Fisheries and Oceans Canada / Pêches et Océans Canada

Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Quebec Region

Canadian Science Advisory Secretariat
Science Advisory Report 2022/006

ASSESSMENT OF NORTHERN SHRIMP STOCKS IN THE ESTUARY AND GULF OF ST. LAWRENCE IN 2021

Image of Northern Shrimp

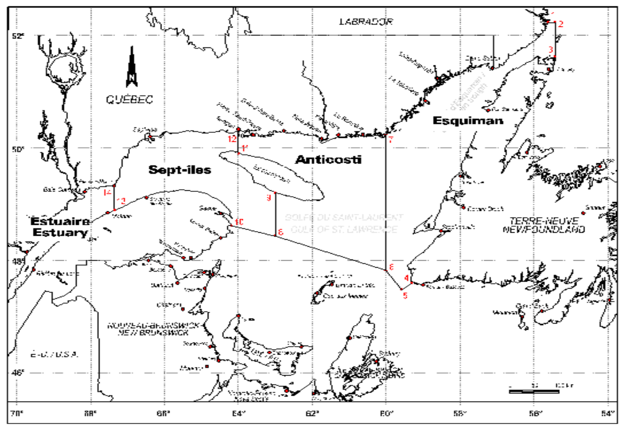

Figure 1. Shrimp fishing areas in the Estuary and Gulf of St. Lawrence.

Context

The northern shrimp (Pandalus borealis) fishery began in the Gulf of St. Lawrence in 1965. The exploitation is conducted by trawlers in four shrimp fishing areas (SFA): Estuary (SFA 12), Sept-Iles (SFA 10), Anticosti (SFA 9) and Esquiman (SFA 8) (Figure 1).

Shrimp fishing is regulated by a number of management measures, including the setting of total allowable catches (TAC) in each area. TAC-based management limits fishing to protect the reproductive potential of the population. The essential elements for the establishment of a precautionary approach were adopted in 2012. Reference points were determined and harvest guidelines were established based on the main indicator and its position in relation to the stock status classification zones (healthy, cautious and critical). These guidelines are consistent with a precautionary approach. Once the harvest is projected, decision rules are applied to determine the TAC.

This Science Advisory Report is from the January 27-28, 2022 meeting on the Assessment of Estuary and Gulf of St. Lawrence Northern Shrimp Stocks. Participants in the science review included representatives from DFO Science, DFO Fisheries Management, the fishing industry, provincial governments, university researchers, and Aboriginal organizations. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available.

SUMMARY

- In 2020 and 2021, preliminary landings for all shrimp fishing areas were respectively 17 845 t and 17 217 t from a TAC of 17 999 t.
- Since 2008, the research survey shows a decrease in the area where northern shrimp concentrate. This minimum area has decreased from over 50 000 km^2 to less than

30 000 km^2. In the commercial fishery, the surface of the area where trawling activities took place has decreased from 15 000 km^2 to 10 000 km^2 since 2012.

- The male and female numbers per unit of effort (NPUE) from the commercial fishery for the last four years are decreasing in Estuary, stable in Esquiman, and increasing in Sept-Iles and Anticosti. They are comparable to or above the average of the historical series.
- The male and female abundances observed in the DFO survey show downward trends since 2005. The estimates for 2020 and 2021 are among the lowest of the historical series.
- In recent years, there has been a discrepancy between the indices from the fishery and those from the DFO survey. Fishermen have succeeded to maintain their NPUEs at average levels while the shrimp abundance indices reached their lowest historical level. This divergence suggests that the main stock status indicator is currently overestimated since it uses these two sources of information with equal weight.
- Exploitation rates in the Sept-Iles, Anticosti and Esquiman areas show an upward trend since 2003 and are above the average of the 1990-2010 reference period. The exploitation rate in the Estuary has been variable since 2016 and below the average (2008-2021) in 2021.
- The low abundance of juveniles and males observed in recent years and the downward trend in the size of females suggest a lower stock productivity.
- Warming of deep waters and increased predation by redfish appear to be important factors contributing to the decline of shrimp. These ecosystemic conditions are not expected to improve in the short to medium term.
- Under the precautionary approach, the main stock status indicator decreased slightly in all four areas in 2021. The indicators are very close to the upper stock reference point. The Estuary, Anticosti and Esquiman stocks are in the healthy zone, while the Sept-Iles stock is in the cautious zone.
- According to the harvest guidelines established as part of to the precautionary approach, the projected harvests for 2022 are 558 t for Estuary, 6 242 t for Sept-Iles, 5 424 t for Anticosti and 5 079 t for Esquiman.
- The sum of evidence (bias in the main stock status indicator, high exploitation rate, increase in predation and in deep waters temperature, and reduction in shrimp distribution area) shows that we are currently operating outside the framework in which the precautionary approach was developed. This situation has the consequence of increasing the risk for the sustainability of the stocks by using the current decision rules.
- The precautionary approach should be revised before the next assessment.

INTRODUCTION

Northern shrimp have several biological and ecological particularities that influence the exploitation strategy, management measures and stock conservation approaches implemented in the fishery. Shrimp play a key role in the ecosystem, acting as an intermediary in the transfer of energy from the lower trophic levels (e.g., zooplankton) to the higher ones (predators such as fish, marine mammals and seabirds). These ecological relationships (e.g., predation and competition) between species that are affected by fishing, both directly and indirectly, support ecosystem resilience to environmental changes and must be maintained within the bounds of natural fluctuations as much as possible.

Species Biology

Northern shrimp change sex over the course of their life. They reach sexual maturity as males at about two and a half years of age, then become females between four and five years of age. The females, which carry their eggs beneath the abdomen, are thus among the largest specimens in commercial catches; the males are smaller because they are younger. Mating takes place in the fall and the females carry their eggs for eight months, from September until April. The larvae are pelagic when they hatch in the spring. They metamorphose and settle to the bottom at the end of the summer. Northern shrimp migrations are associated with breeding (the egg-bearing females migrate to shallower water in winter) and feeding (at night, they leave the ocean floor to feed on small planktonic organisms).

Species Distribution

Northern shrimp are present in the Northwest Atlantic, from Baffin Bay in the north to the Gulf of Maine in the south. The species is generally associated with the deep water mass and is found mainly at depths where the substrate consists of fine, consolidated sediments and where the temperature varies between 1°C and 6°C.

DFO research survey data indicate that northern shrimp are widespread in the Estuary and in the northern Gulf of St. Lawrence (Figure 2). They are distributed over more than 90 000 km^2 at depths between 150 m and 350 m, beneath the cold intermediate layer (CIL), in the bottom layer. The species' area of occupancy has remained relatively stable over the last 30 years. However, since 2008, there has been a decrease in the shrimp concentration area, the minimum area where over 95% of the biomass is distributed. This area has decreased from more than 50 000 km^2 to less than 30 000 km^2 (Figure 3). Northern shrimp are now mainly concentrated at the heads of channels (Figure 2).

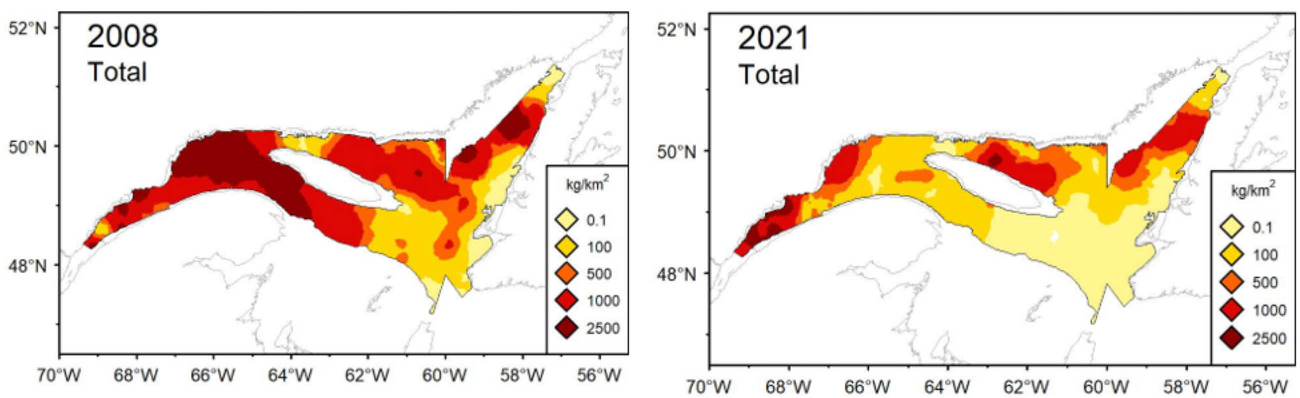

Figure 2. Northern shrimp catch rates (kg/km^2) distribution in the DFO survey in 2008 and 2021.

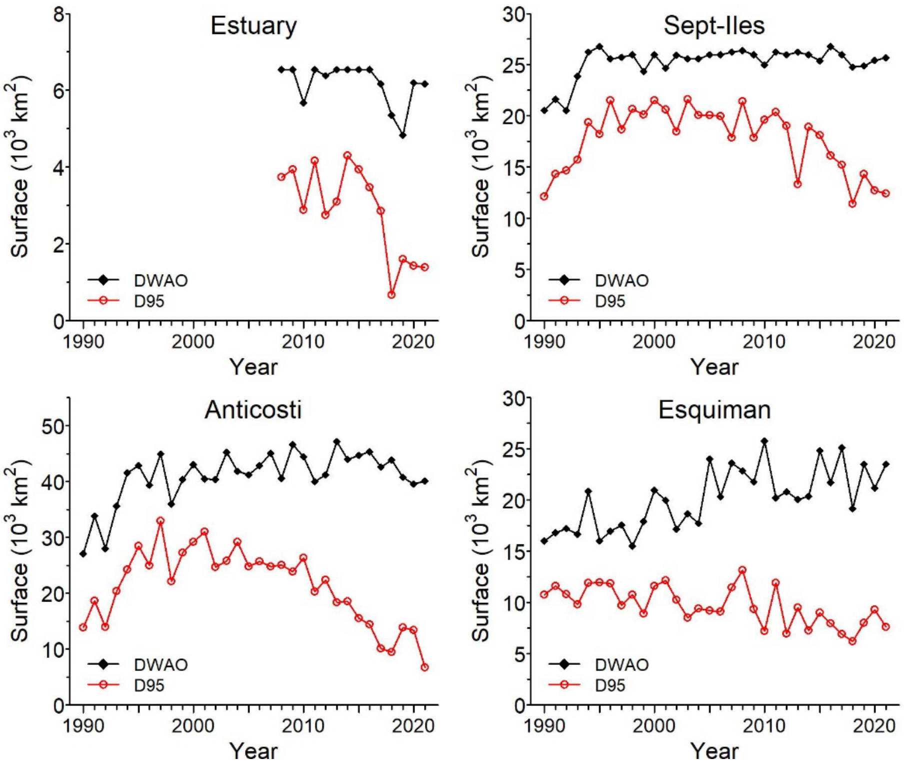

Figure 3. Spatial distribution indices for northern shrimp biomass observed during the August DFO survey, by fishing area. DWAO = design-weighted area of occupancy. D_{95} = minimum area where 95% of the biomass is distributed. The indices for the Estuary begin in 2008 due to the addition of new strata.

