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Assessment of Northern Shrimp (*Pandalus borealis*) and Striped Shrimp (*Pandalus montagui*) in Shrimp Fishing Area 4 in 2022

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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

The status of Northern Shrimp (*Pandalus borealis*) in Shrimp Fishing Area (SFA) 4 has been assessed annually since 2015 and was last assessed in February 2022. The status of Striped Shrimp (*Pandalus montagui*) in SFA 4 is assessed on a biennial basis. It was last assessed in 2021 and a stock status update was conducted in 2022. In SFA 4, the statuses of both stocks have been assessed by examining multiple indicators derived from the fishery-dependent data and the Northern Shrimp Research Foundation (NSRF) - Fisheries and Oceans Canada (DFO) research survey data. Despite a year-over-year decrease of the Northern Shrimp Fishable Biomass (FB) and female spawning stock biomass (SSB) indices in 2022, the recent trend suggests continued increases from a historic low in 2018. In 2022, Northern Shrimp in SFA 4 was in the Healthy zone within the Precautionary Approach Framework, just above the Upper Stock Reference, with a 53% probability of being in the Cautious Zone. Striped Shrimp FB and SSB indices in SFA 4 have increased since 2021 and are above the long-term means (2005–21) of the survey time series. In 2022, Striped Shrimp in SFA 4 is considered in a healthy state in the PA framework (5 times the Limit Reference Point) and other indices of stock health, including the potential predator index, total egg production index, and SFA 4 specific fishable biomass index showed no cause for concern.

1. INTRODUCTION

1.1. SPECIES OVERVIEW

Shrimps (*Pandalus* spp.) are forage species (Policy on New Fisheries for Forage Species) and play a key role in the ecosystem, acting as an intermediary in the transfer of energy from the lower trophic levels (e.g., zooplankton) to the higher ones (i.e., predators, such as fish, marine mammals, and seabirds). Ecological relationships (e.g., predator-prey and competition) must be maintained among the species affected directly or indirectly by the fishery within the bounds of natural fluctuations in these relationships.

1.1.1. Life Cycle

Both Northern (*Pandalus borealis*) and Striped Shrimp (*Pandalus montagui*), together referred to as 'shrimp' throughout this document, are protandrous hermaphrodites; in northern waters, most are born and first mature as males, mate as males for several years beginning in their second year, and then change sex at approximately 17–21 mm carapace length (Bergström 2000; Hansen and Aschan 2000; Baker et al. 2021). Shrimp alter their size of transition in response to environmental and ecological conditions (Charnov and Anderson 1989, Bergstrom 2000, Baker et al. 2021). The transition size of Striped Shrimp in the study area has been linked to the amount of preferred habitat, as well as the average female size in the previous year (Baker et al. 2021). After transitioning, shrimp spend the rest of their lives as mature females. Although accurate ageing in wild populations remains difficult, individuals of both species are generally thought to live for 6–8 years. Shrimp in northern parts of their range, such as those assessed herein, are thought to grow more slowly, have longer life spans, and reach larger sizes than shrimp in more southerly regions (Bergstrom 2000; Baker et al. 2021). Commercial trawls generally catch shrimp with carapace lengths greater than 17 mm (Aschan and Ingvaldsen 2009), thereby, targeting the largest males and females. It has not been possible to infer recruitment from observations of small shrimp on the Newfoundland and Labrador (NL) shelves; no correlation between numbers of small 'pre-fishable' sized shrimp and subsequent changes in fishable biomass has been observed (Orr and Sullivan 2013).

Northern Shrimp Females generally produce eggs in the late summer-fall (late fall to early winter for Striped Shrimp) and carry the eggs on their pleopods until they hatch in the spring (March to April for Striped Shrimp) (Allen 1959, 1963; Bergström 2000; Aschan and Ingvaldsen 2009). Larvae remain pelagic for several months (Ouellet and Chabot 2005; Rasmussen and Aschan 2011). At the end of the summer, larvae increasingly resemble adults and adopt suprabenthic (bottom-based) behavior (Pedersen and Storm 2002). These postlarvae and juveniles are too small to be caught by commercial fishing trawls. Spawning females that survive reproduction are recognizable to those who have never spawned by the disappearance of sternal spines in the prenuptial moult and are called multiparous females (Hansen and Aschan 2000). Environmental conditions (e.g., timing of the spring phytoplankton bloom) influence the reproductive cycle of shrimp (e.g., spring egg hatching) (Koeller et al. 2009). For example, bottom water temperatures influence the duration of egg development on the female abdomen. Different populations of Northern Shrimp have adapted to local temperatures and bloom timing, matching egg hatching to food availability under average conditions (Koeller et al. 2009). However, this strategy is vulnerable to interannual oceanographic variability and long-term climate change.

1.1.2. Habitat

Northern Shrimp are found in the Northwest Atlantic from Baffin Bay south to the Gulf of Maine. Striped Shrimp are found in the Northwest Atlantic from Davis Strait south to the Bay of Fundy. Northern Shrimp are typically found on soft and muddy substrates and in bottom temperatures ranging from 1°C to 6°C (Shumway et al. 1985; Ouellet et al. 2007; Bourdages et al. 2022); however, the majority of Northern Shrimp are caught in waters from 2°C to 4°C. These conditions typically occur at depths of 150–600 m and exist throughout the NL offshore area. In contrast, Striped Shrimp are typically found on hard substrates, with higher concentrations in colder waters, from -0.3 to 2.7°C and shallower depths (100–300 m) (Baker et al. 2021); however, as there are no shrimp survey data at depths less than 100 m, they may have a shallower preference. Although the temperature, depth, and bottom type preferences differ slightly between species, their distributions overlap; the extent of the overlap has not been examined. Environmental conditions (e.g., phytoplankton bloom and sea surface temperatures [SSTs]) also affect Northern Shrimp recruitment from the larval stage until juveniles settle on the bottom (Brosset et al. 2019; Le Corre et al. 2020).

1.1.3. Larval Dispersal and Behavior

There is strong connectivity between the Canadian Arctic areas (Eastern Assessment Zone [EAZ] and Western Assessment Zone [WAZ]) and SFAs 4–7 (Le Corre et al. 2019, 2020). Northern Shrimp larval dispersal modeling shows that larvae may travel several hundreds of kilometers prior to settlement, connecting all the different areas along the northeastern shelves of Canada (SFAs 0 to 7) and western Greenland consistently over the years. Those simulations suggest that Northern Shrimp larvae originating in the north (source: Arctic, SFA 4 and 5) provide most of the potential settlers to southern populations (mostly directed towards SFA 6). However, research on Northern Shrimp larval dispersal did not consider potentially important factors such as temperature-dependent development or mortality (e.g., predation and post-settlement), and there were no recruitment data for Northern Shrimp to validate the simulated dispersal patterns. Original genetic studies between Northern Shrimp populations in SFAs 0–7 demonstrated that individuals in these areas are largely genetically homogenous, but more recent preliminary research identified genetically-distinct pools in localized areas (e.g., SFA 6) that may be linked to smaller-scale oceanographic profiles (i.e., gyres) (Jorde et al. 2015; DFO 2023a). This is most likely due to larval and pelagic transport by the Labrador Current.

The degree of adult and larval Striped Shrimp transfer throughout the area has not been quantified and is assumed to vary through time. Larval studies in West Greenland waters (Pedersen et al. 2002) concluded that Striped Shrimp likely have an earlier hatch and slower development time than Northern Shrimp based on sizes of the different larvae sampled. Given this information, recent larval drift modelling of Northern Shrimp (Le Corre et al. 2019, 2020) is unlikely to apply to Striped Shrimp on the same scale.

1.1.4. Vertical and Horizontal Movements of Adults

In some regions, shrimp perform daily vertical migrations (Crawford et al. 1992; Hudon et al. 1992). They rise in the water column at night to feed on plankton, and then return to the bottom during the day (Hudon et al. 1992; Baker et al. 2021). The scale of vertical migrations varies depending on the individual's developmental stage and local conditions (Hudon et al. 1992; Bergström 2000).

In addition to being found in SFA 4, both Northern and Striped shrimp are found in the EAZ and WAZ, directly to the north of SFA 4 (DFO 2021). Near the Hudson Strait, being a highly dynamic system with strong currents and mixing (Drinkwater 1986), some adult shrimps (i.e., not only larvae) could be transported a great distance in a relatively short period of time, resulting in rapid shifts of shrimp into and out of SFA 4. Currently, the rates of exchange (export/import) are between these zones are unknown; therefore, understanding resource dynamics as a whole requires integrating information from all assessment areas (DFO 2023a).

1.1.5. Predators

Northern and Striped Shrimp are important prey for many species such as Atlantic Cod (*Gadus morhua*), Greenland Halibut (*Reinhardtius hippoglossoides*), Redfish (*Sebastes* spp.), American Plaice (*Hippoglossoides platessoides*), skates (*Raja radiata*, *Raja spinicauda*), wolffish (*Anarhichas* spp.), and Harp Seal (*Pagophilus groenlandicus*), especially during the period of low groundfish abundance on the NL shelves (Pedersen et al. 2022). Varying predation rates play an important role in regulating Northern Shrimp abundance across a wide range of regions, including Greenland (Wieland et al. 2007), Iceland (Jónsdóttier et al. 2012), the Gulf of Maine (Richards and Hunter 2021), and the Gulf of St. Lawrence, although recent studies in the Gulf of St. Lawrence also highlight the important role of plankton dynamics on Northern Shrimp growth (Brosset et al. 2019).

Similar to Northern Shrimp, Striped Shrimp have been documented in the stomachs of Greenland Halibut, Redfish, Roughhead Grenadier (*Macrourus berglax*), American Plaice, and skates (*Rajidae*) caught during summer surveys (Polaczek et al. 2023). Predators, such as Atlantic cod and squid (*Gonatus* spp.), are known to be significant drivers of biomass and population dynamics in other *Pandalus* sp. stocks (e.g., Richards and Hunter 2021; Pedersen et al. 2022).

The amount of shrimp consumed by predators varies in response to predator stock size, spatial overlap, and alternative prey options.

1.2. COMMERCIAL FISHERY

The fishery for Northern Shrimp off the coast of Labrador began in SFA 5 in the mid-1970s, primarily in the Hopedale and Cartwright Channels. Soon after, concentrations of Northern Shrimp were located within SFAs 4 and 6, leading to an expansion of the fishery into those areas (DFO 2007, 2009; Baker et al. 2024, in press).The fishery expanded to Hawke Channel, St. Anthony Basin, Funk Island Deep, and slope edges of the continental shelf in SFAs 4–6 during the early-1990s, with associated Total Allowable Catches (TACs) periodically increased over the next two decades (Figure 1). Based on available at-sea observer data, commercial catch of Striped Shrimp in SFA 4 is taken as both a targeted species and also as by-catch in the SFA 4 Northern Shrimp fishery.

All Northern and Striped Shrimp fisheries in eastern Canada are subject to the Atlantic Fisheries Regulations, established under the *Fisheries Act*. Pertinent regulations apply to by-catch, discards, vessel logs, etc., and include a minimum mesh size of 40 mm and mandatory use of sorting grates to minimize by-catch of non-target species (DFO 2023a). Grate size is dependent upon the area fished. In SFAs 4–5 the maximum bar spacing is 28 mm. At-sea observers are required on all trips by the large vessel (LV) fleet (i.e., 100% observer coverage). A target of 10% observer coverage has been established for the small vessel (SV) fleet (DFO 2023a), although coverage has ranged between 5–8% over the last 10 years. Observers onboard vessels are responsible for recording positions (Figure 2), catch size, and discards.

Over the 1978–2022/23 period, the Northern Shrimp TAC in SFA 4 has changed from a minimum of 500 t (1978–88) to a maximum of 15,725 t in 2018/19, and was 12,944 t in 2022/23 (Figure 3, Table 1).

Until 2012, the sole source of catch information for Striped Shrimp was logbooks; however, by-catch was recorded in the Canadian Atlantic Quota Report [CAQR, now Atlantic Quota Monitoring System (AQMS)] beginning in 2013, and continues to be recorded under the AQMS. A by-catch limit of 4,033 t was implemented in 2013/14 and has remained unchanged (Figure 4, Table 2).

Despite the connectivity between SFAs 0–7, the assessments for both species are conducted at spatial scales reflecting management units that accommodate management preferences and historic practices, rather than ecological and biological process. The biological units for each species are recognized to be larger than the assessment scales and caution in interpreting and applying stock status information at smaller assessment scales is warranted (DFO 2023a).

2. MATERIAL AND METHODS

The assessment addresses general key considerations inherent in biological measurement of any renewable resource including how fast the resource is renewing itself, how renewal rates might change, and how human activity can affect renewal rates. In management terms, the rate at which a resource renews itself informs decisions on harvest rates that are sustainable.

In 2023, resource status of Northern and Striped Shrimp in SFA 4 was assessed based on NSRF- DFO summer trawl survey data, commercial catch landings from the AQMS, and details on commercial shrimp fishing from at-sea observer (NL, Nova Scotia, Quebec regions) and logbook (NL region) datasets. The assessments focus on a variety of stock indicators including biomass indices of various Northern and Striped Shrimp maturity stages, length frequencies, distribution, and fishery catch statistics. Trends in fishery performance were inferred from TAC, commercial catch-to-date, fishery catch per unit effort (CPUE), and fishing patterns. Data related to ecosystem status in SFA 4 are limited, but examination of available oceanographic conditions, biological community structure, predator-prey interactions, and some human impacts (including trends in fishery performance) were made.

2.1. COMMERCIAL FISHERY DATA

2.1.1. TACs and Catches

TACs and catches from 1977 to 2022/23 for the LV and SV fleets fishing Northern Shrimp in SFA 4 were based upon the AQMS as of February 17, 2023. In 2003, the fishing season was switched from a calendar year to a management year such that the catches shown for 2003/04 are based on a 15-month fishing season. Quota transfers, bridging, and overruns were reflected in all catches and, since 2016/17, in the adjusted TAC column. All 2022/23 catches and adjusted TACs were preliminary. At-sea observer data were incomplete for 2022, such that LV fishery results shown for 2021/22–2022/23 management years are preliminary.

2.1.2. Catch Per Unit Effort

CPUE is a measure of fishery performance for the Northern Shrimp fisheries in SFA 4. The observer database was used to determine CPUE for the LV shrimp fishing fleet in SFA 4. Observed data were used because that dataset includes the number of trawls and usage of windows (escape openings) whereas the logbook dataset does not. However, the assessment took place while the fishery was ongoing and there was a delay receiving the data such that the most recent commercial data were not available for analyses in the assessment (i.e., 2022/23 data was incomplete for the 2023 assessment) and the most recent values presented are preliminary. Commercial CPUE models for Northern Shrimp are outlined in Orr and Sullivan (2013).

Raw CPUE data were standardized by multiple regression and weighted by effort, in an attempt to account for variation due to year, month, number of trawls, vessel, etc. The CPUE models for Northern and Striped Shrimp directed fisheries in SFA 4 were based on LV CPUE models for SFA 5 and 6, and included all significant class variables over the 1989–2022 time series to track the trend in fishing performance over time. The difference (or similarity) between the first year parameter estimate and those of subsequent years was inferred from the output statistics. In order to track only experienced fishers, the standard dataset included only data from vessels with more than one year of shrimp fishing experience. The analyses were performed with the generalized linear model (GLM) procedure of the SAS software (SAS 9.4). Unstandardized CPUE (kg/hour) was calculated by depth range and stratum (i.e., the area and depth-based strata utilized for allocation of research survey sets) for the LV fleet fishing Northern and Striped Shrimp in SFA 4. The spatial distributions of catches, and CPUE by 0.1° grid square were compiled for LVs (> 500 t) from 2020/21 to 2022/23 for both species with the ACON mapping software, noting that the most recent data were incomplete. Seasonal variations of the unstandardized CPUE values (raw catch/effort averaged by year and week) were also presented for the LV fleet targeting Northern Shrimp in SFA 4, based on the commercial fishing management year from 1993 to 2022/23.

2.1.3. Length Frequencies (Observer Data)

Observers onboard vessels targeting Northern and Striped shrimp in NL waters measured random detailed samples of Northern Shrimp, which consisted of 250–300 individuals and included information on maturity (male, primiparous female [Fe1], multiparous females [Fe2], and ovigerous females), lengths (cephalothorax length to the closest 0.1 mm), and pathogens. This dataset was used to provide annual estimates of commercially caught size frequencies in SFA 4 and the annual mean carapace length of Northern and Striped Shrimp caught by the LV fleet in SFA 4. There was no observer length data available for Striped Shrimp in 2022.

2.1.4. Logbook Data

Logbooks are completed for every Canadian vessel targeting Northern and Striped Shrimp. They are returned to the province in which the vessel is registered and stored in databases that differ by province. These data include information such as catch size, position, and discards. Given the low observer coverage rates of the SV Northern Shrimp fishery in SFA 4, logbooks were only utilized to determine the spatial distribution of the fishing effort.

2.2. NORTHERN SHRIMP RESEARCH FOUNDATION SURVEY

The NSRF-DFO stratified random trawl survey, henceforth referred to as the NSRF survey, occurred in the summer months utilizing a commercial shrimp trawler with similar gear and survey protocols in place as the DFO spring and autumn multispecies surveys (McCallum and Walsh 1996). The survey is deemed to effectively cover the entire distribution range of Northern and Striped Shrimp in the WAZ, EAZ, and SFA 4, where SFA 4 data are sufficient for generating survey indices from 2005 to 2022. In most years the survey occurred from July through August using the Ocean Choice International (OCI) vessel *Aqvik*. However, operational issues sometimes resulted in alternate OCI vessels being utilized or delays/breaks/extensions in survey timing. The effects of these adjustments have not been quantified. Sampling locations within each depth strata are allocated in accordance with Doubleday's (1981) method. The sampling locations were proportionally allocated to the size of the stratum area, with a minimum of two sets per stratum until 2018, regardless of its size (Blais et al. 2021). In 2018, the Hatton Basin Marine Refuge (MR) area was removed from the NSRF survey sampling area and set allocation exercise. This resulted in several strata that were redefined as a large portion of them was covered by the Hatton Basin MR. Given that the assessment methodology utilized for SFA 4 do not require two sets per stratum, three small strata with minimal historical shrimp catches were allocated only one set per strata from 2018 to present.

Vessels used to conduct the NSRF survey have varied since its inception in 2005. These included the F/V (Fishing Vessel) *Cape Ballard* (2005–11), F/V *Paamiut* (2007, 2009, 2011, 2013; SFA3 only), F/V *Kinguk* (2014), F/V *Katsheshuk* II (2015,2020), and F/V *Aqviq* (2012, 2013, 2016–19, 2021–22). The *Cape Ballard*, *Aqviq* and *Kinguk* had similar specifications, but the *Katsheshuk II* was a larger, more powerful vessel. Considering the strong similarities in specification among these sampling platforms it has been concluded that conversion factors are not required to continue with a comparable time series (S. Walsh, DFO Emeritus, pers. comm.). However, this assumption has not been empirically tested and research has demonstrated that there are catchability effects resulting from vessel changes despite survey gear and protocols being equal (Benoit 2006; Perez-Rodriguez and Koen-Alonso 2010; Thorson and Ward 2014). Frequent vessel changes are undesirable and lead to uncertainty in interpreting survey results due to the likely violation of an assumed constant annual survey catchability.

The NSRF survey used a standard Campelen 1800 shrimp trawl. Each tow aimed for 15 minutes of bottom contact travelling at a targeted speed of 3.0 knots. A trawl-mounted Conductivity-Temperature-Depth (CTD) instrument recorded bottom temperature, salinity, and depth values corresponding with each tow. Further details on the survey are available in Siferd (2015).

During the survey, shrimp were subsampled ($n \approx 300$ individuals) during each tow and sorted to species, counted, and weighed. Maturity/sex (male, transitional, primiparous, multiparous or ovigerous stages), overall condition (e.g., presence of parasites), shell condition, and carapace length were recorded (Siferd 2015). Fish and invertebrates (i.e., by-catch) were sorted to species-level, then counted and weighed. Following the survey, all weights and numbers were standardized to a 0.8 nm tow. Catches were further standardized to account for male Striped Shrimp diurnal migrations (Baker et al. 2021). Work is ongoing to account for Northern Shrimp diurnal migrations (not presented during 2023 assessment). More details on design and practices, trawl monitoring, environmental data sampling, shrimp catch processing, and additional field sampling during the NSRF survey are available in Fulton et al.2024.

2.2.1. Assessment Data Analysis

For both Northern and Striped Shrimp, all biomass and abundance indices (by SFA or survey stratum) are calculated using Ogive Mapping (Ogmap) methodology applied on survey data spanning 2005 to present (Evans 2000; Evans et al. 2000; Orr and Sullivan 2013). Based on a dense set of Delauney triangles of known position and depth, Ogmap weighted values are calculated according to distances (horizontal and vertical) from each sample location. Points closer to the sample location receive higher weights (Evans et al. 2000). Ogmap is then used to compute the distribution of the biomass and other metrics across the area of interest (i.e., SFA or stratum). The point estimates were provided from the entire survey dataset, while the probability distribution is determined through Monte Carlo simulation ($n = 500$) and provide 95% confidence intervals.

In 2014 there were important refinements made to Ogmap which included the following corrections:

- Formerly, Ogmap chose bandwidths to minimize mean prediction error, whereas the updated version uses tests of the assertion that the survey observations are independent random samples from their respective probability distributions.

- The previous version of Ogmap used a kernel smoothing function that peaked at the origin and dropped exponentially with distance. This tended to overweight the nearest observation, possibly reducing the variability generated from resampling. The updated version utilizes a smoothing function with a flatter top and estimates the degree of flatness.
- Area of integration used in the previous version tended to omit all areas close to the border of the area of interest. This was particularly problematic when the highest concentrations of shrimp tended to be found on, or straddling, the borders. The revised version includes those areas.
- The bootstrapping methods for determining confidence limits were changed; unlike the other changes which are clear improvements, this is an area of ongoing research.

The annual fishable (>17 mm carapace length), female, total, and male biomass and abundance indices (and associated lower and upper confidence intervals) were presented in the current assessment. Changes (indicated by % change) from the previous year were also calculated and presented. In addition, total biomass (kt) of Northern and Striped Shrimp were calculated by strata and depth range (101–750 m) from 2005 to 2022. The latter was also utilized to calculate the percent contribution to total biomass per depth range over the survey period.

Additionally, the proportions of total fishable vs pre-fishable (≤ 17 mm carapace length) biomass, total male vs. female biomass, male vs. female within the fishable biomass, and proportion of various maturities were calculated for Northern and Striped Shrimp in SFA 4 based on the NSRF subsampled catches. Using the length frequency module of Ogmap on the NSRF summer shrimp data, Northern and Striped Shrimp abundance at length (expressed as a percentage of total abundance) were determined for the 2005–22 period. The NSRF subsample catches were also utilized to calculate the mean size of shrimp of various maturities. Based on NSRF trawl survey data, predator standardized survey catch rates and bottom temperature were calculated.

2.2.2. Size at 50% Transition

The annual size of transition was estimated using NSRF survey data for each combination of SFA and year using a generalized additive model (GAM) with a binomial distribution (Eq. 1):

Eq. 1:

$$Y_i \sim binomial(1, p_i)$$

$$E(Y_i) = p_i$$
$$var(Y_i) = p_i \times (1 - p_i)$$

$$logit\ (p_i) = \beta_o + f_j(CL_i) + SFA\_year_i$$

where, Y_i represents transitioned (i.e., transitional or female) or not yet transitioned (i.e., male) for an individual of a given carapace length (mm) in a given SFA and year, β_o is the intercept, and f_j is a unique smooth function of carapace length (CL) estimated using a thin plate smoothing spline for each SFA/year combination (SFA_year_i) (Baker et al. 2021). Each observation was weighted by the number of individuals in the set of that particular transitional-size category. The size at 50% transition was estimated for each SFA and year by determining the length at which the model fitted value was 0 (on the logit scale), which corresponds to 50% probability of transition (since logit(0) = $e^0/(1 + e^0)$ = 50% probability) (Pedersen et al. 2022).

2.2.3. Exploitation Rate

Exploitation rate index (ERI) was determined by dividing the commercial catch (from the AQMS) from the fishing season by the NSRF survey fishable biomass index from the current year (i.e., 2022/23 commercial catch is divided by the 2022 fishable biomass index).

The ERI was expressed as a percentage of the fishable biomass and 95% confidence intervals corresponded to the Ogmap fishable biomass confidence interval estimates. Because the fishing season for Northern Shrimp and Striped Shrimp was still open at the time of the annual assessment, the reported ERI for the current year is considered incomplete and will be updated during the next assessment or update. The TAC is set for SFA 4 Northern Shrimp under the assumption that biomass indices will not change from the most recent survey year to the next survey year. There is no ability to calculate the ERI one year in advance in SFA 4 due to the survey timing (summer) in relationship to the fishery removals timing.

2.2.4. Production Model

A spatially-explicit Northern Shrimp production model (Eq. 2) incorporating environmental and ecosystem drivers was developed and peer reviewed during a Canadian Science Advisory Secretariat (CSAS) framework meeting in May 2019 (Pedersen et al. 2022). The model utilizes North Atlantic Oscillation (NAO) and predation by Atlantic Cod, Greenland Halibut, and redfish to predict productivity changes within each SFA. The model was used to forecast Northern Shrimp total biomass in the following year (with catch removed), with the final year's model prediction assuming various exploitation rate indices of fishable biomass.

Eq. 2:

$$log\left(\frac{D_{i,t}+C_{i,t}}{D_{i,t}}\right) = \hat{r}_i + \beta_i \cdot shrimp\ density_{i,t-1} + \gamma_1 \cdot cod\ density_{i,t-1} + \gamma_2 \cdot other\ predator\ density_{i,t-1} + \gamma_3 \cdot NAO\ index_{t-1} + \epsilon_{i,t}$$

where, D is the density of northern shrimp, C is the recorded catch, r is low density (~density independent) growth rate, β is the density-dependent growth rate, and ϒ are unique smooth functions of cod density, other predator density, and NAO index in the previous year.

While the model was tentatively accepted during the 2019 CSAS Northern Shrimp framework meeting (Pedersen et al. 2022), the consensus from the external reviewers and meeting participants determined that model testing and refinements should take place prior to utilizing biomass projections for management decisions, but model results could be used to provide a general idea of changes in future stock abundance (DFO 2023b).

2.2.5. Precautionary Approach Framework

2.2.5.1. Northern Shrimp

The initial framework for the assessment of Northern Shrimp off Labrador and the northeastern coast of Newfoundland previously followed a traffic light approach (DFO 2007). In 2008, a workshop was held with the objective of establishing a Precautionary Approach (PA) framework for Canadian shrimp and prawn stocks (DFO 2009). During that meeting, reference points based on proxies were introduced for Northern Shrimp resources in SFAs 4–6. The PA framework (which this assessment follows) is described in the Integrated Fisheries Management Plan (IFMP) which was first published in 2007 (DFO 2007) and updated in 2018 (DFO 2018a). This framework was developed in 2008–10 following the 2008 framework workshop attended by a Marine Stewardship Council (MSC) working group and including representation from DFO Science, DFO Fisheries Management, and industry stakeholders. The Limit Reference Point

(LRP) is defined as the stock status below which serious harm is being done to the stock and is based on best available information, and the Upper Stock Reference (USR) is defined based on the female Spawning Stock Biomass index (SSB) over a productive period (DFO 2009).

Northern Shrimp reference points in the IFMP PA Framework were developed using proxies, relatively consistent with guidance in the DFO PA Framework (DFO 2009). The USR was defined as 80%, and LRP as 30%, of the geometric mean of female SSB index over a productive period. The reference period to determine the LRP was 2005–2009 for SFA 4. The values of the reference points were revised slightly in 2016 and again in 2018, in accordance with refinements in the biomass estimation method. In 2019, the reference points for SFA 4 Northern Shrimp were modified to exclude the Hatton Basin MR which was not surveyed beginning in 2018. The PA framework itself has not changed since its implementation. The PA framework was applied over the period 2005–22 using an USR of 51,000 t and a LRP of 19,100 t superimposed upon the ERI trajectory over time.

2.2.5.2. Striped Shrimp

In accordance with DFO's PA Framework, during the 2023 CSAS peer-review meeting, an LRP for SFA 4 Striped Shrimp based on the combined survey data time series (2005–22) of SFA 4, EAZ, and WAZ was developed from a spatiotemporal model that created a new fishable biomass index for the Striped Shrimp population as a whole (FB_{pop}) (Baker et al. 2024, in press). The spatiotemporal model was used to hindcast density estimates for the entire time series and survey area, despite lack of survey coverage in some SFAs in some years (Baker et al. 2024, in press). FB_{pop} was used to determine the stock status in SFA 4 only; there are no current or anticipated changes to the reference points associated with EAZ and WAZ. The adopted LRP was based on FB_{pop} which was calculated as the average of:

- The lowest fishable biomass at which the stock increased and remained above the geometric mean for a period of at least three years
- The lowest observed fishable biomass in the time series
- 40% of the geometric mean of the fishable biomass index throughout the time series.

The methodology forms the basis for this LRP, rather than a precise estimate of FB_{pop}, to allow for future model refinements.

In addition to reporting on the status of the stock in relation to the LRP, three additional indicators of stock health are reported during each assessment:

- Ecosystem outlook – potential predator index: the ecosystem outlook is based on the 3-year moving average of a population-wide (i.e., SFA 4, EAZ, and WAZ combined) potential predator index incorporating available predator data from the NSRF survey (large redfish, Greenland Halibut, skates, and grenadiers) in a spatiotemporal model (Baker et al. in press).
- Reproductive outlook – total egg production index: the reproductive outlook is based on the 3-year moving average of a population-wide total egg production index taking into consideration both the abundance and size distribution of females at each NSRF set location in a spatiotemporal model (Baker et al. 2024, in press).
- Ogmap-derived SFA 4-specific fishable biomass index: The SFA 4-specific fishable biomass index represents the biomass estimates calculated using Ogmap on NSRF survey data in SFA 4 only (Orr and Sullivan 2013).

Those three indicators were assessed against historical values (i.e., long-term average) to identify potential concerns in the stock health.

2.3. ECOSYSTEM AND ENVIRONMENT

2.3.1. Climate Index

The NL climate index (NLCI) (Cyr and Galbraith 2021), summarizes selected time series deemed representative of the ocean climate on the NL shelf and the Northwest Atlantic as a whole. The NLCI is available between 1951 to present and is updated annually. It integrates 10 equally weighted climate indicators over the time series (Cyr and Galbraith 2021). The NLCI can be interpreted as a measure of the overall state of the climate system, with positive values representing warm and fresh conditions with less sea-ice and, conversely, negative values representing cold and salty conditions.

2.3.2. Bottom Temperature and Salinity

The bottom temperature and salinity in SFA 4 between 2006 and 2022 were derived from trawl-mounted CTD instruments: temperature and salinity profiles are available for most of the summer fishing sets collected by the NSRF. These data were combined with other available temperature-salinity profiles (e.g., from DFO's Atlantic Zonal Monitoring Program [AZMP] surveys, DFO's multi-species resource assessments, international oceanographic campaigns, Argo program, etc.), vertically averaged in 5 m bins and linearly interpolated to fill missing bins. All available data taken between July and August are then averaged on a regular 0.1° x 0.1° (latitudinal x longitudinal) grid to obtain one summer profile per grid cell. Since this grid has missing data in many cells, each depth level was horizontally linearly interpolated to fill gaps. For each grid point, the bottom observations were considered as the data at the closest depth to the General Bathymetric Chart of the Oceans (GEBCO) 2014 grid bathymetry (version 20141103), to a maximum 50 m difference. Lastly, bottom observations deeper than 1,000 m were clipped as they were deeper than most data coverage. This method was applied for all years between 2006 and 2022 and climatology (i.e., reference period) was derived using 2006–21 data. Anomalies for 2022 were calculated as the difference between 2022 observations and the climatology. This method is similar to the one used to derive bottom temperature and salinity on the NL shelf (Cyr et al. 2022).

Bottom temperature and salinity maps for 2022 as well as their anomalies are shown together with the 2006–21 climatology. A number of statistics were derived from these maps to characterize the oceanographic seafloor habitat. These are the bottom mean temperature and salinity in the different fishing areas, the area of the bottom covered by water in various temperature ranges, etc. In cases where it was not possible to interpolate the bottom temperature over an entire assessment area due to changes in the random survey, the climatological values were used so the total area remains the same for each year.

2.3.3. Thermal Habitat Index

Simulations from Bedford Institute of Oceanography North Atlantic Model (BNAM, Wang et al. 2016) were utilized to estimate monthly bottom temperature and bottom salinity from 1996 to 2022 over the survey area. BNAM uses a variety of climatic and oceanographic models and data sets to estimate the local oceanographic conditions and has demonstrated reliable estimates in the Labrador Sea (Wang and Greenan 2014; Brickman et al. 2016; Wang et al. 2016).

BNAM data, in conjunction with the estimated broad-scale habitat preferences identified above (Northern Shrimp: 2 to 4°C; Striped Shrimp: -0.3 to 2.7°C), were used to estimate annual habitat indices (km^2) based on the average areal extent of monthly preferred bottom temperatures within any given year. Northern Shrimp habitat indices were examined in assessment areas EAZ–SFA 7, while Striped Shrimp analyses were restricted to EAZ, WAZ, and SFA 4.

2.3.4. Phytoplankton Community

Near-surface chlorophyll-a (chl-a) concentrations, a proxy for phytoplankton biomass, were estimated from satellite ocean colour imagery collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua sensor. Daily mean chl-a concentrations were derived from remote sensing reflectance using the POLY4 regional band-ratio algorithm and spring bloom parameters (e.g., magnitude, onset, duration) were defined based on daily chl a concentration extracted with the PhytoFit application v1.0.0 (Clay et al. 2021). The timing of the spring phytoplankton bloom was estimated annually as the day of the year when chl-a was maximum between April and August. Standardized anomalies were calculated using a 2002–20 reference period.

