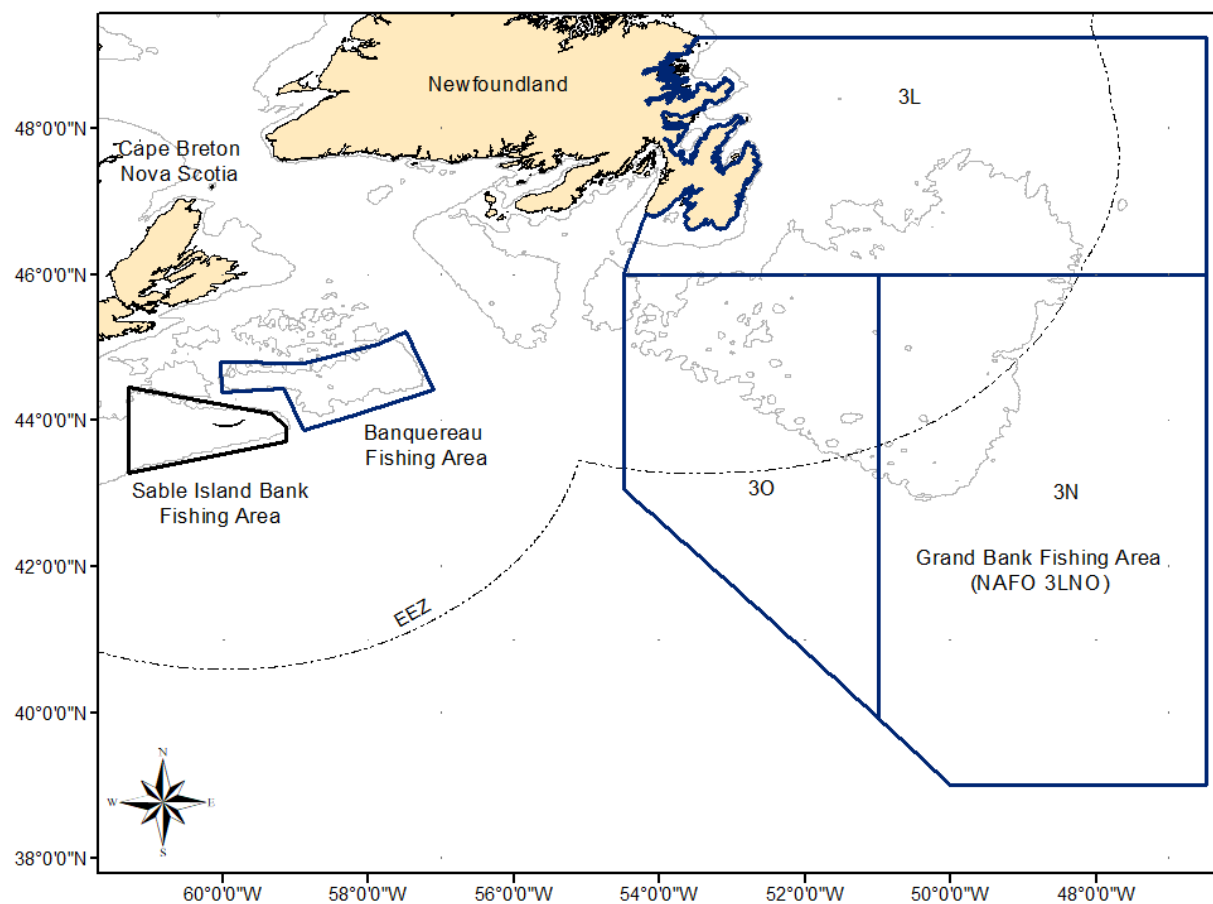


Figure 1. Offshore Clam fishing areas (solid lines) from licence conditions. NAFO refers to Northwest Atlantic Fisheries Organization areas.

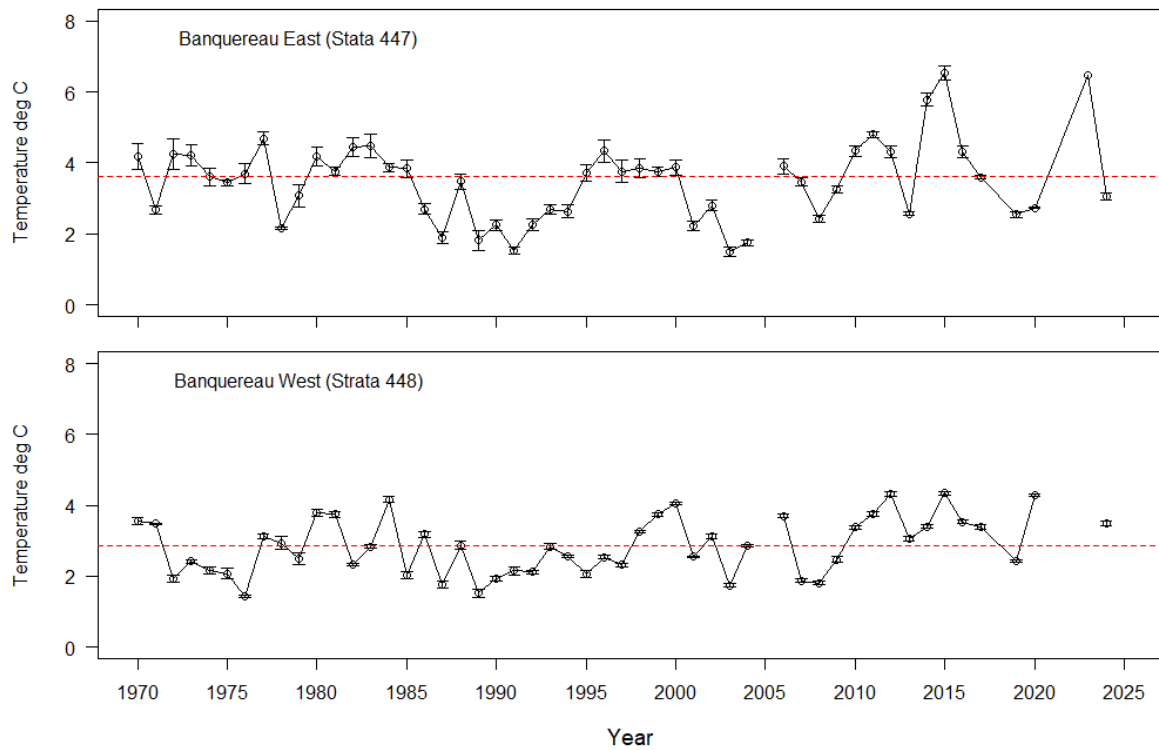


Figure 2. Mean (± 1 standard error) bottom temperatures in degrees Celsius (deg C) on Banquereau collected during the DFO Maritimes Region Summer Ecosystem Research Vessel trawl survey (1970–2024). Top panel is the East portion of Banquereau and bottom panel is the West portion of Banquereau.

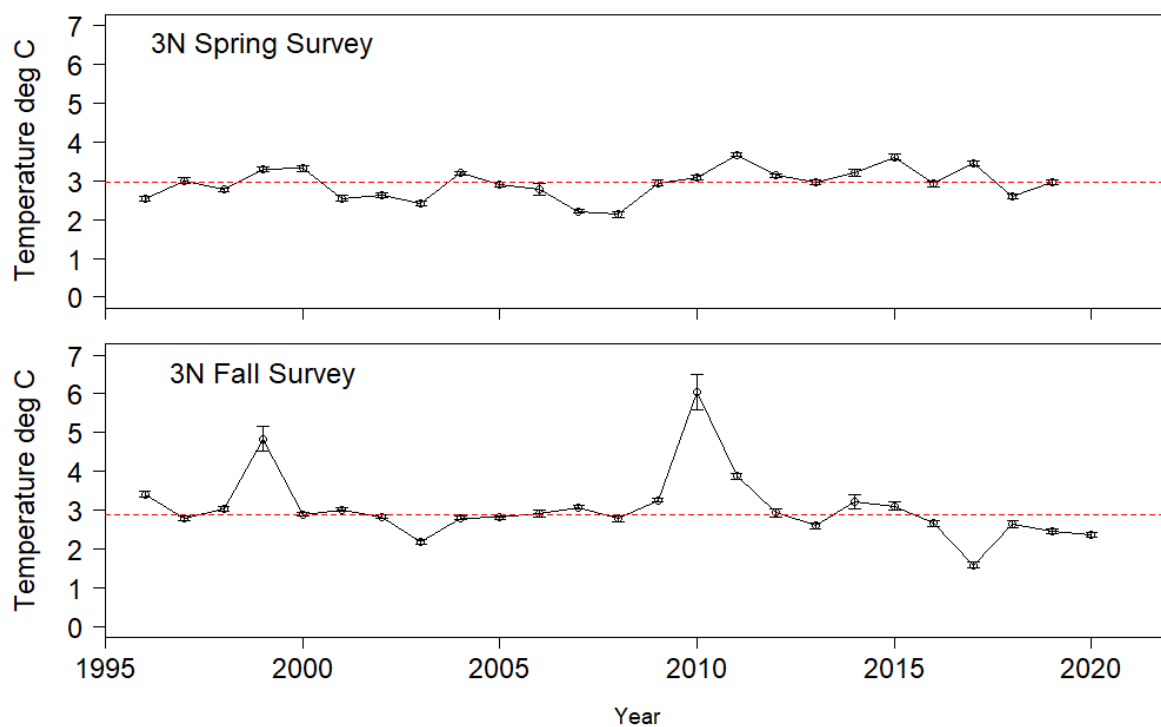


Figure 3. Mean (± 1 standard error) bottom temperatures in degrees Celsius (deg C) collected during the DFO Newfoundland and Labrador Ecosystem Region Research Vessel trawl survey in Northwest Atlantic Fisheries Organization Division 3N. Top panel is the spring survey (1996–2019) and bottom panel is the fall survey (1996–2020).

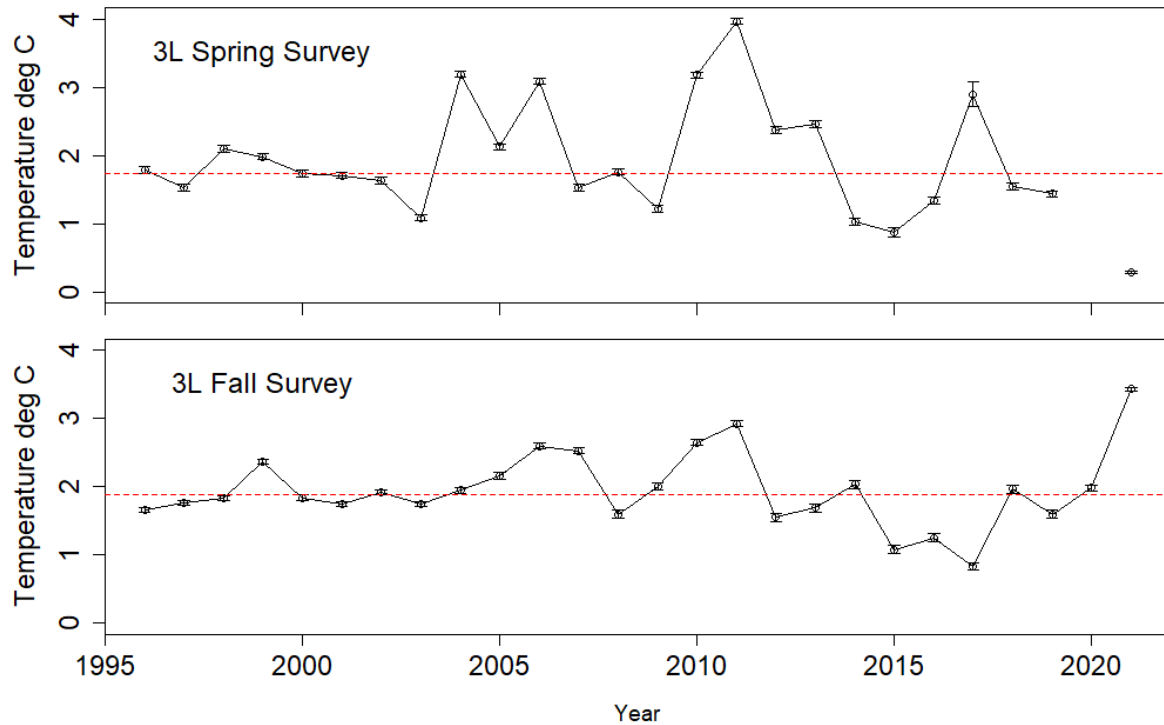


Figure 4. Mean (± 1 standard error) bottom temperatures in degrees Celsius (deg C) collected during the DFO Newfoundland and Labrador Region Ecosystem Research Vessel trawl survey in Northwest Atlantic Fisheries Organization Division 3L. Top panel is the spring survey (1996–2019) and bottom panel is the fall survey (1996–2021).

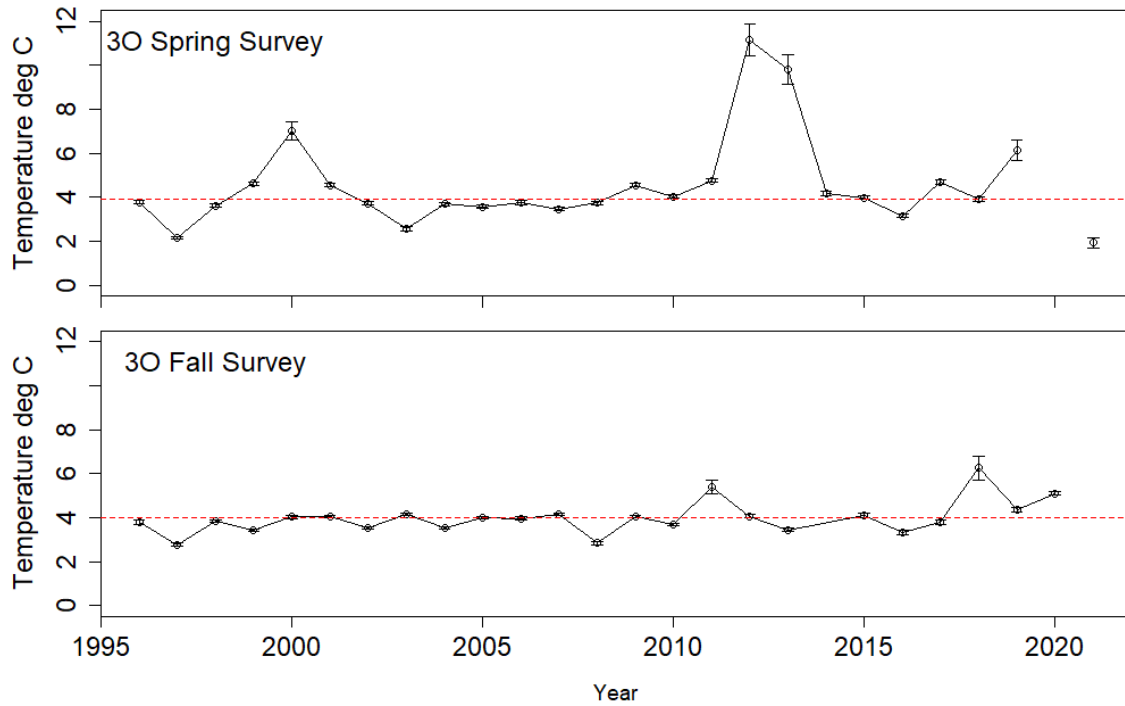


Figure 5. Mean (± 1 standard error) bottom temperatures in degrees Celsius (deg C) collected during the DFO Newfoundland and Labrador Region Ecosystem Research Vessel trawl survey in Northwest Atlantic Fisheries Organization Division 3O. Top panel is the spring survey (1996–2021) and bottom panel is the fall survey (1996–2020).

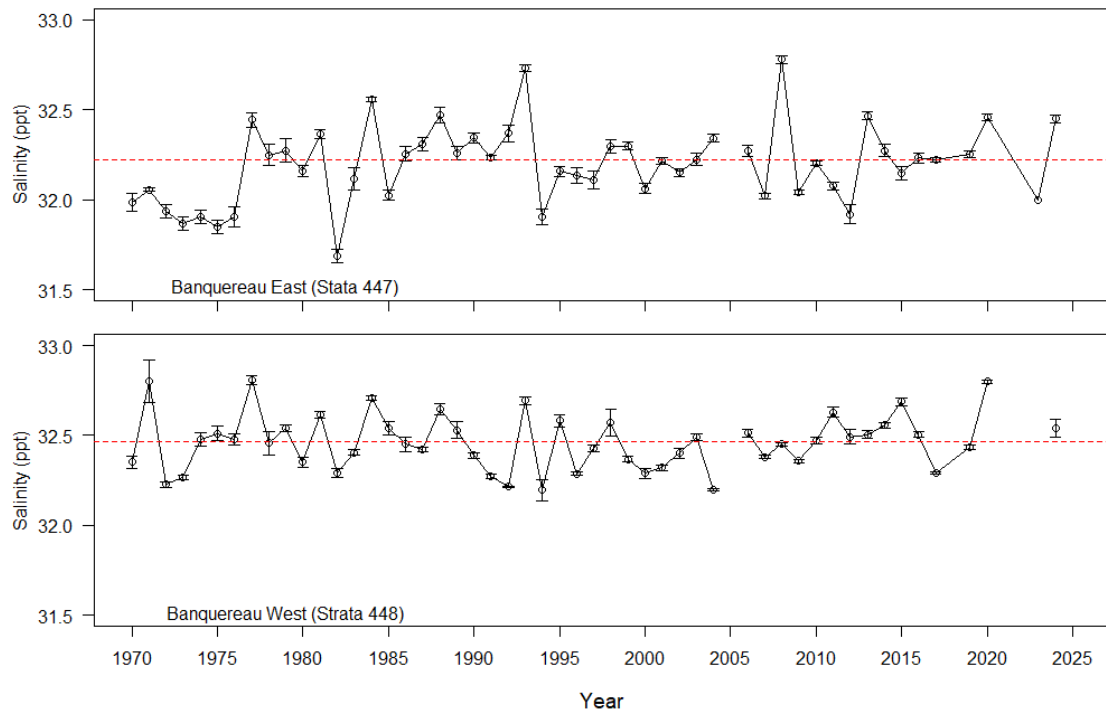


Figure 6. Mean (± 1 standard error) bottom salinity (parts per thousand; ppt) on Banquereau collected during the DFO Maritimes Region Summer Ecosystem Research Vessel trawl survey from 1970 to 2024. Top panel is the East portion of Banquereau and bottom panel is the West portion of Banquereau.

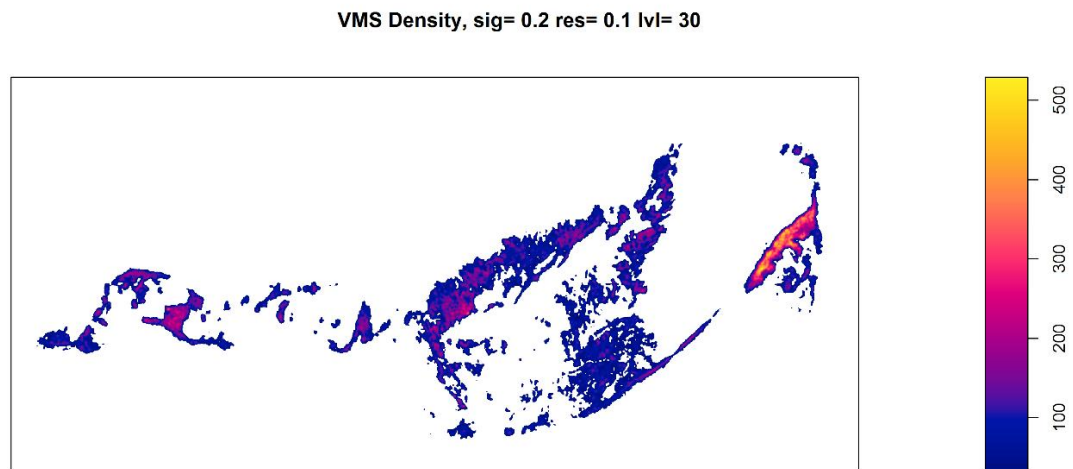


Figure 7. Fishery footprint used to define the Arctic Surf Clam stock on Banquereau from 2017 to 2023. Footprint developed using Vessel Monitoring System (VMS) density estimated from a kernel smoothed intensity function with a Standard Deviation of 0.2 on a 100 m² resolution. The scale bar shows VMS intensity expressed as the number of transmissions (pings) per km² for 2004–16. The colored region shows the area where VMS intensity is greater than 30 pings per km².

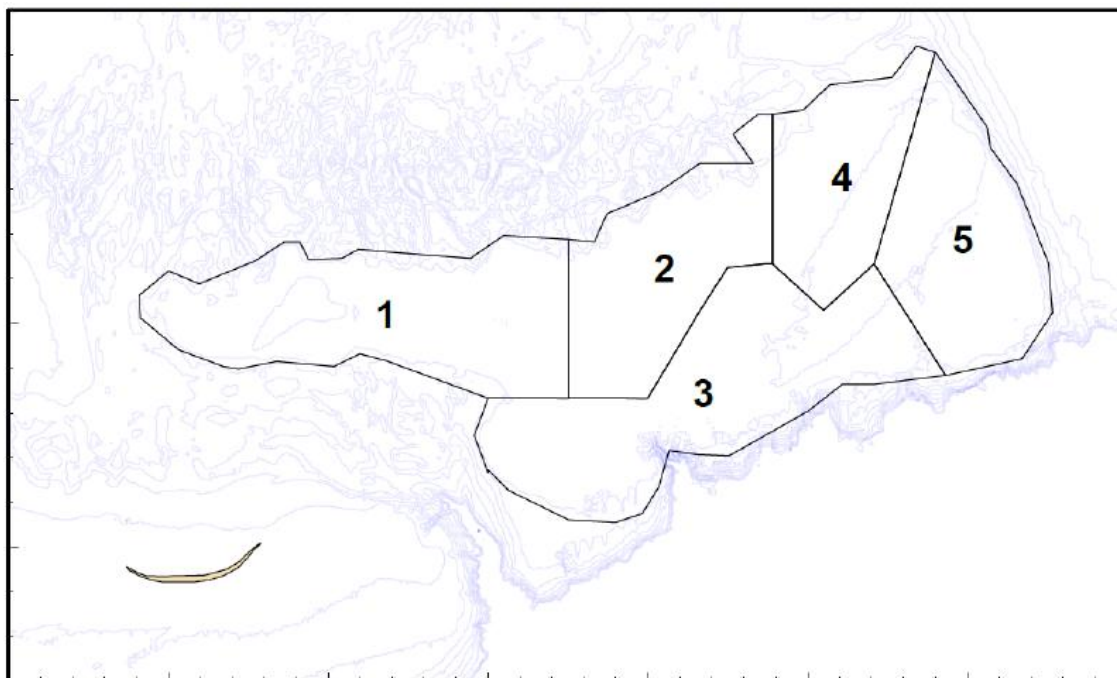


Figure 8. Spatial assessment areas on Banquereau used to assess the stock from 2017 to 2023.

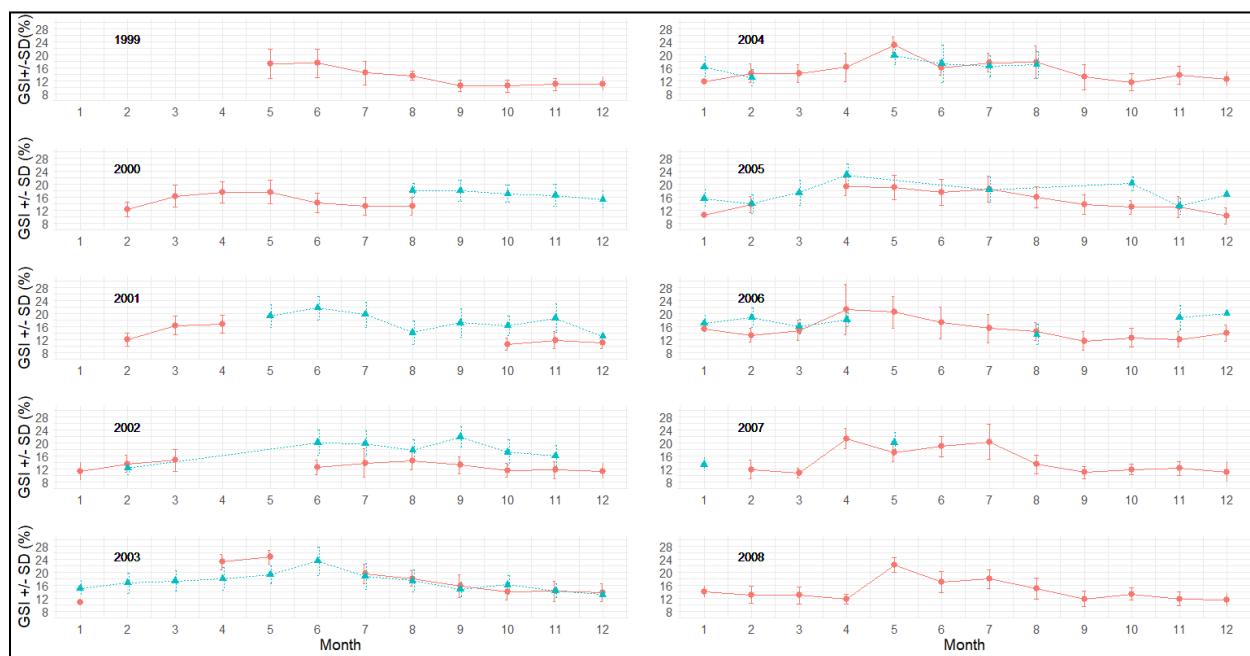


Figure 9. Mean gonad somatic index (GSI) $\pm$ 1 standard deviation (SD) of frozen Arctic Surf Clam on Banquereau (pink circles) and Grand Banks (blue triangles) from 1999 to 2008.

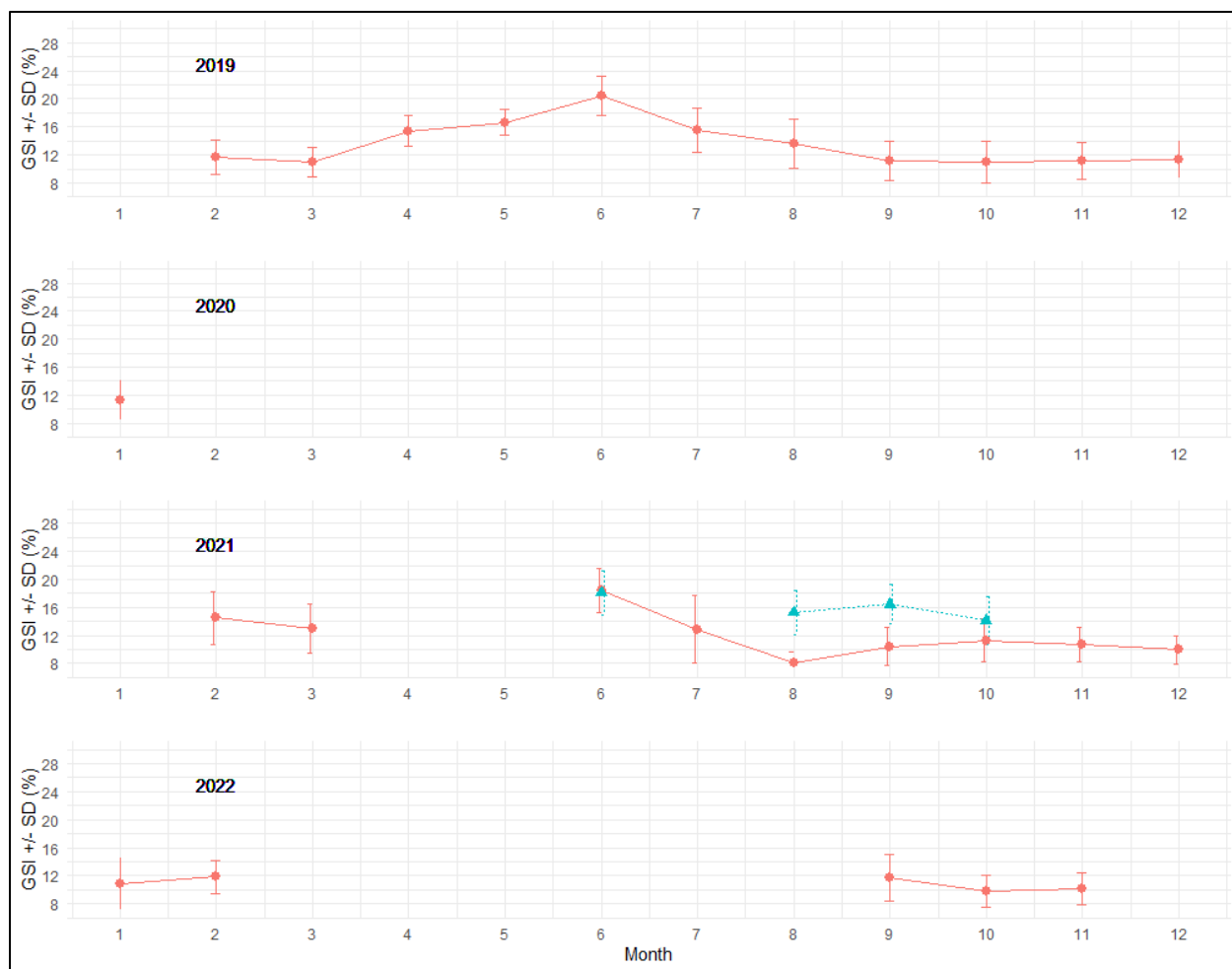


Figure 10. Mean gonad somatic index (GSI) $\pm$ 1 standard deviation (SD) of frozen Arctic Surf Clam on Banquereau (pink circles) and Grand Banks (blue triangles) from 2019 to 2022.

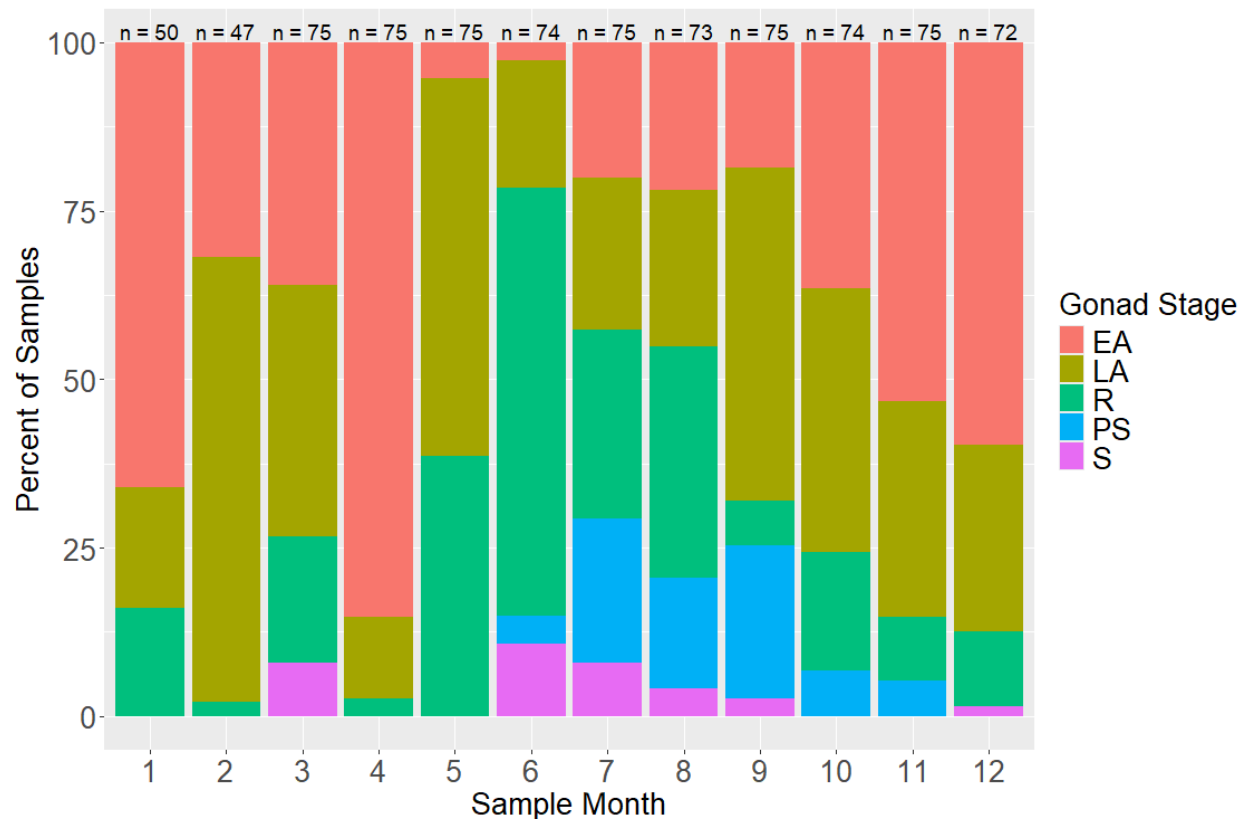


Figure 11. Percentage of clams in each gonadal stage by month for Arctic Surf Clam on Banquereau. Data is a composite of samples ranging from 2019 to 2024. Stages are: EA is early active; LA is late active; R is ripe; PS is partially-spawned, and S is spent. N is the number of clams sampled.

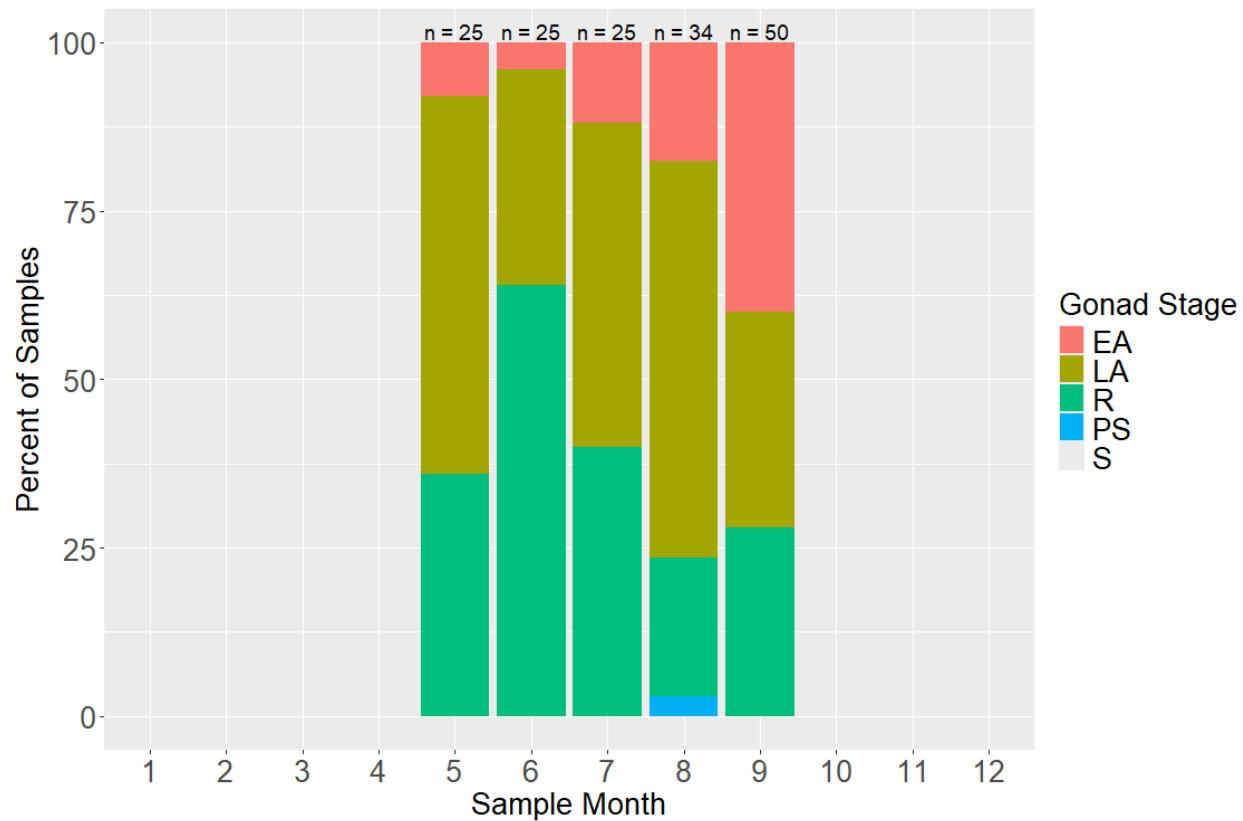


Figure 12. Percentage of clams in each gonadal stage by month for Arctic Surf Clam on Banquereau. Data is a composite of samples ranging from 2022 to 2024. Stages are: EA is early active; LA is late active; R is ripe; PS is partially-spawned, and S is spent (no data). N is the number of clams sampled.

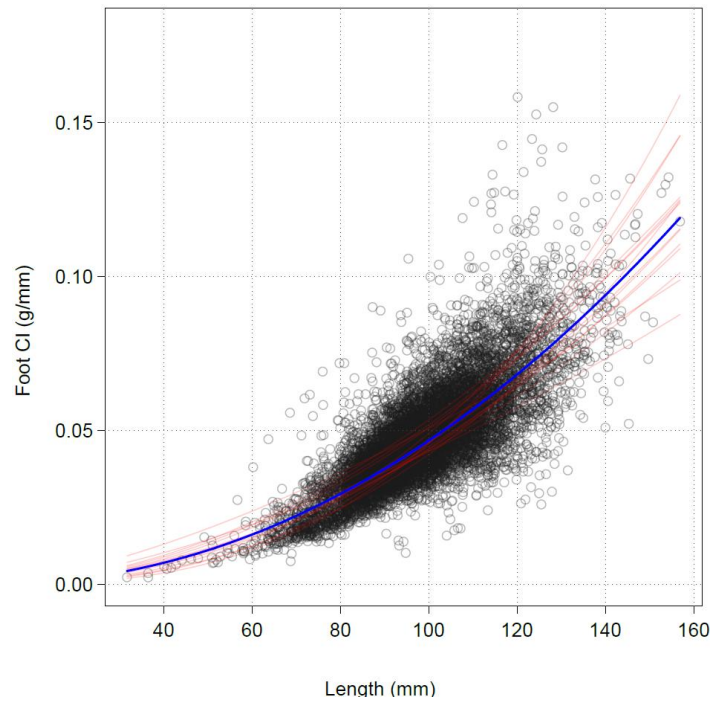


Figure 13: Dry Foot Condition Index (FootCI; g/mm) and shell length (mm) relationship on Banquereau with year as a random effect (red lines). The blue line is the fixed effect.

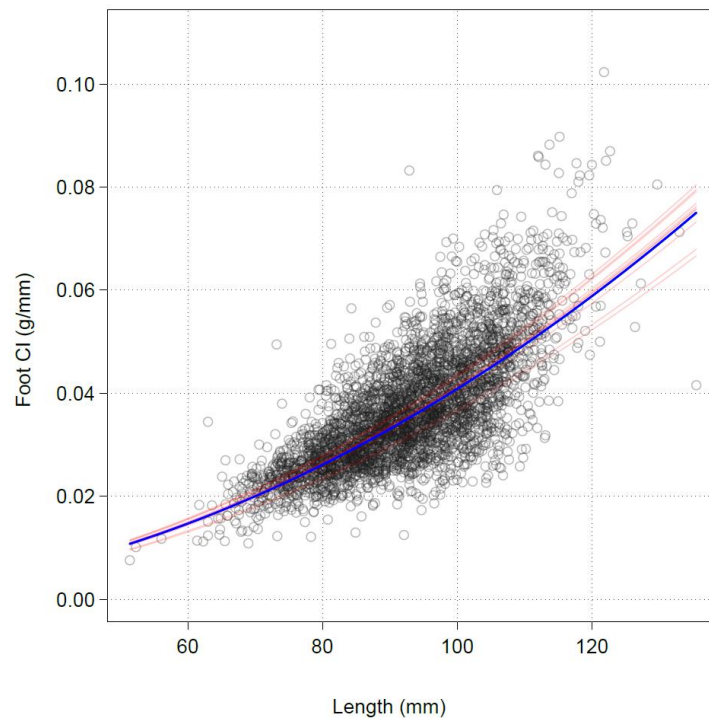


Figure 14. Dry Foot Condition Index (FootCI; g/mm) and shell length (mm) relationship on the Grand Banks with year as a random effect (red lines). The blue line is the fixed effect.

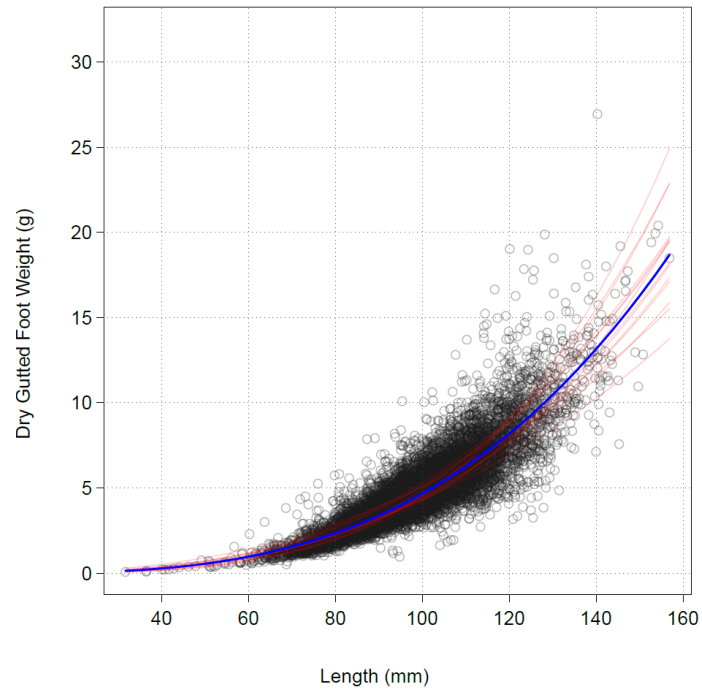


Figure 15. Dry gutted foot weight (g) and shell length (mm) relationship on Banquereau with year as a random effect (red lines). The blue line is the fixed effect.

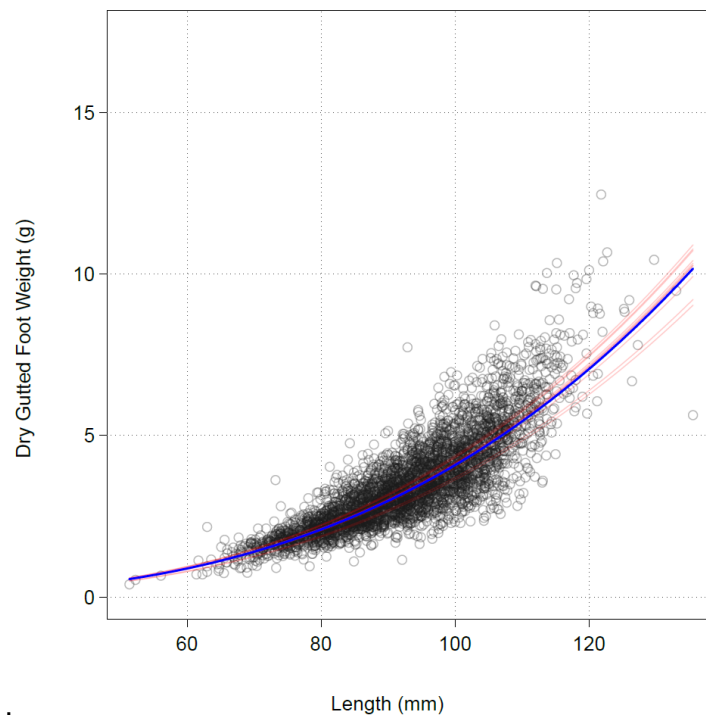


Figure 16. Dry gutted foot weight (g) and shell length (mm) relationship on the Grand Banks with year as a random effect (red lines). The blue line is the fixed effect.

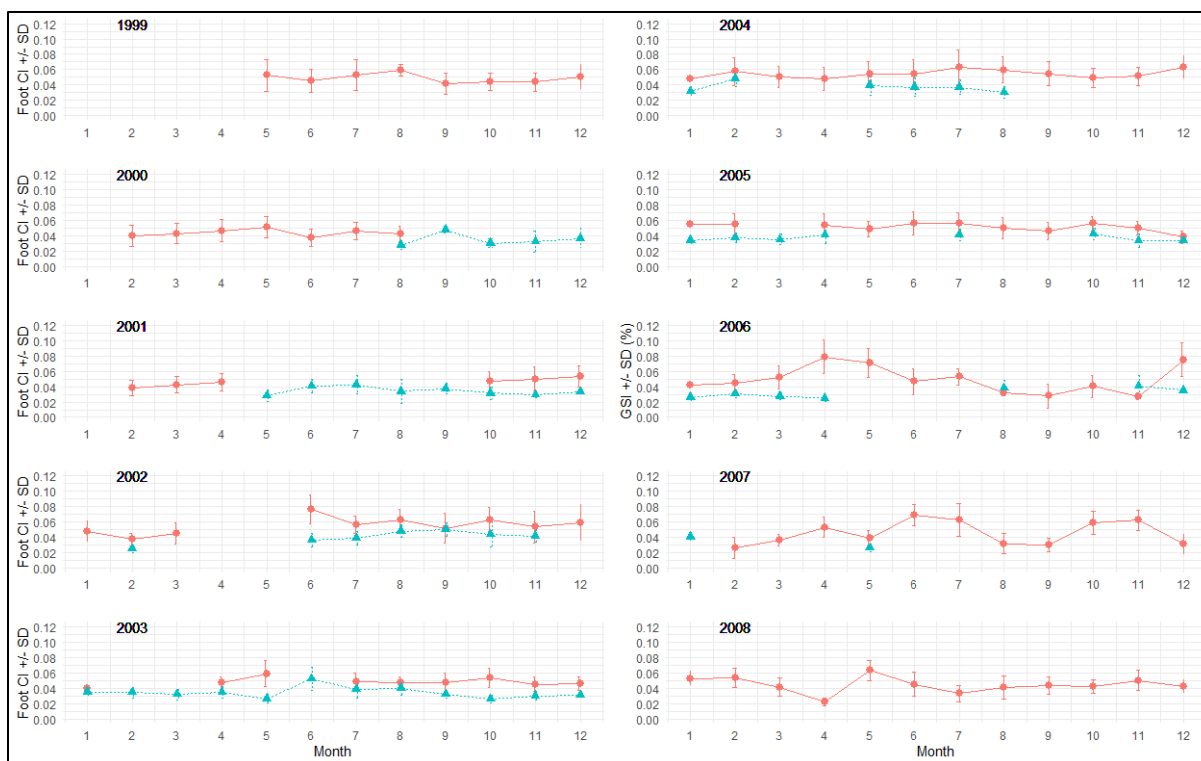


Figure 17. Mean monthly Foot Condition Index (FootCI; g/mm) $\pm$ 1 standard deviation (SD) of frozen Arctic Surf Clam on Banquereau (pink circles) and Grand Banks (blue triangles) from 1999 to 2008.

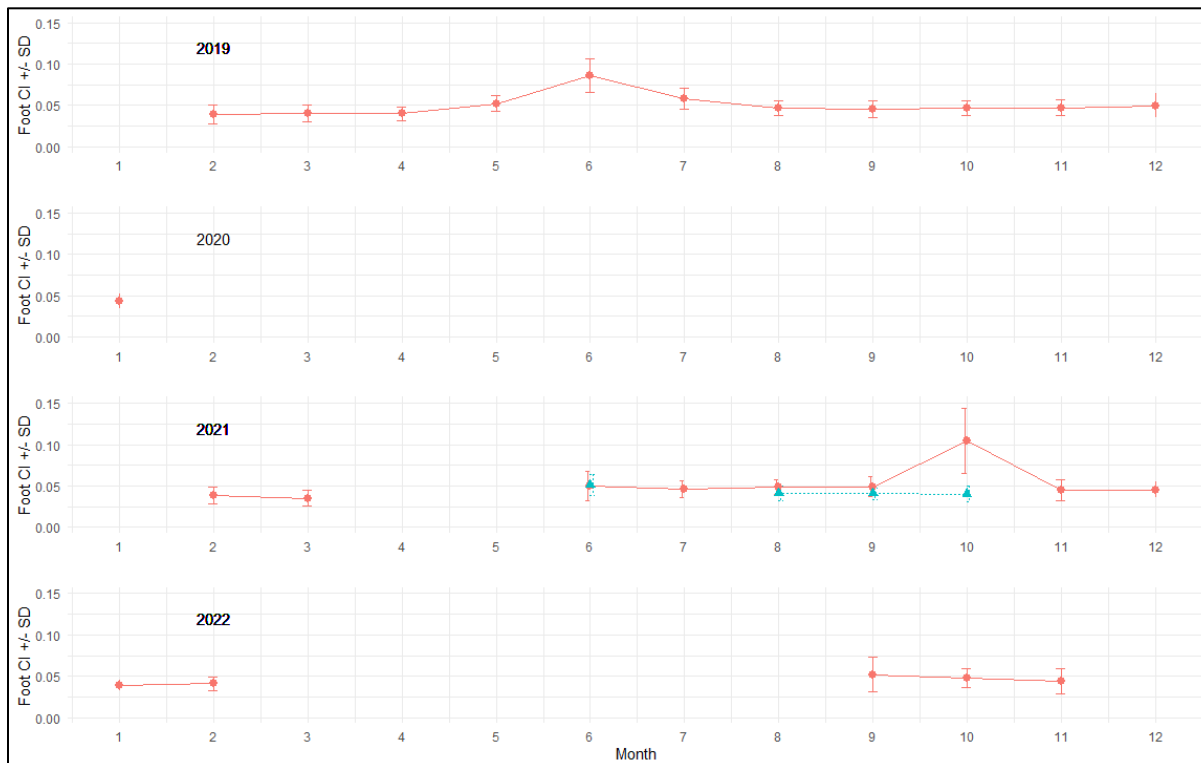


Figure 18. Mean monthly Foot Condition Index (FootCI; g/mm) $\pm$ 1 standard deviation (SD) of frozen Arctic Surf Clam on Banquereau (pink circles) and Grand Banks (blue triangles) from 2019 to 2022.



Figure 19. Mean annual Foot Condition Index (FootCI; g/mm) $\pm$ 1 standard deviation (SD) of frozen Arctic Surf Clam on Banquereau (pink circles) and Grand Banks (blue triangles) from 2019 to 2022.

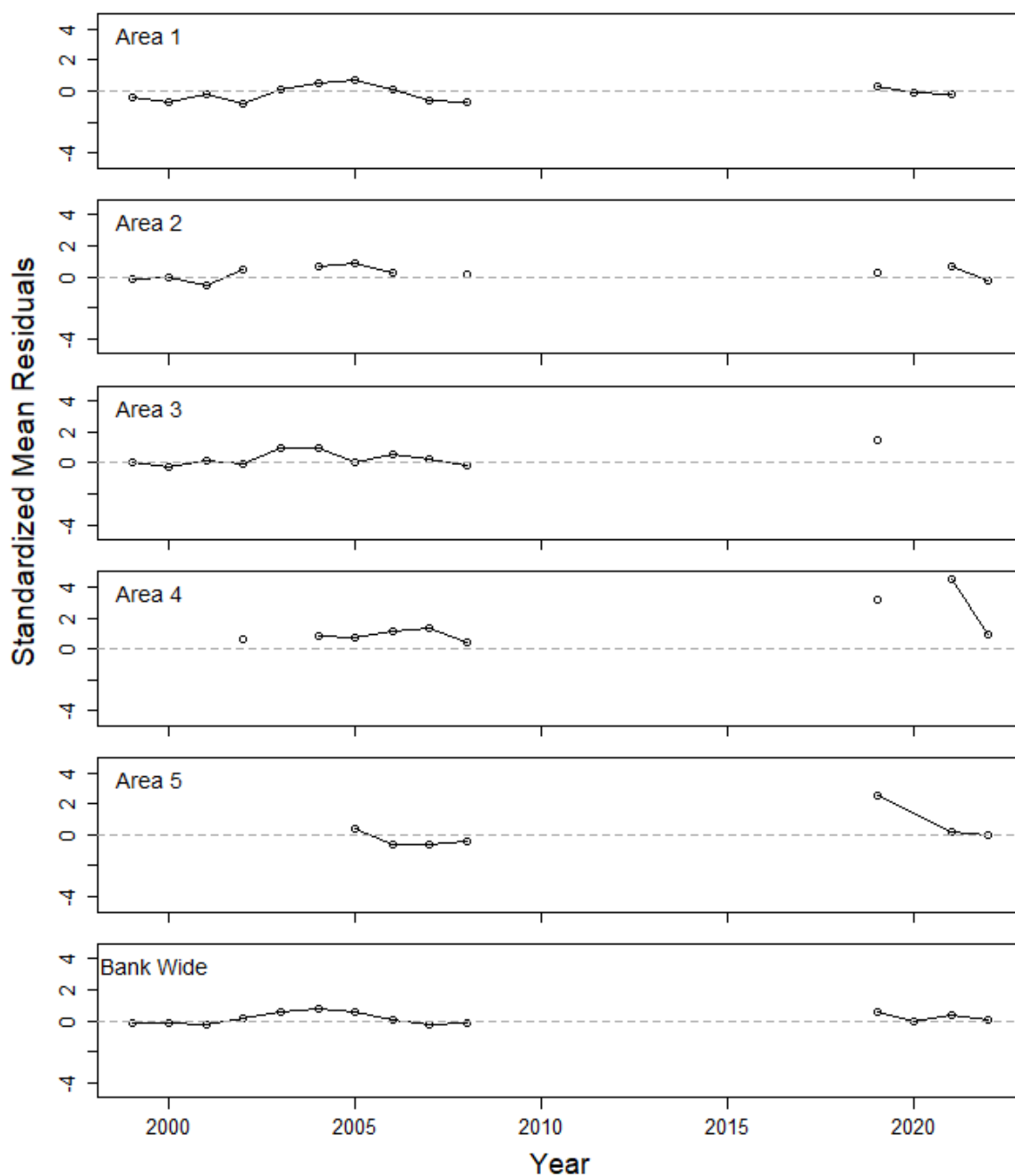


Figure 20. Mean annual residuals between actual and calculated Foot Condition Index based on the regression by assessment areas and bank-wide from the regression line shown in Figure 13 of frozen Arctic Surf Clam on Banquereau.

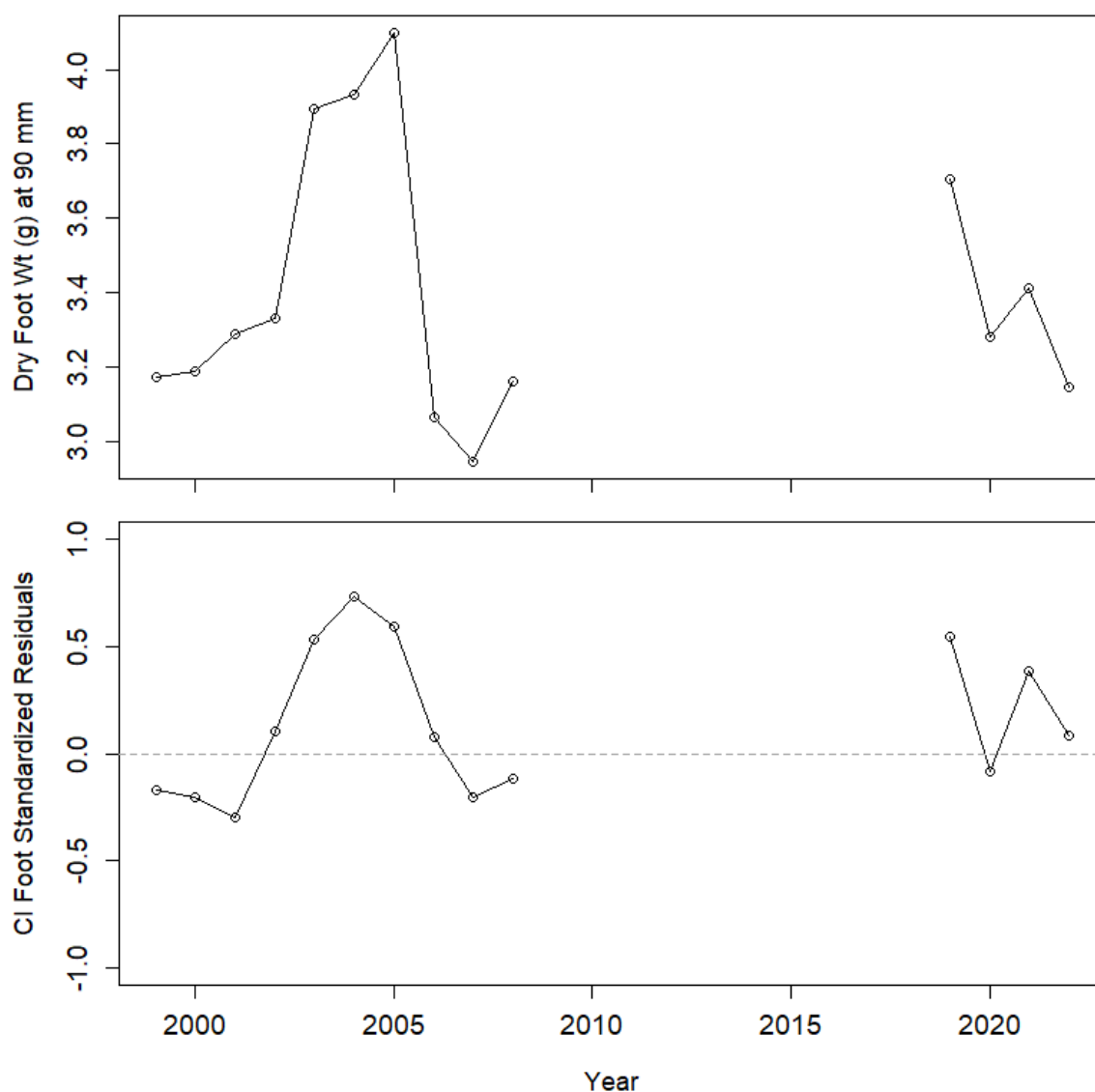


Figure 21. Foot Condition Index based on predicted dry foot weight for a 90 mm clam (top panel; from regression line shown in Figure 15) and index based on mean annual residuals between actual and calculated Foot Condition (CI Foot, g/mm) (bottom panel; from regression line shown in Figure 13) of frozen Arctic Surf Clam on Banquereau.

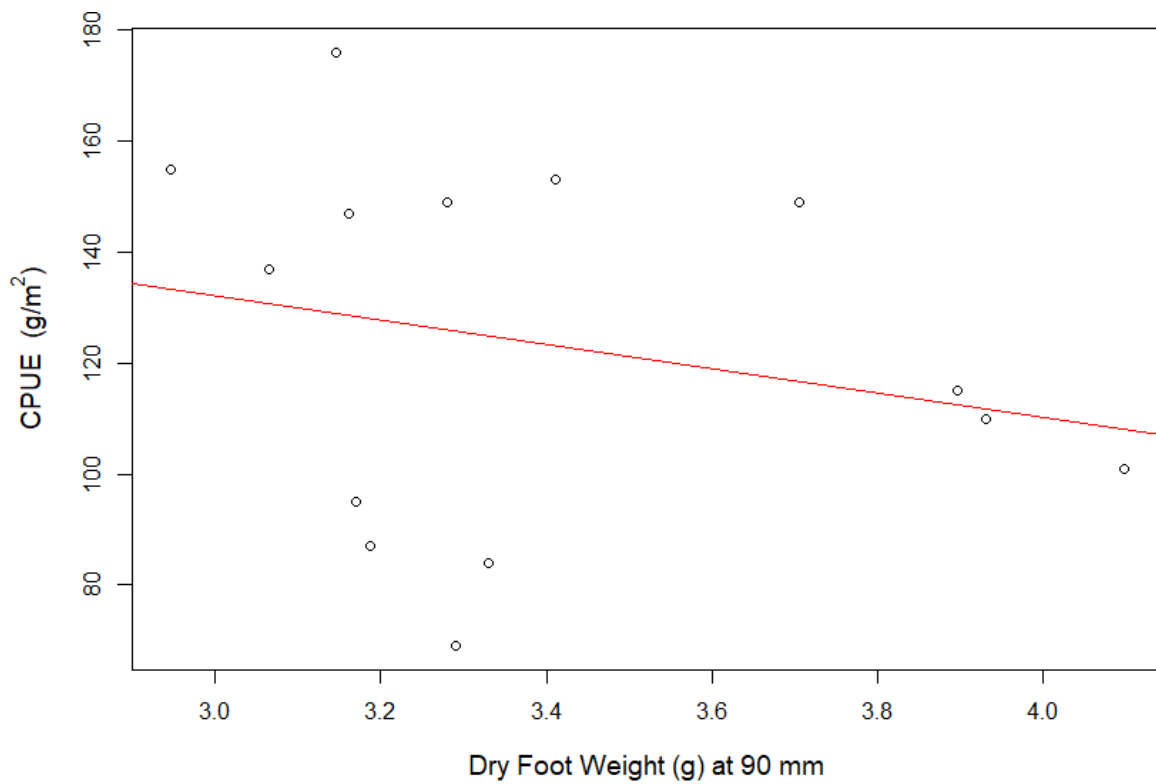


Figure 22. Bank-wide annual catch per unit effort (CPUE, g/m²) and predicted dry foot weight (g) at 90 mm for Banquereau. Non-significant regression line in red.

