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Framework Assessment of the American Lobster (*Homarus americanus*) Stock Status in the Southern Gulf of St. Lawrence (LFAs 23,24, 25, 26A and 26B)

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Foreword

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

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ABSTRACT

Active for more than a century, the American Lobster fishery in the southern Gulf of St. Lawrence (sGSL) has seen varying levels of productivity over this time period. This framework presents indicators of abundance, productivity, fishing pressure and the environment, to be used in future stock assessments. Abundance indicators include landings, Catch per Unit Effort (CPUE), commercial biomass and commercial abundance. These multiple indicators from different data sources show a consistent trend of increasing Lobster abundance since the previous assessment. Indicators of productivity, including pre-recruit CPUE, pre-recruit abundance, juvenile density, young-of-year density and egg production, are positive but the densities of small benthic Lobsters appear to be stabilizing (i.e. juveniles and young-of-year). For fishing pressure, the percent empty traps has decreased while exploitation rates appear stable, indicating that the stock can likely sustain current levels of exploitation. For habitat indicators, reduced Rock Crab densities within the prey availability indicator may be a result of high Lobster abundance. A substantial reduction in the predator pressure indicator has occurred since the 1970s, but the effects of this reduction on the Lobster stock were not evaluated. In terms of seafloor temperature, available Lobster habitat has increased in June in the sGSL since 1985.

Total landings of 39,313 tonnes (t) in 2021 in the sGSL were well above the Limit Reference Point (LRP, 6,899 t), the Upper Stock Reference (USR, 13,798 t) and the Biomass at Maximum Sustainable Yield (BMSY, 17,247 t), placing the stock within the defined healthy zone of the precautionary approach. Changes in Lobster abundance, and observed concurrent changes in the populations of other commercially fished species in the sGSL, may indicate a regime shift. Re-evaluation of the LRP could be considered to ensure it reflects the current ecosystem. The use of fishery-independent data to establish the LRP would be preferable, to remove uncertainty related to changes in the fishery.

INTRODUCTION

BACKGROUND

The last framework assessment of the American Lobster (*Homarus americanus*) stock for the southern Gulf of St. Lawrence [sGSL, Lobster Fishing Areas (LFA) 23, 24, 25, 26A, and 26B] was completed in 2013 (DFO 2013; Rondeau et al. 2015). The present research document updates the stock assessment framework for the sGSL Lobster stock. Indicators of stock status to the 2021 fishing year are provided and the associated science advice is provided in DFO (2023a).

As in other regions in Atlantic Canada (e.g. DFO 2019a, 2019b, 2019c, 2021a; Cook et al. 2020), the Lobster assessment in the sGSL relies on fishery-dependent data (i.e. landing statistics and at-sea sampling programs) and fishery-independent data (i.e. scientific trawling, SCUBA surveys, bio-collectors and temperature data). Indicators of abundance, productivity, fishing pressure and the ecosystem are derived from these data. Current landings are compared to the reference points (DFO 2014a) to determine the status of the sGSL Lobster stock.

SPECIES BIOLOGY

Habitat

The American Lobster is a large-bodied decapod crustacean found in predominantly coastal habitats ranging from southern New England (USA) to Newfoundland and Labrador, in the Northwestern Atlantic Ocean. During the early winter months in the sGSL, larger Lobsters may move from the inshore coastal habitats to waters deeper than 40 m (Comeau and Savoie 2002; Bowlby et al. 2007, 2008) to avoid contact with ice (Ennis 1984; Lawton and Lavalli 1995). Environmental conditions in the sGSL have been changing with warming trends evident, namely increasing sea surface temperatures, reductions in the thickness and warming of the cold intermediate layer, and reductions in both sea ice extent and duration (Galbraith et al. 2021). These changes are thought to be supporting increases in American Lobster abundance in the sGSL (Chassé et al. 2014; Rondeau et al. 2015). Traditionally associated with highly structured habitats, sGSL Lobsters are also found within portions of the Northumberland Strait characterized by softer sediments (Hanson et al. 2014).

Growth and life cycle

The American Lobster's life cycle has initial planktonic life-stages followed by non-planktonic benthic life-stages. Throughout their long-lifespan, Lobsters grow indeterminately by moulting their carapace. The moulting period for Lobsters [86-154 mm carapace length (CL)] in the sGSL occurs mostly from early July to early September (Comeau and Savoie 2001). Females generally have a two-year reproductive cycle whereas mating begins during the summer after the female's moult while the shell is still soft (Atema et al. 1979) and the eggs are extruded and attached to the underside of the tail the following summer (approximately 12 months post-mating). Once extruded, the clutch is carried for another 10-12 months until the following spring or summer when hatching occurs (Aiken and Waddy 1980; Comeau and Savoie 2002). While the two year cycle is considered typical, there is also evidence of a one year cycle for some females (Comeau and Savoie 2002). The hatched larvae enter the water column and are pelagic for 3 moults. Once they metamorphose to a stage IV larva they more closely resemble the benthic stage of Lobster and settle out of the water column in habitat that allows them some protection. Early benthic and juvenile Lobsters are cryptic and closely associated with burrows or other shelter until they reach 35–40 mm CL (Wahle and Steneck 1991; Lawton and Lavalli 1995). As their body-size increases, Lobsters spend an increasing amount outside of their shelter (Lawton and Lavalli 1995). The frequency of moulting is influenced by variables including Lobster density and diet, though temperature is considered to most directly influence the timing of moulting events (Munro and Therriault 1983; Waddy et al. 1995; Tremblay 1998). During the first year Lobsters may moult up to ten times (Cobb 1976), and the frequency of moulting declines with size, as large individuals may transition from moulting annually to once every two to three years (Aiken and Waddy 1980).

Size at maturity

Lobster size at maturity is largely dependent upon local environmental conditions (Aiken and Waddy 1980; Campbell and Robinson 1983; Comeau and Savoie 2002) but can also be impacted by fishing pressure (Haarr et al. 2018). The sGSL has smaller sizes at maturity than regions with cooler summer temperatures, with a CL of 50% female maturity at 72 mm (Comeau and Savoie 2002; DFO 2016) for most LFAs in the sGSL and 75 mm in LFA 26B (Comeau 2003; DFO 2016). Size at maturity of female Lobster has been declining in Atlantic Canada over the past century (Haarr et al. 2018). Large Lobster have a greater relative fecundity as there is an exponential relationship between body-size and the number of eggs produced (Campbell and Robinson 1983; Estrella and Cadrin 1995).

Role in the ecosystem

The marine ecosystem of the Northwest Atlantic, including the sGSL, underwent a shift in trophic structure beginning in the 1980's and 1990's. The change in trophic dynamics is due to decreases in groundfish abundance [e.g. Atlantic cod (*Gadus morhua*)] followed by large increases in crustacean abundance, such as Lobster, and other species (Worm and Myers 2003; Steneck et al. 2004; Frank et al. 2005; Savenkoff et al. 2007; Boudreau et al. 2015). In the ecosystem, Lobsters are both predator and prey and, given their claws, are important competitors in the benthic environment (Boudreau and Worm 2012). The release from top-down pressures is thought to have contributed to Lobster population growth in the region (Boudreau et al. 2015).

While there are few predators of adult Lobster, at smaller life-stages, Lobsters are prey for elasmobranchs, groundfish, forage fishes, and invertebrates (mainly conspecifics and crabs) (Hanson and Lanteigne 2000; Hanson 2009; Boudreau and Worm 2010, 2012; Hanson et al. 2014). Pelagic fishes such as Atlantic Herring (*Clupea harengus*), American Shad (*Alosa sapidissima*), and Rainbow Smelt (*Osmerus mordax*) have been found to consume Lobster larvae, likely by chance while filter-feeding zooplankton (Hanson 2009).

Shorthorn Sculpin (*Myoxocephalus scorpius*) are the demersal fish recorded to consume largest amounts of Lobsters (2.6-11.8% frequency of occurrence in stomach contents, Hanson and Lanteigne 2000; Hanson 2009; Hanson et al. 2014) followed by Cunner (*Tautogolabrus adspersus*; 0.5-3.6% occurrence, Hanson and Lanteigne 2000; Hanson 2009; Hanson et al. 2014). Other recorded predators in the sGSL include White Hake (*Urophysis tenuis*, Hanson 2009; Hanson et al. 2014); Longhorn Sculpin (*M. octodecemspinosus*, Hanson 2009; Hanson et al. 2014), Atlantic Cod (Hanson and Lanteigne 2000), and Thorny Skate (*Raja radiata*, Hanson et al. 2014). Rock Crab have also been recorded to have small amounts of Lobster shell in their stomach contents (Hanson et al. 2014).

Based on research in the Gulf of Maine, additional possible predators of Lobster present in the sGSL are Sea Raven (*Hemitripterus americanus*), Atlantic Wolffish (*Anarhichas lupus*), Winter Skate (*Leucoraja ocellata*), Spiny Dogfish (*Squalus acanthias*), and Atlantic Halibut

(*Hippoglossus hippoglossus*) (Boudreau and Worm 2010). While diet studies in the sGSL did not find evidence of predation by Atlantic Mackerel (*Scomber scombrus*) (Hanson 2009; Hanson et al. 2014), they are known to consume larval crustaceans in other portions of their range (Olaso et al. 2005).

Lobster in the sGSL are found in highly structured hard-bottom habitats and in regions characterized by soft substrates, such as the Northumberland Strait, providing access to a diversity of prey items (Hanson 2009; Hanson et al. 2014). Lobster actively prey at different trophic levels and are considered omnivorous, with their diet shifting through their ontogeny (Hanson 2009; Boudreau and Worm 2012). Prey species also become Lobster predators at different life-stages (Hanson 2009; Boudreau and Worm 2012). Rock Crab are a key diet item for Lobster (Gendron et al. 2001), their importance to the diet in the Northumberland Strait is also evident with Rock Crab being the most commonly identified species in the stomachs of Lobsters > 40 mm CL (Hanson et al. 2014). Additional prey items were small sea stars (*Asterias vulgaris*, 3.8– 10.5% prey biomass, Hanson 2009) and Lobsters (0.7–12.9% of prey biomass, 70% were moulted carapaces) with molluscs, polychaetes and fish remains [Cunner, Three-Spined Stickleback (*Gasterosteus aculeatus*), and Atlantic Herring] not exceeding 7.5% of the prey biomass (Hanson 2009; Hanson et al. 2014).

FISHERY

Fisheries management

Over more than a century, the Lobster fishery in the sGSL has developed as a near-shore small-vessel fishery, involving a large number of harvesters using only Lobster traps as fishing gear (DeWolf 1974). Fisheries and Oceans Canada (DFO)-Gulf Region is responsible for Lobster fisheries that operate in all three Maritime provinces [i.e. New Brunswick (NB), Nova Scotia (NS), and Prince Edward Island (PEI)]. Since 1934, fishing activities have been limited by LFA with LFAs, sub-LFAs and management zones currently used in the management of the fishery (Figure 1). The Lobster fishery in the sGSL is entirely managed by effort controls including a limited number of fishing licences, individual trap allocations, restrictions on gear characteristics, and a fixed fishing season (Table 1).

In addition to the effort controls, increases in Minimum Legal carapace Size (MLS) have been implemented since 1987 (Table 2), with the main objective of increasing egg production, as recommended in two reports by the Fisheries Resource Conservation Council (FRCC) (1995, 2007). The recommendation from the FRCC (2007) of an MLS corresponding to the size at which 50% of females are mature (i.e. SOM50) was met throughout the sGSL by 2013 (DFO 2013). An additional measure to increase egg production was the mandatory release of window-size (115-129 mm CL) females, implemented in 2003 (DFO 2003). In 2004, in LFA 25 only, the window-size female regulation was replaced by a maximum legal size of 115 mm CL for females (Fisheries and Oceans Canada 2004), which was reduced to 114 mm CL in 2005 (Fisheries and Oceans Canada 2005) and increased back to 115 mm CL in 2017 (DFO 2017). These restrictions on window-size females or maximum legal size females remain in place in LFAs 23, 24, 25 and 26A (DFO 2022a, 2022b). The restriction on window-size females was removed in LFA 26B in 2011 (DFO 2011).

The FRCC reports also concluded that exploitation levels were too high and that a reduction in fishing effort was needed (Fisheries Resource Conservation Council 1995, 2007). Reductions in the number of licences and in trap allocations were put in place from 2006 to 2013 to reduce fishing effort (detailed in Rondeau et al. 2015).

There are two Lobster fishing seasons in the sGSL: the spring fishery (LFAs 23, 24, 26A and 26B) that takes place mostly during the months of May and June, and the summer/fall fishery (LFA 25) that generally operates from August 9 or 10th to October 9 or10th. The spring season start and end dates are generally May 1st to June 30, with harvesters setting traps on April 30, but, as of 2022, the fishery can now open up to 72 hours early (DFO 2022a). The season opening is delayed by weather at times, and can be lengthened at the end of the season by up to four days to compensate for lost days at the start of the season (DFO 2022a). A portion of LFA 26B (referred to as LFA 26B North) has a slightly later spring season (e.g. May 7 to July 7 in 2022, DFO 2022a).

Historical landings

Historical records of Lobster landings for the sGSL date back to the 1890s (Williamson 1992). As outlined in Rondeau et al. (2015), high Lobster landings above 15,000 t reported at the end of the 19th century were followed by lower catches of approximately 8,000 t from around 1920 to the mid-1970s. Starting in the mid-1970s, Lobster landings in the sGSL increased sharply (> 2.5-fold) and reached a high of 22,000 t in 1990. While part of the increase in landings from 1975 to 1990 can likely be attributed to improvements in reporting, increases in fishing effort, expansion of fishing grounds and favourable environmental conditions are also thought to have contributed to strong Lobster recruitment in the Northwest Atlantic (Pezzack 1992).

Bycatch

There are three categories of fisheries bycatch in the sGSL Lobster fishery: (1) non-harvestable Lobsters (i.e. outside of legal-size regulations and berried females), (2) retainable per licensing conditions for personal use (e.g. bait) or sale (i.e. male Rock Crab, Sculpins, and Cunners), and (3) other incidentally caught species to be returned to the water unharmed.

The amount of male Rock Crab bycatch landed and sold to registered buyers is recorded and incorporated in science assessments (e.g. DFO 2023b). Very little information is available for Rock Crab used as bait. Prior to 2021, Lobster licence holders were entitled to keep any size of male Rock Crab for use as bait or to land as bycatch, as per the Atlantic Fishery Regulations, 1985 (55). Since 2021, as a condition of licence in the Lobster fishery, the use of male Rock Crabs as bait has been restricted to crabs with a minimum carapace width of 102 mm (DFO 2021b) but male Rock Crabs of any size can still be landed as bycatch. In a Gulf Region phone survey of Lobster fishers, the majority of respondents (85.3% in 2011 and 96.5% in 2016) did not retain Rock Crab bycatch to land at the wharf (Boudreau and Giard 2022) and total landings of Rock Crab as bycatch during the Lobster fishery were only 1.4 t in 2021 (DFO 2023b). Removals of Rock Crab, Cunner and Sculpin have been included in lobster fishery logbooks since 2014 (see section 2.1.2) but these data have not been quality controlled or analysed.

A systematic study undertaken during the 2015 spring (LFAs 23, 24 and 26A) and summer/fall (LFA 25) fishing seasons established a baseline of bycatch in the sGSL Lobster fisheries (Boudreau and Hanley 2023). Over 80% of the bycatch in both fishing seasons, by weight and number, were non-harvestable Lobster, with over two thirds of the discarded Lobster catch being females (undersized, berried, window/maximum size combined). By weight, undersized Lobsters were estimated to comprise 71% and 63% of bycatch in the spring and the summer 2015 fishery, respectively. Undersized Lobsters (male and female) were the most abundant bycatch in all LFAs. Twenty-seven different taxa, excluding Lobster, were recorded in 2015, 21 in the spring fishery and 16 in the summer/fall fishery. Excluding Lobster, Rock Crab (male and female) were the next most abundant species of bycatch by weight, comprising 49% and 88% of non-Lobster bycatch in the spring and summer fisheries, respectively.

ASSESSMENT REGIONS

As the LFAs, sub-LFAs and management zones were not established based on a biological or oceanographic rationale, but rather for socio-economic reasons, they encompass a range of habitats. In previous assessments (Comeau et al. 2008; Rondeau et al. 2015), nine sub-regions were used in analyses. Fewer regions were used in this assessment as the nine sub-regions used by Rondeau et al. (2015) and Comeau et al. (2008) are not used in fisheries management and some fisheries-dependent data (e.g. landings) are not collected at this spatial scale. For this assessment, in LFA 23 only, as in previous assessments (Comeau et al. 2008; Rondeau et al. 2015), two regions were used, 23bc (i.e. 23 “Baie des Chaleurs”) and 23g (i.e. 23 “Gulf”), for areas within Baie des Chaleurs and outside the bay, respectively, to capture the geographical differences between these two portions of LFA 23 (Figure 2). In other LFAs (i.e. 24, 25, 26A and 26B) the LFA was used as the assessment region. When relevant, indicators were also estimated for the sGSL as a whole.

DATA SOURCES

FISHERY DEPENDENT DATA

Official statistics

Official Lobster catch statistics were obtained from the Policy and Economics Branch of DFO. The database consists of sale transactions conducted between registered Lobster buyers and harvesters, with data by statistical district from 1968 to 2021. Landings by LFA for 1947 to 1967 are from Williamson (1992), as cited in Rondeau et al. (2015) and Comeau et al. (2008). Landings from 1892 to 1946 are only available for the sGSL as a whole (Williamson 1992; as reported in Comeau et al. 2008; Rondeau et al. 2015).

Information on licences issued and individual trap allocations were obtained from the Fisheries and Harbour Management Branch of DFO.

Logbooks

A completion of a daily logbook has been mandatory in the sGSL Lobster fishery since 2014 (DFO 2014b). Data collected in logbooks include the number of traps hauled, the soak time (in days), an estimate of the catch weight and the landing port. Currently, logbooks are completed on paper and data are entered and managed by the Statistics and Strategic Services Branch of DFO. For this assessment, data were available for 2014 to 2020.

At-sea sampling program

DFO initiated an at-sea sampling program in 1982 in all LFAs (Mallet et al. 2006). Since 1998, the PEI provincial government and the Prince Edward Island Fishermen’s association have collaborated with DFO to conduct at-sea sampling with PEI fishers in LFAs 24, 25 and 26A. For the other provinces, at-sea sampling programs, managed by various harvesters’ associations, were carried out during the 2012 to 2022 fishing seasons (Table 3). At-sea sampling was completed by Lobster industry personnel, trained by DFO, aboard commercial fishing vessels.

In all areas, the sampling protocol has been consistent throughout the duration of the program (i.e. 1982 to 2022, detailed in Mallet et al. 2006). One sample was defined as one day at sea with one harvester from a given port. Generally, three to four samples are collected from each participating fisher over the course of the season. Data collected include information on trap types and characteristics, Lobster size (CL to the lowest mm), sex, carapace condition and, for berried females, egg stage. Other information recorded includes the trap's position on the line of traps (where applicable), precise geographic position of the line using a GPS and water depth.

In previous assessments, for LFA 25, only at-sea sampling program data collected in August were used in analyses as almost 60% of all catches occurred in the first three weeks of the fishery in this LFA (Rondeau et al. 2015). Currently, the fishery landings are more evenly spread out over the season (Figure 4) and the full season of data was used over the whole time series, as in other LFAs.

Recruitment-index program

Initiated in 1999, the recruitment-index program is a harvester-based at-sea sampling program that collects information on catch composition throughout the fishing season. Participating harvesters complete a daily logbook of their total catch and the number of traps hauled. Six pre-identified traps, three of which have blocked escape vents, are fished in the same general area and the same manner as regular fishing traps. The CL and sex of all Lobsters were recorded with Lobster CL measured using a gauge graduated in 13 size classes (Figure 5). The gauge is adjusted to the MLS in place in the sample area such that Lobsters in group size 4 and below are sub-legal Lobsters and those in size groups 5 and 6 represent animals from the first moulting group into the fishery. Class size 1 represents Lobsters at least 20 mm smaller than the MLS. Class size 2 is a 10-mm size class, and class sizes 3 to 10 are 5-mm size classes. Since 2004, class size 11 is adjusted in size to ensure that class size 12 corresponds to the lower end of the window-size for females. Class size 13 represents Lobsters 50 mm above the MLS. Sampling effort has changed over the years (Table 4), largely as the program transitioned from a DFO-led study prior to 2007 to a collaborative project with the PEI provincial government and harvesters' associations beginning in 2007.

FISHERY INDEPENDENT DATA

Northumberland Strait multi-species bottom trawl survey

In 1999, DFO initiated a bottom trawl survey in Northumberland Strait (the Northumberland Strait survey) to collect fishery-independent data for use in stock assessments for sGSL Lobster (Hanson 2001). Completed annually from 1999 to 2022, the sampling methods and study area have changed over the years (Figure 3 and Asselin et al. 2021; Asselin et al. 2023).

Field methods for 1999 to 2018 are described in Asselin et al. (2021). From 2019 to 2022, station selection and sampling were the same as in 2018 (detailed in Asselin et al. 2021). In 2019 and 2020, a new fishing trawl, the Northumberland trawl, was introduced and a comparative fishing experiment was completed to calibrate the catch data from the previously used no. 286 otter trawl to what would have been caught by the Northumberland trawl (Asselin et al. 2023). In 2021 and 2022, the Northumberland trawl was used. Consistent with previous analyses of this time series (e.g. Rondeau et al. 2015; DFO 2016, 2019d), data from 1999 and 2000 were excluded as fishing and sampling methods were inconsistent and data from 2010 and 2011 were excluded from the analyses as a Bigouden Nephrops trawl was used those years (Asselin et al. 2021), and a calibration experiment was not completed to standardize the catch data.

Specific to Lobster, beginning in 2017, sub-sampling was used at times for large Lobster catches, above approximately 50 kg in a set, whereas a minimum of 200 Lobsters were sampled in detail. CL (to the lower mm) and sex were recorded. For female Lobster, the presence or absence of eggs was noted and, starting in 2010, the stage of development of the eggs (i.e. new or old) when present was also recorded. Carapace condition (i.e. stage of moult) was recorded starting in 2010.

September ecosystem survey of the southern Gulf of St. Lawrence

A groundfish trawl survey has been conducted annually in September in the sGSL since 1971 (Figure 6, Savoie 2016; Ricard et al. 2024). Data from this survey have been used in assessments of multiple potential Lobster predators in the sGSL including Atlantic Cod (Swain et al. 2019), White Hake (Swain et al. 2016), Atlantic Halibut (Desgagnés 2016), Atlantic Wolffish (Collins et al. 2015), American Shad (Chaput and Bradford 2003), Thorny Skate (Swain et al. 2012), Winter Skate (Swain and Benoît 2017) and Spiny Dogfish (Hurlbut et al. 1995). Standardized abundance indices from this survey, in kg per tow, are available for fish species from 1971 to 2022 and for Lobster and crab species from 1988 to 2022 (Ricard et al. 2024).

SCUBA surveys

Annual SCUBA surveys were initiated in 2000 in coastal areas of the sGSL (Comeau et al. 2008; Rondeau et al. 2015). The main objective was to assess the density of small Lobsters in rocky reef habitat within diveable depths (i.e. <10 m) from the Baie des Chaleurs to the eastern portion of the Northumberland Strait. Sampling sites were initially chosen based on anecdotal information from biologists and harvesters. Rocky reef habitat at each site was then identified using ship-based seafloor mapping (e.g. Olex). The adequacy of prospective sampling sites was confirmed by SCUBA divers and underwater photography. At each site, a minimum of three 100 m long transects were distributed either systematically as sets of parallel lines or randomly scattered over targeted rocky reef habitats. Transects were generally oriented parallel to tidal currents to facilitate diving and improve visibility.

Over the years, transects were added or removed due to logistical reasons (e.g. financial, ease of access), changes in research objectives (e.g. specific regions of interest), variation in substrate quality (e.g. encroaching sand dunes), or if the substrate was deemed too complex for divers to find and capture Lobsters (e.g. too much seaweed). In addition, steady increases in densities of small Lobsters (DFO 2019d) eventually caused logistical challenges in that sampling in some transects became overly labour intensive. This resulted in many transects being only partially sampled and some transects left unsampled.

The sampling design was modified in 2019 in an effort to even out the number of transects per site and reduce the inter-annual variation in survey coverage. Nine sites were subsequently retained for regular monitoring, corresponding to those with a longer data time series (Figure 7). Within each site, 5 to 12 transects were retained, again favoring more consistently sampled transects which had also been sampled in recent years (Figure 8). Transects which were part of other studies or short-term monitoring projects were not included in the current sampling design. The Cocagne and Caraquet sites were assigned more transects as they were considered representative of general trends in their respective regions. Only transects selected for ongoing monitoring were included in the analysis.

In all years, transects were laid-out from a small vessel using buoys, anchors and a 100 m leaded rope along the bottom, marked at 5 m intervals, dividing the transect into 20 sections. A visual strip transect survey method was used whereas two divers sampled either side of the rope. Up until 2018, the strip width covered by each diver was 2 m. Starting in 2019, the strip width was reduced to 1 m at sites with an average density of ≥ 0.5 Lobster per m^2 the previous year. For 2 m strips, strip width was measured using the diver’s arm span as a reference, while a reference cord tied to the clipboard was used for 1 m strips.

Within each sampled 5 m transect section, divers searched for Lobsters thoroughly, including within shelters and under rocks. All Lobsters caught were measured (i.e. CL) and all Lobsters ≥ 20 mm CL were sexed. Egg-stage was recorded for berried females. Lobsters which were observed but escaped measurement by divers were left unsexed and their size was estimated to the nearest 5 or 10 mm CL. Information on substrate and habitat complexity was recorded, but this was done inconsistently over the time series. Transect sections were left unsampled if the area was deemed too complex to detect Lobsters (e.g. too much seaweed). Also, prior to 2019, recorded data from some sections were removed from the database if the habitat was deemed unsuitable for Lobster (e.g. soft or hard-bare substrate).

Bio-collectors

Since 2008, vessel-deployed bio-collectors, developed to passively assess post-larval settlement of Lobster (Wahle et al. 2009, 2013), have been deployed annually in the sGSL (Rondeau et al. 2015). Bio-collectors are rectangular, measuring 61.0 cm x 91.5 cm x 15.0 cm in width, length and height, respectively, for a total surface area of 0.55 m^2 (see additional design details in Wahle et al. 2009; Rondeau et al. 2015). To mimic Lobster settlement habitat, a layer of gravel (10-20 mm) was placed on the bottom of the collector which was then filled with cobble (10-15 cm).

For deployment and retrieval, each collector was fitted with a bridle to permit lowering and lifting in a horizontal position, which is important for retention of contents, as demonstrated by Wahle et al. (2009). The bio-collector project is a collaboration between DFO, the Prince Edward Island's Fishermen's association, the Prince Edward Island Department of Fisheries and Communities and the Gulf Nova Scotia Fleet Planning Board. Annually, bio-collectors were deployed and retrieved by commercial fishermen in July and September-October, respectively. For this analysis, data from eight sites were used, with depths ranging from 7.5 m to 11 m (Figure 9). At each site, 30 bio-collectors were deployed.

Within hours after retrieval, the contents of bio-collectors were processed. Specifically, they were opened and the cobble and gravel were removed and examined to inspect for Lobsters, crabs and fish. All Lobsters were measured to the 0.1 mm, Lobsters 20 mm CL and above were sexed and all Lobsters were released immediately. Crabs and fish were frozen and brought back to the lab for processing where they were identified to species and measured.

ENVIRONMENTAL DATA

Data on physical oceanographic conditions in the Gulf of St. Lawrence are analyzed annually by DFO's oceanographic group (e.g. Galbraith et al. 2021). Most temperature data are collected using Conductivity-Temperature-Depth (CTD) sensors during DFO research surveys, but other data sources are also used (Galbraith et al. 2021). Sea bottom temperatures are interpolated to a 500 m resolution grid of the sGSL using an objective analysis method (see Chassé et al. 2014 for additional details).

METHODS

As in previous frameworks (Comeau et al. 2008; Rondeau et al. 2015), and as in other regions in Atlantic Canada (e.g. DFO 2019a, 2019b, 2019c, 2021a; Cook et al. 2020), an indicator-based approach is proposed, with indicators of abundance, productivity, fishing pressure and the ecosystem. Equations used in analyses for length-weight conversions, maturity and eggs per female are given in Table 5.

ABUNDANCE INDICATORS

Landings

For the sGSL Lobster stock, landings are considered to be a proxy for the abundance of Lobster (DFO 2013, 2014a; Rondeau et al. 2015). As in the previous sGSL Lobster framework (Rondeau et al. 2015), landings were totaled by assessment region (1968-2021), by LFA (1947-2021) and for the sGSL as a whole (1892-2021) using data on sales transactions. Total landings for the sGSL were compared to the reference points from DFO (2014a). Landings by LFA were compared to the long-term median landings (75 years, 1946-2021) the mid-term median landings (1968-2021), and the short-term median landings [2012-2021; since the last stock assessment (Rondeau et al. 2015)]. Landings by assessment region were compared to the median mid-term (1968-2021) and the short term landings (2012-2021).

CPUE

Catch-per-unit-effort (CPUE), in comparison with landings, is an indicator of abundance that does not rely on the assumption that effective effort will be constant through time (as noted in Cook et al. 2020). Four methods were used to calculate CPUEs of commercial lobsters: one using at-sea sampling program data (available for 2001 to 2021), one using recruitment-index program data (regular traps) and two using logbook and sales slips data (available for 2014 to 2020). For the at-sea sampling program data and recruitment-index program data, average seasonal CPUEs were calculated for each assessment region using the method described in Rondeau et al. (2015) whereas CPUEs were first calculated by size, and then converted to CPUEs by weight using a length-weight conversion (see Table 5 for equations and reference). For recruitment-index program data, where CLs are measured in bins, the mid-size of the bin was used.

For the CPUEs calculated using logbook data (for traps hauled) and sales slip data (for landings), preliminary analyses indicated some slip data were reported for multiple days of landings (e.g. by week), which would greatly bias un-standardized average daily CPUE estimates. As a first step, logbook data were filtered to remove obvious errors (e.g. 0 traps hauled, daily number of traps above limit).

Two methods were then used to estimate CPUEs from the logbook and slip data. First, trap hauls and landings were summed by week of season. Logbook entries were then matched with associated landings from the slip data. As this analysis requires the number of traps hauled from the logbook data and the weight of the landing from the slip data, only matched entries were retained. Weekly average CPUEs (kg/trap) were calculated by licence from the weekly total trap hauls from the logbook data and the weekly weight of landings from the slip data. To limit the impact of erroneous logbook or slip data, the weekly CPUE estimates by licence id were further filtered and the top and bottom 2.5% of the data were removed from further analysis. For each year and region, the maximum weekly average CPUE (kg/trap) is used as an indicator, referred to as the “Logbook, unstandardized” CPUE estimate.

The second CPUE estimation method using logbook and slip data used a modelling approach to standardize the daily CPUE estimates. Daily logbook entries were first matched with associated slip data and daily CPUEs (kg/trap) were calculated by licence id using the number of traps hauled from the logbook entry and the weight of the associated landing from the slip data. Again, to limit the impact of erroneous logbook or slip data, the daily CPUE estimates by licence id were filtered and the top and bottom 2.5% of the data were removed from further analysis. A Generalized Additive Mixed Model (GAMM) was used to standardize these daily CPUEs.

Nonlinear relationships were assumed between the log-scale CPUEs and the day since the start of the fishery. Log-scale landings were also assumed to vary by assessment region.

Formally the statistical model is:

$$\ln \mathrm{C_{ij}} = \alpha_\mathrm{r} + \mathrm{s}(\mathrm{d_{ij}}) + \mathrm{p_j} \qquad (1)$$

Where C_{ij} is the CPUE for licence id i and logbook entry j. The model components are: the intercept parameters by fishing zone (α_r), a smoothing spline over fishing day ($s(dij)$) and a random effect for each landing port (p_j). Each year of data was analyzed independently using the gamm function from the R package *mgcv*, version 1.8 (Wood 2011). For each year and region, the maximum daily model predicted average CPUE (kg/trap) is used as the indicator, and is referred to as the “Logbook, standardized” CPUE estimate.

Commercial biomass and abundance

Data from the 2001 to 2009 and 2012 to 2022 Northumberland Strait survey were standardized by trawl swept area and fishing gear using methods and calibration coefficients presented in Asselin et al. (2023). A spatio-temporal random effects model, fit using the *sdmTMB* library (Anderson et al. 2022) in R (R Core Team 2021) was used to account for missing data in certain years and regions of the survey. Depth was included as a covariate and its coefficients were allowed to vary by year. The model assumed a Matern covariance function for the spatial process and first-order auto-regressive processes (AR-1) for the temporal processes. A cut-off of 5 km was used for the mesh and barriers were not used as the study area is relatively convex. Formally, the statistical model is:

$$\ln \mu = \alpha + \sum_{j=1}^{6} \beta_{j,y} B_j(d) + \Omega_y(p) + \epsilon_{y,p} + \ln a \qquad (2)$$

Where α is an intercept parameter, $\beta_{j,y}$ are time-varying coefficients, indexed by 6 B-spline basis functions B_j indexed by j and year y over water depth d, $\Omega_y(p)$ is a time-varying spatial process defined over coordinate space p, $\epsilon_{y,p}$ is an independent Gaussian error term over time y and space p, and $\ln a$ is an offset term for trawl swept area a, in square kilometers. The depth coefficients $\beta_{j,y}$ and the spatial process $\Omega_y(p)$ are both assumed to follow an AR-1 process. The B-spline basis functions for the depth effect were obtained from the bs function from the *splines* R package (R Core Team 2021), defined over a set of internal knots at 15, 20, and 27.5 meter depths, corresponding roughly to the 25th, 50th and 75th percentiles from the survey station depths from the data. For commercial abundance estimates, Lobster counts were assumed to follow a negative binomial distribution with mean μ and dispersion parameter r [i.e. $z \sim NB(\mu, r)$]. Similarly, for commercial biomass estimates, Lobster weights were assumed to follow a Tweedie distribution with mean μ and variance parameter σ^2 [i.e $z \sim TD(\mu, \sigma^2)$]. The annual spatial distribution of model residuals were examined to ensure a lack of systematic spatial bias.

PRODUCTIVITY INDICATORS

Pre-recruit abundance in Northumberland Strait multi-species bottom trawl survey

The abundance of pre-recruits, defined as Lobsters less than legal size, was estimated from Northumberland Strait survey data for 25 and 26A using the same modelling approach as described for the commercial abundance (see section 3.1.3). Three size-classes were analyzed: less than MLS but ≥ 10 mm below legal size, less than 10 mm below legal size but ≥ 20 mm below legal size, less than 20 mm below legal size but ≥ 30 mm, hereafter referred to as pre-recruits 1, pre-recruits 2 and pre-recruits 3, respectively. Lobsters within the size range of pre-recruits 1, 2, 3 are considered to be approximately one moult (i.e. one year), two moults (i.e. two years) and three moults (i.e. three years) away from legal size, respectively (Comeau and Savoie 2001).

Pre-recruit CPUE in Recruitment-index program data

The CPUE (n/trap) of one-year pre-recruit lobsters (less than MLS but ≥ 10 mm below legal size, bins 3 and 4) was calculated from recruitment-index program data. Only data from traps with blocked escapes vents were used.

Juvenile Lobsters in SCUBA surveys

Examination of length frequencies indicated that Lobsters of CL ≤ 20 mm were under-represented in the database, indicating incomplete detection by divers. Lobsters from 21 to 40 mm CL were more consistently captured by divers and fall within the sizes described as Early Benthic Phase (Wahle and Steneck 1991). Within this phase, Lobsters are cryptic, shelter seeking, and strongly associated with shallow water cobble habitat (Wahle and Steneck 1991), such as the habitat included within the SCUBA survey transects. The shelter seeking behaviour means they are less likely to move away or towards approaching divers, and thus data from the SCUBA surveys were thought to represent an unbiased census of these size Lobsters within transects.

Given the inconsistent sampling design, inferences of spatial and temporal trends from this data set were problematic. Potential biases exist at each level of sampling, be they at sites and transects (e.g. selection and retention), divers (e.g. detection, measurement and extent of area sampled) and sections (e.g. selection). The approach was to account for some sources of bias in the analysis, and to temper inferences where it was felt that important sources of bias remained. Diver sampling biases (e.g. Lobster detection and extent of area being sampled) were included as random effects in the statistical model to correct for both observer bias and changes in divers over time (Figure 10). Missing observations at the site and transect levels were partially accounted for through the use of temporally correlated random effects. Comparison of Lobster densities between sampling sites are presented, but not overly emphasized as they are likely subject to spatial sampling biases.

