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**Gulf Region**

# Scallop Fishery Assessment of the Southern Gulf of St. Lawrence to 2023: Commercial Fishery and Survey Data

Monique Niles, Andrew Harbicht, Jeff Barrell, Jeff C. Clements, Rémi Sonier

Fisheries and Oceans Canada
Gulf Fisheries Centre
343 Université Avenue, P.O. Box 5030
Moncton, NB, E1C 9B6

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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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## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## ABSTRACT

The 2024 sea scallop stock assessment for the southern Gulf of St. Lawrence (sGSL) incorporates data from the commercial fishery (1923-2023) and research surveys (2019-2023). We present landings, effort and catch rates (CPUE) at the Scallop Fishing Area (SFA) level, the bed level, and the core area (SFAs 22 and 24) level for the available time series.

Annual landings in the sGSL were 69 tonnes (t) in 2022 and preliminary landings 83 t in 2023, averaging 75 t since 2017, with the majority (94%) originating from the core area, specifically, SFAs 22 (59%) and 24 (35%). Spatial analysis of logbooks revealed that approximately 61% of core landings were from the three major beds: West Point and Cape Tormentine in SFA 22 and Pictou in SFA 24. Commercial catch rates for the core area averaged 6.6 kg $h^{-1}$ (8.09 kg $h^{-1}$ and 5.24 kg $h^{-1}$ for SFAs 22 and 24, respectively), higher than the rates reported in the previous assessment. In fact, catch rates in 2023 were the highest in the time series (2003 to 2023). A depletion model was fit to landings and catch rate data from 2003 to 2023, revealing high exploitation rates for the two major scallop beds in SFA 22 (average 50%), suggesting overfishing. The failure to fit the model to SFA 24 data highlights uncertainties in fishery-dependent data. Logbook accuracy and completeness remain critical for reliable assessments and science advice.

Annual research surveys were initiated in 2019 to build a time series of data for the major scallop beds in the sGSL. Condition monitoring on these same beds during the fishery began in 2021. Survey biomass indices increased by 26% and 22% from 2022 to 2023 for West Point bed and Cape Tormentine bed, respectively, while commercial scallop numbers increased only by 5%. The biomass index remained relatively stable for the Pictou bed at around 36 t and the survey index for commercial scallop numbers decreased by 10%, from 2022 to 2023. Recruit numbers peaked in 2021 in Cape Tormentine bed. Higher biomass indices for the West Point and Cape Tormentine beds (SFA 22) in 2023 coincided with higher (≈18%) condition and fishery catch rates observed that year. Strong cohorts of small scallops were observed on Pictou bed in 2023. Survey estimates of exploitable biomass before the fishery and prorated for the core area ranged between 250 t and 390 t. Survey exploitation rate indices on the core area averaged 24% for the time series.

According to the updated JABBA model, using commercial catch and CPUE up to 2023, as well as research survey biomass indices, biomass levels for the core sGSL sea scallop stock have been relatively constant around 250 t since the late 1990s to 2021 when the levels begin to increase, reaching 300 t by 2023. Applying the 0.4 $B_{MSY}$ recommendation from the Precautionary Approach framework results in a limit reference point (LRP) for the core sGSL sea scallop stock of 556 t. Biomass estimates for 2021, 2022 and 2023 indicate the sGSL stock is currently below this LRP, and removals need to be kept to a minimum as this level of abundance places the stock in the Precautionary approach's Critical zone. Consequently, a rebuilding plan to bring the scallop stock above the LRP will be required within two years.

# 1. INTRODUCTION

## 1.1. BIOLOGY

The sea scallop (*Placopecten magellanicus*) is a bivalve mollusk found in the Northwest Atlantic Ocean ranging from the north shore of the Gulf of St. Lawrence, Canada to Cape Hatteras, North Carolina, USA (Posgay 1957; Squires 1962). It is an epibenthic and mostly sedentary species. Sea scallops feed by filtering phytoplankton, microzooplankton and detritus particles from the water column. Scallops are frequently found in dense aggregations commonly called beds. In the southern Gulf of St. Lawrence (sGSL), scallop beds are located at depths between 15 m and 37 m, mostly on hard bottom types such as sand-gravel or gravel-pebble substrates.

Sea scallops can grow in water temperatures ranging from 8 to 18 °C, with the optimal temperature for growth being 10-15 °C (Young-Lai and Aiken 1986; Stewart and Arnold 1994; Frenette 2004). Temperatures above 18 °C can induce physiological stress to sea scallops while sustained temperatures above 21 °C can be lethal (Dickie 1958; Stewart and Arnold 1994). Scallop mass mortality has historically been reported in portions of the sGSL experiencing high temperatures (Needler 1933; Chiasson 1949; Dickie 1951; Dickie 1958).

In the sGSL, scallops can commonly reach a shell height (from umbo to shell margin) between 125 and 145 mm. Annual growth rings (Tan et al. 1988) are formed on the shell in late winter and are especially pronounced in northern shallow-water populations (Naidu 1975) such as in the sGSL. Scallops can be aged by counting these rings and growth rates can be determined by measuring the distance between two subsequent growth rings (Stevenson and Dickie 1954). Growth rates are highly variable, dependent on numerous factors such as the sampling location (Naidu and Robert 2006), water temperature, food availability, water depth, current velocity, standing stock biomass and fishing intensity (Harris and Stokesbury 2006).

Sea scallops are harvested mainly for their meat (i.e., adductor muscle). Generally, the weight of the meat increases exponentially and follows an approximately cubic relationship with shell height (Froese 2006); however, discrepancies are notable in same size scallops where meat weight can vary spatially and temporally (annually and seasonally). Drivers of this meat weight variation include temperature (MacDonald and Thomson 1985), food availability (Shumway et al. 1987; MacDonald et al. 2006), current speed (Wildish and Saulnier 1993; Pilditch and Grant 1999), and their reproductive cycle (Robinson et al. 1981; Bonardelli and Himmelman 1995). In a nine-year study, Sarro and Stokesbury (2009) found 29% variability in meat weight among months and 31% variability between different areas on Georges Bank (USA) within a single month.

The sexes are separate, with males and females being easily identified by their white and orange-colored gonads, respectively (Drew 1906). Sex ratio of males to females is normally 1:1, with the occasional hermaphrodite (Worms and Davidson 1986b). Sea scallops reach sexual maturity (i.e., fully emptying their follicles) at shell heights greater than 60 mm (Davidson and Worms 1989; Davidson 1998) at approximately three years old in the sGSL (Chouinard 1984). Scallops are highly fecund with a single female having the capacity to produce from 1 to 270 million eggs per annual spawning event. Notably, egg production increases exponentially with shell height (MacDonald and Thompson 1985) and significant contributions to egg production may not occur until scallops reach 85 to 90 mm (Hart and Chute 2004). Spawning is triggered by physiological and environmental cues, mainly temperature but also the lunar cycle, current speed and food supply (Parsons et al. 1992; Barber and Blake 2016). But in the sGSL, sudden changes in temperature from the vertical mixing of warm waters were linked to spawning (Bonardelli et al. 1996). Scallops are broadcast spawners, involving the release of male and female gametes synchronously into the water column. Fertilization is external, hence the importance of individual scallops being in close proximity to one another on beds. In the sGSL, spawning time varies annually but typically begins between mid-August and mid-September, lasting from 2 to 4 weeks (MacLean and Gillis 1996; Davidson et al. 2019).

Following fertilization, scallop larvae are planktonic for 4 to 5 weeks before their settlement on a suitable substrate when they begin benthic life as juveniles (Culliney 1974). Suitable substrate can consist of pebbles, filamentous fauna (i.e., hydroids, bryozoans), and shell fragments as well as shells colonized with hydroids (Caddy 1972; Larsen and Lee 1978; Minchin 1992; Harvey et al. 1993; Stewart and Howarth 2016). Adult scallop shells can also effectively provide substrate for juvenile's byssal attachment and provide them with refuge from predation (Bourgeois et al. 2006). Juvenile scallops are also vulnerable to disturbances of the sediment (habitat) caused by scallop dredging, or any other epibenthic disruption. Current scientific knowledge supports the avoidance of scallop dredging during spawning events and during spat settlement periods, between August and October. Another potential benefit of avoiding dredging during these crucial periods is allowing the recovery of fast-growing hydroids which act as a suitable substrate for spat settlement (Bradshaw et al. 2005). Adult scallops, on the other hand, have a low natural mortality. Their main predators in the sGSL are sea stars (e.g., *Asterias rubens* and *Leptasterias polaris*) and crustaceans (e.g., *Cancer irroratus* and *Homarus americanus*). While sea scallops are considered mostly sedentary, they can swim short distances as an escape response to predators and to unfavorable environmental conditions (Manuel and Dadswell 1993). The most efficient swimmers are scallops between 40 and 80 mm shell height (Dadswell and Weihs 1990), while scallops above 100 mm are seldom seen swimming in their natural environment (Mason et al. 2014).

# 2. DESCRIPTION OF THE FISHERY

The sGSL sea scallop fishery is essentially a Northumberland Strait fishery. Commercial, recreational, and limited Indigenous Food, Social and Ceremonial fisheries for sea scallop occur in the sGSL. The fishery is important to many coastal communities, often supplementing the lobster, herring, and groundfish fisheries (Lanteigne and Davidson 1991). It is a competitive fishery without quotas and managed under the jurisdiction of the Department of Fisheries and Oceans (DFO) Gulf Region by input controls including a limited number of licences, fishing seasons, spatial closures, gear restrictions, and meat count limits (Table 1). Catches are monitored through sales slips from registered buyers and logbooks from scallop harvesters. An historical review of the sGSL scallop fishery can be found in Lanteigne and Davidson (1991). An attempt has been made to document relevant changes in the scallop fishery over the years, with a particular focus on fishing gear regulations (Table A1).

## 2.1. FISHING AREAS

Management of the scallop fishery in the sGSL is structured into four (21, 22, 23, and 24) Scallop Fishing Areas (SFAs). Furthermore, one zone (SFA 21) is divided into three sub-zones since 1996 (21A, 21B, 21C) (Figure 1). Each SFA and sub-zone has its own management measures (Table 1).

## 2.2. BUFFER ZONES

In the Gulf Region, buffer zones have been implemented as marine refuges under the Fisheries Act to prevent trawling and dredging, including scallop dredging, over selected areas to primarily to protect habitat of juvenile American lobster (*H. americanus*) (Davidson et al. 2007) (Figure 1). Over the last twenty years, the fishing industry and DFO fishery managers collaborated to establish these buffer zones, which can be revisited and redefined as needed through a formal process. As a result, buffer zone depth criteria can vary from one SFA to another (Niles et al. 2021). These buffer zones are contributing to Canada's marine conservation target of 30% by 2030.

## 2.3. AREA CLOSURES

In the sGSL, temporary fishery closures have been used over the years for resource management purposes. For example, from 2005 to 2010, a 210 km$^2$ area west of the Confederation Bridge was closed at the request of the scallop harvesters in SFA 22. This area was closed to allow the scallop stock to rebuild; however, this area covered only 2% (1.7 km$^2$) of the main Cape Tormentine bed (as defined by the 20 days per km$^2$ contour, Niles et al. 2021). In the Chaleur Bay, the entirety of SFA 21A has been closed twice (2010−2012 and 2016−2018) following a catch rate decision rule unique to this SFA which states that the fishery will be closed for a period of three years following a year in which the catch rate is below 0.5 kg h$^{-1}$ m$^{-1}$ (i.e. 3 kg h$^{-1}$). This catch rate limit is founded on an economic threshold as opposed to a stock productivity threshold. SFA 21A has again been closed in 2023 and 2024 for different reasons.

## 2.4. FISHING SEASONS

Scallop fishing in the sGSL is limited to the ice-free period occurring generally from mid-April to mid-December. Within this overall fishing period, one of the management strategies in place to control fishing effort is the implementation of fishing seasons. Seasons vary across SFAs and are defined following discussions and agreements by the scallop advisory committees comprised of representatives from DFO, provincial government, the fishing industry, aboriginal groups and other stakeholders. The timing of the season is often influenced by that of other commercial fisheries, particularly the lobster fishery, since most scallop licences holders also have licences to fish other species. SFA 22 has a four-week spring fishery, while SFA 21 and SFA 23 have mostly a summer fishery. Since 1998, SFA 24 has been a fall-only fishery of six weeks duration. Prior to 1998, SFA 24 also included a spring fishery (Lanteigne and Davidson 1992). Most SFAs restrict fishing to between 6 am and 6 pm and include weekend closures (Saturday and/or Sunday). SFA 21B is an exception to the general rule, as it has no time restrictions and no weekend closures. Table 1 provides specific information about the fishing season dates, the times when fishing is open, weekend closures, and total number of fishing days allowed per season for each SFA for 2021 and 2022.

## 2.5. FISHING GEAR

Commercial scallop fishing takes place with fishing vessels less than 14 m (45') in length. Most industry members use a Digby-type drag (Figure 2) while a few use sweep chain drags. There is no restriction for crew size. The drag size (i.e., the maximum outside measurement of the cumulative width) permitted varies from one SFA to another from 4.88 m to 6 m. The total length of the drag, the ring size (diameter), ring type, and number washers as well as tow bar specifications are described in the condition of licence for each SFA (Table 1).

Since the beginning of the fishery, many changes have occurred to industry practices, notably to the scallop drag components, mostly as a conservation measure with the goal to reduce the catch of small scallops. For instance, the minimum ring size diameter used in SFA 22 increased from 76 mm (3") to 82.6 mm (3¼") in 2001. Following a selectivity study conducted in the Northumberland Strait (Poirier et al. 2021), SFA 22 further increased the ring size to 89 mm (3½") in 2019. The study had shown that a change in ring size from 82.6 mm to 88.9 mm leads to an increase in the $L_{50}$ (length at which 50% of scallops are retained) from 72.8 mm to

95.5 mm. This increase in minimum ring size is expected to significantly reduce the capture of 45–90 mm scallops by 65%. While there is also a temporary decline in the catch of larger scallops due to the change in ring size, the expectation is that a shift in size distribution to larger scallops will occur following this change, (Poirier et al. 2021). The minimum ring size diameter for all other SFAs remains at 82.6 mm (3¼").

## 2.6. MEAT COUNT

There are no minimum size regulations for scallops landed in the sGSL fishery; however, size is, to a certain extent, dictated by the selectivity of the drag due to the ring size (82.6 mm). Otherwise, there is a meat count regulation (number of meats per 500 g), which varies between SFAs (Table 1). The regulatory meat count is highest in SFA 24, which at 52 per 500 g reflects the smaller meat weights relative to shell height in this area (Worms 1984). In SFA 22, the meat count decreased from 52 to 44 meats per 500 g in 2001, in line with the ring size increase at that time. All other SFAs have a maximum meat count of 39; however, the common practice of blending the catch allows for small scallops to be shucked together with larger ones while still making the meat count limit. This renders the meat count regulation rather ineffective in protecting small scallops from being harvested (Worms and Davidson 1986a).

## 2.7. LICENCES

The scallop fishery in the Gulf Region has had a limited entry since 1978 when the number of licences was already at very high levels (Robert and Jamieson 1983). There were 763 commercial scallop fishing licences issued in 2022, including 44 communal commercial licences held by 15 Indigenous groups. Over half of the commercial licences are in SFA 24 (Table 2). For the purpose of this research document, a scallop licence is said to be active if at least one landing is reported under that licence during the fishing season. Active licences, estimated from records of landings in official statistics and from logbooks, are far fewer than issued licences and ranged from 118 to 149 over the 2017 to 2022 time period. In 2022, approximately 15% of the licence holders were active. The highest percentage of active licences has been in SFA 22 (26%) and the lowest in SFA 23 (0%) (Table 2). The trend in number of active licences (Figure 3) shows that recent participation in the fishery has declined to around 120 active licences compared to over 500 active licences between 1993 and 1998. Therefore, there is a substantial amount of latent effort (85% of licences were inactive in 2022) that presents a concern for future management decisions. The reactivation of these licences may lead to overfishing and a depletion of the stock.

## 2.8. LANDINGS AND LOGBOOKS

The previous assessment was conducted in 2018 using data up to 2016 (Niles et al. 2021). Empirical (i.e., depletion) models were used for the first time to model fishing effort and landings for the 2003 to 2016 period. A spatial focus was also initiated, which identified scallop beds based on the spatial concentration of fishing effort. Results from these analyses were used to inform subsequent data analysis and surveys conducted since the previous assessment. The present assessment will continue these efforts through analysis of logbook and survey data through a spatial lens, focusing on scallop bed definitions established in the previous assessment. Similarly to previous assessments (Davidson et al. 2012, Niles et al. 2021), commercial landings in this 2024 assessment are reported in meat weights and are obtained from sale slips from registered buyers and also, since 2001, from scallop harvesters logbooks.

Logbooks are included in the licence conditions and are mandatory. Fish harvesters must log fishing activity for each day fished. Daily information includes date fished, hours fished, landings in pounds, drag width in feet, latitude and longitude of general fishing location, as well as a comment box for observations such as meat count and any anomalies. Since 2003, the number and average duration of tows in minutes were added to the logbook to improve the quality of effort data. Completed logbooks (in paper form) need to be submitted to DFO within two weeks following the end of the fishing season. A new version of the logbook was implemented in 2020. Commercial data to 2022 and preliminary data to 2023 were available and are included in this assessment.

Each logbook record is matched to its corresponding sales slip from registered buyers. Logbooks that do not have a corresponding sales slip are interpreted as local sales or personal consumption. On the other hand, sales slips without corresponding logbooks are considered as non-compliant to the licence conditions.

## 2.9. RECREATIONAL FISHERY

Recreational catches by scuba divers have been recorded in logbooks since 2003. There were 295 recreational licences issued in 2022. Management measures in this fishery include maximum daily limit of 50 scallops per diver, except in SFA 24 where it is 100; a season (May 1 – Oct. 31); and minimum size limit (102 mm in shell height). The number of annual active licences (i.e., reporting landings in logbooks) varied between 4 and 55 over the 2003 to 2022 period (Table 3). Most (90%) of the activity occurred in SFA 21, principally 21A.

# 3. ASSESSMENT

## 3.1. METHODS - FISHERY DEPENDANT DATA

Over 50,000 scallop fishing records (logs and sales slips from Statistics section of DFO Gulf; 2003 to 2023) from the sGSL were analyzed. Inappropriate records were screened out using various categories of errors or were corrected, when possible, with corroborating evidence as described in Niles et al. (2021). Science staff conducted a review of logbook data using paper logbooks dating from 2009 onward and corrected where discrepancies were found between the paper and the electronic versions. Spatial coordinates in some cases could not be verified due to errors in entry, transcription, and/or digitization; these records were excluded from mapping and spatial analysis. However, these records were retained for use in modeling following an allocation procedure described in the 'Spatial Analysis' section below.

While data from all of the sGSL were analyzed, this assessment focused on three spatial scales: core area, bed area and survey strata (Figure 4). The core area represented the core scallop habitat in the sGSL and encompassed the entirety of SFAs 22 and 24. The bed area represented the areas of the major scallop beds (West Point, Cape Tormentine and Pictou) where the majority of fishing effort is concentrated, delineated by a threshold of 20 days per $km^{2,}$ as described by Niles et al. (2021). The survey strata delineated the areas covered by surveys from 2019 to 2023, and respectively encompassed each of the three major beds and adjacent areas.

As described in Harbicht et al. (2024), the core scallop habitat area, the Northumberland Strait which spans much of SFA 22 and SFA 24, represents the area of highest density within the sGSL, as indicated by higher catch rates throughout the fishery. Due to the importance of scallops in this area for maintenance of subpopulations throughout the Gulf, these authors focused on the core area only when applying a suite of data limited models to catch and effort data to derive estimates of stock status and reference points for the sGSL. For this reason, this assessment also focused on this core area and the three major scallop beds therein: West Point, Cape Tormentine and Pictou.

### 3.1.1. Catch statistics

The Science Branch of DFO used the sales slips and logbook data to calculate landings, the amount of fishing effort and the catch rates or catch per unit effort (CPUE). Effort was expressed in hours (h). Effort was obtained from the logbook data using the equation below:

$$Effort\ (h) = number\ of\ tows * average\ duration\ of\ tows\ (h)\ (1)$$

Effort data was not available for all catch records. For catches without effort data (catch $_{no\ logs}$), the effort (Effort $_{no\ logs}$) was calculated using the known catch rate (catch rate $_{logs}$) of the SFA (or bed), where catch rate was the catch in kilograms of scallop meat divided by hours towed of fishing effort (kg $h^{-1}$) from logs that had effort data (equation 2):

$$Effort\ _{no\ logs}(h) = \frac{\text{catch}\ _{no\ logs}(kg)}{catch\ rate_{logs}\ (kg\ h^{-1})}\ (2)$$

When effort was expressed as hours-meter (hm), effort in hours was multiplied by the width of the drag in meters. This allowed for the comparison of effort and catch rates when drag width is different (e.g., between DFO regions). In this assessment, overall catch rate was expressed as kilograms of scallop meat per hour (kg $h^{-1}$), where the nominator is the total catch (kg) and the denominator is the effort in hours towed (data available since 2003) (equation 3). Furthermore, catch per hours towed is considered a more accurate and informative index of abundance than catch per hours fished (Caddy 1989).

$$catch\ rate(kg\ h^{-1})\ = \frac{\sum catch\ (kg)}{\sum effort\ (h)}\ (3)$$

### 3.1.2. Spatial analysis

Using the daily fishing geolocations from the logbooks from 2003 to 2023, this assessment examined the data spatially by scallop bed as defined by the spatial concentration of fishing effort. This makes sense biologically for sea scallops, which are a mostly sedentary species that commonly aggregate on beds (Caddy 1989). The focus on beds can improve our understanding of how the fishery affects scallop populations since this is where the fishing pressure is concentrated. When fishery data are not segregated spatially, it can inadvertently mask catch rate declines while beds are sequentially being depleted and keeping average catch rates stable. Spatial analysis is particularly valuable in tracking changes in the expansion or contraction of a stock and quantifying the footprint of fishing activity over time (Smith and Rago 2004, Orensanz et al. 2016, Smith et al. 2017, McDonald et al. 2021).

Scallop bed boundaries were identified in the previous assessment through a kernel density function applied to logbook records (i.e., days fished) with a threshold value of 20 days $km^{-2}$ from 2003 to 2016 (Niles et al. 2021). These boundaries were retained and used to define scallop beds in the present assessment. Fishing activity for the period from 2017 to 2023 was visualized through a similar kernel density function applied to total landings (kg) over this time period. This function was also applied to logbook data from the earlier time period to show the change in fishing activity since the last assessment (Figure A2-a). For direct comparison between the previous and current assessments, the function was also adjusted to express effort in terms of days $km^{-2}$ $y^{-1}$. These analyses were conducted using ArcGIS Pro v2.9.

Logbook records were assigned to scallop beds within SFAs as determined by the daily fishing location. Landings within an SFA without specific fishing locations were assigned to beds by proration based on landings data from the SFA with fishing locations. We assumed that the proportion of landings per bed reported in the logbooks reflected the proportion of landings without fishing locations. These proportions vary annually and also weekly during the season. Therefore, we applied the weekly proportions to obtain the prorated landings for each bed. In the same manner, it was assumed that catch rates reported in logbooks were equal to catch rates for the landings data for which effort is unknown. The geographic data allowed for effort and catch rate to be spatially examined and separated by scallop bed.

To spatially represent catch rates, logbook average catch rates for all records with valid geolocation information were mapped by interpolating continuous surfaces using an inverse-distance weighted (IDW) scheme. This approach is an exact interpolator that preserves data values at sample point locations, fitting a surface based on the value and proximity of neighboring points. For this application, the interpolation was based on a minimum of ten neighboring points, and weights were adjusted by the inverse distance squared. Mean values were used for coincident points. Survey data were also interpolated following the same approach for comparison to logbook data. The use of IDW was intended for the purposes of exploratory data visualization and should not be considered a statistically rigorous approach. The analysis was conducted using the Geostatistical Analyst extension in ArcGIS Pro v2.9.

### 3.1.3. Depletion model

A Leslie stock assessment depletion model was applied to the logbook reported data of daily catch rates (kg $h^{-1}$) against cumulative landings for SFAs 22 and 24 and the three major scallop beds in the sGSL. Logbook and landings data considered for each bed were defined by the kernel density 20 days $km^{-2}$ contour (Niles et al. 2021). The Leslie depletion model described in Leslie and Davis (1939) has been used successfully for other scallop stocks to estimate exploitation rates (e.g., Bay of Fundy - Scallop Production Areas (SPAs) 3 and 6; SFA 29 (Smith et al. 2008, Sameoto et al. 2012); Québec –SFA 16E, 16F, 19A and 20A (Trottier et al. 2017)). This model assumes that the population is closed (i.e., no recruitment, no migration, minimal growth and minimal natural mortality), which, considering the short duration of the fishing season and the mostly sedentary and low natural mortality characteristics of the species, is a reasonable assumption. It also assumes that the commercial catch rate is proportional to the exploitable biomass and that catchability is constant within the season.

For each year, from 2003 to 2023, the Leslie method was used to estimate the fishery exploitable biomass ($B_0$) (i.e., biomass of commercial scallops, ≥80 mm shell height) prior to fishing, by referring to the linear regression between daily catch rate (kg $h^{-1}$) and cumulative landings (t) (Figure 5). From this analytical method, two subsequent depletion estimates can be obtained, which are the catchability (q) and the annual exploitation rate (Ê) (Ricker 1975, Ogle 2017). These estimates are for the effective area fished which is smaller than the SFA or bed area and varies over years.

Using the Leslie method, the biomass of the population before the fishery ($B_0$) should decrease as a function of catches ($C_i$) up to time *t*, such that:

$$B_t = B_0 - \sum_{i=0}^{t-1} C_i \quad (4)$$

Where $B_t$ is the population biomass at time *t*. Assuming catch rate ($K_i$) observed at time *t* is proportional to the biomass over time, then:

$$K_t = qB_t \quad (5)$$

Therefore, by replacing $B_t$ by equation 4,

$$K_t = q\left(B_0 - \sum_{i=0}^{t-1} C_i\right) \quad (6)$$

and

$$K_t = qB_0 - q\sum_{i=0}^{t-1} C_i \quad (7)$$

Where $q$ is the catchability coefficient for the fishery, or the fraction of the biomass that can be caught by one unit of effort, $-q$ is the slope of the linear regression, and $qB_0$ is the intercept on the y-axis. Visually, as illustrated in Figure 5, $B_0$ is the intercept of the regression line with the x-axis when catch rate is equal to zero. We therefore obtain $B_0$ by dividing the intercept by the catchability coefficient.

Exploitation rate (i.e., catch in year *t* divided by biomass in year *t*) at the end of the fishery, $\hat{E}$, is then:

$$\hat{E} = \frac{\sum_{i=0}^{t} C_i}{B_0} \quad (8)$$

The model was run on commercial data for each year for which reliable catch rate data was available, that is, from 2003 to 2023. Daily cumulative catch is the sum of the daily reported landings (per SFA or bed) up to that day. Daily commercial catch rates (kg $h^{-1}$) are obtained from the logbook data as in equation 3. To estimate the total daily landings for each bed for landings for which no positional information was available, we applied the weekly proportion of landings from the bed to the total SFA reported landings for that day. A statistically significant model is one for which the slope of the linear relationship between daily catch rate and cumulative catch over the season is significantly different from zero ($p < 0.05$) and negative in sign, indicating a decline in biomass. The mean results from the depletion model are presented to provide a relative index of exploitable biomass (i.e., catchable biomass of sea scallops > 80 mm) and exploitation rate. Confidence intervals (lower and upper) for the $B_0$ were derived from the corresponding confidence intervals of the intercept divided by the confidence interval of the slope.

### 3.1.4. Limit Reference Point

Since 2019, the Fisheries Act contains new provisions which: ‘’add requirements to implement management measures to maintain prescribed major fish stocks at or above levels that promote sustainability, or above the limit reference point and to implement rebuilding plans for such stocks that have declined to or below their limit reference point (with some exceptions), all while taking into account the biology of the fish and environmental conditions affecting the stock.’’

In order to implement DFO’s Precautionary Approach policy, each major fish stock is required to have a Limit Reference Point (LRP) and be classified into a stock status. According to the precautionary approach, stocks can be classified into one of three mutually exclusive categories: Healthy, Cautious, and Critical. The Healthy and Cautious stock status zones are separated by a biological reference point called the Upper Stock Reference Point (USR), while the Cautious and Critical zones are separated by the LRP. Above the USR, removal rates can be set at or below the maximum sustainable yield (MSY), while below the LRP, the stocks recruitment ability may be jeopardized, and so removals must be kept to the lowest possible level.

For the sGSL scallop stock, an LRP was set to 40% of the harvestable biomass at the maximum sustainable yield ($B_{MSY}$), as per the recommendation of the Precautionary Approach framework. To identify $B_{MSY}$, a suite of data-limited models were fit to the catch and effort data for the core sea scallop stock in the sGSL (SFAs 22 and 24) from 1923 to 2021 (Harbicht et al. 2024). Among the models assessed by Harbicht et al. (2024), a surplus production model - the JABBA model (Just Another Bayesian Biomass Assessment, Winker et al. 2023) - was selected as the primary model from which the LRP would be calculated due to its production of credible results, ease of use, and its assumptions which were not violated by the scallop stock in question.

### 3.1.5. Just Another Bayesian Biomass Assessment (JABBA) model

A JABBA model was fit to the commercial catch and CPUE data from 1923 to 2021 (Harbicht et al. 2024) using a Pella-Tomlinson surplus production model and the following priors: carrying capacity (K) of 3000 tonnes (t) (CV = 0.3, lognormal); intrinsic rate of population growth (r) of 0.5 (sd = 0.2, lognormal), initial biomass ($B_{1923}$) of 99% of K (CV = 0.005, beta), and a relatively low certainty final biomass ($B_{2021}$) estimate of 5% of K (CV = 0.1, lognormal). The final biomass prior was chosen based on a range of biomass estimates in 2019 of ~150 t (Leslie depletion model) to ~350 t (pro-rated spring survey biomass index), and the expected range of K (1000 – 6000). These values produced a range of possible saturation levels from 0.026 to 0.36 with a high likelihood around 0.05. The resulting model fit produced a K estimate of 3658 t, a $B_{MSY}$ estimate of 1377 t and an LRP of 551 t. According to this model fit, the harvestable biomass levels in 2021 were 249 t, placing the stock below the LRP, in the Critical zone.

Presently, an updated fit of the JABBA model was produced by extending the commercial catch time series to 2023, updating the priors, adding the survey CPUE timeseries, and separating the commercial CPUE timeseries into multiple sections to allow for variation in the catchability coefficient over time (Winker et al. 2019). To update the model's priors, the estimate of K produced by the previous model fit (3658 t) was used as the mean with the same level of uncertainty as before. The final biomass prior was also adjusted according to the results of the research survey in 2023. First, the 2023 biomass index levels from the fall research survey were combined for the three main beds within the core area, producing a combined biomass of 176 t. As this estimate was produced after the fishery, harvest removals from the beds in 2023 were added to this, producing a pre-fishery biomass estimate of 238 t. Next, landings from the main beds accounted for 61% of the total landings from the core area in 2023, so if we assume equal catchability both within beds and within secondary beds outside of the three main beds, we can assume that the biomass estimate of the main beds represents 61% of the core area as a whole. This assumption produced the rough pre-fishery biomass estimate for the entire core area of 390 t, or 0.11K with the new K prior. To reflect the uncertainty in this estimate, a coefficient of variation of 0.1 was used. Finally, to capture the effect that changes over the course of the fishery had on the catchability coefficient, the commercial CPUE time series was split into multiple separate time series. Splits were set at or around years where major changes to the scallop fishery management regulations occurred that likely affected catchability: 1991, meat count limit implemented throughout the core area; 1997, dredge width was increased throughout core area; 2001, ring size was increased throughout core area; and 2020, ring size was increased in SFA 22. Upon assessing initial model fits and residuals, a sixth split was added in 2012, around the time when fishing season and hours-per-day were reduced (Table A1).

## 3.2. METHODS - FISHERY INDEPENDENT DATA

Between 1986 and 2011, only one sea scallop research survey occurred in the Gulf Region, conducted in 1997 in SFA 22 (Hanson 1998). Since then, a newer survey series spanning 2012 to 2016 was conducted, but these surveys lacked the necessary spatial and temporal resolution for meaningful data in assessing the Gulf scallop stock (DFO 2019). Notably, sparse coverage of main beds, especially in SFA 24, coupled with sampling over large areas of non-scallop habitat, weakened any signal from the beds. In fact, 63% of survey tows from 2012 to 2016 failed to capture any scallops. Starting in 2019, a new fishery- independent research survey looked to address these limitations by targeting the major scallop beds. It is assumed that managing the major beds at or above sustainable levels benefits the overall scallop population within the sGSL (Smith and Sameoto 2016). In particular, three beds in the Northumberland were targeted (West Point and Cape Tormentine within SFA 22, Pictou within SFA 24), which collectively account for 61% (2019 to 2023) of the core Gulf scallop landings. Due to their importance within the sGSL scallop fishery, these beds were surveyed annually in the fall (October) between 2019 and 2023, except for the Pictou bed in 2020 due to COVID-19 restrictions. Additionally, the West Point and Cape Tormentine beds were surveyed in the spring (April) of 2022 and 2023 to generate pre-fishing season abundance indices. These surveys collected data on various aspects of scallops, including abundance, size and age composition, growth, meat condition, and spatial distribution. Additionally, these surveys sought to collect data on other species caught in the drag, particularly scallop predators.

The 2019 and 2020 fall surveys were conducted aboard the Canadian Coast Guard Ship (CCGS) M. Perley. Subsequent surveys from 2021 to 2023 were conducted aboard chartered commercial scallop vessels. The survey gear consisted of an eight-gang toothed Digby scallop drag constructed of 82.6 mm (diameter) rings (Figure 6). Two of the eight buckets were lined with a Vexar® liner (mesh size of 18 mm) to retain small scallops and benthic species. Data from the two lined buckets were excluded from the main analysis but were used for descriptive statistics, particularly for size distribution and abundance of recruit scallops.

At each sampling station, a 4-minute tow at a speed of approximately 2.5 knots was conducted. The catch of each tow was immediately sorted, counted, and weighed by species. All scallops were measured for shell height to the nearest 0.01 mm increment (i.e., the maximum distance from the umbo to the outer shell margin). Clappers (dead scallops with attached shells) were counted and measured as an index of natural mortality. Biological subsamples from scallops > 50 mm in length were collected during the surveys (3 scallop per 1 mm shell height bin) and brought to the lab to obtain individual wet meat and gonad weights (to the nearest 0.1 g), sex, and age.

Shell height-meat weight relationships were determined by using a generalized linear mixed effects model (GLMM) in R (R package version 4.4.0). A GLMM gamma family with a log link and tow as the grouping variable was fit to data of the major scallop beds (West Point, Cape Tormentine, Pictou) for each year from 2019 to 2023. Shell height was scaled to improve model fit. The meat weights were predicted from shell heights to estimate biomass for all scallops measured using the following equation :

$$\mathrm{E}\,(W_i) = \exp\,(B_0 - B_{0j}) + (B_1 + B_{1j})\,log(H_{ij}) + \varepsilon_i \qquad (9)$$

Where;

- $W_{ij}$= meat weight of scallop *i* from tow *j*
- $H_{ij}$= shell height for scallop *i* from tow *j*
- $B_0,\ B_{0j}$ = fixed and random intercept parameter
- $B_1, B_{1j}$ = fixed and random slope parameter
- $\varepsilon_i$ = error term

An index of natural mortality of scallops was estimated using the ratio of live scallops to clappers in the following equation from Merrill and Posgay 1964:

Clapper Index = (C/C+L) (52/t) (10)

Where;

- C= number clappers (> 80 mm) in sample
- L= number of live scallops (> 80 mm) in sample
- t = time in weeks that clappers remain attached (33 weeks based on Merrill and Posgay 1964)

A stratified random design was employed in the survey, which excluded areas with water depths < 5.5 m, the navigational limit of the research vessel. Strata were defined based on the distributional pattern of scallop fishing effort according to logbook data (analyzed in Niles et al. 2021). Each bed consisted of two strata: inside bed (based on effort) and outside bed (based on the boundary of scallop distribution) (Table 4, Figure 4). Sampling occurred over the entire survey strata with the exception of a 20 km$^2$ section of the Pictou bed stratum in all years due to the presence of Atlantic herring spawning grounds in October. As a result, we assumed that scallop density was similar in the surveyed and non-surveyed portions of the Pictou bed stratum.

