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Information to Support the Assessment of Northern Shrimp, *Pandalus borealis*, and Striped Shrimp, *Pandalus montagui*, in the Eastern and Western Assessment Zones, February 2023

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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 the Northern Shrimp (*Pandalus borealis*) and Striped Shrimp *(P. montagui*) resources in the Eastern Assessment Zone (EAZ) and the Western Assessment Zone (WAZ) were assessed based on the results of fishery-independent surveys jointly conducted by Fisheries and Oceans Canada (DFO) and the Northern Shrimp Research Foundation (NSRF) and commercial catch information. Data for the EAZ assessment spans the years 2009–2022 while the current WAZ time series began in 2014. Results from individual survey areas within the EAZ are also provided. *Pandalus borealis* stock in the EAZ is currently above the established Limit Reference Point (LRP; 15,800 t), but below the proposed Upper Stock Reference (USR). Based on the proposed USR of 31,600 t, this would place the stock in the cautious zone with a 98.3% probability. Both the reported and potential exploitation rates were the highest in the time series. The reported exploitation rate index for 2022/23 was 19.4% with 67% of the Total Allowable Catch (TAC) taken. Should the entire 2022/23 TAC of 10,732 t be taken, the potential exploitation rate index would be 29.1%. *Pandalus montagui* stock in the EAZ is currently well above the established LRP (3,100 t) and the proposed USR (6,100 t). This would place the stock in the healthy zone with a 93.1% probability. The full 2022 TAC of 1,400 t has been reported as catch, resulting in a 9.9% exploitation rate. *Pandalus borealis* stock in the WAZ is currently well above the established LRP (4,100 t) and the proposed USR (8,200 t). This would place the stock in the healthy zone with a 98.8% probability. The reported exploitation rate index for 2022/23 was 1.3% with 8.0% of the TAC taken. Should the entire 2022/23 TAC of 3,958 t be taken, the potential exploitation rate index would be 16.5%. *Pandalus montagui* stock in the WAZ is currently well above the established LRP (12,300 t) and the proposed USR (24,600 t). This would place the stock in the healthy zone with a > 99.9% probability. The reported exploitation rate index for 2022/23 was 10.7% with 92.6% of the TAC taken. Should the entire 2022/23 TAC of 12,096 t be taken, the potential exploitation rate index would be 11.5%.

INTRODUCTION

Fisheries and Oceans Canada (DFO) Resource Management (National Capital Region) requested an assessment of the shrimp resources in the East and West DFO management units of Nunavut, Nunavik and Davis Strait (Figure 1). The shrimp resources were assessed within the Eastern Assessment Zone (EAZ) and Western Assessment Zone (WAZ) based on four survey areas each with independently allocated stations (Figure 2).

SPECIES OVERVIEW

Unless otherwise noted, the information presented below is summarized from previous biological synopses for *Pandalus borealis* (Shumway et al. 1985) and *P. montagui* (Simpson et al. 1967). Northern Shrimp (*P. borealis)* are found in the Northwest Atlantic from Baffin Bay to the Gulf of Maine, while Striped Shrimp (*P. montagui*) are found from Davis Strait south to the Bay of Fundy. Both species have known depth and temperature ranges in which they are most consistently found: *P. montagui* are found in cooler water (-1 to 2 °C) than *P. borealis* (0 to 4 °C). In the assessment area, cooler waters tend to occur at shallower depths, and survey catches indicate the bulk of the biomass of *P. borealis* is located at depths of 300–500 m, while *P. montagui* occur mainly at depths of 200–500 m. *Pandalus borealis* are associated with soft substrates whereas *P. montagui* are mostly found at harder bottoms. Due to the degree of overlap in preferred thermal range and depth distribution, these two species are often caught in the same locations.

Both species of shrimp are protandric hermaphrodites. They develop as males early in their lives then change sex and reproduce as females for the remainder of their lives. Females usually produce eggs once a year in the late summer-fall for *P. borealis* while spawning occurs slightly later for *P. montagui* (late fall–early winter). Both species then carry the eggs, attached to their abdomen, through the winter until the spring, when they hatch. The timing of both egg development and hatching is related to water temperature, with lower temperatures resulting in a longer period of egg development. Newly hatched shrimp spend three to four months as pelagic larvae. At the end of this period the larvae settle at the bottom and take up the life style of the adults. Both species dwell at the bottom and migrate upwards into the water column during the night. This diurnal migration consists mainly of males and smaller females, who are less likely to be vulnerable to the fishery. Shrimp are opportunistic feeders on or near the sea floor and in the water column. Precise shrimp lifespan is uncertain but shrimp in the north are thought to live five to eight years (note: an average of six years is used for assessment purposes, the last three years being the period when they are vulnerable to the fishery). Growth rates and maturation are likely slower in the northern populations. *Pandalus spp*. are important forage species, particularly in boreo-arctic ecosystems, where alternative food sources may not be as readily available.

FISHERY

In general, the shrimp fishery began in the late 1970s in Shrimp Fishing Area (SFA) 1. Exploratory fishing expanded into what is now Davis Strait-East management unit (previously SFA 2) and then to areas southeast of Resolution Island in Hudson Strait. Quotas in these areas were initially based on fishery performance and not scientific survey data. In the mid-1990s, the fishery moved southeast of Resolution Island in the former SFA2, where the main fishery remains to date. Implementation of the Nunavut Agreement in 1999 shifted the main fishery east of the Nunavut Settlement Area.

The fishery is currently managed by four annual Total Allowable Catches (TACs), one per species of shrimp in both the EAZ and WAZ, which is further divided into quotas for 17 offshore license holders and special allocations for Nunavut and Nunavik fishing interests. The fishery is managed through management units that comprise the EAZ and WAZ (Figure 2). The 17 offshore license holders have access to fishing grounds in Davis Strait by enterprise allocation, with each receiving a 1/17 share per license. Nunavut and Nunavik interests each have special allocation quotas in their respective land claims areas as well as adjacent areas. Nunavut interests also have quota within the Davis Strait-East and Davis Strait-West management units, while Nunavik interests have quota in the Davis Strait-West management unit. The Nunavut Wildlife Management Board (NWMB) and Nunavik Marine Region Wildlife Board (NMRWB) provide decisions and recommendations on the management of *P. borealis* and *P. montagui* in the EAZ and WAZ. Past Board decisions have approved harvesting of allocations in Nunavut-East and Nunavik-East in either management unit, regardless of land claim boundary. The same applies for Nunavut-West and Nunavik-west management units. All fishing to date has been conducted by vessels > 100 feet Length Overall with a requirement of 100% at-sea observer coverage. Dockside monitoring is not required for shrimp fisheries.

The fishing gear consists of single and, more recently, twin shrimp trawls requiring a minimum codend mesh size of 40 mm and separator grates (maximum 28 mm bar spacing). Since 2003, the management year has been April 1 to March 31. The fishing season is limited by the seasonality of sea ice, and is conducted between May and December in most years.

Pandalus borealis has been the main commercially targeted species throughout the history of the shrimp fishery in these areas. Historically, most of the harvest of *P. montagui* occurred as by-catch in the directed *P. borealis* fishery. In recent years, directed fishing for *P. montagui* has become more important, with quotas available in areas Nunavut-West and Nunavik-West beginning with the 2013/14 fishing season. Additionally, recent increases in *P. montagui* biomass in the WAZ (i.e., in 2018), and the subsequent increase in TAC, has increased the importance of this stock to the commercial fishery.

BASIS FOR REFERENCE POINTS

Fisheries in the Eastern and Western Assessment Zones are managed pursuant to an Integrated Fisheries Management Plan (DFO 2018). A previously established PA Framework for *P. borealis* in the EAZ is under review, although provisional harvest decision rules remain in effect when setting TACs. A complete PA Framework for stocks in the WAZ has not yet been established.

For both species of shrimp, reference points are based on a suitable alternative for biomass at maximum sustainable yield (Bmsy) due to Bmsy not being directly estimated for these stocks. In 2009 (DFO 2009), the geometric mean of spawning stock biomass over a productive period was determined to be a suitable approximation of Bmsy when setting reference points. The original reference points that were set in 2009 for the EAZ were deemed outdated and were re-evaluated and updated in 2020 (DFO 2020). Reference Points for the WAZ were developed in 2012, however, they were not applicable because 2014 was the start of a new survey time series. For the current reference points, the years 2009–2019 were used to represent the productive period in the EAZ while 2014–2019 was used for the WAZ. In each case, the Limit Reference Point (LRP) was set at 40% of the geometric mean and an Upper Stock Reference (USR) was proposed by Science at 80% of the geometric mean over their respective productive periods.

RATIONALE FOR ASSESSMENT FREQUENCY

Both species in the EAZ and WAZ were last fully assessed in 2021 (DFO 2021) with a stock status update in 2022 (DFO 2022). Full assessments are carried out every two years with stock status updates in the intervening years. It was intended that the management decisions made after the full assessment (also considered an intervening year) would be valid for two following years, unless a precipitous change (of more than 25%) in the stock biomass was observed. In reality, a change in the Fishable Biomass of this magnitude has consistently been observed through the annual survey (updated survey biomass estimates are generated every year). A two-year assessment frequency is considered optimal for these shrimp stocks given their life expectancy of roughly 6 years, the last 3 years being the period when they are vulnerable to the fishery.

ECOSYSTEM CONTEXT – LONG-TERM

It is believed that the habitat available to shrimp is shaped, to a great extent, by the oceanographic conditions present in the area. Since both species of shrimp have optimal thermal preferences, one could expect that in years with strong thermal anomalies the stocks will be subject either to more optimal or sub-optimal conditions. The exact relationships between the available habitat and its changes and stock performance are still to be statistically tested.

The emergence of a large biomass of juvenile redfish (*Sebastes* spp.) in the EAZ in recent years (i.e., since 2020) is expected to have a strong negative impact on the availability of food for benthic scavengers, including shrimp. Rapid population increase of a strong food competitor does not allow the ecosystem to react quickly enough to provide sufficient resources for the new consumer. As a consequence, it is expected that juvenile redfish will consume large amounts of pelagic biomass that would otherwise provide for benthic communities. It is expected that this competitive pressure will be reflected negatively in shrimp stocks in EAZ.

Shrimp are known to be an important food source for a number of predator species, *e.g.*, Greenland Halibut (*Reinhardtius hippoglossoides*), American Plaice (*Hippoglossoides platessoides*), Atlantic Cod (*Gadus morhua*), skates (Rajidae) and redfish (*Sebastes* spp.). The amount of shrimp consumed by these predators varies in response to predator stock size and movement within and between assessment areas. Work is ongoing to quantify the impact of these predators on the shrimp stocks in EAZ and WAZ in order to determine the importance of predator-prey dynamics on shrimp biomass variability over the years.

Pandalid shrimp can disperse through various mechanisms but larval dispersion with currents may be a main driver for shrimp movement (Le Corre et al. 2020). It is also known that adult shrimp can move in the water column (particularly males) and be carried away with the currents, thus this mechanism also contributes to shrimp dispersal. The two assessment areas, EAZ and WAZ along with the SFA 4 further south and SFA 0 and SFA 1 to the north, have no physical boundaries between them and are considered interconnected. Hudson Strait is a highly dynamic system with strong tidal currents and mixing. With speeds up to five knots, the strong currents could result in quick shifts in shrimp distribution and catchability (Drinkwater 1986, Hudon 1990). The extent of shrimp exported/imported between these areas remains unknown for both larval and adult stages, however, it could be one of the important drivers of year-to-year variability observed in any particular assessment area over time.

MATERIALS AND METHODS

DATA COLLECTION

Data used in the assessment of *P. borealis* and *P. montagui* in the EAZ and WAZ comes from two primary sources: the Northern Shrimp Research Foundation (NSRF) survey and records of commercial catch reported by the Atlantic Quota Management System (AQMS). Starting in 2005, the NSRF has conducted a multi-species, stratified random bottom trawl survey for *P. borealis* and *P. montagui*. Since the survey's inception, data have been collected in Shrimp Fishing Areas (SFAs) 2–4 to be used in annual assessments, although not all areas were surveyed each year. Data from the survey have been used to create a biomass index since 2009 in the EAZ (a combination of SFA 2 and the area around Resolution Island) and since 2014 in the WAZ (SFA 3). The annual NSRF survey is also the source of ancillary data such as bottom temperature and salinity and biological information from bycatch species. Commercial catch records in the AQMS are compiled based on the reporting of landed catch data from regional databases on a weekly basis.

Northern Shrimp Research Foundation Survey

Design and Practices

There are four survey areas within the boundaries of the EAZ and WAZ (Figure 2): SFA 2, RISA-East and RISA-West in the EAZ; and SFA 3 in the WAZ. The historical background pertinent to establishing the survey areas can be found in Siferd (2015).

Survey areas in the EAZ cover depths between 100 and 750 m, and are divided into 100–200, 200–300, 300–400, 400–500, and 500–750 m depth strata. Over time, the total survey area in both SFA 2 and RISA have been reduced from their original sizes of 103,331 km^2 and 28,321 km^2 respectively due to removal of locations with unsuccessful fishing attempts or untrawlable bottom. Additionally, establishment of the Hatton Basin (2018) and Davis Strait Conservation (2020) areas further reduced the total area surveyed in both areas. Currently, the SFA 2 covers a total area of 71,795 km^2 while RISA (East and West) has a total area of 17,346 km^2. The majority of areas removed were areas of low shrimp densities and their removal had minimal effect on the overall biomass estimates.

Prior to 2014, the WAZ covered depths of 100 to 1,000 m. In 2014, the 750–1,000 m strata could not be fished, requiring that it be dropped in this and future surveys of the area. From 2014 onwards the depth strata in the WAZ were defined in the same way as the EAZ. The bathymetry of the WAZ is such that natural strata were produced and no further subdivision of the contours was made. Due to several changes, 2014 is considered the start of a new time series in the WAZ, and since then has been surveyed annually covering an area of 56,831 km^2.

Sampling locations within each depth strata are allocated in accordance with Doubleday's (1981) method. A detailed description of the development and revisions of the stratification scheme can be found in Siferd (2015). In short, the sampling locations are proportionally allocated to the size of the stratum area with a minimum of two sets per stratum regardless of its size. All possible sampling sites within a survey stratum, based on a 3 x 3 km grid overlaying an equal-area projection of the area, were assigned to individual strata. In SFA 2 and RISA, buffering between sampling sites was accomplished by further allocating the sampling sites into "blocks" and limiting selected sites to one per block. In the WAZ, buffering around sites was achieved using a program developed by the Greenland Institute of Natural Resources (GINR; Kingsley et al. 2004). Sites were selected iteratively and once a site was selected, all other sites within a buffer zone (sized relative to the overall size of strata and allocation of sites) were removed from the available selection.

Vessels used to conduct the NSRF survey have varied since its inception in 2005. These included the F/V *Cape Ballard* (2005–2011), F/V *Paamiut* (2007, 2009, 2011, 2013; SFA 3 only), F/V *Kinguk* (2014), F/V *Katsheshuk* II (2015, 2020), and F/V *Aqviq* (2012, 2013, 2016–2019, 2021–2022). 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.

For the current time series (i.e., 2009 to present in the EAZ and 2014 to present in the WAZ), all sampling has been performed using the modified Campelen 1800 shrimp trawl (12.7 mm codend mesh; Siferd and Legge 2014). The trawl is equipped with 21'' footgear, as opposed to the standard 14'', with the rest of the specification remaining identical to the standard Campelen trawl. Standard sampling procedures are to maintain a speed of 2.6 knots for 15 minutes for all tows. However, any tow with a duration greater than or equal to 10 minutes was considered successful providing the integrity of the equipment and catch remained intact. Sampling was conducted on a 24-hour basis. Experimental work done by DFO in 2007 in the Resolution Island area suggests that survey results may be affected by the tidal cycle. In order to reduce the impact of the tidal currents, the surveys were conducted at neap tides (i.e., the point in the lunar cycle when the difference between high and low tide is less than average). However, the survey is conducted around the clock over a 2-week period, so strong tidal currents could still be expected during the survey and may result in either an over- or underestimate of biomass. At this time the number of trawls conducted during different tidal cycles is not quantified.

Trawl Monitoring and Environmental Data

Trawl monitoring was performed with a Marport® MBAR acoustic receiver coupled with Marport spread sensors to measure both the door and wing spread. A Furuno® trawl eye mounted on the headline was also used to visually observe trawl touchdown and therefore the start and end times of each tow. Water temperature and salinity were recorded with a trawl-mounted Seabird 19plus CTD. Sampling of catch onboard the vessel was conducted on a 24-hour basis.

The swept area during each tow was calculated as the product of vessel speed, bottom time and wing spread. Vessel speed was derived as the average of all speeds from GPS GPRMC strings recorded by the Marport system over the duration of the tow. Wing spread was determined through direct measurements from the wing sensors. In cases when direct measurements of wing spread were not available, a conversion from door spread through a formula derived from a comparison of door spread to wing spread over tows where both measures were present was used. All available wing spread measurements (direct or derived) were averaged over the duration of the tow. Bottom time was determined from the Marport recordings of the Furuno trawl eye. Mean bottom temperature and salinity were calculated as the averages of all measurements taken between the start and end of a tow while the trawl was on the bottom.

