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

Canadian Science Advisory Secretariat (CSAS)

Research Document 2023/082

Quebec Region

Delineation of stock assessment units for northern shrimp in the Estuary and northern Gulf of St. Lawrence

Hugo Bourdages, Audrey Bourret and Geneviève J. Parent

Fisheries and Oceans Canada
Maurice Lamontagne Institute
850 route de la Mer
Mont-Joli, Quebec G5H 3Z4

November 2023

Canada

Foreword

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

Published by:

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

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-68514-4 Cat. No. Fs70-5/2023-082F-PDF

Correct citation for this publication:

Bourdages, H., Bourret, A. and Parent, G.J. 2023. Delineation of stock assessment units for northern shrimp in the Estuary and northern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/082. vi + 30 p.

Aussi disponible en français :

Bourdages, H., Bourret, A. et Parent, G.J. 2023. Délimitation des unités d'évaluation des stocks de crevette nordique de l'estuaire et du nord du golfe du Saint-Laurent. Secr. can. des avis sci. du MPO. Doc. de rech. 2023/082. vi + 30 p.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In the Estuary and Gulf of St. Lawrence, four assessment units have been used since 1993 for the assessment of northern shrimp stocks, namely the Estuary, Sept-Iles, Anticosti and Esquiman areas. These stock assessment units correspond to locations where high concentrations of shrimp are generally observed during the research survey.

Information on northern shrimp abundance and the distribution of fishing effort over the last several decades suggests that the stock assessment units in the Estuary and northern Gulf of St. Lawrence need to be changed. A new delineation of the stock assessment units is proposed and supported by findings from a population genomics study. The stock indicators have been updated based on the new delineation, which provides an improved correspondence between assessment units and biological units.

INTRODUCTION

In 1993, the management units for the northern shrimp stocks in the Estuary and northern Gulf of St. Lawrence (ENGSL) were redefined to take into account the distribution of shrimp and contemporary fishing patterns (Figure 1). As part of this process, the number of management units was reduced from five to four, specifically the Estuary, Sept-Iles, Anticosti and Esquiman (Figure 2) (shrimp fishing areas (SFA) 12, 10, 9 and 8, respectively). These four units were redefined so that they would better correspond to the biological units based on the knowledge available at the time. Since the ENGSL is a highly dynamic environment, it is possible that the biological boundaries of these stocks may have changed since the last time they were delineated. A number of factors could cause changes in the species' distribution and abundance, including climate-driven changes and pressure from competing or predatory species. Besides, new knowledge can be used to better define the existing biological units.

Several of the terms used in this document need to be defined from the outset, since the definitions used in the literature may differ among studies depending on the topic being addressed (e.g. stock assessment, genomics). A stock may be described as a semi-distinct group of individuals of a given species that have some definable attributes in common which are of interest to fisheries managers and that can be assessed as a unit (DFO 2023). Alternatively, a stock may be defined on a functional basis for the purpose of fisheries management, in part due to uncertainties in defining spatial and temporal boundaries for biological units or due to historical considerations related to the fisheries. It is generally recognized that stocks should be defined on the basis of biological information first, after which management needs can be considered (Cadrin 2020). In this document, a stock refers to the individuals in an assessment or management unit. A biological unit can be defined as a group of individuals that have some attributes and characteristics in common, including the fact that they occupy the same space and have limited contact with other, similar groups. A biological unit may be more accurately defined as a population if it consists of a group of individuals that seldom breed with, or are reproductively isolated, from other groups (Waples and Gaggiotti 2006). Population genomic analyses enable information to be collected on the reproductive isolation between populations, among other things.

It is easier to assign a limit reference point (LRP, the level below which serious harm could occur to the resource) to a stock when the defined management unit is the same as the biological unit (Cadrin 2020). This match between the spatial and temporal scales at which biological processes and management and assessment activities occur helps to ensure the efficacy of stock assessment and management systems aiming to avoid serious harm to stocks. Therefore, the indicators, LRPs and stock status metrics should be selected based on the best available information for the stock.

During the stock assessment conducted in winter 2022 (DFO 2022), it was concluded that the precautionary approach should be revised before the next assessment. This revision was considered justified because ecosystem conditions were no longer the same as when the precautionary approach was developed in the early 2010s (DFO 2011) and because bias had been observed in the main stock status indicator. Furthermore, northern shrimp stocks are now prescribed stocks pursuant to section 6 in the modernized *Fisheries Act*, Bill C-68, which came into force on April 4, 2022. A new LRP must be established for all prescribed stocks in keeping with the guidelines associated with the fish stocks provisions (DFO 2023).

The need to adjust the LRP for the different shrimp stocks in the ENGSL provided the opportunity to review the assessment units for shrimp stocks in light of new information on the species' spatial distribution, the distribution of fishing effort and the genomic structure of the stocks, in order to ensure that the stock status indicators provide a reliable picture of the biological units.

The geographic locations mentioned in the text and the bathymetry of the Estuary and the Gulf of St. Lawrence are presented in Figure 3.

DELINEATION OF BIOLOGICAL UNITS

In the ENGSL, the sites with the greatest shrimp abundance are separated by a considerable distance. All maturity stages (juveniles, males and females) are present at these sites (Bourdages et al. 2022b), which indicates that the capacity to ensure a certain level of recruitment to the population exists.

HISTORY OF MANAGEMENT UNITS

In the early 1980s, five management units were established for the shrimp fishery based on the five areas exploited by harvesters, specifically the Estuary, Sept-Iles, North Anticosti, South Anticosti and Esquiman areas (Figure 2). Already in 1978, stock assessments were based on this delineation (CAFSAC 1978). However, the expansion of the fishery during the 1980s raised questions about some of the boundaries between these management units. During the stock assessment in 1992 (CSCPCA 1992) and at the second symposium on Gulf of St. Lawrence shrimp, held in 1993 (Savard and Boudreau 1993), it was recommended that the management units be restructured to better reflect fishing activities and prevent conflicts.

Accordingly, the management units were modified in 1993 so that their boundaries would better reflect fishing patterns, which are determined by the spatial distribution of areas with high concentrations of shrimp. At the time, there were four spatially isolated areas with substantial concentrations of shrimp, namely the Estuary, Sept-Iles, Anticosti and Esquiman areas (Figure 2). The boundaries between the management units adopted in 1993 were located in sectors where no fishing was carried out and shrimp abundance was low.

POPULATION GENOMICS

A population genomics study was conducted on 1,513 adults of northern shrimp, predominantly females, from 54 stations sampled between May and December 2019 in the area from Davis Strait to the Bay of Fundy. The sampling included 231 individuals from 8 stations in the ENGSL (Figure 4A). This study allowed knowledge acquisition on the species' connectivity and its vulnerability to climate change (Bourret et al. in prep.[1]). The shrimp were genotyped using 14,331 genomic markers consisting of single nucleotide polymorphisms (SNPs). The markers were obtained through a genotyping-by-sequencing approach, namely ddRADseq (Poland et al. 2012).

Results from this study using the full set of genomic markers suggest that the shrimp in the ENGSL form a distinct population from the populations of the Scotian Shelf and Newfoundland/Labrador/Arctic. The levels of genetic differentiation (Fst) between the ENGSL (n = 231) and these adjacent populations range from 0.0006 (Newfoundland/Labrador/Arctic, n =

---

[1] Bourret, A., Leung, C., Puncher, G., Le Corre, N., Deslauriers, D., Skanes, K., Bourdages, H., Di Cassista Ross, M., Walkusz, W., Jeffery, N. W., Stanley, R. E. E., Parent, G. J. 2023. Diving into large scale genomics to decipher drivers of structure and climatic vulnerability in a widespread marine shrimp. In preparation.

823) to 0.0018 (Scotian Shelf, n = 345; $P < 0.001$). These results point to a reduced level of connectivity between the three populations.

Furthermore, based on the genomic marker data, the connectivity between some management units in the ENGSL appears to be limited. The shrimp from two stations (i.e., 8-1 and 8-2) in the Esquiman management unit show levels of genomic differentiation that are significantly different from most stations in the ENGSL (average Fst = 0.0006, Figure 4B). The average Fst estimated for shrimp at stations 8-1 and 8-2 appears to be equivalent to that between the ENGSL and Newfoundland/Labrador/Arctic populations. However, the sample size for stations 8-1 and 8-2 is smaller, and the error associated with this estimated Fst is greater. By contrast, Savard et al. (1993) did not observe a genetic difference in their study which involved the use of eight enzyme-based genetic markers. The genomics study of Bourret et al. (in prep.[2]), which used a much larger number of genetic markers, enabled the detection of lower levels of genetic differentiation between management units. These levels of genetic differentiation, albeit low, are significant and therefore provide information that can be used to identify reproductive isolation between the groups of shrimp in the ENGSL.

At the scale of the genomics study (Davis Strait to Bay of Fundy), the explanatory analyses of genomic variance show that the genomic structure of northern shrimp is strongly linked to environmental gradients such as temperature and salinity in the surface or bottom layer (Bourret et al. in prep.[2]). At this scale, 249 loci on the 14,331 genomic markers were identified as possibly being linked to adaptations to the environment. In the ENGSL, the adaptive landscape constructed with these adaptive loci is not spatially homogeneous and suggests local adaptation or selection driven by environmental conditions. These results suggest that the selective pressures projected for the year 2075 in the ENGSL would have a greater effect on shrimp in the Estuary and western Gulf of St. Lawrence (i.e., the Estuary, Sept-Iles and Anticosti management units) and a lesser effect on shrimp in the eastern Gulf of St. Lawrence (i.e., the Esquiman management unit).

The proposed changes to the boundaries of the stock assessment units in the ENGSL appear to slightly improve genetic homogeneity between the units using the 249 adaptive loci. The four present management units explain a significant proportion of the genetic variance observed at the adaptive loci in northern shrimp (Table 1), which provides support for the use of these units. The proposed modification to the stock assessment units (i.e., incorporate 9-2 in unit 10, Figure 4A) explains a larger proportion of the genomic variance (0.80%) than that explained by the current units (0.51%; with a slightly lower AICc for the new units). The increase in the amount of variance (difference of 0.29%) explained is substantial in a context of genomic analysis. A delineation separating unit 8 from units 9, 10 and 12 to reflect the limited connectivity between Esquiman and the western part of the ENGSL would explain a slightly smaller proportion of the genetic variance than the proposed changes (0.78%). It should be noted that the amount of genetic variance explained by the current management units and the proposed ones is not significant when the entire set of genetic markers is used (i.e., 14,311 markers).

DISTRIBUTION OF FISHING EFFORT

The sectors that sustain the fishery in the four management units correspond to locations where large concentrations of shrimp are generally observed during the research survey (see below).

[2] Bourret, A., Leung, C., Puncher, G., Le Corre, N., Deslauriers, D., Skanes, K., Bourdages, H., Di Cassista Ross, M., Walkusz, W., Jeffery, N. W., Stanley, R. E. E., Parent, G. J. 2023. Diving into large scale genomics to decipher drivers of structure and climatic vulnerability in a widespread marine shrimp. In preparation.

Fishing intensity therefore varies in both space and time as a function of stock abundance (Figure 5).

In the Estuary, fishing is concentrated on the north slope of the Laurentian Channel between Portneuf-sur-Mer, to the west, and Pointe des Monts, to the east. Beginning in 2011, a shift in fishing effort from east of the Manicouagan Peninsula to west of this peninsula was observed. Since 2014, more than 96% of the catch has come from shallower depths in the area west of this peninsula.

Fishing was conducted on the north slope of the Gaspé Peninsula and from there eastward to the south slope of the Laurentian Channel from 1994 to 2017. Since then, very little or no fishing effort has taken place on the south slope of the Laurentian Channel.