The number of survey tows was allocated proportionally to the size of the strata. Strata area was superimposed with a 2 kmX2 km grid (tessellation tool). Tow locations were randomly generated in each grid polygon using the create random points tool and assigning a minimum distance of 300 m between points (ArcGIS v10.1).

Catch data were standardized to a tow distance of 308 m (target tow duration of 4 minutes at 2.5 knots), and a tow area of 657 m$^2$ based on the inside width of the survey gear (2.13 m; 6 unlined buckets). The standard approach for bottom trawl surveys (Gunderson 1993; Smith and Gavaris 1993; Smith 1996; Smith 1997) was used to adjust the scallop catch metric or variable (abundance or biomass) data from the survey, that is:

$$\frac{standard\ tow\ distance\ (308.7\ m)}{actual\ distance\ from\ GPS\ (m)} * \text{catch metric} \quad (11)$$

The mean per standard tow was calculated for each stratum and total survey area.

Commercial size was defined as scallops greater or equal to 80 mm shell height, while recruit size was defined as scallops between 65 and 80 mm shell height. The meat weight (kg) per standard tow of commercial size scallops was used to obtain indices of exploitable biomass and exploitation rate for each stratum as well as for the survey area.

An inverse-distance weighted (IDW) scheme was applied to the research survey catch rate (kg $h^{-1}$ $m^{-1}$) data for each year for the Cape Tormentine, West Point, and Pictou beds. This spatial analysis helps in understanding the distribution and variability of catch rates across different areas.

The quantities needed to calculate the indices are defined below (R package: BIOSurvey2 version 1.0-1, Smith 1996; Smith et al. 2017):

$N_h$ = the total number of sample units in stratum $h$ ($h$ = 1,…, $H$).

$N = \sum_{h=1}^{H} N_h$ = the total number of sample units in the survey.

$W_h = N_h/N$ = proportion of sample units in stratum $h$.

$n_h$ = the number of sample units actually sampled in stratum $h$

$y_{hi}$ = measurement of interest (e.g., number of scallops) from tow $i$ in stratum $h$. ($i$ =

1,…., $n_h$).

$\bar{y}_h = \sum_{i=1}^{n_h} y_{hi} / n_h$ = stratum mean.

$s_h^2 = \sum_{i=1}^{n_h}(y_{hi} - \bar{y}_h)^2 / (n_h - 1)$ = stratum variance.

Sampling is independent over strata and the survey mean per tow (or total) number (or weights) is a weighted average of the means (or totals) from each stratum. That is,

$$y_h = \sum_{h=1}^{H} W_h \, \bar{y}_h \quad (12)$$

and for variance of the mean,

$$\mathrm{Var}\,(\bar{y}_h) = \sum_{h=1}^{H} \frac{N_h(N_h - n_h)}{N^2} \frac{s_h^2}{n_h} \quad (13)$$

For example, for the indices in Table A8-b (2019), the $y_h$ = 140.36 g and Var ($\bar{y}_h$) = 142.56. The total meat weight $Y_h$ of scallops over the whole survey area is simply $N \times y_h$ = 113,565,470 g or 113.57 t. To obtain the biomass estimate before the fishery ($B_0$), the commercial landings from the corresponding area (61 t) was added to the biomass index. To prorate biomass to the core area (SFAs 22 and 24) the landings ratio (surveyed area:core area, 0.58) was used which in 2019 was 251 t.

# 4. RESULTS

## 4.1. LANDINGS, LOGBOOK REPORTS AND DATA QUALITY

The sGSL sea scallop fishery only accounts for 1% of all sea scallops caught in Canada (Mallet 2010). The first sGSL sea scallops were caught in the early 1900s (Lanteigne and Davidson 1991: Lanteigne and Davidson 1992). Catches peaked in 1968 with 900 t of meat, but rapidly declined until the mid-1970s. This rapid decline was followed by a more gradual decline until catches stabilized around 100 t annually since 2002 (DFO 2019). Catches have been below the long- term (1968-2023) median of 195 t since 2001.

Commercial landings and the number of days fished in the sGSL scallop fishery to 2023 are presented in Table A3 and Figure 7. Landings have been low and relatively stable since 2014, below 100 t annually, following a persisting decrease in landings since 1996. Landings for 2022 and for 2023 were 69 t and 83 t, respectively, well below the long term (1968 to 2010) median of 195 t.

Scallop Fishing Areas were established around 1987 and corresponding proportion of annual landings by SFA for the period 2003 to 2023 are shown in Figure 8. On average, landings from SFA 22 (59%) and SFA 24 (35%) account for 94% of the total annual landings from the sGSL over the 2017 to 2023 period, while SFAs 21(6%) and 23 (<1%) account for the remainder (Figure 8). Annual landings for the core area (SFAs 22 and 24) are shown in Figure 9. Annual landings and number of days by SFA for the period 1987 to 2023 are shown in Figure 10.

Recreational landings (i.e., by scuba diving) based on logbook reports are estimated to range between 0.02 t and 0.19 t per year over the 2003 to 2022 period summed across all SFAs in the sGSL, mostly (85%) from SFA 21A (Table 3). In terms of landings, the recreational fishery is considered negligible (average of 0.01% of total Gulf landings) in comparison to the commercial fishery and is therefore not included in this assessment.

The spatial distribution of landings (Figure 11), based on geographic positions reported in logbooks for each day of fishing from 2003 to 2023, corresponds fairly well with scallop beds delineated from past surveys (Worms and Chouinard 1983, 1984). The maps clearly depict three major scallop beds: Cape Tormentine (SFA 22 south), West Point (SFA 22 north) and Pictou (SFA 24), all within the Northumberland Strait. Notably, the Richibucto bed, a historically significant fishing area, experienced very little fishing effort compared to historical accounts

(Jamieson 1978; Worms 1984, Figure A2-b). This change was first reported by Hanson (1998) and corroborated by anecdotal reports from fishers. In more recent years (2017−2023), a shift in fishing effort towards Wood Island, off Prince Edward Island, is noticeable in SFA 24 if compared to an earlier period (2003-2016; Figure A2-a).

The science review of logbooks resulted in a 15% increase in useable reports for spatial analysis compared to those reported for the 2011 to 2016 period (Niles et al. 2021).

From 2011 to 2023, compliance with the requirement to complete and return paper logbooks to DFO within two weeks of the end of the season has been variable (Tables 5−8, Figure 12). Since the implementation of the new version of the logbook in 2020, compliance rates remained between 73 and 84% for SFA 22. This suggests that approximately 15 to 27% of trips reported by sales slips do not have a corresponding logbook report. Furthermore, there is no system in place at the present time to independently monitor scallop landings reported in logbooks nor to quantify unreported landings, i.e., landings without sales slips and for which no logbooks were returned. In contrast, compliance (i.e., the number of logbooks in relation to sales slips) in SFA 24 has been closer to 100% since 2020. This is attributed to a high percentage (near 100%) of the catch being reported as local sales, which doesn't involve the production of sales slips. In terms of high quality logbooks that are usable for spatial analysis, there has been an improvement since 2020 in SFA 24 (as well as in SFA 21) with rates above 84% and between 70 to 80% in SFA 22; however, this latter range is considered suboptimal. Consequently, missing and inaccurate logbook data is the main driver of uncertainty of the landings and the effort data that are used in this assessment.

### 4.1.1. SFA 21

#### 4.1.1.1. Catch statistics

From 2017 to 2023, annual landings from SFA 21 have declined from a peak of 7 t in 2017 to 3 t in 2023 (Figure 13). Mean catch rates varied between a low of 4.5 kg $h^{-1}$ in 2021 and a peak of 11.9 kg $h^{-1}$ in 2018 (Table 9). The highest catch rates in the time series (2003−2023) were recorded between 2017 and 2019 and are attributable in large part to SFA 21B (13−17 kg $h^{-1}$) (Figure 13).

### 4.1.2. SFA 22

#### 4.1.2.1. Catch statistics and spatial analysis

SFA 22 landings for the logbook time series (2017−2023) vary annually between 34 t (2021) and 62 t (2018), accompanied by a decline in effort over this period and a marked increase in catch rates in 2023 (Table 9). According to recent logbook records from 2017 to 2023, the majority of SFA 22 landings (about 76%) are shared between the Cape Tormentine and West Point beds (bed as defined in Niles et al. 2021; Table A3-c and Figure 14). Seasonally, the partition between the two beds varies, sometimes starting with a higher proportion of landings from Cape Tormentine in the first weeks of the season and ending with a higher proportion of landings from West Point or *vice versa* possibly indicating that serial depletion is occurring on these beds (Niles et al. 2021).

Annual catch rates averaged 8 kg $h^{-1}$ (2017−2023) and reached a peak of 14.5 kg $h^{-1}$ in 2023 (Figure 13). While 2023 data are preliminary, this is the highest on record since the beginning of the time series in 2003. Results at the SFA 22 level need to be interpreted with caution in consideration of the fluctuations of catch rates over the season between the two major beds. This dynamic would tend to dampen any fluctuation, necessitating bed-level analysis to interpret trends in SFA 22.

#### 4.1.2.2. Depletion model estimates

The depletion model, fit to SFA 22 commercial landings and catch rate data for 2003−2023, was significantly negative for all years ($p < 0.05$). The exploitable biomass estimates from the depletion models varied between 61 t in 2016 and 184 t in 2011, while the annual exploitation rates varied from 30% to 60%, averaging 51% (Figure 15). A drop in exploitation rate was observed in 2005 and 2019. The decrease in exploitable biomass estimates observed since 2016 may be an indication that fishing is occurring at unsustainable levels.

### 4.1.3. West Point bed

#### 4.1.3.1. Catch statistics and spatial analysis

From 2017 to 2023, annual prorated landings from the West Point bed ranged from 3 t (2023) to 16 t (2017) of scallop meat and represented between 8% and 49% of SFA 22 landings (Table A3-c, Figure 16). Low landings in West Point typically coincide with higher landings in Cape Tormentine. Landings and effort have shown a decreasing trend since 2016 (Figure 16). Mean annual catch rates for the 2017 to 2023 period fluctuated between 6.96 kg $h^{-1}$ (2019) and 9.13 kg $h^{-1}$ (2023), slightly higher than previous years (2003−2016) (Figure 16). The spatial variation of catch rates are illustrated in Figures 28a and b (in the Research Surveys 2019−2023 section).

#### 4.1.3.2. Depletion model estimates

The depletion model, fit to the West Point commercial landings and catch rate data for 2003−2023, was significantly negative for all years ($p < 0.000$). The exploitable biomass estimates from the depletion models varied between 5 t in 2016 and 92 t in 2007, while the annual exploitation rates varied from 29% to 59%, averaging 52% (Figure 17). The decrease in exploitable biomass estimates observed over the last eight years may be an indication that fishing is occurring at unsustainable levels (depletion model estimates are shown for years 2017-2023 in Table A3-d and Figure A3-a).

### 4.1.4. Cape Tormentine bed

#### 4.1.4.1. Catch statistics and spatial analysis

From 2017 to 2023, annual prorated landings from the Cape Tormentine bed ranged from 8 t (2022) to 23 t (2023) of scallop meat and represented between 27% and 70% of SFA 22 landings (Table A3-c, Figure 14). Higher landings in Cape Tormentine typically coincided with low landings in West Point. Landings and effort generally display a “boom and bust” pattern since 2003 (i.e., periodic increases and decreases in landings and effort) (Figure 16). Mean annual catch rates from 2017 to 2023 period fluctuated between 6.38 kg $h^{-1}$ in 2022 and 17.45 kg $h^{-1}$ in 2023. This latter value represents the highest catch rates in the time series (2003-2023) for Cape Tormentine, and for all beds (Figure 16). The spatial variation of catch rates are illustrated in Figures 29a and b (in the Research Surveys 2019-2023 section).

#### 4.1.4.2. Depletion model estimates

The depletion models for the Cape Tormentine bed from 2003 to 2023 provided usable parameter estimates for catchability ($q$), initial Biomass ($B_0$), and exploitation rate ($\hat{E}$) ($p < 0.001$). The annual exploitation rates estimated from the depletion model varied between 28% and 58%, with a mean of 49% (Figure 17). The exploitable biomass fluctuated from a low of 18 t (2010) to 141 t (2013) and averaged 46 t (depletion model estimates are shown for years 2017-2023 in Table A3-d and Figure A3-b).

## 4.1.5. SFA 23

Low landings are not disclosed in accordance with the *Privacy Act*, as fewer than five fishing licences were active.

## 4.1.6. SFA 24

In contrast to other SFAs, most landings from SFA 24 are categorized as local sales, potentially increasing uncertainty around unreported catches, as local sales do not have corresponding sales slips to be used for data verification (Figure A4). Between 2017 and 2023, annual landings varied from 20 t (2019) to 30 t (2021−2023) (Table 9, Figure 13). Landings remained relatively consistent over the last four years, while effort has decreased gradually. Annual catch rates from 2017 to 2023 averaged 5.24 kg $h^{-1}$ with a narrow range between 4.27 kg $h^{-1}$ (2017) and 6.81 kg $h^{-1}$ (2022) (Figure 13). Catch rates for 2017-2023 are notably higher than previous years when the average was 3.6 kg $h^{-1}$ (2003−2016) (Niles et al. 2021).

## 4.1.7. Pictou bed

### 4.1.7.1. Catch statistics and spatial analysis

Over the 2017 to 2023 period, 24% of SFA 24 landings were taken from the Pictou bed (bed as defined in Niles et al. 2021; Table A3-c). Annual trends in the proportion of landings attributed to the Pictou bed are presented in Figure 18. The annual prorated landings for the Pictou bed ranged between 3 t to 9 t of scallop meat for the time series (2017−2023) (Figure 16). During 2017 to 2023, catch rates fluctuated between 3.80 kg $h^{-1}$ (2017) to 6.79 kg $h^{-1}$ (2022), with a mean of 4.87 kg $h^{-1}$ and were slightly higher than previous years (2003−2016) (Figure 16). The spatial variation of catch rates for the Pictou bed are illustrated in Figure 30 for each year from 2019 to 2023. (in the Research Surveys 2019−2023 section). The spatial variation in effort over two periods (2003-2016 and 2017-2023) is shown in Figure A2-a.

### 4.1.7.2. Depletion model estimate

The depletion model relating catch rates and cumulative landings from the Pictou bed of SFA 24 was statistically significantly with a negative slope for 2003, 2011 and 2021 (Figure 17) with p values of 0.000, 0.01 and 0.02 respectively. The catch rates were low for this area relative to other areas analyzed for this assessment, and there were little to no declines in catch rates over the season, as reported in the previous assessment (Niles et al. 2021). The model estimate for exploitable biomass before the fishery in 2021 was 25 t for a corresponding exploitation rate of 20% (depletion model estimates are shown for years 2017-2023 in Table A3-d and Figure A3-c). The fact that catch rates were so low suggests that the population is at low abundance level, and this area may not be suitable for the application of Leslie depletion methods.

## 4.1.8. Core area (SFAs 22 and 24 combined)

Landings in the core area for the logbook time series (2017−2023) vary annually between 62 t (2019) and 84 t (2018), accompanied by a decline in effort over this period and a marked increase in catch rates in 2023. Annual catch rates averaged 6.64 kg $h^{-1}$ (2017−2023) and peaked at 9.39 kg $h^{-1}$ in 2023. A depletion model was not able to be fit to the core area data. Instead, estimates were obtained from the sum of depletion model biomass estimates for SFAs 22 and 24, when both were available (i.e., 180 t in 2003, 339 t in 2011 and 227 t in 2021).

## 4.1.9. Limit Reference Point – updated JABBA model

Key model parameters for the updated JABBA model showed adequate mixing of its three MCMC chains (Figure A5-a) and all key parameters passed the built-in Heidelberger and

Welch (1992), and Gelman and Rubin (1992) convergence tests. Residuals from the log transformed observed and predicted fleet specific CPUE indices were evenly distributed around zero and showed no systemic patterns of autocorrelation through time (as indicated by the loess model fit, Figure A5-b). The posterior parameter distributions tended to be narrower than the prior distribution. Posterior distributions tended to lie within the prior distribution although for the intrinsic growth rate, the mean of the posterior distribution was at the lower limit of the prior distribution and the inverse was true for the shape parameter 'm' (Figure A5-c). Furthermore, process error deviates showed no consistent trends throughout the time series (Figure A5-d). A retrospective analysis with the updated model found biomass estimates across peels did not exceed the confidence intervals of the full model (Figure A5-e) and the average Mohns rho across peels for the biomass estimates (-0.21) was within the recommended limits for short-lived species (-0.22 to 0.3, Hurtado-Ferro et al. 2015).

The updated model produced a time series of biomass estimates for the core area which closely resembled the estimates from the initial reference model which used a catch time series spanning 1923 – 2021, a single commercial CPUE time series, and no survey CPUE data. Differences between the two models were minor, with the newer model predicting a slightly lower K and a reduced decrease in abundance in the late 1960 and early 1970s (Figure 19). The predicted biomass levels from the updated model remained above those predicted by the reference model between 1972 and 2000, when the updated model predicted biomass levels dropping below those of the reference model for the remainder of the timeseries. The parameter estimates indicated a slightly lower K (3509 t, 2872 – 4510 t 95% CI), MSY (293 t, 250 – 338 t 95% CI), and $F_{MSY}$ (0.205, 0.158 - 0.282 95% CI), but a slightly higher estimate for $B_{MSY}$ (1391 t, 1143 – 1894 t 95% CI) and r (0.25, 0.17 - 0.34, Figure A5-f). All parameter estimates from the updated model fell within the 95% confidence regions of the reference model.

The updated model parameter estimates produced an LRP for scallops in the sGSL of 556 t (meat weight for harvestable sized scallops), which exceeds the current estimated biomass level in 2023 of 300 t. According to the model, the stock has been in the Critical zone since 1982. Indeed, if we look at the trajectory of relative biomass versus relative fishing pressure (Figure 20) we can see that while the population's status entered the overfished and overfishing quadrant (top left) by 1971, and has remained there ever since, recent harvest levels have brought the stock closer to $F/F_{MSY}$ = 1. In fact, the 95% confidence intervals overlap the $F/F_{MSY}$ = 1 line and the relative biomass levels have been moving towards $B/B_{MSY}$ = 1 for the past 4 years. The fishing mortality rates from the JABBA model were < 0.01 from 1923 to the early 1950s, increased to a peak of 0.71 in 2000, and then decreased to the current estimated level of 0.22 in 2023 (Figure 21). If fishing removals continue to decrease, dropping below $F_{MSY}$, then it stands to reason that the stock abundance will increase in the short term.

## 4.2. RESEARCH SURVEYS 2019−2023

Annual surveys were conducted on the three major scallop beds in the Northumberland Strait from 2019 to 2023 (Table 10). A total of 863 survey tows were sampled over the five-year period. (Figures 22 to 27). Spatial distribution of scallops from the survey (Figures 28 to 30) are visually compared to commercial fishing location data from logbooks. Scallops were found at depths ranging between 9 to 39 m, with a mean depth of 23 m (Figure 31).

Biological characteristics of scallops sampled during the research survey are summarized in Tables 11 and 12. More than 26,000 scallops were measured over the five-year survey period. Shell heights ranged from 9 to 141 mm. The shell height size frequency distributions from the survey catches are shown in Figures 32 to 35. Scallop recruitment to the fishery was observed in all sampled areas in most years. Pulses in small scallops (20-50 mm shell height) are visible in the Cape Tormentine bed in 2021 and 2022 (Figure 34) as well as in the Pictou bed in 2023 (Figure 35). As reported previously (Niles et al. 2021), there were very few scallops with shell height greater than 110 mm on the Cape Tormentine bed, and the maximum shell height recorded at this site was 125 mm.

The size distribution of scallops retained by the larger survey gear type (ring diameter of 82.6 mm) reflected the size selectivity of the commercial drag for the larger sizes. The survey gear (82.6 mm ring size with steel washers) had an $L_{50}$ (the shell height of scallops with 50% probability of being retained by the gear) of 76 mm, meaning the gear will retain most of the scallops above that size (Poirier et al. 2021). In contrast, the mesh (18 mm) that lined two gangs of the survey gear is non-selective.

Overall, the mean meat weight of commercial scallops caught by the survey gear (82.6 mm) was 13.4 g (Figure 36). The age of scallops retained by the survey drag ranged from 2 to 14 years old. An index of natural mortality, based on the proportion of clappers (total in survey bed) with shell heights ≥ 80 mm, ranged from 0.24 to 0.40 (Table 12). In Pictou, an exceptionally high clapper ratio of 0.50 was observed in October 2023, corroborating anecdotal concerns from fishers about high clapper numbers during fishery in November 2023 (Figure 37).

### 4.2.1. Scallop condition

Condition is the predicted meat weight in grams of a 100 mm scallop, derived from the shell height to meat weight relationship (methods described in section 3.2). Condition can vary spatially and temporally, up to 30%. Factors affecting condition include environmental conditions and the physiological state of the scallop (Sarro and Stokesbury 2009; Nasmith and Smith 2017). Since 2019, research surveys conducted in October provided annual condition data for scallops from the three major scallop beds (Tables 13 and 14). Diagnostic analysis for the shell height to meat weight relationship can be found in Figure A6. April surveys provided condition of scallops closer to the timing of the West Point and Cape Tormentine fisheries (in May) (Figure 38). Condition in the core scallop habitat averaged 14 g based on all October surveys from 2019 to 2023 with exceptionally low condition observed on the Cape Tormentine bed in 2021 (Table 14). Broken down by bed, the condition in October averaged 16 g for West Point, 12 g for Cape Tormentine and 13 g for Pictou. Condition increased by around 18% between 2022 and 2023 for the West Point and Cape Tormentine scallops, while it decreased by 2% for Pictou scallops.

Condition was also monitored during the fishing season, from 2021 to 2023, with weekly samples taken at the wharf (Figure 39). Condition in Pictou (SFA 24) tended to increase as the season progressed. Based on this at-wharf sampling, condition during the fishery averaged between 14 and 18.7 g of meat weight (Figure 40). The highest condition values were observed during the May 2023 fishery in West Point (18.4 g) and Cape Tormentine (18.7 g) beds (SFA 22) and in the fall 2022 fishery in Pictou bed (17.7 g) (SFA 24). Generally, condition from the surveys conducted before the respective fisheries agree with condition during the fishery (Figure 40). During the respective fisheries, scallop conditions were on average 4 g higher (range: -0.3, 6.3) than condition in the October surveys (Figure 41).

### 4.2.2. Survey indices

#### 4.2.2.1. Bed

At the bed scale (bed strata), Pictou bed exhibited the highest meat yield per standard tow over the time series despite Cape Tormentine having the highest densities of commercial size scallops (Figure 42). The West Point bed generally showed stable and lower scallop meat yields and densities. Mean number of recruits (65−95 mm) per standard tow (18 mm mesh only) was highest in 2021 on the Cape Tormentine bed.

Survey indices (i.e., biomass of commercial, i.e., ≥ 80 mm shell height scallops, and commercial scallop numbers) derived from the research surveys conducted on the three major scallop fishing beds are presented in Table 15 and Figure 43. Landings from each bed corresponding to the year of the survey were from the commercial logbook data. Exploitation rates were calculated using commercial landings and indices of exploitable biomass from the research surveys. Exploitation rate represents the proportion of available biomass that was harvested during the fishing season. Note that exploitation rate estimates are unadjusted for gear efficiency. For SFA 22 beds, reported landings are added to the October biomass indices to calculate exploitation rates. This adjustment accounts for known removals by fishing when estimating biomass before the fishery ($B_0$), which occurs in May for SFA 22.

#### 4.2.2.2. West Point bed

The West Point bed was surveyed in October, after the fishing season, of each year from 2019 to 2023. The exploitable biomass index, in meat weight, varied between 30 and 40 t across the surveyed years and increased by 26% from 2022 to 2023. However, the survey index of commercial scallop numbers only increased by 5% from 2022 to 2023. The average exploitation rate was estimated at 26%.

#### 4.2.2.3. Cape Tormentine bed

The Cape Tormentine bed was surveyed in October of each year (2019−2023), also after the fishing season. The exploitable biomass index, measured in meat weight, varied from 14 to 43 t. An increasing trend in exploitable biomass was observed over this period and increased by 22% from 2022 to 2023. However, the survey index of commercial scallop numbers only increased by 5% from 2022 to 2023. The average exploitation rate was calculated to be 41%.

#### 4.2.2.4. April (Spring) vs October (Fall) survey indices

In addition to October surveys, West Point and Cape Tormentine beds were surveyed in April in 2022 and 2023 (Table 16). The objective was to obtain biomass indices just before the SFA 22 fishing season in May and compare them with October indices, from surveys conducted five months after the fishing season. Biomass indices from April surveys were higher compared to those from October surveys. Condition varied over time and space, typically being higher in the spring compared to the fall. In fact, the condition in April was considerably higher than in October, except in Cape Tormentine in 2022 where it was unusually low. To adjust biomass indices, the meat weight to shell height relationship of the October survey was applied to the April survey shell heights to control for the difference in biomass between the two surveys. After controlling for condition, biomass indices became more comparable between the two surveys for Cape Tormentine bed but remained higher for West Point bed particularly in April 2022 (Figure 44). Here, higher biomass indices observed in April surveys may have been reduced by fishing activity at levels greater than what could be explained by reported landings. Scallop density (number per standard tow) was generally higher in the April surveys compared to the October surveys except for West Point in 2023 (Figure 44). These higher densities from the survey results explain the remaining biomass differences. Adjustments were not made to October survey biomass indices or numbers of scallops between the two surveys to account for fishery removals.

#### 4.2.2.5. Pictou

The Pictou bed was surveyed in October of each year, except in 2020, just before the fishing season, which takes place in November and December. The exploitable biomass index, measured in meat weight, ranged from 20 to 37 t over the time series, with a mean of 29 t (Figure 43). The commercial scallop numbers varied between 1.3 to 2.9 million (M). An increasing trend in exploitable biomass and commercial scallop numbers was observed over the survey time series but the biomass index remained stable between 2022 and 2023. The commercial scallop numbers index decreased by 10% between 2022 and 2023. The commercial landings that occurred after the survey fluctuated between 3 and 8 t. The average exploitation rate for the Pictou bed was estimated at 20%.

#### 4.2.2.6. SFAs

The exploitable biomass at the SFA 22 level was estimated by summing the biomass indices from the West Point and Cape Tormentine beds. Two important assumptions were made in the estimation process for the SFA level: 1) The landings ratio reported in logbooks is representative of the landings ratio not reported; and 2) Landings are proportional to biomass. The resulting biomass from the summation of the two beds was then converted to SFA biomass by using the landings ratio (beds: SFA 22) for each corresponding year. Strictly according to the October research surveys, $B_0$ for SFA 22 ranged roughly from 96 to 124 t between 2019 and 2023. There appeared to be a modest increase in biomass in 2023. Considering SFA 22 landings (34 to 46 t, 2019 to 2023), this resulted in an average exploitation rate of 36% (range: 33%-38%).

The exploitable biomass at the SFA 24 level was estimated using the biomass from the Pictou bed. Under the same assumptions applied above for SFA 22, the biomass from the Pictou bed was then converted to SFA 24 biomass using the landings ratio (bed:SFA 24) for each corresponding year. Strictly according to the October research surveys, $B_0$ for SFA 24 ranged roughly from 148 t to 309 t between 2019 and 2023. The last year shows a slight increase. Considering SFA 24 landings (19 t to 30 t, 2019 to 2023), this leads to an average exploitation rate of 15% (range: 10%, 20%).

#### 4.2.2.7. Core area (SFA 22 and SFA 24 combined)

The core area of scallop habitat in the sGSL is defined as the region occupied by the beds in SFA 22 and SFA 24 (Harbicht et al. 2024). Survey results from the three major scallop beds were used to estimate survey area abundance and biomass indices (Table 17, Figures 45 to 49). Missing Pictou indices in certain surveys (Oct. 2020, April 2022, and April 2023) were derived from the mean of the time series (2019−2023; number of commercial scallops mean = 5 million (M), number of recruits mean = 0.12 M, and biomass mean = 29 t.

Using the landings ratio (survey area:core area, ≈0.61) for each corresponding year, survey area abundance and biomass were converted to core area indices for certain JABBA model inputs (see Sections 3.1.5 and 4.1.9).

According to the October research surveys, the commercial scallop numbers index showed an upward trend, increasing from 7 million to 14 million scallops in the survey strata over the survey time series (Figure 46). A modest peak in numbers of recruits (65−79 mm shell height) was observed in 2022 (Figure 47). Biomass indices (B) for the survey strata, ranged roughly from 91 t to 185 t between 2019 and 2023 (Figure 48). The trend over the last three years showed a slight increase in exploitable biomass indices. The exploitation rates (percent of the estimated exploitable biomass that was reported in landings) estimated from the research survey for the core area of the sGSL decreased from 30% to 21% between 2020 and 2023 (Figure 49).

When comparing between fishery independent (survey) and fishery dependent (depletion models) biomass estimates, survey biomass indices before the fishery for the three major scallop beds (Cape Tormentine, West Point, Pictou) generally tracked well within the ranges of the depletion model estimates (Table 18; Figure 50). This was also the case at the SFA level (Figure 51).

# 5. ECOSYSTEM CONSIDERATIONS

Because they are ectothermic, environmental conditions can influence the biology of sea scallops. As such, it is important to consider the potential effects of climate change on sea scallops to plan for effective management of this fishery. While climate change studies conducted specifically on the sGSL stock are non-existent, existing literature can provide some insight to inform a precautionary approach as the climate changes.

Perhaps most notably, sea scallop biology is strongly dependent on seawater temperature and scallops are thus vulnerable to the effects of ocean warming. Although the optimal temperature range has yet to be quantified for sea scallops in the sGSL, it is generally accepted that sea scallops can grow at 8−18 °C with optimal growth occurring between 10 and 15 °C (Young-Lai and Aiken 1986; Stewart and Arnold 1994; Frenette 2004); sea scallops become physiologically stressed above 18 °C and temperatures exceeding 21 °C can be lethal (Dickie 1958, Stewart and Arnold 1994).

If these temperature requirements also apply to sGSL scallops, temperature may already be impacting these scallop stocks and may further impact these stocks in the future as the climate continues to warm. The maximum surface temperatures in the Northumberland Strait region are the warmest in the Gulf, averaging 18.8 °C (1991−2020) in August (Galbraith et al. 2023). In 2022, based on the AVHRR SST data, the Northumberland Strait average monthly temperature in August was 20.5 °C, about 2 °C warmer than climatology (Galbraith et al. 2023). Furthermore, based on data from DFO Gulf's Temperature Monitoring Program (1995−2021), bottom temperature extremes during summer months (July−September) in the Northumberland Strait appear to be increasing in both frequency and severity over time. Herein, the maximum bottom temperature recorded across Northumberland Strait sites with depths of 9−25 m (i.e., within the observed depth range of sGSL scallops; see Figure A7) appears to be increasing over time, with the highest maximum bottom temperature being recorded in 2019 (25.4 °C, Figure 52, A). In addition, the number of days in which the daily maximum bottom temperature exceeds the 21 °C upper limit for scallops are also increasing in frequency. Eight of the 11 years from 1995−2006 had zero days where the maximum bottom temperature was > 21 °C, with only one of those years having > 20 days of > 21 °C; in stark contrast, 13 of the 14 years from 2007−2021 had at least 10 days with maximum bottom temperatures > 21 °C, with 11 of those years having > 20 days of > 21 °C (Figure 52, B). It is thus possible that the increasing frequency and severity of extreme temperatures in the Northumberland Strait are already affecting these scallop stocks; however, research directly investigating such effects for the sGSL stocks remains absent.

In addition to the increasingly warmer temperature occurring in the Northumberland Strait, a recent study from the northeastern USA estimated that ocean warming beyond 2 °C was likely to reduce scallop size in this region, resulting in substantially lower shell height and biomass (Zang et al. 2023). The authors also suggested that the effects of warming on scallop size in this area were most pronounced for scallops < 60 m depth, while fishing mortality was a greater driver of reduced size for scallops > 60 m depth (Zang et al. 2023). Given that sGSL scallops are found at depths of 9−37 m (Pavone et al. 2022), warming temperatures may thus negatively affect the size structure of scallops in our region.

Alongside increasing seawater temperature, other climate change related processes are also of concern for sea scallops in the sGSL. Chief among these are ocean acidification (reduction in seawater pH due to oceanic absorption of excess atmospheric $CO_2$; Guinotte and Fabry 2008) and deoxygenation (reduction in seawater oxygen due to increasing seawater temperatures, as warmer waters hold less oxygen and prevent oxygen from reaching deeper water; Breitburg et al. 2018). In coastal regions, effects of ocean acidification and deoxygenation can be compounded by human activities that result in increased nutrients being forced into nearshore waters (Clements and Chopin 2017; Cormier et al. 2023). Pousse et al. (2023) reported that sea scallops were sensitive to ocean acidification, with acidification having negative effects on scallop physiology and growth; the authors also suggested that scallops have limited capacity to physiologically cope with ocean acidification, while changes in energetic physiology can help scallops deal with increased seawater temperature. With respect to fishery-related effects, Rheuban et al. (2018) reported that, in the northeast USA, ocean acidification may reduce sea scallop biomass > 50% by 2100 under the IPCC's RCP8.5 climate scenario (business as usual); they also suggested that setting catch limits and partial area closures (10% of the fishing area) could only partially offset the negative effects of acidification on stock biomass, and biomass reductions of > 25% could still be expected despite these management measures. While research regarding the effects of low oxygen on sea scallops is not available (to our knowledge), evidence suggests that low oxygen conditions, particularly in combination with warming, can negatively affect growth, survival, and predator escape responses in other scallop species, including bay scallops, *Argopecten irradians* (Tomasetti et al. 2023), Peruvian scallops, *A. purpuratus* (Brokordt et al. 2013), and Zhikong scallops, *Chlamys farreri* (Li et al. 2019).

Another human-induced environmental stressor of contemporary interest with respect to bivalves is anthropogenic noise generated from human activities on or near the oceans (Solé and André 2023). While research on this topic remains in its infancy, recent evidence suggests that sound may affect the behaviour of juvenile sea scallops when sounds are of low frequency and high intensity (Jézéquel et al. 2022, 2023). However, much more research regarding the effects of sound on sea scallops is needed before effects on scallop fisheries can be determined. While each of these stressors can independently affect sea scallop biology and future fishery yields, it is important to consider how these parameters might affect sea scallop biology in combination, as warming, acidification, deoxygenation, and anthropogenic noise are likely to occur simultaneously, not in isolation. Indeed, cumulative effects of these stressors can be expected in the Northumberland Strait (Beauchesne et al. 2020), where the scallop stocks addressed here are located. Unfortunately, such multi-stressor studies for sea scallops are limited and any conclusions regarding combined effects would be premature. More research regarding the combined effects of these environmental parameters on scallop fisheries is needed. Furthermore, it is critical to note that while the aforementioned studies apply to sea scallops, none of the studies apply directly to the sGSL stock for which this assessment process applies. Given the importance of local adaptation in dictating bivalve responses to stressors like ocean acidification (Vargas et al. 2017), experimental studies assessing the vulnerability of sGSL scallops to these environmental stressors are much needed. Ultimately, understanding the effects of climate change and other associated stressors on sGSL scallop stocks and the sustainability of the scallop fishery requires more research. Once such effects are known, existing management frameworks from the USA (Cooley et al. 2015; Rheuban et al. 2018) have the potential to help shape adaptive management strategies for this fishery into the future.