Shrimp Catch Processing

In all survey areas the catch was processed in the same manner aboard the vessel. From the catch, a random shrimp sample containing up to approximately 300 individuals was sorted to species. *Pandalus borealis* and *P. montagui* were further divided into male, transitional, primiparous, multiparous or ovigerous stages based on characteristics according to Rasmussen (1953), Allen (1959) and McCrary (1971). These stages were further divided into batches by disease condition, carapace condition and whether head roe was present. Each batch was weighed to the nearest 0.0001 kg. The oblique carapace length (CL) of all *P. borealis* and *P. montagui* individuals within each batch was measured using digital calipers and electronically recorded to the nearest 0.01 mm. Additional samples of both *P. borealis* and *P. montagui* have been collected opportunistically from the NSRF survey for numerous follow-on analyses including food-web linkages (i.e., stable isotopes and fatty acids), genomics, and diet analysis.

Additional Field Sampling

All non-Pandalid catch (henceforth referred to as 'bycatch') was sorted to the lowest taxonomic level possible, weighed (0.001 kg), and, where appropriate, counted. Individual length measurements (cm) were taken of select bycatch species (e.g., Greenland Shark; *Somniosus microcephalus*). Additional bycatch sampling has been conducted sporadically during the NSRF survey to assist with taxonomic identifications of benthic invertebrate, coral, and sponges, as well as for genomics studies of Greenland Halibut, Arctic Cod (*Boreogadus saida*), and cephalopods.

From 2018 to 2022 additional sampling was conducted to collect information on the fish predators of Pandalid shrimps. Locations and predator taxa were selected in advance of the survey with the objectives of maximizing geographic coverage while considering available human resources for onboard processing. At designated stations, up to 10 predators of each taxa were randomly sampled from the catch. Predators were frozen whole and shipped to the lab for further processing. Fork and total length (cm), weight (0.5 g), sex, and maturity were recorded, and tissues were extracted for follow-on analysis including otoliths for ageing, stomach contents, stable isotopes, fatty acids and DNA. Occasionally, stomachs were extracted on the vessel and sent for further processing with only length information accompanying the stomach; no additional tissue sampling was conducted for these fish.

Commercial Catch Data

Catches from the directed commercial harvest of *P. borealis* and *P. montagui*, along with bycatch estimates are reported annually to regional data centres. These data are then compiled within the AQMS system. Records in the AQMS system are updated throughout the fishing season as logbooks and landings are reported and minor adjustments may be made as data passes through a quality control process. Total catch (in tonnes) for *P. borealis* and *P. montagui* are reported according to management units and aggregated into the EAZ and WAZ for assessment purposes.

DATA ANALYSIS

Pandalus Assessment

Biomass data from the annual NSRF survey are used to calculate an index of biomass in order to determine the status of *P. borealis* and *P. montagui* stocks in the EAZ and WAZ following the framework from DFO (2007). Commercial catch data from the AQMS is used to determine the exploitation rates for both species in each assessment zone.

Distribution of Catch

Maps showing the distribution of standardized catch (kg/km^2) per trawl in 2022 for both *P. borealis* and *P. montagui* from the NSRF survey were produced using ArcGIS (ESRI 2020). The assessment does not currently incorporate distribution data into the assessment in a quantitative way, but is provided as part of a qualitative look into the areas of high density during the survey.

Biomass Estimation

Using the NSRF survey data, biomass indices are calculated annually for total, fishable and spawning stock biomass categories. Catchability of the trawl (i.e., how efficient the trawl is at capturing shrimp in its path), is less than one and may also vary between size classes of shrimp. The exact value is unknown but assumed to be consistent across years resulting in biomass estimates that represent an index of abundance and not an absolute value.

The overall biomass of each trawl is weighed but only a subsample is selected for further breakdown into species and maturity categories. In some instances, when the subsample contains a large volume of shrimp, a further subsample of shrimp is removed. Because of this subsampling, the recorded weights of each category must be extrapolated to the entire trawl and standardized by the swept area of the trawl to produce a standardized biomass (kg/km^2) for each set.

During processing, shrimp subsamples are broken down into sex and maturity categories. Categories are then aggregated during the biomass extrapolation depending on the type of biomass being calculated. The three types of categories are:

1. **Total biomass** is all sizes and maturity categories of shrimp caught;
2. **Fishable biomass** is all shrimp with a carapace length over 17mm and may include male, transitional and female shrimp;
3. **Spawning Stock Biomass** is all female or transitional stage shrimp.

Shrimp Species Biomass of a particular shrimp species (*i*) and biomass type (*j*) caught at a sampling station in kilograms per square kilometer was calculated as:

$$Eq.1: \; ShrimpCatch_{ij} = \frac{ShrimpWt_i \times BumpFactor}{Swept\ Area}$$

The *Bump Factor* refers to the extrapolation value used to convert the weight of measured shrimp to the total shrimp catch in the trawl. Four ratios are multiplied together to give the final bump factor used in the extrapolation. A detailed description of equations can be found in Siferd (2014) and a worked example in Appendix A.

1. **Ratio 1:** the weight of the portion of shrimp sampled before it was sorted in single species/maturities dived by the sum of the individual categories. This ratio acts as a correction factor and should be around 1.
2. **Ratio 2:** the combined weight of all shrimp species in the subsampled catch divided by the portion of the shrimp sampled before it was sorted into single shrimp species. These two values may be equivalent if the shrimp sample was not further subsampled after the initial catch subsample.
3. **Ratio 3:** the weight of the subsample divided by the sum of the individual species categories. This ratio acts as a correction factor and should be around 1.
4. **Ratio 4**: the catch weight from the trawl divided by the subsample weight

Once standardized biomass (kg/km^2) is calculated per trawl, the biomass estimate for each assessment area is calculated by;

$$Eq.2: \quad Biomass = \sum_k \left[\frac{\sum_s ShrimpCatch_{st}}{n_t} \times \; StratumArea_t \right]$$

Where, *s* is one station of n_t stations sampled in stratum *t* of which there are *k* strata within the survey area.

Upper and lower confidence intervals (CI) were estimated by resampling statistics (Bruce et al. 2000). CIs were calculated by resampling from the observed catch with replacement to produce a new biomass estimate for the survey area as described above. A set of 15,000 estimates was produced from additional runs based on a new sampling of the observed catch with replacement. Estimates at the 2.5 and 97.5 percentiles of all runs were used to provide the 95% CI for the biomass estimates. In addition to the CI, the proportion of the 15,000 estimates that fell into each of the Stock status zones (Healthy, Cautious, Critical) provide a measure of uncertainty when reporting the Stock Status (which is based off the point estimate calculation without replacement). The mean value reported for each index was calculated as the geometric mean of the time series; 2009-present for the EAZ and 2014-present for the WAZ.

Exploitation Rate Index

Exploitation rates are a measurement of the proportion of removals relative to the available biomass. Although catch is known, the total fishery-induced mortality is unknown (landed catch plus incidental mortality from trawling) and therefore exploitation rates are a relative index rather than an absolute value. For shrimp, two exploitation rate indices are calculated on an annual basis: reported exploitation and potential exploitation. The reported exploitation rate index is calculated as:

$$Eq. 3: \quad Reported\ Exploitation = \frac{Reported\ Catch}{Fishable\ Biomass}$$

where

Reported Catch is the total catch in tonnes, including both directed and bycatch, aggregated by assessment zone and species. Bycatch includes catch from sets directed at the other Pandalid species.

Fishable Biomass is calculated following the protocol in section 2.2.1.2 – Biomass estimation

$$Eq. 4: \quad Potential\ Exploitation = \frac{Total\ Allowable\ Catch}{Fishable\ Biomass}$$

where

Total Allowable Catch is the total fishing quota aggregated by assessment zone and species.

Because the fishing season for *P. borealis* and *P. montagui* is still open at the time of the annual assessment, the reported exploitation rate index for the current year is considered incomplete and is updated in the following year's assessment. Confidence intervals around the exploitation rate are calculated by substituting the lower and upper confidence interval values of the Fishable Biomass index in the exploitation rate equations. The upper confidence interval for exploitation is calculated using the lower confidence interval of the Fishable Biomass, and vice versa for the lower. The mean value for each index is calculated as the geometric mean of the time series; 2009-present for the EAZ and 2014-present for the WAZ.

Precautionary Approach Framework

DFO's *Fishery decision-making framework incorporating the precautionary approach* (Precautionary Approach; DFO 2009) is used as the basis to determine the status of fish stocks in Canada. The LRP defines the boundary between the critical and cautious zones, while the USR defines the boundary between the cautious and healthy zone. For *P. borealis* and *P. montagui* in the EAZ and WAZ, the current LRPs and proposed USR points can be found in Table 1.

Bottom Temperature and Salinity

Temperature (T) and salinity (S) profiles are available for most of the summer fishing sets collected in the EAZ, WAZ and SFA 4 between 2006 and 2022 from the trawl-mounted CTD (in the WAZ, sampling occurred every second year between 2007 and 2013, and every year after).

These data were combined with other available T-S profiles (from DFO's Atlantic Zone Monitoring Program surveys, DFO's multi-species resources assessments, international oceanographic campaigns, Argo program, etc.), vertically averaged in 5-m bins and linearly interpolated vertically to fill missing bins. All available data taken between July and August were then averaged on a regular 0.1° x 0.1° grid (latitudinal x longitudinal) to obtain one summer profile per grid cell. Since this grid had missing data in many cells, each depth level was spatially linearly interpolated to fill gaps. For each grid point, the bottom observation was extracted using the closest depth to the depth GEBCO_2014 Grid bathymetry (version 20141103). Lastly, bottom observations deeper than 1,000 m were clipped as they are in a depth range with much lower data coverage (i.e., down the continental slope). This method was applied for all years between 2006 and 2022 from which the 2006–2021 climatology was derived. Anomalies for 2022 were calculated as the difference between annual observations and the climatology. This method is similar to the one used to derive bottom temperature and salinity on the Newfoundland and Labrador shelf (e.g., Cyr et al. 2022).

Diet Study – Competition with Sebastes spp.

Samples of redfish (*Sebastes* spp.) for gut analyses were collected in 2021 from commercial fishery operations in the Labrador Sea (SFA 4, 5, and 6). Size classes used to characterise diet of juvenile redfish were determined from the 2021 distribution of juvenile redfish collected in Eastern and Western Assessment Zones. Prey items from individual fish were identified to the lowest taxonomic level possible, usually species, and weighed. Prey taxa weights from individuals were then aggregated by size class to provide a summary of wet weight and percent gut content per taxa.

An estimate of annual zooplankton removals by the juvenile *Sebastes* spp. was calculated by:

$$Eq.5: \quad x = A * \left(\frac{B}{W}\right) * 365$$

where:

x = annual zooplankton removal by the juvenile redfish in EAZ

A = average meal weight of a single juvenile redfish

B = estimated biomass of juvenile redfish

W = average juvenile redfish weight

365 = number of meals each juvenile redfish consumes in a year (Pedersen and Riget 1993)

The resulting estimate of annual zooplankton removal using the above equation provides a preliminary estimate that can be further refined as more information is acquired on the diet, size and total biomass of juvenile redfish in the system.

Diet Study – Predator Diet Analysis

Six predator groups were included in the study of Pandalid shrimp as a prey item: Atlantic Cod, Greenland Halibut, American Plaice, Redfish, Grenadiers (*Macrourus spp.*), and Skates (*Raja spp. and Amblyraja spp*.). For each individual predator, whole stomachs were weighed (0.001g), tissue and mucus were separated from stomach contents, contents were weighed together (0.001 g), and individual prey items were identified to the lowest taxonomic level possible. Individual prey items were further categorized based on digestive state, then weighed and counted (where possible). Non-diet items such as parasites or sand were excluded. For detailed sampling protocol see Polaczek et al. (2021). Data were combined for analysis using four aggregations, each with increasing specificity.

First, a broad overview of prey diversity was conducted by counting the number of stomachs per predator group (all years combined) where each prey taxa was present. Prey taxa were aggregated by Class, with the exception of Pandalid shrimp which were included as their own taxa. Empty and/or everted stomachs were included in this summary. Because an individual predator can consume more than one prey taxa at a time, the sum of each taxa within a predator group is greater than the number of stomachs investigated.

Second, the presence/absence of *P. borealis*, *P. montagui* and *Pandalus* spp. relative to the total number of stomachs examined was summarized by sorting individual predator stomachs into five discrete categories: empty/everted, containing only non-Pandalid prey taxa, containing mixed Pandalids, containing only *P. montagui*, and containing only *P. borealis*. The mixed Pandalid category included instances where prey items were identified only to *Pandalus* sp. as well as more than one Pandalid species. Results were further presented either by year, or length category (5-cm bins).

Third, the proportion of non-empty stomachs containing *P. borealis* and *P. montagui* was split by assessment area (WAZ, EAZ, and SFA 4) and 20-cm length bins. Only Greenland Halibut were included in this assessment due to the limited sample size for the other predator groups.

Finally, using only stomachs where *P. borealis* and *P. montagui* were present, the average number of individuals per stomach per 5-cm length bin was calculated. Highly digested individuals were counted as whole shrimp even when only partial individuals were found. Redfish and American Plaice were excluded from this analysis due to limited sample size.

RESULTS AND DISCUSSION

SURVEY SUMMARY – 2021 AND 2022

Since the last full assessment in 2021 (DFO 2021), the NSRF survey was successfully conducted in both assessment zones in 2021 and 2022 aboard the fishing vessel *Aqviq*. Both surveys collected biomass data in all four areas of the EAZ and WAZ.

In 2021, the RISA was surveyed first from August 4th–11th, followed by SFA 2 (August 11th–22nd) and finally the WAZ from August 23rd–30th. All 68 stations were sampled in the WAZ, while 70 of 70 and 109 of 111 were sampled successfully in RISA and SFA2, respectively.

In 2022, sampling in the RISA occurred in three separate legs between August 10 and September 5th. Sampling in SFA 2 occurred between August 16th–28th followed by the WAZ August 30th–Sept 4th. Due to challenges with vessel logistics, only 46 of 68 stations were sampled successfully in the WAZ, while 65 of 70 and 110 of 111 were sampled successfully in RISA and SFA2, respectively. Despite the overall reduction in number of stations sampled in the 2022 NSRF survey, sampling was conducted in all strata and the minimum of two sets per strata was still achieved. Note that the reduction of samples taken in areas of high variability in the WAZ impacted the characterization of sample variance and resulting confidence intervals in this zone for this assessment.

EASTERN ASSESSMENT ZONE 2022

Pandalus borealis

Similar to previous years the highest concentrations of *P. borealis* catch in the SFA 2 portion of the EAZ (Figure 3A) were found in a relatively continuous band within the 300–400 m and 200–300 m strata in 2022. In the RISA, *P. borealis* concentrations were primarily on the eastern side in the 200–400 m depth range. In the EAZ overall, strata less than 200 m or greater than 400 m made up 34% of the assessment area and contributed only 2.5% of the estimated biomass index. Relative to the other areas in the EAZ, biomass in RISA-E showed relatively large CA over the time series. Both RISA-W and RISA-E have displayed a declining trajectory since 2019 (Figure 4), while SFA 2 has remained relatively stable around the long-term mean since 2013.

The fishable biomass index was below the long-term mean (63,642 t) and was 36,911 t in 2022 (Figure 5A, Table 2). The female spawning stock biomass index (SSB) was below the long-term mean (40,374 t) and was 23,771 t in 2022.

Catch has varied without trend around 6,000 t from 1997 through 2022/23 (Figure 5B, Table 3). The total reported catch for 2022/23, based on the AQMS, as of January 20, 2023, was 7,145 t, 66.6% of the 10,732 t TAC.

The reported exploitation rate index has increased annually since 2019/2020 and for 2022/23 it was 19.4% with 66.6% of the TAC taken (Figure 5C). Based on the 2022/23 TAC of 10,732 t, the potential exploitation rate index was 29.1% (Figure 5C).

The *P. borealis* stock in the EAZ is currently above the established LRP (15,800 t), but below the proposed USR (Figure 5D). Should the USR be established at the proposed level of 31,600 t suggested by Fisheries and Oceans Canada (DFO) Science sector (i.e., 80% of the geometric mean of the SSB index; DFO 2020), this would place the stock in the Cautious zone of the PA Framework with a 98.3% probability.

Pandalus montagui

As expected, presence of *P. montagui* across the EAZ is low, with the highest concentrations in RISA-W near the border of the WAZ (Figure 3B and Figure 6). Total biomass in each of the three EAZ areas is close to the long-term mean, with > 80% of the total biomass in 2022 occurring in RISA-W of which the majority was within a single 400–500 m strata.

The fishable biomass index of *P. montagui* in the EAZ is subject to considerable interannual variability, potentially associated with resource distribution. Fluctuations in fishable biomass may also differ across adjacent assessment areas within the same year for this stock. Since 2017, it has generally been above or near the long-term mean (12,397 t) and was 14,325 t in 2022 (Figure 7A, Table 4). The female spawning stock biomass (SSB) index was above the long-term mean (8,267 t) and was 10,428 t in 2022 (Figure 7A, Table 4).

Total catch in 2022/23 was 1,419 t, 101.4% of the 1,400 t TAC (Figure 7B, Table 3). Catch statistics in 2022/23 are preliminary and based on the AQMS data as of January 20, 2023.The reported exploitation rate index for 2022/23 was 9.9% with 101.4% of the TAC taken (Figure 7C).

Pandalus montagui stock in the EAZ is currently well above the established LRP (Figure 7D). Although there is currently no established USR and the stock biomass index is subject to considerable interannual variability, the stock is considered to be in a healthy state.