Selection/retention biases for transect sections posed a more complex issue as the proportion of transect sections sampled varied considerably through time due to multiple factors (Figure 11). The earliest transects in the study were sampled in Caraquet in 2003, followed by Shediac and Toney River in 2005, Neguac in 2006, Cocagne in 2008 and Murray Corner in 2015. Due to COVID-19, SCUBA sampling was suspended in 2020. Prior to 2019, the proportion of sections sampled varied much between sites and years. These proportions decreased from 2015 to 2018, ostensibly due to high densities of small Lobsters, which required divers to cut transects short due to lack of time.

The possibility that mainly sections with higher abundances were targeted was considered by performing the analysis on two data sets: one using the original data set and another which considered only the 50% of sections with the highest densities from each transect, called the truncated data set. This also had a secondary aim of bridging the recent series from 2019, which sampled most transect sections, and the series leading up to the 2018 survey which saw large portions of its transect sections left unsampled (Figure 11).

A total of 598 samples on 57 transects at 9 sites sampled from 2003 to 2022 were used for the analysis (Figures 7 and 8). Total Lobster counts from 21 to 40 mm CL, were tabulated for each transect, representing a total of 35,106 measured Lobsters for the original data set and 31,498 Lobsters for the truncated data set. Imprecise Lobster CL measurements, for example estimates from escaped Lobsters or other approximate measures, were treated by spreading observed counts to adjacent size categories using a Gaussian distribution with standard error equal to half of the assumed precision. For example, a count of n 25 mm CL Lobsters with a precision of 5 mm, would be partitioned into adjacent size categories using a N (25, $\sigma = 2.5$) Gaussian distribution.

A Generalized Linear Mixed Model (GLMM) with a negative binomial distribution was used for the analysis. Where appropriate, temporally correlated random effects were used, with the aim of smoothing out Lobster densities and filling out missing transect-year combinations.

The log-linear mean of the model is given by:

$$\ln \mu_{ytd} = \alpha + \beta_y + \tau_t + \delta_d + \gamma_{yt} + \ln a_{ytd} \qquad (3)$$

Where μ_{ytd} specifies the mean Lobster counts per square meter for year y, transect t and diver d. The α term is an intercept term, while β_y and γ_{yt} are year random effects assumed to follow first-order autoregressive [i.e. AR(1)] distributions. Transect $\tau_t \sim N(0, \sigma_\tau^2)$ and diver effects $\delta_d \sim N(0, \sigma_\delta^2)$ were assumed to follow zero-mean Gaussian distributions. An offset term corresponding to the area a_{ytd} covered by each diver, year and transect in m^2 was also included. We assumed that observed Lobster counts n_{ytd} follow a negative binomial distribution, written as $n_{ytd} \sim NB(\mu_{ytd}, r)$, where r is a dispersion parameter. Diver effects are treated as nuisance terms and inferences were based on an average diver from the set of divers that was considered. The model was fit using the R library *glmmTMB* (Brooks et al. 2017).

Young-of-year Lobsters in bio-collectors

Lobster observations from the bio-collector dataset were used to estimate the density of young-of-year (YOY) Lobsters at the study sites. YOY Lobsters are Lobsters that settled as stage IV larvae directly from the water column into the bio-collectors. Size-frequency distributions of Lobsters sampled were examined to determine the size-cutoff by site/year combination. Specifically, for each site/year combination, a gap in the size frequency around 14 mm was identified to separate the YOY Lobsters that settled directly into the collectors from older Lobsters that walked in. YOY settle at a size of around 5 mm CL and by the following year they are above 14 mm CL (Hudon 1987; Gendron and Sainte-Marie 2006). The annual mean density of YOY at each study site was estimated in R (R Core Team 2021) using a full interaction generalized linear model (GLM, with family=poisson), by site and year. Formally, the statistical model is:

$$\ln \mu_{sy} = \alpha + \beta_s + \tau_y + (\beta\tau)_{sy} \qquad (4)$$

Where μ_{sy} specifies the mean YOY counts per collector for site s and year y. Results were standardized to one square meter by dividing by the area of the collectors (i.e. 0.557 m^2).

Egg production

Following an approach similar to Cook et al. (2020), indexes of egg production were calculated by assessment region using at-sea sampling program data, recruitment-index program data, Northumberland Strait survey data and commercial landings.

For at-sea sampling program data and recruitment-index program data, as a first step, the weight of commercial Lobsters within the at-sea samples for each assessment region were calculated by converting the CL measurements to weights (see Table 5 for formulas and reference). As CL is measured in bins in the recruitment-index program, the middle size of the bin was used in all calculations.

Annual sampling ratios were calculated for each assessment region by dividing the calculated total weights of commercial landings in each of the at-sea sampling program data and the recruitment-index program data by the total weight of commercial landings (from slip data) in the assessment region. These ratios were then used to scale up the number of berried females at each size in the at-sea sampling program data and the recruitment-index program data to estimate total numbers in the fishable population.

An annual index of egg production was calculated for each dataset (i.e. at-sea sampling program data and recruitment-index program data) per assessment region using a modified version of the egg production model in Fogarty and Idoine (1988):

$$E = \sum_i f_i \cdot N_i \qquad (5)$$

where f_i is eggs per female (see formula in Table 5) and N_i is the number of females indexed over size i.

For the Northumberland Strait survey data, as it is conducted annually in July and August, when females may have released their eggs or not yet extruded them, a modified approach was used. Specifically, the number of eggs for each tow was estimated using:

$$E = \frac{\sum_i P_i \cdot f_i \cdot N_i}{2} \qquad (6)$$

where P_i is the proportion of females that are sexually mature (see formula in Table 5). The total is divided by 2 as, in any given year, an estimated half of the sexually mature females in the population will produce eggs (Aiken and Waddy 1980; Comeau and Savoie 2002). Annual egg production in 25 and 26A was then estimated using the same model as for commercial biomass (see section 3.1.3).

COMPARISONS OF ABUNDANCE AND PRODUCTIVITY INDICATORS

Pairwise comparisons of some abundance and productivity indicators in 25 and 26A were completed to assess how they relate to each other. Specifically, pairwise comparisons were completed for:

- Commercial biomass from the Northumberland Strait multi-species bottom trawl survey;
- Commercial abundance from the Northumberland Strait multi-species bottom trawl survey;
- Landings;
- CPUE for the at-sea sampling program in 25 and the recruitment-index program in 26A;
- Pre-recruit abundance 1, 2 and 3 from the Northumberland Strait multi-species bottom trawl survey; and
- Density of juveniles from the SCUBA survey.

FISHING PRESSURE INDICATORS

Percent empty traps

As in Rondeau et al. (2015) and Comeau et al. (2008), the percentage of empty traps was used as an indicator of fishing pressure. At-sea sampling program data and recruitment-index program data were used to calculate the percentage of empty traps. A trap was considered “empty” if there were no commercial Lobsters within the trap (i.e. excluding Lobsters below the MLS, berried females and window/maximum size females). The percent of empty traps was calculated annually for each assessment region, when data were available.

Exploitation rate

Three approaches were used to calculate the exploitation rates: two from the recruitment-index program and one from the Northumberland Strait survey data.

Following Rondeau et al. (2015), the estimator from Miller et al. (1987) was used, which compares the first moult class recruited to the fishery to the second moult class the following year (hereafter referred to as the 'moult class method'). Only males were used to avoid potential bias associated with the females' reproductive cycle [i.e. females have a 2-year reproductive cycle alternating between moulting and spawning (Comeau and Savoie 2002) while males moult annually at sizes close to the MLS (Comeau and Savoie 2001)]. The moult-class estimator relies on the assumption that the catchability is comparable for Lobsters from MLS to < MLS+20 mm and also from year to year (Tremblay 1998). Data from vented traps from the recruitment-index program were used and the instantaneous mortality rate (Z) for the first moult class was calculated as:

$$Z = -ln(N_2/N_1) \qquad (7)$$

where N_1 is the number of Lobsters in the first moult class and N_2 is the number of Lobsters in the second moult class the following year. The number of Lobsters by moult class was standardized to the number of traps sampled. The first moult class includes Lobsters ≥ MLS to < MLS+10 mm (bin sizes 5-6 for the recruitment-index program). The second moult class includes Lobsters ≥ MLS + 10 mm to < MLS+20 mm (bin sizes 7-8). The size of the first moult class was adjusted as needed to the MLS in place in the region. The MLSs from year to year+1 were always similar.

The estimated instantaneous mortality rate (Z) was used to estimate the exploitation rate (U) using the equation from Ricker (1980):

$$U = F/Z(1 - e^{-Z}) \qquad (8)$$

with the assumption that natural mortality ($M = 0.1$), such that $F = Z - 0.1$. Samples with less than 200 Lobsters for the first moult class were excluded.

Following Cook et al. (2020), data from the ventless traps from the recruitment-index program were used to calculate the exploitation rate using the "Continuous Change in Ratio" method (hereafter referred to as the CCIR method) (Claytor and Allard 2003). The CCIR method estimates exploitation rates by monitoring the change in the abundance ratio of commercial and sub-legal size Lobsters throughout the fishing season. Commercial Lobsters (y) were those ranging from the MLS to < MLS+20 mm (bin sizes 5 to 8, representing approximately two moult classes). Sub-legal Lobsters (r) were ≥ MLS-10 mm to < MLS (size bins 3-4). Classes were adjusted to MLS changes as needed and berried females were excluded from the analysis.

As in Cook et al. (2020), the CCIR model from Claytor and Allard (2003) was implemented in a Bayesian binomial setting which was used to estimate both the annual exploitation rates and 95% credibility intervals.

For each sampling trip (k) the number of commercial lobsters (y_k) was assumed to follow a binomial distribution; $y \sim Bin(n_k, \hat{\theta}_k)$, where:

$$\hat{\theta}_k = \frac{1}{\left(1+exp\left(-(A+Bg_k)\right)\right)} \qquad (9)$$

and A and B are constants and g_k represents the cumulative sum of annual sampling effort at trip k.

The *rstan* package (Stan Development Team 2022) was used to obtain posterior estimates of A and B and estimates of $\hat{\theta}_k$. Uninformative normal priors were used for A and B and four chains were run for 35,000 iterations, following a burn-in of 200. Every 20th sample was maintained for posterior analyses.

Distributions of exploitation rates at each interval u_k were obtained from the posterior samples of $\hat{\theta}_k$:

$$u_k = 1 - \frac{\hat{\theta}_k/1-\hat{\theta}_k}{\hat{\theta}_0/1-\hat{\theta}_0} \qquad (10)$$

where $\hat{\theta}_0$ is the $\hat{\theta}$ for the first day of the fishery.

For both the moult class and the CCIR methods, the following assumptions apply:

- the population is closed;
- the catchability of the size classes under consideration is equal;
- data from the recruitment-index trap are representative of non-monitored commercial traps; and
- the fishing effort is constant over the time period evaluated.

For the CCIR method only, the additional assumption is that the monitoring effort is directly proportional to the fishing effort.

Exploitation rates were also calculated using commercial biomass estimates from the Northumberland Strait survey (see section 3.1.3). For 25, as the survey is the month prior to the commercial fishery, exploitation rate was calculated as the commercial landings divided by the commercial biomass estimate from the survey (i.e. the pre-fishery biomass). For 26A, as the survey is the month after the commercial fishery, the total pre-fishery biomass was estimated by summing the commercial landings and the commercial biomass estimate from the survey. The exploitation rate was then calculated by dividing the commercial landings by this estimate of total biomass. For both 25 and 26A, 95% confidence intervals (CI) for the exploitation rate were calculated, using the 95% CI from the survey commercial biomass estimate.

Three-year rolling averages of the exploitation rates were calculated for all methods.

ECOSYSTEM INDICATORS

Prey availability

To develop an index of prey availability, data from the bio-collectors were examined to determine which Lobster prey species (as detailed in Hanson 2009; Boudreau and Worm 2012; Hanson et al. 2014) were represented. Lobster, Rock Crab and Cunner were captured and sampled consistently in the dataset. Other fish species (e.g. Three-Spined Stickleback and Atlantic Herring) were not represented in the dataset and other invertebrates (e.g. molluscs, polychaetes), while captured in the bio-collectors, were not sampled consistently. For Rock Crab and Lobster, only individuals ≤ 45 mm CW or CL, respectively, were included in the analysis. For Cunner, as only small individuals were captured in the bio-collectors, all individuals were included.

The annual mean density of Rock Crab, Lobster and Cunner at the eight study sites was estimated in R (R Core Team 2021) using a full interaction GLM (with family=poisson), by site and year. Formally, the statistical model is:

$$\ln \mu_{sy} = \alpha + \beta_s + \tau_y + (\beta\tau)_{sy} \quad (11)$$

where μ_{sy} specifies the mean number of individuals per collector for site s and year y. Results were standardized to one square meter by dividing by the area of the collectors (i.e. 0.557 m^2).

Predator pressure

An index of predator pressure was calculated from the September ecosystem survey abundance indices (Ricard et al. 2024) as the sum of the annual average catch (kg/tow) of potential Lobster predators [i.e. Cunner, Shorthorn Sculpin, White Hake, Longhorn Sculpin, American Shad, Rainbow Smelt, Atlantic Mackerel, Atlantic Cod, Sea Raven, Atlantic Wolffish, Winter Skate, Thorny Skate, Atlantic Halibut, Spiny Dogfish and Rock Crab (Hanson and Lanteigne 2000; Olaso et al. 2005; Boudreau and Worm 2010; Hanson et al. 2014)]. While Atlantic Herring have also been found to consume Lobster larvae (Hanson et al. 2014), they were excluded from the analysis as their highly aggregated distribution results in high inter-annual variability in bottom trawl survey catches that likely do not reflect true changes in abundance.

Habitat index - bottom temperature

An index of available Lobster habitat in June and September was calculated using June and September bottom temperature data following the method described in Chassé et al. (2014). Lobster density (in t per km^2) was calculated per statistical district from reported landings over the period 1968-2021. The 95% distribution of Lobster density was calculated for the full time series as a function of bottom water temperature. The habitat index (1985-2021) was defined as the total area of sea bottom within this 95% range, calculated from the gridded (resolution of 500 m) temperature data from the oceanographic group.

RESULTS

ABUNDANCE INDICATORS

Landings

Landings in the sGSL Lobster fishery continued to increase since the previous stock assessment (Rondeau et al. 2015) and the previous update to the stock status indicators (DFO 2019d). Total landings of 39,313 t in 2021 in the sGSL are well above the Limit Reference Point (LRP, 6,899 t), the Upper Stock Reference (USR, 13,798 t) and the Biomass at Maximum Sustainable Yield (BMSY, 17,247 t) (Figure 12, as defined in DFO 2014a), placing the stock within the defined healthy zone of the precautionary approach. Since the previous update to the Lobster stock assessment indicators in 2019, landings in each LFA increased and were above the long-term, mid-term and short-term median landings in 2021 (Table 7 and Figure 13). Landings in 23bc and 23g were also above the mid-term median landings since the previous assessment but landings in 23bc were below the short-term median landings from 2019 to 2021 (Figure 14), indicating a potential slight decrease in commercial abundance in this assessment region. Landings in 2021 in 23bc (1,616 t) are approximately 10% lower than the highest landings on record, 1,787 t in 2014.

Lower landings in 2020 in LFAs 23, 24, 26A and 26B are considered to be the results of a 2-week delay in the fishing season start (season opening on May 15, DFO 2020), and a coincidental 2-week reduction in season length, as an implication of the COVID-19 pandemic.

CPUE

All methods are showing increases in the CPUE of commercial Lobsters over the time series (2001 to 2022, Figure 15). Where multiple sources of data are available, temporal trends are generally consistent between methods. In 23bc, the inter-annual variability in the unstandardized CPUE estimate from logbook data makes it more difficult to identify a trend, but the estimates from the three methods are similar, when data are available. In all assessment regions, the highest standardized CPUE estimates were in 2020 at 1.4 , 1.4, 1.6, 2.7, 2.5, and 2.3 kg/trap in 23bc, 23g, 24, 25, 26A and 26B, respectively. While CPUEs in 2020 may have been impacted by the later start to the fishing season in LFAs 23, 24, 26A and 26B related to the COVID-19 pandemic (DFO 2020), in all assessment regions, 2019 had the second highest standardized CPUE estimates. The lowest standardized CPUE estimates (available for 2014 to 2020 only) were in 2016 in 23bc and 23g (0.9 kg/trap in both regions), in 2014 in 24 and 25 (1.0 and 1.1 kg/trap, respectively), in 2015 in 26A (1.0 kg/trap) and in 2017 in 26B (1.0 kg/trap). For CPUEs from the at-sea sampling program data, in 24 and 25, where data are available from 2001 to 2022, the time series highs were in 2022 (1.2 kg/trap) and 2019 (2.3 kg/trap), respectively. The time series lows in 24 and 25 were in 2004 (0.6 kg/trap) and 2001 (0.3 kg/trap), respectively. For CPUEs from the recruitment-index program data in 24, 25 and 26A (available for 2001 to 2022), the time series highs were in 2022 (1.6 kg/trap), 2021 (2.1 kg/trap) and 2020 (2.2 kg/trap), respectively. The time series lows in 24, 25 and 26A were in 2001 (0.6 kg/trap), 2004 (0.3 kg/trap) and 2007 (0.4 kg/trap), respectively.

Since 2020, CPUE estimates from at-sea sampling program data have decreased in 23bc, 23g and 25, to 0.9, 0.8 and 1.5 kg/trap in 2022, respectively. Similarly, in 26A, CPUE estimates from recruitment-index program data are showing a decrease to 1.5 kg/trap in 2022. As logbook data are unavailable for 2021 and 2022, it is not possible to compare these values to those that would have been obtained from logbook data.

Commercial biomass and abundance

In 25 and 26A, the abundance of commercial sized Lobster (i.e. number of Lobsters of commercial size, Figure 16) and the commercial biomass (i.e. tons of commercial Lobsters, Figure 17) have increased over the time series (2001 to 2022) reaching maximum values in 2022. In 25, the abundance and biomass of commercial Lobster were 37.8 million (95% CI 21.1-67.6 million) and 15.7K tons (95% CI 9.4-26.3K tons) in 2022, respectively. In 26A, the abundance and biomass of commercial Lobster were 33.1 million (95% CI 18.4-59.3 million) and 15.6K tons (95% CI 9.4-25.9K tons) in 2022, respectively. These increases are the result of a combination of increases in density and increases in distribution within 25 and 26A (Figure 18). The increases in density are most notable in central portions of the strait that were relatively devoid of commercial-sized Lobsters in the early years of the survey and now largely have densities above 3000 Lobsters per km^2.

Size distributions in both 25 and 26A show even proportions of males and females until the MLS is reached (Figure 19 and 20). At larger sizes, the sex-ratio is skewed towards males.

PRODUCTIVITY INDICATORS

Pre-recruit abundance in Northumberland Strait multi-species bottom trawl survey

Following a period of lower abundance from 2001 to 2012, the estimated abundance of pre-recruits 1, 2, and 3 has increased in both 25 and 26A since 2012 (Figures 21, 22 and 23). The increases in abundance are the result of a combination of increases in density and increases in distribution within 25 and 26A (Figures 24, 25 and 26). Specifically, high densities of pre-recruits are now found in both western and eastern portions of Northumberland Strait.

Pre-recruit CPUE in Recruitment-index program data

The CPUE of one-year pre-recruits has increased over the time series in 24, 25, 26A and 26B and generally follows the trend of the abundance of one-year pre-recruits in the Northumberland Strait survey in 25 and 26 (Figure 27).

Juvenile Lobsters in SCUBA surveys

Model parameters from the SCUBA GLMM are given in Table 6. The diver effect as calculated by the model indicates variations between divers were generally less than +/-10%, with the exception of one diver for which the diver effect was 23.6% above average (Figure 28). We consider the detection of Lobsters for the sizes used in the analysis (i.e. 21-40 mm CL) was likely high and that variation between divers in large part reflects differences in the width of the area sampled along the transect (i.e. to what extent divers sampled the correct 1 m or 2 m strip, without searching outside the boundary, or searching too narrow of a strip).

The global year effect from the truncated model shows a steady increase on the log-scale from 2003 up until 2016, which then stabilized or decreased slightly from 2016 to 2022 (Figure 29).

Site by year interaction effect values were generally high in the four most northerly sites, from Richibucto to Pointe-Verte; the central sites Cocagne and Shediac showed increases starting in 2011 to 2014; and the three southerly sites were generally low with Fox Harbour being the lowest (Figure 30). Transect by year interaction effects varied by transect and over time at each site (Figure 31).

Model outputs of the estimated mean number of Lobsters per 100 m^2 for each of the nine sampling sites (2003-2022) show steady or exponential increases in juvenile Lobster densities in the first half of the time series at most sites, followed by a steadying or decreasing in densities in recent years (Figure 32). Densities are highest at the Pointe-Verte (23bc), Caraquet (23bc), Richibucto (25) and Cocagne (25) sites, but are generally much lower in the southernmost sites, with the lowest being Fox Harbour (26A). Murray Corner (25), Fox Harbour (26A) and Toney River (26A) show some signs of having reached peak densities in 2016, 2016 and 2014, respectively, but subsequently declining in recent years. Cocagne (25) and Shediac (25) both show marked increases in densities around 2014, which have remained high since then. Only Richibucto (25) shows a seeming sustained gradual increase over the study period.

The overall pattern in density by year predicted by the model for the truncated dataset reflect that seen in the year random effect: a steady increase up until 2016 to 14.5 Lobsters per 100 m^2 (95% CI 3.6-57.6 Lobster per 100 m^2), followed by tapering high densities in recent years (Figure 33). The prediction errors are high as the densities between sampling sites are highly variable.

Young-of-year Lobsters in bio-collectors

YOY Lobsters were observed consistently at six of the eight bio-collector sites (Figure 34). Higher densities, and increases in densities, are observed at sites along the northern and northwestern coasts of PEI [i.e. Alberton (24), Covehead (24) and Skinner’s Pond (25)] and lower densities are observed at sites within western [i.e. Cape Egmont (25)] and eastern [i.e. Fortune (26A) and Murray Harbour (26A)] portions of Northumberland Strait. In central Northumberland Strait, only two YOY were detected over the time series in Nine Mile Creek (26A), one in 2009 and one in 2014. None have been observed in the four years of sampling in

Wallace (26A). In 2018, record high levels of YOY were detected at both Skinner's Pond (21.3 YOY/m^2, 95% CI 19.2-23.8) and Covehead (13.7 YOY/m^2, 95% CI 12.0-15.8) but densities have been much lower since. Alberton (24), shows less inter-annual variability and a time-series high of 14.6 YOY/m^2 (95% CI 12.8-16.6) in 2022.

Egg production

Despite large inter-annual variability, three independent datasets (i.e. at-sea sampling program, recruitment-index program and Northumberland Strait survey), and two analytical approaches (i.e. one based on berried females and one based on all females) yielded similar trends for egg production. While increases were observed in all assessment regions over the time series (Figure 35), there is large inter-annual variability in the results from at-sea sampling program data in 23bc and 23g and from the recruitment-index program data in 26B. In 24, 25 and 26A, where multiple data sets were available, the increasing trend is prevalent. Increases in egg production are likely the result of the combination of slight increases in the size of females in the at-sea samples (Figure 38) and of increases in landings (Figure 14), in all assessment regions.

COMPARISONS OF ABUNDANCE AND PRODUCTIVITY INDICATORS

In 25 and 26A, correlations between the various abundance and productivity indicators were strong overall, but higher in 25 than in 26A (Figures 36 and 37).

FISHING PRESSURE INDICATORS

Percentage empty traps

In all assessment regions, the percentage of empty traps (i.e. traps containing no commercial Lobsters) has decreased over the time series (2001 to 2022) and has been below 30% in all assessment regions since 2015 (Figure 39). In 24, 25 and 26A, where both data sources were available, the percentage of empty traps follows very similar trends, with the recruitment-index program results being generally slightly higher.

Exploitation rate

Data were not available to calculate exploitation rates in 23bc and 23g after 1999 and 2004, respectively, and none are presented here. Showing large amounts of inter-annual variability, in years when both the moult class and CCIR methods could be applied, exploitation rates from the CCIR analysis are generally higher, and consistently above 50% (Figure 40). In 25 and 26A, exploitation rates based on the commercial biomass from the Northumberland Strait survey analysis are generally the lowest of the three methods. In 26B, data were unavailable for many years but exploitation rates appear to be increasing in the last decade. Three-year average exploitation rates from the CCIR method (2020-2022) for 24, 25 and 26A were 80%, 51% and 83%, respectively. In 26B, sampling was not completed in 2020 and a three-year average exploitation rate could not be calculated for 2020-2022. Annual estimates are 81% in 2021, and 75% in 2022.

In 26A, results from the moult class analysis were more variable, diverged from the CCIR results and produced very low estimates in some years (e.g. 10% in 2012, 21% in 2013 and 18% in 2016).

ECOSYSTEM INDICATORS

Prey availability

Prey availability varied between sites and inter-annually within each site (Figure 41). Prey densities were highest in Alberton and Covehead (both in 24) but have decreased since 2016-2017. Prey densities were lowest in Wallace (26A).

From the eight sites, the three prey species (i.e. Rock Crab, Lobster and Cunner) were observed annually at five of the sites [Alberton (24), Murray Harbour (26A), Covehead (24), Skinner's Pond (25) and Fortune (26A)]. Rock Crab was not detected at Cape Egmont (25) while Cunner was not detected at Wallace (26A). Nine Mile Creek (26A) included a few observations of Lobster. In all but Nine Mile Creek (26A), Rock Crab densities have decreased over the time series while Cunner densities are variable and Lobster densities are either stable or generally increasing.

Predator pressure

From the start of the September survey time series in 1971, large decreases in the predator index were seen up until the early 2000s, driven by decreases in groundfish densities over that period (Figure 42). Looking only at data from 1991 to 2021 (Figure 43), decreases in the densities of Spiny Dogfish since 2003 are also evident, and modest increases in densities of pelagic fish (i.e. Rainbow Smelt, Atlantic Mackerel).

Habitat index - bottom temperature

The time series of average bottom temperature within the statistical district boundaries in each assessment region, as well as over the full assessment regions, were derived from the June and September survey temperature data (Figures 44 to 47). For June, the warmest years were observed in 1995 and 2020 for many assessment regions. For the deeper areas (e.g. 23bc, 23g, 24), the time series patterns are different than for those of shallower areas, demonstrating the effect of stratification typically observed in the deeper areas. The warmest assessment region is 25. The coolest region is 24 due to a large portion of its areas extending within the cold intermediate layer. Trends are not significant in June, but clear warming trends can be observed in September in the statistical districts of most assessment regions. However, the trend is not significant when combining all the regions together (bottom panel in Figure 45).

Average Lobster densities (1968-2021) were determined using information from sales slips (Figure 48). In June, 95% of the Lobsters were caught in bottom water temperatures between 0.4 and 14.0 °C (Figure 49). In September, 95% of the Lobsters were caught in bottom water temperatures between 3.3 and 18.0 °C (Figure 50). Based on these distributions there are indications that Lobster tend to avoid temperatures below 0.4 °C and above 18.0 °C.

Using the bottom water temperatures occupied by Lobster, time series of the surface area available to the species were then calculated for the entire sGSL for June (Figure 51) and September (Figure 52). Although there is a lot of inter-annual variability, the temperature habitat potentially suitable for Lobster has been clearly increasing in June during the 1985-2021 period (Figure 51). The June thermal habitat expansion rate is 585 km^2/yr. In September, the habitat index also shows marked variability but no significant trend is observed over the long term (Figure 52). The Lobster thermal habitat expansion in June mostly occurred in the deeper portions of the sGSL that are connected to the Laurentian Channel (Figure 53) where deep waters have been consistently warming up since 2009 (Galbraith et al. 2022). For September, the surface area has not increased significantly over the time series (1985-2020) but coastal areas and Northumberland Strait have warmed (Figure 54).

DISCUSSION

ABUNDANCE INDICATORS

The three abundance indicators support a conclusion that Lobster abundance in the sGSL has increased since the previous assessment (with data to 2012, Rondeau et al. 2015). While landings are commonly used as an indicator of abundance in Lobster stock assessments (e.g. Gendron and Savard 2012; Rondeau et al. 2015; Cook et al. 2020), and are used here, they are not equivalent to abundance, in that they are impacted by changes in the fishery, including increases in MLS and changes in effort, and they are incomplete as they only include sales through registered buyers (e.g. cash sales are not included). As noted by Cook et al. (2020), increases in MLS confound the relationship between landings, measured in weight, and abundance as fewer larger Lobsters are needed to reach the same weight in landings. In addition, as abundance increases, the relationship between landings and abundance could weaken if landings reach a ‘logistical’ maximum (i.e. the maximum quantity of lobsters that can be landed by fishers during a defined fishing season).

CPUEs can provide a better indicator of abundance as they combine information on landings but are standardized by the level of fishing effort. For the CPUEs calculated using data from the at-sea sampling program and the recruitment index program, the assumption is that the sampled traps in each assessment region are representative of the fishery as a whole within that assessment region. For CPUEs calculated using logbook data, the dataset is much larger, and thus more likely to be representative of the commercial fishery but inaccuracies or missing information in logbook entries and sales slip resulted in a portion of the data being discarded. CPUEs are impacted by changes in the fishable population that are not related to true abundance (e.g. changes in MLS). For example, increases in MLS in 2022 in 23bc, 23g and 25 (Table 2 and DFO 2022a, 2022b) may partially explain the decreases in CPUEs observed in those regions. For both CPUE estimates from logbook data (unstandardized and standardized), maximum values were used as these were considered to be more indicative of abundance and less impacted by annual differences in catchability at the start of the season.

For both landings and CPUEs, a 2-week delay in season opening in 2020 in LFAs 23, 24, 26A and 26B (DFO 2020), as a result of the COVID-19 pandemic, likely impacted the results. Landings were lower in 2020 than in 2021 in all of the impacted LFAs. For CPUEs, higher values in 2020 are likely the result of the fishing season starting later in the spring, when waters were warmer than usual, thus increasing catchability (McLeese and Wilder 1958; Green et al. 2014) at the start of the season, when densities are also at their highest.

As fisheries dependent data, landings and CPUEs are also dependent on an active fishery. If fishing activity ceases (e.g. cod moratorium) or effort is reduced (e.g. Rock Crab, DFO 2023b), data are no longer available to assess the fishery.

The fisheries-independent biomass and abundance indicators presented here have the advantage of not being impacted by changes in effort within the fishery, or inaccuracies in recorded data (e.g. logbooks and sales slips). The spatio-temporal modelling approach we used allowed us to estimate the commercial biomass for two years (2010 and 2011) when the fishing gear was different and calibration coefficients were not available, and to account for variability in sampling effort (e.g. no sampling in 26A in 2020). In 2022, fewer stations were sampled due to logistical constraints, which increased the confidence intervals (i.e. increased the uncertainty) for both the abundance and biomass estimates that year. When available, fisheries-independent trawl surveys can provide more consistent indicators of abundance than fisheries-dependent data. The higher proportion of commercial size males may be partially explained by the slower growth of mature females that generally moult (and thus grow) every two years (Comeau and

Savoie 2002), as opposed to mature males that continue to moult annually. Alternatively, sampling bias, whereas males may be captured more efficiently by the trawl due to behavioural or distribution differences between males and females, may also contribute to the observed pattern in the trawl survey data.

PRODUCTIVITY INDICATORS

The productivity indicators presented follow Lobsters from eggs (egg production), to first settlement (young-of-year Lobsters in bio-collectors), to juveniles (juvenile Lobsters in SCUBA survey) and finally to pre-recruits (CPUEs of pre-recruits in the recruitment-index program and pre-recruit abundance in the Northumberland Strait survey).

Collectively, these productivity indicators suggest that while egg production remains high, the habitat may be nearing capacity in terms of increasing Lobster densities on the seafloor. Alternatively, high natural mortality from egg to YOY may explain the slight disjunct between egg-production and densities of YOY and juvenile Lobsters. Haarr et al. (2020) found that the onset of hatching of eggs in the sGSL in 2014 was five weeks earlier than it had been in 1989. This type of change in Lobster phenology, likely related to warming, could result in a mismatch between planktonic Lobster larvae and their prey (as discussed in Haarr et al. 2020), thus reducing larval survival.

For the SCUBA survey results, comparisons between sites should be approached with caution. The study area of each site and the transect layout within each study area may not be representative of overall densities in those areas. As transect retention over the time series was largely based on retaining transects with higher densities, the transects within the current sampling plan likely represent areas with highest local densities. Future research could validate the predictive values of the densities presented here to better determine if densities of juvenile Lobsters on the SCUBA transects are indicative of future landings in the local area.

For egg production estimates from at-sea sampling program data and recruitment-index program data, sub-legal mature females are under-represented in the datasets as commercial traps are designed to minimize catches of sub-legal Lobsters. This negatively biases the egg production estimates from these two datasets. In addition, the egg production indicator is highly reliant on fecundity estimates at length and, to a lesser degree on maturity estimates. The proportion of females that are mature at length was calculated with equations from (Comeau and Savoie 2002). Future research could include updating these maturity curves, now over 20 years old, especially in light of recent document changes in size at maturity for Lobsters in the sGSL (Haarr et al. 2018). For fecundity, size-fecundity parameters presented in Table 2 of Currie and Schneider (2011) for Northumberland Strait and Bay of Fundy, Nova Scotia, for CL 65-163 mm, were used. These were calculated by Currie and Schneider (2011) using the results of Campbell and Robinson (1983), which included samples from Northumberland Strait, Eastern Nova Scotia and the Bay of Fundy. By combining the results from Campbell and Robinson (1983), the parameters presented in Currie and Schneider (2011) are more conservative at larger sizes than the parameters in Campbell and Robinson (1983) for Northumberland Strait, which were estimated from very few individuals above CLs of 100 mm (from Figure 3 in Campbell and Robinson 1983). Future work could include updating fecundity and maturity estimates to better reflect the spatial variability in the sGSL.

FISHING PRESSURE INDICATORS

For the percentage of empty traps, values presented here (i.e. lower than 30% in all assessment regions) are lower than those presented in Comeau et al. (2008) who reported values near or above 50% in four of five LFAs. In 23bc and 23g, the only indicator of fishing pressure that could be estimated was the percentage of empty traps. The lack of at-sea sampling program data between 2004 and 2012 leaves a gap in the series that coincides with a decrease in the percentage of empty traps. As 23bc is showing decreases in landings and decreases in the densities of juvenile Lobsters, additional information on exploitation rates in this region would provide a better understanding of potential changes in the fishery and Lobster stock. When lobster catch rates are relatively high, the percentage of empty traps is less informative as only one commercial size lobster in a trap means the trap is not ‘empty’. As such, this metric is not as sensitive to change as exploitation rates.

Exploitation rates in 24, 25, 26A and 26B, while high and variable, are largely stable through time. This stability supports the conclusion that increases in landings are the result of increases in abundance, as opposed to the result of a change in fishing pressure. The accuracy of exploitation rates calculated from the Northumberland Strait survey biomass estimates were impacted by the precision of the survey estimate but also the timing of the moult. As the survey takes place mainly in early to mid-July in 25 and mid-July to early August in 26A, the survey overlaps with the moulting period, which generally occurs from early July to early September (Comeau and Savoie 2001). Consequently, estimates of the exploitation rate in 25 are likely positively biased as Lobsters that will moult to legal size by the opening of the fishery in August are not included in the biomass estimate. Conversely, estimates of the exploitation rate in 26A are likely negatively biased as Lobsters that were sub-legal when the fishery closed at the end of June will have moulted to commercial size prior to the survey, and thus be included in the biomass estimate. Further work could consider inclusion of moult-stage in the analysis. Exploitation rates calculated using the moult class method are not as informative as those calculated using the CCIR approach.

ECOSYSTEM INDICATORS

Ecosystem indicators have been included in this framework as a step towards an ecosystem approach to the management of the sGSL Lobster stock. By incorporating prey, predators and the habitat, these indicators can give us a fuller picture of the status of the Lobster stock and the sustainability of the fishery. For the included prey items, decreases in Rock Crab abundance at all monitored sites could indicate that the observed high densities of Lobster are negatively impacting Rock Crab populations. As Rock Crab are a main prey for Lobster (Hanson et al. 2014), supporting growth and reproduction (Gendron et al. 2001), and the target of a commercial fishery (DFO 2023b), additional research on Rock Crab is needed to better inform the management of these two inter-related stocks.

The predator index is currently calculated based on data from one scientific survey, the September survey, which largely targets groundfish. Future work could include expanding to other species that are considered potential predators (e.g. Grey Seals) or for which there is anecdotal evidence of predation (e.g. Cormorants). American Lobster are also known to predate on conspecifics but were not included within the predator index estimates as increasing Lobster abundance would necessarily lead to an increase in predator-pressure, and would not be informative for stock assessment purposes.

The habitat index analysis showed increases in Lobster habitat in the sGSL, as a result of increases in bottom temperature. While temperature is an important factor in the distribution of Lobsters, additional factors could be considered in the future, including substrate and prey availability.