In addition to climate change, it is also important to consider biotic stressors in the environment, such as predation. Two main predators of scallops found in the Northumberland Strait include the Atlantic rock crab (*Cancer irroratus*) and the northern sea star (*Asterias rubens*). Rock crabs can consume up to three scallops per crab per day and sea stars up to one scallop per day (Nadeau 2012). While sea stars prefer mussels (*Mytilus edulis*), they can switch to scallops when mussels are not available. Of these two predators, rock crabs are the most efficient and are of most concern in the Northumberland Strait. As such, their abundance and biomass were monitored during the annual surveys, and indices are presented at both the bed strata and the survey strata levels over the time series in Figures 53 and 54, respectively. Rock crab abundances were highest on the West Point bed, with a range of 2.6-3.8 crabs per standard tow. A noticeable peak in rock crab abundance was evident in Pictou (2.8 crabs per standard tow) in 2022. The rock crab biomass index in the survey area ranged between 127 to 268 t with a mean of 214 t. Interestingly, rock crab abundance displayed a linear increase between 2019 and 2023 on the West Point and Cape Tormentine beds (Figure 55). While the drivers of this trend are unknown, increases in rock crab abundance could have ecological implications for the scallop beds, as increases in predator abundance may negatively affect scallop recruitment and survival (Barbeau et al. 1994, 1996, 1998). As such, future surveys should continue to monitor predator abundances in the Northumberland Strait.

# 6. DISCUSSION

The sea scallop fishery in the sGSL is managed by the DFO's Gulf Region through input controls including seasons, area closures, limited entry of licences, gear restrictions and meat count limitations. Both landings and the number of active licences have been low since 2002 relative to previous years (DFO 2019). Only 15% of the 767 licences participated in the scallop fishery in 2022 down from 19% in 2016, suggesting a large amount of latent effort. This implies that there could be reactivation of latent licences at the first signs of recovery of the scallop stock or changes in socio-economic factors affecting fisheries. This warrants consideration in future management strategies. Since 2014, sGSL-wide landings have been less than 100 t per year. Landings were 69 t in 2022 and preliminary landings 83 t in 2023. Over recent years (2017 to 2023), SFA 22 (59%) and SFA 24 (35%) together account for 94% of the Gulf landings, consistent with the past history of the fishery (Jamieson 1979). Spatial analysis highlights that fishing occurs primarily on three beds: West Point (SFA 22), Cape Tormentine (SFA 22) and Pictou (SFA 24), all located within the Northumberland Strait. Approximately 61% of the Gulf landings were harvested from these three beds alone based on 2017 to 2023 logbooks. Smaller beds, in terms of effort and landings, were found in patches throughout the sGSL.

Certain notable changes in management measures for the scallop fishery have occurred in the last 20 years, and more recently since the last assessment in 2018 (DFO 2019). An increase in ring size from 76 mm to 82.6 mm was established in the early 2000s aimed at reducing the number of small scallops caught by the drag as a conservation measure. At around the same time, a decrease in the meat count limit was adopted in SFA 22 from 52 to 44 per 500 g and intended to shift fishing pressure towards larger scallops. Ring size in SFA 22 increased again to 88.9 mm in 2019. Fishing effort was reduced recently with shorter days (2016) and a season shortened by 20% (2018) in SFA 22. Since 2009, SFA 21A adopted a catch rate decision rule, closing the fishery when catch rate is low (< 3 kg $h^{-1}$), and since 2013, has expanded its closed area (i.e., scallop buffer zone).

Mean catch rates, based on information that more accurately reflects actual fishing effort (i.e., kg per hours towed; Orensanz et al. 2016), are only available since 2003 while corresponding to a time period when the resource was already considered to be at low abundance in the sGSL (DFO 2019). Catch rates from the sGSL fishery were generally lower than 10 kg $h^{-1}$. In the 2003 to 2023 time series covered by this assessment, catch rates have mostly been highest in SFA 22, with a mean value of 6.5 kg $^{h-1}$. A mean catch rate of 14.5 kg $^{h-1}$ in 2023 was a record high for the time series and coincided with high condition. Exceptionally high catch rates of 11.5−11.9 kg $^{h-1}$ were also recorded in SFA 21 between 2017 and 2019, mostly attributable to sub zone 21B. This situation raises concerns about potential depletion in SFA 21 since only core area beds are monitored for biomass indices, leaving depletion outside these zones undetected. In contrast, catch rates generally remained below 6.8 kg $^{h-1}$ in SFA 24. Catch rates from the commercial fishery may be hyperstable (i.e., catch rates remains high as true biomass decreases) due to seasonal and annual changes in the spatial distribution of fishing effort. This may introduce bias in the catch rate indices. Overall, annual catch rates are relatively low in the Gulf compared to those reported in other Atlantic Canadian scallop fisheries such as the Bay of Fundy (10 to 25 kg $^{h-1}$) (DFO 2006, Sameoto et al. 2012, Nasmith et al. 2016). SFA 22 catch rates are however within the range of those observed in the Magdalen Islands scallop fishery (i.e., SFA 20, Quebec Region), also in the sGSL (DFO 2013, Trottier et al. 2017). Low catch rates can be concerning when it implies low scallop density. As broadcast spawners, the fewer the neighbors the less chances of fertilization and this compromises reproductive success of a scallop population.

A stock assessment depletion model was fitted to the logbook-reported data representing landings and catch rates for the most important scallop beds in the sGSL. This allows an understanding of the impact of the fishery on the scallop population. Estimates of exploitable biomass and exploitation rates were derived from statistically significant models for each year analyzed (i.e., 2003 to 2023) for the Cape Tormentine and West Point beds in SFA 22.

For the Pictou bed in SFA 24, the model was only significant for the 2003, 2011 and 2021 data. Even for these models, the confidence intervals were too large to display on depletion plots and add to the uncertainty around the biomass indices for the Pictou bed. One explanation is that the amount of scallops removed during the fishing season was insufficient to detect a decline in abundance. In fact, catch rates were so low in this area that they suggest the population is at low abundance level. Consequently, this area may not be suitable for the application of Leslie depletion methods. The failure to fit the model to SFA 24 data likely contributed to the inability to fit the model to the entire core area data (i.e., SFAs 22 and 24 combined). Further, condition monitoring shows that meat weight increased during the fall fishery (in SFA 24) which could potentially mask depletion. Another factor to consider is the particular fishing practices in SFA 24, where scallop landings are primarily sold to local buyers and once orders are filled, the fisher may reduce fishing effort according to local market demands. In general, the levels of exploitation from the depletion model are high, averaging 50% (range: 28%–59%) for the two major scallop beds in SFA 22 over the time series. A noticeable drop in exploitation rates on both major beds in 2019 may be a consequence of the ring size increase that occurred in SFA 22 that year. Despite the uncertainty surrounding fishery-dependent data, exploitation rates are at levels well above what could be considered sustainable fishing. As far back as 1978, Jamieson recognized that the Northumberland Strait scallop resource was greatly overexploited. Likewise, Worms (1984) reported exploitation rates averaging 50% and expressed concern for the sustainability of the Gulf scallop resource at that level of fishing intensity. In contrast, the inshore Bay of Fundy sea scallop fisheries, considered sustainable and are found on some of the most productive beds for this species, sets target exploitation rates at 15% (Smith et al. 2012; Smith and Hubley 2012). This maximum exploitation rate has been adopted as the removal reference point for this area in relation to the Precautionary Approach (DFO 2015).

Missing and inaccurate data in commercial fishery logbooks is the main driver of uncertainty of the landings and the effort data that are used in this assessment. Anecdotal reports suggest that there may be an increase in unreported logbook entries due to a shift to local sales since the early 2000s. The assumption is made that catch rates and fishing locations for complete logbook records are representative of incomplete records. While improvements in reporting are noticeable since the last assessment (Niles et al. 2021), the percentage of logbook reports that are usable for spatial catch rate analysis varies annually from 59% to 94% in the core habitat of the sGSL. Certainly, an independent verification system to corroborate the quality and accuracy of logbooks would improve confidence in the data. A Science review and verification of logbooks resulted in a 15% increase in logbook records available for spatial analysis.

The importance of accurate and high-quality logbook data for the production of scientific advice towards appropriate and effective management of the scallop fishery needs to be emphasized. More complete and accurate fishery data leads to a better understanding of the stock status and better (appropriate and effective) management measures and ultimately improves both the ecological and economical sustainability of the scallop fishery as implied in Report 9 (2023): Reports of the Commissioner of the Environment and Sustainable Development to the Parliament of Canada. Conversely, incomplete or unreturned logbooks and misreporting impact on the confidence in the fishery data and in the advice given to fishery managers.

There is also a substantial amount of unrealized effort (53% of licences were inactive in 2022, amounting to 483 licences across the core area of the sGSL) that presents a concern for future management decisions, particularly given that this is a competitive fishery without quota. The reactivation of these licences could lead to overfishing and further depletion of the stock.

A new fishery-independent survey was conducted between 2019 and 2023, focusing on major scallop beds (West Point, Cape Tormentine, and Pictou) in the sGSL. The survey aimed to address previous limitations by collecting data annually from these three main beds. Abundance indices were obtained for the core scallop habitat in the Northumberland Strait, specifically in SFAs 22 and 24 and for the major beds within. The core area accounts for 90% of the landed sGSL scallops. These survey indices follow similar trends as estimates from the depletion model derived from commercial catch rates. One exception is the drop in biomass estimate in 2022 from the depletion model in the Cape Tormentine bed. That year is when particularly unhealthy looking scallops on the Cape Tormentine bed were noted during the April survey (samples were kept for subsequent histological and PCR analysis) and by fisher observations. Fishers may have avoided these less marketable scallops and fished elsewhere. Nevertheless, this gives some confidence in the estimates presented in this assessment. Exploitation rates remained relatively constant at around 24%. These rates were lower than those derived from the depletion model (50%). Commercial size scallop densities show an upward trend over the survey time series. Moreover, the number of scallop recruits peaked in 2022.

Surveys were conducted on three different vessels (CCGS Perley 2019-2020, chartered vessel-1 2021-2023 and chartered vessel-2 April surveys 2022-2023) potentially contributing to differences in catchability that are not accounted for in the biomass indices. Furthermore, a significant source of uncertainty around the survey coverage around the Pictou strata where a small but important bed near Wood Island PE has undergone an increase in fishing effort in since 2019. This uncertainty underscores the necessity of incorporating the Wood Island bed into future survey designs, as currently, this vital bed remains unmonitored. Moreover, the inclusion of the Richibucto bed, once exploited in the past, is imperative. Monitoring this bed would enable the detection of any signs of recovery, contributing valuable insights into the overall health of the scallop stock.

The survey also provided insights into the condition of scallops, which varied spatially and temporally. The overall average of condition from surveys conducted in October was 14 g, similar to the condition (15 g) reported from the 2012 to 2016 surveys conducted in summer (Niles et al. 2021). The peak in catch rates in SFA 22 during the 2023 fishery is partially explained by the above average condition (18.5 g) but also by the higher densities of scallops in the Cape Tormentine bed. Annual variations in condition may affect interpretation in variations of biomass and violate an important assumption in assessments that biomass is proportional to abundance. The higher condition observed in the sGSL in 2023 compared to previous years, which has also been observed in other regions (DFO 2024), highlights this potential issue and the need for ongoing monitoring efforts. The risk here is that if condition increases, seemingly healthy levels of biomass will yield lower estimates of abundance. This may be what is happening in the 2022 and 2023 where we see increases in biomass estimates and indices which may be inflated by increases in condition in 2023 (SFA 22) and 2022 (SFA 24).

There are uncertainties around using the clappers as a quantitative index of natural mortality (Hart and Chang 2022). The proportion is based on the time in weeks that clappers remain attached and is highly variable. Clapper integrity, beyond natural deterioration of the hinge membrane, can be compromised by disturbance events (e.g., interactions with the fishing gear, storms, etc.), making the clapper proportion inappropriate in cases when data are collected after the fishery as it would underestimate natural mortality. Nonetheless, clapper proportions do represent a reasonable qualitative indicator of changes in natural mortality over time.

Based on existing literature, sea scallops in the sGSL can be considered vulnerable to the effects of climate change and ocean acidification; however, a lack of regional data precludes quantitative assessments of potential climate change impacts on these stocks. While it is possible that warming seawater temperatures are already affecting sGSL scallop stocks, detailed experiments quantifying temperature thresholds and sensitivities specifically for sGSL scallops would provide more confidence. Furthermore, with respect to acidification, CO2 experiments with sGSL scallops are non-existent. While previous studies underscore sea scallop sensitivity to ocean acidification (Rheuban et al. 2018; Pousse et al. 2023), data specific to sGSL stocks are needed, as local adaptation may render scallop populations in this region more robust to acidification. Indeed, oysters in this area appear to be more resilient to acidification thanks to a history of being naturally exposed to periodic episodes of low pH conditions (Clements et al. 2021). Additional stressors including deoxygenation and anthropogenic noise also deserve research attention.

Despite the inherent uncertainties within the fishery-dependent data, it remains evident that catch rates within the core area of the sGSL are notably low. Furthermore, research surveys conducted between 2019 and 2023 indicate low densities of scallops in the region compared to historical densities (Jamieson 1979; Worms 1984).

A limit reference point (LRP) of $0.4B_{MSY}$ has been applied to the sGSL scallop stock and was initially calculated to be 551 t of harvestable biomass (Harbicht et al. 2024). An updated version of the same model used to produce the original LRP has increased this value slightly to 556 t within the core area. Biomass estimates derived from the updated JABBA model indicate the sGSL stock is currently below this threshold and has been since 1982, placing the stock in the Precautionary Approach's Critical zone. As stipulated in the Fish Stock Provisions, a rebuilding plan to bring the scallop stock above the LRP will need to be developed within two years (DFO 2021).

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# 8. TABLES

*Table 1.Summary of management measures for the scallop fishery in the southern Gulf of St. Lawrence.*

| Management measure | Scallop Fishing Area (SFA) | | | | | |
|---|---|---|---|---|---|---|
| | **21A** | **21B** | **21C** | **22** | **23** | **24** |
| Season in 2021 | July 5 to July 18 | May 10 to Aug. 8 | July 5 to July 30 | May 3 to May 29 | July 1 to Aug. 21 | Nov. 1 to Dec. 15 |
| Season in 2022 | July 11 to July 22 | May 10 to Aug. 8[a] | July 4 to July 29 | May 2 to May 28 | July 4 to Aug. 20 | Nov. 1 to Dec. 15 |
| Number of fishing days in season | 10 | 42 | 20 | 24 | 42 | 39 |
| Time open | 6:00 to 18:00 | No time closures[d] | 4:00 to 21:00 | 6:00 to 17:00 | 6:00 to 18:00 | 6:00 to 18:00 |
| Days closed | Saturday & Sunday | No closures[d] | Saturday & Sunday | Sunday | Sunday | Sunday |
| Meat count (number per 500 g) | 35 | 39 | 39 | 44 | 33 | 52 |
| Ring size (mm) | 82.6 | 82.6[e] | 82.6[e] | 88.9[b] | 82.6 | 82.6 |
| Drag size (m) | 6 | 6 | 6 | 4.88 | 6 | 5 |
| Tow bar specifications [c] | ns | ns | ns | with 50.8 mm runners | ns | ns |
| Washers | Steel (8 max) & Chaffing gear or 2 rubbers on the vertical | | | no rubber washers | Steel (8 max) & Chaffing gear or 2 rubbers on the vertical | |

[a] maximum of 42 consecutive days within this season
[b] new ring size effective since 2019
[c] not specified
[d] since 2013
[e] will increase to 88.9 mm in 2024

*Table 2. Distribution of commercial scallop fishing licences and estimates of active fishing licences and total fishing licences (in parentheses) by Scallop Fishing Area (SFA) and for the whole southern Gulf of St Lawrence (sGSL) from 2017 to 2022 showing percent active in 2016 and 2022.*

| SFA | Status | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Active in 2016 | Active in 2022 |
|---|---|---|---|---|---|---|---|---|---|
| 21 | Active (total) | 6 | 11 | 7 | 9 | 8 | 11 (100) | 6% | 11% |
| 22 | Active (total) | 73 | 82 | 69 | 57 | 54 | 52 (200) | 42% | 26% |
| 23 | Active (total) | 3 | 1 | 1 | 0 | 1 | 0 (78) | 6% | 0% |
| 24 | Active (total) | 62 | 55 | 52 | 56 | 57 | 55 (385) | 13% | 14% |
| sGSL | Active (total) | 144 | 149 | 129 | 122 | 120 | 118 (763) | 19% | 15% |

*Table 3. Number of licences, logbook returns, landings (in number of scallops) and estimate of meat weight of sea scallops in the recreational fishery of the southern Gulf of St Lawrence from 2017 to 2022.*

| Year | Number of Scallop recreational licences | Number of recreational logbooks returned | Number of ACTIVE recreational logbooks returned | Number of days fished | Landings Number of scallops | Landings Estimate of meat weight (kg)* |
|---|---|---|---|---|---|---|
| 2017 | 290 | 49 | 44 | 97 | 4117 | 68 |
| 2018 | 297 | 33 | 30 | 88 | 3441 | 57 |
| 2019 | 320 | 37 | 31 | 91 | 2631 | 44 |
| 2020 | 283 | 13 | 4 | 8 | 188 | 3 |
| 2021 | 288 | 30 | 25 | 65 | 2395 | 40 |
| 2022 | 295 | 25 | 21 | 55 | 2442 | 41 |

* based on 16.6 g per 100 mm scallop

*Table 4. Stratum descriptions and area ($km^2$) for the scallop Northumberland scallop surveys from 2019 to 2023.*

| **Stratum (h)** | **Scallop Fishing Area (SFA)** | **Bed name based on 20 days $km^{-2}$** | **Area ($km^2$)** |
|---|---|---|---|
| 1 | 22 | West Point | 137 |
| 2 | 22 | Outside West Point | 34 |
| 3 | 22 | Cape Tormentine | 92 |
| 4 | 22 | Outside Cape Tormentine | 63 |
| 5 | 24 | Pictou | 78 |
| 6 | 24 | Outside Pictou | 128 |
| Total | | | 454 |

*Table 5. Commercial scallop logbook reporting in relation to sales slip reporting for Scallop Fishing Area 21, from 2011 to 2022 after science review of logbooks. Note that data for 2023 are preliminary.*

| Year | Sales slips | Logbook records | | | | | |
|---|---|---|---|---|---|---|---|
| | Total number of days reported | Total | Percent reporting (%) | Usable for location | Useable for effort (hours towed) | Useable for location and effort | Percent usable logs (%) |
| 2011 | 31 | 28 | 90 | 18 | 22 | 16 | 52 |
| 2012 | 15 | 15 | 100 | 7 | 10 | 7 | 47 |
| 2013 | 141 | 140 | 99 | 116 | 109 | 97 | 69 |
| 2014 | 137 | 130 | 95 | 109 | 95 | 91 | 66 |
| 2015 | 24 | 24 | 100 | 20 | 20 | 20 | 83 |
| 2016 | 58 | 58 | 100 | 36 | 47 | 35 | 60 |
| 2017 | 54 | 54 | 100 | 51 | 41 | 39 | 72 |
| 2018 | 63 | 56 | 89 | 51 | 42 | 37 | 59 |
| 2019 | 51 | 50 | 98 | 34 | 27 | 26 | 51 |
| 2020 | 86 | 85 | 99 | 77 | 83 | 75 | 87 |
| 2021 | 59 | 59 | 100 | 55 | 55 | 51 | 86 |
| 2022 | 56 | 56 | 100 | 50 | 51 | 45 | 80 |
| 2023p | 60 | 55 | 92 | 50 | 50 | 50 | 83 |

*Table 6. Commercial scallop logbook reporting in relation to sales slip reporting for Scallop Fishing Area 22, from 2011 to 2022 after science review of logbooks. Note that data for 2023 are preliminary.*

| Year | Sales slips | Logbook records | | | | | |
|---|---|---|---|---|---|---|---|
| | Total number of days reported | Total | Percent reporting (%) | Usable for location | Useable for effort (hours towed) | Useable for location and effort | Percent usable logs (%) |
| 2011 | 1631 | 1456 | 89 | 1336 | 1020 | 984 | 60 |
| 2012 | 1773 | 1290 | 73 | 1175 | 1021 | 963 | 54 |
| 2013 | 1734 | 1291 | 74 | 1173 | 1034 | 980 | 57 |
| 2014 | 1516 | 1156 | 76 | 1067 | 880 | 833 | 55 |
| 2015 | 1231 | 930 | 76 | 837 | 670 | 598 | 49 |
| 2016 | 1006 | 874 | 87 | 767 | 724 | 623 | 62 |
| 2017 | 1077 | 868 | 81 | 801 | 683 | 634 | 59 |
| 2018 | 1188 | 923 | 78 | 877 | 812 | 769 | 65 |
| 2019 | 956 | 733 | 77 | 695 | 679 | 646 | 68 |
| 2020 | 792 | 663 | 84 | 634 | 658 | 631 | 80 |
| 2021 | 748 | 596 | 80 | 585 | 588 | 577 | 77 |
| 2022 | 734 | 534 | 73 | 529 | 526 | 523 | 71 |
| 2023p | 647 | 434 | 67 | 425 | 394 | 385 | 60 |

*Table 7. Commercial scallop logbook reporting in relation to sales slip reporting for Scallop Fishing Area 23, from 2011 to 2022 after science review of logbooks. Note that data for 2023 are preliminary.*

| Year | Sales slips | Logbook records | | | | | |
|---|---|---|---|---|---|---|---|
| | Total number of days reported | Total | Percent reporting (%) | Usable for location | Useable for effort (hours towed) | Useable for location and effort | Percent usable logs (%) |
| 2011 | 11 | 11 | 100 | 11 | 11 | 11 | 100 |
| 2012 | 25 | 25 | 100 | 0 | 9 | 0 | 0 |
| 2013 | 38 | 38 | 100 | 21 | 21 | 21 | 55 |
| 2014 | 94 | 52 | 55 | 52 | 44 | 44 | 47 |
| 2015 | 51 | 25 | 49 | 25 | 25 | 25 | 49 |
| 2016 | 66 | 48 | 73 | 48 | 33 | 33 | 50 |
| 2017 | 26 | 21 | 81 | 21 | 21 | 21 | 81 |
| 2018 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2019 | 8 | 8 | 100 | 8 | 8 | 8 | 100 |
| 2020 | 0 | 0 | NA | 0 | 0 | 0 | NA |
| 2021 | 6 | 6 | 100 | 6 | 6 | 6 | 100 |
| 2022 | 0 | 0 | NA | 0 | 0 | 0 | NA |
| 2023p | 0 | 0 | NA | 0 | 0 | 0 | NA |

*Table 8.Commercial scallop logbook reporting in relation to sales slip reporting for Scallop Fishing Area 24, from 2011 to 2022 after science review of logbooks. Note that data for 2023 are preliminary.*

| Year | Sales slips | Logbook records | | | | | |
|---|---|---|---|---|---|---|---|
| | Total number of days reported | Total | Percent reporting (%) | Usable for location | Useable for effort (hours towed) | Useable for location and effort | Percent usable logs (%) |
| 2011 | 1135 | 1129 | 99 | 962 | 680 | 667 | 59 |
| 2012 | 1107 | 1099 | 99 | 952 | 639 | 634 | 57 |
| 2013 | 951 | 951 | 100 | 839 | 559 | 552 | 58 |
| 2014 | 843 | 832 | 99 | 795 | 569 | 566 | 67 |
| 2015 | 672 | 668 | 99 | 629 | 419 | 418 | 62 |
| 2016 | 697 | 696 | 100 | 656 | 511 | 502 | 72 |
| 2017 | 739 | 710 | 96 | 636 | 495 | 469 | 63 |
| 2018 | 585 | 574 | 98 | 558 | 456 | 452 | 77 |
| 2019 | 606 | 583 | 96 | 544 | 451 | 442 | 73 |
| 2020 | 820 | 815 | 99 | 757 | 765 | 713 | 87 |
| 2021 | 722 | 720 | 100 | 715 | 681 | 676 | 94 |
| 2022 | 523 | 508 | 97 | 494 | 478 | 464 | 89 |
| 2023p | 668 | 658 | 99 | 654 | 565 | 561 | 84 |

*Table 9. Landings, fishing effort and catch per unit effort from commercial logbook for Scallop Fishing Areas 21, 22 and 24 and core (SFAs 22 and 24) from 2017 to 2023, in the southern Gulf of Saint Lawrence. Note that landings for 2023 are preliminary.*

| Year | Landings (t) | | | | Effort (number of hours towed) | | | | Catch per unit effort (kg/hours towed) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 21 | 22 | 24 | Core | 21 | 22 | 24 | Core | 21 | 22 | 24 | Core |
| 2017 | 7 | 50 | 24 | 74 | 628 | 7378 | 5691 | 13069 | 11.62 | 6.79 | 4.27 | 5.69 |
| 2018 | 6 | 62 | 22 | 84 | 511 | 7780 | 4615 | 12395 | 11.90 | 8.02 | 4.69 | 6.78 |
| 2019 | 4 | 42 | 20 | 62 | 372 | 6379 | 4066 | 10445 | 10.47 | 6.58 | 4.80 | 5.89 |
| 2020 | 5 | 37 | 28 | 65 | 725 | 5398 | 6323 | 11722 | 7.57 | 6.86 | 4.44 | 5.56 |
| 2021 | 3 | 34 | 30 | 64 | 580 | 5070 | 5286 | 10356 | 4.53 | 6.76 | 5.67 | 6.20 |
| 2022 | 3 | 36 | 30 | 66 | 465 | 5039 | 4351 | 9390 | 6.34 | 7.13 | 6.81 | 6.98 |
| 2023p | 3 | 49 | 30 | 80 | 584 | 3409 | 5078 | 8488 | 5.13 | 14.50 | 5.97 | 9.39 |

*Table 10. Description of research vessel scallop survey dates, beds, proportion of area in stratum, number of randomly selected tows, number of scallops measured and dissected and number of rock crab measured for each survey year.*

| Year | Dates | Description of beds surveyed | Number of Tows | Number of Scallop measured | Number of Scallop dissected | Number of Rock Crab measured |
|---|---|---|---|---|---|---|
| 2019 | 16-31 Oct. | West Point, Cape Tormentine, Pictou | 99 | 1485 | 509 | 825 |
| 2020 | 11-27 Oct. | West Point, Cape Tormentine | 70 | 1205 | 331 | 943 |
| 2021 | 8-21 Oct. | West Point, Cape Tormentine, Pictou | 216 | 5576 | 602 | 1888 |
| 2022 | 15–29 Apr. | West Point, Cape Tormentine | 77 | 4762 | 403 | 1753 |
| 2022 | 4-18 Oct. | West Point, Cape Tormentine, Pictou | 150 | 5779 | 563 | 1670 |
| 2023 | 14–26 Apr. | West Point, Cape Tormentine | 100 | 3773 | 391 | 2345 |
| 2023 | 4-26 Oct. | West Point, Cape Tormentine, Pictou | 151 | 4135 | 567 | 1334 |
| ***Total*** | | | 863 | 26715 | 3366 | 10758 |

*Table 11. Number of scallops (n), mean and standard deviation of shell height, size range, maximum meat weight, mean and maximum age of sea scallop for each survey year (2019-2023), both mesh sizes (18 mm and 82.6 mm). Note that the April surveys (month 4) were conducted before the fishery.*

| | | | Shell Height (mm) | | | | Max Meat Weight (g) | Mean Age | Max Age |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Month** | **n** | **Mean** | **SD** | **Min** | **Max** | | | |
| 2019 | 10 | 1485 | 88.9 | 20.02 | 20 | 135 | 39.0 | 6 | 14 |
| 2020 | 10 | 1205 | 86.7 | 20.00 | 14 | 124 | 31.7 | 6 | 11 |
| 2021 | 10 | 5576 | 87.5 | 19.26 | 15 | 141 | 35.5 | 6 | 14 |
| 2022 | 4 | 4762 | 88.4 | 15.64 | 17 | 131 | 41.1 | 6 | 13 |
| 2022 | 10 | 5779 | 88.7 | 19.27 | 13 | 137 | 29.4 | 6 | 14 |
| 2023 | 4 | 3773 | 92.0 | 14.37 | 20 | 133 | 41.2 | 6 | 13 |
| 2023 | 10 | 4135 | 90.2 | 19.64 | 9 | 132 | 32.9 | NA | NA |

*Table 12. Number of scallops (n), mean and standard deviation of shell height, size range, maximum meat weight, mean, and clapper ratio (Merrill and Posgay 1964) of sea scallop for each survey year (2019-2023), mesh size = 82.6 mm. Note that the April surveys (month 4) were conducted before the fishery.*

| | | | Shell Height (mm) | | | | Max Meat Weight (g) | Mean Meat Weight (g) | Clapper ratio |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Month** | **n** | **Mean** | **SD** | **Min** | **Max** | | | |
| 2019 | 10 | 958 | 96.2 | 12.28 | 29 | 127 | 38.2 | 16.4 | 0.34 |
| 2020 | 10 | 746 | 94.5 | 13.97 | 14 | 124 | 27.1 | 11.8 | 0.16 |
| 2021 | 10 | 3416 | 94.7 | 11.81 | 31 | 141 | 42.3 | 10.0 | 0.29 |
| 2022 | 4 | 3555 | 92.1 | 11.06 | 21 | 128 | 36.9 | 11.5 | 0.18 |
| 2022 | 10 | 2659 | 96.1 | 10.94 | 14 | 137 | 30.5 | 11.8 | 0.38 |
| 2023 | 4 | 2435 | 96.4 | 7.80 | 47 | 133 | 49.2 | 18.5 | 0.24 |
| 2023 | 10 | 2700 | 97.0 | 10.58 | 12 | 132 | 34.5 | 12.9 | 0.54 |

*Table 13. Number of scallops sampled for condition or predicted meat weight in grams of a 100 mm shell height scallop, from October and April surveys and from at-wharf sampling during the fishing season from 2019 to 2023 for each of the three main scallop beds (West Point, Cape Tormentine and Pictou) in the southern Gulf of St. Lawrence.*

| Bed | Year | October survey | April survey | May fishery | November fishery |
|---|---|---|---|---|---|
| West Point | 2019 | 190 | - | - | - |
| | 2020 | 212 | - | - | - |
| | 2021 | 194 | - | 441 | - |
| | 2022 | 192 | 215 | 434 | - |
| | 2023 | 160 | 194 | 345 | - |
| Cape Tormentine | 2019 | 149 | - | - | - |
| | 2020 | 121 | - | - | - |
| | 2021 | 182 | - | 370 | - |
| | 2022 | 161 | 186 | 333 | - |
| | 2023 | 195 | 195 | 425 | - |
| Pictou | 2019 | 170 | - | - | - |
| | 2020 | - | - | - | - |
| | 2021 | 222 | - | - | 396 |
| | 2022 | 209 | - | - | 646 |
| | 2023 | 102 | - | - | 513 |

*Table 14. Condition, or predicted meat weight in grams of a 100 mm shell height scallop, from October and April surveys and from at-wharf sampling during the fishing season from 2019 to 2023 for each of the three main scallop beds (Cape Tormentine, West Point, and Pictou) in the southern Gulf of St. Lawrence.*

| Bed | Year | October survey | April survey | May fishery | November fishery |
|---|---|---|---|---|---|
| West Point | 2019 | 20.31 | - | - | - |
| | 2020 | 14.47 | - | - | - |
| | 2021 | 16.56 | - | 15.7 | - |
| | 2022 | 11.32 | 16.8 | 16.7 | - |
| | 2023 | 15.18 | 19.6 | 18.4 | - |
| Cape Tormentine | 2019 | 15.7 | - | - | - |
| | 2020 | 11.0 | - | - | - |
| | 2021 | 7.83 | - | 14.0 | - |
| | 2022 | 12.97 | 11.2 | 14.0 | - |
| | 2023 | 13.59 | 20.2 | 18.7 | - |
| Pictou | 2019 | 15.24 | - | - | - |
| | 2020 | - | - | - | - |
| | 2021 | 11.36 | - | - | 15.0 |
| | 2022 | 12.51 | - | - | 17.7 |
| | 2023 | 12.22 | - | - | 16.9 |

*Table 15. Bed specific research vessel scallop October survey commercial size (≥ 80 mm shell height) exploitable biomass indices (not corrected for drag efficiency) of scallop as number (number per $m^2$) and meat weight (kg per standard tow of 657 $m^2$; mean, standard error (SE)), density (g $m^{-2}$), corresponding area for the bed (km²) according to the 20 days $km^{-2}$ contour, biomass index (meat weight, t), pro-rated landings to the bed and resulting exploitation rates for 2019 to 2023.*

| | SFA 22 | | | | | SFA 22 | | | | | SFA 24 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed | West Point | | | | | Cape Tormentine | | | | | Pictou | | | | |
| Year | 2019 | 2020 | 2021 | 2022 | *2023* | 2019 | 2020 | 2021 | 2022 | *2023* | 2019 | 2020 | 2021 | 2022 | 2023 |
| Abundance (number per $m^2$) | | | | | | | | | | | | | | | |
| Mean | 0.013 | 0.020 | 0.016 | 0.018 | 0.019 | 0.013 | 0.017 | 0.036 | 0.036 | 0.038 | 0.017 | NA | 0.024 | 0.037 | 0.024 |
| Standard error | 0.002 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 | 0.008 | 0.008 | 0.002 | NA | 0.003 | 0.004 | 0.003 |
| Abundance (kg per standard tow) | | | | | | | | | | | | | | | |
| Mean | 0.162 | 0.190 | 0.154 | 0.142 | *0.179* | 0.129 | 0.103 | 0.166 | 0.254 | 0.31 | 0.172 | NA | 0.185 | 0.310 | 0.31 |
| Standard error | 0.026 | 0.033 | 0.023 | 0.020 | *0.030* | 0.027 | 0.024 | 0.024 | 0.053 | 0.06 | 0.021 | NA | 0.018 | 0.034 | 0.04 |
| Density (g per $m^2$) | 0.25 | 0.29 | 0.23 | 0.22 | *0.27* | 0.20 | 0.16 | 0.25 | 0.39 | 0.47 | 0.26 | NA | 0.28 | 0.47 | 0.47 |
| Surface area of the stratum ($km^2$) | 137 | - | - | - | - | 92 | - | - | - | - | 78 | - | - | - | - |
| Biomass (t) index | 34 | 40 | 32 | 30 | *37* | 18 | 14 | 23 | 35 | 43 | 20 | NA | 22 | 37 | 36 |
| Landings (t) | 16 | 11 | 11 | 18 | *4** | 12 | 17 | 17 | 11 | 35* | 3 | 5 | 5 | 8 | 4* |
| Exploitation rate | 32% | 22% | 26% | 38% | *10%* | 40% | 54% | 42% | 24% | 45% | 15% | NA | 23% | 22% | 11% |

*Preliminary data - 2023

*Table 16. Bed specific research vessel scallop April survey commercial size (≥ 80 mm shell height) biomass indices (not corrected for drag efficiency) of scallop as meat weight (kg per standard tow of 657 $m^2$; mean, standard error (SE)), density (g $m^{-2}$), corresponding area for the bed (km²) according to the 20 days $km^{-2}$ contour, biomass index (meat weight, t), pro-rated landings to the bed, and resulting exploitation rate for 2022 and 2023. The two shaded columns reflect the results adjusted (controlled) for differences in condition between the April and October surveys.*

| **Characteristic** | **SFA 22** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bed | West Point | | Cape Tormentine | | West Point | | Cape Tormentine | |
| Year | 2022 | *2023* | 2022 | *2023* | *2022* | *2023* | *2022* | *2023* |
| Abundance (number per $m^2$) | | | | | | | | |
| Mean | 0.056 | 0.022 | 0.066 | 0.057 | 0.056 | 0.022 | 0.066 | 0.057 |
| Standard error | 0.011 | 0.003 | 0.013 | 0.017 | 0.011 | 0.003 | 0.013 | 0.017 |
| Abundance (kg per standard tow) | | | | | | | | |
| Mean | 0.56 | 0.27 | 0.44 | 0.71 | 0.441 | 0.215 | 0.454 | 0.471 |
| Standard error | 0.10 | 0.04 | 0.08 | 0.20 | 0.079 | 0.031 | 0.083 | 0.136 |
| Density (g per $m^2$) | 0.86 | *0.41* | 0.67 | 1.08 | 0.67 | 0.33 | 0.69 | 0.72 |
| Surface area of the stratum ($km^2$) | 137 | - | 92 | - | 137 | - | 92 | - |
| Biomass (t) index | 100 | *53* | 51 | 64 | 92 | 64 | 45 | 66 |
| Landings (t) | 18 | *4** | 11 | 35* | 18 | *4** | 11 | 35* |
| Exploitation rate | 13% | *7%* | 15% | 35% | 20% | 6% | 25% | 53% |

*Preliminary data.