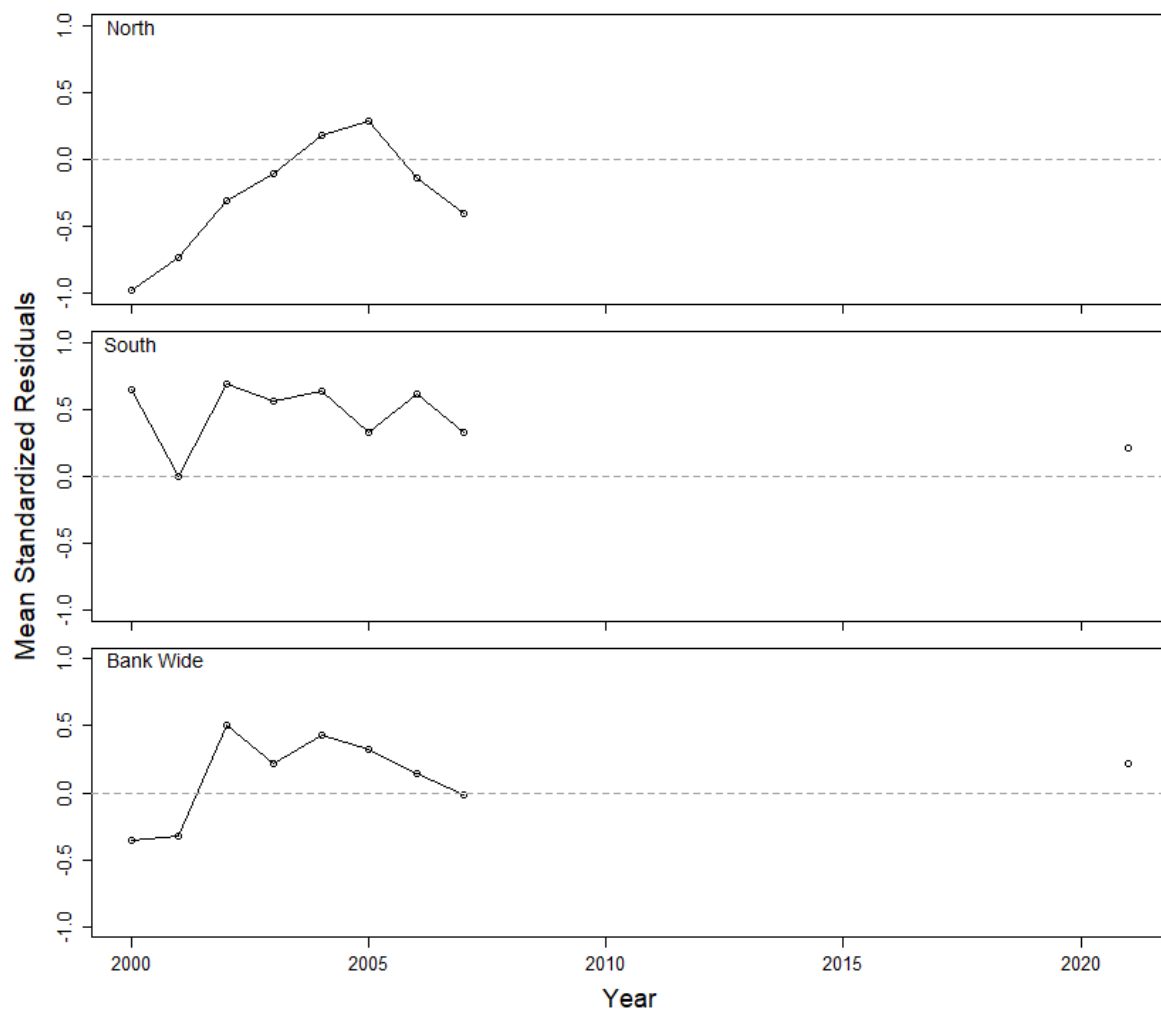


Figure 23. Mean annual residuals between actual and calculated Foot Condition Index based on the regression by assessment areas and bank-wide from the regression line shown in Figure 14 of frozen Arctic Surf Clam on the Grand Banks.

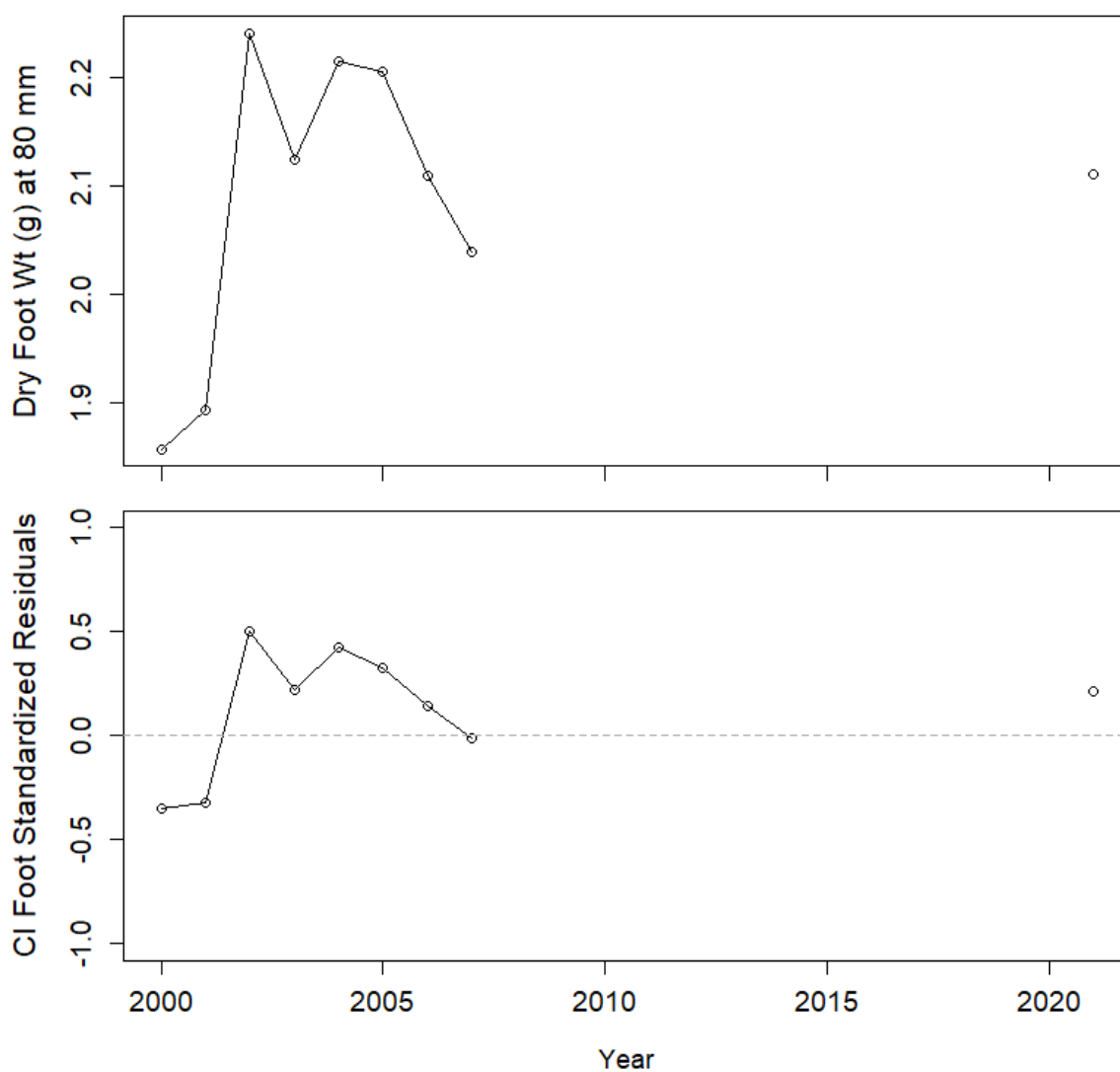


Figure 24. Foot Condition Index based on predicted dry foot weight for an 80 mm clam (top panel; from regression line shown in Figure 16) and index based on mean annual residuals between actual and calculated Foot Condition (CI Foot, g/mm) (bottom panel; from regression line shown in Figure 14) of frozen Arctic Surf Clam on the Grand Banks.

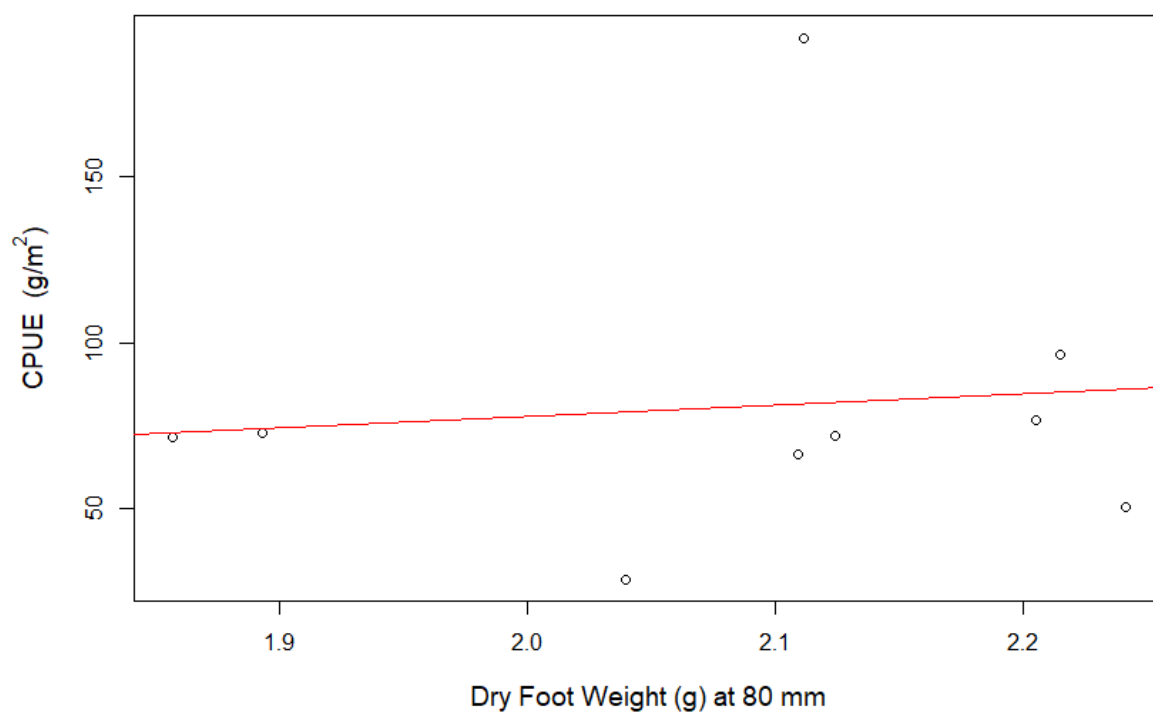


Figure 25. Bank-wide annual catch per unit effort (CPUE, g/m²) and predicted dry foot weight (g) at 80 mm for Grand Banks. Non-significant regression line in red.

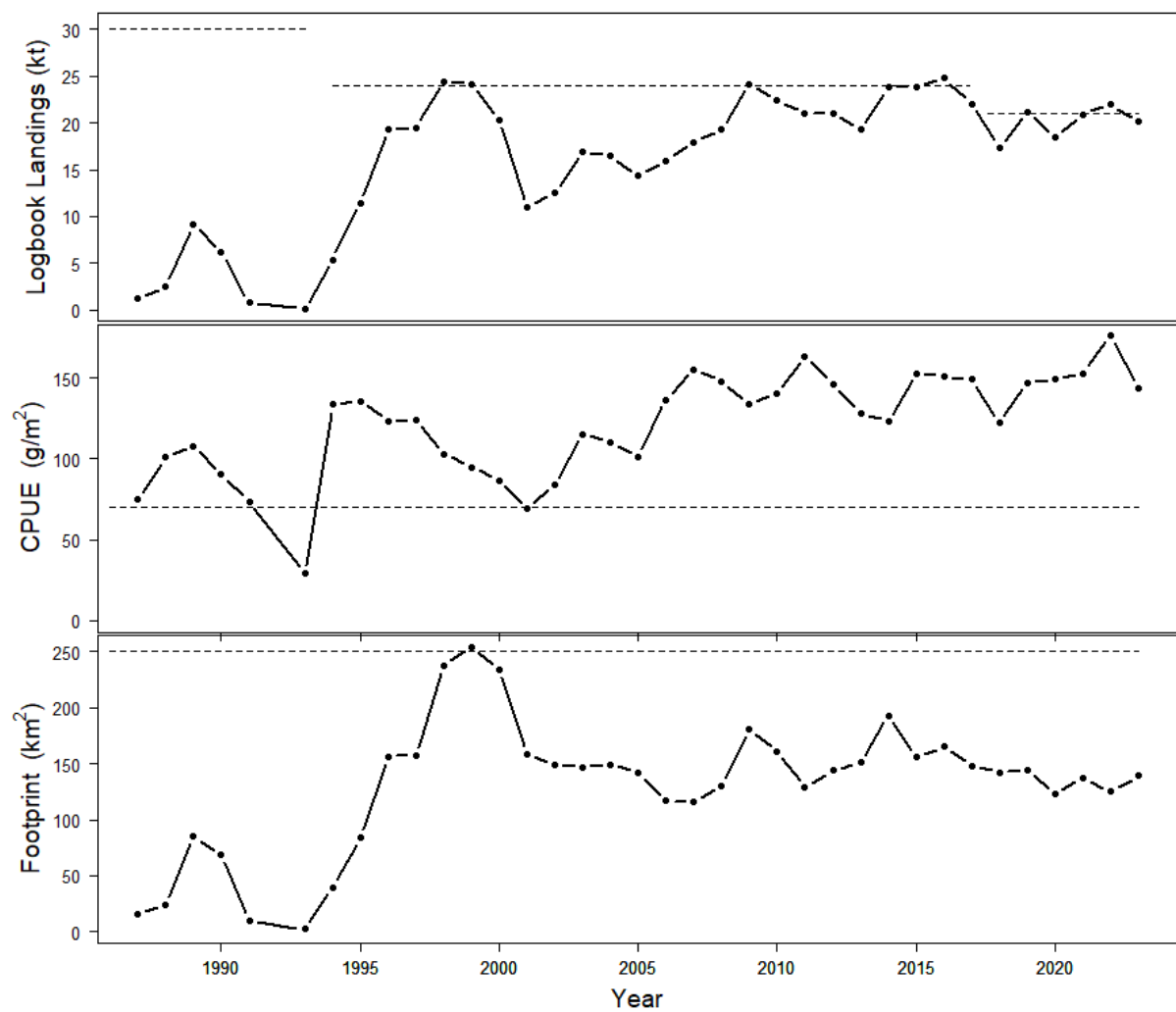


Figure 26. Logbook landings (kt) [top panel], catch per unit effort (CPUE; g/m²) [middle panel], and fishery footprint (km²) [bottom panel] for Banquereau from 1987 to 2023. Horizontal lines represent total allowable catch (top panels) or threshold levels for secondary indicators.

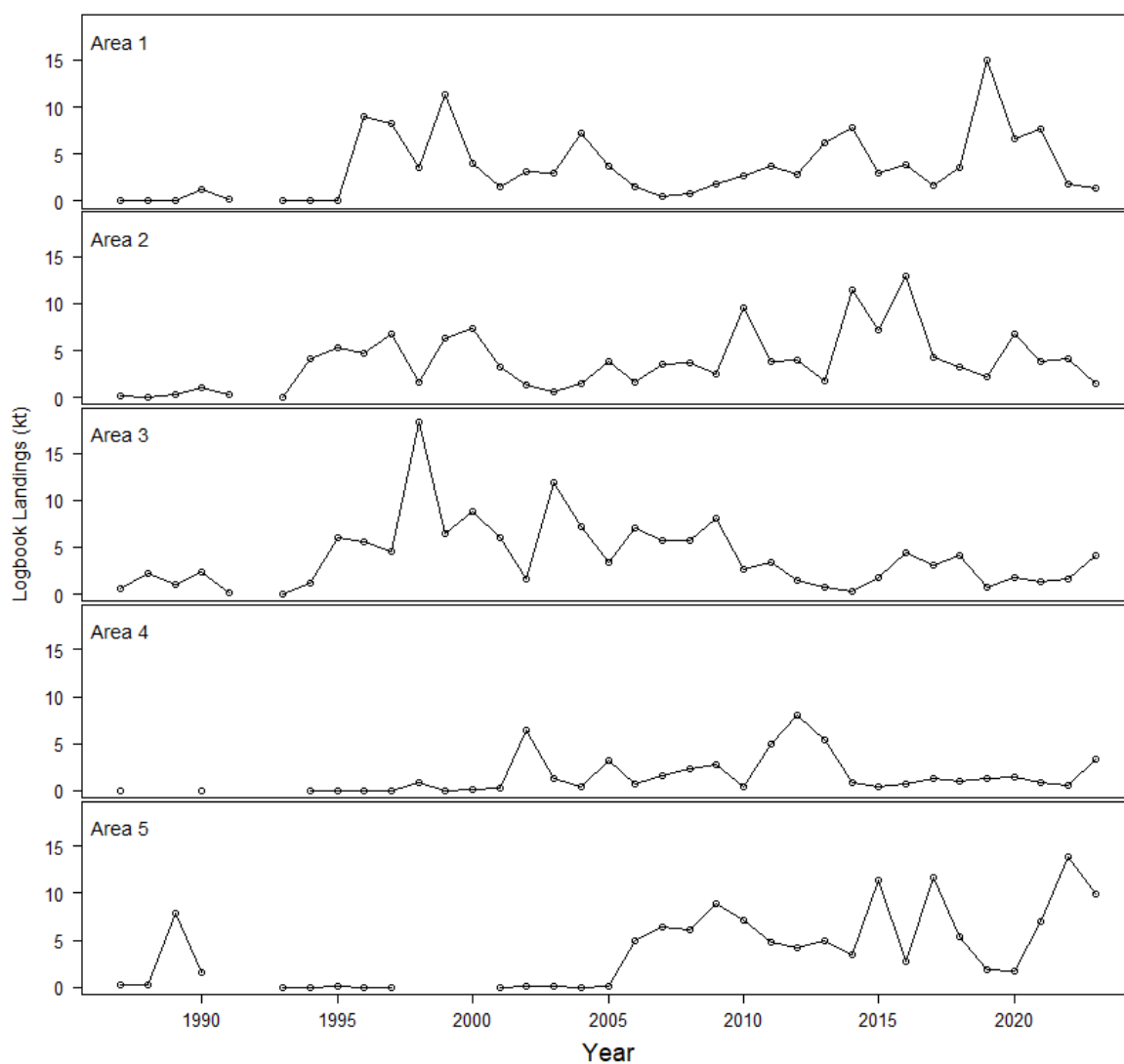


Figure 27. Logbook landings (kt) by assessment area for Banquereau from 1987 to 2023. See Figure 8 for a map of the assessment areas.

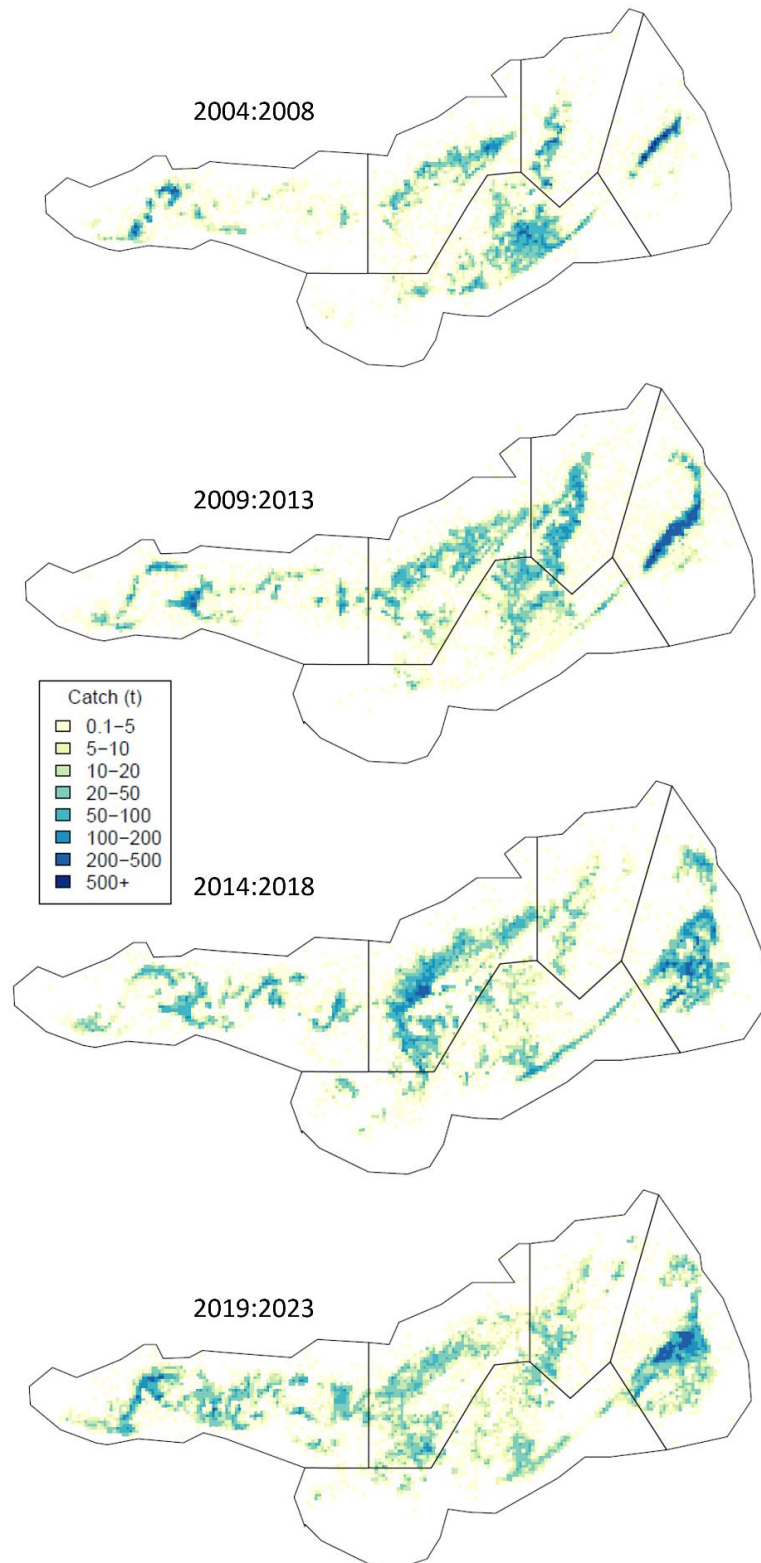


Figure 28. Catch (t) aggregated in five-year increments for Banquereau.

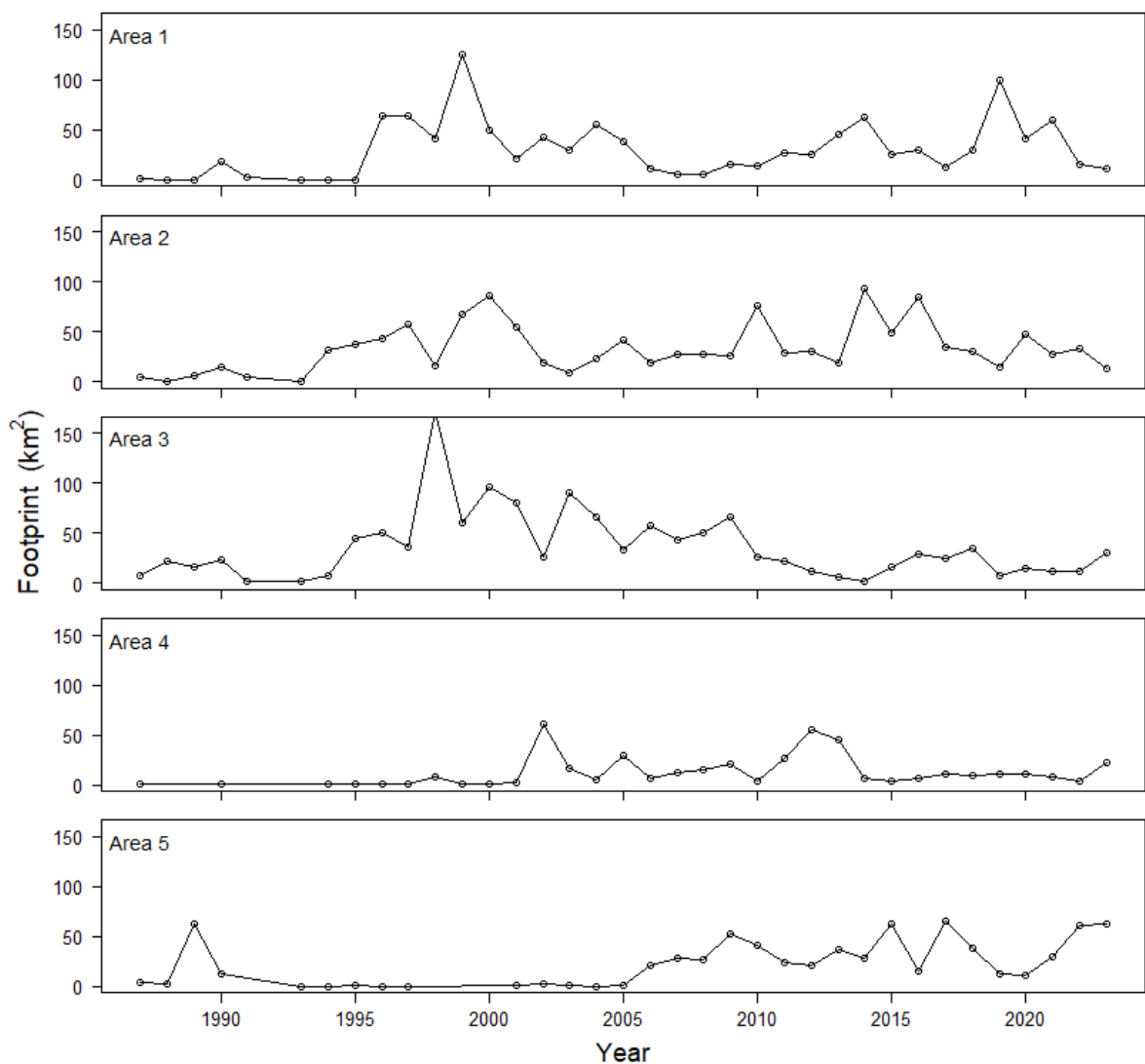


Figure 29. Footprint (effort in km²) by assessment area for Banquereau from 1987 to 2023. See Figure 8 for a map of the assessment areas.

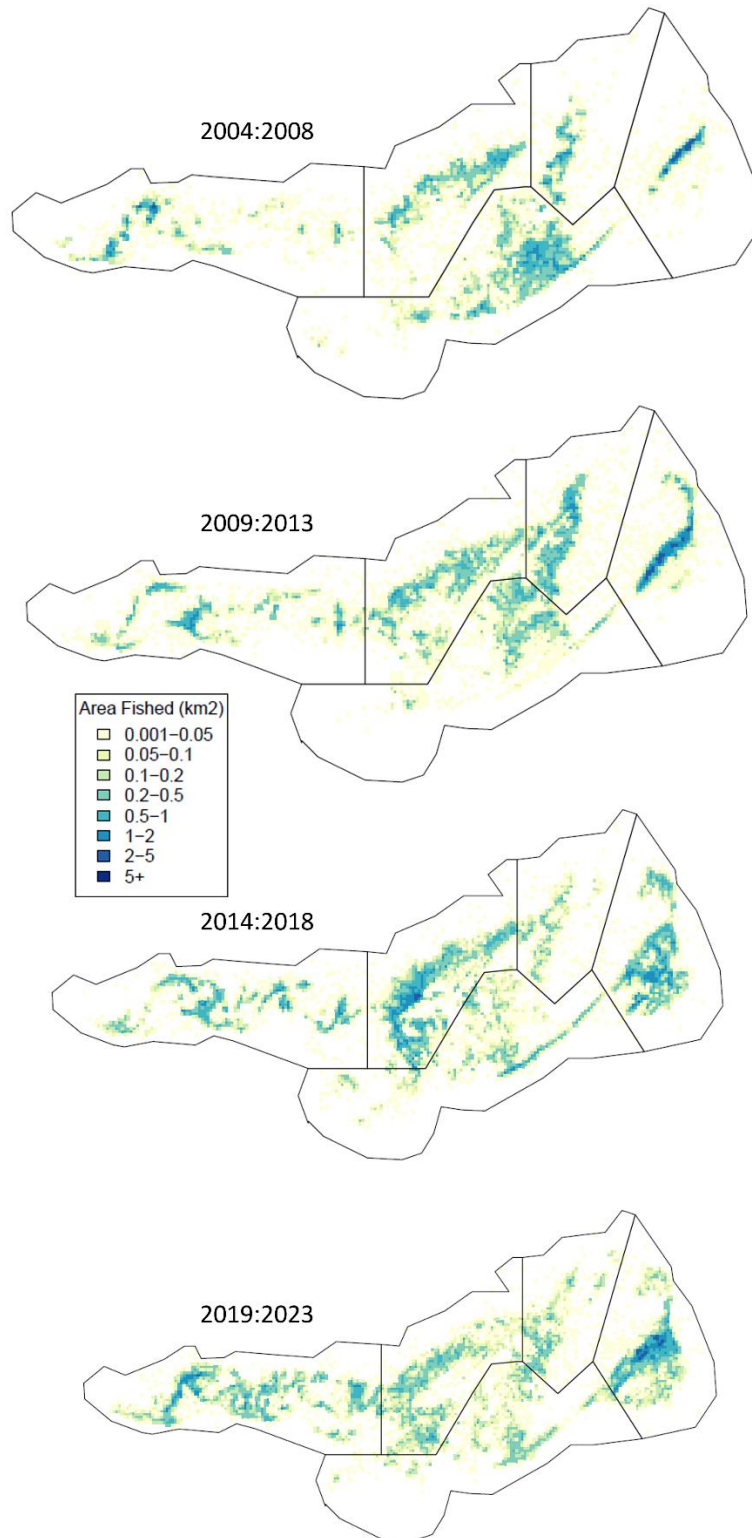


Figure 30. Effort (km²) aggregated in five-year increments for Banquereau.

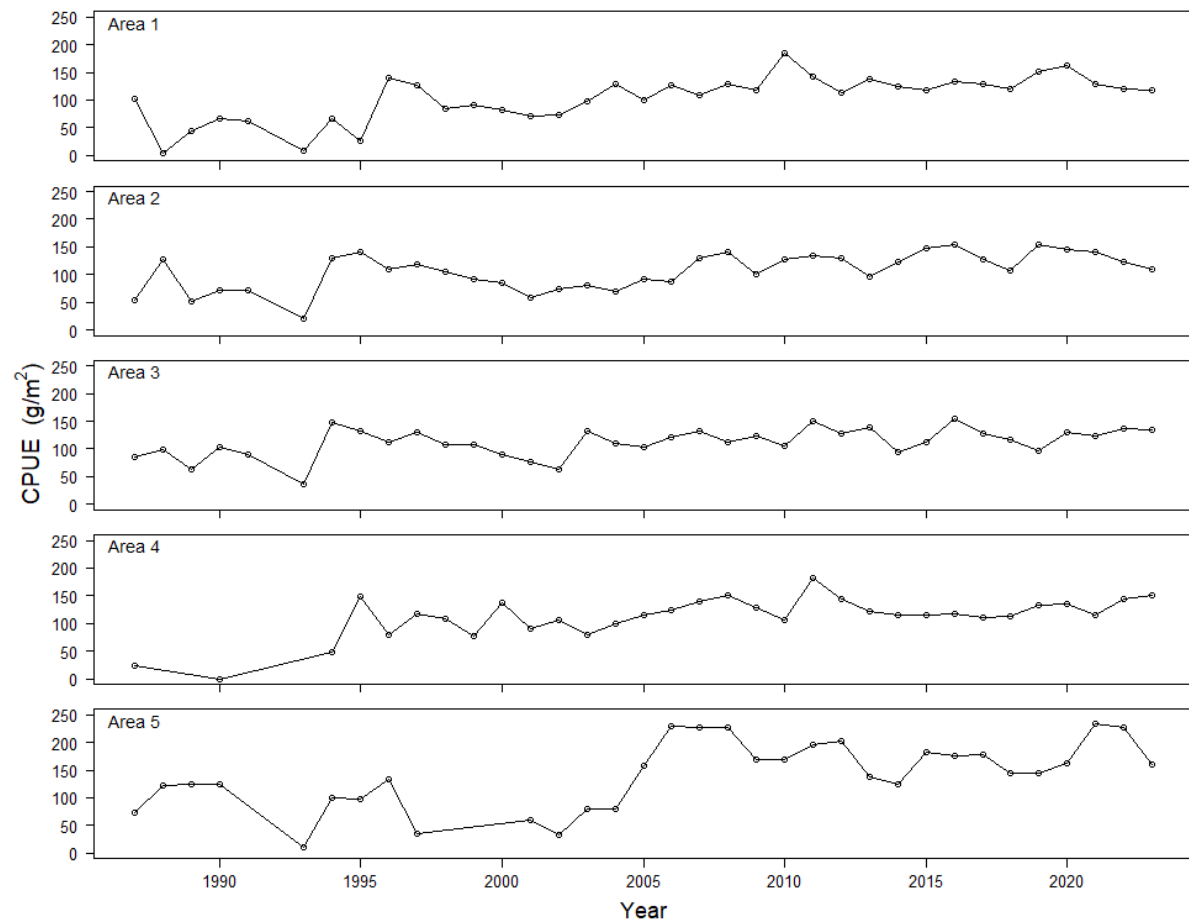


Figure 31. Catch per unit effort (CPUE, g/m²) by assessment area for Banquereau from 1987 to 2023.

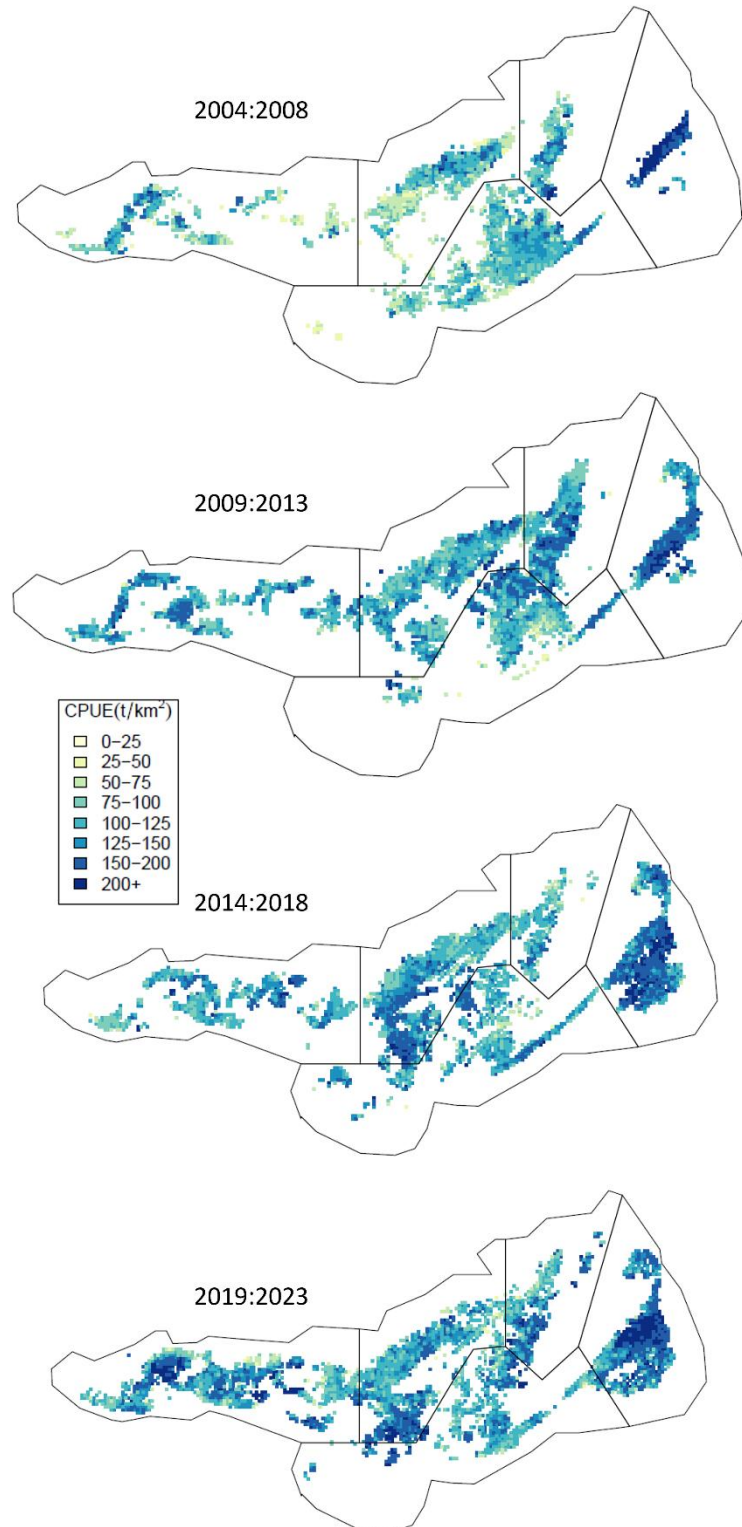


Figure 32. Catch per unit effort (CPUE, t/km²) aggregated in five-year increments for Banquereau.

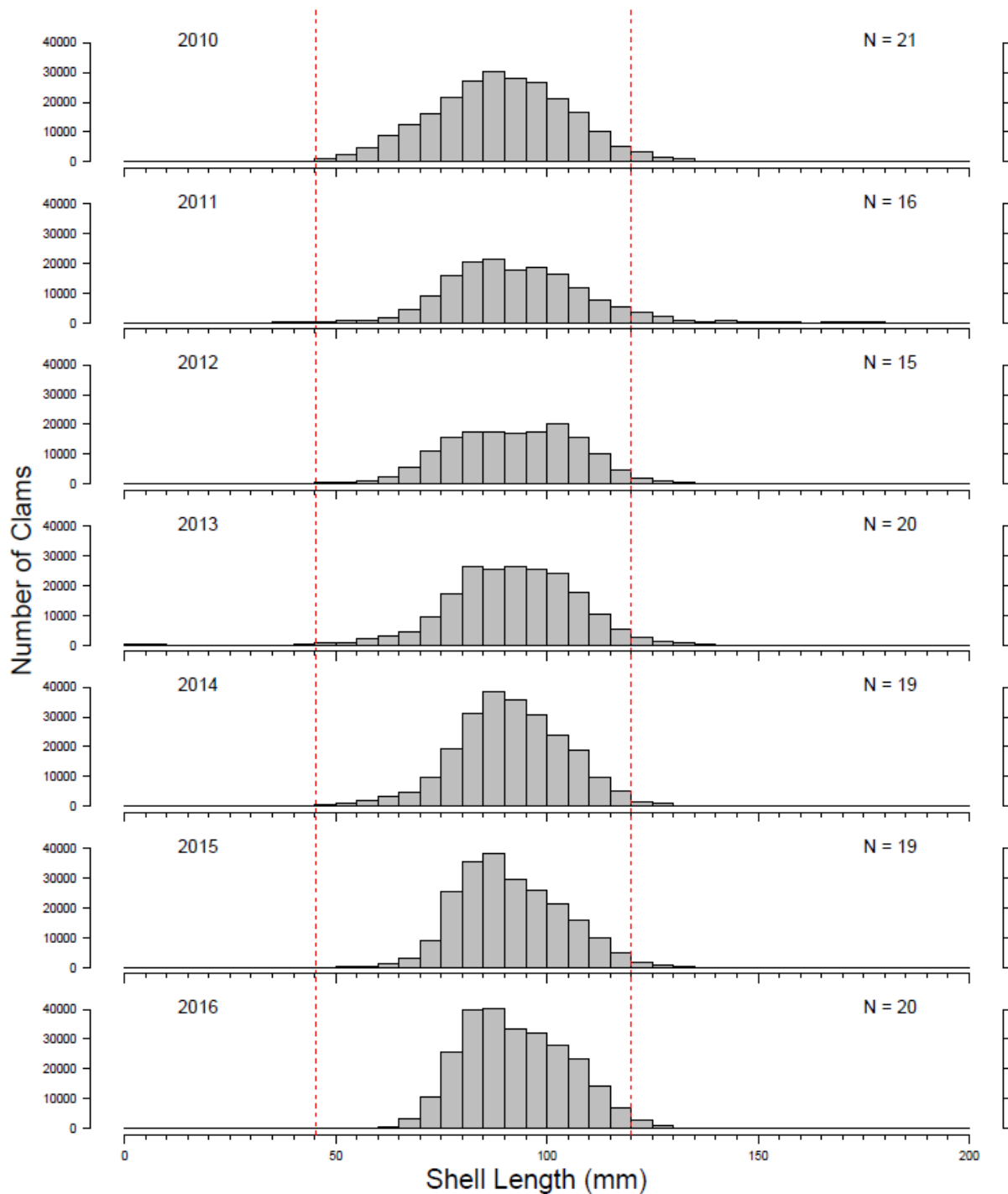


Figure 33. Shell length frequencies for Banquereau from 2010 to 2016. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for Length Indicator 1.

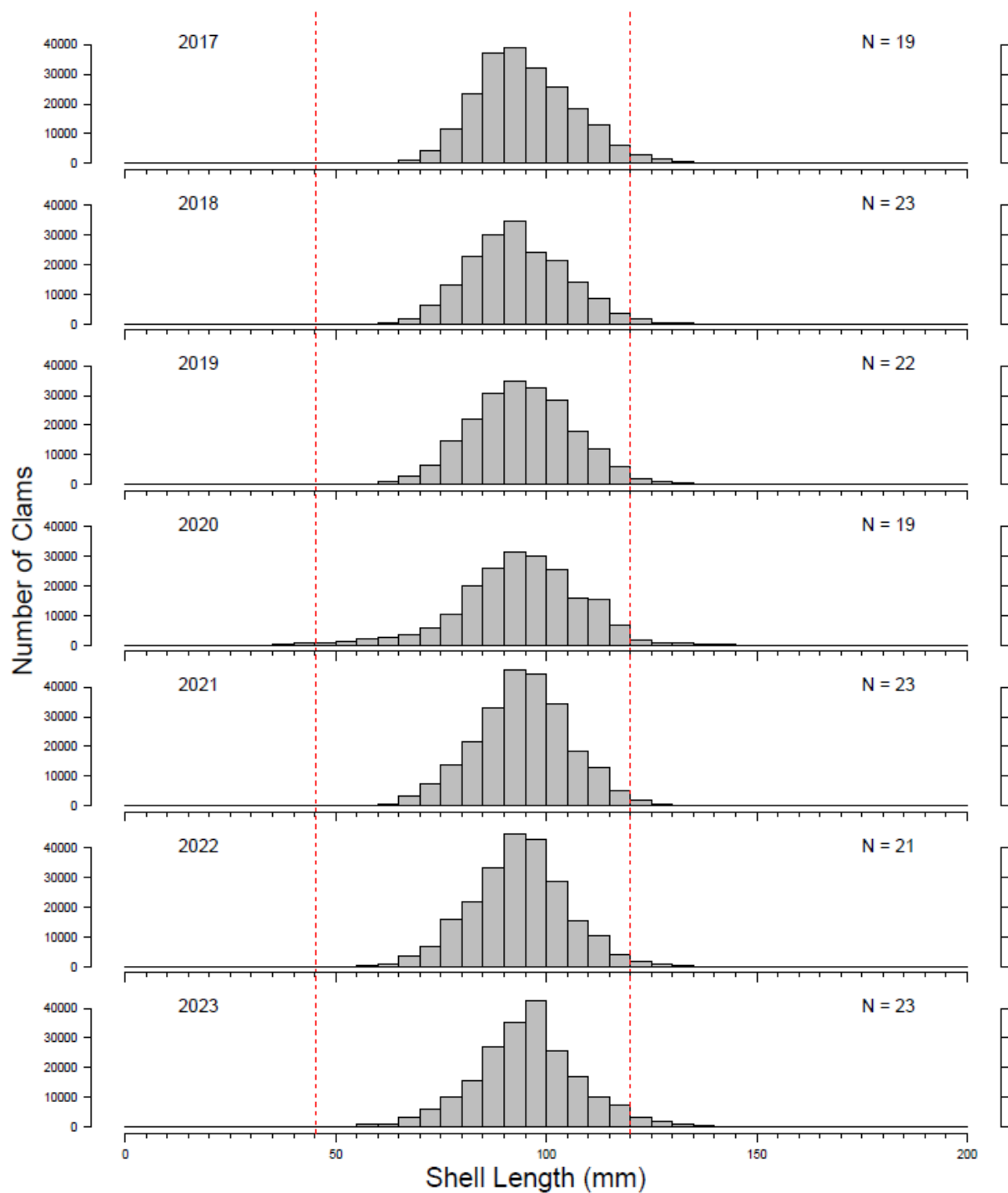


Figure 34. Shell length frequencies for Banquereau from 2017 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for Length Indicator 1.

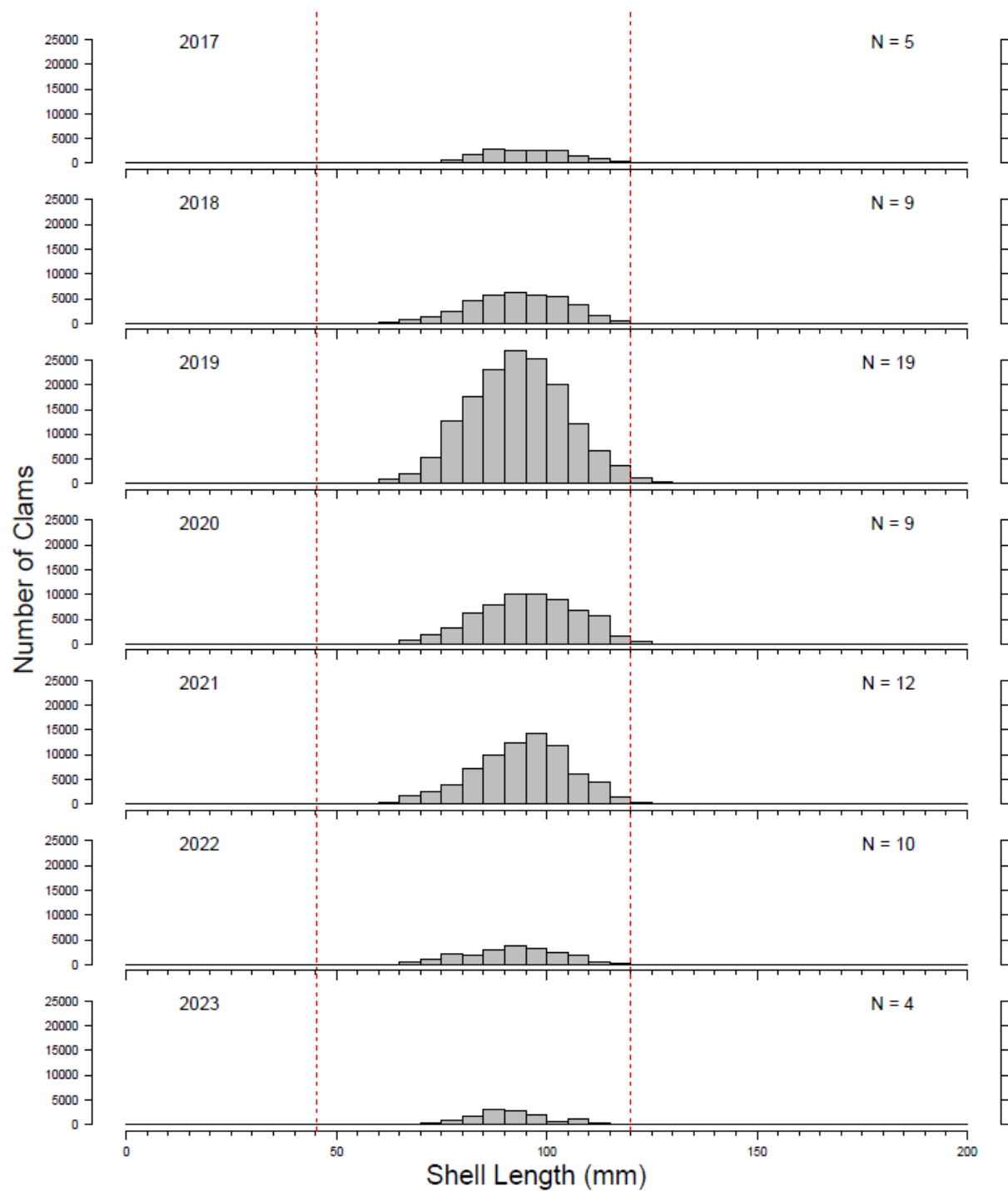


Figure 35. Shell length frequencies for Area 1 Banquereau from 2017 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for Length Indicator 1.

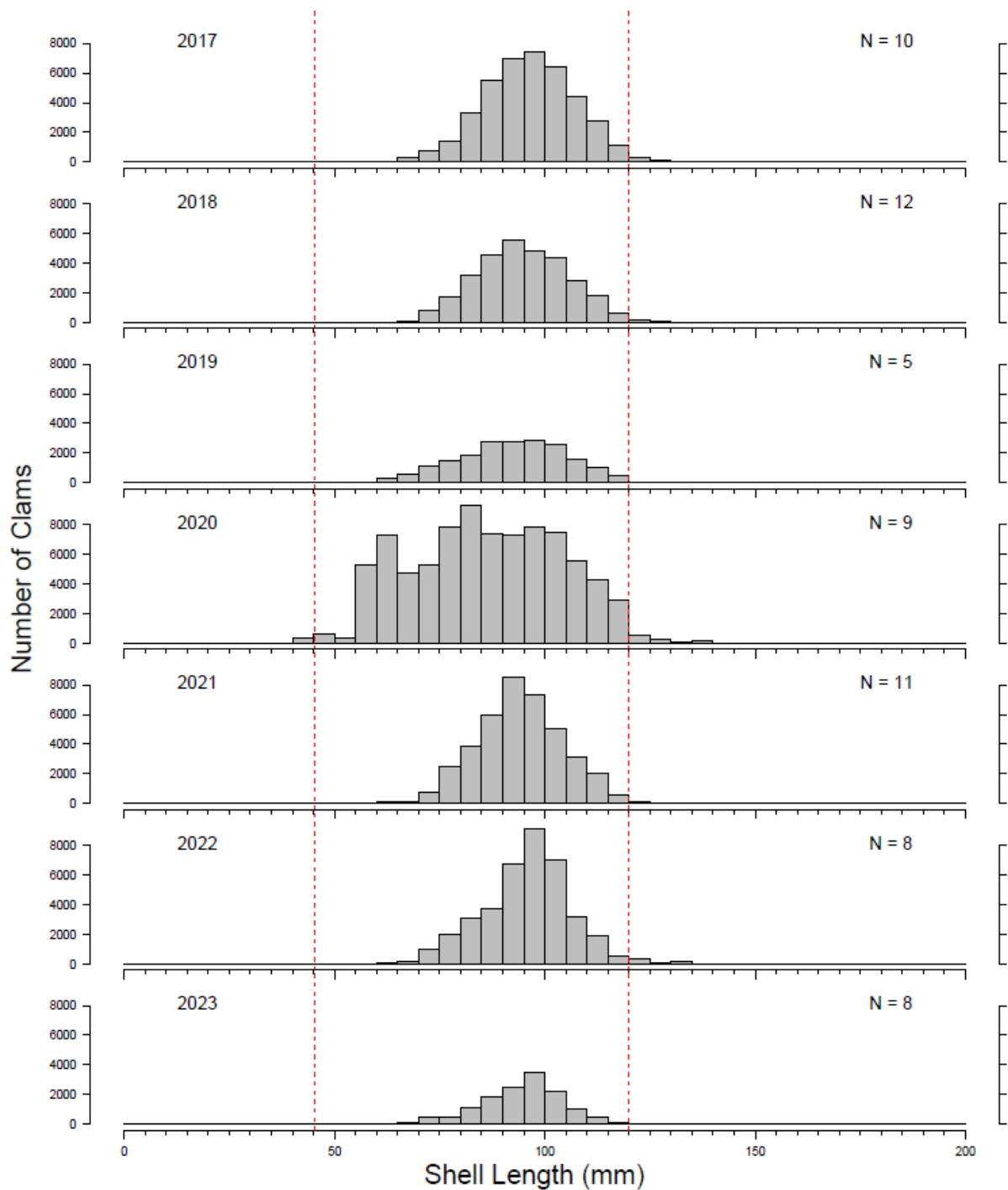


Figure 36. Shell length frequencies for Area 2 Banquereau from 2017 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for Length Indicator 1.

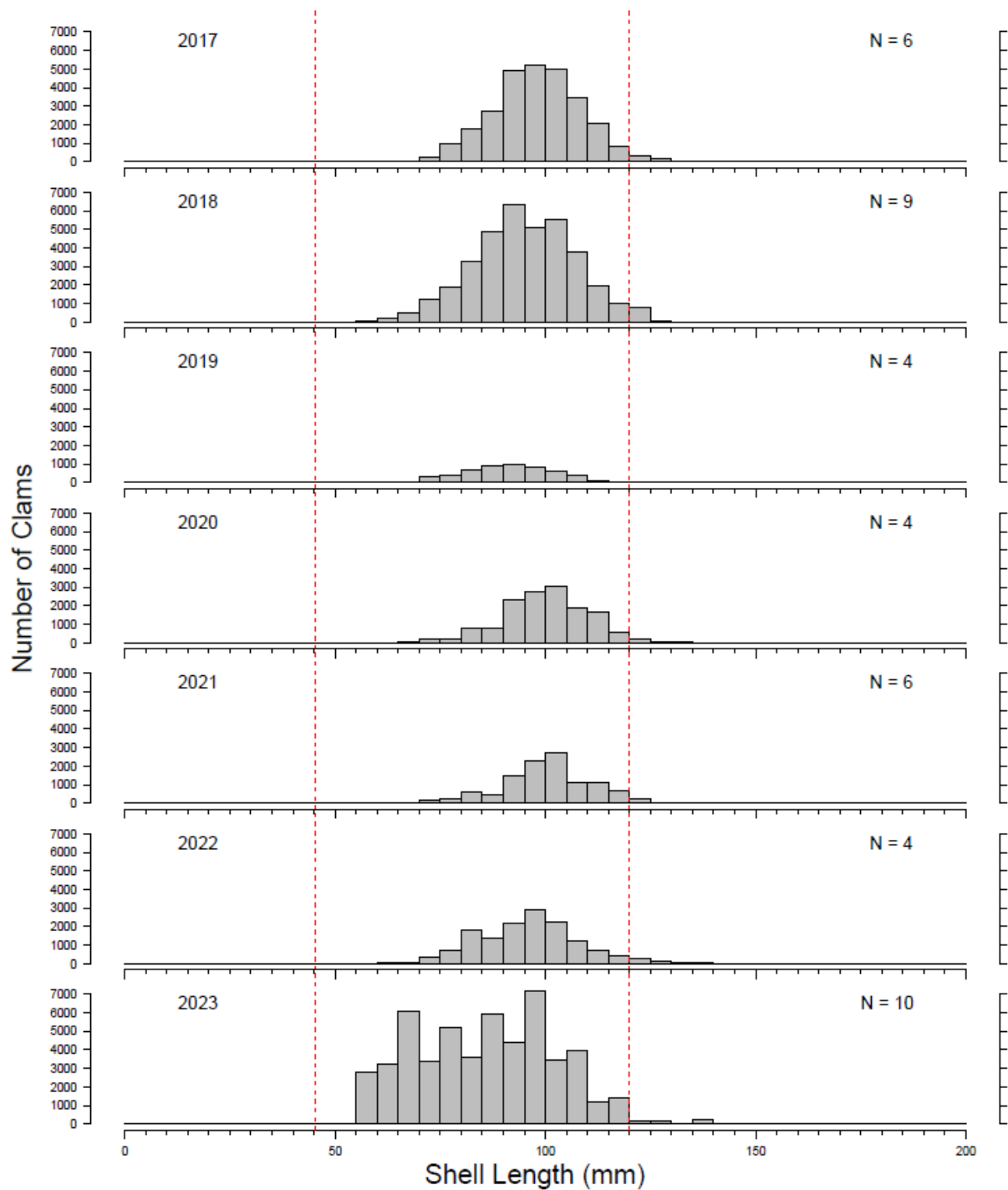


Figure 37. Shell length frequencies for Area 3 Banquereau from 2017 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for Length Indicator 1.

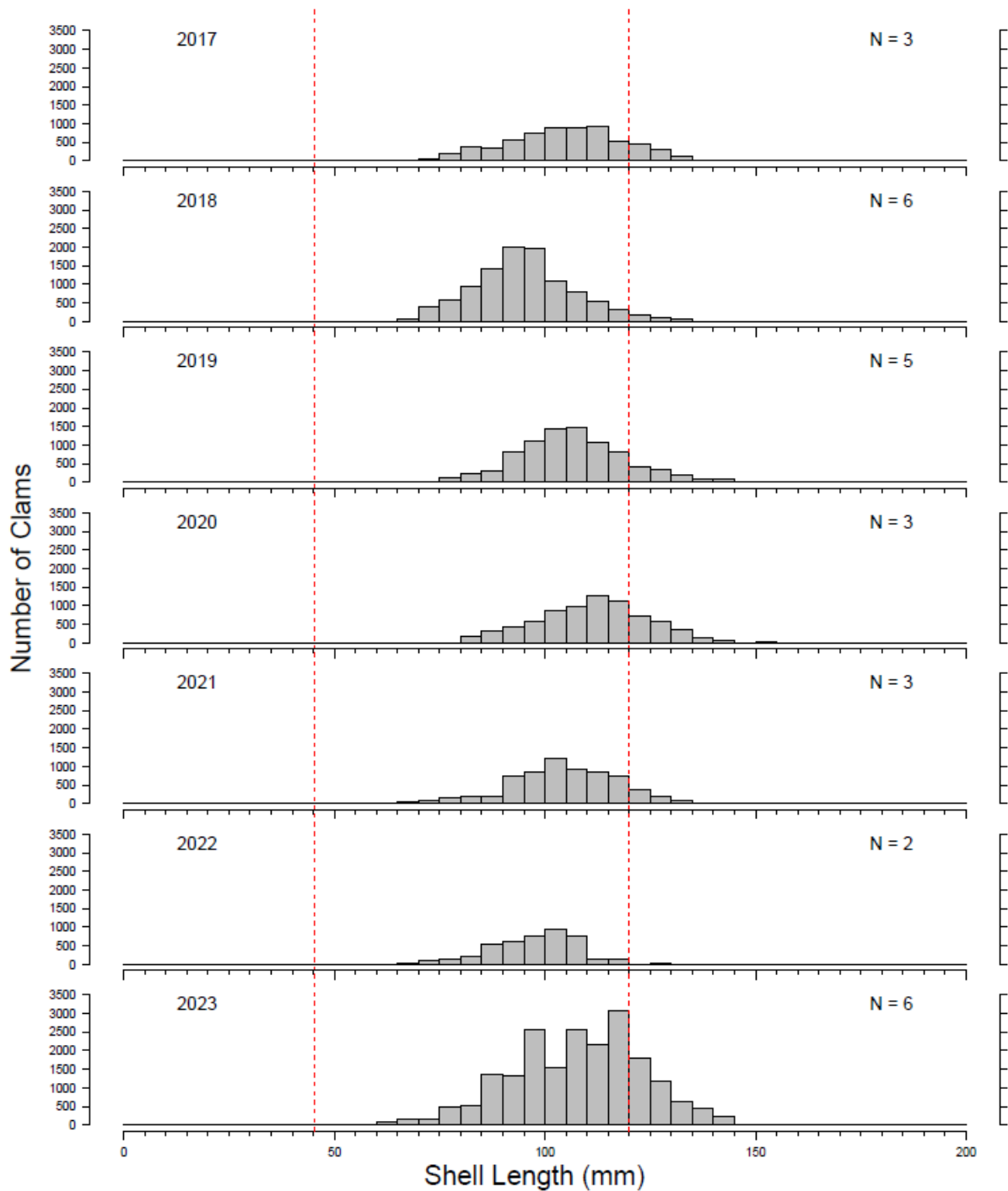


Figure 38. Shell length frequencies for Area 4 Banquereau from 2017 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for Length Indicator 1.

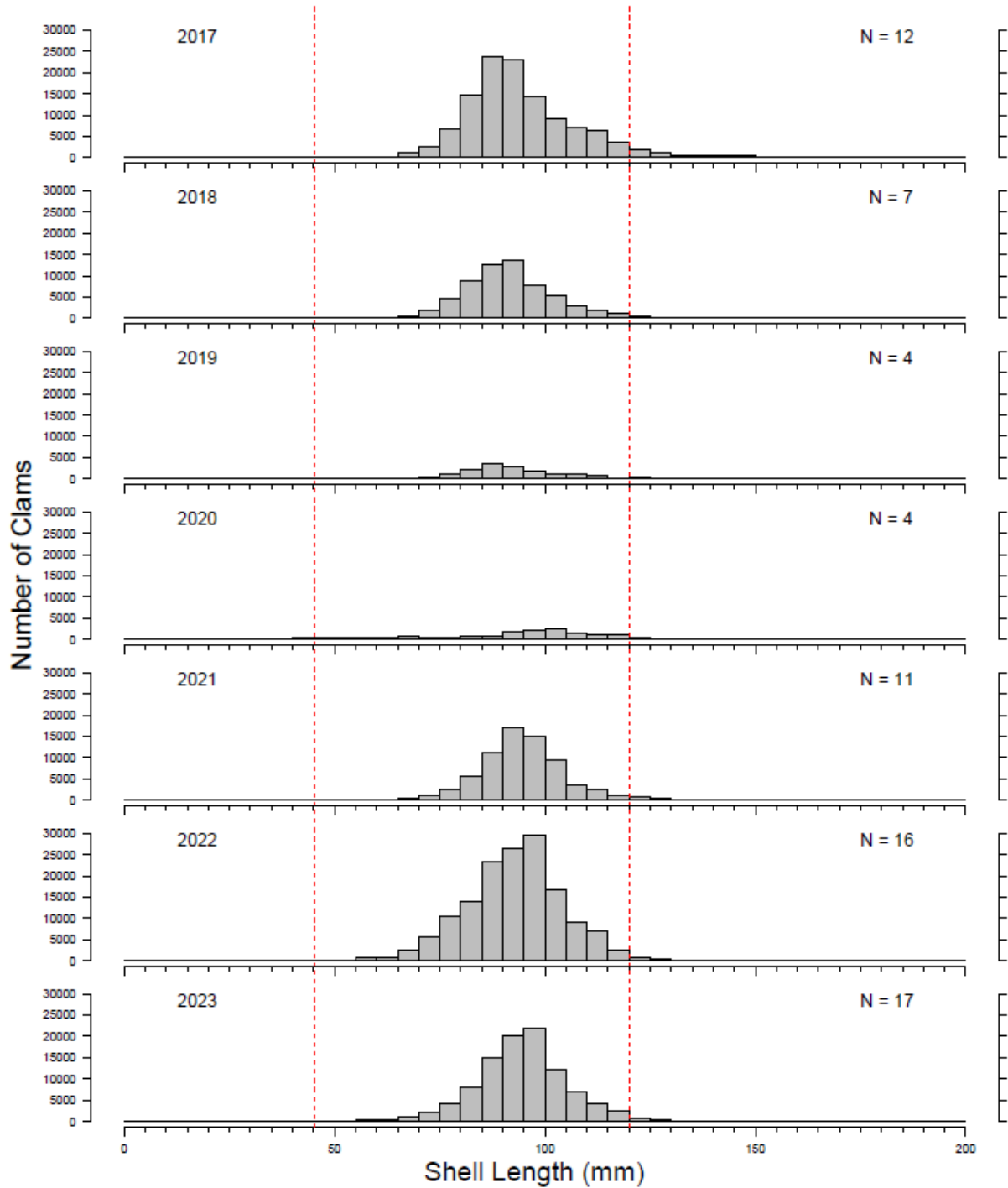


Figure 39. Shell length frequencies for Area 5 Banquereau from 2017 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used Length Indicator 1.