Should the USR be established at the Science Sector proposed level of 6,100 t (i.e., 80% of the geometric mean of the SSB; DFO 2020), the stock in 2022 would be placed well in the Healthy zone of the PA Framework with a 93.1% probability.

WESTERN ASSESSMENT ZONE 2022

Pandalus borealis

Pandalus borealis in the WAZ are found almost exclusively in the northern portion of the area (Figure 8A), with two of the eleven survey stratum contributing 68% of the biomass. Very few trawls in the southern part of the assessment zone contained non-zero *P. borealis* catch.

Due to a change in survey methodology, the 2014 survey began a new time series making the 2022 survey the ninth in the new time series. Since the start of the new series both the fishable biomass and SSB indices varied without a trend. The fishable biomass index in 2022 remained above the long-term mean (19,994 t) and was 23,939 t (Figure 9A, Table 5). The female SSB index in 2022 remained above the long-term mean (11,402 t) and was 15,899 t (Figure 9A, Table 5).

Total catch in 2022/23 was 318 t, which is 8.0% of the 3,958 t TAC (Figure 9B, Table 3). Catch statistics in 2022/23 are based on the AQMS, as of January 20, 2023. The reported exploitation rate index for 2022/23 was 1.3% with 8.0% of the TAC taken (Figure 9C). Based on the 2022/23 TAC of 3,958 t, the potential exploitation rate index was 16.5% (Figure 9C)

Pandalus borealis stock in the WAZ is currently well above the established LRP (Figure 9D). Although there is currently no established USR, the stock is considered to be in a healthy state. Should the USR be established at the proposed level (i.e., 80% of the geometric mean of the SSB index; DFO 2020), this would place the stock in the Healthy zone of the PA Framework with a 98.8% probability.

Pandalus montagui

Pandalus montagui are found throughout the WAZ with large concentrations of biomass in both the northwest and southeast (Figure 8B).

Due to a change in survey methodology, the 2014 survey began a new time series making the 2022 survey the ninth in the new time series. Since the start of the new series, the fishable biomass and SSB indices varied without trend. Movement across management areas is suspected to contribute to interannual variability in the fishable biomass index. In 2022, the fishable biomass index was well above the long-term mean (56,440 t) and was 104,737 t (Figure 10A, Table 6). The SSB index was above the long-term mean (30,937 t) and was 61,058 t in 2022 (Figure 10A, Table 6).

Total catch in 2022/23 was 11,195 t, which is 92.6% of the 12,096 t TAC and the highest reported catch in the time series (Figure 10B, Table 3). Catch statistics in 2022/23 are based on the AQMS, as of January 20, 2023. The reported exploitation rate index for 2022/22 was 10.7% with 92.6% of the TAC taken (Figure 10C). Based on the 2022/23 TAC of 12,096 t, the potential exploitation rate index was 11.5%.

Although there is currently no established USR for *P. montagui* stock in the WAZ, the stock is well above the LRP relevant to a PA Framework (Figure 10D). Should the USR be established at the proposed level (i.e., 80% of the geometric mean of the SSB index; DFO 2020), the stock in 2022 would be placed within the Healthy zone of the PA Framework with a > 99.9% probability.

BOTTOM TEMPERATURE AND SALINITY

EAZ

Bottom temperature and salinity maps for 2022 as well as their anomalies are shown together with the 2006–2021 climatology (Figure 11 and Figure 12, respectively). A number of statistics were derived from these maps to characterize the oceanographic seafloor habitat including the bottom mean temperature and salinity in the different fishing areas; and the area of the bottom covered by water in various temperature ranges, etc. (Figure 13 and Figure 14).

For most of the northern part of the EAZ, there is an offshore-onshore gradient in bottom temperature, with temperature ranging from 3–4°C along the shelf break to near freezing < -1°C close to Baffin Island (Figure 11). This temperature gradient is also accompanied with salinity changes, with the fresher waters along the coast and the saltier water offshore (Figure 12). The Hatton Basin, a deeper trough located in the southern part of the EAZ, is generally characterized with warmer (T > 4°C) and saltier (S > 34.5) waters compared to the rest of the EAZ.

Despite the relatively short time series available (since 2006), it is possible to identify interannual fluctuation in bottom conditions (Figure 13 and Figure 14). For example, years 2010 and 2011 stand as the warmest and saltiest years of the time series in the EAZ. To a lesser extent, years 2018 and 2019 were also warmer than average. In contrast, 2009 was the coldest and freshest year of the time series. In 2022, bottom conditions in the EAZ were slightly colder (for the first time since 2017) and fresher than normal.

The distribution of shrimp biomass (both species) in the EAZ in 2022 generally follows the slope area near the shelf break where the water is generally warmer and saltier than in the shallower areas (Figure 11 and Figure 12; red and gray circles). There is a nearly complete absence of biomass (black dots without color) in waters with temperatures < 0°C (darkest shades of blue).

WAZ

The Baffin Island Current, which carries part of the Davis Strait outflow southward along Baffin Island in the EAZ, partially bifurcates into the northern part of the WAZ where it meets the outflow from the Hudson Bay. The latter mostly flows along the southern part of Hudson Strait, so that the southern part of the WAZ (including the shallower Ungava Bay) contains some of the freshest (reaching S < 31) and coldest (near 0°C) waters of the assessment zone (Figure 11 and Figure 12). The waters at the bottom of the deeper Hudson Strait are generally slightly warmer and saltier.

Interestingly, the interannual fluctuations in the bottom temperature and salinity anomalies in the WAZ are generally not in phase with those from the EAZ (Figure 13 and Figure 14). For example, 2021 stands as the warmest year (by far) and 2016 and 2017 as the coldest (compared to 2010–2011 and 2009, respectively in the EAZ). In terms of salinity anomalies, 2015 was the saltiest (by a wide margin) and 2017 the freshest. The year 2022 was also the third warmest year in the WAZ since 2007 (after 2021 and 2018, but second warmest after 2021 when considering water shallower than 200 m), but salinities were normal.

In terms of shrimp biomass distribution in the WAZ for 2022, low biomass of *P. borealis* are found in the warmest waters of the assessment zone, mostly along the northern slope of the Hudson Strait (Figure 11). Conversely, the largest biomass of *P. montagui* are mostly found on the shallower and colder areas of the WAZ where *P. borealis* is virtually absent.

DIET STUDY

Competition with Sebastes

Redfish (*Sebastes* spp.) is a commonly occurring species in the Eastern and Western Assessment Zones, with the former being more frequently occupied by redfish. Higher bycatch of juvenile redfish was observed in 2010, but then quickly subsided to relatively low abundances in subsequent years (Figure 15). Starting in 2020, both research survey results and fishery reports indicated the resurgence of juvenile redfish in the catches, primarily in the EAZ.

While juvenile redfish were caught in the bottom trawls, they frequently dwell in the water column (Rooper et al. 2010), creating dense aggregations that may potentially move along with the surveying vessel (raising the potential of encountering the same aggregation twice). Thus, any quantification of the redfish biomass based on the shrimp survey may be biased and not reflective of the true underlying biomass. Juvenile redfish are known for having a pelagic diet when small and progressing towards larger benthic items as they grow, including an increased consumption of shrimp (Brown-Vuillemin et al. 2022).

Samples of redfish for gut analyses were collected in 2021 from commercial fishery operations in the Labrador Sea (SFA 4, 5, and 6). In total, 294 stomach contents were analyzed from three redfish size classes (Table 7). Size classes used to characterize diet of juvenile redfish were determined from the 2021 distribution of juvenile redfish collected in the Eastern and Western Assessment Zones (Figure 16).

Juvenile redfish diets consisted almost solely of pelagic prey (Table 8). The total weight of the meal increased nearly 4 fold (from 49.3 mg to 182.9 mg) between the smallest (50–85 mm) and medium sized (86–120 mm) fish, however, it did not increase as much for the fish in the largest size category (121–229 mm; 187.6 mg). The smallest fish in our study (50–85 mm) fed primarily on Copepods with emphasis on *C. hyperboreus*. The medium size fish (86–120 mm) increased the contribution of Amphipods and Mysids in their diet. Redfish of the largest size class (121–229 mm) fed again on Copepods, with *C. hyperboreus* being the main diet item.

The emergence of the large biomass of juvenile redfish in 2020 has resulted in the re-appearance of planktivorous species that will compete with other zooplankton consumers, including various pelagic stages of demersal fishes, pelagic fish species (such as Arctic Cod) as well as scavengers such as shrimp. While redfish larger than 20 cm have been shown to actively feed on shrimp (Pedersen and Riget 1993), the indirect effect of competition for resources with shrimp may also have a negative impact on shrimp stocks.

For 2019–2022, the total number of redfish was estimated following the same protocol as shrimp biomass (Section 2.2.1.2), although using numbers per trawl instead of weight. Similar to patterns in biomass, redfish numbers increased from 2019 to 2021. While biomass increased by a large margin in 2022, redfish counts decreased indicating an increase in the size of individual fish. Using these count estimates and the assumption that each juvenile redfish consumes one meal a day (Lee et al. 2000), annual zooplankton consumption in 2022 can be estimated at 2.26 g dry weight/m^2 or 1.13 g C /m^2 which corresponds to an approximate removal of 20% zooplankton available in the water (5.73 g Carbon/ m^2; Darnis et al. 2022). 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.

Predator Diet Analysis

This preliminary analysis of predator diets provided a summary of data collected to date and helped to identify predator species and areas of interest that may require more data collection as the study continues. In total, 2,704 predator stomachs from 12 predator taxa were examined for this analysis from the 2018–2021 NSRF surveys including: 38 Atlantic Cod, 1,423 Greenland Halibut, 258 Grenadier (*Macrourus berglax*), 171 American Plaice, 398 Redfish (*Sebastes* sp., *S. mentella*, *S. norvegicus*, and *S. fasciatus*), and 416 Skates (Rajidae family, *Raja* sp., *Amblyraja radiata*, and *A. hyperborea*). Prey items were identified from a total of 11 phyla and 15 classes with additional categories of unidentified material, empty, and everted stomachs (Table 9). The highest diversity of prey items were found in Grenadier and Greenland Halibut stomachs with 23 and 22 taxonomic categories, respectively (excluding unidentified material, empty and everted). Redfish and Atlantic Cod had the lowest diversity of prey items with 11 and 9 taxonomic categories respectively.

The relative proportion of pandalid prey items within predator groups remained consistent across years (Figure 17). Pandalid prey items were present in all length classes of Atlantic Cod examined (25–30 to 50–55 cm), though notably this predator category had the least number of samples (n = 38; Figure 18). For all other predator groups pandalid prey items were present in distinct length classes; Greenland Halibut (20–25 to 65–70, and 75–80 cm), American Plaice (20–25 and 30–35 cm), Redfish (25–30 to 35–40 cm), Grenadiers (30–35 to 55–60 cm), and Skates (15–20 to 50–55 cm; Figure 18).

The proportion of non-empty Greenland Halibut stomachs containing *P. borealis*, *P. montagui*, and mixed pandalids varied between assessment areas (Figure 19). *Pandalus borealis* was the dominant pandalid prey item in the EAZ and SFA 4. As predator size increased the proportion of *P. montagui* also increased and, in the EAZ, *P. montagui* surpassed *P. borealis* as the dominant pandalid prey item in the largest length category (60–80 cm). This shift may be representative of the overlapping habitats between *P. montagui* and larger Greenland Halibut. *Pandalus montagui* was the dominant pandalid prey item for all length categories in the WAZ.

The average number of *P. borealis* found in predator stomachs was between 1 and 5.5 (SD = 0 to 4.7; Table 10). *Pandalus borealis* was found in stomachs of Greenland Halibut from most length categories (20–25 to 60–65 and 75–80 cm). For the other predator groups, *P. borealis* was found in the following length categories: Atlantic Cod (25–30 to 50-55 cm), Grenadier (30–35 and 50–55 cm), and Skates (15–20 to 25–30, and 40–45 to 45–50 cm). Although the sample size was small, Atlantic Cod had both the largest mean number of *P. borealis* and largest standard deviation. Unlike the other species where the range in number of prey items was relatively narrow, Atlantic Cod had up to 12 shrimp in a single stomach.

The average number of *P. montagui* found in predator stomachs was between 1 and 1.6 (SD = 0–0.9; Table 11). *Pandalus montagui* was found in stomachs of Greenland Halibut from all length categories (15–20 to 75–80 cm). For the other predator groups *P. montagui* was found in the following length categories: Atlantic Cod (50–55 cm), Grenadier (35–40 and 55–60 cm), and Skates (15–20 to 25–30, and 40–45 to 45–50 cm).

CONCLUSIONS

The 2023 assessment used annual data (i.e., biomass indices and exploitation rates) to evaluate four Pandalid stocks within their respective PA frameworks. Although the current assessment framework does not directly incorporate ancillary environmental data into the PA framework, additional information regarding habitat (i.e., bottom temperature and salinity), competition from emerging redfish, and predation pressure were presented in order to provide a broad ecosystem context.

Overall, both *P. borealis* and *P. montagui* stocks in the EAZ and WAZ have demonstrated considerable volatility over their respective biomass time series. The 2022 fishable biomass estimates placed *P. montagui* in the EAZ, *P. borealis* in the WAZ and *P. montagui* in the WAZ within the healthy zone of the PA, while *P. borealis* in the EAZ fell within the cautious zone.

It is believed that the available shrimp habitat is shaped, to a great extent, by the oceanographic conditions present in the area. The ocean climate in the NW Atlantic experiences fluctuations at decadal time scales, with potential impacts on availability of optimal Pandalid habitat and/or predator-prey interactions in the EAZ/WAZ. In 2022, bottom temperatures in the EAZ were lower than the 2006–2021 average for the first time since 2017, while in the WAZ, they remained higher than the average after the record high observed in 2021.

The emergence of a large biomass of juvenile redfish in the EAZ over the last three years has been identified as one such 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 known. Quantification of *P. montagui* and *P. borealis* as a prey in the EAZ and WAZ is ongoing. A qualitative overview of gut data from six predator taxa collected between 2018 and 2021 provided a preliminary look at potential trends in the size and species of Pandalid predators.

Overall drivers of stock variability are poorly understood and research is needed on foraging (e.g., water column productivity estimates), ecosystem linkages (e.g., stable isotopes and fatty acids that connect various food chain elements), predation pressure (e.g., gut contents of shrimp predators), and recruitment (larval dispersal) in order to provide a more comprehensive stock assessment.

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TABLES AND FIGURES

Table 1. Limit Reference Points (LRP) and proposed Upper Stock Reference (USR), in tonnes, for Pandalus borealis *and* Pandalus montagui *in the Eastern and Western Assessments Zones from DFO (2020).*

Species	Eastern LRP	Eastern USR (proposed)	Western LRP	Western USR (proposed)
Pandalus borealis	15,800	31,600	4,100	8,200
Pandalus montagui	3,100	6,100	12,300	24,600

Table 2. Total, Fishable and Female Spawning Stock Biomass index estimates for Pandalus borealis *in the Eastern Assessment Zone for the 2009–2022 surveys (in tonnes). LCL and UCL are the lower and upper confidence limits defining the 95% confidence interval. Year over year (YOY) change indicates the relative change in comparison to the previous year.*

Year	Biomass	YOY change (%)	Weight (tonnes)		
			Biomass	LCL	UCL
2022	Total	-28.4	37,912	28,186	48,983
2021	Total	-38.1	52,975	35,576	74,162
2020	Total	-10.3	85,528	26,679	175,816
2019	Total	102.6	95,367	48,333	146,788
2018	Total	19.0	47,079	36,493	58,788
2017	Total	-41.9	39,549	30,394	49,037
2016	Total	-15.4	68,079	44,318	96,479
2015	Total	56.5	80,458	52,380	108,696
2014	Total	2.0	51,410	39,659	63,161
2013	Total	-17.3	50,421	38,679	61,927
2012	Total	-26.9	60,985	43,497	80,408
2011	Total	16.1	83,462	23,956	143,793
2010	Total	-11.6	71,887	41,392	108,846
2009	Total	-	81,363	51,479	113,556
2022	Fishable	-29.8	36,911	27,548	47,900
2021	Fishable	-40.5	52,617	35,405	73,870
2020	Fishable	-7.1	88,361	26,090	170,892
2019	Fishable	102.8	95,138	48,333	146,788
2018	Fishable	19.6	46,900	36,344	58,928
2017	Fishable	-40.2	39,198	30,225	48,907
2016	Fishable	-17.0	65,570	42,137	93,569
2015	Fishable	56.5	78,984	50,852	106,962
2014	Fishable	1.5	50,458	38,914	62,340
2013	Fishable	-17.9	49,697	38,427	60,631
2012	Fishable	-22.9	60,534	43,074	79,960
2011	Fishable	10.5	78,530	23,900	135,037
2010	Fishable	-9.8	71,065	40,234	108,703
2009	Fishable	-	78,755	48,850	110,115
2022	Female SS	-32.1	23,771	17,810	30,820
2021	Female SS	-41.6	35,000	23,322	48,492
2020	Female SS	4.9	59,935	17,534	125,168
2019	Female SS	74.0	57,143	28,420	87,654
2018	Female SS	32.4	32,842	23,548	44,126
2017	Female SS	-28.8	24,800	19,888	30,252
2016	Female SS	-42.8	34,827	24,220	46,979
2015	Female SS	78.7	60,869	33,379	88,386
2014	Female SS	6.3	34,069	25,157	43,000
2013	Female SS	-22.2	32,049	26,762	37,607
2012	Female SS	-13.8	41,190	29,498	54,383
2011	Female SS	9.1	47,807	13,470	82,926
2010	Female SS	12.7	43,800	19,025	79,665
2009	Female SS	-	38,856	23,122	56,820