*Table 17. Research vessel scallop October survey commercial size (≥ 80 mm shell height) exploitable biomass indices (not corrected for drag efficiency) of scallop as number (number per m²) and meat weight (kg per standard tow of 657 m²; mean, standard error (SE) ), density (g m⁻²), corresponding survey area (km²), biomass index (meat weight, t), pro-rated landings to the survey area for 2019 to 2023, landings ratio (surveyed area:core area) for the core area of the Gulf Region (SFA 22 and SFA 24). Note that Pictou bed was not surveyed in 2020, therefore the missing Pictou biomass index was estimated from the mean biomass (29 t) of the time series. April survey results, adjusted for condition are presented for 2022a and 2023a (shaded columns).*

| **Characteristic** | | | **SFA 22 and SFA 24 core area** | | | | |
|---|---|---|---|---|---|---|---|
| Year | 2019 | *2020* | 2021 | *2022* | *2023* | *2022a* | *2023a* |
| Abundance (number per m$^2$) | | | | | | | |
| Mean | 0.012 | 0.015 | 0.021 | 0.025 | 0.026 | 0.056 | 0.035 |
| Standard error | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.007 | 0.006 |
| Abundance (kg per standard tow) | | | | | | | |
| Mean | 0.14 | 0.12 | 0.14 | 0.20 | 0.23 | 0.41 | 0.30 |
| Standard error | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.05 | 0.05 |
| Density (g per m$^2$) | 0.21 | 0.19 | 0.22 | 0.30 | 0.35 | 0.63 | 0.46 |
| Surface area of the stratum (km$^2$) | 454 | *454* | 454 | 454 | 454 | *326* | *326* |
| Biomass (t) index | 114 | 126 | 117 | 162 | 185 | 205 | 150 |
| Landings (t) – survey area | 35 | 38 | 37 | 40 | 46 | 40 | 46 |
| Landings (t) – core area | 61 | *65* | 64 | 64 | 79* | 64 | 79* |
| Landings (survey:core) ratio | 0.58 | 0.61 | 0.60 | 0.66 | 0.58 | 0.66 | 0.58 |

*Preliminary data.

*Table 18. Exploitable biomass estimates ($B_0$) for the core scallop area (SFAs 22 and 24) from 2017 to 2023, in the southern Gulf of Saint Lawrence, derived from a data-limited JABBA model (with data up to 2023, including survey, landings, and effort), depletion model exploitable biomass estimates and survey biomass indices. Note that April survey indices are not adjusted for condition.*

| Year | JABBA Model | JABBA Model updated | Depletion Model | Survey Indices | |
|---|---|---|---|---|---|
| | | | | October | April |
| 2017 | 293 | 258 | - | - | - |
| 2018 | 312 | 267 | - | - | - |
| 2019 | 280 | 254 | - | 251 | - |
| 2020 | 290 | 259 | - | 253 | - |
| 2021 | 249 | 290 | 227 | 250 | - |
| 2022 | - | 354 | - | 295 | 442 |
| 2023 | - | 298 | - | 390 | 467 |

# 9. FIGURES

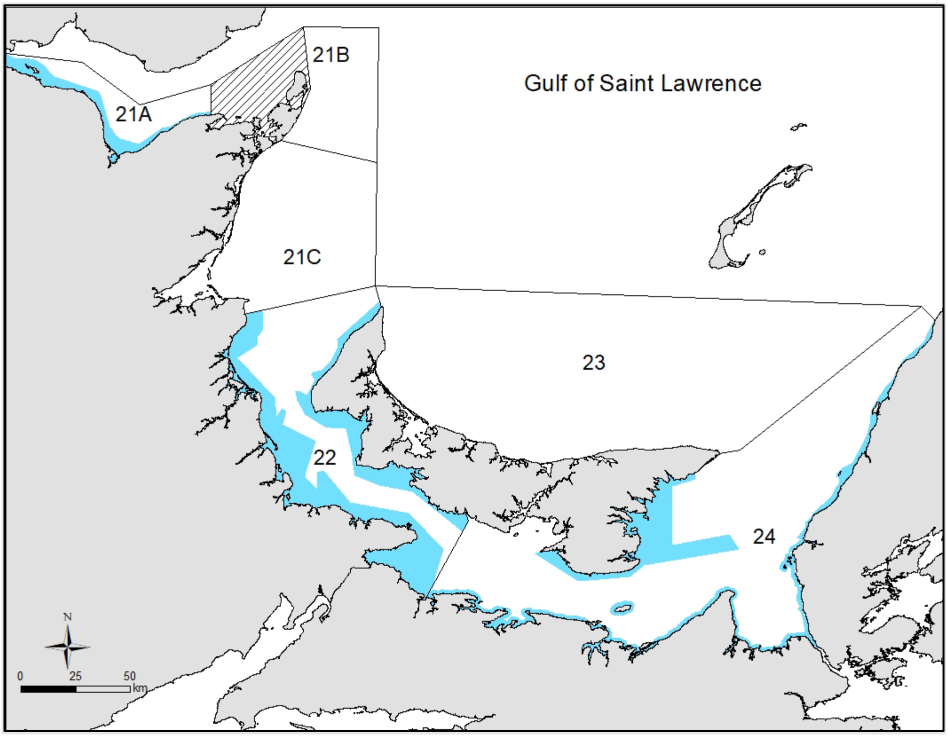



*Figure 1. The Scallop Fishing Areas (SFA) in the Gulf Region showing buffer zones (shaded in blue) and closed zones (shaded in hash), Gulf of St. Lawrence.*

*Figure 2. Nine gang Digby-type dredge commonly used to fish sea scallops in the Gulf Region.*

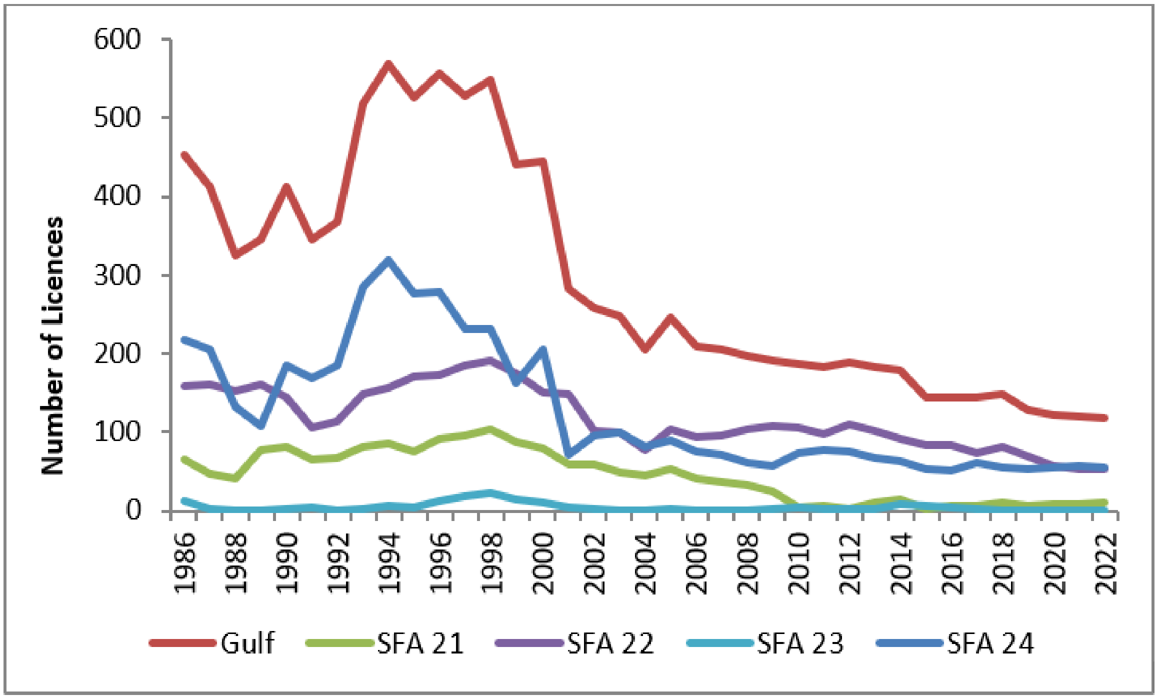



*Figure 3. Number of active commercial scallop licences from 1986 to 2022 in the Gulf Region and in each Scallop Fisheries Area (SFA).*

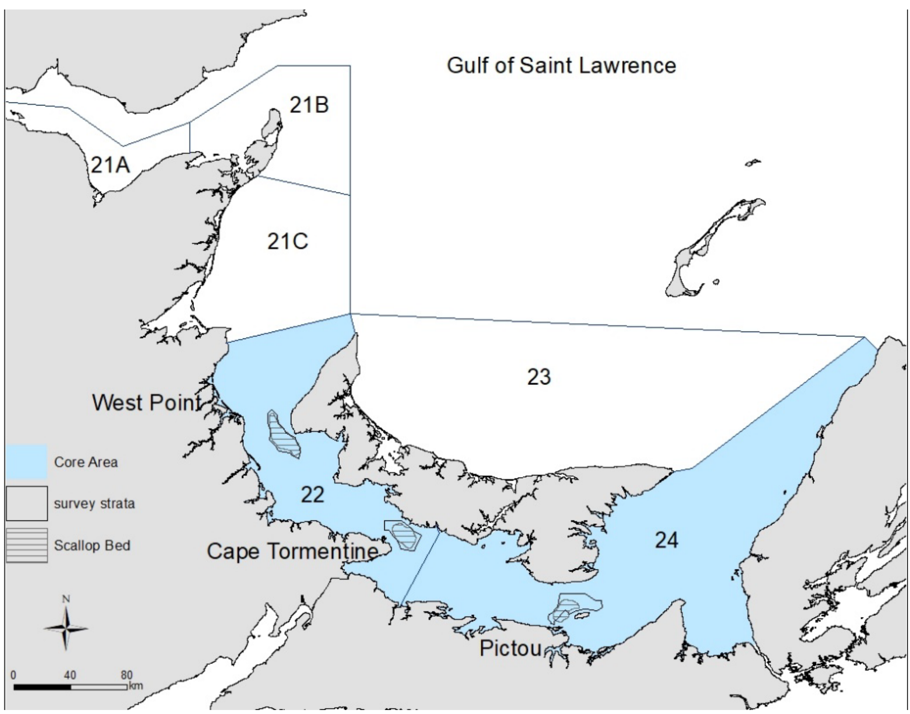



*Figure 4. Map of core area (SFA 22 and SFA 24; light blue shaded area), scallop bed strata (from north to south, West Point and Cape Tormentine in SFA 22 and Pictou in SFA 24 as defined by the 20 days km$^{-2}$ contour (hashed area)) and survey sampling strata (solid line polygons) in the southern Gulf of Saint Lawrence (sGSL). Also shown are the outside bed strata for each bed (exterior polygon minus bed strata area).*

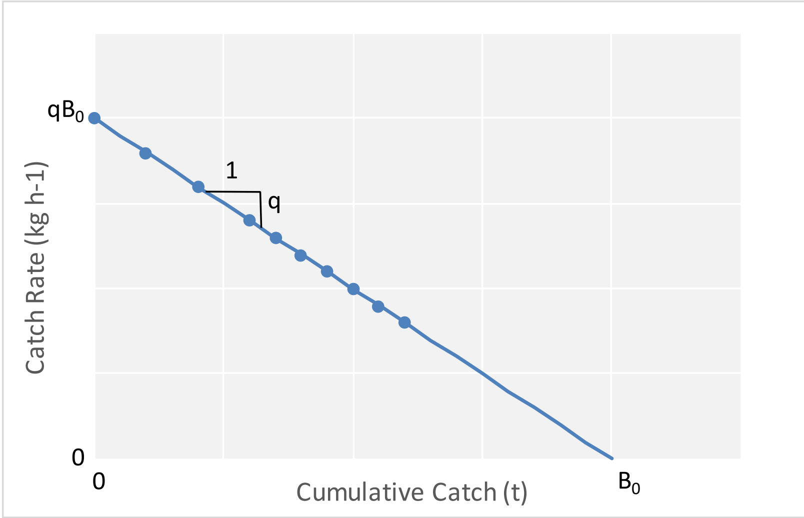



*Figure 5. Plot of theoretical linear regression model of the decline in the index of abundance with increasing cumulative catch used to estimate fishable biomass before the fishery ($B_0$), slope (q) and intercept ($qB_0$). Modified from Ogle 2016.*

*Figure 6. Research survey gear composed of a toothed 8-gang scallop drag (82.6 mm rings) with two of the drags lined (18 mm mesh) used in the 2019 and 2023 scallop surveys in the southern Gulf of St. Lawrence.*

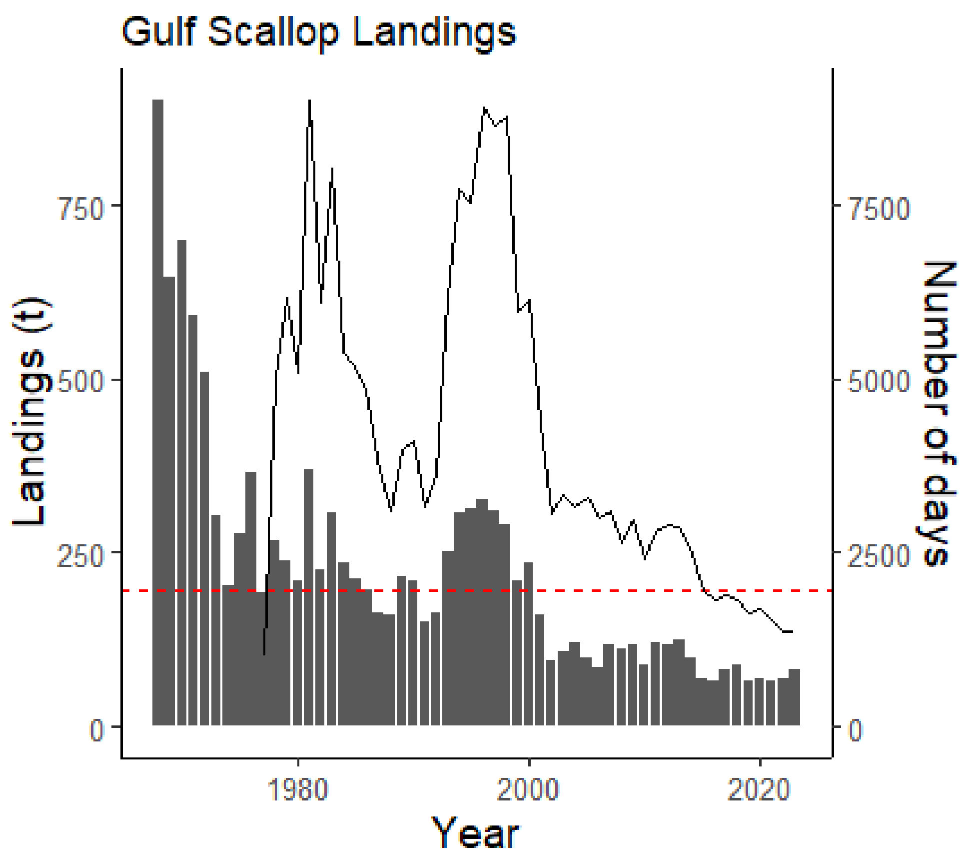



*Figure 7. Recorded sea scallop landings (tons of meat weight), long term median (dotted line) and the number of trips (days fished) in the southern Gulf of St. Lawrence, 1968 to 2023.*

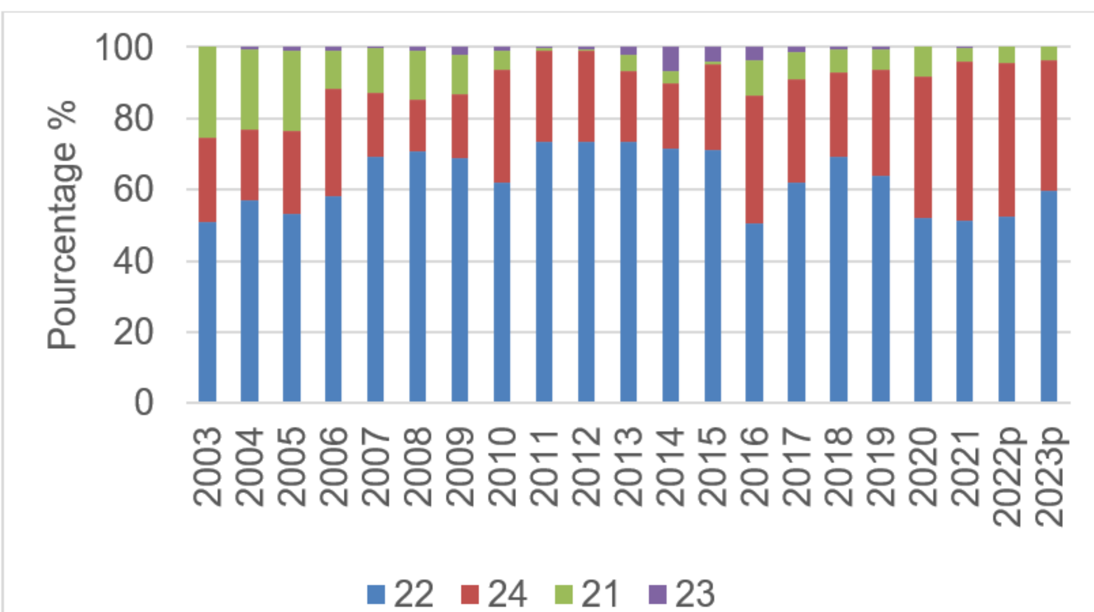



*Figure 8. Proportion of Gulf landings from Scallop Fishing Areas (SFAs) 21, 22 ,23 and 24 between 2003 and 2023 according to commercial logbooks and sales slips.*

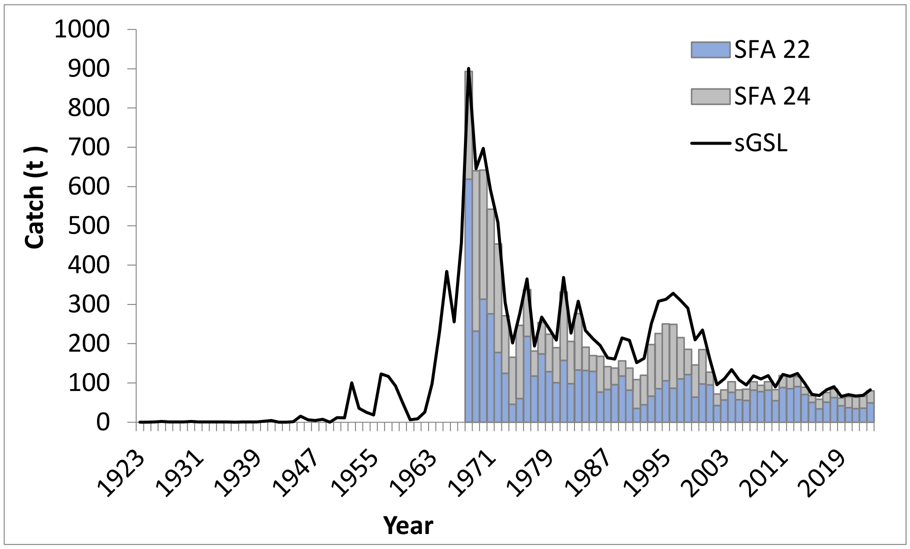



*Figure 9. Recorded sea scallop landings (tons of meat weight), for the core area (SFAs 22 and 24) and total southern Gulf of St. Lawrence, 1923 to 2023.*

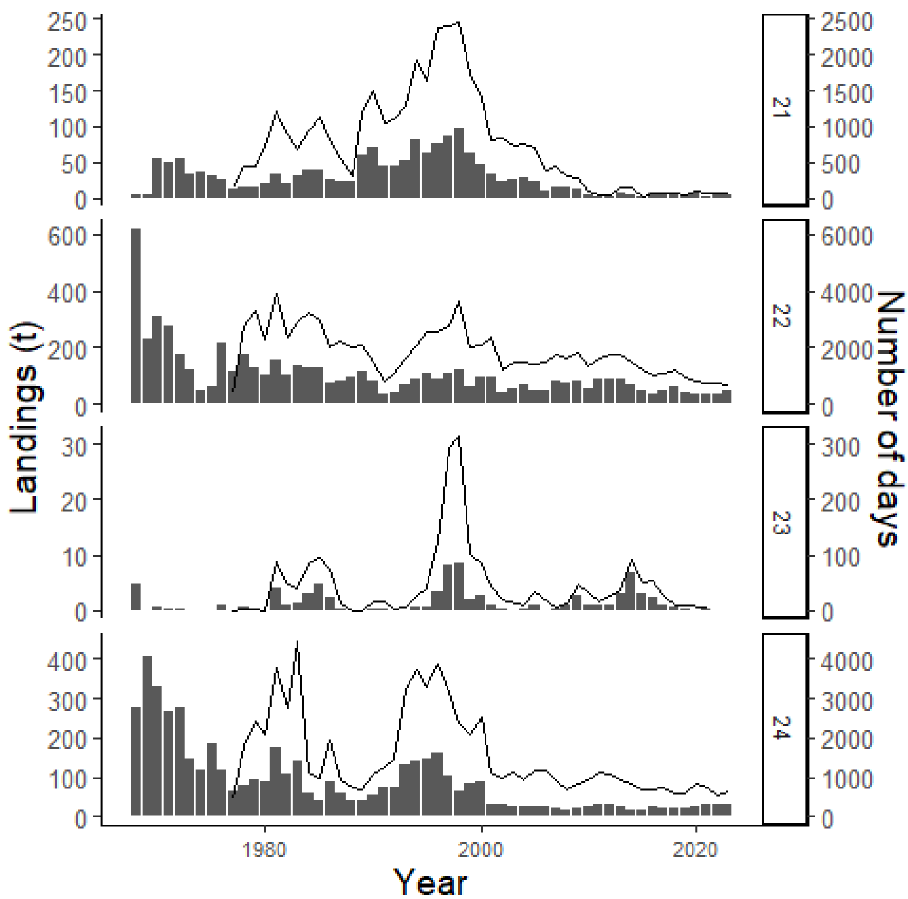



*Figure 10. Commercial sea scallop landings (bars; tons of meat weight) and the number of trips (line; sum of days with individual reported landings) in Scallop Fishing Areas (SFAs) 21, 22, 23 and 24 in the southern Gulf of St. Lawrence fishery, 1987 to 2016. Note differences in y-axis scale when comparing SFAs.*

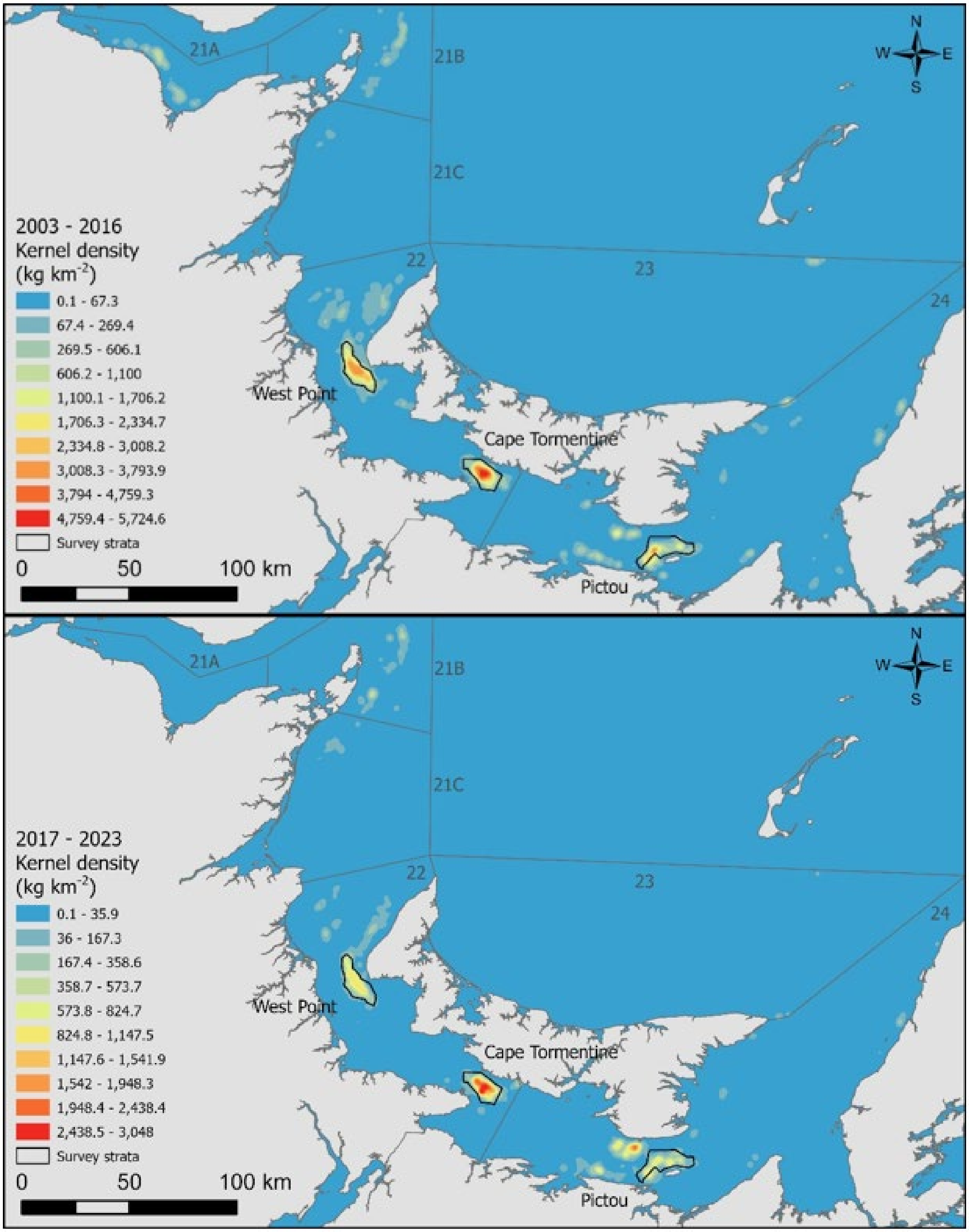



*Figure 11. Kernel density plot of scallop fishing, expressed as kg of meat weight with positional data from logbooks per km², for the southern Gulf of St. Lawrence commercial scallop fishery, summed over years 2003 to 2016 (top panel) and 2017 to 2023 (bottom panel). Fishing effort occurs primarily in three main scallop beds: from north to south, West Point and Cape Tormentine in SFA 22 and Pictou in SFA 24. Also shown are the respective survey sampling strata (black line) used during the scallop research surveys (2019 to 2023).*

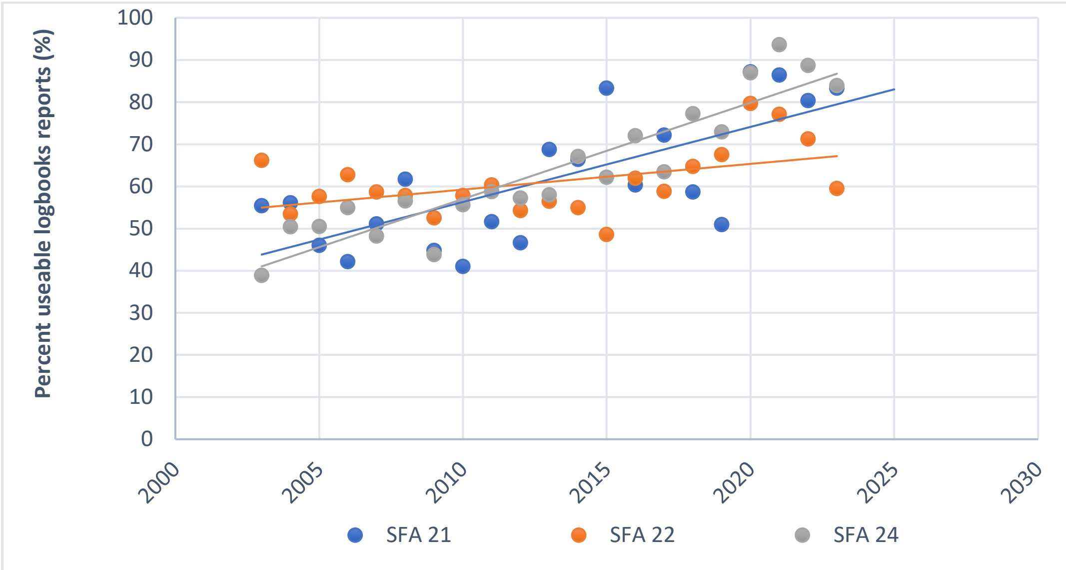



*Figure 12. The percentage (and trends) of useable (for spatial catch rate analysis) logbook reports versus total fishing days reported by SFA for 2001 to 2023. Note that SFA 23 reporting is not included in graph.*

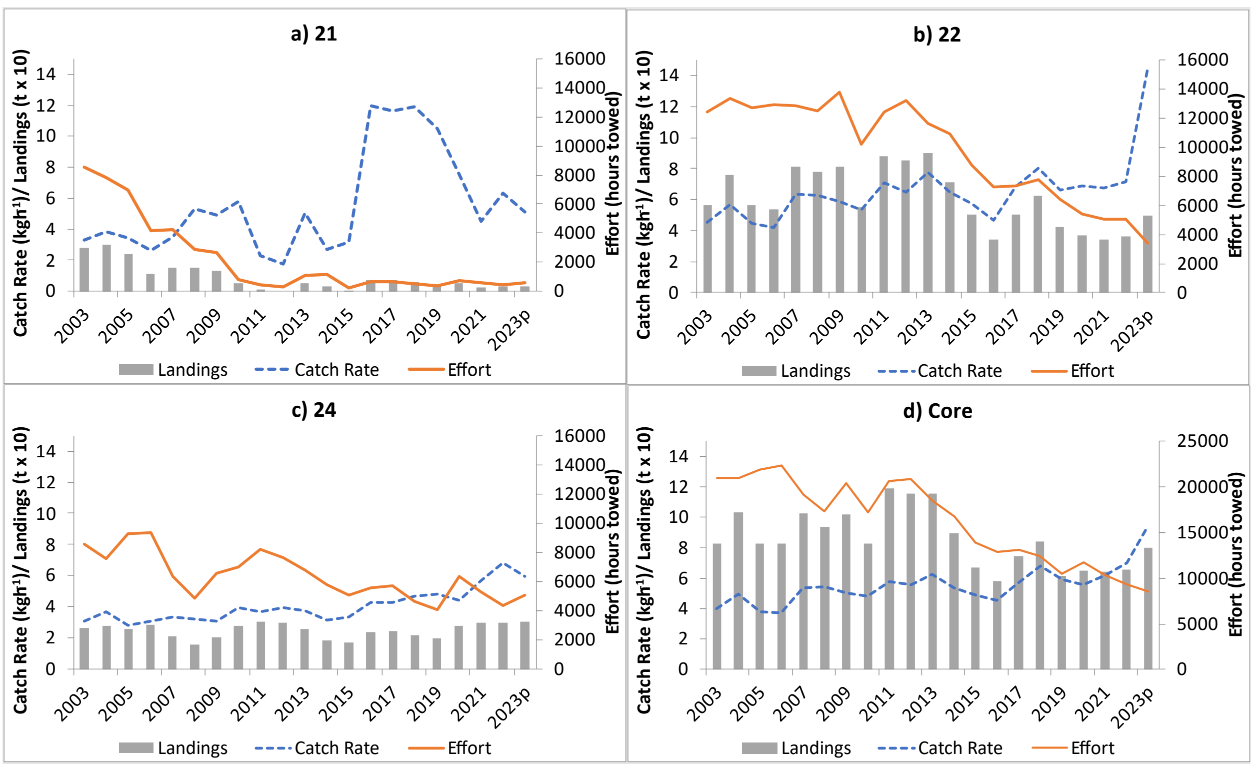



*Figure 13. Annual landings (tons of meat) and corresponding catch rates (kg $^{h-1}$) and prorated effort (hours towed) for Scallop Fishing Area (SFAs) 21, 22 and 24 and core area (SFAs 22 and 24) according to logbooks and sales slips from 2003 to 2023p (p=preliminary). Note that the fishery was closed in SFA 21A from 2010 to 2012, 2016 to 2018, and 2023.*

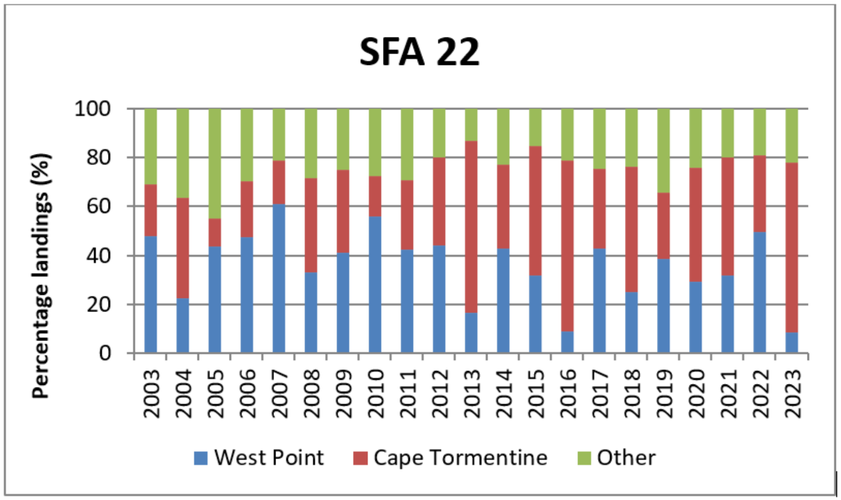



*Figure 14. Proportion of Scallop Fishing Area (SFA) 22 landings from the West Point and Cape Tormentine beds (defined by the 20 days per km² contour, Niles et al. 2021) between 2003 and 2023 according to fishing positions reported in logbooks.*

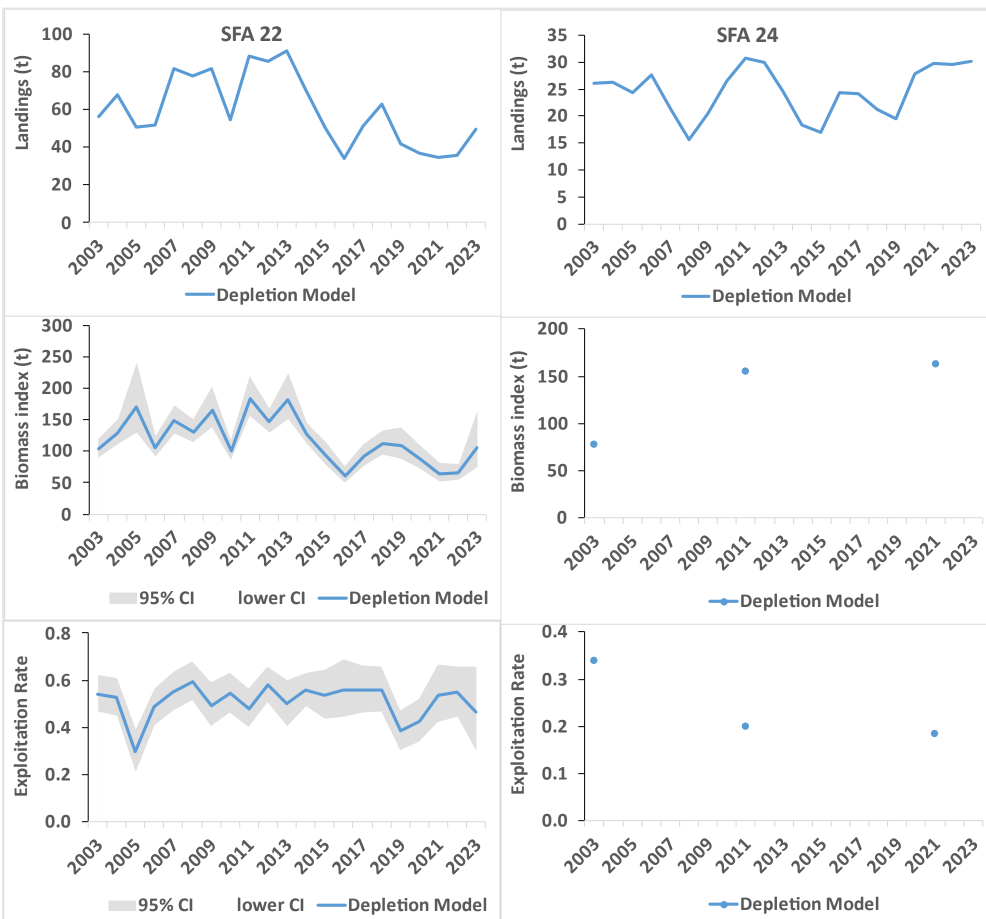



*Figure 15. Depletion model estimates of exploitable biomass ($B_0$) at the start of the fishery and exploitation ($\hat{E}$) rate from 2003 to 2023 for the major Scallop Fishing Areas (SFAs 22 and 24) in the southern Gulf of St Lawrence, also shown are the 95% Confidence Intervals (CI). Only statistically significant models are presented.*