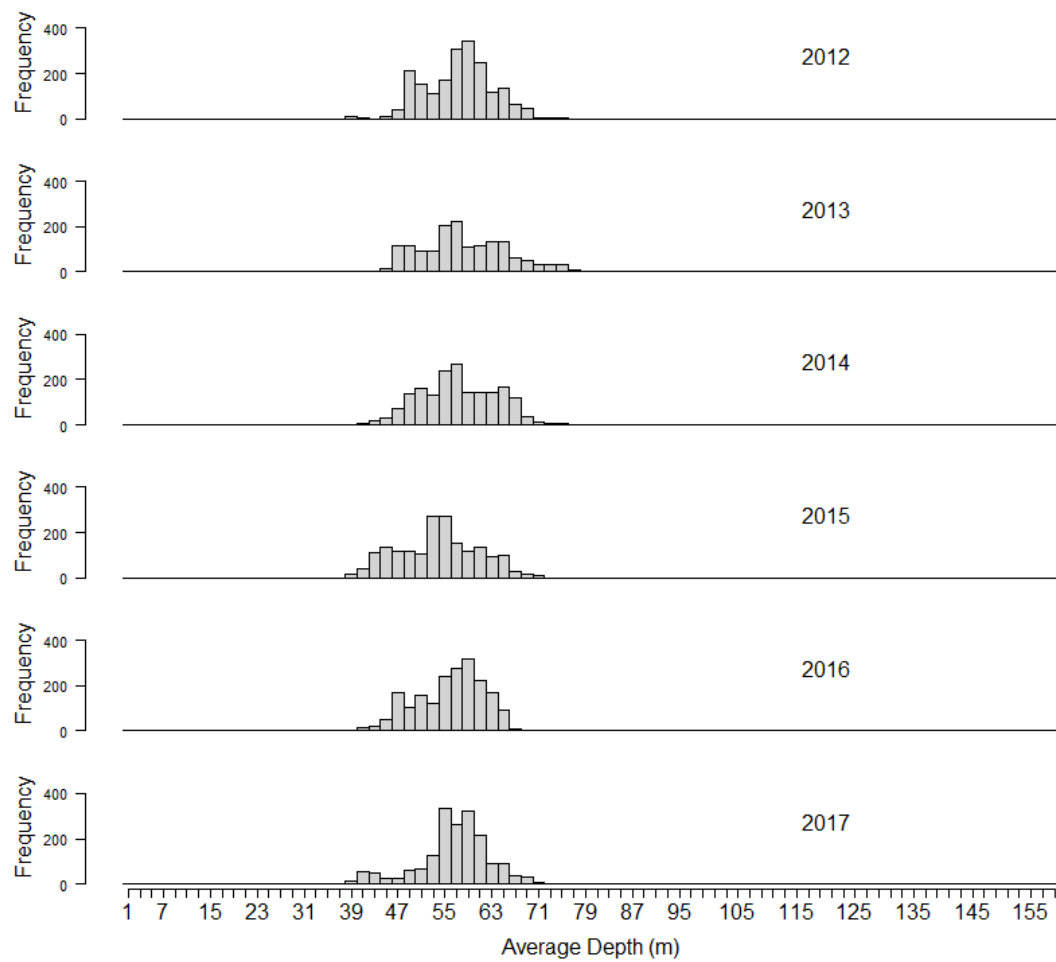


Figure 40. Histograms of average depth (m) by watch for Banquereau from 2012 to 2017.

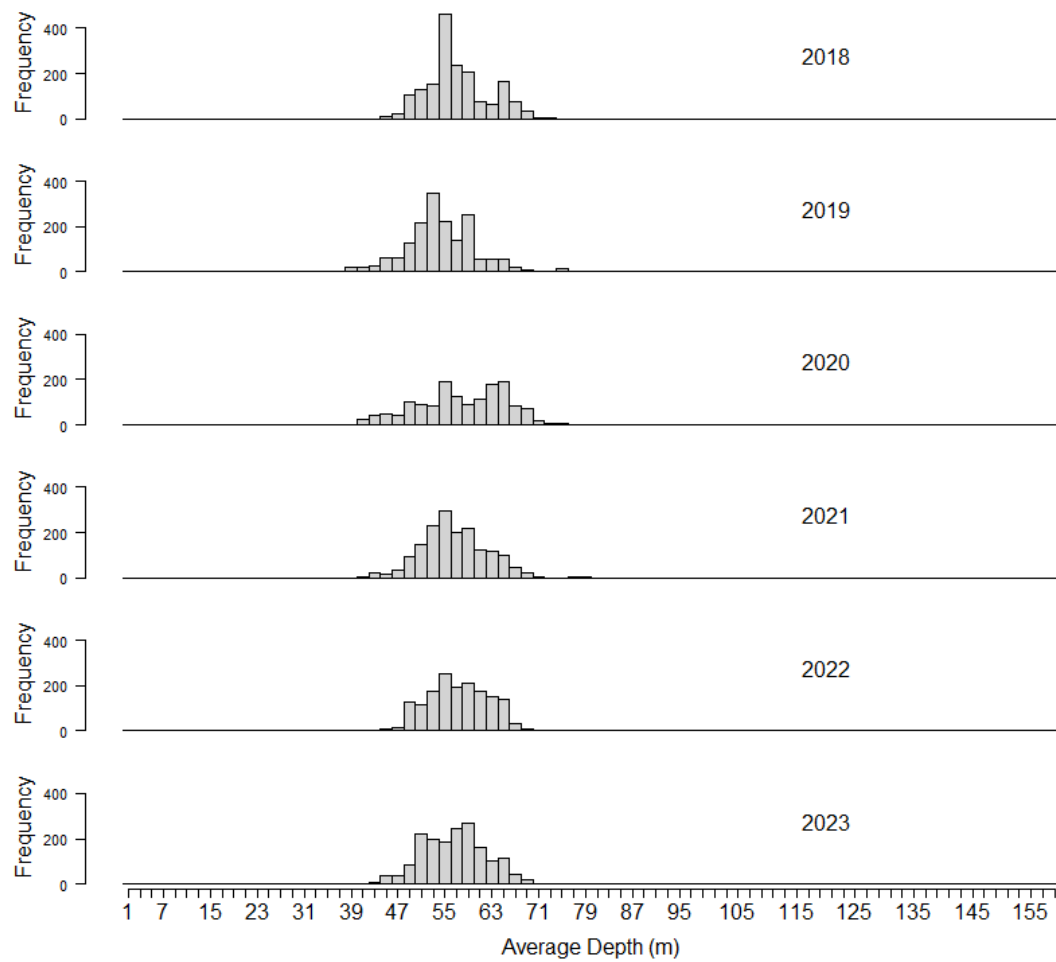


Figure 41. Histograms of average depth (m) by watch for Banquereau 2018 to 2023.

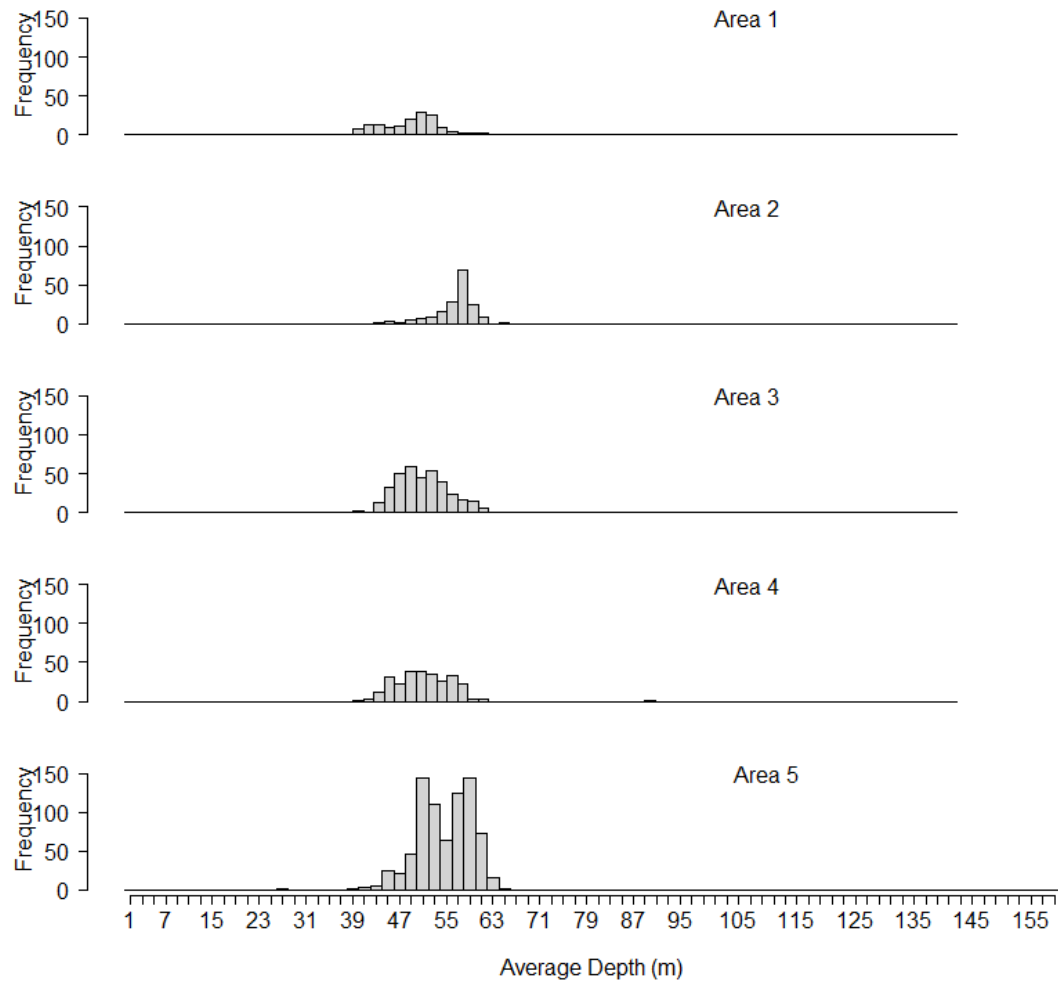


Figure 42. Histograms of average depth (m) by assessment area for Banquereau for 2023.

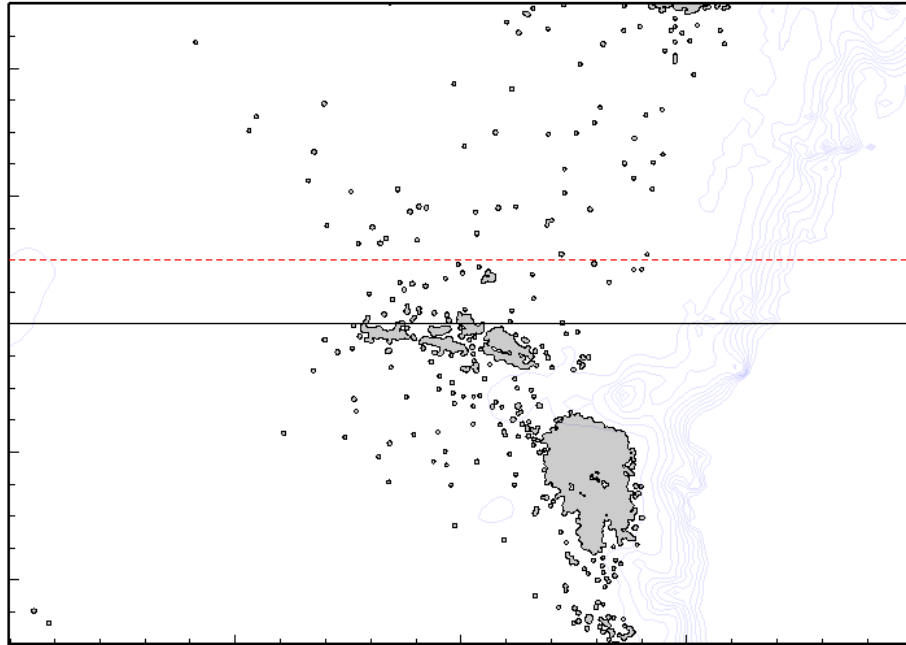


Figure 43. Aggregated Vessel Monitoring System (VMS) data (at 1-hour intervals for 2014 to 2023,) and the survey north/south division (solid black line) and the north/south division (dashed red line) proposed in this research document for Grand Banks.

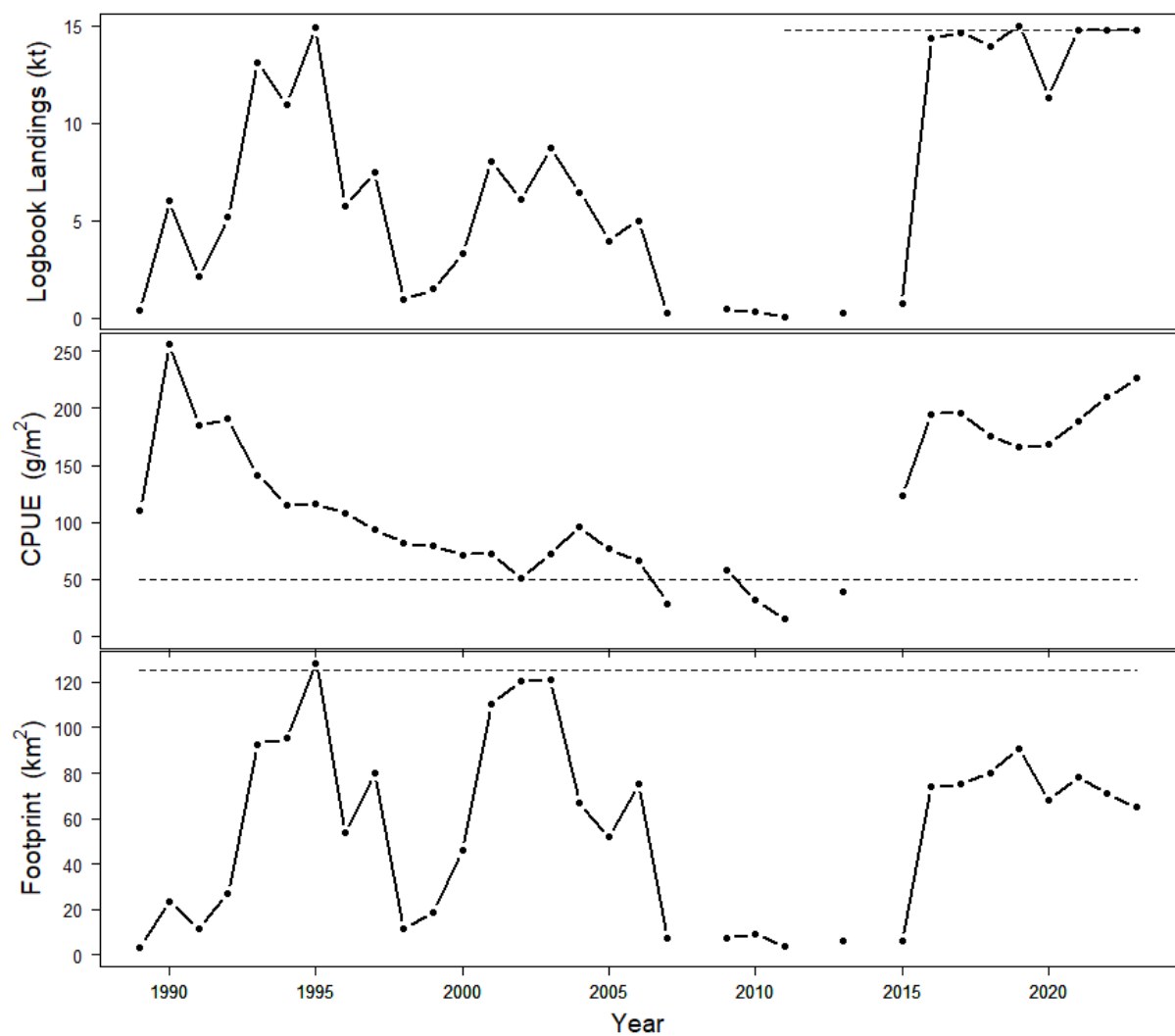


Figure 44. Logbook landings (kt) [upper panel], catch per unit effort (CPUE; g/m²) [middle panel], and fishery footprint (km²) [bottom panel] for Grand Banks from 1989 to 2023. Horizontal dashed lines represent total allowable catch (upper panel) or threshold levels for secondary indicators (middle and lower panels).

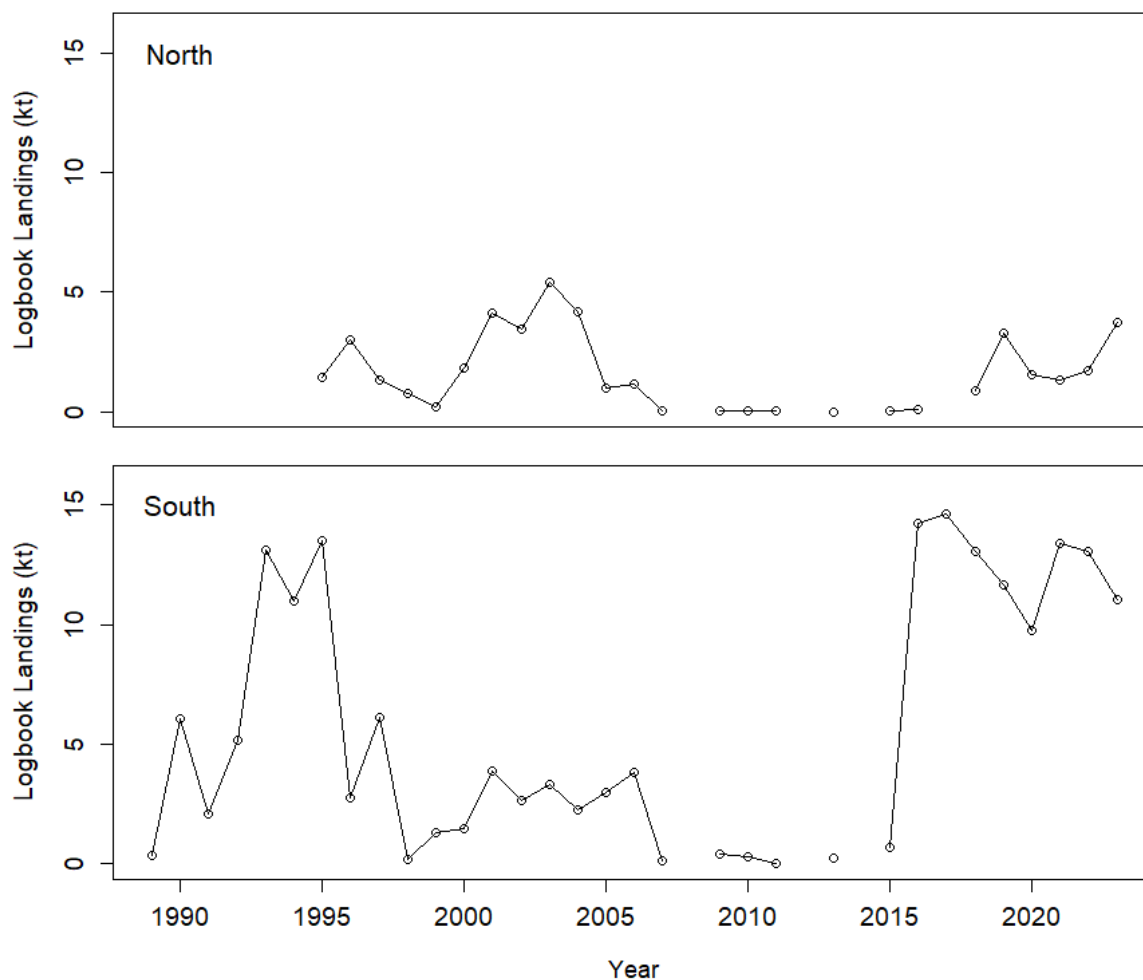


Figure 45. Catch (kt) for North and South Grand Banks from 1989 to 2023.

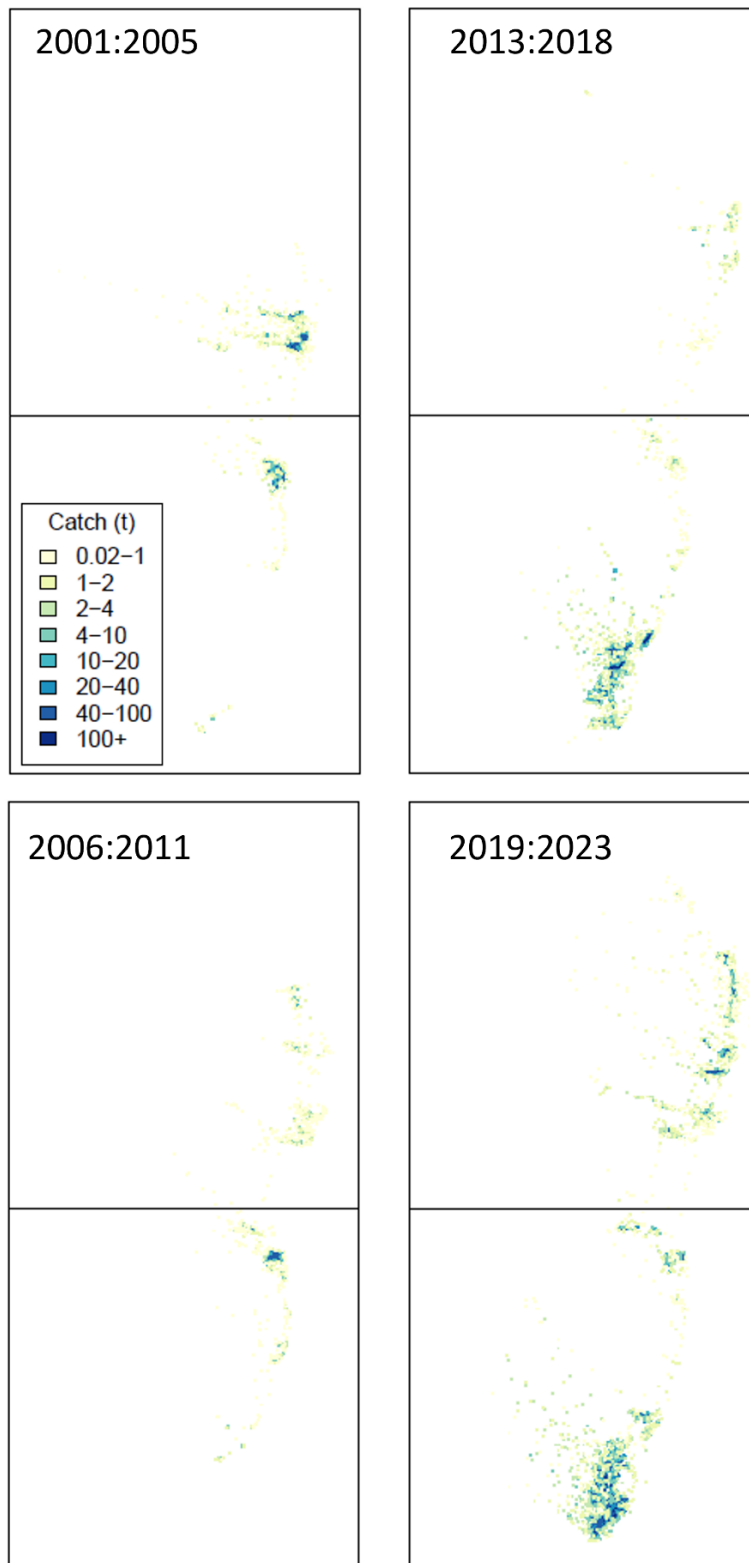


Figure 46. Catch (t) aggregated in five-year increments for Grand Banks. Horizontal black line in each sub-panel is the north-south division. Only years with landings are included in the five-year aggregates.

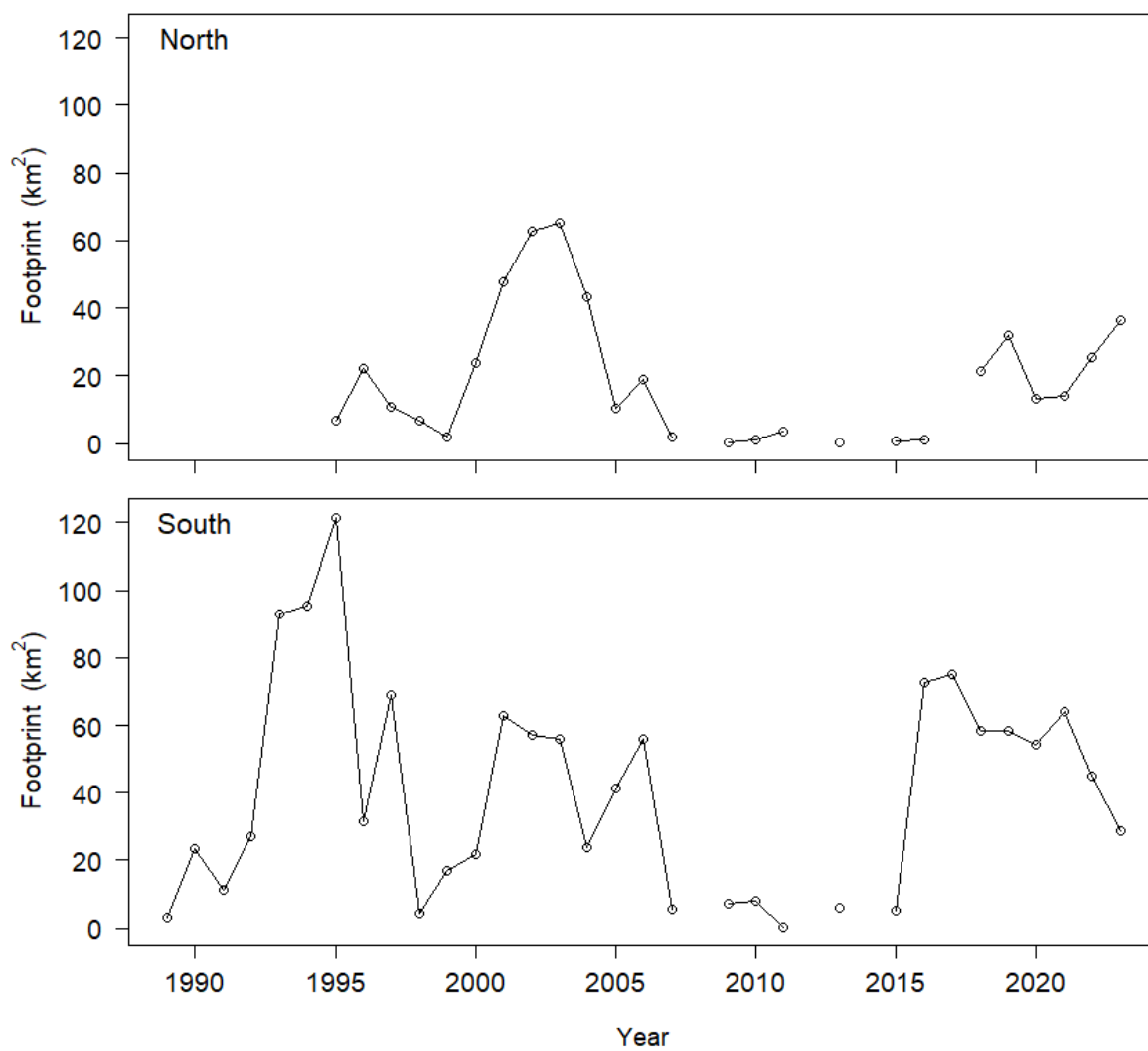


Figure 47. Footprint (Effort, km²) for North and South Grand Banks from 1989 to 2023.

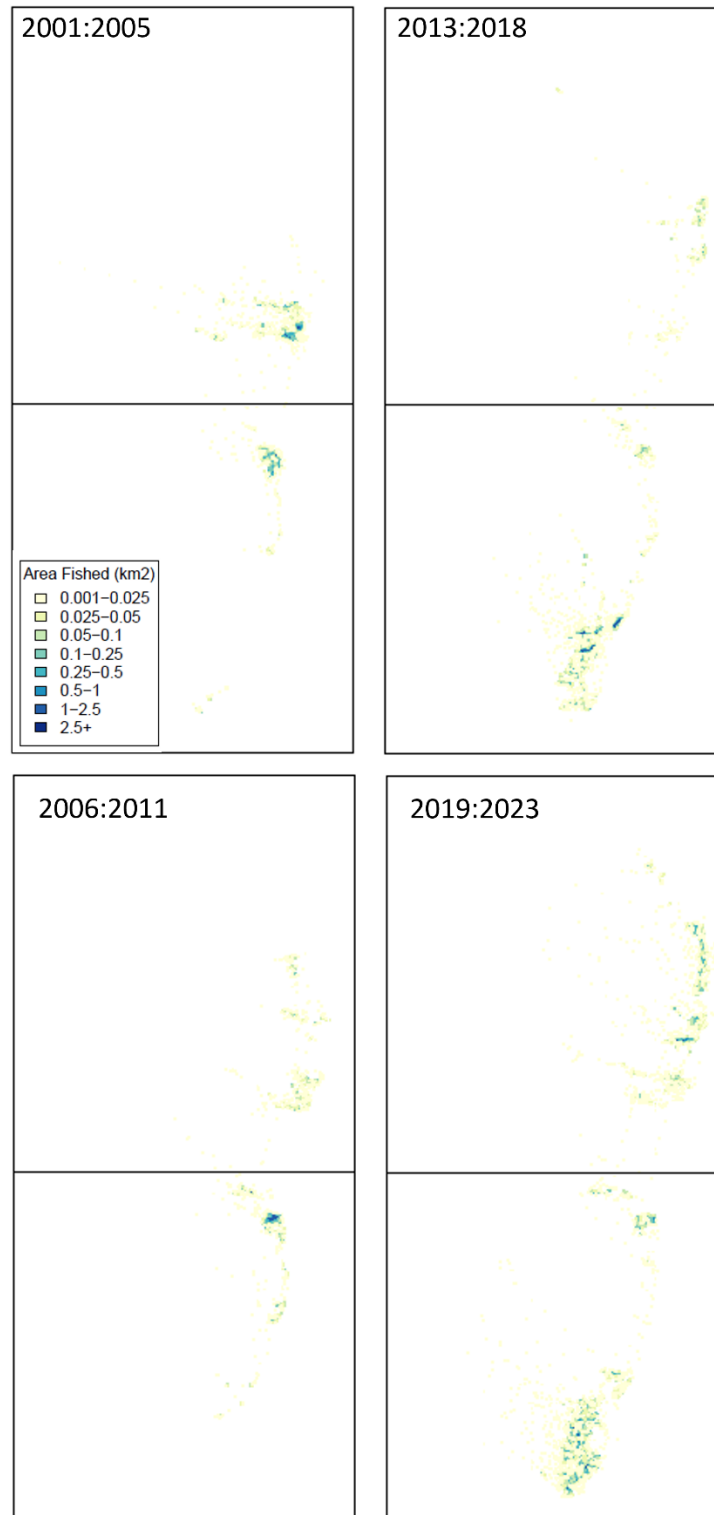


Figure 48. Effort (km²) aggregated in five-year increments on the Grand Banks. Horizontal black line in each sub-panel is the north-south division. Only years with landings are included in the five-year aggregates.

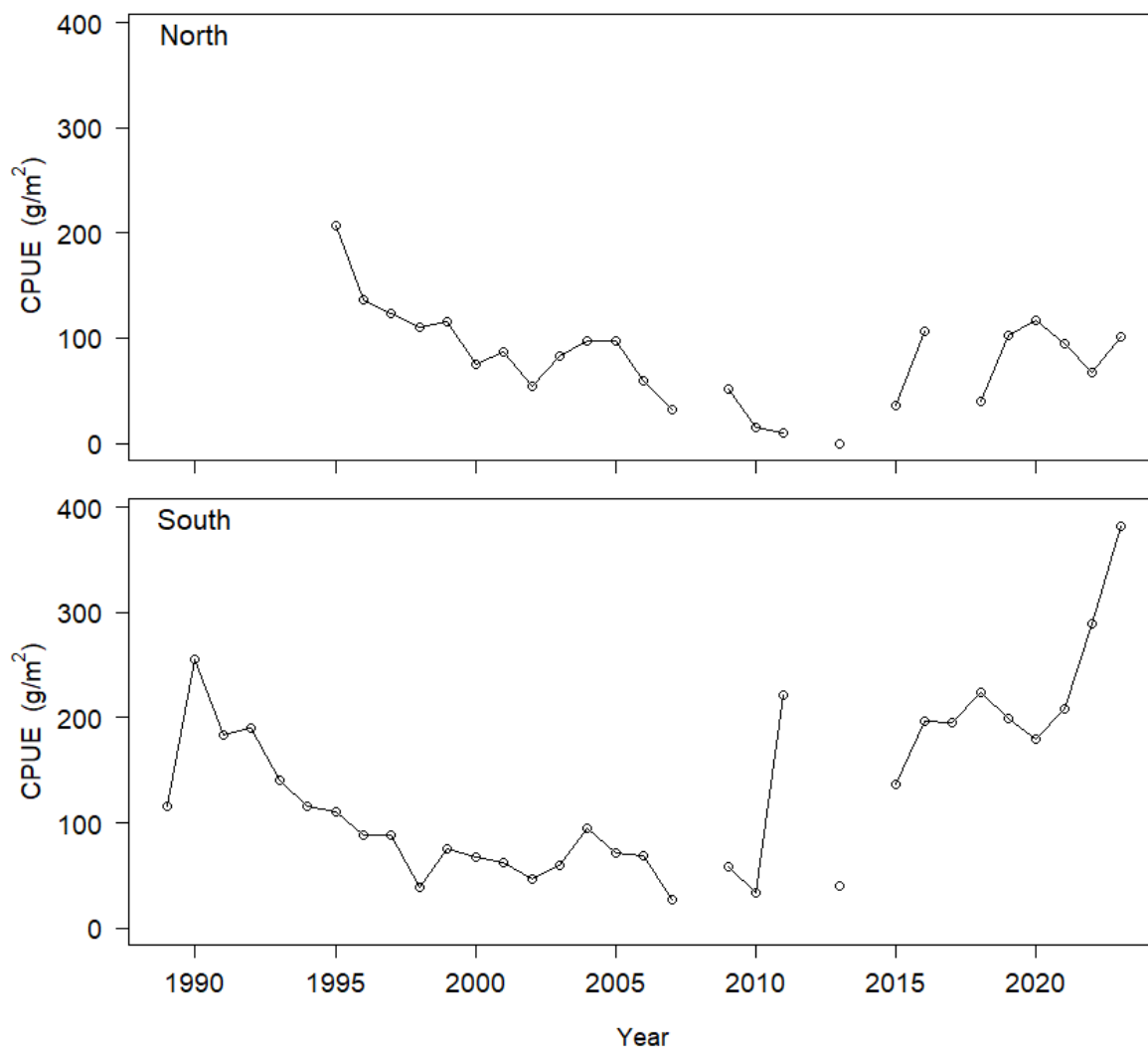


Figure 49. CPUE (g/m²) for North and South Grand Banks from 1989 to 2023.

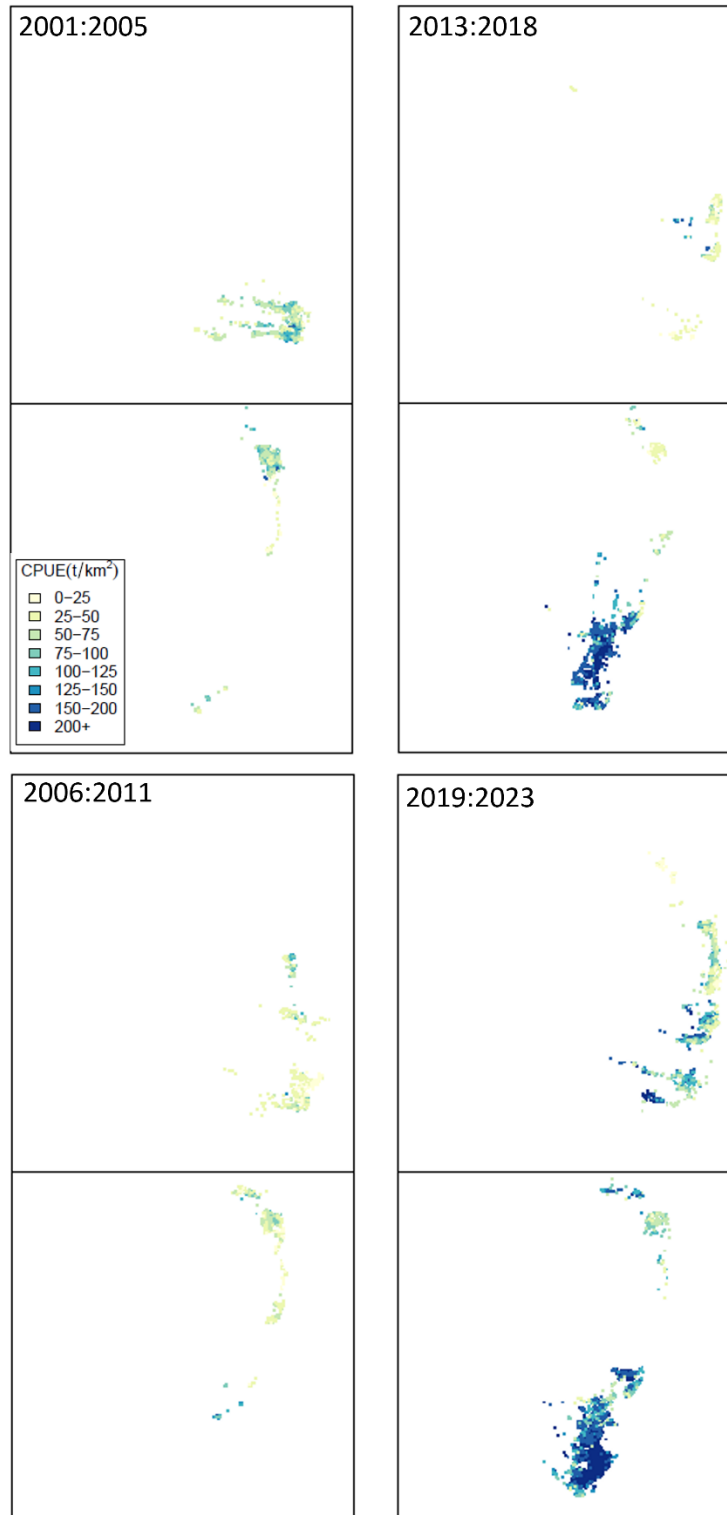


Figure 50. Catch per unit effort (CPUE, t/km^2) aggregated in five-year increments on the Grand Banks. Horizontal black line in each sub-panel is the north-south division. Only years with landings are included in the five-year aggregates.

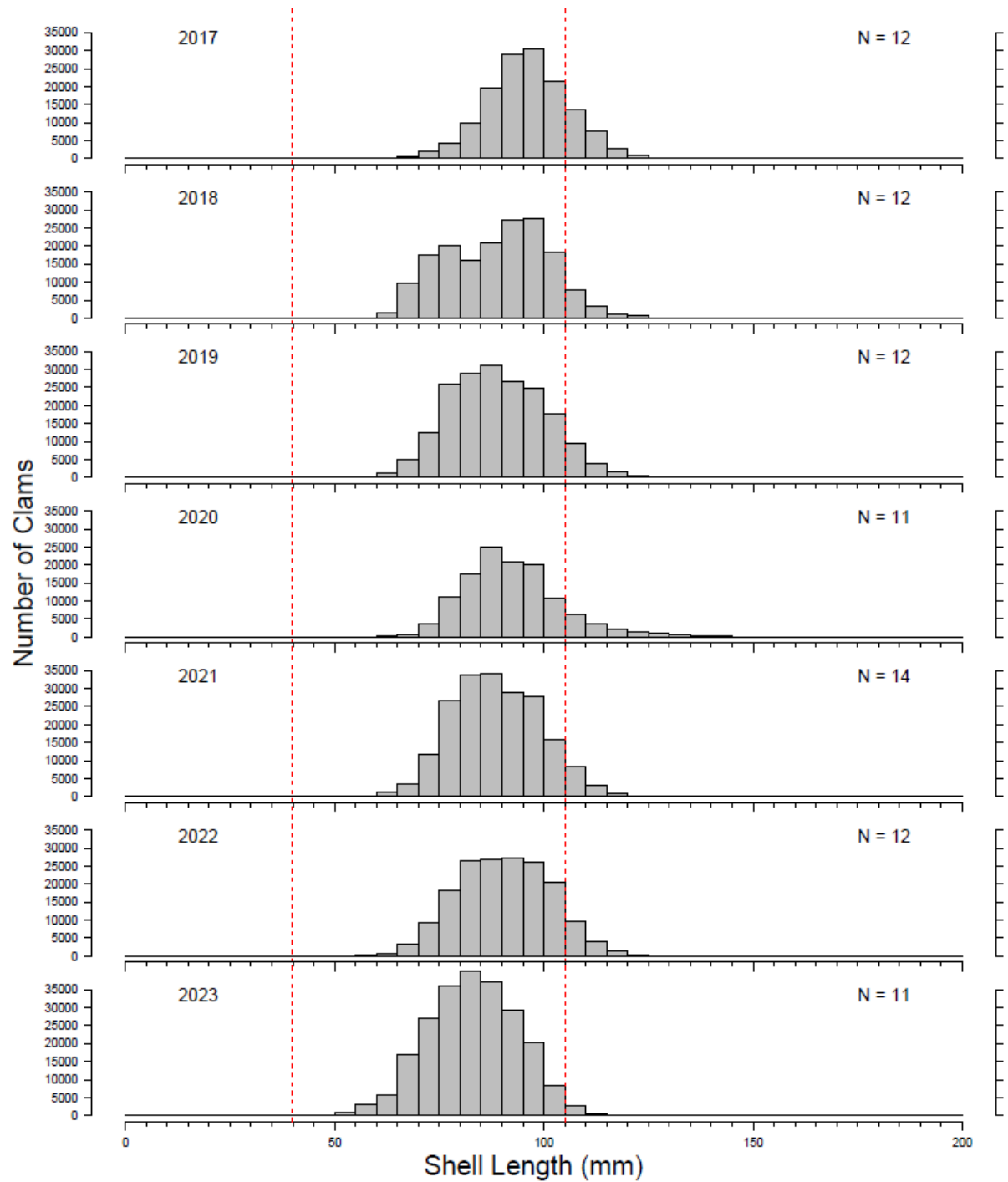


Figure 51. Shell length frequencies for Grand Banks from 2017 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (39.9 mm) and right-hand, dashed red vertical line is the length (105 mm) used for Length Indicator 1.

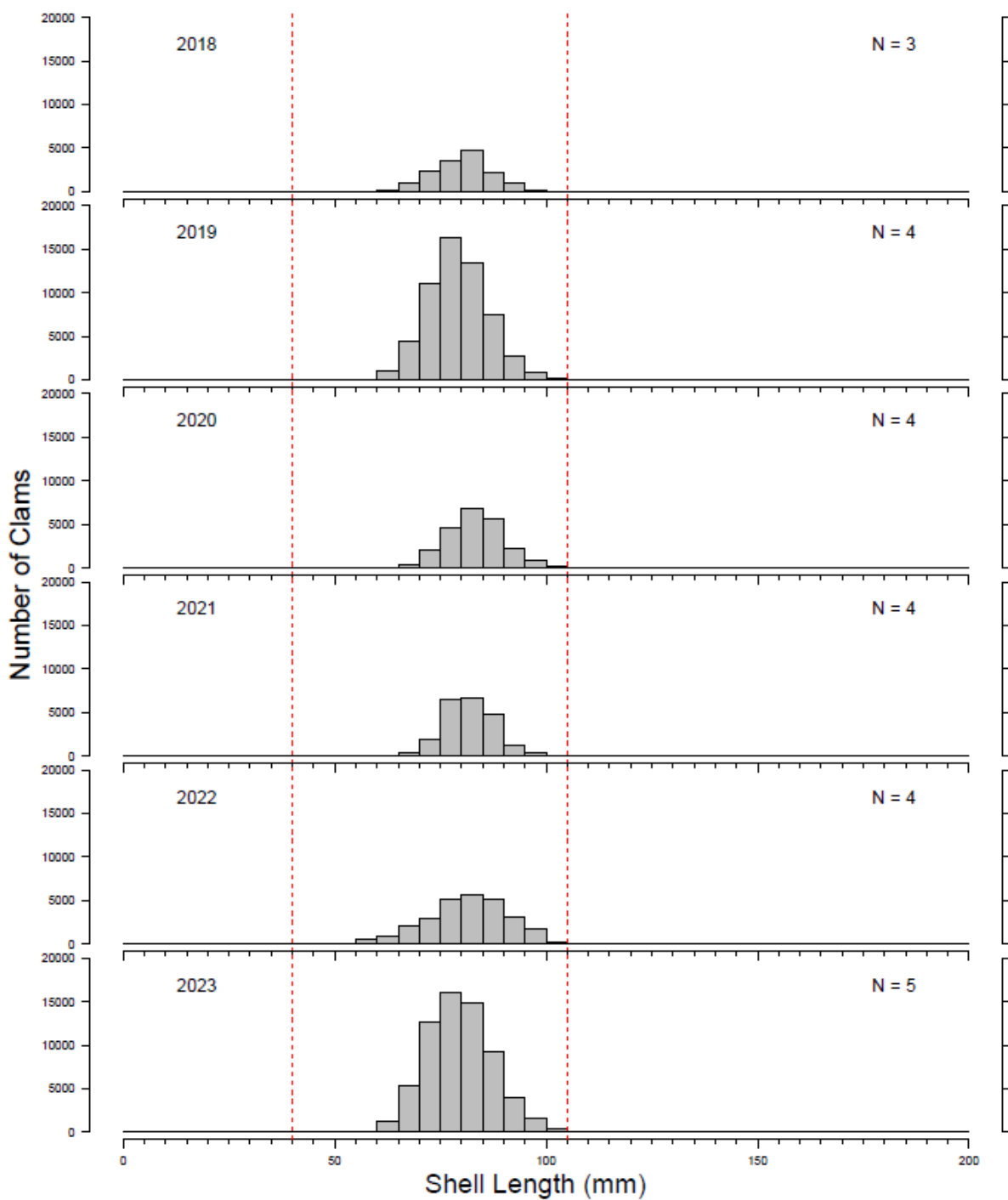


Figure 52. Shell length frequencies for the north portion of Grand Banks from 2018 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (39.9 mm) and right-hand, dashed red vertical line is the length (105 mm) used for Length Indicator 1.

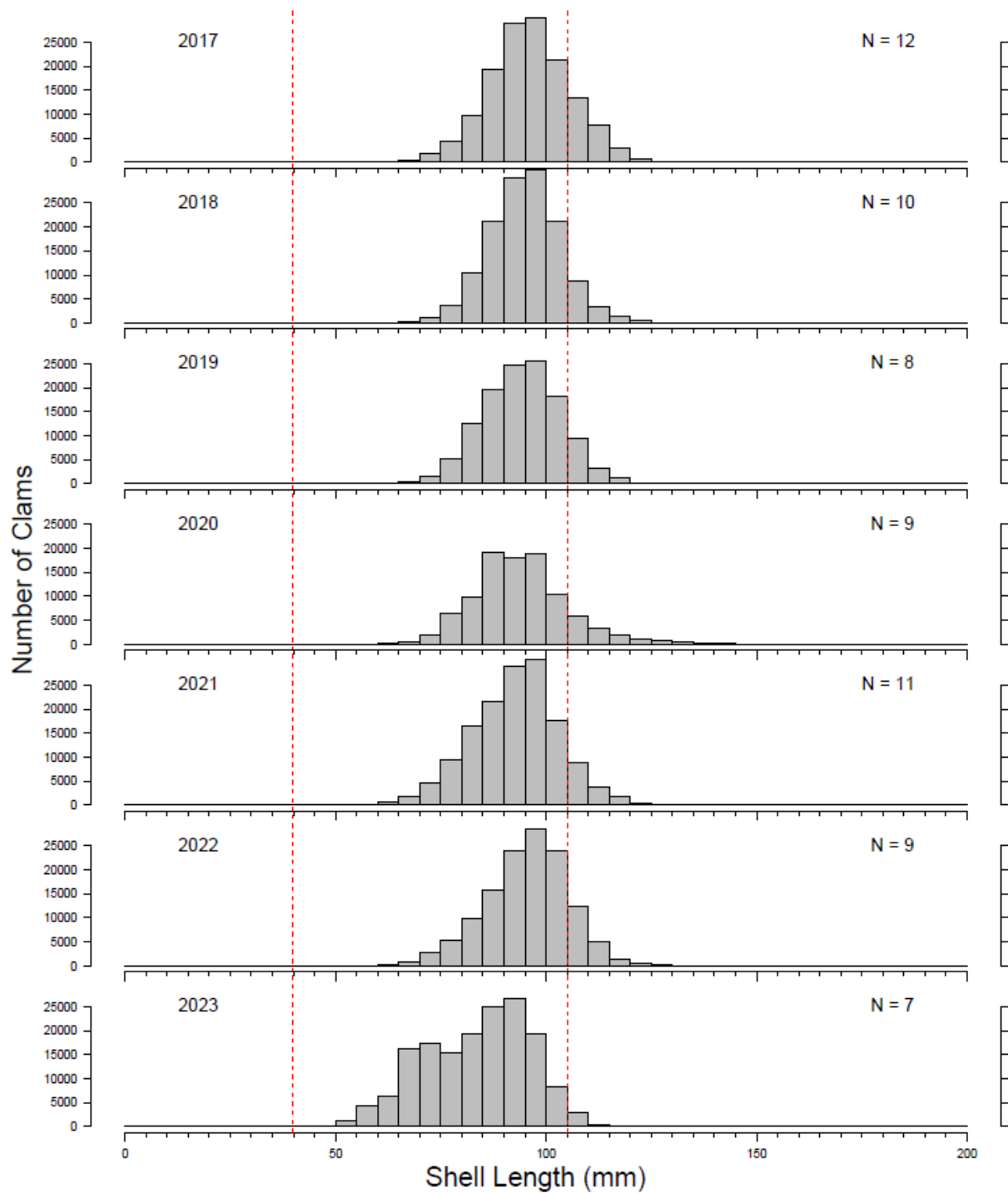


Figure 53. Shell length frequencies for the south portion of Grand Banks from 2017 to 2023. Numbers adjusted for catch weights. N is number of trips with samples. Left-hand, dashed red vertical line is size at 50% sexual maturity (39.9 mm) and right-hand, dashed red vertical line is the length (105 mm) used for Length Indicator 1.

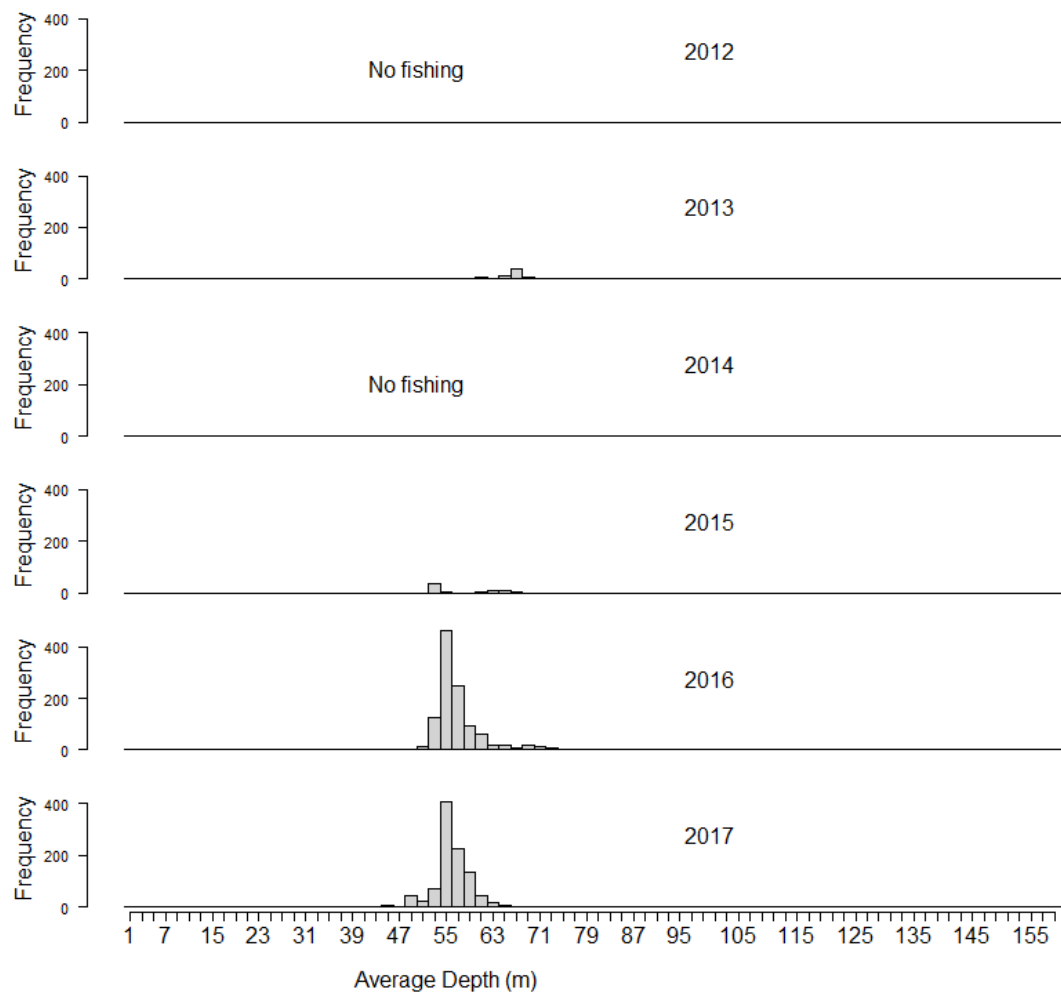


Figure 54. Histograms of average depth (m) by watch for Grand Banks from 2012 to 2017.

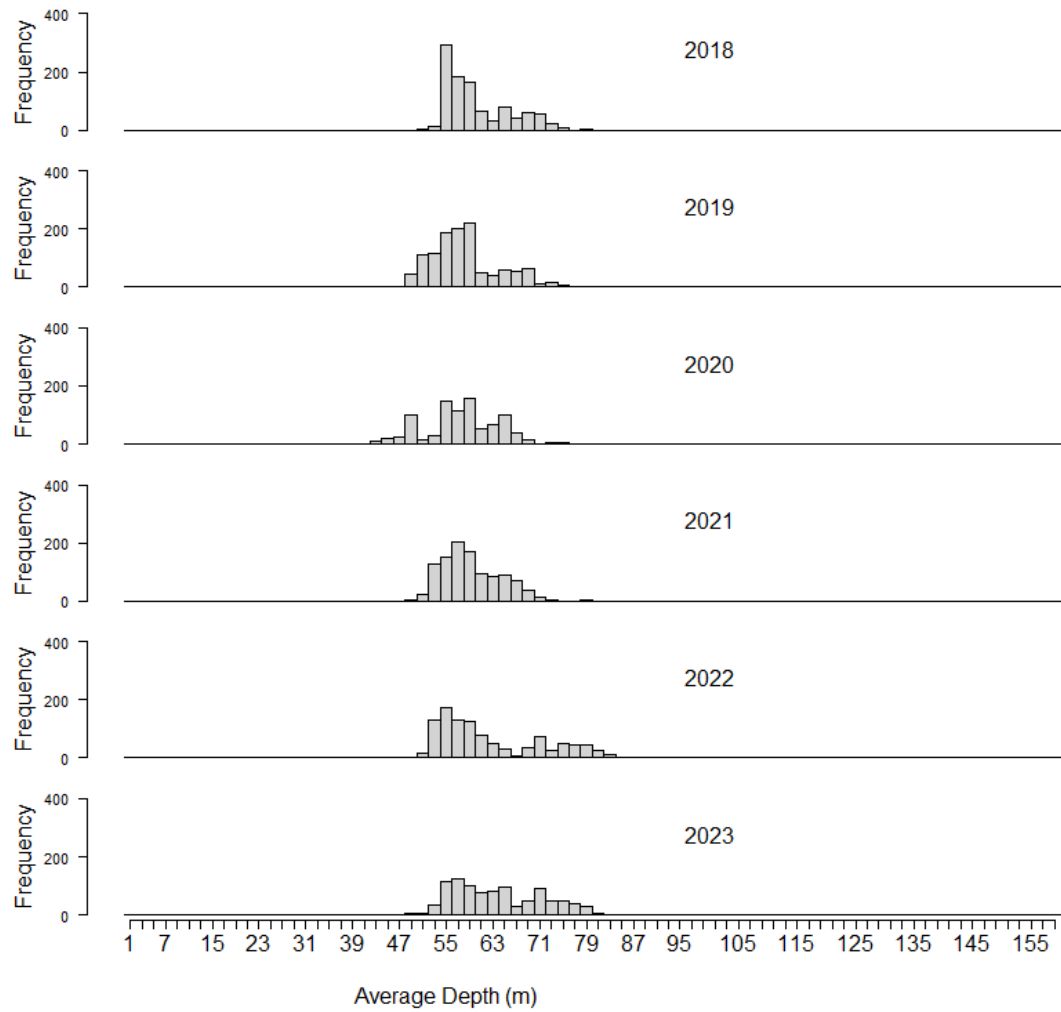


Figure 55. Histograms of average depth (m) by watch for Grand Banks from 2017 to 2022.

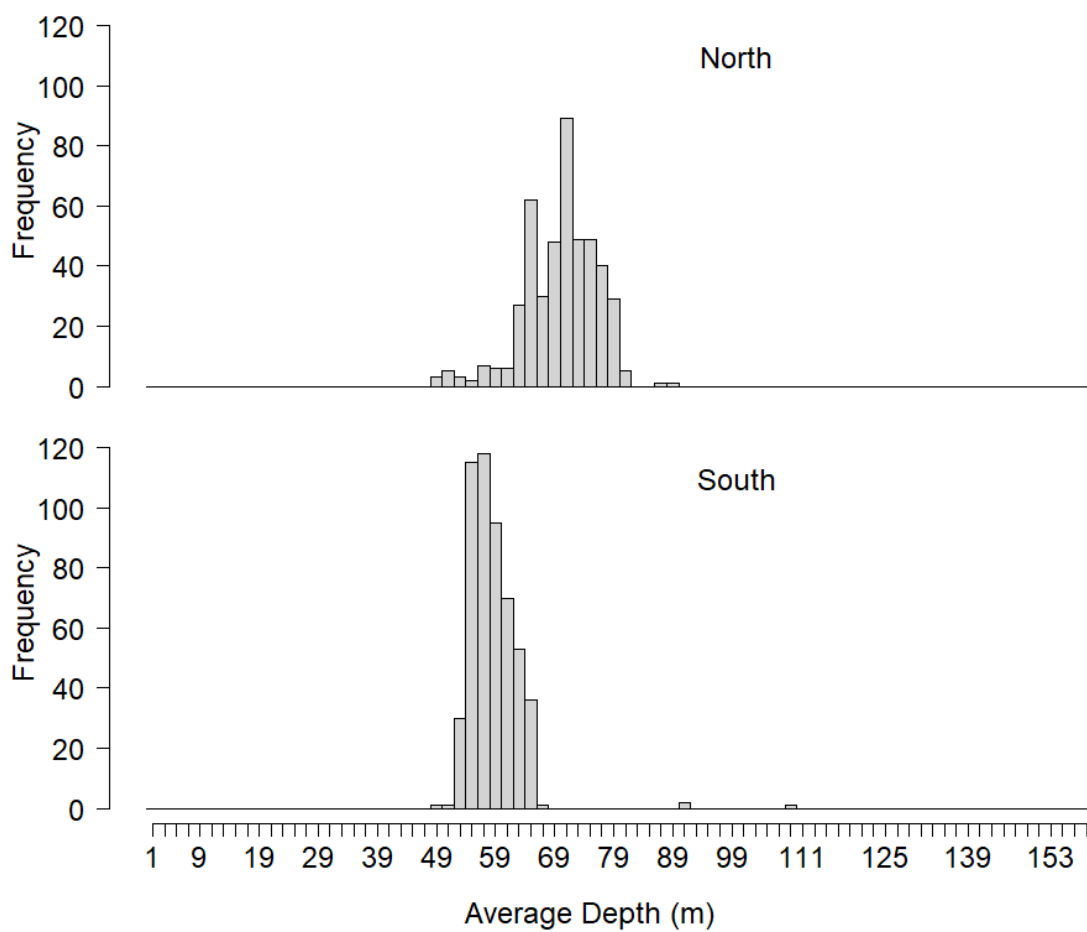


Figure 56. Histograms of average depth (m) by watch for the North (upper panel) and South (lower panel) portions of Grand Banks for 2023.

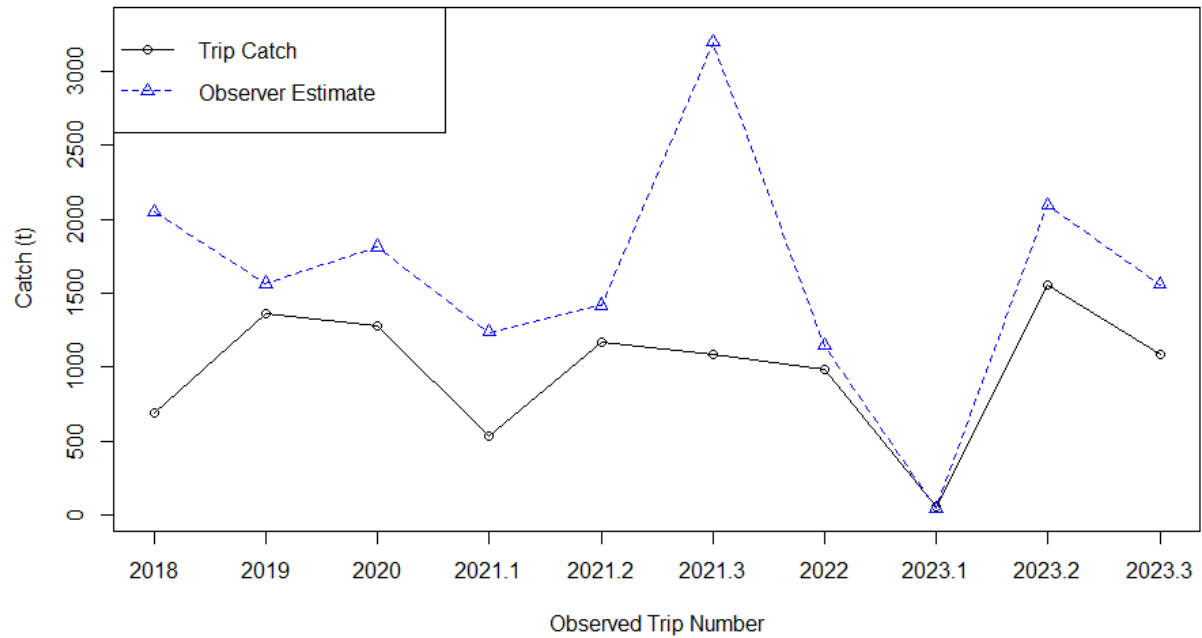


Figure 57. Banquereau trip catch (t ; black circles and solid line) of Arctic Surf Clam compared to Observer estimates for those trips (blue triangles and dashed line). Note that the x-axis is categorical and not continuous.