3. RESULTS AND DISCUSSION

3.1. SURVEY SUMMARY

In 2022, the NSRF survey was conducted aboard the fishing vessel *Aqviq* and collected shrimp data from 78 survey sets in SFA 4, corresponding to all planned sets being surveyed (Table 3). In 2022, sampling in SFA 4 occurred between July 30 and August 9.

3.2. NORTHERN SHRIMP (*PANDALUS BOREALIS)* ASSESSMENT IN SFA 4

3.2.1. Biomass

The NSRF shrimp survey indicated a decrease in biomass indices in 2022 compared to the 2021 levels, which were among the highest in the historical time series (Figure 5). However, as indicated by wide confidence intervals, the unusually high estimates in 2021 were influenced by two large, localized sets that could be considered as potential outliers in view of the biomass estimates in contiguous years (i.e., 2020 and 2022). It is uncertain how much of this 2021 index was due to changes in local shrimp productivity, sampling variation, or movement of shrimp into SFA 4 from neighboring areas. The degree to which the vertical distribution of Northern and Striped Shrimp changes within years, among years, or between spatial locations at a given time, is currently unknown. As biomass estimates are based on bottom trawl surveys (which will not sample shrimp that are not immediately adjacent to the benthos), an unquantified amount of observed biomass fluctuations may be due to changes in vertical distribution rather than the size of the shrimp population.

Fishable biomass and female SSB indices have decreased since 2021, by 47% (to 79,500 t) and 55% (to 51,300 t), respectively (Table 4 and Table 5). Despite a sharp decrease since 2021, the fishable and female SSB indices are higher, by 86% and 57% respectively, from the lowest levels in the time series in 2018. Similar to most years, in 2022, the highest concentrations of Northern Shrimp catch in SFA 4 (Table 6, Figure 6-8) were found in a relatively continuous band within strata shallower than 200 m (24%) and within 201–300 m strata (68%) (Table 7). The fishable biomass index was below the long-term mean (98,533 t) and was 79,500 t in 2022 (Figure 5, Table 4). The fishable abundance showed a similar trend as the fishable biomass (Table 8). The female SBB index was below the long-term mean (62,878 t) and was 51,300 t in 2022 (Figure 5, Table 5).

The female SSB that is relevant to the PA for an area consists of the animals whose spawning products will ultimately be caught in that area (as opposed to the animals that spawn in the area). The strong currents that likely affect all sizes of shrimp, especially larvae, into an area create especially severe problems with estimating female SSB, for SFA 4 in particular. Accordingly, the true female SSB differs from the females observed by the survey alone. The existing management areas do not represent biological units and, therefore, changes in one management area quite likely produce effects in other management areas.

In SFA 4, Northern Shrimp size at 50% transition (22.2 mm) was above the long-term mean for the third consecutive year, decreasing from 23 mm, the highest value in the time series, in 2021 (Figure 9). The mean carapace length of most Northern Shrimp maturity indices (females, males, fishable, and total) decreased since 2021, the highest values of the time series, but remained above the long-term mean (Figure 10, Table 9). The pre-fishable (also reported as pre-recruit size in some figures) mean carapace length increased since 2021 and was above the long-term mean. The proportion of males in the total and fishable biomass increased since 2021, and was near the long-term mean in 2022 (Table 10, Figure 11, Figure 12).

3.2.2. Fishery

TAC in SFA 4 increased from 8,658 t in 2020/21 to 9,957 t in 2021/22, and increased, by 30%, to 12,944 t in 2022/23 (Table 1, Table 11, and Figure 3). LV standardized CPUE varied without trend over 1989–2021/22 but has been at or above the long-term mean for the past 5 years (Figure 13). Several factors including changes in management measures (i.e., different allocation tables) and species composition of catches (i.e., catches of both Northern and Striped Shrimp in the same area such that less Northern Shrimp catch might be recorded for equivalent effort) makes the interpretation of LV fishery performance more complex in this area. LV weekly CPUE varied without clear trend over the last 5 years (Figure 14).

Exploitation rate is far from being spatially uniform in all fisheries, areas, and time. Commercial effort is impacted by a variety of factors, including but not limited to ice cover, bycatch, and market conditions. Additionally, changing fishing practices impact CPUE in unknown ways.

Commercial catch typically follows the same pattern as the TAC. Catch decreased from 15,697 t in 2018/19 to 8,280 t in 2020/21, and then increased to 10,272 t in 2021/22, and to 12,178 t in 2022/23 (94% of the TAC, based on reported catch as of February 17, 2023) (Table 1, Figure 3). Data from 2022/23 are considered preliminary.

The areas that sustain Northern Shrimp fishing in SFA 4 (Table 12, Figure 2, Figure 15–17) have barely changed in recent years and visually correspond to the spots where high concentrations of shrimp were generally observed during the NSRF survey (Figure 6–8). The LV fleet fishes along the northeastern edge of the Saglek Bank, in depths as great as 750 m, and in the Ogak Channel (Figure 15–17).

In the last 3 years (2020–22), observer length frequency data showed a higher proportion of large multiparous females (Figure 18). The mean carapace length of Northern Shrimp caught by LVs in SFA 4 decreased in the last three years from 23.1 mm to 21.9 mm (Figure 19).

3.2.3. Exploitation Rate Index

The ERI ranged between 5.8% and 36.7% from 2005/06 to 2021/22 and was 15.3% in 2022/23. If the TAC is taken, the ERI will be 16.3% (Table 4, Figure 20). The ERI increased from 2012/13 to 2018/19, corresponding to a period of declining biomass indices. The ERI was high in 2018 due to the significant decrease in fishable biomass index from 2017 to 2018.

For the ERI calculation, both the numerator (catch) and denominator (fishable biomass) are uncertain. Trawls used in the surveys have shrimp catchability less than one, but the true value is unknown. Therefore, the survey underestimates biomass by an unknown percentage which may vary annually. Although the commercial catch is asserted to be known without error, the total fishery-induced mortality (i.e., landed catch plus incidental mortality from trawling) is unknown. Therefore, the exploitation rate index is likely underestimated by an unknown percentage.

3.2.4. Production Model Prediction

In 2022, the observed total biomass index (i.e., using Ogmap) was much higher than the production model prediction (Figure 21) of Northern Shrimp total biomass with catch removed. This deviation might be associated to various factors that were previously documented with regards to the poorer performance of the model in SFA 4 (Pedersen et al, 2022). For example, some changes in the environment might not be considered or are misrepresented in the model parameterization (e.g., shrimp movement, predation, bottom-up effect). In 2023, the production model predicted that biomass will be lower than the 2022 observed biomass, with the overall predicted decline dependent on the various exploitation scenarios. There is a significant level of uncertainty associated with the predicted biomass index from the production model. During the March 2023 shrimp assessment meeting, the majority of participants expressed that the outputs from the surplus production model should not be presented in the future unless significant improvements are made to enhance its predictive capacity.

3.2.5. Precautionary Approach Framework

In 2022, the female SSB index for Northern Shrimp in SFA 4 was in the Healthy zone, just above the USR, within the IFMP PA Framework. This represents the second consecutive year that the female SSB index was in the Healthy zone, after four years in the Cautious zone (2017 to 2020), however there was a 53% probability of it being in the Cautious zone (Figure 22).

Given the relatively wide and asymmetric confidence intervals, there is a >50% chance the 2022 SFA 4 Northern Shrimp SSB index is not in the Healthy zone. In certain years (e.g., 2017 and 2022, DFO 2018b), the biomass index was primarily influenced by a low number of large survey catches such that the uncertainty (i.e., error bars) around estimates was higher and asymmetrical. Those large and asymmetrical confidence intervals could lead to Ogmap female SSB point estimates to be into the Healthy zone, with a higher probability of being in the Cautious zone (e.g., 2022).

3.3. STRIPED SHRIMP (*PANDALUS MONTAGUI)* ASSESSMENT IN SFA 4

3.3.1. Biomass

The NSRF shrimp survey indicated an increase in most Striped Shrimp biomass indices in 2022 (e.g., Table 13). Fishable biomass and female SSB indices calculated with Ogmap have increased since 2021, by 25% (to 38,800 t) and 37% (to 30,600 t) respectively (Table 14 and Table 15). The biomass indices have increased since 2020 (Table 13), and remained above the long-term mean for the last two years.

Similar to previous years, in 2022, the highest concentrations of Striped Shrimp catch in SFA 4 were found in a relatively continuous band within strata less than 200 m (67%) and 201–300 m (31%) (Figure 23–25, Table 16–17).

The fishable biomass index was above the long-term mean (29,122 t) at 38,800 t in 2022 (Table 14). The fishable abundance index showed a similar trend as the biomass (Table 18). The female SSB index was above the long-term mean (22,399 t) at 30,600 t in 2022 (Table 15).

In SFA 4, the Striped Shrimp size at 50% transition was around the long-term mean (20.0 mm), at a similar level as in 2021 (Figure 26). The mean carapace length of most maturities of Striped Shrimp (i.e., females, males, fishable, and total) increased since 2021, and remained above the long-term mean (Figure 27 and Table 19). The pre-fishable mean carapace length decreased since 2021 but remained above the long-term mean. The proportion of males in the total and fishable biomass decreased since 2021, and was below the long-term mean in 2022 (Figure 28, Figure 29).

3.3.2. Fishery

Striped Shrimp by-catch quota in SFA 4 remained unchanged since 2013/14 at 4,033 t in 2022/23 (Table 2). LV unstandardized CPUE per strata (based on observer data) varied without trend over the 1998–2021/22 period (Table 19).

Striped Shrimp catch has increased from 2,483 t in 2020/21 to 3,498 t in 2022/23 (87% of the TAC, based on reported catch as of February 17, 2023) (Figure 4, Table 2).

Since 2006, the proportion of the LV catch reported by at-sea observers as directed towards the Striped Shrimp (vs by-catch) varied from 20% to 97% (Table 2). In 2022/23, 97% of the Striped Shrimp catches, based on incomplete observer data, were deemed as directed catch and the remaining 3% as by-catch. This result might change significantly once the observer data are fully available for 2022/23. This notable interannual variability, coupled with the fact that Striped Shrimp fisheries are ostensibly intended as by-catch fisheries (i.e., no directed fishery should be observed), underscores the critical importance of accurately quantifying, documenting, and reporting any discrepancies in the monitoring of Striped Shrimp fishing by at-sea observers in SFA 4.

The areas that sustain Striped Shrimp fishing in SFA 4 have barely changed in recent years and correspond to the locations where high concentrations of shrimp were observed during the NSRF survey. The LV fleet fishes along the northern and northeastern edge of the Saglek Bank, in depths shallower than 300 m (Table 20, Figure 30–32).

In 2020 and 2021 (no data in 2022), observer length frequency data showed higher proportion of large multiparous females (Figure 33). The mean carapace length of Striped Shrimp caught by LVs in SFA 4 was at its highest levels in the time series in 2020/21 at 20.96 mm and remained high in 2021/22 (20.83 mm) (Table 21, Figure 34).

3.3.3. Exploitation Rate Index

The ERI ranged between 0.8% and 23.3% from 2005/06 to 2021/22 and was 9.0% in 2022/23 (Table 14, Figure 35). If the TAC is taken, the ERI would be 10.4%. The ERI had been decreasing since 2020/21.

The confidence intervals, which are calculated based on the fishable biomass indices compared to commercial landings, surrounding the 2019/20–2021/22 exploitation rate indices were wide, particularly the upper interval, but were narrower in 2022/23 (Figure 35).

3.3.4. Precautionary Approach Framework

In 2022, Striped Shrimp biomass (FB_{pop}) in SFA 4 was estimated to be 5 times the LRP (Figure 36) and is considered in a healthy state in the PA framework. The stock has remained above the LRP since 2007. Other indices of stock health, including the potential predator index (Figure 37), total egg production index (Figure 38), and SFA 4 specific fishable biomass index (Figure 39) showed no cause for concern.

3.4. ECOSYSTEM AND ENVIRONMENT

3.4.1. Oceanography and Climate Index

The NL shelves and the Northwestern Atlantic Ocean as a whole experience important natural climatic fluctuations at decadal time scales (Figure 40). The NLCI highlights the different climate regimes prevailing since the early 1950s. For example, the 1960s stands out as one of the warmest periods in the time series while the early 1990s is the coldest. The warming trend from the early 1990s that peaked in 2010 was followed by recent cooling that culminated in 2015. While the NLCI for years 2014 to 2019 were mostly normal (with the exception of 2015 that was colder than normal), a warming trend is emerging since 2020, with 2021 being the warmest years on record. In 2022, the NLCI remained high at +0.7.

The environmental conditions at the seafloor in SFA 4 are partly driven by the mean climate conditions, especially in the winter, and partly by the associated changes in the large-scale ocean circulation that accompany the changing climate (Figure 41–42). Three main water sources converge in the SFA 4. The Baffin Island Current, which carries Arctic-origin waters outflowing from Davis Strait, eventually merges with the outflow from the Hudson Strait to form the Coastal Labrador Current. This current carries frigid and relatively fresh waters southward along the coast of Labrador. Further offshore at the shelf break, the Labrador Current, which carries sub-polar North Atlantic waters originating from the West Greenland Current, flows southward after bifurcating to the west and eventually to the south at the northern end of the Labrador Sea.

These two currents create an offshore-onshore gradient in bottom temperature in SFA 4, with temperature ranging from 3 to 4°C along the shelf break to near freezing <-1°C close to the coast of Labrador (Figure 41). This temperature gradient is also accompanied by salinity changes, with fresher water along the coast and the more saline waters offshore along the shelf break and in the deeper channels (Figure 42). In the Hatton Basin, a deeper trough bounding the northern part of SFA 4, bottom temperatures are generally characterized by warmer (temperature >4°C) and saltier (salinity >34.5) sub-polar waters.

Despite the relatively short time series available (since 2006), it is possible to identify near decadal fluctuations in bottom conditions of SFA 4 (Figure 43–44). For example, the year 2011 stands as the warmest and saltiest years of the time series. While 2021 stands as the second warmest year of the time series, a low-salinity anomaly has been ongoing since about 2017, with 2017 and 2018 being the freshest years of the time series. In 2022, the bottom temperature in SFA 4 remained slightly warmer than the long-term average.

3.4.2. Phytoplankton Bloom

In SFA 4, seasonal variation of the chlorophyll concentrations indicated that Spring bloom generally starts in early May and peaks in early June (Figure 45). Fall bloom generally starts in September and chlorophyll concentration keeps increasing through the fall. Over the 2003–22 period, spring bloom timing showed high interannual variability. Since the mid-2010s, trend of earlier blooms was observed in SFA 4. The Spring phytoplankton bloom in SFA 4 in 2021 was the earliest in the time series but returned to more normal timing in 2022.

3.4.3. Ecosystem/Predation

The NSRF survey by-catch data showed high catch rates of several potential shrimp predators in 2022 (grenadier, redfish, skate, Greenland Halibut), whereas Atlantic Cod catch rates remained at a low level (Figure 46). NSRF survey catch in SFA 4 (Figure 46) and predation analysis in the SFA 4, EAZ and WAZ (Figure 37) showed the emergence of a large biomass of juvenile redfish over the last three years, which has been identified as a potential driver that may have indirect (competition) and/or direct (future predation) impacts on the shrimp population. The magnitude and duration of these impacts are currently not fully known, but it seems justifiable to assume that juvenile redfish resurgence, indirectly, will have a major impact on the ecosystem, including potential productivity of the shrimp population (Fulton et al. 2024. Moreover, a study on the quantification of Northern and Striped Shrimp as a prey species from different predator taxa in SFA 4, EAZ and WAZ (2018–21) showed that *P. borealis* was the dominant pandalid prey item of Greenland Halibut in SFA4 (Fulton et al. 2024). Atlantic Cod had the largest mean number of Northern Shrimp in their stomach compared to other potential predators (Fulton et al. 2024).

Overall, drivers of stock variability are poorly understood and additional research is needed on foraging (e.g., water column productivity estimates), predation (e.g., gut contents of shrimp predators), and ecosystem tracers (e.g., stable isotopes and fatty acids to connect various food chain elements).

3.4.4. Habitat Index

In 2022, the Northern Shrimp thermal habitat index in SFA 4, representing the area where the annual average bottom-temperature was between 2 and 4°C, increased to its highest level in the time series (Figure 47).

The Striped Shrimp thermal habitat index (-0.3–2.7°C) varied without trends from 1996 to 2017, but has shown its highest values over time series in the 2018–22 period (Figure 48). A considerable increase of the habitat index was also noticed in the northern surrounding areas, with 2021 and 2022 showing the highest habitat index values in the WAZ, and the 2018–22 period showing the highest values in the time series in the EAZ.

The habitat Index is based on an ice-ocean model that was primarily validated in more southern areas. The bottom temperature is a highly variable feature and further validation and comparison with survey data on the Labrador Shelf and further North would allow a better assessment of the habitat index uncertainties. Some discrepancies were observed in the interannual comparison of observed bottom temperature anomalies (Figure 43) with thermal habitat indices (Figure 47–48). These discrepancies could be attributed to a combination of factors, including differences in integration periods (e.g., punctual (summer) vs. annually averaged), different spatial interpolation methods, handling of missing observations (e.g., linear interpolation of climatological observations, but no use of spatiotemporal statistical models), or biases inherent to BNAM (e.g., climatology used for freshwater runoff and open boundaries, no tide considered). However, multiple analyses suggest that thermal habitat available to Pandalid Shrimp in SFA 4 has been favorable since the late-2010s.

4. CONCLUSION

4.1. SFA 4 NORTHERN SHRIMP (*PANDALUS BOREALIS)*

Despite a year-over-year decrease of biomass indices in 2022, the recent trend suggests continued increases from a historic low in 2018. In 2022, Northern Shrimp in SFA 4 was in the Healthy zone within the PA Framework, just above the USR, with a 53% probability of being in the Cautious zone. If the TAC is fully taken in 2022/23, the ERI will be 16.3%.

4.2. SFA 4 STRIPED SHRIMP (*PANDALUS MONTAGUI)*

The fishable biomass index and female biomass index are above the long-term mean and on an increasing trend since 2020. In 2022, the SFA 4 Striped Shrimp stock was 5 times higher than the adopted LRP, and was considered in a healthy state in the PA framework. If the by-catch limit is taken, the ERI will be 10.4% in 2022/23.

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REFERENCES CITED

Allen, J.A. 1959. On the biology of *Pandalus borealis* Krøyer, with reference to a population off the northumberland coast. J. Mar. Biol. Assoc. United Kingdom. 38(1): 189–220.

Allen, J.A. 1963. Observations on the biology of *Pandalus montagui* [Crustacea: Decapoda]. J. Mar. Biol. Assoc. United Kingdom. 43(3): 665–682.

Aschan, M., and Ingvaldsen, R. 2009. Recruitment of shrimp (*Pandalus borealis*) in the Barents Sea related to spawning stock and environment. Deep-Sea. Res. II. Top. Stud. Oceanogr. 56(21–22): 2012–2022.

Baker, K.D., Anderson, S.C., Coffey, W., Mullowney, D.R.J., Walkusz, W., and Skanes, K.R. In press. Identifying a Limit Reference Point for Striped Shrimp (Pandalus montagui) in Shrimp Fishing Area 4 Using a Multi-Indicator Approach. Can. Sci. Advis. Secr. Res. Doc.

Baker, K.D., Anderson, S.C., Mullowney, D.R.J., Walkusz, W., and Skanes, K.R. 2024. Moving away from a scale mismatch: Spatiotemporal modelling of striped shrimp (*Pandalus montagui*) density in Canada's subarctic. Fish. Res. 270: 106898.

Baker, K.D., Fifield, D.A., Mullowney, D.R.J., and Skanes, K.R. 2021. Ecology and epidemiology of the striped shrimp, *Pandalus montagui* Leach, 1814 (Decapoda: Caridea), in the northern Labrador Sea, Davis Strait, and Ungava Bay, Canada. J. Crustac. Biol. 41(2).

Benoit, H. 2006. Standardizing the southern Gulf of St. Lawrence bottom trawl survey time series: Results of the 2004-2005 comparative fishing experiments and other recommendations for the analysis of the survey data. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/008. iv + 127 p.

Bergström, B.I. 2000. The Biology of *Pandalus*. Adv. Mar. Biol. 38: 1–245.

Blais, M., Galbraith, P.S., Plourde, S., Devred, E., Clay, S., Lehoux, C. and Devine, L. 2021. Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St. Lawrence during 2020. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/060. iv + 67 p.

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

Brickman, D., Wang, Z., and DeTracey, B. 2016. Variability of Current Streams in Atlantic Canadian Waters: A Model Study. Atmos.-Ocean. 54(3): 218–229.

Brosset, P., Bourdages, H., Blais, M., Scarratt, M., and Plourde, S. 2019. Local environment affecting northern shrimp recruitment: a comparative study of Gulf of St. Lawrence stocks. ICES J. Mar. Sci. 76(4): 974–986.

Clay, S., Layton, C., and Devred, E. 2021. BIO-RSG/PhytoFit: First release (v1.0.0). Zenodo.

Le Corre, N., Pepin, P., Burmeister, A.D.A.D., Walkusz, W., Skanes, K., Wang, Z., Brickman, D., and Snelgrove, P.V.R. 2020. Larval connectivity of Northern Shrimp (*Pandalus borealis*) in the northwest Atlantic. Can. J. Fish. Aquat. Sci. 77(8): 1332–1347.

Le Corre, N., Pepin, P., Han, G., Ma, Z., and Snelgrove, P.V.R. 2019. Assessing connectivity patterns among management units of the Newfoundland and Labrador shrimp population. Fish. Oceanogr. 28(2): 183–202.

Crawford, R.E., Hudon, C., and Parsons, D.G. 1992. An acoustic study of shrimp (*Pandalus montagui*) distribution near Resolution Island (eastern Hudson Strait). Can. J. Fish. Aquat. Sci. 49(5): 842–856.

Cyr, F., and Galbraith, P.S. 2021. A climate index for the Newfoundland and Labrador shelf. Earth Syst. Sci. Data. 13(5): 1807–2021.

Cyr, F., Snook, S., Bishop, C., Galbraith, P.S., Chen, N., and Han, G. 2022. Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/040. iv + 48 p.

DFO, 2007. Assessment Framework for Northern Shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland; 28-30 May 2007. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2007/034.

DFO. 2009. Proceedings of the Precautionary Approach Workshop on Shrimp and Prawn Stocks and Fisheries; November 26-27, 2008. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2008/031.

DFO. 2018a. Integrated Fisheries Management Plan: Northern shrimp and striped shrimp – Shrimp fishing areas 0, 1, 4-7, the Eastern and Western Assessment Zones and North Atlantic Fisheries Organization (NAFO) Division 3M.

DFO. 2018b. An assessment of Northern Shrimp (*Pandalus borealis*) in Shrimp Fishing Areas 4-6 in 2017. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/018.

DFO. 2021. Assessment of Northern Shrimp (*Pandalus borealis*) and Striped Shrimp (*Pandalus montagui*) in the Eastern and Western Assessment Zones, February 2021. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/014.

DFO. 2023a. Assessment of Northern Shrimp (*Pandalus borealis*) in Shrimp Fishing Areas 4-6 in 2021. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/038.

DFO. 2023b. Proceedings for the Regional Peer Review for the Development of a new Precautionary Approach Framework for Northern Shrimp in the Newfoundland and Labrador Region; May 15-17, 2019. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2023/045.

Doubleday, W,G. 1981. Manual on groundfish surveys in the Northwest Atlantic.

Drinkwater, K.F. 1986. Physical Oceanography of Hudson Strait and Ungava Bay. Elsevier Oceanogr. Ser. 44: 237–264.

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

Evans, G.T., Parsons, D.G., Veitch, P.J., and Orr, D.C. 2000. A local-influence method of estimating biomass from trawl surveys, with Monte Carlo confidence intervals. J. Northwest Atl. Fish. Sci. 27: 133–138.

Fulton, S., Walkusz, W., Atchison. S., and Cyr, F. 2024. Information to Support the Assessment of Northern Shrimp, *Pandalus borealis*, and Striped Shrimp, *Pandalus montagui*, in the Eastern and Western Assessment Zones, February 2023. DFO Can. Sci. Advis. Sec. Res. Doc. 2024/016. iv + 51 p.

Hansen, H., and Aschan, M. 2000. Growth, Size- and Age-at-Maturity of Shrimp, *Pandalus borealis*, at Svalbard Related to Environmental Parameters. J. Northwest Atl. Fish. Sci. 27: 83–91.

Hudon, C., Parsons, D.G., and Crawford, R. 1992. Diel Pelagic Foraging by a Pandalid Shrimp (*Pandalus montagui*) off Resolution Island (Eastern Hudson Strait). Can. J. Fish. Aquat. Sci. 49(3): 565–576.

Jorde, P.E., Søvik, G., Westgaard, J.I., Albretsen, J., André, C., Hvingel, C., Johansen, T., Sandvik, A.D., Kingsley, M., and Jørstad, K.E. 2015. Genetically distinct populations of northern shrimp, *Pandalus borealis*, in the North Atlantic: Adaptation to different temperatures as an isolation factor. Mol. Ecol. 24: 1742–1757.

Koeller, P., Fuentes-Yaco, C., Platt, T., Sathyendranath, S., Richards, A., Ouellet, P., Orr, D., Skúladóttir, U., Wieland, K., Savard, L., and Aschan, M. 2009. Basin-Scale Coherence in Phenology of Shrimps and Phytoplankton in the North Atlantic Ocean. Science. 324(5928): 791–793.

McCallum, B.R., and Walsh, S.J. 1996. An Update on the Performance of the Campelen 1800 During Bottom Trawl Surveys in NAFO Subareas 2 and 3 in 2001. NAFO SCR Doc.

Orr, D., and Sullivan, D. 2013. The February 2013 assessment of Northern Shrimp (*Pandalus borealis*) off Labrador and Northeastern Newfoundland. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/055. vii + 144 p.

Ouellet, P., and Chabot, D. 2005. Rearing *Pandalus borealis* (Krøyer) larvae in the laboratory : I. Development and growth at three temperatures. Mar. Biol. 147(4): 869–880.

Ouellet, P., Savard, L., and Larouche, P. 2007. Spring oceanographic conditions and northern shrimp *Pandalus borealis* recruitment success in the north-western Gulf of St. Lawrence. Mar. Ecol. Prog. Ser. 339: 229–241.

Pedersen, E.J., Skanes, K., le Corre, N., Koen Alonso, M., and Baker, K.D. 2022. A New Spatial Ecosystem-Based Surplus Production Model for Northern Shrimp in Shrimp Fishing Areas 4 to 6. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/062. v + 64 p.

Pedersen, S.A., and Storm, L. 2002. Northern Shrimp (Pandalus borealis) Recruitment in West Greenland Waters Part II. Lipid Classes and Fatty Acids in Pandalus Shrimp Larvae: Implications for Survival Expectations and Trophic Relationships. J. Northwest Atl. Fish. Sci. 30: 47–60.

Pedersen, S.A., Storm, L., and Simonsen, C.S. 2002. Northern Shrimp (*Pandalus borealis*) Recruitment in West Greenland Waters Part I. Distribution of *Pandalus* Shrimp Larvae in Relation to Hydrography and Plankton. J. Northwest Atl. Fish. Sci. 30: 19–46.

Perez-Rodriguez, A., and Koen-Alonso, M. 2010. Standardization of time series for the EU bottom trawl Flemish Cap survey. NAFO SCR Doc. 10/22.

Polaczek, H., Atchison, S., Deslauriers, D., Skanes, K., Lacasse, O., Roy, V., and Walkusz, W. 2023. Analysis of Atlantic Cod, Greenland Halibut, Redfish, and Skate Stomach Contents from the 2018 NSRF-DFO Summer Shrimp Survey in Hudson Strait, Davis Strait and Labrador Sea. Can. Data. Rep. Fish. Aquat. Sci. 1338: vi + 20 p.

Rasmussen, T., and Aschan, M. 2011. Larval stages of *Pandalus borealis*. Mar. Biol. Res. **7**(2): 109–121.

Richards, R.A., and Hunter, M. 2021. Northern shrimp *Pandalus borealis* population collapse linked to climate-driven shifts in predator distribution. PLoS One. 16(7).

Shumway, S.E., Perkins, H.C., Schick, D.F., and Stickney, A.P. 1985. Synopsis of Biological Data on the Pink Shrimp, *Pandalus borealis* Krøyer, 1838. NOAA Tech. Rep. NMFS 30**.**

Siferd, T.D. 2015. 2015 Assessment of Northern Shrimp (*Pandalus borealis*) and Striped Shrimp (*Pandalus montagui*) in the Eastern and Western Assessment Zones (SFAs Nunavut, Nunavik and Davis Strait). DFO Can. Sci. Advis. Sec. Res. Doc. 2015/010. v + 70 p.

Thorson, J.T., and Ward, E.J. 2014. Accounting for vessel effects when standardizing catch rates from cooperative surveys. Fish. Res. 155: 168–176.

Wang, Z., Brickman, D., Greenan, B.J.W., and Yashayaev, I. 2016. An abrupt shift in the Labrador Current System in relation to winter NAO events. J. Geophys. Res. Ocean. 121(7): 5338–5349.

Wang, Z., and Greenan, B.J.W. 2014. Physical oceanographic conditions on Newfoundland Shelf / Flemish Cap – from a model perspective (1990-2012). NAFO SCR Doc. 14/008.

APPENDIX 1: GLOSSARY

AQMS: Atlantic Quota Monitoring System

AZMP: Atlantic Zonal Monitoring Program

BNAM: Bedford Institute of Oceanography North Atlantic model

CAQR: Canadian Atlantic Quota Report

CPUE: Catch Per Unit Effort

DFO: Fisheries and Oceans Canada

EAZ: Eastern Assessment Zone

ERI: Exploitation Rate Index

FB_{pop}: Fishable Biomass index for the Striped Shrimp population as a whole

F/V: Fishing Vessel

GEBCO: General Bathymetric Chart of the Oceans

IFMP: Integrated Fisheries Management Plan

LV: Large Vessel

LRP: Limit Reference Point

MSC: Marine Stewardship Council

NL: Newfoundland and Labrador

NLCI: Newfoundland and Labrador Climate Index

NSRF: Northern Shrimp Research Foundation

OCI: Ocean Choice International

PA: Precautionary Approach

SFA: Shrimp Fishing Area

SSB: Spawning Stock Biomass

SV: Small Vessel

TAC: Total Allowable Catches

USR: Upper Stock Reference

WAZ: Western Assessment Zone

APPENDIX 2: TABLES

Table 1. TACs and catches in 1977–2022/23 for the LV and SV fleets fishing Northern Shrimp in SFA 4. In 2003 the fishing season was switched from a calendar year to a management year such that the catches shown for 2003/04 are based on a 15-month fishing season. Quota transfers, bridging and overruns are reflected in all catches and, since 2016/17, in the adjusted TAC column. All 2022/23 catches and adjusted TACs are preliminary and based upon the AQMS as of February 17, 2023.

Year	LV TAC (t)	LV Adjusted TAC (t)	LV Catch (t)	SV TAC (t)	SV Adjusted TAC (t)	SV Catch (t)	Total TAC (t)	Total Catch (t)
1978	500	-	-	-	-	-	500	-
1979	500	-	3	-	-	-	500	3
1980	500	-	1	-	-	-	500	1
1981	500	-	2	-	-	-	500	2
1982	500	-	5	-	-	-	500	5
1983	500	-	30	-	-	-	500	30
1984	500	-	-	-	-	-	500	-
1985	500	-	-	-	-	-	500	-
1986	500	-	2	-	-	-	500	2
1987	500	-	7	-	-	-	500	7
1988	500	-	1,083	-	-	-	500	1,083
1989	2,580	-	3,842	-	-	-	2,580	3,842
1990	2,580	-	2,945	-	-	-	2,580	2,945
1991	2,635	-	2,561	-	-	-	2,635	2,561
1992	2,635	-	2,706	-	-	-	2,635	2,706
1993	2,735	-	2,723	-	-	-	2,735	2,723
1994	4,000	-	3,982	-	-	-	4,000	3,982
1995	5,200	-	5,104	-	-	-	5,200	5,104
1996	5,200	-	5,160	-	-	-	5,200	5,160
1997	5,200	-	5,216	-	-	-	5,200	5,216
1998	8,008	-	7,918	312	-	133	8,320	8,051
1999	8,008	-	7,793	312	-	91	8,320	7,884
2000	8,008	-	7,300	312	-	82	8,320	7,382
2001	8,008	-	8,104	312	-	13	8,320	8,117
2002	8,008	-	8,322	312	-	65	8,320	8,387
2003/04	12,685	-	12,944	437	-	76	13,122	13,020
2004/05	9,883	-	9,549	437	-	95	10,320	9,644
2005/06	9,883	-	10,247	437	-	-	10,320	10,247
2006/07	9,883	-	10,084	437	-	-	10,320	10,084
2007/08	9,883	-	10,009	437	-	-	10,320	10,009
2008/09	10,783	-	9,682	537	-	-	11,320	9,682
2009/10	10,783	-	10,656	537	-	-	11,320	10,656
2010/11	10,783	-	11,134	537	-	-	11,320	11,134
2011/12	10,783	-	10,441	537	-	-	11,320	10,441
2012/13	12,041	-	13,908	977	-	-	13,018	13,908
2013/14	13,969	-	14,969	1,002	-	-	14,971	14,969
2014/15	13,969	-	14,642	1,002	-	316	14,971	14,958
2015/16	13,969	-	14,766	1,002	-	284	14,971	15,050
2016/17	13,594	14,316	13,722	1,377	655	655	14,971	14,377
2017/18	13,579	15,002	15,124	2,146	1,315	1,315	15,725	16,439
2018/19	13,579	14,457	14,311	2,146	1,277	1,386	15,725	15,697
2019/20	9,415	10,595	10,360	1,430	847	872	10,845	11,232
2020/21	7,563	8,575	7,672	1,095	1,095	608	8,658	8,280

Year	LV TAC (t)	LV Adjusted TAC (t)	LV Catch (t)	SV TAC (t)	SV Adjusted TAC (t)	SV Catch (t)	Total TAC (t)	Total Catch (t)
2021/22	8,663	9,040	9,621	1,294	654	651	9,957	10,272
2022/23	10,827	12,043	11,416	2,117	901	762	12,944	12,178

Table 2. Catches, by-catch quota (established in 2013), and percentage of catch recorded as directed for Striped Shrimp in SFA 4 for the 2005–2022/23 period. Data from 2013 to present were converted to management year. 2022/23 catches are preliminary and based on the February 17, 2023, AQMS.