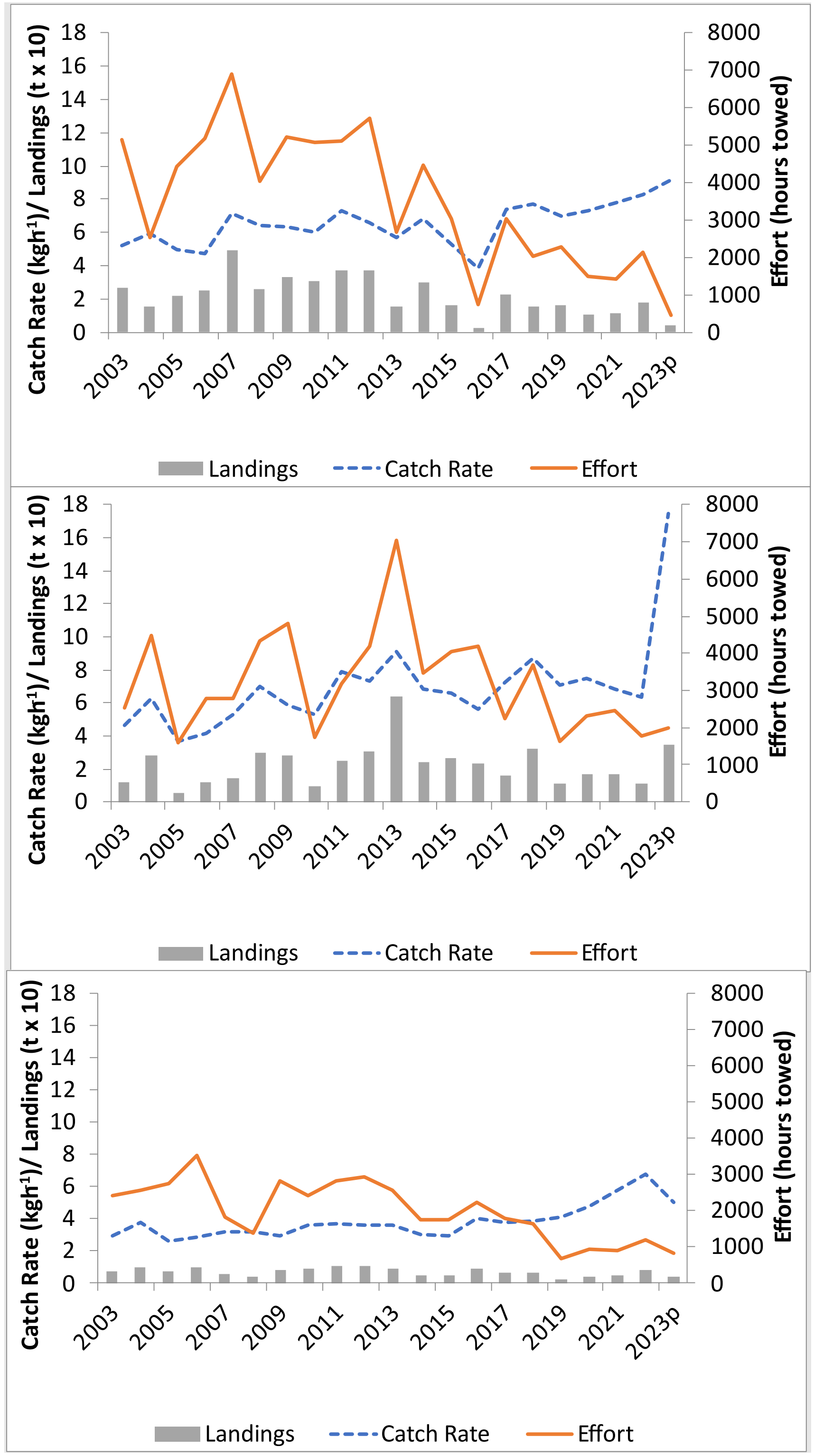



*Figure 16. Annual landings (tons of meat) and corresponding catch rates (kg h$^{-1}$) and prorated effort (hours towed) from 2003 to 2023 scallop logbooks for the West Point (top panel), Cape Tormentine (middle panel) and Pictou (bottom panel) beds. Preliminary data are presented for 2023.*

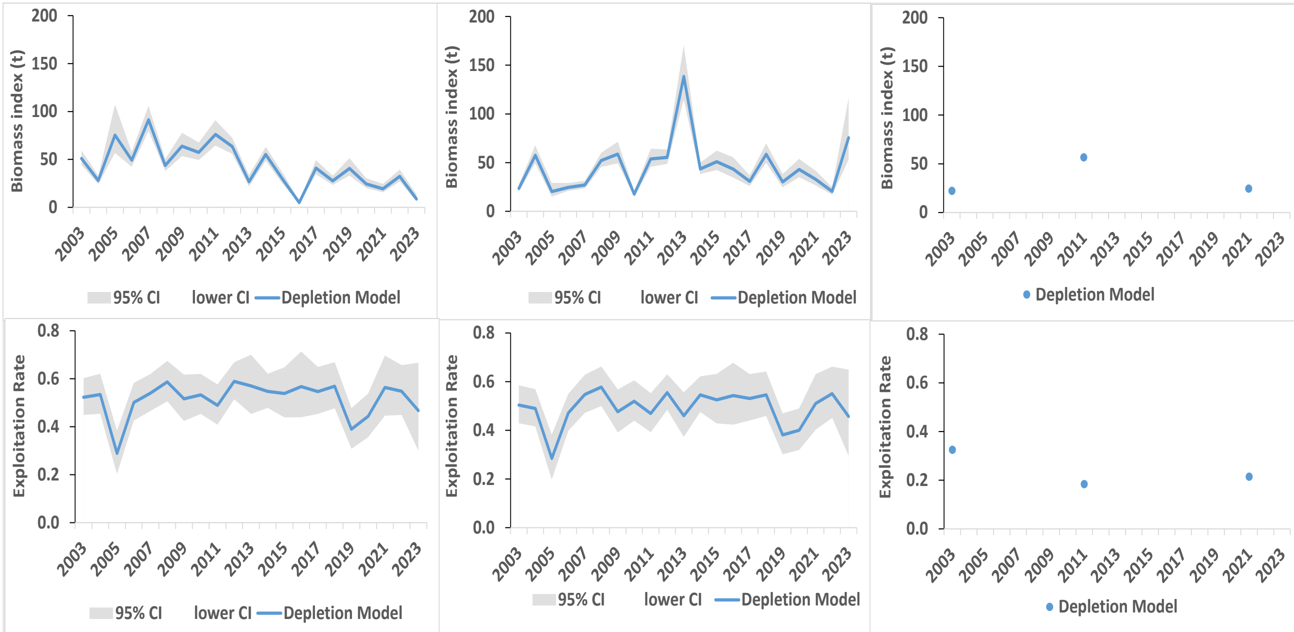



*Figure 17. Depletion model estimates of exploitable biomass ($B_0$) at the start of the fishery and exploitation ($\hat{E}$) rate from 2003 to 2023 for the major scallop beds (West Point, left panel, Cape Tormentine, middle panel, and Pictou, right panel) in the southern Gulf of St Lawrence, also shown are the 95% Confidence Intervals (CI). Only statistically significant models are presented.*

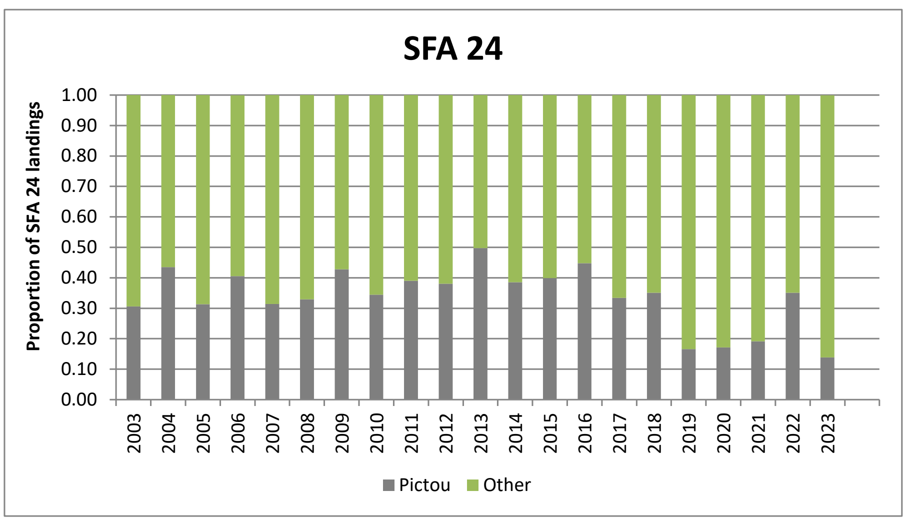



*Figure 18. Proportion of Scallop Fishing Area (SFA) 24 landings from the Pictou bed (defined by the 20 days per km$^2$ contour, Niles et al. 2021) between 2003 and 2023 according to fishing positions reported in logbooks.*

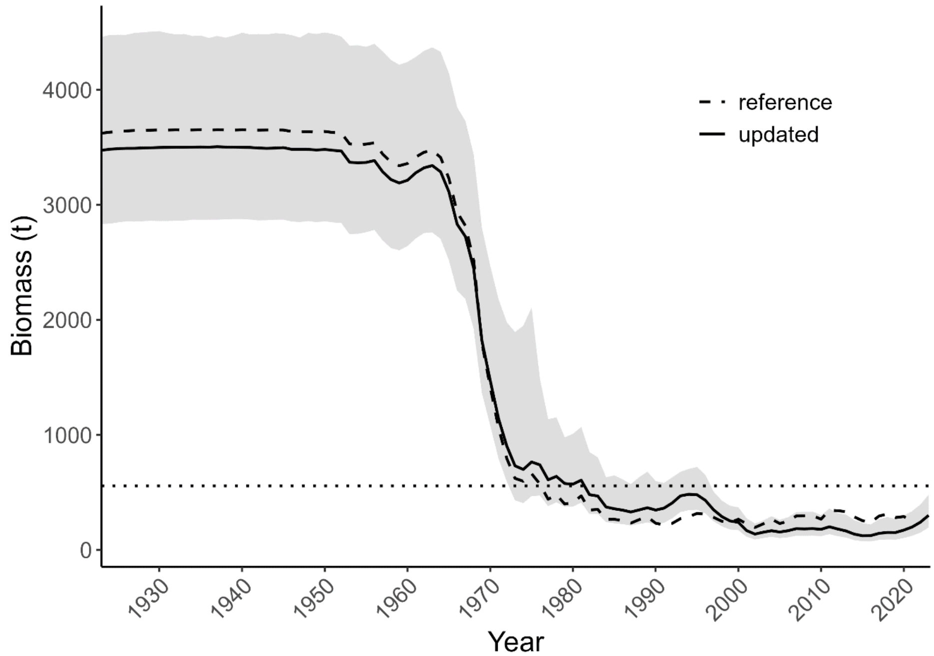



*Figure 19. Estimated sea scallop biomass levels based on commercial catch and effort records (reference model 1923-2021) as well as fall survey biomass estimates (updated model 1923-2023) for the core area of the sGSL sea scallop stock as produced by a JABBA model. The dotted line represents the LRP estimate based on 0.4B<sub>MSY</sub> from the updated model.*

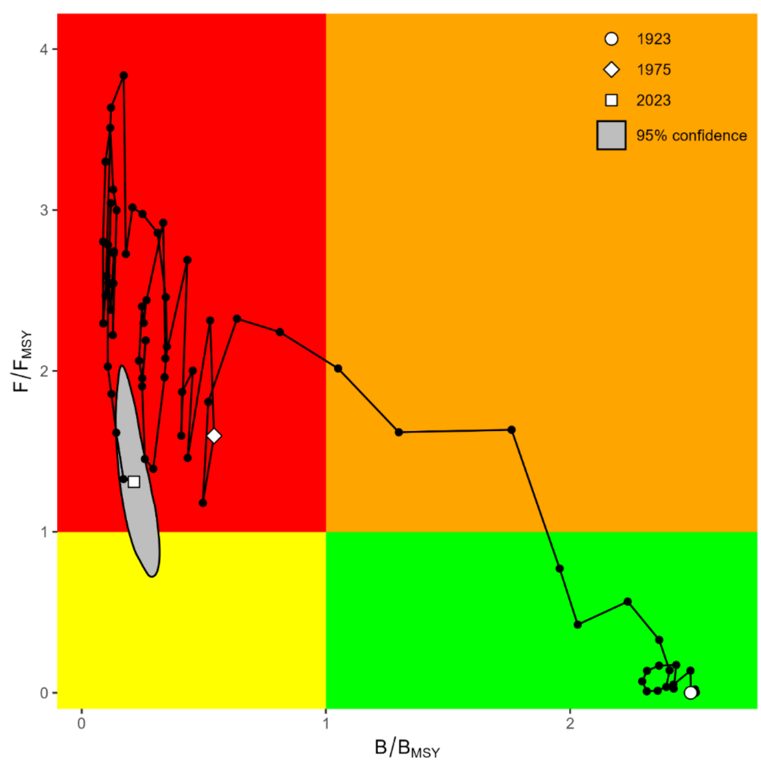



*Figure 20. A Kobe plot of relative fishing mortality as a function of relative biomass estimated by a JABBA model fit to sea scallop landings and effort data from 1923 to 2023. This model estimates $B_{MSY}$ at 1391 tonnes while $F_{MSY}$ is estimated to be 0.205.*

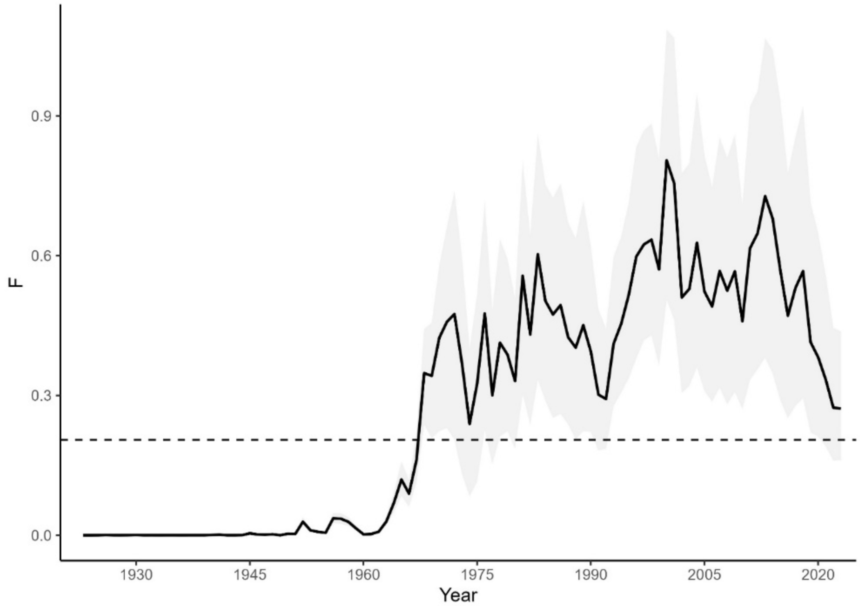



*Figure 21. Sea scallop fishing mortality (F) and 95% confidence interval estimated by the JABBA fit to data from 1923 to 2023. The dashed line represents $F_{MSY}$= 0.2.*

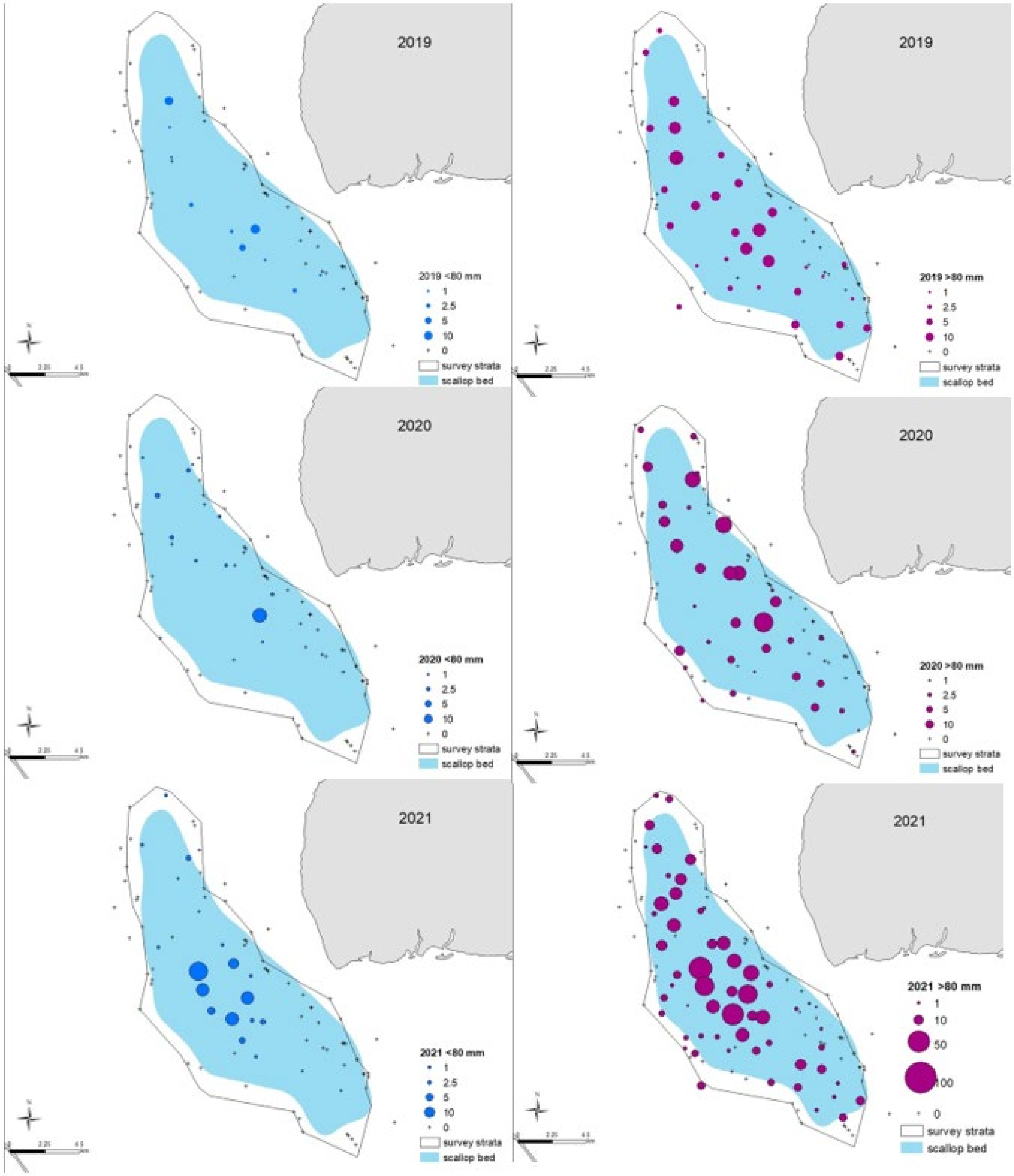



*Figure 22.Spatial distribution of sea scallop density (number per standard tow) in the West Point bed in the Gulf region from surveys in 2019 to 2021. Circle area is proportional to scallop density. Red circles represent commercial size (≥ 80 mm) scallops and blue circles represent small (< 80 mm) scallops.*

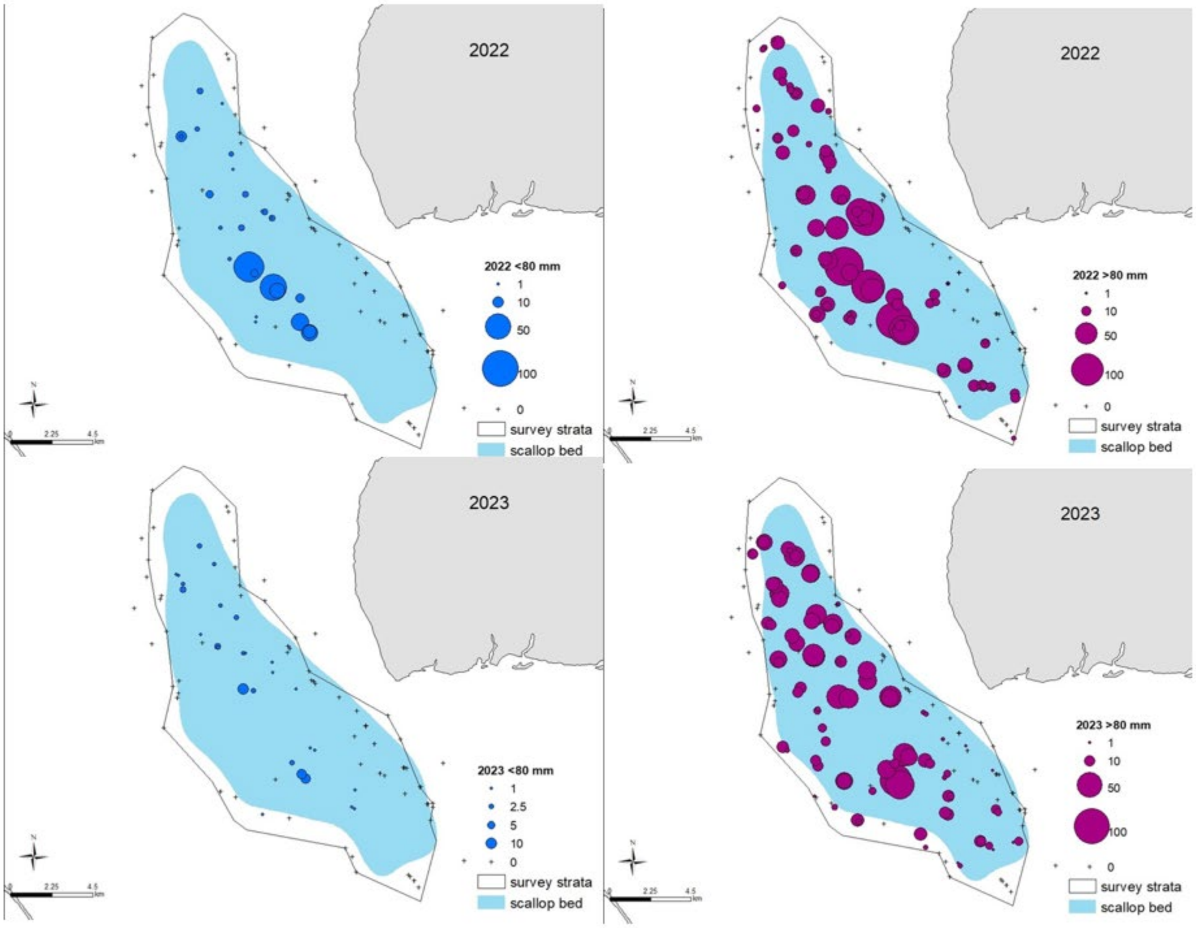



*Figure 23.Spatial distribution of sea scallop density (number per standard tow) in the West Point bed in the Gulf region from surveys in 2022 to 2023. Circle area is proportional to scallop density. Red circles represent commercial size (≥ 80 mm) scallops and blue circles represent small (< 80 mm) scallops.*

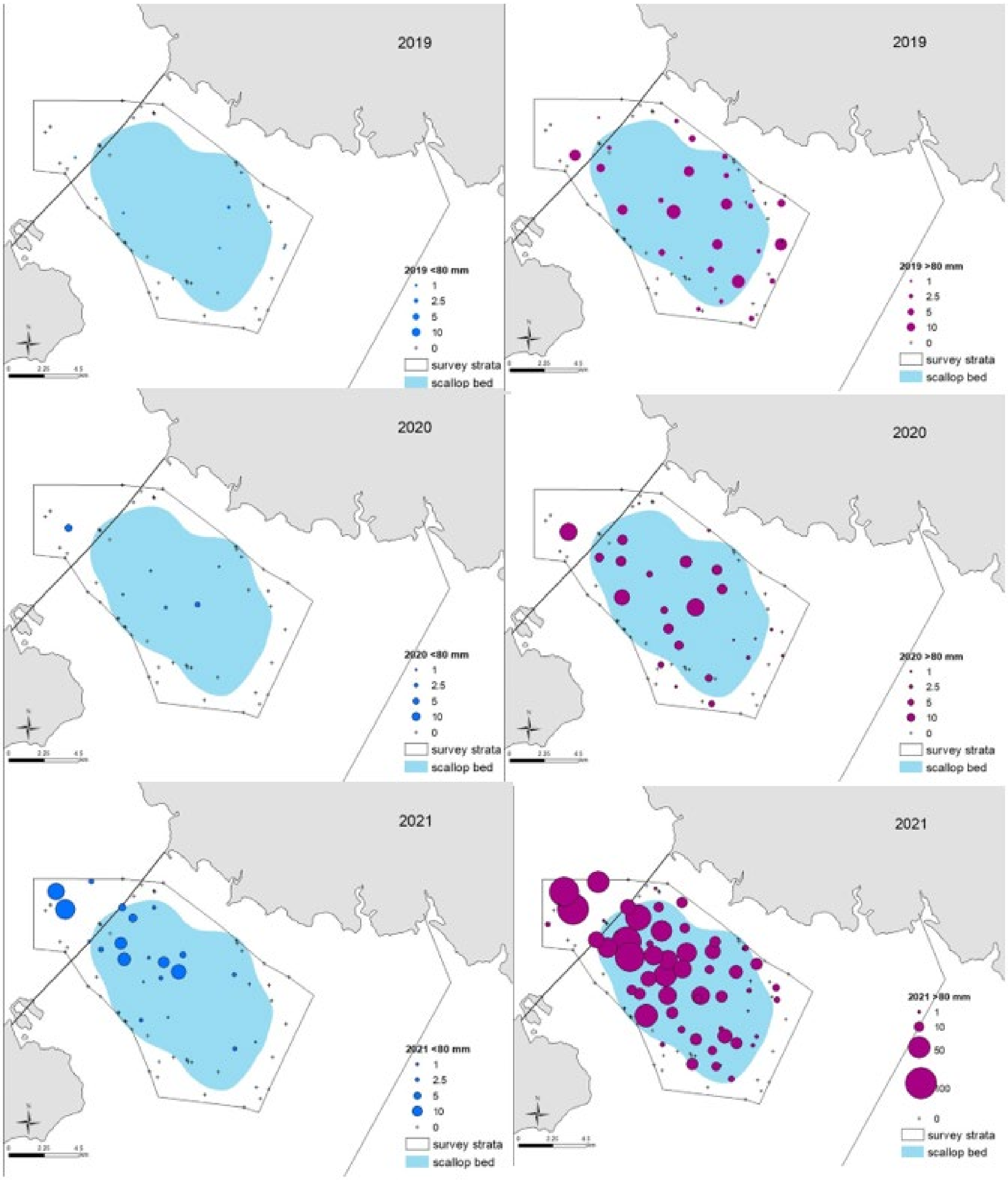



*Figure 24.Spatial distribution of sea scallop density (total number per standard tow) in the Cape Tormentine bed in the Gulf region from surveys in 2019 to 2021. Circle area is proportional to scallop density. Red circles represent commercial size (≥ 80 mm) scallops and blue circles represent small (< 80 mm) scallops.*

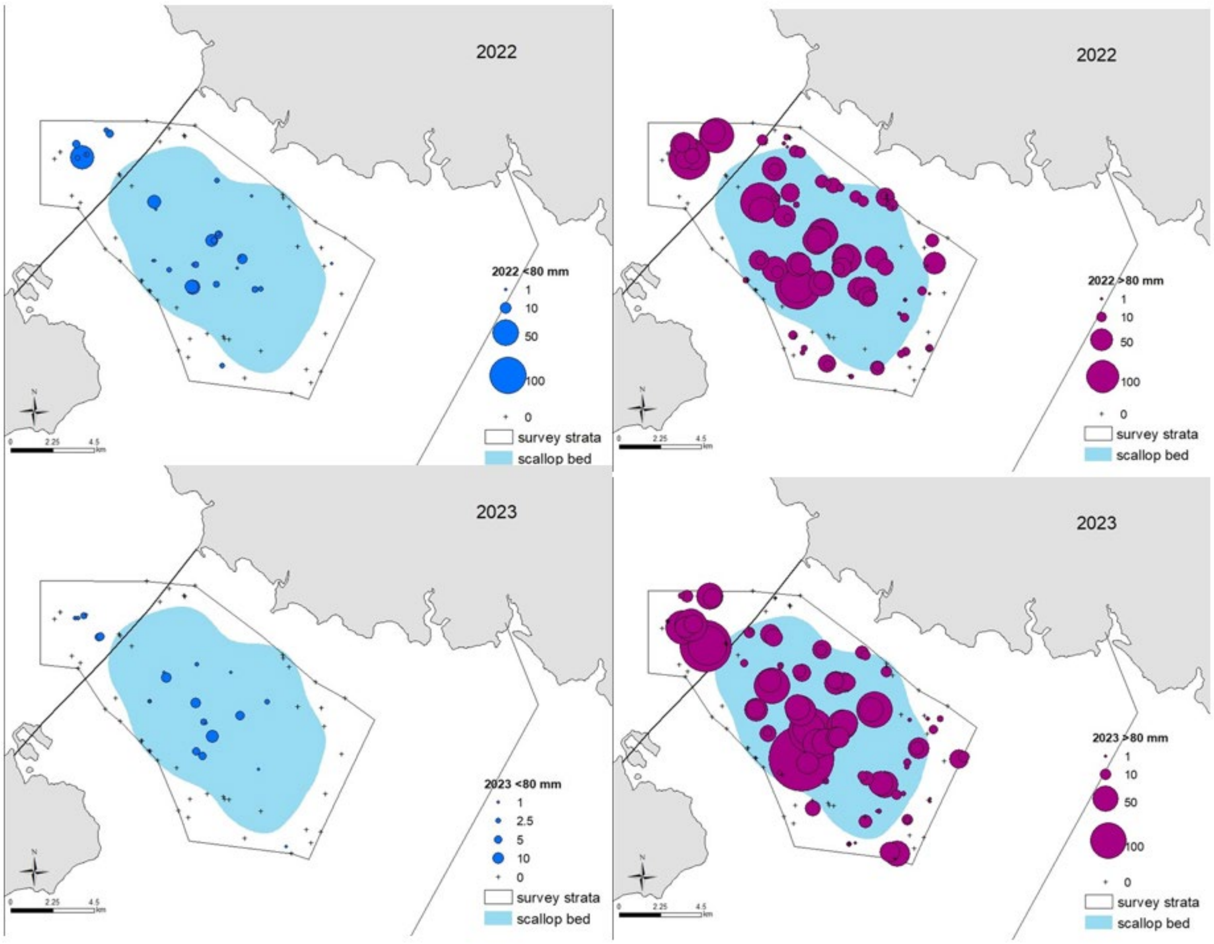



*Figure 25.Spatial distribution of sea scallop density (total number per standard tow) in the Cape Tormentine bed in the Gulf region from surveys in 2022 to 2023. Circle area is proportional to scallop density. Red circles represent commercial size (≥ 80 mm) scallops and blue circles represent small (< 80 mm) scallops.*

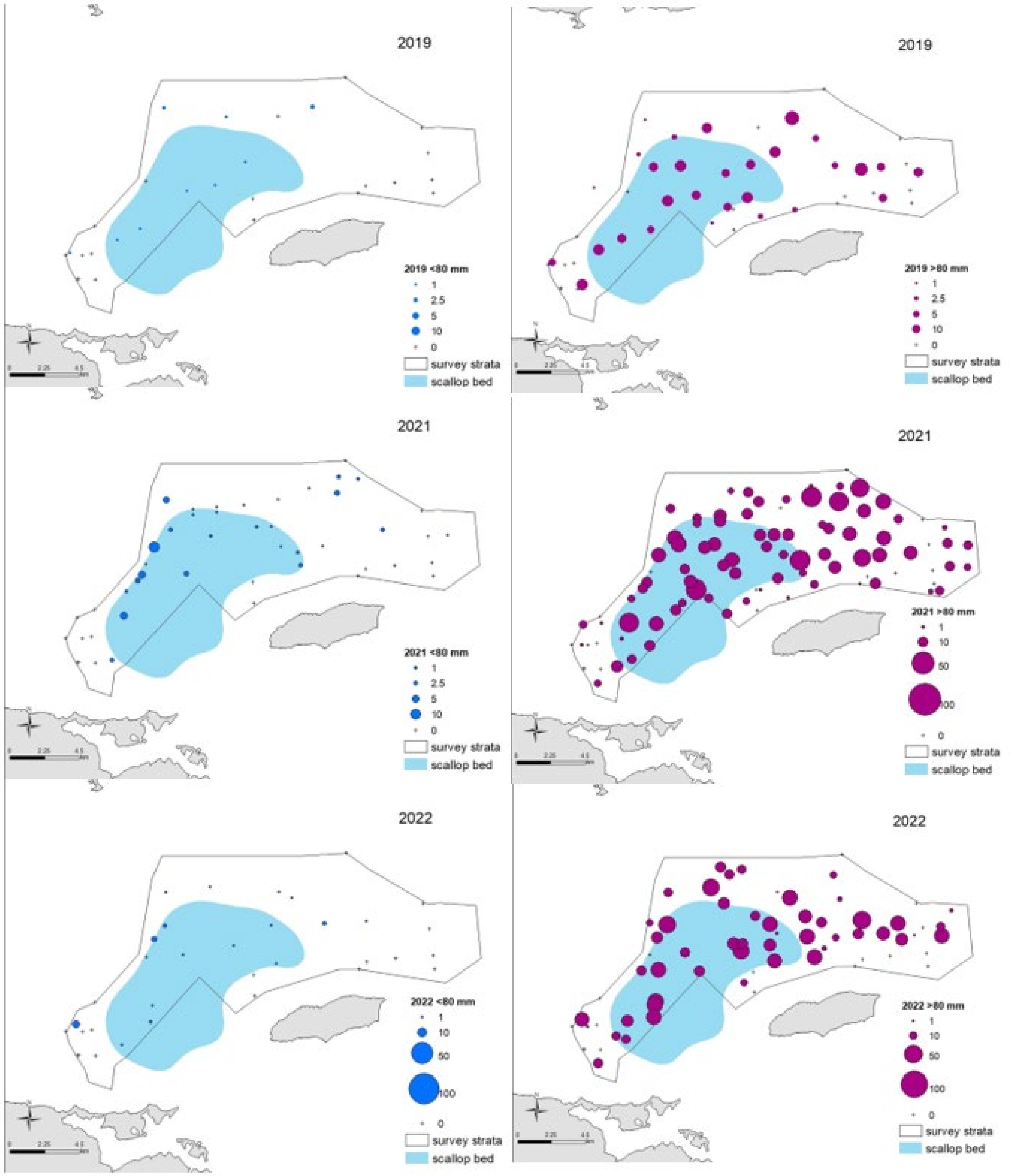



*Figure 26.Spatial distribution of sea scallop density (total number per standard tow) in the Pictou bed in the Gulf region from surveys in 2019 to 2021. Circle area is proportional to scallop density. Red circles represent commercial size (≥ 80 mm) scallops and blue circles represent small (< 80 mm) scallops.*