OTHER CONSIDERATIONS

Assessment regions 25 and 26A, are the most data-rich of the assessment regions, and thus indicators here can be used to validate indicators elsewhere. For example, the high correlation in 25 between the juvenile Lobster indicator from the SCUBA survey and landings, may indicate that, despite the limitations of the SCUBA survey dataset, results from the analysis may provide insights into future landings. Similarly, the high correlation between the Northumberland Strait survey biomass and landings in 25 (Figure 36), may indicate that landings do indeed reflect abundances in 23bc, 23g, 24 and 26B, in the absence of a fisheries-independent trawl survey. The lesser degree of correlation between biomass and landings in 26A is likely due to high inter-annual variability in the biomass estimate for that region (Figure 37).

Future work could consider inclusion of Lobster catch data from the September ecosystem survey of the southern Gulf of St. Lawrence (Savoie 2016; Ricard et al. 2024). Since 2008, Lobster catches within this survey have been steadily increasing (Ricard et al. 2024) and these data may serve as a fisheries-independent dataset in 23bc, 23g, 24 and 26B. The increasing catches in this dataset are likely the result of an expansion in the Lobster distribution to deeper waters, as seen in 25 and 26a in the Northumberland Strait survey dataset (Figure 18).

SOURCES OF UNCERTAINTY

The indicators presented are from multiple sources of data, each with their own caveats. Fishery-dependent data and monitoring activities (e.g. landings, at-sea sampling program, recruitment-index program) are impacted by changes in the fishery including those resulting from changes in regulations or socio-economic factors. For example, a delayed start to the fishing season in 2020 in LFAs 23, 24, 26A and 26B due to the COVID-19 pandemic (DFO 2020) may partially explain the higher CPUE estimates in those regions, as lobster catchability generally increases as water temperature increases in the spring. For the fisheries-independent data sources, sampling can be restricted to small areas (e.g. SCUBA and bio-collectors) and/or only be completed in a portion of the sGSL (e.g. Northumberland Strait survey), thus limiting inferences.

For the predator indicator, an array of potential predators of larval and benthic Lobster found in the September trawl survey dataset were included, but the effects of changes in predator abundance on the Lobster stock were not evaluated. Any interpretation of trends in the predator index would need to include careful consideration of the biases this approach entails, particularly for species found in habitats with low Lobster densities.

For the Lobster habitat analysis, only temperature was considered while other ecosystem variables (e.g. substrate, depth) also contribute to habitat suitability. In addition, year-to-year differences in the timing of the oceanographic surveys can introduce variability in the temperature time series used for the Lobster habitat index. The objective analysis technique used for the interpolation of the temperature fields can under/overestimate values especially near the coast when data need to be extrapolated.

CONCLUSIONS

Based on the reference points (DFO 2014a), the southern Gulf of St. Lawrence (sGSL) American Lobster stock is well within the healthy zone of the precautionary approach, with landings in 2022 almost three times the level of the Upper Stock Reference (USR). Landings in each assessment region have increased since the previous assessment. Other abundance indicators also show an increasing trend in the abundance of Lobster in the sGSL (Table 8). Productivity indicators have also increased since the previous assessment but do show some signs of stabilizing or of reduced growth. Fishing pressure indicators show a decrease in the number of empty traps and relatively stable exploitation rates, which, in combination with increases in abundance, likely indicate the stock can sustain the current level of exploitation. Collectively, the ecosystem indicators provide contextual information on habitat suitability for lobster, in terms of predator-prey relationships and water temperature.

The LRP and the USR were identified using used median landings from 1974 to 2009 as a proxy for the Biomass at Maximum Sustainable Yield (BMSY) (DFO 2014a). Since 1975, landings steadily increased until approximately 1990, after which they decreased until approximately 2005, before beginning a steady increase from 2005 to 2021. While the current LRP is for sGSL landings as a whole, the pattern has largely been similar in the assessment regions, with the exception of 24 where landings have steadily increased since 1975. These changes in Lobster abundance and observed concurrent changes in the populations of other commercially fished species in the sGSL may indicate a regime shift. Re-evaluation of the LRP could be considered to ensure it reflects the current ecosystem. The use of fishery-independent data to establish the LRP would be preferable, to remove uncertainty related to changes in the fishery.

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TABLES

Table 1. Key management measures in place during the 2021 lobster fishery in the southern Gulf of St. Lawrence; by lobster fishing area (LFA), sub-LFA or management zone.

	23A	23B	23C	23D	24	25	26A-1	26A-2	26A-3	26B North	26B South
Season dates	May 4 to July 4	May 4 to July 4	May 4 to July 4	May 4 to July 4	May 4 to July 1	Aug. 9 to Oct. 10	May 4 to July 1	May 4 to July 1	May 4 to July 1	May 7 to July 8	May 4 to July 4
Number of licences											
Category A	64	91	287	130	596	603	444	144	35	86	115
Category B	19	1	-	1	-	5	1	2	-	1	2
Maximum number of traps	300	300	300	300	300	250 NB; 240 PEI; 225 NS	280 NS; 272 PEI	255[a]	250	250	250
Minimum number of traps per line	NA	NA	3 (portion)	3 (portion)	6	NA	6 (part of PEI); 5 NS	6	2	5	NA
Maximum hoop size (mm)	152	152	152	152	NA	152	NA	152	NA	152	NA
Minimum legal carapace size (mm)	77	77	77	77	74	77	74	76	76	82.5	82.5
Window size females (mm)	115-129	115-129	115-129	115-129	115-129	≥ 115	115-129	115-129	115-129	NA	NA

[a] Some communal commercial licence holders have a limit of 275 traps

Table 2. Minimum legal carapace size (MLS, in mm) by fisheries management area, 1957 to 2022.

Year	23A	23B	23C	23D	24	25	26A-1	26A-2	26A-3	26B North	26B South
1957-1986	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5
1987	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	65.1	65.1
1988	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	66.7	66.7
1989	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	68.3	68.3
1990	65.1	65.1	65.1	65.1	63.5	65.1	63.5	63.5	63.5	70.0	70.0
1991-1996	66.7	66.7	66.7	66.7	63.5	66.7	65.1	65.1	65.1	70.0	70.0
1997	66.7	66.7	66.7	66.7	63.5	66.7	65.1	65.1	65.1	70.0	70.0
1998	67.5	67.5	67.5	67.5	65.1	67.5	65.9	65.9	65.9	70.0	70.0
1999	67.5	67.5	67.5	67.5	65.9	67.5	65.9	65.9	65.9	70.0	70.0
2000	67.5	67.5	67.5	67.5	66.7	67.5	66.7	66.7	66.7	70.0	70.0
2001-2002	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	70.0	70.0
2003	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5	72.0	72.0
2004	70.0	70.0	70.0	70.0	69.5	70.0	69.5	69.5	69.5	73.0	73.0
2005	70.0	70.0	70.0	70.0	70.0	70.0	70.0	71.5	73.0	74.0	74.0
2006	70.0	70.0	70.0	70.0	70.0	70.0	70.0	71.5	76.0	75.0	75.0
2007	70.0	70.0	70.0	70.0	70.0	70.0	70.0	71.5	76.0	76.0	76.0
2008	71.0	71.0	71.0	70.0	70.0	70.0	70.0	73.0	76.0	77.0	76.0
2009	72.0	72.0	72.0	70.0	70.0	70.0	70.0	73.0	76.0	79.0	76.0
2010	73.0	73.0	72.0	70.0	70.0	70.0	70.0	73.0	76.0	79.0	77.0
2011	74.0	74.0	72.0	71.0	71.0	71.0	71.0	73.0	76.0	80.0	79.0
2012	75.0	75.0	72.0	71.0	71.0	71.0	71.0	73.0	76.0	81.0	79.0
2013	76.0	76.0	73.0	72.0	72.0	72.0	72.0	73.0	76.0	81.0	79.0
2014	76.0	76.0	74.0	73.0	72.0	72.0	72.0	73.0	76.0	82.5	79.0
2015	76.0	76.0	75.0	74.0	72.0	72.0	72.0	75.0	76.0	82.5	80.0
2016	76.0	76.0	76.0	75.0	72.0	73.0	72.0	76.0	76.0	82.5	81.0
2017	76.0	76.0	76.0	76.0	72.0	75.0	72.0	76.0	76.0	82.5	81.0

Year	23A	23B	23C	23D	24	25	26A-1	26A-2	26A-3	26B North	26B South
2018	77.0	77.0	77.0	77.0	73.0	77.0	73.0	76.0	76.0	82.5	81.7
2019	77.0	77.0	77.0	77.0	73.0	77.0	73.0	76.0	76.0	82.5	82.5
2020	77.0	77.0	77.0	77.0	73.0	77.0	74.0	76.0	76.0	82.5	82.5
2021	77.0	77.0	77.0	77.0	74.0	77.0	74.0	76.0	76.0	82.5	82.5
2022	79.0	79.0	79.0	79.0	75.0	79.0	75.0	76.0	76.0	82.5	82.5

Table 3. Number of ports sampled, number of days at sea (Samples) and number of traps sampled annually in each assessment region through the at-sea sampling program, 2001 to 2022. Years when no sampling *was recorded are shown as "NA".*

	23bc			**23g**			**24**			**25**			**26A**			**26B**		
Year	**Ports**	**Samples**	**Traps**	**Ports**	**Samples**	**Traps**	**Ports**	**Samples**	**Traps**	**Ports**	**Samples**	**Traps**	**Ports**	**Samples**	**Traps**	**Ports**	**Samples**	**Traps**
2001	2	20	4055	1	36	10516	7	64	9049	5	15	2996	5	47	11153	1	28	8046
2002	1	10	2934	1	1	293	8	34	6495	5	13	2941	6	49	12686	1	11	3013
2003	2	7	2037	1	4	1167	12	30	5865	9	27	5942	19	76	19559	2	11	2230
2004	1	1	296	NA	NA	NA	9	24	4843	6	16	3563	10	31	7317	NA	NA	NA
2005	NA	NA	NA	NA	NA	NA	10	28	6374	7	15	3433	10	31	7727	NA	NA	NA
2006	NA	NA	NA	NA	NA	NA	10	30	7321	8	16	3274	9	35	8673	NA	NA	NA
2007	NA	NA	NA	NA	NA	NA	9	25	6615	6	13	2641	9	28	7651	NA	NA	NA
2008	NA	NA	NA	NA	NA	NA	9	25	6266	7	15	3308	8	25	7415	NA	NA	NA
2009	NA	NA	NA	NA	NA	NA	10	30	8049	5	9	1713	9	28	8289	NA	NA	NA
2010	NA	NA	NA	NA	NA	NA	9	22	5927	6	11	2318	9	28	8254	NA	NA	NA
2011	NA	NA	NA	NA	NA	NA	9	25	6465	6	13	2842	8	27	6808	NA	NA	NA
2012	3	26	7549	3	26	7750	9	28	7363	9	38	8596	13	61	15057	6	32	7517
2013	2	18	5345	2	17	4409	9	27	6752	7	28	5893	9	23	6025	6	26	6071
2014	1	7	1730	2	12	3133	9	23	6471	7	23	4123	8	27	7211	NA	NA	NA
2015	NA	NA	NA	NA	NA	NA	11	37	10820	6	14	3457	7	27	7584	NA	NA	NA
2016	2	14	4132	2	14	3692	11	28	8115	7	29	5642	8	27	7580	NA	NA	NA
2017	3	14	3508	2	15	4371	10	25	7258	10	36	6959	8	26	7112	NA	NA	NA

	23bc			23g			24			25			26A			26B		
Year	Ports	Samples	Traps	Ports	Samples	Traps	Ports	Samples	Traps	Ports	Samples	Traps	Ports	Samples	Traps	Ports	Samples	Traps
2018	2	12	2086	2	10	2368	9	23	6593	8	32	5218	8	25	6723	NA	NA	NA
2019	2	13	2344	2	10	1856	11	34	9529	8	29	3959	8	27	7514	NA	NA	NA
2020	1	1	184	1	2	246	NA	NA	NA	1	3	370	NA	NA	NA	NA	NA	NA
2021	2	8	1389	1	3	476	8	25	7181	8	22	3953	8	25	6990	NA	NA	NA
2022	2	8	1476	2	8	1616	8	23	6598	8	19	3485	7	24	6483	NA	NA	NA

Table 4. Number of participants (Part.), number of modified traps sampled (Mod.) and number of regular traps sampled (Reg.) annually in each assessment region through the recruitment-index program, 2002 to 2022. Modified traps have blocked escape vents. Regular traps have functioning escape vents. Years when no sampling was recorded are shown as "NA".

	23g			24			25			26A			26B		
Year	Part.	Mod.	Reg.	Part.	Mod.	Reg.	Part.	Mod.	Reg.	Part.	Mod.	Reg.	Part.	Mod.	Reg.
2002	10	1536	1536	56	7712	7786	27	3078	2982	29	3888	3892	10	1176	1175
2003	10	1395	1395	57	8044	8042	27	2876	2875	28	3803	3803	10	1242	1241
2004	9	1389	1385	53	7373	7379	19	1817	1936	28	3689	3690	9	1029	1028
2005	NA	NA	NA	53	7161	7159	11	1386	1386	27	3566	3569	NA	NA	NA
2006	NA	NA	NA	51	7347	7347	12	1595	1595	25	3349	3349	NA	NA	NA
2007	NA	NA	NA	51	7131	7131	9	1175	1175	24	3297	3302	NA	NA	NA
2008	NA	NA	NA	51	6953	6952	12	1505	1505	26	3402	3402	NA	NA	NA
2009	NA	NA	NA	54	7170	7172	13	1607	1607	27	3464	3465	NA	NA	NA

	23g			24			25			26A			26B		
Year	**Part.**	**Mod.**	**Reg.**	**Part.**	**Mod.**	**Reg.**	**Part.**	**Mod.**	**Reg.**	**Part.**	**Mod.**	**Reg.**	**Part.**	**Mod.**	**Reg.**
2010	NA	NA	NA	52	6876	6879	16	1997	1996	27	3305	3304	NA	NA	NA
2011	NA	NA	NA	52	6789	6789	16	1934	1934	24	3273	3273	NA	NA	NA
2012	NA	NA	NA	51	7037	7036	15	1772	1773	33	4693	4549	5	645	641
2013	NA	NA	NA	49	5958	5976	15	1757	1757	33	4190	4189	4	432	434
2014	NA	NA	NA	50	6645	6645	15	1966	1966	37	5172	5172	10	1177	1165
2015	NA	NA	NA	47	6111	6110	15	1907	1907	25	3104	3105	4	519	519
2016	NA	NA	NA	52	7117	7115	14	1848	1849	35	4984	4984	8	1002	1002
2017	NA	NA	NA	54	7164	7164	13	1697	1697	34	4728	4739	8	945	945
2018	NA	NA	NA	50	6821	6813	14	1845	1855	35	4950	4944	8	927	927
2019	NA	NA	NA	46	5916	5915	11	1326	1355	35	4672	4673	8	906	906
2020	NA	NA	NA	44	4766	4764	12	1478	1472	23	2483	2475	NA	NA	NA
2021	NA	NA	NA	37	4937	4934	10	1153	1153	31	4208	4208	8	930	930
2022	NA	NA	NA	42	5406	5408	9	1074	1074	29	3887	3900	7	726	726

Table 5. Equations used for length-weight conversions, proportion of mature females and number of eggs per female. In all cases, CL refers to carapace length in mm.

Description	Equation	Reference
Length (mm) to weight (g)	Females: $weight = 0.0013 \cdot CL^{2.8822}$ Males: $weight = 0.0006 \cdot CL^{3.0782}$	Rondeau et al. 2015
Proportion females mature	$P = \frac{1}{1 + exp^{[-(-16.94+0.239 \cdot CL)]}}$	Comeau and Savoie 2002
Eggs per female	$E = 0.007 \cdot CL^{3.188}$	Currie and Schneider 2011, Table 2

Table 6. Model parameters from the SCUBA generalized linear mixed model (GLMM).

Parameter	Description	Value
intercept (α)	Global intercept	-2.9032
diver (σ_δ)	Standard error	0.09452
year (σ_β)	Standard error	0.88326
site (σ_ρ)	Standard error	3.35953
transect:site ($\sigma_{\tau\rho}$)	Standard error	0.31245
year (ϕ_β)	AR-1 correlation	0.97
site (ϕ_ρ)	AR-1 correlation	0.98
transect:site ($\phi_{\tau\rho}$)	AR-1 correlation	0.72
Dispersion (r)	NB dispersion	28.7

Table 7. Commercial lobster landings (t) in Lobster Fishing Areas 23, 24, 25, 26A and 26B and in total in the southern Gulf of St. Lawrence, 1947 to 2021.

Year	23	24	25	26A	26B	Total
1947	1,285	497	941	1,720	345	4,788
1948	1,375	738	1,565	2,206	462	6,346
1949	1,508	621	1,891	2,311	445	6,776
1950	1,919	836	2,257	2,989	491	8,492
1951	1,665	712	2,131	2,813	672	7,993
1952	1,568	824	2,039	2,855	512	7,798
1953	1,298	591	1,592	2,282	628	6,391
1954	1,202	905	1,489	2,819	594	7,009
1955	1,009	942	1,988	2,853	611	7,403
1956	1,765	1,055	2,268	3,011	520	8,619
1957	1,550	1,783	3,756	2,533	482	10,104
1958	1,241	1,492	3,655	2,461	426	9,275
1959	1,148	1,426	3,760	2,893	585	9,812
1960	1,529	1,758	4,909	2,999	530	11,725
1961	1,464	1,807	4,186	2,753	475	10,685
1962	1,265	1,685	3,520	2,658	495	9,623
1963	1,038	1,425	2,954	2,377	441	8,235
1964	898	1,562	2,711	2,257	450	7,878
1965	901	1,983	1,997	2,423	511	7,815
1966	977	1,848	1,777	1,901	451	6,954
1967	914	2,232	1,515	1,795	524	6,980
1968	913	1,968	1,880	2,680	495	7,936
1969	791	1,922	2,220	2,524	629	8,087
1970	974	2,230	1,821	2,388	514	7,926
1971	836	1,770	1,935	2,470	519	7,530
1972	811	1,715	1,859	1,830	629	6,844
1973	868	1,860	1,642	1,737	526	6,633

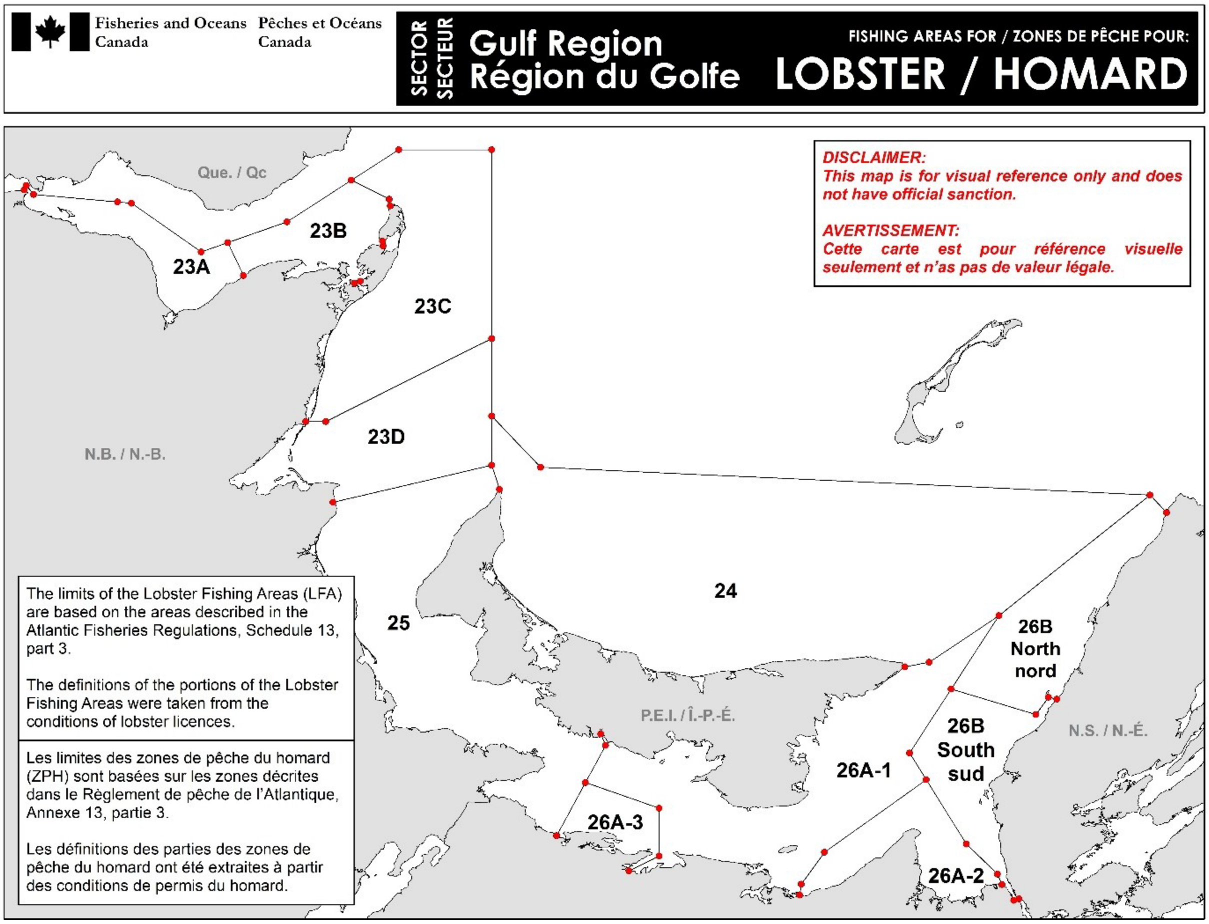
Year	23	24	25	26A	26B	Total
1974	759	1,396	1,647	1,387	406	5,594
1975	1,077	1,947	2,261	2,130	453	7,868
1976	1,157	1,951	2,654	1,809	491	8,062
1977	1,256	2,123	2,373	1,873	487	8,112
1978	1,612	2,345	3,105	2,195	632	9,889
1979	1,640	2,781	3,121	2,658	733	10,933
1980	1,917	2,715	3,111	2,336	700	10,780
1981	1,732	2,616	3,177	2,792	780	11,096
1982	1,730	2,713	3,687	2,693	1,023	11,845
1983	1,864	3,233	4,338	3,865	948	14,249
1984	2,230	2,955	4,427	3,419	883	13,915
1985	2,026	2,701	6,323	3,944	935	15,928
1986	2,478	3,114	5,794	5,724	1,134	18,245
1987	3,009	3,278	5,758	6,194	1,048	19,288
1988	3,114	3,698	5,463	6,691	1,190	20,156
1989	4,528	3,710	5,877	6,284	1,130	21,529
1990	4,508	4,591	5,356	6,363	1,281	22,099
1991	4,186	5,109	4,770	5,844	1,543	21,451
1992	4,264	4,605	4,585	4,594	1,411	19,459
1993	4,485	4,732	4,235	4,715	1,455	19,621
1994	4,111	4,830	4,572	3,480	1,110	18,103
1995	4,069	5,109	4,376	3,536	1,152	18,243
1996	3,784	4,628	4,255	3,720	1,126	17,513
1997	3,547	4,836	3,863	3,472	1,079	16,796
1998	3,723	5,044	4,144	3,933	1,111	17,955
1999	3,661	5,100	3,950	3,555	1,068	17,334
2000	3,808	5,198	3,573	3,992	1,112	17,683
2001	3,594	5,436	3,506	3,856	1,180	17,572

Year	23	24	25	26A	26B	Total
2002	3,344	5,441	3,369	4,279	1,213	17,645
2003	3,295	5,918	2,694	3,909	1,095	16,911
2004	3,028	6,338	2,423	3,381	1,093	16,263
2005	2,909	5,767	2,477	3,181	1,138	15,472
2006	3,261	6,448	2,763	3,510	1,178	17,160
2007	3,217	5,910	3,261	3,431	967	16,786
2008	3,446	6,288	3,332	3,837	1,089	17,991
2009	4,019	6,497	3,960	4,099	1,083	19,658
2010	4,602	6,550	4,329	4,255	1,080	20,816
2011	4,648	5,472	4,018	3,872	1,069	19,078
2012	5,043	7,170	5,037	4,893	1,455	23,598
2013	6,523	7,493	5,040	5,698	1,727	26,480
2014	7,201	7,059	5,914	6,444	1,569	28,186
2015	7,546	8,403	5,787	5,753	1,593	29,082
2016	6,569	7,386	6,668	5,185	1,524	27,332
2017	7,703	8,586	8,019	6,827	1,930	33,065
2018	8,095	8,688	9,019	7,739	1,723	35,264
2019	8,864	9,340	10,137	8,611	1,731	38,683
2020	7,714	8,639	9,826	6,926	1,799	34,905
2021	9,351	10,362	9,715	7,721	2,164	39,313

Table 8. Summary of trends since 2013 (i.e. previous stock assessment) for the stock status indicators for the southern Gulf of St. Lawrence (sGSL) Lobster stock in assessment regions 23bc, 23g, 24, 25, 26A and 26B. The letters U, S and D, represent upward (U), stable (S) and downward (D) trends, respectively. NA indicates data were not available for a specific indicator, or the analysis was not completed at the spatial scale of the region indicated.

Category	**Indicator**	**sGSL**	**23bc**	**23g**	**24**	**25**	**26A**	**26B**
Abundance	*Landings*	U	S	U	U	U	U	U
	CPUE	U	U	U	U	U	U	U
	Commercial biomass	NA	NA	NA	NA	U	U	NA
Productivity	*Pre-recruit abundance*	NA	NA	NA	NA	U	U	NA
	Pre-recruit CPUE	NA	NA	NA	U	U	U	U
	Juvenile Lobsters	NA	U	S	NA	U	D	NA
	YOY Lobsters	NA	NA	NA	U	U	S	NA
	Egg production	U	U	U	U	U	U	U
Fishing pressure	*Percent empty traps*	NA	S	S	D	D	D	S
	Exploitation rate	NA	NA	NA	S	S	S	U
Ecosystem	*Prey availability*	NA	NA	NA	D	S	D	NA
	Predator pressure	S	NA	NA	NA	NA	NA	NA
	Habitat index (June)	U	NA	NA	NA	NA	NA	NA
	Habitat index (September)	S	NA	NA	NA	NA	NA	NA

FIGURES



DISCLAIMER:
This map is for visual reference only and does not have official sanction.

AVERTISSEMENT:
Cette carte est pour référence visuelle seulement et n'as pas de valeur légale.

The limits of the Lobster Fishing Areas (LFA) are based on the areas described in the Atlantic Fisheries Regulations, Schedule 13, part 3.

The definitions of the portions of the Lobster Fishing Areas were taken from the conditions of lobster licences.

Les limites des zones de pêche du homard (ZPH) sont basées sur les zones décrites dans le Règlement de pêche de l'Atlantique, Annexe 13, partie 3.

Les définitions des parties des zones de pêche du homard ont été extraites à partir des conditions de permis du homard.

Figure 1. Map of southern Gulf of St. Lawrence American Lobster Fishing Areas (LFAs), sub-LFAs and management zones.

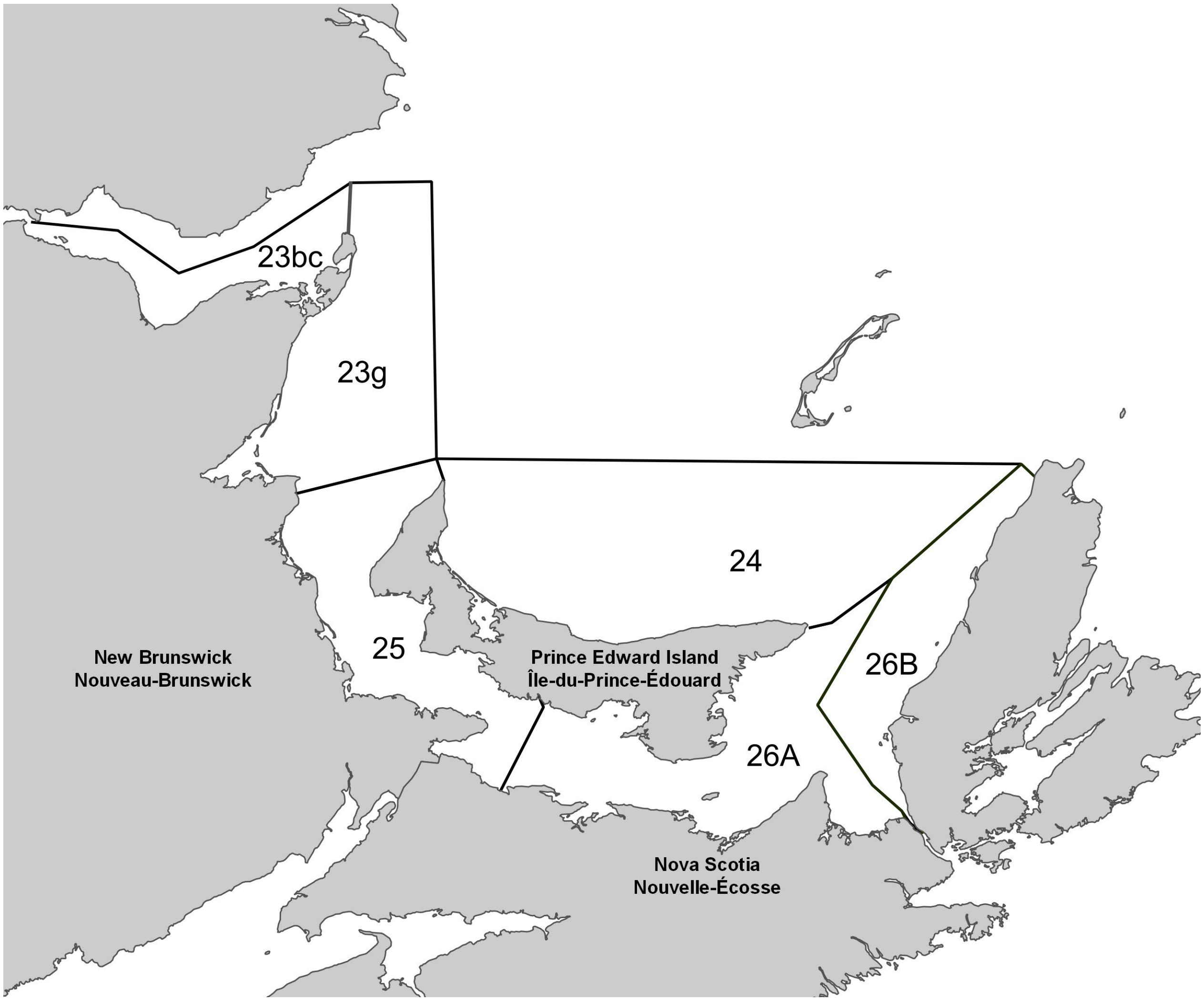


Figure 2. Map of regions used in southern Gulf of St-Lawrence American Lobster stock assessment indicator calculations.

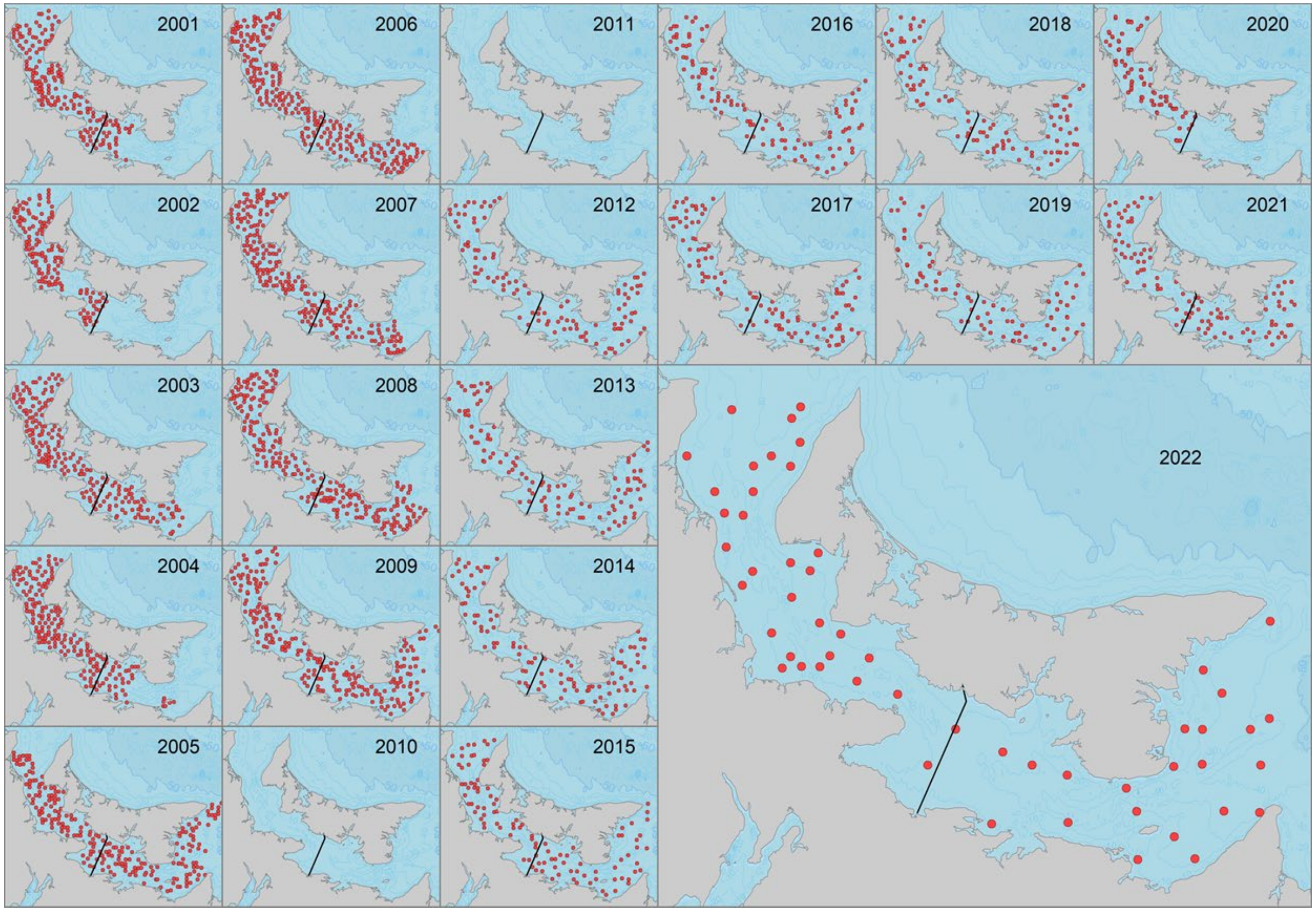


Figure 3. Northumberland Strait multi-species bottom trawl survey, set locations, 2001 to 2022.

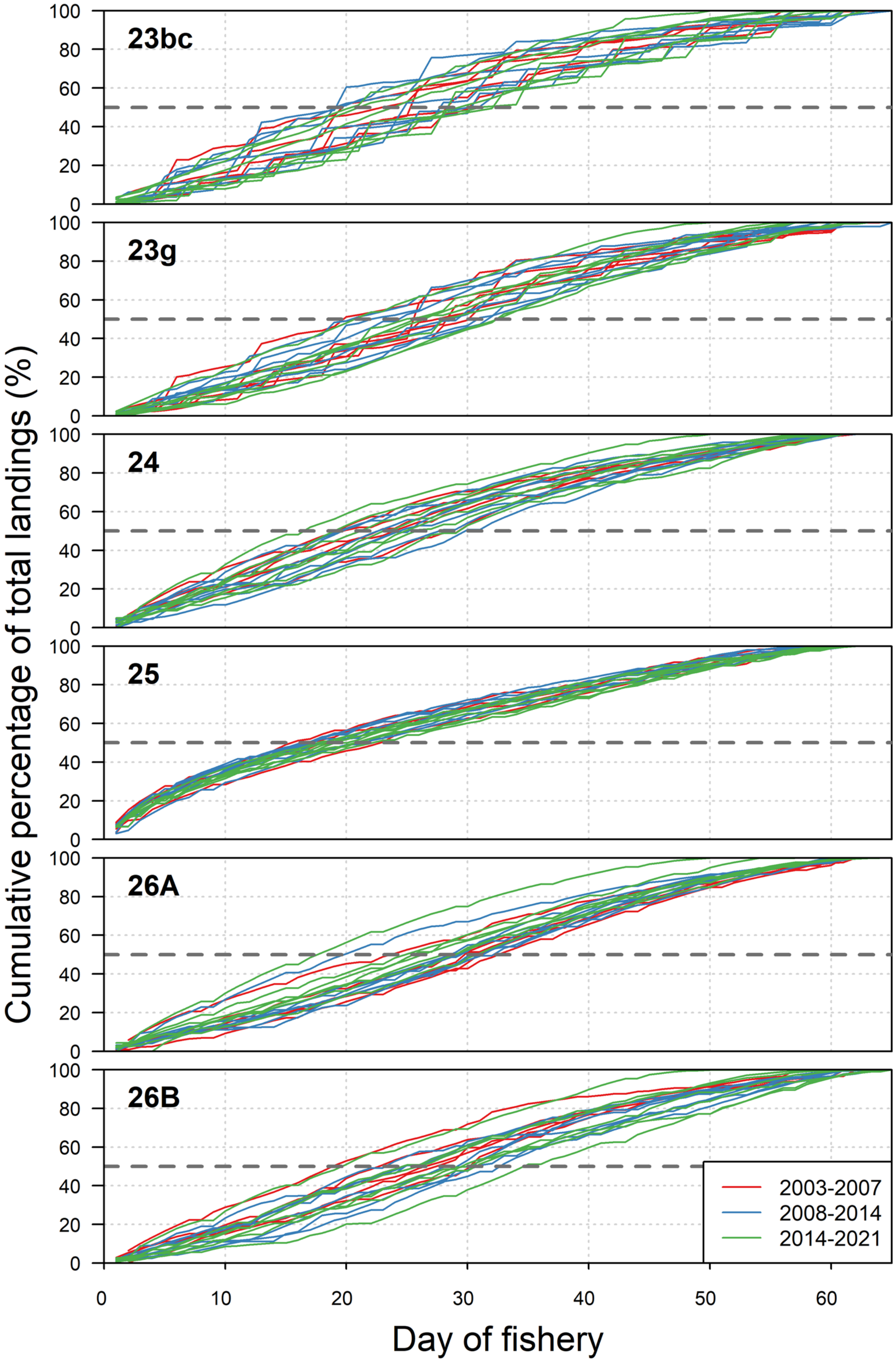


Figure 4. Cumulative percentage landings by day of season in assessment regions 23bc and 23g and LFAs 24, 25, 26A and 26B, 2003 to 2021.