Management Year	By-Catch Quota (t)	Fleet Catch (t)	Catch percentage recorded as directed catch (vs by-catch) by at-sea observers (%)
2005	-	813	-
2006	-	1,805	88
2007	-	2,182	82
2008	-	278	93
2009	-	617	75
2010	-	1,115	64
2011	-	3,236	75
2012	-	4,708	81
2013/14	4,033	1,611	91
2014/15	4,033	1,236	75
2015/16	4,033	2,135	66
2016/17	4,033	1,113	71
2017/18	4,033	2,611	63
2018/19	4,033	2,572	20
2019/20	4,033	3,035	49
2020/21	4,033	2,483	80
2021-22	4,033	3,146	48
2022-23	4,033	3,498	97

Table 3. SFA 4 Northern Shrimp total biomass and abundance indices (2005–22). Indices were derived from Ogmap using the NSRF summer survey data.

Year	Total Biomass Lower CI (x 1,000 t)	Total Biomass Index (x 1,000 t)	Total Biomass Upper CI (x 1,000 t)	Change in Total Biomass Index from Previous Years (%)	Total Abundance Lower CI (x 10^9)	Total Abundance Index (x 10^9)	Total Abundance Upper CI (x 10^9)	Change in Total Abundance Index from Previous Year (%)	Number of Survey Sets in SFA 4	% Sets with *P. borealis*
2005	35.8	76.4	133.0	-	6.4	14.8	25.7	-	78	64
2006	55.2	97.9	167.0	28	9.5	18.1	31.3	22	76	76
2007	67.9	118.0	173.0	21	12.0	20.6	30.3	14	77	66
2008	61.6	124.0	189.0	5	12.9	24.7	37.0	20	69	80
2009	63.4	168.0	286.0	35	14.1	34.2	56.9	38	75	88
2010	58.1	130.0	225.0	-23	12.3	27.7	47.4	-19	72	64
2011	53.0	128.0	213.0	-2	10.2	24.7	41.1	-11	76	66
2012	89.8	167.0	240.0	30	19.3	35.1	50.9	42	77	66
2013	43.7	121.0	232.0	-28	8.5	24.9	47.1	-29	73	60
2014	61.0	107.0	165.0	-12	12.1	21.4	33.8	-14	75	65
2015	61.1	96.3	134.0	-10	12.0	18.5	26.2	-14	77	75
2016	51.5	98.3	163.0	2	9.7	18.5	30.1	0	75	59
2017	22.1	78.2	117.0	-20	5.5	14.2	21.2	-23	73	56
2018	21.9	44.8	68.9	-43	3.8	7.6	11.6	-47	75	56
2019	20.9	53.9	104.0	20	3.8	8.8	16.4	16	78	59
2020	22.4	60.4	106.0	12	3.5	9.1	15.9	4	78	56
2021	50.2	154.0	276.0	155	7.8	20.4	34.5	124	77	56
2022	41.3	83.3	130	-45.9	6.2	12.4	19.4	-39	78	65

Table 4. Fishable biomass and exploitation rate indices for Northern Shrimp in SFA 4. Biomass indices calculated using Ogmap on the NSRF summer shrimp survey data. ERI is the total commercial catch divided by the fishable biomass index in the same year.

Catch Year	TAC (t)	Catch (t)	Survey Year	Fishable Biomass Index Lower CI (x 1,000 t)	Fishable Biomass Index (x 1,000 t)	Fishable Biomass Index Upper CI (x 1,000 t)	Change in Fishable Biomass Index from Previous Year (%)	ER Index Lower CI (%)	ER Index (%)	ER Index Upper CI (%)
2005/06	10,320	10,247	2005	33.3	72.7	127.0	-	8.1	14.1	30.8
2006/07	10,320	10,084	2006	51.9	91.6	157.0	26	6.4	11.0	19.4
2007/08	10,320	10,009	2007	64.1	112.0	169.0	22	5.9	8.9	15.6
2008/09	11,320	9,682	2008	51.8	110.0	173.0	-2	5.6	8.8	18.7
2009/10	11,320	10,656	2009	56.3	152.0	264.0	38	4.0	7.0	18.9
2010/11	11,320	11,134	2010	51.5	118.0	207.0	-22	5.4	9.4	21.6
2011/12	11,320	10,441	2011	48.1	119.0	202.0	1	5.2	8.8	21.7
2012/13	13,018	13,908	2012	81.1	156.0	228.0	31	6.1	8.9	17.1
2013/14	14,971	14,969	2013	37.4	111.0	215.0	-29	7.0	13.5	40.0
2014/15	14,971	14,958	2014	52.6	95.2	148.0	-14	10.1	15.7	28.4
2015/16	14,971	15,050	2015	54.8	88.4	123.0	-7	12.2	17.0	27.5
2016/17	14,971	14,377	2016	45.8	90.4	151.0	2	9.5	15.9	31.4
2017/18	15,725	16,439	2017	18.2	72.7	112.0	-20	14.7	22.6	90.3
2018/19	15,725	15,697	2018	21.1	42.8	66.0	-41	23.8	36.7	74.4
2019/20	10,845	11,232	2019	20.7	52.4	102.0	22	11.0	21.4	54.3
2020/21	8,658	8,280	2020	21.5	58.9	104.0	12	8.0	14.1	38.5
2021/22	9,957	8,696	2021	49.3	151.0	275.0	156	3.2	5.8	17.6
2022/23	12,944	12,178	2022	40.0	79.5	126.0	-47	9.7	15.3	30.4

Table 5. Female biomass and abundance indices of Northern Shrimp in SFA 4.

Year	Female Biomass Lower CI (x 1,000 t)	Female Biomass Index (x 1,000 t)	Female Biomass Upper CI (x 1,000 t)	Change in Female Biomass Index from Previous Years (%)	Female Abundance Lower CI (x 10^9)	Female Abundance Index (x 10^9)	Female Abundance Upper CI (x 10^9)	Change in Female Abundance from Previous Year (%)
2005	19.5	37.5	60.9	-	2.7	5.1	8.3	-
2006	31.2	49.5	77.7	32	3.8	6.1	9.6	20
2007	42.7	71.5	104.0	44	5.5	9.1	13.2	49
2008	33.3	73.7	117.0	3	4.5	9.9	15.8	9
2009	39.4	108.0	190.0	47	5.4	15.8	28.4	59
2010	24.0	60.9	109.0	-44	3.2	8.5	15.1	-46
2011	38.5	73.1	113.0	20	5.4	10.5	16.8	24
2012	51.8	87.2	121.0	19	8.3	14.0	19.8	33
2013	25.4	68.2	133.0	-22	3.8	10.4	20.1	-26
2014	33.7	64.3	93.8	-6	4.7	9.1	13.3	-13
2015	36.4	56.9	77.6	-12	5.0	8.0	10.9	-12
2016	27.1	52.9	87.7	-7	3.6	7.0	11.5	-12
2017	10.3	49.3	77.3	-7	1.3	6.4	9.8	-9
2018	15.5	32.6	50.6	-34	2.1	4.4	7.0	-30
2019	13.9	38.7	79.5	19	1.8	5.2	10.6	16
2020	15.2	43.2	78.7	12	1.8	5.3	9.9	3
2021	34.1	113.0	218.0	162	3.8	12.0	22.3	127
2022	25.4	51.3	79.9	-55	2.8	5.7	9.1	-52

Table 6. Total biomass (x 1,000 t) of Northern Shrimp in SFA 4 by strata and depth range from 2005–22. Biomass indices shrimp survey data. Boundaries for deciding colours were based on quartiles of the available survey data were generated using Ogive Mapping on NSRF summer survey data.

Legend:		Index <= 2070					2070 < Index < 6880							6880 <= Index					
Depth Range (m)	STRATUM	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
<=200	909	4.7	1.9	6.2	5.6	8.0	3.8	12.3	8.7	5.4	3.4	8.6	1.7	3.5	3.7	1.7	1.7	3.9	3.3
<=200	910	3.2	1.7	3.4	4.8	3.2	2.9	6.9	6.5	2.5	3.7	6.4	1.9	3.5	2.0	1.1	2.0	4.7	7.9
<=200	925	1.3	3.7	4.4	5.4	2.2	2.7	2.2	6.9	2.1	4.8	4.9	4.2	2.7	1.3	1.9	1.3	6.1	4.7
<=200	965	4.8	2.3	6.7	5.0	7.4	4.3	10.9	9.4	8.1	3.3	9.0	1.5	2.8	4.4	2.3	1.8	3.4	2.8
<=200	966	1.1	0.9	2.4	1.0	2.1	1.1	1.7	1.3	2.1	0.8	1.7	0.4	0.3	0.9	0.7	0.8	0.5	1.1
201–300	901	14.6	13.6	32.2	33.1	48.0	25.7	19.7	28.4	42.2	13.9	13.7	9.5	7.8	7.3	12.2	12.5	11.2	7.6
201–300	908	19.1	14.6	21.9	25.9	53.5	30.0	32.8	33.2	39.6	14.9	17.2	10.2	12.1	10.3	16.1	14.0	13.8	10.1
201–300	911	12.0	3.3	6.9	7.4	8.2	10.0	22.3	23.0	5.5	8.4	10.7	3.5	10.8	6.2	1.8	6.2	13.7	17.1
201–300	924	6.9	20.2	21.8	23.0	17.9	20.8	12.1	37.1	7.5	18.8	14.9	29.4	18.8	5.6	10.1	11.8	48.7	16.5
201–300	926	2.3	11.9	5.1	3.5	6.3	8.7	3.0	5.8	1.4	27.2	6.0	20.1	7.1	1.3	1.8	2.9	17.9	5.1
301–400	902	1.2	0.7	2.0	4.4	4.4	2.9	1.2	3.5	3.8	1.2	0.5	2.5	0.8	0.4	0.9	1.1	0.9	0.4
301–400	912	0.1	0.1	0.1	0.1	0.3	0.3	0.2	0.3	0.1	0.4	0.1	0.2	0.2	0.1	0.1	0.4	0.1	0.1
301–400	923	4.1	17.1	3.1	2.4	4.5	9.4	2.1	2.1	0.4	3.1	1.3	8.0	5.1	0.8	1.7	2.7	22.7	4.5
301–400	927	0.6	4.5	1.1	1.3	1.5	6.5	0.4	0.5	0.1	2.3	1.0	4.2	2.1	0.3	1.1	0.8	4.9	1.5
401–500	903	0.1	0.2	0.1	0.2	0.3	0.2	0.1	0.2	0.2	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0
401–500	913	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
401–500	967	0.2	1.3	0.3	0.4	0.5	1.1	0.1	0.2	0.1	0.4	0.3	0.8	0.6	0.1	0.3	0.3	1.2	0.3
501–750	904	0.0	0.1	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
501–750	914	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All:		76	98	118	124	168	130	128	167	121	107	96	98	78	45	54	60	154	83

Table 7. Percent contribution to total biomass index of Pandalus borealis by surveyed depth range in SFA 4.

Depth Range(m)	**Number of Strata**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
<=200	5	20	11	20	18	14	11	27	20	17	15	32	10	16	28	14	12	12	24
201–300	5	72	65	75	75	80	73	70	76	79	78	65	74	72	68	78	79	68	68
301–400	4	8	23	5	7	6	15	3	4	4	7	3	15	10	3	7	8	19	8
401–500	3	0	1	0	1	0	1	0	0	0	1	0	1	1	0	1	1	1	0
501–750	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8. Fishable abundance indices of Northern Shrimp in SFA 4.

Year	Fishable Abundance Lower CI (x 10^9)	Fishable Abundance Index (x 10^9)	Fishable Abundance Upper CI (x 10^9)	Change in Fishable Abundance from Previous Years (%)
2005	5.5	12.9	23.1	-
2006	8.1	15.1	26.0	17
2007	10.0	17.9	27.2	19
2008	8.8	18.1	28.3	1
2009	9.7	26.9	46.8	49
2010	9.0	22.6	40.6	-16
2011	7.2	20.5	36.7	-9
2012	15.4	30.0	44.9	46
2013	6.8	20.6	39.5	-31
2014	8.6	15.7	24.7	-24
2015	9.2	14.8	21.1	-6
2016	7.9	15.0	25.1	1
2017	3.7	11.5	17.6	-23
2018	3.2	6.7	10.4	-42
2019	3.2	8.0	15.5	20
2020	2.8	8.4	15.0	5
2021	6.7	18.8	32.8	125
2022	5.2	10.9	17.4	-42

Table 9. SFA 4 mean size of Northern Shrimp (mm) from NSRF shrimp surveys by various maturity/size categories including females, males, fishable (≥17.5 mm), pre-fishable (<17.5 mm) and totals.

Year	Females	Males	Fishable	Pre-fishable	Totals
2005	23.58	18.81	21.25	14.98	20.45
2006	23.93	18.66	21.52	15.13	20.45
2007	23.34	18.52	21.49	15.10	20.66
2008	23.65	17.81	21.79	15.67	20.15
2009	22.63	17.72	21.12	15.85	19.99
2010	23.06	18.20	20.55	15.87	19.70
2011	22.41	17.98	20.93	14.63	19.86
2012	22.06	18.43	20.55	15.92	19.88
2013	22.15	18.18	20.67	15.87	19.84
2014	22.87	17.47	21.42	15.19	19.76
2015	22.69	17.76	21.03	15.20	19.86
2016	23.20	18.17	21.08	15.58	20.06
2017	23.53	18.12	21.77	15.29	20.52
2018	23.19	18.64	22.07	15.60	21.30
2019	23.53	18.83	22.28	14.69	21.59
2020	24.46	19.73	23.12	15.20	22.47
2021	25.15	19.78	23.63	14.91	22.95
2022	24.08	19.32	22.35	15.56	21.51

Table 10. Male biomass and abundance indices of Northern Shrimp in SFA 4.

Year	Male Biomass Lower CI (x 1,000 t)	Male Biomass Index (x 1,000 t)	Male Biomass Upper CI (x 1,000 t)	Change in Male Biomass Index from Previous Years (%)	Male Abundance Lower CI (x 10^9)	Male Abundance Index (x 10^9)	Male Abundance Upper CI (x 10^9)	Change in Male Abundance from Previous Year (%)
2005	15.2	39.0	77.5	-	3.7	9.7	19.0	-
2006	21.7	48.4	94.8	24	5.4	12.0	22.3	23
2007	24.7	46.3	71.7	-4	6.4	11.4	17.3	-5
2008	25.5	50.1	78.4	8	7.8	14.8	22.9	30
2009	23.9	60.8	100.0	21	7.8	18.4	30.1	24
2010	25.7	69.5	130.0	14	7.6	19.2	35.1	4
2011	14.1	55.0	108.0	-21	4.6	14.2	26.4	-26
2012	36.8	79.9	126.0	45	10.5	21.1	32.6	49
2013	10.9	52.8	108.0	-34	3.7	14.5	28.7	-31
2014	23.0	42.7	77.3	-19	6.6	12.4	21.9	-14
2015	24.5	39.4	58.2	-8	6.7	10.6	15.4	-15
2016	23.1	45.4	77.3	15	5.9	11.5	19.1	8
2017	11.8	28.9	47.3	-36	3.3	7.9	12.7	-32
2018	6.2	12.2	19.4	-58	1.6	3.1	4.9	-60
2019	5.1	15.2	28.7	25	1.4	3.6	6.6	16
2020	6.1	17.2	30.6	13	1.5	3.8	6.6	5
2021	17.0	40.5	66.3	135	3.8	8.3	12.8	119
2022	15.0	32.0	53.2	-21	3.3	6.7	10.7	-19

Table 11. Multiplicative specification for LV Northern Shrimp CPUE for SFA 4 Pandalus borealis 1989–2022/23 (single + double + triple trawl, observer data up to 2022, no windows, fishing history >1 year, standardized to 1989 values). Data from 2003 to present were converted to management year.

Management Year	TAC (t)	Fleet Catch (t)	Percent catch captured in model	CPUE relative to 1989	Modelled CPUE (kg/hour)	Calculated Effort (hours)
1978	500	-	-	-	-	-
1979	500	3	-	-	-	-
1980	500	1	-	-	-	-
1981	500	2	-	-	-	-
1982	500	5	-	-	-	-
1983	500	30	-	-	-	-
1984	500	-	-	-	-	-
1985	500	-	-	-	-	-
1986	500	2	-	-	-	-
1987	500	7	-	-	-	-
1988	500	1,083	-	-	-	-
1989	2,580	3,842	19	1.00	607	6,334
1990	2,580	2,945	74	0.94	573	5,144
1991	2,635	2,561	79	4.57	2,769	925
1992	2,635	2,706	80	2.94	1,781	1,519
1993	2,735	2,723	75	3.79	2,297	1,185
1994	4,000	3,982	69	5.89	3,570	1,115
1995	5,200	5,104	74	2.00	1,213	4,207
1996	5,200	5,160	69	1.99	1,207	4,276
1997	5,200	5,216	66	4.38	2,657	1,963
1998	8,008	7,918	94	3.33	2,019	3,922
1999	8,008	7,793	97	3.58	2,169	3,593
2000	8,008	7,300	101	3.97	2,409	3,031
2001	8,008	8,104	96	6.02	3,653	2,218
2002	8,008	8,322	101	3.67	2,225	3,740
2003–04	12,685	12,944	101	4.02	2,438	5,309
2004–05	9,883	9,549	109	3.40	2,060	4,636
2005–06	9,883	10,247	102	3.18	1,929	5,312
2006–07	9,883	10,084	99	3.41	2,070	4,871
2007–08	9,883	10,009	97	3.82	2,316	4,322
2008–09	10,783	9,682	108	3.76	2,283	4,242
2009–10	10,783	10,656	115	5.85	3,550	3,002
2010–11	10,783	11,134	101	6.28	3,810	2,922
2011–12	10,783	10,441	92	5.04	3,057	3,416
2012–13	12,041	13,908	97	4.39	2,661	5,226
2013–14	13,969	14,969	91	5.16	3,129	4,784
2014–15	13,969	14,642	99	4.88	2,958	4,949
2015–16	13,969	14,766	95	3.70	2,246	6,576
2016–17	13,594	13,722	102	5.75	3,487	3,936
2017–18	13,579	15,124	100	4.67	2,832	5,340
2018–19	13,579	14,311	83	4.63	2,810	5,093
2019–20	9,415	10,360	99	6.03	3,661	2,830
2020–21	7,563	7,672	90	5.71	3,466	2,213
2021–22	8,663	8,043	113	4.58	2,777	2,896
2022–23	10,827	11,416	48	5.08	3,084	3,701

Table 12. Unstandardized CPUE (kg/hour) by depth range and stratum for the LV fleet fishing Northern Shrimp in SFA 4. Data were taken from observer data set; colour ranges are based on quartiles of the data from 1999 to 2021/22. Data for 2021/22 and 2022/23 are preliminary.

Legend:		CPUE <= 3,056 kg/hr							3,056 kg/hr < CPUE < 4,366 kg/hr									4,366 kg/hr <= CPUE							
Depth Range	Stratum	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
<= 200	909				13,707	433																1,533			
	910																								
	925	1							47				1,742	1,030	660	2,151	2,497	451	174	331	804	1,042		429.4	1691
	965				4,169	4,744			3,184		1826							3,015			4,044	5,213			3,240
	966					1,261	1,650			2,681			3,162	4,514	4,160	2,403	6,374	7,072		2,354	6,602	2,051		3,942	2,780
201–300	901			3			910	126	6,598	2,644	1764	4,216	3,582	4,481	3,478	3,215	6,273	5,072	3,244	4,289	4,358	2,190		2,376	3,697
	908	1,843	2,877	3,783	2,983	2,593	2,990	2,694	3,208	3,376	3452	5,934	4,397	4,370	4,341	5,558	4,833	3,686	5,722	3,770	5,339	3,207	5,389	3,868	2,945
	911	2,455	2,616		1,479	2,134	469	2,490	681	1,576	2107	5,369	2,906	4,153			2,933		1,610	15,278	3,047	1,542			
	924	3,775	2,812	4,038	2,196	3,466	2,914	1,897	2,911	2,437	2322	3,771	4,529	4,391	3,289	3,281	3,201	2,510	4,059	3,914	5,499	5,455	5,013	3,647	5,001
	926	11,090	4,804		1,637			1,824	963	2,164	2102	3,234	4,301	2,831	2,503	2,399	2,997	1,334	1,973	604	2,381	485	6,904	725.2	3,451
301–400	902	1,764	2,831	5,173	2,893	3,095	2,374	2,970	3,266	4,205	3832	4,769	2,447	3,955	3,885	7,021	5,622	2,619	7,826	5,872	6,870	2,789	7,762	4,134	3,566
	912	2,677			1,522																				
	923	2,424	2,680	3,969	2,698	3,432	2,405	2,088	2,578	2,395	2078	4,401	4,365	2,807	1,805	3,571	4,723	3,421	3,625	3,871	8,269	3,947	3,111	3,639	7,637
	927	1,171	2,272	1,225	1,134	826	4,108	1,071	3,064	2,404	1604	2,907	3,246	3,111		2,463			1,181	1,530	7,787	1,052	771.4	472.6	
401–500	903	1,810	2,186	5,931	4,512	4,694	2,295	3,926	2,453	3,793	5615	6,120		1,834	4,128	9,871	5,406	2,767	8,477	10,756	6,644	9,309	6,962	3,859	0.222
	913	1,667							588																
	967	2,243	2,077	4,181	2,860	3,534	2,095	2,604	1,116	2,290	373	4115	4,513			26				2,651	49,669	5,222	2,031	1,536	
501–750	904	1,679		5,128	3,593	3,340	1,291	2,676	3,739		5,206	5910			4,976	26,588	5,794	2,124	4,441	5,762	5,454	10,76 2			
	914																								

Table 13. Total biomass and abundance indices of Striped Shrimp in SFA 4. Indices derived from Ogmap using NSRF summer shrimp survey data.

Year	Total Biomass Lower CI (x 1,000 t)	Total Biomass Index (x 1,000 t)	Total Biomass Upper CI (x 1,000 t)	Change in Total Biomass Index from Previous Years (%)	Total Abundance Lower CI (x 10^9)	Total Abundance Index (x 10^9)	Total Abundance Upper CI (x 10^9)	Change in Total Abundance Index from Previous Year (%)	Number of Survey Sets in SFA 4	% Sets with *P. montagui*
2005	10.9	20.5	34.3	-	2.3	4.1	6.9	-	10.9	20.5
2006	7.81	15.4	24.5	-25	1.9	3.2	5.0	-22	7.81	15.4
2007	11	19.3	29.8	25	2.0	3.9	6.1	22	11	19.3
2008	24.4	40.6	59.8	110	4.9	7.8	11.5	100	24.4	40.6
2009	13.3	22.4	36.3	-45	2.5	4.4	7.1	-44	13.3	22.4
2010	11.2	17.1	27.7	-24	2.2	3.5	5.7	-20	11.2	17.1
2011	10.2	15.7	24.6	-8	1.9	3.1	4.8	-12	10.2	15.7
2012	11.6	27.9	42.4	78	2.5	5.1	7.6	67	11.6	27.9
2013	28.7	43.4	61	56	5.5	8.6	12.0	69	28.7	43.4
2014	25	35.5	52	-18	4.8	7.1	10.3	-18	25	35.5
2015	33.5	51.5	78.4	45	7.0	9.9	14.7	41	33.5	51.5
2016	18.5	26.4	42.1	-49	3.7	5.3	8.2	-47	18.5	26.4
2017	27.8	47.3	71.3	79	5.5	8.8	14.0	67	27.8	47.3
2018	38.9	57.6	84.1	22	6.9	9.9	14.1	13	38.9	57.6
2019	25.6	43.3	65.7	-25	5.0	8.2	12.5	-17	25.6	43.3
2020	18.1	27.5	41.2	-36	3.5	5.4	8.4	-35	18.1	27.5
2021	18.6	35.7	53.4	30	3.9	7.1	10.6	32	18.6	35.7
2022	33.1	42.2	59.5	18	5.4	7.3	10.4	3	33.1	42.2

Table 14. Fishable biomass and exploitation rate indices for Striped Shrimp in SFA 4. Biomass indices calculated using Ogmap on the NSRF summer shrimp survey data. ERI is the total commercial catch (includes directed and incidental catch) divided by the fishable biomass index in the same year. Catch data are preliminary and based upon the February 8, 2023, AQMS.

Catch Year	By-catch Quota (t)	Catch (t)	Survey Year	Fishable Biomass Index Lower CI (x 1,000 t)	Fishable Biomass Index (x 1,000 t)	Fishable Biomass Index Upper CI (x 1,000 t)	Change in Fishable Biomass Index from Previous Year (%)	ER Index Lower CI (%)	ER Index (%)	ER Index Upper CI (%)
2005/06	-	813	2005	9.27	18	30.3	-	2.68	4.52	8.77
2006/07	-	1,805	2006	7.82	13.4	21.7	-26	8.32	13.47	23.08
2007/08	-	2,182	2007	8.96	16.7	26.1	25	8.36	13.07	24.35
2008/09	-	278	2008	19.7	35.6	54.3	113	0.51	0.78	1.41
2009/10	-	617	2009	11.6	20	33.6	-44	1.84	3.09	5.32
2010/11	-	1,115	2010	8.35	14.3	22.5	-28	4.96	7.80	13.35
2011/12	-	3,236	2011	8.73	13.9	23.8	-3	13.60	23.28	37.07
2012/13	-	4,708	2012	9.58	25.3	39.4	82	11.95	18.61	49.15
2013/14	4,033	1,611	2013	25	36.9	53.8	46	2.99	4.37	6.44
2014/15	4,033	1,236	2014	22.7	31.5	46.8	-15	2.64	3.92	5.44
2015/16	4,033	2,135	2015	29.1	44.7	68.7	45	3.11	4.78	7.34
2016/17	4,033	1,113	2016	16.4	23.2	36.4	-49	3.06	4.80	6.78
2017/18	4,033	2,611	2017	27.5	43.7	70.5	97	3.70	5.98	9.50
2018/19	4,033	2,572	2018	34.1	53.7	78.6	18	3.27	4.79	7.54
2019/20	4,033	3,035	2019	21.6	38.9	60.4	-28	5.02	7.80	14.05
2020/21	4,033	2,734	2020	16.3	24.6	36.9	-37	7.41	11.12	16.78
2021/22	4,033	3,146	2021	16.1	31	46.3	26	6.80	10.15	19.54
2022/23	4,033	3,498	2022	29	38.8	54.6	25	6.41	9.02	12.06

Table 15. Female biomass and abundance indices for Striped Shrimp in SFA 4. Indices calculated using Ogmap on the NSRF summer shrimp survey data.

Year	Female Biomass Lower CI (x 1,000 t)	Female Biomass Index (x 1,000 t)	Female Biomass Upper CI (x 1,000 t)	Change in Female Biomass Index from Previous Years (%)	Female Abundance Lower CI (x 10^9)	Female Abundance Index (x 10^9)	Female Abundance Upper CI (x 10^9)	Change in Female Abundance from Previous Year (%)
2005	6.2	12.2	21.2	-	0.9	1.7	3.0	-
2006	3.3	7.5	13.3	-38	0.5	1.0	1.8	-42
2007	5.1	9.0	13.9	19	0.7	1.2	1.8	19
2008	15.2	28.5	46.2	218	2.4	3.9	6.3	224
2009	8.3	15.7	26.1	-45	1.2	2.3	4.1	-40
2010	7.0	11.1	18.0	-29	1.0	1.6	2.6	-30
2011	5.6	8.9	14.3	-20	0.7	1.2	2.0	-23
2012	9.8	21.0	32.3	136	1.2	3.0	4.6	144
2013	20.2	29.6	43.9	41	2.9	4.3	6.3	43
2014	17.5	24.8	38.7	-16	2.8	3.9	5.9	-11
2015	19.9	34.4	53.1	39	3.2	4.8	7.4	26
2016	12.6	17.7	28.0	-49	1.8	2.7	4.1	-45
2017	19.4	33.5	54.7	89	3.0	4.8	7.6	80
2018	29.7	45.9	68.6	37	4.1	6.4	9.6	33
2019	18.1	32.3	51.3	-30	2.9	4.8	7.6	-26
2020	11.3	18.1	27.7	-44	1.8	2.6	4.0	-45
2021	12.1	22.4	32.7	24	1.6	3.2	4.8	20
2022	23.9	30.6	44.5	37	3.1	4.2	5.9	33

Table 16. Percent contribution to total biomass index of Striped Shrimp by surveyed depth range in SFA 4.

Depth Range(m)	Number of Strata	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
<=200	5	28	23	38	57	37	53	64	58	34	52	83	50	40	47	39	33	39	67
201–300	5	69	69	60	42	59	46	35	39	64	46	16	46	54	51	57	64	59	31
301–400	4	2	7	2	1	3	1	1	2	1	1	0	3	5	2	3	2	2	1
401–500	3	0	1	0	0	1	0	0	1	0	0	0	0	1	1	1	1	1	0
501–750	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 17. Total biomass (x 1,000 t) of Striped Shrimp in SFA 4 by strata and depth range from 2005–22. Biomass indices were generated using Ogive Mapping on NSRF summer shrimp survey data. Boundaries for deciding colours were based on percentiles of the data from 101–750 m depth ranges.

Legend:		Index <= 460 t					460 t < Index < 2,847 t						2,847 t<= Index						
Depth Range (m)	**STRATUM**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
<=200	909	1.4	0.7	1.5	4.4	2.6	2.4	1.9	3.2	3.4	4.0	9.5	3.3	3.9	4.9	4.2	2.3	4.4	4.2
	910	1.6	1.3	2.1	6.9	2.1	2.9	2.9	5.6	4.6	4.5	12.8	4.7	4.8	7.9	3.7	2.7	3.7	6.1
	925	1.5	1.2	2.6	9.2	2.0	2.2	4.2	5.9	4.6	6.6	14.1	3.3	7.4	10.6	5.0	2.2	2.3	13.6
	965	0.8	0.4	0.8	2.1	1.4	1.5	0.8	1.3	1.8	3.1	4.8	1.6	2.7	2.9	3.6	1.7	2.9	3.7
	966	0.4	0.1	0.2	0.3	0.2	0.1	0.2	0.1	0.4	0.4	1.7	0.3	0.4	0.7	0.3	0.2	0.5	0.7
201–300	901	3.0	0.9	2.2	2.2	1.1	1.4	1.6	1.7	8.9	4.0	3.0	1.5	2.6	6.3	2.9	4.3	4.1	3.1
	908	1.9	1.3	1.1	1.8	1.8	1.4	0.9	0.9	3.5	4.1	1.5	1.4	3.1	3.3	3.2	2.8	5.2	3.1
	911	2.2	1.3	2.2	3.2	3.5	2.7	1.1	2.6	7.9	3.9	1.5	3.4	4.0	3.6	4.7	3.6	5.6	2.3
	924	2.4	3.0	1.6	4.2	1.9	1.2	1.0	3.1	3.9	2.1	1.5	3.4	9.8	5.5	7.4	4.4	3.5	2.3
	926	4.6	4.2	4.5	5.5	4.9	1.1	1.0	2.8	3.7	2.1	0.7	2.5	6.2	10.5	6.5	2.6	2.6	2.5
301–400	902	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1
	912	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	923	0.2	0.5	0.1	0.2	0.2	0.0	0.0	0.2	0.2	0.2	0.1	0.4	1.1	0.4	0.6	0.2	0.3	0.2
	927	0.2	0.5	0.2	0.3	0.4	0.1	0.1	0.3	0.2	0.2	0.1	0.3	0.8	0.5	0.7	0.2	0.2	0.2
401–500	903	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	913	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	967	0.1	0.1	0.1	0.2	0.3	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.2	0.1	0.2	0.1
501–750	904	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	914	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All:		20	15	19	41	22	17	16	28	43	35	51	26	47	58	43	28	36	42

Table 18. Fishable abundance indices for SFA 4 Striped Shrimp.

Year	Fishable Abundance Lower CI (x 10^9)	Fishable Abundance Index (x 10^9)	Fishable Abundance Upper CI (x 10^9)	Change in Fishable Abundance from Previous Years (%)
2005	1.59	3.02	5.6	-
2006	1.41	2.29	3.84	-24
2007	1.3	2.83	4.48	24
2008	3.28	5.43	8.16	92
2009	1.81	3.33	5.46	-39
2010	1.47	2.34	3.93	-30
2011	1.53	2.36	3.88	1
2012	2.18	3.95	6.09	67
2013	4.05	6.08	8.55	54
2014	4.09	5.5	8.35	-10
2015	4.76	7.07	10.6	29
2016	2.89	3.95	6.41	-44
2017	4.63	7.23	11.3	83
2018	5.56	8.16	12	13
2019	4	6.26	10.2	-23
2020	2.56	4.19	6.44	-33
2021	2.66	5.21	7.97	24
2022	4.48	5.97	8.28	15

Table 19. SFA 4 mean size of Striped Shrimp (mm) from NSRF shrimp surveys by various maturity/size categories including females, males, fishable (≥17.5 mm), pre-fishable (<17.5 mm), and totals.