In the western Gulf, fishing activities are distributed between Pointe des Monts and the area south of Parent Bank to the west of Anticosti Island. The distribution of fishing effort is shaped like a crescent that follows the seafloor bathymetry along the North Shore. Harvesters have abandoned the sector south of Parent Bank in recent years.

After the management units were modified in 1993, the distribution of shrimp showed an eastward expansion to an area south of Anticosti Island beyond the boundary separating the Sept-Iles and Anticosti management units (Figure 5). As early as 1994, fishing began to take place in the Anticosti management unit, specifically in the sector south of Anticosti Island (Figure 6). From 1995 to 2006, approximately 50% of the TAC was taken in the sector south of the island (in the Anticosti management area), whereas little or no fishing was carried out in this sector prior to 1992. The boundary south of Anticosti Island therefore no longer corresponds to the delineation rationale applied in 1993 for these units, which involved locating boundaries in sectors of low shrimp abundance in order to separate them from zones with large shrimp concentrations exploited by the industry. From 1993 to 2007, a significant amount of fishing took place in the area south of the island in the Anticosti unit. However, in subsequent years, the entire TAC, or most of it, was taken north of the island.

In the area north of Anticosti Island, fishing is distributed in the Anticosti Channel from Jacques-Cartier Strait to Beaugé Bank.

In the eastern Gulf, on the west coast of Newfoundland (NAFO Division 4R), fishing is concentrated in the Esquiman Channel, that is, from the head of the channel, which is bordered to the north by the Strait of Belle Isle, southwestward in the depths of the channel right to Beaugé Bank. No fishing effort has occurred south of the 49th parallel in Division 4R.

The distribution of shrimpers' fishing effort in the ENGSL has varied over time as a function of shrimp abundance and distribution. When there is an increase in shrimp abundance, the distribution of fishing effort expands as well. In contrast, when abundance decreases, fishing effort becomes more concentrated. The main sectors sustaining the fishery in the four management units have changed little over the years and correspond to the locations where the highest concentrations of shrimp have been observed during the research survey. However, in recent years, harvesters have abandoned some fishing grounds because of the low shrimp abundance. This includes the area east of the Manicouagan Peninsula in the Estuary, the northeastern tip of the Gaspé Peninsula, the area southeast of Anticosti Island, and the southwestern part of the Esquiman Channel (Figure 7).

DISTRIBUTION OF NORTHERN SHRIMP

Every summer since 1990, DFO has conducted a research trawl survey in the ENGSL with the goal of assessing the abundance of several species, including shrimp (Bourdages et al. 2022a). This survey is the main source of fishery-independent data for the assessment of northern shrimp stocks in the ENGSL. It provides information that is used to describe the distribution of northern shrimp, estimate the abundance and biomass of the stocks, and determine stock dynamics, among other things. The survey covers an area of 118,391 km^2 and extends to depths of over 37 m. Northern shrimp is generally confined to depths greater than 150 m, beneath the cold intermediate layer (CIL). The survey is therefore considered to provide good coverage of the distribution of northern shrimp in the ENGSL.

Following the decline in the abundance of large groundfish species in the early 1990s, shrimp abundance and biomass followed an increasing trend until the 2010s. Beginning in 1990, an increase was observed in the area occupied by shrimp, which went from 65,000 km^2 to over 90,000 km^2 in 1994 (Figure 8), with the same trend observed for their area of concentration. This increasing trend in the distribution area of shrimp was observed in all four stocks. Since 2008, however, there has been a decrease in the area where shrimp concentrate, that is, the minimum area where over 95% of the biomass is distributed. This area has decreased from over 50,000 km^2 to less than 30,000 km^2. Northern shrimp are now mainly concentrated at the heads of channels (Figure 9).

In the northern GSL, there are several locations where the abundance of shrimp is low. The low levels of abundance can be explained by the unsuitability of the habitat due to the water depth. The surface layer, depths that intersect the CIL, and depths greater than 350 m are not suitable habitat for the species. The main areas of spatial discontinuity in the GSL are the Jacques Cartier Strait, the Strait of Belle Isle, Beaugé and Parent Banks, and the deep Laurentian Channel.

Additionally, shrimp size has been found to vary along an east-west gradient, with the smallest individuals observed in the Esquiman Channel and the largest in the Estuary.

The distribution of northern shrimp in the ENGSL has thus been influenced by the size of the shrimp stocks. Whether shrimp abundance is low or high, the concentration areas where the highest abundances of shrimp in a given stock are observed, specifically at the heads of channels, have not changed. Furthermore, regardless of the time period, there are spatial discontinuities between these areas of large shrimp concentrations which are delineated by sectors with low abundances.

DEFINITION OF PROPOSED ASSESSMENT UNITS

Although northern shrimp are widely distributed in the ENGSL and fishing has been carried out in a variety of sectors over the years, the major shrimp concentrations are confined to a few fairly well-defined areas. The proposed assessment units are defined below taking into account areas of discontinuity in the distribution of shrimp as well as population genomics findings (Figure 2).

Estuary

The Estuary assessment unit is defined as being located west of Pointe des Monts at longitude 63º27’W. Even if shrimp are distributed both to the north and south of the Laurentian Channel, the main concentrations are found north of the channel.

With the increase in water temperatures and the depletion of oxygen in the bottom layer, a significant shift of shrimp to new depths was observed in the Estuary beginning in 2018 (Bourdages et al. 2022b). For example, between 2008 and 2017 females were found at depths of between 110 and 320 m; however, since 2018, they have been found closer to the CIL, at depths of between 70 et 170 m. This depth-based change in distribution is very pronounced in the Estuary but is present to a lesser extent in the other units where the waters are continuing to warm and become more depleted in oxygen. In addition, redfish abundance is lower in the Estuary unit than in the other assessment units (Senay et al. 2023). In light of these observations, it is considered appropriate to maintain the present boundary between the Estuary and Sept-Iles assessment units.

The Estuary assessment unit has nonetheless been expanded so that it corresponds to the area covered by the DFO survey which was expanded in 2008 to incorporate the 37 m to 183 m depth strata (Figure 10, strata 851, 852, 854 and 855). This new definition of the assessment unit represents an improved correspondence with the biological unit and takes into account the changes in shrimp distribution.

Sept-Iles

The Sept-Iles assessment unit is bounded on the west by the longitude of Pointe des Monts and on the east along the North Shore by the Strait of Jacques Cartier, which is located northwest of Anticosti Island (shallow area). The area also includes the portion of the Laurentian Channel south of Anticosti Island to the boundary linking the eastern tip of Anticosti Island and the junction of NAFO Divisions 4RST in the middle of the Laurentian Channel, an area of discontinuity in the distribution of shrimp. This area is also characterized by the counter-clockwise currents of the Anticosti Gyre (Figure 11). The change to the southeastern boundary of this area increases the genomic consistency (i.e. a greater amount of adaptive genomic variance is explained) of this proposed stock assessment unit.

Anticosti

The Anticosti assessment unit corresponds to the Anticosti Channel, which is located north of Anticosti Island. Shrimp aggregations are found mainly within the channel, particularly at its head. This unit is separated from the Sept-Iles unit by the shoals of the Jacques Cartier Strait, which is located farther to the west, and by Anticosti Island to the south. It is also separated from the Esquiman unit to the east by Beaugé Bank (a shallower zone) and by the deep Laurentian Channel. In addition, the change to the southwestern boundary of this unit enhances the genomic consistency (i.e., a greater amount of adaptive genomic variance is explained) of this proposed stock assessment unit.

Esquiman

The Esquiman assessment unit corresponds to NAFO Division 4R and the northeastern part of Division 4S east of the 60th parallel. Shrimp aggregations occur mainly at the head of the Esquiman Channel. There is a spatial discontinuity in the distribution of shrimp between the Esquiman and Anticosti units which is attributable to the topography. Beaugé Bank (a shallower zone) serves as a natural boundary between these two units as does the deep Laurentian Channel to the south of Division 4R. The shrimp present in the Esquiman Channel appear to be genomically differentiated from, and have a different adaptive potential than, the shrimp in the other assessment units in the ENGSL (Figure 4).

In summary

In light of these new definitions of the biological units, it is proposed that the assessment units be modified to provide a better spatial alignment of the stock status indicators with the biological units. In summary, the proposed modifications are:

- The stock assessment unit for the Estuary is expanded to take into account research survey information from the trawl stations covering the 37 m to 183 m depth strata. The time series of biomass indices begins in 2008, and the survey area corresponds to depths of over 37 m in the Estuary.

- The boundary separating the Sept-Iles and Anticosti management units is moved from the south-central part of Anticosti Island to the eastern tip of the island. The stock assessment unit Sept-Iles is enlarged eastward in the Laurentian Channel, and the unit Anticosti is reduced so that it corresponds mainly to the Anticosti Channel, that is, the area north of the island.

UPDATE OF STOCK STATUS INDICATORS

The stock status indicators were recalculated based on the geographic boundaries of the proposed new stock assessment units. The use of georeferenced data makes it possible to obtain updated indicators representative of the proposed units, beginning in 1982 for landings and in 1990 for the biomass indices derived from the research survey.

In the case of landings, only those in the Sept-Iles and Anticosti stock assessment units were affected by the proposed changes in the units. The landings figures for the Estuary and Esquiman units remained unchanged as a result of the new unit delineations. Similarly, the biomass indices for the Sept-Iles and Anticosti assessment units also changed. In addition, the biomass indices for the Estuary unit changed from 2008 onwards, reflecting the fact that the sampling area was expanded to cover the 37 m to 183 m depth strata to correspond more closely to the current distribution of shrimp in this unit. The biomass indices for the Esquiman unit remain the same.

LANDINGS

Harvesters are required to describe their fishing activities in a logbook. The positions of fishing sites recorded by the harvester are used to identify the shrimp fishing area where fishing operations took place. Positions are expressed in latitude and longitude or by identifying the corresponding fishing quadrant (10 minutes of longitude by 10 minutes of latitude square, Figure 12), depending on the type of form provided to the harvester's fleet and the year. Since 1982, almost all catches have been georeferenced to at least the fishing quadrant level.

The logbook data obtained from the ZIFF (Zonal Interchange File Format) files correspond to one fishing day at a given site, with the resolution the same as that recorded in the logbook. Each catch in the ZIFF file was assigned to a proposed assessment unit based on the fishing quadrant where it took place.

The total catches recorded in the ZIFF files and the official DFO statistics on landings by shrimp fishing area, which can be found in the Gulf Quota Reports, differ slightly. Consequently, the official DFO statistics were used as a baseline, and the ZIFF-file catches had to be adjusted proportionally so that, when totalled, they were equal to the official statistics. In addition, a second correction had to be made to the catch data, since some were not georeferenced to the fishing quadrant level (roughly 17% before 1990 and less than 1% from 1990 onwards, but only 5% and 0% in the Sept-Iles and Anticosti assessment units, respectively). Georeferenced catches were therefore adjusted proportionally so that their sum was equal to the official statistics. Following these corrections, the total catches in each quadrant were calculated annually for the current management units and the proposed stock assessment units. The resulting figures for landings per unit and year are shown in Table 2.

The modifications of the stock assessment units boundaries only affect the Sept-Iles and Anticosti units in the case of landings (Figure 13), and landings in the Estuary and Esquiman units did not change as a result of the new delineation of units. Since the Sept-Iles unit was expanded to include a portion southeast of Anticosti Island, landings in that unit increased, while those in the Anticosti unit decreased. These changes in landings mainly affect the period from 1994 to 2006, since very few catches occurred in the portion southeast of Anticosti Island before and after this period.