Environmental and Ecosystem Conditions

Temperature is a dominant environmental factor that influences the biology of ectothermic or cold-blooded organisms, including northern shrimp. These organisms have an optimal temperature window in which their productivity (growth, reproduction and survival) is optimized. Moderate deviations from the optimal temperature can affect productivity and reduce resistance to environmental stressors such as hypoxia and acidification.

The northern shrimp is a cold-water species that prefers temperatures between 1°C and 6°C. The Gulf of St. Lawrence is near the southern limit of the species' distribution, and water temperatures there are close to the upper threshold of its thermal preference range. Larvae that emerge in the surface layer are exposed to a much wider range of temperatures, from 0°C to more than 10°C. Northern shrimp are therefore vulnerable to warming of both the surface layer and the deeper waters.

Temperatures in the deep waters of the Gulf have been rising for over a decade. These waters result from the mixing of cold Labrador current water and warm Gulf Stream water. There is currently a higher proportion of warm, oxygen-poor Gulf Stream water in the deep water mass. Waters entering through the Cabot Strait at depth move upstream undergoing little mixing with shallower, colder waters. The area of seabed covered by waters warmer than 6°C has increased across the Estuary and the northern Gulf of St. Lawrence. Part of the bottom area along the Anticosti and Esquiman channels has even been covered by waters warmer than 7°C since 2020 (Figure 4). Before 2009, bottom temperatures in these channels ranged from 5°C to 6°C. The CIL, which is located higher in the water column, was much warmer in August 2021 than in August 2020, reaching the warmest values in the modern oceanographic record.

At depths of 200 m and 250 m, the Anticosti and Esquiman shrimp stocks are found in warmer waters than the Sept-Iles and Estuary stocks. However, at a depth of 150 m, the inverse is generally observed, waters are colder in Anticosti and Esquiman because the CIL is colder there than it is in Sept-Iles and the Estuary.

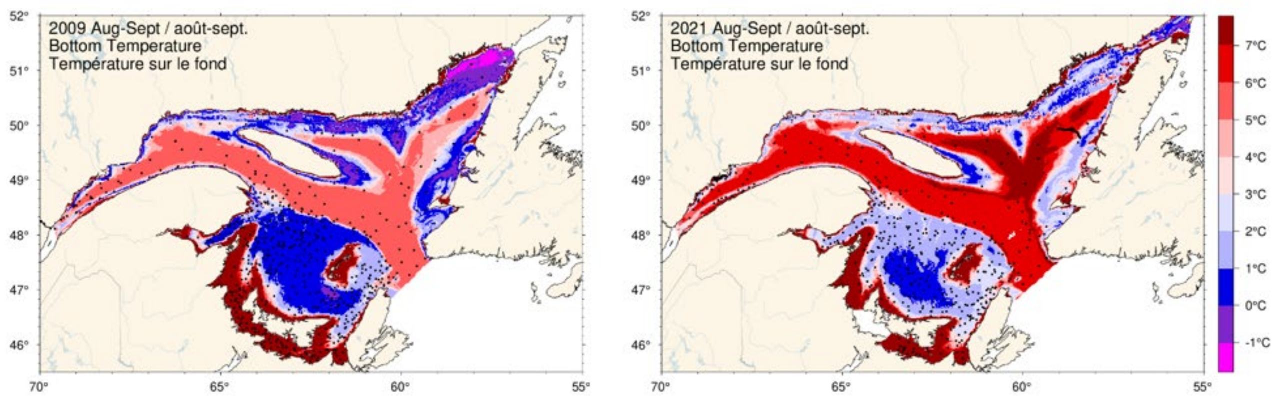

Figure 4. Maps of bottom temperature observed in August-September in 2009 and 2021.

In recent years, deep water warming and dissolved oxygen depletion have had effects on shrimp distribution. Temperature and dissolved oxygen conditions on the seabed have changed over the last 15 years, with the magnitude of this trend varying from one area to another (Figure 5). During the 2018–2021 period, the range of depths occupied by shrimp decreased in the Estuary, Sept-Iles and Anticosti. These changes suggest a movement of shrimp from warmer, oxygen-poor bottoms to colder, oxygenated water layers, but always in association with the bottom to avoid unfavorable environmental conditions. As example, in the Estuary, from 2008 to 2017, warming (from 2.5°C to 4.2°C) and a decrease in dissolved oxygen (from 50% to 37%) occurred in the waters in which female shrimp used to be found, specifically at depths of between 110 m and 320 m. Beginning in 2018, a significant shift of shrimp to new depths was observed. They are now found closer to the CIL at depths of between 70 m and 170 m, in colder (1.4°C to 4.0°C), more oxygenated (40% to 80%) waters. The changes in depth have been less dramatic in Sept-Iles and Anticosti, where shrimp that used to be found at greater depths are also moving to shallower depths. The median depth of distribution has decreased by roughly 15 m to 20 m as the environmental conditions in which the shrimp find themselves continue to warm and deplete in oxygen in both area. Over a period of 15 years, the median temperature has increased by about 1.0°C, to over 6.0°C, and the dissolved oxygen saturation level has decreased from 30% to 23% in Sept-Iles and from 43% to 25% in Anticosti. Warming and declining oxygen levels have also been observed in Esquiman. Since 2008, the water temperature has risen from 5.1°C to 6.7°C in the areas used by females, and the dissolved oxygen saturation level has decreased from 38% to 27%. Despite these changes, no migration of concentrations of shrimp to shallower depths has been observed in this area, and the depth occupied by shrimp has not changed.

Although the northern shrimp is particularly well adapted to withstand hypoxia, female shrimp are less tolerant than male shrimp and both sexes become more sensitive to hypoxia as the temperature rises. For example, at 5°C and 8°C, the lethal threshold is 9% and 14% respectively for males and 15% and 22% respectively for females. In addition to tolerating severe hypoxia, in persistent hypoxic conditions, shrimp can adapt to oxygen levels close to lethal thresholds. Part of the Sept-Iles, Anticosti and Esquiman populations therefore live in

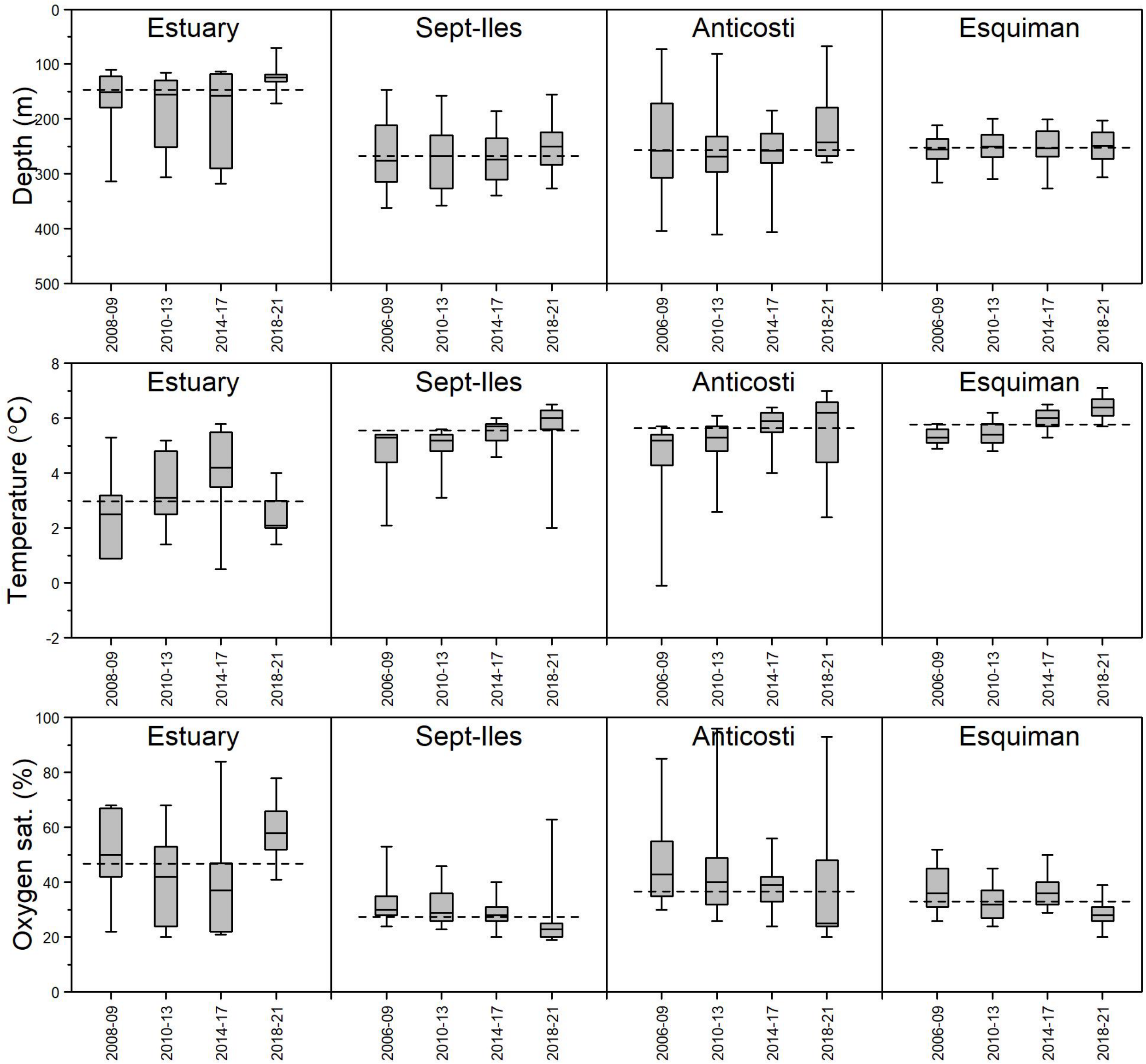

Figure 5. Female shrimp biomass distributions based on depth, temperature and dissolved oxygen concentration in bottom water per four-year period observed during the August DFO survey in the northern Gulf from 2006 to 2021 (2008 to 2021 in the Estuary).