Year	Females	Males	Fishable	Pre-Fishable	Totals
2005	23.59	17.50	21.65	15.58	20.08
2006	22.83	17.45	20.76	15.01	19.15
2007	22.70	17.61	20.63	15.20	19.17
2008	22.44	16.63	21.58	14.70	19.52
2009	22.02	16.92	21.02	15.13	19.62
2010	21.90	16.84	20.94	15.56	19.17
2011	21.99	17.49	20.45	15.54	19.31
2012	22.05	16.56	21.30	14.76	19.80
2013	21.82	16.63	20.84	15.36	19.22
2014	21.65	17.25	20.78	15.65	19.65
2015	21.72	16.51	20.76	14.83	19.05
2016	21.73	17.15	20.86	15.31	19.48
2017	22.07	17.68	21.14	15.21	20.09
2018	22.40	16.87	21.68	14.76	20.44
2019	22.24	16.79	21.53	14.92	19.95
2020	22.67	17.55	21.29	15.68	20.05
2021	22.31	17.34	20.95	15.64	19.54
2022	22.54	17.43	21.48	15.35	20.34

Table 20. Unstandardized CPUE (kg/hour) by depth range and stratum for the LV fleet fishing Striped Shrimp in SFA 4 from 1998 to 2022/23. Data were taken from observer data set for all records of Striped Shrimp (directed effort or by-catch) colour ranges are based on quartiles of the data from 1998 to 2021/22. Data for 2021/22 and 2022/23 are preliminary.

Legend:		CPUE <= 483 kg/hr							483 kg/hr < CPUE < 1,560 kg/hr								1,560 kg/hr <= CPUE									
Depth Range	Stratum	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
<= 200	909																									
<= 200	910																									
<= 200	925		5							2,585	1,238	1,545		2,512	1,979	2,050	1,965	1,634	1,333	1,260	1,149	1,536	1,808	1,687	1,797	1,973
<= 200	965																									
<= 200	966																27	165			98					
201–300	901												107			277	115	449		558	285					
201–300	908		75			70	138	32	48	99	287	468	701	366	769	608	465	408	128	557	815	588	1,595	79	483	56
201–300	911						48			686		456	328													
201–300	924	38		177	102	33	94	4	245	162	244	393	402	271	3,066	768	988	374	1,752	545	1,239	1,017	1,249	1,676	1,786	2,116
201–300	926		2,720	10					2,602	2,111	1,840	1,586	2,121	3,126	2,541	1,764	3,441	947	1,525	3,133	1,929	1,869	2,527	2,376	2,137	3,611
301–400	902		41	170	733	2	327	369	296	179	90	1,383	512	450		784	584	544		763	375	556	2,164	210	854	
301–400	912																									
301–400	923	1,275	1	197	115	151	93	60	120	320	334	29	460	5	3,236	84		88	2,230	428	473	4,704	161	869	118	
301–400	927			63		48	116		1,582	2,284	2,185	347	497	4,629	3,357	1,219	4,800		3,488	1,203	1,455		3,898	2,003	2,177	
401–500	903				65	42	77	68	47	167	6	1,770	477		814	381	500	160		749	212	597	443	572	595	
401–500	913																									
401–500	967	2,173			312	183	313	13	142												802	1,291	482	242	949	
501–750	904					1	56		2,061							1,565		6			46					
501–750	914																									

Table 21. Mean carapace length, in mm, of Striped Shrimp as measured during detailed at-sea observer sampling.

Year	Mean Carapace Length (mm)
2014	19.63
2015	19.73
2016	20.86
2017	20.37
2018	20.11
2019	20.12
2020	20.96
2021	20.83
2022	-

APPENDIX 3: FIGURES

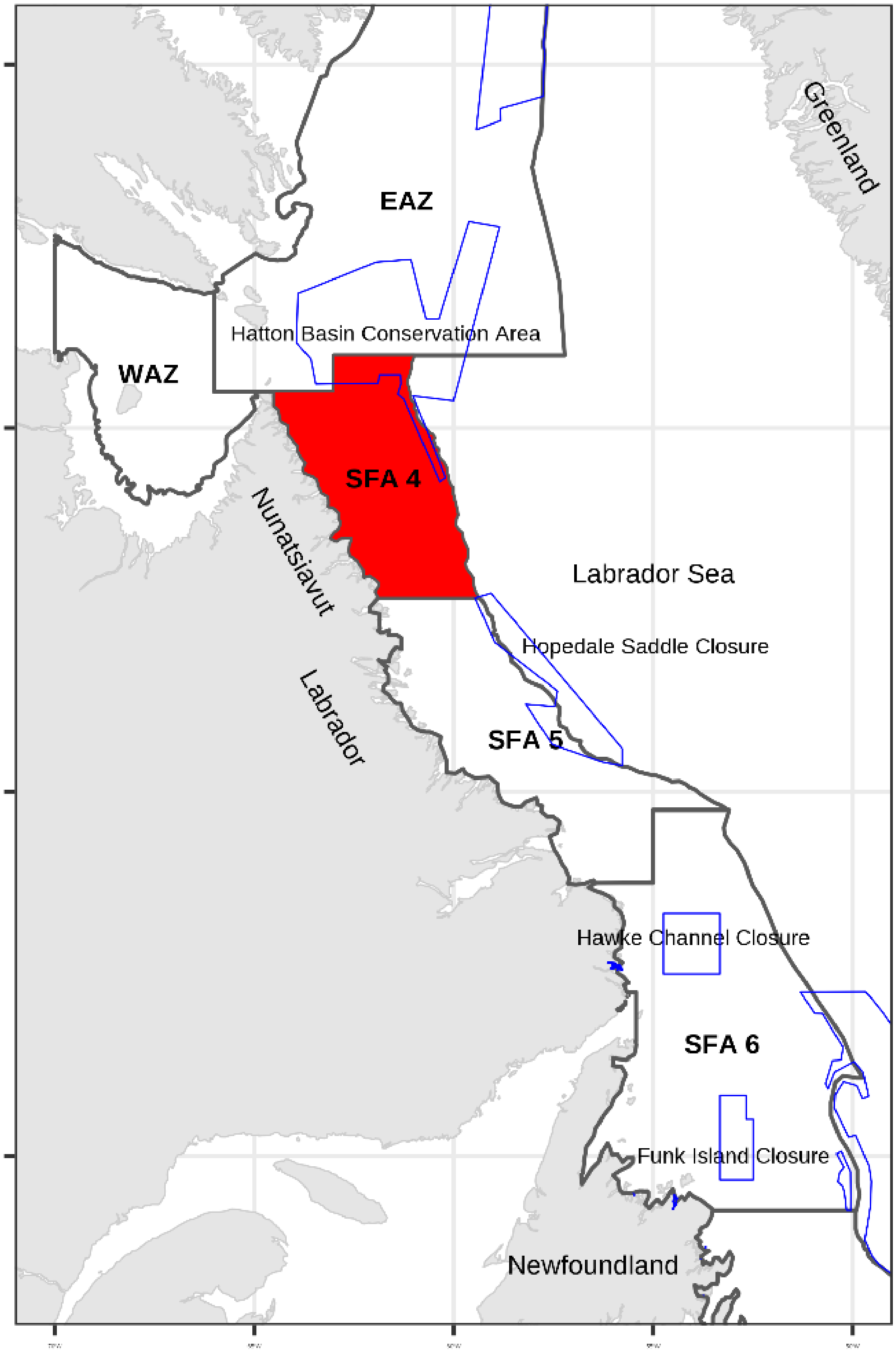

Figure 1. Shrimp Fishing Areas (SFAs) 4 (filled in red), 5, 6, and the East and West Assessment Zone (EAZ and WAZ) (black lines). Hatton Basin Conservation Area, Hopedale Saddle, Hawke Channel and Funk Island Closures are represented with blue lines.

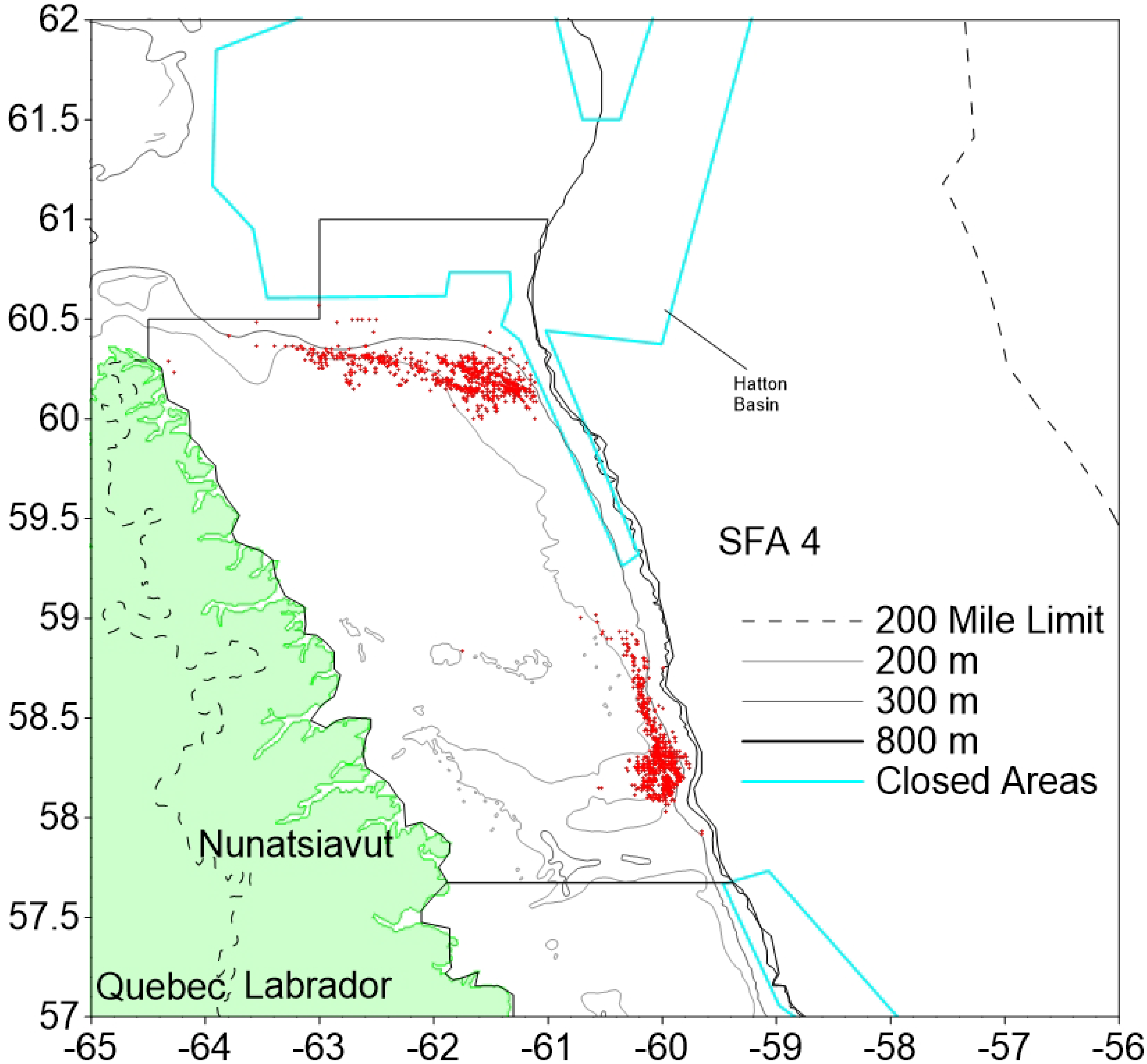

Figure 2. Preliminary Northern Shrimp fishing positions for 2022/23; red crosses indicate fishing positions of vessels directing for Northern Shrimp. Light blue outlines indicate closed areas. LV positions were taken from preliminary observer data and SV.

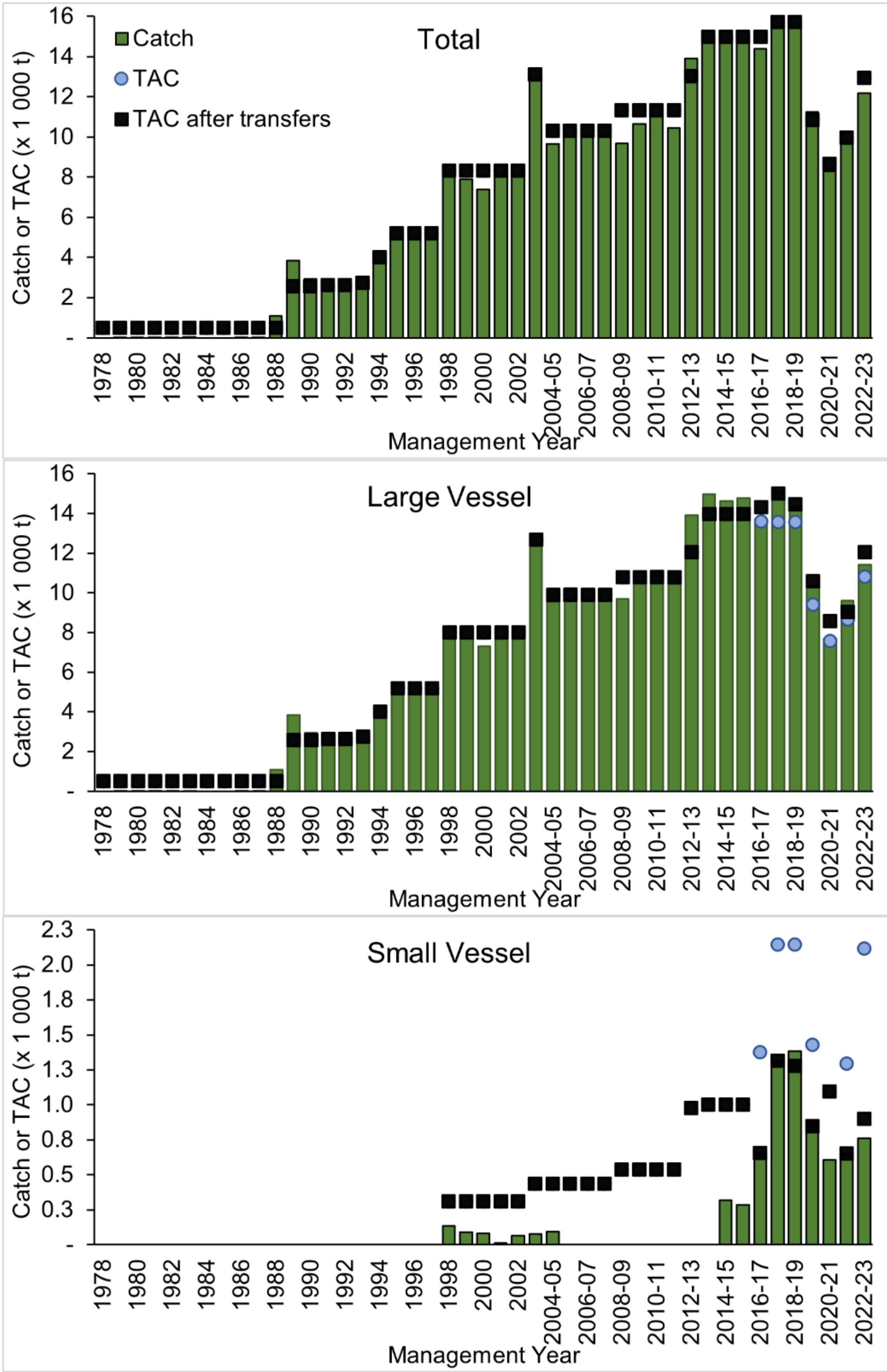

Figure 3. Historical Northern Shrimp TACs and commercial catch for 1977–2022/23 in SFA 4. Catches are preliminary as of the February 17, 2023, AQMS. In 2003, the management year was switched from a calendar year to a management year such that 2003/04 represents a 15-month long fishing season. While quota transfers and bridging are reflected in catch numbers, they are only reflected in TACs from 2016/17–2022/23.

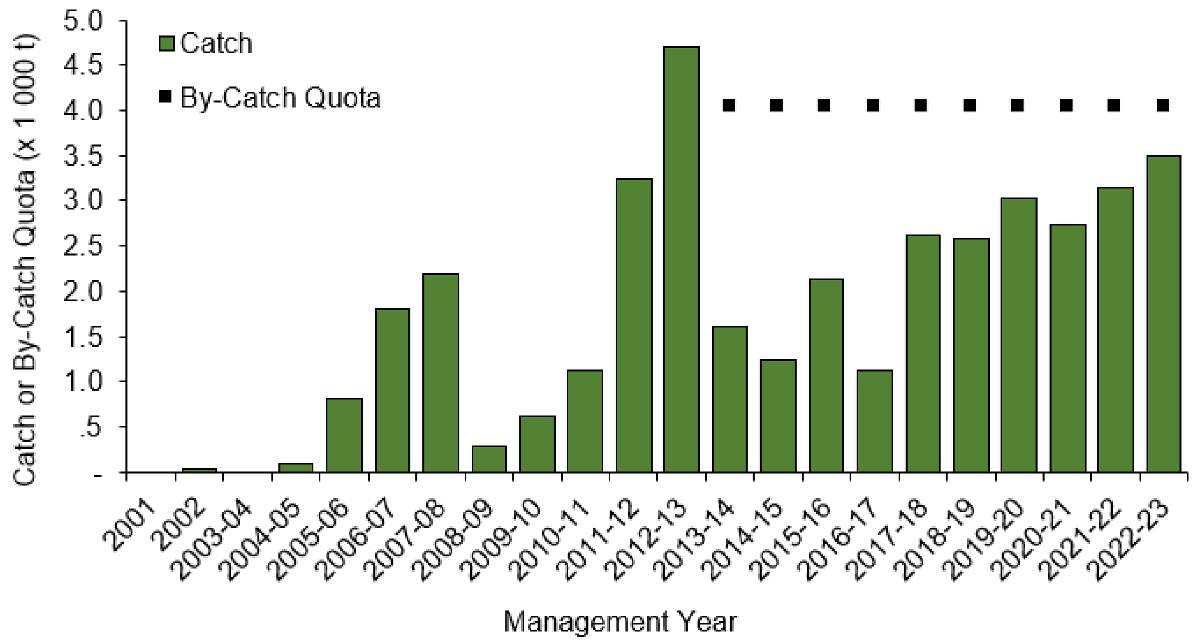

Figure 4. SFA 4 historical Striped Shrimp catches and by-catch quotas for the period 2001–22/23. Catches are preliminary as of the February 17, 2023, AQMS.

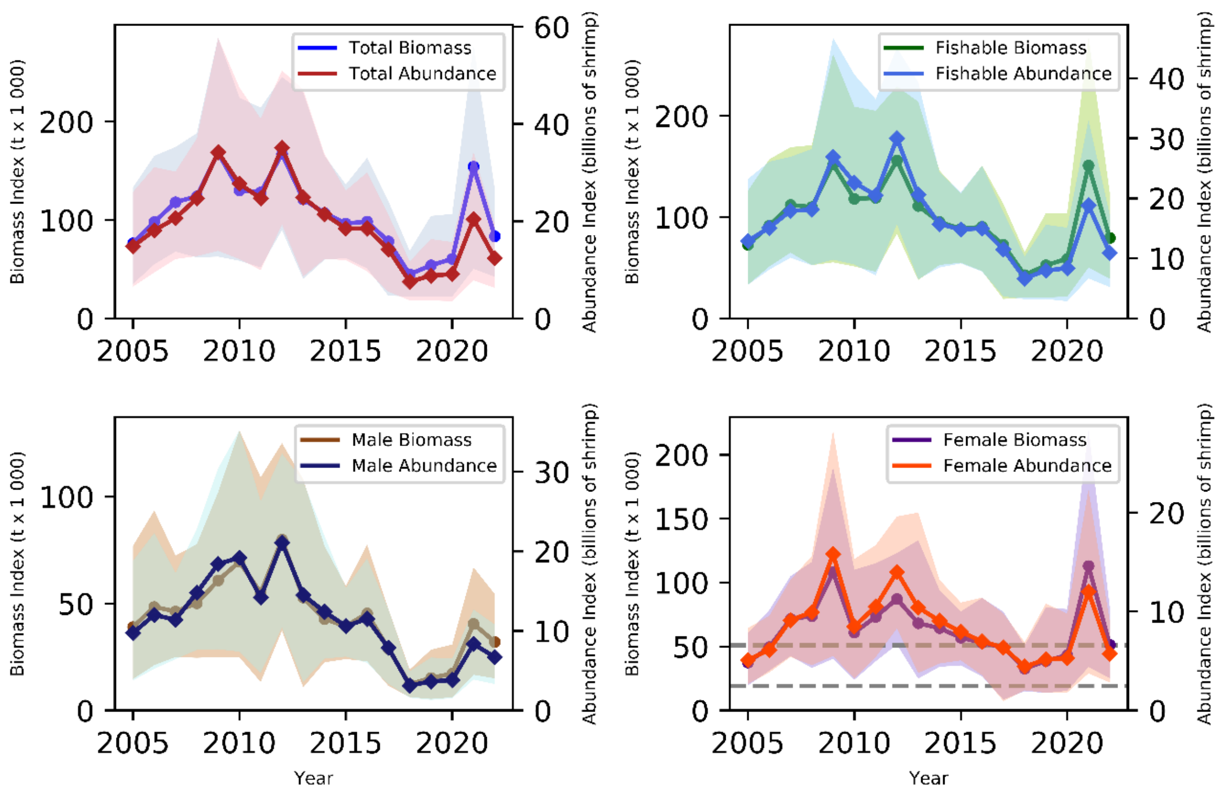

Figure 5. SFA 4 biomass and abundance indices of Northern Shrimp as derived by Ogmap using NSRF summer shrimp survey data. Shaded areas indicate 95% confidence intervals and the dashed lines in the female figure represent the LRP and USR as used in the PA Framework.

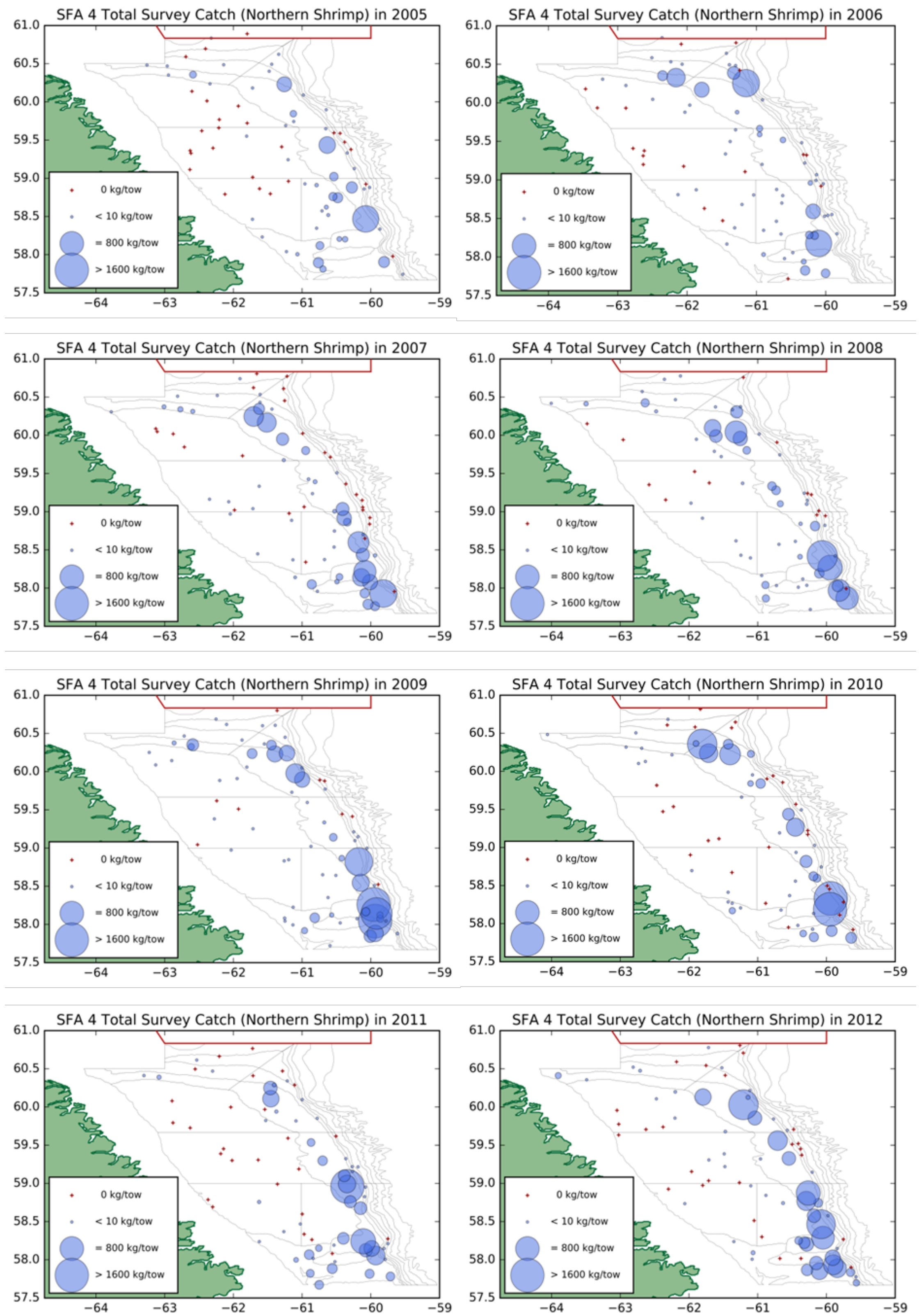

Figure 6. SFA 4 Pandalus borealis NSRF shrimp survey data catches for 2005–12. Circle sizes are scaled to size of Northern Shrimp catch and red crosses indicate zero catch. Solid red lines indicate closed areas.

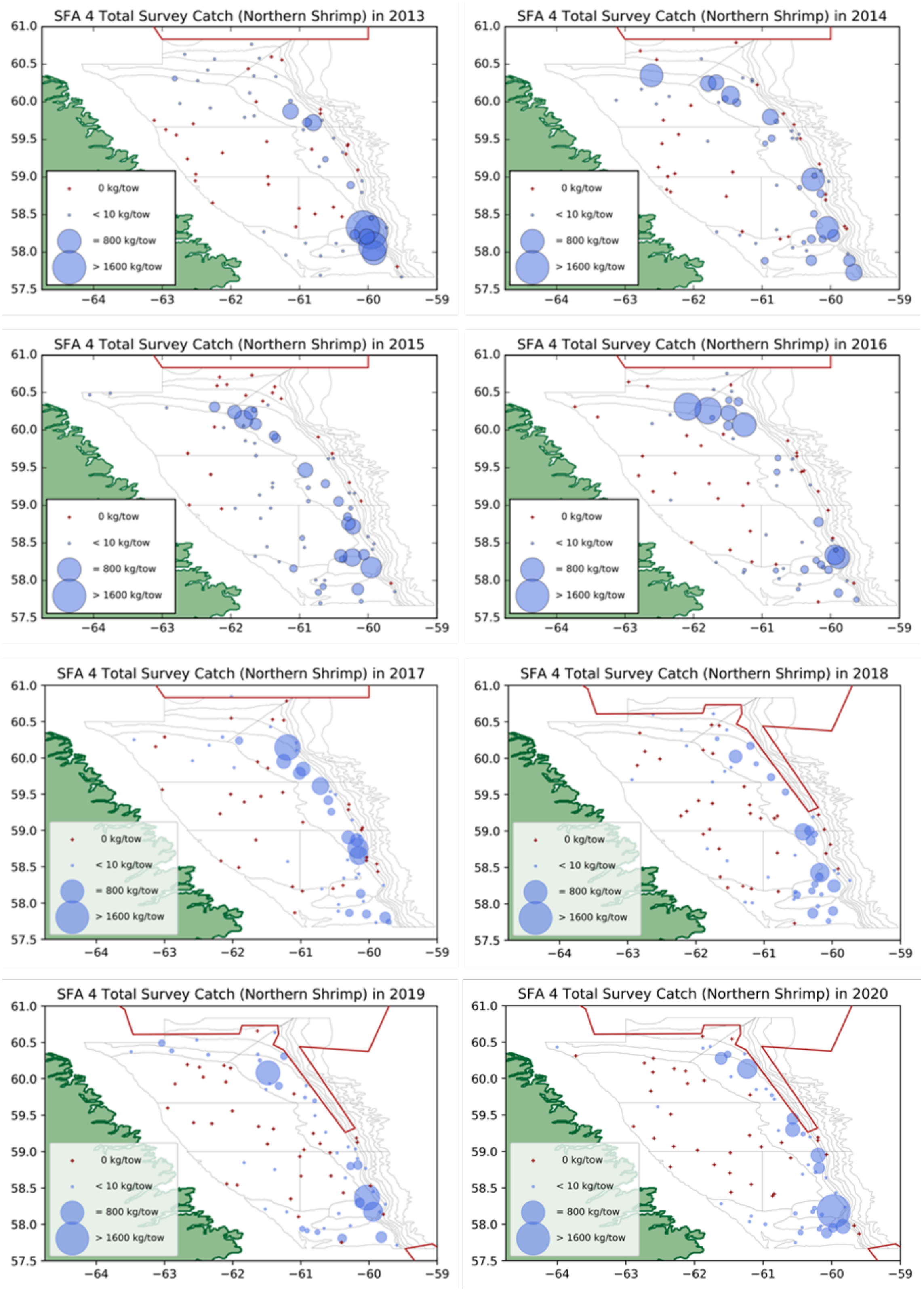

Figure 7. SFA 4 Pandalus borealis NSRF shrimp survey data catches for 2013–20. Circle sizes are scaled to size of Northern Shrimp catch and red crosses indicate zero catch. Solid red lines indicate closed areas.

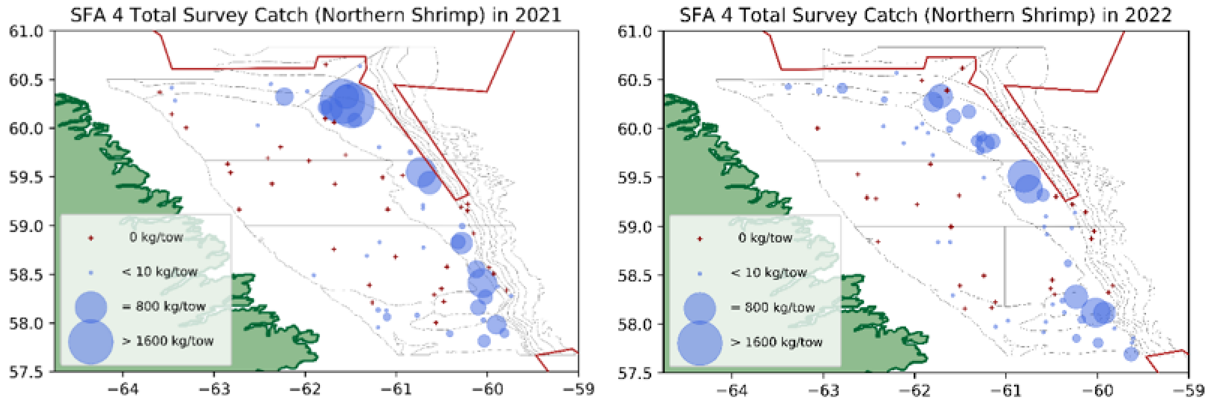

Figure 8. SFA 4 Pandalus borealis NSRF shrimp survey data catches for 2021 and 2022. Circle sizes are scaled to size of Northern Shrimp catch and red crosses indicate zero catch. Solid red lines indicate closed areas.

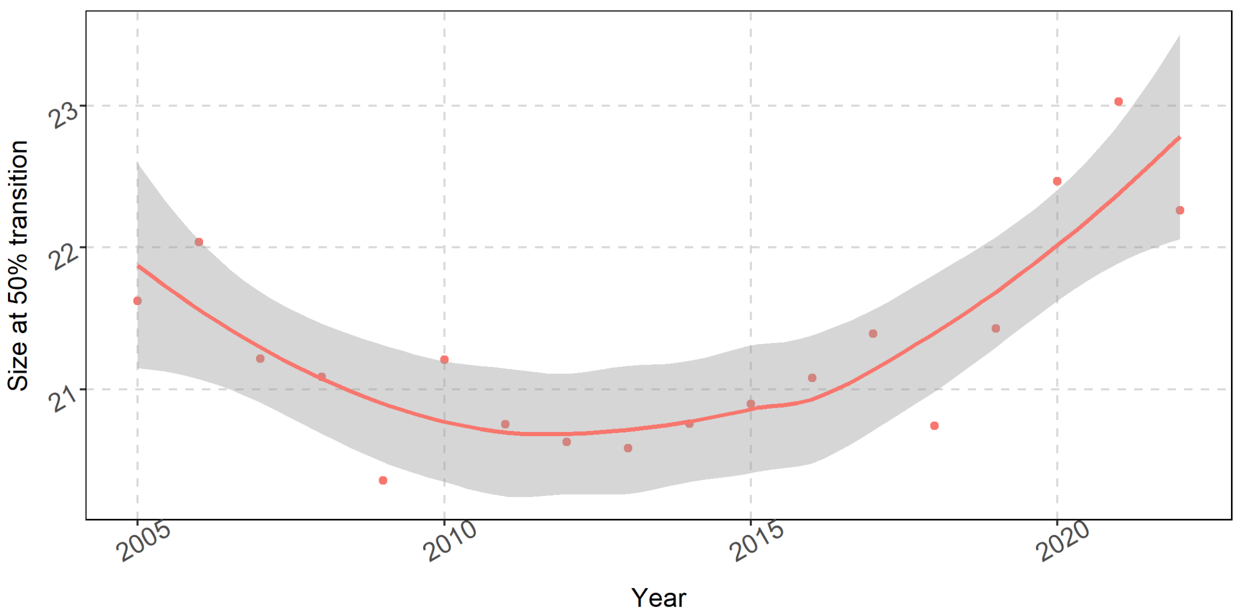

Figure 9. Annual estimated size at 50% transition of Northern Shrimp in SFA 4.