Increases in landings in the Sept-Iles unit ranged from 11% to 61% (average 34%) during the 1994–2006 period, but averaged less than 1% during the period before 1994 and after 2006. Conversely, landings in the Anticosti area declined by 15% to 78%, or an average of 47%, during the 1994–2006 period, but only by approximately 1% during the period before 1994 and after 2006.

DFO SURVEY BIOMASS INDICES

Total biomass and the variance of estimates were kriged by using an interpolation grid covering the study area of the DFO survey. The method is presented in Bourdages et al. 2022b. Annual estimates were calculated for each assessment unit, based on the currently defined management units and the proposed assessment units. The results are shown in Tables 3 and 4 and Figure 15.

Beginning in 2008, the area covered in the DFO research survey in Division 4T was expanded to include the upstream portion of the Lower Estuary, in order to sample depths between 37 m and 183 m. Before 2008, only depths greater than 183 m were covered in the Estuary unit and consequently a portion of the stock was not sampled in the survey. The proposed Estuary assessment unit corresponds to the area sampled in the survey since 2008, and therefore is more representative of the biomass in this unit. Consequently, from now on, the time series will begin in 2008. The addition of these new, shallower depth strata has increased annual biomass by 684% on average, with annual increases ranging between 56% and 2,481%. The variations have been greater in recent years because of the movement of shrimp to shallower depths in order to reach the colder waters found there (Bourdages et al. 2022b).

The proposed expansion of the Sept-Iles assessment unit is associated with higher biomass estimates. For the 1994–2013 period, biomass increases in a range between 8% and 44%, with an average increase of 17%. However, for the years 1990–1993 and 2014–2022, the biomass are comparable, with annual increases of less than 10%. Since the area added to the proposed Sept-Iles assessment unit was taken from the Anticosti management unit, the opposite trend is observed in the latter, i.e. biomass values in the proposed Anticosti unit are smaller, with decreases ranging from 13% to 30% during the 1994–2013 period, with an average of 21%.

Since no modifications were made to the Esquiman assessment unit, biomass estimates there remain the same.

CONCLUSION

The sites in the ENGSL with the greatest shrimp abundance are spatially isolated from one another. In light of historical information on the distribution of fishing effort and shrimp in the ENGSL, as well as a recent population genomics study, it is proposed that changes be made to the stock assessment units in order to obtain a better spatial alignment between the stock status indicators and the biological units. In brief, these modifications involve expanding the Estuary assessment unit and moving the boundary between the Sept-Iles and Anticosti assessment units to south of Anticosti Island.

We were able to recalculate landings and biomass indices based on these new stock assessment units because this information was georeferenced. Therefore, indicators were defined based on the best information available on these stocks. The improved correspondence between the assessment units and biological units will make it easier to assign a LRP to each stock.

The upcoming science advice and science advisory reports will be formulated based on the newly delineated stock assessment units presented in this document. Subsequently, Fisheries Management will decide on the spatial delineation of the stock management units in consultation with the industry.

REFERENCES CITED

Bourdages, H., Brassard, C., Chamberland, J.-M., Desgagnés, M., Galbraith, P., Isabel, L. and Senay, C. 2022*a*. Preliminary results from the ecosystemic survey in August 2021 in the Estuary and northern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/011. iv + 95 p.

Bourdages, H. Roux, M.-J., Marquis, M.C., Galbraith, P. and Isabel, L. 2022b. Assessment of northern shrimp stocks in the Estuary and Gulf of St. Lawrence in 2021: commercial fishery and research survey data. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/027. xiv + 195 p.

Cadrin, S.X. 2020. Defining spatial structure for fishery stock assessment. Fisheries Research 221: 105397.

CAFSAC. 1978. Invertebrates subcommittee report. Canadian Atlantic Fisheries Scientific Advisory Committee, Advisory Document. 78/2.

CSCPCA. 1992. Évaluation des agrégations de crevettes du golfe du Saint-Laurent. Comité scientifique consultatif des pêches canadiennes dans l'Atlantique, Document consultatif. 92/12.

DFO. 2011. Reference points consistent with the precautionary approach for northern shrimp in the Estuary and Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec., Sci. Advis. Rep. 2011/062.

DFO. 2022. Assessment of Northern Shrimp stocks in the Estuary and Gulf of St. Lawrence in 2021. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/006.

DFO. 2023. Science Advice on Guidance for Limit Reference Points under the Fish Stocks Provisions. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/009.

Galbraith, P.S., Chassé, J., Dumas, J., Shaw, J.-L., Caverhill, C., Lefaivre, D. and Lafleur, C. 2022. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/034. iv + 83 p.

Poland, J.A., Brown, P.J., Sorrells, M.E., and Jannink, J.L. 2012. Development of high-density genetic maps for barley and wheat using a novel two-enzyme genotyping-by-sequencing approach. PLoS One 7(2). doi:10.1371/journal.pone.0032253.

Savard, L. and Boudreau, M.-M. 1993. Compte-rendu du Colloque sur la crevette du golfe du Saint-Laurent, exploitation de la ressource. MPO région du Québec. Février 1993. 14 p.

Savard L., Hurtubise S. and Sévigny J.M. 1993. Les nouvelles unités de gestion de la pêche à la crevette nordique (*Pandalus borealis*) dans le nord du golfe du Saint-Laurent. MPO Pêches de l'Atl. Doc de Rech 93/21.

Senay, C., Rousseau, S., Brûlé, C., Chavarria, C., Isabel, L., Parent, G.J., Chabot, D. and Duplisea, D. 2023. Unit 1 Redfish (*Sebastes mentella* and *S. fasciatus*) stock status in 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/036. xi + 125.

Waples, R.S., Gaggiotti, O. 2006. What is a population? An empirical evaluation of some genetic methods for identifying the number of gene pools and their degree of connectivity. Molecular Ecology 15: 1419–1439.

TABLES

Table 1. Partitioning of genetic variance, taking into account the (A) current and (B) proposed assessment units or (C) by considering SFA 8 versus the other units (SFAs 9, 10, and 12). The analysis of genetic variance (AMOVA) was conducted using 249 adaptive loci. A corrected Akaike information criterion (AICc) was calculated for each model.

Model	d.f.	SS	Variance	% of variance explained	P
A) Current assessment units (AICc = 327.656)					
Between units	3	15.71	0.02	0.51	0.043
Within units (error)	227	929.28	4.09	99.49	-
Total	230	944.99	4.11	-	-
B) Proposed assessment units (AICc = 327.235)					
Between units	3	17.40	0.03	0.80	0.013
Within units (error)	227	927.59	4.09	99.20	-
Total	230	944.99	4.12	-	-
C) SFA 8 unit vs. other units (AICc = 329.632)					
Between units	1	7.73	0.03	0.78	0.002
Within units (error)	229	937.26	4.09	99.22	-
Total	230	944.99	4.13	-	-

Table 2. Landings (t) by shrimp management unit, according to their 1993 definition (cur.) and the proposed (prop.) new stock assessment units. Years with a difference of more than 1% are shown in bold.

Year	Estuary		Sept-Iles		Anticosti		Esquiman		Total	
	Cur.	Prop.	Cur.	Prop.	Cur.	Prop.	Cur.	Prop.	Cur.	Prop.
1982	152	152	**3774**	**3836**	**2464**	**2402**	2111	2111	8501	8501
1983	158	158	**3647**	**3711**	**2925**	**2861**	2242	2242	8972	8972
1984	248	248	**4383**	**4443**	**1336**	**1276**	1578	1578	7545	7545
1985	164	164	4399	4418	2786	2767	1421	1421	8770	8770
1986	262	262	4216	4242	3340	3314	1592	1592	9410	9410
1987	523	523	5411	5430	3422	3403	2685	2685	12041	12041
1988	551	551	6047	6047	2844	2844	4335	4335	13777	13777
1989	629	629	6254	6281	4253	4226	4614	4614	15750	15750
1990	507	507	6839	6839	4723	4723	3303	3303	15372	15372
1991	505	505	6411	6447	4590	4554	4773	4773	16279	16279
1992	489	489	4957	4973	4162	4146	3149	3149	12757	12757
1993	496	496	**5485**	**5654**	**4791**	**4622**	4683	4683	15455	15455
1994	502	502	**6165**	**7196**	**4854**	**3823**	4689	4689	16210	16210
1995	486	486	**6386**	**9177**	**4962**	**2171**	4800	4800	16634	16634
1996	505	505	**7014**	**11306**	**5469**	**1177**	5123	5123	18111	18111
1997	549	549	**7737**	**10551**	**6058**	**3244**	5957	5957	20301	20301
1998	634	634	**8981**	**10003**	**6932**	**5910**	6554	6554	23101	23101
1999	646	646	**9239**	**12487**	**7022**	**3774**	6732	6732	23639	23639
2000	739	739	**10160**	**13904**	**7941**	**4197**	7396	7396	26236	26236
2001	832	832	**10965**	**12709**	**5399**	**3655**	7815	7815	25011	25011
2002	799	799	**11493**	**16108**	**8638**	**4023**	8250	8250	29180	29180
2003	796	796	**11357**	**16645**	**8742**	**3454**	6773	6773	27668	27668
2004	1033	1033	**15932**	**20790**	**10429**	**5571**	8593	8593	35987	35987
2005	1001	1001	**12793**	**17664**	**8047**	**3176**	8867	8867	30708	30708
2006	1029	1029	**15312**	**19013**	**8754**	**5053**	8957	8957	34052	34052
2007	1022	1022	**15645**	**16464**	**10180**	**9361**	9208	9208	36055	36055
2008	1017	1017	**15972**	**16325**	**9635**	**9282**	9110	9110	35734	35734
2009	993	993	**15873**	**16074**	**9644**	**9443**	9473	9473	35983	35983
2010	906	906	15756	15768	10099	10087	9541	9541	36302	36302
2011	880	880	**14376**	**14646**	**9831**	**9561**	9177	9177	34264	34264
2012	956	956	12516	12596	8267	8187	10244	10244	31983	31983
2013	1117	1117	14217	14227	7681	7672	9149	9149	32165	32165
2014	984	984	12416	12440	8738	8714	8408	8408	30546	30546
2015	1075	1075	12415	12425	9171	9161	8220	8220	30882	30882
2016	1027	1027	12139	12141	8681	8680	7081	7081	28928	28928
2017	899	899	6939	6946	6935	6928	7024	7024	21797	21797
2018	214	214	4175	4189	6300	6285	5971	5971	16660	16660
2019	199	199	3999	4012	6861	6848	5981	5981	17040	17040
2020	570	570	5096	5101	6187	6182	5992	5992	17845	17845
2021	579	579	4970	4982	6245	6233	5535	5535	17329	17329
2022*	497	497	3905	3909	3720	3717	4253	4253	12376	12376

* 2022: as of February 1, 2023

Table 3. Total biomass (t) in the stock assessment units of Estuary, Sept-Iles and Anticosti to their 1993 definition (current) and the proposed new units.