Table 3. Nominal reported catches (in tonnes) for the Eastern Assessment Zone and Western Assessment Zone for Pandalus borealis *and* P. montagui*. *Catch based on AQMS as of January 20, 2023. Since the fishery is still open the catch is preliminary for 2022.*

Year	Eastern Assessment Zone		Western Assessment Zone	
	P. borealis	***P. montagui***	***P. borealis***	***P. montagui***
2022	7,145	1,419	318	11,195
2021	8,359	965	1,245	8,106
2020	6,165	447	1,438	7,841
2019	5,508	225	1,612	8,114
2018	6,198	234	1,307	5,531
2017	6,488	233	918	5,609
2016	6,667	358	643	5,660
2015	4,816	59	353	4,616
2014	4,972	401	847	5,836
2013	6,793	1,075	973	4,775
2012	5,555	1,173	13	1,105
2011	7,687	135	0	857
2010	6,908	483	57	345
2009	5,159	564	0	0
2008	5,184	808	0	0
2007	6,359	1,832	0	0
2006	6,028	925	0	0
2005	6,387	1,427	-	0
2004	5,842	2,301	-	0
2003	5,617	1,217	-	0
2002	5,695	3,081	-	0
2001	6,275	3,867	-	0
2000	5,718	4,238	-	0
Avg. 1995–99	4,533	3,288	-	0
Avg. 1990–94	904	190	-	1
Avg. 1985–89	1,211	470	-	5
Avg. 1979–84	93	28	-	5

Table 4. Total, Fishable and Female Spawning Stock Biomass index estimates for Pandalus montagui *in the Eastern Assessment Zone for the 2009–2022 surveys (in tonnes). LCL and UCL are the lower and upper confidence limits defining the 95% confidence interval. Year over year (YOY) change indicates the relative change in comparison to the previous year.*

Year	**Biomass**	**YOY change (%)**	**Weight (tonnes)**		
			Biomass	**LCL**	**UCL**
2022	Total	-5.5	14,897	7,657	20,627
2021	Total	-16.3	15,772	5,743	28,306
2020	Total	114.0	18,837	6,803	31,475
2019	Total	-61.8	8,803	3,930	14,275
2018	Total	-13.1	23,028	13,517	33,034
2017	Total	71.9	26,489	18,355	34,636
2016	Total	129.7	15,412	8,206	22,756
2015	Total	-61.9	6,709	3,858	9,346
2014	Total	381.8	17,589	11,922	23,295
2013	Total	-87.8	3,651	1,822	6,367
2012	Total	243.3	29,967	8,922	50,956
2011	Total	11.1	8,729	3,266	16,395
2010	Total	-54.9	7,860	6,089	9,795
2009	Total	-	17,438	7,427	32,323
2022	Fishable	-5.9	14,325	7,195	20,024
2021	Fishable	-19.0	15,225	5,674	27,430
2020	Fishable	121.1	18,802	6,583	31,371
2019	Fishable	-59.3	8,503	3,930	13,948
2018	Fishable	-16.3	20,895	12,617	29,450
2017	Fishable	81.0	24,957	17,246	32,311
2016	Fishable	124.7	13,792	6,452	21,126
2015	Fishable	-63.0	6,137	3,445	8,629
2014	Fishable	371.0	16,600	11,203	22,084
2013	Fishable	-87.8	3,524	1,738	6,208
2012	Fishable	272.7	28,845	8,582	48,946
2011	Fishable	4.3	7,740	2,871	14,285
2010	Fishable	-52.7	7,423	5,714	9,290
2009	Fishable	-	15,679	6,190	29,774
2022	Female SS	-6.9	10,428	4,465	15,564
2021	Female SS	-22.4	11,200	4,073	22,834
2020	Female SS	227.0	14,437	4,392	24,991
2019	Female SS	-68.0	4,415	1,742	7,275
2018	Female SS	-19.8	13,806	9,362	20,052
2017	Female SS	64.4	16,537	9,866	23,250
2016	Female SS	159.4	10,056	2,986	17,280
2015	Female SS	-69.5	3,877	2,085	5,452
2014	Female SS	357.1	12,696	8,834	16,622
2013	Female SS	-88.2	2,778	1,301	4,949
2012	Female SS	653.8	23,552	6,218	40,985
2011	Female SS	-46.3	3,124	1,599	4,721
2010	Female SS	-33.7	5,819	4,509	7,136
2009	Female SS	-	8,776	4,205	13,955

Table 5. Total, Fishable and Female Spawning Stock Biomass index estimates for Pandalus borealis *in the Western Assessment Zone for the 2014–2022 surveys (in tonnes). LCL and UCL are the lower and upper confidence limits defining the 95% confidence interval. Year over year (YOY) change indicates the relative change in comparison to the previous year.*

Year	Biomass	YOY change (%)	Weight (tonnes)		
			Mean	LCL	UCL
2022	Total	37.3	27,168	15,676	41,254
2021	Total	-39.7	19,784	11,287	29,324
2020	Total	58.9	32,835	15,499	57,356
2019	Total	-7.6	20,662	13,090	29,082
2018	Total	99.8	22,373	12,703	36,281
2017	Total	-18.4	11,198	5,133	18,729
2016	Total	-55.6	13,725	8,079	19,955
2015	Total	36.4	30,930	20,258	42,366
2014	Total	-	22,674	14,640	32,979
2022	Fishable	19.9	23,939	13,476	37,179
2021	Fishable	-42.8	19,967	11,230	29,631
2020	Fishable	71.4	34,929	14,867	52,744
2019	Fishable	-3.4	20,378	12,852	29,080
2018	Fishable	101.0	21,088	12,627	33,452
2017	Fishable	-20.0	10,487	5,073	17,185
2016	Fishable	-54.0	13,116	7,867	18,868
2015	Fishable	31.4	28,532	18,531	39,501
2014	Fishable	-	21,713	14,353	31,046
2022	Female SS	12.9	15,899	8,948	24,431
2021	Female SS	-19.8	14,083	7,076	22,531
2020	Female SS	48.2	17,555	8,943	27,150
2019	Female SS	-8.1	11,845	7,529	16,299
2018	Female SS	147.0	12,884	7,121	19,203
2017	Female SS	-34.9	5,216	3,045	7,676
2016	Female SS	-45.5	8,015	4,780	11,590
2015	Female SS	19.5	14,710	9,270	20,379
2014	Female SS	-	12,309	8,792	16,398

Table 6. Total, Fishable and Female Spawning Stock Biomass index estimates for Pandalus montagui *in the Western Assessment Zone for the 2014–2022 surveys (in tonnes). LCL and UCL are the lower and upper confidence limits defining the 95% confidence interval. Year over year (YOY) change indicates the relative change in comparison to the previous year.*

Year	Biomass	YOY change (%)	Weight (tonnes)		
			Mean	LCL	UCL
2022	Total	112.5	140,377	87,318	198,406
2021	Total	22.9	66,061	43,525	89,314
2020	Total	-17.9	53,733	23,151	94,916
2019	Total	-28.5	65,418	30,900	111,457
2018	Total	92.5	91,497	38,445	147,587
2017	Total	34.4	47,543	30,111	67,087
2016	Total	-50.3	35,385	22,276	49,582
2015	Total	-17.9	71,209	40,881	108,035
2014	Total	-	86,739	50,609	125,916
2022	Fishable	61.1	104,737	67,777	143,958
2021	Fishable	27.7	65,026	42,563	89,148
2020	Fishable	-20.8	50,911	22,199	90,802
2019	Fishable	-19.5	64,268	29,711	112,173
2018	Fishable	77.7	79,835	34,057	132,111
2017	Fishable	41.6	44,915	29,179	63,381
2016	Fishable	-42.5	31,724	19,507	44,908
2015	Fishable	-28.4	55,194	35,769	76,429
2014	Fishable	-	77,078	44,854	111,562
2022	Female SS	63.3	61,058	38,042	87,351
2021	Female SS	39.5	37,398	24,651	50,850
2020	Female SS	-7.8	26,811	12,310	46,349
2019	Female SS	-39.2	29,079	14,930	45,581
2018	Female SS	57.8	47,834	19,926	81,534
2017	Female SS	62.1	30,305	18,830	43,434
2016	Female SS	-31.6	18,691	11,090	27,334
2015	Female SS	-29.7	27,324	18,282	37,041
2014	Female SS	-	38,875	23,553	55,849

Table 7. Number of stomachs analysed and empty stomachs in each size class (mm) of juvenile redfish caught during 2021 commercial fishery operations in SFA 4,5 and 6 (Labrador Sea).

Size class (mm, fork length)	**50-85**	**86–120**	**121–229**
Stomachs analyzed	86	183	25
Empty stomachs	43	91	11

Table 8. List of taxa consumed, average weights (mg, wet weight) of each taxon and average relative abundance of each food item found in juvenile redfish in 2021. Samples originate from commercial shrimp operations in Labrador Sea (SFA 4,5,and 6).

Size class (mm, fork length)	**50-85**		**86–120**		**121–229**	
Juvenile redfish diet	**Gut content (mg, ww)**	**%**	**Gut content (mg, ww)**	**%**	**Gut content (mg, ww)**	**%**
Mysids:						
Boreomysis arctica	9.6	19.5	50.2	27.4	0.0	0.0
Copepods:						
Calanus hyperboreus	18.6	37.7	23.3	12.7	154.7	82.5
Paraeuchaeta glacialis	8.2	16.6	5.5	3.0	11.6	6.2
Metridia longa	3.1	6.2	2.9	1.6	0.1	0.0
Amphipods:						
Themisto libellula	9.0	18.2	85.1	46.5	14.3	7.6
Euphausids:						
Thysanoessa spp.	0.2	0.3	15.1	8.3	4.5	2.4
Other:						
Calanus finmarchicus	0.5	1.1	0.2	0.1	0.3	0.2
Copepoda ndet.	0.0	0.0	0.1	0.1	0.8	0.4
Crustacea ndet. (fragments)	0.0	0.0	0.0	0.0	0.0	0.0
Gaetanus tenuispinus	0.0	0.0	0.0	0.0	0.0	0.0
Gammarus oceanicus	0.0	0.0	0.0	0.0	0.0	0.0
Heterorhabdus norvegicus	0.0	0.0	0.0	0.0	0.0	0.0
Meganyctiphanes norvegica	0.0	0.0	0.0	0.0	0.0	0.0
Mysida *(Mysis* sp.*)*	0.1	0.2	0.0	0.0	0.0	0.0
Pandalus borealis	0.0	0.0	0.0	0.0	0.0	0.0
Pandalus spp.	0.1	0.2	0.0	0.0	0.0	0.0
Pasiphea multidentata	0.0	0.0	0.5	0.3	0.0	0.0
Pasiphea tarda	0.0	0.0	0.0	0.0	1.3	0.7
Rozinante fragilis	0.0	0.0	0.0	0.0	0.0	0.0
Parasagitta elegans	0.0	0.0	0.0	0.0	0.0	0.0
Grand Total	**49.3**	**100.0**	**182.9**	**100.0**	**187.6**	**100.0**

Table 9. Number of stomachs containing each prey taxa for six predator species. All years (2018–2021) and predator sizes are aggregated. Cod, Halibut, and Plaice categories represent a single species (Atlantic Cod, Greenland Halibut and American Plaice respectively) while Grenadier, Redfish and Skate categories are an aggregation of multiple species. Phylum labeled as 'Unidentified" refers to stomach contents that were biological in nature, but not identifiable to phylum. Class levels denoted with a – indicate no identification beyond Phylum level was completed. Malacostraca counts do not include Pandalus species as they are presented separately as a distinct grouping.

Phylum	Class	Cod (n = 38)	Grenadier (n = 258)	Halibut (n = 1422)	Plaice (n = 169)	Redfish (n = 398)	Skate (n = 416)
Annelida	Polychaeta	2	36	5	1	-	63
	-	-	9	-	4	-	16
Arthropoda	Copepoda	-	3	3	-	32	6
	Malacostraca	9	150	650	14	96	311
	P. borealis	29	16	101	6	2	43
	P. montagui	1	6	65	3	1	8
	Pandalus spp.	14	4	16	-	2	9
	Pycnogonida	-	1	1	-	-	-
	-	2	45	121	3	44	109
Bryozoa	-	-	3	2	2	-	-
Chordata	Teleostei	7	18	236	13	7	27
	Unidentified fish	17	20	225	14	20	89
Cnidaria	Anthozoa	-	4	1	-	-	-
	Hydrozoa	-	3	-	-	-	-
	-	-	-	1	-	-	-
Echinodermata	Asteroidea	-	-	1	-	1	-
	Echinoidea	-	2	1	1	-	-
	Holothuroidea	-	1	1	1	-	-
	Ophiuroidea	-	26	4	38	-	5
Foraminifera	Monothalamea	-	5	1	-	-	2
Mollusca	Bivalvia	-	6	-	5	1	-
	Cephalopoda	2	3	42	2	11	30
	-	-	22	1	1	-	1
Nemertea	-	-	-	-	-	-	7
Porifera	Demospongiae	-	1		-	-	-
	-	-	1	5	-	-	-
Priapulida	-	-	-	1	-	-	1
Unidentified	-	8	113	222	10	28	202
Empty	-	-	39	458	86	144	44
Everted	-	-	8	-	-	111	-

Table 10. Average number of Pandalus borealis *in stomachs of four predator species, aggregated by 5 cm length bins. Cod and Halibut represent a single species (Atlantic Cod and Greenland Halibut respectively) while Grenadier and Skate categories are an aggregation of multiple species. Means do not include zero values. Standard deviation (SD) is in brackets; (-) denotes no SD available as there was only a single observation.*

Length bin (cm)	Cod (n = 17)	Grenadier (n = 13)	Halibut (n = 74)	Skate (n = 28)
15–20	-	-	-	-
20–25	-	-	1.0 (0.0)	1.3 (0.6)
25–30	4.0 (-)	-	1.0 (0.0)	1.0 (0.0)
30–35	1.0 (0)	1.0 (-)	1.1 (0.3)	1.0 (0.0)
35–40	2.0 (-)	2.0 (-)	1.5 (0.9)	1.5 (0.6)
40–45	1.0 (0)	1.2 (0.4)	1.3 (0.5)	1.4 (1.1)
45–50	5.5 (4.7)	1.0 (0.0)	1.8 (1.0)	1.0 (0.0)
50–55	3.0 (2.4)	1.0 (0.0)	1.0 (0.0)	1.0 (-)
55–60	-	-	1.5 (0.7)	-
60–65	-	-	1.0 (0.0)	-
65–70	-	-	-	-
75–80	-	-	1.0 (-)	-

Table 11. Average number of Pandalus montagui *in stomachs of four predator species, aggregated by 5 cm length bins. Cod and Halibut represent a single species (Atlantic Cod and Greenland Halibut respectively) while Grenadier and Skate categories are an aggregation of multiple species. Means do not include zero values. SD is in brackets; (-) denotes no SD available as there was only a single observation.*

Length bin (cm)	Cod (n = 1)	Grenadier (n = 3)	Halibut (n = 43)	Skate (n = 5)
15–20	-	-	1.0 (-)	1.0 (-)
20–25	-	-	1.0 (0.0)	1.0 (-)
25–30	-	-	1.0 (0.0)	1.0 (-)
30–35	-	-	1.4 (0.8)	-
35–40	-	1.5 (0.7)	1.2 (0.4)	-
40–45	-	-	1.6 (0.9)	1.0 (-)
45–50	-	-	1.0 (0.0)	1.0 (-)
50–55	1.0 (-)	-	1.0 (0.0)	-
55–60	-	1.0 (-)	1.2 (0.4)	-
60–65	-	-	1.3 (0.6)	-
65–70	-	-	1.3 (0.6)	-
75–80	-	-	1.0 (-)	-

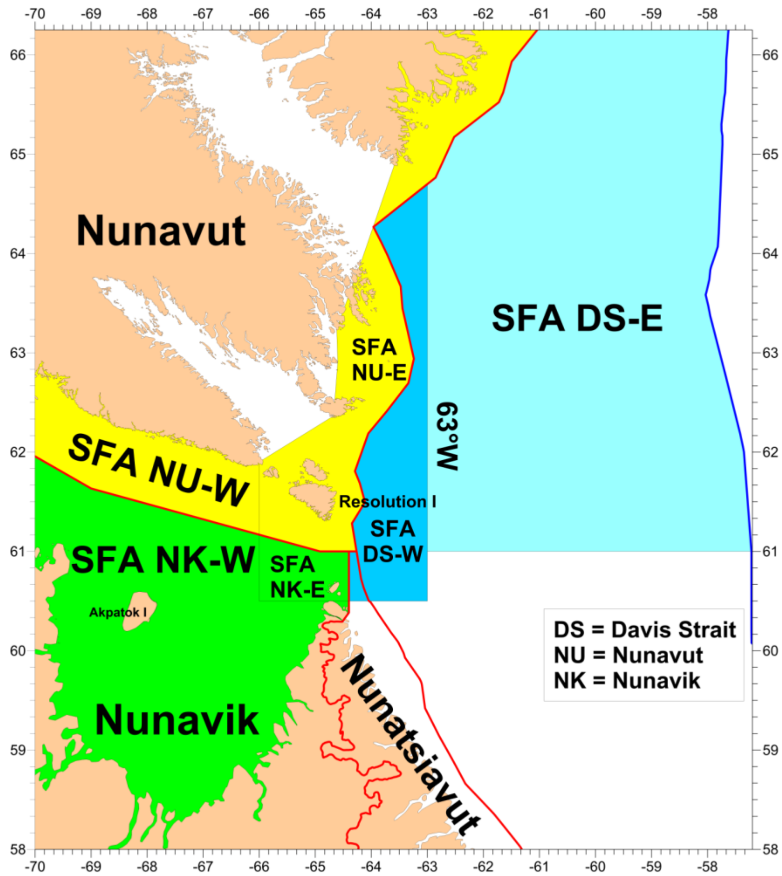

Figure 1. Shrimp Fishing Areas Nunavut (NU), Nunavik (NK) and Davis Strait (DS) and their East and West management units within DFO's Central and Arctic Region