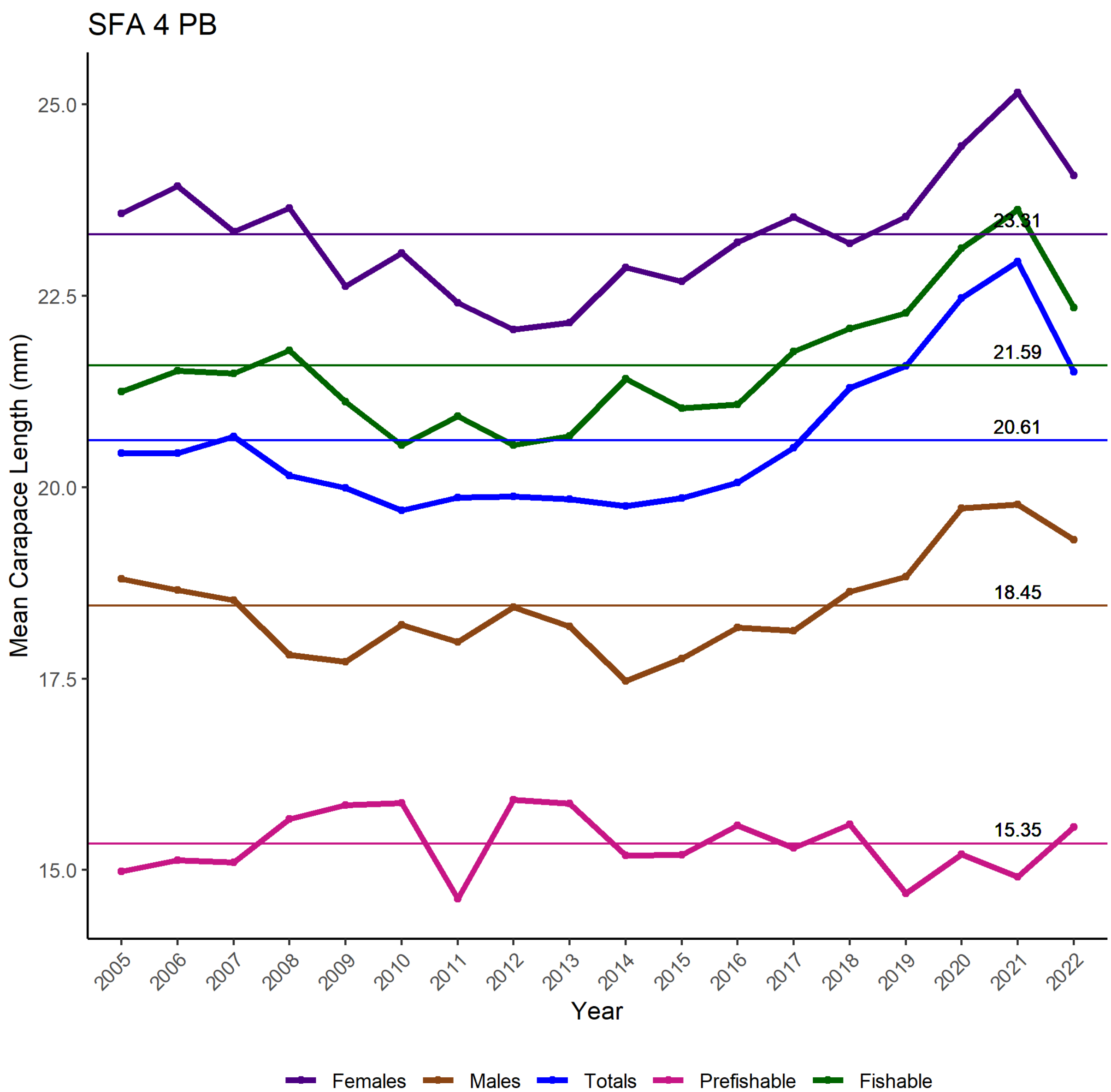

Figure 10. SFA 4 mean size of Northern Shrimp of various maturities including totals, females, males, pre-fishable (or pre-recruit, CL <17.5 mm) and fishable (CL ≥17.5 mm). Long-term average size for each maturity is indicated by the straight line and number at the right of each series.

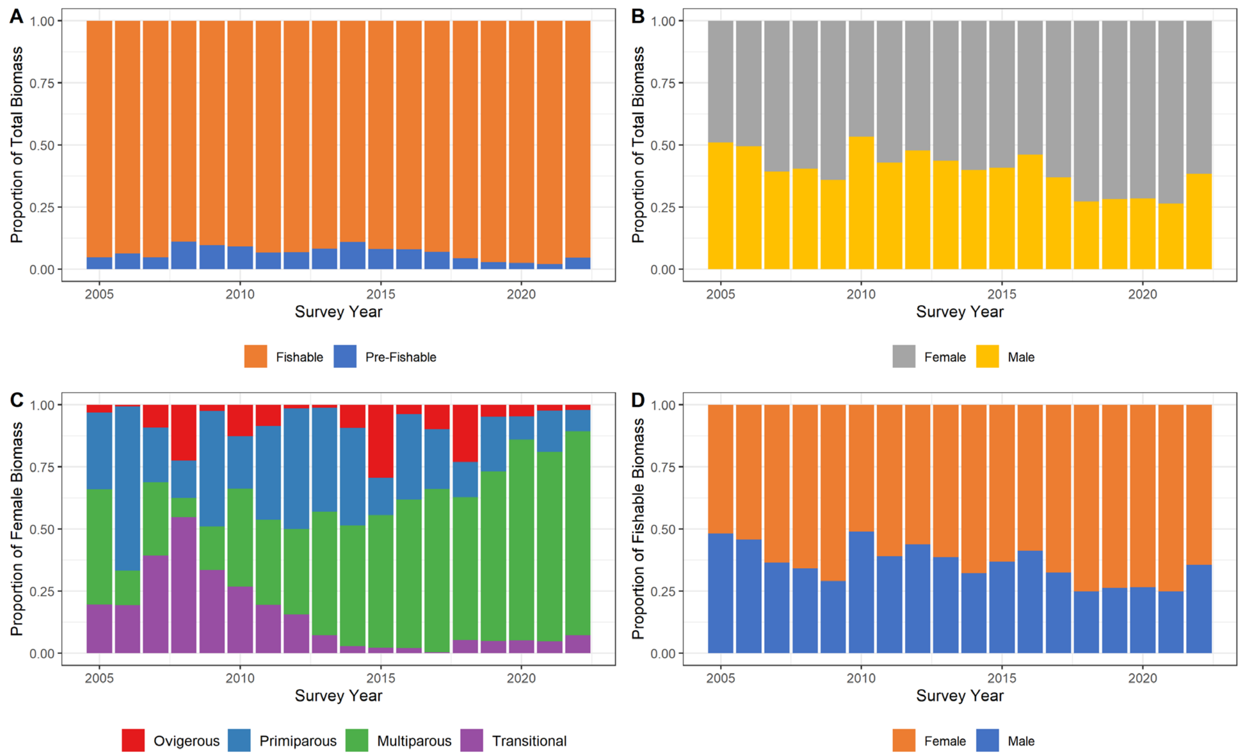

Figure 11. Proportions of biomass of various Northern Shrimp maturities in SFA 4 as sampled during the NSRF summer survey. Top left: Proportion of fishable size (≥17.5 mm carapace length) compared to pre fishable (pre-recruit) size of the total biomass index. Top Top right: Proportion of female versus male of the total biomass index. Bottom left: Proportion of ovigerous, primiparous, multiparous and transitional shrimp in the female biomass index. Bottom right: Proportion of female versus male shrimp in the fishable biomass index.

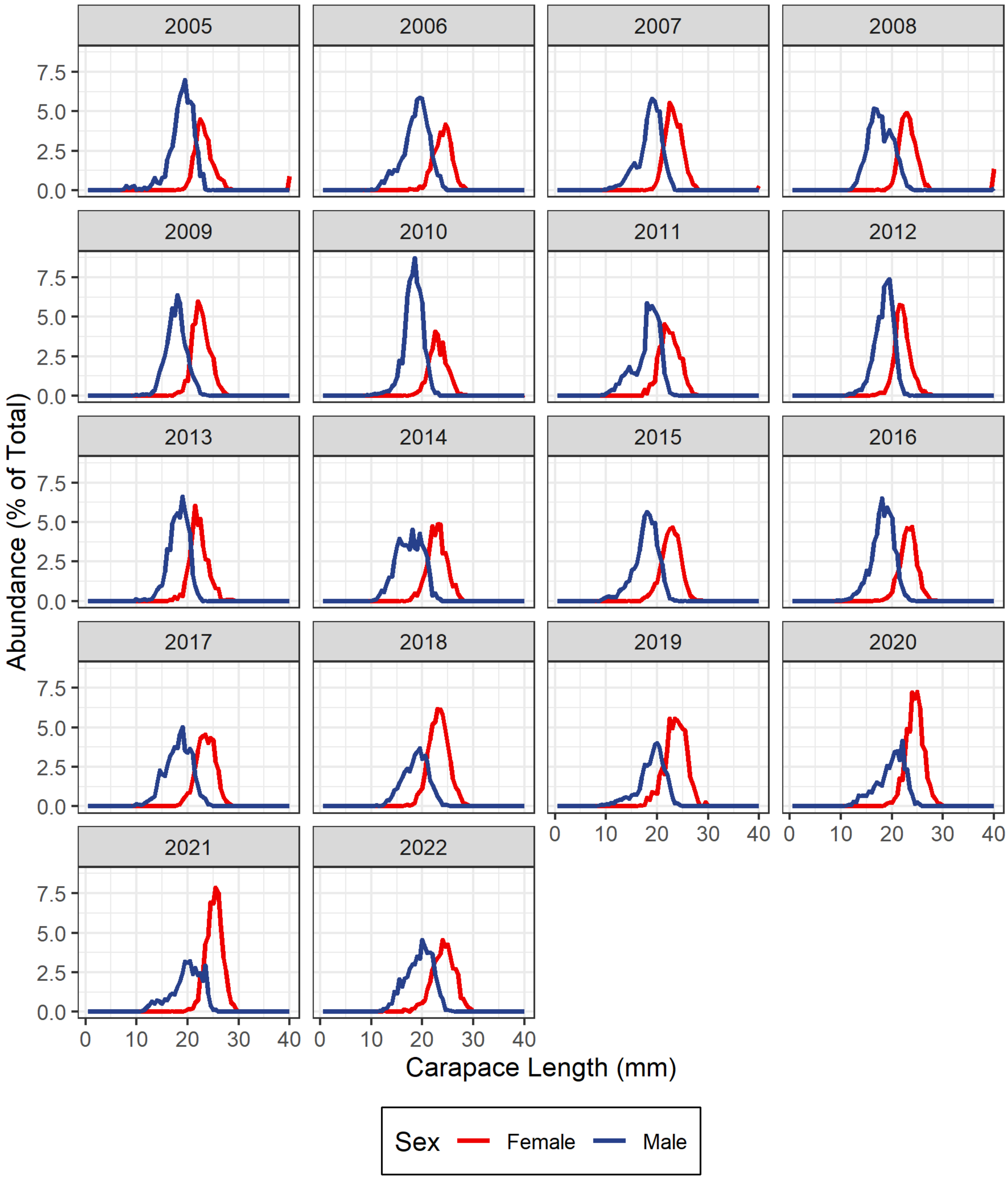

Figure 12. SFA 4 Northern Shrimp abundance at length (expressed as a percentage of total abundance), as determined using Ogmap on NSRF summer shrimp data for 2005–22.

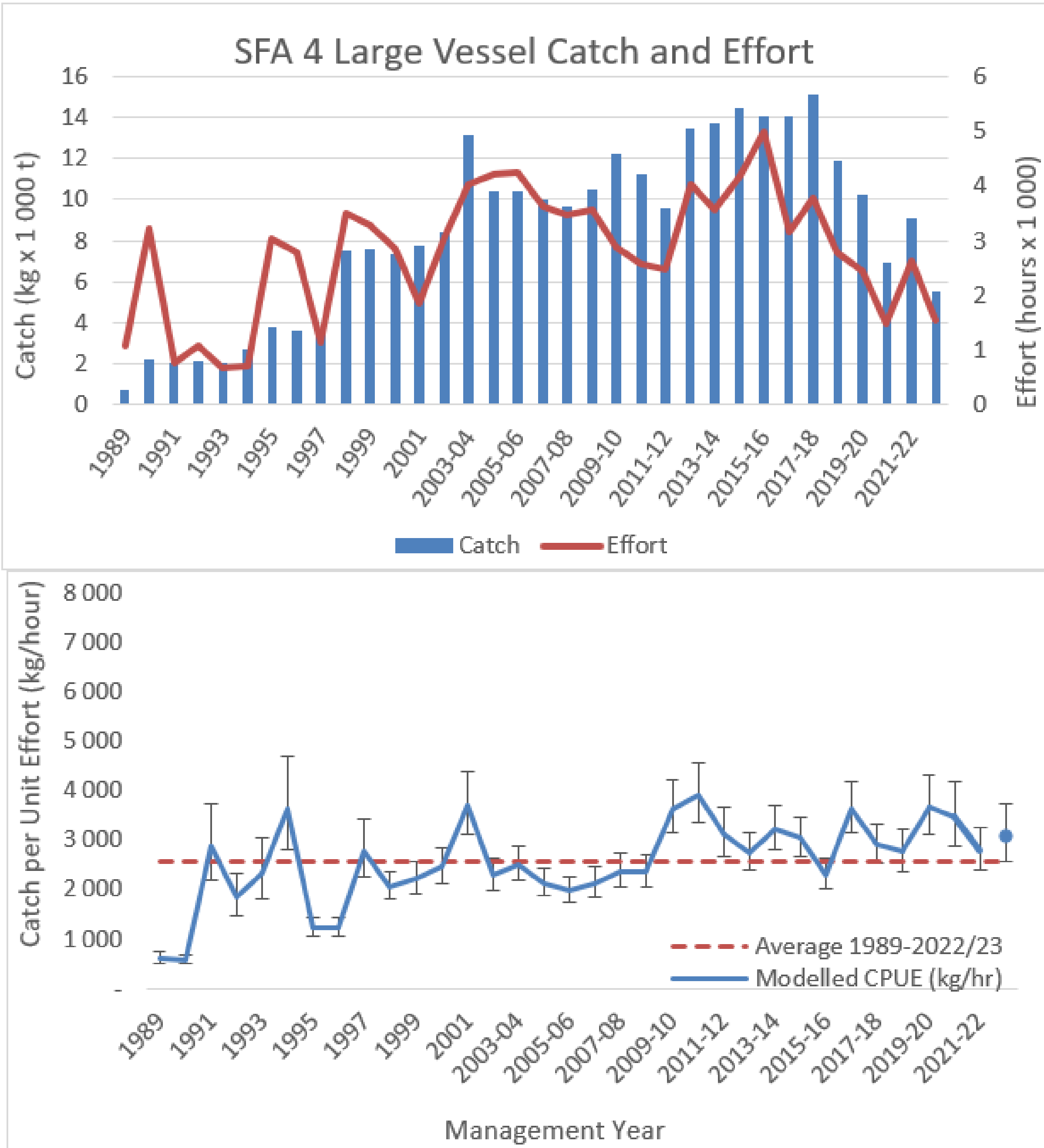

Figure 13. Catch and effort (top panel) as captured in observer records and used in the CPUE model and CPUE (bottom panel) for the LV fleet fishing for Northern Shrimp in SFA 4 from 1989–2022/23. Data for 2021/22–2022/23 are incomplete.

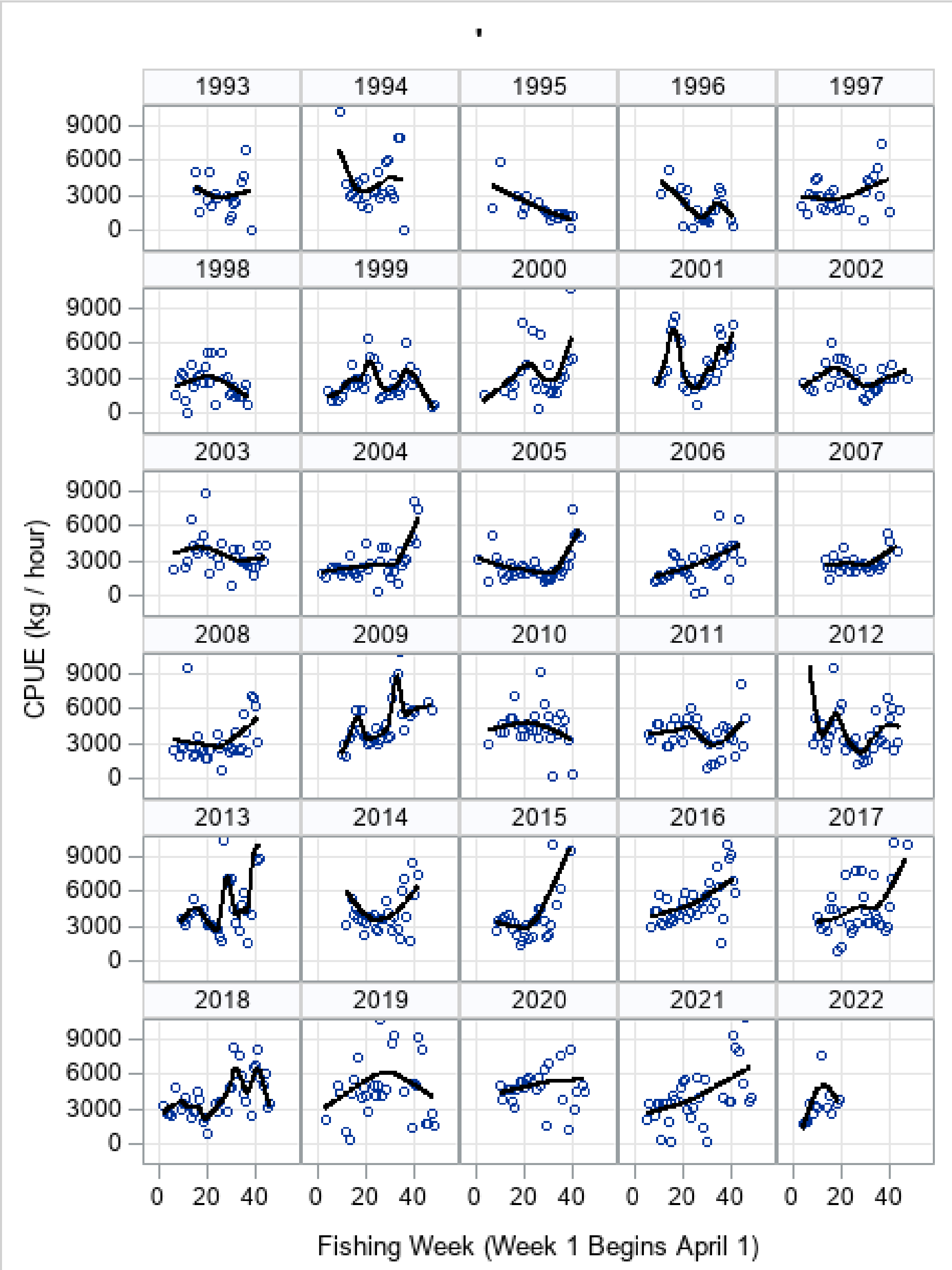

Figure 14. CPUE by year and week (of fishing season starting April 1) for the LV fleet targeting Northern Shrimp in SFA 4.

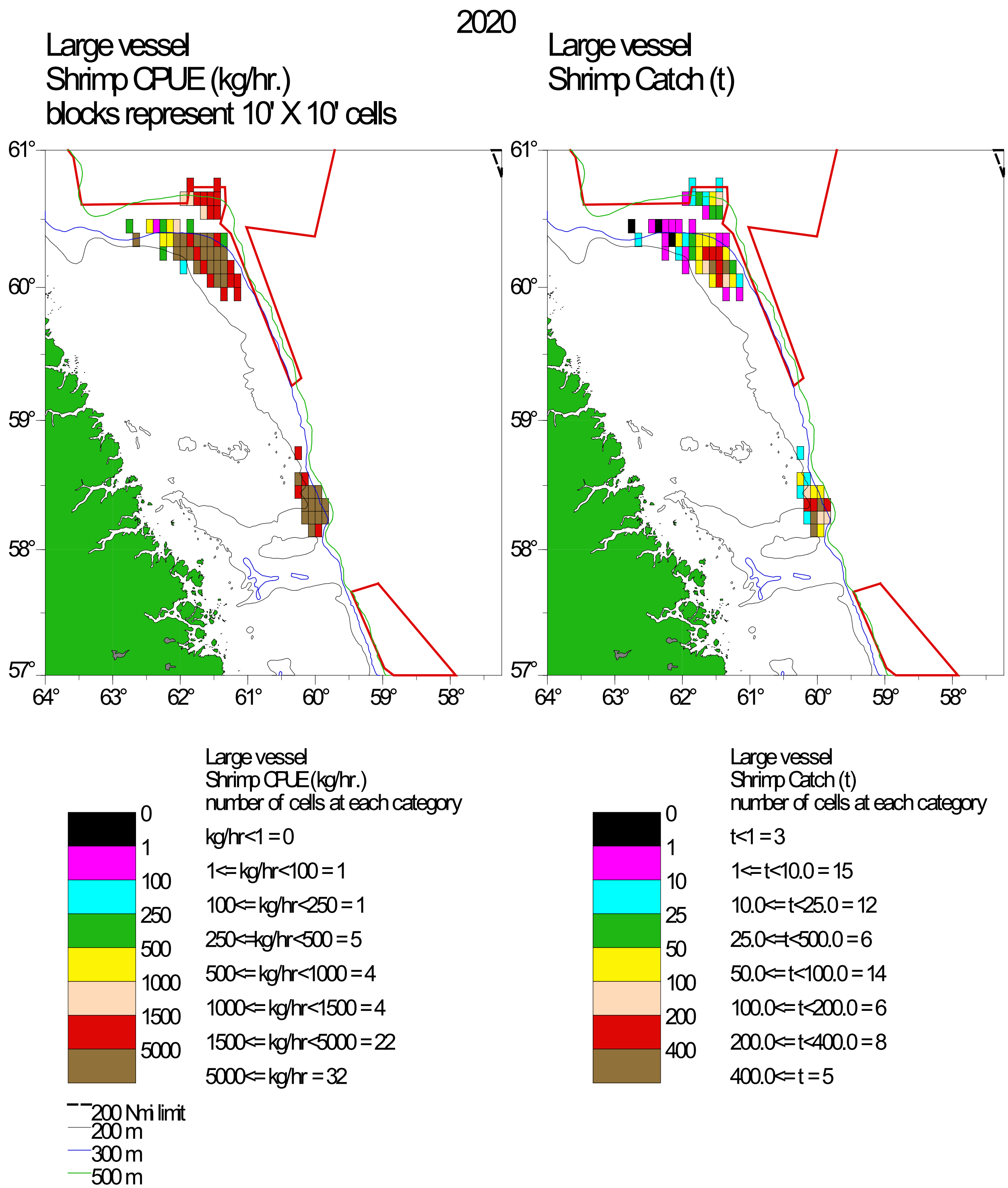

Figure 15. LV (>500 t) catch and average fishery performance within the 2020/21 SFA 4 Northern Shrimp fishery. Positions of catch and effort taken from observer data set with 90% of the LV commercial catch represented in these maps.

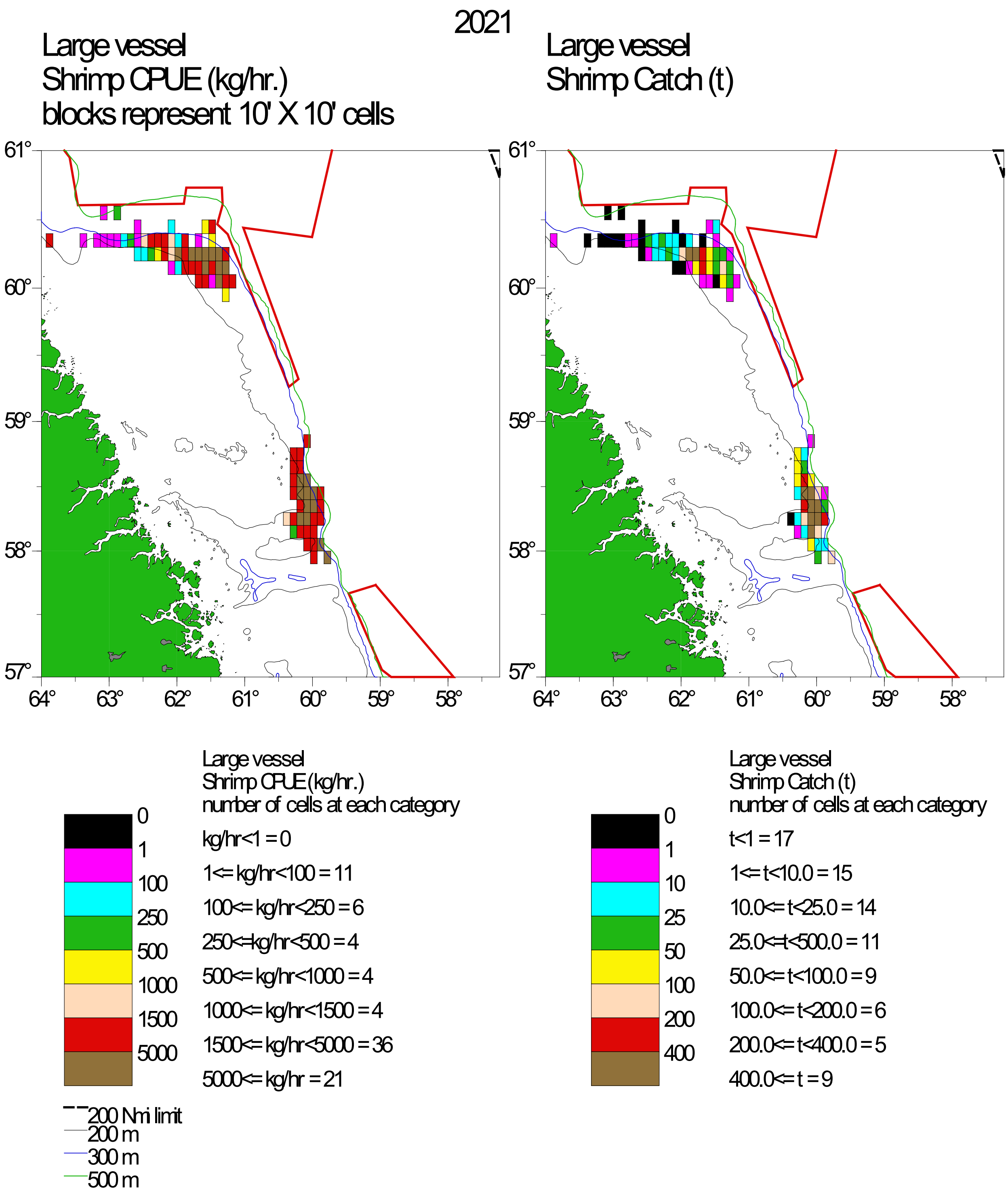

Figure 16. LV (>500 t) catch and average fishery performance within the 2021/22 SFA 4 Northern Shrimp fishery. Positions of catch and effort taken from observer data set with 113% of the LV commercial catch represented in these maps.

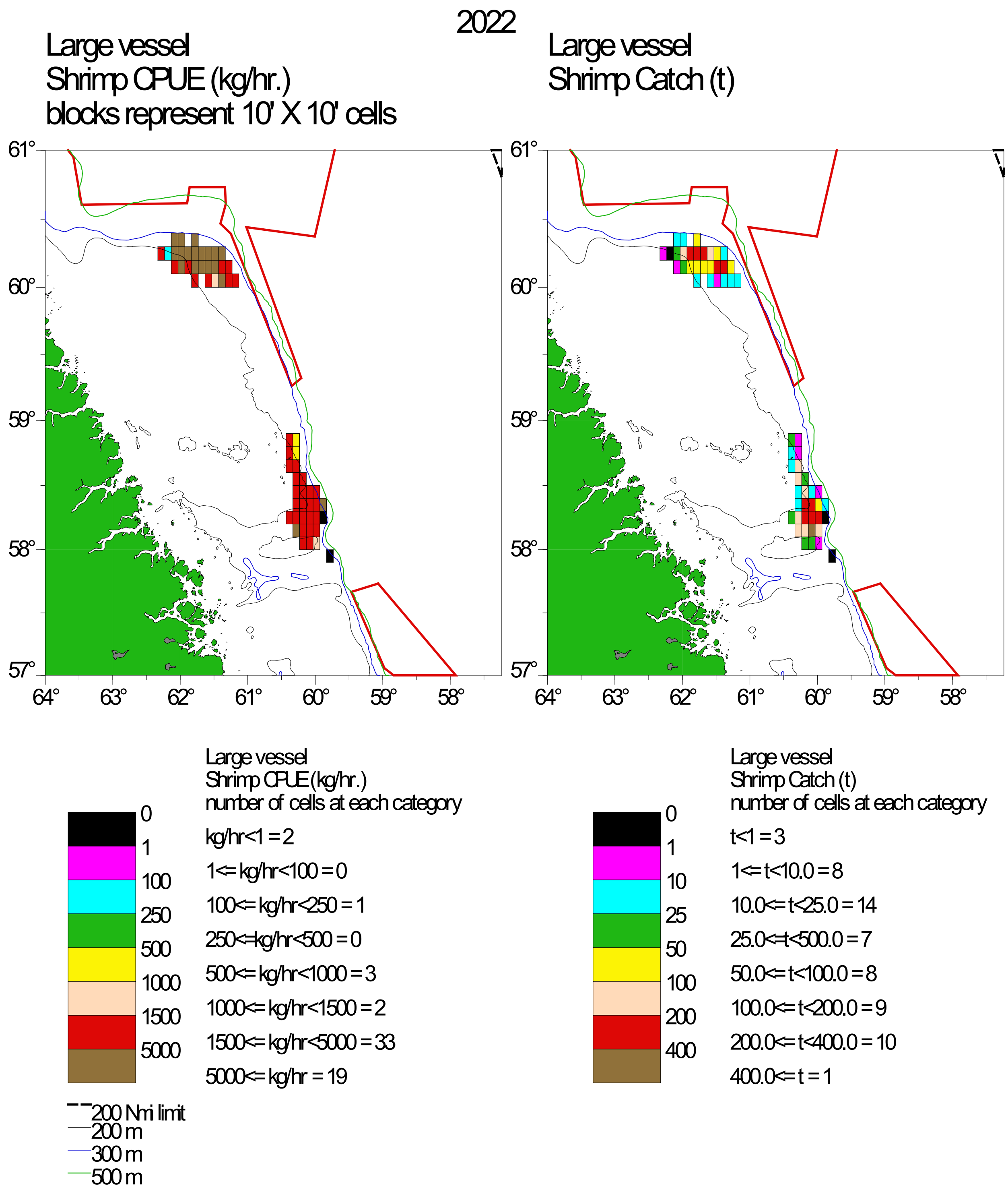

Figure 17. LV (>500 t) catch and average fishery performance within the 2022/23 SFA 4 Northern Shrimp fishery. Positions of catch and effort taken from observer data set with 48% of the LV commercial catch represented in these maps.

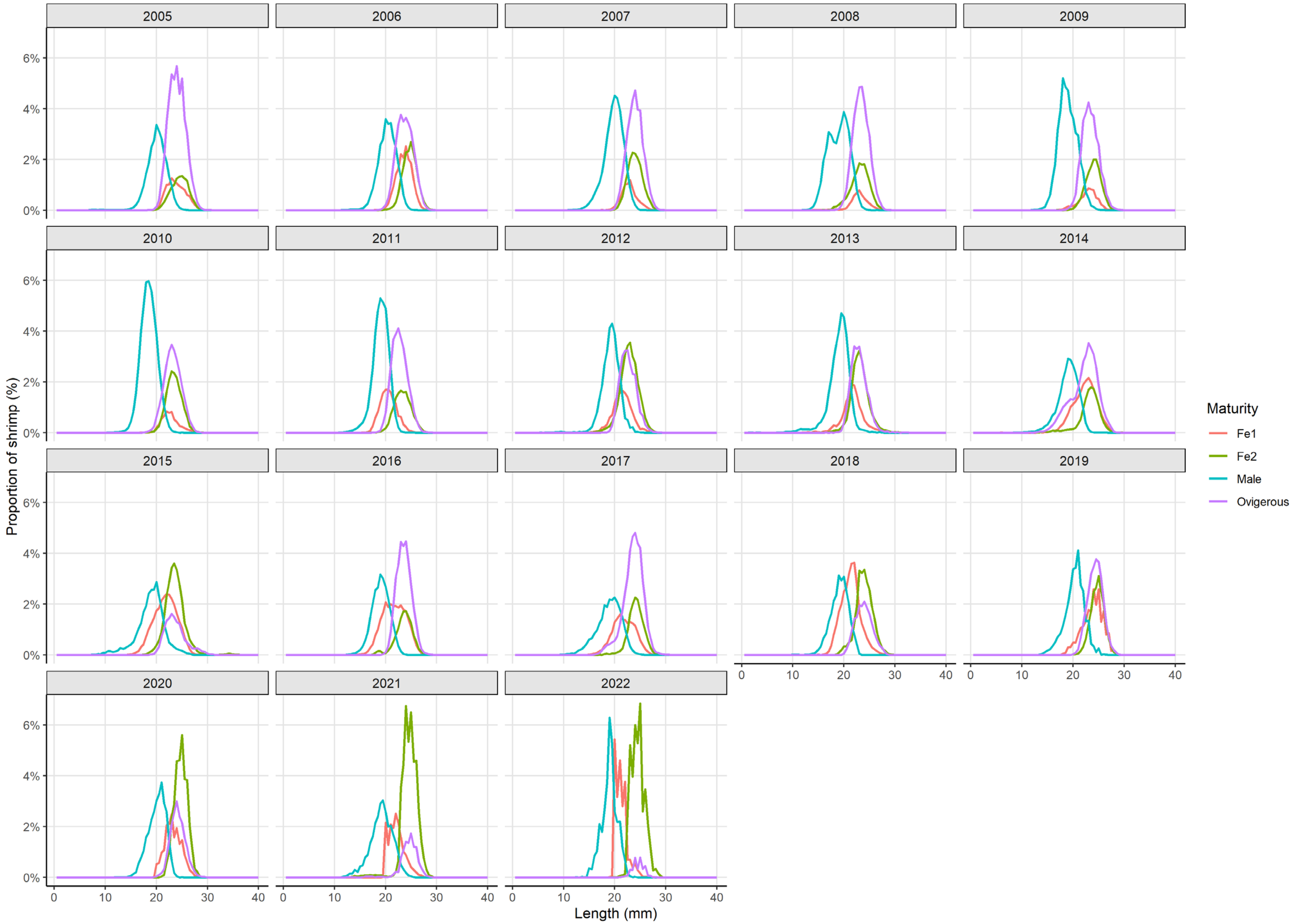

Figure 18. Observer length frequencies from LVs targeting for Northern Shrimp in SFA 4. Data for 2022–23 are preliminary.