The reproductive cycle of shrimp is influenced by environmental conditions. Bottom water temperatures influence the development duration of the eggs the females carry under their abdomen. Furthermore, the hatching of the eggs in spring must be synchronized with the timing of the spring phytoplankton bloom to ensure better larval survival. The reproductive cycle of shrimp in the Sept-Iles fishing area was studied from samples taken in the fishery (Figure 6). Changes in shrimp phenology seem to be linked to the increase in deep-water temperatures. Maturation and hatching are delayed for several days and the larvae development duration is shorter. Larval release therefore varies little and remains synchronized with the spring phytoplankton bloom.

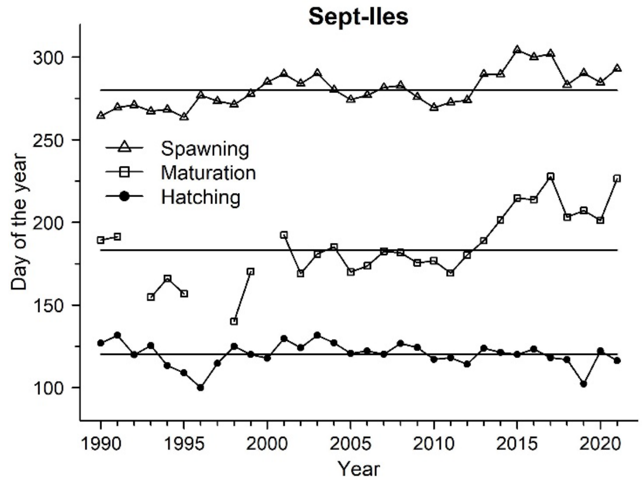

Figure 6. Day of the year where 50% of female shrimp were maturing (maturation), where 50% had spawn there eggs (spawning) and where 50% of females had released larvae (hatching) from samples collected in the area of Sept-Iles from 1990 to 2021. Solid horizontal lines represent the averages for the 1990-2021 series.

The ecosystem, dominated by groundfish until the early 1990s, has transitioned to an ecosystem dominated by forage species. Thus, following the decline in the abundance of large groundfish species, the shrimp population increased from the 1990s to the 2010s. Redfish and Atlantic halibut are currently increasing in abundance whereas northern shrimp and Greenland halibut are declining. Three strong cohorts (2011, 2012 and 2013) of deepwater redfish (*Sebastes mentella*) have contributed to the increase in redfish abundance since 2013. The redfish population now has a higher biomass than in the early 1990s. The 2011 cohort, which is the most abundant, now has a modal length of 24 cm and is distributed throughout the deep channels of the northern Gulf and to a lesser extent in the Estuary (Figure 7).

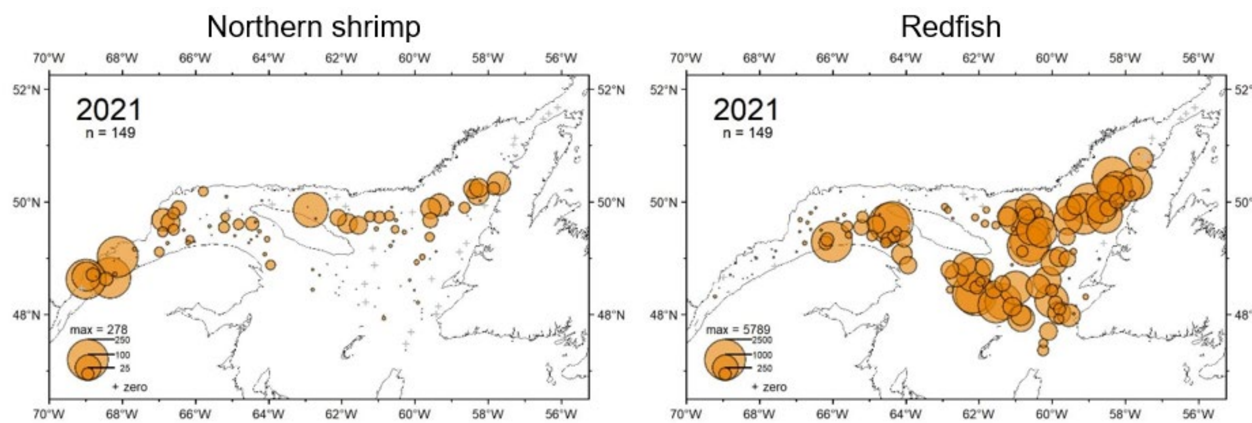

Figure 7. Distribution of northern shrimp and redfish catch rates (kg/15-minute tow) in the August 2021 DFO survey in the northern Gulf of St. Lawrence.

The redfish diet varies according to the size of the fish. Small redfish mainly consume zooplankton. As they grow, they consume progressively more shrimp and fish. The northern shrimp is a significant prey species for redfish over 25 cm in length. Estimated predation by redfish on northern shrimp has increased substantially in the past five years, and the situation is not expected to improve in the near future. However, the impact of this phenomenon may be lessened if the spatial overlap between the two species diminishes due to the expected migration of redfish as adults to depths of over 300 m.

Description of the fishery

The fishery has been managed by TACs since 1982, and individual quotas have been allocated to harvesters since the mid-1990s. In 2021, the number of active licenses for northern shrimp fishing in the Estuary and Gulf of St. Lawrence was 114. The operators are from five provinces and seven First Nations communities. The fishery management measures include the imposition of a minimum mesh size (40 mm) and, since 1993, the compulsory use of the Nordmøre grate, which significantly reduces groundfish bycatch. A protocol to limit the bycatch of small fish is in place. Shrimpers must also keep a logbook, have their catches weighed at dockside and agree to have an observer on board at DFO's request (5% coverage). Use of the Vessel Monitoring System (VMS) has been mandatory since 2012. The season begins on April 1 and ends on December 31.

Northern shrimp landings in the Estuary and Gulf of St. Lawrence have gradually increased since the fishery began, rising from about 1 000 t at the start of exploitation in the 1970s to more than 35 000 t at the end of the 2000s (Figure 8). Landings then began to decrease, falling to 17 217 t in 2021. In 2020, the TAC was increased by 154% in the Estuary and by 20% in Sept-Iles, was decreased by 8% in Anticosti and was kept the same in Esquiman. These TACs were set for two management years, 2020 and 2021. The TACs are considered to have been reached in the four management areas during these two years. The preliminary statistics for 2021 indicate landings of 607 t in the Estuary, 4 907 t in Sept-Iles, 6 205 t in Anticosti and 5 498 t in Esquiman (Figure 9).

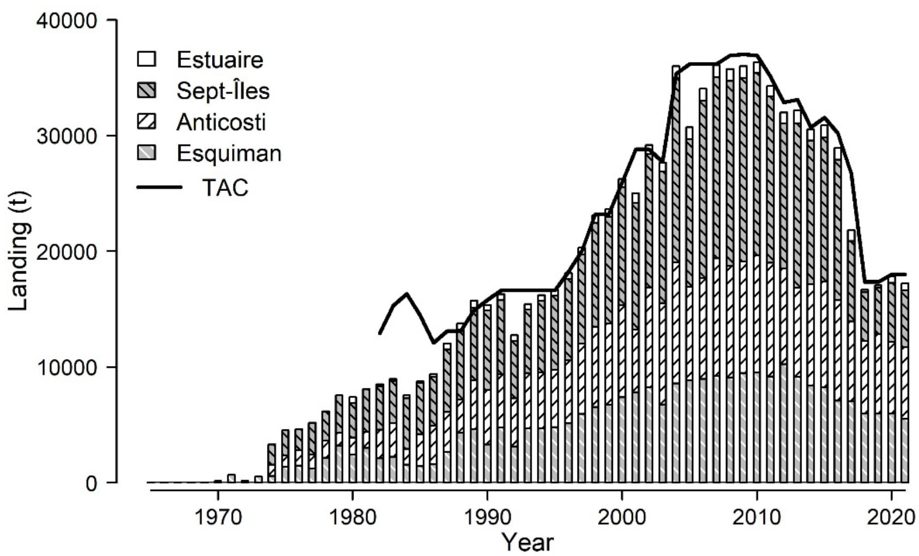

Figure 8. Landing and total allowable catches (TAC) by fishing area and by year. The 2021 data are preliminary.

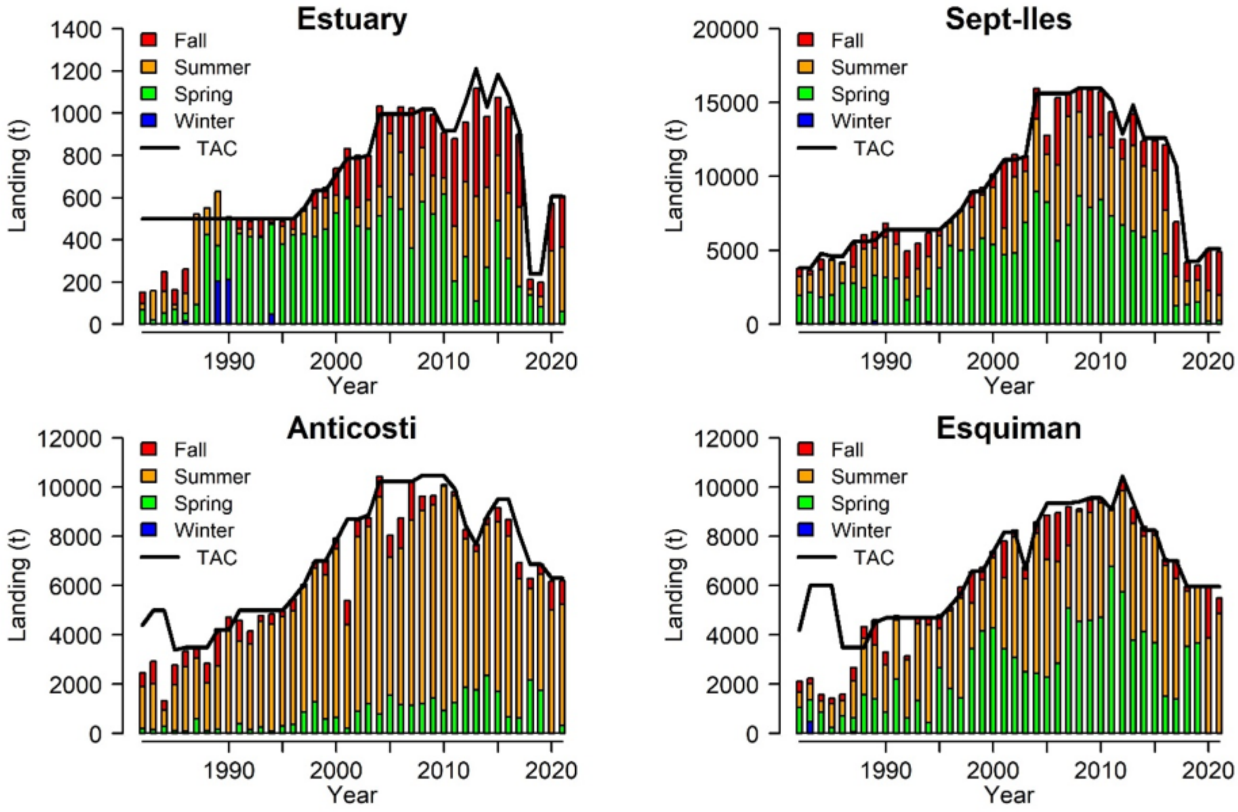

Figure 9. Seasonal landing and total allowable catches (TAC) by fishing area and by year. The 2021 data are preliminary.