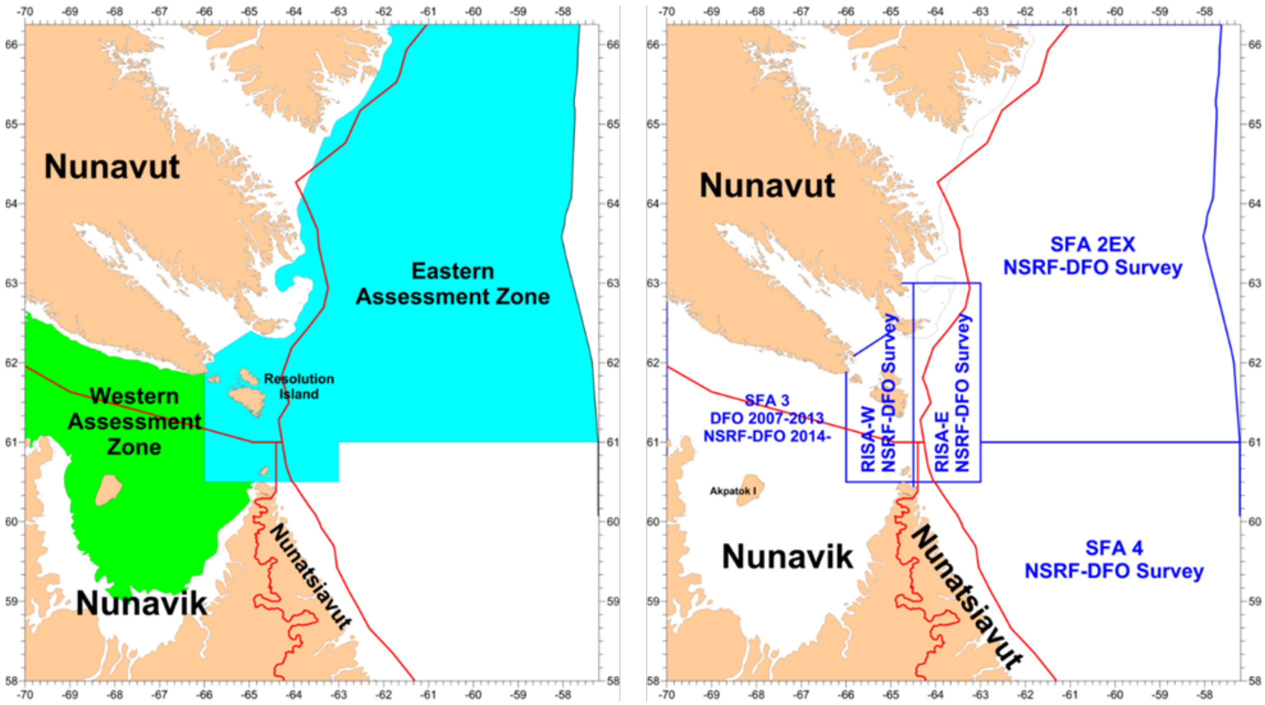

Figure 2. Left: The Eastern (blue) and Western (green) Assessment Zones. Red line shows the borders of the Nunavut, Nunatsiavut and Nunavik Land Claims Areas. Right: Location of the northern survey areas within the Eastern and Western Assessment Zones, Shrimp Fishing Area (SFA) 2 Exploratory (EX), Resolution Island Study Area (RISA)–East (E), RISA–West (W) and SFA 3, used in the assessment of domestic Canadian Pandalid Stocks by the DFO's Central and Arctic Region. SFA 4 is assessed by the DFO's Newfoundland and Labrador Region. Red line shows the borders of the Nunavut, Nunatsiavut and Nunavik Land Claim Areas.

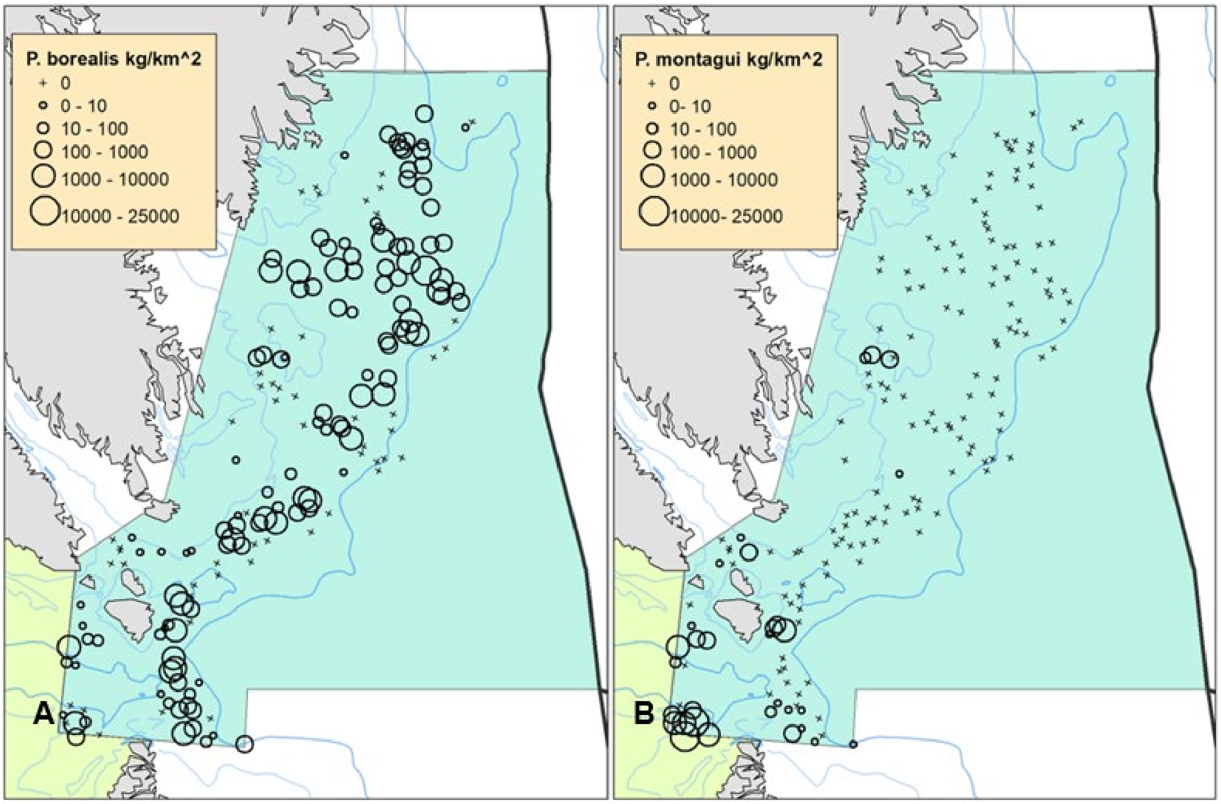

Figure 3. Standardized Pandalus borealis *(A) and* Pandalus montagui *(B) catch (kg km*$^{-2}$*) from the 2022 EAZ survey areas.*

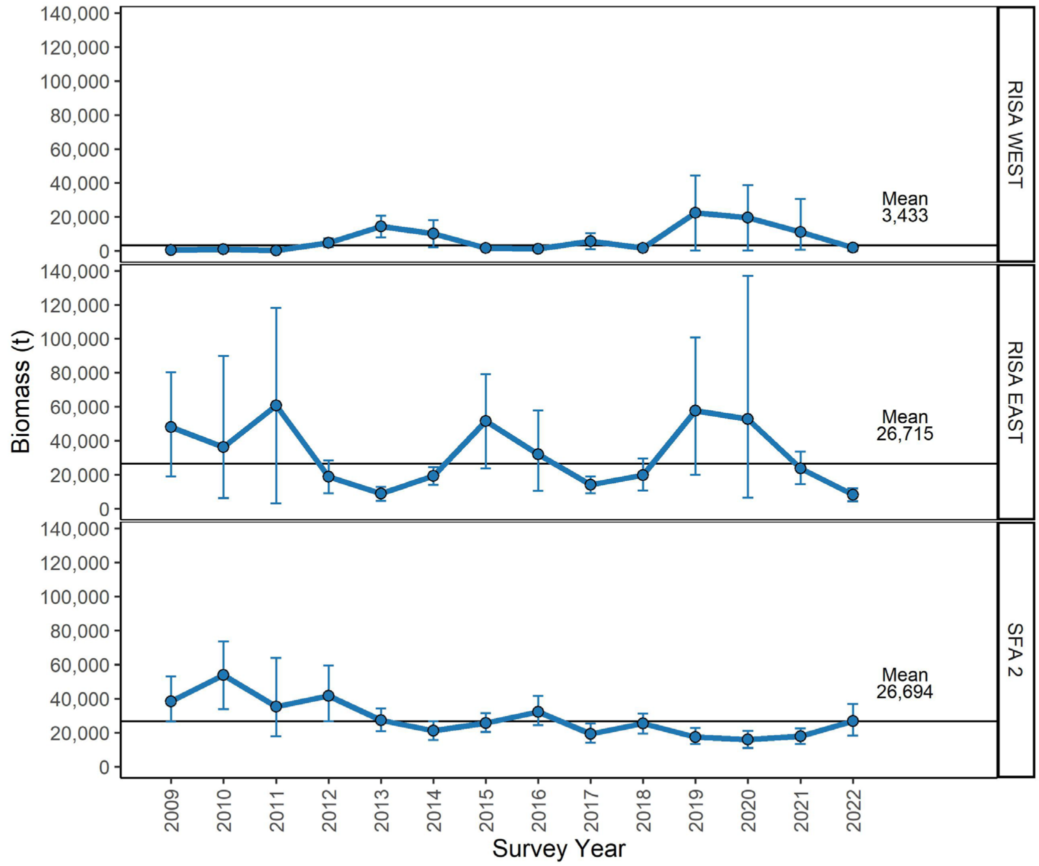

Figure 4. Pandalus borealis *total biomass indices for RISA-W, RISA-E, and SFA 2 for survey years 2009–2022. Error bars are bootstrapped 95% confidence ranges with horizontal lines indicating the geometric mean of the time series.*

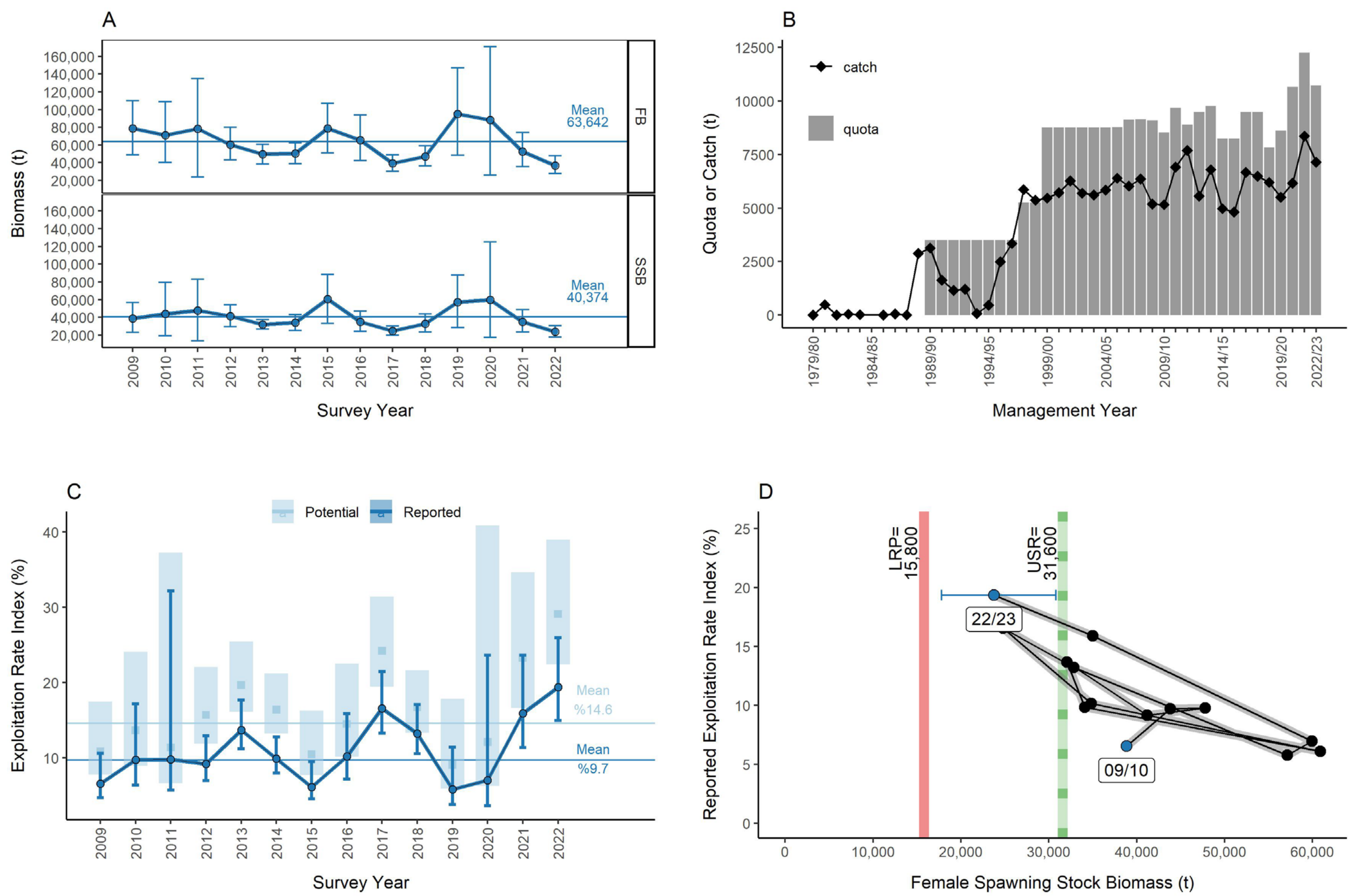

Figure 5. Pandalus borealis *in the Eastern Assessment Zone: A: Fishable biomass (FB, top) and female spawning stock biomass (SSB; bottom) indices for the survey years 2009–2022. Error bars are bootstrapped 95% confidence range and horizontal lines are long-term (2009–2021) geometric means; B: Total Allowable Catch (grey bars) and reported catch from DFO harvest records (black line). Harvest records may be incomplete for 2022/23 (data as of January 20, 2023); C: Exploitation rate indices for management years 2009/10–2022/23 at the reported rate based on the total catch (blue line) and at the potential rate if the TAC was fully harvested (blue shading). Error bars based on bootstrapped 95% confidence ranges of the FB and lines are long-term (2009–2021) geometric means; D: Female spawning stock biomass and reported exploitation rate in reference to Limit Reference Points (LRPs) calculated using the proxy developed in DFO (2020). Dashed green line indicates the proposed Upper Stock Reference (USR) and the solid red line indicates the LRP, each referring to the 80% and 40%, respectively, of the geometric mean of the female spawning stock biomass indices from the 2009–2019 surveys. Since the USR has not been formally accepted, final location of the dashed line is yet to be determined.*