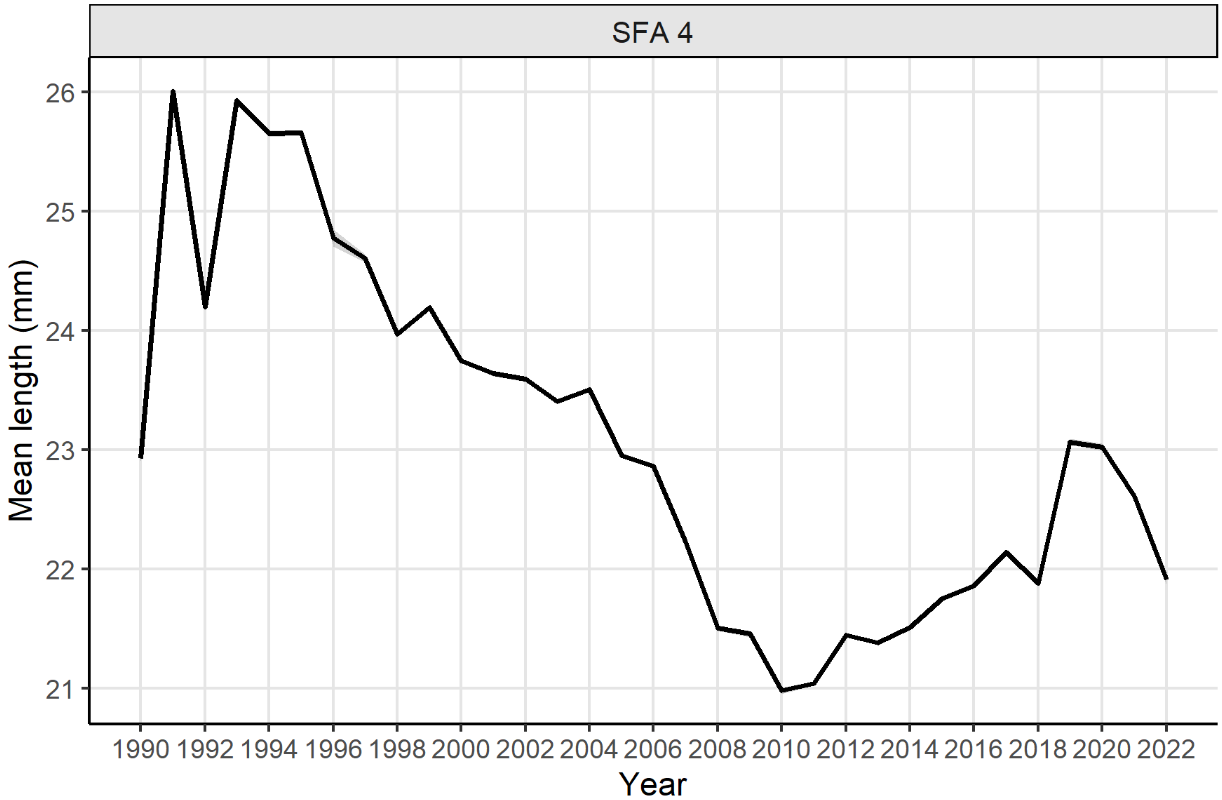

Figure 19. Mean (±95% Confidence Intervals) carapace length of northern shrimp caught by LVs in SFA 4. Data are from detailed observer sampling. Please note that confidence intervals are shown but barely visible.

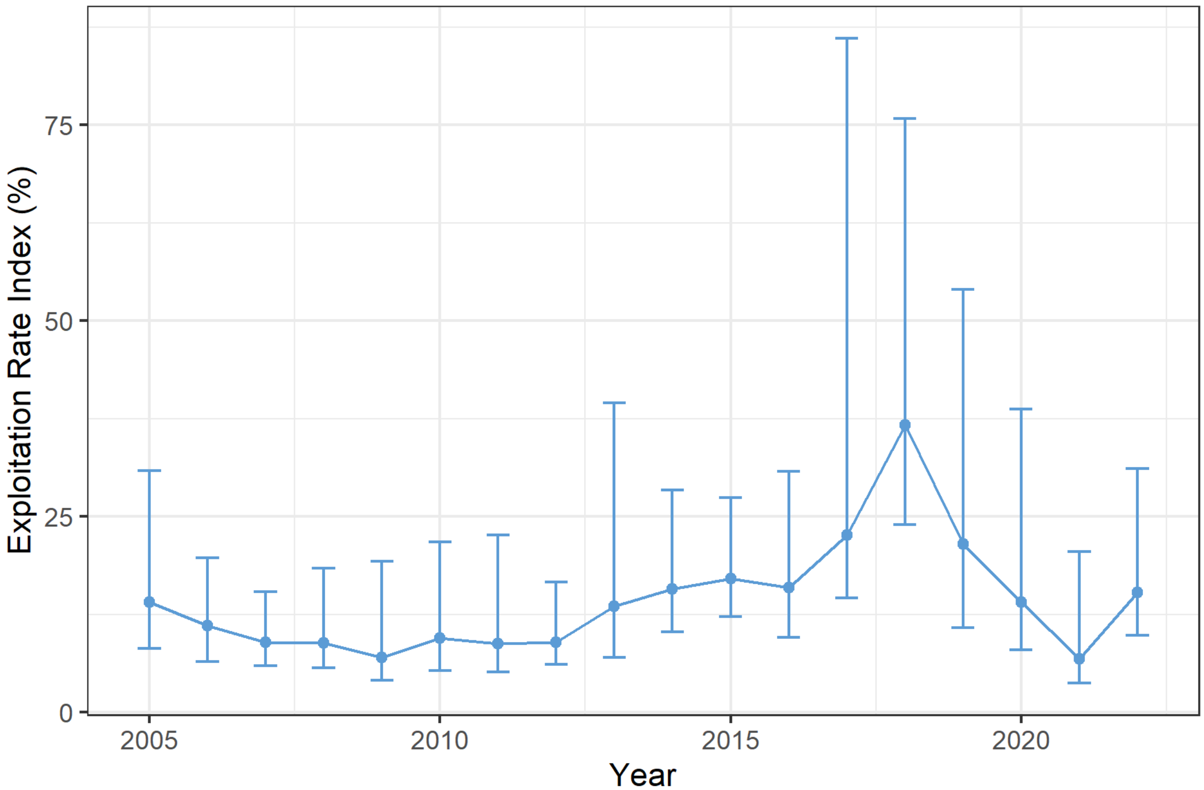

Figure 20. SFA 4 Pandalus borealis ERI based on total catch/fishable biomass from the same year, expressed as a percentage. Error bars indicate 95% confidence intervals. The 2022/23 value is based on the catch (94% of the TAC) as of the February 17, 2023, AQMS.

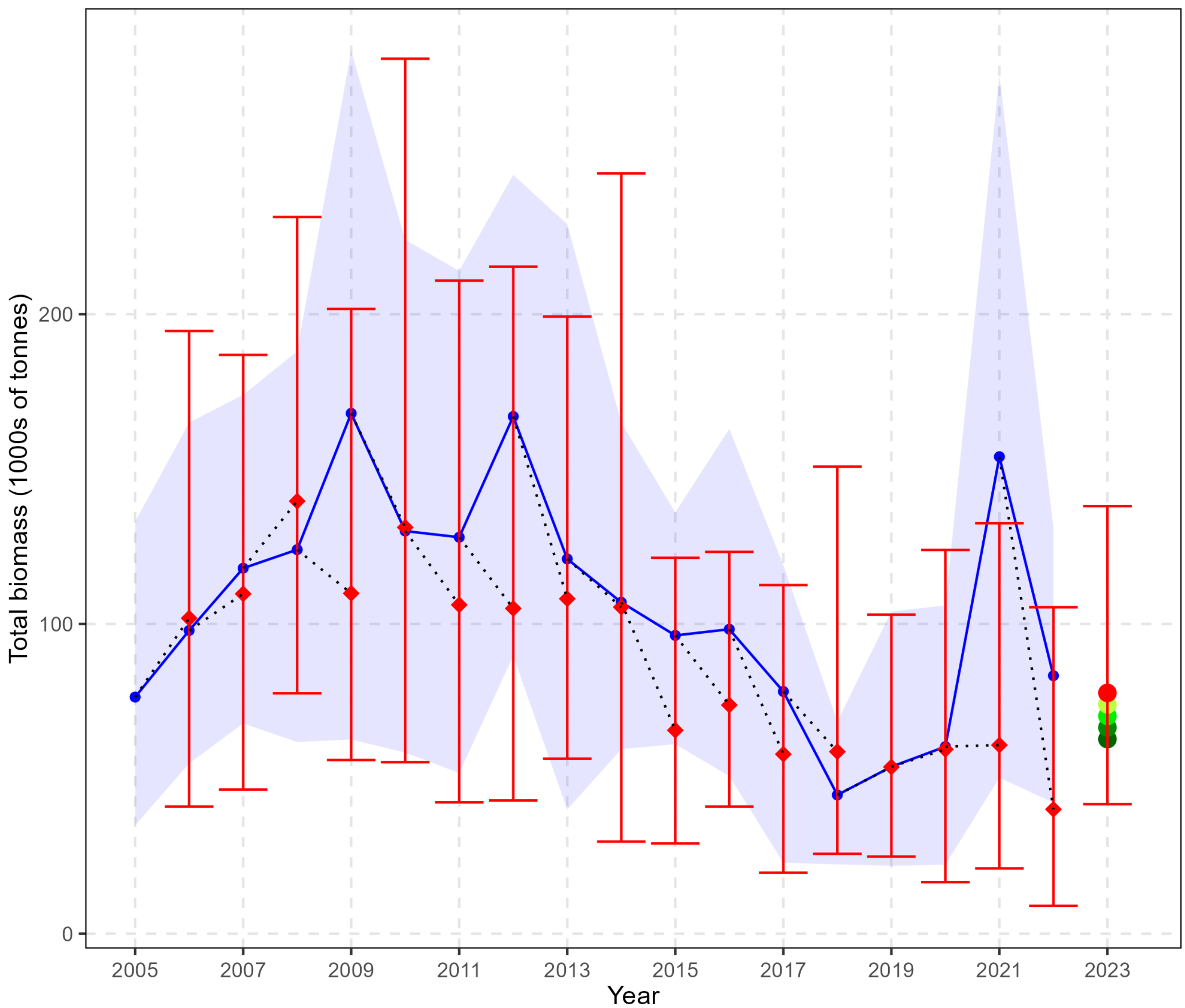

Figure 21. Model-predicted Northern Shrimp total biomass with catch removed (1,000s of tonnes) (red points) compared to observed total biomass estimated using Ogmap (blue points) in SFA 4. Dotted black lines represent that model predictions are based on the previous year's Ogmap index, not the previous year's model prediction. The final year's model prediction is presented assuming zero catch (red point), and 5%, 10%, 15%, and 20% exploitation rate indices of fishable biomass.

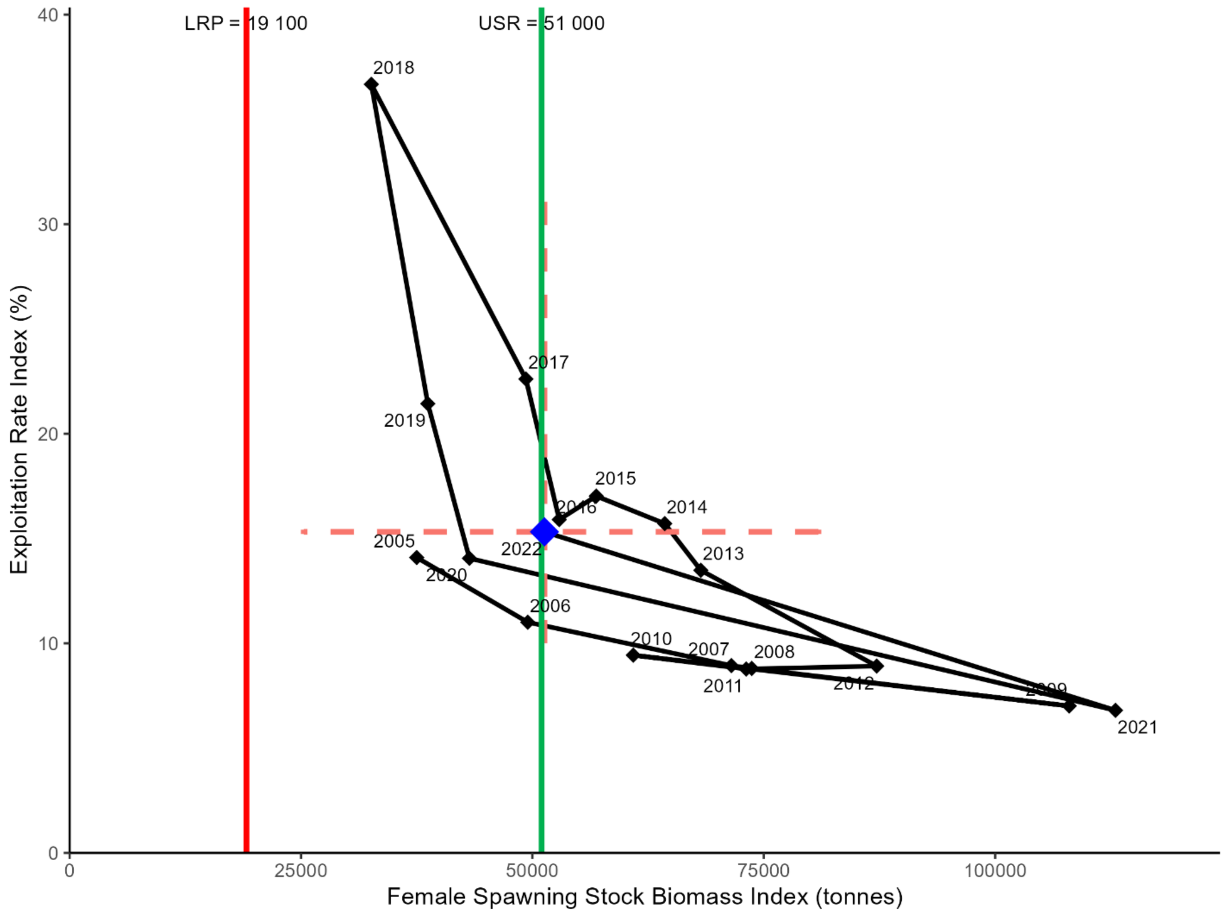

Figure 22. SFA 4 Northern Shrimp IFMP PA Framework with ERI versus female SSB index. Data point labels denote management year. The 2022/23 fishery was ongoing; therefore the 2022/23 point is preliminary (in blue); the February 17, 2023, AQMS indicated that the TAC had been 94% taken. The red cross indicates 95% confidence intervals for the summer 2022 female SSB index (horizontal line) and the 2022/23 ERI (vertical line).

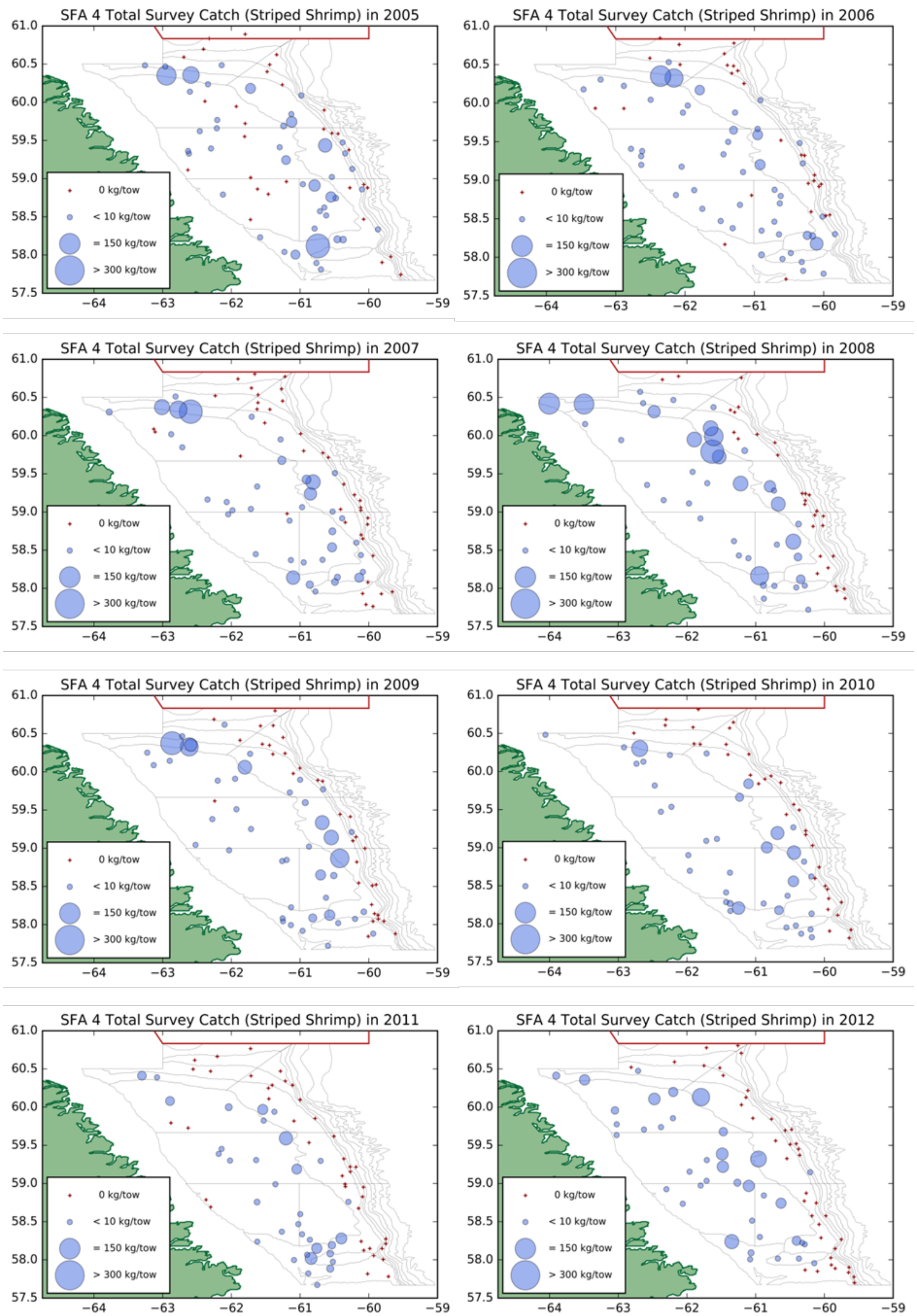

Figure 23. SFA 4 Pandalus montagui NSRF shrimp survey data catches for 2005–12. Closed areas are indicated by red outlines.

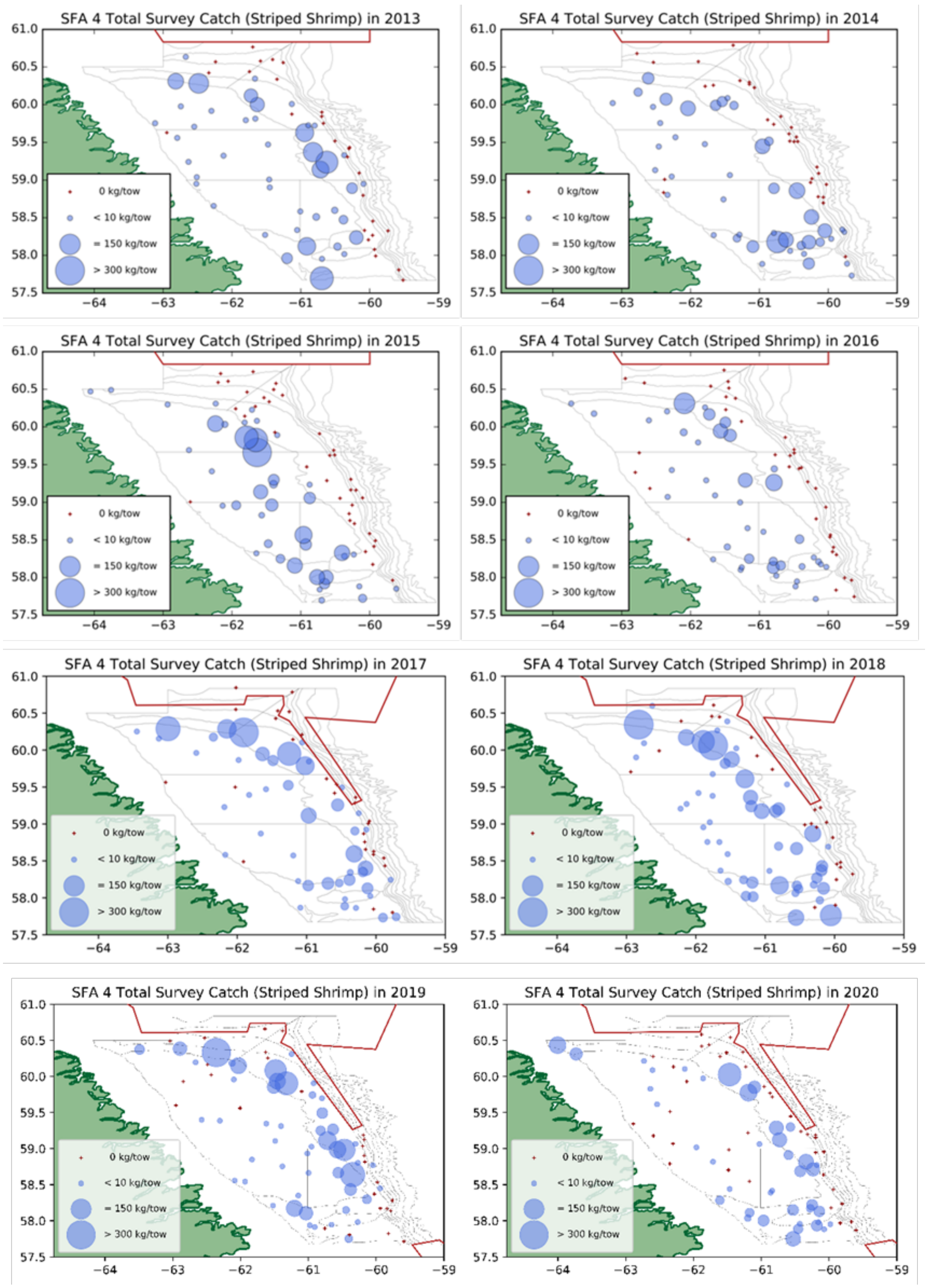

Figure 24. SFA 4 Pandalus montagui NSRF shrimp survey data catches for 2013–20. Closed areas are indicated by red outlines including the new Hatton Basin closed area in 2018.

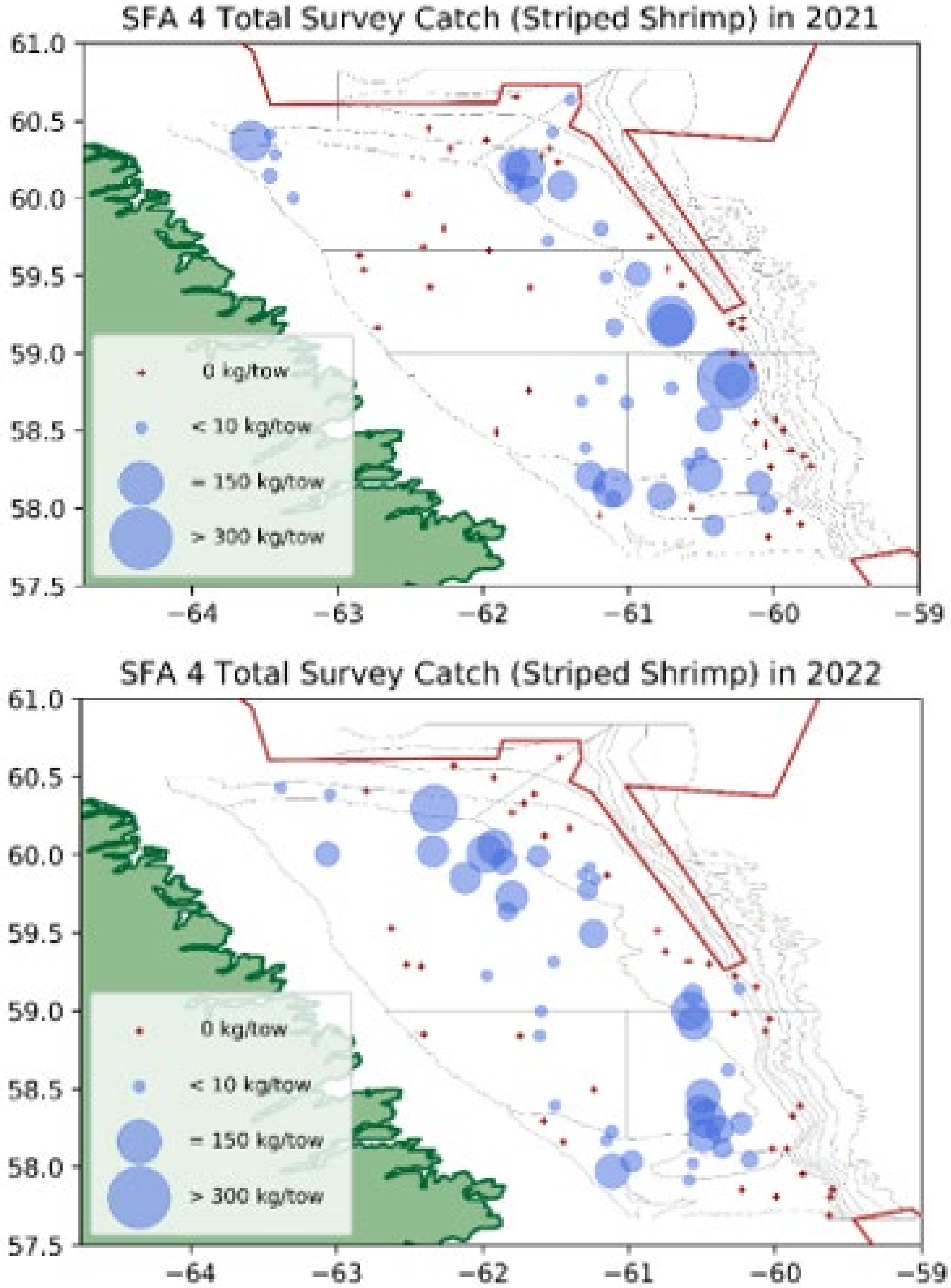

Figure 25. SFA 4 Pandalus montagui NSRF shrimp survey data catches for 2021-22. Closed areas are indicated by red outlines including the new Hatton Basin closed area in 2018.

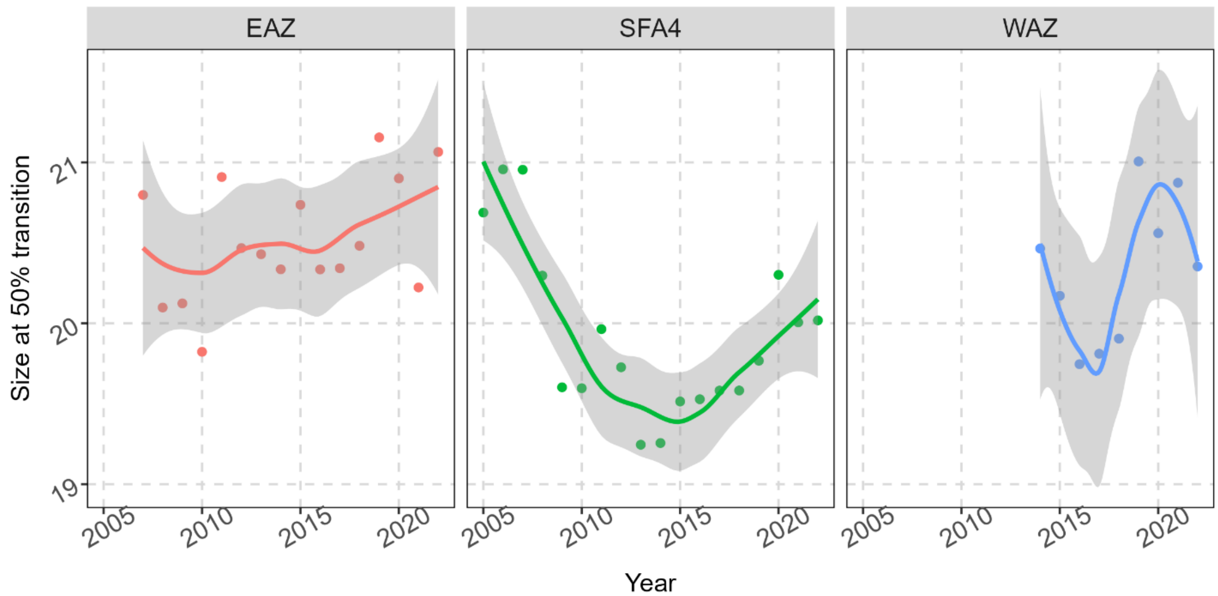

Figure 26. Annual estimated size at 50% transition of Striped Shrimp in EAZ, SFA 4, and WAZ.

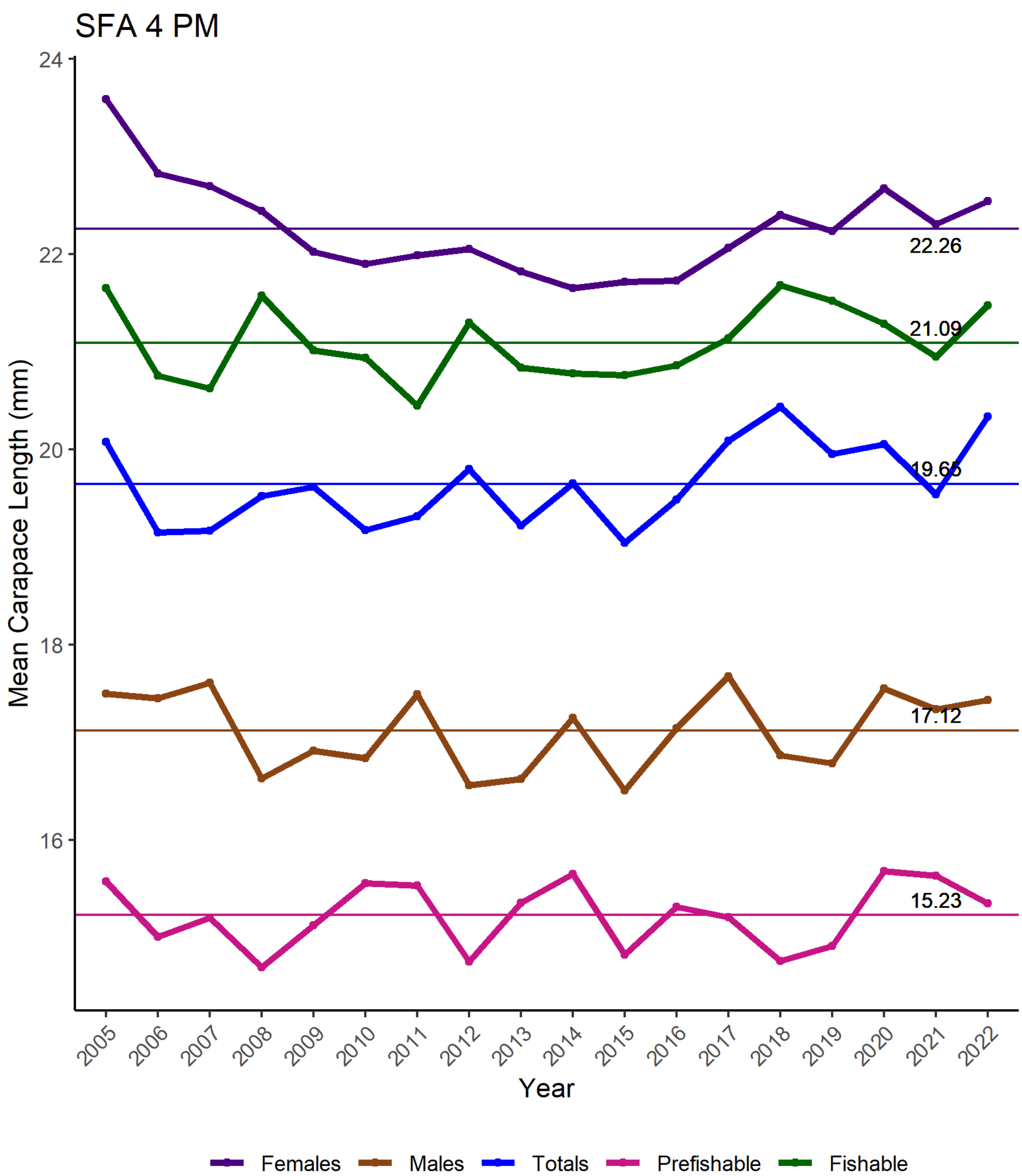

Figure 27. SFA 4 mean size of Striped Shrimp of various maturities including totals, females, males, pre fishable (or pre-recruit: CL <17.5 mm) and fishable (CL ≥17.5 mm). Long-term average size for each maturity is indicated by the straight line and number at the right of each series.