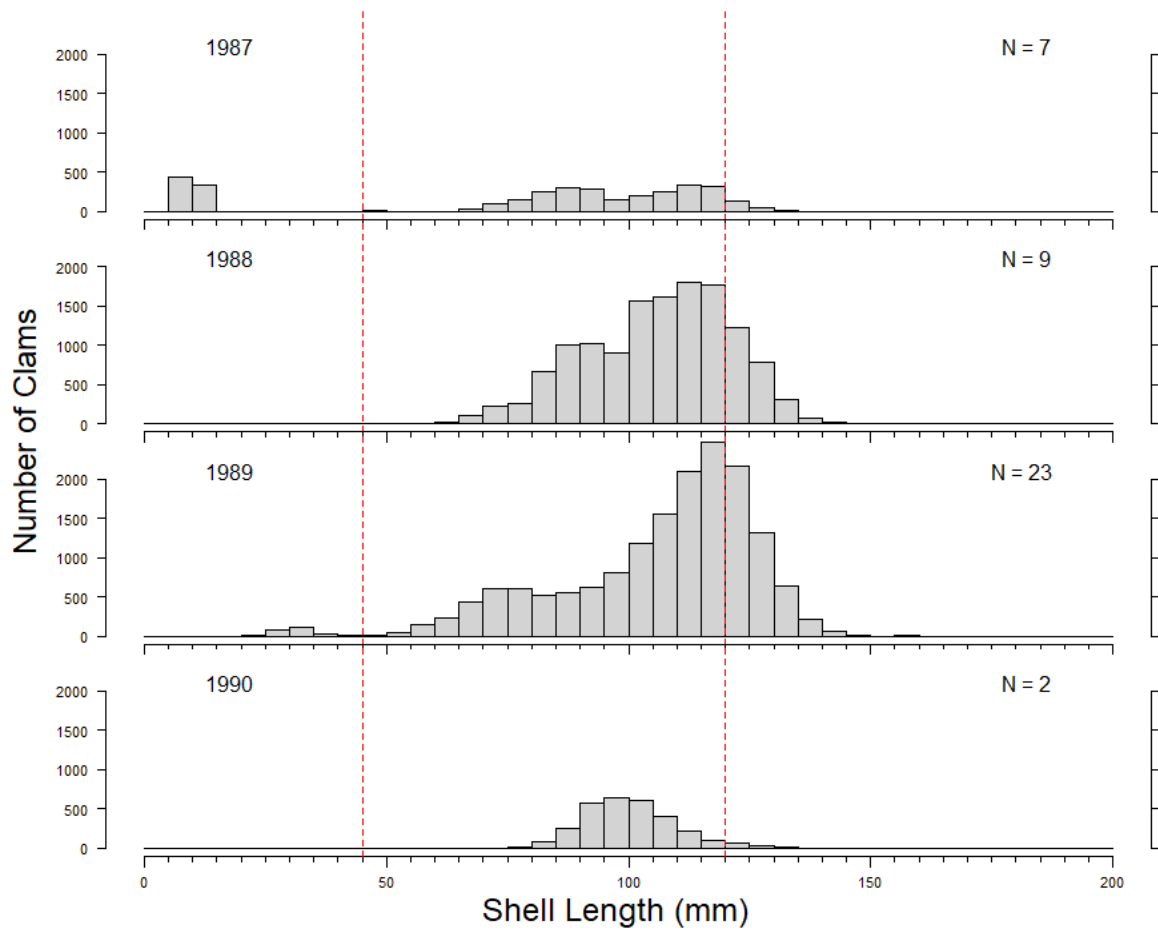


Figure 58. Shell length frequencies from Observed fishing trips on Banquereau from 1987 to 1990. N is number of trips. Left-hand dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for Length Indicator 1.

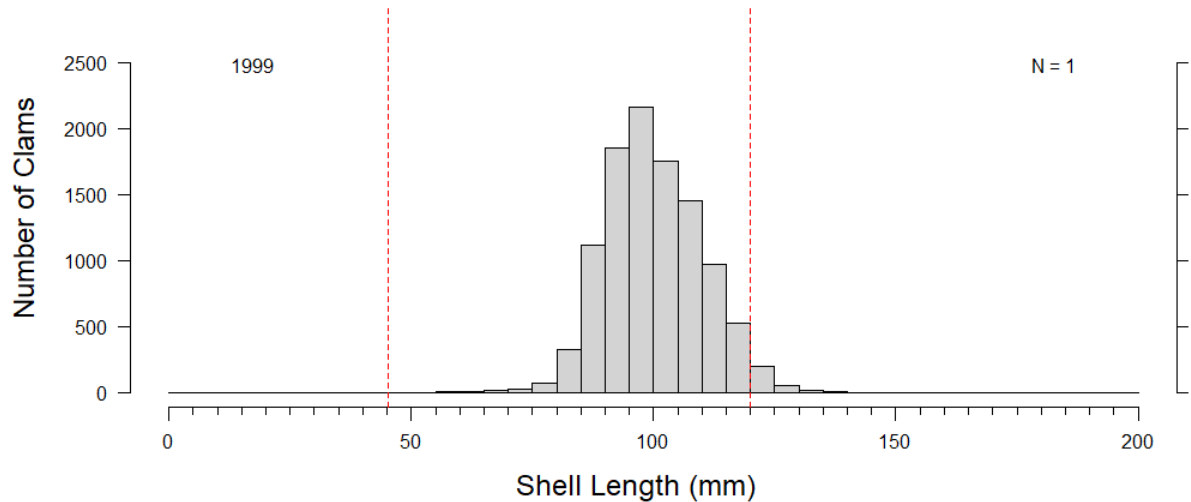


Figure 59. Shell length frequencies from Observed fishing trips on Banquereau for 1999. *N* is number of trips. Left-hand dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for Length Indicator 1.

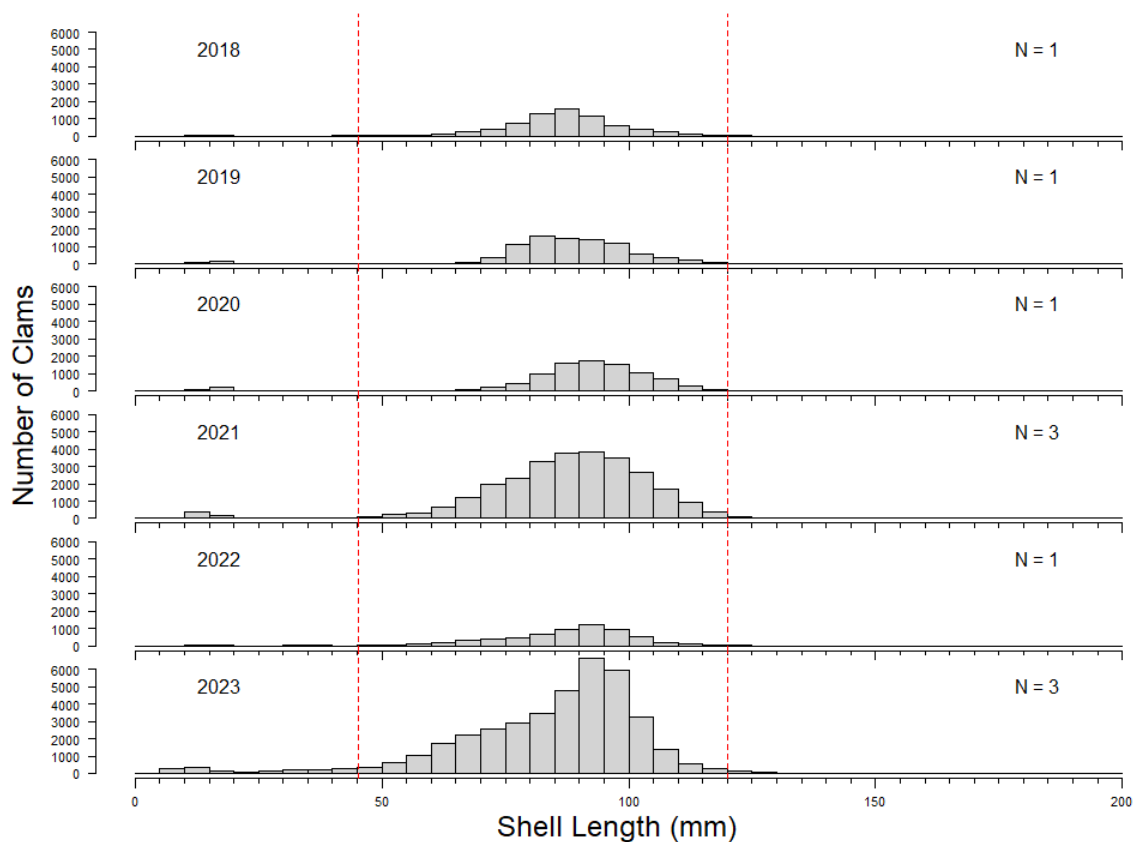


Figure 60. Shell length frequencies from Observed fishing trips on Banquereau from 2018 to 2023. *N* is number of trips. Left-hand dashed red vertical line is size at 50% sexual maturity (45.2 mm) and right-hand, dashed red vertical line is the length (120 mm) used for the Length Indicator 1.

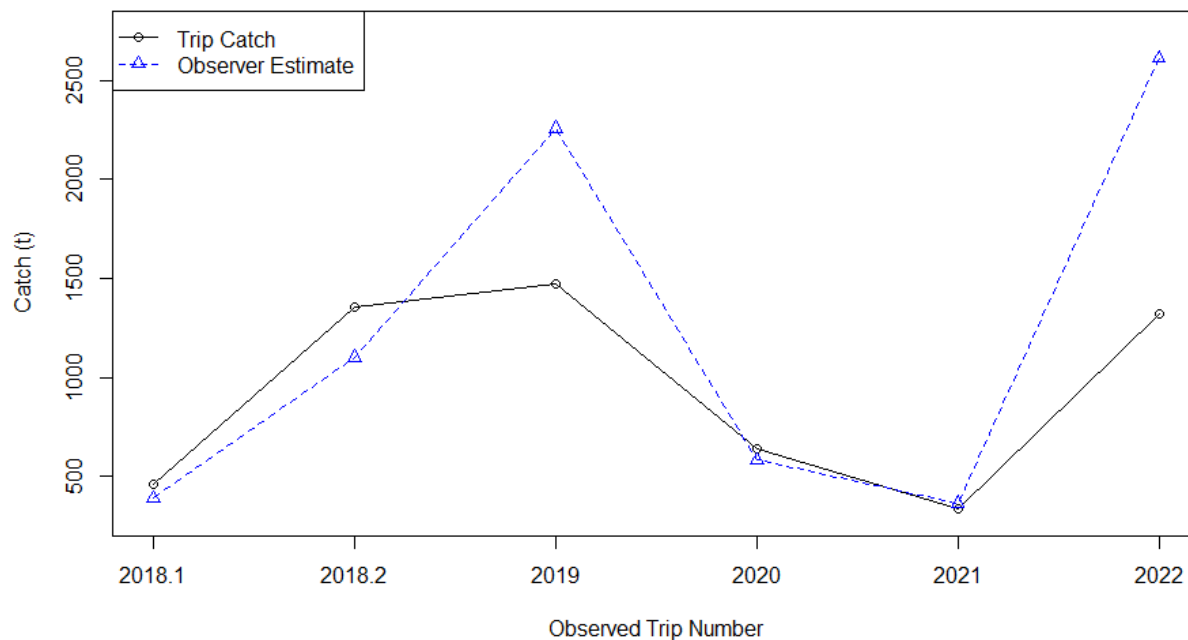


Figure 61. Grand Banks trip catch (t ; black circles and solid line) of Arctic Surf Clam compared to Observer estimates for those trips (blue triangles and dashed line). Note that the x-axis is categorical and not continuous.

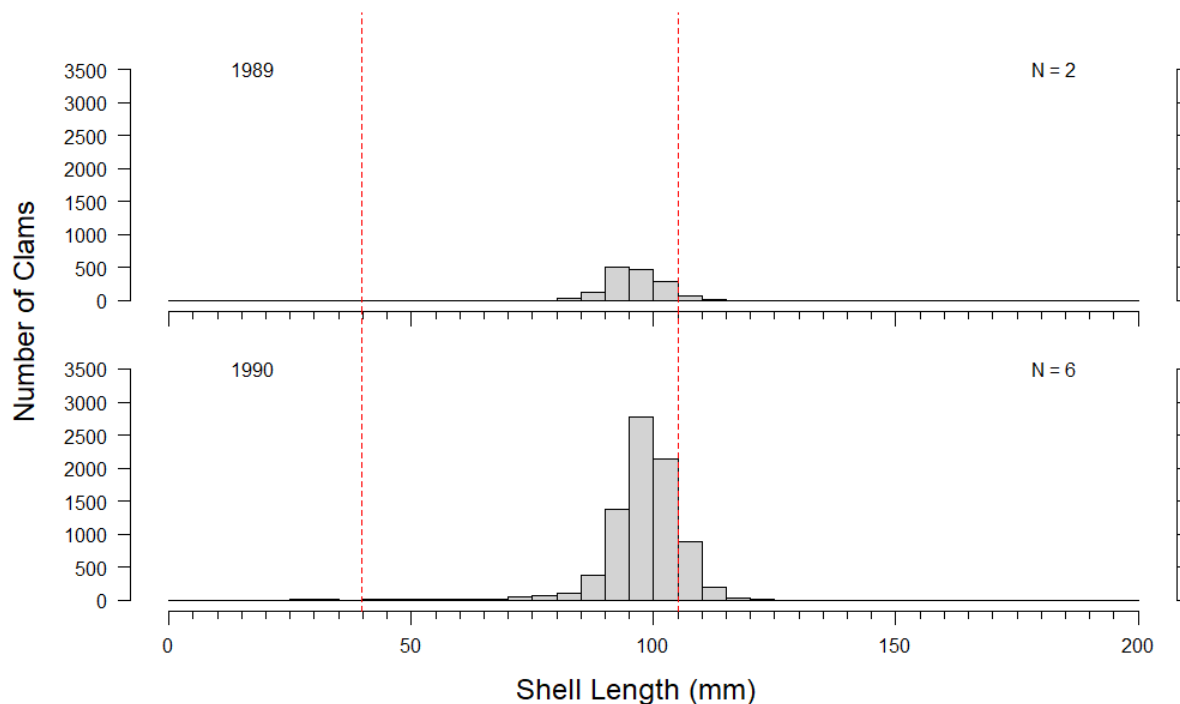


Figure 62. Shell length frequencies from Observed fishing trips on the Grand Banks from 1989 to 1990. N is number of trips. Left-hand dashed red vertical line is size at 50% sexual maturity (39.9 mm) and right-hand, dashed red vertical line is the length (105 mm) used for Length Indicator 1.

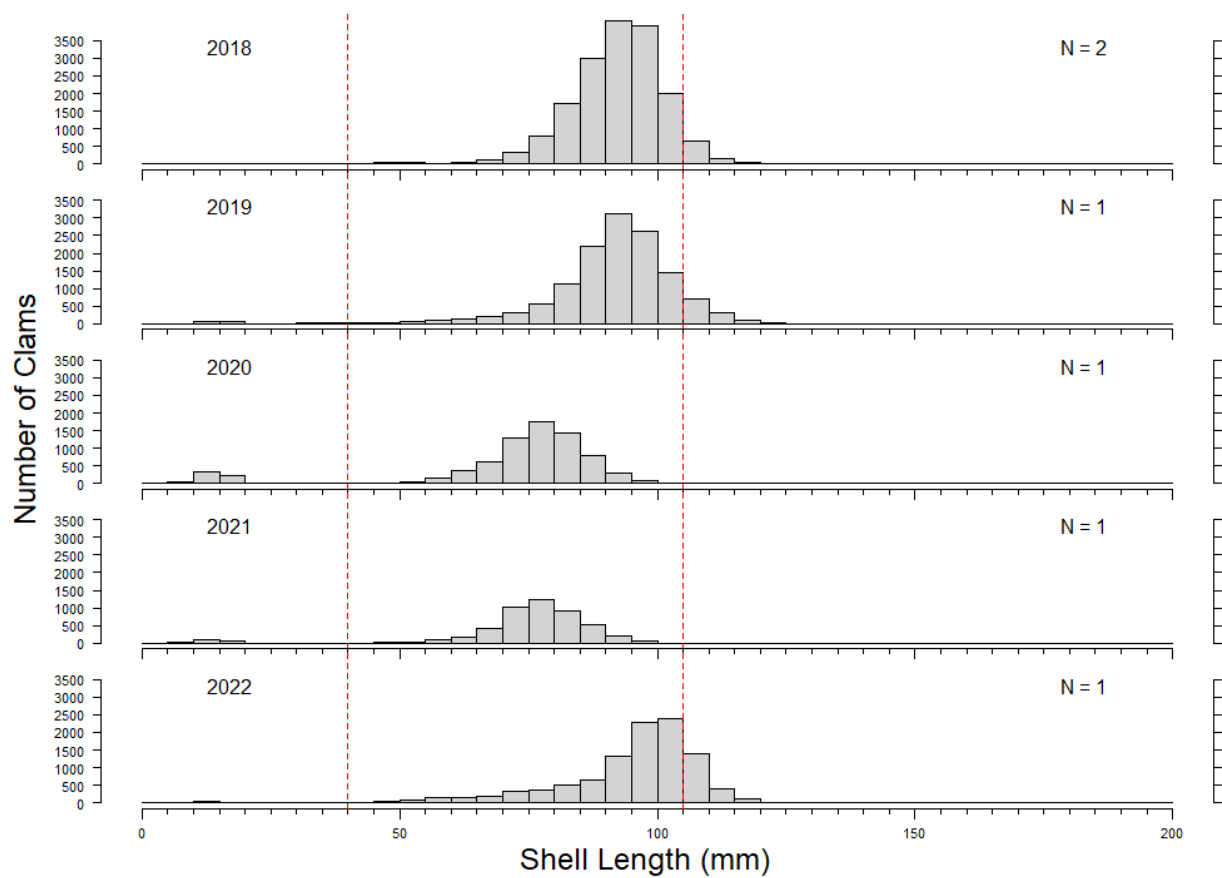


Figure 63. Shell length frequencies from Observed fishing trips on the Grand Banks from 2018 to 2022. *N* is number of trips. Left-hand dashed red vertical line is size at 50% sexual maturity (39.9 mm) and right-hand, dashed red vertical line is the length (105 mm) used for Length Indicator 1.

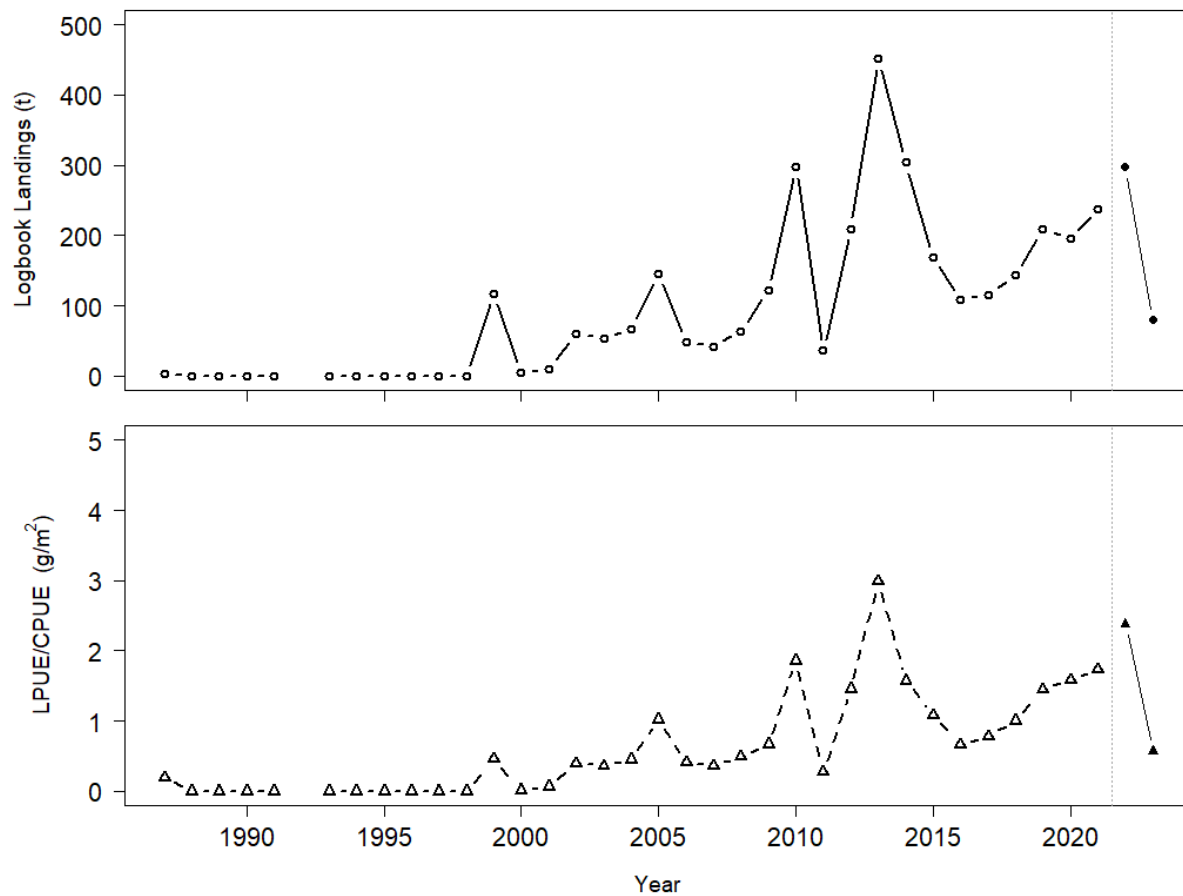


Figure 64. Banquereau Greenland Cackle landings (t; top panel), landings per unit effort (LPUE g/m²; bottom panel, open triangles) and catch per unit effort (CPUE, g/m²; bottom panel, solid triangles). Vertical dashed line represents change in fishing practice to 100% retention. Corresponding effort is presented in Figure 26.

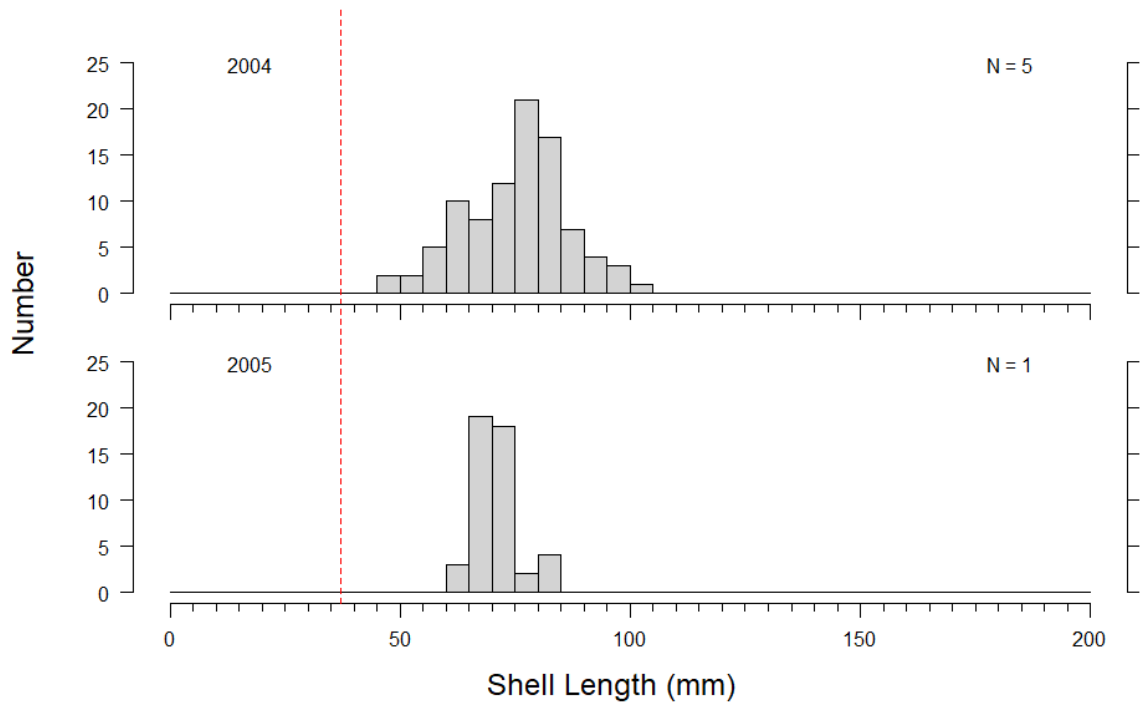


Figure 65. Banquereau Greenland Cockle shell length frequencies from onboard sampling from 2004 and 2005. *N* is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (37.2 mm).

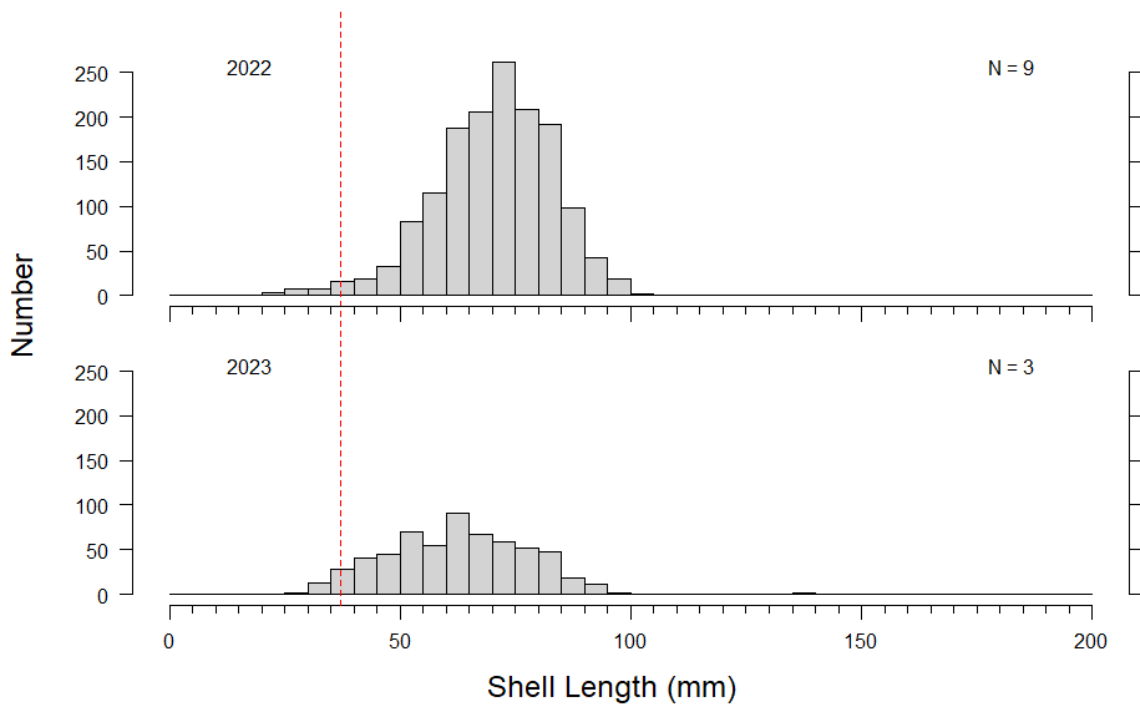


Figure 66. Banquereau Greenland Cockle shell length frequencies from onboard sampling from 2022 and 2023. *N* is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (37.2 mm).

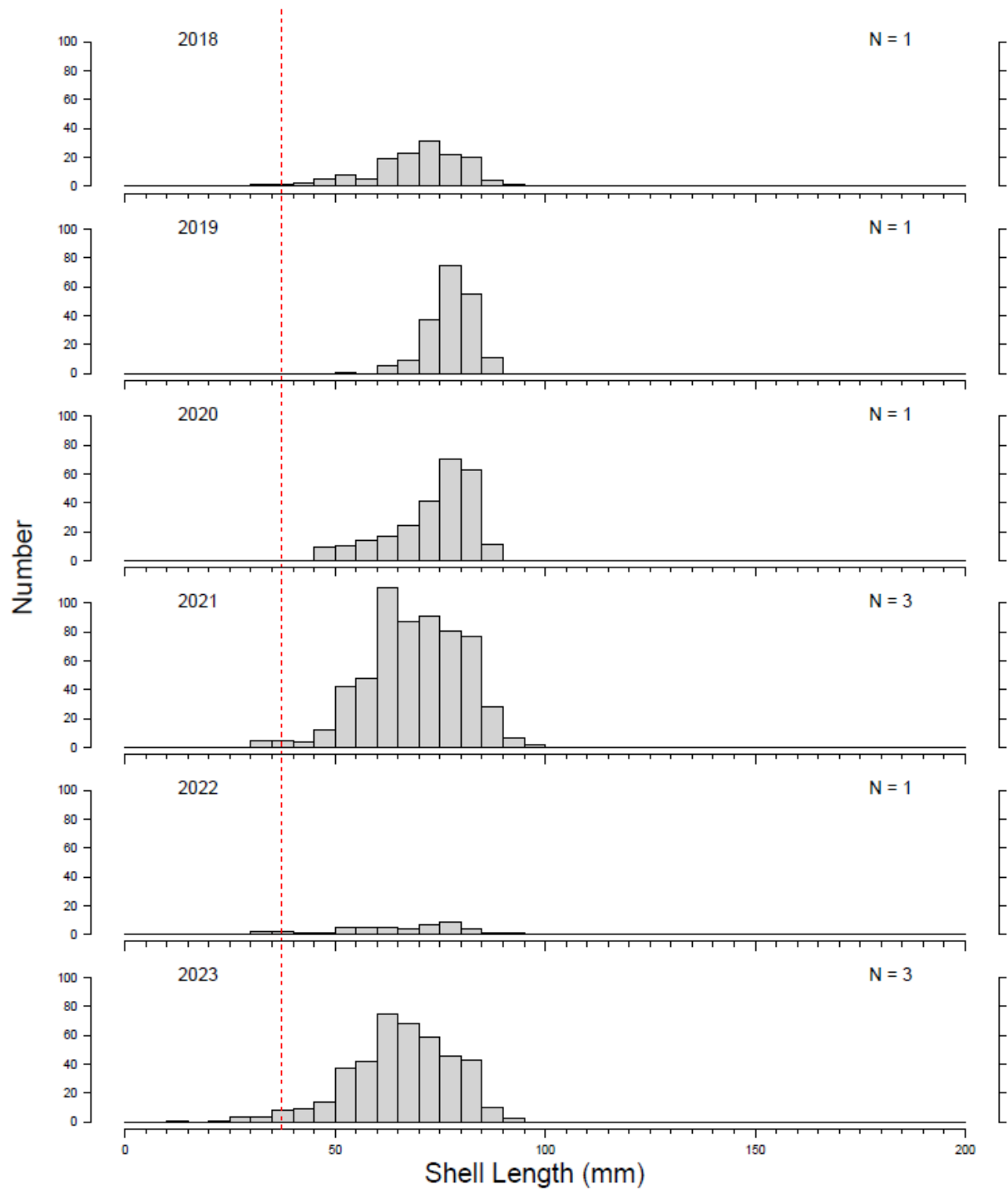


Figure 67. Banquereau Greenland Cockerle shell length frequencies from Observed fishing trip from 2018 to 2023. N is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (37.2 mm).

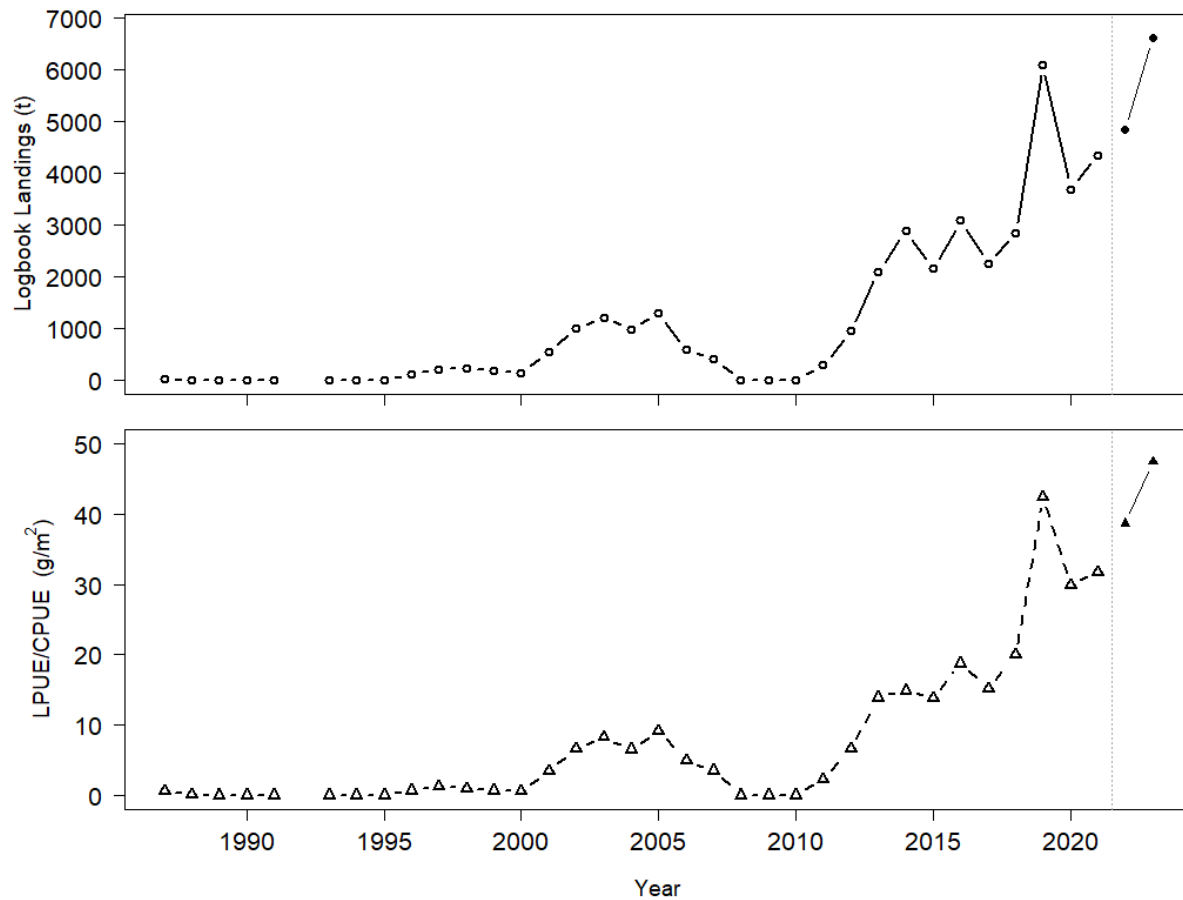


Figure 68. Banquereau Northern Propeller Clam landings (t; top panel), landings per unit effort (LPUE g/m²; bottom panel, open triangles) and catch per unit effort (CPUE, g/m²; bottom panel, solid triangles). Vertical dashed line represents change in fishing practice to 100% retention. Corresponding effort is presented in Figure 26.

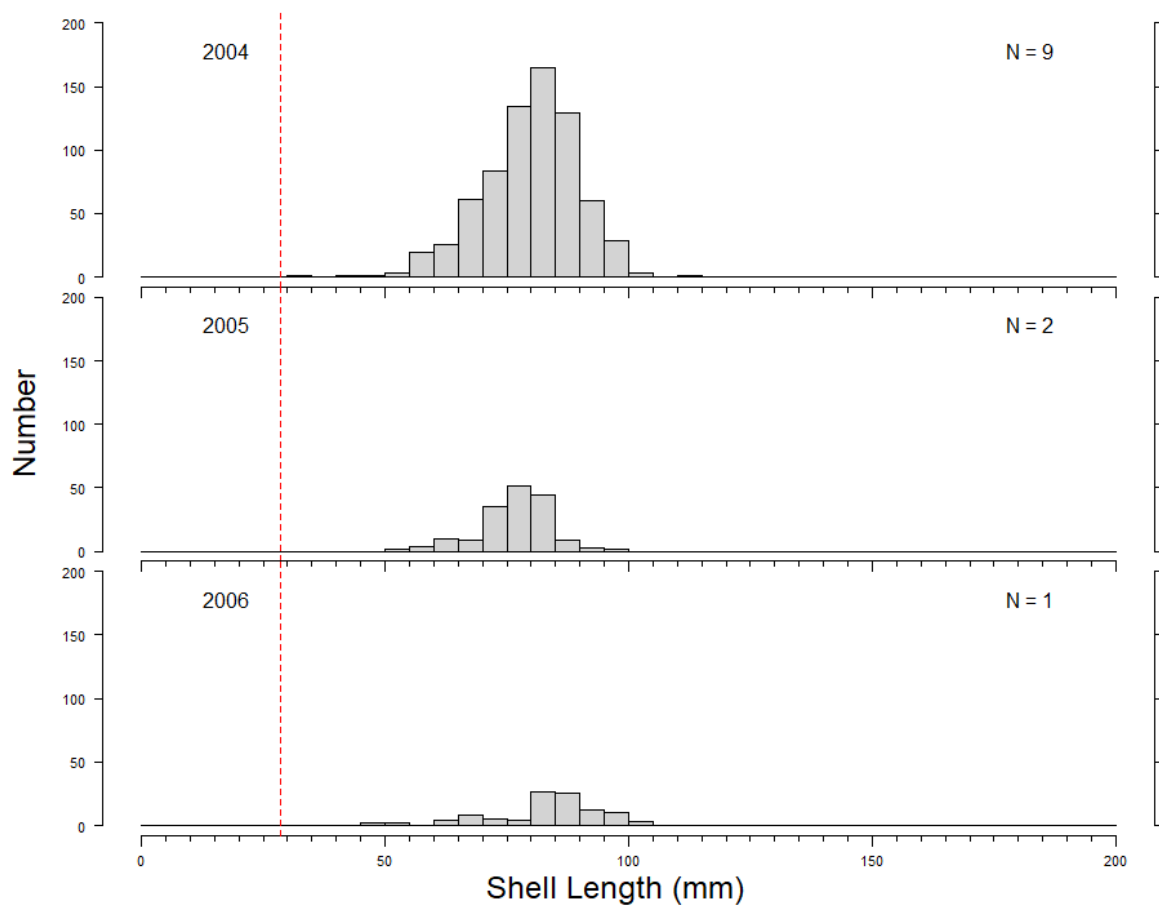


Figure 69. Banquereau Northern Propeller Clam shell length frequencies from onboard sampling from 2004 to 2006. N is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (28.6 mm).

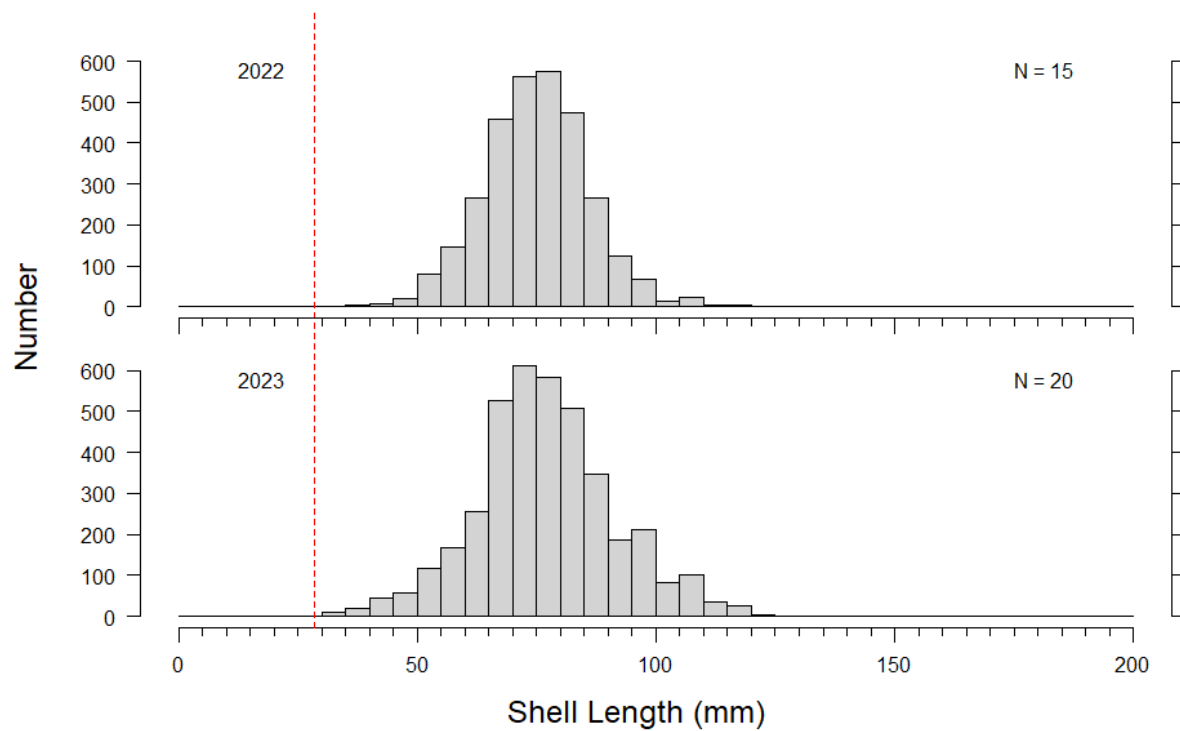


Figure 70. Banquereau Northern Propeller Clam shell length frequencies from onboard sampling from 2022 and 2023. N is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (28.6 mm).

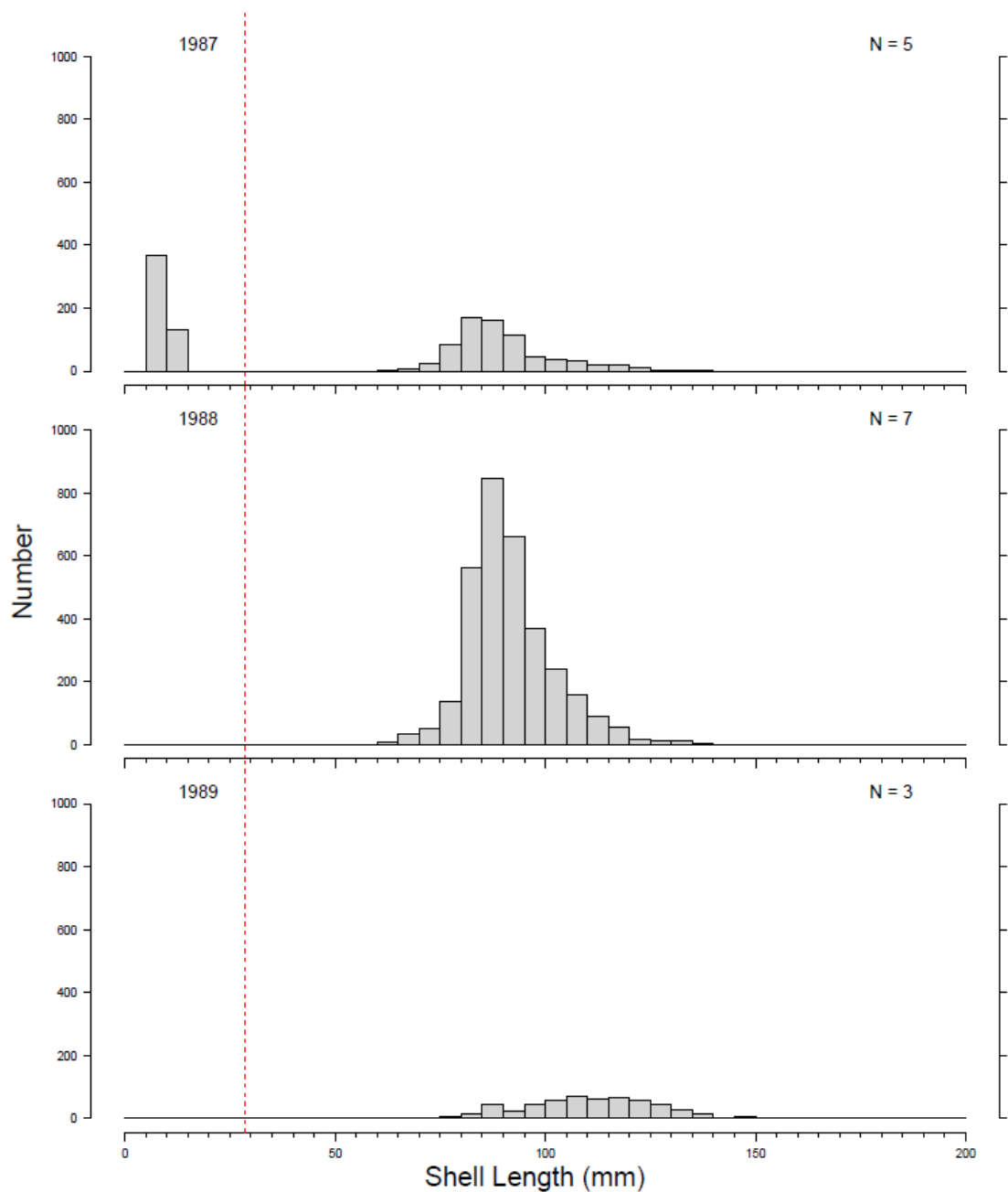


Figure 71. Banquereau Northern Propeller Clam shell length frequencies from Observed fishing trip from 1987 to 1989. N is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (28.6 mm).

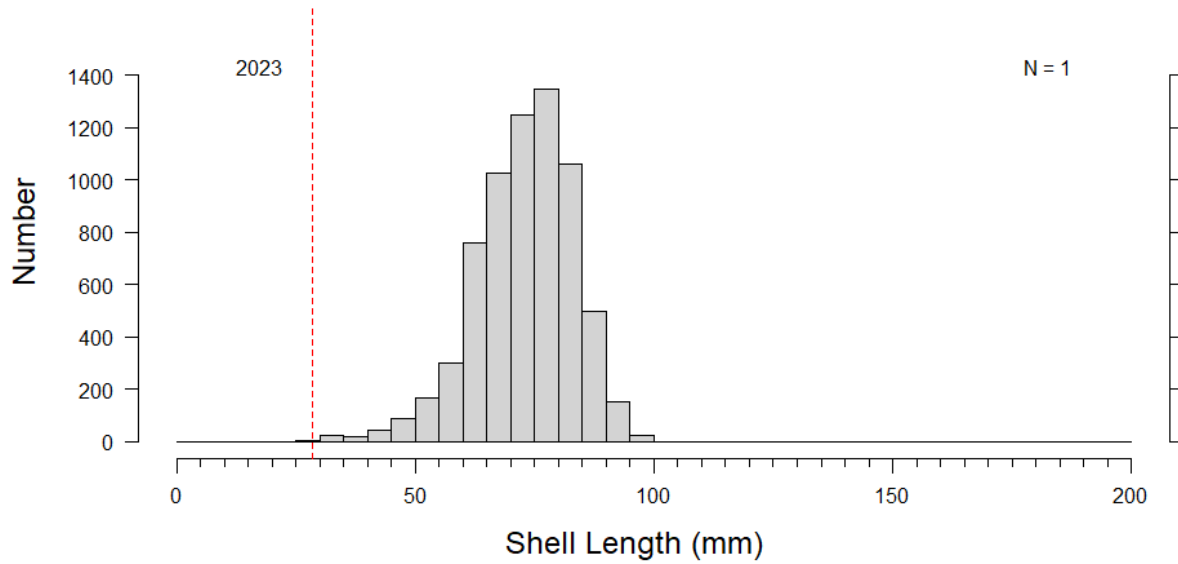


Figure 72. Banquereau Northern Propeller Clam shell length frequencies from the Observed fishing trip in 2023. *N* is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (28.6 mm).

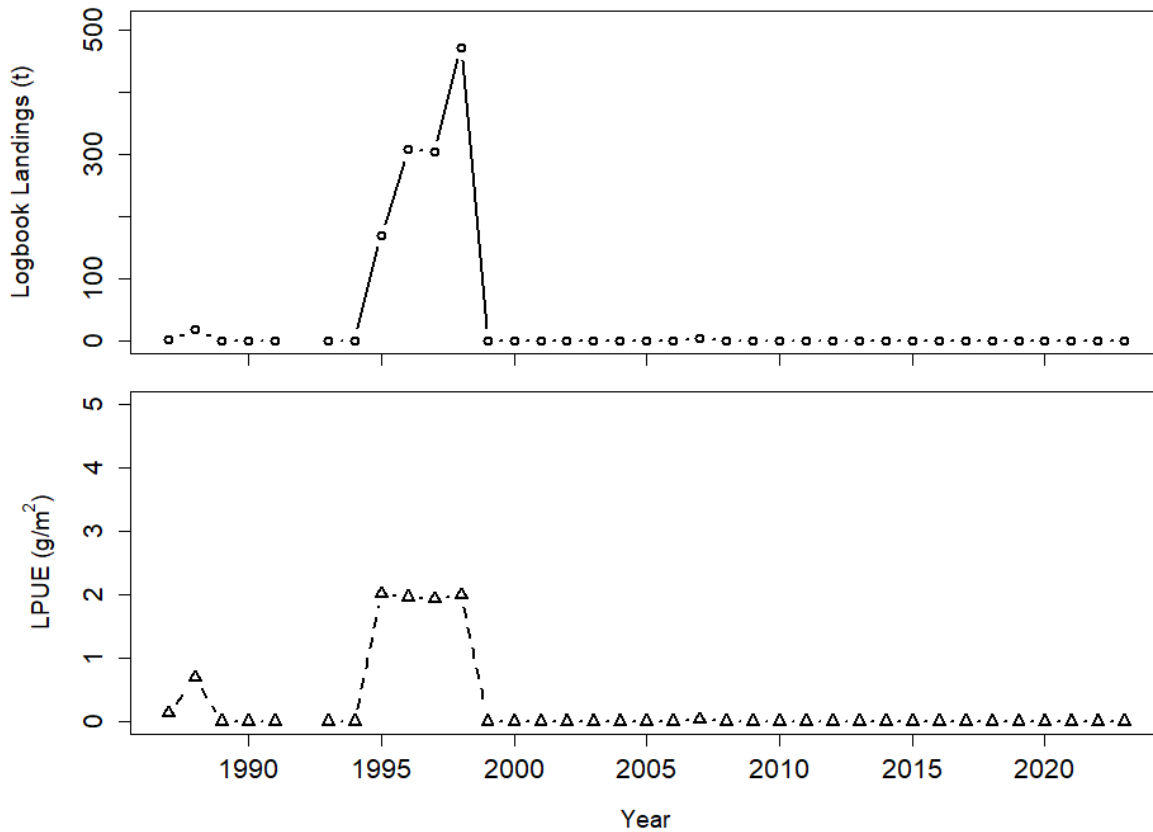


Figure 73. Banquereau Ocean Quahog landings (t; top panel), and landings per unit effort (LPUE g/m²; bottom panel). Total allowable catch since 2005 is 800 tonnes. Corresponding effort is presented in Figure 26.

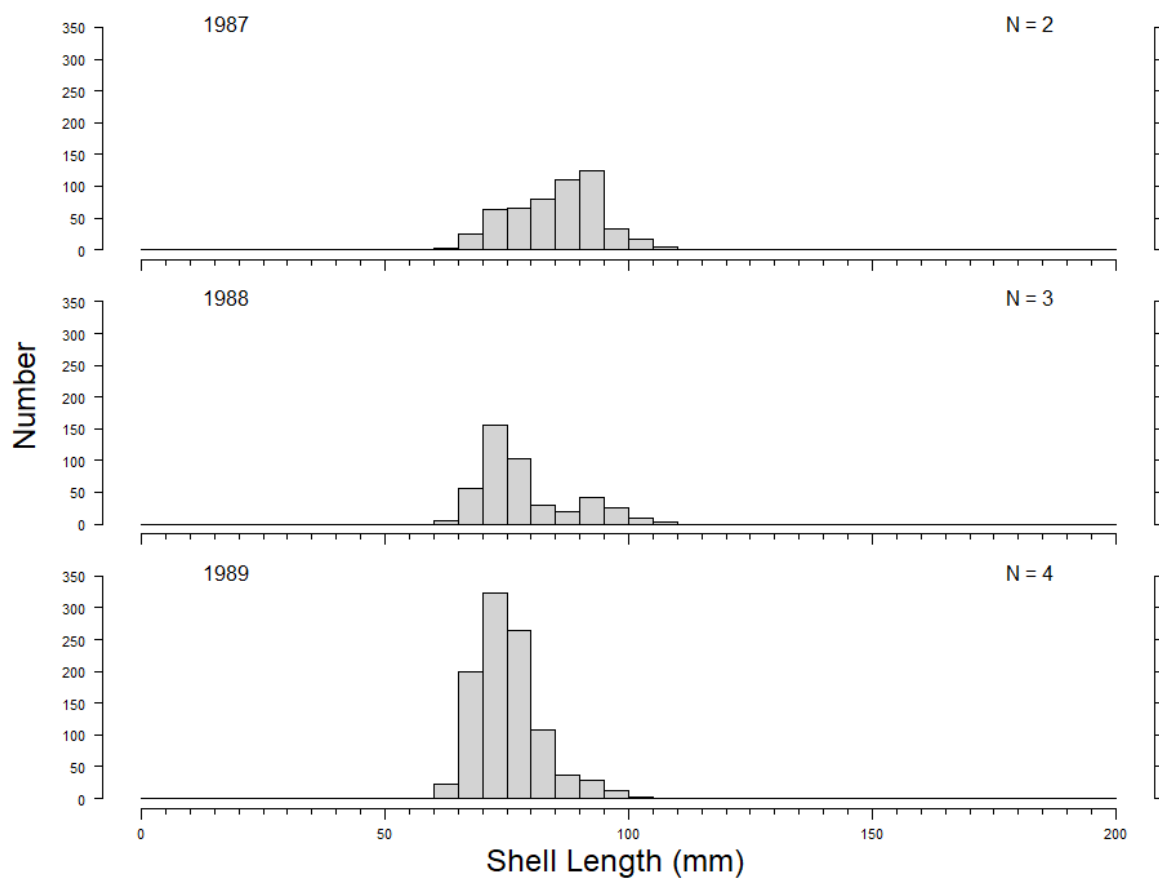


Figure 74. Banquereau Ocean Quahog shell length frequencies from Observed fishing trips in 1987 to 1989. N is number of trips.

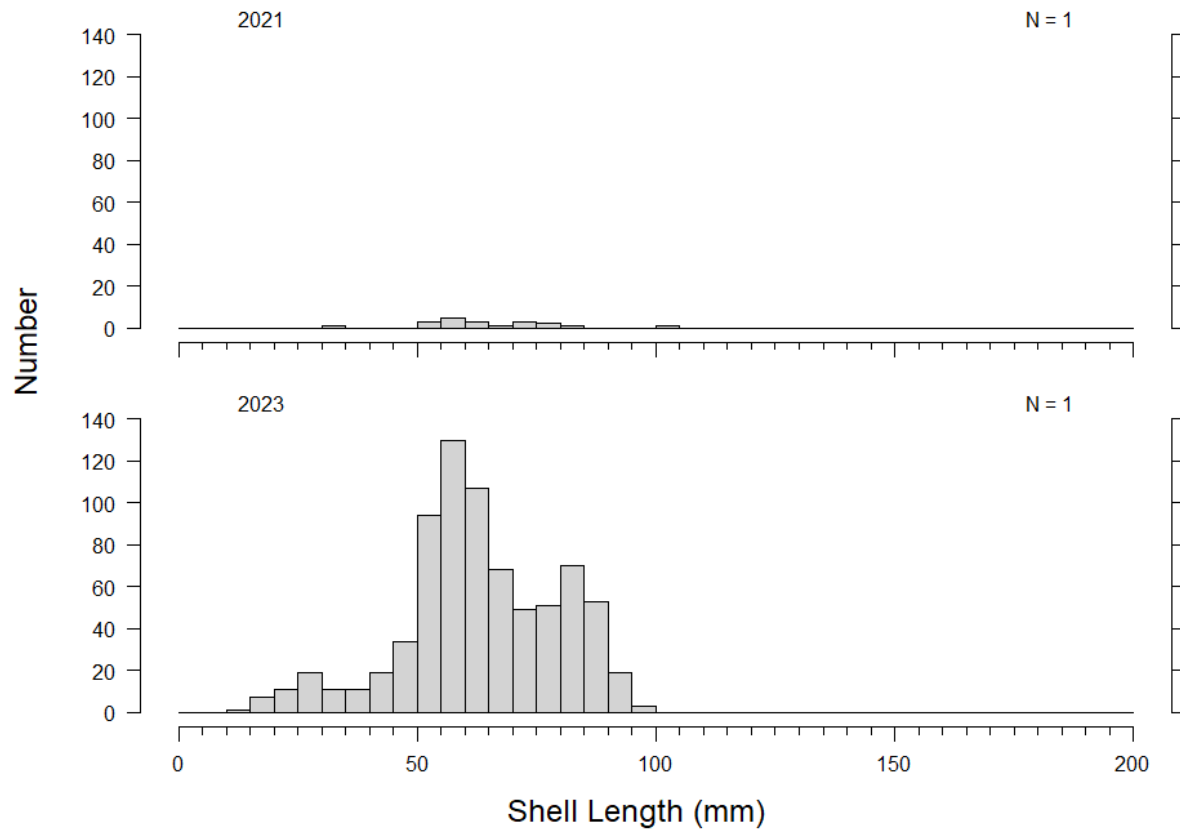


Figure 75. Banquereau Ocean Quahog shell length frequencies from Observed fishing trips in 2021 and 2023. N is number of trips.

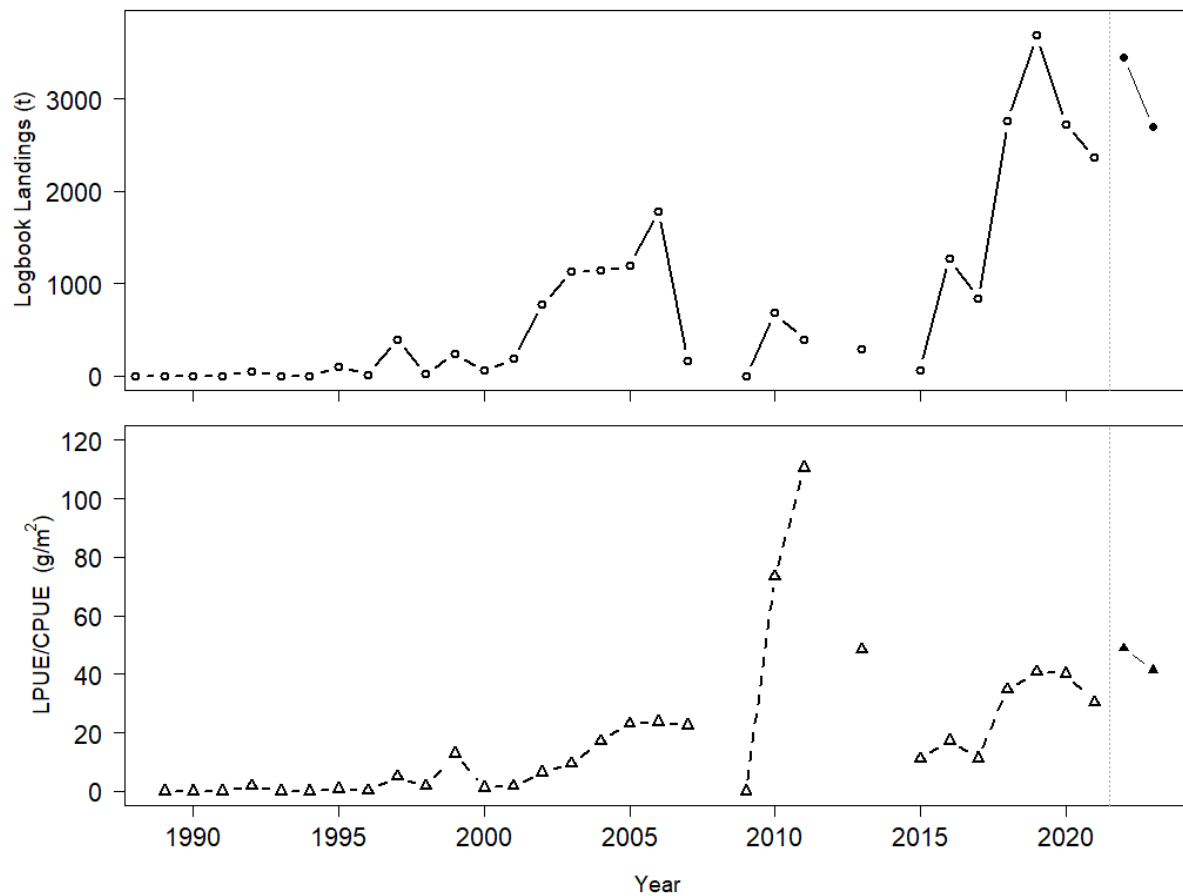


Figure 76. Grand Banks Greenland Cockerle landings (t; top panel), landings per unit effort (LPUE g/m²; bottom panel, open triangles) and catch per unit effort (CPUE, g/m²; bottom panel, solid triangles). Vertical dashed line represents change in fishing practice to 100% retention. Corresponding effort is presented in Figure 44.