ASSESSMENT

Programs were implemented in the 1980s and 1990s to monitor the fishery and the status of northern shrimp populations in the Estuary and Gulf of St. Lawrence on an annual basis. Commercial fishery statistics (shrimpers' catches and effort) are used to estimate the fishing effort and calculate catch rates. Commercial catch samples are used to estimate the number of shrimp harvested by size class and by sexual maturity stage. Every August, a research survey is conducted from a DFO vessel in the Estuary and Gulf of St. Lawrence. Biomass indices are calculated using a geostatistical method. The survey provides abundance estimates of shrimp by size class and by stage of sexual maturity.

The sectors that sustain the fishery in the four fishing areas correspond to the locations where high concentrations of shrimp are generally observed during the research survey. In recent years, some fishing areas have been abandoned because of the low abundance of shrimp. These include the area east of the Manicouagan Peninsula in the Estuary, the northeastern tip of the Gaspé Peninsula, the area south of Anticosti Island, and the southwestern part of the Esquiman Channel (Figure 10).

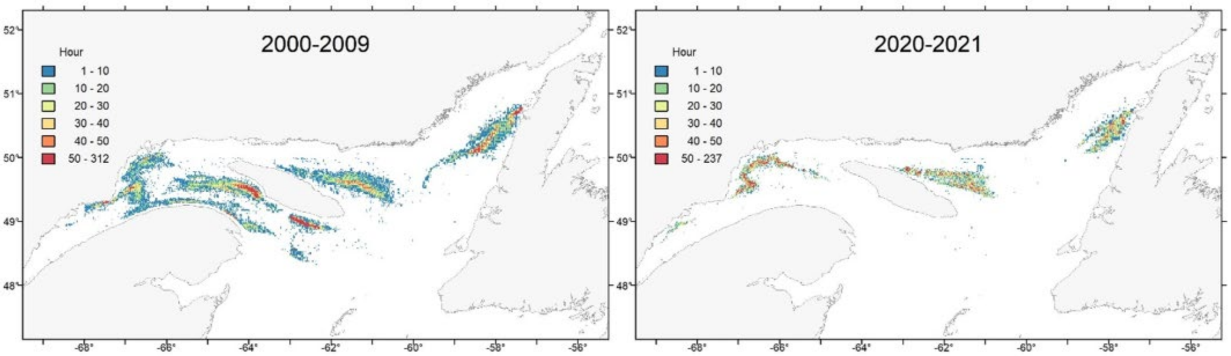

Figure 10. Average distribution of annual shrimper fishing effort in the Gulf of St. Lawrence for the periods 2000–2009 and 2020–2021 (number of hours per 1-minute square) from logbook data.

Total annual shrimp fishing effort has declined from more than 100 000 hours of fishing to less than 80 000 hours of fishing since 2018 (Figure 11). Effort over the past two years (69 400 and 75 400 hours) has been below the historical average of 108 900 hours and represents the lowest annual fishing effort observed since 1982. While the decrease in fishing effort is noticeable in all four fishing areas, the magnitude of the decline is greater in the Estuary and Sept-Iles areas. The use of the VMS since 2012 has made it possible to describe the locations fished. The area of the trawled zone decreased from 15 000 km^2 to 10 000 km^2 during this period. This points to a potential decline in the impact of the fishery on habitat.

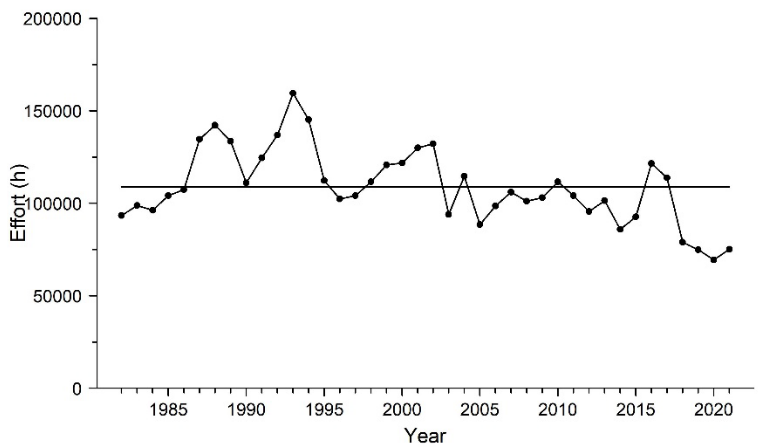

Figure 11. Total number of fishing hours per year for all management areas in the Estuary and the Gulf of St. Lawrence. The horizontal line represents the mean of the series.

The annual catch per unit effort (CPUE) is standardized to take into account changes in fishing capacity and seasonal fishing patterns. CPUE values have varied widely over time and have followed similar trends since 1982 in all four areas. CPUEs were low from 1983 to 1995; they began increasing in 1995 and reached a peak around 2005. Catch per unit effort then remained high for a few more years (Figure 12). From 2014–2015 to 2017–2018, CPUEs declined sharply in Sept-Iles, Anticosti and Esquiman but then stabilized. CPUEs in the Estuary dropped sharply between 2006 and 2010, but remained fairly stable between 2011 and 2018. In 2020 and 2021, CPUEs increased in the Estuary, Sept-Iles and Anticosti relative to 2018 and 2019. The Esquiman CPUE has been more variable since 2018. CPUEs in the four areas are comparable to those observed in the early 2000s but are higher than those observed in the early 1990s.

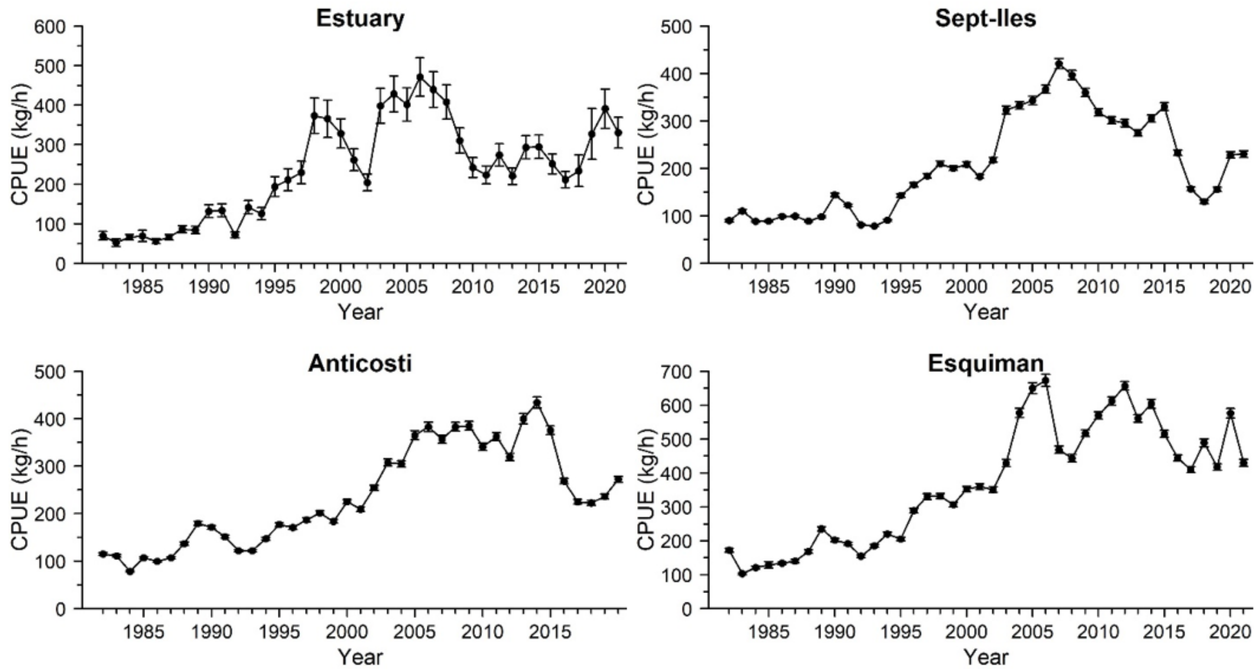

Figure 12. Standardized CPUE in the fishery (95% confidence interval).

Indices of total biomass (Figure 13) and male and female biomass for Sept-Iles, Anticosti and Esquiman showed upward trends from 1990 to 2003, but have shown downward trends since. The biomass values observed since 2017 are comparable to the low values of the early 1990s. The total biomass values estimated in 2021 in Sept-Iles and Anticosti are the lowest observed since 1990. Large interannual variations have been observed in the biomass estimates for the Estuary: the values in 2020 and 2021 were among the lowest in the time series, while the 2019 value was among the highest. The biomass index for the Estuary area, which was enlarged in 2008 with strata from the shallower portion, was high in 2021 compared to the low value estimated in 2020.