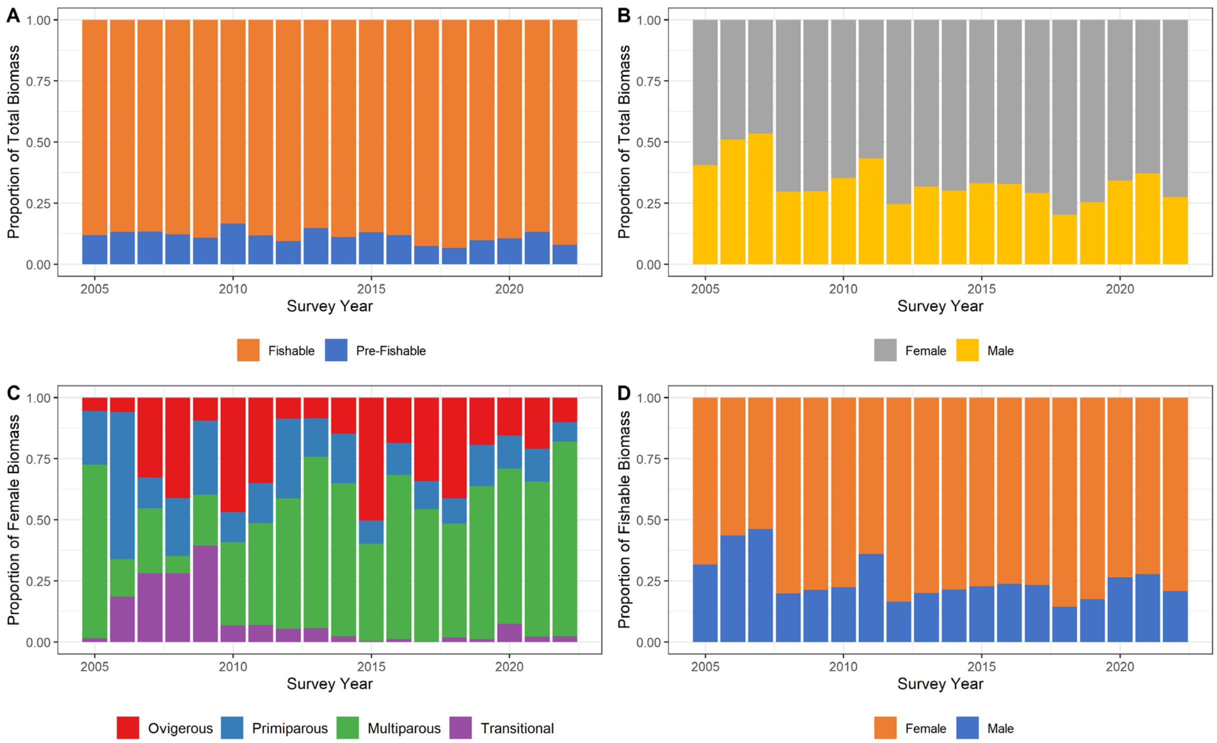

Figure 28. Proportions of biomass of various Striped Shrimp maturities in SFA 4 as sampled during the DFO Multi-species survey. Top left: Proportion of fishable size (≥17.5 mm carapace length) compared to pre-fishable (or pre-recruit) size of the total biomass index. Top right: Proportion of female versus male of the total biomass index. Bottom left: Proportion of ovigerous, primiparous, multiparous and transitional shrimp in the female biomass index. Bottom right: Proportion of female versus male shrimp in the fishable biomass index.

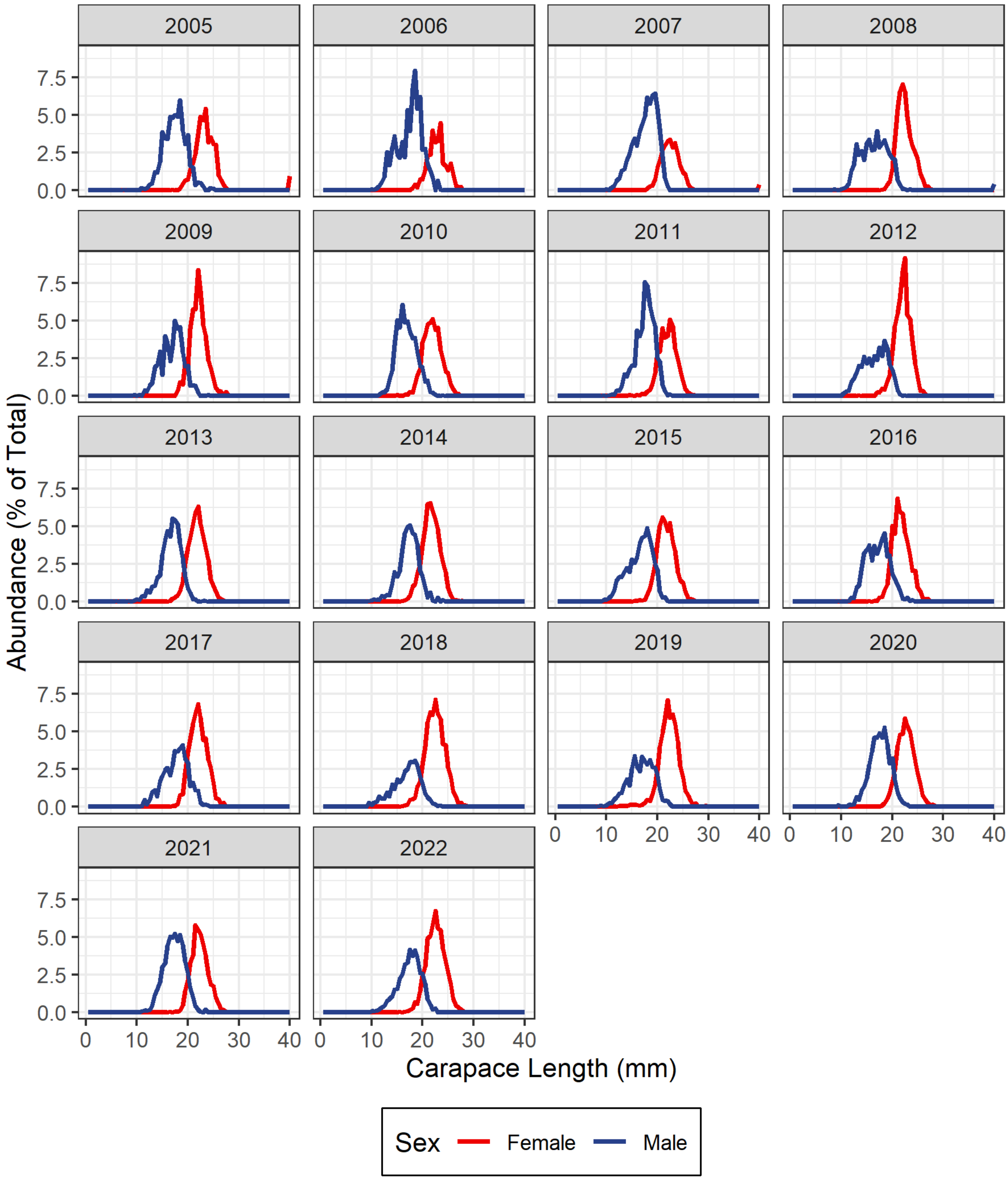

Figure 29. SFA 4 Striped Shrimp abundance at length (expressed as a percentage of total abundance), as determined using Ogmap on NSRF summer shrimp data for 2005–22.

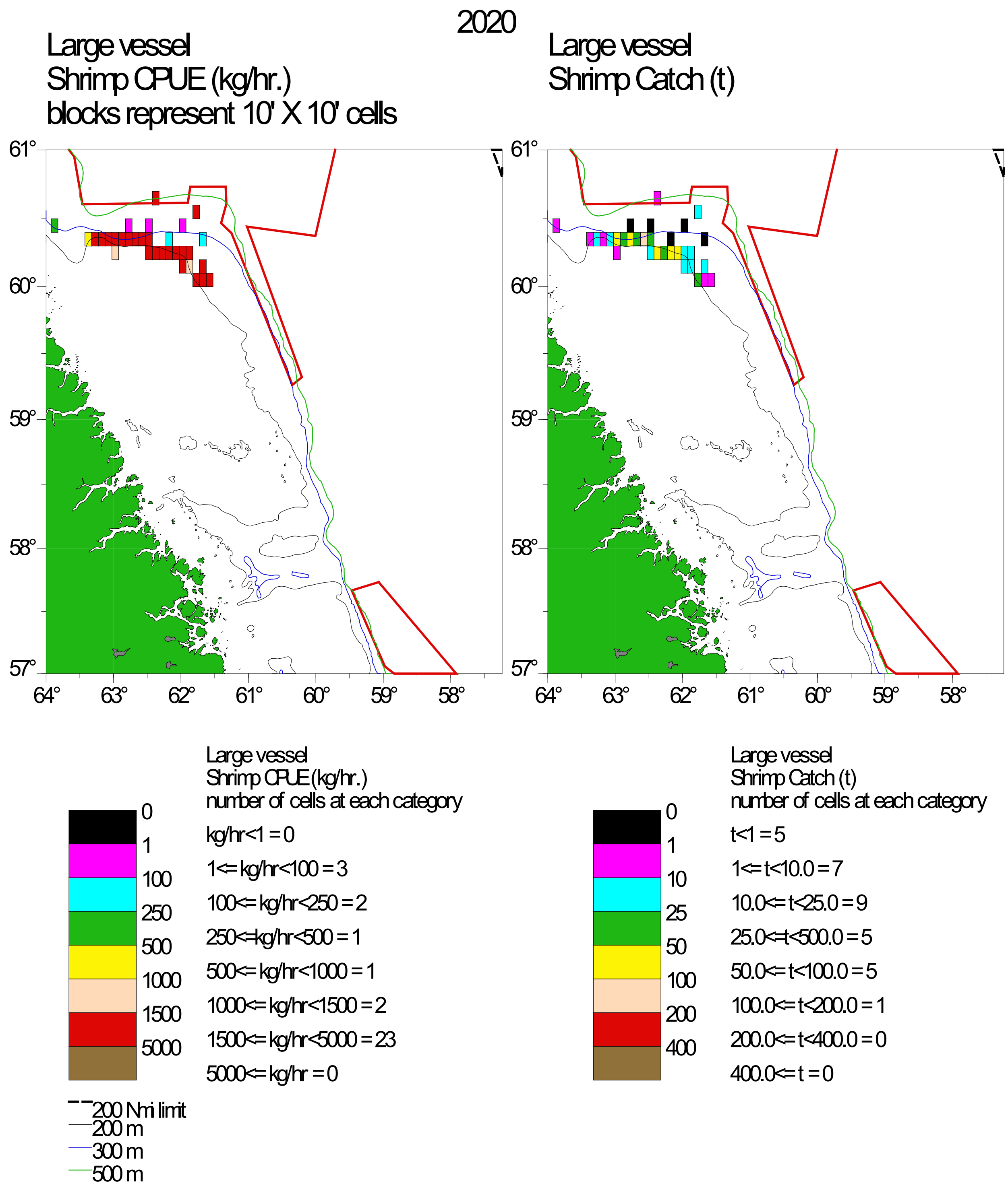

Figure 30. LV (>500 t) catch and average fishery performance within the 2020/21 SFA 4 Striped Shrimp fishery. Positions of catch and effort taken from observer data set with 32% of the commercial catch represented in these maps.

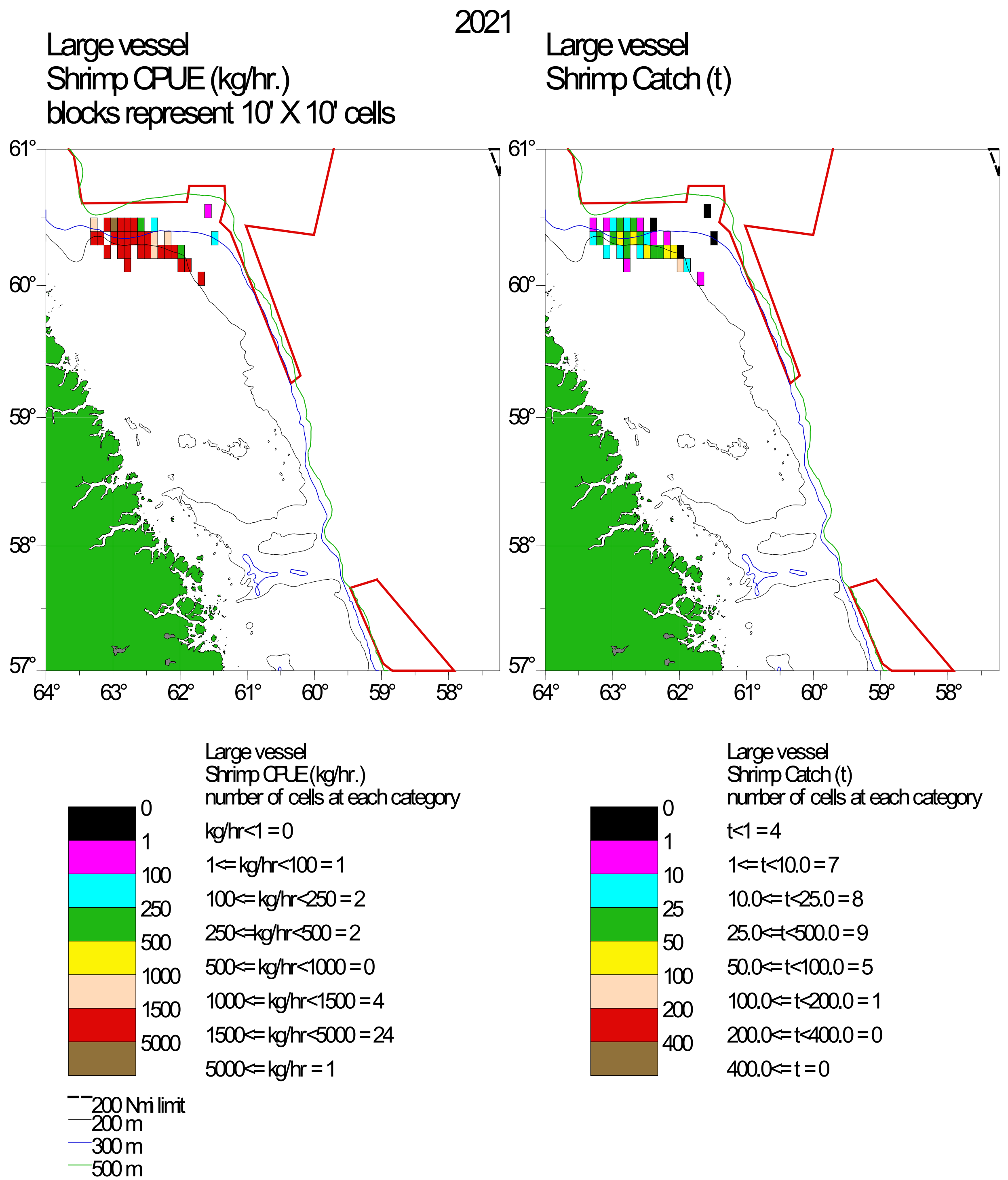

Figure 31. LV (>500 t) catch and average fishery performance within the 2021/22 SFA 4 Striped Shrimp fishery. Positions of catch and effort taken from observer data set with 29% of the commercial catch represented in these maps.

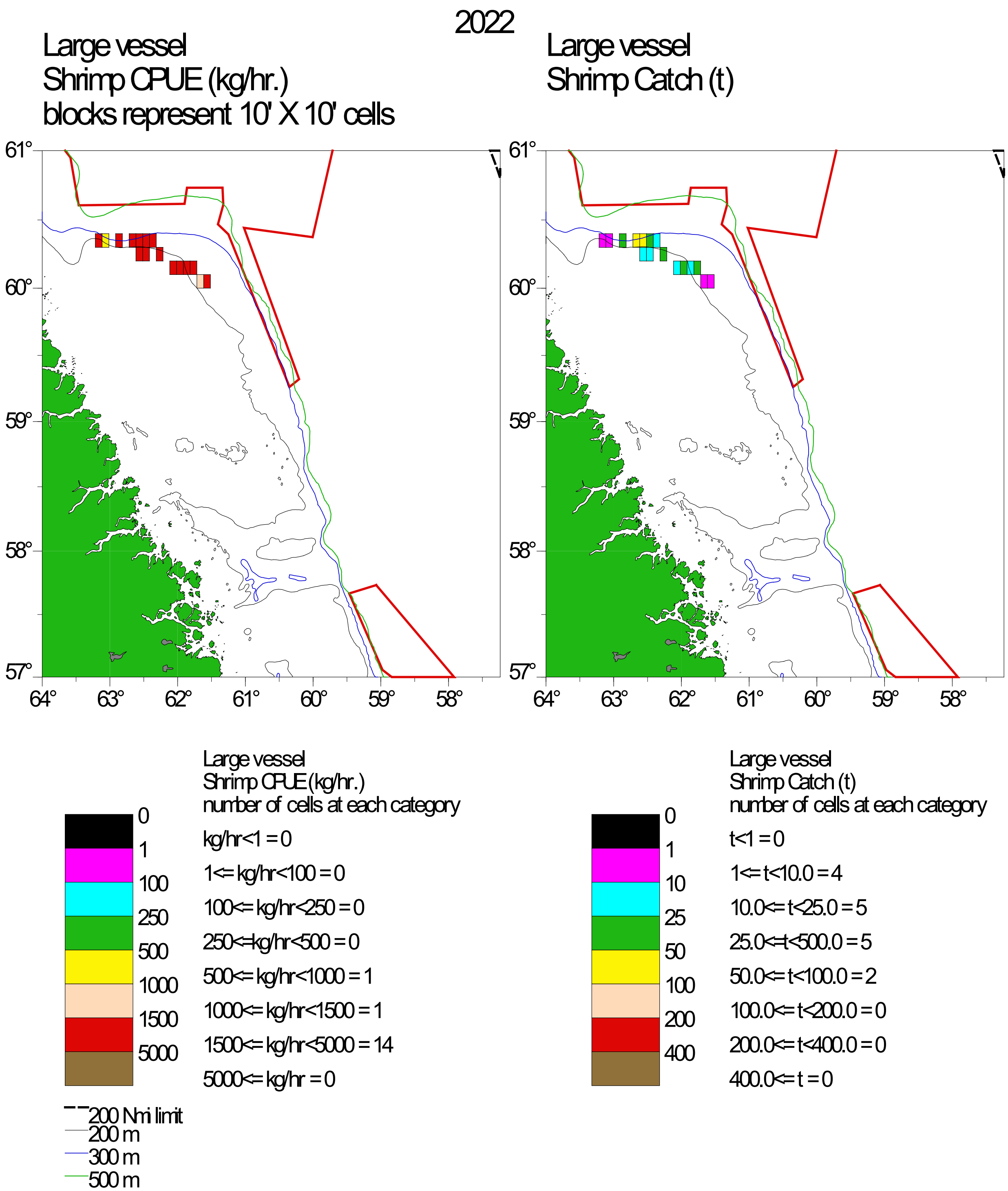

Figure 32. LV (>500 t) catch and average fishery performance within the 2022/23 SFA 4 Striped Shrimp fishery. Positions of catch and effort taken from observer data set with 12% of the commercial catch to date represented in these maps.

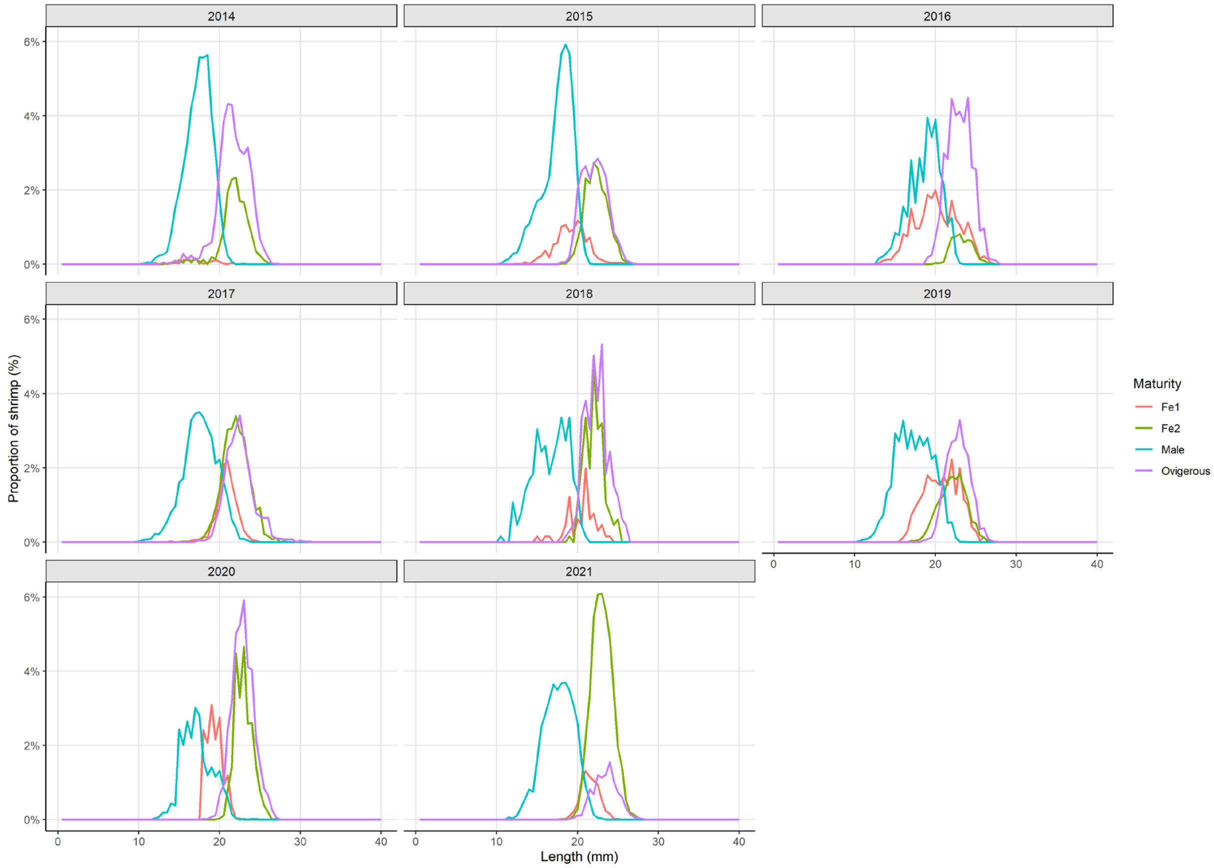

Figure 33. Observer length frequencies from LVs targeting for Striped Shrimp in SFA 4 from 2014/15 to 2021/22, where the year label corresponds to the year at the start of the fishery management year. Data for 2021/22 are preliminary and there was no data available for 2022/23.

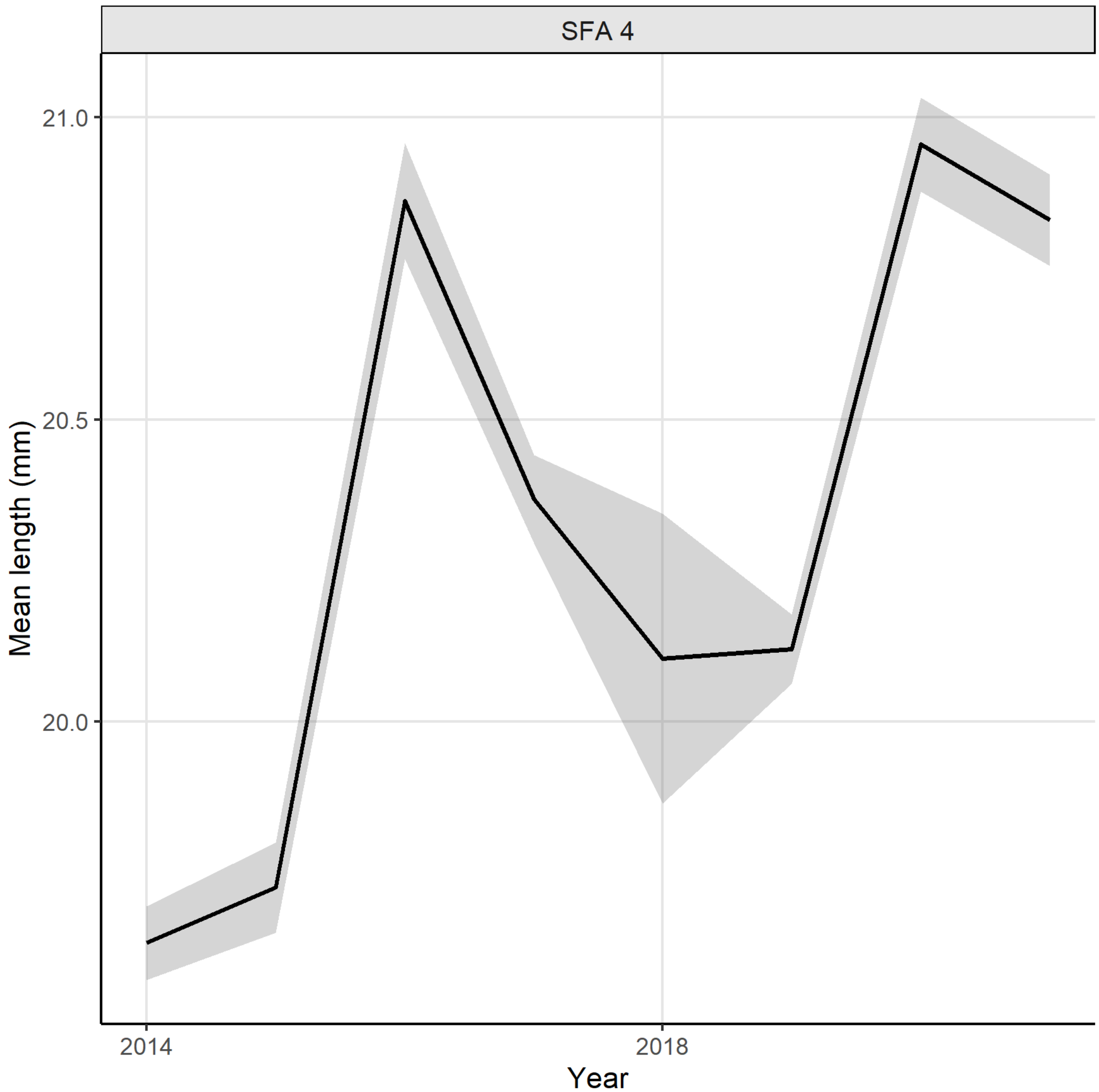

Figure 34. Mean carapace length of Striped Shrimp caught by LVs in SFA 4. Data are from detailed observer sampling.

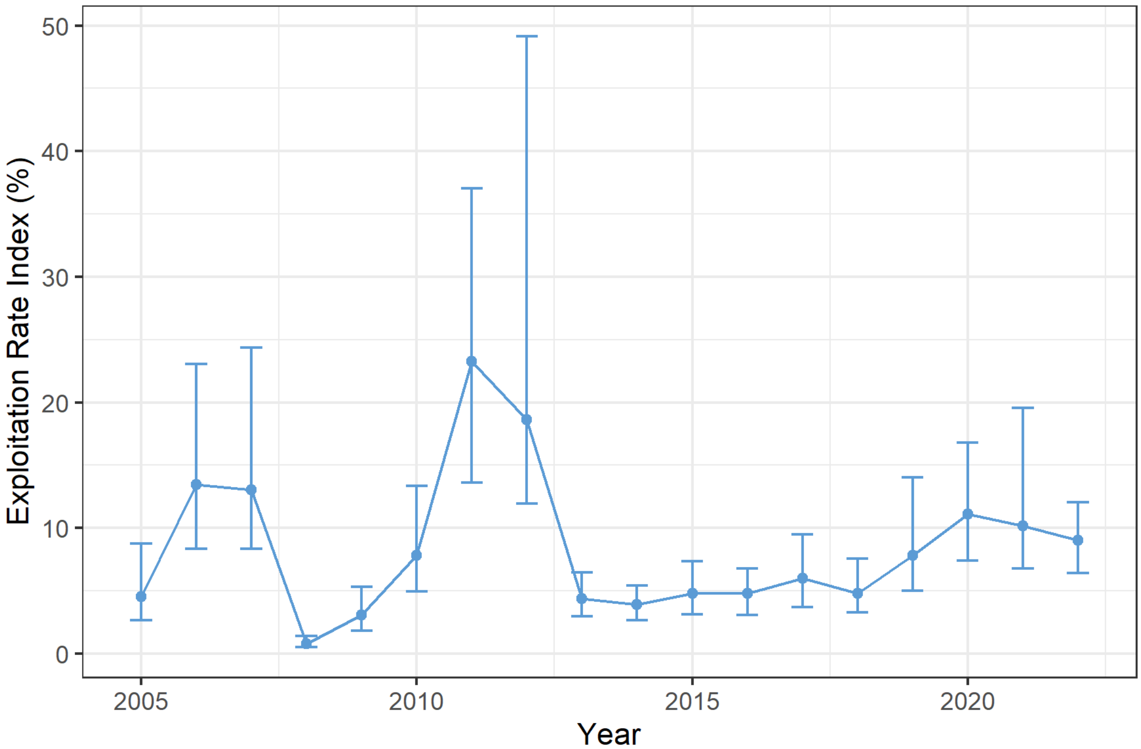

Figure 35. SFA 4 Striped Shrimp ERI based on total catch/fishable biomass from the same year, expressed as a percentage. Error bars indicate 95% confidence intervals. The 2022/23 value is based on the catch (87% of by-catch quota) as of the February 17, 2023, AQMS.

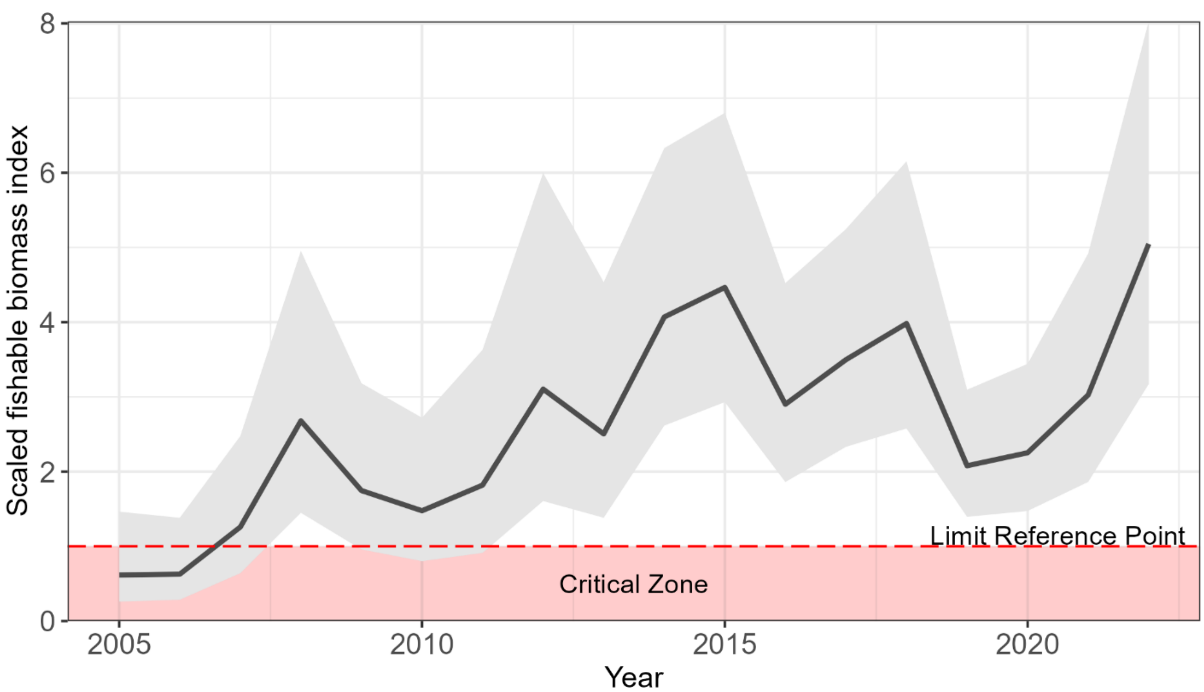

Figure 36. SFA 4 Striped Shrimp PA Framework: modelled striped shrimp fishable biomass index in the WAZ, EAZ, and SFA 4 combined (solid line) based on NSRF surveys, 2005 to 2022 with 95% confidence limits (values scaled to LRP).

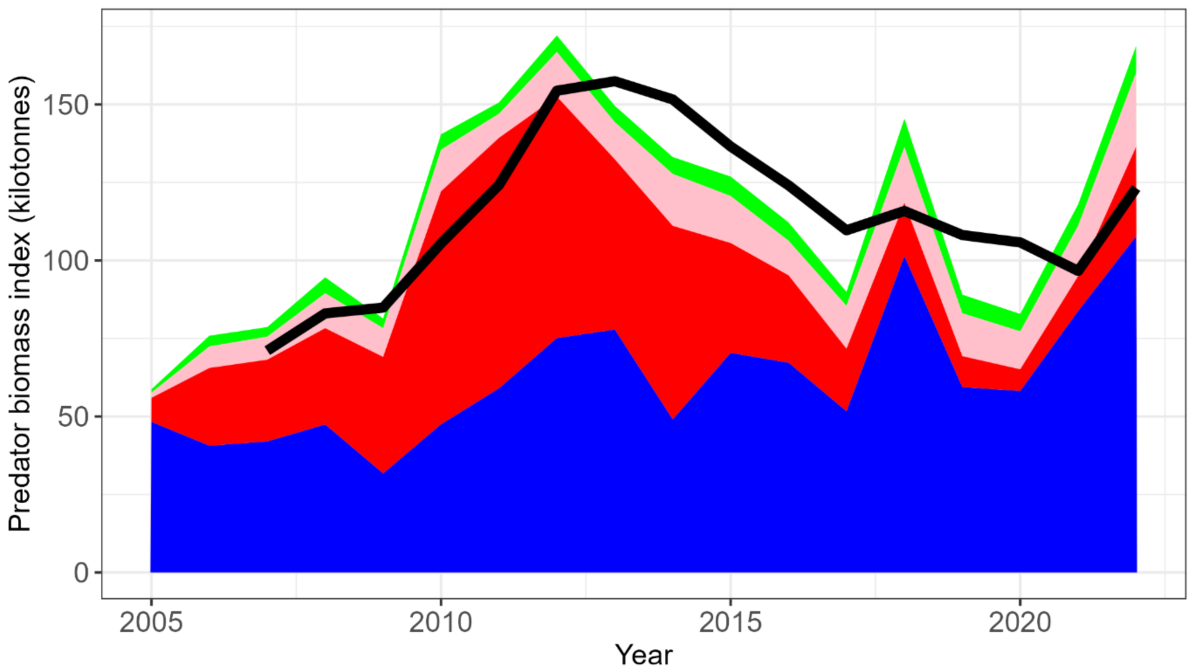

Figure 37. Modelled annual biomass indices (stacked shaded areas) and 3-year moving average (black solid line) of potential predator indices (kilotonnes) in the WAZ, EAZ, and SFA 4 combined. Blue area – annual Greenland Halibut biomass index, red area – annual large redfish biomass index, pink – annual skate biomass index, green – annual grenadier biomass index.