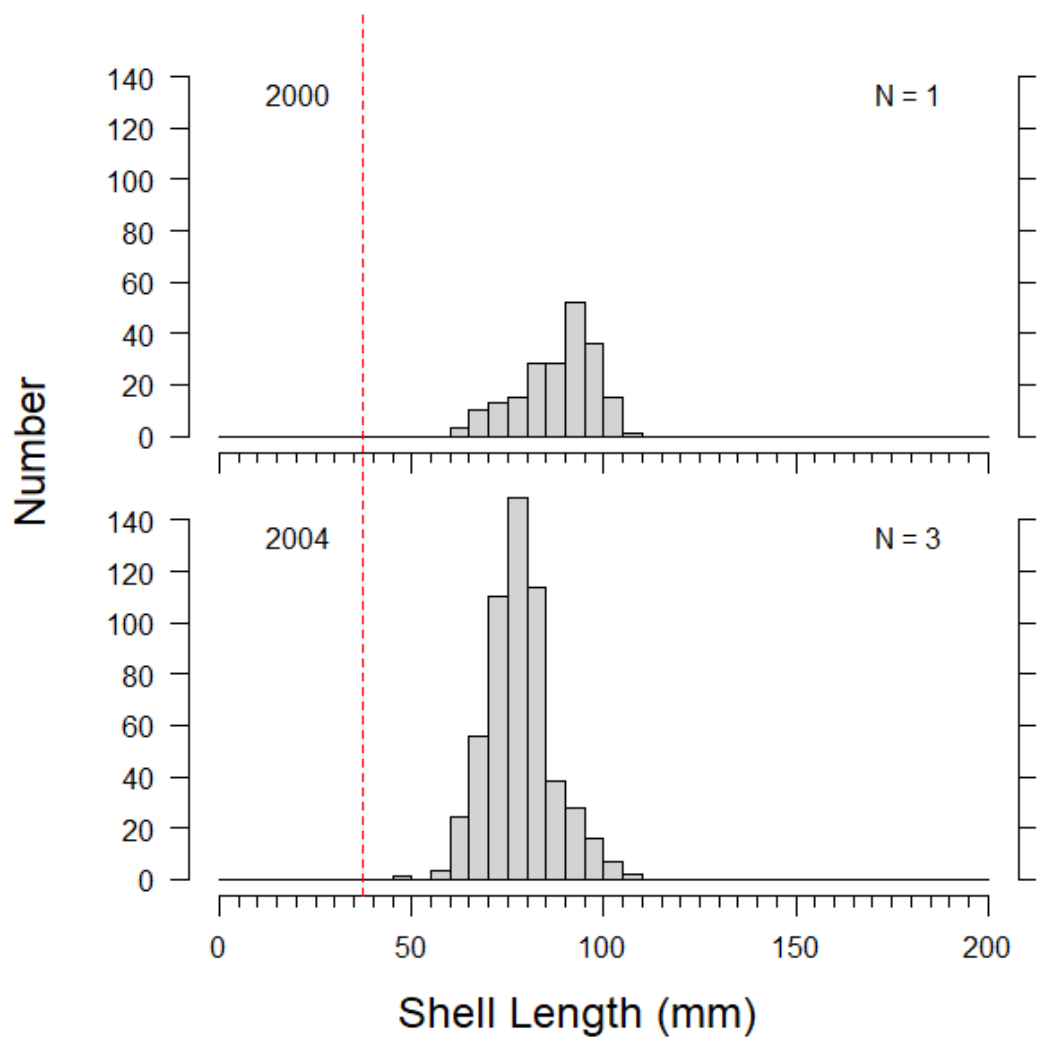


Figure 77. Grand Banks Greenland Cackle shell length frequencies from the onboard sampling in 2000 and 2004. *N* is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (37.2 mm).

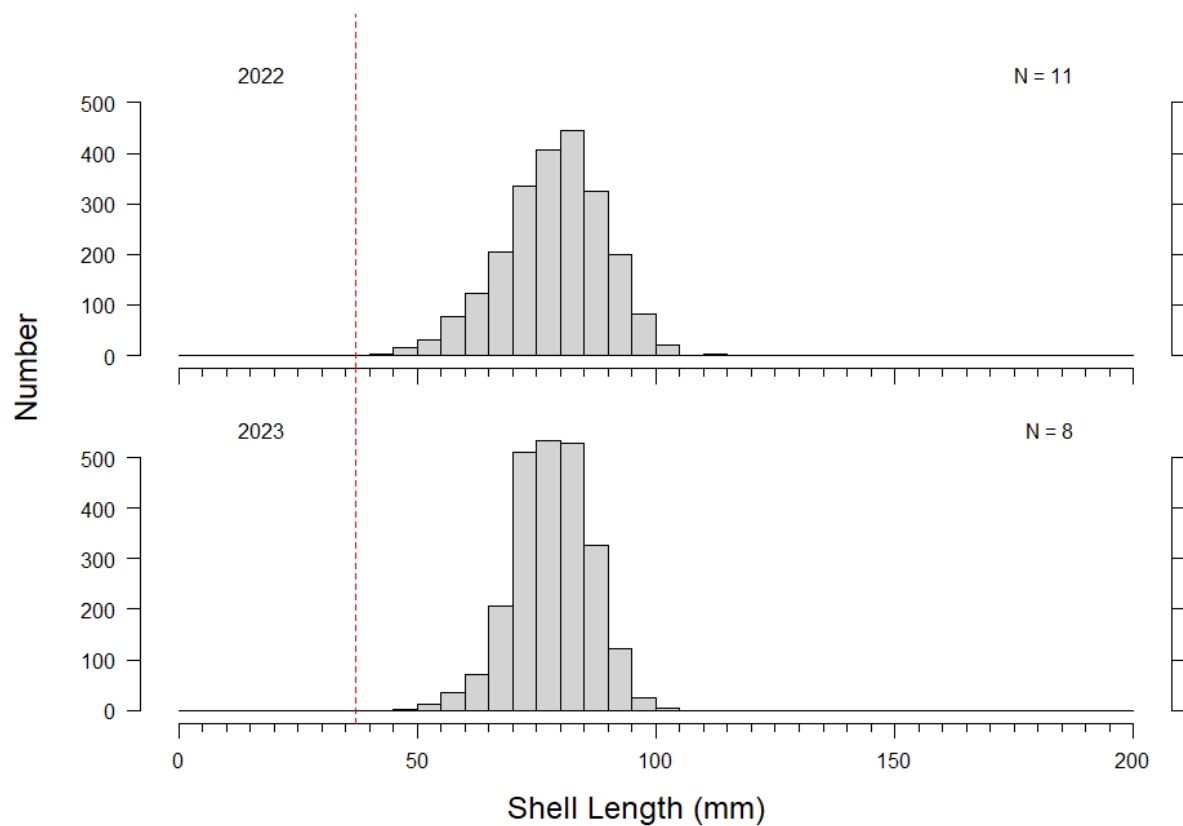


Figure 78. Grand Banks Greenland Cockleshell length frequencies from the onboard sampling in 2022 and 2023. N is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (37.2 mm).

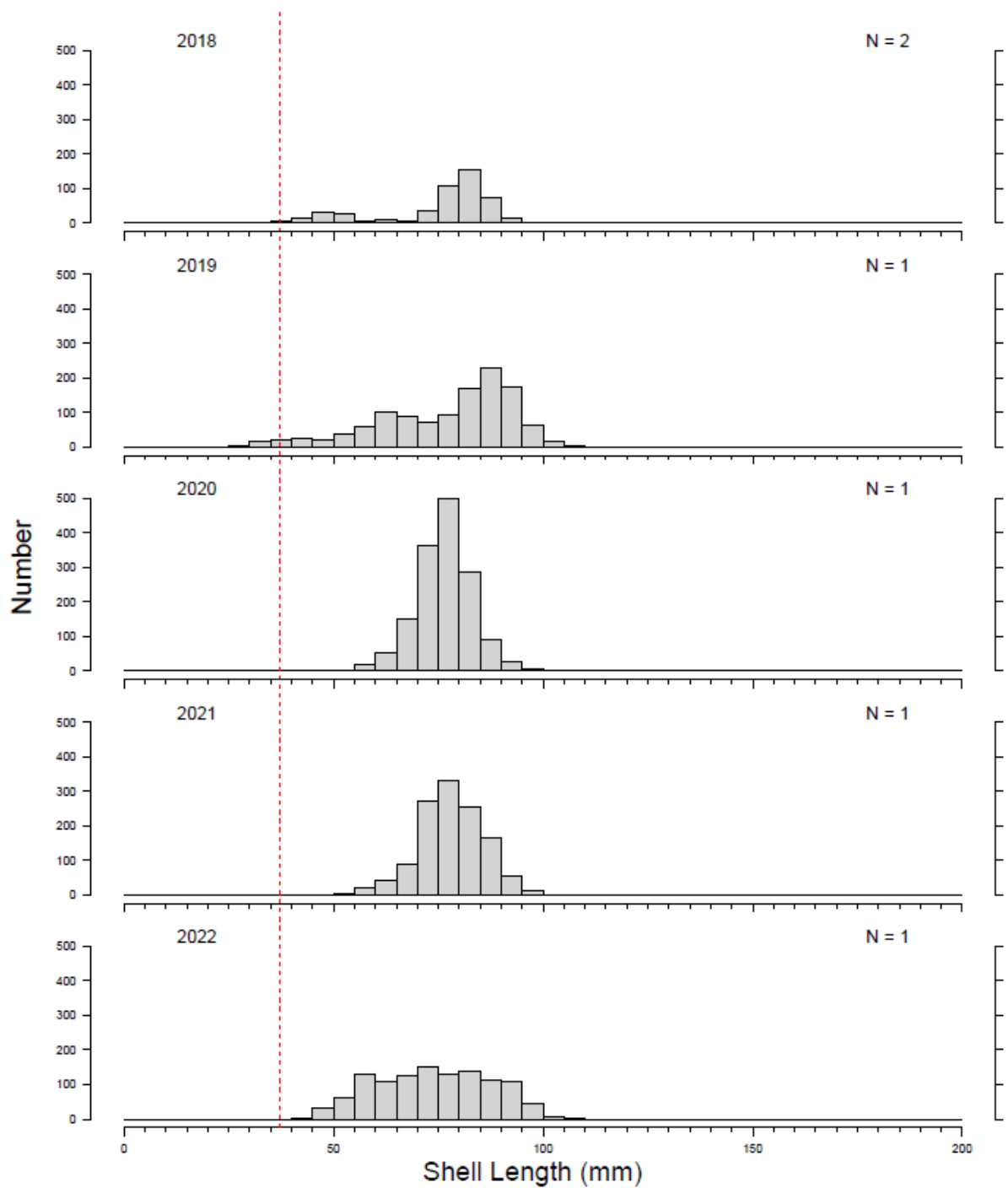


Figure 79. Grand Banks Greenland Cockerle shell length frequencies from Observed fishing trips in 2018 to 2022. N is number of trips. Left-hand, dashed red vertical is size at 50% sexual maturity (37.2 mm).

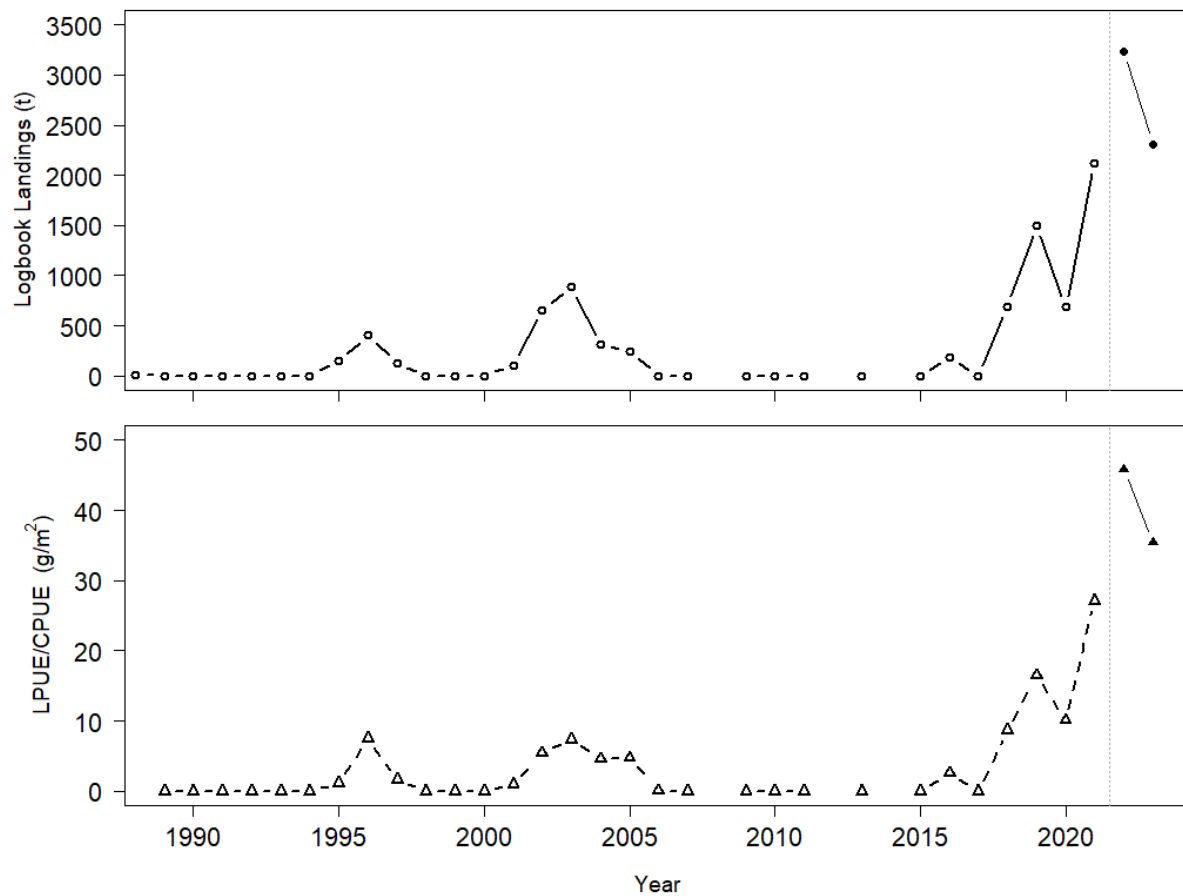


Figure 80. Grand Banks Northern Propeller Clam landings (t; top panel), landings per unit effort (LPUE g/m²; bottom panel, open triangles) and catch per unit effort (CPUE, g/m²; bottom panel, solid triangles). Vertical dashed line represents change in fishing practice to 100% retention. Corresponding effort is presented in Figure 44.

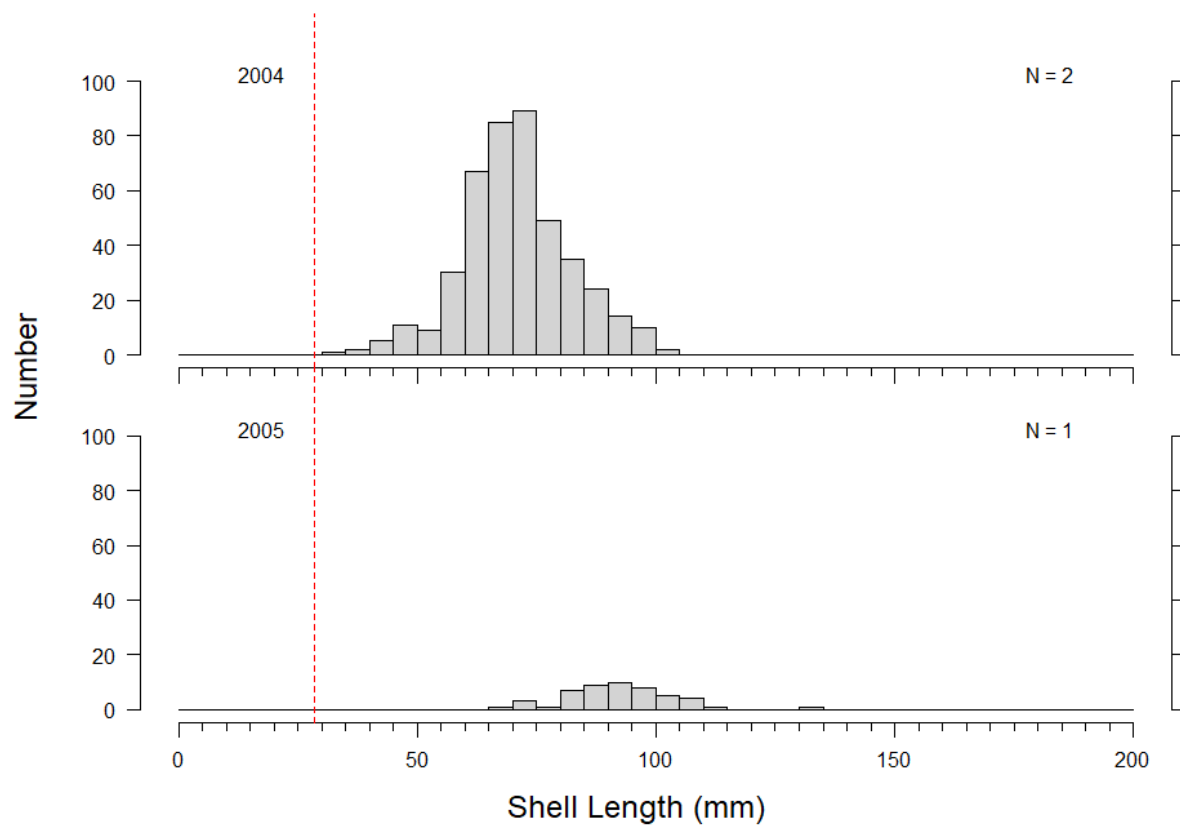


Figure 81. Grand Banks Northern Propeller Clam shell length frequencies from the onboard sampling in 2004 and 2005. N is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (28.6 mm).

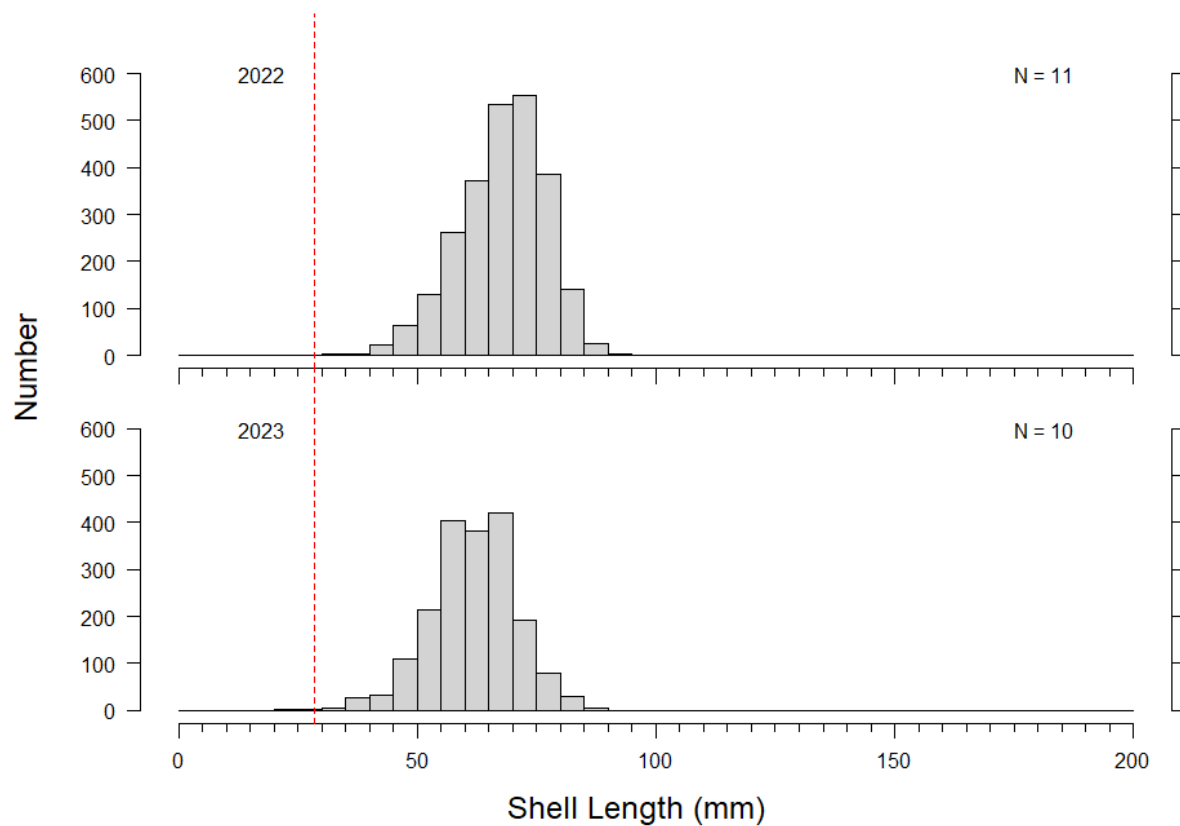


Figure 82. Grand Banks Northern Propeller Clam shell length frequencies from the onboard sampling in 2022 and 2023. N is number of trips. Left-hand, dashed red vertical line is size at 50% sexual maturity (28.6 mm).

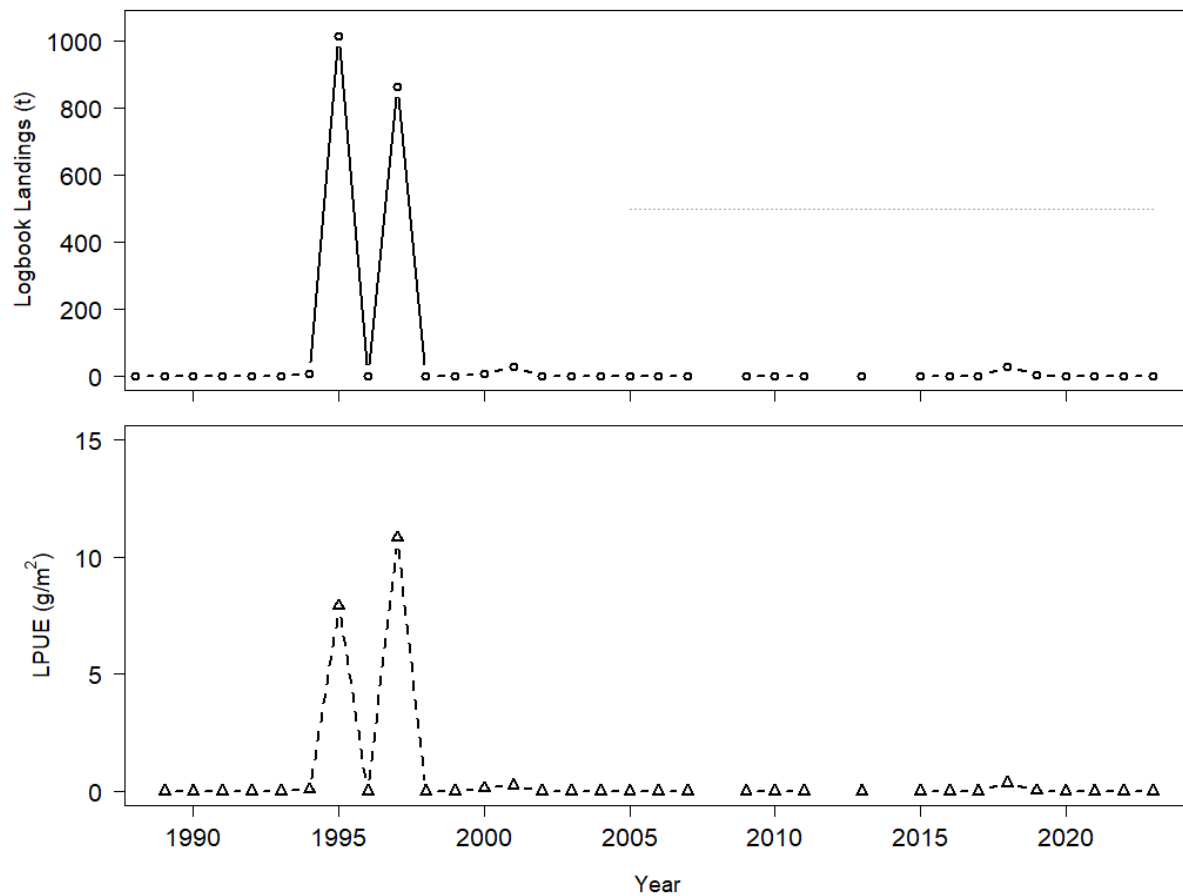


Figure 83. Grand Banks Ocean Quahog landings (t; top panel), and landings per unit effort (LPUE g/m²; bottom panel). Dashed horizontal line is maximum total allowable catch (10% of Arctic Surf Clam Landings to a maximum of 500 t). Corresponding effort is presented in Figure 44.

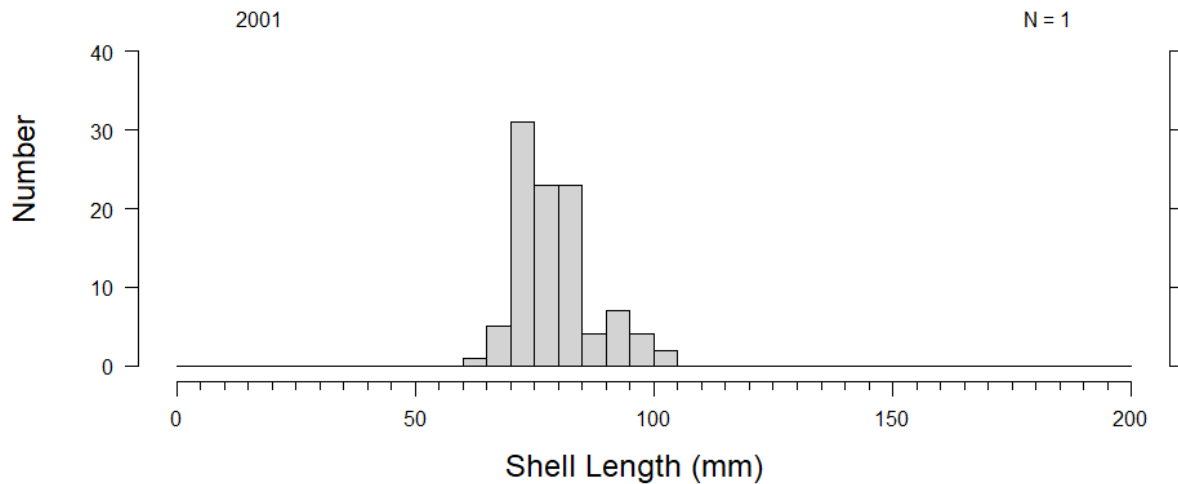


Figure 84. Grand Banks Ocean Quahog shell length frequencies from the onboard sampling in 2001. N is number of trips.

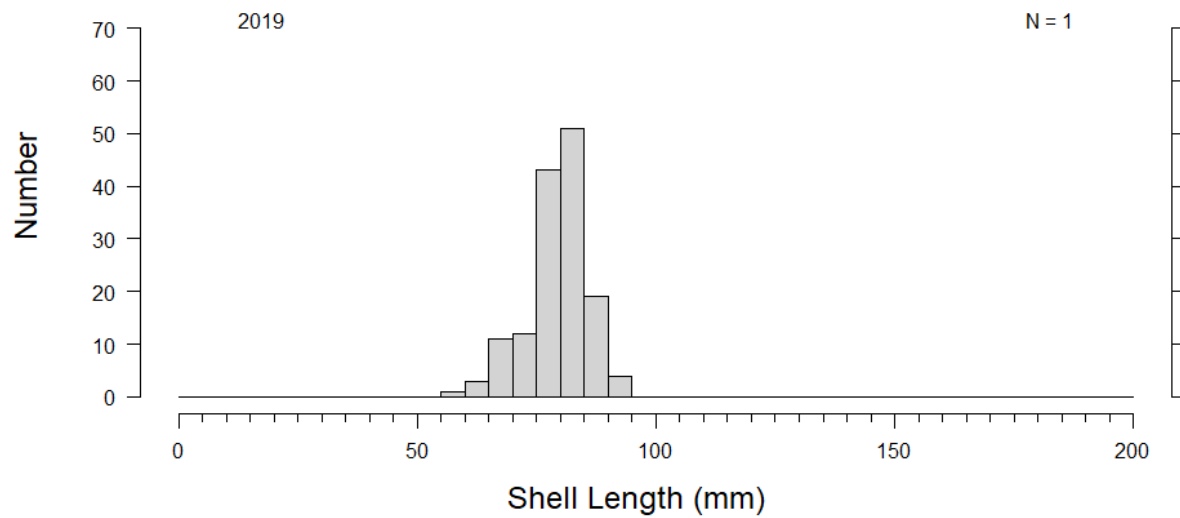


Figure 85. Grand Banks Ocean Quahog shell length frequencies from an Observed fishing trip in 2019. *N* is number of trips.

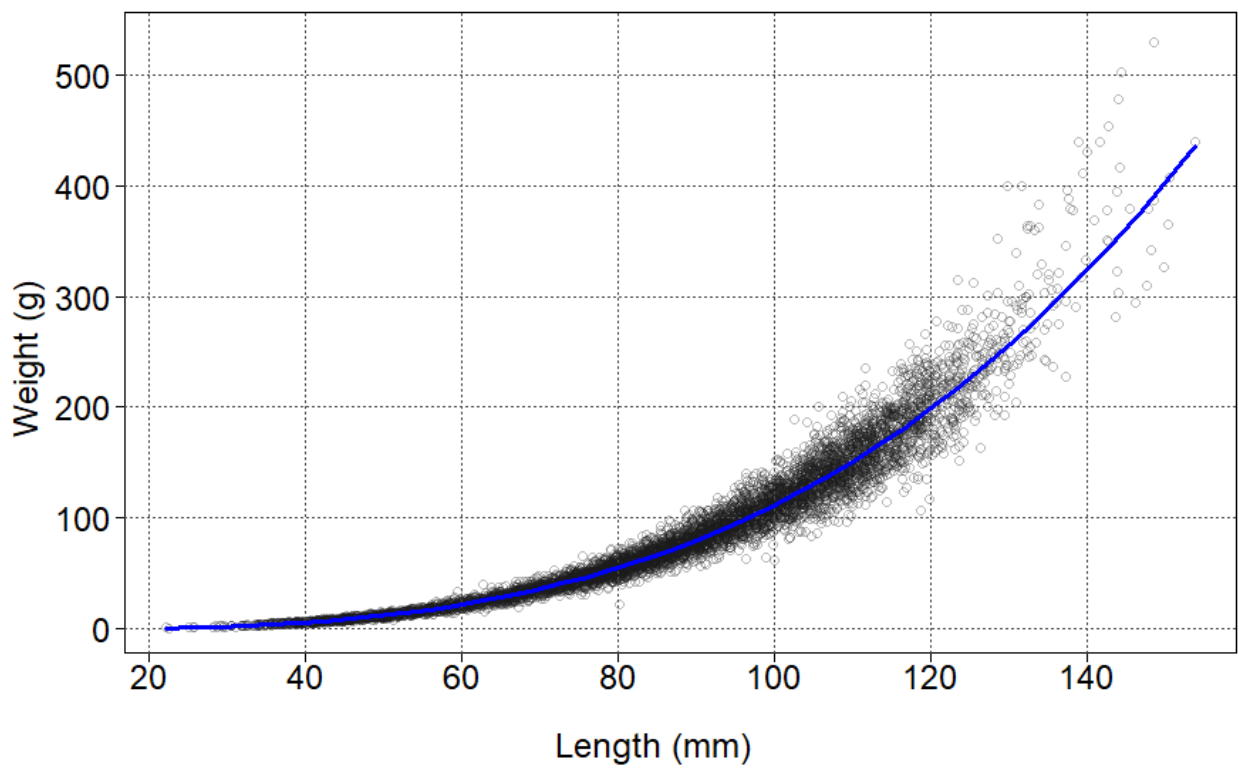


Figure 86. Length-weight relationship from the Banquereau survey for 2011. Data was log-transformed for analysis. Solid blue line of overall relationship. Random effects (individual tows) are not shown.

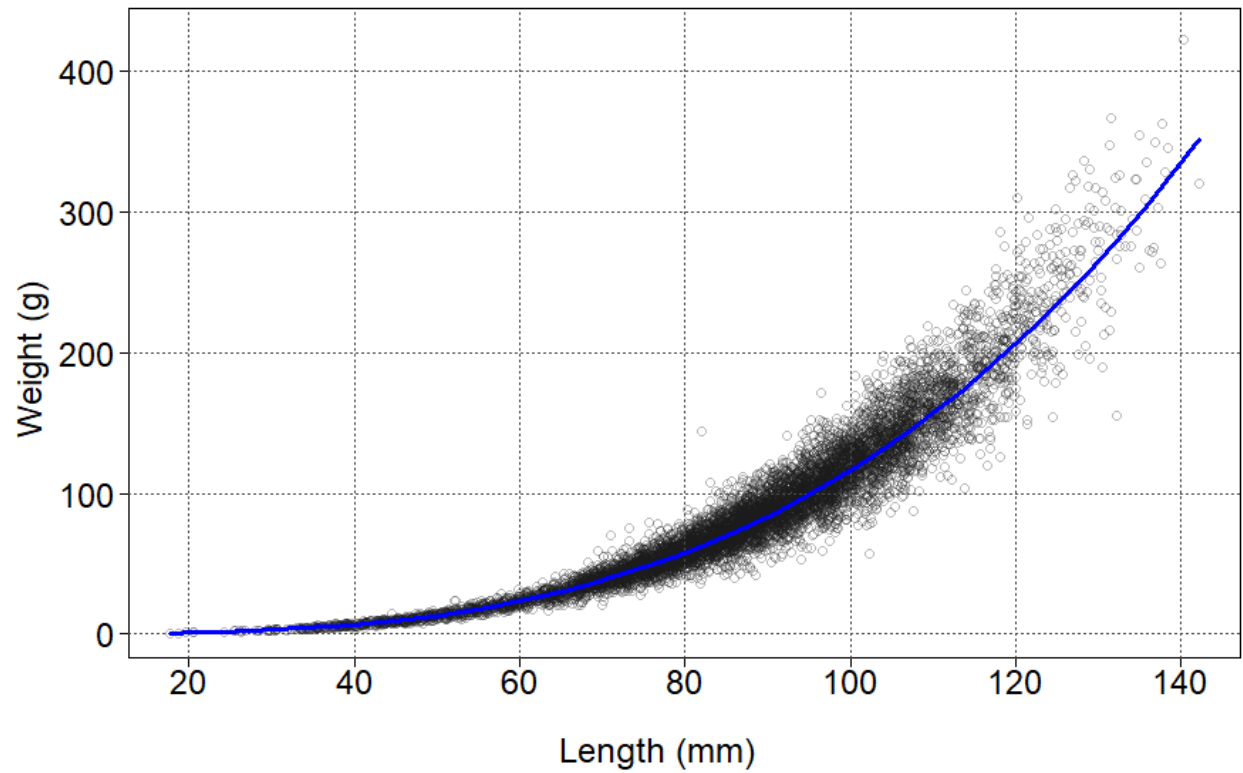


Figure 87. Length-weight relationship from the Grand Banks survey for 2006, 2008, and 2009 combined. Data was log-transformed for analysis. Solid blue line of overall relationship. Random effects (individual tows) are not shown.

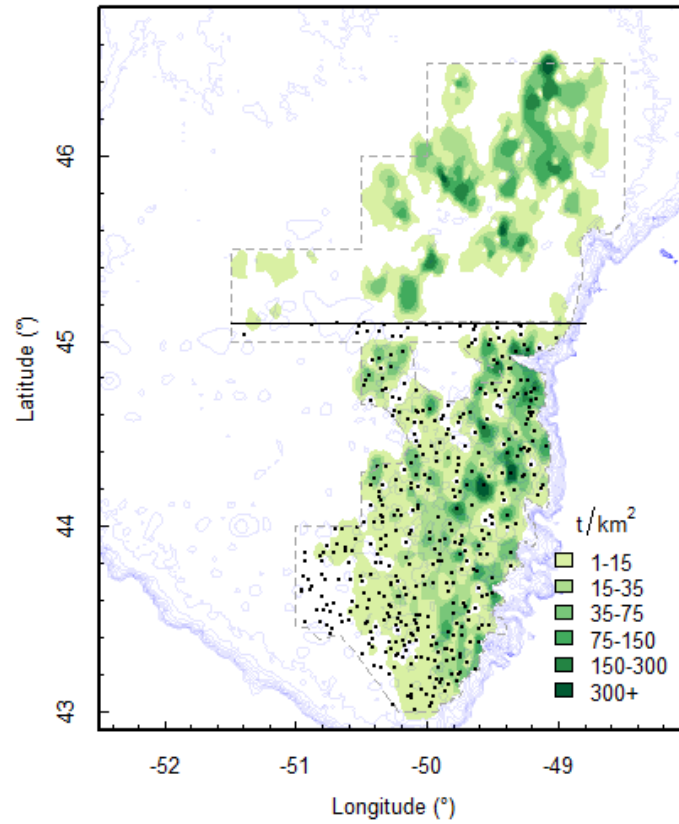


Figure 88. Contour plot of the estimated biomass density of Arctic Surf Clam (t/km^2) from the 2006, 2007, and 2009 Grand Banks survey. Survey extent is shown in light gray (Roddick et al. 2011). The solid horizontal line is the north/south divide proposed in this research document.

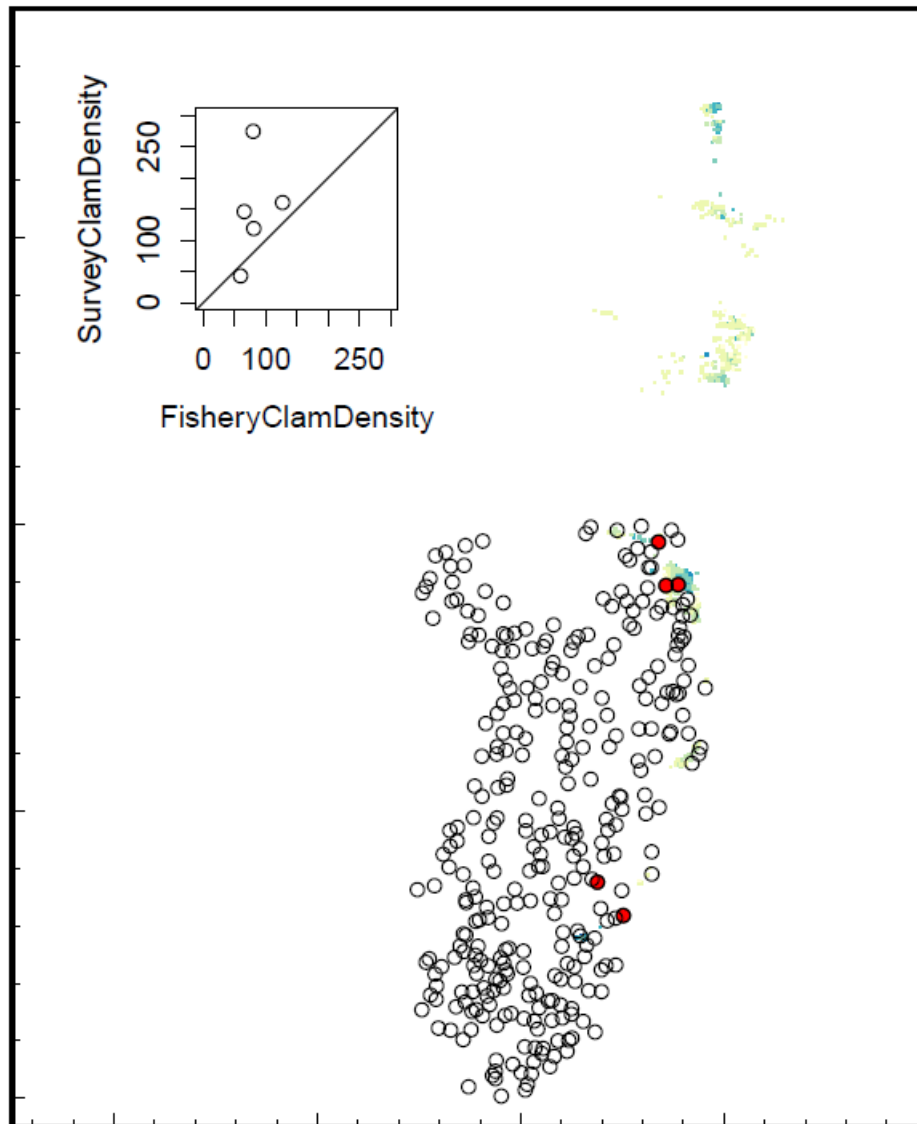


Figure 89. Comparison of survey station locations for the 2006 Grand Banks Arctic Surf Clam survey and 2006 fishery catch per unit effort (CPUE; g/m²). Circles represent survey stations, with the red circles showing locations of overlap between the survey and fishery effort. Density estimates from these locations are included in the inset plot of clam density estimated from the fishery versus density estimated from the survey.

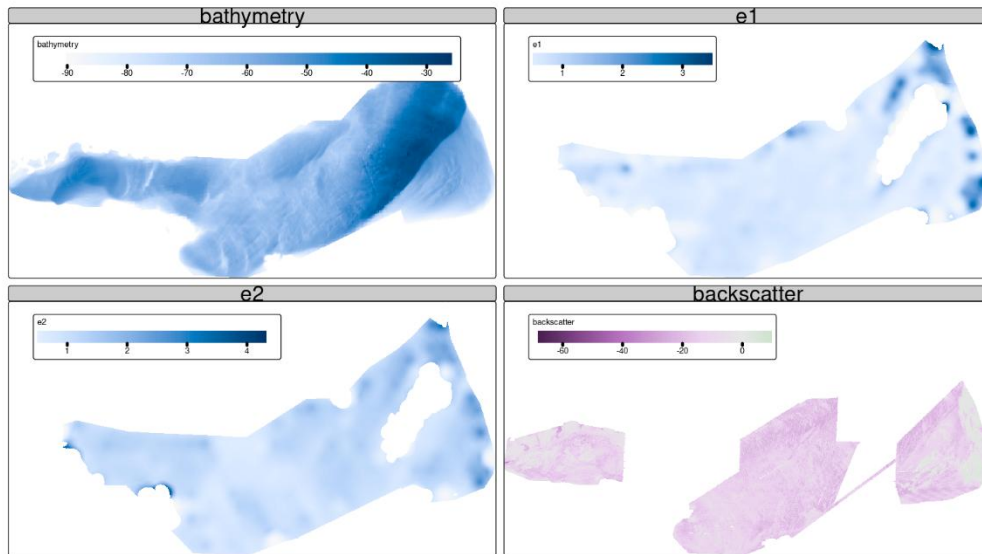


Figure 90. Environmental covariates used to predict habitat suitability for Banquereau.

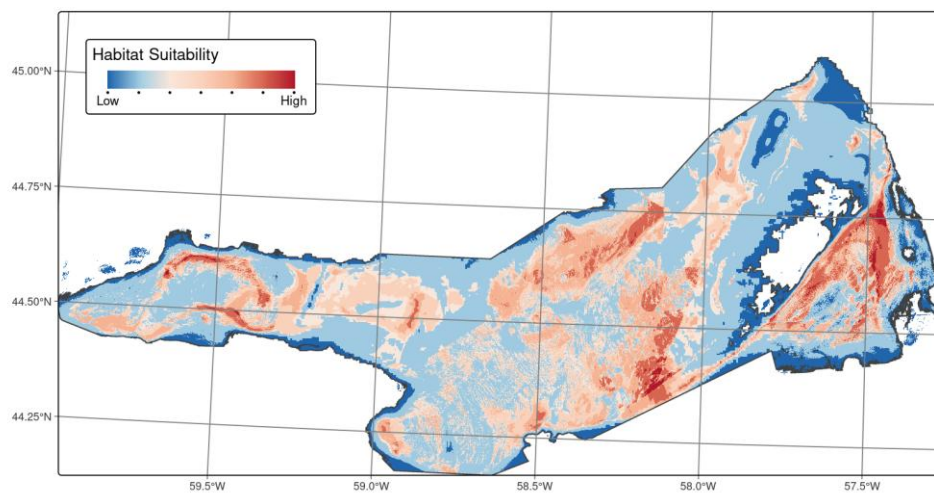


Figure 91. Estimated habitat suitability for Banquereau. Areas of high habitat suitability are areas that are likely to be targeted by fishing. Since fishing effort has been consistently high and covers most of the bank, high habitat suitability areas are also expected to be areas of high density of Arctic Surf Clam.

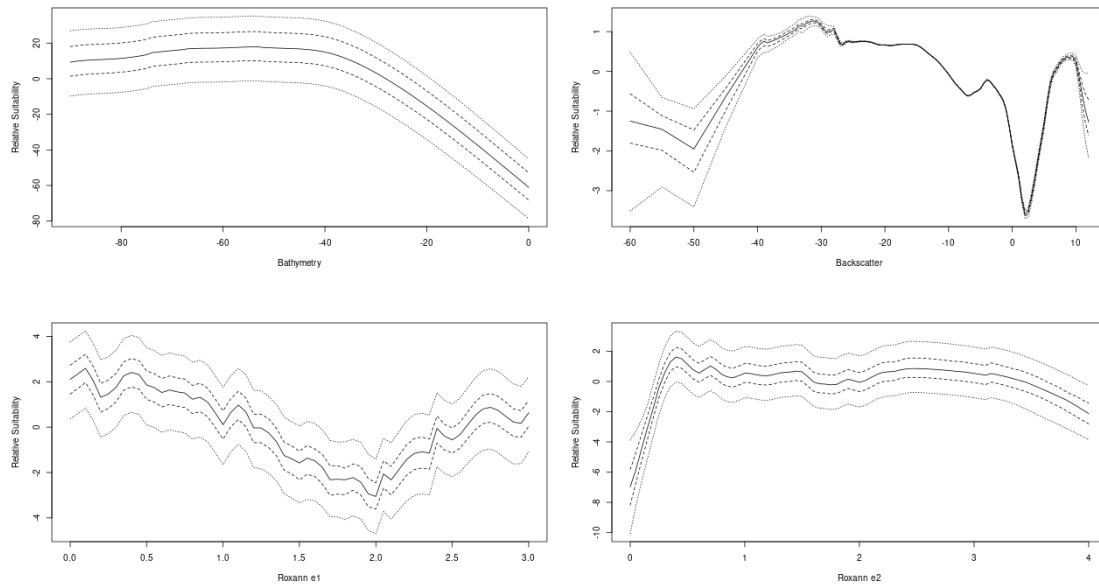


Figure 92. Estimated effects of covariates on habitat suitability for Banquereau. In each plot the solid line is the maximum likelihood estimate, the dotted lines give the 50% confidence interval, and the dashed lines give the 90% confidence interval.

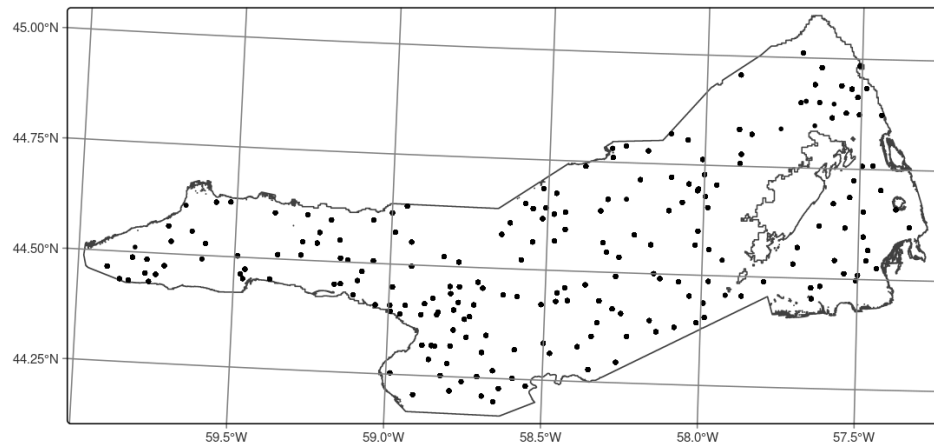


Figure 93. Sample locations for the Banquereau survey in 2010.

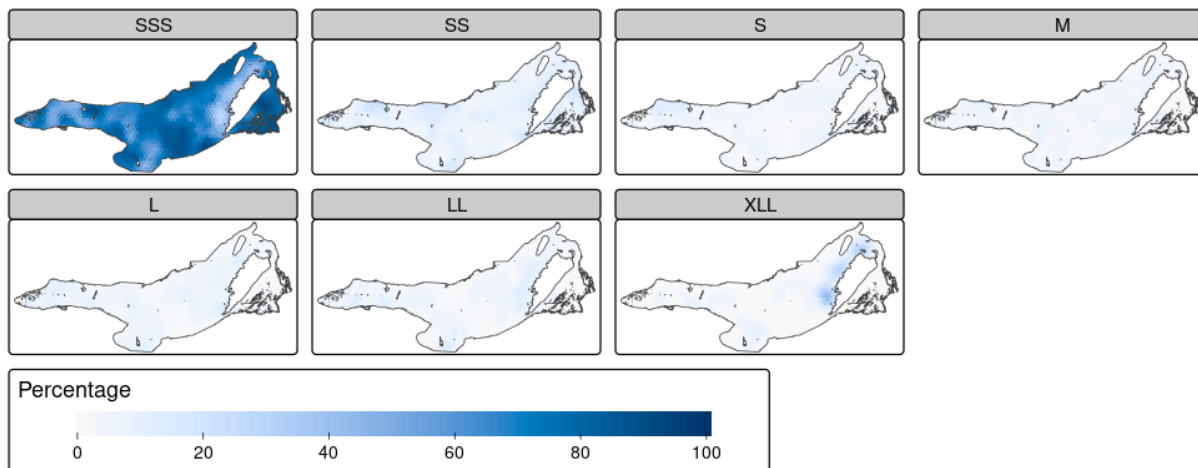


Figure 94. Estimated size class composition of Arctic Surf Clam for Banquereau using data from the 2010 survey.

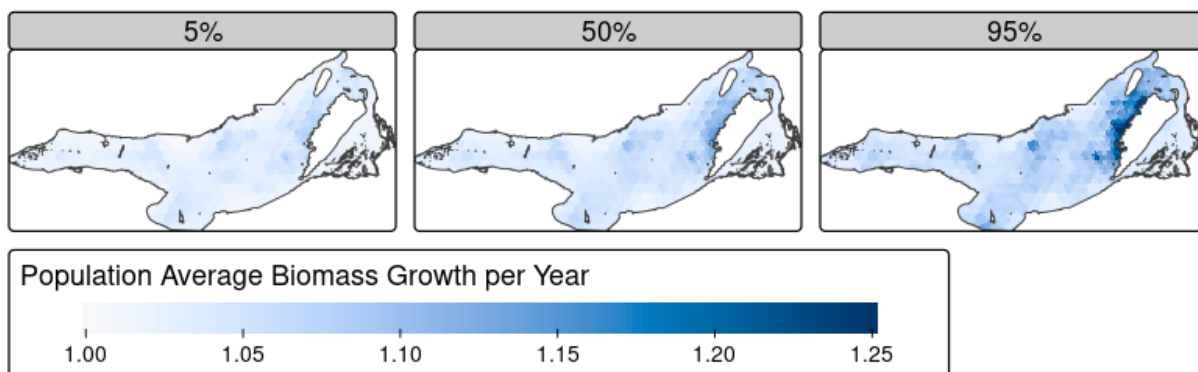


Figure 95: Estimated population average biomass growth rate of Arctic Surf Clam for Banquereau using data from the 2010 survey. The middle panel (50%) is the maximum likelihood estimate, while the top (95%) and bottom (5%) panels are the endpoints of a 90% confidence interval.

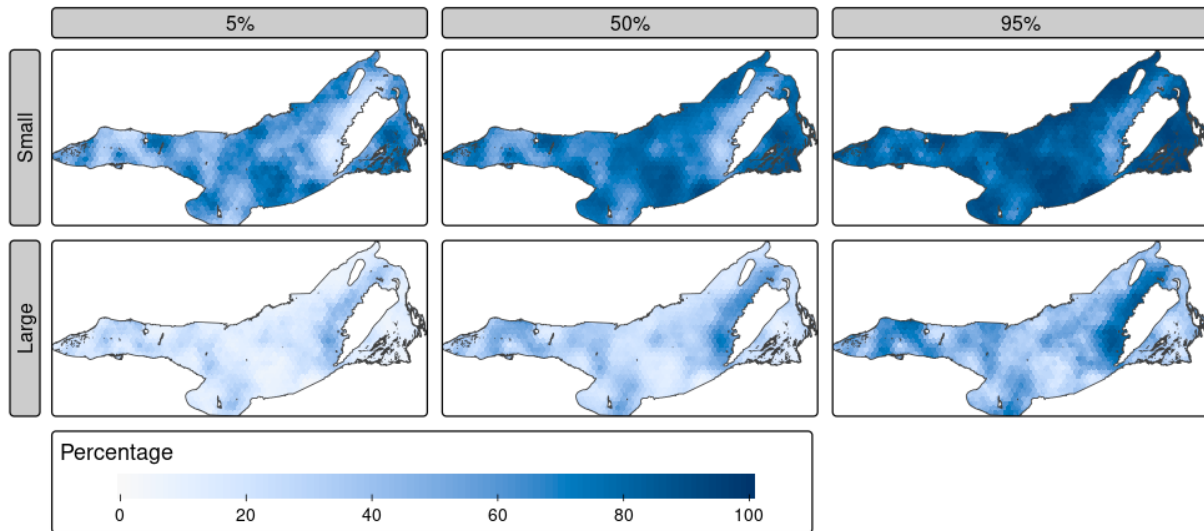


Figure 96. Small and Large class composition of Arctic Surf Clam for Banquereau using data from the 2010 survey. The middle column is the maximum likelihood estimate, while the left (5%) and right (95%) columns are the endpoints of a 90% confidence interval.

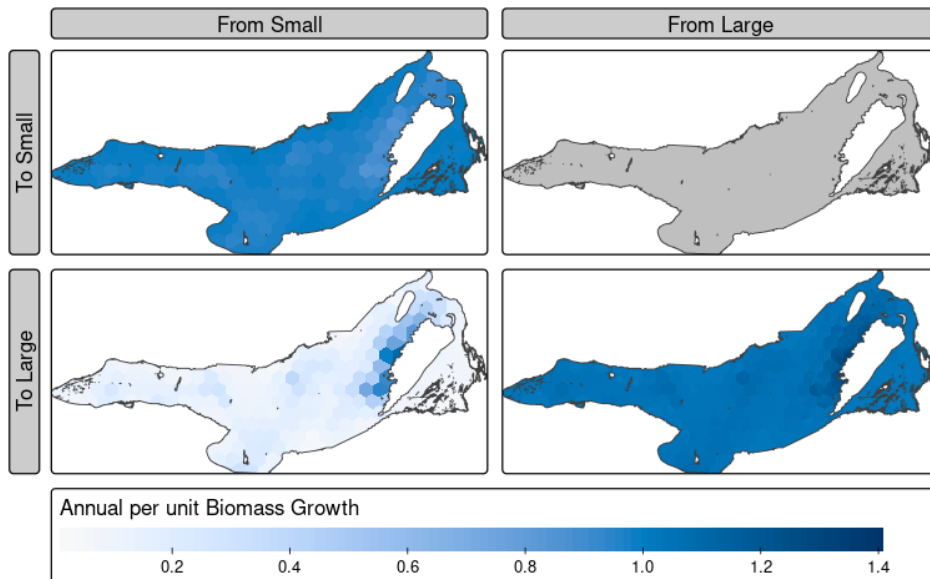


Figure 97. Estimated biomass transition matrix G_s' for Small and Large class clams. The top left panel (Small column, Small row) is the estimated (multiplicative) change in biomass within the Small class from one year to the next. The bottom left panel (Small column, Large row) is the estimated transition of biomass from the Small class to the Large class. If the Small biomass is b then the biomass added to the Large class from the Small class will be $G_{2,1}b$. The bottom right panel (Large column, Large row) is the estimated (multiplicative) change in biomass within the Large class from one year to the next.

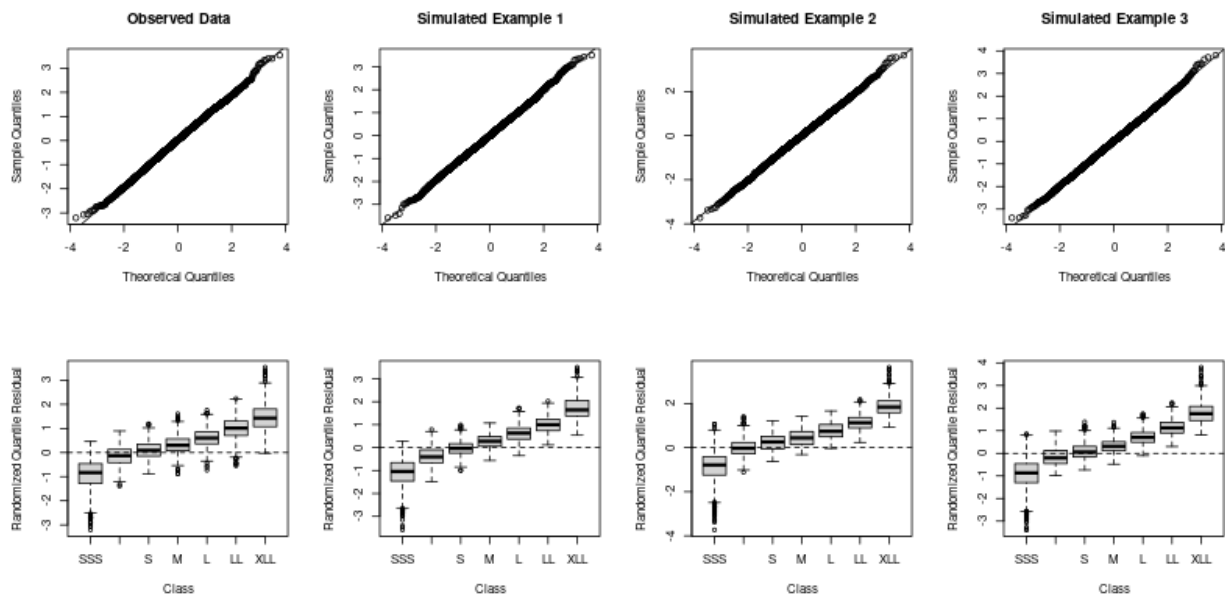


Figure 98. Composition model residuals for real data (left) and three simulated examples (remainder). The residuals for the real data do not seem to have any major differences from the residuals for the simulated data, indicating that the model accurately reflects the true data-generating mechanism.

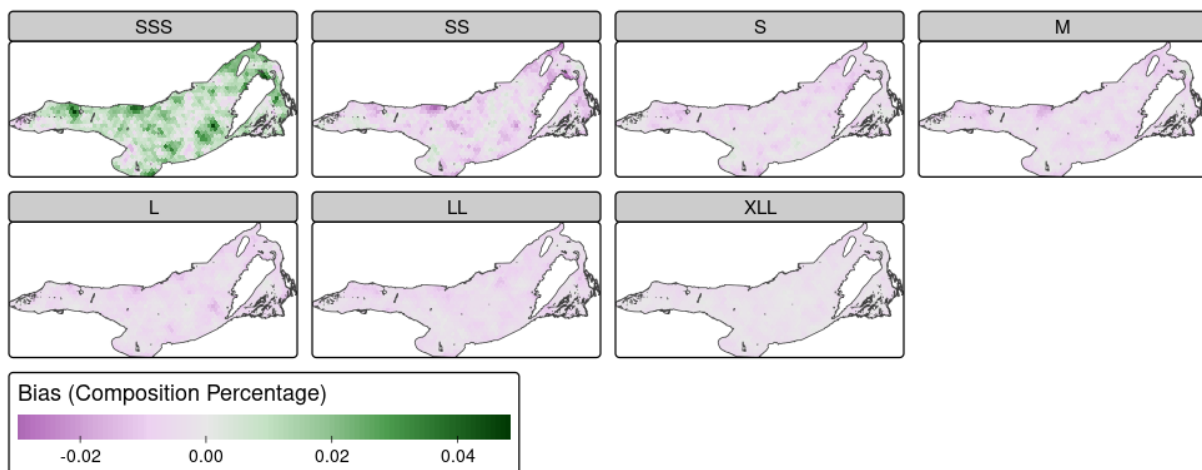


Figure 99. Composition modeled bias for Banquereau.

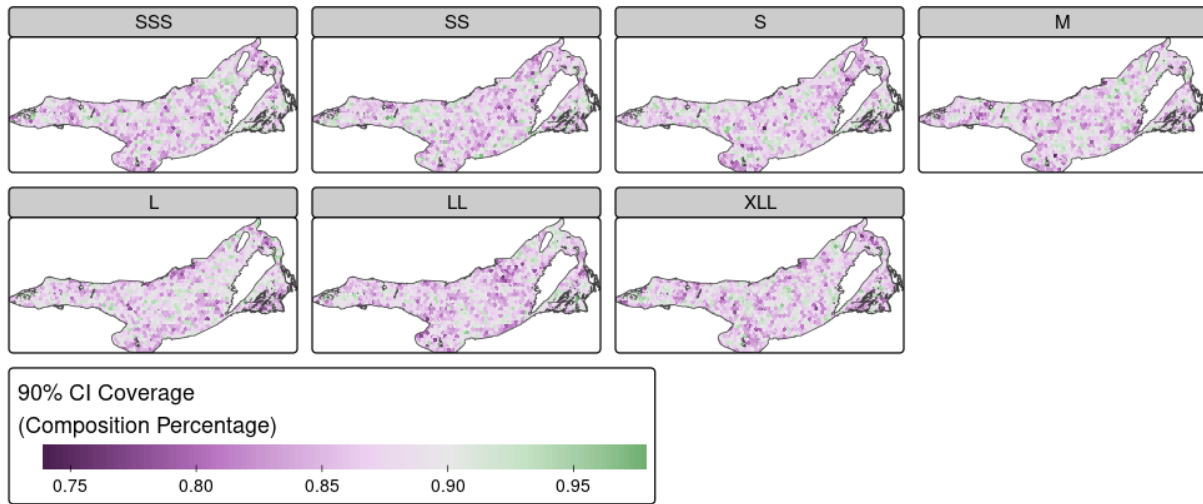


Figure 100. Composition modeled coverage for 90% confidence intervals (CI) for Banquereau.