	Estuary		Sept-Iles		Anticosti	
Year	Current	Proposed	Current	Proposed	Current	Proposed
1990	2011	-	31030	31876	37064	36219
1991	2219	-	41295	43085	23701	21921
1992	1803	-	17436	18721	24984	23703
1993	1486	-	23500	25059	16505	14946
1994	2088	-	28994	33280	16016	11738
1995	344	-	29351	42234	42574	29705
1996	2862	-	40025	56384	74124	57799
1997	1764	-	52690	63678	46584	35615
1998	727	-	62366	72954	38278	27722
1999	3015	-	56187	66432	41669	31433
2000	3371	-	82987	97237	57412	43173
2001	1858	-	71043	80373	39373	30051
2002	1526	-	78920	87112	61638	53461
2003	3343	-	170437	194798	101171	76818
2004	2893	-	111739	122603	68470	57621
2005	2385	-	86361	99604	83311	70071
2006	1947	-	74851	82834	50523	42543
2007	3482	-	99025	111330	85211	72908
2008	2578	10715	88057	98036	38827	28806
2009	1653	9991	70712	77601	53005	46250
2010	1798	7898	66526	79335	51060	38396
2011	2733	7266	45266	53437	30090	21798
2012	3185	7993	66831	72122	33847	28490
2013	1806	6764	51608	57732	35086	28870
2014	5437	10940	78809	84446	39553	33538
2015	3446	5381	66613	69187	37332	34482
2016	1410	7486	43745	44593	21708	20736
2017	406	2420	20861	21691	27423	26617
2018	268	6924	14767	14972	19272	19170
2019	4148	9742	19869	20942	19304	18904
2020	374	2315	27146	27459	21170	20946
2021	633	12949	11840	11967	15674	15382
2022	1043	25504	3798	4143	9191	8924

Table 4. Stock biomass (t) estimated by kriging in each proposed stock assessment unit, by year and for males (M) and females (F).

Estuary (SFA 12)

Year	Male	Female	Total	> 17 mm	Primiparous	Multiparous
2008	1800	8889	10715	10438	-	-
2009	2665	7319	9991	8873	3247	4072
2010	3415	4484	7898	6537	2962	1523
2011	3529	3724	7266	6515	1840	1883
2012	3104	4930	7993	7636	3629	1301
2013	1434	5033	6764	6111	4075	957
2014	3380	6945	10940	9292	6584	361
2015	1654	3730	5381	4340	3376	353
2016	2840	4480	7486	7116	3241	1239
2017	1010	1413	2420	2125	916	497
2018	2998	3742	6924	6258	2888	854
2019	3098	6742	9742	9818	2645	4096
2020	765	1603	2315	2199	795	808
2021	5267	6286	12949	11133	2216	4070
2022	7239	18758	25504	25769	6724	12034

Beginning in 2008, sampling was expanded by adding strata in the shallow portion (37–183 m depths) of the Estuary.

Sept-Iles (SFA 10)

Year	Male	Female	Total	> 17 mm	Primiparous	Multiparous
1990	11837	20046	31876	31401	10041	10006
1991	17430	24309	43085	39093	8194	16115
1992	7041	11410	18721	15777	6366	5044
1993	10587	14161	25059	21884	11952	2209
1994	12719	20557	33280	30363	16885	3673
1995	16842	25392	42234	40859	22247	3145
1996	20264	36151	56384	54300	26648	9503
1997	27611	36246	63678	60235	29291	6955
1998	19097	53886	72954	71786	43589	10297
1999	26469	39999	66432	60041	34080	5920
2000	33963	63103	97237	96091	52857	10246
2001	40831	40473	80373	74482	-	-
2002	31848	56262	87112	86750	-	-
2003	94838	100060	194798	189776	-	-
2004	45274	77528	122603	119822	-	-
2005	31674	67992	99604	97002	-	-
2006	20856	61518	82834	81197	-	-
2007	32443	78406	111330	107946	-	-
2008	29405	68541	98036	93954	-	-
2009	33455	43971	77601	71173	20212	23759
2010	26321	53322	79335	74597	33198	20123
2011	18340	34880	53437	51021	19359	15521
2012	38444	33486	72122	69525	24587	8899
2013	22079	34682	57732	55447	27095	7586
2014	30208	54356	84446	81598	51007	3348
2015	26373	42617	69187	66852	38260	4357
2016	16168	27751	44593	41846	17363	10388

Year	Male	Female	Total	> 17 mm	Primiparous	Multiparous
2017	8278	13737	21691	20669	9953	3784
2018	5257	9697	14972	13465	3611	6086
2019	9909	11025	20942	20384	5619	5406
2020	12349	15657	27459	26445	7263	8394
2021	5442	6513	11967	11384	3918	2594
2022	1107	3113	4143	4037	1445	1668

Anticosti (SFA 9)

Year	Male	Female	Total	> 17 mm	Primiparous	Multiparous
1990	18459	18131	36219	33886	12399	5732
1991	9051	12721	21921	21099	7219	5502
1992	11782	12124	23703	21779	7951	4173
1993	9060	5962	14946	12090	5041	921
1994	6152	5597	11738	10859	4477	1120
1995	14071	14916	29705	25227	13221	1695
1996	24263	33302	57799	54669	28011	5291
1997	16723	19185	35615	30561	17547	1638
1998	9836	18469	27722	28018	15846	2623
1999	13049	18306	31433	27779	14052	4254
2000	14706	28424	43173	41031	23555	4869
2001	12443	17107	30051	26624	-	-
2002	24929	29067	53461	47944	-	-
2003	37909	39531	76818	67670	-	-
2004	23919	33335	57621	51598	-	-
2005	26292	43886	70071	69213	-	-
2006	15850	26047	42543	39495	-	-
2007	24627	48735	72908	67941	-	-
2008	12283	16643	28806	25870	-	-
2009	24832	20602	46250	36374	12750	7852
2010	19821	18765	38396	34624	9255	9510
2011	6423	15488	21798	20653	10456	5032
2012	10478	18589	28490	26948	13591	4998
2013	8779	19680	28870	27231	15726	3954
2014	15457	18453	33538	29158	15514	2938
2015	14297	20721	34482	31149	19255	1465
2016	7633	13246	20736	18831	9947	3299
2017	10833	15609	26617	23125	11372	4237
2018	7334	11669	19170	15952	6944	4725
2019	8868	10050	18904	16120	5300	4751
2020	9037	13031	20946	19105	7770	5261
2021	5846	9126	15382	13907	6202	2924
2022	3259	5715	8924	8394	2360	3355

Esquiman (SFA 8)

Year	Male	Female	Total	> 17 mm	Primiparous	Multiparous
1990	7577	13010	20358	20004	10568	2443
1991	5999	9219	15336	14906	4787	4433
1992	2989	6547	9490	9235	5348	1200
1993	3697	3465	9116	6590	2151	1314

Year	Male	Female	Total	> 17 mm	Primiparous	Multiparous
1994	5678	6334	11988	11369	5356	978
1995	10820	10590	21198	19503	8947	1643
1996	10652	9652	20525	18026	6821	2831
1997	24167	22428	46764	39676	15940	6488
1998	11858	15537	27492	26317	13274	2263
1999	14721	14806	33550	24567	9651	5155
2000	14204	17355	31272	29543	12617	4738
2001	14631	14635	29755	23156	-	-
2002	6378	7027	13395	12413	-	-
2003	28240	32297	60250	52835	-	-
2004	14059	24825	38719	35922	-	-
2005	19290	27601	46872	45792	-	-
2006	23085	27401	50305	42401	-	-
2007	16743	14968	31708	25859	-	-
2008	15936	13784	29685	25211	-	-
2009	17694	17361	35140	31350	12076	5285
2010	14481	18367	32947	31153	7343	11024
2011	20206	26904	47211	42062	19370	7534
2012	14647	16422	31079	26155	12255	4167
2013	14075	21347	35399	33804	17795	3552
2014	15591	15525	31002	28972	12737	2788
2015	9659	12790	22056	20114	8695	4095
2016	12861	12363	25432	23744	8527	3836
2017	8004	11312	18996	18587	6595	4717
2018	4125	13170	17478	16177	6121	7049
2019	9744	13440	23251	21419	7766	5675
2020	3313	8105	11470	10624	5004	3101
2021	5515	9039	14404	13859	4775	4264
2022	2734	8995	11619	11267	4154	4841

FIGURES

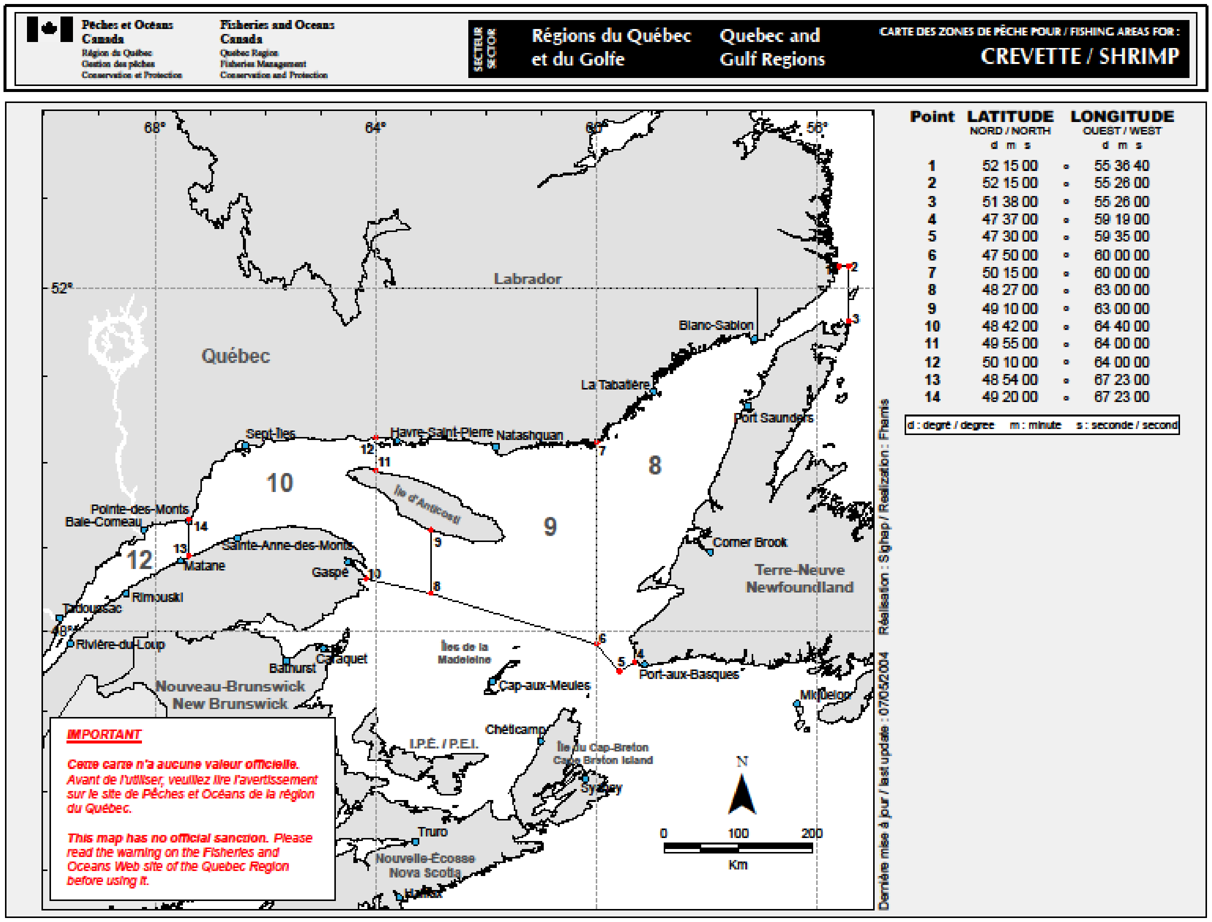

Figure 1. Management units (shrimp fishing areas) in the Estuary and Gulf of St. Lawrence as defined since 1993: Estuary (SFA 12), Sept-Iles (SFA 10), Anticosti (SFA 9) and Esquiman (SFA 8).