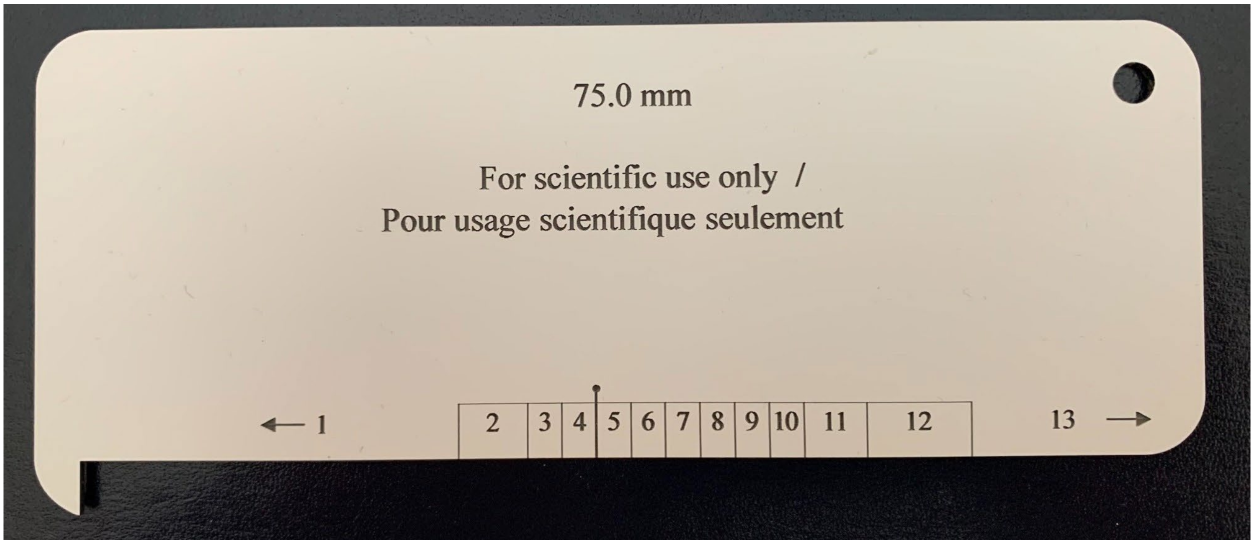


Figure 5. Example of gauge used to measure Lobster carapace length during the recruitment-index program.

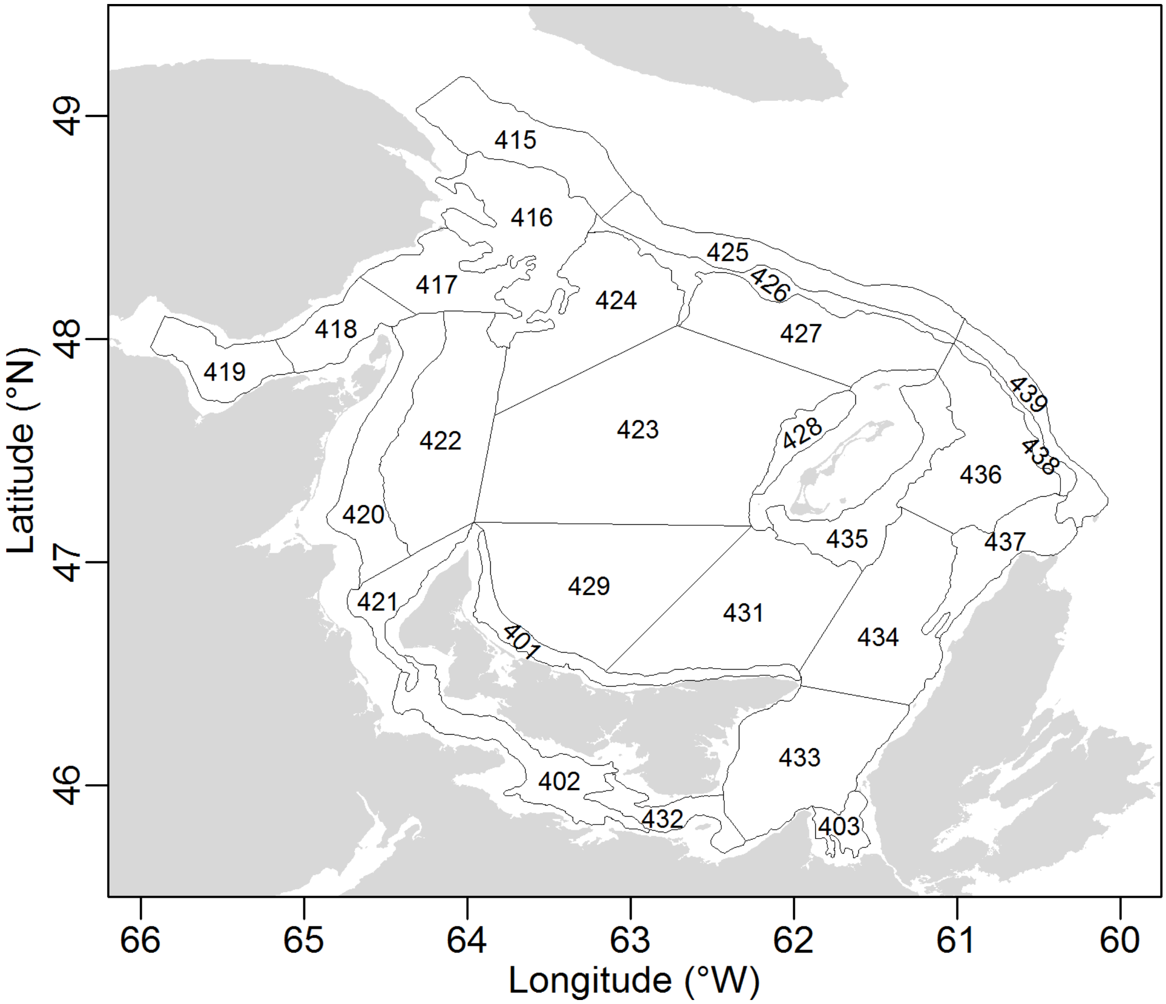


Figure 6. Map of study area and strata from the annual September ecosystem system of the southern Gulf of St. Lawrence.

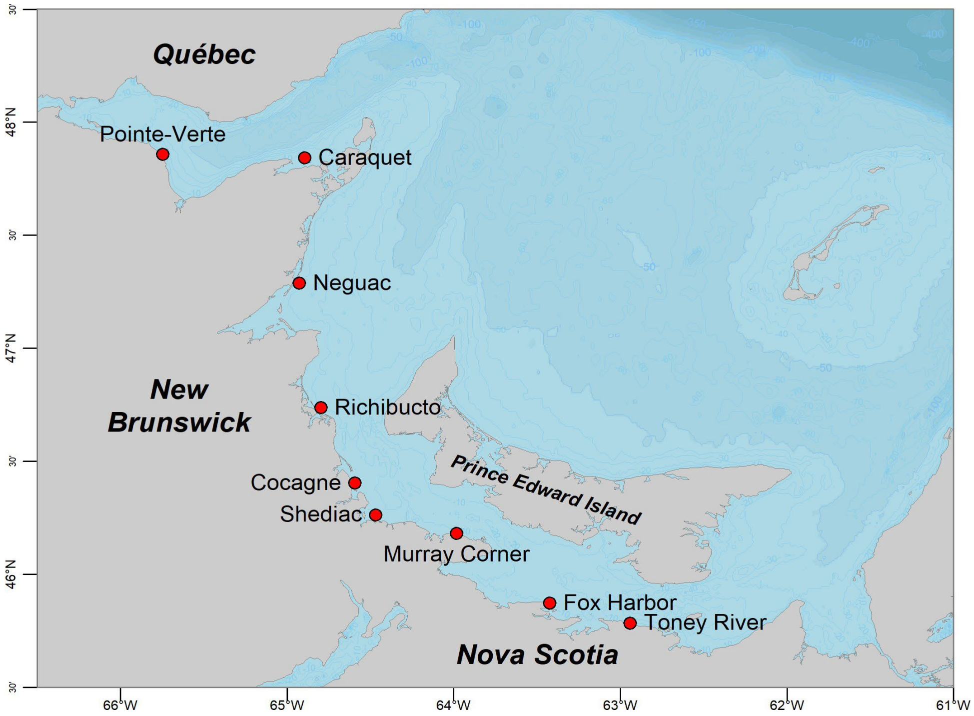


Figure 7. SCUBA survey study sites.

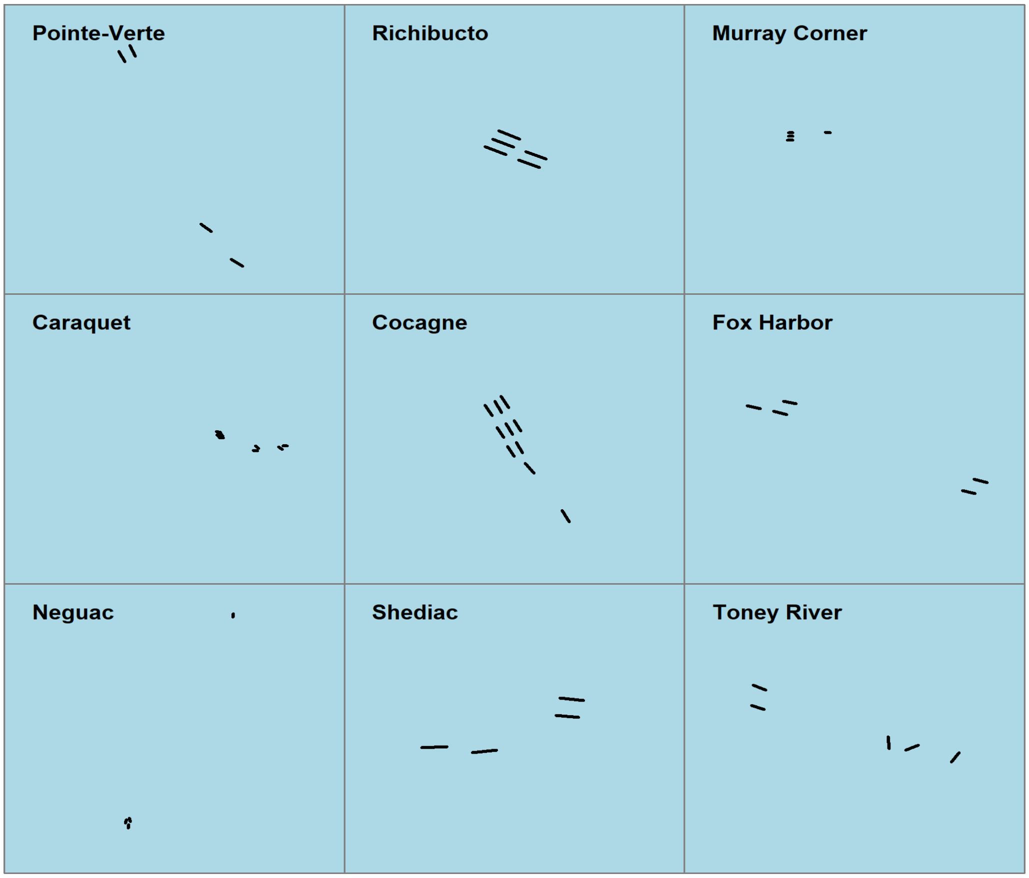


Figure 8. Transects used in SCUBA survey analysis, by site.

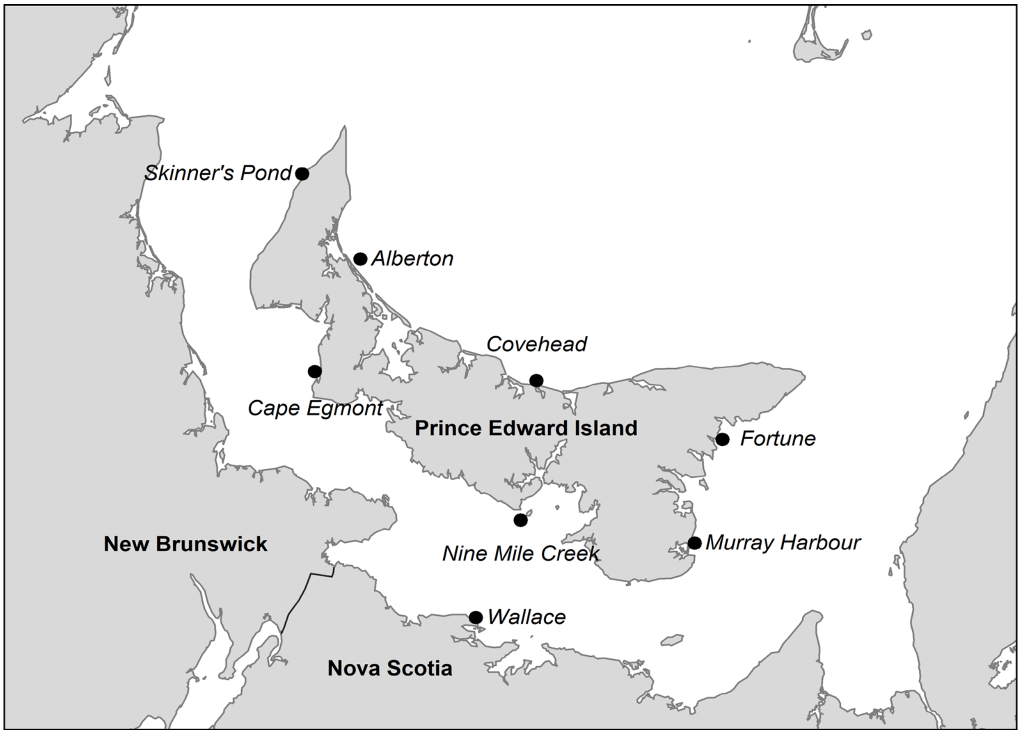


Figure 9. Bio-collector study sites.

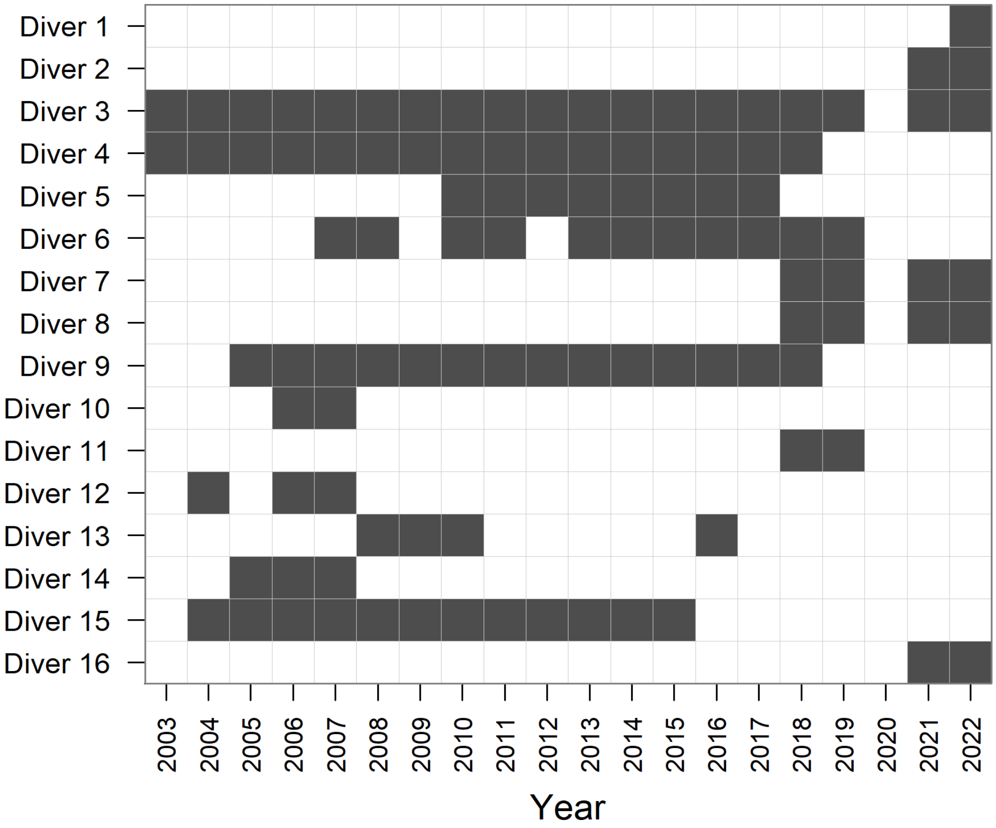


Figure 10. Summary of SCUBA diver participation in survey, 2003 to 2022. Note: diver labels are consistent between this figure and Figure 28.

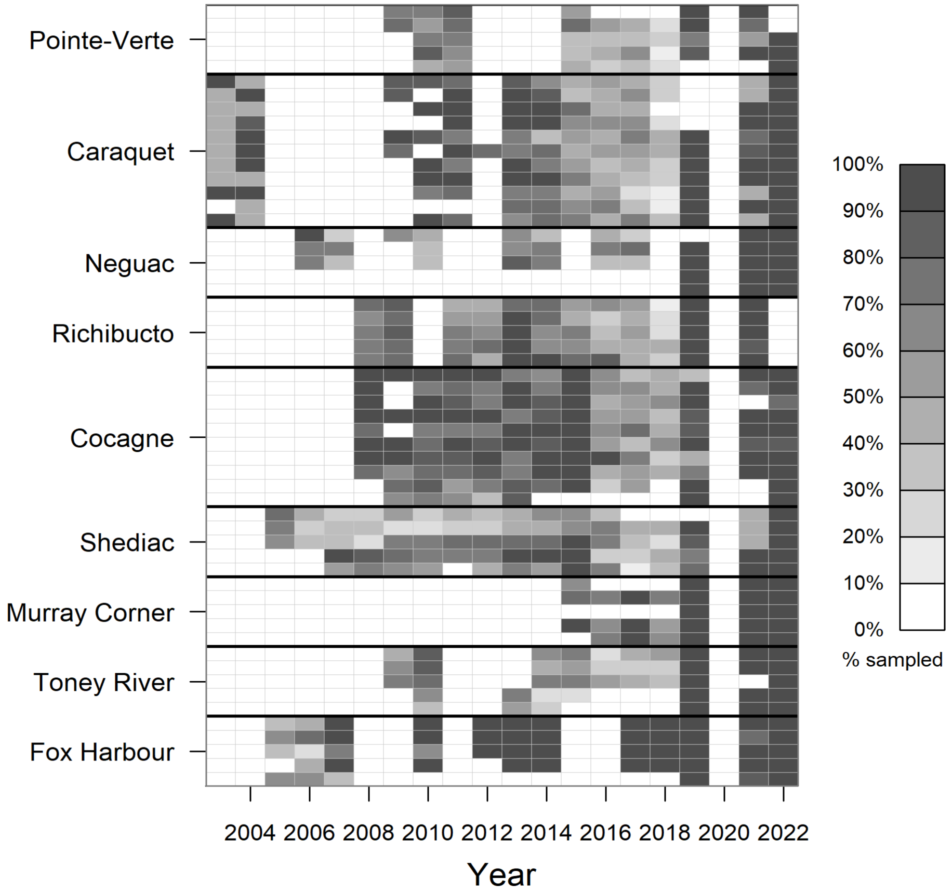


Figure 11. Summary of SCUBA transect sampling data availability by sampling site and transect over time. Shading is proportional to the percentage of transect sections that were sampled.

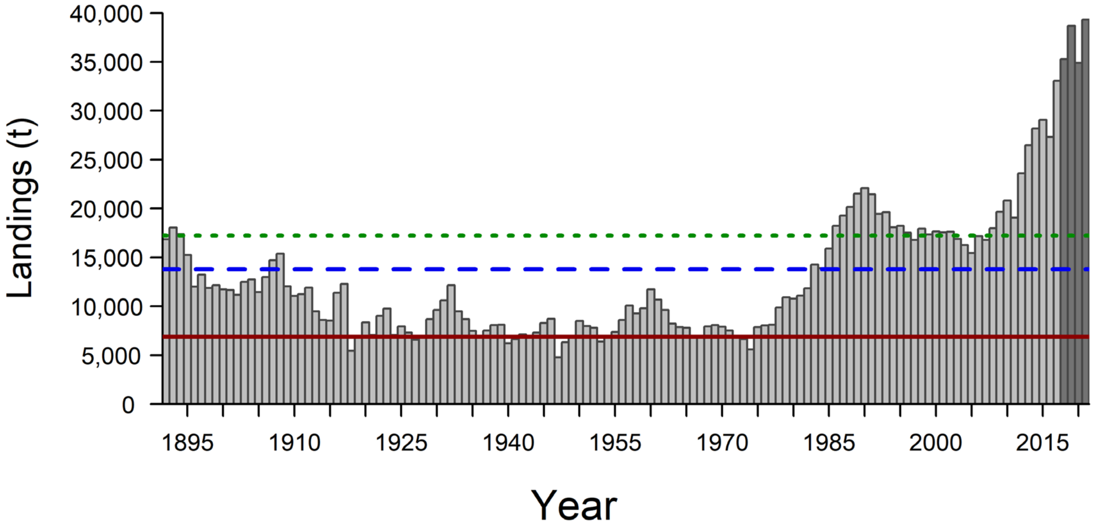


Figure 12. Reported Lobster landings (t) in the southern Gulf of St. Lawrence (DFO Gulf Region) from 1892 to 2021. The red solid line, the blue dashed line and the green dotted line represent the limit reference point (6,899 t), the upper stock reference (13,798 t) BMSY (17,247 t) for the southern Gulf of St. Lawrence Lobster fishery (DFO 2014a). Data added since the last update (2018 to 2021) are in a darker grey shading. Data for 2021 are preliminary.

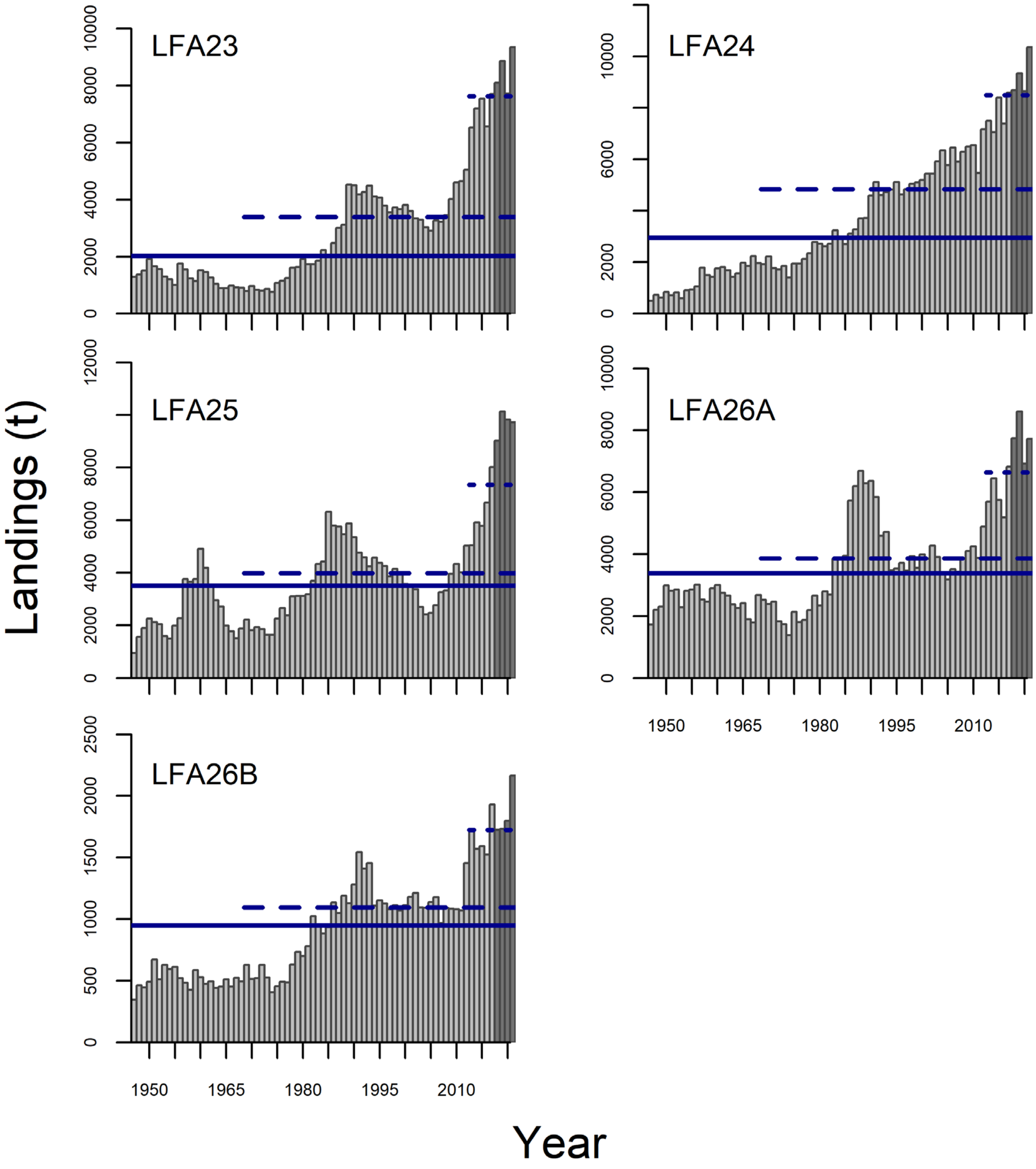


Figure 13. Reported Lobster landings (t) by Lobster Fishing Areas (23, 24, 25, 26A, 26B) in the southern Gulf of St. Lawrence, 1947 to 2021. The solid line, the dashed line and the dotted line represent the median long-term (1947-2021), mid-term (1968-2021) and short-term (2012-2021) landings, respectively. Data added since the last assessment update (2018-2021) are in a darker grey shading. Data for 2021 are preliminary.

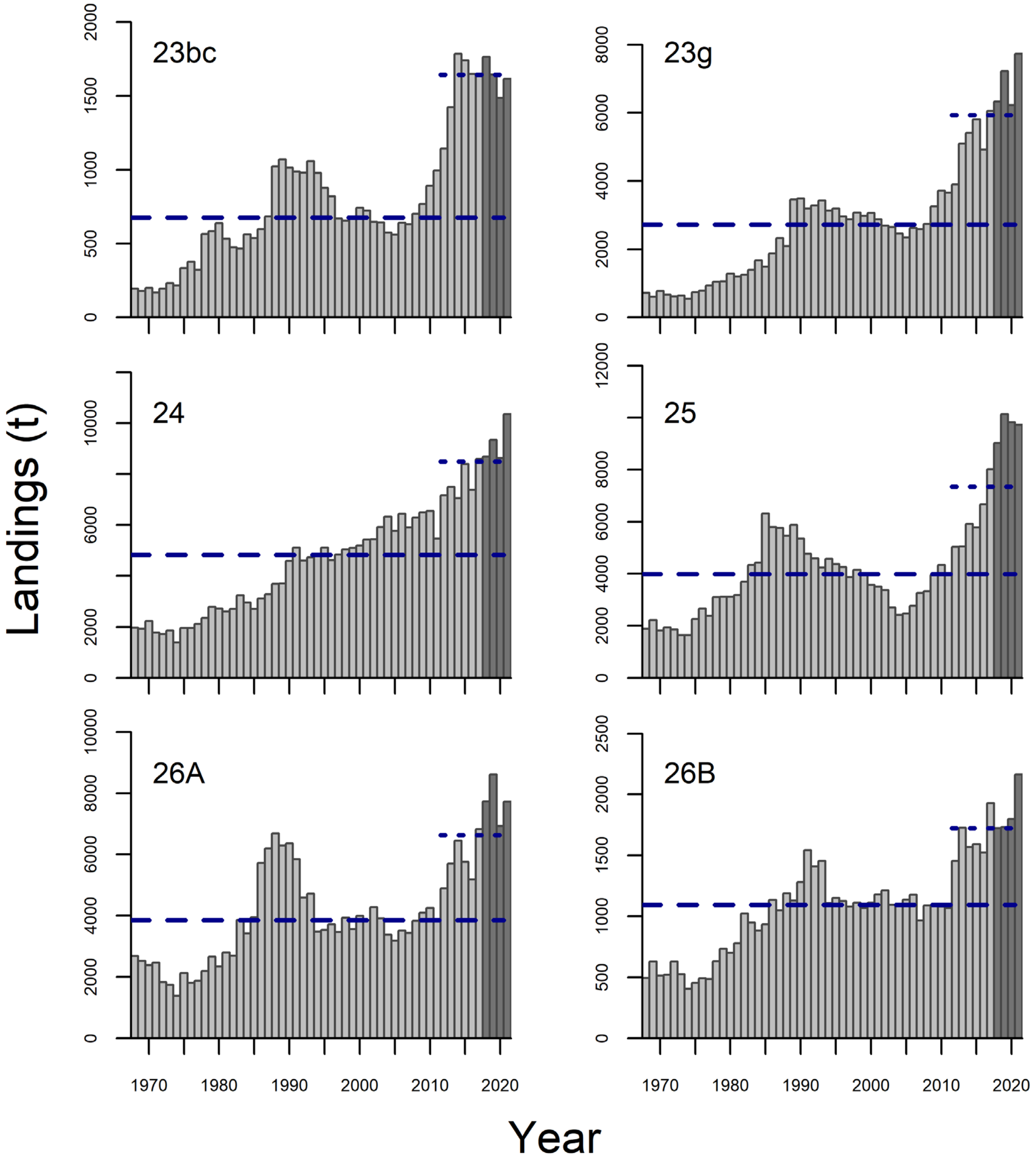


Figure 14. Reported Lobster landings (t) by assessment region (23bc, 23g, 24, 25, 26A, 26B) in the southern Gulf of St. Lawrence, 1968 to 2021. The dashed line and the dotted line represent the median mid-term (1968-2021) and short-term (2012-2021) landings, respectively. Data added since the last assessment update (2018-2021) are in a darker grey shading. Data for 2021 are preliminary.

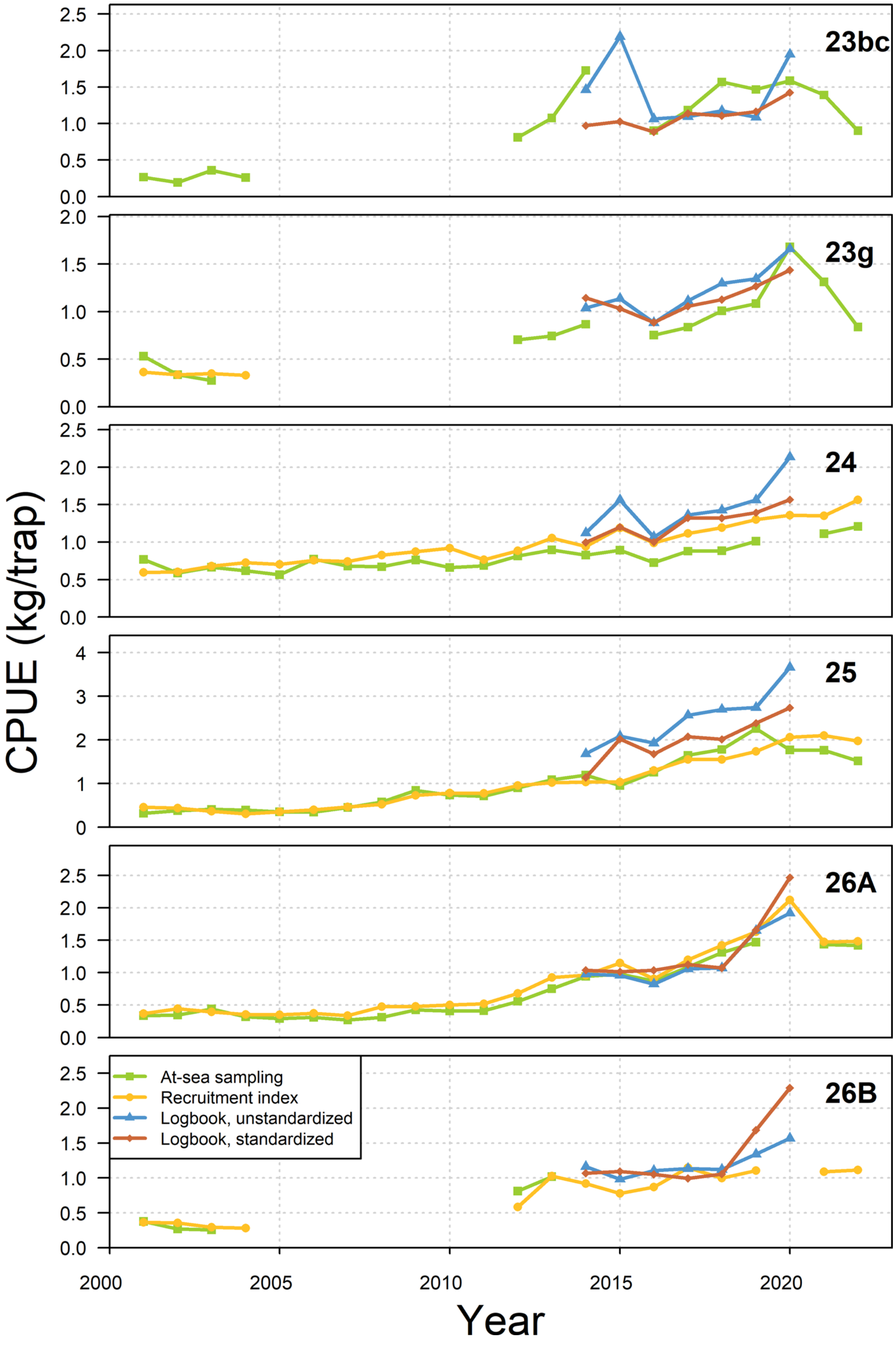


Figure 15. Catch per unit effort (CPUE, kg/trap) estimates from at-sea sampling data and from logbook data, 2001 to 2022. CPUE estimates from at-sea sampling data are seasonal averages, unstandardized logbook CPUEs are maximum weekly averages and standardized logbook CPUEs are modelled maximum daily averages.