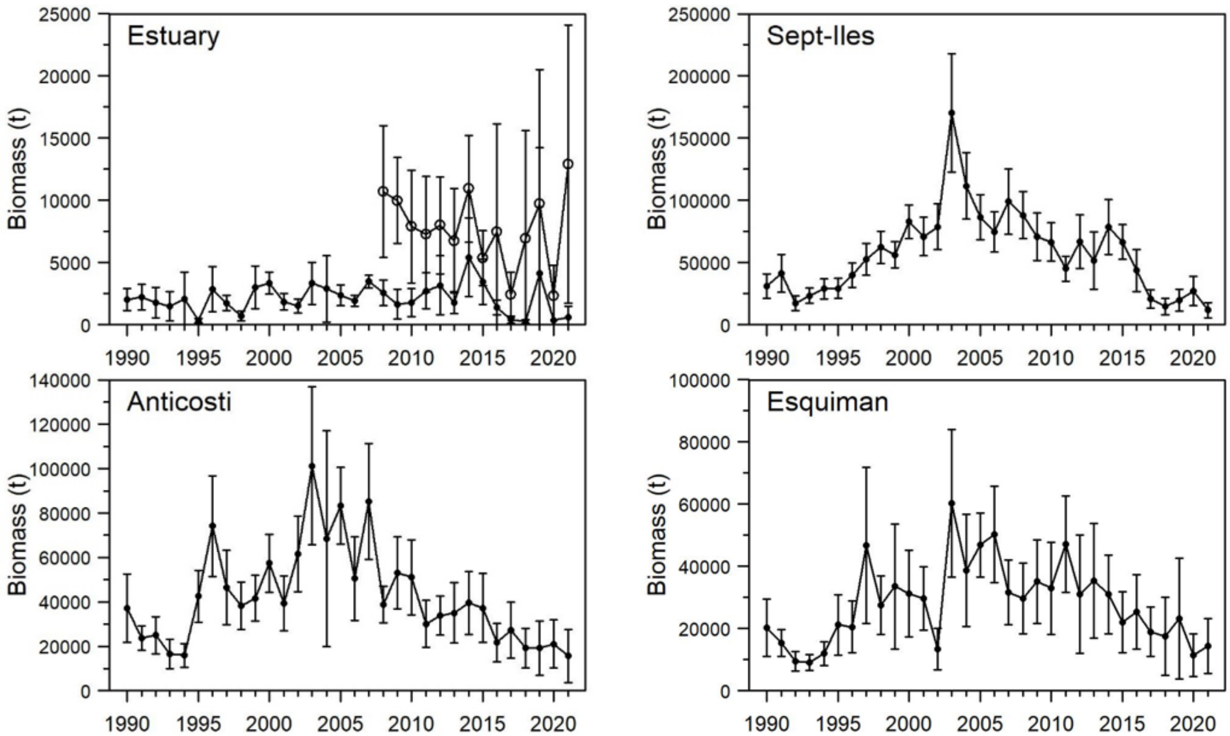

Figure 13. Biomass index from the research survey (95% confidence interval). For the Estuary, the open circles represent results obtained by including the shallow strata added in 2008.

The population structure data obtained from the 2021 DFO survey show that the abundance of small males is very low in all four areas, while the abundance of larger males is above the series average in the Estuary and below the series average in the other three areas (Figure 14). The abundance of females is very low in Sept-Iles, Anticosti and Esquiman. However, in the Estuary, female abundance is higher than the series average despite having been lower than the average in 2020.

A recruitment index is obtained by estimating the abundance of juveniles with cephalothorax length shorter than 12.5 mm. Individuals of this size are around 15 months old. In 2021, the abundance of juveniles was very low in all four areas. In 2020, the recruitment index was also very low in all the areas except for Anticosti, where it was average (Figure 15).

Shrimp size varies along an east-west gradient, with the smallest shrimp observed in the Esquiman Channel and the largest shrimp in the Estuary. In all four areas, the average size of male and female shrimp showed a declining trend over the 1990–2021 time series. In 2021, the average size of males and females in the Estuary and Anticosti areas, and the average size of males in the Esquiman area, was larger than that recorded in 2020 (Figure 16).

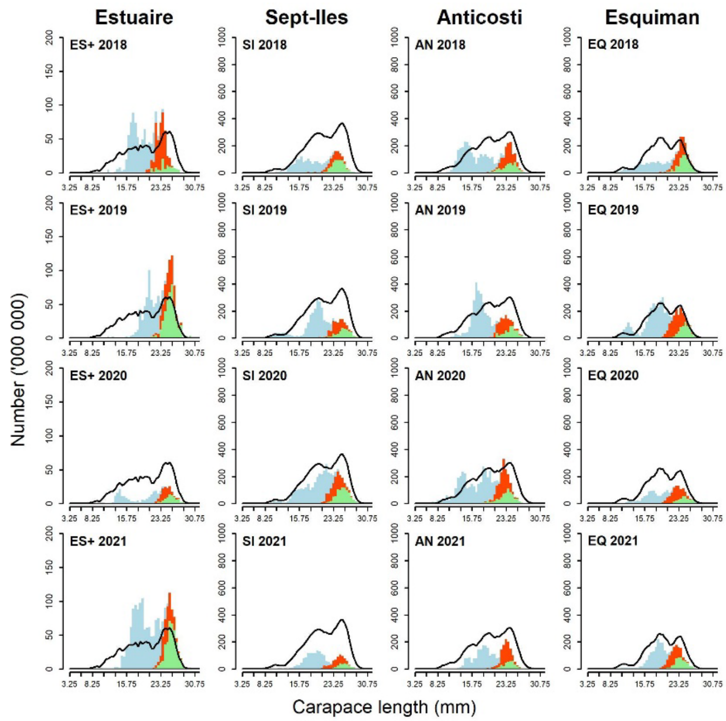

Figure 14. Shrimp abundance (in number) by sex, fishing area and size from the 2018–2021 research surveys. The histograms represent males (in blue), primiparous females (in red) and multiparous females (in green) and the solid line represents the mean for the years 1990–2019 (2008–2019 for the Estuary). The + attached to the Estuary area indicates that the results obtained include the new strata from the shallow portion (37–183 m).

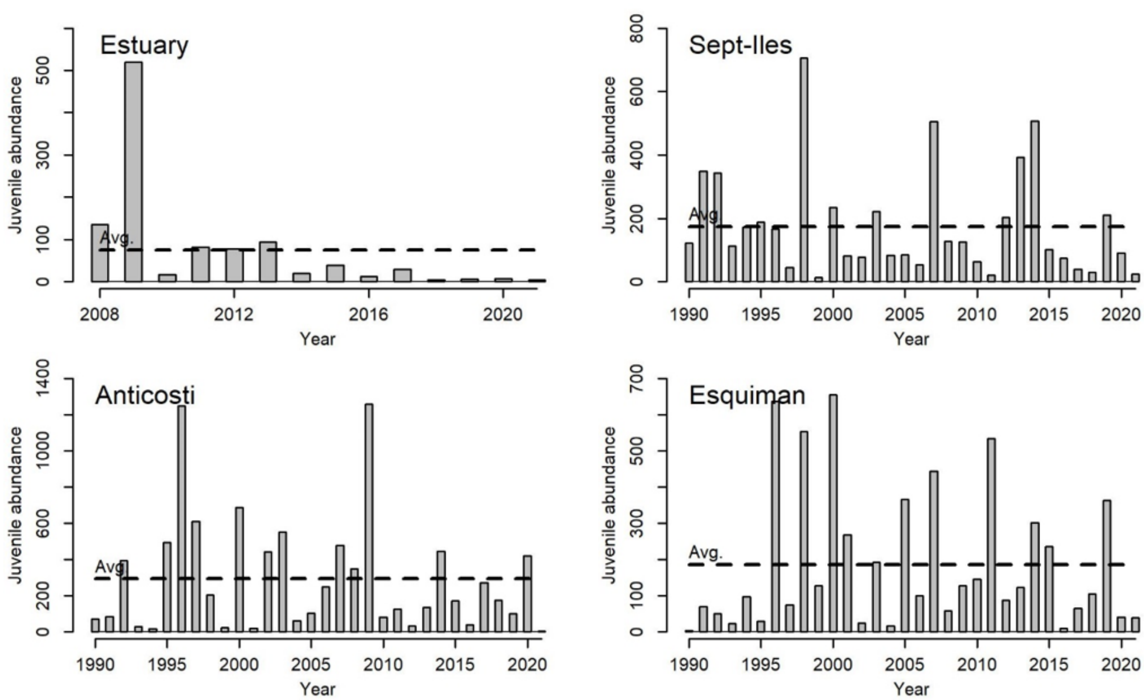

Figure 15. Abundance of juveniles (in millions) by fishing area and by year. The Estuary estimates take into account the strata from the shallow portion (37–183 m).

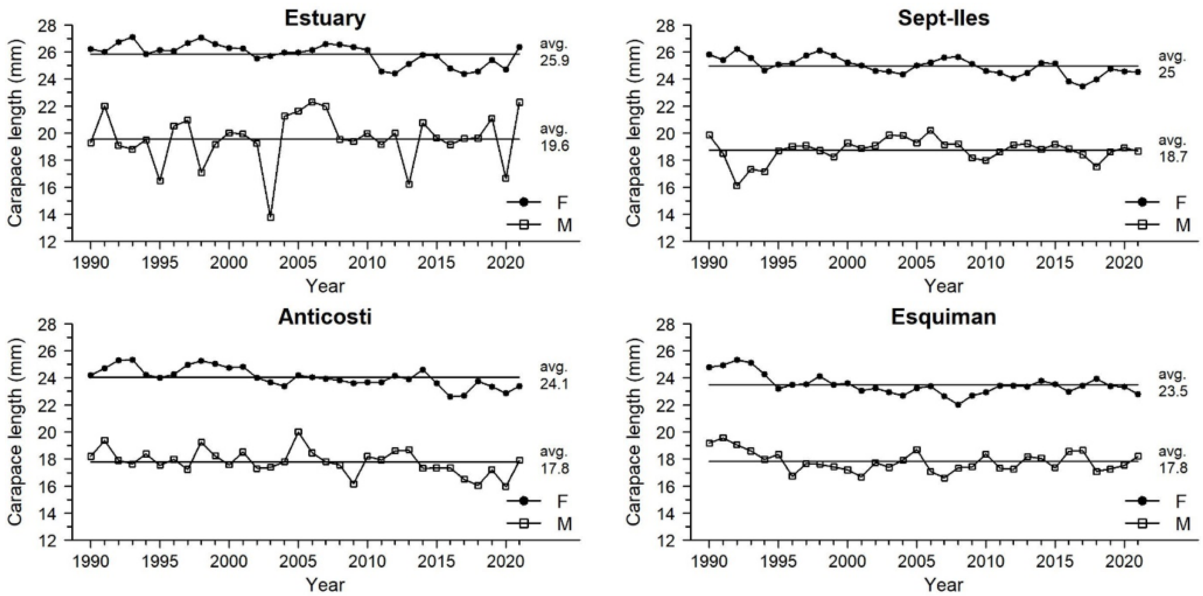

Figure 16. Mean carapace length of male and female shrimp by fishing area in the research survey.