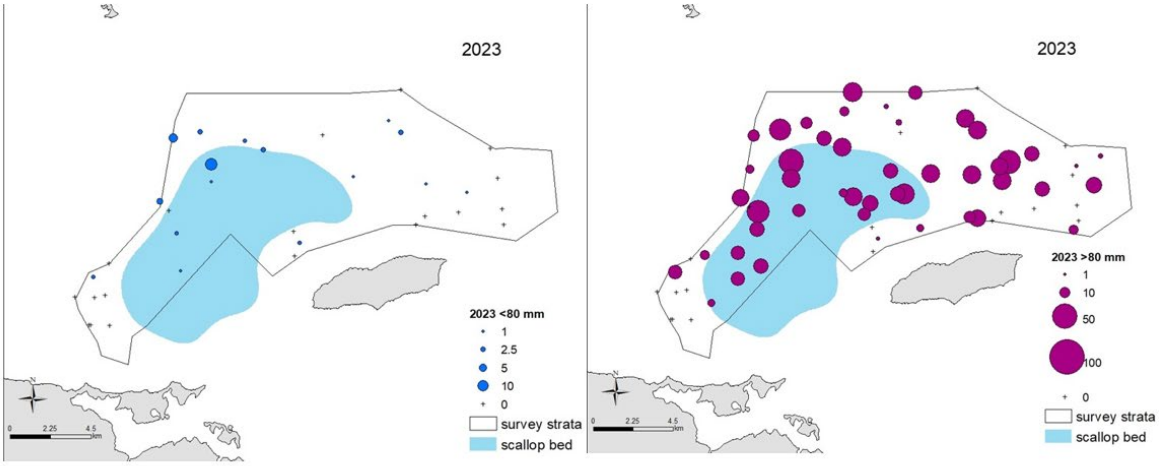



*Figure 27.Spatial distribution of sea scallop density (total number per standard tow) in the Pictou bed in the Gulf region from surveys in 2022 to 2023. Circle area is proportional to scallop density. Red circles represent commercial size (≥ 80 mm) scallops and blue circles represent small (< 80 mm) scallops.*

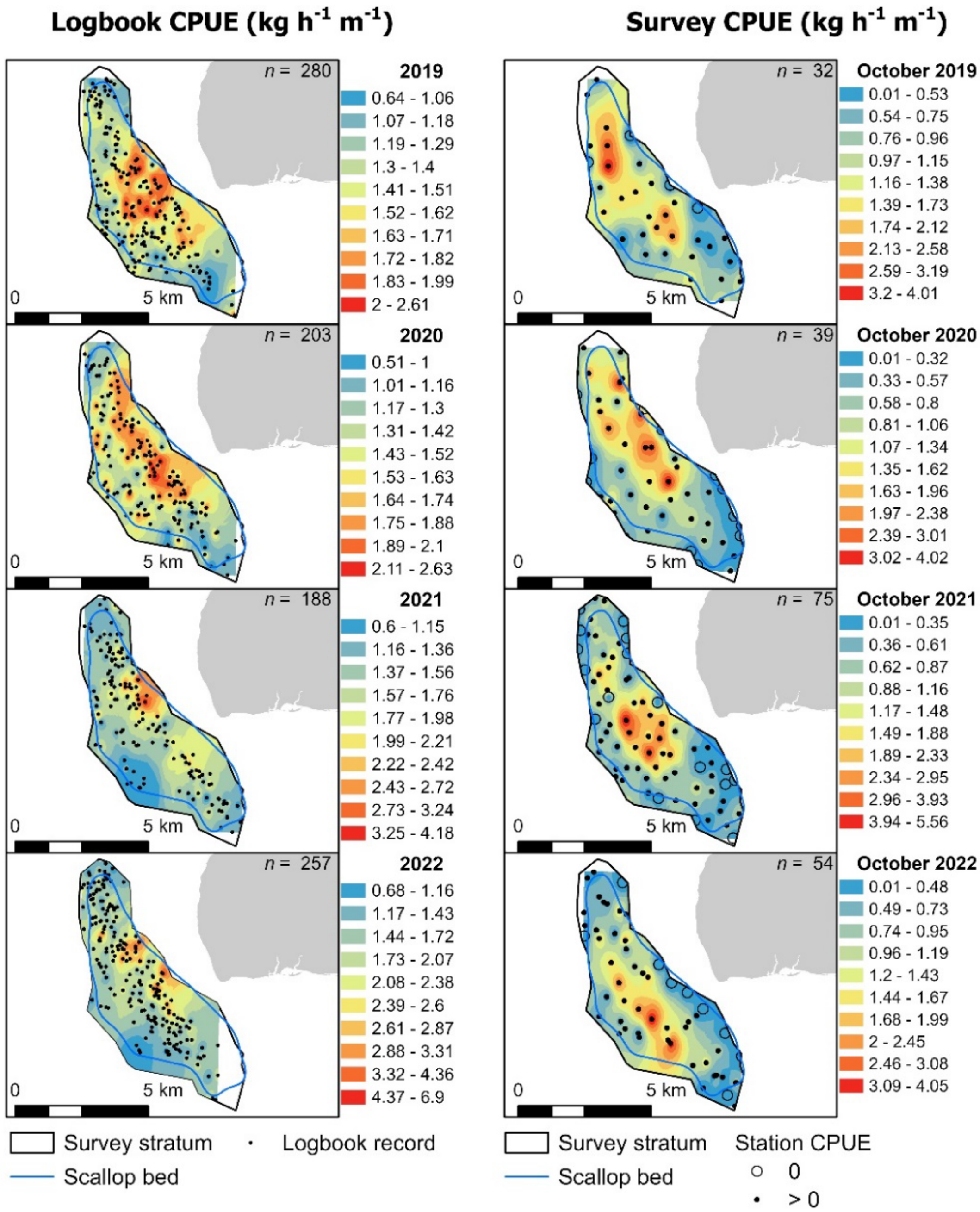



*Figure 28a. Spatial plot of average catch rate (kg $h^{-1}m^{-1}$) of the West Point bed (SFA 22) from the commercial logbook data (left) and from the research survey data (right) from 2019 to 2022. Surveys were conducted in both April and October.*

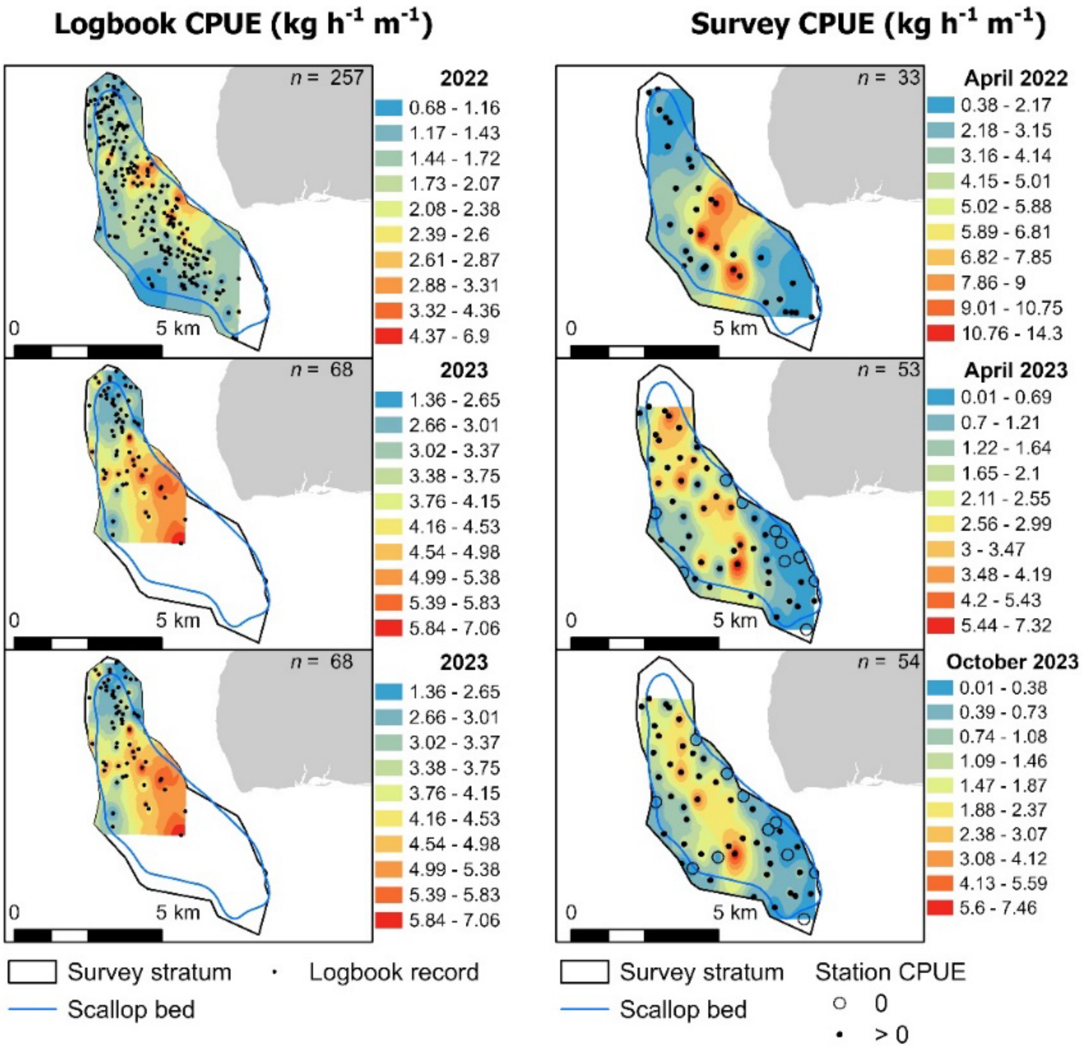



*Figure 28b. Spatial plot of average catch rate (kg $h^{-1}m^{-1}$) of the West Point bed (SFA 22) from the commercial logbook data (left) and from the research survey data (right) from 2022 to 2023. Surveys were conducted in both April and October during 2022 and 2023.*

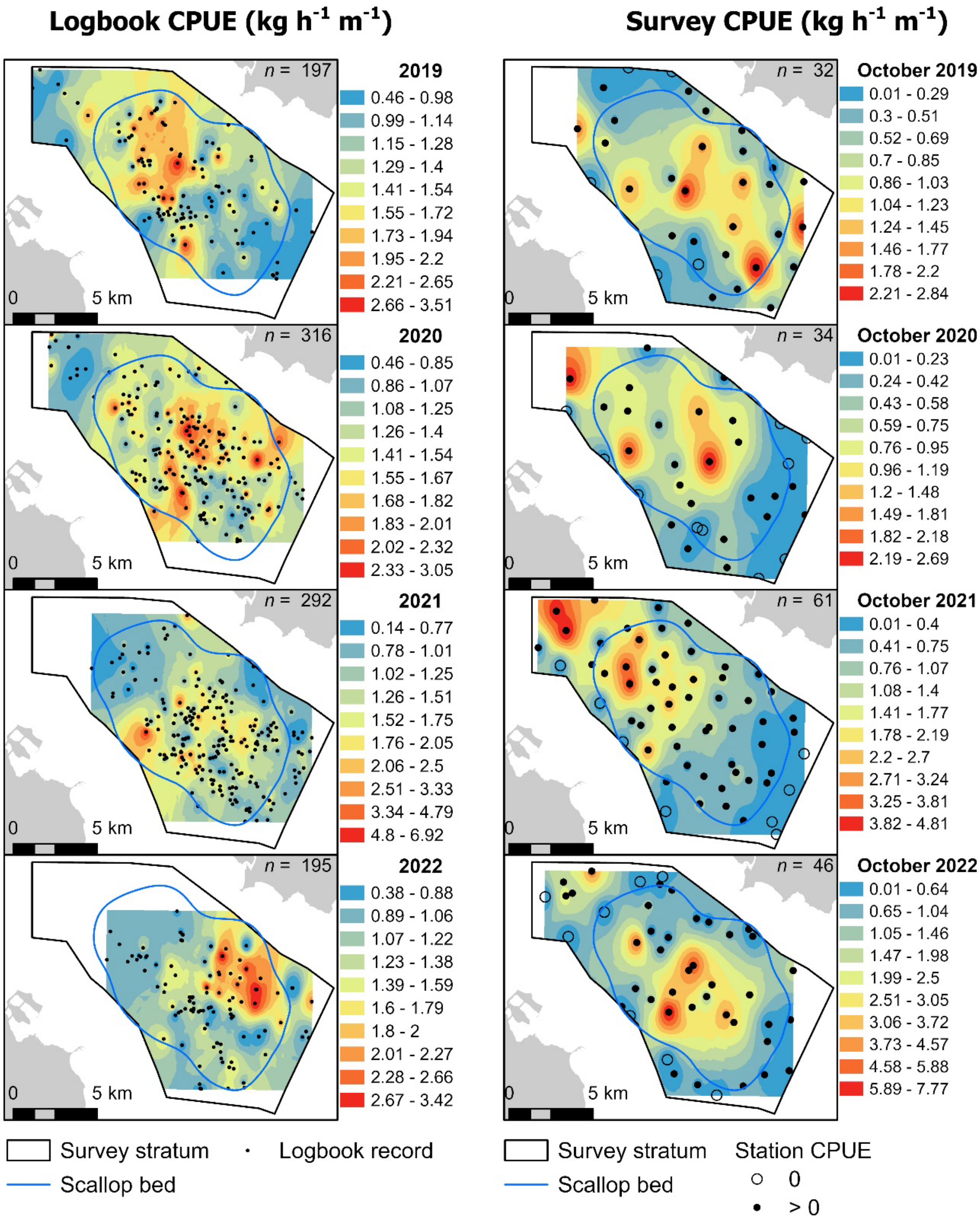



*Figure 29a. Spatial plot of average catch rate (kg $h^{-1}m^{-1}$) of the Cape Tormentine bed from the commercial logbook data (left panel) and from the research survey data (right panel) from 2019 to 2022. Surveys were conducted in both April and October.*

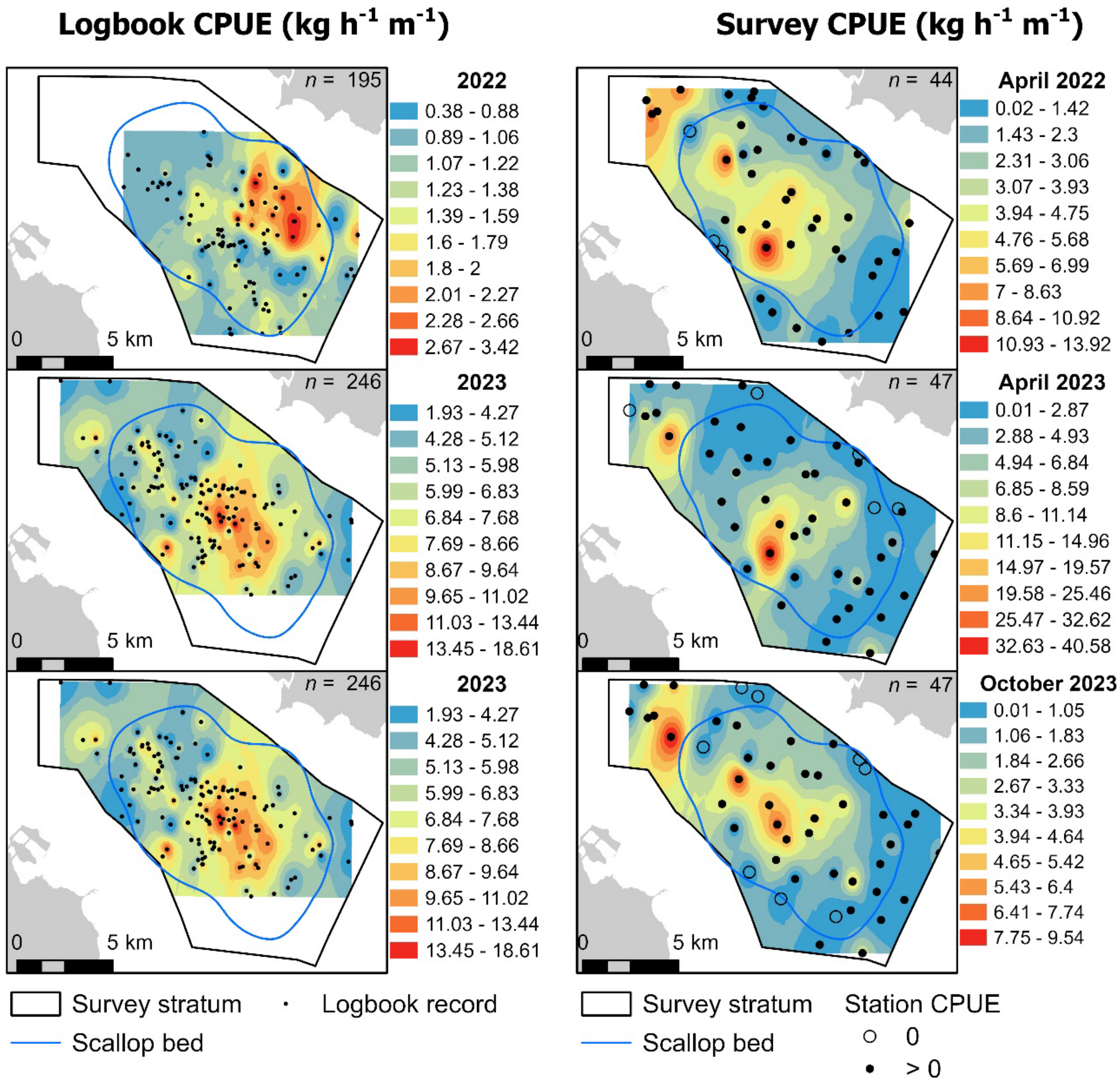



*Figure 29b. Spatial plot of average catch rate (kg $h^{-1}m^{-1}$) of the Cape Tormentine bed from the commercial logbook data (left panel) and from the research survey data (right panel) from 2022 to 2023. Surveys were conducted in both April and October.*

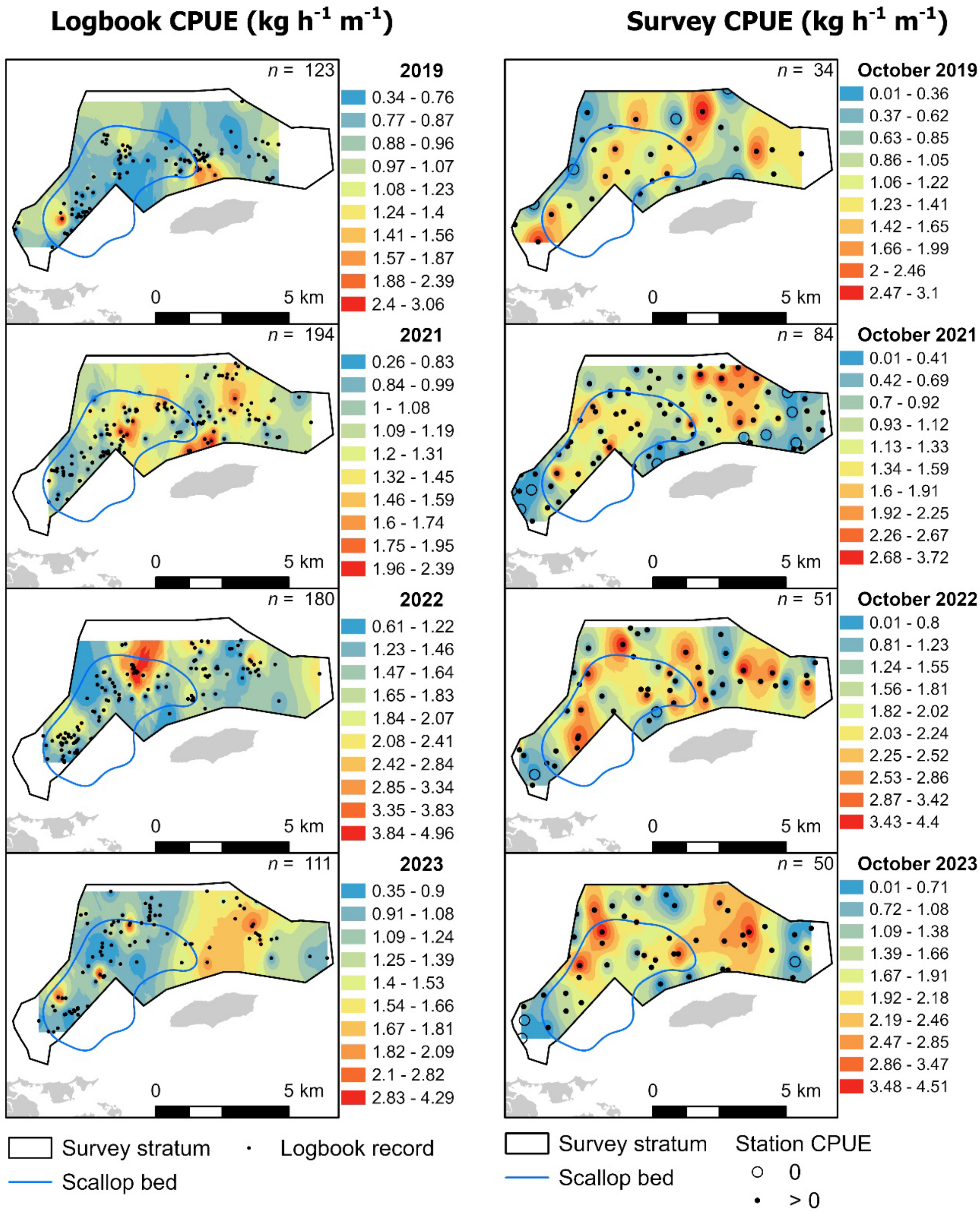



*Figure 30. Spatial plot of average catch rate (kg h-1m-1) of the Pictou bed from the commercial logbook data (left panel) and from the research survey data (right panel) from 2019 to 2023, with the exception of 2020 when a survey was not conducted.*

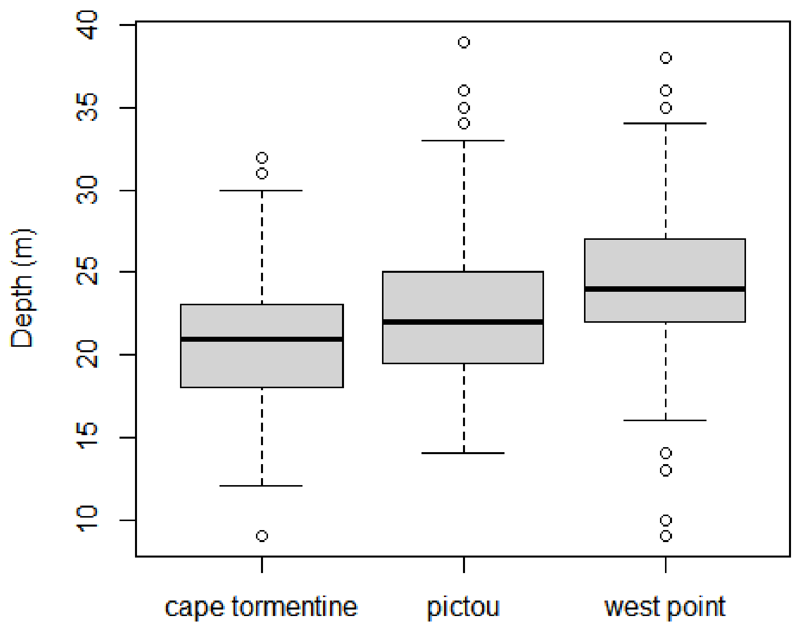



*Figure 31. Boxplot of water depth in meters of survey tows with scallop catch on each bed (Cape Tormentine, Pictou and West Point) over the survey time series (2019 to 2023), within the Northumberland Strait, in the southern Gulf of St. Lawrence.*

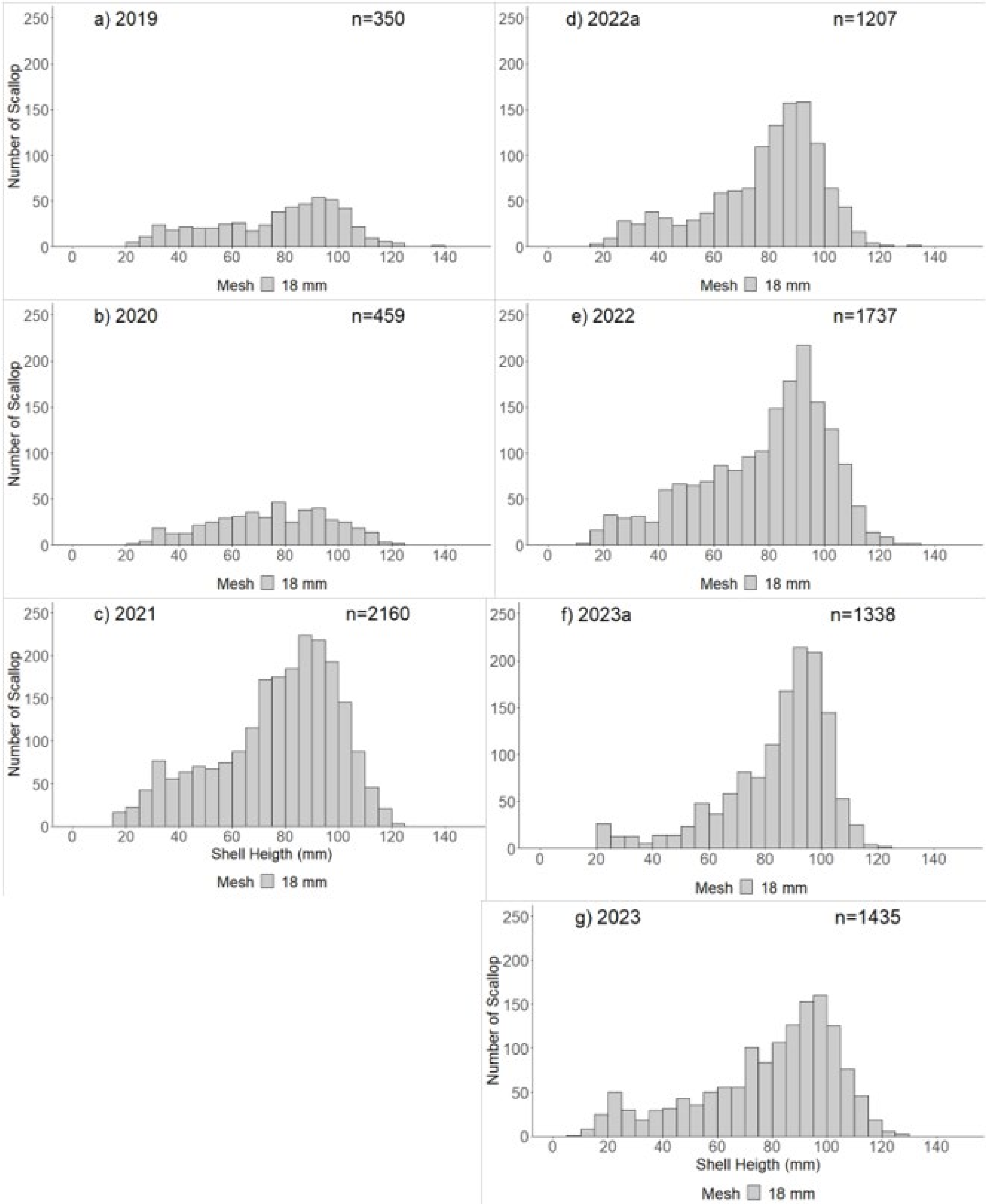



*Figure 32. Shell height distribution of sea scallop on core beds (SFAs 22 and 24) based on research surveys using an 8-gang scallop drag (shown here are the scallop sizes from the 2 gangs lined with 18 mm mesh) conducted between 2019 and 2023.*

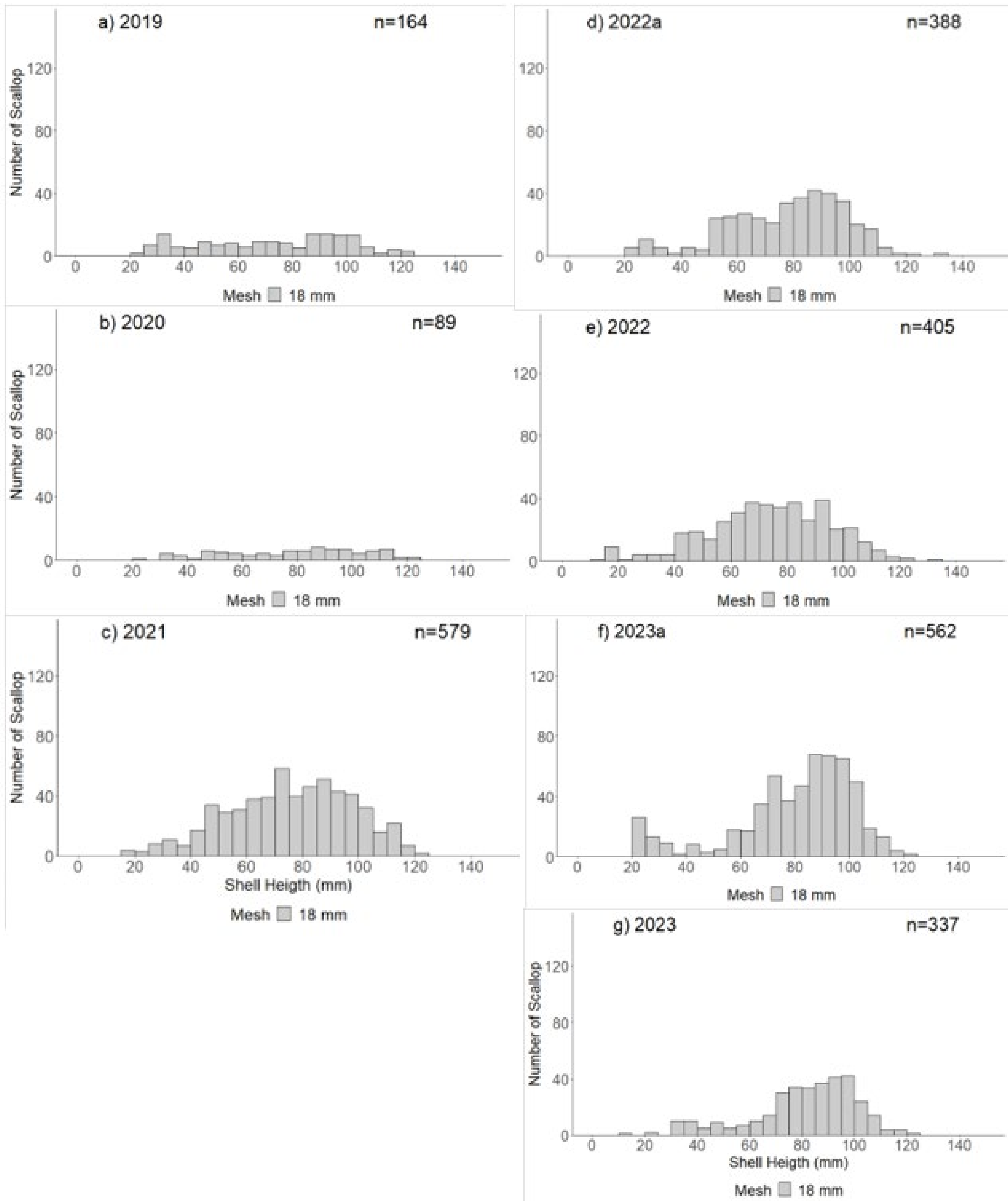



*Figure 33. Shell height distribution of sea scallop on the West Point bed (SFA22) based on research surveys using an 8-gang scallop drag (shown here are the sizes from the 2 gangs lined with 18 mm mesh) conducted between 2019 and 2023.*

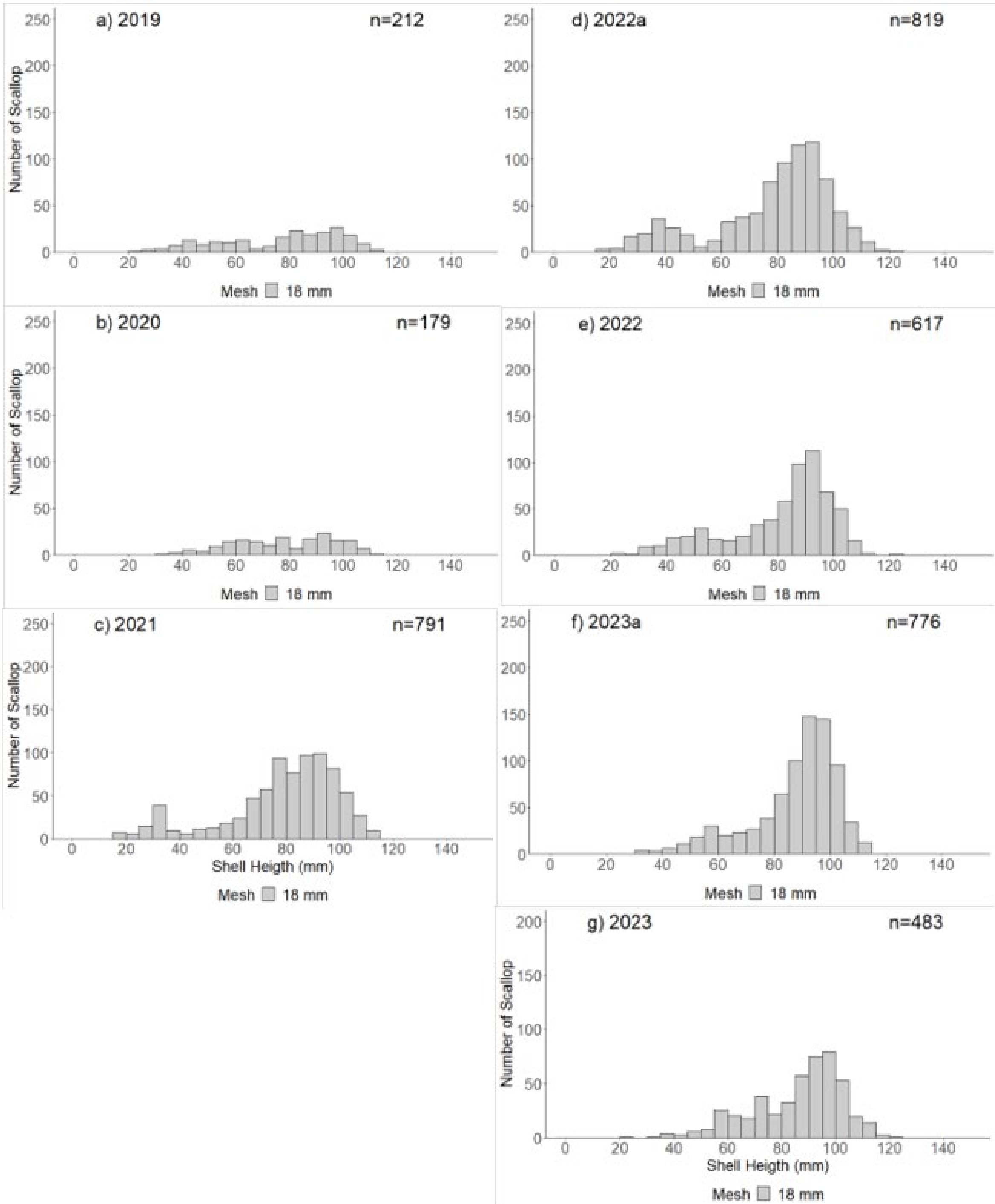



*Figure 34. Shell height distribution of sea scallop on the Cape Tormentine bed (SFA 22) based on research surveys using an 8-gang scallop drag (shown here are the sizes from the 2 gangs lined with 18 mm mesh) conducted between 2019 and 2023.*