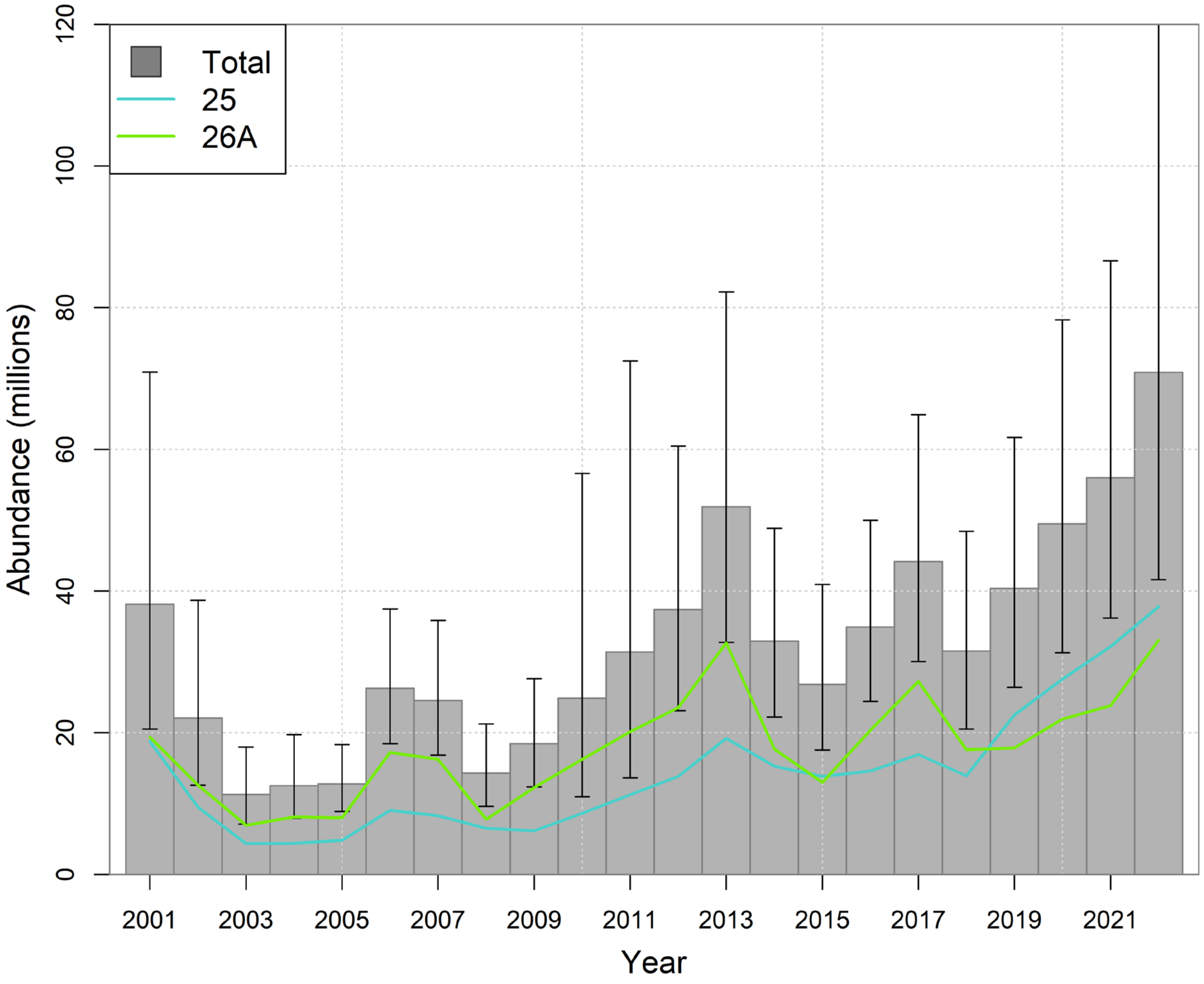


Figure 16. Estimated abundance of commercial Lobsters in LFAs 25 and 26A, 2001 to 2022. Confidence intervals are indicated by black lines on each bar.

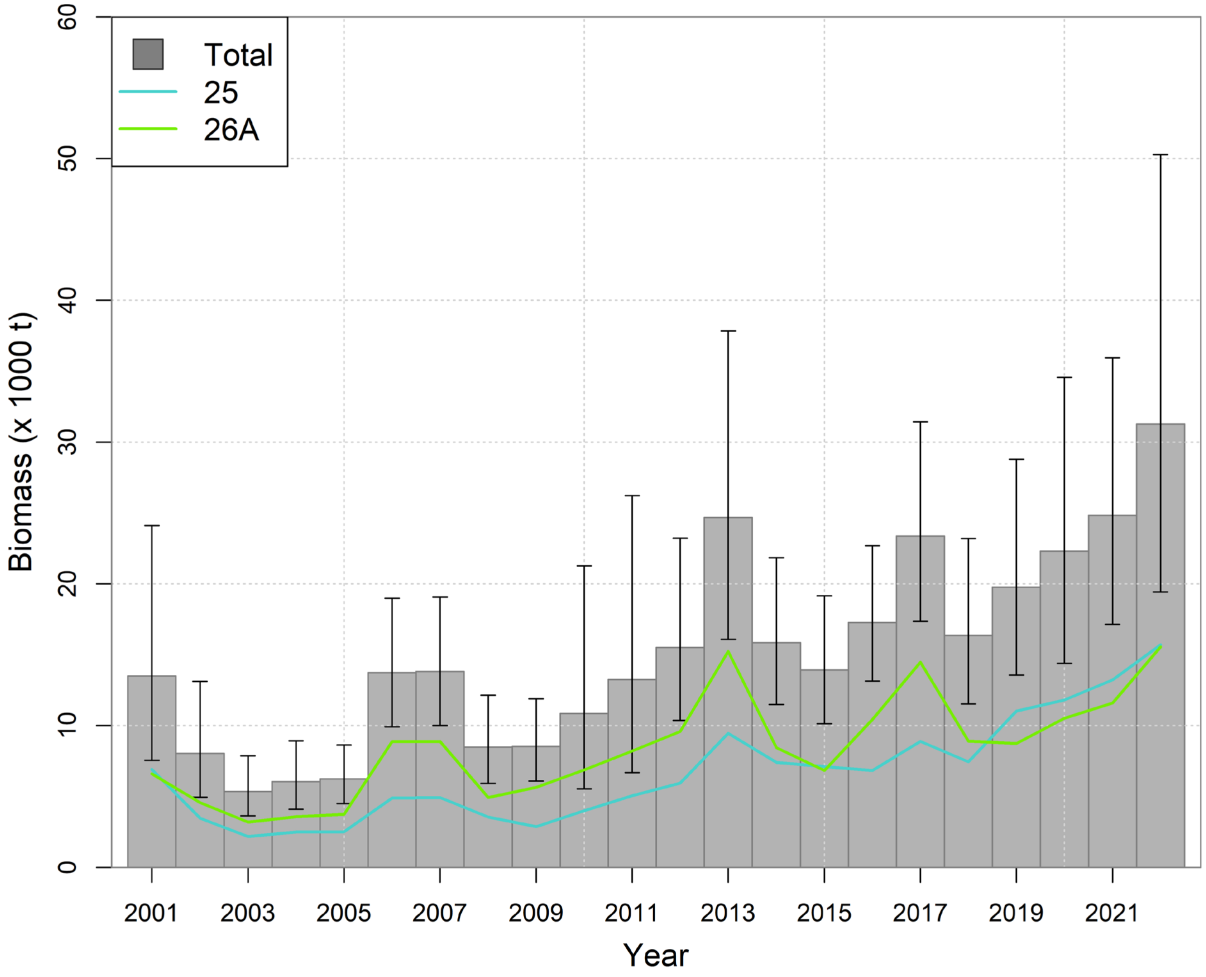


Figure 17. Estimated biomass of commercial Lobsters in LFAs 25 and 26A, 2001 to 2022. Confidence intervals are indicated by black lines on each bar.

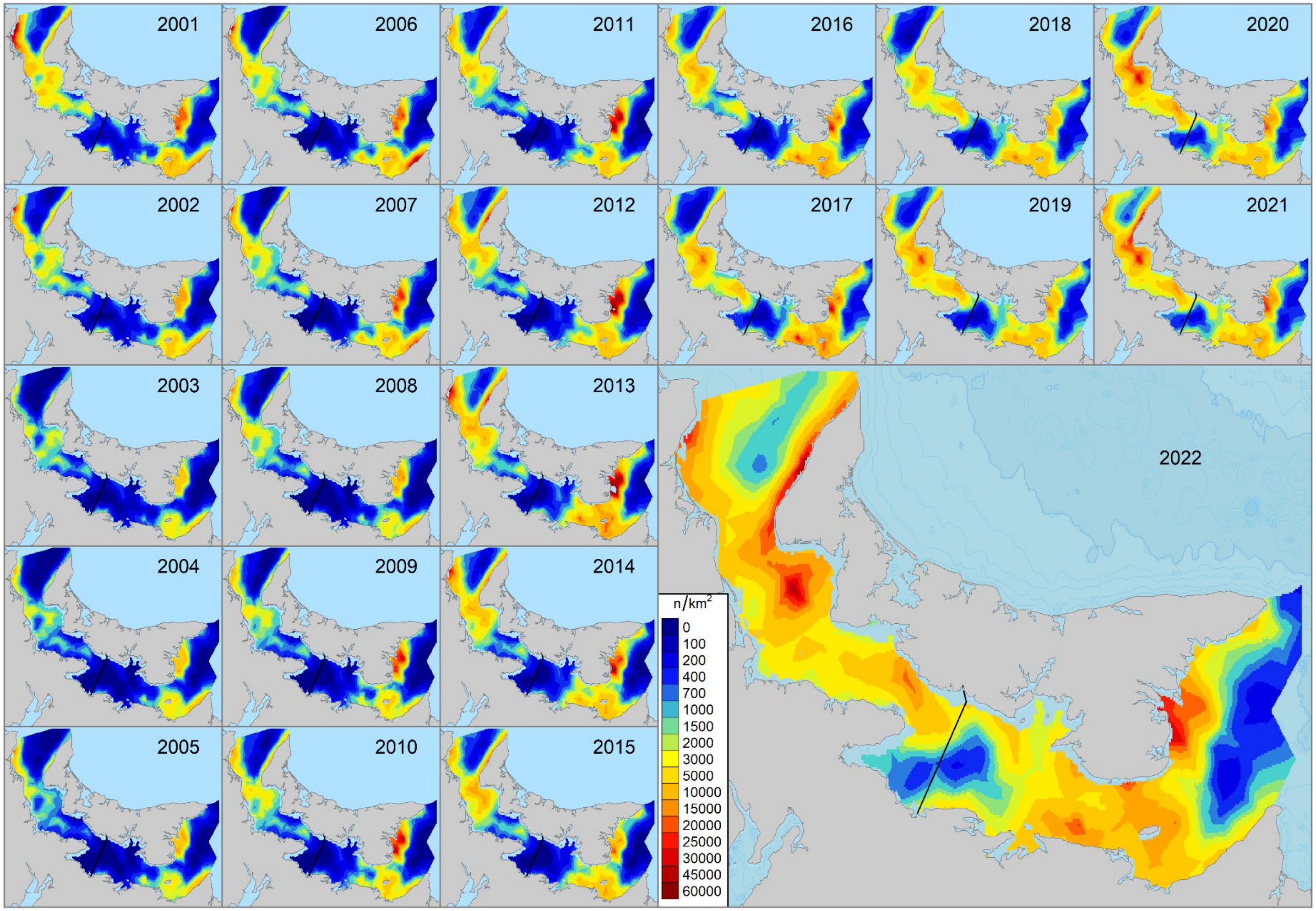


Figure 18. Estimated density of commercial Lobsters in LFAs 25 and 26A, 2001 to 2022.

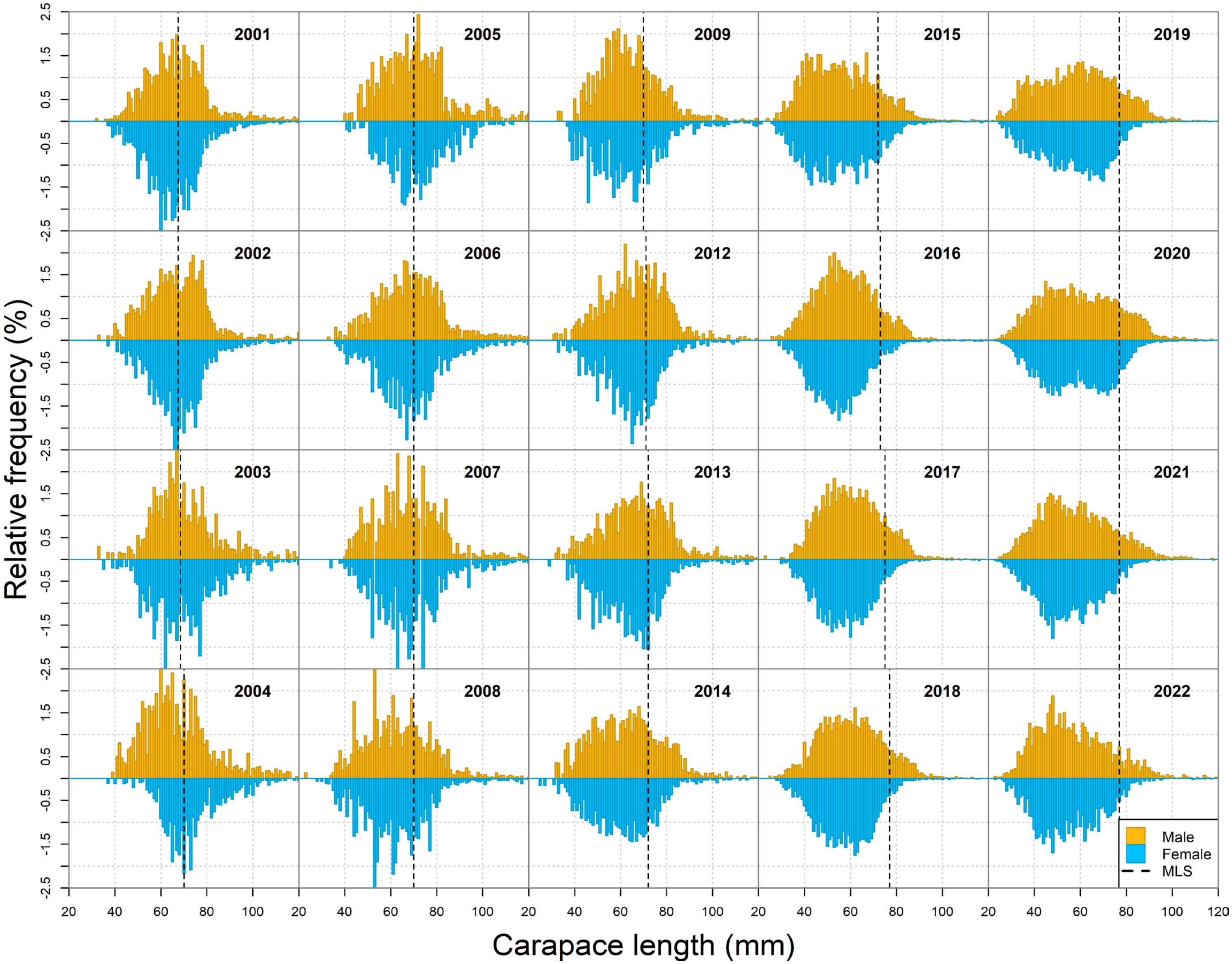


Figure 19. Relative size-frequencies of Lobster by sex in LFA 25, 2001 to 2022.

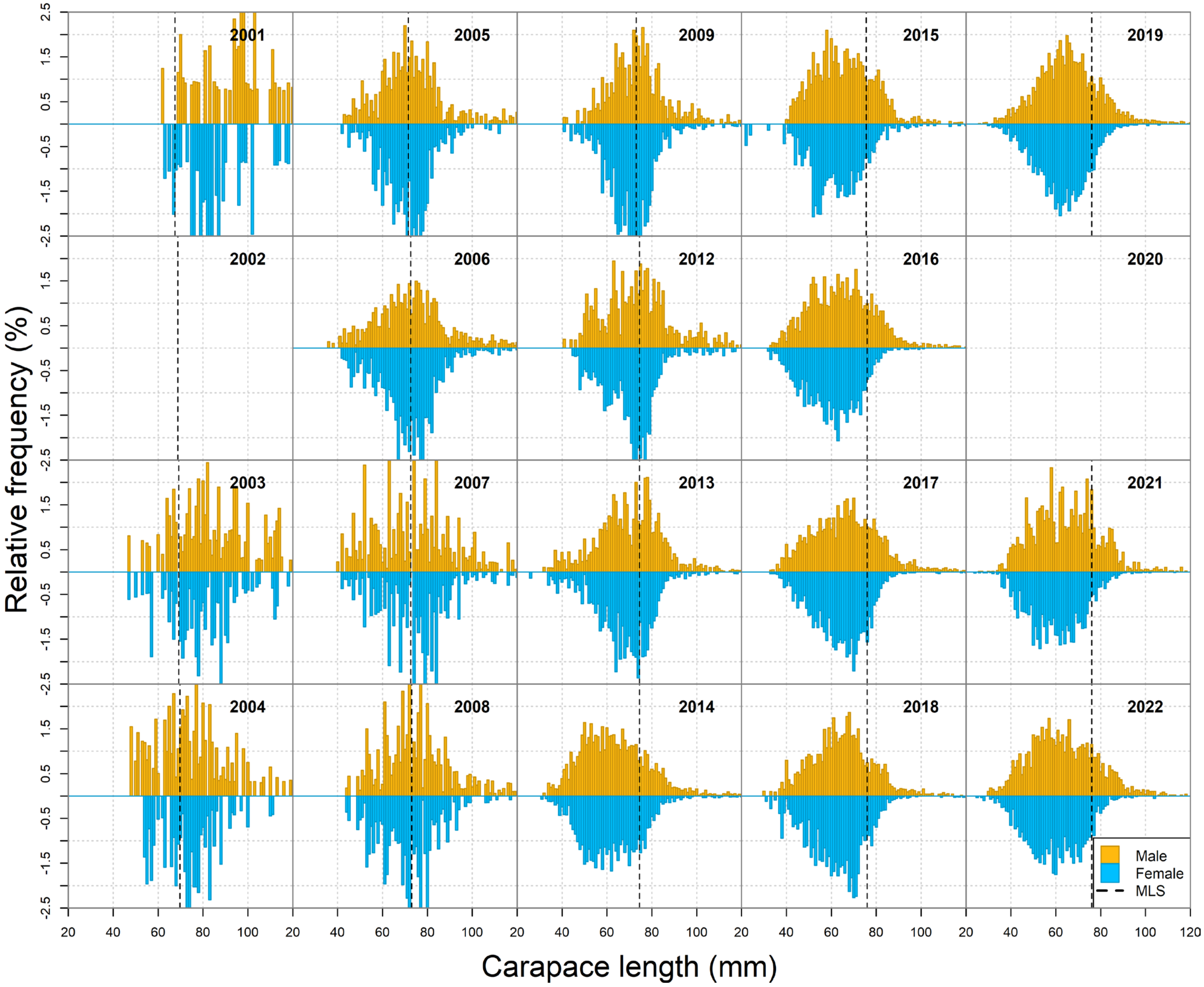


Figure 20. Relative size-frequencies of Lobster by sex in LFA 26A, 2001 to 2022.

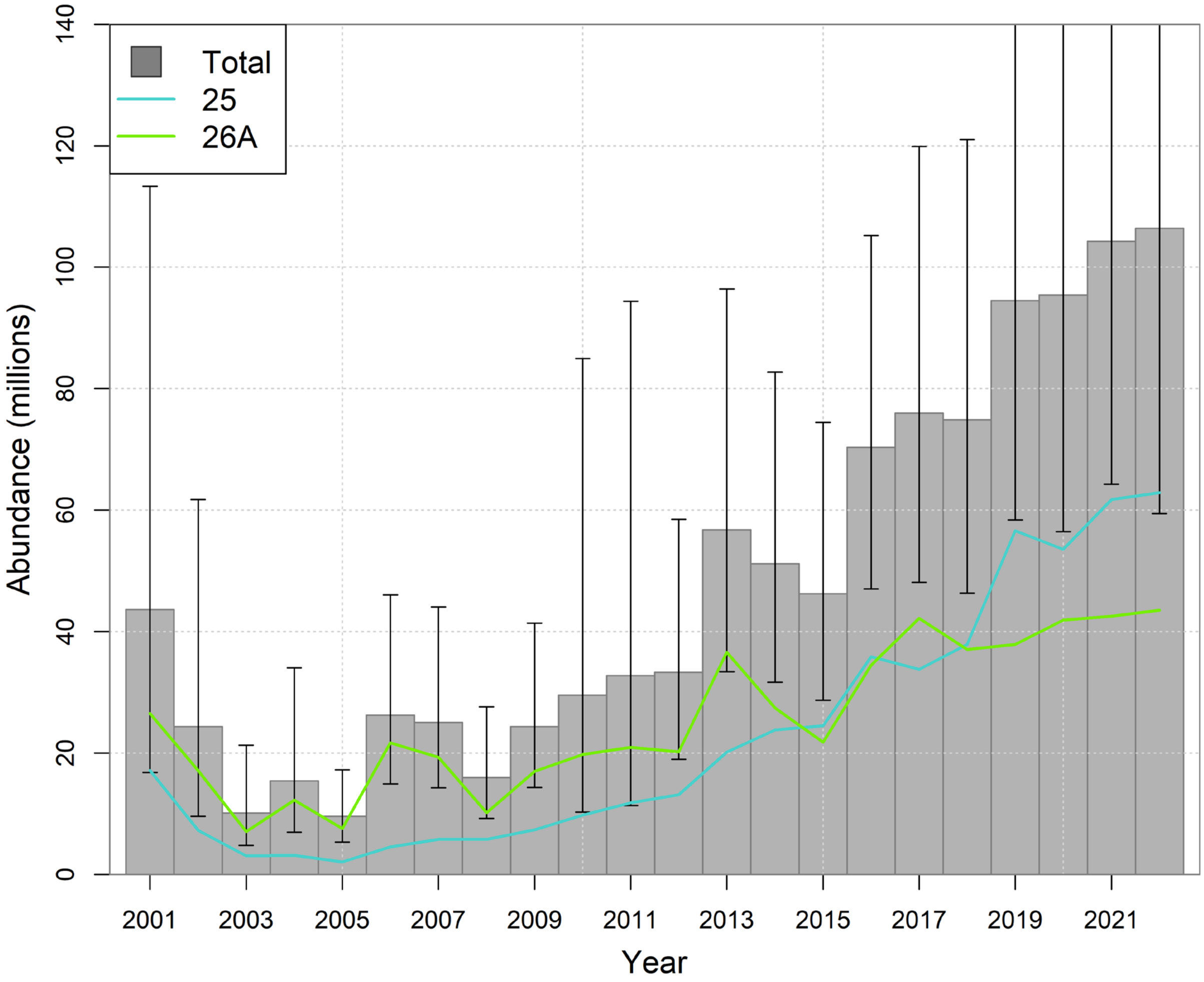


Figure 21. Estimated abundance of pre-recruit 1 Lobsters in LFAs 25 and 26A, 2001 to 2022. Pre-recruit 1 Lobsters are those below the MLS but ≥ 10 mm below legal size. Confidence intervals are indicated by black lines on each bar.

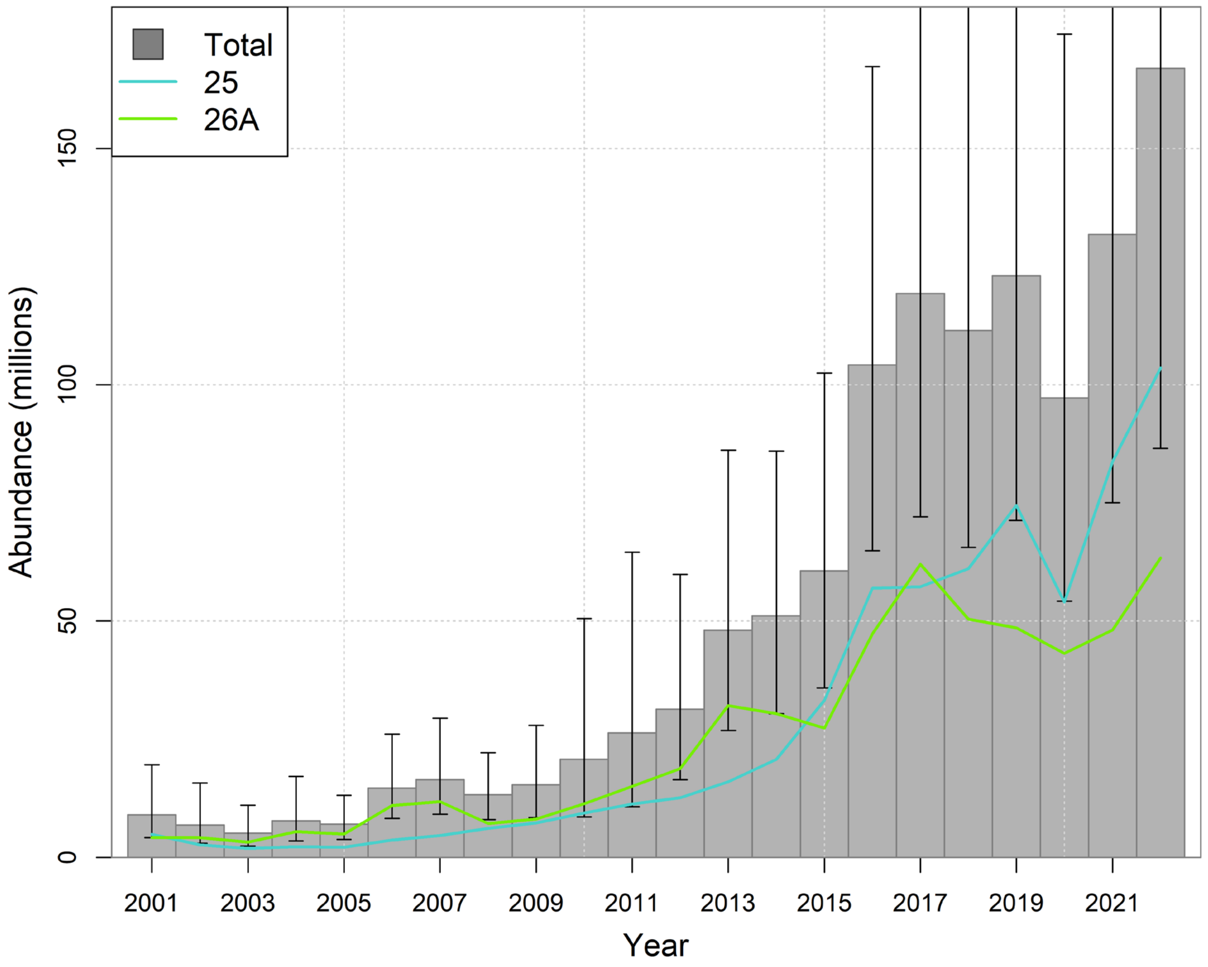


Figure 22. Estimated abundance of pre-recruit 2 Lobsters in LFAs 25 and 26A, 2001 to 2022. Pre-recruit 2 Lobsters are those less than 10 mm below the MLS but ≥ 20 mm below legal size. Confidence intervals are indicated by black lines on each bar.

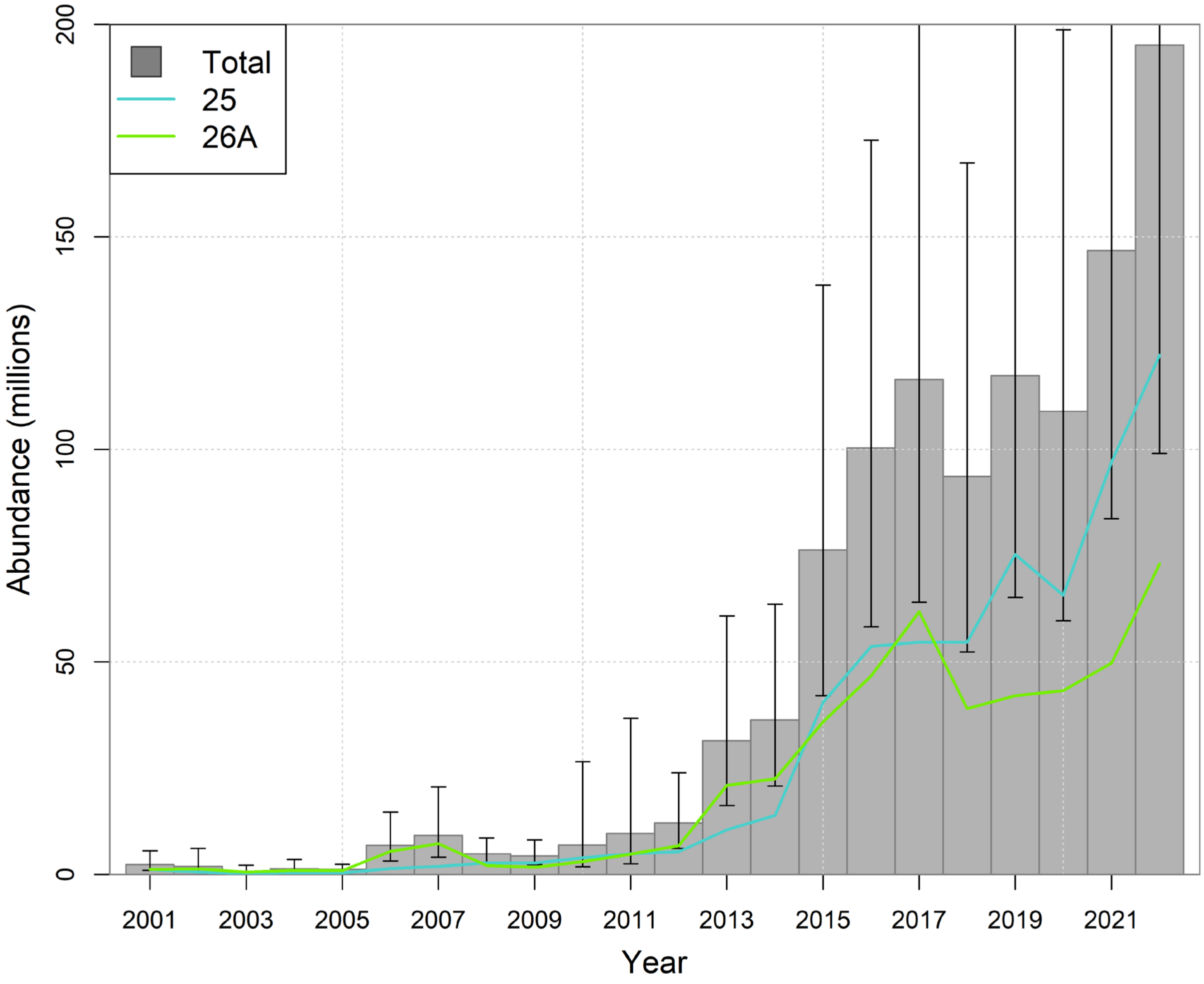


Figure 23. Estimated abundance of pre-recruit 3 Lobsters in LFAs 25 and 26A, 2001 to 2022. Pre-recruit 3 Lobsters are those less than 20 mm below the MLS but ≥ 30 mm below legal size. Confidence intervals are indicated by black lines on each bar.

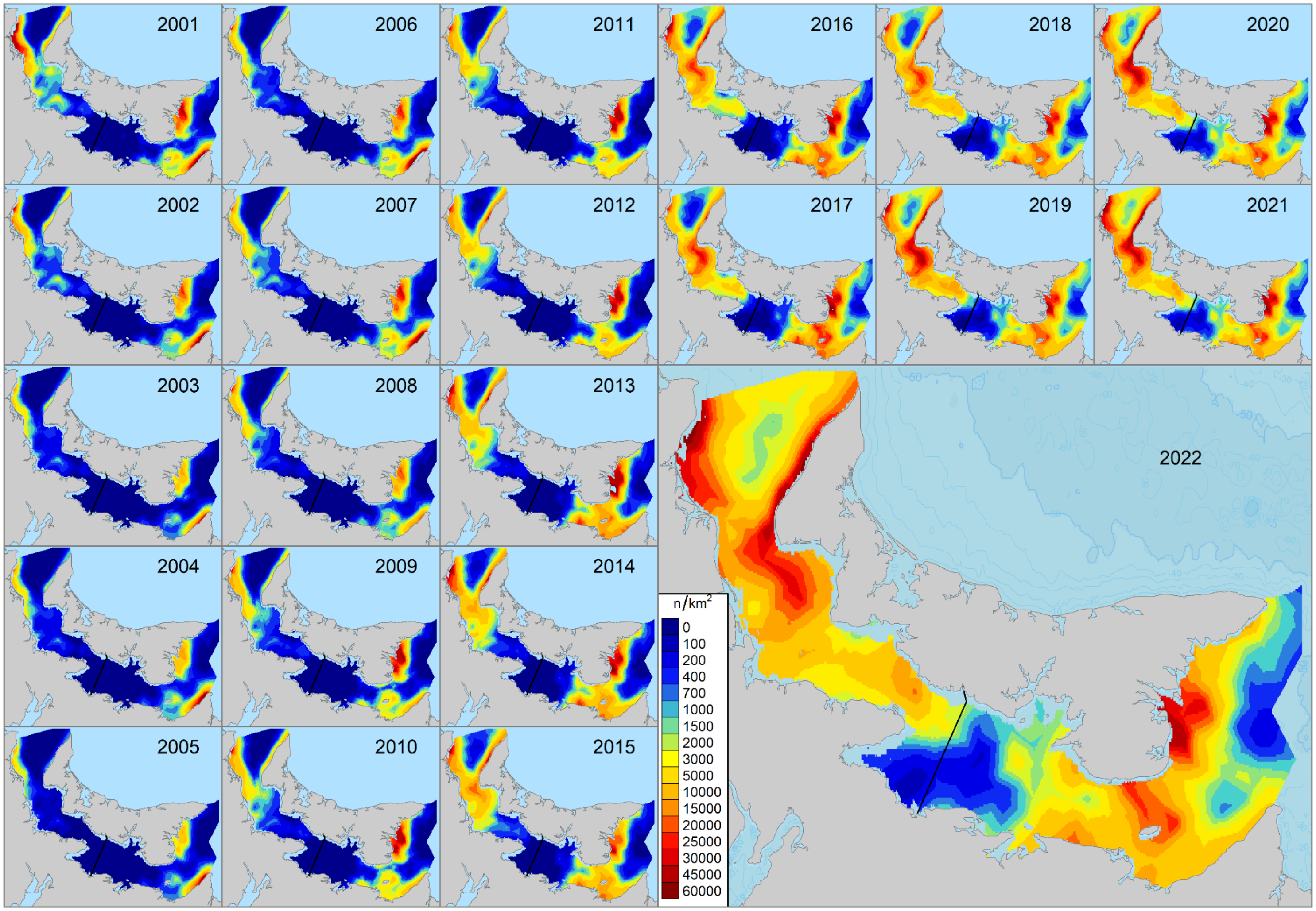


Figure 24. Estimated density of pre-recruit 1 sized Lobsters in LFAs 25 and 26A, 2001 to 2022.

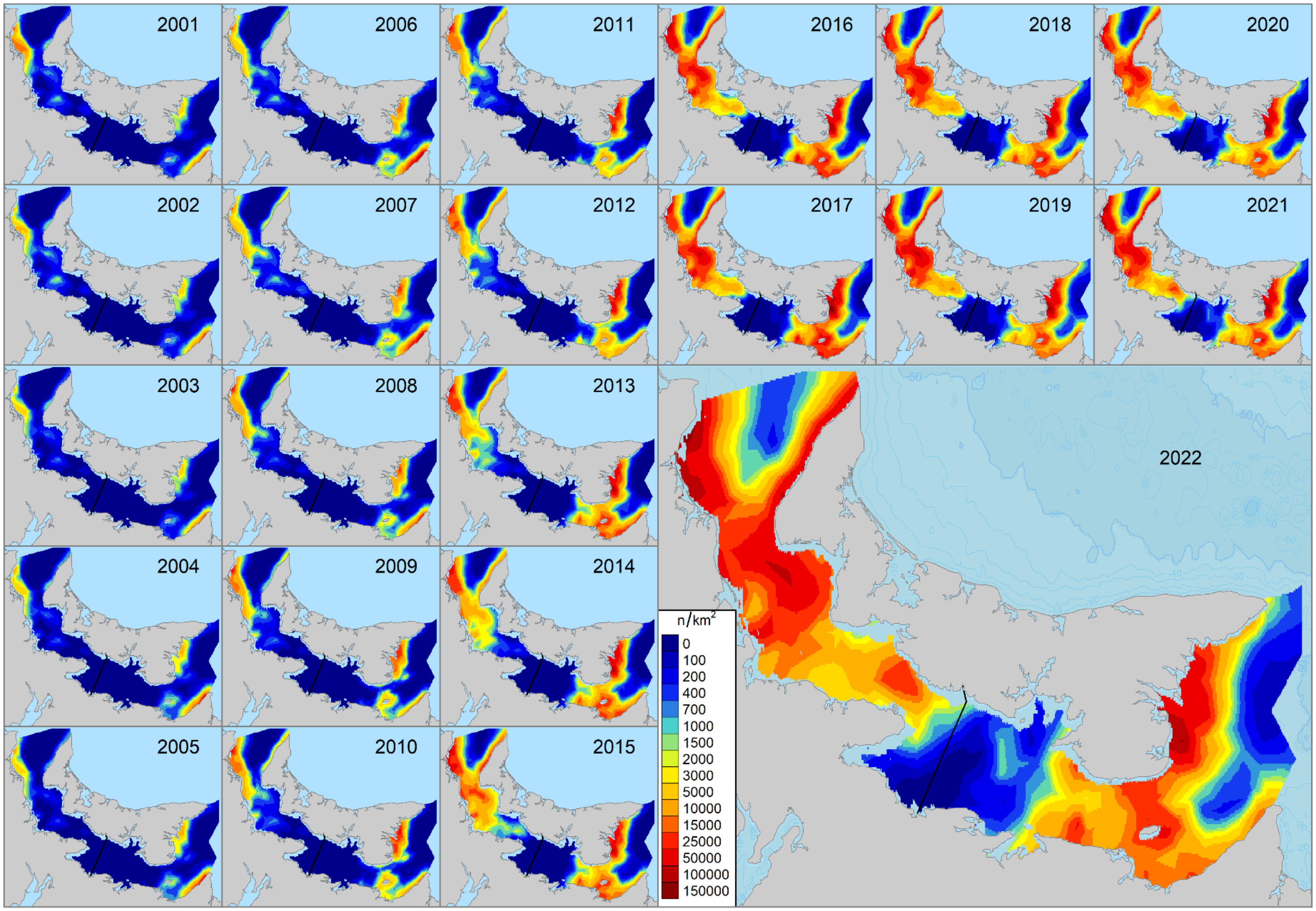


Figure 25. Estimated density of pre-recruit 2 sized Lobsters in LFAs 25 and 26A, 2001 to 2022.