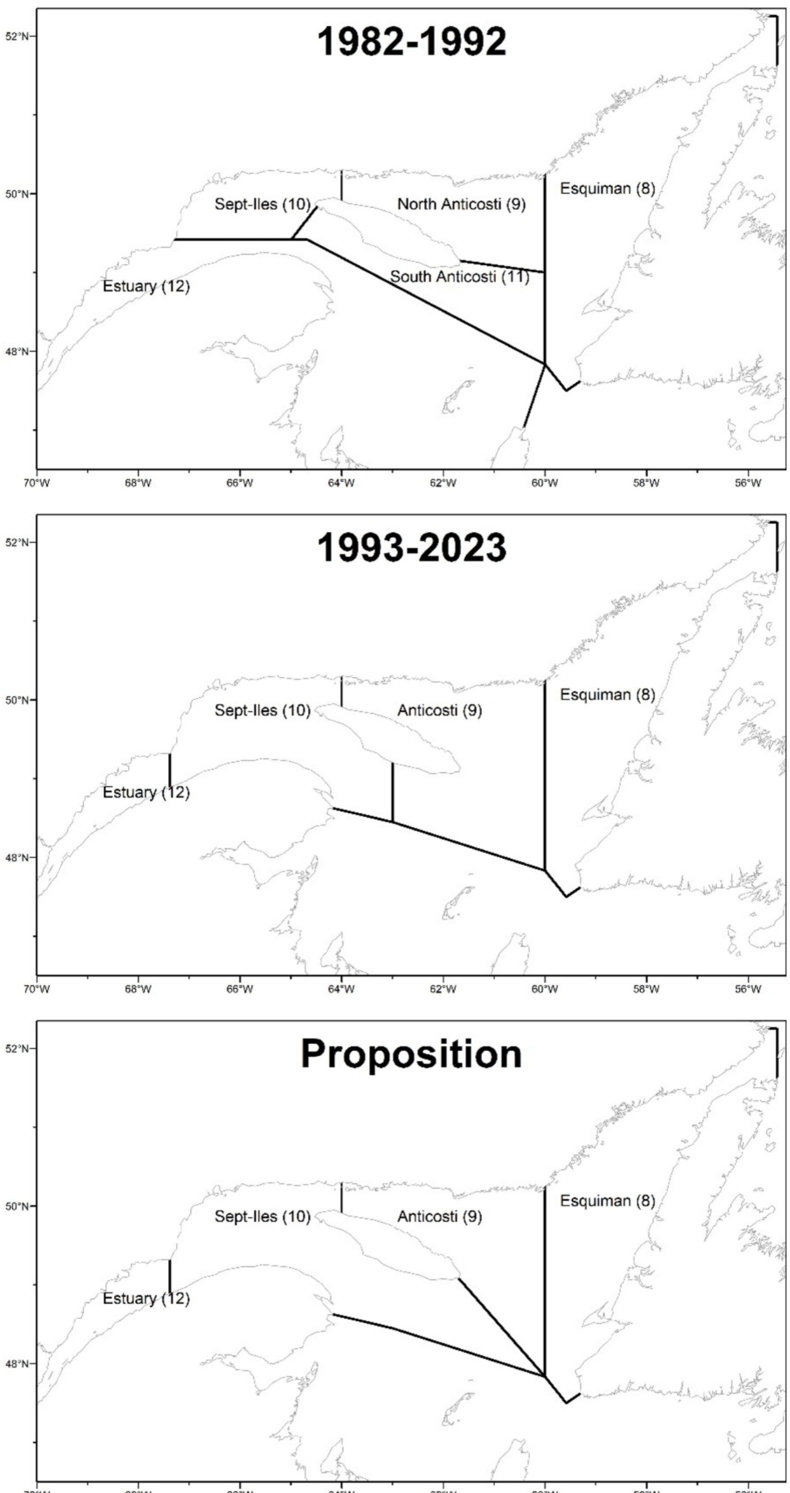

Figure 2. Shrimp fishing areas in the Estuary and Gulf of St. Lawrence as defined during the 1982–1992 and 1993–2023 periods and according to the proposed new delineations.

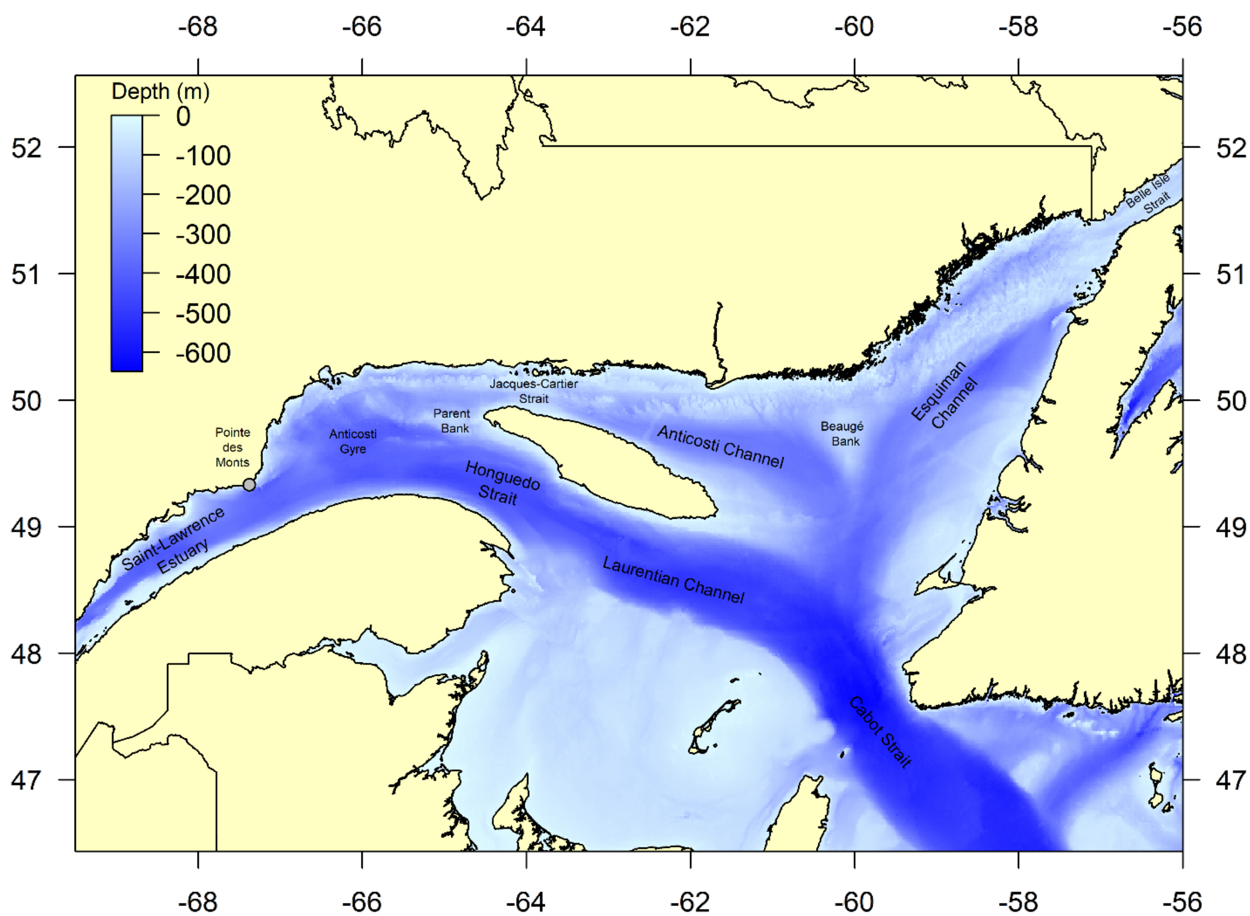

Figure 3. Bathymetry of the Estuary and Gulf of St. Lawrence and the locations mentioned in the text.

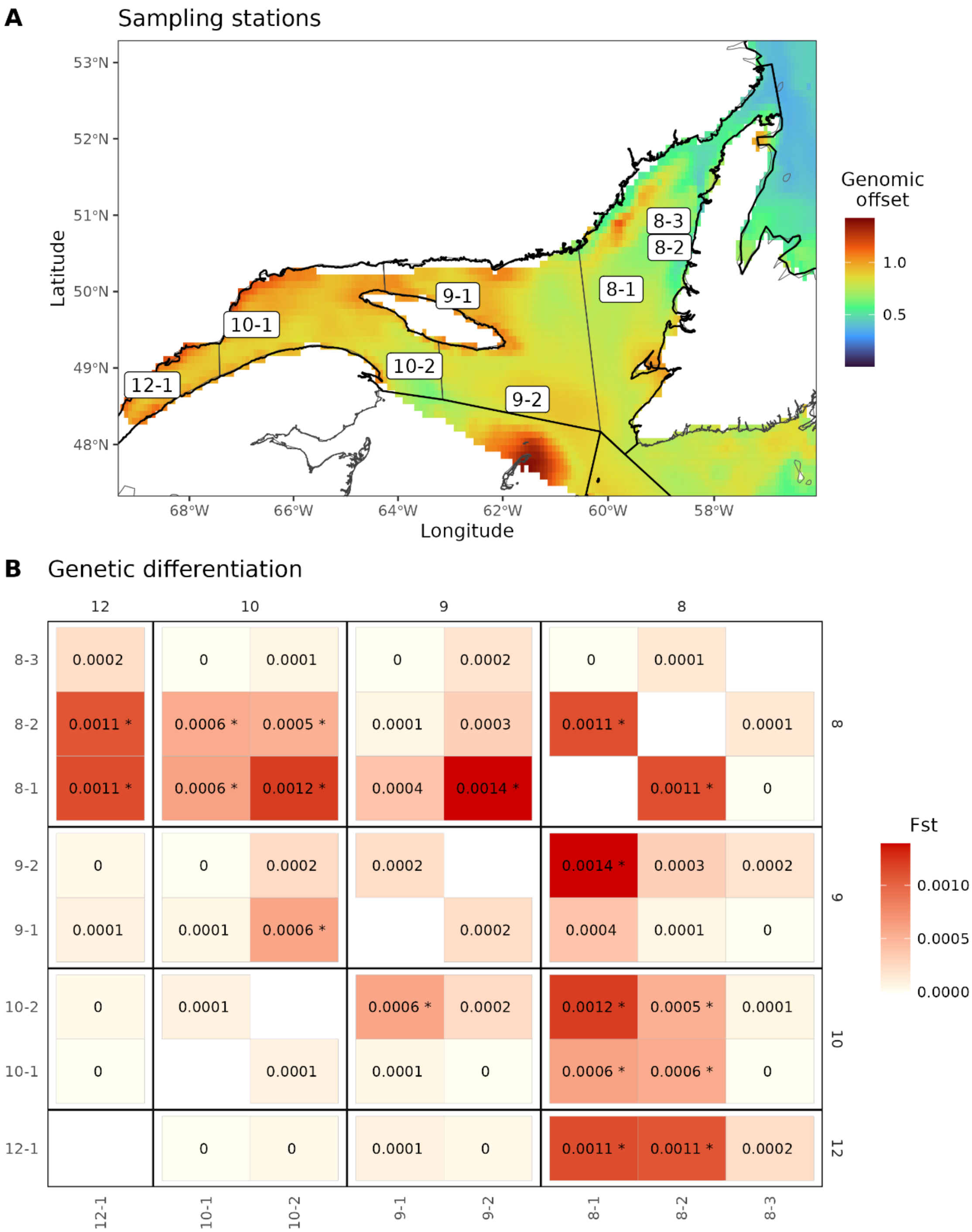

Figure 4. Sampling stations, genomic offset and genetic differentiation in the Estuary and northern Gulf of St. Lawrence. A) Distribution of the eight sampling stations along the predicted genomic offset. The lines show the boundaries separating the current assessment units. B) Measure of genetic differentiation (Fst) calculated between all stations. Asterisks (*) indicate Fst values significantly different from 0.