An exploitation rate index is obtained by dividing the commercial catches in number by the abundance value estimated from the research survey. This method does not allow the absolute exploitation rate to be estimated or the index to be related to the target exploitation rates. However, the method does make it possible to track relative changes over the years. The exploitation rate in the Estuary has been variable since 2016 and was lower than the average (for 2008–2021) in 2021 (Figure 17). The exploitation rates in the Sept-Iles, Anticosti and Esquiman areas have shown an increasing trend since 2003. In 2021, these rates increased in Sept-Iles and Anticosti and decreased in Esquiman. The exploitation rates for these three areas are higher than the exploitation rate for the reference period (1990–2010) and are among the highest values in their respective series.

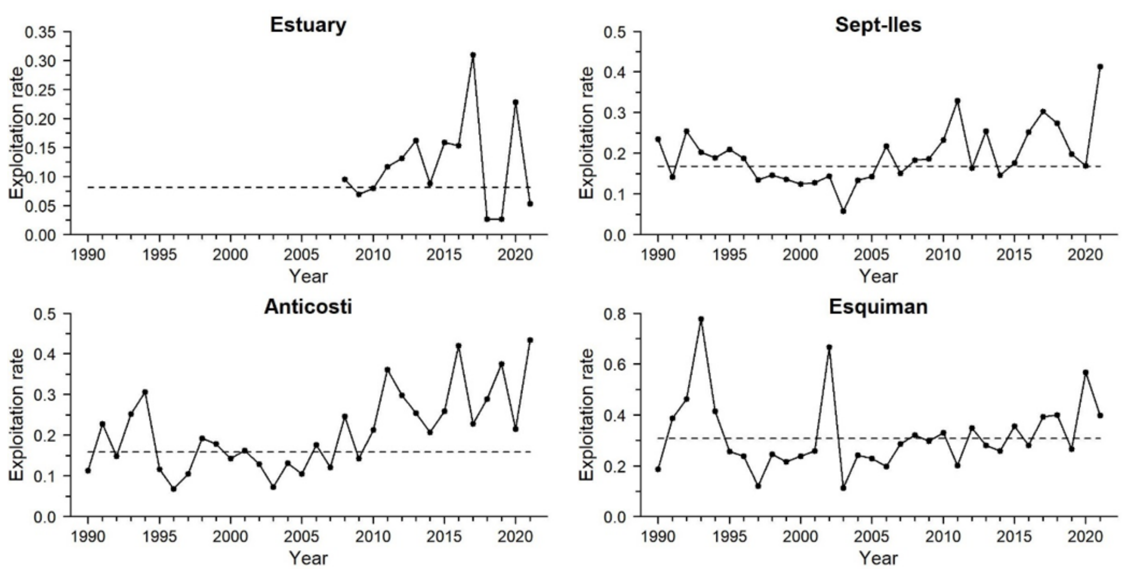

Figure 17. Exploitation rate index by fishing area and by year. The horizontal line represents the 1990–2010 mean. For the Estuary, the index includes the shallow strata added in 2008.

Main Stock Status Indicator

The quantity of (primiparous) females recruited in a given year depends on the number of males that changed sex in the preceding winter. The abundance of reproductive females that will release larvae in the spring can be predicted from the spawning stock estimated in the summer, which is made up of primiparous females that have just changed sex and of multiparous females that survived larval release.

The main stock status indicator is calculated from the male and female abundance indices derived from the summer fishery (number per unit effort [NPUE] for June, July and August) and the research survey (abundance in August). In order to be combined, each index is first standardized in relation to a reference period. The main stock status indicator represents the mean of the four indices from each area. For the Estuary, the survey indices are based on the original sampling area established in 1990 (shallow strata excluded).

The standardized male and female abundance indices from the fishery and from research surveys generally indicate similar trends for the Sept-Iles, Anticosti and Esquiman stocks from the 1980s to 2005 (Figure 18). The indices were low in the 1980s and the early 1990s. They showed an upward trend from the mid-1990s until 2003. In subsequent years, the fishery indices remained stable and high, while the survey indices began to decline. The fishery indices began declining in 2015.

For the past four years, the NPUEs for males and females in the commercial fishery have been declining in the Estuary, have remained stable in Esquiman and have been increasing in Sept-Iles and Anticosti. They are comparable to or higher than the historical series average. The abundance of males and females recorded in DFO surveys has shown a downward trend since 2005. The 2020 and 2021 estimates are among the lowest in the historical series.

In recent years, there has been a discrepancy between the fishery indices and the DFO survey indices. The commercial fishery has maintained its NPUE at average levels, while shrimp abundance indices have reached historic lows. This discrepancy suggests that the main stock status indicator is currently overestimated because these two sources of information are given equal weight.

In 2021, the main stock status indicator declined slightly in all four areas (Figure 19). The indicators for the four areas are very close to the upper reference point. The Estuary, Anticosti and Esquiman stocks are in the healthy zone, while the Sept-Iles stock is still in the cautious zone. Although the Sept-Iles stock indicator has shown some improvement compared to 2018, this is the fifth consecutive year that it has been in the cautious zone.

Harvest guidelines were established according to the main indicator and its position relative to the stock status classification zones (healthy, cautious and critical) in accordance with the precautionary approach. Based on the guidelines, the projected harvest levels for 2022 are 558 t for the Estuary, 6,242 t for Sept-Iles, 5,424 t for Anticosti and 5,079 t for Esquiman (Figure 20). Fisheries Management will set the 2022 TACs based on these projected harvests by applying the decision rules of the precautionary approach currently in effect.

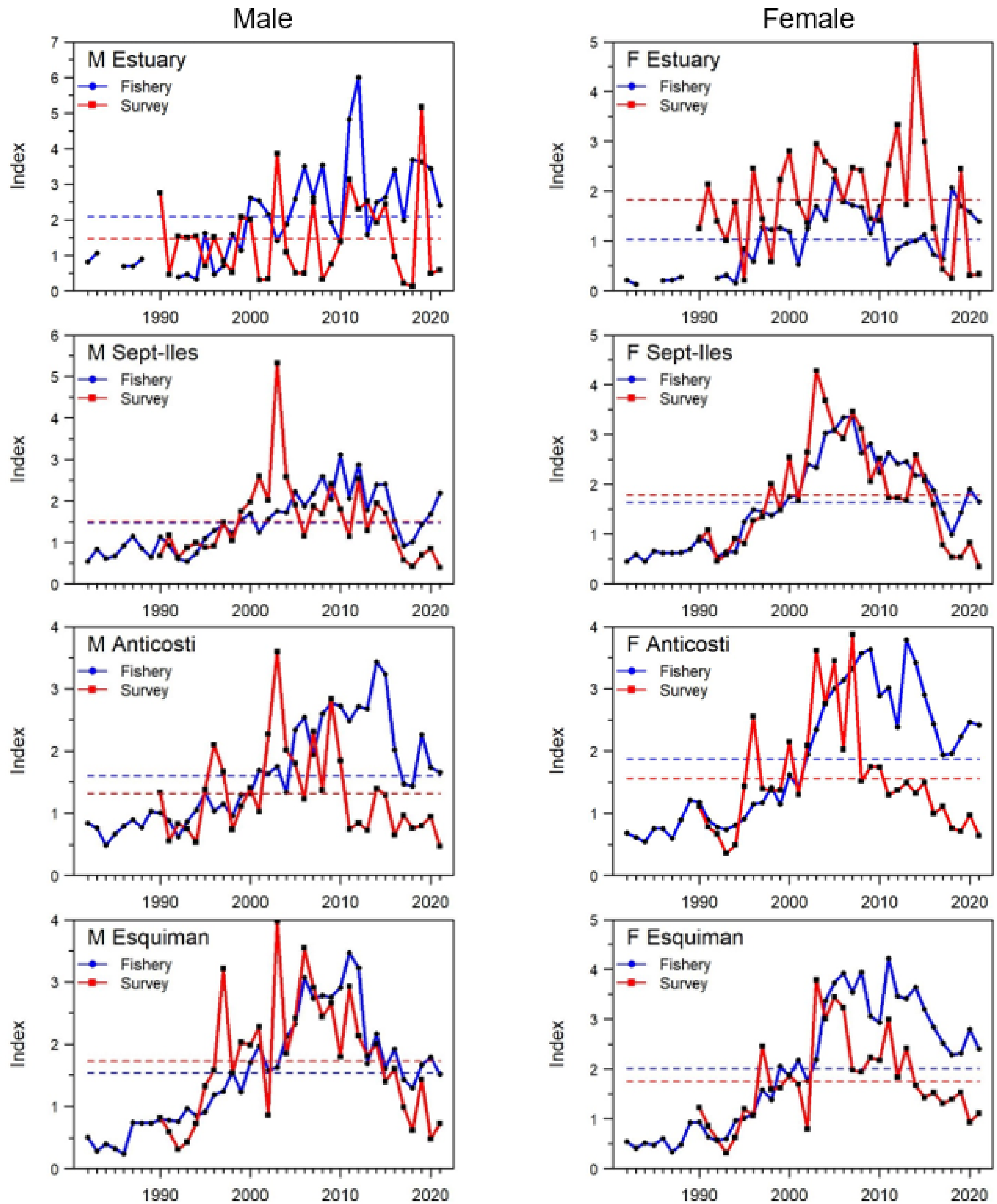

Figure 18. Standardized abundance indices contributing to the main stock status indicator, that is, the abundance of male and female shrimp from the DFO survey and the NPUE of male and female shrimp in the summer commercial fishery. The horizontal lines represent the time series average.