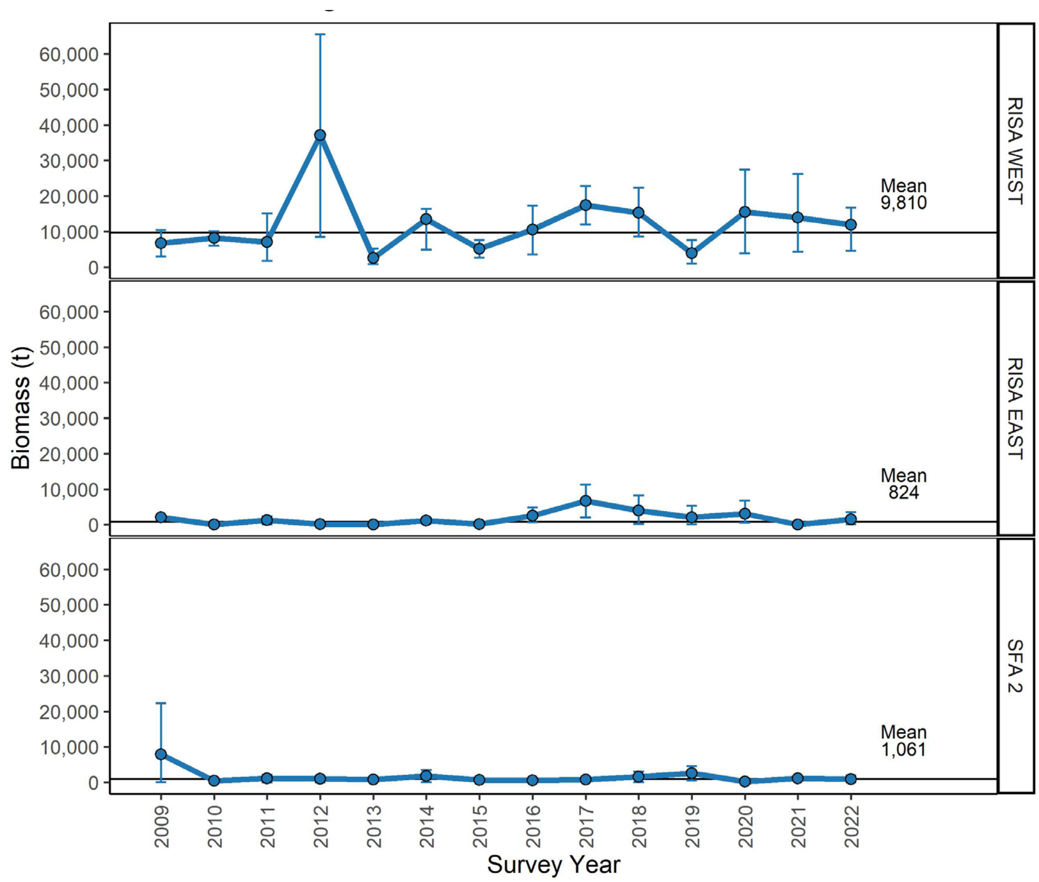

Figure 6. Pandalus montagui *total biomass indices for RISA-W, RISA-E, and SFA 2 for survey years 2009–2022. Error bars are bootstrapped 95% confidence ranges with horizontal lines indicating the geometric mean of the time series.*

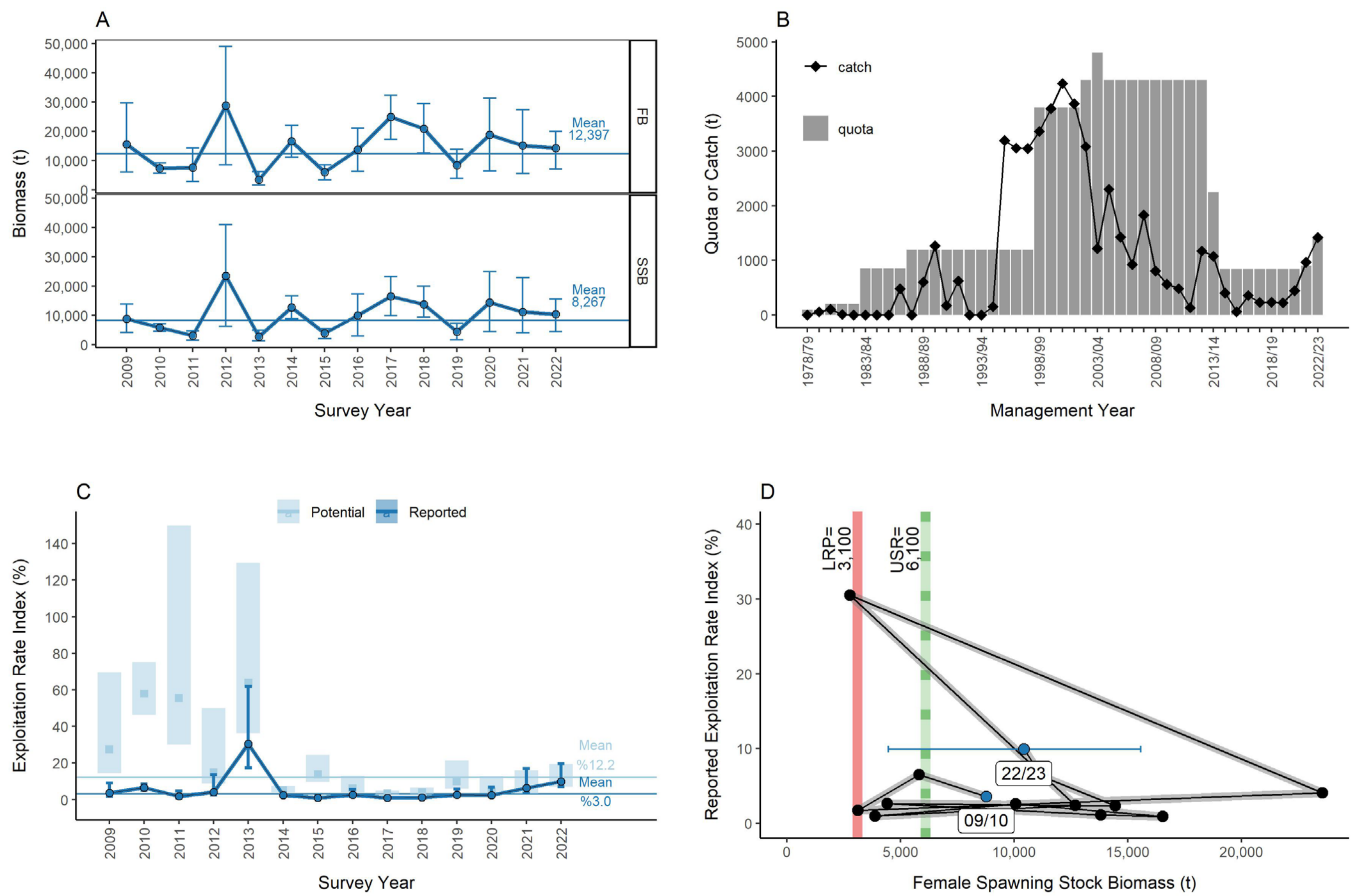

Figure 7. Pandalus montagui *in the Eastern Assessment Zone. A: Fishable biomass (FB, top) and female spawning stock biomass (SSB; bottom) indices for the survey years 2009–2022. Error bars are bootstrapped 95% confidence range and horizontal lines are long-term (2009–2021) geometric means; B: Total Allowable Catch (grey bars) and reported catch from DFO harvest records (black line). Harvest records may be incomplete for 2022/23 (data as of January 20, 2023); C: Exploitation rate indices for management years 2009/10–2022/23 at the reported rate based on the total catch (blue line) and at the potential rate if the TAC was fully harvested (blue shading). Error bars based on bootstrapped 95% confidence ranges of the FB and lines are long-term (2009–2021) geometric means; D: Female spawning stock biomass and reported exploitation rate in reference to Limit Reference Points (LRPs) calculated using the proxy developed in DFO (2020). Dashed green line indicates the proposed Upper Stock Reference (USR) and the solid red line indicates the LRP, each referring to the 80% and 40%, respectively, of the geometric mean of the female spawning stock biomass indices from the 2009–2019 surveys. Since the USR has not been formally accepted, final location of the dashed line is yet to be determined.*

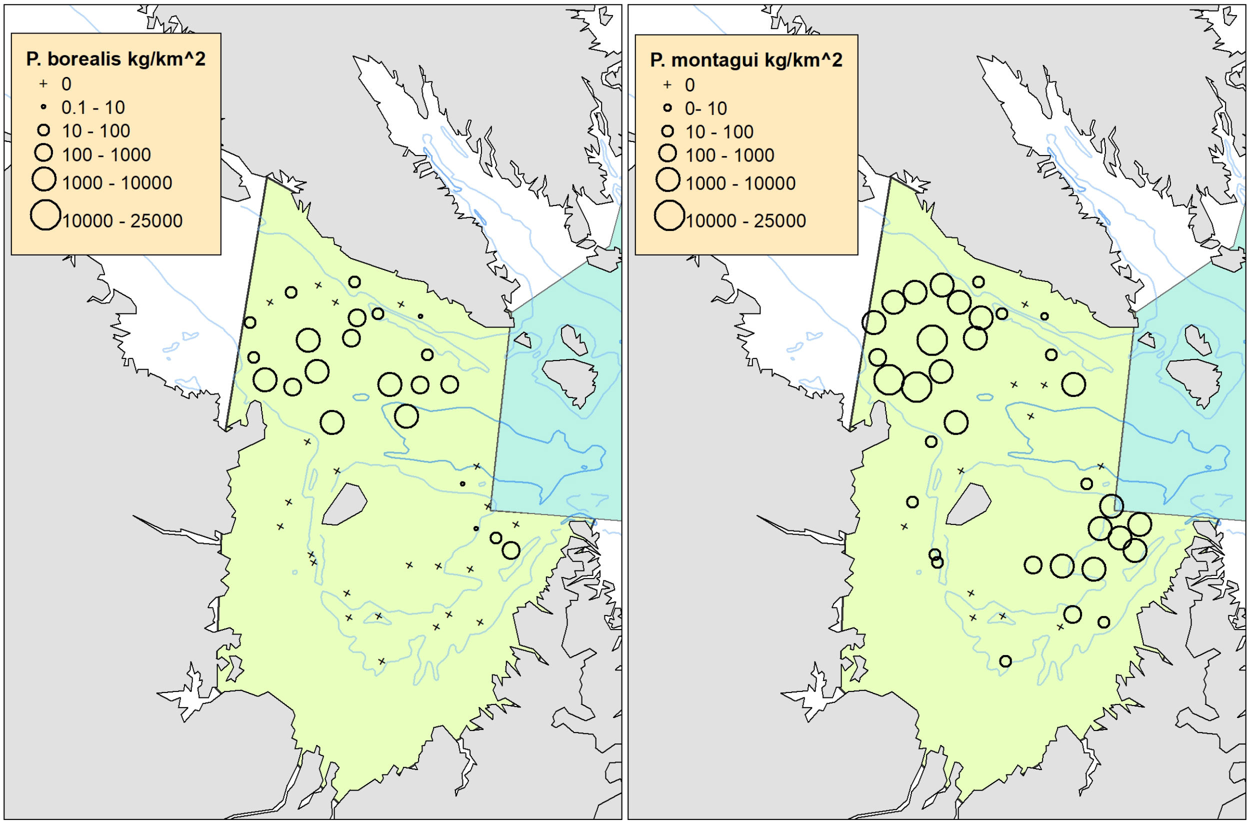

Figure 8. Standardized Pandalus borealis *(A) and* Pandalus montagui *(B) catch (kg km^{-2}) from the 2022 Western Assessment Zone survey area.*

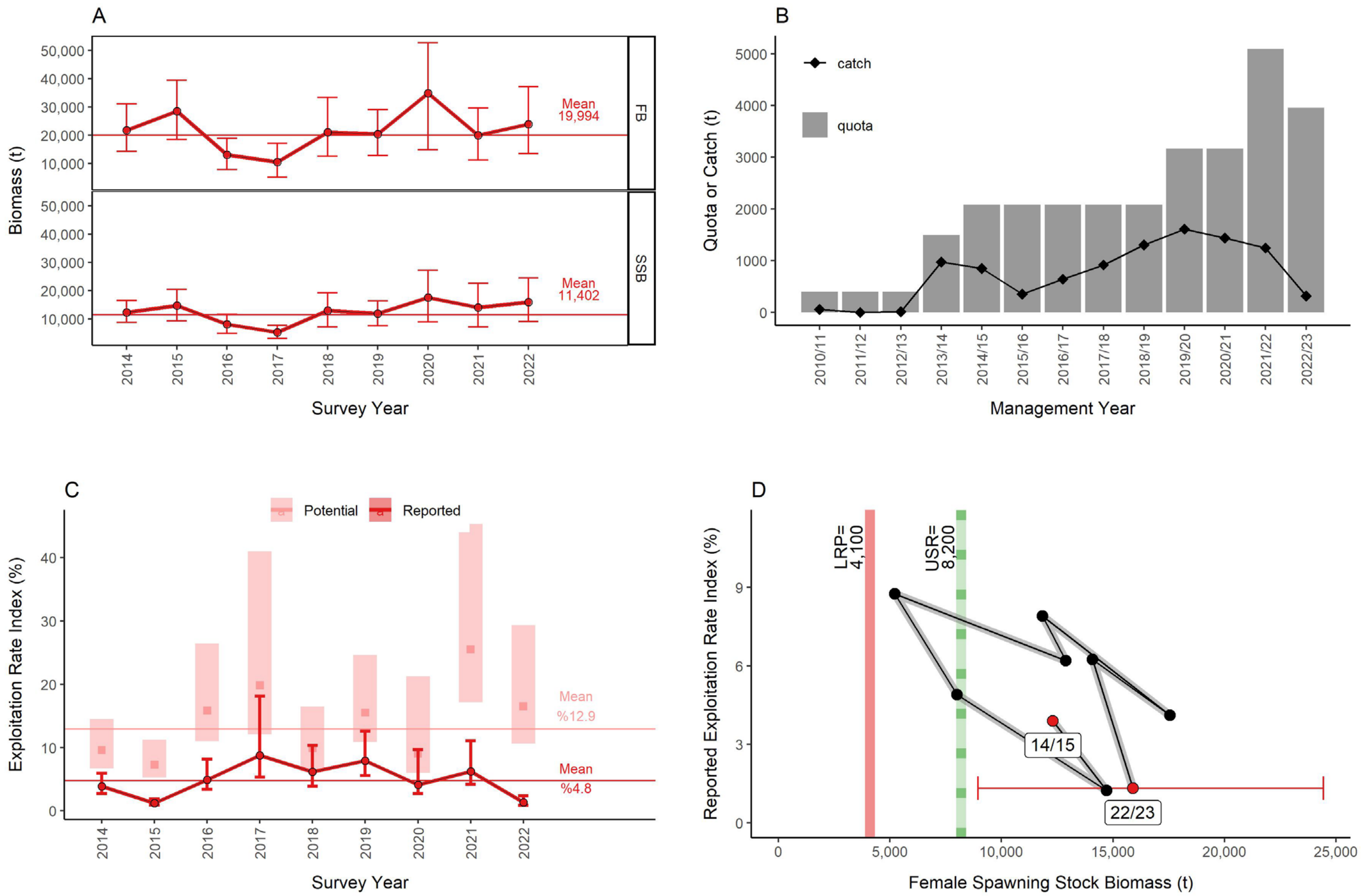

Figure 9. Pandalus borealis *in the Western Assessment Zone. A: Fishable biomass (FB, top) and female spawning stock biomass (SSB; bottom) indices for the survey years 2014–2022. Error bars are bootstrapped 95% confidence range and horizontal lines are long-term (2014–2021) geometric means; B: Total Allowable Catch (grey bars) and reported catch from DFO harvest records (black line). Harvest records may be incomplete for 2022/23 (data as of January 20, 2023); C: Exploitation rate indices for management years 2010/11–2022/23 at the reported rate based on the total catch (red line) and at the potential rate if the TAC was fully harvested (red shading). Error bars based on bootstrapped 95% confidence ranges of the FB and lines are long-term (2014–2021) geometric means; D: Female spawning stock biomass and reported exploitation rate in reference to Limit Reference Points (LRPs) calculated using the proxy developed in DFO (2020). Dashed green line indicates the proposed Upper Stock Reference (USR) and the solid red line indicates the LRP, each referring to the 80% and 40%, respectively, of the geometric mean of the female spawning stock biomass indices from the 2014–2019 surveys. Since the USR has not been formally accepted, final location of the dashed line is yet to be determined.*