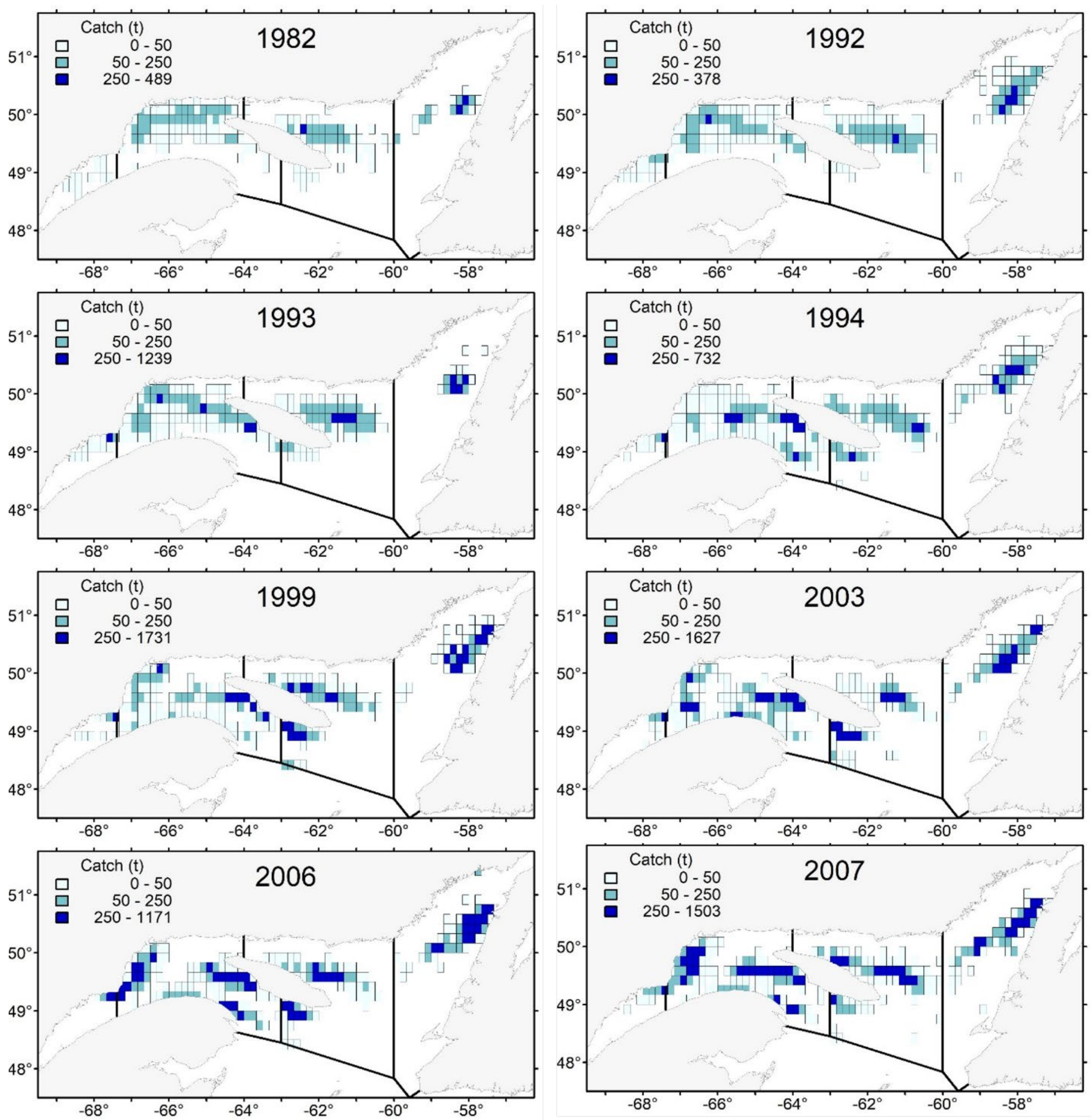

Figure 5. Catch (t) by fishing quadrant in certain years of interest (panels).

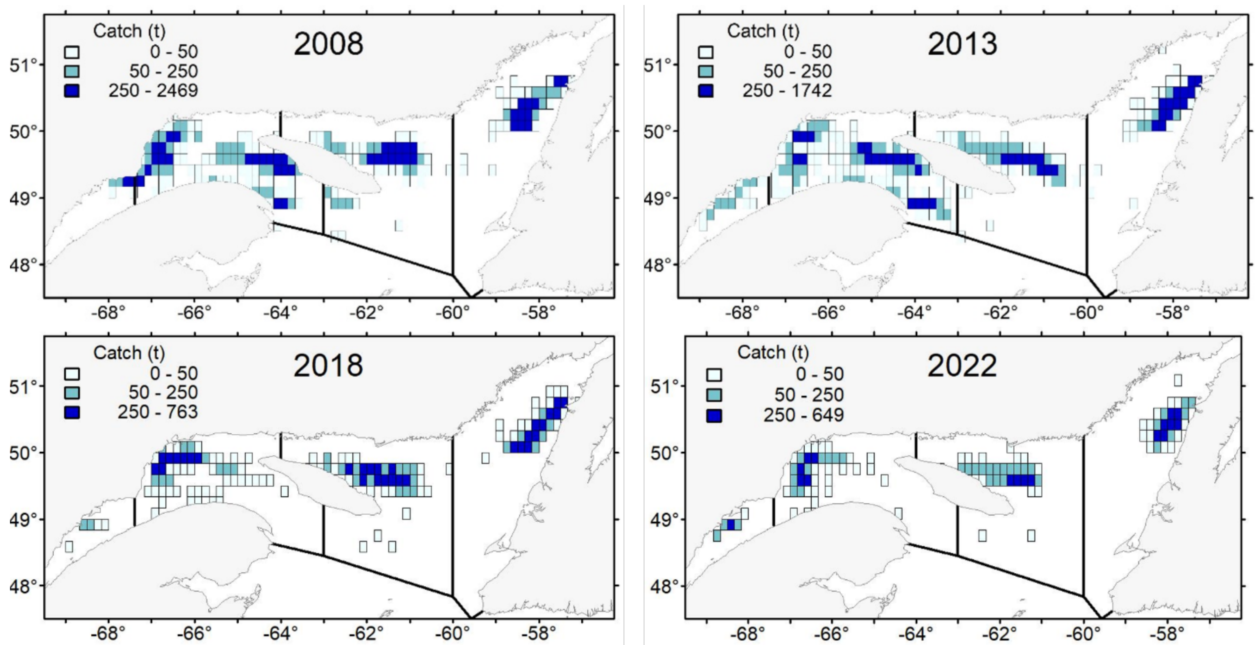

Figure 5. Cont'd.

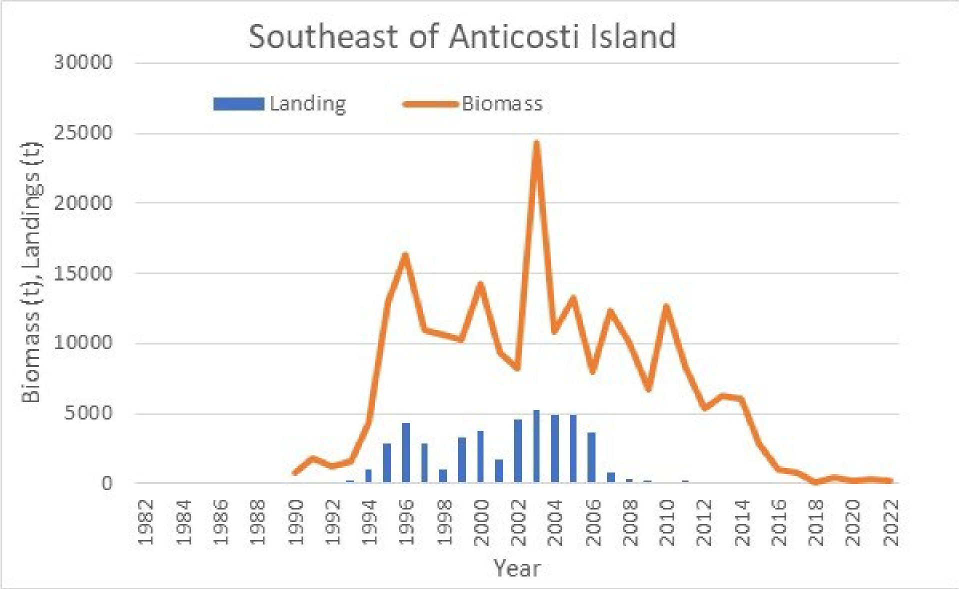

Figure 6. Estimated landings and biomass of northern shrimp in the sector southeast of Anticosti Island which is the sector targeted in the modification of the boundary between the Sept-Iles and Anticosti assessment units.

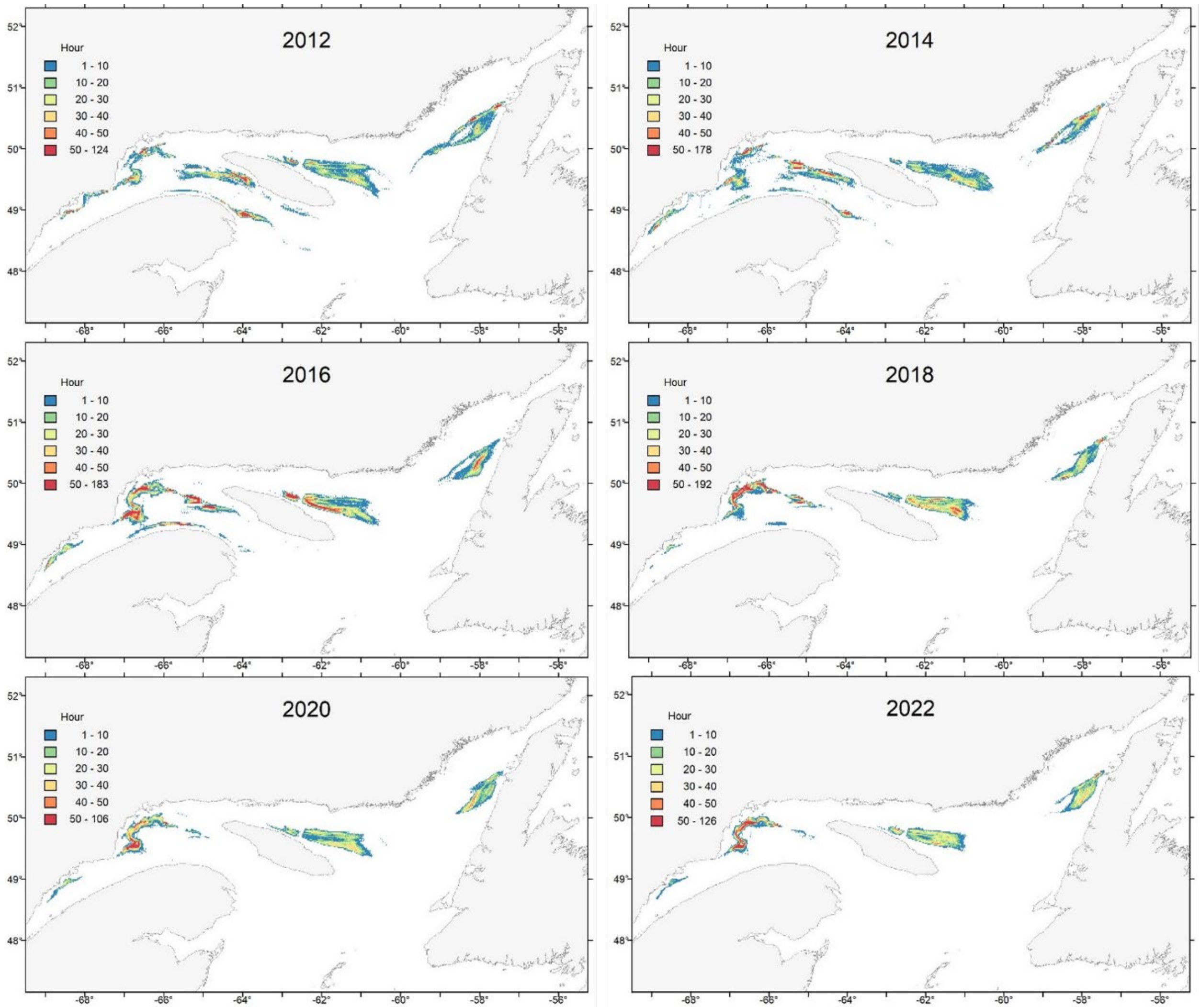

Figure 7. Distribution of fishing effort by shrimpers in the Gulf of St. Lawrence from 2012 to 2022 (only even years are shown) based on Vessel Monitoring System (VMS) data, expressed as the number of hours spent in directed shrimp fishing per 1 minute x 1 minute square.