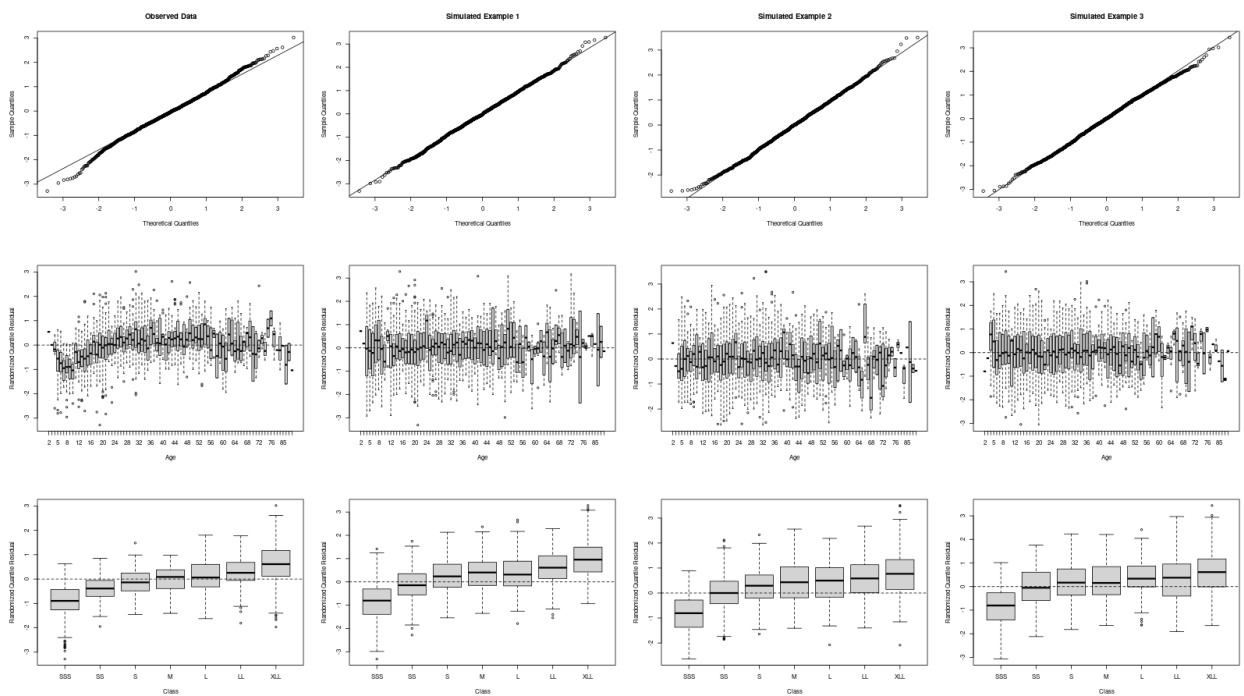


Figure 101. Composition-at-age modeled residuals for Banquereau.

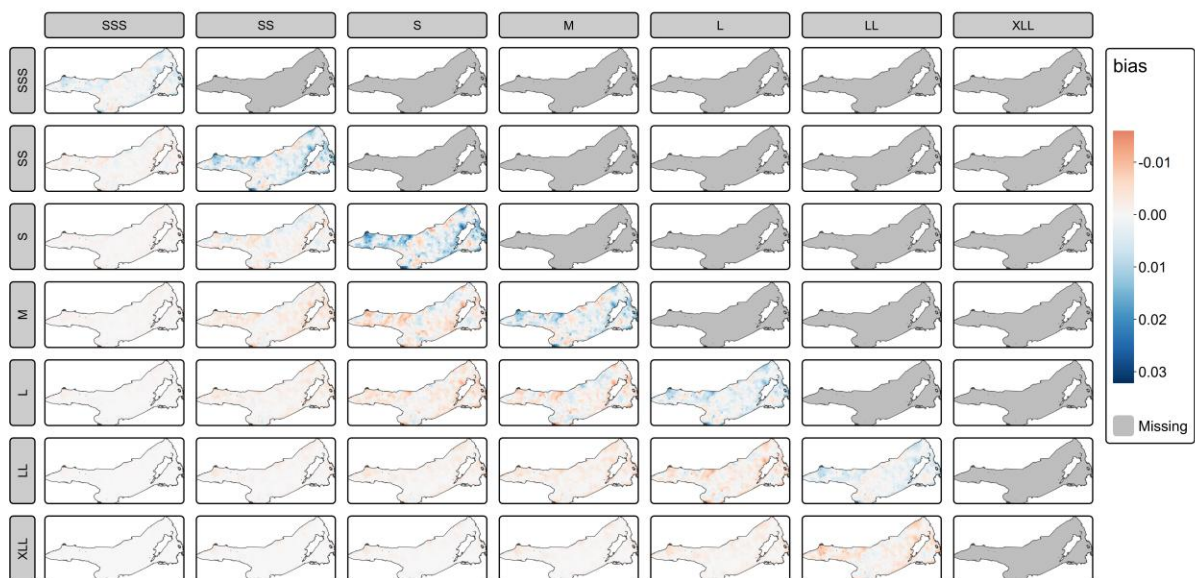


Figure 102. Composition-at-age modeled transition matrix bias for Banquereau.

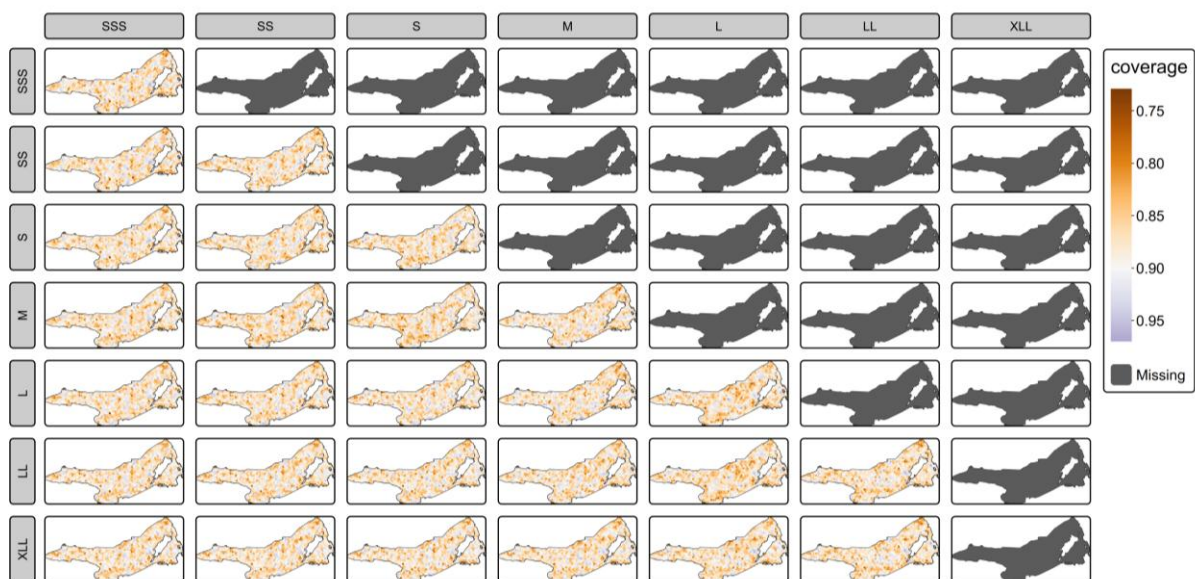


Figure 103. Composition-at-age transition matrix coverage for a 90% confidence interval for Banquereau.

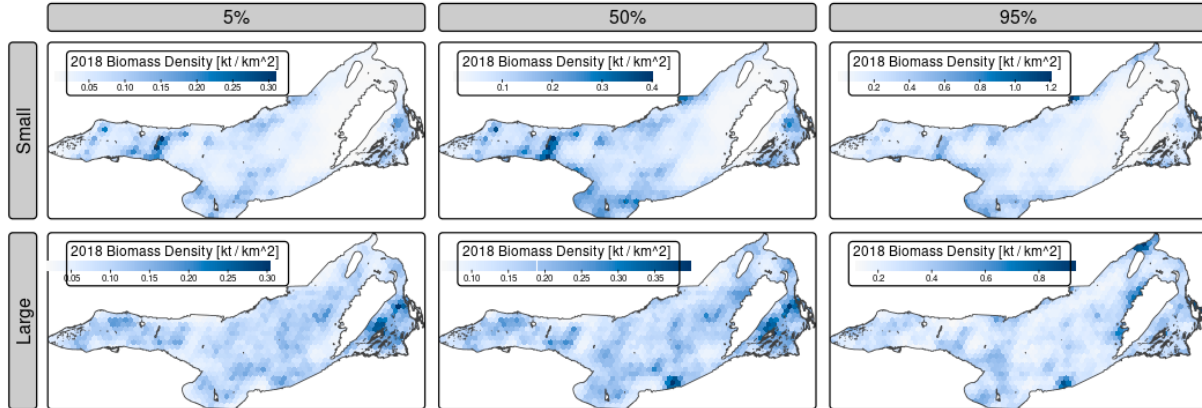


Figure 104. An example year (2018) of estimated biomass (kt/km²) with a 90% confidence interval. The middle row is the maximum likelihood estimate for the biomass of Small (left) and Large (right) clams. The top (95%) and bottom (5%) rows are the endpoints of a 90% confidence interval for each cell.

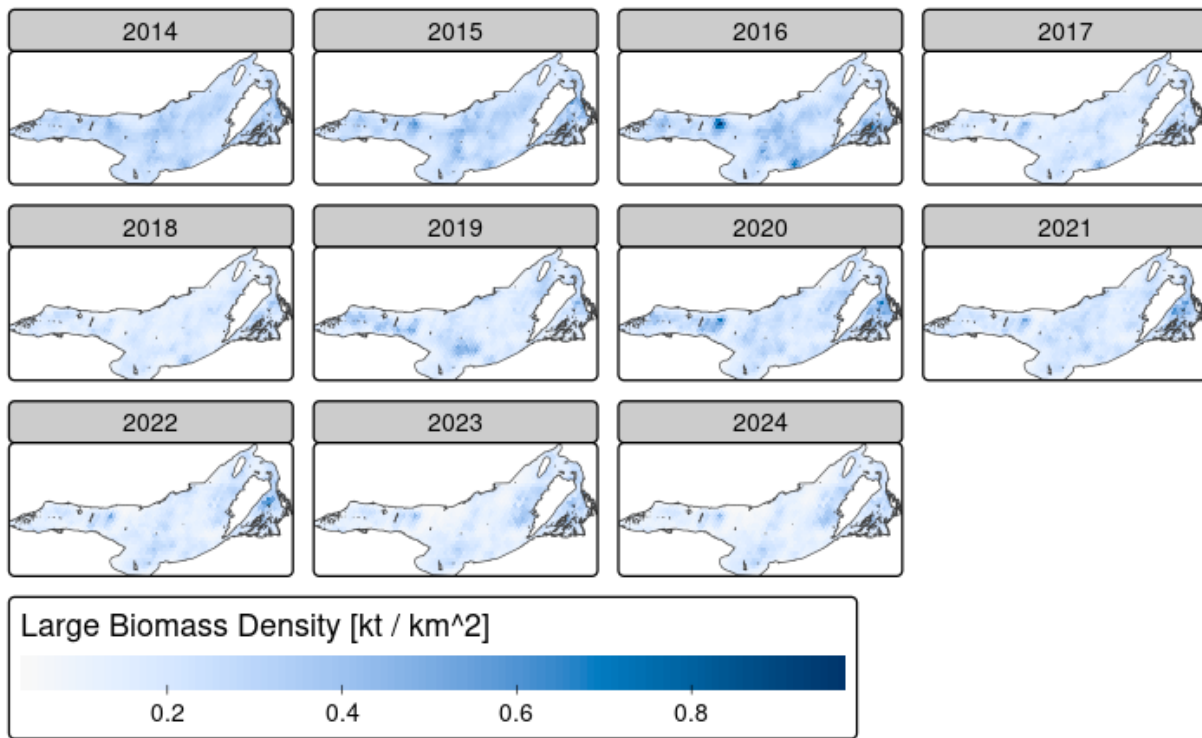


Figure 105. Estimated Large biomass (kt) from 2014 to 2024 for Banquereau. The biomass in 2024 is a one-year-forward prediction.

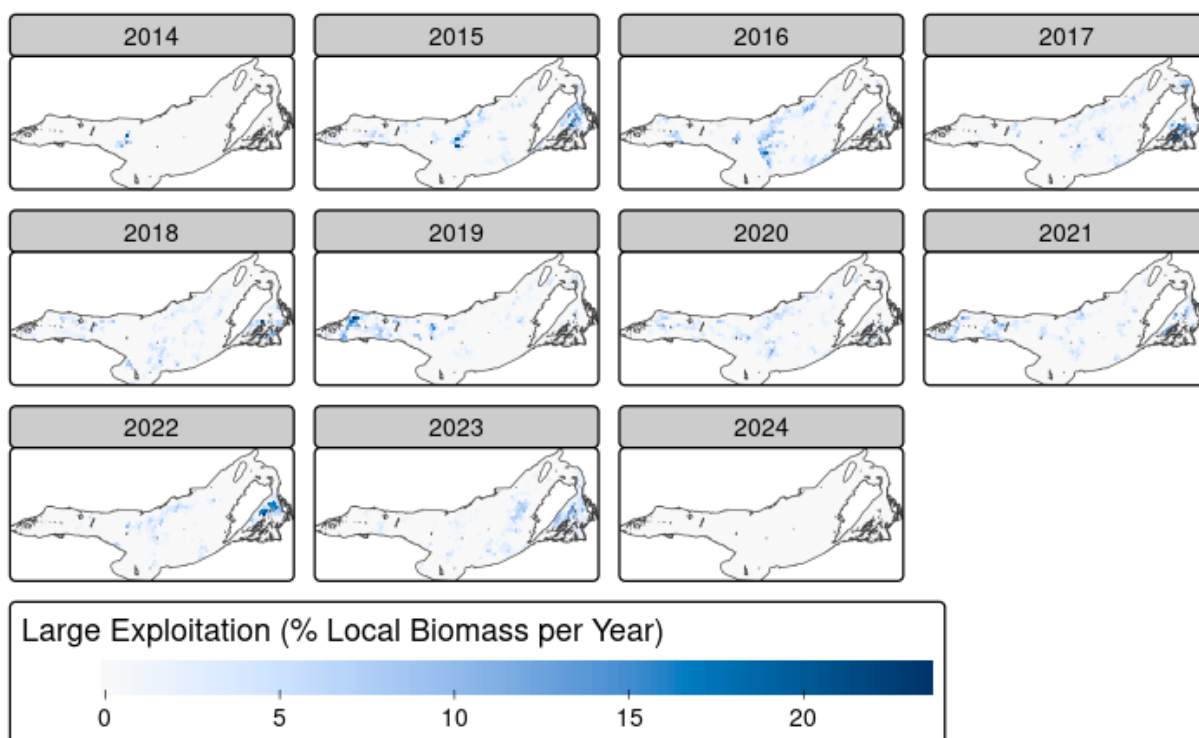


Figure 106. Estimated local exploitation rates of Large biomass from 2014 to 2024 for Banquereau.

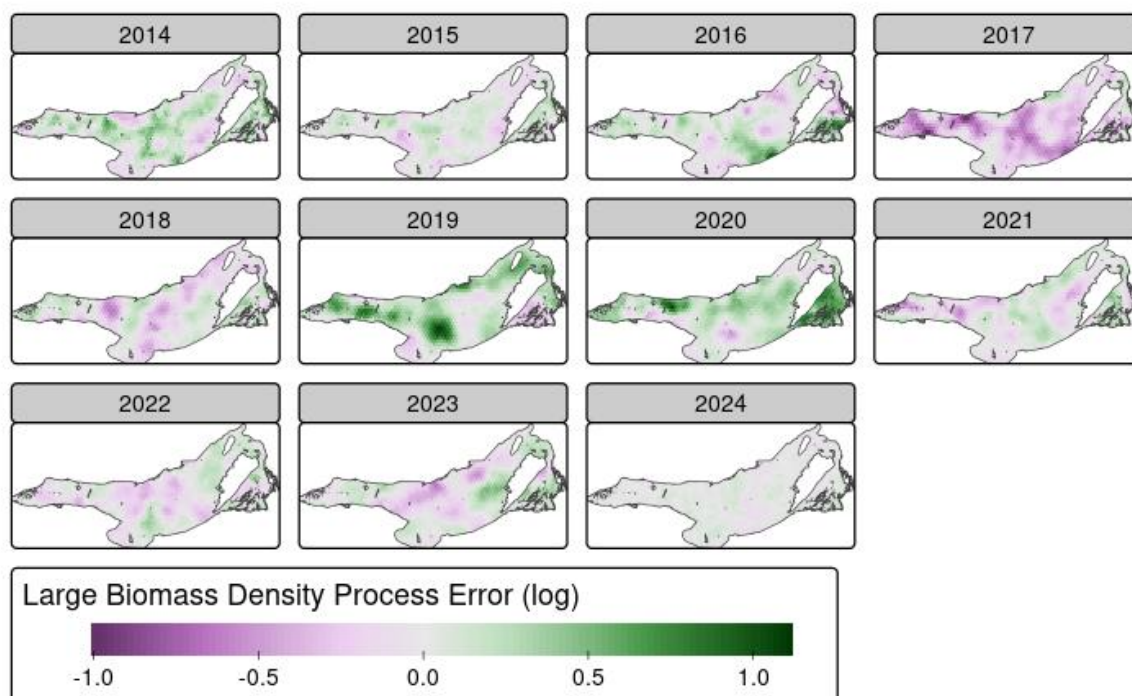


Figure 107. Estimated random error in Large biomass dynamics. Random error accounts for any annual spatial difference in the bank-wide average mortality and growth. Random error is shown as the percent change in actual biomass relative to the expected biomass estimated from the model.

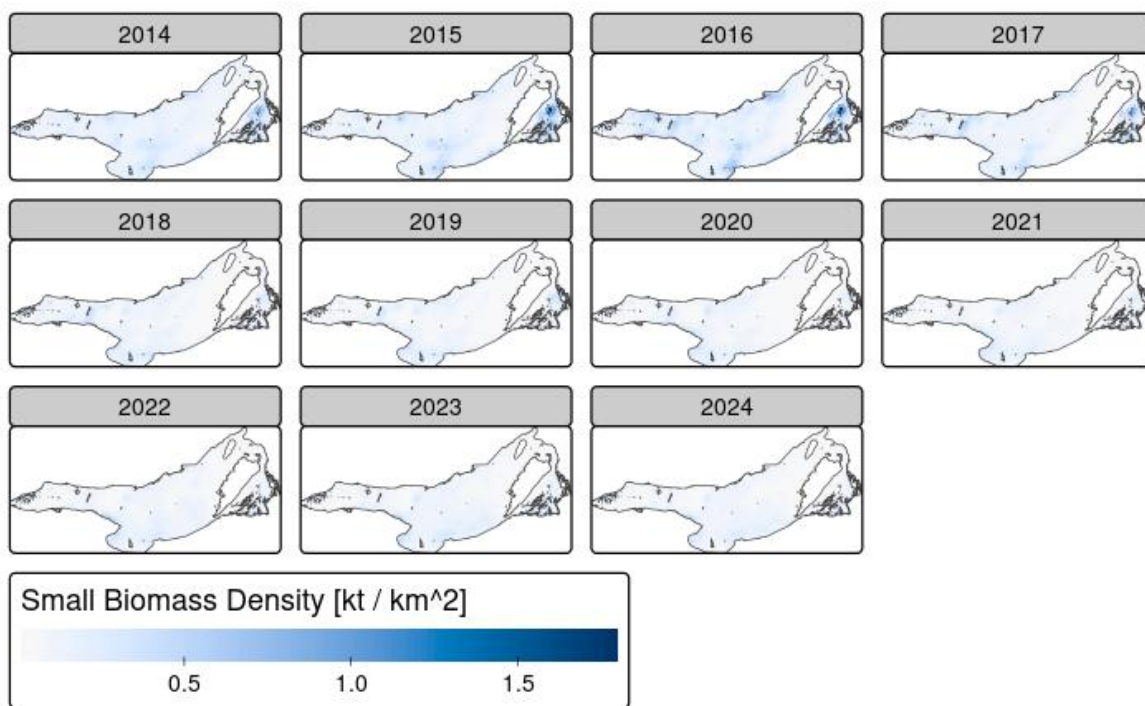


Figure 108. Estimated Small biomass (kt/km^2) from 2014 to 2024 from Banquereau. The biomass in 2024 is a one-year-ahead prediction.

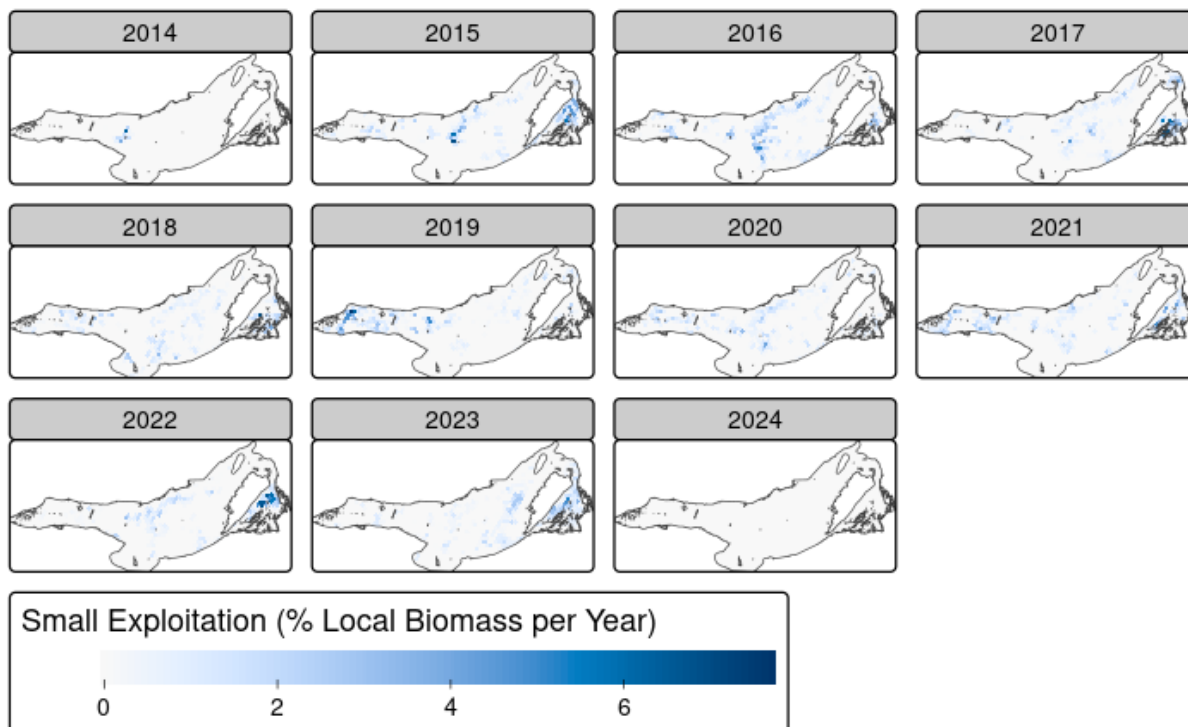


Figure 109. Estimated local exploitation rates of Small biomass from 2014 to 2024 for Banquereau.

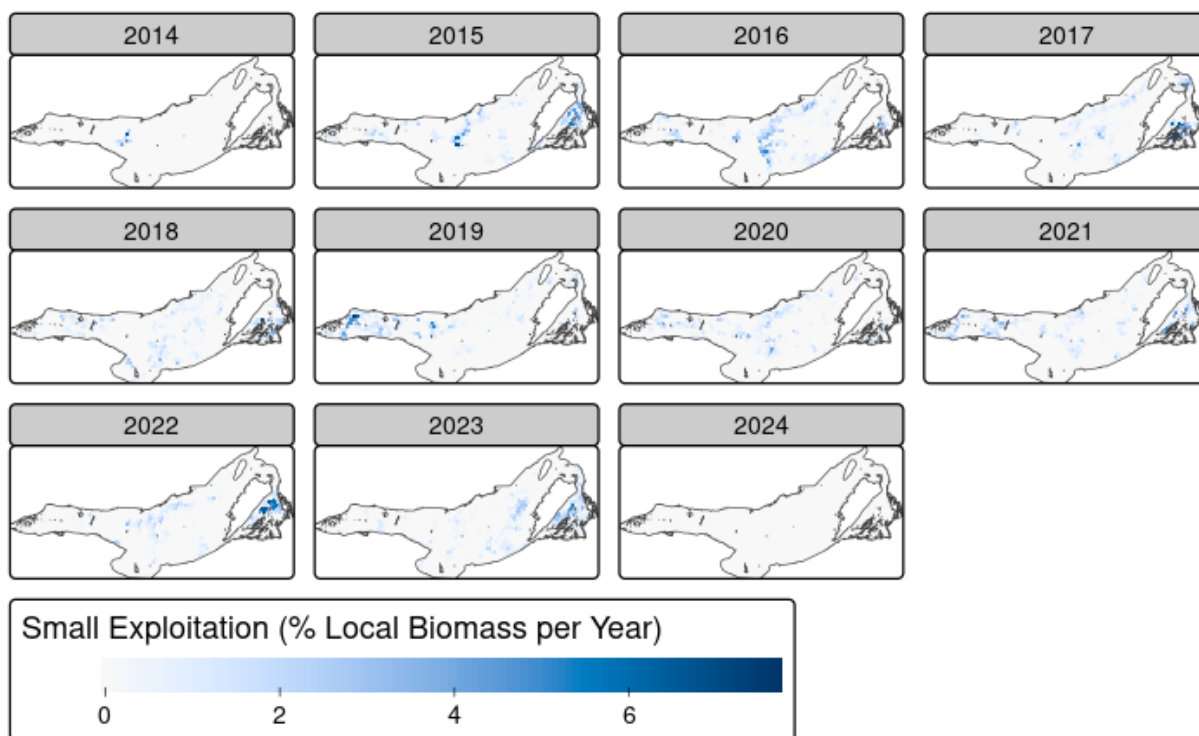


Figure 110. Estimated random error in Small biomass dynamics. Random error accounts for any annual spatial difference in the bank-wide average mortality and growth. Random error is shown as the percent change in actual biomass relative to the expected biomass estimated from the model.

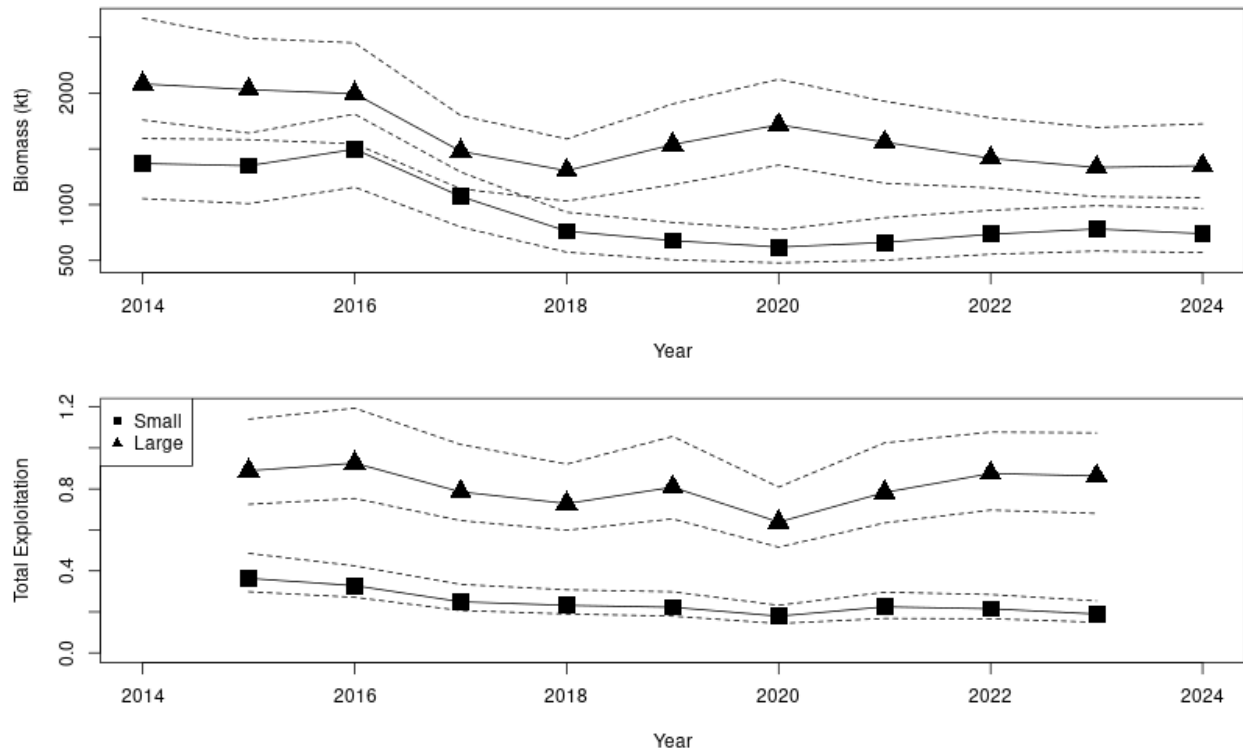


Figure 111. Estimated bank-wide biomass (kt) and exploitation rate for both Small and Large clams. Each solid line is the maximum likelihood estimate, while each pair of dashed lines are a 90% confidence interval.

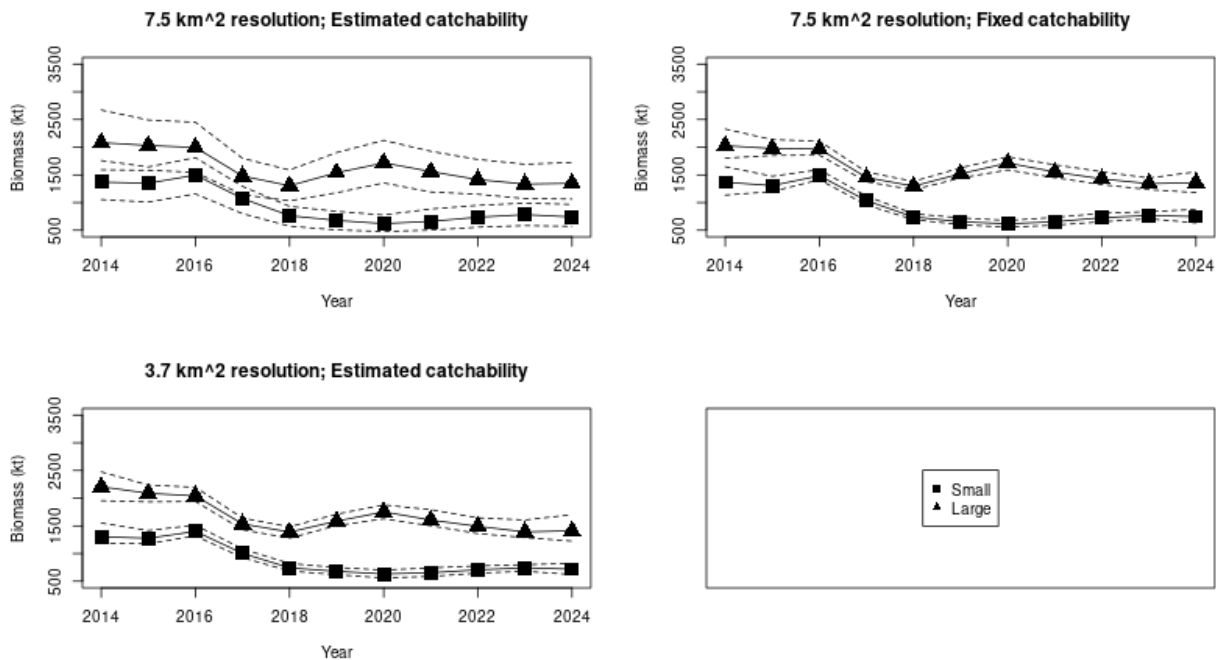


Figure 112. Comparison of total biomass (kt) estimates when changing the spatial resolution and when estimating catchability compared to fixing catchability at the estimated value.

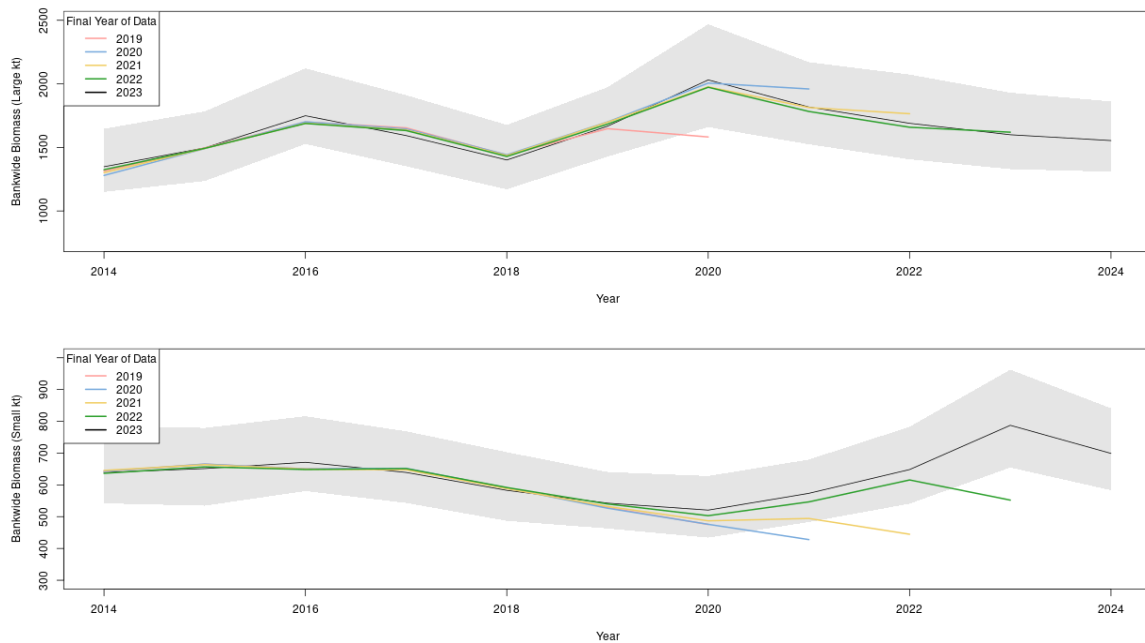


Figure 113. Retrospective analysis for Large (top panel) and Small (bottom panel) clams for Banquereau. The predicted biomass (kt) for the truncated model is scaled to have the same average biomass in the first six years as the complete model to account for differences in the estimate of catchability.

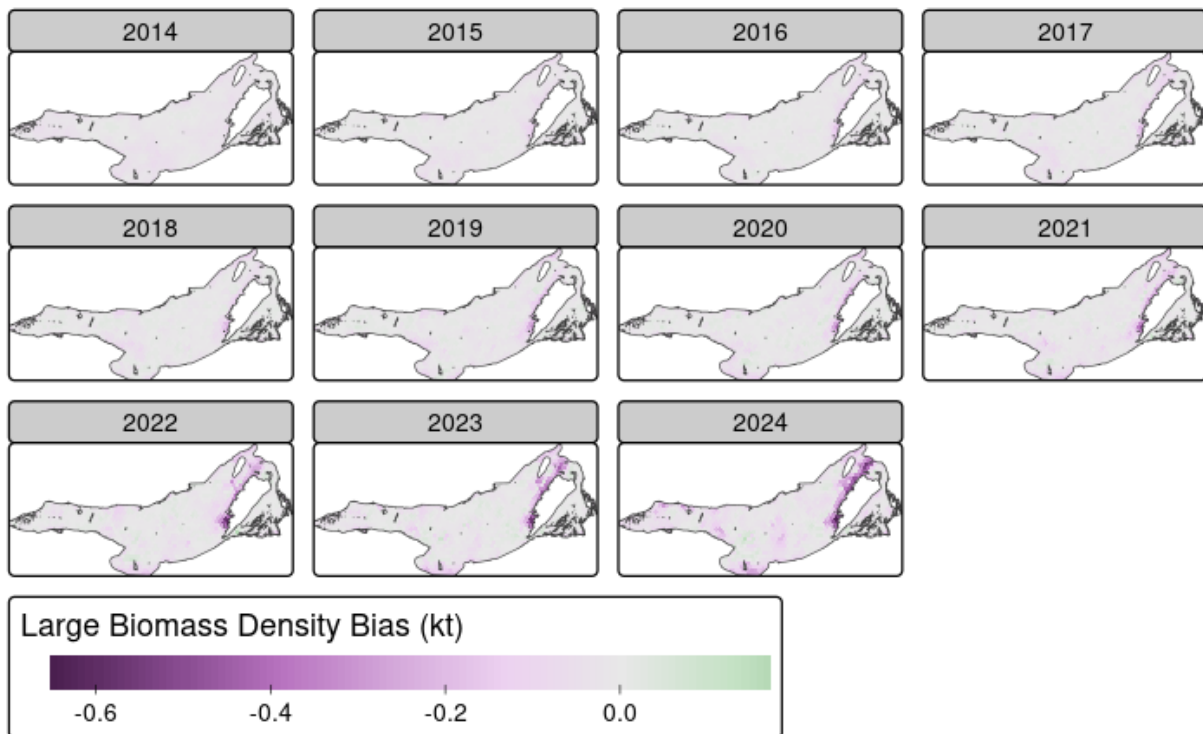


Figure 114. Large biomass (kt) density bias on Banquereau.

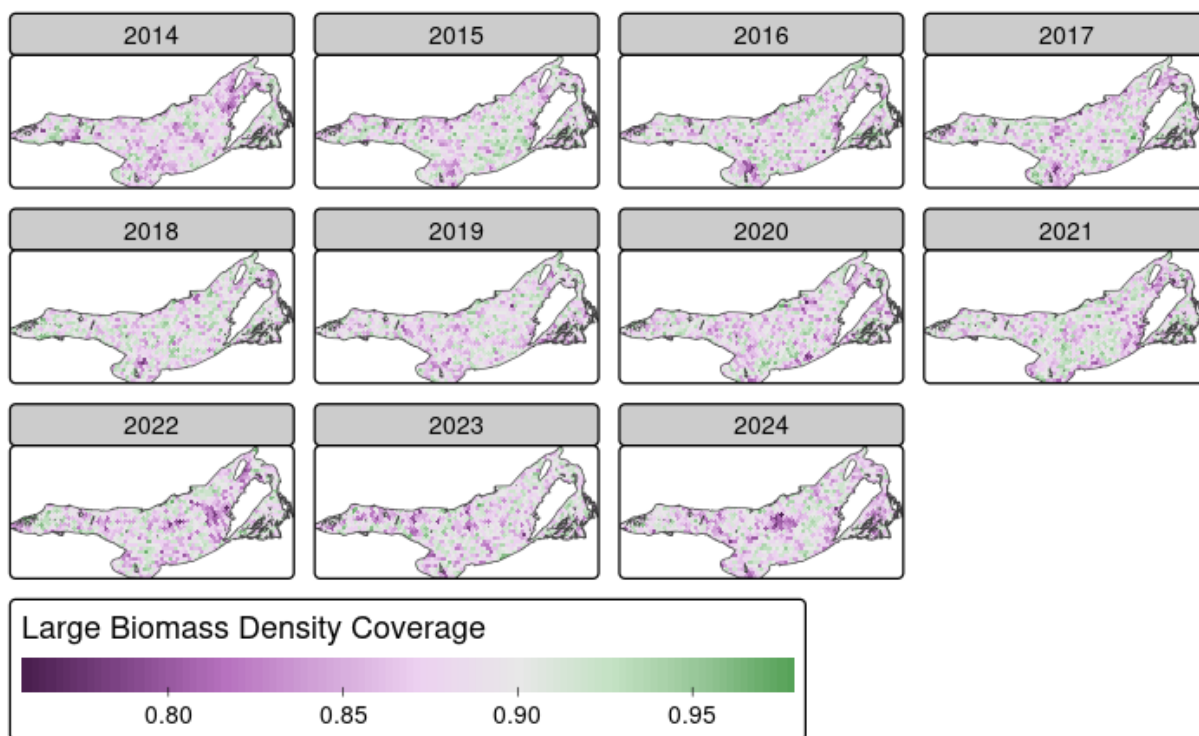


Figure 115. Large biomass density coverage for 90% confidence intervals on Banquereau.

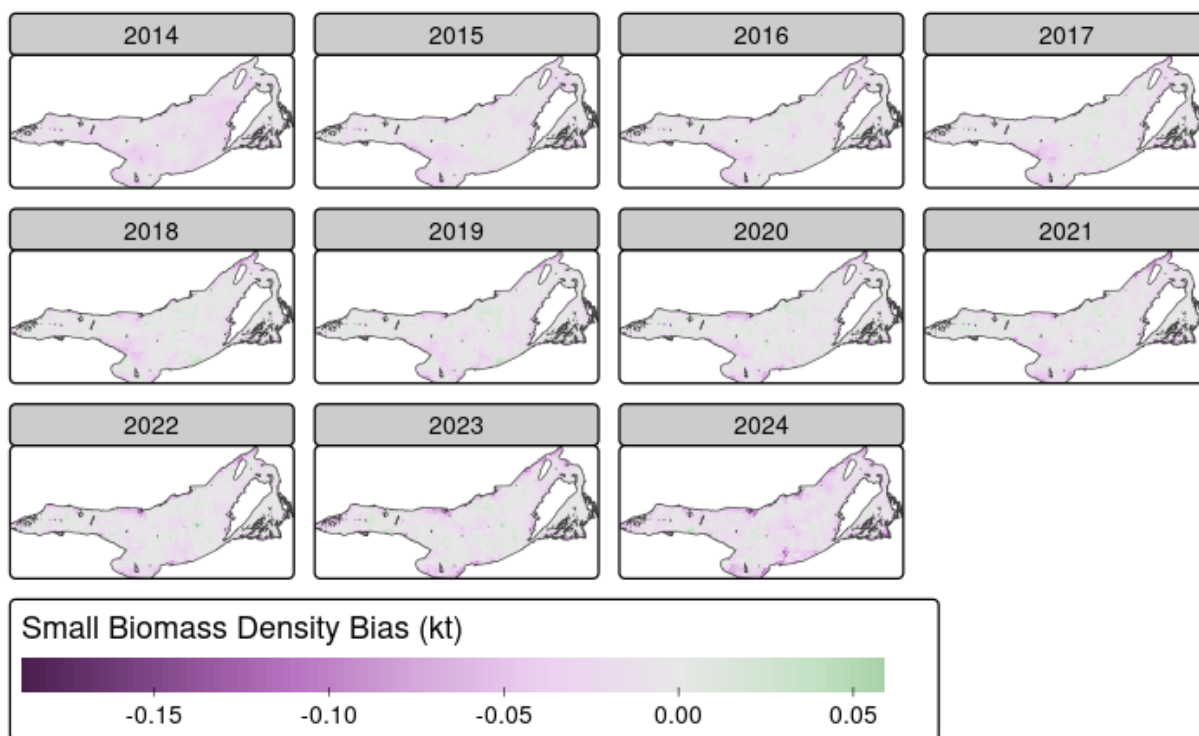


Figure 116. Small biomass (kt) density bias on Banquereau.

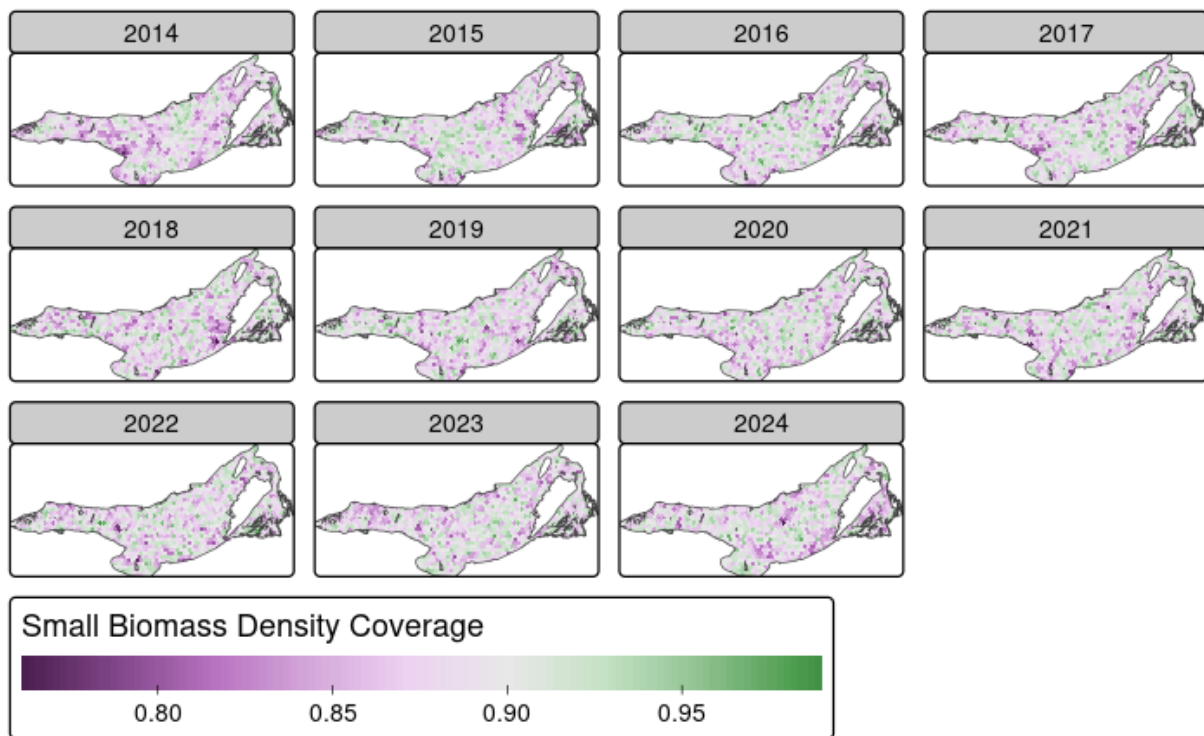


Figure 117. Small biomass density coverage for 90% confidence intervals on Banquereau.

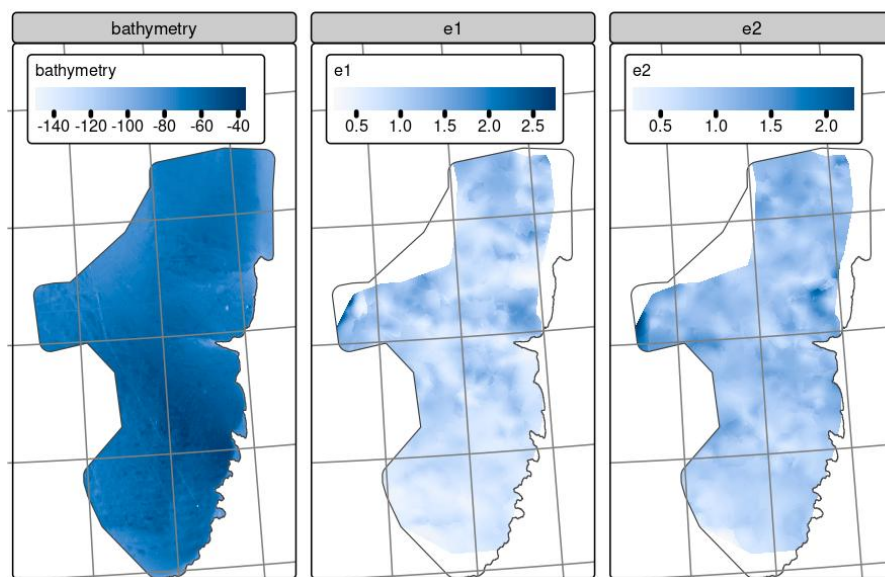


Figure 118. Environmental covariates used to predict habitat suitability on the Grand Banks.

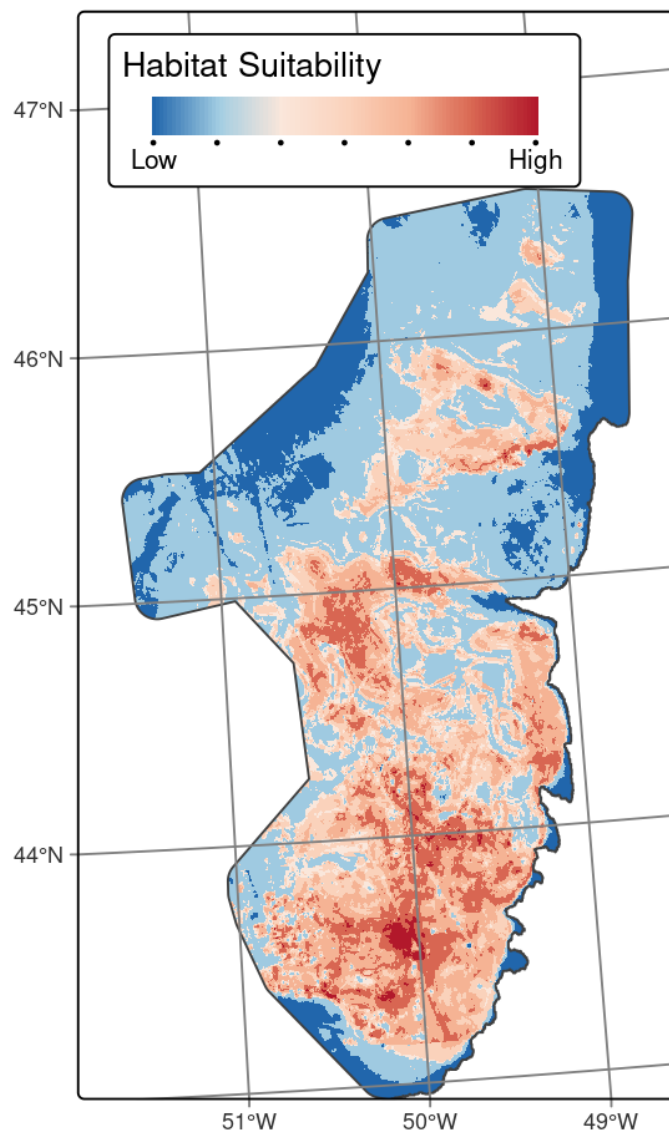


Figure 119. Predicted habitat suitability on the Grand Banks. Areas of high habitat suitability are those that look similar to areas on Banquereau, which are targeted by fishing operations.

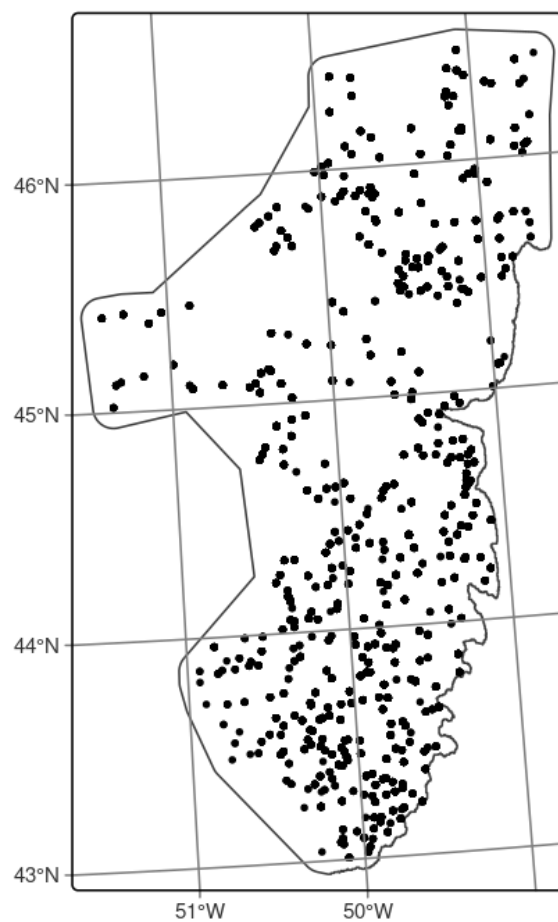


Figure 120. Sample locations for the Grand Banks surveys from 2006 to 2009.

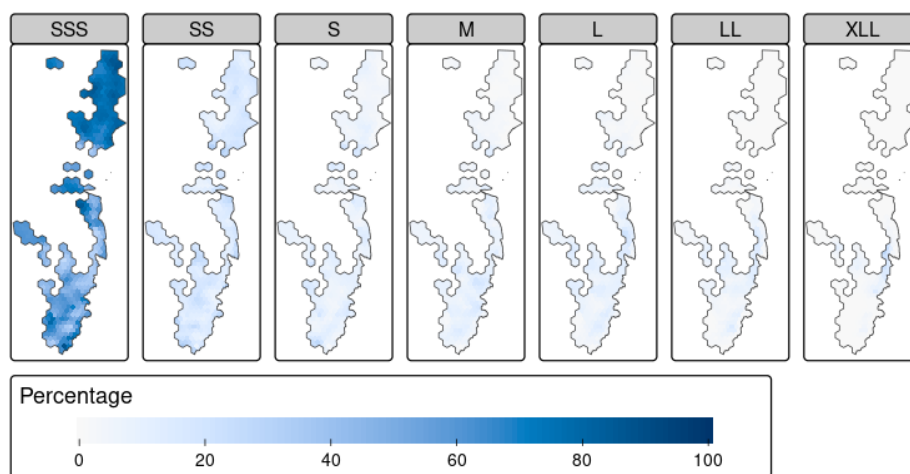


Figure 121. Estimated size class composition of Arctic Surf Clam using data from the 2006 to 2009 Grand Banks surveys.

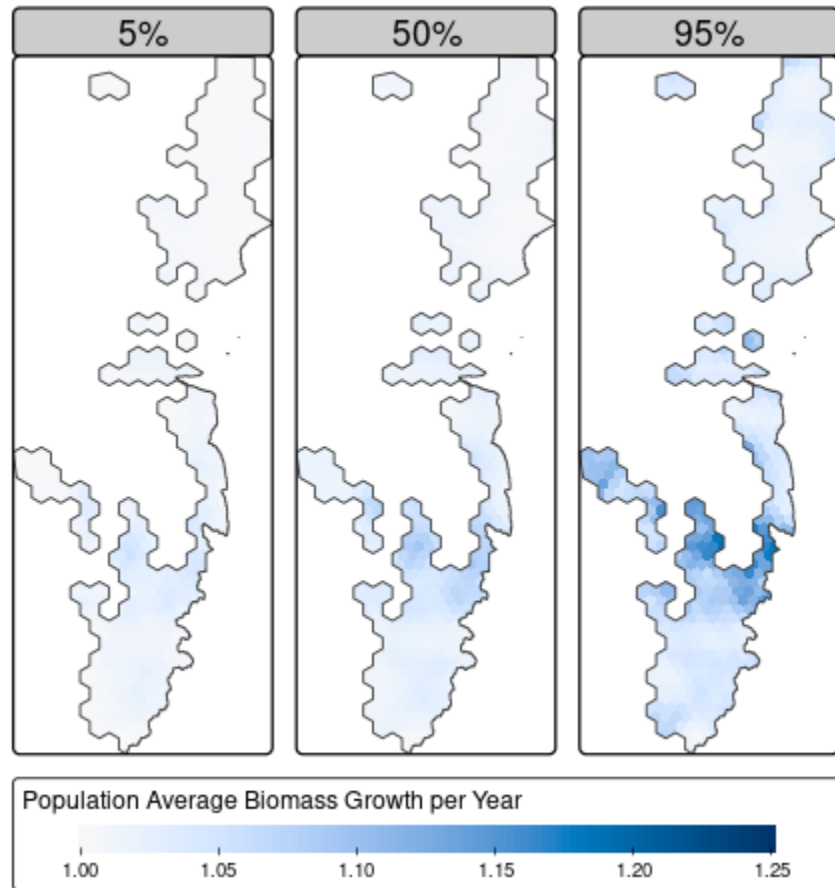


Figure 122. Estimated population average biomass growth rate of Arctic Surf Clam using data from the 2006 to 2009 Grand Banks surveys. The middle panel (50%) is the maximum likelihood estimate, while the left-hand panel (5%) and right-hand panel (95%) are the endpoints of a 90% confidence interval.

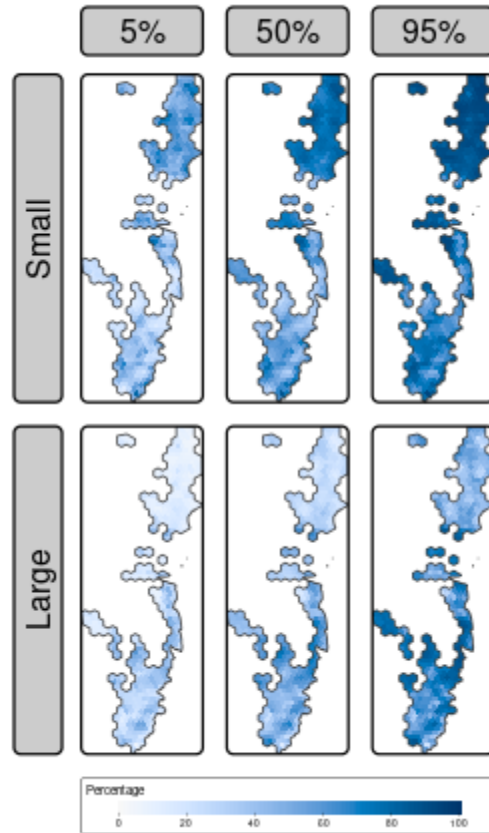


Figure 123. Small and Large class composition of Arctic Surf Clam using data from the 2006 to 2009 Grand Banks surveys. The middle column is the maximum likelihood estimate, while the left-hand column (5%) and right-hand column (95%) are the end points of a 90% confidence interval.

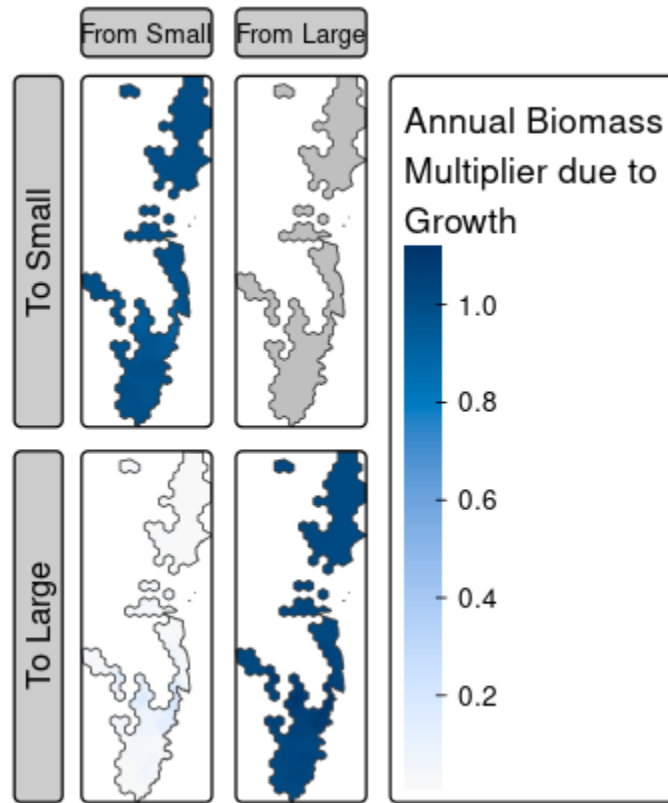


Figure 124. Estimated biomass transition matrix for Small and Large class clams. The top left panel (Small column, Small row) is the estimated (multiplicative) change in biomass within the Small class from one year to the next. The bottom left panel (Small column, Large row) is the estimated transition of biomass from the Small class to the Large class.

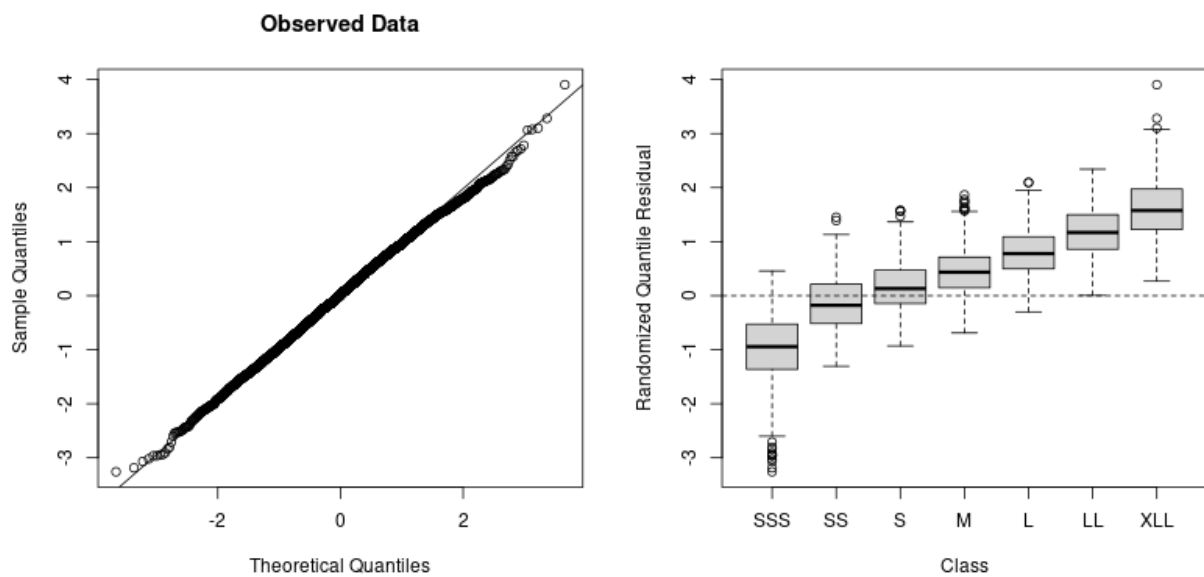


Figure 125. Residuals for the composition modeled on the Grand Banks.

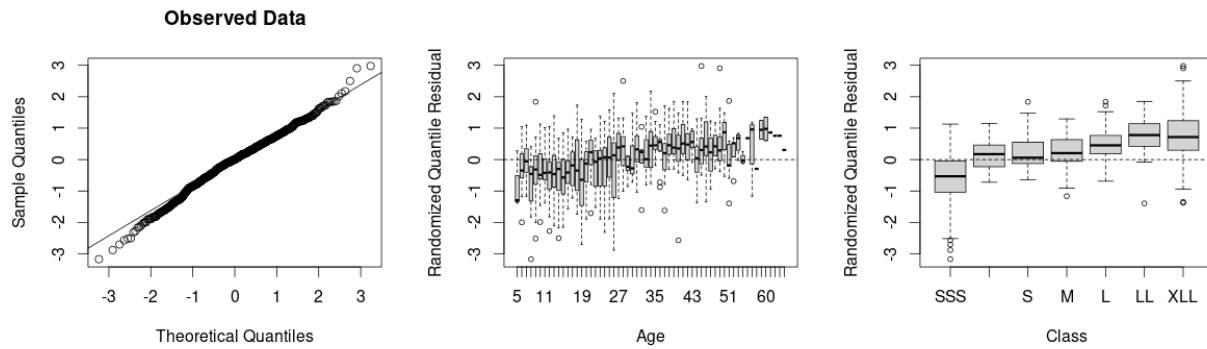


Figure 126. Residuals for the composition-at-age modeled on the Grand Banks.