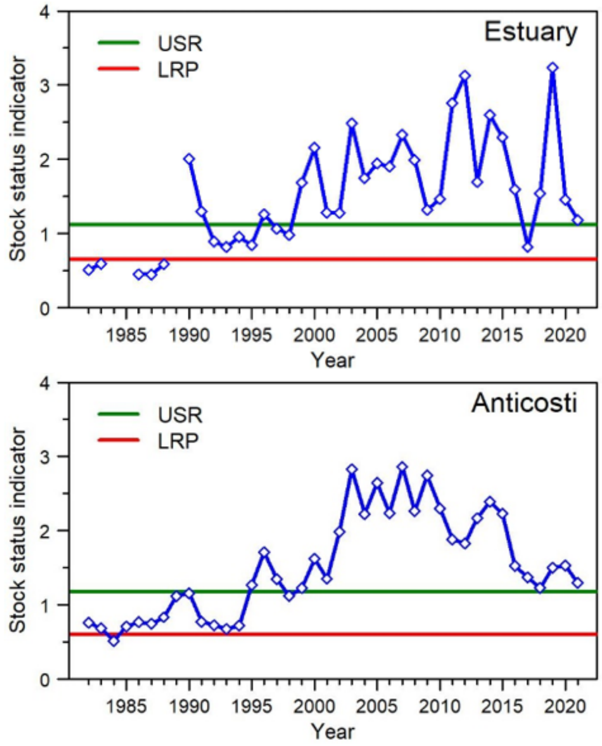

Figure 19. Main stock status indicator and limit reference point (LRP) and upper stock reference (USR) by fishing area.

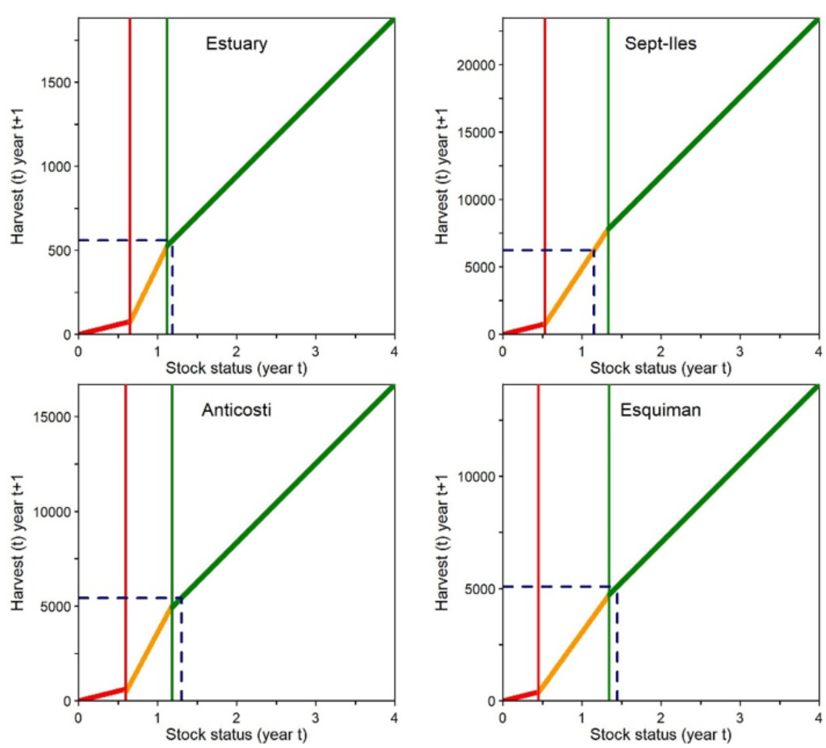

Figure 20. Harvest guidelines by fishing area. The projected harvest for 2022 is determined based on the main stock status indicator for 2021 and is indicated by the dotted lines.

Outlook

The northern shrimp is a cold-water species. In the Gulf of St. Lawrence, the species is near the southern limit of its distribution and temperatures are near the upper threshold of its thermal preference range. Deep water warming and oxygen depletion are exposing the northern shrimp to adverse environmental conditions. The low abundance of juveniles and males observed in recent years, as well as the declining trend in the size of females, indicate lower stock productivity. Migration of northern shrimp to shallower depths has been observed in three areas; in each case, the shrimp have moved closer to the colder and more oxygenated waters of the CIL. This depth-based change in distribution is very pronounced in the Estuary and is present to a lesser extent in the other areas, where the waters are continuing to warm and become more depleted in oxygen.

The decline in stock abundance and the decrease in the area of concentration have resulted in a greater than 50% decrease in realized, or occupied, shrimp habitat across the Gulf. As a result of their concentration in smaller areas, the stocks will be more vulnerable to predation and fishing pressure. In recent years, fish harvesters have successfully maintained or improved CPUEs despite the fact that the biomass of the shrimp population is at a historic low level. Data from the commercial fishery do not reflect stock status, and exploitation rates are rising.

Changes observed in the ecosystem, the increase in the exploitation rate and uncertainty surrounding the stock status indicator indicate that there is an increased risk of undesirable biological and ecological consequences for the sustainability of the stocks and ecosystem (Table 1). Currently, the risk to stock sustainability is greater than it was during the reference period used in establishing the precautionary approach.

Table 1. Evaluation of the risk and anticipated consequences for northern shrimp stocks due to ecosystem changes observed in recent years.

Observations	Anticipated consequence	Risk evaluation
↓ Shrimp distribution range	↑ Shrimp vulnerability to predation and fishing	↑
↑ Uncertainty surrounding the accuracy and representativeness of the main indicator	↑ Potential bias	↑
↑ Predation (redfish)	↑ Natural mortality	↑
↑ Exploitation rate	↑ Fishing mortality	↑
↑ Water temperature	↓ Productivity	↑
↓ Dissolved oxygen	↓ Productivity	↑

The outlook for these stocks depends on pressure from fishing and the sensitivity of northern shrimp to environmental changes, including its adaptive capacity. The warming and oxygen depletion observed in deep waters, as well as the high predation pressure from redfish, are not expected to improve in the short and medium term. The situation of the northern shrimp stocks in the Estuary and Gulf of St. Lawrence is therefore not expected to improve in the short term.

Sources of Uncertainty

When the precautionary approach was developed in the early 2010s, the commercial catch rate and the research survey abundance index were relatively consistent. From 1993 to 2005, the stocks were growing, and the fishery and survey indices were following the same trend. In 2005, research survey indices began to decline, while the commercial catch rate remained stable at relatively high levels. The commercial fishery indices began to decline in 2015, 10 years after the research survey indices. This time lag is consistent with the dynamics observed for other exploited species, where harvesting is focusing on areas of high concentration after an effective search for these areas has been conducted. The pattern observed in the NPUEs is described as “hyperstability,” or a maintenance of commercial catch NPUEs as the population abundance declines. The two indices are therefore not sampling the same fraction of the population. The research survey covers the shrimp’s entire range in the Estuary and northern Gulf of St. Lawrence, while the commercial fishery targets the highest concentrations of shrimp at the channel heads.

Technological developments in the fishery, such as the use of seabed mapping, echo sounding and new trawls, have improved fish harvesters’ efficiency. This means that, given the same abundance, a recent NPUE will be greater than an older NPUE. As a result, the comparison of these NPUEs in a historical series will be skewed.

The area of occupied shrimp habitat is shrinking every year. As their habitat becomes increasingly concentrated in a smaller and smaller area, shrimp are becoming more vulnerable to fishing. Today, given the same abundance, shrimp are more densely concentrated on the seabed.

If the goal is to have an indicator to monitor population trends, these factors indicate that the use of commercial fishery NPUEs has overestimated stock abundance during the most recent period of decline.

The average size of male and female shrimp has been declining in all four stocks since the early 1990s. This trend can be observed in both the commercial fishery data and the DFO research survey data. For populations of similar abundance, a decrease in the average size of individuals will have a negative impact on the stock’s reproductive potential since fewer eggs will be produced per female. The main stock status indicator is calculated from indices based on number of shrimp, which are related to harvests expressed in weight. Continuing to use a decision rule based on this relation could increase the rate at which the spawning component of the stock is exploited.

For these reasons, the main stock status indicator is considered overestimated for the most recent period.

CONCLUSIONS AND ADVICE

Changes in environmental and ecosystem conditions observed in the Gulf of St. Lawrence have an impact on the northern shrimp population dynamics through their effects on such factors as abundance, spatial distribution, growth, reproduction and trophic relationships. Deep water warming, dissolved oxygen depletion and increased predation by redfish appear to be major factors in the northern shrimp’s decline. These conditions are not expected to improve in the short and medium term. Furthermore, the low abundance of juveniles and males observed in recent years, as well as the downward trend in the size of females, indicate lower stock productivity.

The northern shrimp must adapt to the changes observed in its ecosystem as it is vulnerable to these adverse conditions. Migration of northern shrimp to shallower depths has been observed in three areas, where the shrimp have moved closer to the colder, more oxygenated waters of the CIL. The species can also adapt its reproductive cycle so that larval release remains synchronized with the spring phytoplankton bloom. As the shrimp migrate to a more suitable habitat, the area of occupied habitat is decreasing. This is increasing the species' vulnerability to predation and the impact of fishing.

The current ecosystem conditions differ from the conditions that existed when the precautionary approach was developed in the early 2010s. The uncertainties are greater. The sum of evidence (main stock status indicator, high exploitation rate, increased predation, higher deep-water temperatures and decrease in the species' distribution) indicates that we are currently working outside of the framework in which the precautionary approach was developed. This situation is increasing the risk to stock sustainability given the current decision rules.

OTHER CONSIDERATIONS

The bycatch of small fish in the shrimp fishery between 2000 and 2021 was examined using at-sea observer data. Most of these catches amounted to approximately 1 kg or less of fish per species in each tow sampled. From 2000 to 2012, the average annual bycatch totaled about 500 t (Figure 21). Beginning in 2013, this bycatch increased rapidly reaching a historical peak of over 1 500 t in 2016 before beginning to decline again. In 2020 and 2021, bycatches of 470 t and 449 t were recorded respectively; these values are comparable to the values recorded before 2013. The upward trend that began in 2013 can be explained by the increase in catches of small redfish due to the strong redfish recruitment observed in recent years. The decrease in redfish bycatches since 2018 is attributable to the fact that the fish are now larger and can no longer fit through the openings in the Nordmøre grate. From 2000 to 2012, bycatch ranged from 1% to 2% of the northern shrimp catch by weight (Figure 21). However, this ratio has increased since 2013 due to a sharp increase in catches of small redfish and a decrease in northern shrimp catches. In 2021, the main species in bycatch were, in order of importance, redfish, Greenland halibut, capelin, witch flounder, herring, American plaice and white barracudina. The total estimated bycatch by species nonetheless represents less than 1% of the species' respective estimated biomass calculated from the DFO survey results.