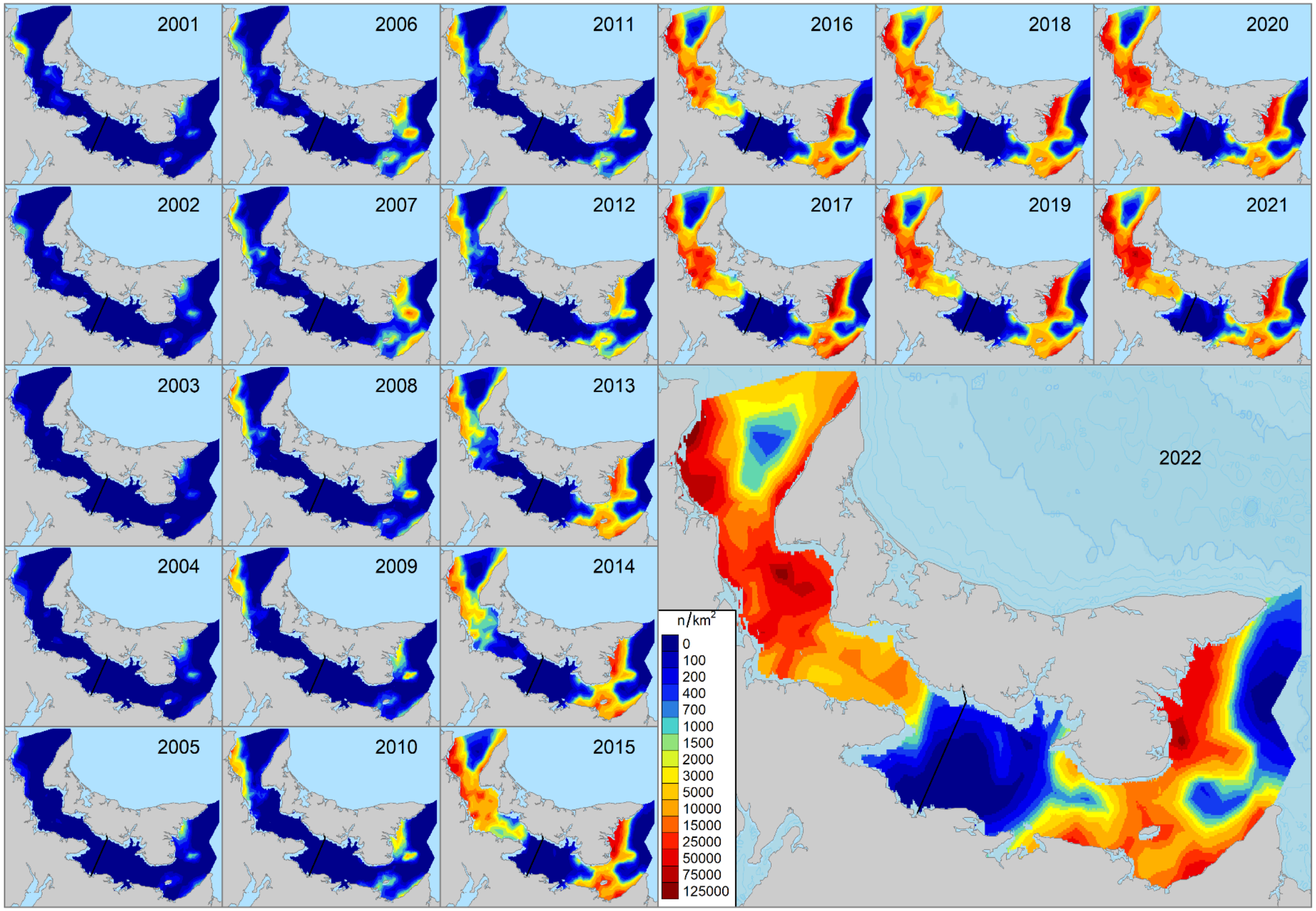


Figure 26. Estimated density of pre-recruit 3 sized Lobsters in LFAs 25 and 26A, 2001 to 2022.

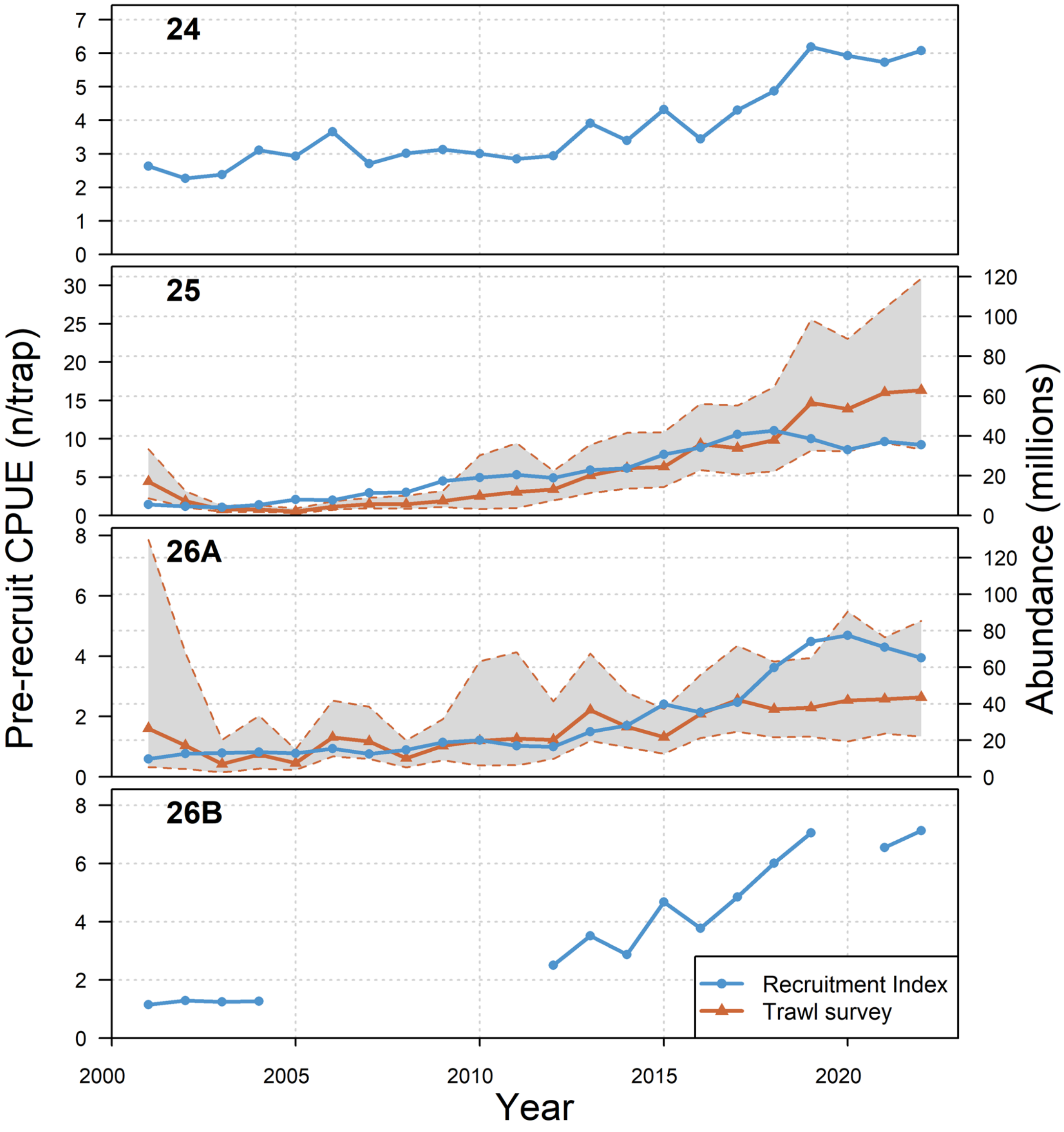


Figure 27. Catch per unit effort (n/trap) of one-year pre-recruit Lobsters in the recruitment-index program (left axis) and estimated abundance (millions) of one-year pre-recruit (i.e. pre-recruit 1) Lobsters in LFAs 25 and 26A (right axis) from the Northumberland Strait multi-species bottom trawl survey, 2002 to 2022. Confidence intervals for the survey estimate are indicated by the grey area above and below the red line.

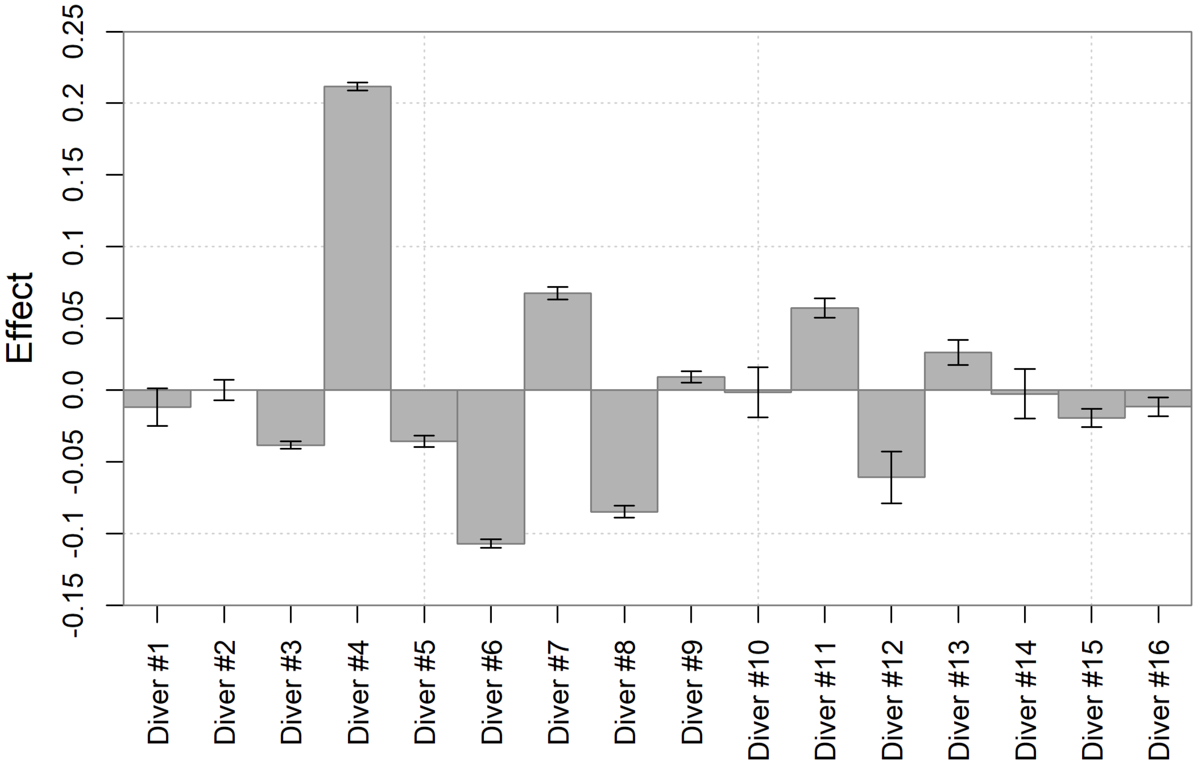


Figure 28. Estimated diver effects from the SCUBA transect analysis. Note: diver labels are consistent between this figure and Figure 10.

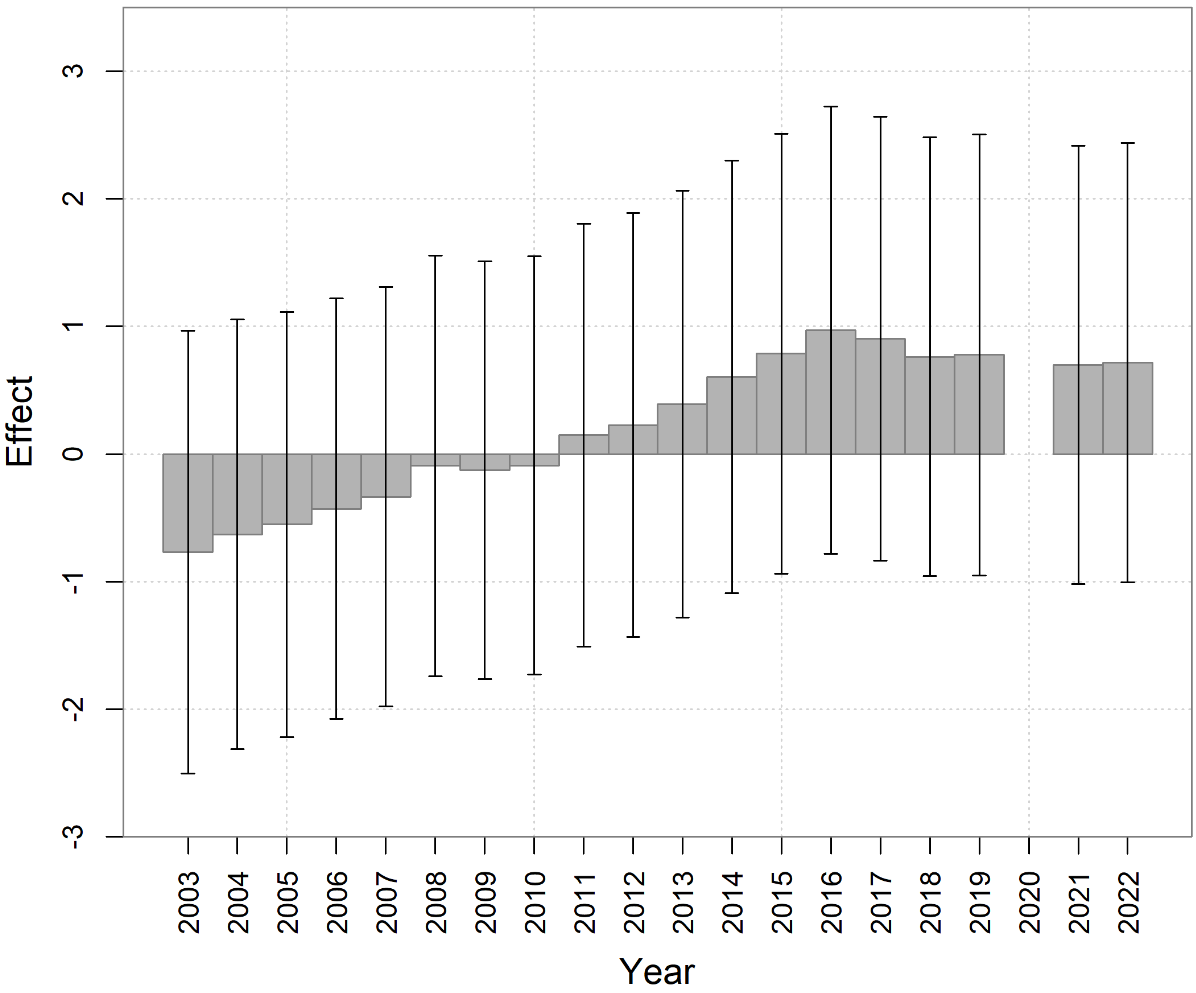


Figure 29. Estimated year effects from the SCUBA transect analysis.

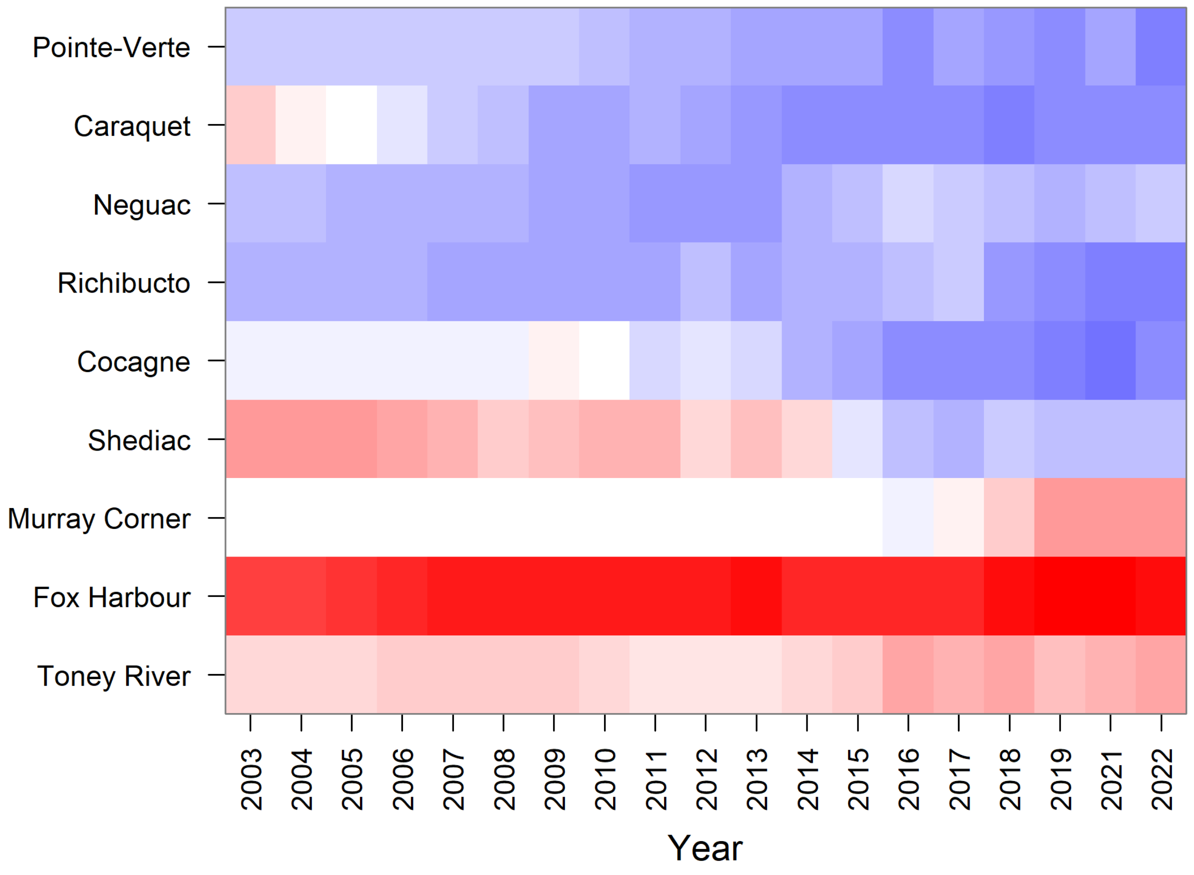


Figure 30. Estimated site by year effects from the SCUBA transect analysis. Red indicates negative values while blue indicates positive values.

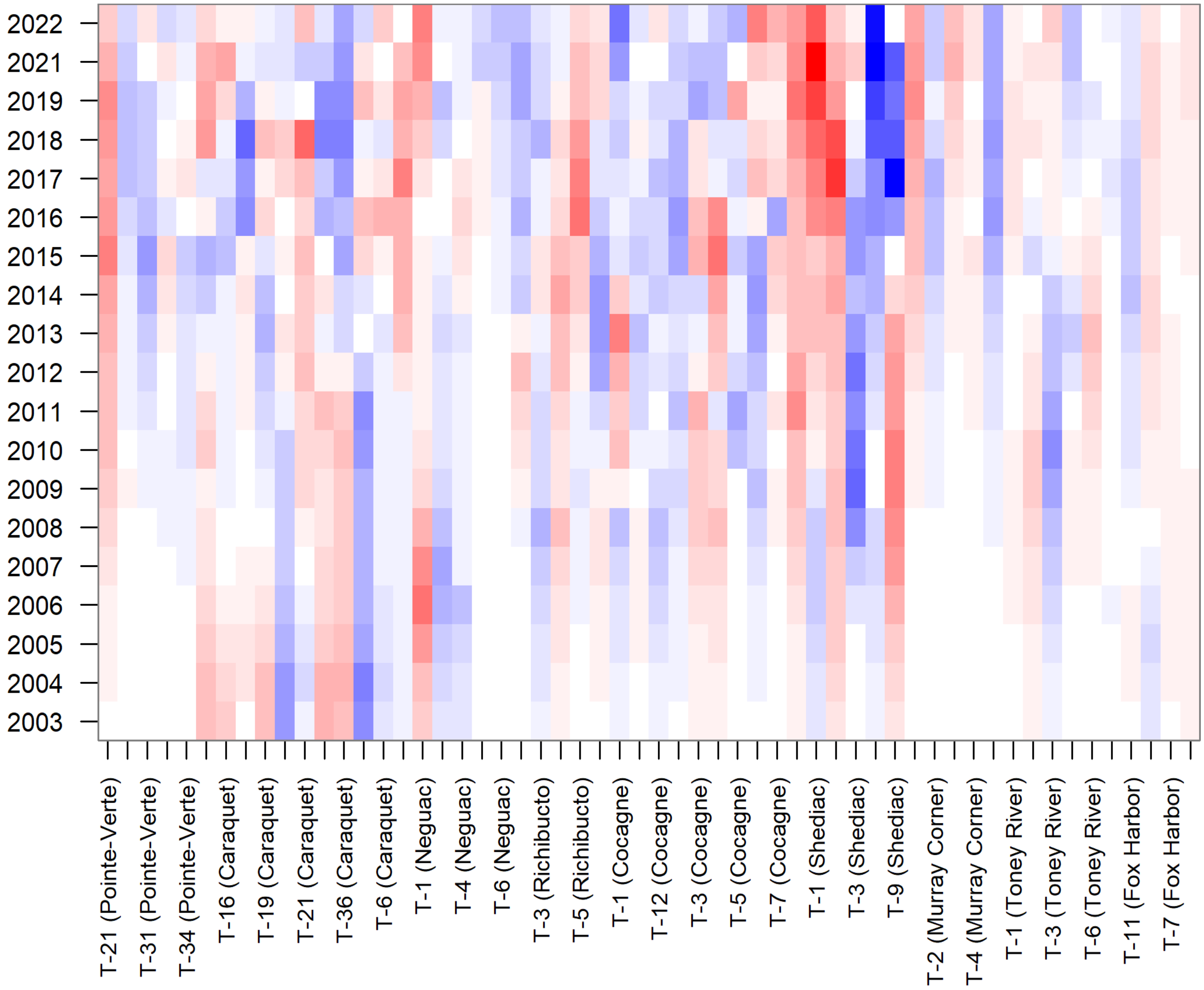


Figure 31. Estimated transect by year effects from the SCUBA transect analysis. Red indicates negative values while blue indicates positive values.

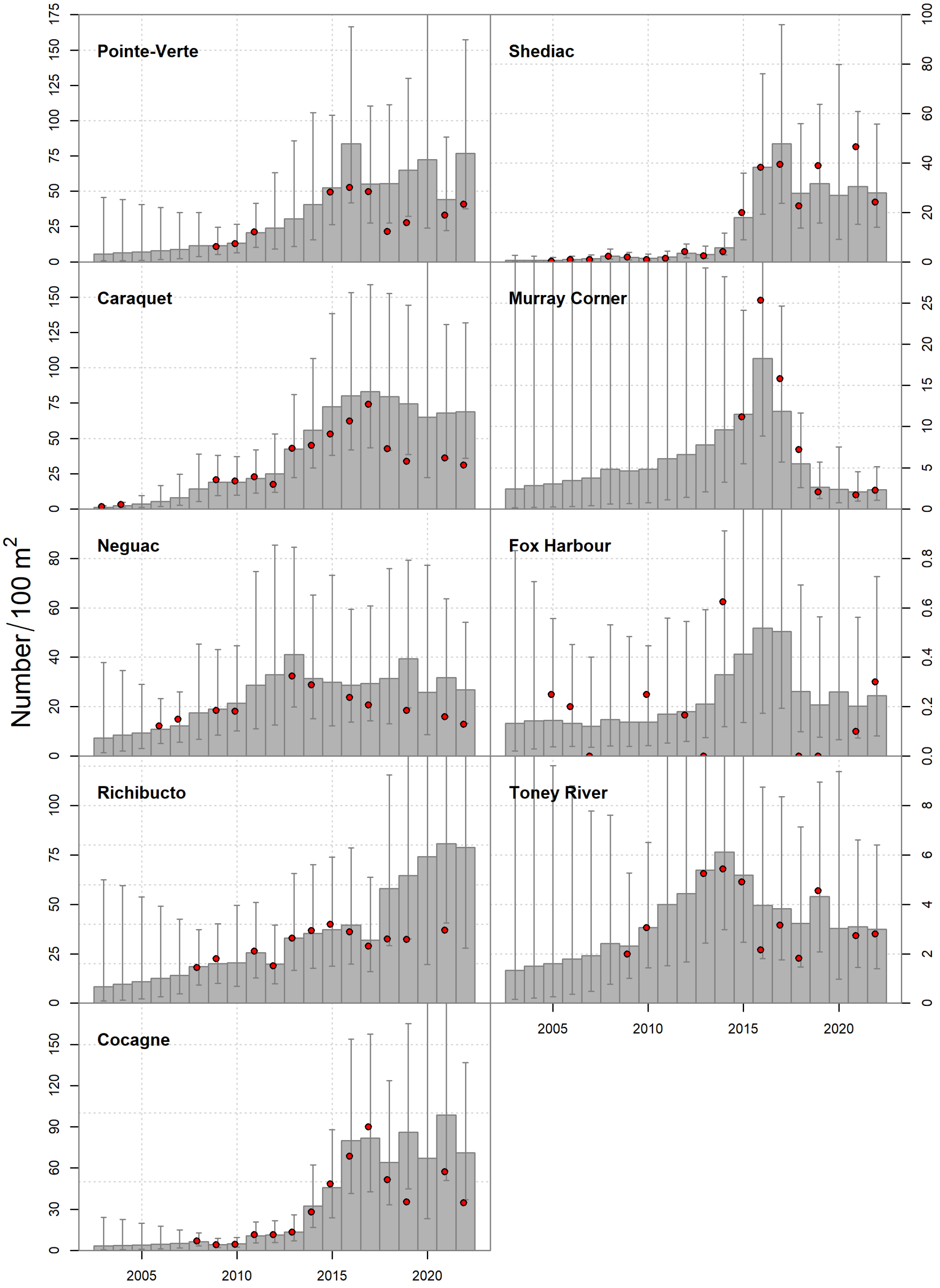


Figure 32. Time series of Lobster recruitment indices by study site from the SCUBA transect analysis, 2003 to 2022. Confidence intervals (95%) are shown as vertical black bars. Red circles show observed means. Grey bars without a red circle are interpolated by the model. Note: the range of values for the y-axis is defined for each study site.

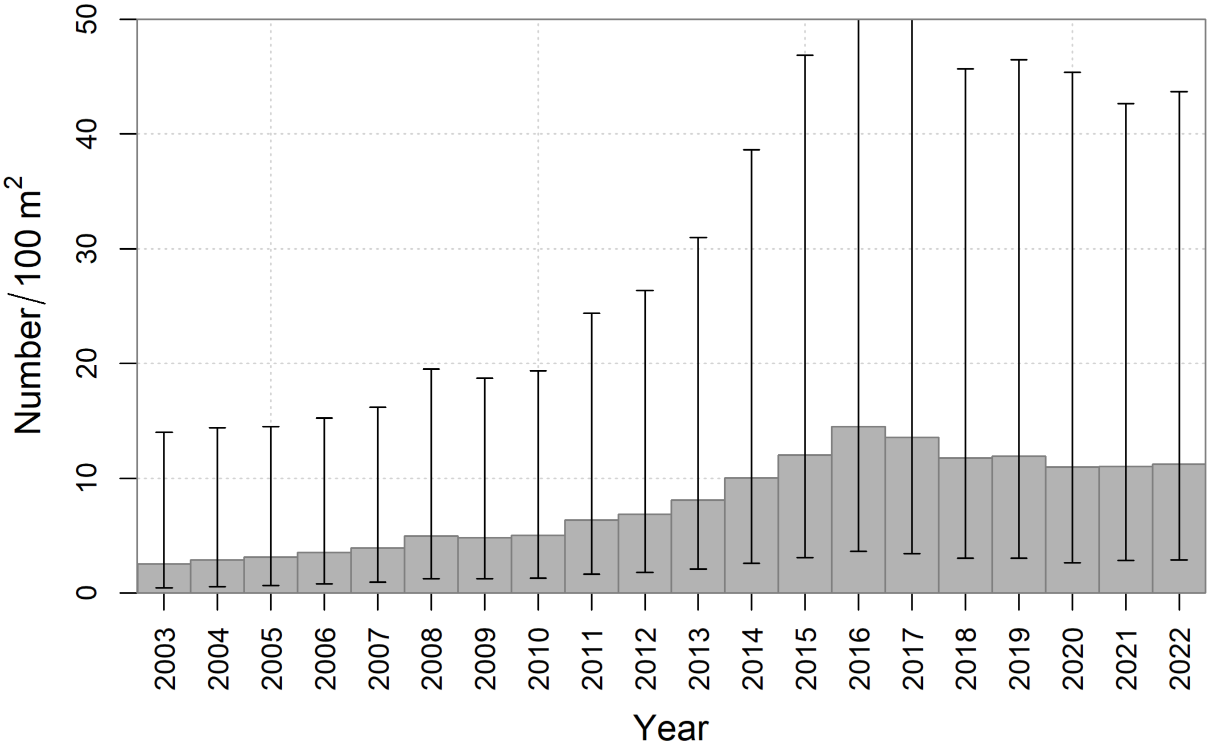


Figure 33. Average estimated Lobster recruitment over time from the SCUBA transect analysis, 2003 to 2022. Confidence intervals (95%) are shown as vertical black bars.

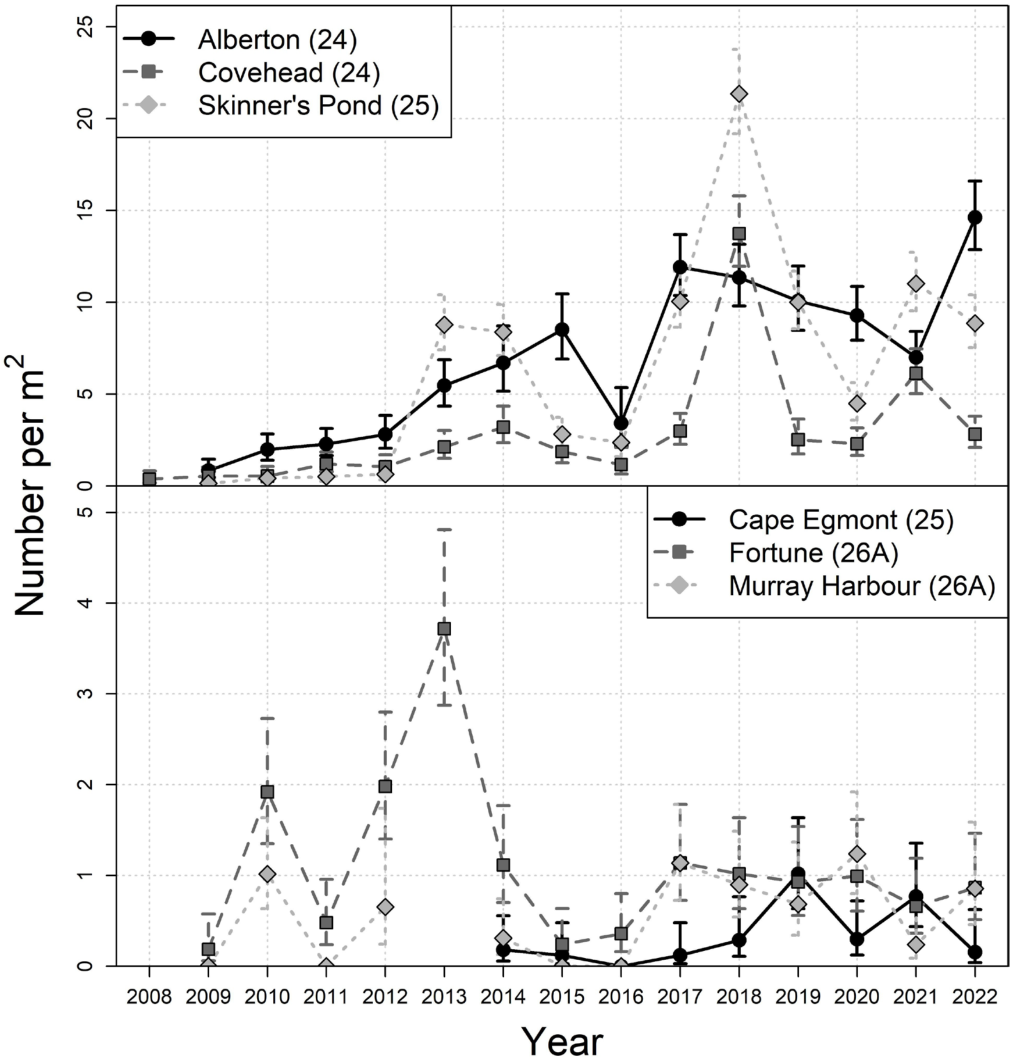


Figure 34. Density of young-of-year (YOY) Lobsters in bio-collectors at eight locations in LFAs 24, 25 and 26A in the southern Gulf of St. Lawrence, 2008 to 2022.

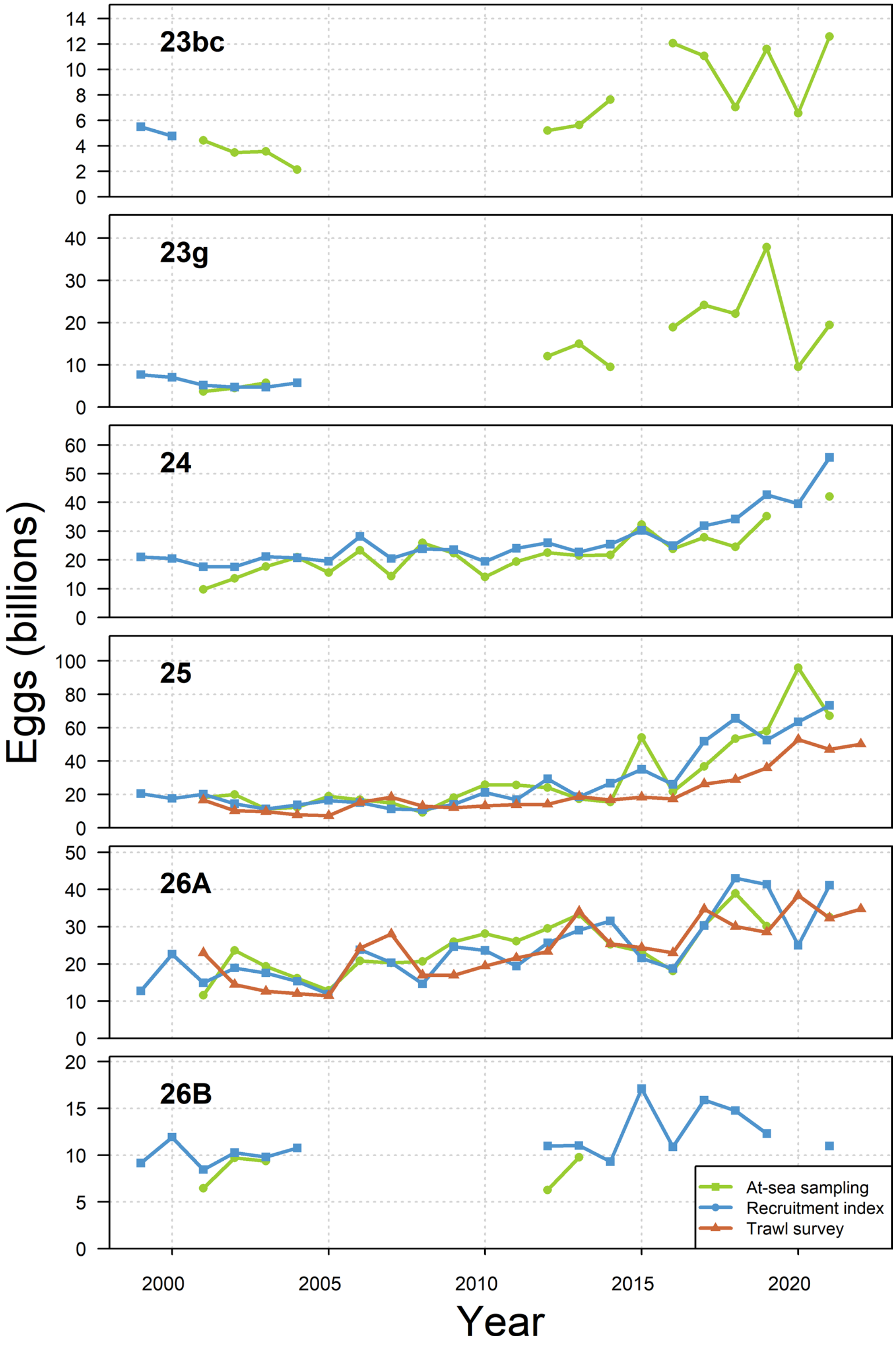


Figure 35. Egg production based on at-sea sampling data, recruitment index program data and Northumberland Strait multi-species bottom trawl survey data per assessment regions 23bc and 23g and Lobster Fishing Areas 24, 25, 26A and 26B, 1999 to 2022.