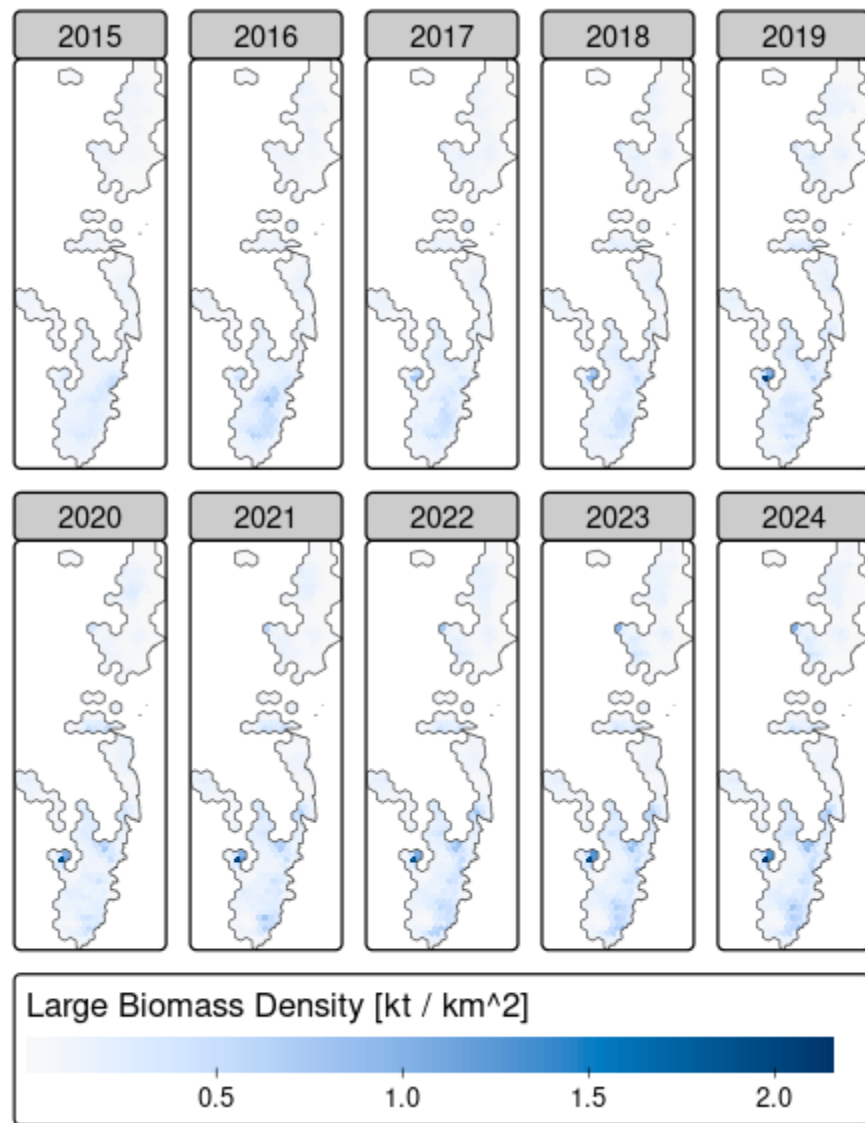


Figure 127. Estimated Large biomass density (kt/km^2) for the Grand Banks from 2015 to 2024. The biomass in 2024 is a one-year-forward prediction.

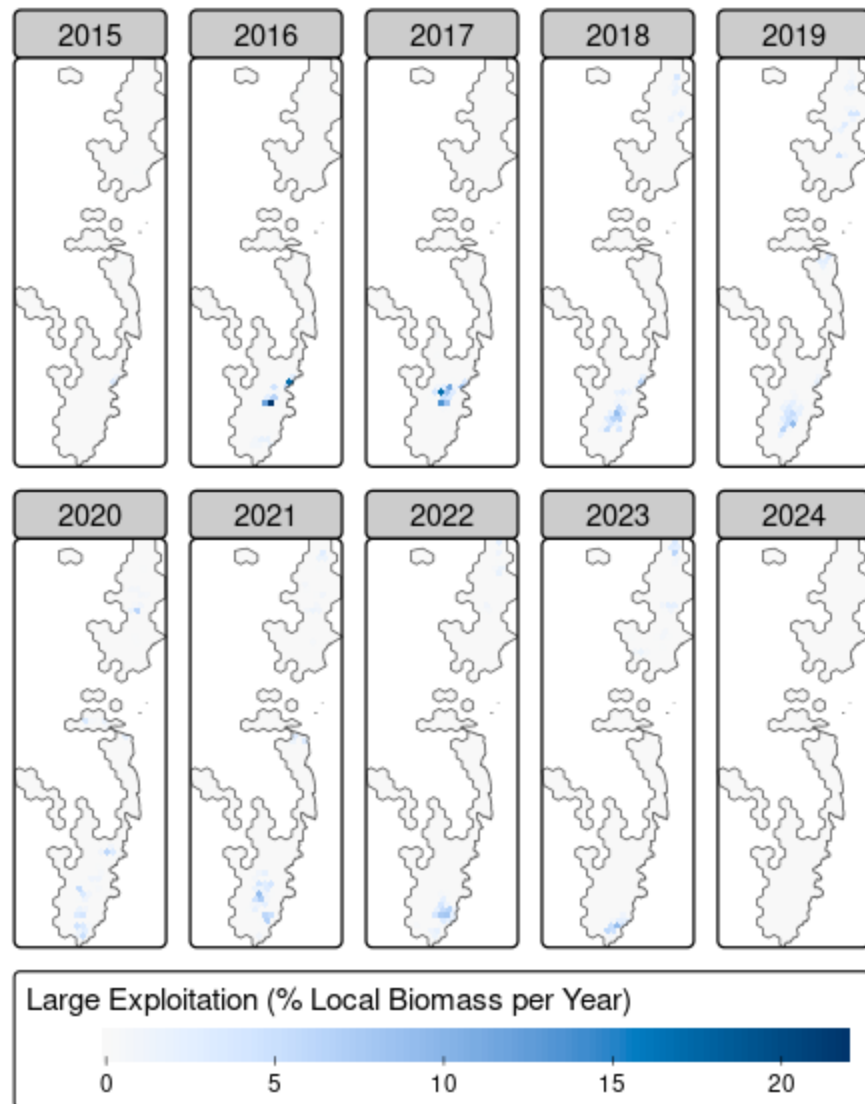


Figure 128. Estimated local exploitation rates of Large biomass for the Grand Banks from 2015 to 2024.

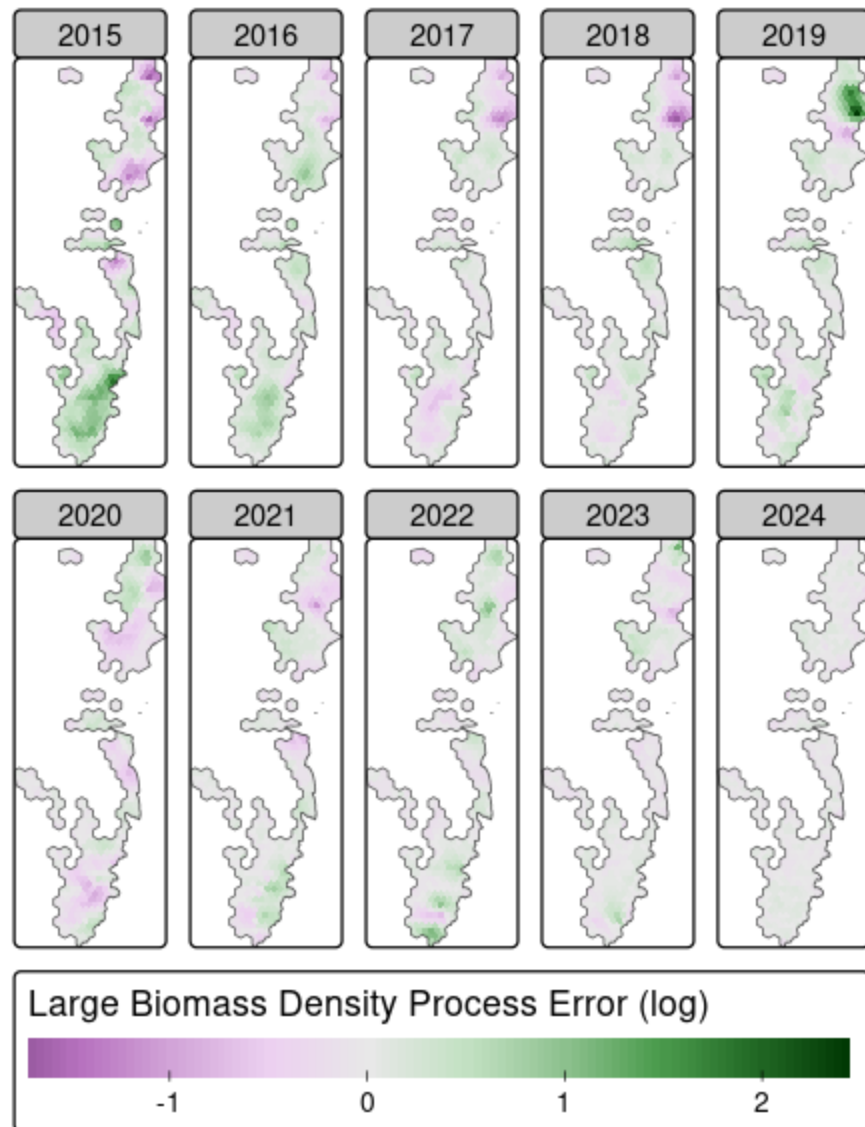


Figure 129. Estimated random error in Large biomass dynamics for the Grand Banks.

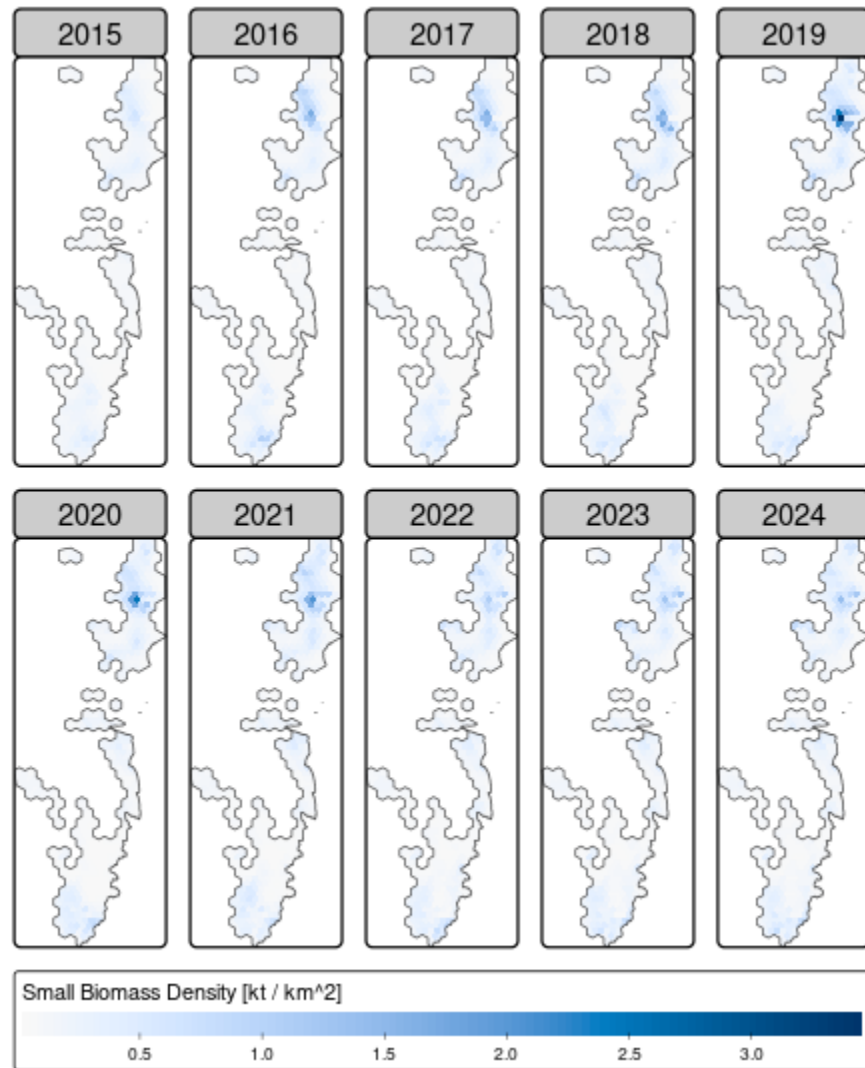


Figure 130. Estimated Small biomass density (kt/km^2) for the Grand Banks from 2015 to 2024. The biomass density in 2024 is a one-year-ahead prediction.

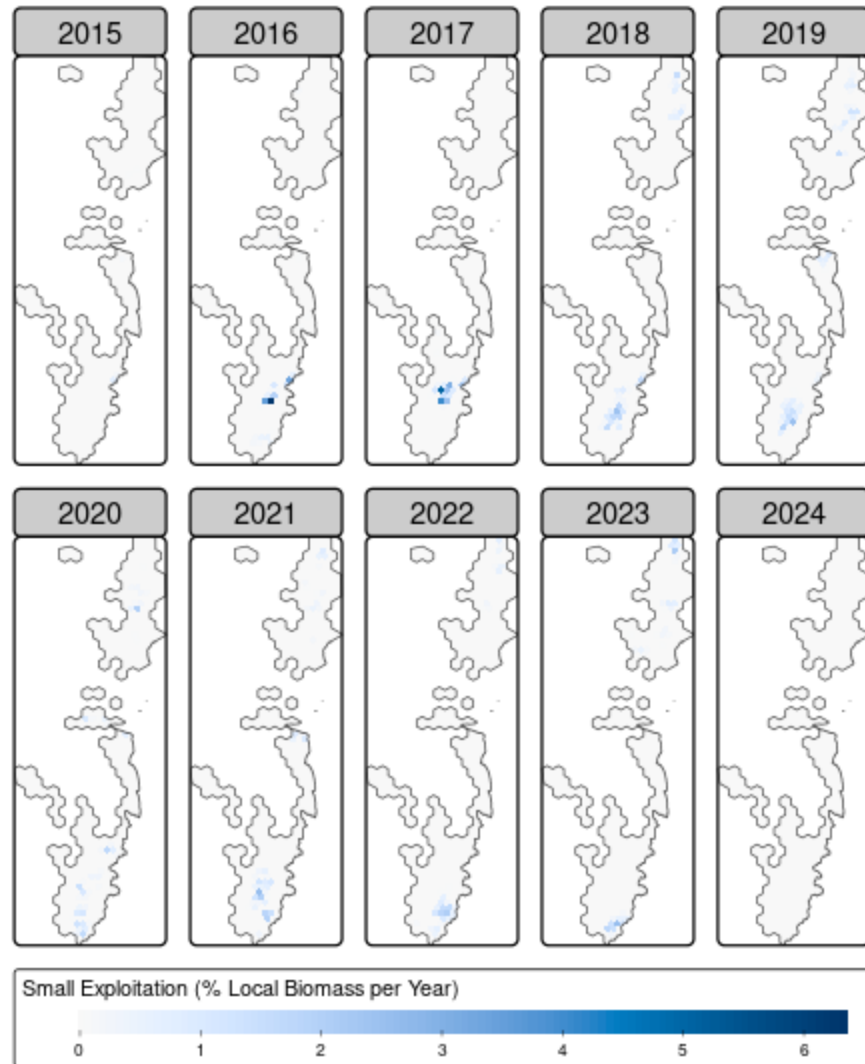


Figure 131. Estimated local exploitation rates of Small biomass for the Grand Banks from 2015 to 2024.

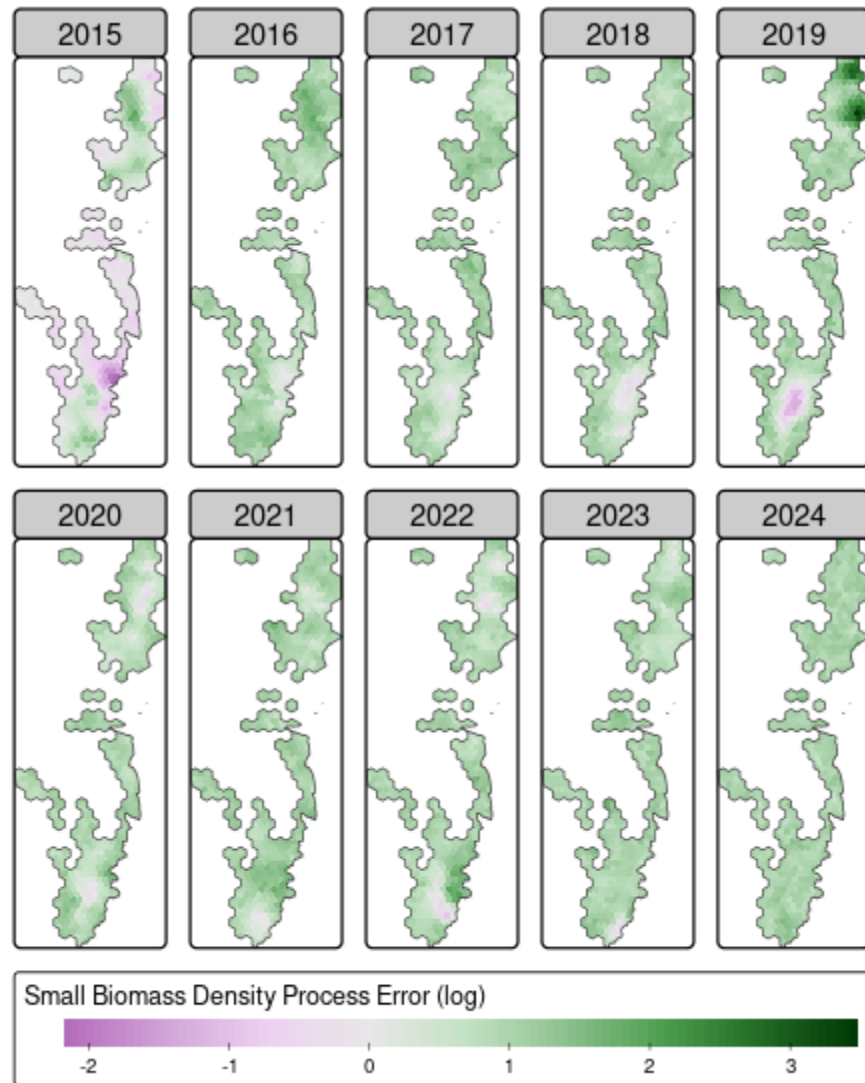


Figure 132. Estimated random error in Small biomass dynamics for the Grand Banks.

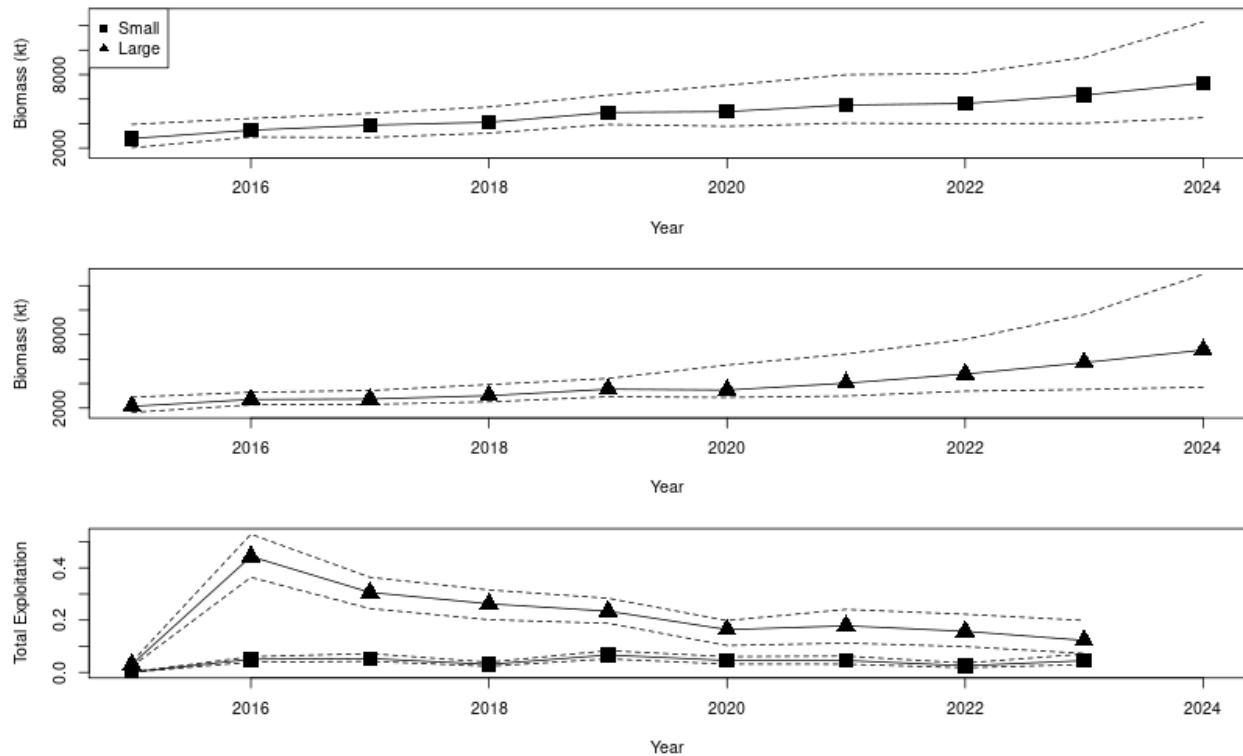


Figure 133. Estimated bank-wide biomass (kt) and exploitation rate for both Small and Large clams on the Grand Banks. Each solid line is the maximum likelihood estimate while each pair of dashed lines give a 90% confidence interval.

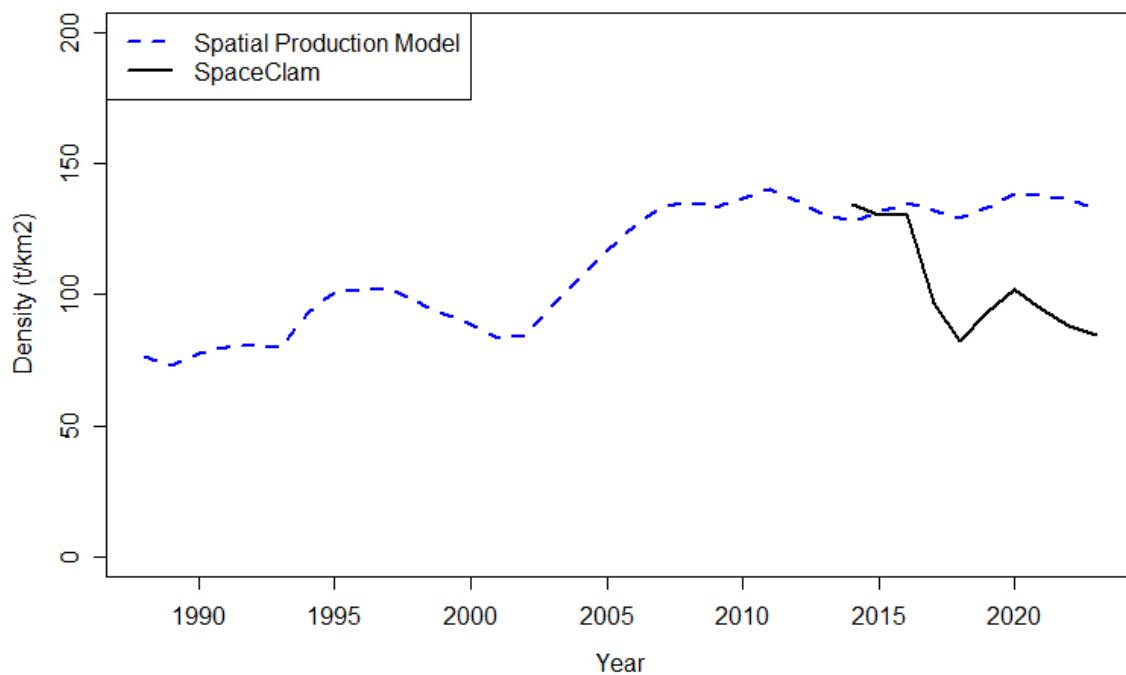


Figure 134. Comparison of modeled biomass density estimates (t/km^2) from the Spatial Production Model (dashed blue line) and the SpaceClam model (solid black line) for Banquereau using the same area and adjusting for selectivity.

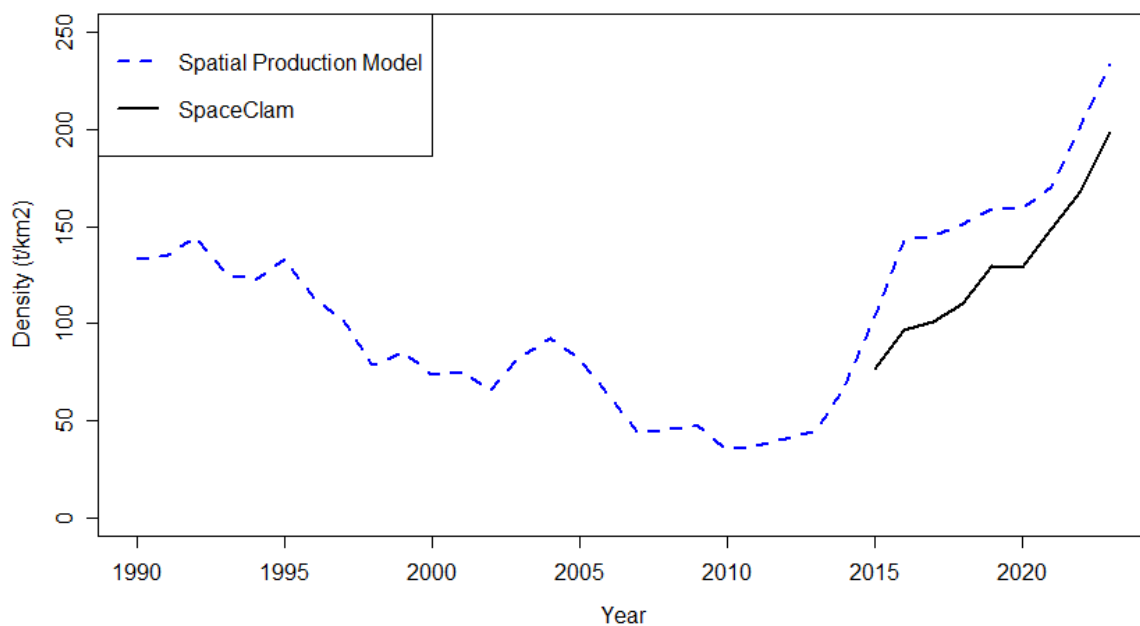


Figure 135. Comparison of modeled biomass density (t/km^2) estimates from the Spatial Production Model (dashed blue line) and the SpaceClam model (solid black line) for the Grand Banks using the same area and adjusting for selectivity.

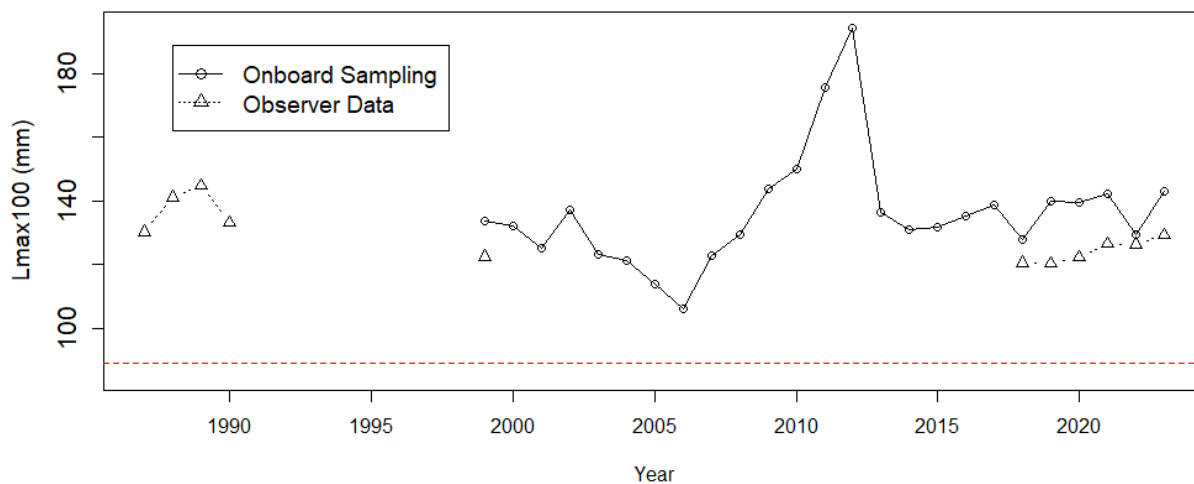


Figure 136. L_{max100} (mm) Length Indicator 2 based on bank-wide onboard sampling (open circle) and observer data (triangles) for Banquereau. Horizontal red dashed line is a reference level of $0.8L_{inf}$ (89 mm). L_{max} is mean total length of the largest n number of individuals caught. L_{inf} is the asymptotic length.

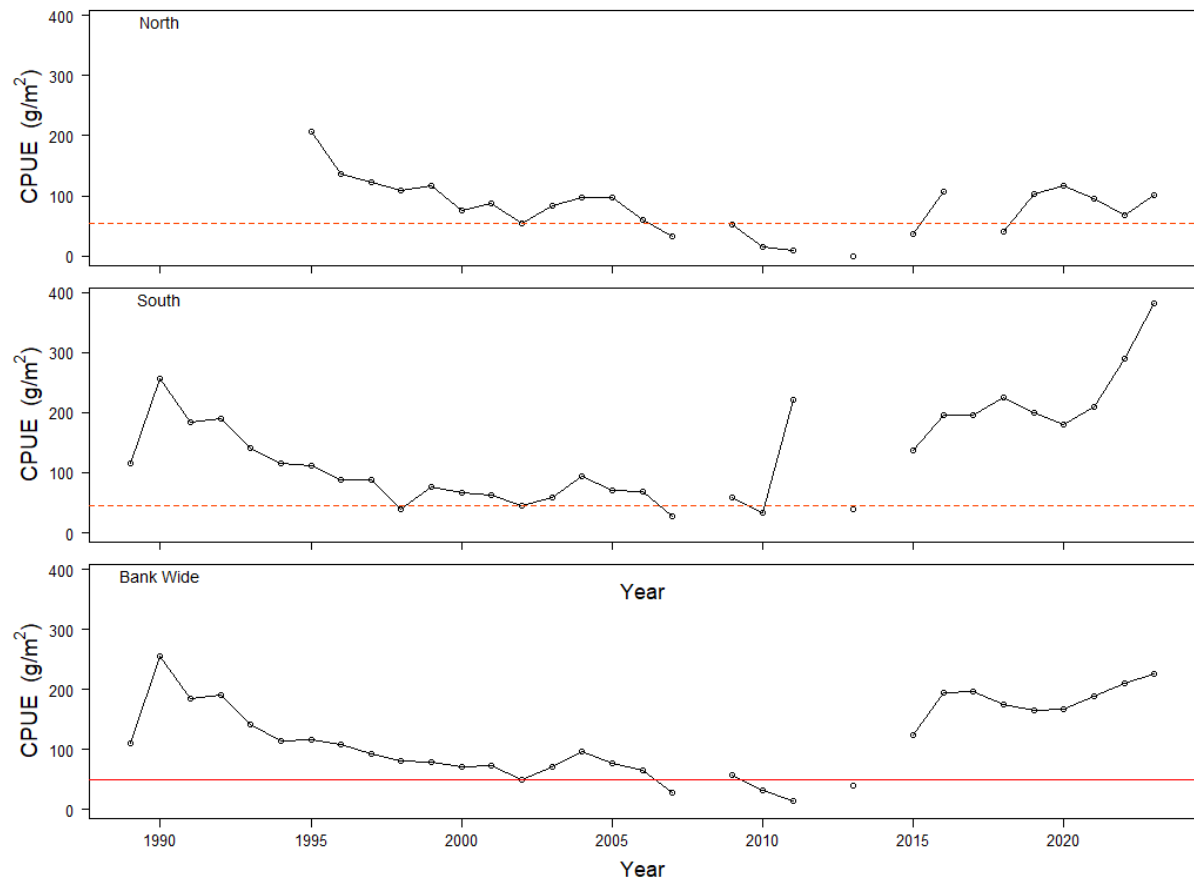


Figure 137. Catch per unit effort (CPUE, g/m^2) indicator by assessment area and bank-wide for the Grand Banks. Solid horizontal red line is bank-wide CPUE indicator level of 50 g/m^2 . Horizontal red dashed line is area-specific indicator (see: Table 24).

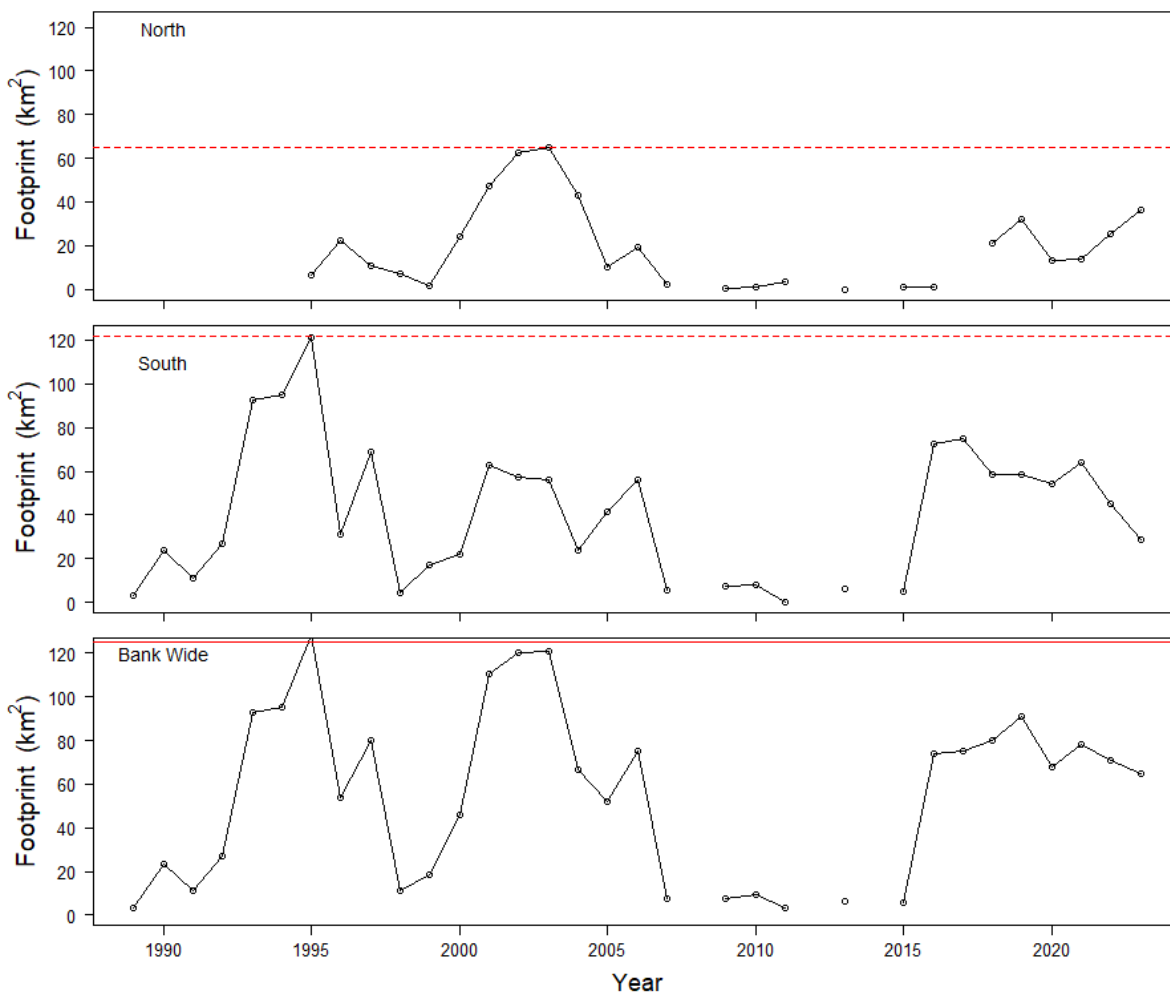


Figure 138. Fishery footprint (km^2) indicator by assessment area and bank-wide for the Grand Banks. The solid horizontal red line is a bank-wide indicator level of 125 km^2 . Horizontal red dashed line is an area-specific indicator (see: Table 24).

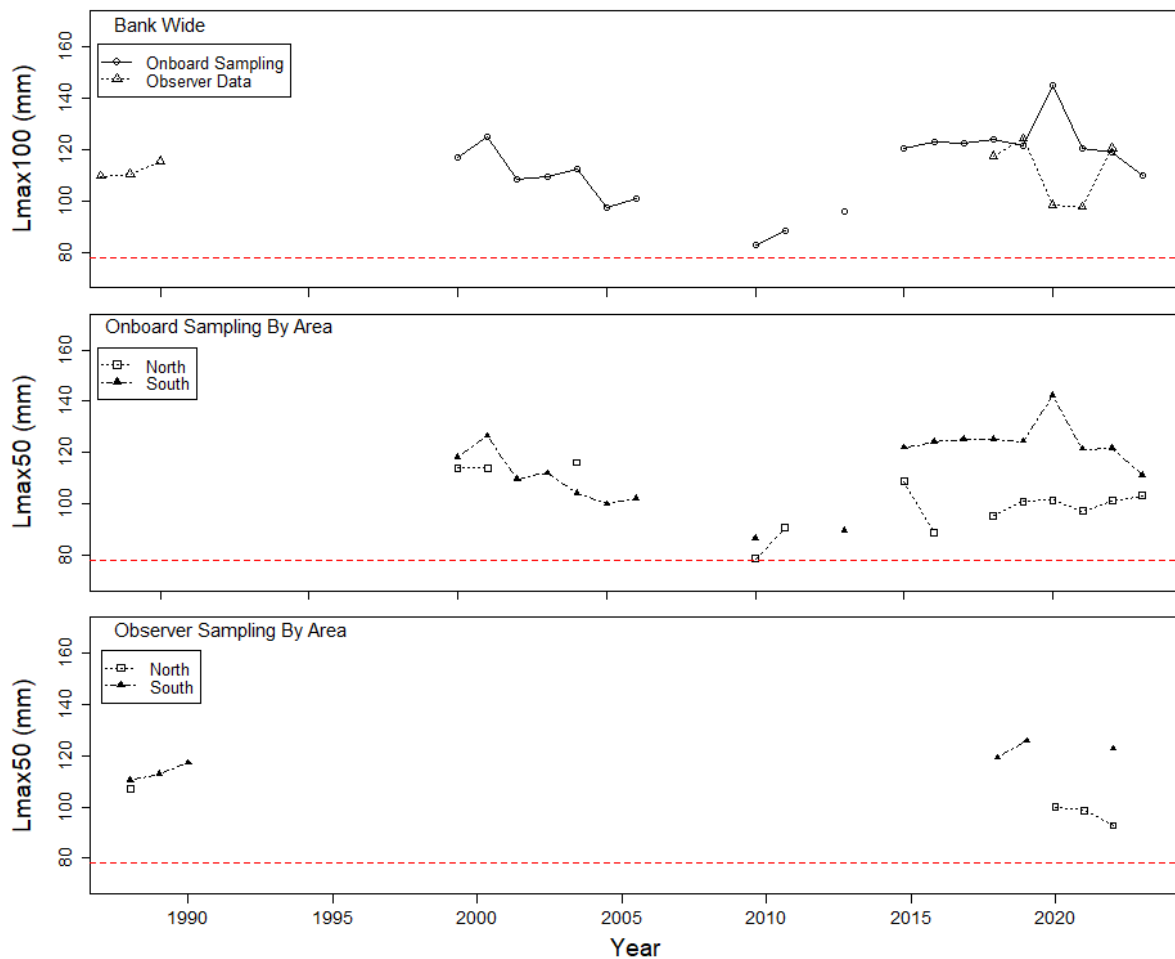


Figure 139. L_{max} (mm) Length Indicator 2 bank-wide (L_{max100} ; top panel) from onboard sampling (open circle) and observer data (triangles) for the Grand Banks. Middle panel is onboard sampling by assessment area (L_{max50}). Bottom panel is observer data by assessment area (L_{max50}). Horizontal red dashed line is a reference level of $0.8L_{inf}$ (78 mm). L_{max} is mean total length of the largest n number of individuals caught. L_{inf} is the asymptotic length.

APPENDIX A: OBSERVER SUMMARIES

Table A1. Banquereau 2018: Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch /Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Arctic Surf Clam	942.68	2.11	445.85	4.62	2059.8	37.02	100.00
Shells	898.43	2.11	424.92	4.62	1963.2	35.28	95.31
Northern Propeller Clam	255.62	2.11	120.90	4.62	558.5	10.04	27.12
Sand Dollar	200.73	2.11	94.94	4.62	438.6	7.88	21.29
Stones and Rocks	131.26	2.11	62.08	4.62	286.8	5.15	13.92
Sea Cucumber (NS)	52.13	2.11	24.66	4.62	113.9	2.05	5.53
Buccinidae F.	25.66	2.11	12.14	4.62	56.1	1.01	2.72
Greenland Cockle	8.29	2.11	3.92	4.62	18.1	0.33	0.88
Sea Urchin	7.22	2.11	3.42	4.62	15.8	0.28	0.77
Sea Mouse	6.62	2.11	3.13	4.62	14.5	0.26	0.70
Scallop NS	5.04	2.11	2.38	4.62	11.0	0.20	0.53
Sea Scallop	4.81	2.11	2.27	4.62	10.5	0.19	0.51
Hermit crab	1.84	2.11	0.87	4.62	4.0	0.07	0.20
Ocean Quahog	1.80	2.11	0.85	4.62	3.9	0.07	0.19
Asteroidea S.C.	1.27	2.11	0.60	4.62	2.8	0.05	0.13
Sand Lance	1.14	2.11	0.54	4.62	2.5	0.04	0.12
Skate NS	0.76	2.11	0.36	4.62	1.7	0.03	0.08
Sea Anemone	0.51	2.11	0.24	4.62	1.1	0.02	0.05

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch /Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Yellowtail Flounder	0.24	2.11	0.11	4.62	0.5	0.01	0.03
Hyas coarctatus	0.19	2.11	0.09	4.62	0.4	0.01	0.02
Acanthocephala P.	0.14	2.11	0.07	4.62	0.3	0.01	0.02
Hyas araneus	0.07	2.11	0.03	4.62	0.2	<0.01	0.01

Table A2. Banquereau 2019: Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Stones and Rocks	1643.73	2.64	621.92	5.49	3414.4	45.07	218.42
Arctic Surf Clam	752.54	2.64	284.73	5.49	1563.2	20.63	100.00
Shells	714.62	2.64	270.38	5.49	1484.4	19.59	94.96
Sand Dollar	169.22	2.64	64.03	5.49	351.5	4.64	22.49
Northern Propeller Clam	144.65	2.64	54.73	5.49	300.5	3.97	19.22
Sea Cucumber (NS)	100.10	2.64	37.88	5.49	207.9	2.74	13.30
Sea Mouse	23.03	2.64	8.71	5.49	47.8	0.63	3.06
Asteroidea S.C.	13.99	2.64	5.29	5.49	29.1	0.38	1.86
Buccinidae F.	13.19	2.64	4.99	5.49	27.4	0.36	1.75
Hermit Crab	13.07	2.64	4.95	5.49	27.1	0.36	1.74

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Sea Scallop	11.97	2.64	4.53	5.49	24.9	0.33	1.59
Sea Urchin	11.49	2.64	4.35	5.49	23.9	0.32	1.53
Greenland Cockle	9.41	2.64	3.56	5.49	19.5	0.26	1.25
Sand Lance	6.70	2.64	2.54	5.49	13.9	0.18	0.89
Ocean Quahog	4.86	2.64	1.84	5.49	10.1	0.13	0.65
Sea Anemone	4.37	2.64	1.65	5.49	9.1	0.12	0.58
Atlantic Rock Crab	4.10	2.64	1.55	5.49	8.5	0.11	0.54
Acanthocephala P.	3.81	2.64	1.44	5.49	7.9	0.10	0.51
Snow Crab	1.04	2.64	0.39	5.49	2.2	0.03	0.14
Icelandic Scallop	0.77	2.64	0.29	5.49	1.6	0.02	0.10
Longhorn Sculpin	0.25	2.64	0.10	5.49	0.5	0.01	0.03
Yellowtail Flounder	0.17	2.64	0.06	5.49	0.3	<0.01	0.02
Hyas coarctatus	0.10	2.64	0.04	5.49	0.2	<0.01	0.01
American Plaice	0.09	2.64	0.03	5.49	0.2	<0.01	0.01

Table A3. Banquereau 2020: Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shells	1,837.06	3.18	578.18	6.24	3607.8	35.32	199.12

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Stones and Rocks	1,587.86	3.18	499.74	6.24	3118.4	30.53	172.10
Arctic Surf Clam	922.61	3.18	290.37	6.24	1811.9	17.74	100.00
Northern Propeller Clam	334.61	3.18	105.31	6.24	657.1	6.43	36.27
Sand Dollar	256.04	3.18	80.58	6.24	502.8	4.92	27.75
Sea Cucumber (NS)	99.89	3.18	31.44	6.24	196.2	1.92	10.83
Sea Mouse	35.25	3.18	11.10	6.24	69.2	0.68	3.82
Buccinidae F.	19.53	3.18	6.15	6.24	38.3	0.38	2.12
Greenland Cockle	13.24	3.18	4.17	6.24	26.0	0.25	1.43
Sea Urchin	13.01	3.18	4.09	6.24	25.5	0.25	1.41
Sea Scallop	12.86	3.18	4.05	6.24	25.2	0.25	1.39
Asteroidea S.C.	11.48	3.18	3.61	6.24	22.5	0.22	1.24
Sand Lance	10.57	3.18	3.33	6.24	20.8	0.20	1.15
Hermit Crab	10.50	3.18	3.30	6.24	20.6	0.20	1.14
Acanthocephala P.	7.75	3.18	2.44	6.24	15.2	0.15	0.84
Sea Anemone	7.45	3.18	2.35	6.24	14.6	0.14	0.81
Snow Crab	5.98	3.18	1.88	6.24	11.7	0.11	0.65
Ocean Quahog	4.62	3.18	1.45	6.24	9.1	0.09	0.50
Icelandic Scallop	3.86	3.18	1.22	6.24	7.6	0.07	0.42
Atlantic Rock Crab	3.04	3.18	0.96	6.24	6.0	0.06	0.33
American Plaice	0.93	3.18	0.29	6.24	1.8	0.02	0.10
Thorny Skate	0.71	3.18	0.22	6.24	1.4	0.01	0.08

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Longhorn Sculpin	0.48	3.18	0.15	6.24	1.0	0.01	0.05
Mussels NS	0.40	3.18	0.13	6.24	0.8	0.01	0.04
Clams NS	0.38	3.18	0.12	6.24	0.7	0.01	0.04
Spider Crab (NS)	0.20	3.18	0.06	6.24	0.4	<0.01	0.02
Sea Sponge	0.13	3.18	0.04	6.24	0.3	<0.01	0.01
Hyas coarctatus	0.07	3.18	0.02	6.24	0.1	<0.01	0.01

Table A4. Banquereau 2021 (Observed Trip 1): Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Arctic Surf Clam	598.39	0.58	1,038.24	1.19	1235.5	70.99	100.00
Shells	90.23	0.58	156.55	1.19	186.3	10.70	15.08
Mussels NS	36.92	0.58	64.05	1.19	76.2	4.38	6.17
Ocean Quahog	34.76	0.58	60.32	1.19	71.8	4.12	5.81
Buccinidae F.	16.75	0.58	29.06	1.19	34.6	1.99	2.80
Greenland Cockle	16.54	0.58	28.70	1.19	34.2	1.96	2.76
Stones and Rocks	15.68	0.58	27.21	1.19	32.4	1.86	2.62
Sea Mouse	12.73	0.58	22.09	1.19	26.3	1.51	2.13

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Sea Cucumber (NS)	6.72	0.58	11.66	1.19	13.9	0.80	1.12
Hermit Crab	4.90	0.58	8.50	1.19	10.1	0.58	0.82
Sea Scallop	2.87	0.58	4.98	1.19	5.9	0.34	0.48
Northern Propeller Clam	2.62	0.58	4.55	1.19	5.4	0.31	0.44
Asteroidea S.C.	1.47	0.58	2.55	1.19	3.0	0.17	0.25
Sand Dollar	1.29	0.58	2.24	1.19	2.7	0.15	0.22
Razor Shell Clam	0.50	0.58	0.87	1.19	1.0	0.06	0.08
Sea Urchin	0.17	0.58	0.29	1.19	0.3	0.02	0.03
Jonah Crab	0.16	0.58	0.28	1.19	0.3	0.02	0.03
Thorny Skate	0.13	0.58	0.23	1.19	0.3	0.02	0.02
Acanthocephala P.	0.09	0.58	0.16	1.19	0.2	0.01	0.02
Sand Lance	0.01	0.58	0.02	1.19	0.02	<0.01	<0.01

Table A5. Banquereau 2021 (Observed Trip 2): Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Arctic Surf Clam	633.23	3.50	181.08	7.84	1419.6	37.70	100.00

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shells	518.63	3.50	148.31	7.84	1162.7	30.87	81.90
Stones and Rocks	248.38	3.50	71.03	7.84	556.9	14.79	39.23
Sand Dollar	119.78	3.50	34.25	7.84	268.5	7.13	18.92
Northern Propeller Clam	53.50	3.50	15.30	7.84	119.9	3.18	8.45
Hermit Crab	25.09	3.50	7.17	7.84	56.2	1.49	3.96
Ocean Quahog	19.85	3.50	5.68	7.84	44.5	1.18	3.14
Buccinidae F.	15.73	3.50	4.50	7.84	35.3	0.94	2.48
Sea Urchin	13.33	3.50	3.81	7.84	29.9	0.79	2.11
Sea Mouse	9.91	3.50	2.83	7.84	22.2	0.59	1.57
Sea Cucumber (NS)	5.34	3.50	1.53	7.84	12.0	0.32	0.84
Snow Crab	4.91	3.50	1.40	7.84	11.0	0.29	0.78
Greenland Cockle	4.53	3.50	1.29	7.84	10.2	0.27	0.72
Sea Scallop	3.33	3.50	0.95	7.84	7.5	0.20	0.53
Astroidea S.C.	2.31	3.50	0.66	7.84	5.2	0.14	0.37
Sand Lance	1.19	3.50	0.34	7.84	2.7	0.07	0.19
Yellowtail Flounder	0.53	3.50	0.15	7.84	1.2	0.03	0.08
Acanthocephala P.	0.25	3.50	0.07	7.84	0.6	0.02	0.04
Jonah Crab	0.03	3.50	0.01	7.84	0.1	<0.01	<0.01

Table A6. Banquereau 2021 (Observed Trip 3): Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Arctic Surf Clam	1358.32	3.68	369.53	8.65	3196.4	33.11	100.00
Northern Propeller Clam	824.83	3.68	224.39	8.65	1941.0	20.11	60.72
Shells	726.05	3.68	197.52	8.65	1708.6	17.70	53.45
Sand Dollar	376.38	3.68	102.40	8.65	885.7	9.17	27.71
Stones and Rocks	136.12	3.68	37.03	8.65	276.7	3.32	10.02
Buccinidae F.	116.80	3.68	31.77	8.65	274.9	2.85	8.60
Greenland Cockle	111.32	3.68	30.28	8.65	262.0	2.71	8.20
Sea Urchin	75.03	3.68	20.41	8.65	176.6	1.83	5.52
Sea Mouse	46.70	3.68	12.70	8.65	109.9	1.14	3.44
Thorny Skate	45.59	3.68	12.40	8.65	107.3	1.11	3.36
Sand Lance	44.99	3.68	12.24	8.65	105.9	1.10	3.31
Sea Cucumber (NS)	35.33	3.68	9.61	8.65	82.6	0.86	2.60
Hermit Crab	29.21	3.68	7.95	8.65	68.7	0.71	2.15
Sand	25.40	3.68	6.91	8.65	59.8	0.62	1.87
Icelandic Scallop	22.08	3.68	6.01	8.65	52.0	0.54	1.63
Acanthocephala P.	14.85	3.68	4.04	8.65	43.6	0.36	1.09
Tunicata	12.66	3.68	3.44	8.65	34.9	0.31	0.93
Brittle star	11.97	3.68	3.26	8.65	29.8	0.29	0.88
Witch Flounder	11.33	3.68	3.08	8.65	28.2	0.28	0.83

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Scallop NS	9.17	3.68	2.50	8.65	26.7	0.22	0.68
Ocean Quahog	7.81	3.68	2.12	8.65	21.6	0.19	0.57
Asteroidea S.C.	7.54	3.68	2.05	8.65	18.4	0.18	0.56
American Plaice	7.52	3.68	2.05	8.65	17.7	0.18	0.55
Smooth Skate	5.85	3.68	1.59	8.65	17.7	0.14	0.43
Yellowtail Flounder	5.76	3.68	1.57	8.65	13.8	0.14	0.42
Silver Hake	3.59	3.68	0.98	8.65	13.6	0.09	0.26
Longhorn Sculpin	3.50	3.68	0.95	8.65	8.4	0.09	0.26
Skate NS	3.32	3.68	0.90	8.65	8.2	0.08	0.24
Snow Crab	3.20	3.68	0.87	8.65	7.8	0.08	0.24
Sun Star	3.15	3.68	0.86	8.65	7.5	0.08	0.23
Sea Scallop	2.63	3.68	0.72	8.65	7.4	0.06	0.19
Sea Anemone	2.32	3.68	0.63	8.65	6.2	0.06	0.17
Debris/Foreign Material	2.13	3.68	0.58	8.65	5.5	0.05	0.16
Seasnail (NS)	1.99	3.68	0.54	8.65	5.0	0.05	0.15
Atlantic Rock Crab	1.86	3.68	0.51	8.65	4.7	0.05	0.14
Hyas coarctatus	1.37	3.68	0.37	8.65	4.4	0.03	0.10
Skate Egg Case	1.34	3.68	0.37	8.65	3.2	0.03	0.10
Coral NS	1.23	3.68	0.33	8.65	3.2	0.03	0.09
Sea Sponge	1.13	3.68	0.31	8.65	2.9	0.03	0.08
Sea Weed	0.65	3.68	0.18	8.65	2.7	0.02	0.05

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Lumpfish	0.37	3.68	0.10	8.65	1.5	0.01	0.03

Table A7. Banquereau 2022: Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shells	618.06	3.38	182.66	7.15	1,305.20	41.04	110.81
Arctic Surf Clam	557.74	3.38	164.84	7.15	1,177.82	37.03	100.00
Sand Dollar	145.64	3.38	43.04	7.15	307.57	9.67	26.11
Northern Propeller Clam	83.06	3.38	24.55	7.15	175.41	5.52	14.89
Ocean Quahog	43.29	3.38	12.79	7.15	91.41	2.87	7.76
Stones and Rocks	29.42	3.38	8.70	7.15	62.13	1.95	5.28
Buccinidae F.	9.30	3.38	2.75	7.15	19.63	0.62	1.67
Sea Mouse	4.37	3.38	1.29	7.15	9.23	0.29	0.78
Mussels NS	3.54	3.38	1.05	7.15	7.48	0.24	0.64
Sea Urchin	2.03	3.38	0.60	7.15	4.28	0.13	0.36
Hermit Crab	1.26	3.38	0.37	7.15	2.66	0.08	0.23
Sand Lance	1.02	3.38	0.30	7.15	2.16	0.07	0.18
Thorny Skate	0.98	3.38	0.29	7.15	2.08	0.07	0.18

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Skate Egg Case	0.92	3.38	0.27	7.15	1.95	0.06	0.17
Sea Cucumber (NS)	0.78	3.38	0.23	7.15	1.65	0.05	0.14
Asteroidea S.C.	0.76	3.38	0.22	7.15	1.60	0.05	0.14
Razor Shell Clam	0.73	3.38	0.22	7.15	1.54	0.05	0.13
Greenland Cockle	0.59	3.38	0.18	7.15	1.26	0.04	0.11
Scallop NS	0.55	3.38	0.16	7.15	1.16	0.04	0.10
Sea Anemone	0.52	3.38	0.15	7.15	1.10	0.03	0.09
Atlantic Rock Crab	0.37	3.38	0.11	7.15	0.78	0.02	0.07
Jonah Crab	0.33	3.38	0.10	7.15	0.69	0.02	0.06
Longhorn Sculpin	0.24	3.38	0.07	7.15	0.51	0.02	0.04
Acanthocephala P.	0.23	3.38	0.07	7.15	0.48	0.02	0.04
Silver Hake	0.19	3.38	0.05	7.15	0.39	0.01	0.03
Snow Crab	0.09	3.38	0.03	7.15	0.18	0.01	0.02
Brittle star	0.03	3.38	0.01	7.15	0.07	<0.01	0.01

Table A8. Banquereau 2023 (Observed Trip 1): Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shells	57.02	0.16	360.63	0.30	109.45	63.27	260.31
Arctic Surf Clam	21.90	0.16	138.54	0.30	42.05	24.30	100.00
Sand Dollar	6.80	0.16	43.03	0.30	13.06	7.55	31.06
Stones and Rocks	2.92	0.16	18.44	0.30	5.60	3.24	13.31
Northern Propeller Clam	1.02	0.16	6.45	0.30	1.96	1.13	4.66
Buccinidae F.	0.21	0.16	1.31	0.30	0.40	0.23	0.95
Asteroidea S.C.	0.09	0.16	0.55	0.30	0.17	0.10	0.40
Ocean Quahog	0.05	0.16	0.34	0.30	0.10	0.06	0.24
Sea Urchin	0.04	0.16	0.26	0.30	0.08	0.04	0.18
Acanthocephala P.	0.03	0.16	0.20	0.30	0.06	0.03	0.14
Greenland Cockle	0.03	0.16	0.16	0.30	0.05	0.03	0.12
Razor Shell Clam	0.01	0.16	0.05	0.30	0.02	0.01	0.04
Hermit Crab	0.004	0.16	0.03	0.30	0.01	<0.01	0.02
Mussels (NS)	0.004	0.16	0.03	0.30	0.01	<0.01	0.02

Table A9. Banquereau 2023 (Observed Trip 2): Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Arctic Surf Clam	1,057.64	4.08	259.14	8.08	2094.54	44.97	100.00
Shells	566.19	4.08	138.72	8.08	1121.28	24.08	53.53
Northern Propeller Clam	465.72	4.08	114.11	8.08	922.32	19.80	44.03
Sand Dollar	146.45	4.08	35.88	8.08	290.03	6.23	13.85
Stones and Rocks	27.91	4.08	6.84	8.08	55.28	1.19	2.64
Buccinidae F.	22.86	4.08	5.60	8.08	45.26	0.97	2.16
Ocean Quahog	15.12	4.08	3.70	8.08	29.95	0.64	1.43
Greenland Cockle	9.83	4.08	2.41	8.08	19.47	0.42	0.93
Sea Mouse	9.06	4.08	2.22	8.08	17.95	0.39	0.86
Mussels NS	3.79	4.08	0.93	8.08	7.50	0.16	0.36
Thorny Skate	3.37	4.08	0.83	8.08	6.67	0.14	0.32
Sea Scallop	3.31	4.08	0.81	8.08	6.56	0.14	0.31
Brittle Star	2.87	4.08	0.70	8.08	5.67	0.12	0.27
Sea Cucumber (NS)	2.79	4.08	0.68	8.08	5.52	0.12	0.26
Yellowtail Flounder	2.18	4.08	0.53	8.08	4.31	0.09	0.21
Sea Urchin	2.11	4.08	0.52	8.08	4.17	0.09	0.20
Hermit Crab	1.75	4.08	0.43	8.08	3.47	0.07	0.17
Sea Sponge	1.39	4.08	0.34	8.08	2.75	0.06	0.13
Icelandic Scallop	1.16	4.08	0.28	8.08	2.29	0.05	0.11

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Winter Skate	0.99	4.08	0.24	8.08	1.97	0.04	0.09
Razor Shell Clam	0.85	4.08	0.21	8.08	1.69	0.04	0.08
Sand Lance	0.68	4.08	0.17	8.08	1.35	0.03	0.06
Astroidea S.C.	0.68	4.08	0.17	8.08	1.34	0.03	0.06
Anemone	0.61	4.08	0.15	8.08	1.20	0.03	0.06
Mud	0.46	4.08	0.11	8.08	0.92	0.02	0.04
Debris/Foreign Material	0.41	4.08	0.10	8.08	0.81	0.02	0.04
Coral (NS)	0.36	4.08	0.09	8.08	0.72	0.02	0.03
Hyas araneus	0.25	4.08	0.06	8.08	0.49	0.01	0.02
Skate (NS)	0.18	4.08	0.04	8.08	0.36	0.01	0.02
Seasnail (NS)	0.17	4.08	0.04	8.08	0.33	0.01	0.02
Acanthocephala P.	0.15	4.08	0.04	8.08	0.31	0.01	0.01
American Plaice	0.13	4.08	0.03	8.08	0.26	0.01	0.01
Smooth Scallop	0.10	4.08	0.02	8.08	0.19	>0.01	0.01
Snow Crab	0.07	4.08	0.02	8.08	0.15	>0.01	0.01
Scallop (NS)	0.04	4.08	0.01	8.08	0.08	>0.01	>0.01
Leptasterias polaris	0.01	4.08	0.003	8.08	0.03	>0.01	>0.01
Sun Star	0.01	4.08	0.002	8.08	0.02	>0.01	>0.01
Red Hake	0.01	4.08	0.002	8.08	0.01	>0.01	>0.01
Eggs NS	0.01	4.08	0.002	8.08	0.01	>0.01	>0.01
Sea Weed	0.003	4.08	0.001	8.08	0.01	>0.01	>0.01

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Skate Egg Case	0.003	4.08	0.001	8.08	0.01	>0.01	>0.01

Table A10. Banquereau 2023 (Observed Trip 3): Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shells	1,776.84	4.39	404.95	9.09	3681.66	47.99	236.16
Arctic Surf Clam	752.38	4.39	171.47	9.09	1558.95	20.32	100.00
Northern Propeller Clam	362.08	4.39	82.52	9.09	750.25	9.78	48.13
Stones and Rocks	346.54	4.39	78.98	9.09	718.05	9.36	46.06
Sand Dollar	341.83	4.39	77.91	9.09	708.29	9.23	45.43
Ocean Quahog	37.88	4.39	8.63	9.09	78.49	1.02	5.04
Buccinidae F.	20.24	4.39	4.61	9.09	41.94	0.55	2.69
Greenland Cockle	11.81	4.39	2.69	9.09	24.47	0.32	1.57
Asteroidea S.C.	7.67	4.39	1.75	9.09	15.90	0.21	1.02
Sea Cucumber (NS)	6.57	4.39	1.50	9.09	13.62	0.18	0.87
Skate (NS)	5.57	4.39	1.27	9.09	11.54	0.15	0.74
Hermit Crab	5.51	4.39	1.26	9.09	11.42	0.15	0.73
Sea Urchin	4.89	4.39	1.12	9.09	10.14	0.13	0.65