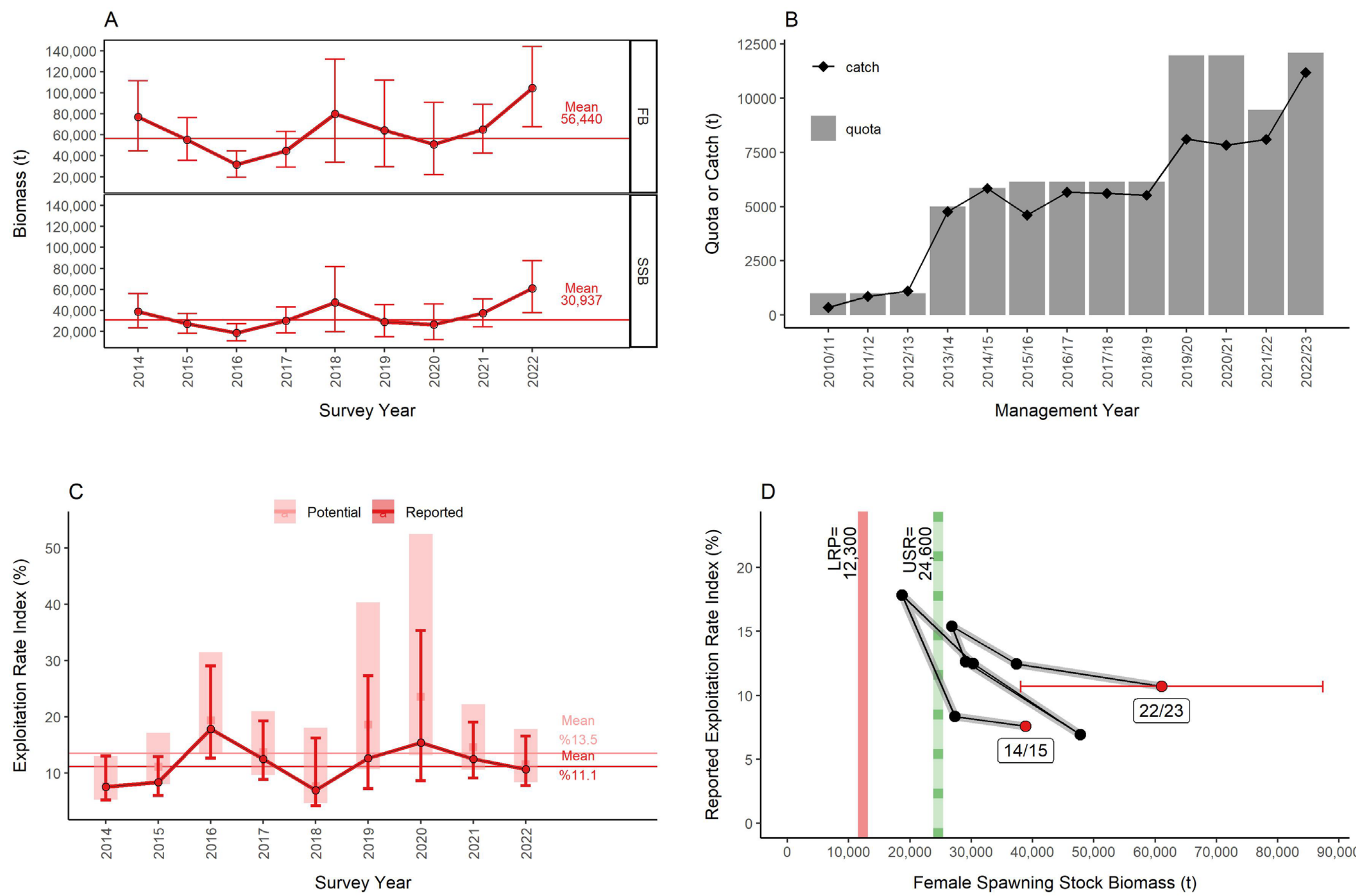

Figure 10. Pandalus montagui *in the Western Assessment Zone. A: Fishable biomass (FB, top) and female spawning stock biomass (SSB; bottom) indices for the survey years 2014–2022. Error bars are bootstrapped 95% confidence range and horizontal lines are long-term (2014–2021) geometric means; B: Total Allowable Catch (grey bars) and reported catch from DFO harvest records (black line). Harvest records may be incomplete for 2022/23 (data as of January 20, 2023); C: Exploitation rate indices for management years 2010/11–2022/23 at the reported rate based on the total catch (red line) and at the potential rate if the TAC was fully harvested (red shading). Error bars based on bootstrapped 95% confidence ranges of the FB and lines are long-term (2014–2021) geometric means; D: Female spawning stock biomass and reported exploitation rate in reference to Limit Reference Points (LRPs) calculated using the proxy developed in DFO (2020). Dashed green line indicates the proposed Upper Stock Reference (USR) and the solid red line indicates the LRP, each referring to the 80% and 40%, respectively, of the geometric mean of the female spawning stock biomass indices from the 2014–2019 surveys. Since the USR has not been formally accepted, final location of the dashed line is yet to be determined*

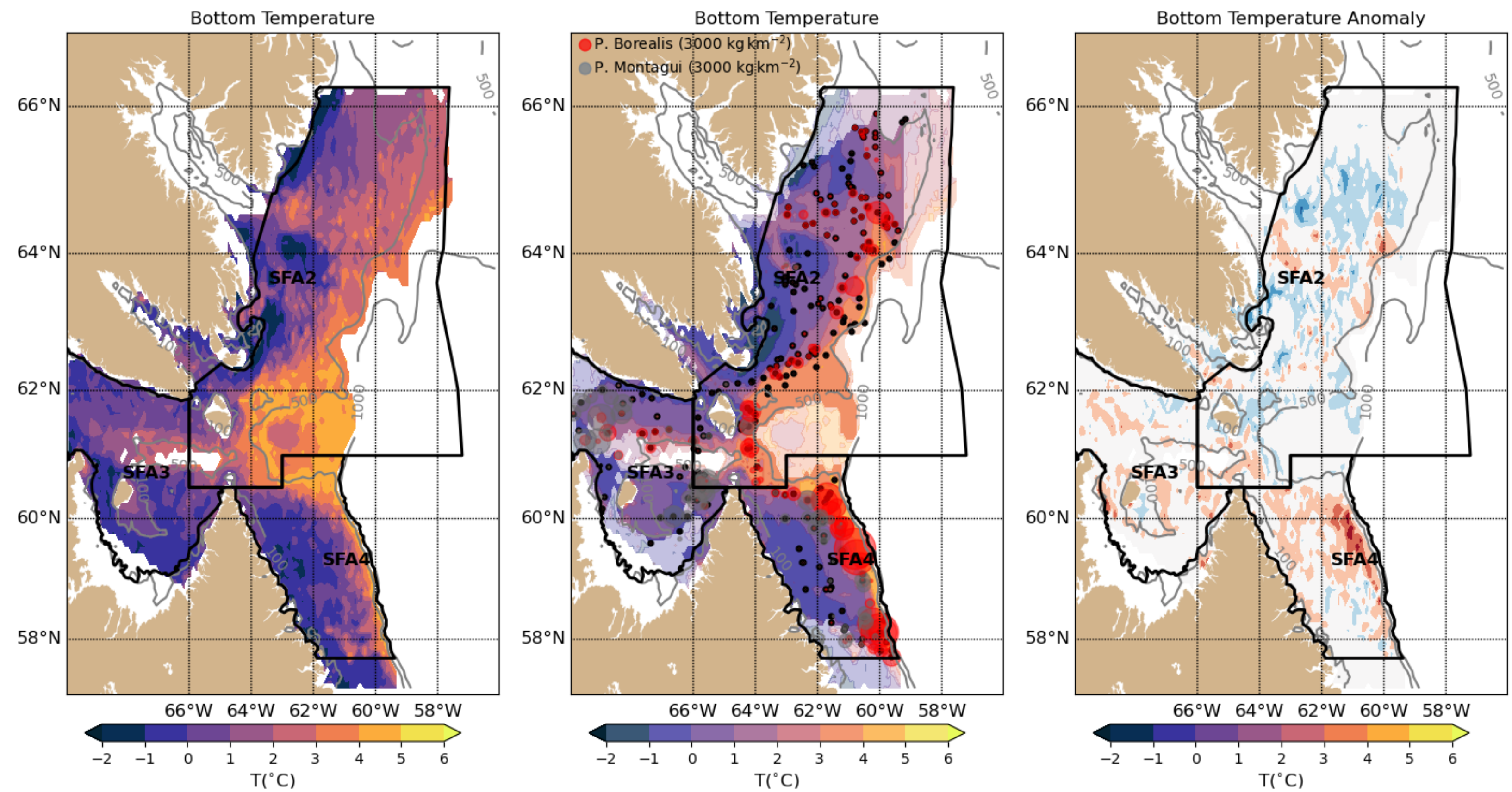

Figure 11. Maps of the climatological (2006–2021) mean summer bottom temperature (left), and summer 2022 bottom temperature (center) and anomalies (right) for SFA 2–4. The location of observations used to derive the temperature field is shown as black dots in the center panel. In areas where the spatial 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.*

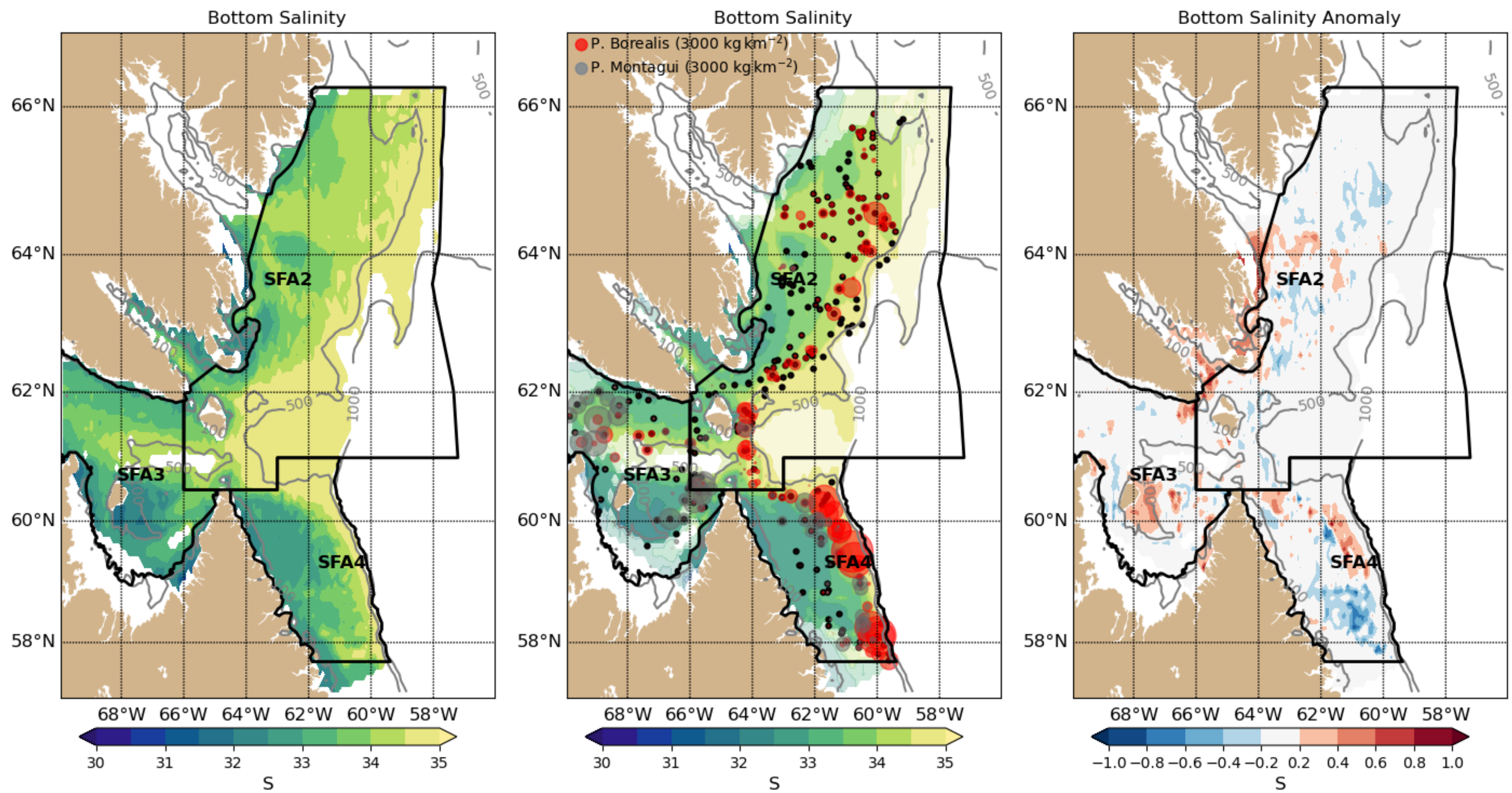

Figure 12. Maps of the climatological (2006–2021) mean summer bottom salinity (left), and summer 2022 bottom salinity (center) and anomalies (right) for SFA 2–4. The location of observations used to derive the salinity field is shown as black dots in the center panel. In areas where the spatial interpolation 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 research survey is also shown with red and gray circles, respectively.*

	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	x̄	sd
	-- SFA2 / EAZ --																		
T_{bot}	-0.4	-0.2	-0.4	-1.6	2.0	1.9	-0.5	-0.1	-0.6	-0.3	-0.7	-0.8	1.1	0.5	-0.2	0.4	-0.6	1.9	0.3
$T_{bot<200m}$	-0.4	-0.5	-0.3	-1.1	1.2	2.7	-0.6	-0.4	-0.2	-0.3	-0.6	-0.9	1.2	0.5	-0.2	0.6	-0.2	-0.7	0.4
$Area_{>2°C}$	-0.2	-0.1	-0.7	-1.4	2.0	1.7	-1.1	-0.3	-0.7	-0.5	0.1	-0.6	1.3	0.6	-0.1	0.7	-0.8	70.4	10.7
$Area_{<1°C}$	0.7	0.4	0.6	1.5	-1.6	-2.0	0.5	0.2	0.9	0.4	0.4	0.4	-1.3	-1.0	0.0	-0.6	0.7	39.6	10.2
	-- SFA3 / WAZ --																		
T_{bot}		0.3		0.3		0.7		0.3	-0.1	0.6	-2.1	-1.7	1.0	0.8	-0.2	2.2	0.9	0.2	0.2
$T_{bot<200m}$		0.4		0.4		0.6		0.6	0.6	0.5	-2.2	-1.5	0.8	0.4	-0.6	2.1	1.2	-0.3	0.2
$Area_{>2°C}$		0.1		0.1		1.2		0.1	-1.3	1.0	-1.8	-1.2	0.3	0.6	0.8	3.9	0.9	3.3	0.7
$Area_{<1°C}$		-0.1		-0.1		-1.2		0.0	0.8	-0.1	1.8	1.4	-1.3	-1.0	-0.2	-1.8	-0.7	44.0	2.7

Figure 13. 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 the EAZ and the WAZ. Each cell is coloured according to the departure from the average (darker reds indicate warmer temperatures, and darker blues indicate colder temperatures). White cells indicates anomalies within ±0.5 SD of the mean, a range considered "normal". Gray cells indicate an absence of data.

	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	x̄	sd
	-- SFA2 / EAZ --																		
S_{bot}	0.5	0.3	-0.3	-1.8	2.1	1.9	-0.3	-0.8	-0.8	-0.2	0.1	-0.5	0.2	0.6	-0.9	0.0	-0.7	34.3	0.1
$S_{bot<200m}$	0.2	0.5	0.4	-1.2	0.7	2.6	-0.3	-1.1	-0.5	0.2	-0.2	-1.1	0.2	0.6	-1.5	0.6	-0.2	33.3	0.1
	-- SFA3 / WAZ --																		
S_{bot}		-0.1		-0.1		0.2		-0.4	-0.5	2.2	0.6	-2.0	-0.4	0.8	-0.6	0.5	0.2	33.2	0.1
$S_{bot<200m}$		-0.2		-0.2		-0.1		-0.4	-0.4	2.5	1.1	-1.5	-0.7	0.5	-0.3	-0.3	0.3	32.6	0.1

Figure 14. Scorecards of normalized anomalies (expressed in terms of standard deviations (SD) above or below average) of summer bottom salinity (mean salinity and mean salinity for area shallower than 200 m) for the EAZ and the WAZ. Each cell is coloured according to the departure from the average (darker reds indicate higher salinity, darker blues indicate lower salinity). White cells indicate anomalies within ±0.5 SD of the mean, a range considered "normal". Gray cells indicate an absence of data.

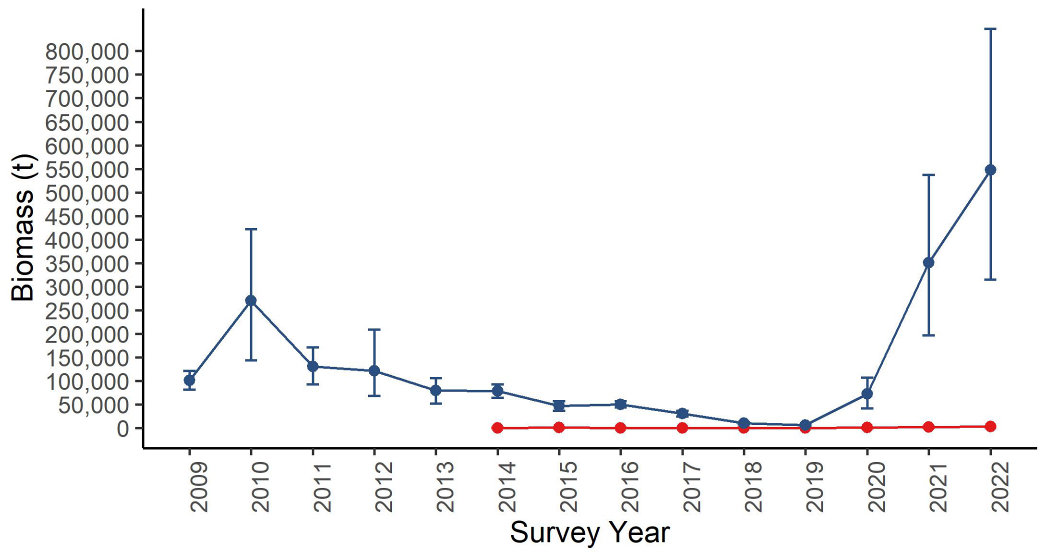

*Figure 15. Redfish (*Sebastes *spp.) biomass index calculated for Eastern and Western Assessment Zones (blue and red lines respectively). The index is based on the results from the shrimp survey and the biomass estimate employs the same principle as for shrimp (i.e., buffered stratified random sampling).*

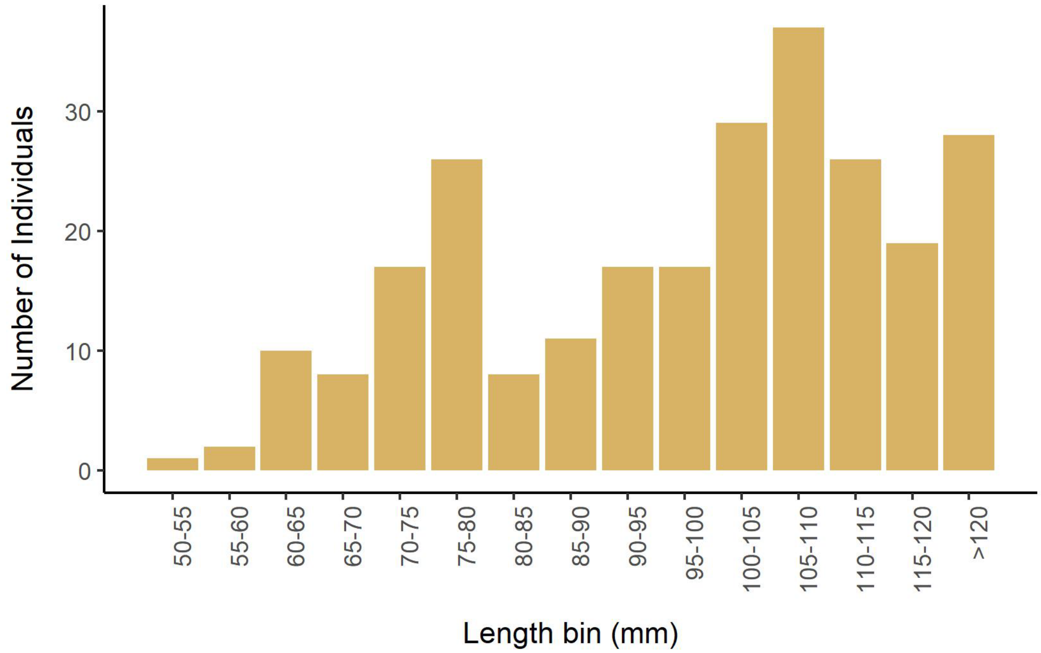

Figure 16. Fork length distribution of Redfish collected in 2021 in Eastern and Western Assessment Zones.