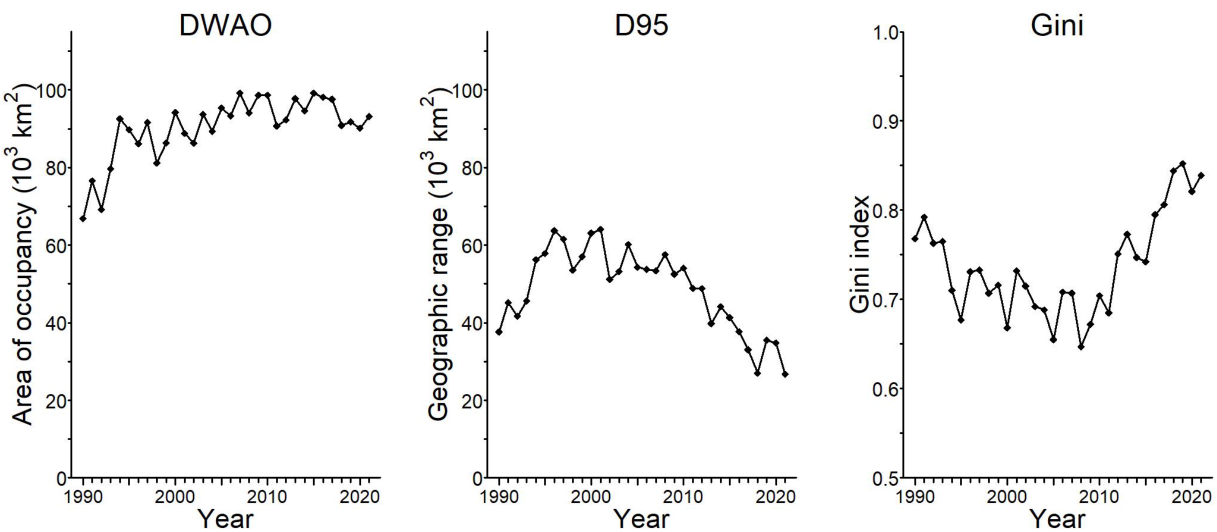

Figure 8. Indices of the spatial distribution of shrimp in the Estuary and Gulf of St. Lawrence: 1) DWAO (design-weighted area of occupancy); 2) D95, or minimum area where 95% of the biomass is distributed; and 3) Gini index. The total study area is 116,115 km^2.

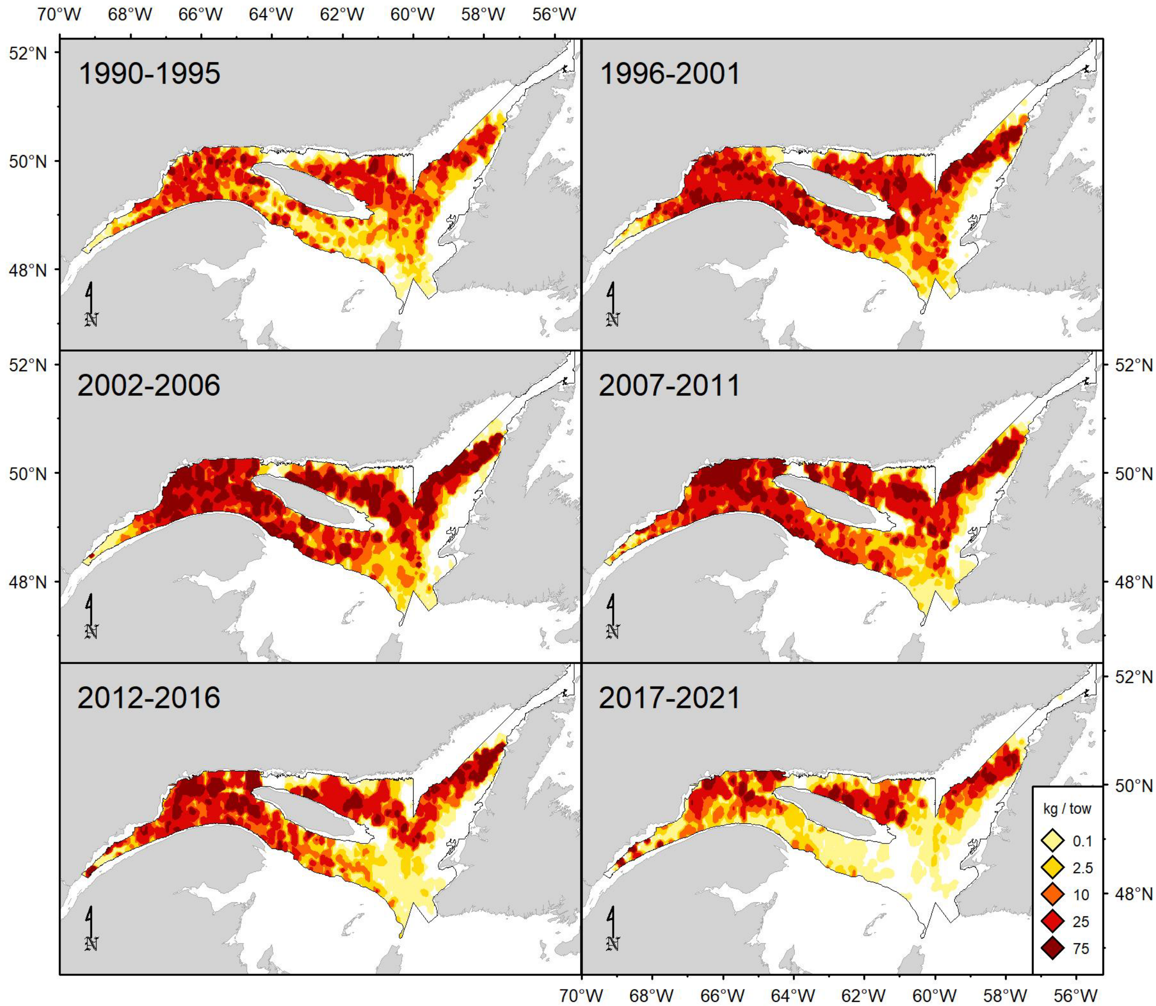

Figure 9. Distribution of northern shrimp catch rates (kg/15 min tow) in the DFO research survey in August.

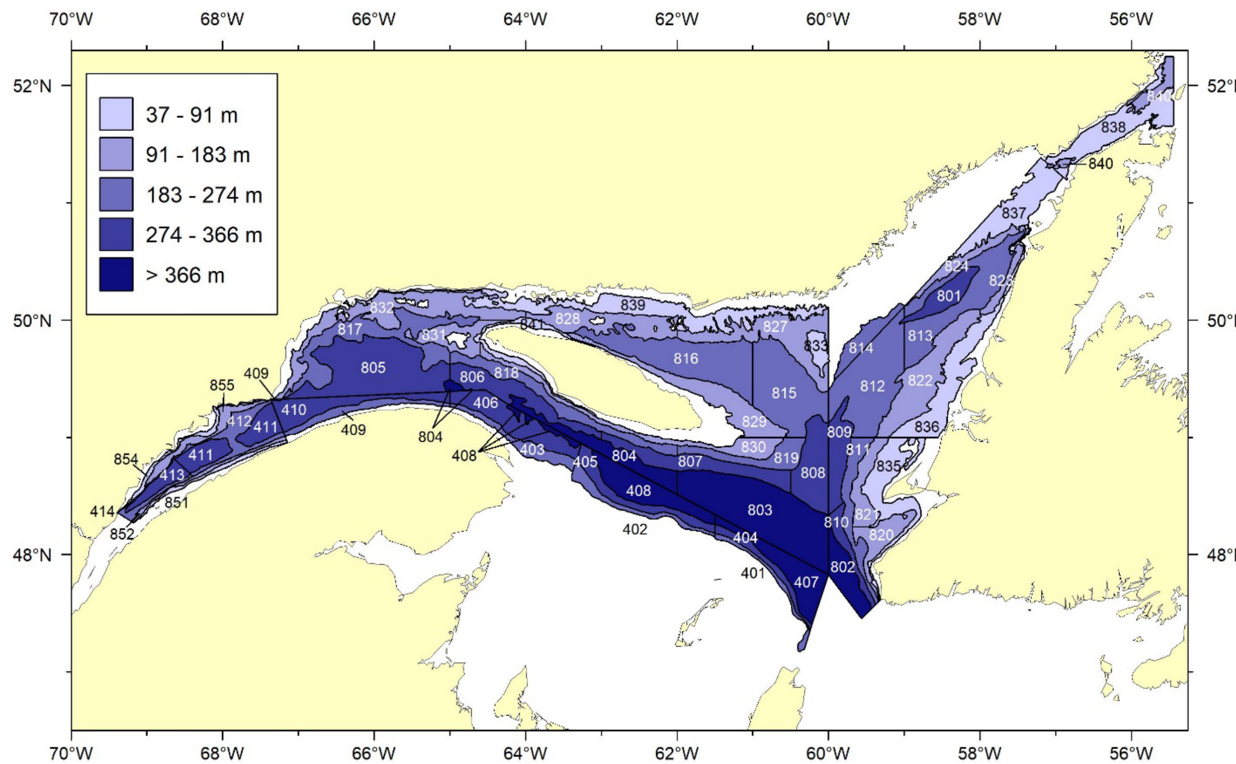

Figure 10. Stratification scheme used in the groundfish and shrimp research survey in the Estuary and northern Gulf of St. Lawrence.