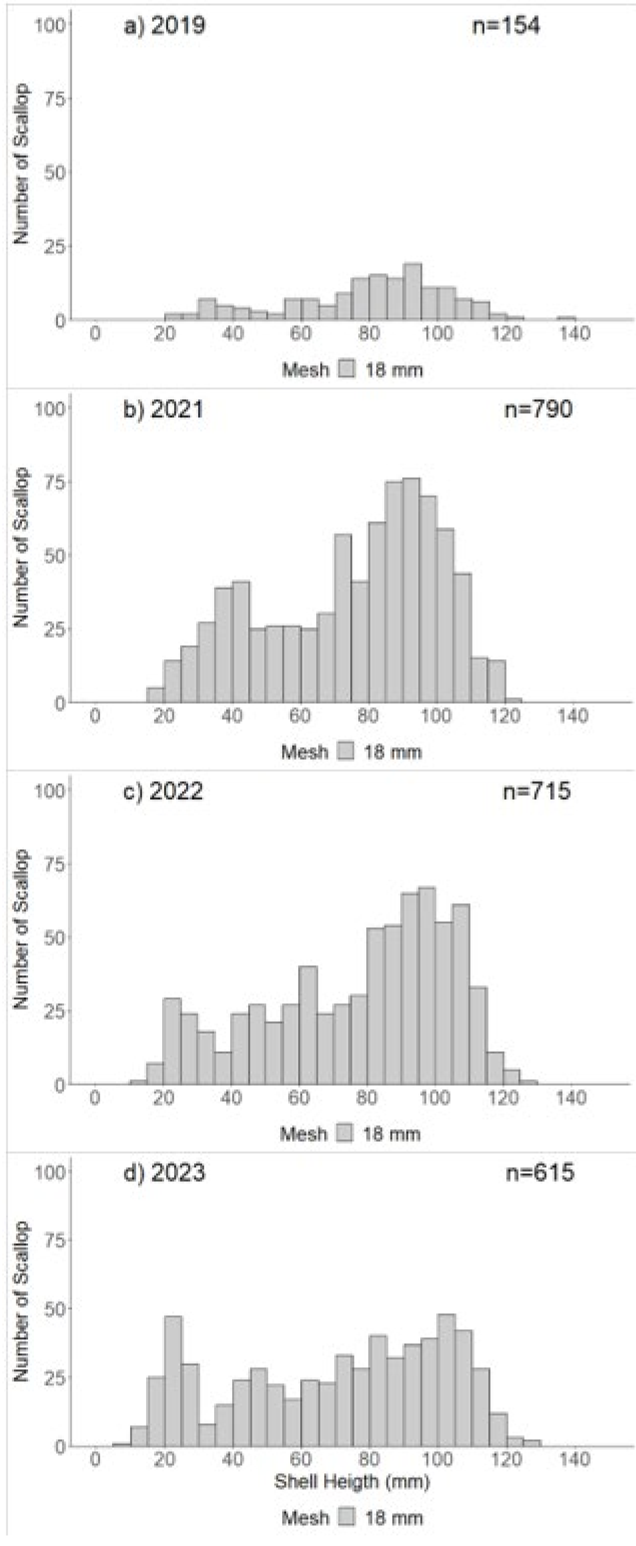



*Figure 35. Shell height distribution of sea scallop on the Pictou bed (SFA 24) based on research surveys using an 8-gang scallop drag (shown here are the sizes from the 2 gangs lined with 18 mm mesh) conducted between 2019 and 2023 (note that the Pictou bed was not surveyed in 2020).*

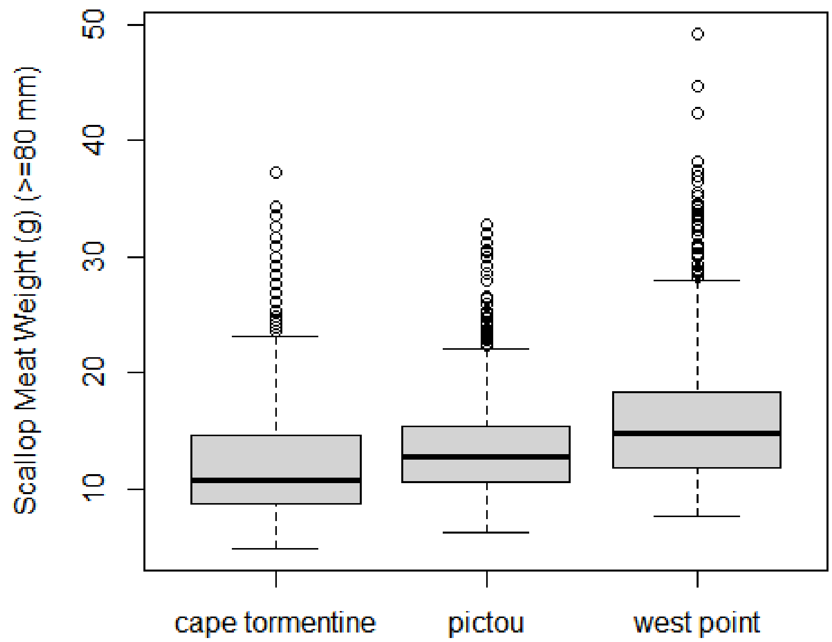



*Figure 36. Boxplot of meat weight (g) of sea scallop >= 80 mm in shell height from each major bed for all survey years combined (2019-2023), mesh size = 82.6 mm).*

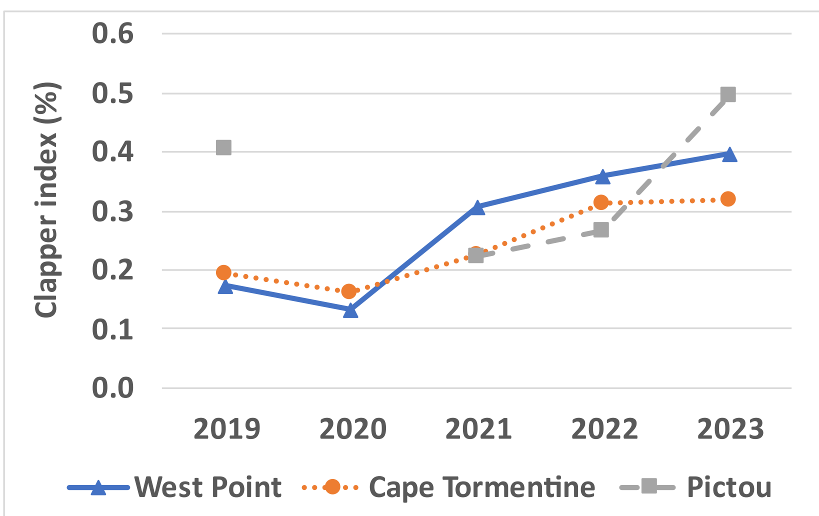



*Figure 37. Clapper Index (%) as a proportion of clappers from research surveys conducted in October (2019 to 2023) on the major scallop beds (West Point, solid line, Cape Tormentine, dotted line, and Pictou, long dash line) in the southern Gulf of St. Lawrence.*

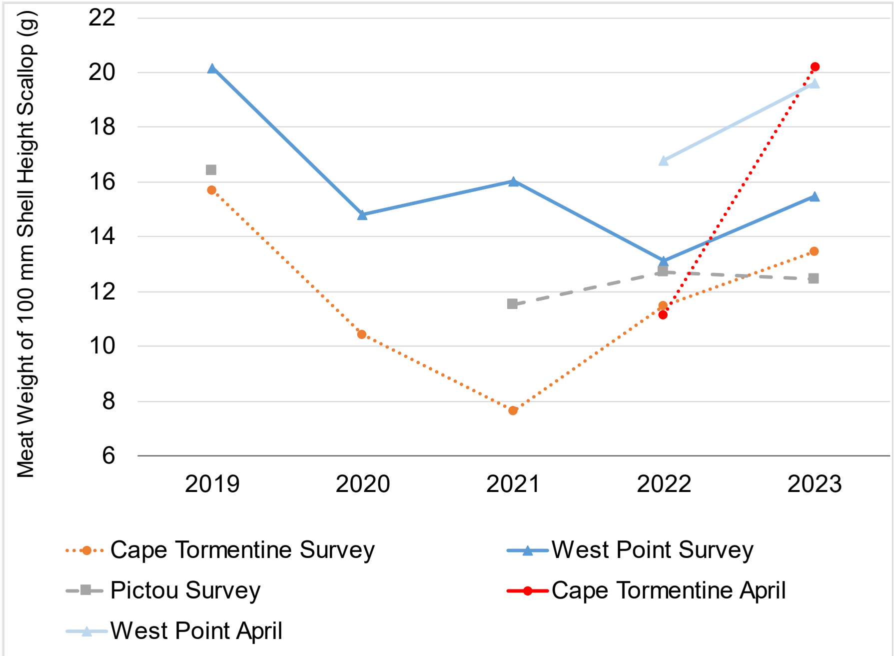



*Figure 38. Condition, or predicted meat weight of a 100 mm scallop, from research surveys conducted in October (2019 to 2023) and April (2022-2023) of the three main scallop beds (Cape Tormentine, dotted line; West Point, solid line; and Pictou, long dash line) in the southern Gulf of St. Lawrence.*

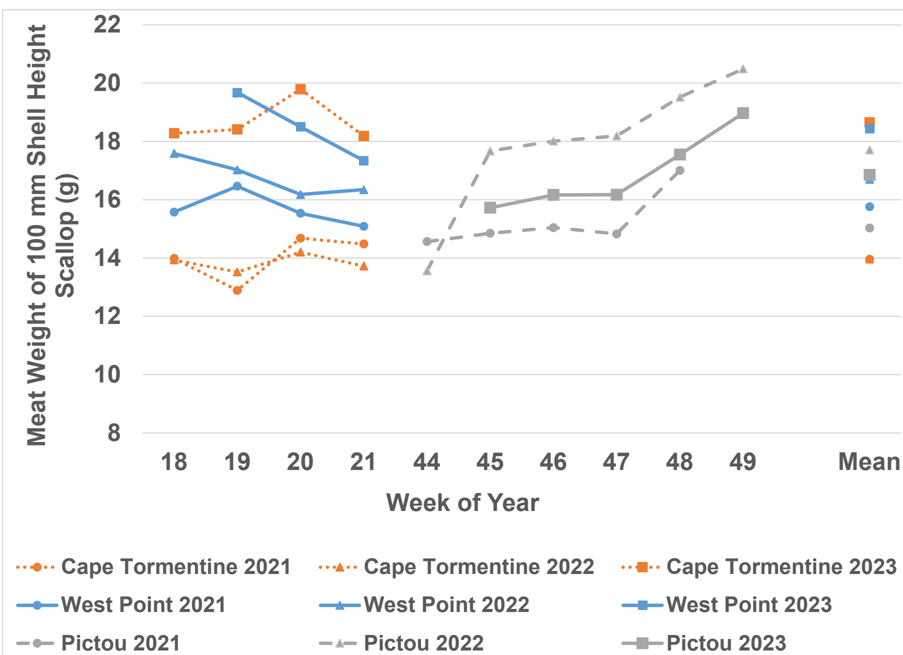



*Figure 39. Condition, or predicted meat weight in grams of a 100 mm shell height scallop, from at-wharf sampling for each week (and mean) of the fishing season in 2021(circle), 2022 (triangle) and 2023 (square) of the three main scallop beds (Cape Tormentine, dotted line; West Point, solid line; and Pictou, long dash line) in the southern Gulf of St. Lawrence.*

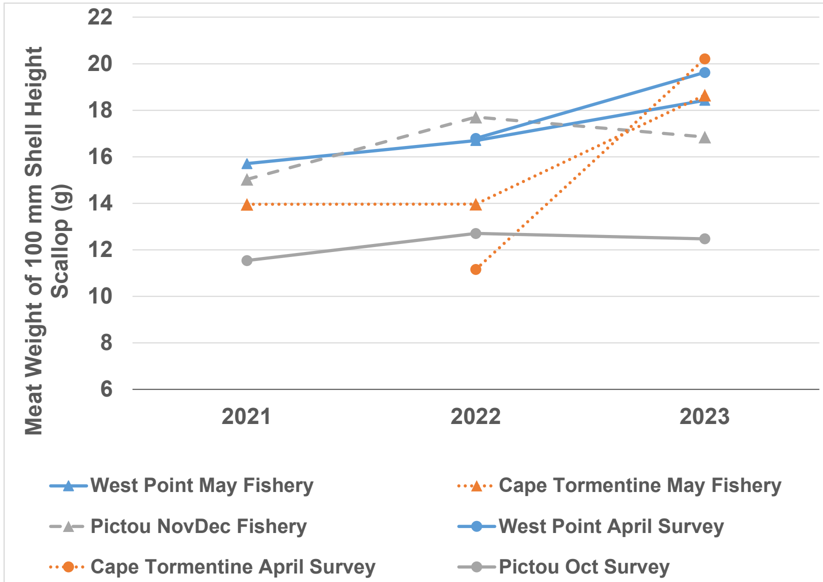



*Figure 40. Condition, or predicted meat weight in grams of a 100 mm shell height scallop, from at-wharf sampling during the fishing season (triangle) and corresponding survey condition (circle) from 2021 to 2023 for each of the three main scallop beds (Cape Tormentine, dotted line; West Point, solid line; and Pictou, long dash line) in the southern Gulf of St. Lawrence.*

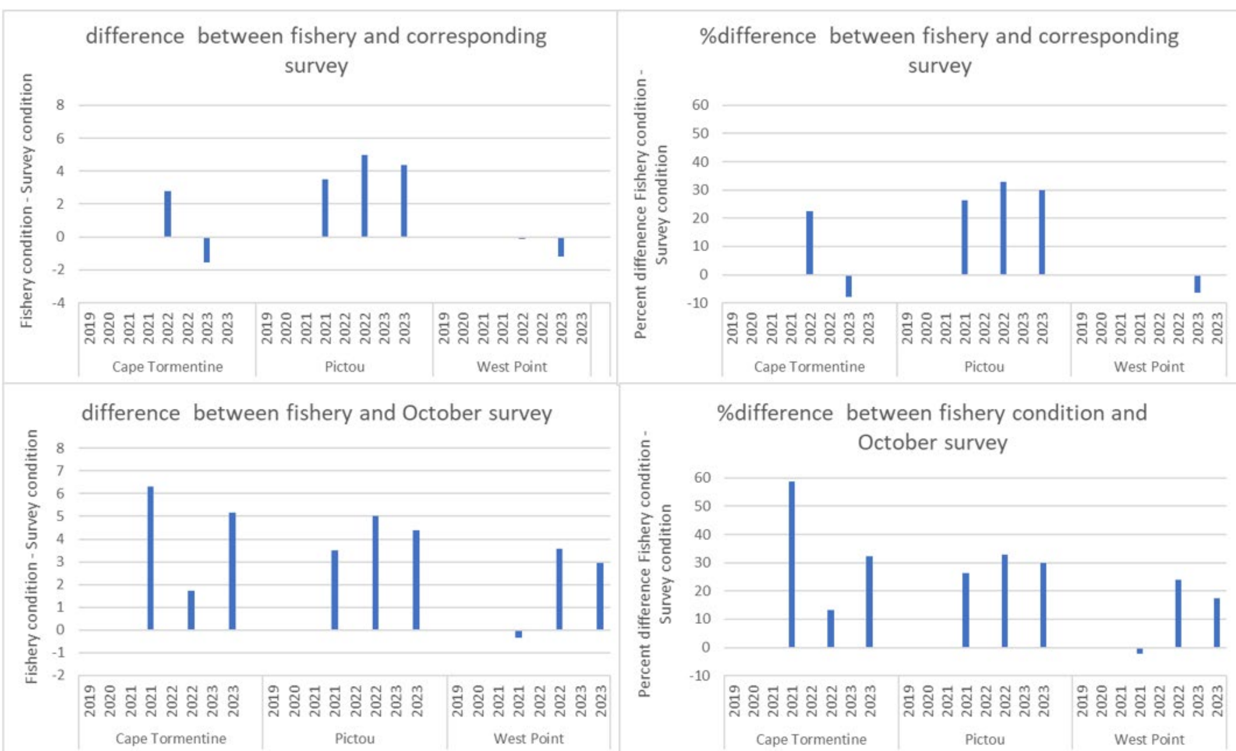



*Figure 41. Difference (left panels) and percent difference (right panels) between fishery condition (predicted meat weight in grams of a 100 mm shell height scallop), and survey condition when available for 2021, 2022 and 2023 of the three main scallop beds (Cape Tormentine, West Point, and Pictou) in the southern Gulf of St. Lawrence. Top panels compare between fishery condition and corresponding survey (spring survey for Cape Tormentine and West Point and fall survey for Pictou) condition. Bottom panels compare fishery condition to the October survey condition for all beds.*

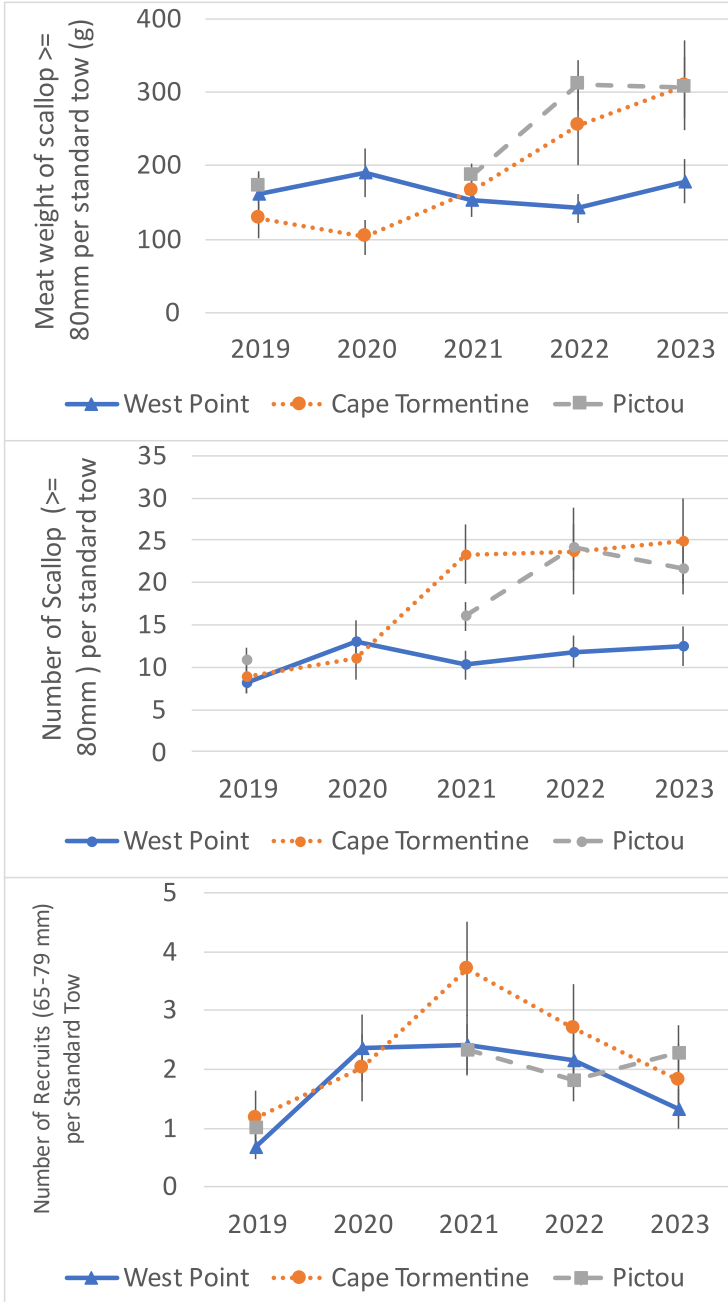



*Figure 42. Mean (SE) meat weight (g) (top panel) and number of scallop (shell height > 80 mm)(middle panel) per standard tow (657 $m^2$) and number of recruits (shell height 65 to 79 mm) (bottom panel) per standard 18 mm mesh tow (219.2 $m^2$) for the West Point (triangles) Cape Tormentine (circles) and Pictou (squares) beds (as defined by the 20 days $km^{-2}$ contour, see Niles et al. 2021) from the October surveys, 2019 to 2023.*

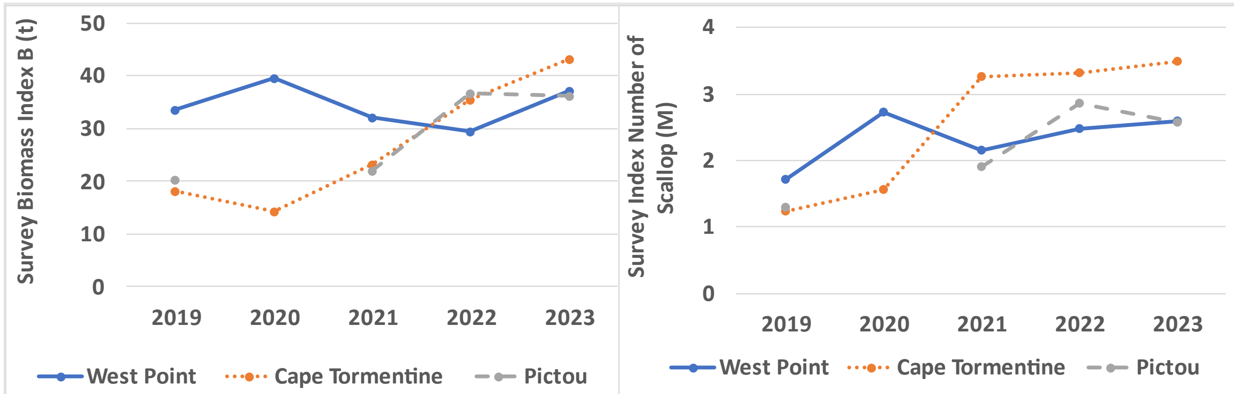



*Figure 43. October survey biomass indices (circles) of exploitable biomass (B, tonnes)(left panel) and commercial scallop numbers (M, millions)(right panel), for the West Point bed (solid line), Cape Tormentine bed (short dash) and Pictou bed (long dash) (as defined by the 20 days km$^{-2}$ contour, see Niles et al. 2021) from 2019 to 2023. Note that the 2020 survey was not conducted in Pictou due to COVID-19 related travel restrictions.*

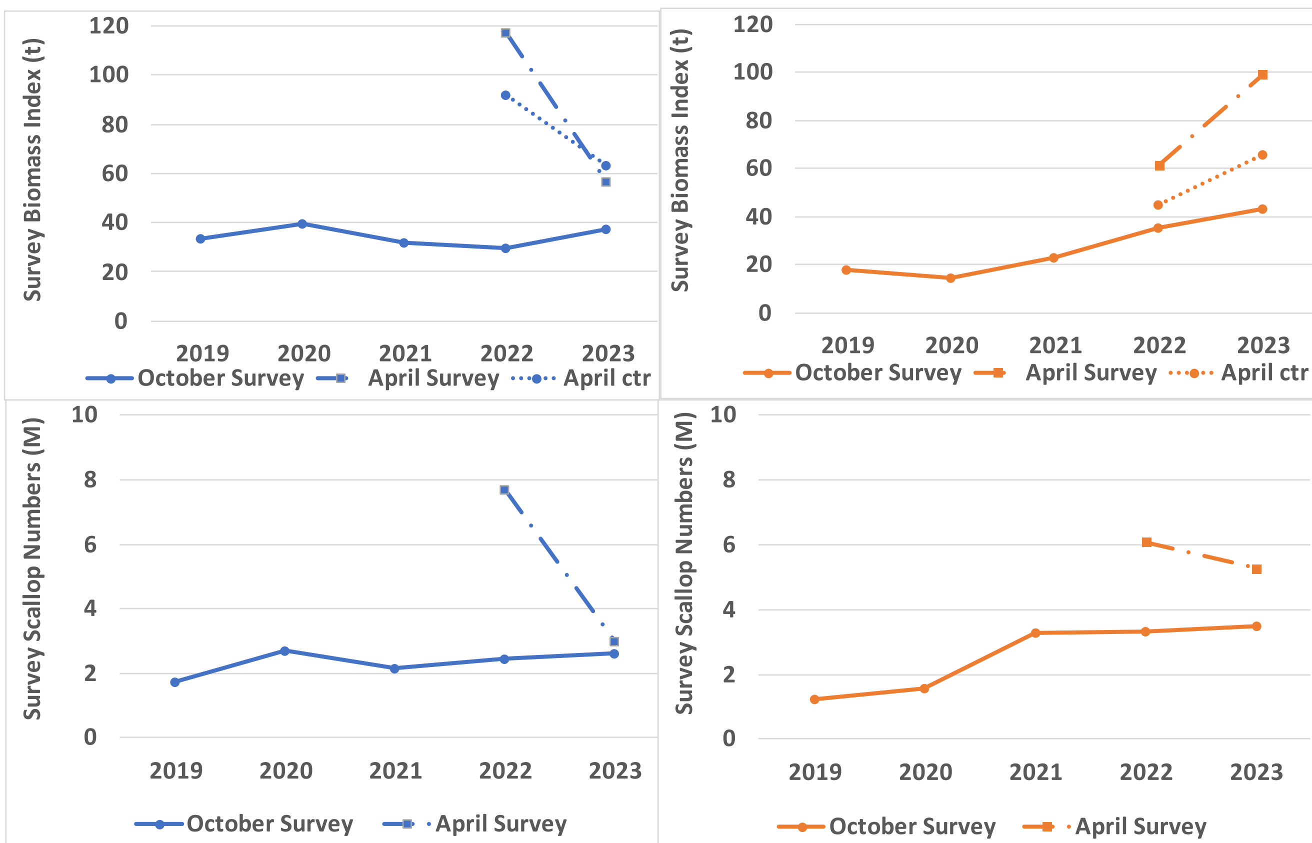



*Figure 44. October 2019 to 2023 (circles) April 2022 and 2023 (triangles) and April adjusted for condition (short dash) biomass indices of exploitable biomass (B) (upper panels) and survey indices of number of scallop (shell height > 80 mm) in millions (M) (lower panels), for the West Point bed (left panel) and the Cape Tormentine bed (right panel) (as defined by the 20 days km$^{-2}$ contour, see Niles et al. 2021).*

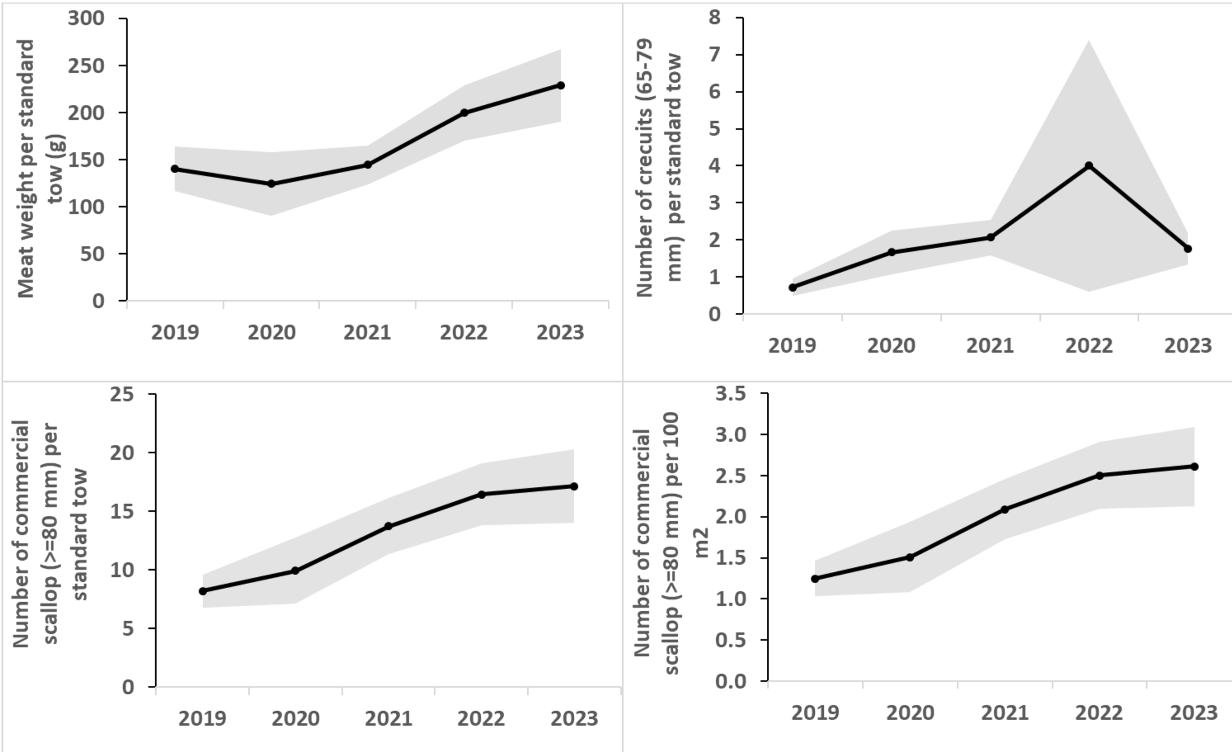



*Figure 45. Mean meat weight of commercial size (≥ 80 mm shell height) scallop (top left), mean number of recruit size (65-79 mm shell height, 18 mm mesh only) scallop (top right) and mean number of commercial size (≥ 80 mm shell height) scallop (bottom right) per standard tow and per 100 $m^2$ (bottom right) from the October surveys for the three major beds (West Point, Cape Tormentine, and Pictou) (beds are defined by the survey strata). Shaded areas show the 95% confidence intervals.*

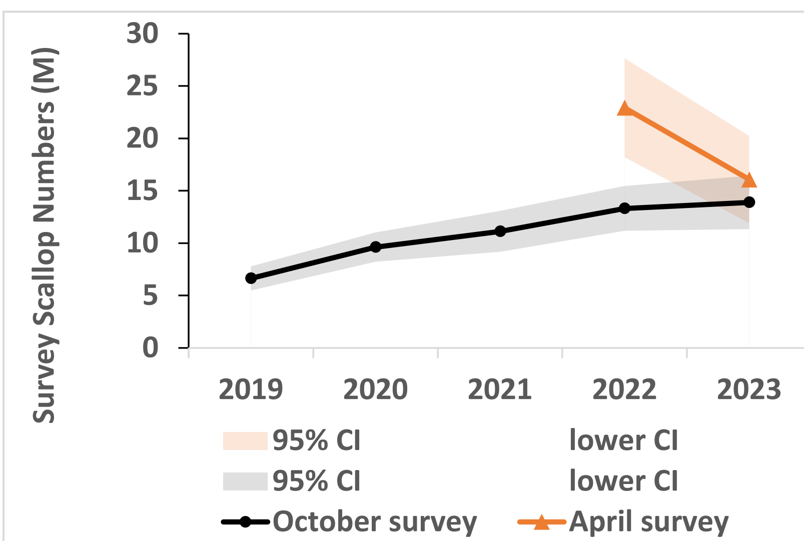



*Figure 46. Number of commercial size scallops in millions (M) from the October (circles) and April (triangles) surveys expressed as the number of scallops (M) for the three major beds (West Point, Cape Tormentine, and Pictou) (beds are defined by survey strata). Removals during the May fishery are not accounted for in the October survey estimates. Note that Pictou bed was not surveyed in 2020, nor in the April surveys, therefore the missing Pictou numbers were estimated from the mean numbers of the time series (mean = 4.7 M).*

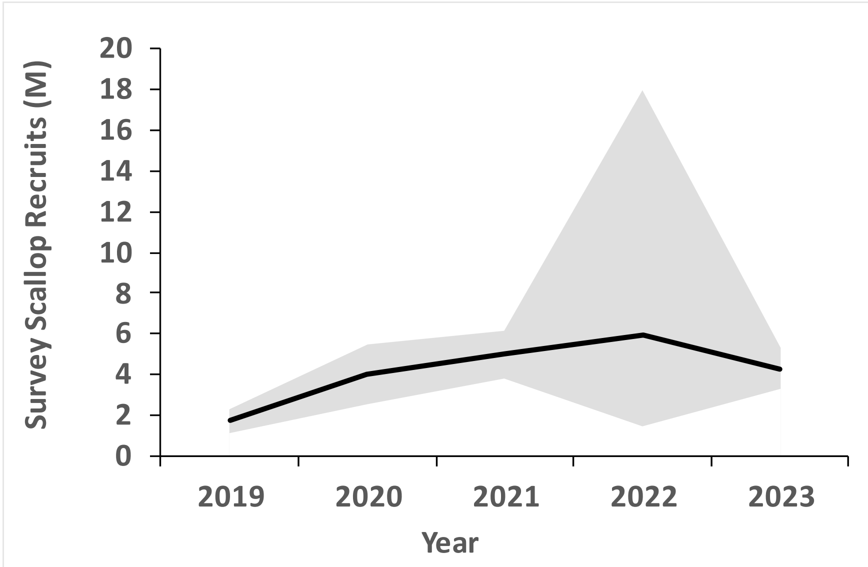



*Figure 47. Number of recruits from the October surveys based on the lined drags (18 mm mesh) expressed as the total number of recruits in millions (M) for the three major beds (West Point, Cape Tormentine, and Pictou) (beds are defined by survey strata). Grey shading represents 95% Confidence Intervals.*

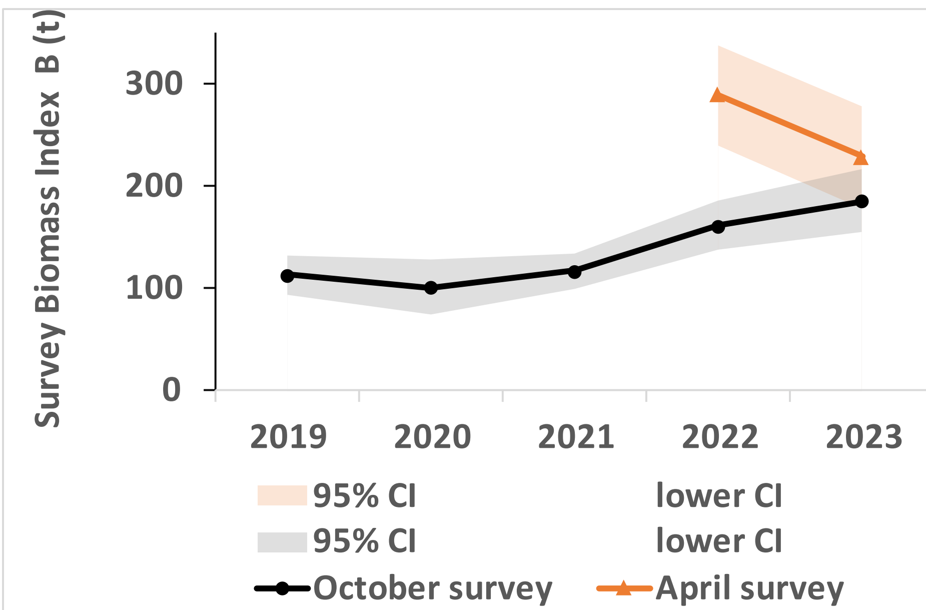



*Figure 48. Biomass index from the October (circles) and April (triangles) surveys expressed as the exploitable biomass ($B_0$) for the three major beds (West Point, Cape Tormentine, and Pictou) (beds are defined by survey strata). Grey shading represents 95% Confidence Intervals. Note that Pictou bed was not surveyed in 2020, nor in the April surveys, therefore the missing Pictou biomass was estimated from the mean biomass of the time series (mean = 29 t). The April survey biomass estimates have been controlled for condition by using October survey meat weight to shell height relationship on the April survey scallops.*

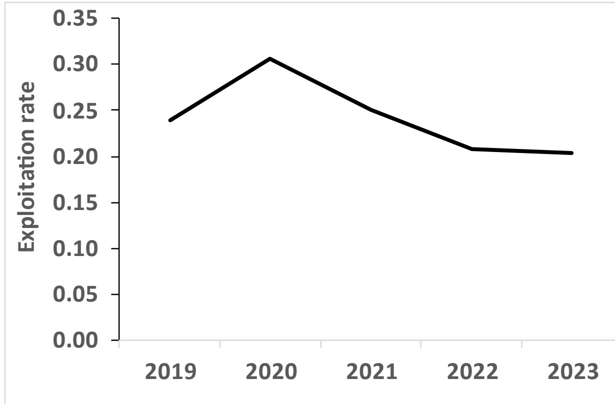



*Figure 49. Exploitation rate on commercial sea scallops for the three major beds (West Point, Cape Tormentine, and Pictou) (beds are defined by survey strata). Note that Pictou bed was not surveyed in 2020, therefore the missing Pictou biomass was estimated from the mean biomass of the time series.*