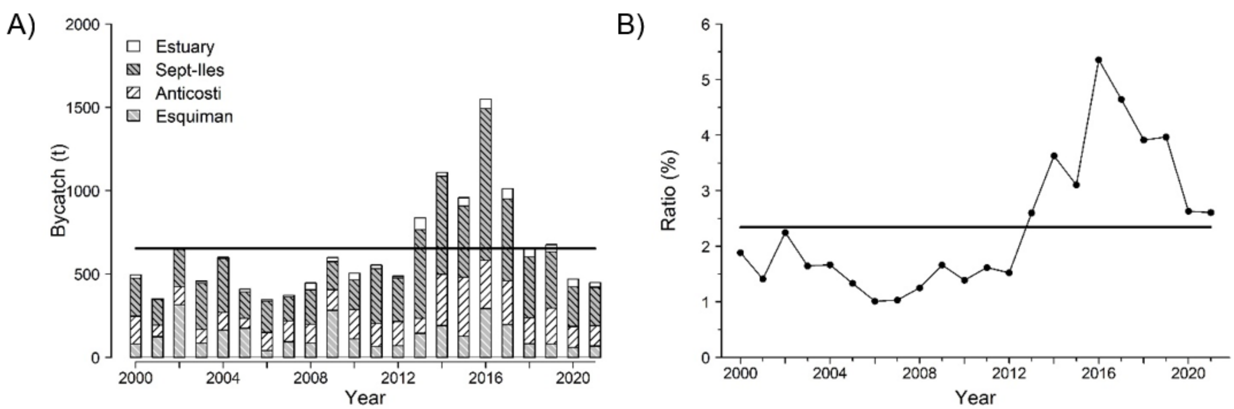

Figure 21. A) Estimated bycatch for all species combined, by year and by fishing area, during directed fishing for northern shrimp in the presence of an at-sea observer. B) Ratio (%) of bycatch to the total northern shrimp catch. Solid lines indicate the mean for the years 2000 to 2019.

Catches of other shrimp species during commercial fishing activities are very low compared to northern shrimp catches. Two shrimp species are common in catches: pink glass shrimp (*Pasiphaea multidentata*) and striped shrimp (*Pandalus montagui*). From 2000 to 2021, the share of *P. multidentata* and *P. montagui* in the total shrimp catch is estimated at 0.8% and 0.2% respectively, according to the samples collected during landings.

The trawls used in the shrimp fishery come into contact with the sea floor. The erect and rather rigid biogenic structures of the benthic ecosystem, essentially corals and sponges, are generally considered to be most affected by the disturbances caused by fishing activities. Information on coral and sponge bycatch in shrimp fishing gear suggests that a relatively small proportion of shrimper trawl tows catch these organisms. Sea pen (soft coral) and sponge bycatch is observed in 2.5% and 0.3% of shrimp tows, respectively. To conserve corals and sponges in the Estuary and Gulf of St. Lawrence, fishery management measures were put in place in 11 areas totalling 8 571 km^2 on December 15, 2017 (Figure 22). The use of bottom-contact gear, such as that used by shrimpers, is prohibited in these areas.

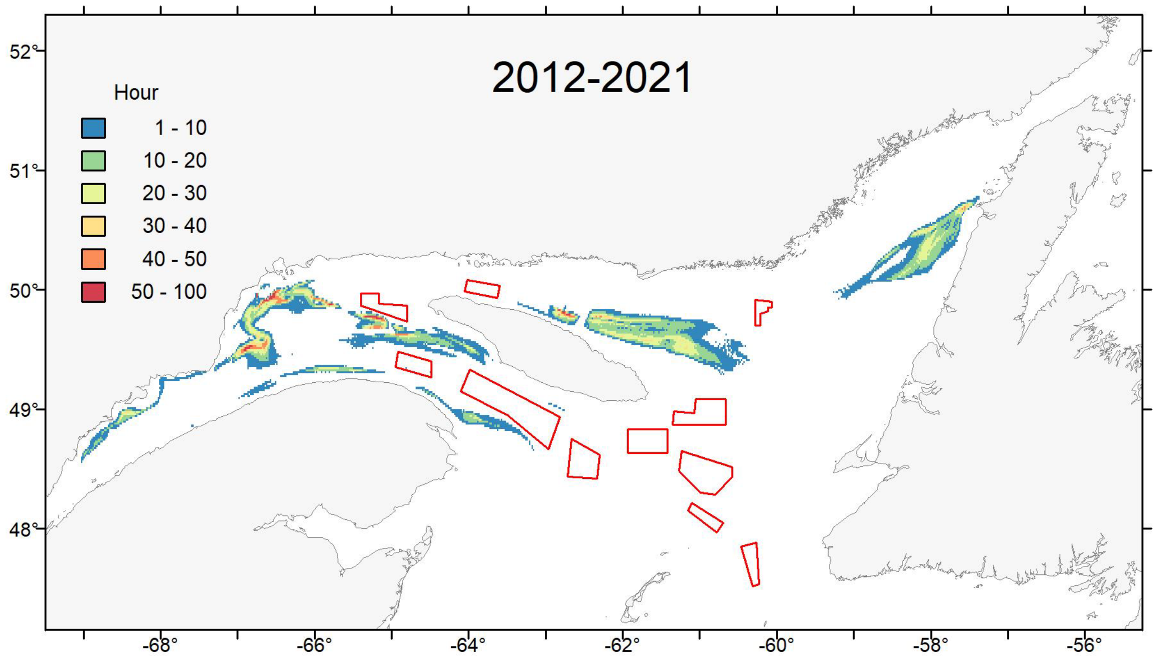

Figure 22. Distribution of mean annual fishing effort from 2012 to 2021 according to VMS data. The red polygons represent the 11 coral and sponge conservation areas in the Estuary and Gulf of St. Lawrence where shrimp fishing is banned.

LIST OF MEETING PARTICIPANTS

Name	Affiliation	Jan. 27	Jan. 28
Beaulieu, Jérôme	DFO – Fisheries Management	x	x
Bélanger, Michel	MAPAQ	x	x
Boudreau, Mathieu	DFO – Science	x	x
Bourdages, Hugo	DFO – Science	x	x
Bourdages, Yan	ACPG	x	x
Bourret, Audrey	DFO – Science	x	x
Bowlby, Heather	DFO – Science	x	-
Brassard, Claude	DFO – Science	x	x
Brown-Vuillemin, Sarah	UQAR	x	-
Brûlé, Caroline	DFO – Science	x	-
Bruneau, Benoît	DFO – Science	x	x
Cantin, Pierre	Fisher - Québec	x	x
Carruthers, Erin	FFAW	x	x

Name	Affiliation	Jan. 27	Jan. 28
Chabot, Denis	DFO – Science	x	x
Chamberland, Jean-Martin	DFO – Science	x	x
Chavarria, Caroline	DFO – Science	x	x
Couillard, Catherine	DFO – Science	x	x
Cyr, Charley	DFO – Science	x	x
Desgagnés, Mathieu	DFO – Science	-	x
Desjardins, Christine	DFO – Science	x	-
Dewland, Jennifer	PEIFA	x	x
Dubé, Sonia	DFO – Science	x	x
Duplisea, Daniel	DFO – Science	x	x
Duprey, Nick	DFO – Science	x	x
Dupuis, Dan	Fisher - Québec	x	x
Dupuis, Vincent	Fisher - Québec	-	x
Élément, Patrice	ACPG	x	x
Émond, Kim	DFO – Science	x	-
Galbraith, Peter	DFO – Science	x	x
Gianasi, Bruno	DFO – Science	x	x
Genge, Rendell	Fisher – NL	x	x
Grégoire, Benjamin	DFO – Science	x	-
Guscelli, Ella	UQAR	x	x
Isabel, Laurie	DFO – Science	x	x
Juillet, Cédric	DFO – Science	x	x
Lanteigne, Jean	ACAG - FRAPP	x	x
Leblanc, Léonard	Gulf Nova Scotia Fleet Planning Board	x	x
Leung, Christelle	DFO – Science	x	x
Loboda, Sarah	DFO – Science	x	-
Lussier, Jean-François	DFO – Science	x	x
MacPherson, Ian	PEIFA	x	x
Mallet, Pierre	DFO – Fisheries Management	x	x
Marquis, Marie-Claude	DFO – Science	x	x
Munro, Daniel	DFO – Science	x	-
Ouellette-Plante, Jordan	DFO – Science	x	x
Parent, Geneviève	DFO – Science	x	-
Pelletier, Claude	Province – NB	x	x
Plourde, Stéphane	DFO – Science	x	x
Puncher, Gregory	DFO – Science	x	x
Rondeau, Marie-Maude	DFO – Science	x	x
Roussel, Eda	ACAG – FRAPP	x	x
Roux, Marie-Julie	DFO – Science	x	x
Rowsell, Nicole	Province – NL	x	-
Roy, Virginie	DFO – Science	-	x
Sainte-Marie, Bernard	DFO – Science	x	x
Sandt-Duguay, Emmanuel	AGHAMM	x	x
Senay, Caroline	DFO – Science	x	x
Sigouin, Éveline	DFO – Science	x	x
Small, Daniel	UQAR	x	x
Spingle, Jason	FFAW	x	x
Tamdrari, Hacène	DFO – Science	x	x
Thériault, Stéphane	ACAG	-	x
Tilley, Anna	Province – NL	x	x
Van Beveren, Élisabeth	DFO – Science	x	x
Weiner, Guy-Pascal	Wolastoqiyik Wahsepikuk First Nation	x	x

Name	Affiliation	Jan. 27	Jan. 28
Watts, Taylor	Gulf Nova Scotia Fleet Planning Board	x	x

SOURCES OF INFORMATION

This Science Advisory Report is from the January 27-28, 2022 regional peer review meeting on the Assessment of Estuary and Gulf of St. Lawrence Northern Shrimp Stocks. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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THIS REPORT IS AVAILABLE FROM THE:

Center for Science Advice (CSA)
Quebec Region
Fisheries and Oceans Canada
Maurice Lamontagne Institute
850 route de la Mer
P.O. Box 1000
Mont-Joli (Quebec)
Canada G5H 3Z4

E-Mail: bras@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087
ISBN 978-0-660-43449-0 N° cat. Fs70-6/2022-006E-PDF

Correct Citation for this Publication:

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.

Aussi disponible en français :

MPO. 2022. Évaluation des stocks de crevette nordique de l’estuaire et du golfe du Saint-Laurent en 2021. Secr. can. des avis sci. du MPO. Avis sci. 2022/006.