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Sea Scallop	3.92	4.39	0.89	9.09	8.12	0.11	0.52
Sea Mouse	3.62	4.39	0.82	9.09	7.50	0.10	0.48
Sand Lance	2.20	4.39	0.50	9.09	4.56	0.06	0.29
Icelandic Scallop	2.17	4.39	0.49	9.09	4.50	0.06	0.29
Silver hake	1.12	4.39	0.26	9.09	2.32	0.03	0.15
Razor Shell Clam	1.06	4.39	0.24	9.09	2.19	0.03	0.14
Mussels (NS)	1.06	4.39	0.24	9.09	2.19	0.03	0.14
Acanthocephala P.	0.98	4.39	0.22	9.09	2.03	0.03	0.13
Anemone	0.88	4.39	0.20	9.09	1.83	0.02	0.12
Snow Crab	0.87	4.39	0.20	9.09	1.81	0.02	0.12
Hyas araneus	0.82	4.39	0.19	9.09	1.71	0.02	0.11
Seasnail (NS)	0.70	4.39	0.16	9.09	1.45	0.02	0.09
Yellowtail Flounder	0.57	4.39	0.13	9.09	1.18	0.02	0.08
Psolus phantapus (SC)	0.50	4.39	0.11	9.09	1.04	0.01	0.07
Sculpin (NS)	0.42	4.39	0.10	9.09	0.88	0.01	0.06
Sun Star	0.37	4.39	0.08	9.09	0.76	0.01	0.05
Moon snail	0.34	4.39	0.08	9.09	0.70	0.01	0.04
Debris/Foreign Material	0.28	4.39	0.06	9.09	0.58	0.01	0.04
Sea Raven	0.18	4.39	0.04	9.09	0.37	<0.01	0.02
Jonah Crab	0.14	4.39	0.03	9.09	0.29	<0.01	0.02
Brittle Star	0.13	4.39	0.03	9.09	0.28	<0.01	0.02

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shorthorn sculpin	0.12	4.39	0.03	9.09	0.25	<0.01	0.02
Cod	0.06	4.39	0.01	9.09	0.12	<0.01	0.01
Coral (NS)	0.04	4.39	0.01	9.09	0.07	<0.01	<0.01
Skate Egg Case	0.02	4.39	0.003	9.09	0.03	<0.01	<0.01
Sea Weed	0.01	4.39	0.002	9.09	0.02	<0.01	<0.01
Red Hake	0.002	4.39	0.001	9.09	<0.01	<0.01	<0.01

Table A11. Grand Banks 2018 (Observed Trip 1): Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shells	681.68	1.71	397.83	2.39	958.4	58.73	246.72
Arctic Surf Clam	276.29	1.71	161.24	2.39	388.4	23.80	100.00
Sea Cucumber (NS)	59.03	1.71	34.45	2.39	83.0	5.09	21.37
Northern Propeller Clam	45.65	1.71	26.64	2.39	64.2	3.93	16.52
Sand Dollar	45.10	1.71	26.32	2.39	63.4	3.89	16.32
Stones and Rocks	15.83	1.71	9.24	2.39	22.3	1.36	5.73
Sea Mouse	6.67	1.71	3.89	2.39	9.4	0.57	2.41
Whelk	5.39	1.71	3.15	2.39	7.6	0.46	1.95

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Clam (NS)	4.99	1.71	2.91	2.39	7.0	0.43	1.81
Asteroidea S.C.	4.07	1.71	2.37	2.39	5.7	0.35	1.47
Greenland Cockle	3.84	1.71	2.24	2.39	5.4	0.33	1.39
Sea Urchin	3.27	1.71	1.91	2.39	4.6	0.28	1.18
Ocean Quahog	3.18	1.71	1.85	2.39	4.5	0.27	1.15
Yellowtail Flounder	2.28	1.71	1.33	2.39	3.2	0.20	0.82
Hermit Crab	2.21	1.71	1.29	2.39	3.1	0.19	0.80
Hyas coarctatus	0.56	1.71	0.32	2.39	0.8	0.05	0.20
Witch Flounder	0.41	1.71	0.24	2.39	0.6	0.04	0.15
Spider Crab NS	0.15	1.71	0.09	2.39	0.2	0.01	0.06
Razor Shell Clam	0.05	1.71	0.03	2.39	0.1	<0.01	0.02

Table A12. Grand Banks 2018 (Observed Trip 2): Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shells	1,642.95	4.25	386.92	5.98	2284.85	48.67	207.45
Arctic Surf Clam	791.98	4.25	186.51	5.98	1101.40	23.46	100.00
Sea Cucumber (NS)	448.47	4.25	105.62	5.98	623.68	13.28	56.63

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Stones and Rocks	190.66	4.25	44.90	5.98	265.16	5.65	24.07
Sand Dollar	144.87	4.25	34.12	5.98	201.46	4.29	18.29
Northern Propeller Clam	46.28	4.25	10.90	5.98	64.36	1.37	5.84
Greenland Cockle	22.86	4.25	5.38	5.98	31.79	0.68	2.89
Sea Mouse	20.62	4.25	4.86	5.98	28.68	0.61	2.60
Whelk	13.01	4.25	3.06	5.98	18.09	0.39	1.64
Clam (NS)	11.23	4.25	2.64	5.98	15.62	0.33	1.42
Ocean Quahog	10.11	4.25	2.38	5.98	14.06	0.30	1.28
Asteroidea S.C.	8.54	4.25	2.01	5.98	11.88	0.25	1.08
Hermit Crab	5.89	4.25	1.39	5.98	8.19	0.17	0.74
American Plaice	5.64	4.25	1.33	5.98	7.85	0.17	0.71
Sea Urchin	4.75	4.25	1.12	5.98	6.61	0.14	0.60
Yellowtail Flounder	3.01	4.25	0.71	5.98	4.18	0.09	0.38
Mussel (NS)	1.63	4.25	0.38	5.98	2.26	0.05	0.21
Spider Crab (NS)	1.25	4.25	0.30	5.98	1.74	0.04	0.16
Hyas coarctatus	0.76	4.25	0.18	5.98	1.06	0.02	0.10
Sand Lance	0.61	4.25	0.14	5.98	0.85	0.02	0.08
Thorny Skate	0.47	4.25	0.11	5.98	0.65	0.01	0.06
Sea Weed	0.21	4.25	0.05	5.98	0.30	0.01	0.03
Sea Potato	0.09	4.25	0.02	5.98	0.12	<0.01	0.01

Table A13. Grand Banks 2019: Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Arctic Surf Clam	1,057.05	3.64	290.74	7.69	2257.97	34.94	100.00
Shells	1,007.77	3.64	277.19	7.69	2152.71	33.31	95.34
Northern Propeller Clam	298.21	3.64	82.02	7.69	637.01	9.86	28.21
Sand Dollar	233.21	3.64	64.15	7.69	498.17	7.71	22.06
Sea Cucumber (NS)	232.20	3.64	63.87	7.69	495.99	7.67	21.97
Stones and Rocks	82.34	3.64	22.65	7.69	175.88	2.72	7.79
Greenland Cockle	64.44	3.64	17.72	7.69	137.64	2.13	6.10
Whelk	16.28	3.64	4.48	7.69	34.78	0.54	1.54
Ocean Quahog	8.39	3.64	2.31	7.69	17.93	0.28	0.79
Sea Mouse	6.32	3.64	1.74	7.69	13.49	0.21	0.60
Clam (NS)	6.21	3.64	1.71	7.69	13.27	0.21	0.59
Astroidea S.C.	4.02	3.64	1.10	7.69	8.58	0.13	0.38
Sea Urchin	1.72	3.64	0.47	7.69	3.68	0.06	0.16
Hermit Crab	1.67	3.64	0.46	7.69	3.57	0.06	0.16
Thorny Skate	1.35	3.64	0.37	7.69	2.89	0.04	0.13
Acanthocephala P.	0.95	3.64	0.26	7.69	2.03	0.03	0.09
Mussel (NS)	0.78	3.64	0.21	7.69	1.66	0.03	0.07
Yellowtail Flounder	0.64	3.64	0.18	7.69	1.36	0.02	0.06
American Plaice	0.49	3.64	0.13	7.69	1.04	0.02	0.05

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Sand Lance	0.46	3.64	0.13	7.69	0.99	0.02	0.04
Sea Anemone	0.35	3.64	0.10	7.69	0.75	0.01	0.03
Hya araneus	0.34	3.64	0.09	7.69	0.72	0.01	0.03
Snow Crab	0.27	3.64	0.07	7.69	0.58	0.01	0.03
Tunicata	0.16	3.64	0.04	7.69	0.35	0.01	0.02
Hya coarctatus	0.09	3.64	0.02	7.69	0.19	<0.01	0.01
Sea Potato	0.03	3.64	0.01	7.69	0.06	<0.01	<0.01

Table A14. Grand Banks 2020: Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Sand Dollar	402.92	1.63	247.40	3.43	863.75	36.73	139.72
Arctic Surf Clam	288.37	1.63	177.06	3.43	618.18	26.29	100.00
Shells	267.94	1.63	164.52	3.43	574.40	24.43	92.92
Greenland Cockle	52.12	1.63	32.00	3.43	111.72	4.75	18.07
Northern Propeller Clam	41.72	1.63	25.62	3.43	89.44	3.80	14.47
Stones and Rocks	33.13	1.63	20.34	3.43	71.02	3.02	11.49
Sand Lance	3.61	1.63	2.22	3.43	7.74	0.33	1.25

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Snow Crab	2.42	1.63	1.49	3.43	5.19	0.22	0.84
Asteroidea S.C.	1.84	1.63	1.13	3.43	3.96	0.17	0.64
Seasnail (NS)	1.27	1.63	0.78	3.43	2.73	0.12	0.44
Scallop (NS)	0.56	1.63	0.34	3.43	1.20	0.05	0.19
Sea Urchin	0.36	1.63	0.22	3.43	0.78	0.03	0.13
Acanthocephala P.	0.23	1.63	0.14	3.43	0.49	0.02	0.08
Hermit Crab	0.14	1.63	0.09	3.43	0.31	0.01	0.05
Yellowtail Flounder	0.14	1.63	0.08	3.43	0.30	0.01	0.05
Whelk	0.10	1.63	0.06	3.43	0.20	0.01	0.03
Eel	0.05	1.63	0.03	3.43	0.11	<0.01	0.02

Table A15. Grand Banks 2021: Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Sand Dollar	217.48	1.32	164.27	2.73	456.7	38.85	125.10
Arctic Surf Clam	173.85	1.32	131.31	2.73	365.1	31.06	100.00
Northern Propeller Clam	66.38	1.32	50.14	2.73	139.4	11.86	38.18
Greenland Cockle	48.16	1.32	36.38	2.73	101.1	8.60	27.70

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Shells	45.06	1.32	34.04	2.73	94.6	8.05	25.92
Stones and Rocks	4.17	1.32	3.15	2.73	8.8	0.74	2.40
Astroidea S.C.	1.42	1.32	1.07	2.73	3.0	0.25	0.82
Sand Lance	1.31	1.32	0.99	2.73	2.7	0.23	0.75
Snow Crab	0.82	1.32	0.62	2.73	1.7	0.15	0.47
Seasnail (NS)	0.46	1.32	0.34	2.73	1.0	0.08	0.26
Thorny Skate	0.25	1.32	0.19	2.73	0.5	0.04	0.14
Yellowtail Flounder	0.21	1.32	0.16	2.73	0.4	0.04	0.12
Acanthocephala P.	0.08	1.32	0.06	2.73	0.2	0.02	0.05
Sea Urchin	0.08	1.32	0.06	2.73	0.2	0.01	0.05
Hermit Crab	0.02	1.32	0.02	2.73	0.1	<0.01	0.01
Scallop (NS)	0.02	1.32	0.02	2.73	0.05	<0.01	0.01

Table A16. Grand Banks 2022: Observed catch and effort values used to expand observed catch to trip catch. Last two columns represent the portion relative to total trip catch and Arctic Surf catch for the trip. Both values based on effort-expanded observed catch. Taxa/objects are listed in order of descending observed catch. (NS) indicates non-specified. < indicates less than.

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Arctic Surf Clam	1,025.14	2.03	504.88	5.18	2615.87	35.32	100.00
Shells	812.76	2.03	400.28	5.18	2073.94	28.00	79.28

Taxa/Object	Observed Catch (t)	Observed Effort (km ²)	Rate (Catch/ Effort)	Trip Effort (km ²)	Trip Catch (t)	Portion Relative to Total Catch (%)	Portion Relative to Arctic Surf Catch (%)
Northern Propeller Clam	544.16	2.03	267.99	5.18	1388.54	18.75	53.08
Greenland Cockle	236.21	2.03	116.33	5.18	602.74	8.14	23.04
Sand Dollar	163.00	2.03	80.28	5.18	415.93	5.62	15.90
Whelk	44.77	2.03	22.05	5.18	114.24	1.54	4.37
Sea Cucumber (NS)	29.78	2.03	14.67	5.18	75.99	1.03	2.90
Asteroidea S.C.	25.01	2.03	12.32	5.18	63.81	0.86	2.44
Yellowtail Flounder	7.31	2.03	3.60	5.18	18.65	0.25	0.71
Stones and Rock	6.64	2.03	3.27	5.18	16.93	0.23	0.65
Eggs NS	2.41	2.03	1.19	5.18	6.16	0.08	0.24
Sea Mouse	2.31	2.03	1.14	5.18	5.88	0.08	0.22
Hermit Crab	1.14	2.03	0.56	5.18	2.92	0.04	0.11
Thorny Skate	1.02	2.03	0.50	5.18	2.60	0.04	0.10
Sand Lance	0.45	2.03	0.22	5.18	1.15	0.02	0.04
Hyas araneus	0.40	2.03	0.20	5.18	1.03	0.01	0.04
Snow Crab	0.17	2.03	0.08	5.18	0.44	0.01	0.02
Atlantic Rock Crab	0.11	2.03	0.06	5.18	0.29	<0.01	0.01
Seasnail (NS)	0.05	2.03	0.02	5.18	0.13	<0.01	<0.01
Skate Egg Case	0.005	2.03	0.002	5.18	0.01	<0.01	<0.01

APPENDIX B: SPATIAL PRODUCTION MODEL (2016–2023)

The SPM model used to estimate biomass and determine stock status on Banquereau from 2016 to 2023 was developed by Hubley and Heaslip (2018). It is described in this Appendix for comparative purposes with the newly-adopted SpaceClam model; the SpaceClam approach has been accepted for Arctic Surf Clam stock assessment purposes on Banquereau and the Grand Banks moving forward. Potential use of SPM on the Grand Banks was reviewed in this stock assessment framework peer review, but was rejected for stock assessment purposes moving forward.

B.1 DATA CENSORING

Catch and Effort Censoring

The previous Arctic Surf Clam stock assessment framework of Hubley and Heaslip (2018) identified minimum and maximum thresholds for catch and effort to be included in data used in the SPM model. This was done to remove extreme highs and lows, as well as to mitigate the issue of catch in one watch being processed and reported in a previous watch. At the time, it was assumed that records of very high catch within a single watch were errors. Data collected since the stock assessment framework described by Hubley and Heaslip (2018) has gone through extensive review and correction by DFO Science. There is now greater confidence in the data collected since the Hubley and Heaslip (2018) framework, with extreme values less likely to be errors.

Catch and effort are reported by watch with censor values applied at the watch level. Catch and effort censor levels for each bank are summarized in Table B1. On Banquereau, the catch and effort thresholds exclude small (less than 1%) amounts of catch and effort in any given year. On the Grand Banks, the catch and effort thresholds exclude small (less than 1%) amounts of catch and effort in any given year, with the exception of 2.7% of the effort in 2015 being excluded by the upper effort threshold.

Table B1. Summary of catch and effort lower and upper thresholds used to censor data for the SPM model.

Bank	Lower Catch (kg)	Upper Catch (kg)	Lower Effort (m ²)	Effort Upper (m ²)
Banquereau	1,500	40,000	15,000	200,000
Grand Banks	1,000	45,000	10,000	200,000

Spatial Censoring

Data is spatially-censored to ensure that only data in the area of interest is being considered. Fishing locations that fall outside the spatial area are routinely checked for errors and corrected, where possible. On Banquereau, the spatial censor is the 100-m isobath and on the Grand Banks it is the bounding polygon that combines the 100-m isobath on the northern, eastern, and southern reaches, as well as the western extent of the survey (Figure B1). On Banquereau, the censor removes less than 0.6% of the catch and effort for all years, except 2008. When the threshold is applied to 2008, 2.8% of the catch and 3.5% of the effort in that year is removed. On the Grand Banks, the polygon primarily excludes catch on the eastern edge of the bank. No

catch is excluded after 2013. Prior to 2013, this polygon excludes 0 to 38% of the catch and 0 to 30% of the effort across years in the time series.

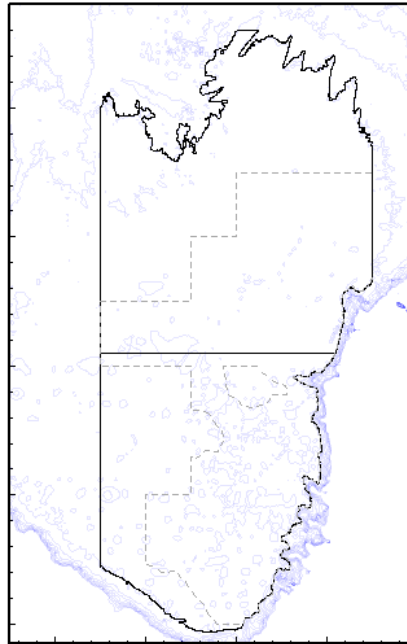


Figure B1. Polygon (solid black line) for spatial censoring on the Grand Banks. Survey polygon (dashed line) included for reference. Horizontal line is the north/south division.

There are records at the watch level in the data that have no latitude and/or longitude information. In some cases, however, these records do have reported NAFO areas or NAFO areas can be determined based on other trip information. This data can be included in bank-wide summaries and trends. In contrast, without positional information, these records are excluded from any spatial analysis. For Banquereau, the annual amount of catch associated with such records ranges from 1.5 to 564 t (Table B2). For the Grand Banks, the annual amount of catch associated with such records ranges from 0.6 to 69.1 t (Table B3). The records are predominantly watches with no effort, but with reported catch. This often happens when catch from one watch is not processed until the next watch.

Table B2. Summary of Banquereau catch from logbooks that reported in DFO Statistical Unit Area 4Vsc with no corresponding latitude or longitude information. This catch would be excluded from any analysis based on specific positions.

Year	Catch (t)	Year	Catch (t)	Year	Catch (t)
1988	23.1	2006	38.7	2017	49.3
1989	25.6	2007	64.4	2018	44.4
1995	9.6	2008	36.0	2019	66.5
1998	16.8	2011	390.2	2020	16.3

Year	Catch (t)	Year	Catch (t)	Year	Catch (t)
1999	14.0	2012	546.4	2021	23.3
2000	23.7	2013	1.5	2022	26.0
2001	12.5	2015	30.2	2023	12.2

Table B3. Summary of the Grand Banks catch from the logbooks that reported in Northwest Atlantic Fisheries Organization Division 3N with no corresponding latitude or longitude information. This catch would be excluded from any analysis based on specific positions.

Year	Catch (t)	Year	Catch (t)
1989	1.2	2016	3.9
1991	15.4	2017	53.1
1995	4.5	2018	50.5
2000	7.8	2019	69.1
2002	13.5	2020	33.3
2005	1.2	2021	39.2
2006	6.4	2022	12.5
2007	0.6	2023	37.3

B.2 SPATIAL ASSESSMENT AREAS

On Banquereau, five assessment areas are used (Figure 8). For the Grand Banks, two areas are used (Figure B1). These areas are used to divide the catch and effort for use in the model, which helped facilitate fitting of the model to the suitable habitat contained in the assessment area. The differing trends in the assessment areas provide useful context to bank-wide indices and modeled results.

B.3 HABITAT SUITABILITY

A map of habitat based on VMS is used to define fishery footprint and the extent of the stock. This was assumed at the time to represent all areas that contained fishable concentrations of clams. The footprint is developed by first assigning logbook catch, which is aggregated per 6-hour watch, across the corresponding VMS locations during that watch. VMS location is collected once per hour. Logbook data is corrected and censoring levels are applied before this step; therefore, the VMS footprint can change slightly as errors are corrected and if exclusion thresholds change. VMS locations are then plotted on the bank and summed within 1 km² grids. The sum within the gridded squares are compared against a threshold for inclusion in, or

exclusion from, the habitat map. The maps are produced using a kernel-smoothed intensity function from the Spatstat package (Baddely et al. 2015).

The Banquereau habitat map was updated for the stock assessment framework discussed in this research document using a ratio of 2.5 VMS pings (hours of fishing) per year per grid to determine the threshold. This results in a cut-off of 50 pings/km², creating a footprint with an area of 2,075 km² (Figure B2). A Grand Banks habitat map based on VMS was also developed for the stock assessment framework discussed in this research document. For the Grand Banks, a threshold of 5 ping/km² was chosen as a balance between being so low as to possibly include transit between areas and so high as provide too small of an area in which to model biomass. This creates of footprint with an area of 2,056 km² (Figure B3).

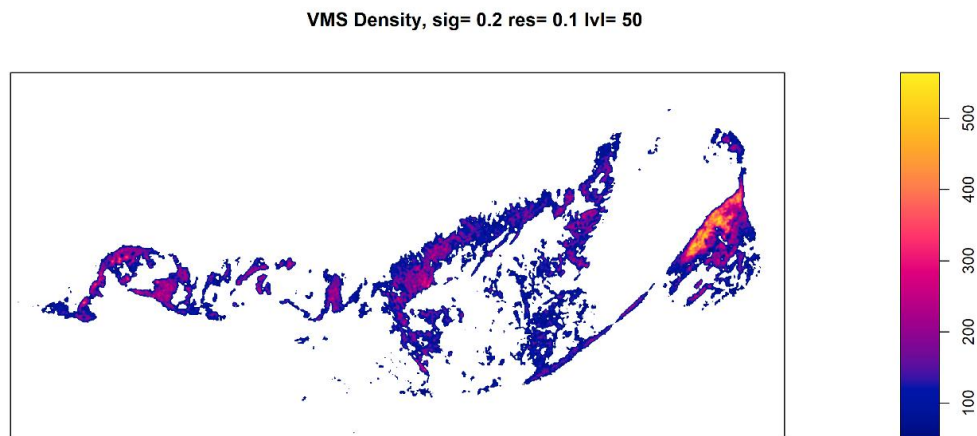


Figure B2. Fishery footprint used to define the Arctic Surf Clam stock on Banquereau. Developed using Vessel Monitoring System (VMS) density estimated from a kernel-smoothed intensity function with a standard deviation of 0.2 on a 100 m² resolution. The scale bar shows VMS intensity expressed as the number of transmissions (pings) per km² for 2004–23. There is a cut off of 50 pings per km².

VMS Density, sig= 0.3 res= 0.1 lvl= 5

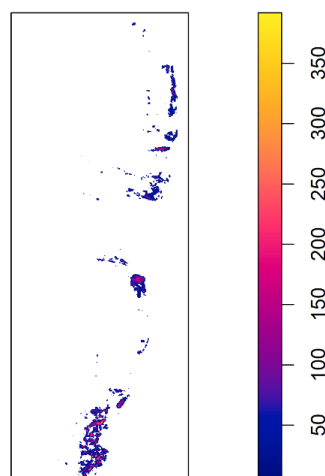


Figure B3. Fishery footprint used to define the Arctic Surf Clam stock on the Grand Banks. Developed using Vessel Monitoring System (VMS) density estimated from a kernel-smoothed intensity function with a standard deviation (sigma) of 0.3. The scale bar shows VMS intensity expressed as the number of transmissions (pings) per km² for 2004–23. There is a cut off of 5 pings per km².

B.4 SPATIAL PRODUCTION MODEL

Again, the SPM model was developed by Hubley and Heaslip (2018). The time series of catch and CPUE data is used to incorporate biomass dynamics into the analysis in the form of logistic biomass dynamics or surplus production models (Schaefer 1954) fit simultaneously to each area (j). Implementing the model in a Bayesian state-space framework provides ability to realistically propagate credible errors from both the data and previous analyses (e.g., efficiency estimates and standard error of the CPUE index).

$$B_{t+1,j} = B_{t,j} + r_j B_{t,j} \left(\frac{B_{t,j}}{K_j} \right) - C_{t,j}$$

This type of model is easier to implement than a full age-structured model and estimates only a few parameters of interest: fishable biomass (B); carrying-capacity (K); intrinsic population (r) growth rate; commercial dredge efficiency (q); process error (σ); and observation error (τ). Dividing the banks into separate areas (five areas on Banquereau and two areas on the Grand Banks) introduces a spatial aspect to the model whereby parameters can be estimated across all areas or separately for each area. Given there is no information to indicate that dredge efficiency would vary between areas, the q parameter was shared across all areas:

$$O_{t,j} = B_{t,j} \times q$$

where O is the area expanded biomass estimates from the CPUE analysis for each area (j) and year (t). Carrying-capacity was assumed to be related to the habitat area within each area. This was implemented by scaling K by habitat for each area as:

$$K_j = \bar{K} \times \left(\frac{H_j}{\bar{H}} \right)$$

Although the population growth rate parameter, r , may be spatially variable, it was assumed to be similar across the stock area. As such, the r parameter was estimated for each area, but was constrained by a hierarchical structure where the mean and standard deviation is estimated for all areas and then used to define the prior on individual r for each area.

$$\bar{r} \sim \text{unif}(0,1)$$

$$\sigma_r^2 \sim \text{LN}(-0.35, 0.08)$$

$$r_j \sim \text{LN}(\log(\bar{r}), \sigma_r^2)$$

The prior for catchability was informed by dredge efficiency estimates. A beta distribution was assumed for the prior with a mean equal to the mean of dredge efficiency estimates from depletion experiments (0.45; Roddick et al. 2012) and a variance that produced a similar 95% confidence interval (CI: 0.20, 0.71).

$$q \sim \text{beta}(a = 6, b = 7.3)$$

State-space methods used to estimate parameters from the SPM give the model an ability to estimate unobserved states (“true” fishable biomass) and to simultaneously estimate modeled process errors and data observation errors. Process errors (σ^2) are the uncertainties that propagate into future states via the recursive form of the logistic equation (i.e., errors in B_{t+1} in the state space of B_t vs B_{t+1}). Observation errors (σ^2) are the uncertainties associated with measurement and observation (i.e., measurement/data-related errors of both variables in the state space of B_t vs B_{t+1}). This former ability is particularly important, as parameter estimates and forecasts based on observation-only errors provide unrealistically-optimistic (small and constant) error bounds; parameter estimates and forecasts based on process-only errors

expand rapidly into the future, resulting in potentially unrealistically-pessimistic (large and usually growing) error bounds (Choi et al. 2012). A uniform prior was selected for process error:

$$\sigma_{\tau} \sim \text{unif}(0,5)$$

whereas the prior on the observation error was informed by the average coefficient of variation (CV) from the CPUE index. Assuming the CPUE index follows a log-normal distribution, the relationship between its CV and the variance of its logarithm can be used to estimate an observation error directly (Hubley et al. 2014, Johnson and Kotz 1970).

$$\hat{\sigma}_{\varepsilon}^2 = \log(CV^2 + 1)$$

This value was used to construct an informative gamma prior on the observation precision (Hubley et al. 2014, Smith and Hubley 2014).

$$\frac{1}{\sigma_{\varepsilon}^2} \sim \text{gamma}(\text{shape} = 3, \text{rate} = 0.4)$$

The posterior distribution of the parameters of interest conditional upon the data were estimated using a Gibbs sampling algorithm (Markov chain Monte Carlo method) using the Just Another Gibbs Sampler (JAGS) platform (Plummer 2003, Plummer 2013). Data to the end of 2023 was included. Two Markov chains were followed to ensure convergence with the first 250,000 replicates discarded as a burn-in and then every twentieth replicate of the next 700,000 replicates (Banquereau) and 950,000 replicates (Grand Banks) were kept to describe the posterior distributions of the parameters.

The fit of predicted CPUE from the SPM to the CPUE index with 50% and 95% credible intervals for each bank are provided in Figures B4 and B5.

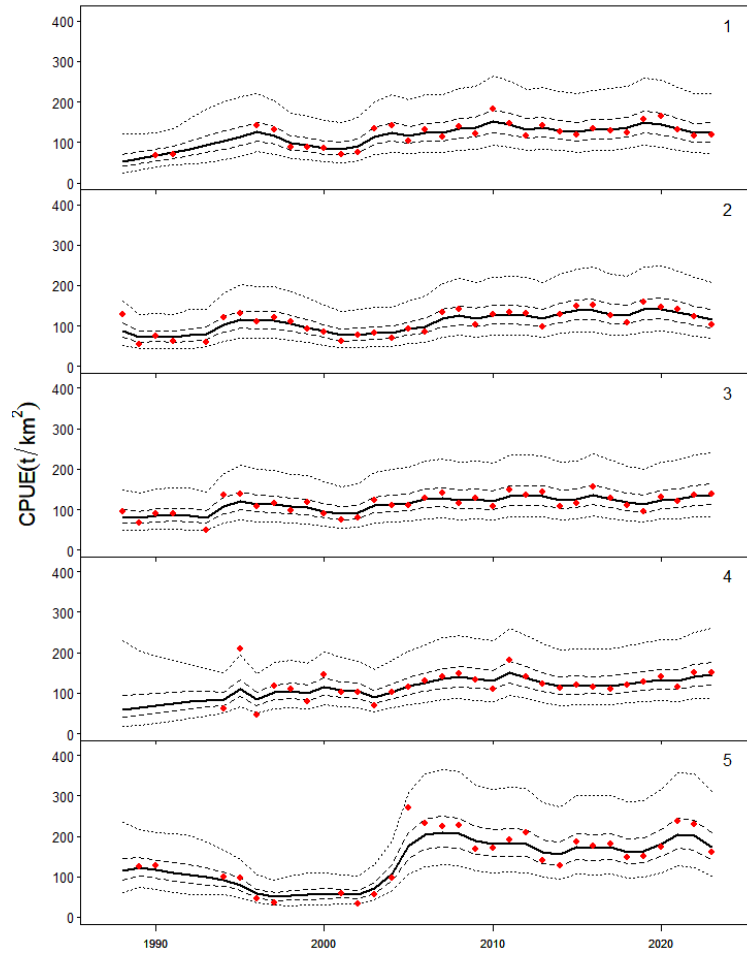


Figure B4. Banquereau Spatial Production Model fit to the annual catch per unit effort (CPUE) index (red points) (t/km^2) for each area for 1988–2023. Lines indicate the median (solid), 50% credible interval (dashed), and 95% credible interval (dotted).

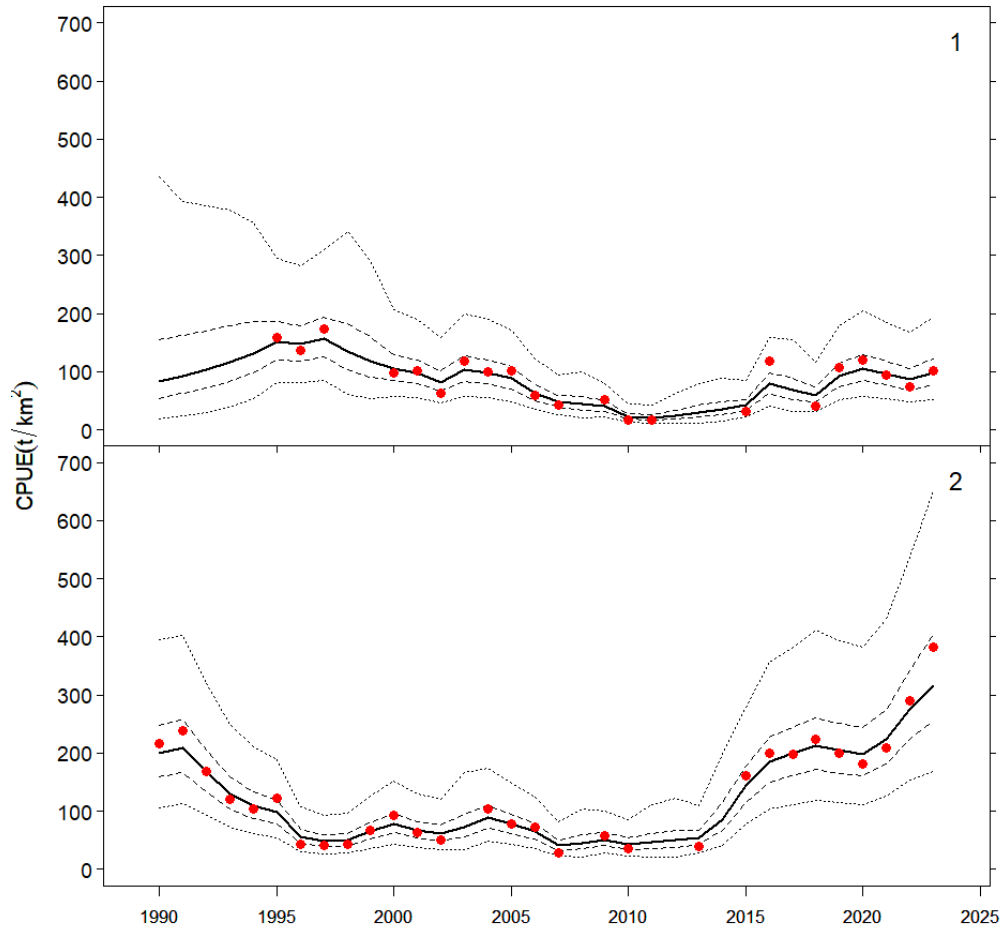


Figure B5. Grand Banks Spatial Production Model fit to the annual catch per unit effort (CPUE) index (red points) (t/km^2) for each area (1: North, 2: South) for 1990–2023. Lines indicate the median (solid), 50% credible interval (dashed), and 95% credible interval (dotted).

On Banquereau, the posterior density distributions for the shared parameters generally indicate that information in the data has updated the parameter estimates from the prior distributions, with the exception of the standard deviation of r and q (Figure B6). The posterior for standard deviation of r had a hyperprior that was intentionally informative to prevent the resulting priors on the r in each area from being too informative and to give r the opportunity to vary between areas. The estimates of r varied only slightly between areas (0.117–0.118; Figure B7). Median K values vary more among the areas, as they are tied to the habitat in those areas (71,392–174,571; Figure B8). The median estimate of dredge efficiency (0.451) is similar to the results of the survey dredge efficiency experiment (0.45) that informed the prior. This is a change from the framework of Hubley and Heaslip (2018) where median q was 0.38.

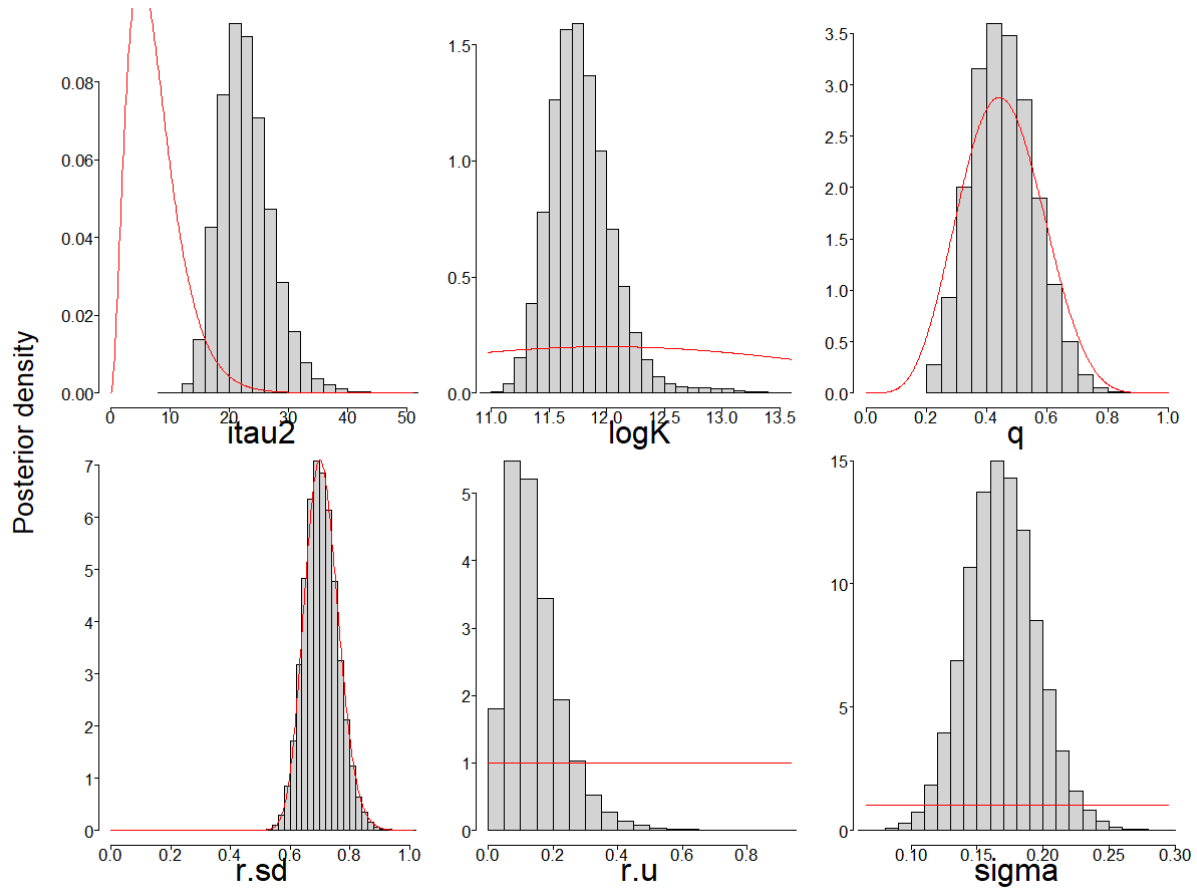


Figure B6. Histograms showing the marginal posterior density values for the shared parameter estimates included in the Spatial Production Model for Banquereau. Top, left to right: observation precision ($itau2$; this prior was based on the inverse of the variance of the catch per unit effort time series), log of mean carrying-capacity ($logK$), and dredge efficiency (q). Bottom, left to right: standard deviation of the population growth rate ($r.sd$), mean population growth rate ($r.u$), and process standard deviation ($sigma$). Horizontal red lines indicate the prior density distributions.

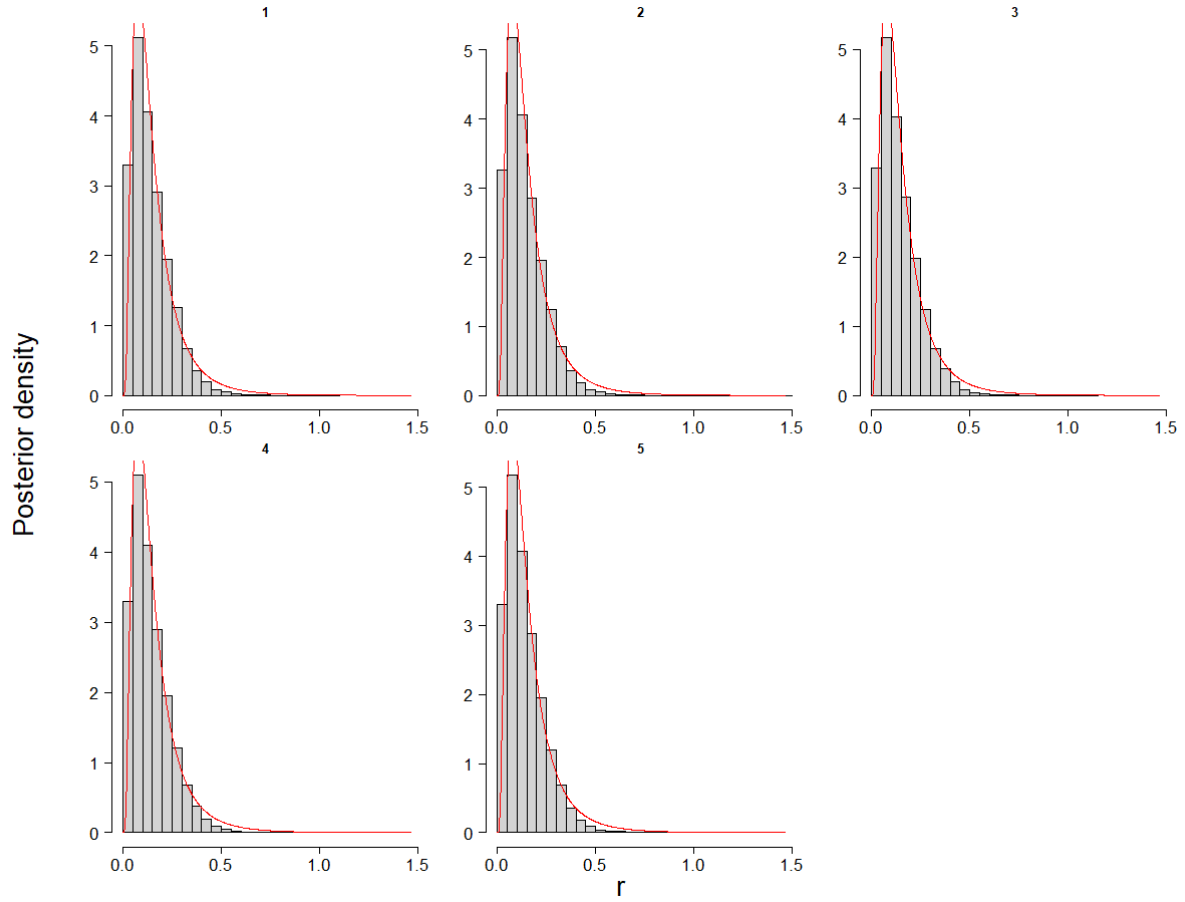


Figure B7. Histograms showing the marginal posterior density values for the estimates of population growth rate (r) for each area from the Spatial Production Model for Banquereau. Red lines indicate the prior density distributions of these estimates defined by the mean and standard deviation of the parameters shown in Figure B6.

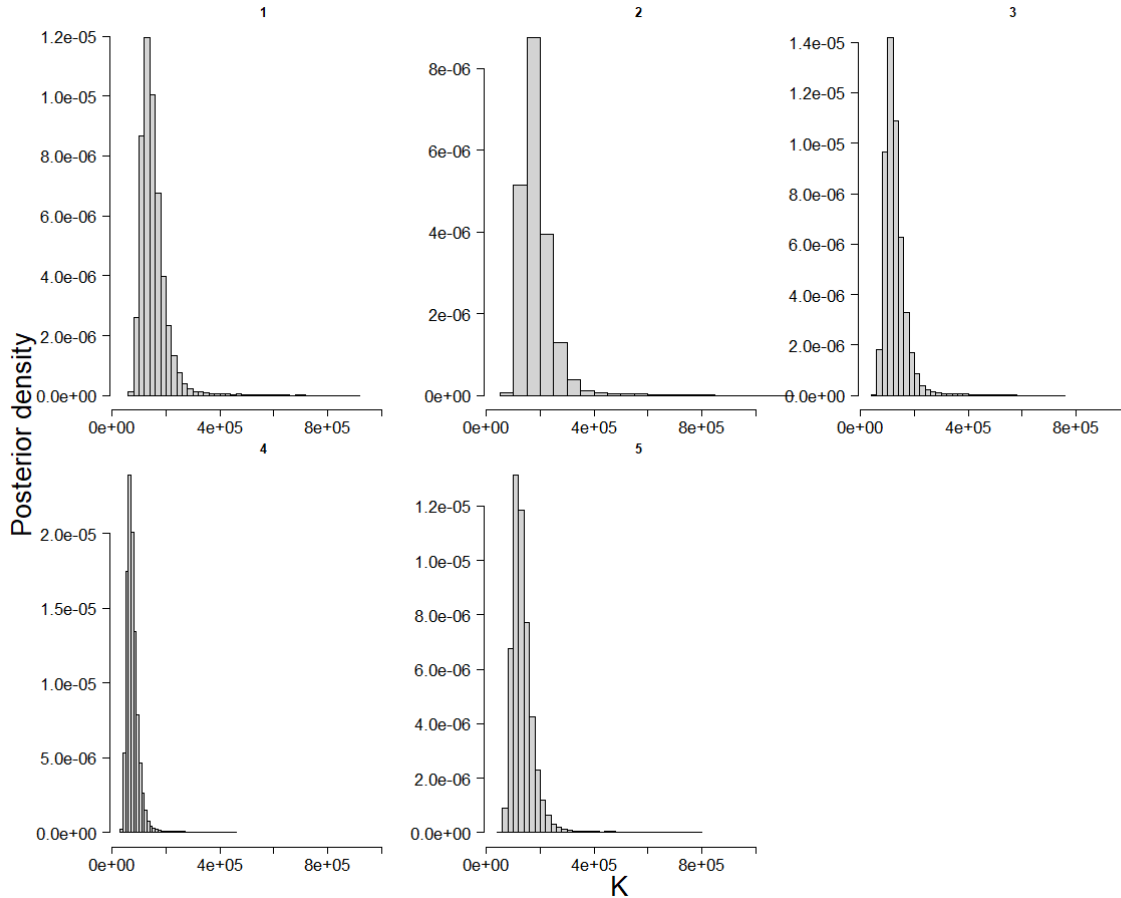


Figure B8. Histograms showing the marginal posterior density values for the estimates of carrying-capacity (K) for each area from the Spatial Production Model for Banquereau.

For the Grand Banks model, the posterior density distributions for the shared parameters generally indicate that information in the data has updated the parameter estimates from the prior distributions, with the exception of the standard deviation of r (Figure B9). The posterior for standard deviation of r had a hyperprior that was intentionally informative to prevent the resulting priors on the r in each area from being too informative and to give r the opportunity to vary between areas. The estimates of r varied only slightly between areas: 0.0799, 0.0784 (Figure B10). These estimates are smaller than what is seen on Banquereau (0.117–0.118; Figure B7).

Median K values vary more among the areas, as they are tied to the habitat in those areas: 145,198 and 276,782 (Figure B11). The area of the two Grand Banks assessment areas are both greater than the habitat of any of the five Banquereau assessment areas. The overall habitat is similar (2,075 km² on Banquereau and 2,056 km² on the Grand Banks). The sum of median K on the Grand Banks is 421,980, which is less than the sum of 634,639 on Banquereau.

The median estimate of dredge efficiency, q is 0.54 (Figure B9), which is greater than the median q on Banquereau (0.451), as well as the results of the survey dredge efficiency experiment (0.45) that informed the prior.

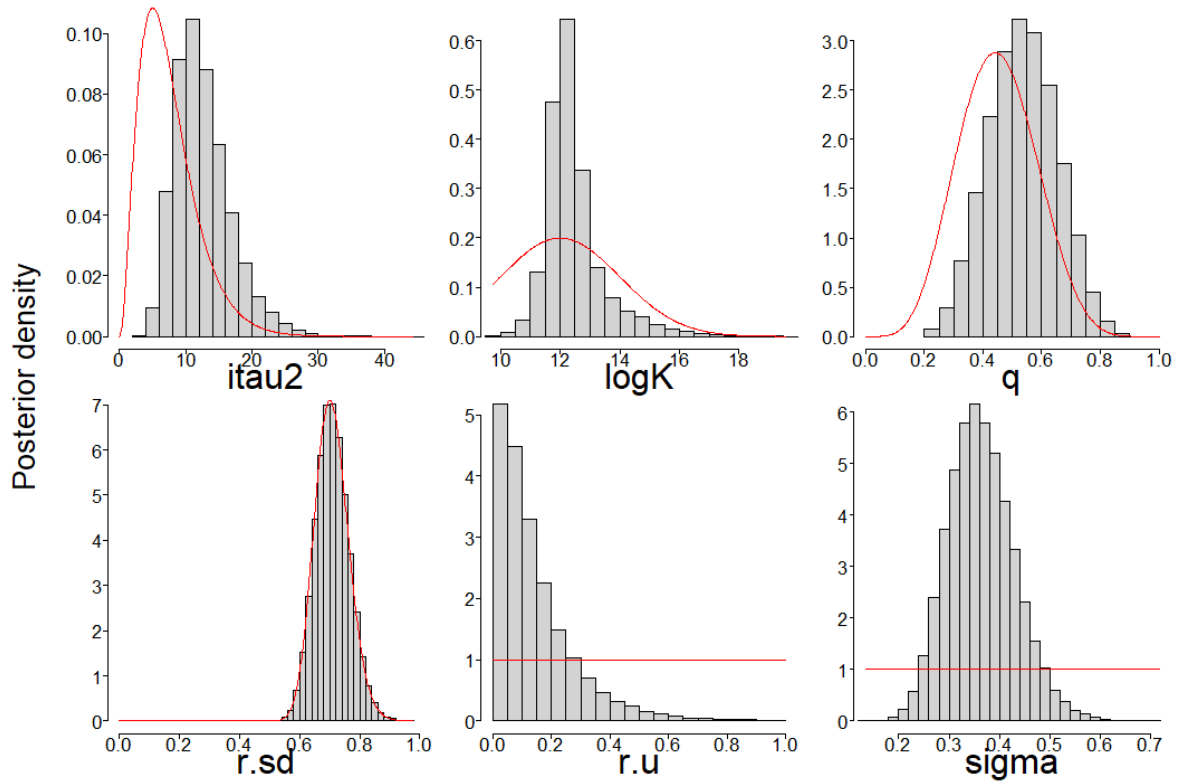


Figure B9. Histograms showing the marginal posterior density values for the shared parameter estimates included in the Spatial Production Model for the Grand Banks. Top, left to right: observation precision ($itau2$; this prior was based on the inverse of the variance of the catch per unit effort time series), log of mean carrying-capacity ($logK$), and dredge efficiency (q). Bottom, left to right: standard deviation of the population growth rate ($r.sd$), mean population growth rate ($r.u$), and process standard deviation ($sigma$). Red lines indicate the prior density distributions.

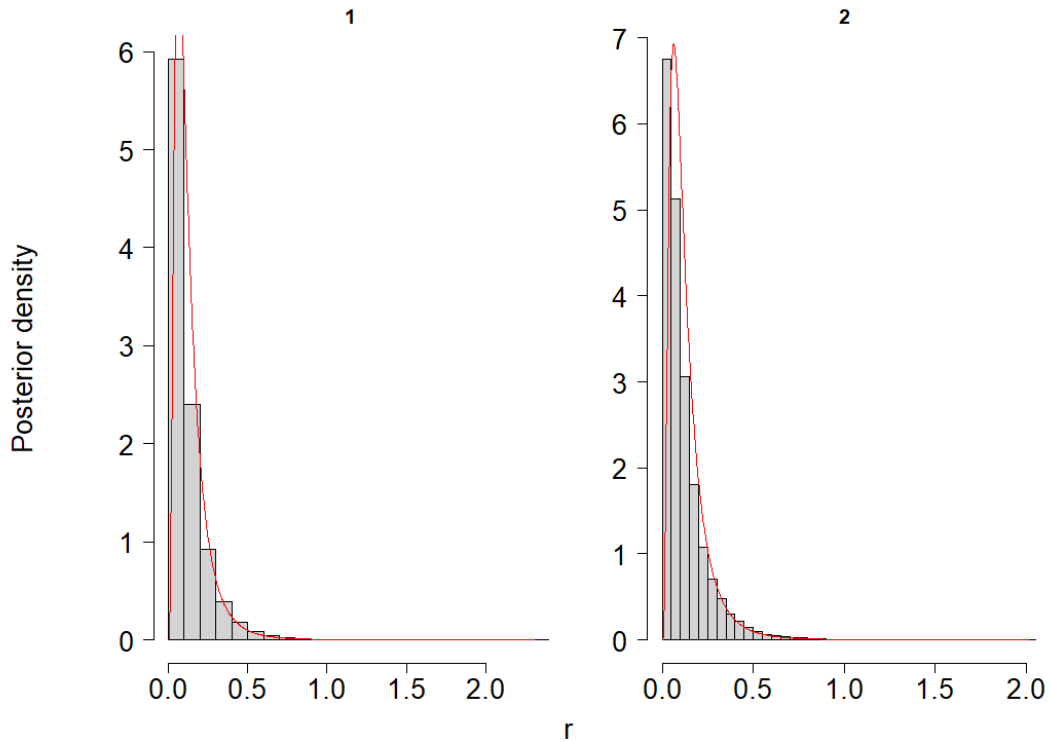


Figure B10. Histograms showing the marginal posterior density values for the estimates of population growth rate (r) for each area from the Spatial Production Model for the Grand Banks (1: North, 2: South). Red lines indicate the prior density distributions of these estimates defined by the mean and standard deviation of the parameters shown in Figure B9.

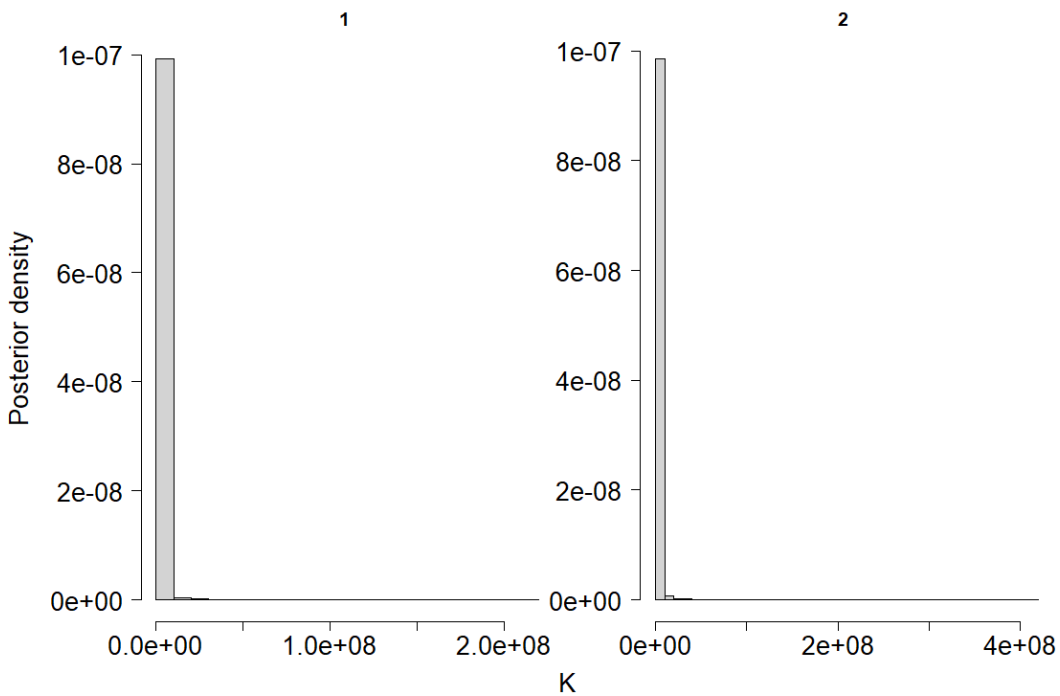


Figure B11. Histograms showing the marginal posterior density values for the estimates of carrying-capacity (K) for each area from the Spatial Production Model for the Grand Banks (1: North, 2: South).

The median bank-wide biomass estimates are shown in Figures B12 and B13. On Banquereau, biomass increased from 2018 to a time series high in 2021. Since 2021, biomass has declined. The decline from 2022 to 2023 was 5%. The bank-wide biomass estimate for 2023 was 621,259 t (95% CI: 373,349–1,121,132 t). On the Grand Banks, the bank-wide biomass trend is largely driven by the southern portion of the bank. Biomass has increased almost every year since 2010, with annual increases ranging from 3 to 58% since that time. The bank-wide biomass estimate for 2023 was 933,669 t (95% CI: 493,093–1,895,215 t).

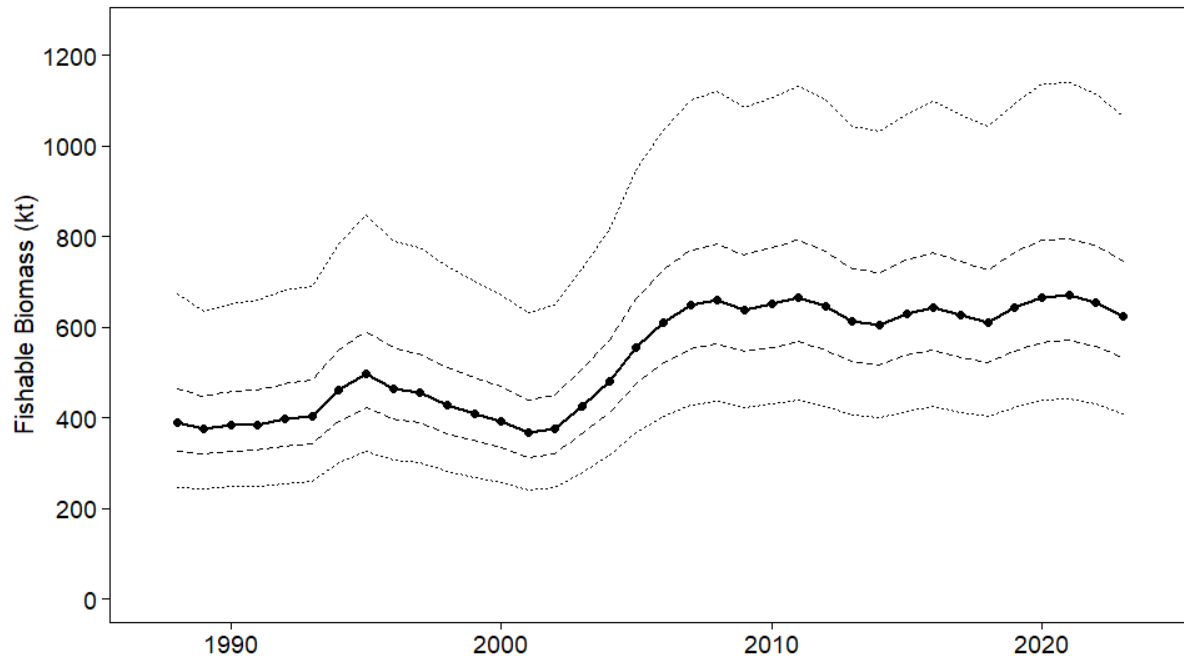


Figure B12. Bank-wide estimate of fishable biomass (kt) from the Spatial Production Model for Banquereau from 1988–2023. Lines denote the median (solid), 50% credible interval (dashed), and 95% credible interval (dotted).

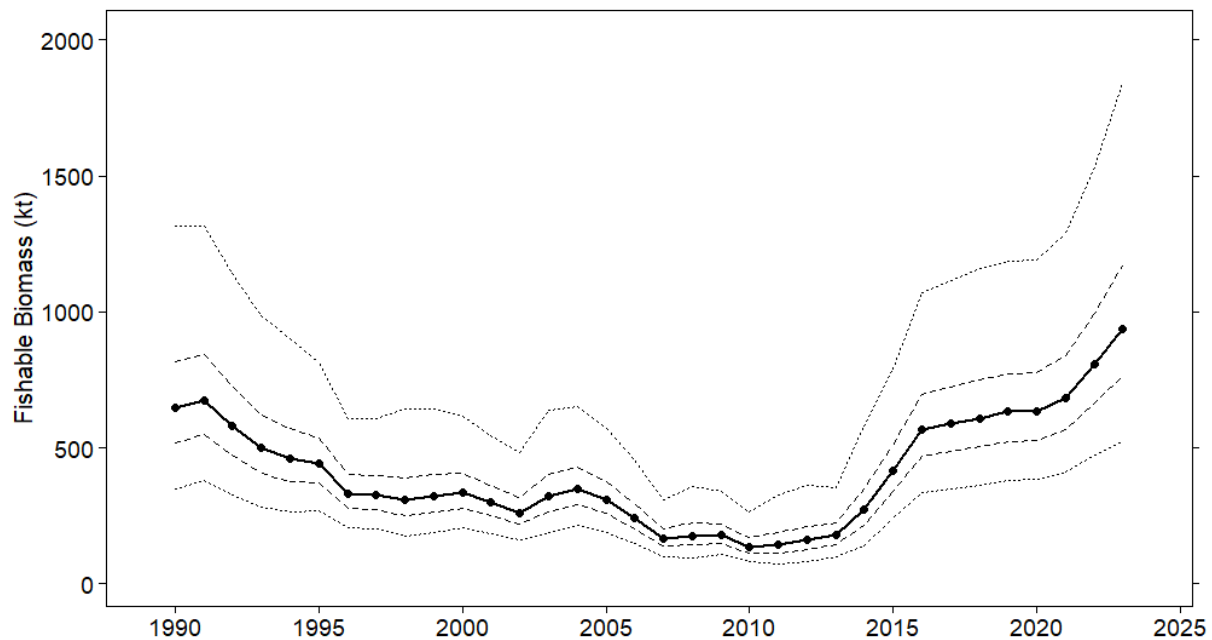


Figure B13. Bank-wide estimate of fishable biomass (kt) from the Spatial Production Model on the Grand Banks from 1989–23. Lines denote the median (solid), 50% credible interval (dashed), and 95% credible interval (dotted).

B.5 REFERENCE POINTS

The SPM approach provides parameter estimates that allow for an estimation of Maximum Sustainable Yield (MSY)-based reference points, where:

$$MSY = 0.25rK$$

$$B_{MSY} = 0.5K$$

$$F_{MSY} = 0.5r$$

As outlined in Hubley et al. (2020), the median of the posterior densities was used as the basis to determine reference points. F_{MSY} values estimated with this approach were 0.06 for Banquereau and 0.04 for Grand Banks. The B_{MSY} based reference points based on this approach are listed in Table B4.

Table B4. Limit reference point (LRP), upper stock reference (USR), catch upper unit effort (CPUE) indicator ($CPUE_{70}$ on Banquereau and $CPUE_{50}$ on the Grand Banks) for each bank.

Bank	LRP (t)	USR (t)	CPUE (t)
Banquereau	125,109	250,217	322,327
Grand Banks	66,562	139,123	191,916

The SPM parameters for growth rate and carrying-capacity are partly confounded and potentially biased because of a high growth rate (r) and low carrying-capacity (K), which give the model more flexibility to fit the data. If the growth rate estimate is too high, and the

carrying-capacity is too low, reference points are likely to be overly optimistic. The F_{MSY} (0.5 r) value will be higher, increasing the removal reference. The B_{MSY} (0.5 K) value will be lower, artificially reducing the value that the 0.4 and 0.8 B_{SMY} LRP and USR, respectively. This is believed to be happening for reference points based on the SPM model when applied to Banquereau and the Grand Banks.