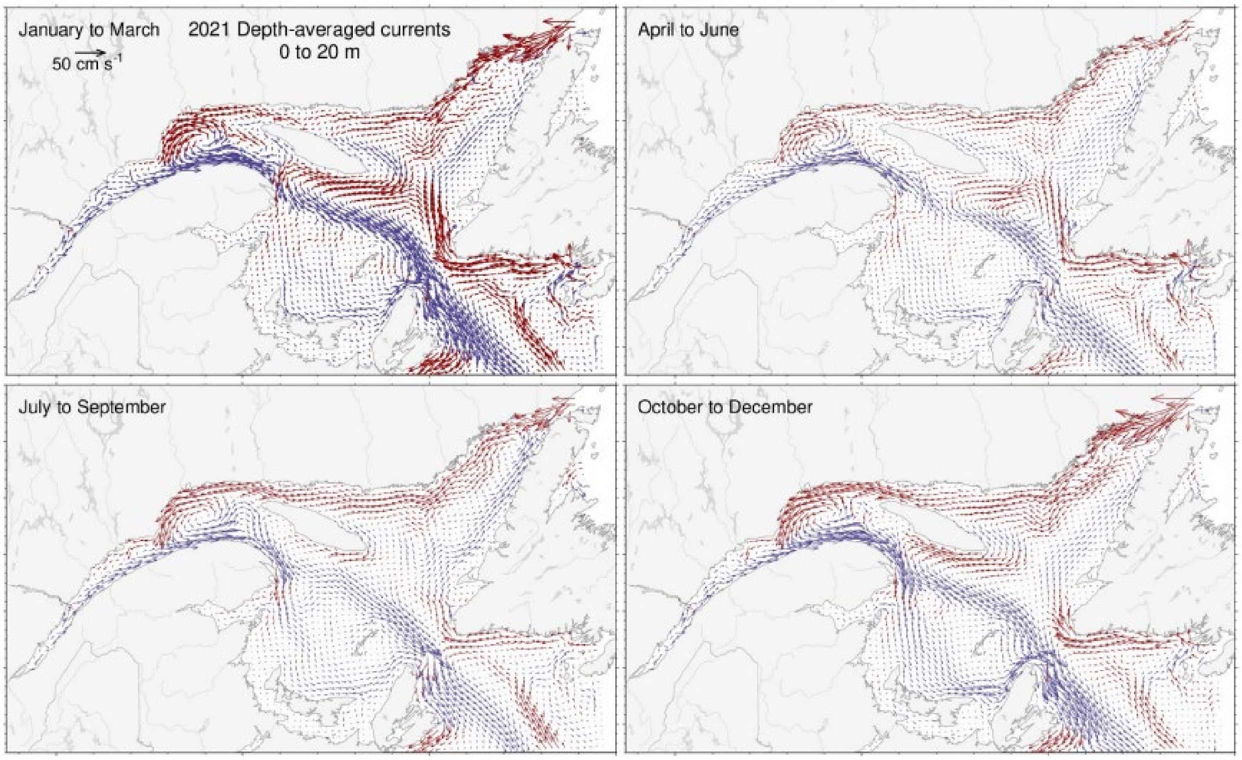

Figure 11. Depth-averaged currents from 0 m to 20 m for each three-month period in 2021. Vectors drawn in blue show eastward movement and those drawn in red, westward movement. Taken from Galbraith et al. 2022.

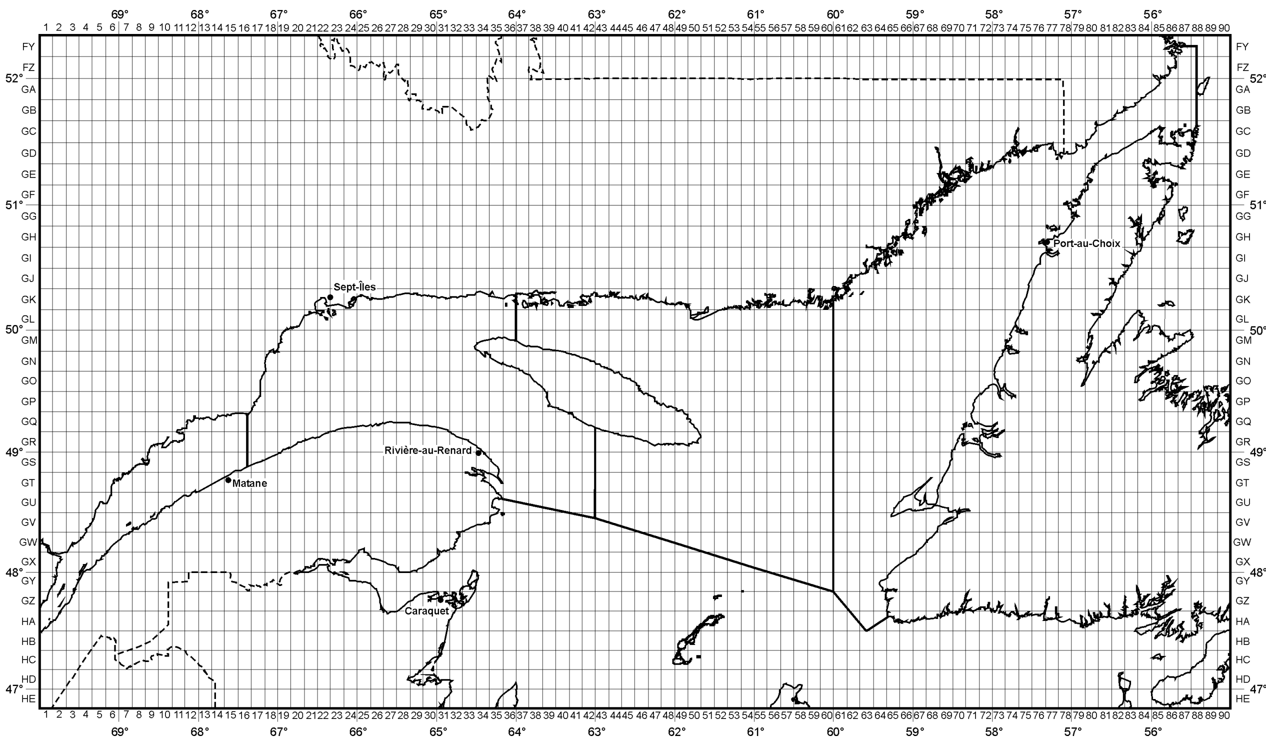

Figure 12. Fishing quadrants (10 minutes longitude x 10 minutes latitude squares) used to map fishing effort spatially in the Canadian Atlantic.

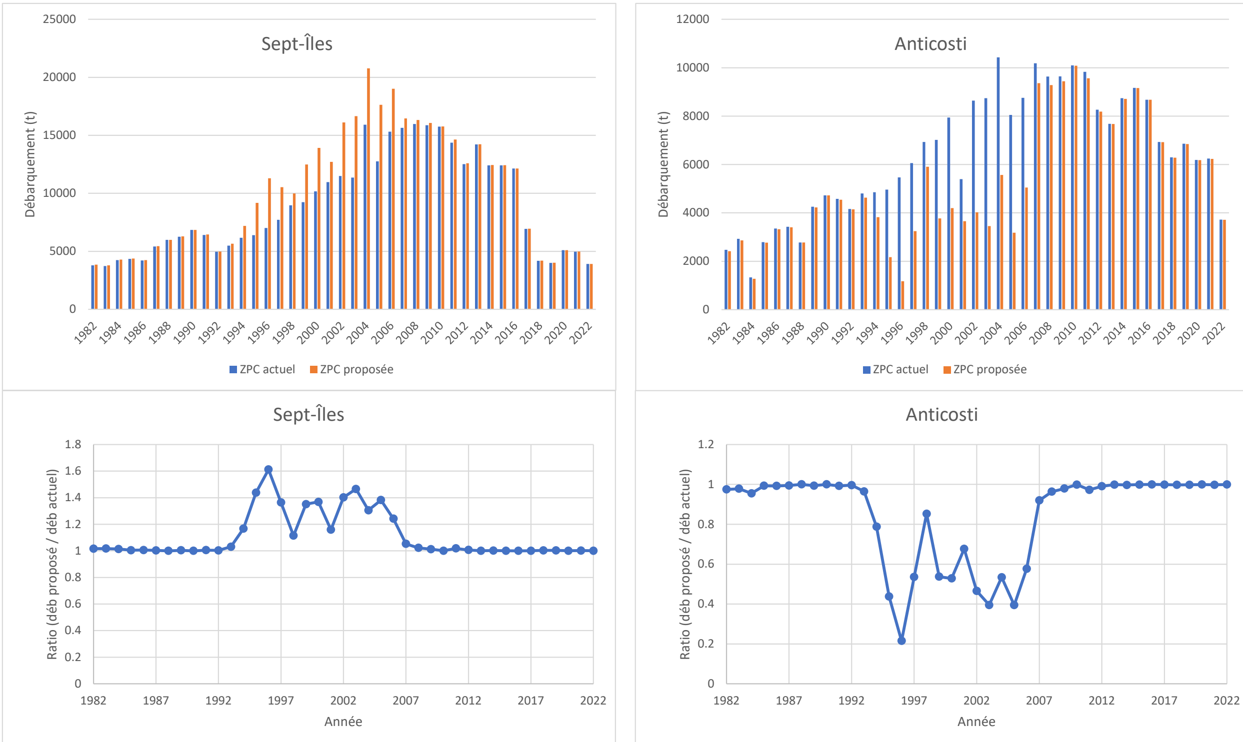

Figure 13. Landings in the Sept-Iles and Anticosti assessment units as defined in the current and proposed delineations (top). The bottom graphs show the ratio between landings in the proposed and current units.

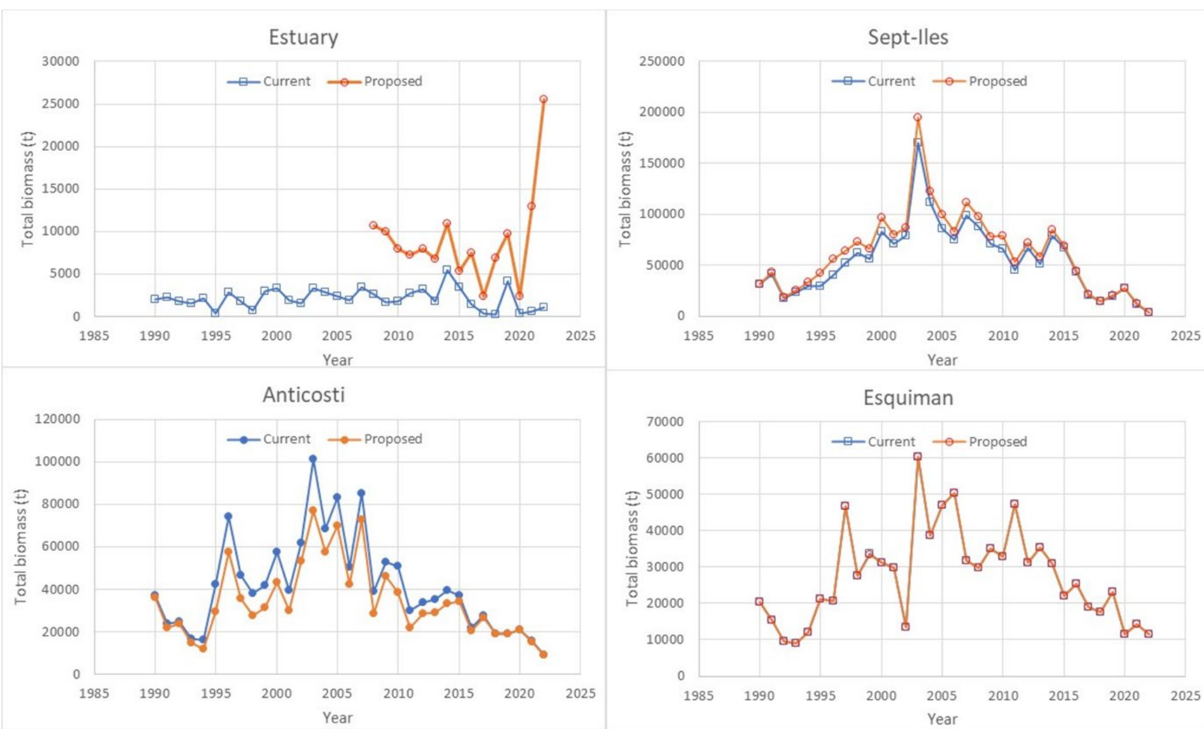

Figure 14. Estimated biomass in the current and proposed assessment units.