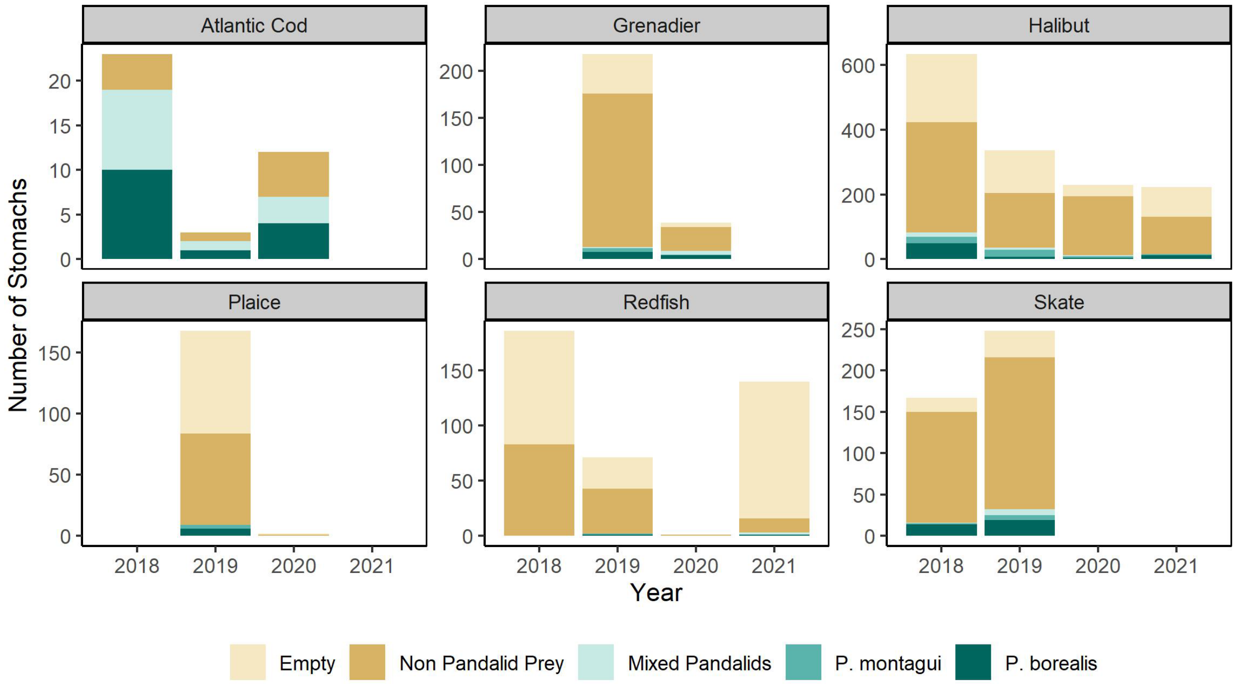

Figure 17. Number of stomachs per predator group by year (2018–2021) with all predator lengths combined for five discrete prey categories. The "Mixed Pandalid" category included instances where prey items were identified only to Pandalus sp. as well as if there was more than one pandalid species. The "Empty" category contains both empty and everted stomachs. Cod, Halibut, and Plaice categories represent a single species (Atlantic Cod, Greenland Halibut and American Plaice, respectively) while Grenadier, Redfish and Skate categories are aggregations of multiple species.

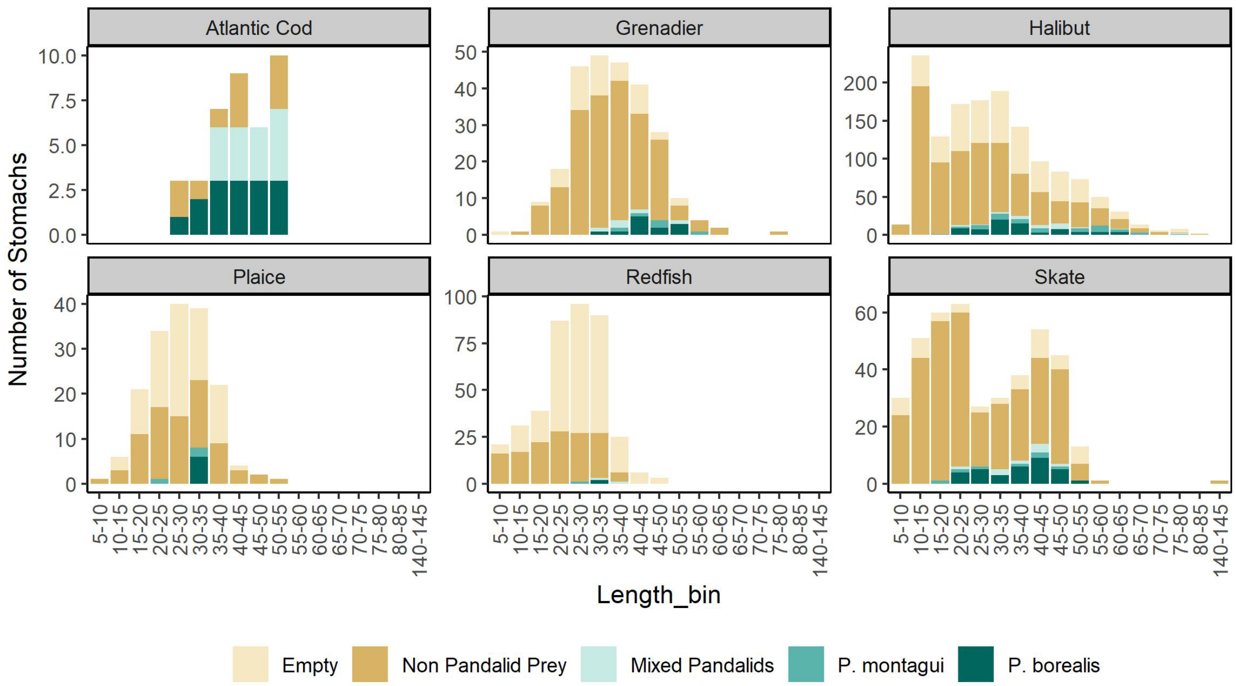

Figure 18. Number of stomachs per predator group by length category, with all years (2018–2021) combined for five discrete prey categories. The "Mixed Pandalid" category included instances where prey items were identified only to Pandalus sp. as well as if there was more than one pandalid species. The "Empty" category contains both empty and everted stomachs. Cod, Halibut, and Plaice categories represent a single species (Atlantic Cod, Greenland Halibut and American Plaice, respectively) while Grenadier, Redfish and Skate categories are aggregations of multiple species.

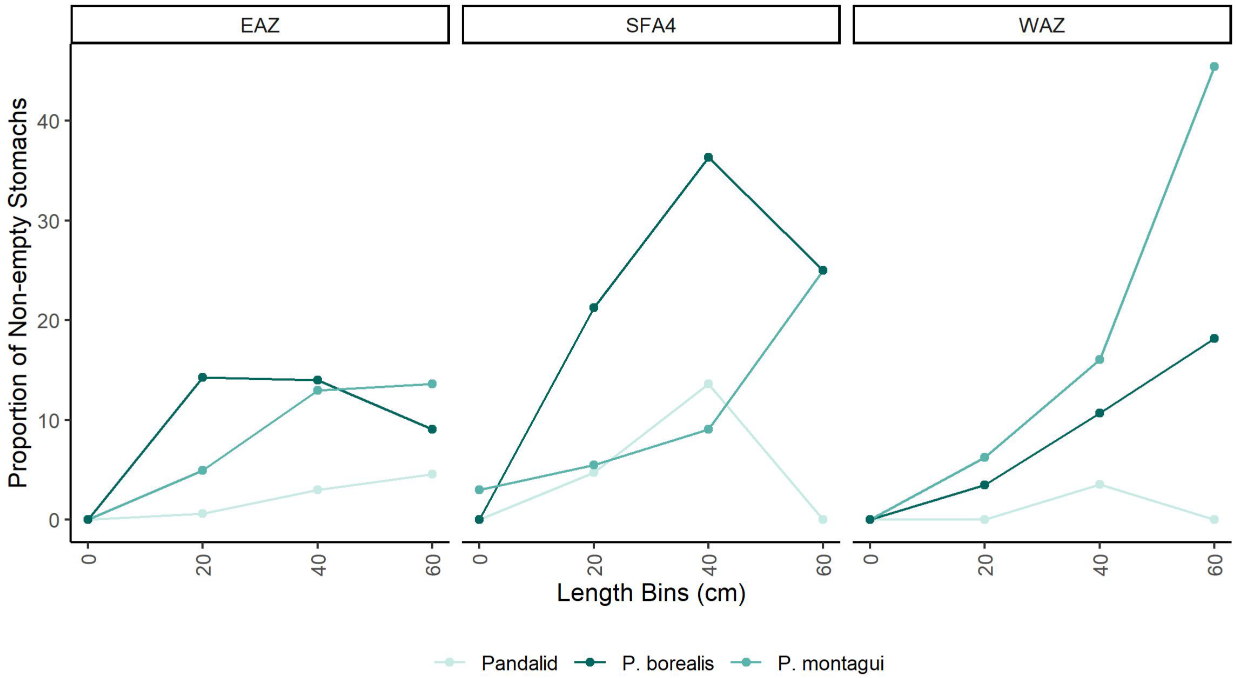

Figure 19. Proportion of non-empty Greenland Halibut stomachs containing only P. borealis, *only* P. montagui, *or a combination of species including unidentified Pandalus spp., separated by survey area and 20 cm length categories.*

APPENDIX A. BIOMASS EXTRAPOLATION EXAMPLE

The calculation of a standardized biomass per trawl requires that the weight of the shrimp sampled can be extrapolated to represent the entire trawl. This is accomplished through a "bump factor". Figure A1 illustrates how the catch from a single trawl is broken down into components for shrimp and then extrapolated back to calculated the weight of each Pandalid species in the entire trawl.

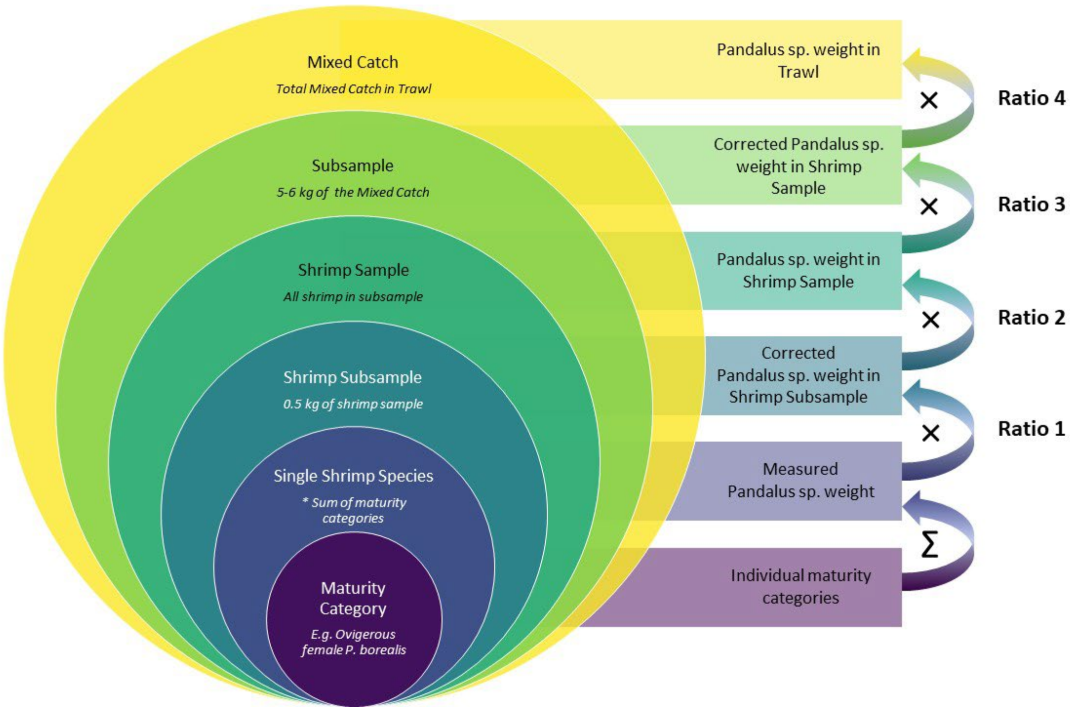

Figure A1. Schematic of nested subsampling protocol for processing mixed species trawls.

Consider the hypothetical scenario: A mixed species catch of 100 kg is brought on board. 5 kg are removed for subsampling and sorted into species (all shrimp are grouped together at this stage). In the 5 kg subsample, 3 kgs are determined to be Greenland Halibut and 1 kg is redfish. The final component of the subsample is 1 kg of shrimp of various species which is determined to be too large a sample for further processing so 500g of the shrimp is selected for further processing. This 500 g shrimp subsample is split into species, and for Pandalid species, further split into individual maturity categories. Three non-pandalid species are determined to weigh 100 g, 75 g, and 25 g respectively. Three maturity categories of *P. borealis* are identified and measured at 175 g, 25 g, and 75 g. No *P. montagui* were caught.

Ratio 1 acts a correction factor for inaccurate measurements by comparing the weight of the shrimp subsample to the sum of each individual shrimp species and is defined as:

$$Ratio\ 1 = \frac{ShrimpSubsampleWt}{\sum ShrimpSpeciesWt_i}$$

where *Shrimp Subsample Wt* is the portion of the Shrimp Sample before it was sorted into single shrimp species.

Shrimp Species Wt_i is the total weight of an individual shrimp species. For Pandalid species, the species weight is considered the sum of the maturity categories.

Using our example situation:

$$Ratio\ 1 = \frac{0.500kg}{(0.100kg + 0.075kg + 0.025kg + 0.175kg + 0.025kg + 0.075kg)} = \mathbf{1.053}$$

Ratio 2 acts to expand the weight of the shrimp subsample to the entire shrimp portion from the catch subsample and is defined as:

$$Ratio\ 2 = \frac{ShrimpSampleWt}{ShrimpSubsampleWt}$$

where *Shrimp Sample Wt* is the weight of all shrimp species in the subsampled catch

Shrimp Subsample Wt is the portion of the Shrimp Sample before it was sorted into single shrimp species.

Note: If the shrimp portion of the catch subsample was not further subsampled, these two values would be equal

Using our example situation:

$$Ratio\ 2 = \frac{1.000kg}{0.500kg} = \mathbf{2.000}$$

Ratio 3 acts a correction factor for inaccurate measurements by comparing the weight of the catch subsample to the sum of each individual species and is defined as:

$$Ratio\ 3 = \frac{SubsampleWt}{\sum ComponentWt_j}$$

where *Subsample Wt* is the portion of catch randomly selected to be sorted into j *ComponentWt$_j$* parts, usually species or higher group, each weighed separately.

Using our example situation.:

$$Ratio\ 3 = \frac{5.000kg}{(3.000kg + 1.000kg + 1.000kg)} = \mathbf{1.000}$$

Ratio 4 acts to expand the weight of the catch subsample to the entire trawl and is defined as:

$$Ratio\ 4 = \frac{CatchWt}{SubsampleWt}$$

where *Catch Wt* is the weight of the total catch of all species during a tow after the removal of species weight whole (i.e., Greenland Sharks)

Subsample Wt is the portion of catch randomly selected to be sorted into individual components.

Using our example situation:

$$Ratio\ 4 = \frac{100.000kg}{5.000kg} = \mathbf{20.000}$$

Multiplying the four Ratios together, gives us the bump factor, which is then multiplied by the weight of the species (or biomass type) of interest.

$$Bump\ Factor = Ratio\ 1\ \times Ratio\ 2\ \times Ratio\ 3\ \times Ratio\ 4$$

$$Shrimp\ Weight\ in\ Trawl = ShrimpSpeciesWt\ \times BumpFactor$$

Using our example situation:

$$Bump\ Factor = 1.053\ \times 2.000\ \times 1.000\ \times 20.000 = 42.12$$

$$Total\ Weight\ of\ P. borealis\ in\ Trawl\ = (0.175kg + 0.025kg + 0.075kg) \times 42.12 = \mathbf{11.583kg}$$