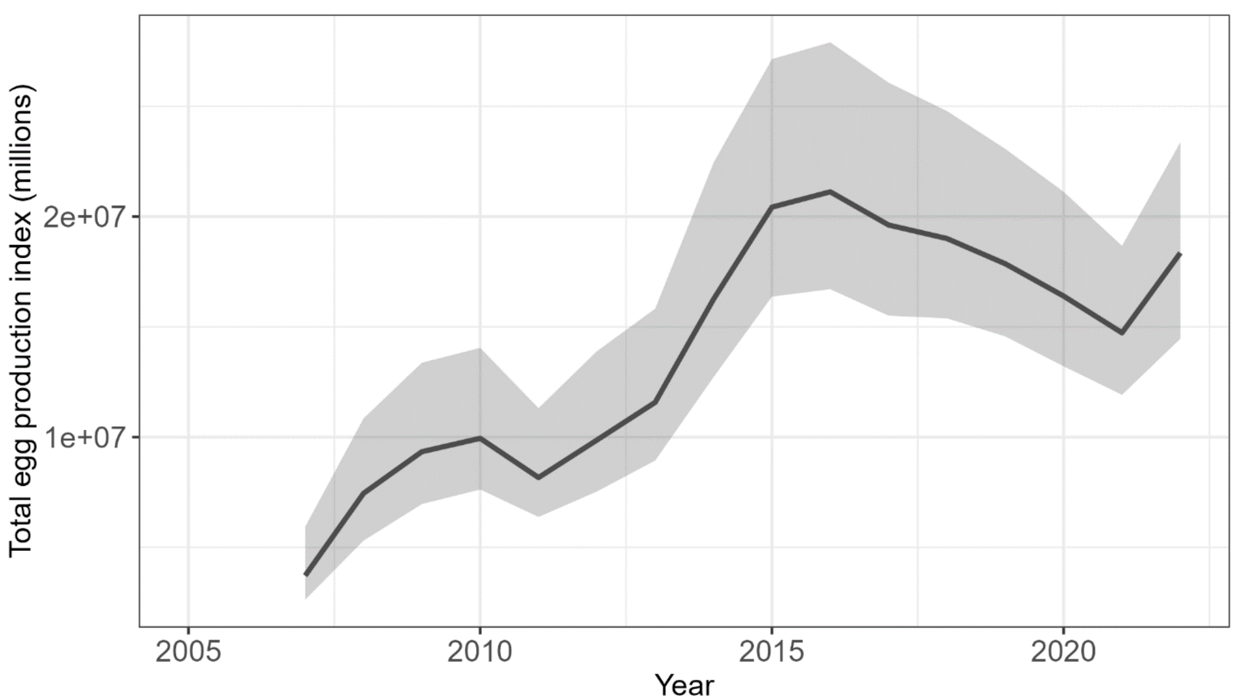

Figure 38. Three-year moving average of modelled total egg production index (millions) of Striped Shrimp in the WAZ, EAZ, and SFA 4 combined, based on NSRF surveys, 2005 to 2022.

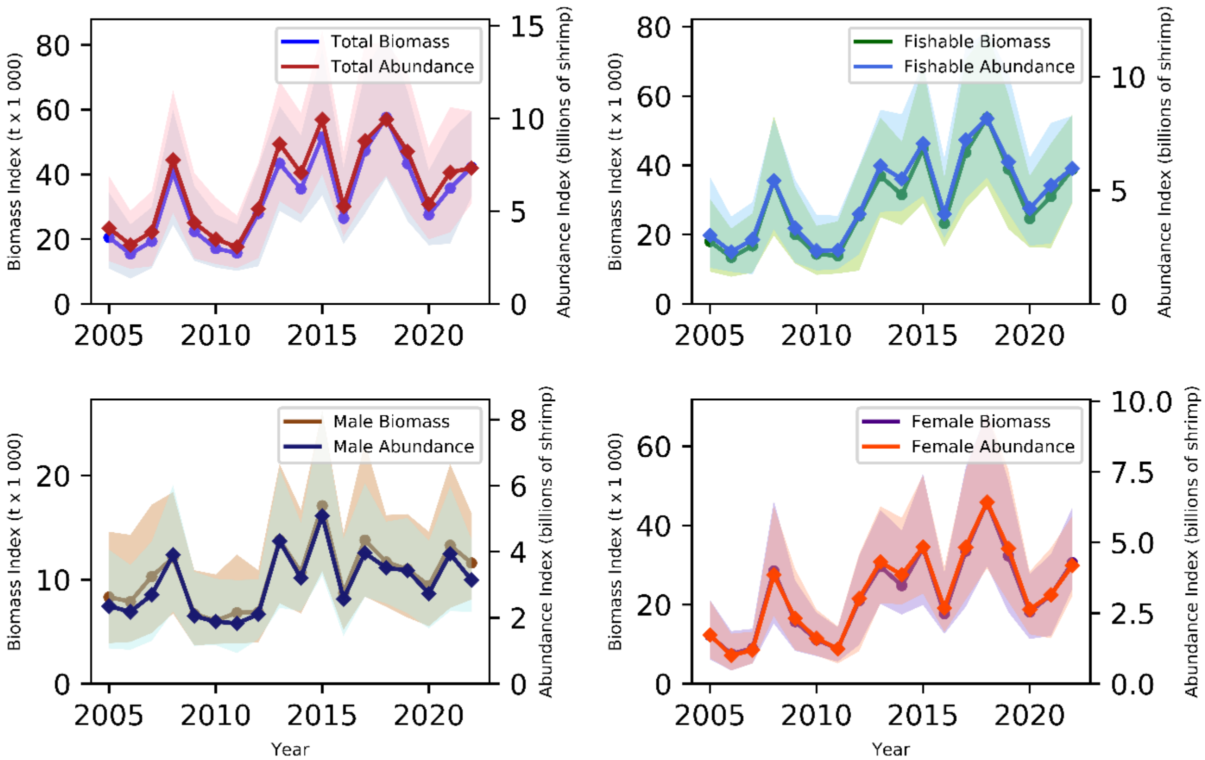

Figure 39. SFA 4 Striped Shrimp biomass and abundance indices as determined by Ogmap on NSRF summer shrimp survey data. Confidence bars indicate 95% confidence intervals.

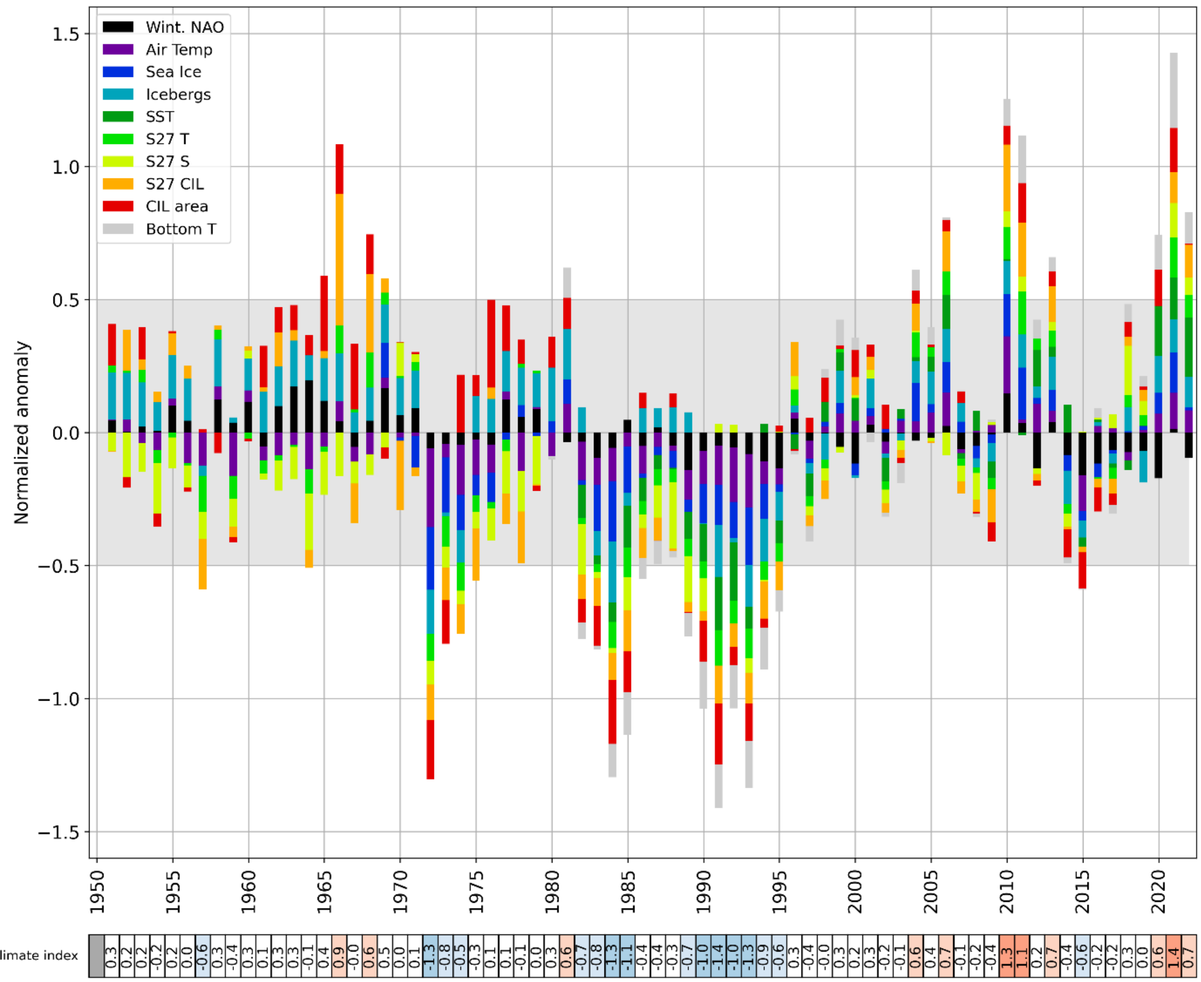

Figure 40. Newfoundland and Labrador Climate Index (Cyr and Galbraith 2021).This normalized index is made of the average of 10 sub-indices representing different aspects of the ocean climate (see legend). It aims to represent the general climate of the NL shelf and the Northwest Atlantic as a whole. A positive index is generally indicative of a warmer climate, while a negative index is indicative of a colder climate. Values within the grayed area (±0.5 SD) are considered normal. See Cyr and Galbraith (2021) for reference to the data and methodology.

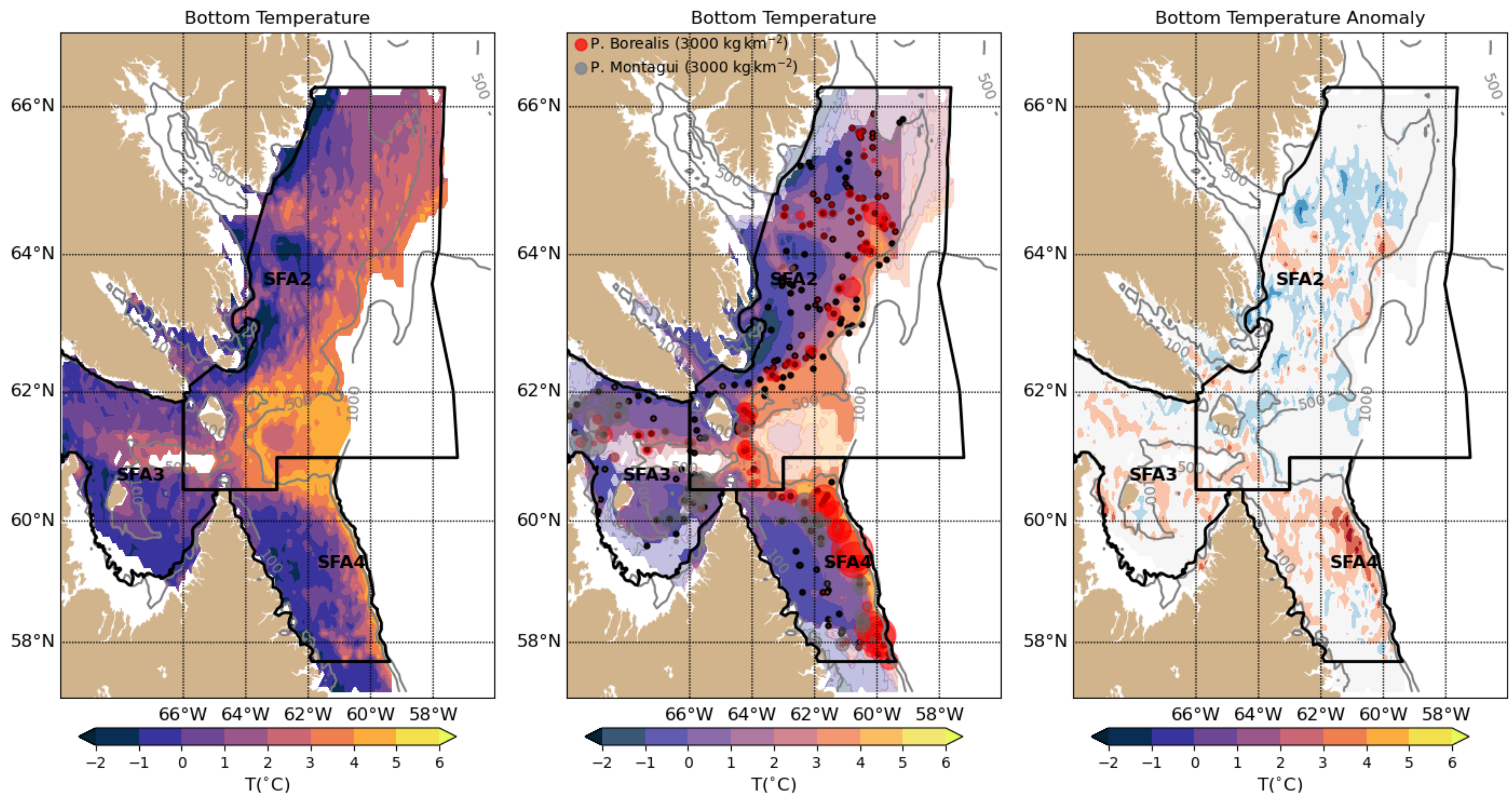

Figure 41. Maps of the climatological (2006–21) mean summer bottom temperature (left), and summer 2022 bottom temperature (center) and anomalies (right) for SFA 2–4. The location of observations used to derive the temperature field is shown as black dots in the center panel. In areas where the spatial interpolation cannot be done (pale areas in the central panel), missing data are filled with the climatology. The biomass of P. borealis and P. montagui collected in the research survey is also shown with red and gray circles, respectively.

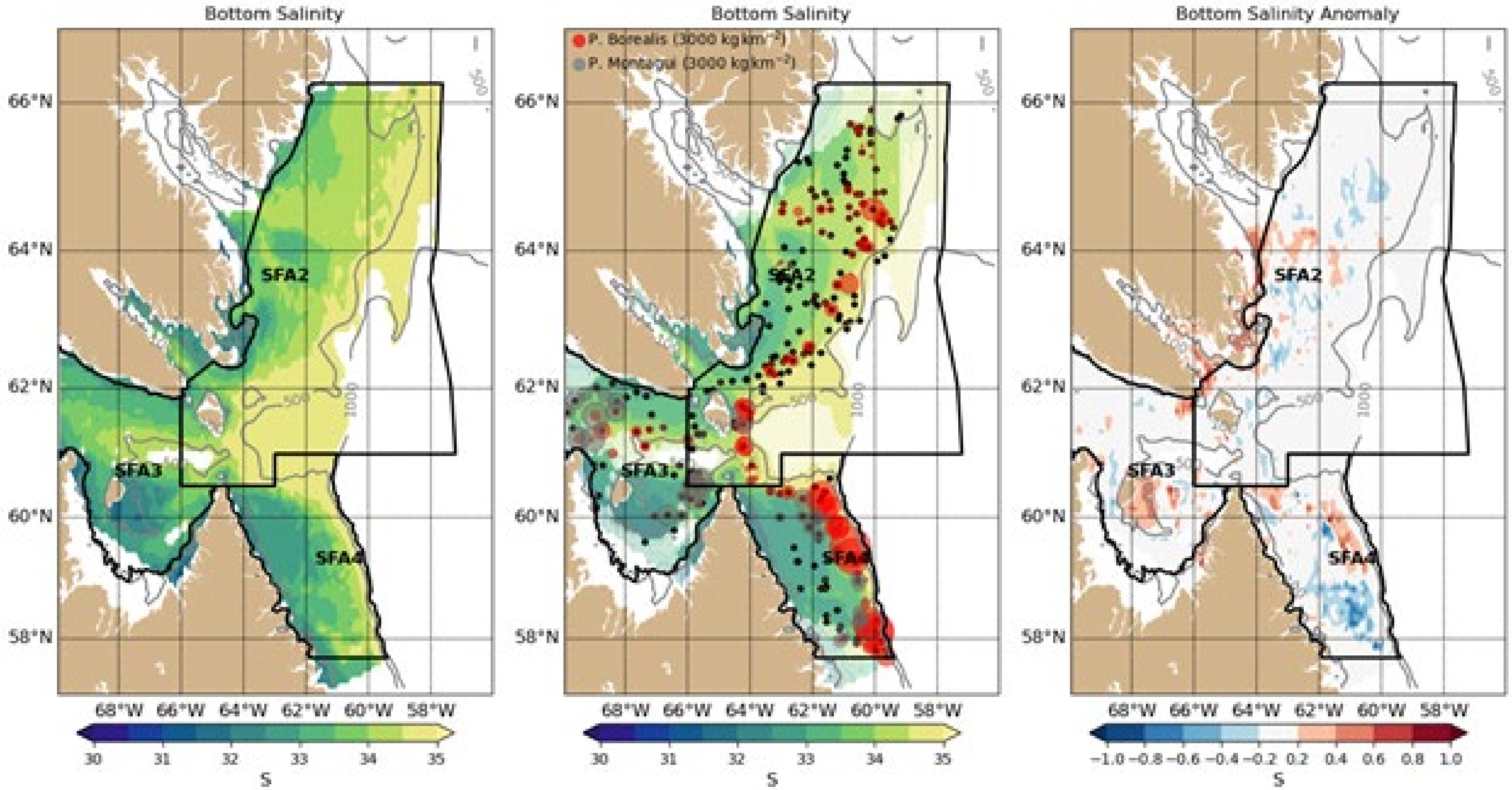

Figure 42. Maps of the climatological (2006–21) mean summer bottom salinity (left), and summer 2022 bottom salinity (center) and anomalies (right) for SFA 2–4. The location of observations used to derive the salinity field is shown as black dots in the center panel. In areas where the spatial interpolation cannot be done (pale areas in the central panel), missing data are filled with the climatology. The biomass of P. borealis and P. montagui collected in the NSRF-DFO research survey is also shown with red and gray circles, respectively.

	-- SFA4 --																		
	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	$\bar{x}$	SD
T_{bot}	-0.6	0.1	0.7	-1.5	0.8	2.2	0.3	-0.9	-1.0	1.2	-0.8	-1.2	0.2	0.2	0.2	1.1	0.5	1.1	0.3
$T_{bot_{<200m}}$	-0.6	0.0	0.5	-1.4	0.8	2.1	-0.1	-1.0	-1.1	1.4	-0.7	-0.9	0.4	0.4	0.3	1.4	0.4	-0.1	0.4
$Area_{>2^{\circ}C}$	-0.3	-0.1	0.8	-1.3	0.7	1.7	0.9	-1.0	-1.0	1.0	-0.8	-1.6	0.1	-0.1	1.1	0.5	0.3	16.8	2.2
$Area_{<1^{\circ}C}$	0.7	0.0	-0.2	1.3	-0.8	-2.4	-0.3	1.0	0.7	-0.8	0.5	1.5	-0.1	-0.1	-0.7	-1.2	-0.2	32.5	3.7

Figure 43. Scorecards of normalized anomalies (expressed in terms of standard deviations (SD) above or below average) of summer bottom temperature (mean temperature, mean temperature for area shallower than 200 m, and area of sea floor covered by water above 2°C and below 0°C, respectively) for SFA 4. Each cell is colored according to the departure to the average (the darker the red the warmer, and the darker the blue the colder). White cells indicate anomalies within ±0.5 SD of the mean, a range considered "normal".

	-- SFA4 --																		
	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	$\bar{x}$	SD
S_{bot}	0.4	0.8	1.2	-0.7	-0.1	1.7	1.0	-1.0	-0.5	0.8	0.6	-1.7	-1.6	-0.5	0.1	-0.5	-0.9	33.6	0.1
$S_{bot_{<200m}}$	0.2	1.0	1.2	-0.4	-0.4	1.8	0.9	-1.1	-0.6	0.8	0.6	-1.6	-1.6	-0.5	0.1	-0.5	-1.2	33.1	0.1

Figure 44. Scorecards of normalized anomalies (expressed in terms of SD above or below average) of summer salinity (mean overall salinity and mean salinity for area shallower than 200 m) for SFA 4. Each cell is colored according to the departure to the average (the darker the red the saltier, and the darker the blue the fresher). White cells indicate anomalies within ±0.5 SD of the mean, a range considered "normal".

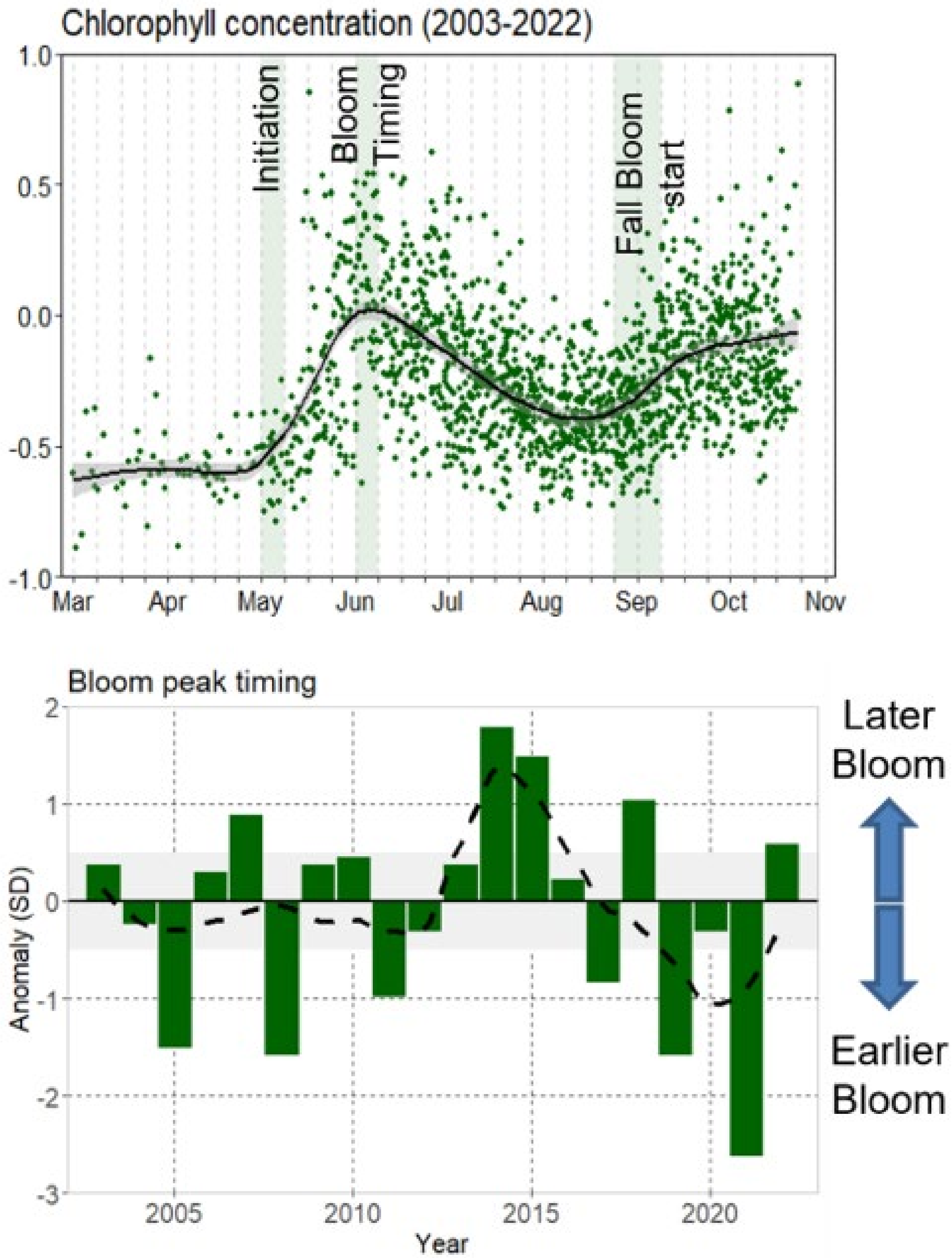

Figure 45. Upper panel: Seasonal variations of chlorophyll concentration in SFA 4 (March-November). Bottom panel: Phytoplankton Spring bloom peak timing anomalies (2003–22); positive or negative anomalies correspond to a later or earlier Spring bloom, respectively.

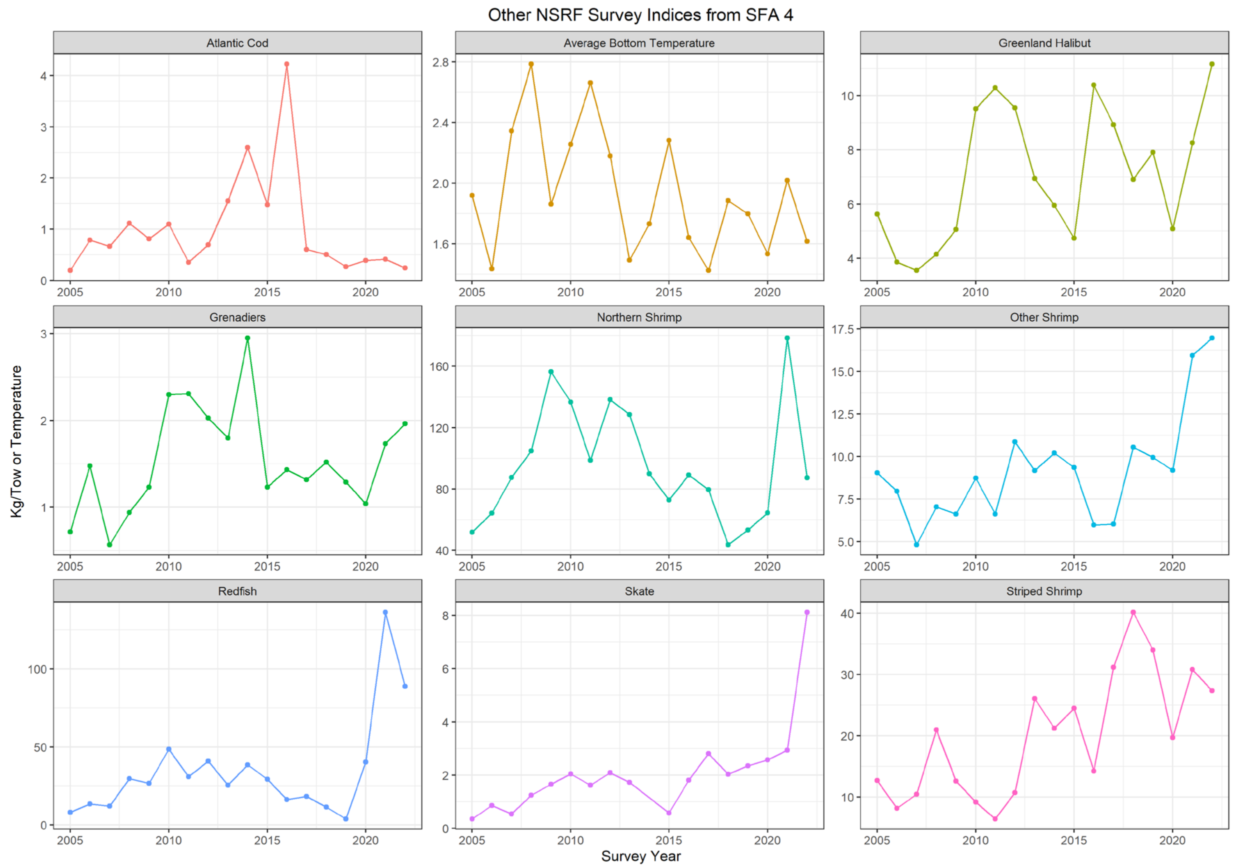

Figure 46. SFA 4 catch rates of predators (Atlantic Cod, Greenland Halibut, grenadiers, redfish, skate) and Shrimp (Northern, Striped, and others) as well as average bottom temperature from NSRF shrimp survey data 2005–22.

Figure 47. Northern Shrimp thermal habitat index in SFA 4–7, EAZ and WAZ from 1996 to 2022 based on BNAM ice-ocean model simulations. The index is based on the areal extent (km2) where bottom temperature corresponds to the Northern Shrimp preferred temperature range (2 to 4°C).

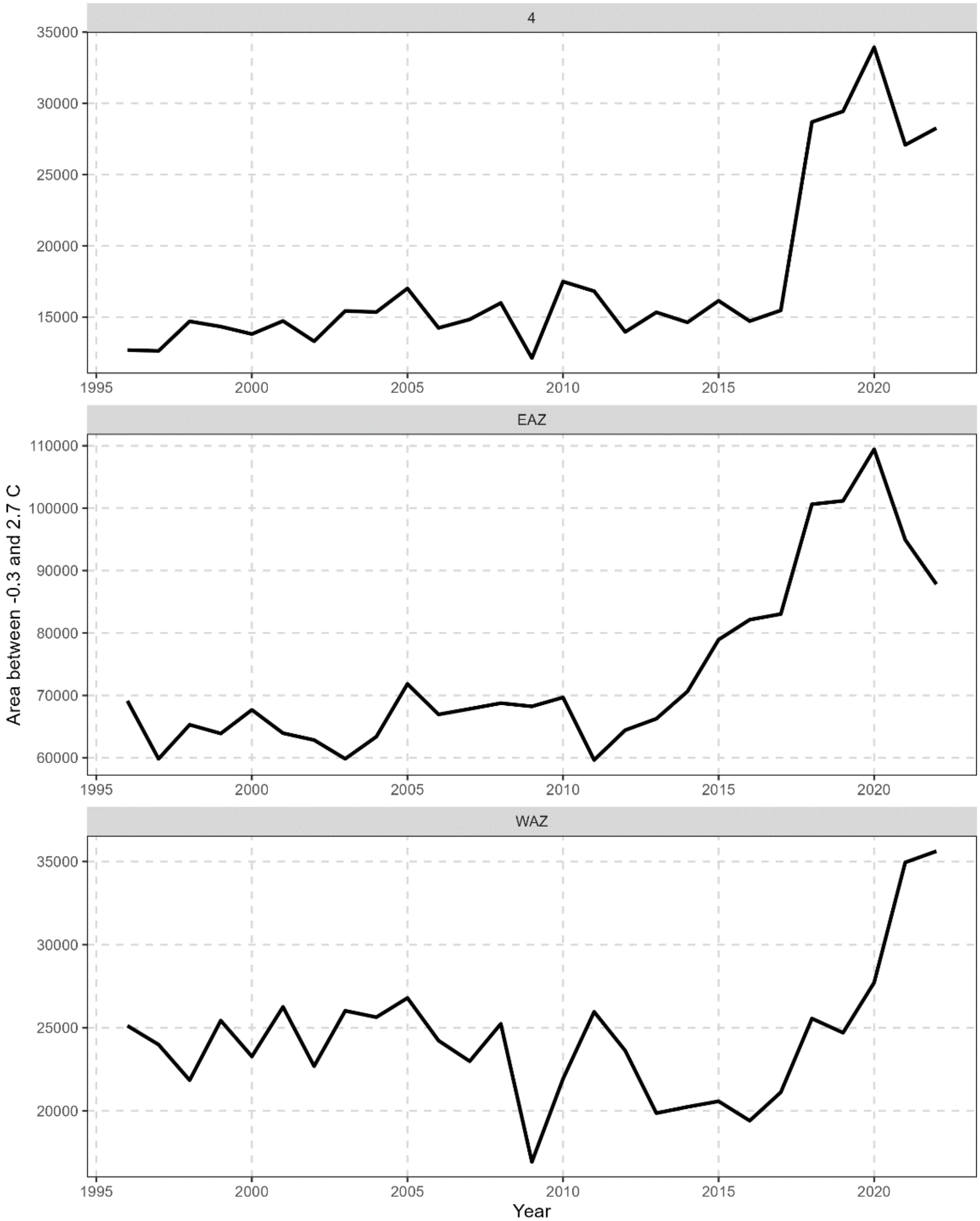

Figure 48. Striped Shrimp thermal habitat index in SFA 4, EAZ and WAZ from 1996 to 2022 based on BNAM ice-ocean model simulations. The index is based on the areal extent (km^2) where bottom temperature corresponds to the Striped Shrimp preferred temperature range (-0.3 to 2.7°C).