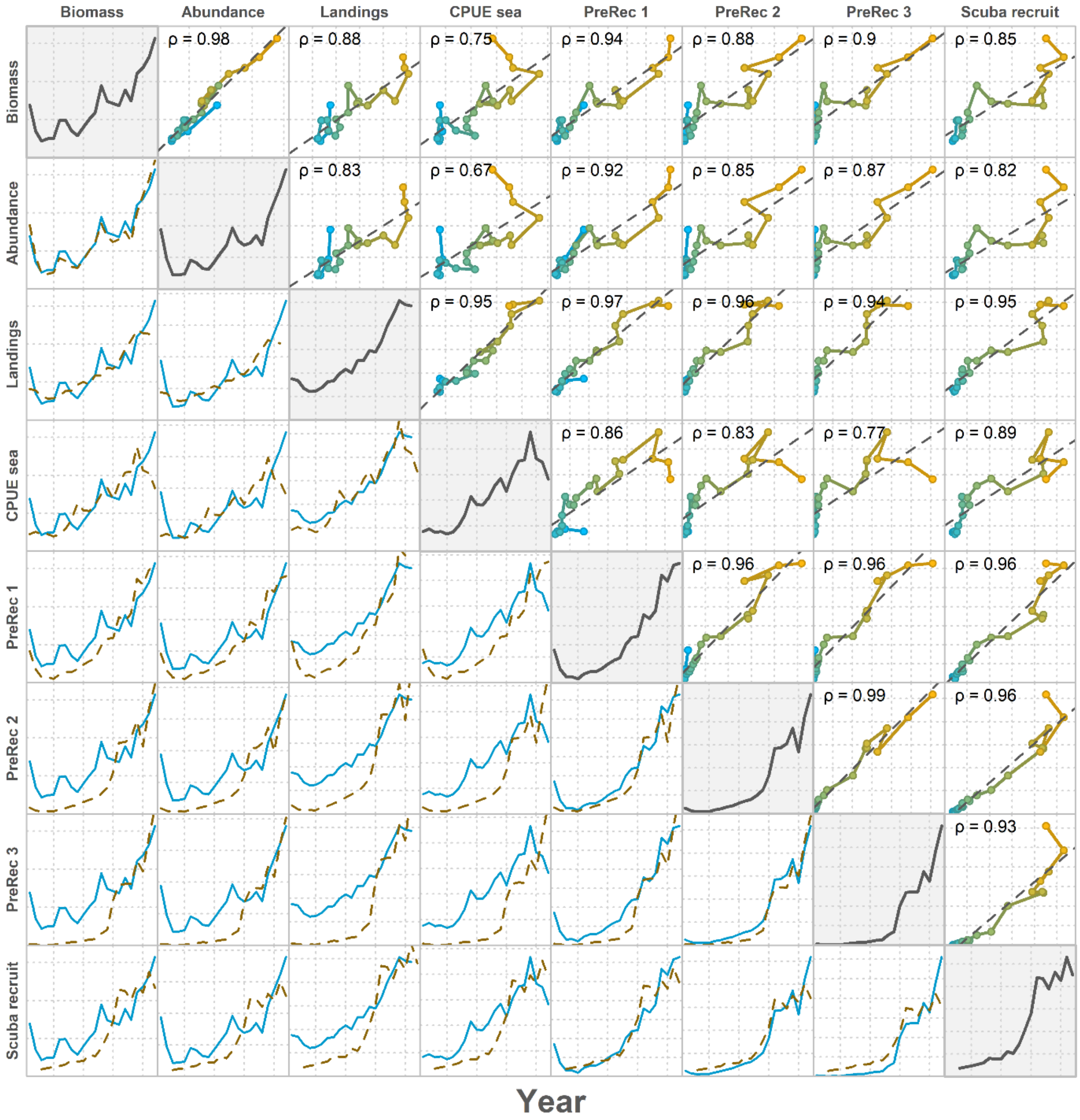


Figure 36. Pairwise comparisons of indicators from LFA 25. Diagonal plots show the time series of each individual indicator. Shown below the diagonal are time series comparisons of for each pairs of time series indicators, standardized to the same scale. Solid blue lines correspond to the indicators indicated by the column labels and dashed yellow lines correspond to those of the row labels. Shown above the diagonal are scatterplots of each indicator variable pair. Blue and yellow coloring corresponds to points earlier and later in the time series, respectively. Indicators are as follows: "Biomass" and "Abundance" labels correspond to commercial indices obtained from the Northumberland Strait survey, "Landings" correspond to reported commercial landings, "CPUE sea" corresponds to catch-per-unit effort estimated from sea sampling data, "PreRec 1", "PreRec 2" and "PreRec 3" correspond to 1-year, 2-year and 3-year fishery pre-recruits obtained from the Northumberland Strait survey, respectively, and "Scuba recruit" corresponds to the SCUBA survey recruitment index.

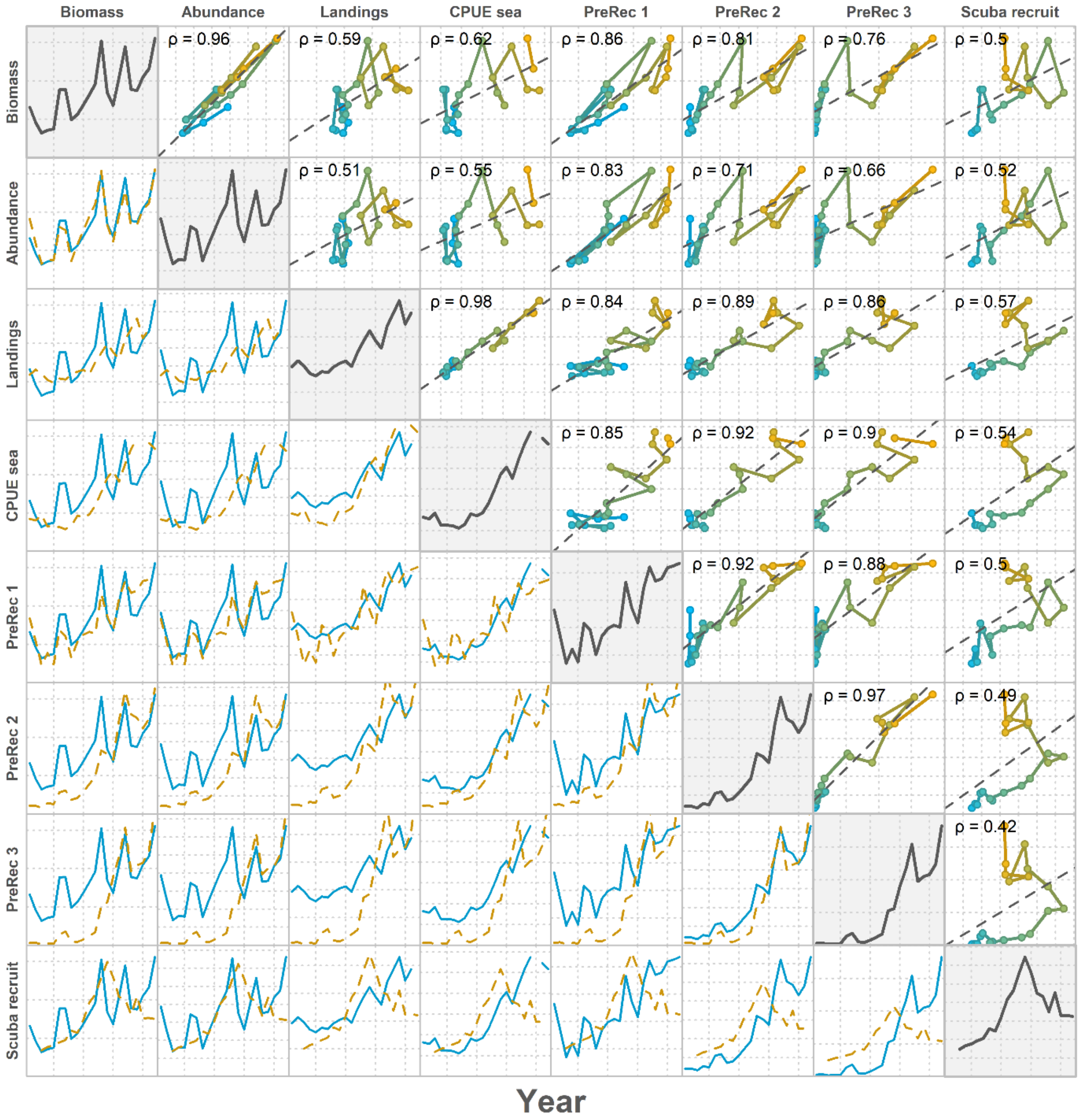


Figure 37. Pairwise comparisons of indicators from LFA 26A. Diagonal plots show the time series of each individual indicator. Shown below the diagonal are time series comparisons of for each pairs of time series indicators, standardized to the same scale. Solid blue lines correspond to the indicators indicated by the column labels and dashed yellow lines correspond to those of the row labels. Shown above the diagonal are scatterplots of each indicator variable pair. Blue and yellow coloring corresponds to points earlier and later in the time series, respectively. Indicators are as follows: “Biomass” and “Abundance” labels correspond to commercial indices obtained from the Northumberland Strait survey, “Landings” correspond to reported commercial landings, “CPUE sea” corresponds to catch-per-unit effort estimated from sea sampling data, “PreRec 1”, “PreRec 2” and “PreRec 3” correspond to 1-year, 2-year and 3-year fishery pre-recruits obtained from the Northumberland Strait survey, respectively, and “Scuba recruit” corresponds to the SCUBA survey recruitment index.

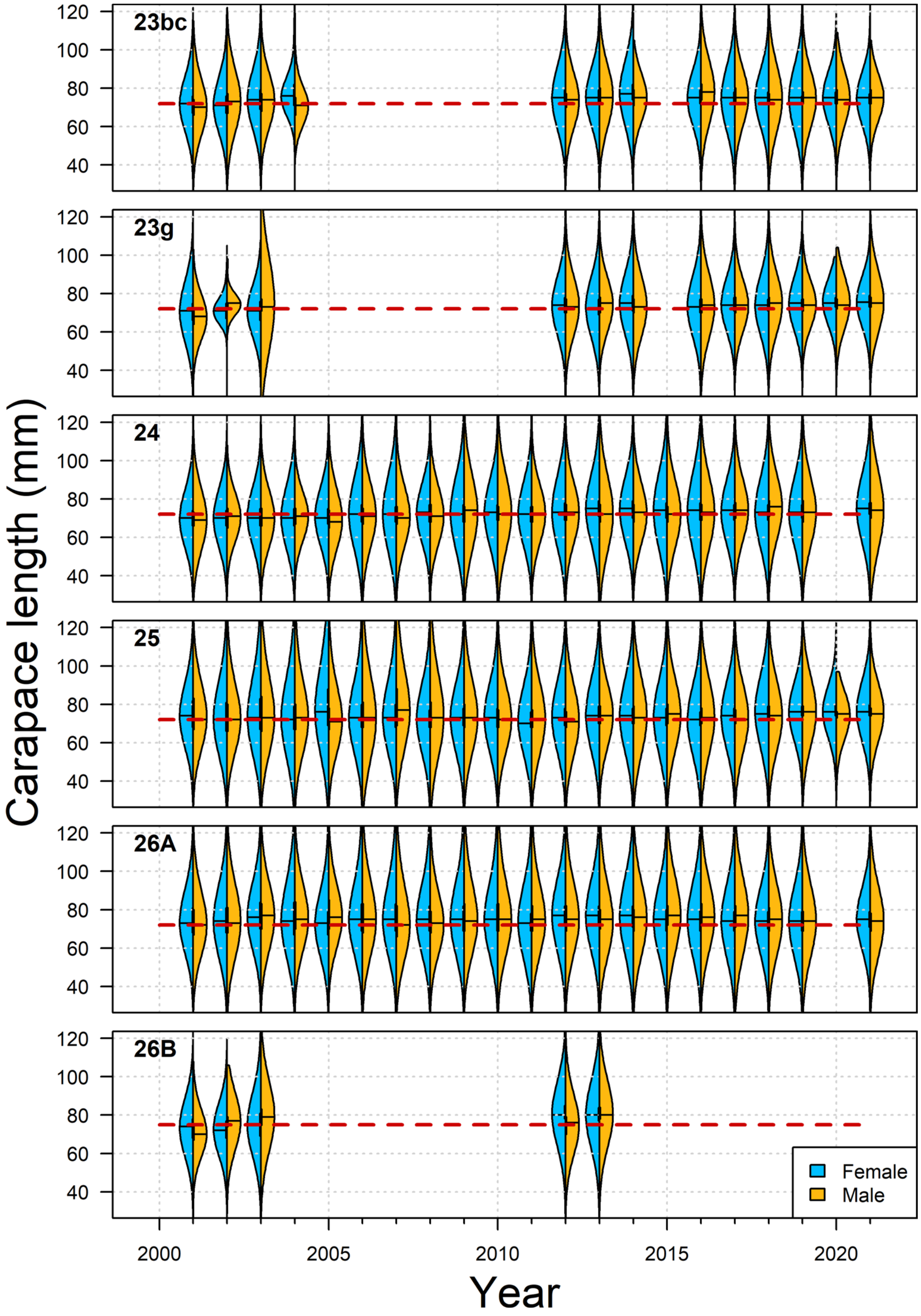


Figure 38. Length distributions of males and females sampled in the at-sea sampling program, 2001 to 2021. The small black line represents the median size in the sample. The red hashed line represents the size at which it is estimated 50% of females are mature [i.e. SOM50, 72 mm in 23bc, 23g, 24, 25 and 26A (Comeau and Savoie 2002, DFO 2016), and 76 mm in 26B (Comeau 2003, DFO 2016)].

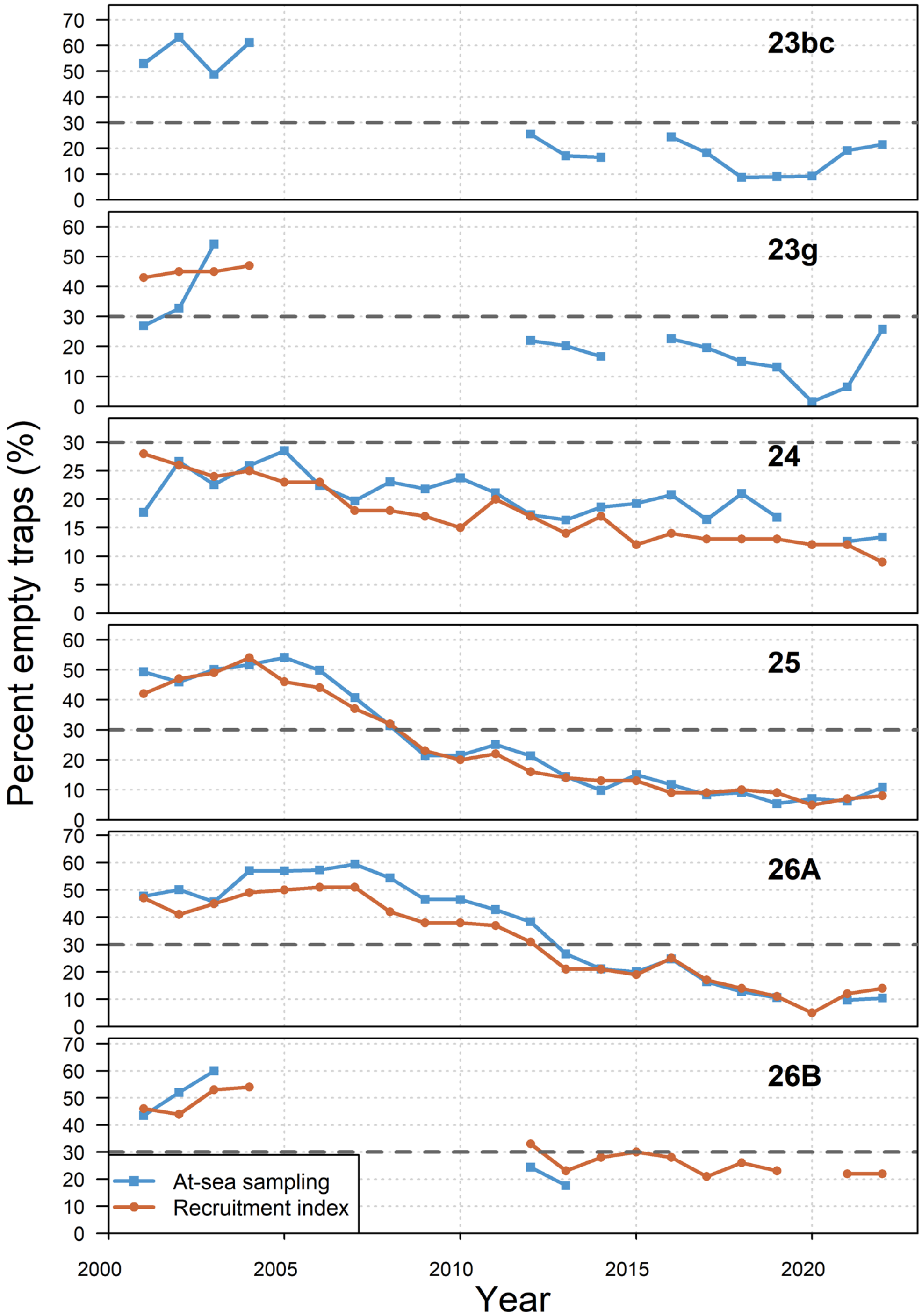


Figure 39. Percentage of empty traps from the at-sea sampling program and the recruitment-index program in assessment regions 23bc and 23g and Lobster Fishing Areas 24, 25, 26A and 26B, 2001 to 2022. The dashed line indicates 30%.

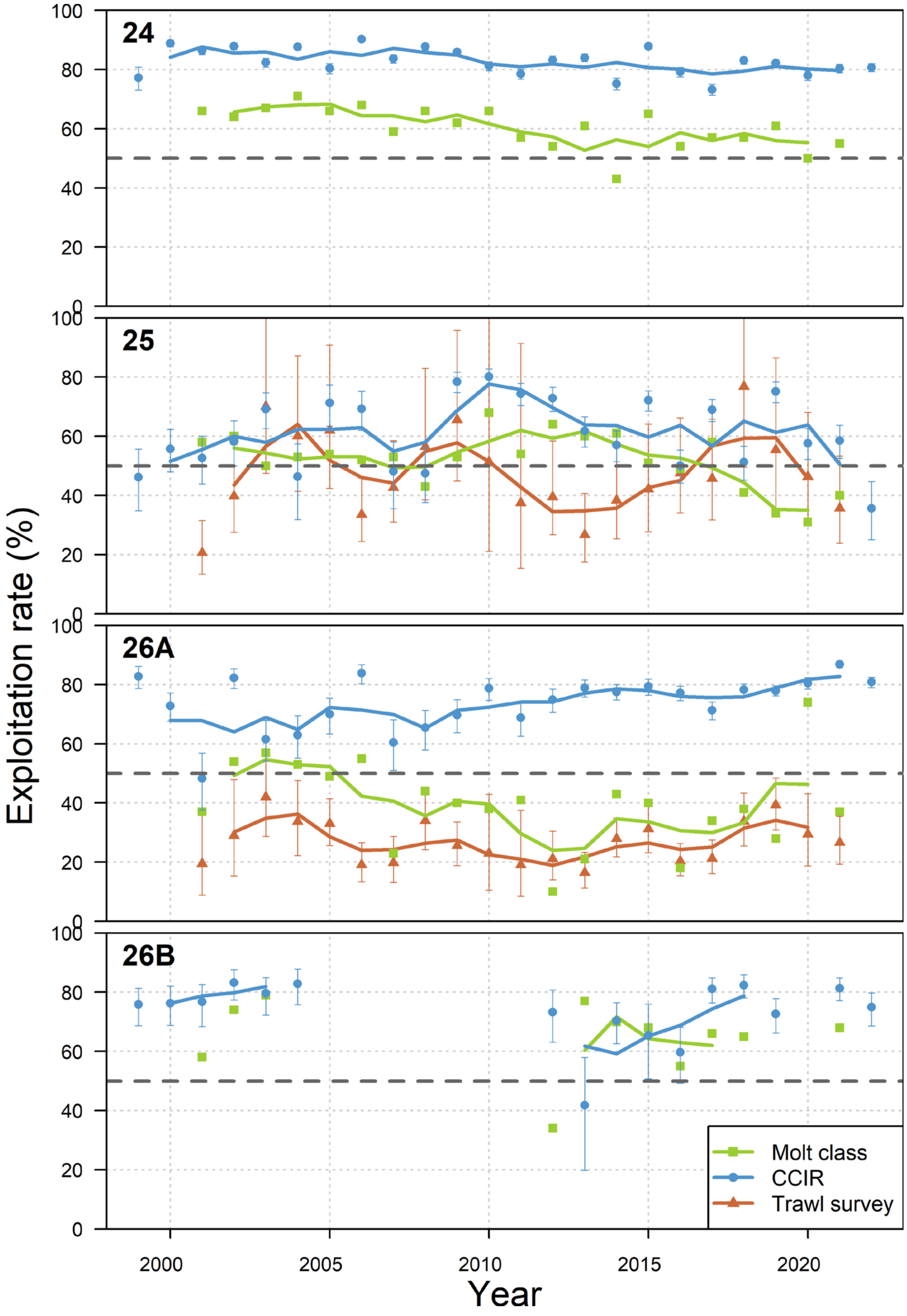


Figure 40. Exploitation rates from the molt class method, the continuous change-in-ratio (CCIR) method and from the Northumberland Strait multi-species bottom trawl survey commercial biomass estimate, in Lobster Fishing Areas 24, 25, 26A and 26B, 1999 to 2022. The vertical lines represent the 95% credibility intervals and 95% confidence intervals for the exploitation rates from the CCIR method and the Northumberland Strait trawl survey, respectively. The solid lines represent the three-year rolling averages of the annual results.

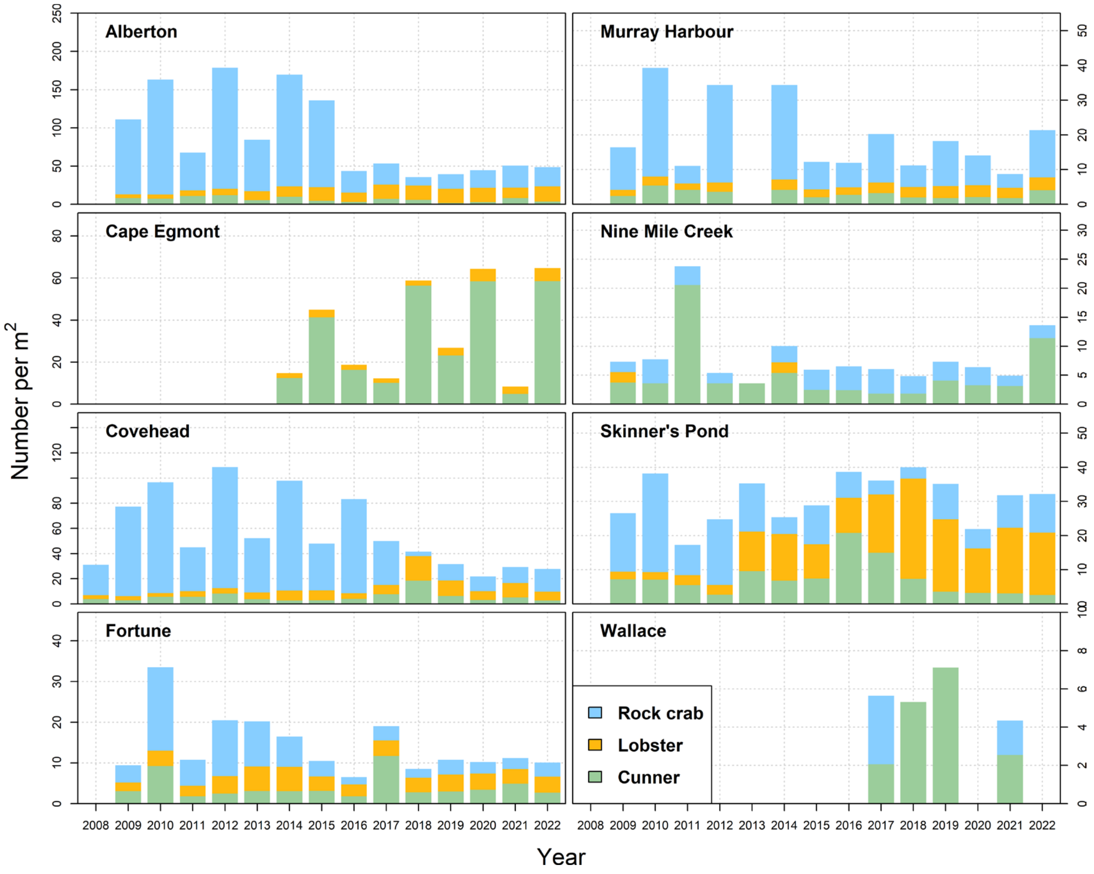


Figure 41. Density of Cunner, small Rock Crab and small Lobster in bio-collectors at eight sites, 2008 to 2022.

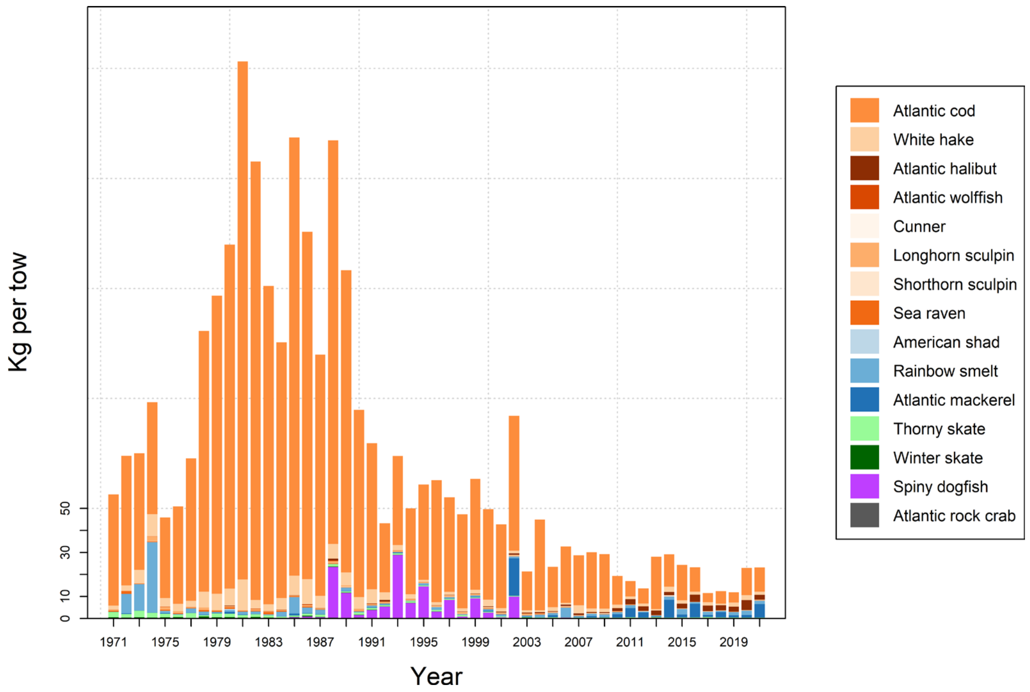


Figure 42. Total average annual catch (kg/tow) of potential Lobster predators in the September ecosystem survey, 1971 to 2021.

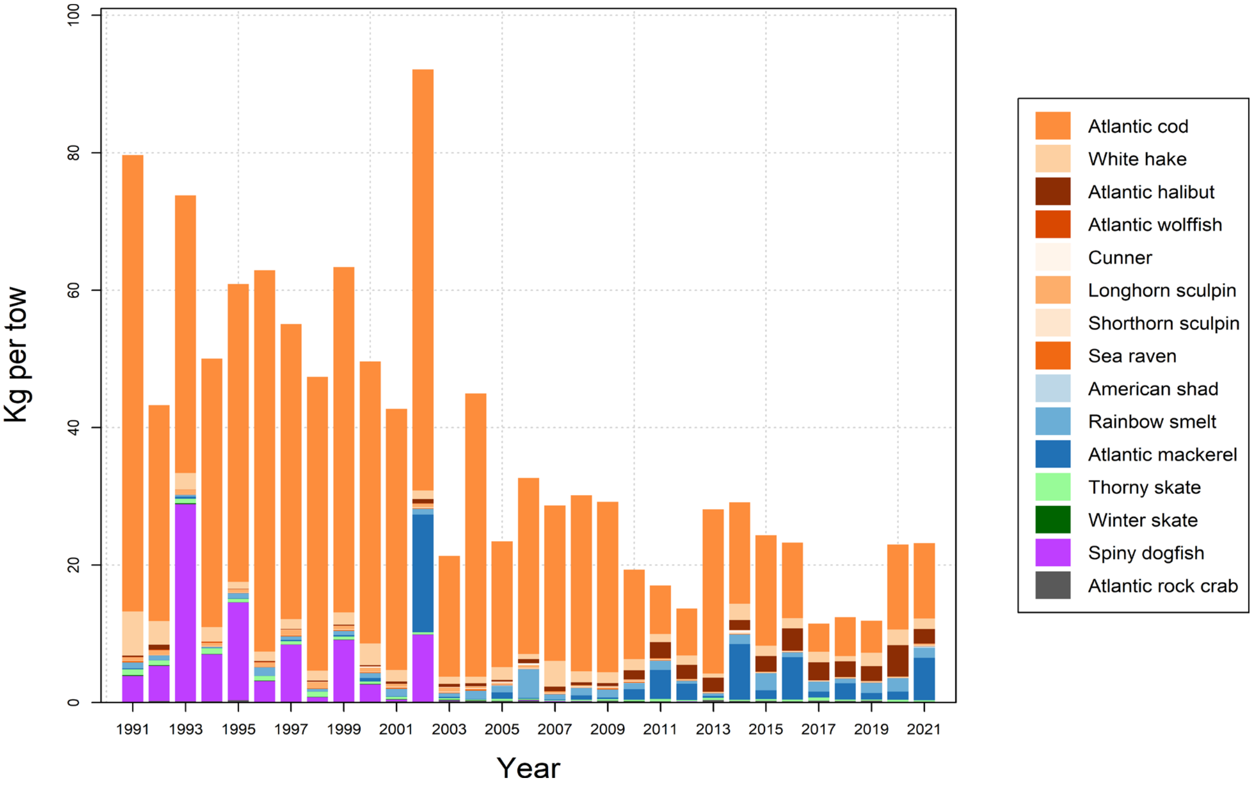


Figure 43. Total average annual catch (kg/tow) of potential Lobster predators in the September ecosystem survey, 1991 to 2021.

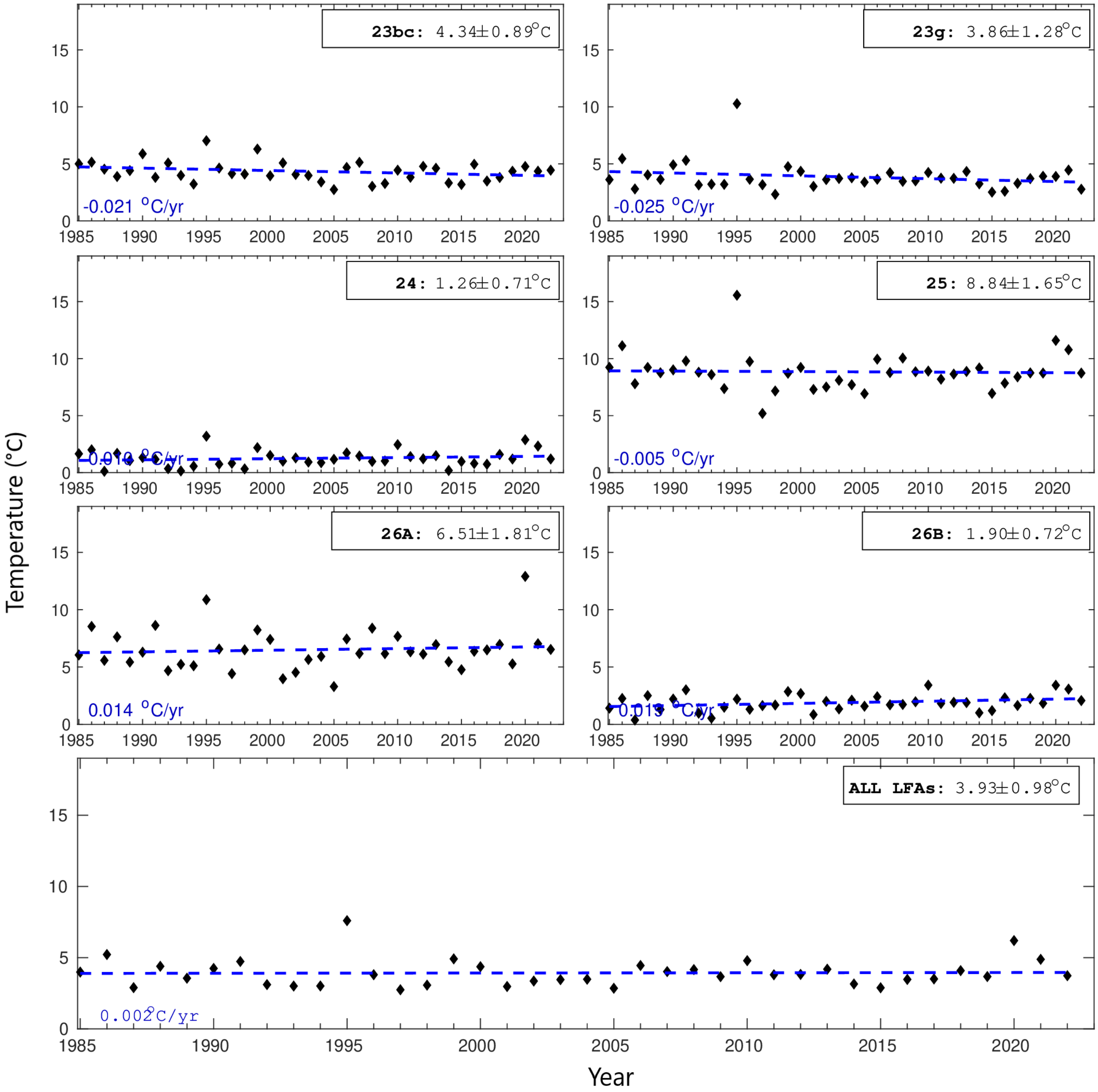


Figure 44. Bottom water temperature time series for each assessment region and for all Lobster Fishing Areas combined from the June survey, 1985-2022. The average temperature was calculated over the full domain of the assessment regions (i.e. not only within the limits of the statistical districts).

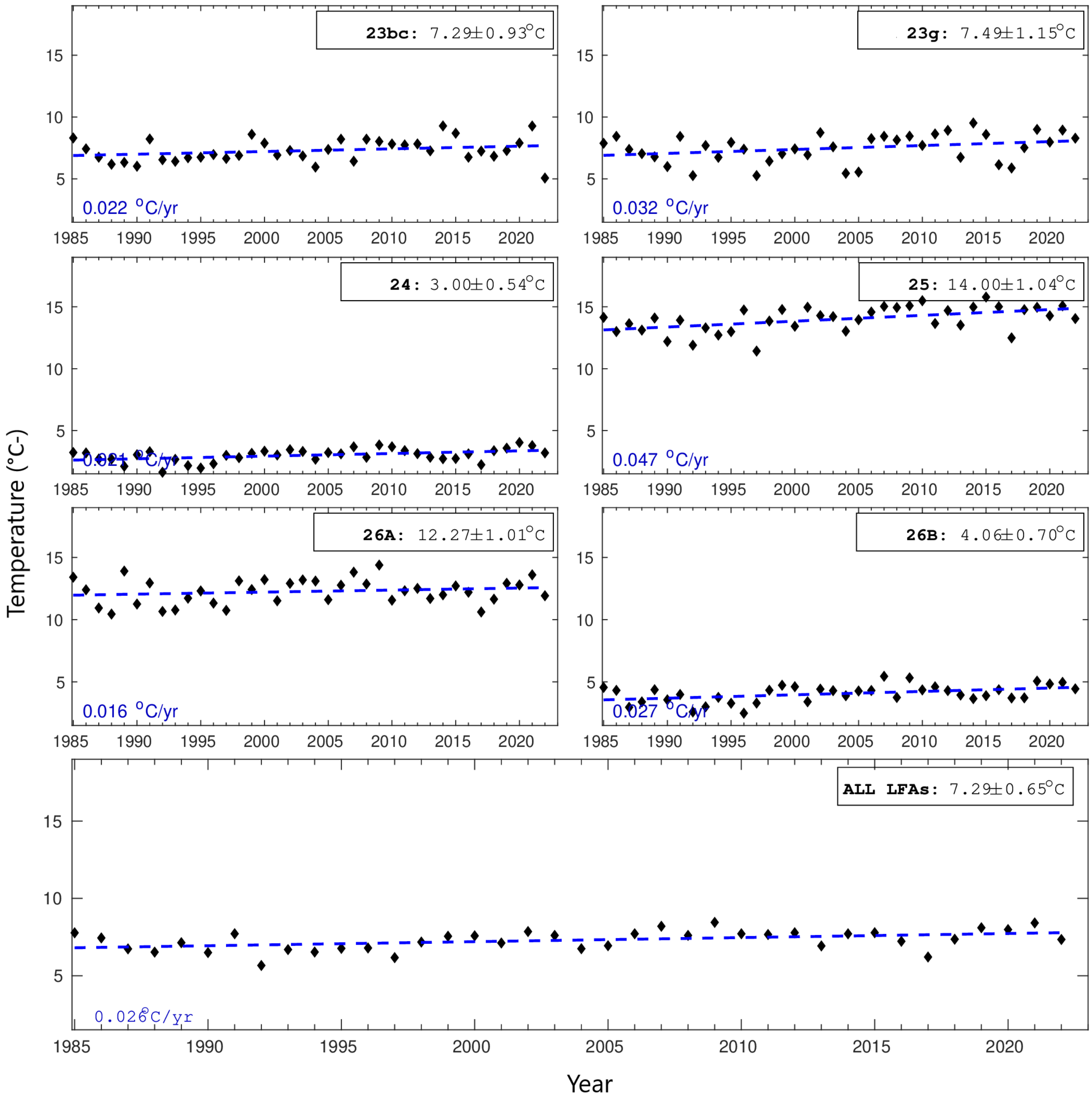


Figure 45. Bottom water temperature time series for each assessment region and for all Lobster Fishing Areas combined from the September survey, 1985-2022. The average temperature was calculated over the full domain of the assessment regions (i.e. not only within the limits of the statistical districts).

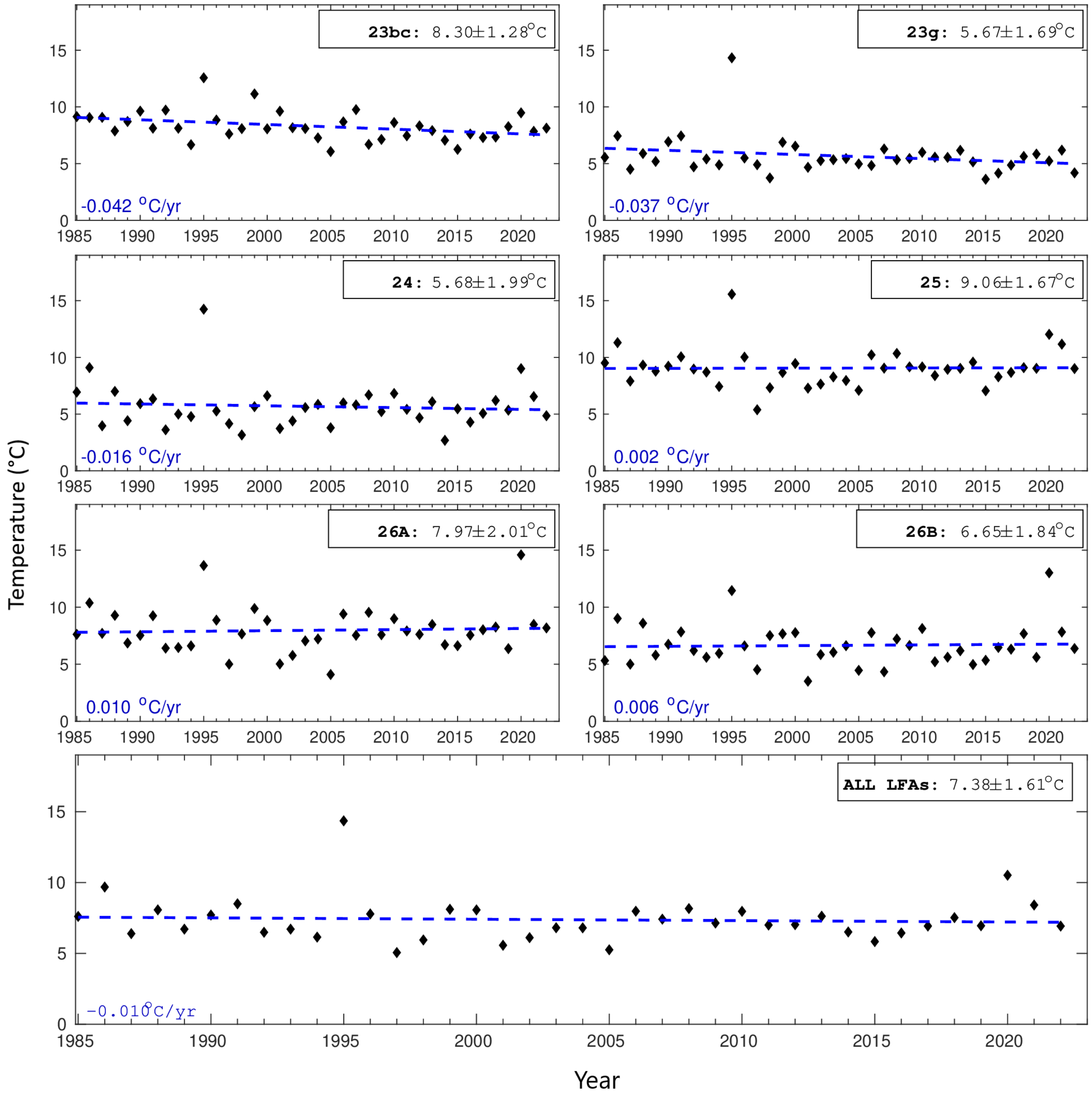


Figure 46. Bottom water temperature time series for each assessment region and for all Lobster Fishing Areas combined from the June survey, 1985-2022. The average temperature was calculated only within the limits of the statistical districts.

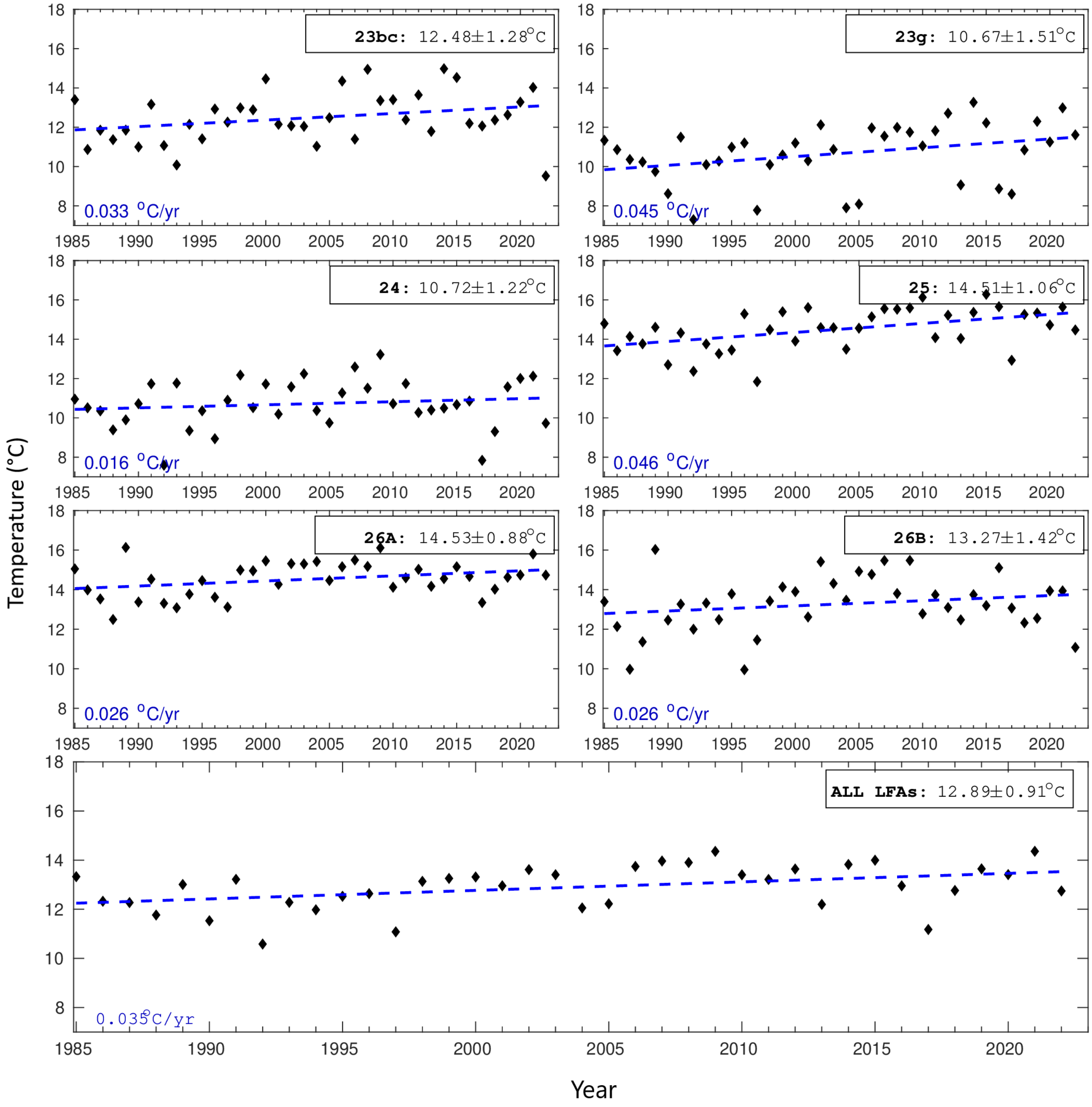


Figure 47. Bottom water temperature time series for each assessment region and for all Lobster Fishing Areas combined from the September survey, 1985-2022. The average temperature was calculated only within the limits of the statistical districts.

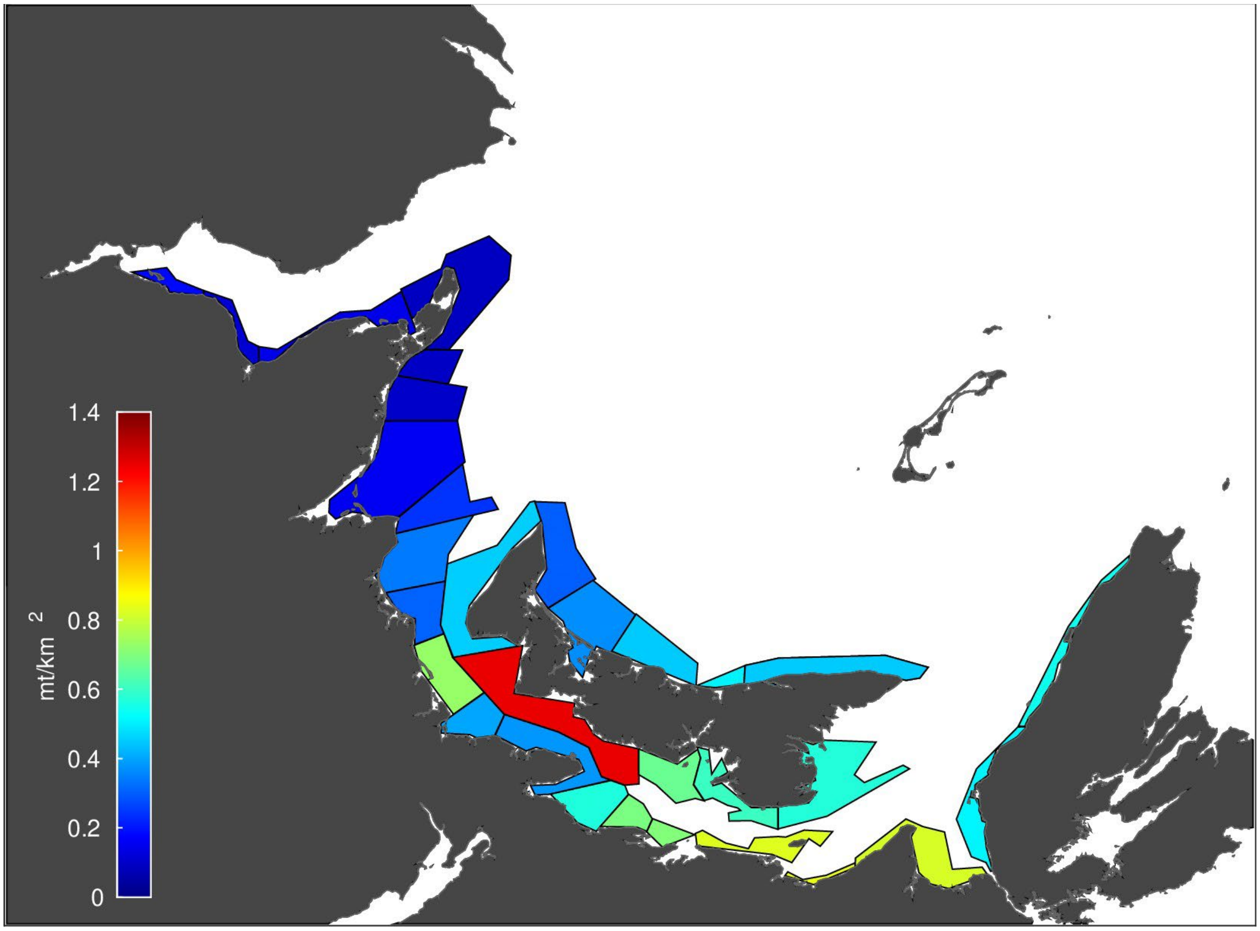


Figure 48. Average Lobster concentration (t/km^2) between 1968 and 2021 for each statistical district located in the southern Gulf of St. Lawrence (Lobster Fishing Areas 23-26) Lobster fishery. The Lobster concentration is based on commercial landings obtained from DFO Statistical Branch in the Gulf Fisheries Centre (Moncton, NB).

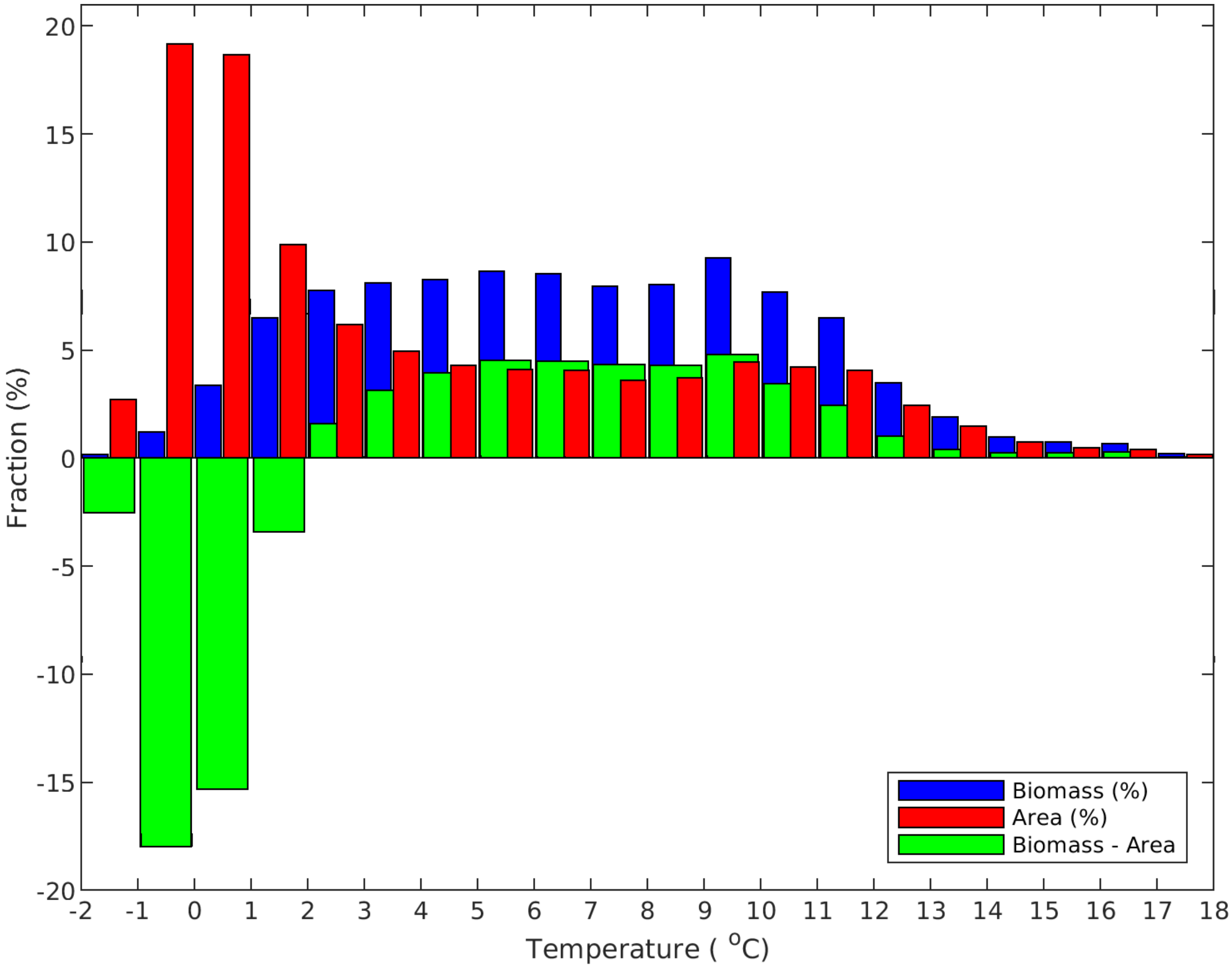


Figure 49. Bottom area and Lobster biomass frequency distributions as a function of bottom water temperature in June, 1983-2021. The green bars represent their difference. 95% of Lobster biomass is found in 0.4 °C-14.0 °C.

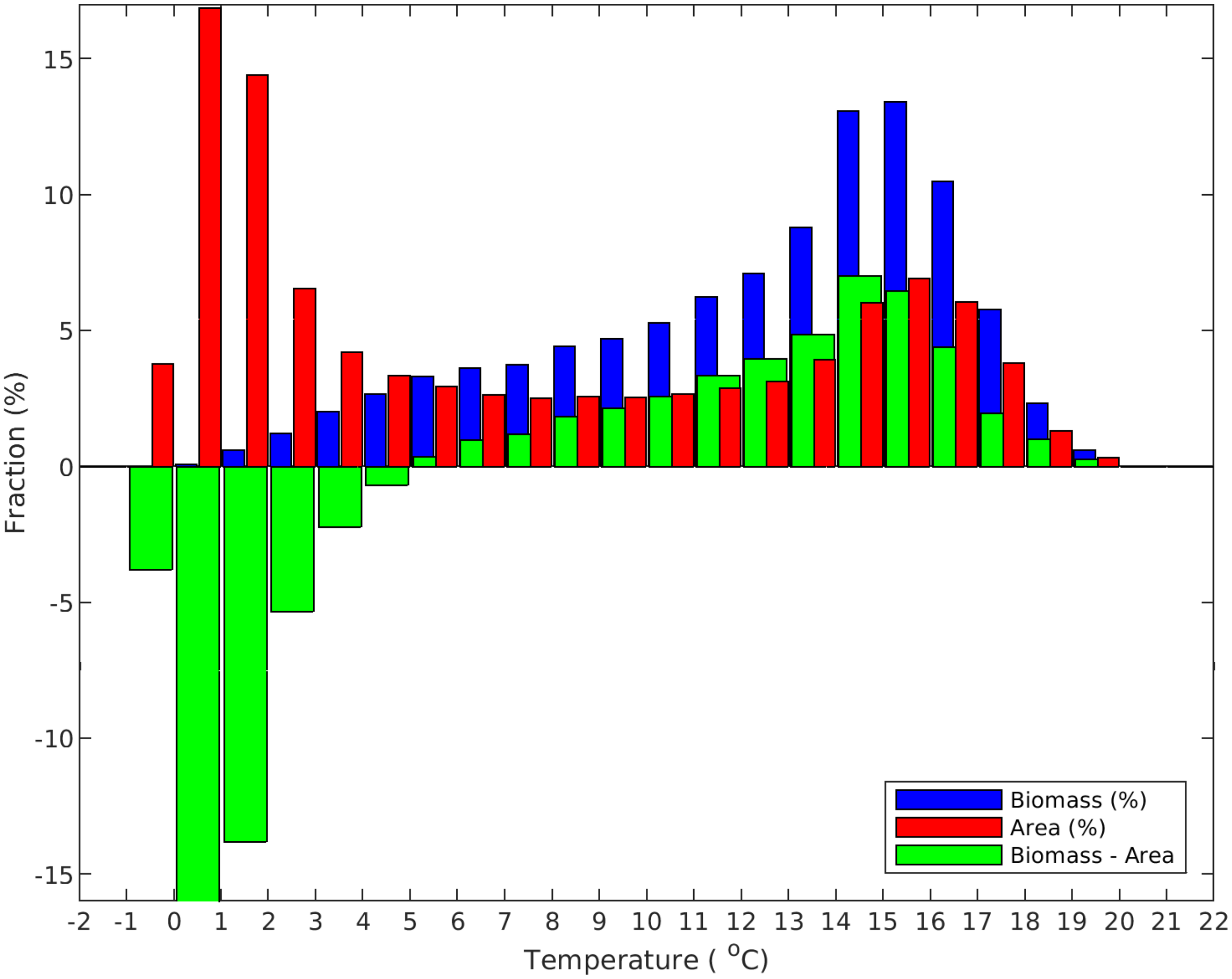


Figure 50. Bottom area and Lobster biomass frequency distributions as a function of bottom water temperature in September, 1983-2021. The green bars represent their difference. 95% of Lobster biomass is found in 3.3 °C-18.0 °C.

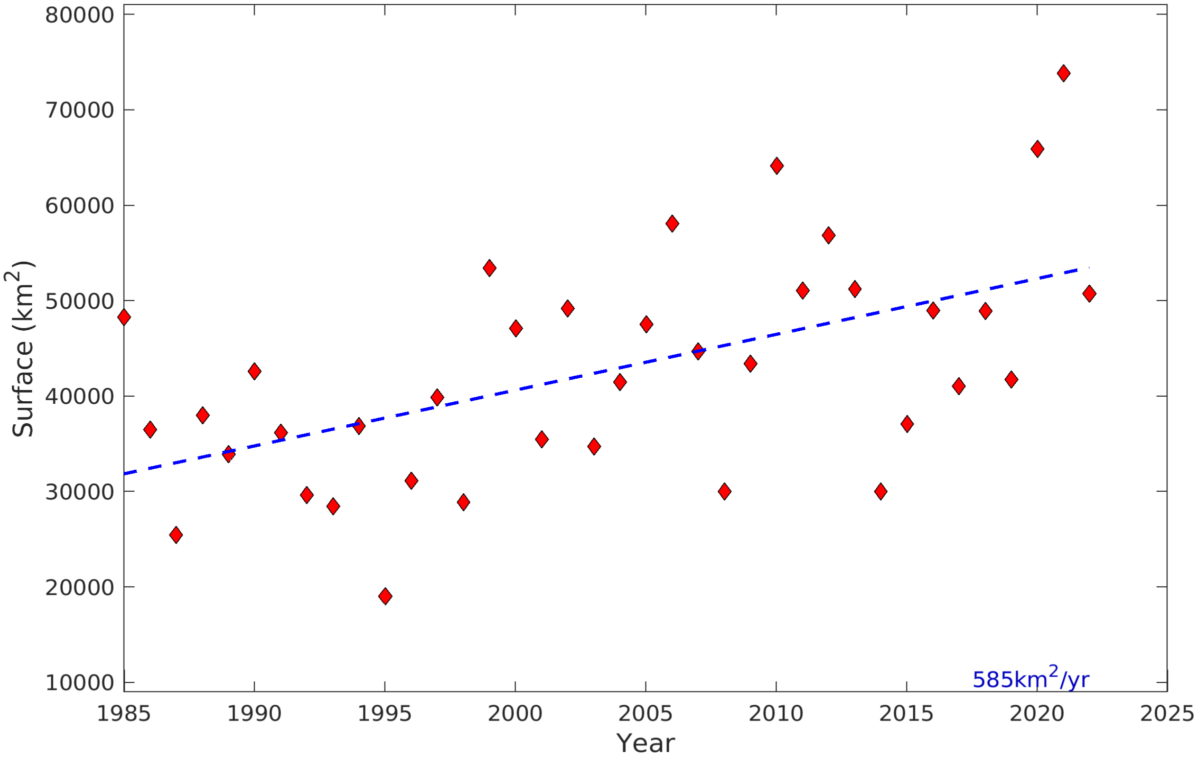


Figure 51. Time series of available June Lobster habitat surface (temperature range 0.4 °C-14.0 °C) in the southern Gulf of St. Lawrence, 1985-2022.

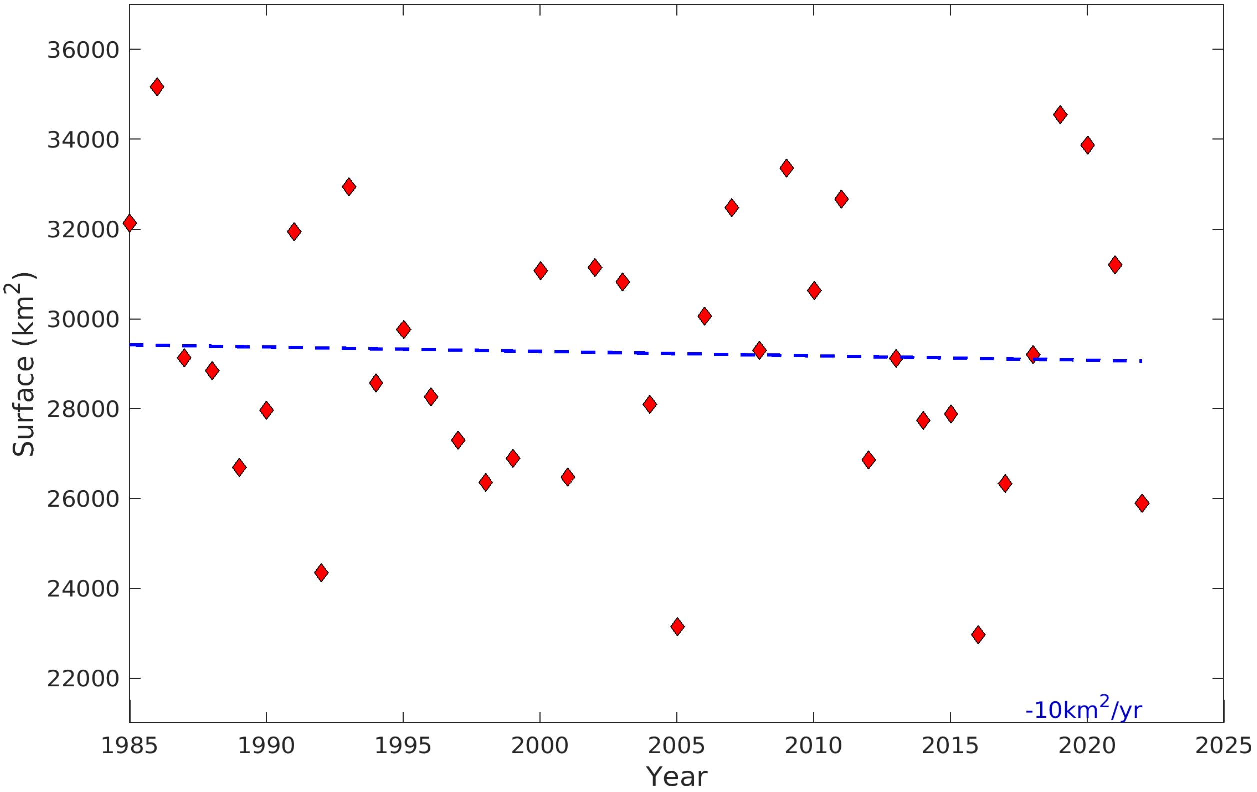


Figure 52. Time series of available September Lobster habitat surface (3.3 °C–18.0 °C) in the southern Gulf of St. Lawrence, 1985-2022.

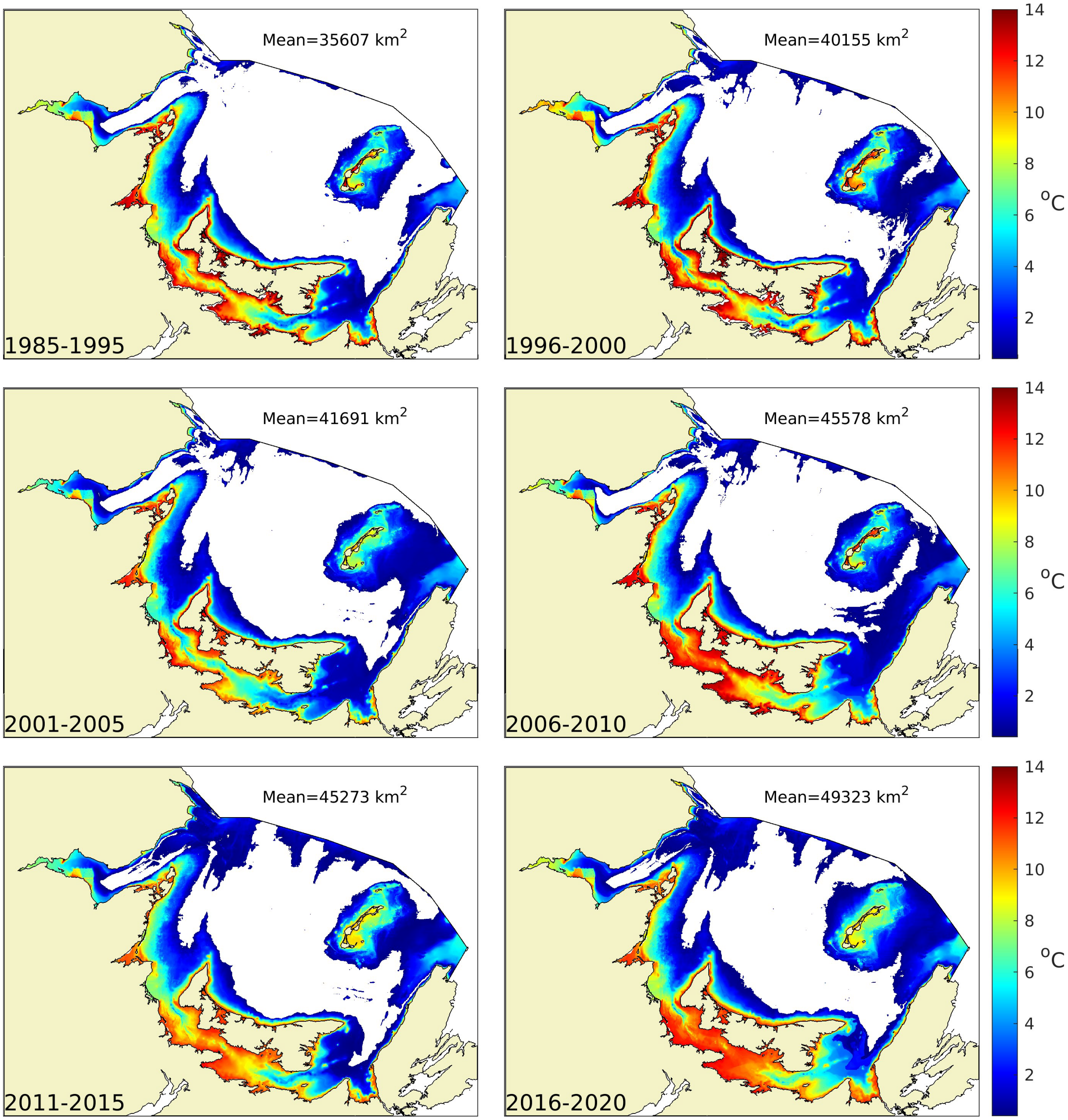


Figure 53. Spatial extend of available Lobster habitat surface in June in the southern Gulf of St. Lawrence for six time periods. The temperature range is 0.4 °C-14.0 °C.

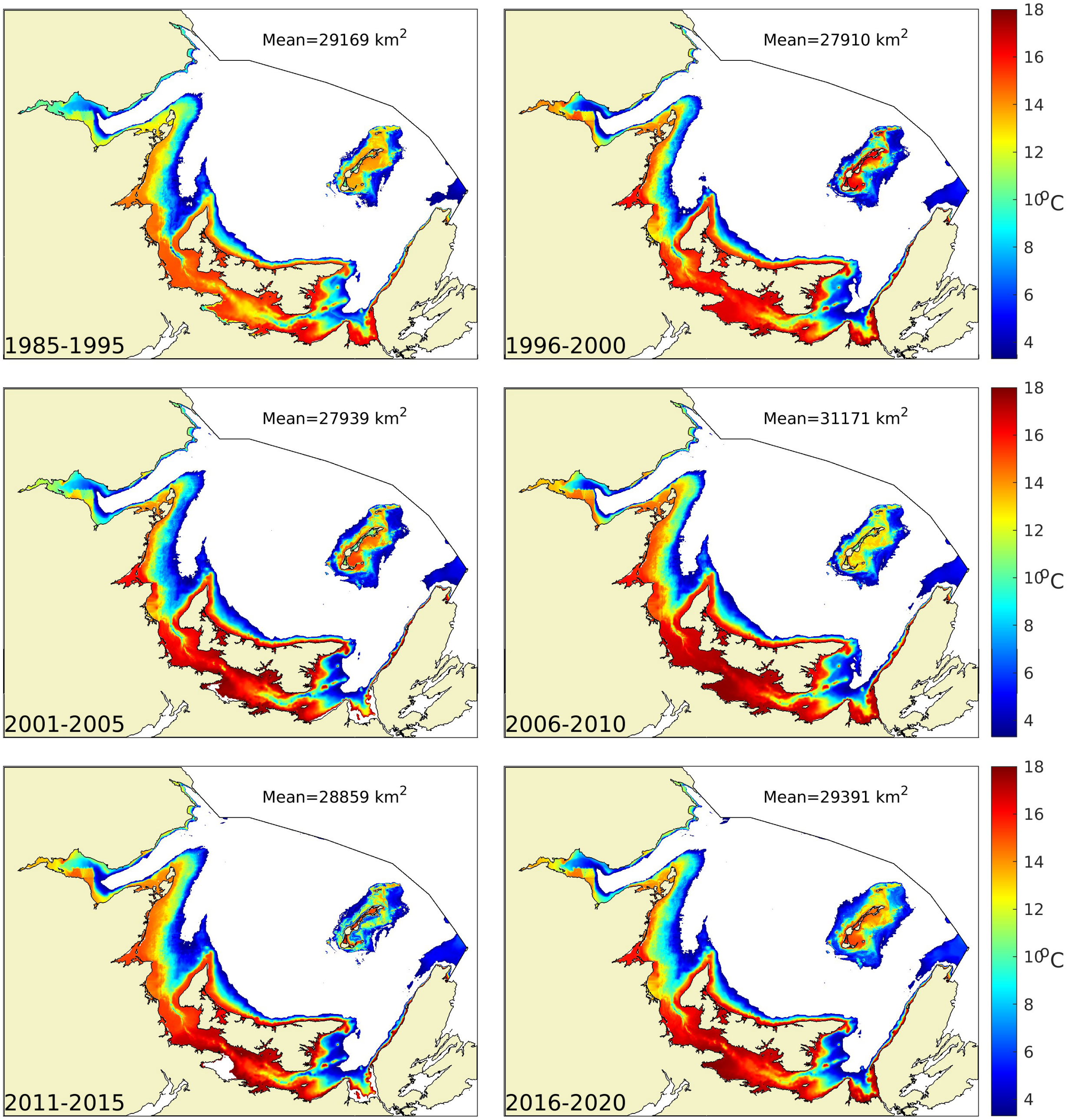


Figure 54. Spatial extend of available Lobster habitat surface in September in the southern Gulf of St. Lawrence for six time periods. The temperature range is 3.3 °C–18.0 °C.