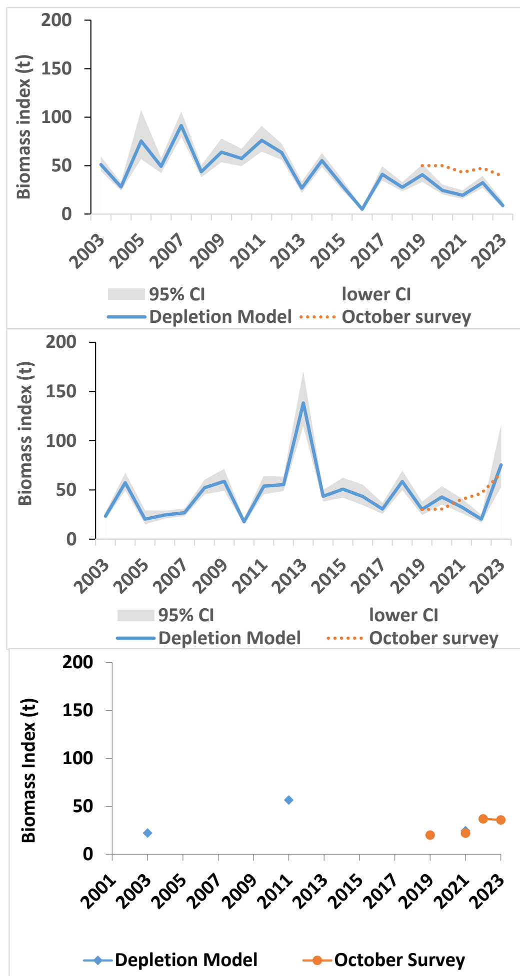
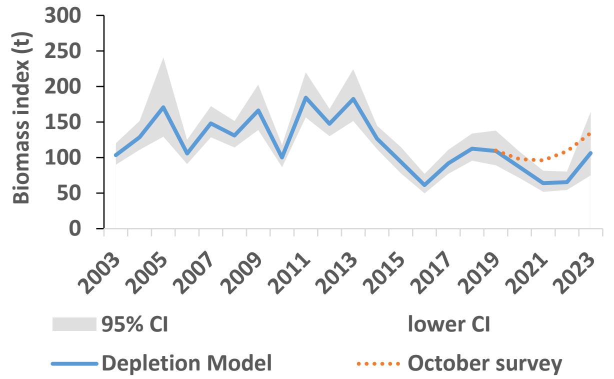



*Figure 50. Depletion model ($p<0.05$) estimates from 2003 to 2023 (solid line, blue) at the start of the fishery ($B_0$) and corresponding 95% Confidence Intervals (CI) for the West Point (top), Cape Tormentine (middle) and Pictou beds (bottom) (as defined by the 20 days km$^{-2}$ contour, see Niles et al. 2021). Only statistically significant models are presented. Also shown are the corresponding October (dashed line, orange) survey biomass estimates of exploitable biomass ($B_0$) before the fishery from 2019 to 2023.*



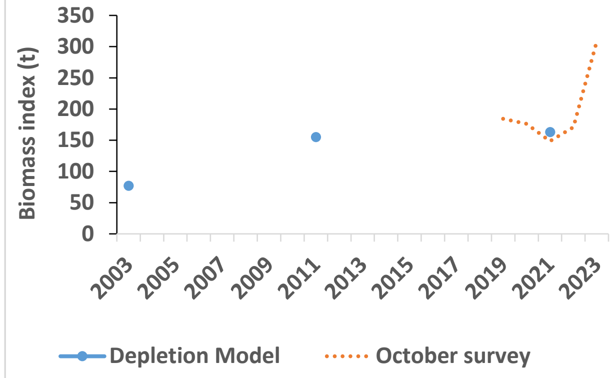




*Figure 51. Depletion model ($p<0.05$) estimates from 2003 to 2023 (solid line) at the start of the fishery ($B_0$) and corresponding 95% Confidence Intervals (CI) for SFA 22 (left) and SFA 24 (right). Only statistically significant models are presented. Also shown are the corresponding October survey (dashed line) estimates of exploitable biomass ($B_0$) before the fishery prorated to SFA area using the landings ratio (survey strata to SFA). from 2019 to 2023 the major scallop beds within each SFA (as defined by the survey strata). Note that the bed landings in SFA 22 are added to the October survey estimates, since surveys occurred after the fishery. Note also that the Pictou bed was not surveyed in 2020, therefore the missing Pictou biomass was estimated from the mean biomass of the time series (mean = 29 t).*

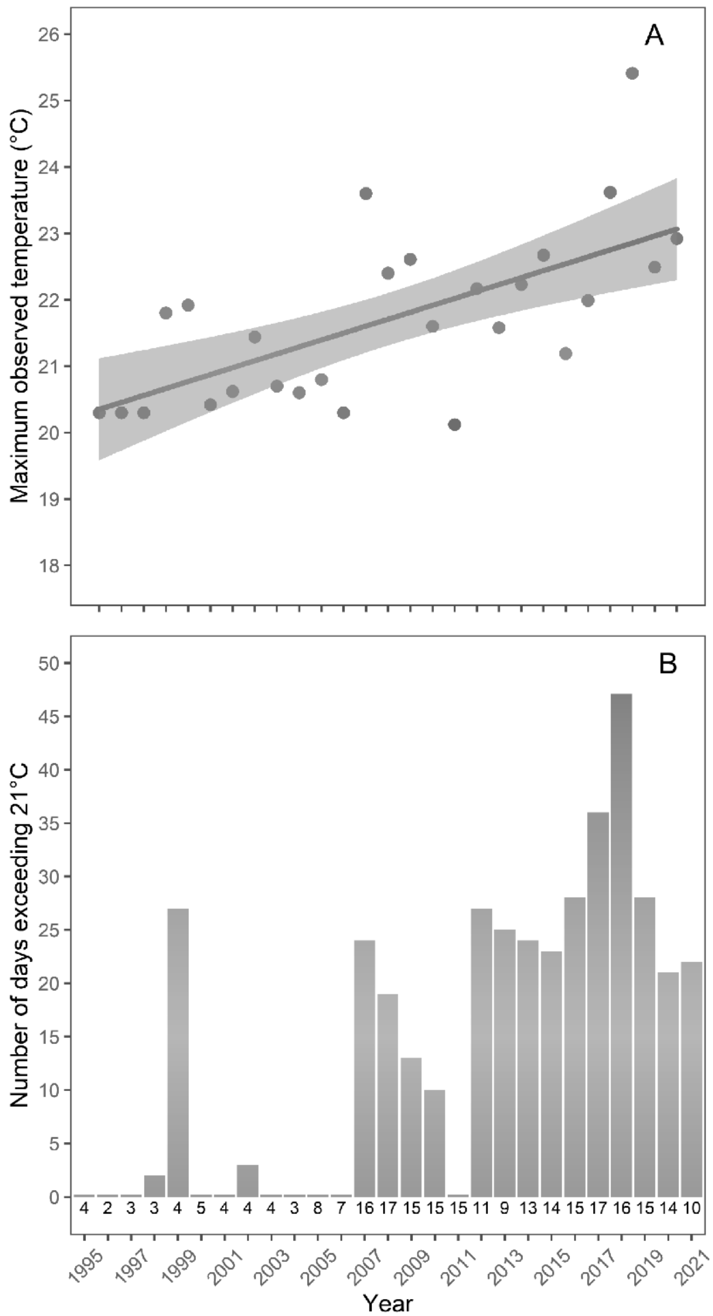



*Figure 52. A. Maximum summer bottom temperatures (July–September) recorded in the Northumberland Strait from 1995–2021. Each point represents the single highest bottom temperature recording across monitored sites with depths ranging from 9–25 m (depth range of scallops in the Northumberland Strait; N = 58). B.* ***.*** *The total number of days during summer (July–September) that at least one monitored site in the Northumberland Strait had a maximum daily temperature exceeding 20.9 °C (reported lethal temperature for sea scallops; Dickie 1958; Stewart and Arnold 1994) from 1995–2021 across monitored sites with depths ranging from 9–25 m. The number of sites monitored each year is denoted by the values below each bar in panel B. Data provided by D. Gagnon (DFO Gulf) and were collected as part of the DFO Gulf Temperature Monitoring Program.*

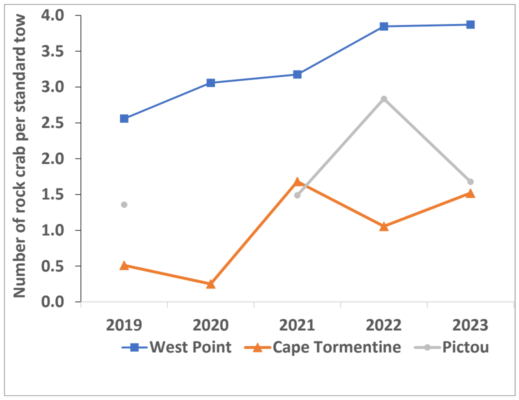



*Figure 53. Mean number of Atlantic rock crab (top panel) per standard tow (657 m$^2$) from the October (circles) on the three major beds (West Point, Cape Tormentine, and Pictou) (as defined by the 20 days km$^{-2}$ contour, see Niles et al. 2021).*

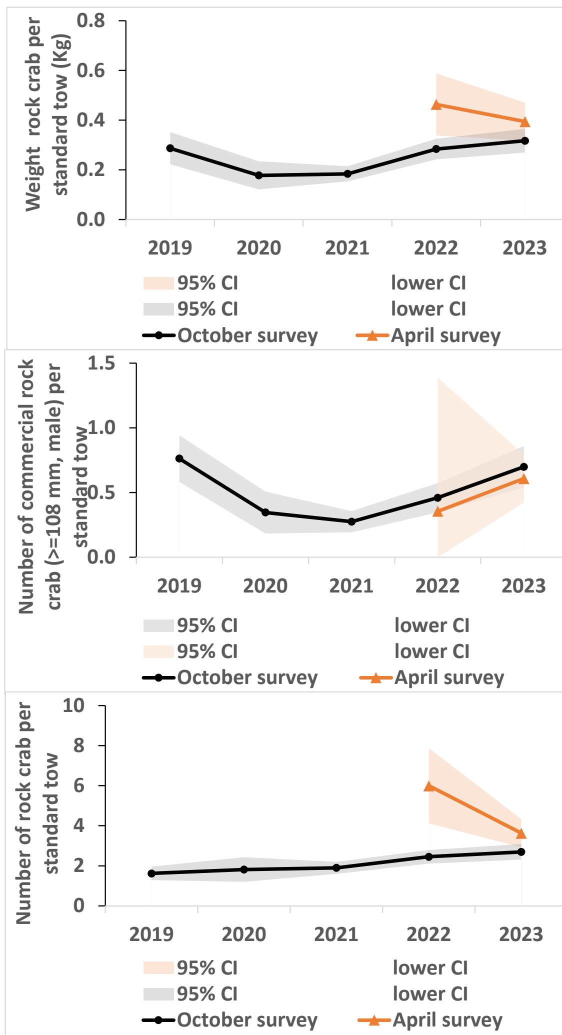



*Figure 54. Mean weight of rock crab (top), mean number of commercial size (≥ 108 mm carapace width, male) rock crab (center) and mean number of rock crab (bottom panels) per standard tow (657 m$^2$) from the October (circles) and April (triangles) surveys for the three major beds (West Point, Cape Tormentine, and Pictou) (beds are defined by the survey strata). Shaded areas show the 95% confidence intervals.*

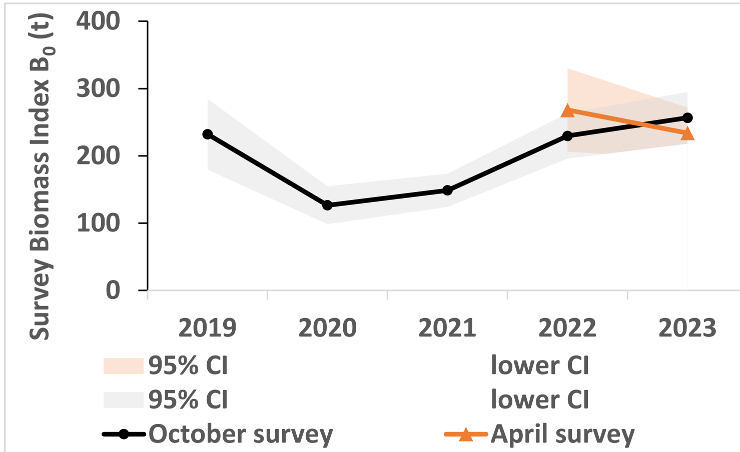



*Figure 55. Biomass index from the October (circles) and April (triangles) surveys expressed as the rock crab biomass ($B_0$) for the three major beds (West Point, Cape Tormentine, and Pictou) (beds are defined by survey strata). Note that Pictou bed was not surveyed in 2020, nor in the April surveys, therefore the missing Pictou biomass was estimated from the mean biomass of the time series (mean = 38.5 t).*

# 10. APPENDICES

## A.1. APPENDIX

*Table A1. Summary of management measure in 2022 and changes over the years (measure in year it took effect) for the sea scallop fishery in the southern Gulf of St. Lawrence.*

| Management measure | Year | Scallop Fishing Area (SFA) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 21A | 21B | 21C | 22 | 23 | 24 |
| Season | 2022 | July 11 to July 22 | May 10 to Aug. 8[a] | July 4 to July 29 | May 2 to May 28 | July 4 to Aug. 20 | Nov 1 to Dec. 15 |
| | 2016 | - | - | - | - | July 4 to Aug. 27; Oct. 24 to Nov. 26 | - |
| | 1999 | - | - | - | - | - | Apr. 15 to Apr. 21; May 5 to June 14;Oct. 1 to Dec. 31 |
| | 1995 | Apr. 29 to Dec. 31 | Apr. 29 to Dec. 31 | Apr. 29 to Dec. 31 | - | Apr. 1 to Dec. 31 | - |
| | 1986 | - | - | - | Apr. 28 to June 28 | - | Apr. 15 to June 30;Oct. 1 to Dec. 31 |
| Number of fishing days in season | 2022 | 10 | 42 | 20 | 24 | 42 | 39 |
| | 2021 | - | - | - | - | - | - |
| | 2019 | 10 | - | - | - | - | - |
| | 2018 | - | - | - | 24 | - | - |
| | 2017 | - | - | 20 | - | - | - |
| | 2015 | - | - | 24 | 30 | 40 | - |
| | 2013 | - | 42 | - | - | - | - |
| | 2012 | - | 50 | - | - | - | - |
| | 2010 | - | - | 25 | - | - | - |
| | 2009 | 20 | - | - | - | - | - |
| | 2008 | 25 | - | - | - | 72 | - |
| | 2007 | 30 | - | - | - | - | - |
| | 1995 | 242 | 242 | 242 | - | 236 | 39 |
| | 1993 | - | - | - | 34 | - | - |

| Management measure | Year | Scallop Fishing Area (SFA) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 21A | 21B | 21C | 22 | 23 | 24 |
| | 1992 | - | - | - | 62 | - | - |
| Time open | 2022 | 6:00 to 18:00 | No time closures | 4:00 to 21:00 | 6:00 to 17:00 | 6:00 to 18:00 | 6:00 to 18:00 |
| | 2016 | - | - | - | 6:00 to 17:00 | - | - |
| | 2015 | - | - | 5:00 to 18:00 | 6:00 to 18:00[c] | 6:00 to 18:00 | 6:00 to 18:00 |
| | 2013 | - | No time closures | - | - | - | - |
| | 2002 | 6:00 to 18:00 | - | - | - | - | - |
| | 2001 | 5:30 to 20:00 | 5:30 Monday to 14:00 Friday | - | - | - | - |
| | 1997 | - | - | 5:30 to 20:00 | 5:30 to 20:00 | - | - |
| Days closed | 2022 | Saturday & Sunday | None | Saturday & Sunday | Sunday | Sunday | Sunday |
| Meat count (number per 500 g) | 2022 | 35 | 39 | 39 | 44 | 33 | 52 |
| | 2015 | 35 | 39 | 39 | - | 33 | - |
| | 2014 | 37 | - | - | - | - | - |
| | 2013 | 39 | - | - | - | - | - |
| | 2002 | - | - | - | 44 | - | - |
| | 2001 | 39 | - | - | - | - | - |
| | 1991 | - | - | - | 52 | 52 | 52 |
| Ring size (mm) | 2024 | - | 88.9 | 88.9 | - | - | - |
| | 2022 | 82.6 | 82.6 | 82.6 | 88.9 | 82.6 | 82.6 |
| | 2019 | - | - | - | 88.9 | - | - |
| | 2003 | 82.6 | 82.6 | 82.6 | - | - | - |
| | 2002 | - | - | - | - | - | 82.6 |
| | 2001 | 76.2 | 76.2 | 76.2 | 82.6 | 82.6 | 76.2 |
| | 2000 | - | - | - | 82.6 | - | - |
| | 1996 | - | - | - | 76.2 | - | - |
| | 2022 | 6 | 6 | 6 | 4.88 | 6 | 5 |

| Management measure | Year | Scallop Fishing Area (SFA) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 21A | 21B | 21C | 22 | 23 | 24 |
| Width of dredge (m)[c] | 1987 | 6 | 6 | 6 | 4.88 | 6 | 5 |
| | 1980 | - | - | - | 3.5 | - | 3.5 |
| Tow bar specifications [b] | 2022 | ns | ns | ns | with 50.8 mm runners | ns | ns |
| | 2002 | ns | ns | ns | with 50.8 mm runners | ns | ns |
| Washers | 2022 | Steel (8 max) & Chaffing gear or 2 rubbers on the vertical | | | no rubber washers | Steel (8 max) & Chaffing gear or 2 rubbers on the vertical | |
| | 2019 | - | - | - | no rubber washers | - | - |
| | 2002 | Steel (8 max) & Chaffing gear or 2 rubbers on the vertical | | | | | |
| Maximum vessel length | 2022 | 14 m | | | | | |
| | 1980 | 15.24 m | | | | | |
| | 1956 | No limit | | | | | |

[a] maximum of 42 consecutive days within this season
[b] ns=not specified
[c] not regulated until 1987, Jamieson et al 1980 reported that the average dredge width used by fishers in 1980 was 3.5 m in the Northumberland Strait and reported a maximum vessel length of 15.24 and gross tonnage of 25.5. Bourne (1964) documents that vessels (> 20 m) from the offshore Maritime Region fished in the sGSL in the 1950-1956 period. Regulation in 1956 restricted the vessels less than 20 m total length.

## A.2. APPENDIX

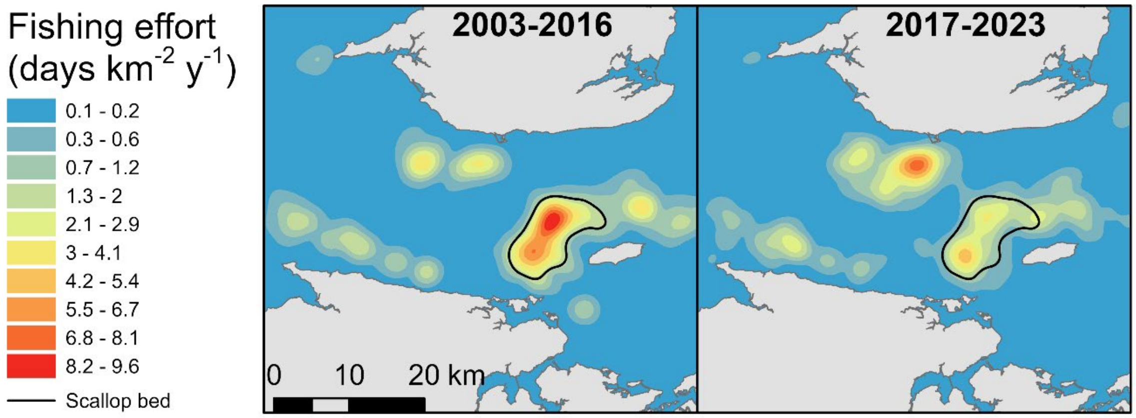



*Figure A2-a. Depiction of the change in fishing effort (kernel density of logbook records; days $km^{-2}$ $y^{-1}$) at the Pictou bed between the time periods of 2003 to 2016 and 2017 to 2023. A larger proportion of effort occurred outside the primary bed in the latter time period, centered largely to the northwest near Wood Islands.*

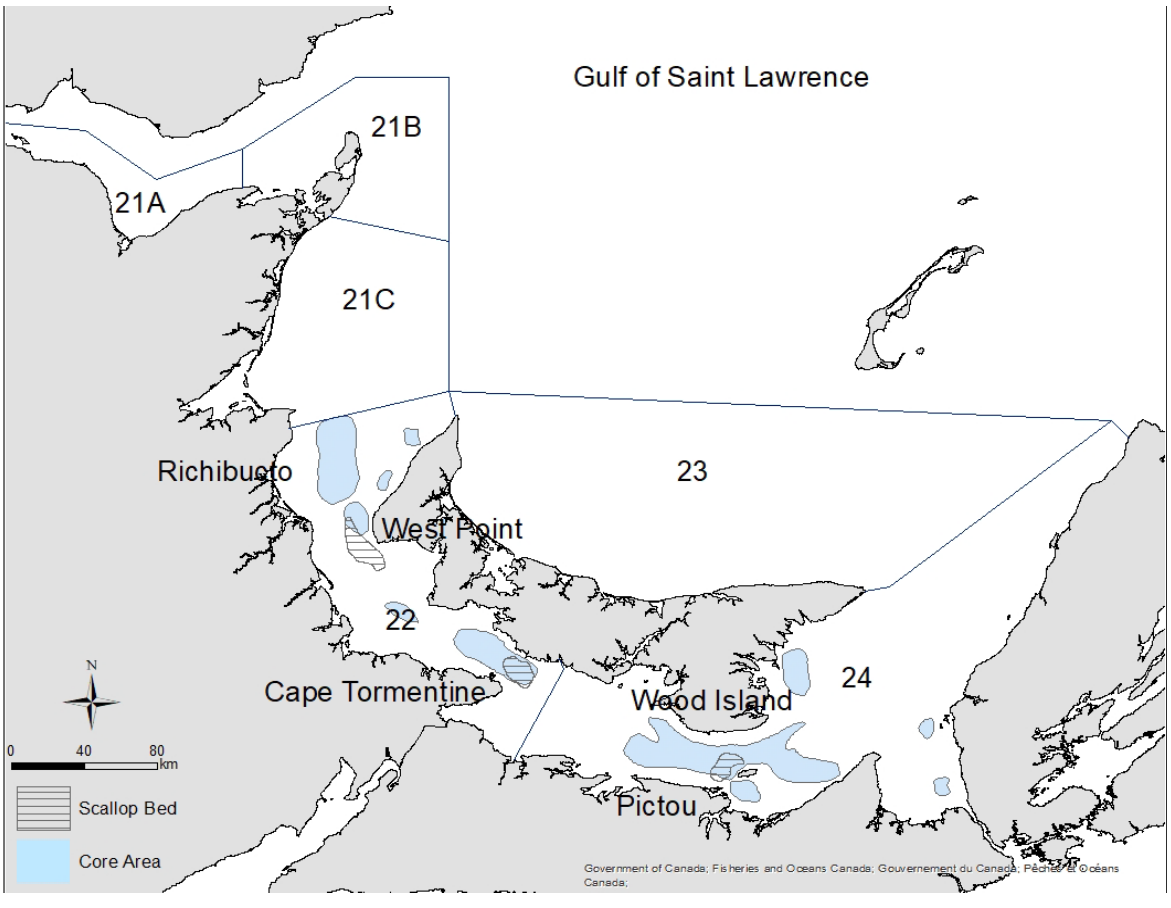



*Figure A2-b. Potential productive scallop ground (shaded blue) in the Northumberland Strait as described in 1978 (modified from Jamieson 1978) and major beds (hashed area, as described in Niles et al. 2021). The Richibucto bed, which has experienced greatly reduced fishing effort in the 2000s, is located in the northwest corner of the Strait, identified as covering 447.61 $km^2$.*

## A.3. APPENDIX

*Table A3-a. Scallop landings (meats, t) for each Scallop Fishing Area (SFA) in the Gulf Region, from 1968 to 2016.*

| Year | SFA 21 | SFA 22 | SFA 23 | SFA 24 | Total (Gulf) | Core |
|---|---|---|---|---|---|---|
| 1968 | 3 | 619 | 5 | 274 | 901 | 893 |
| 1969 | 5 | 232 | 0 | 408 | 645 | 640 |
| 1970 | 55 | 313 | 1 | 329 | 697 | 642 |
| 1971 | 49 | 276 | 0 | 266 | 591 | 542 |
| 1972 | 55 | 178 | 0 | 276 | 509 | 454 |
| 1973 | 34 | 124 | 0 | 147 | 305 | 271 |
| 1974 | 37 | 46 | 0 | 119 | 202 | 165 |
| 1975 | 31 | 60 | 0 | 186 | 278 | 246 |
| 1976 | 26 | 218 | 1 | 120 | 365 | 338 |
| 1977 | 13 | 118 | 0 | 63 | 194 | 181 |
| 1978 | 13 | 174 | 1 | 80 | 268 | 254 |
| 1979 | 14 | 129 | 0 | 95 | 239 | 224 |
| 1980 | 19 | 100 | 0 | 90 | 209 | 190 |
| 1981 | 33 | 158 | 4 | 174 | 368 | 332 |
| 1982 | 20 | 98 | 1 | 108 | 227 | 206 |
| 1983 | 30 | 133 | 1 | 144 | 308 | 277 |
| 1984 | 40 | 132 | 3 | 60 | 234 | 191 |
| 1985 | 39 | 129 | 5 | 41 | 213 | 170 |
| 1986 | 26 | 77 | 2 | 91 | 196 | 168 |
| 1987 | 22 | 83 | 0 | 59 | 164 | 142 |
| 1988 | 23 | 96 | 0 | 42 | 161 | 138 |
| 1989 | 59 | 118 | 0 | 38 | 215 | 156 |
| 1990 | 70 | 82 | 0 | 56 | 208 | 138 |
| 1991 | 43 | 35 | 0 | 73 | 152 | 109 |

| Year | SFA 21 | SFA 22 | SFA 23 | SFA 24 | Total (Gulf) | Core |
|---|---|---|---|---|---|---|
| 1992 | 43 | 44 | 0 | 76 | 163 | 120 |
| 1993 | 53 | 66 | 0 | 132 | 251 | 198 |
| 1994 | 81 | 86 | 1 | 141 | 308 | 226 |
| 1995 | 61 | 105 | 1 | 145 | 313 | 251 |
| 1996 | 76 | 87 | 3 | 162 | 328 | 249 |
| 1997 | 87 | 111 | 8 | 105 | 310 | 216 |
| 1998 | 97 | 121 | 8 | 64 | 291 | 186 |
| 1999 | 62 | 64 | 2 | 82 | 210 | 146 |
| 2000 | 48 | 98 | 3 | 87 | 235 | 185 |
| 2001 | 34 | 95 | 1 | 32 | 162 | 127 |
| 2002 | 23 | 43 | 0 | 29 | 95 | 72 |
| 2003 | 28 | 56 | - | 26 | 111 | 83 |
| 2004 | 30 | 76 | 1 | 27 | 134 | 103 |
| 2005 | 24 | 57 | 1 | 25 | 108 | 83 |
| 2006 | 10 | 55 | 1 | 29 | 95 | 84 |
| 2007 | 15 | 82 | 0 | 21 | 118 | 103 |
| 2008 | 15 | 78 | 1 | 16 | 110 | 94 |
| 2009 | 13 | 82 | 3 | 21 | 119 | 103 |
| 2010 | 5 | 55 | 1 | 28 | 90 | 83 |
| 2011 | 1 | 88 | 0 | 31 | 122 | 119 |
| 2012 | 0 | 86 | 1 | 30 | 117 | 116 |
| 2013 | 5 | 91 | 3 | 25 | 124 | 116 |
| 2014 | 3 | 71 | 7 | 18 | 99 | 89 |
| 2015 | 0 | 51 | 3 | 17 | 71 | 68 |
| 2016 | 7 | 34 | 2 | 24 | 68 | 59 |
| 2017 | 6 | 51 | 1 | 24 | 83 | 75 |

| Year | SFA 21 | SFA 22 | SFA 23 | SFA 24 | Total (Gulf) | Core |
|---|---|---|---|---|---|---|
| 2018 | 6 | 63 | NA | 21 | 91 | 84 |
| 2019 | 4 | 42 | NA | 19 | 66 | 61 |
| 2020 | 6 | 37 | NA | 28 | 71 | 65 |
| 2021 | 3 | 34 | NA | 30 | 67 | 64 |
| 2022 | 3 | 36 | NA | 30 | 69 | 66 |
| 2023p | 3 | 49 | NA | 30 | 83 | 80 |

NA = not available.

*Table A3-b. Scallop days fished (1 trip=1 day) for each Scallop Fishing Area (SFA) in the Gulf Region, from 1968 to 2021.*

| Year | SFA 21 | SFA 22 | SFA 23 | SFA 24 | Total (Gulf) | Core |
|---|---|---|---|---|---|---|
| 1977 | 153 | 424 | NA | 450 | 1027 | 874 |
| 1978 | 441 | 2755 | 1 | 1820 | 5017 | 4575 |
| 1979 | 448 | 3321 | 2 | 2407 | 6178 | 5728 |
| 1980 | 735 | 2262 | NA | 2089 | 5086 | 4351 |
| 1981 | 1206 | 3910 | 88 | 3790 | 8994 | 7700 |
| 1982 | 885 | 2379 | 47 | 2783 | 6094 | 5162 |
| 1983 | 666 | 2867 | 41 | 4440 | 8014 | 7307 |
| 1984 | 942 | 3261 | 86 | 1112 | 5401 | 4373 |
| 1985 | 1123 | 2957 | 95 | 1003 | 5178 | 3960 |
| 1986 | 807 | 2014 | 73 | 1931 | 4825 | 3945 |
| 1987 | 538 | 2216 | 12 | 939 | 3705 | 3155 |
| 1988 | 299 | 2049 | NA | 763 | 3111 | 2812 |
| 1989 | 1174 | 2115 | NA | 710 | 3999 | 2825 |
| 1990 | 1495 | 1496 | 16 | 1101 | 4108 | 2597 |
| 1991 | 1057 | 812 | 17 | 1275 | 3161 | 2087 |
| 1992 | 1104 | 1057 | 2 | 1472 | 3635 | 2529 |
| 1993 | 1293 | 1605 | 6 | 3252 | 6156 | 4857 |

| Year | SFA 21 | SFA 22 | SFA 23 | SFA 24 | Total (Gulf) | Core |
|---|---|---|---|---|---|---|
| 1994 | 1925 | 2073 | 28 | 3719 | 7745 | 5792 |
| 1995 | 1631 | 2574 | 41 | 3291 | 7537 | 5865 |
| 1996 | 2389 | 2531 | 122 | 3881 | 8923 | 6412 |
| 1997 | 2410 | 2793 | 293 | 3164 | 8660 | 5957 |
| 1998 | 2446 | 3644 | 316 | 2378 | 8784 | 6022 |
| 1999 | 1739 | 2047 | 101 | 2070 | 5957 | 4117 |
| 2000 | 1406 | 2120 | 86 | 2514 | 6126 | 4634 |
| 2001 | 802 | 2387 | 45 | 1138 | 4372 | 3525 |
| 2002 | 849 | 1246 | 18 | 973 | 3086 | 2219 |
| 2003 | 724 | 1514 | NA | 1109 | 3298 | 2623 |
| 2004 | 758 | 1487 | 11 | 934 | 3020 | 2421 |
| 2005 | 747 | 1434 | 17 | 1186 | 2995 | 2620 |
| 2006 | 387 | 1511 | 2 | 1209 | 2784 | 2720 |
| 2007 | 448 | 1734 | 5 | 933 | 2824 | 2667 |
| 2008 | 295 | 1618 | 14 | 715 | 2555 | 2333 |
| 2009 | 289 | 1836 | 48 | 853 | 2996 | 2689 |
| 2010 | 95 | 1333 | 33 | 966 | 1866 | 2299 |
| 2011 | 31 | 1635 | 11 | 1138 | 2801 | 2773 |
| 2012 | 15 | 1782 | 25 | 1108 | 2913 | 2890 |
| 2013 | 142 | 1740 | 38 | 951 | 2720 | 2691 |
| 2014 | 137 | 1522 | 95 | 856 | 2593 | 2378 |
| 2015 | 24 | 1234 | 51 | 683 | 1885 | 1917 |
| 2016 | 58 | 1010 | 77 | 707 | 1739 | 1717 |
| 2017 | 54 | 1104 | 26 | 761 | 1896 | 1865 |
| 2018 | 63 | 1196 | NA | 594 | 1842 | 1790 |
| 2019 | 52 | 965 | NA | 606 | 1620 | 1571 |

| Year | SFA 21 | SFA 22 | SFA 23 | SFA 24 | Total (Gulf) | Core |
|---|---|---|---|---|---|---|
| 2020 | 89 | 804 | NA | 828 | 1698 | 1632 |
| 2021 | 59 | 752 | NA | 728 | 1535 | 1480 |
| 2022 | 62 | 762 | NA | 559 | 1383 | 1321 |
| 2023 | 63 | 647 | NA | 668 | 1378 | 1315 |

NA = not available.

*Table A3-c. Proportion of SFA landings attributed to each major scallop bed (Niles et al. 2021, 20 pt contour) according to logbook reports from 2003 to 2023.*

| SFA | 22 | | | 24 |
|---|---|---|---|---|
| Year | Cape Tormentine | West Point | Cape Tormentine and West Point | Pictou |
| 2003 | 0.21 | 0.48 | 0.69 | 0.31 |
| 2004 | 0.41 | 0.22 | 0.64 | 0.43 |
| 2005 | 0.12 | 0.44 | 0.55 | 0.31 |
| 2006 | 0.23 | 0.47 | 0.70 | 0.41 |
| 2007 | 0.18 | 0.61 | 0.79 | 0.31 |
| 2008 | 0.39 | 0.33 | 0.72 | 0.33 |
| 2009 | 0.34 | 0.41 | 0.75 | 0.43 |
| 2010 | 0.17 | 0.56 | 0.72 | 0.34 |
| 2011 | 0.28 | 0.42 | 0.71 | 0.39 |
| 2012 | 0.36 | 0.44 | 0.80 | 0.38 |
| 2013 | 0.70 | 0.16 | 0.87 | 0.50 |
| 2014 | 0.34 | 0.43 | 0.77 | 0.39 |
| 2015 | 0.53 | 0.32 | 0.85 | 0.40 |
| 2016 | 0.70 | 0.09 | 0.79 | 0.45 |
| 2017 | 0.33 | 0.43 | 0.76 | 0.33 |
| 2018 | 0.51 | 0.25 | 0.76 | 0.35 |

| SFA | 22 | | | 24 |
|---|---|---|---|---|
| Year | Cape Tormentine | West Point | Cape Tormentine and West Point | Pictou |
| 2019 | 0.27 | 0.39 | 0.66 | 0.17 |
| 2020 | 0.47 | 0.29 | 0.76 | 0.17 |
| 2021 | 0.48 | 0.32 | 0.80 | 0.19 |
| 2022 | 0.31 | 0.49 | 0.81 | 0.35 |
| 2023p | 0.70 | 0.08 | 0.78 | 0.14 |

*Table A3-d. Depletion model estimates for each major scallop bed corresponding to the bed strata (Niles et al. 2021, 20 pt contour) from 2017 to 2023 showing number of logbook records (n), catchability coefficient (q), cumulative catch in tons of meat (C), estimated Biomass before the fishery ($B_0$ (t)) and estimated exploitation rate ($\hat{E}$). Shaded cells with italic text mean non-significant model ($p > 0.05$).*

| Year | Area | n (logs) | q | C (t) | $B_0$ (t) | $\hat{E}$ |
|---|---|---|---|---|---|---|
| 2017 | Cape Tormentine | 683 | 0.347 | 16 | 30.91 | 0.53 |
| *2018* | Cape Tormentine | 812 | 0.219 | 32 | 57.32 | 0.55 |
| 2019 | Cape Tormentine | 704 | 0.273 | 11 | 31.63 | 0.36 |
| 2020 | Cape Tormentine | 659 | 0.233 | 17 | 40.57 | 0.42 |
| *2021* | Cape Tormentine | 588 | 0.327 | 17 | 32.10 | 0.52 |
| *2022* | Cape Tormentine | 540 | 0.558 | 11 | 20.34 | 0.55 |
| *2023* | Cape Tormentine | 394 | 0.280 | 34 | 75.17 | 0.46 |
| 2017 | West Point | 709 | 0.258 | 22 | 39.55 | 0.55 |
| *2018* | West Point | 820 | 0.471 | 16 | 27.02 | 0.58 |
| 2019 | West Point | 688 | 0.188 | 16 | 43.05 | 0.37 |
| 2020 | West Point | 671 | 0.402 | 11 | 23.05 | 0.46 |
| *2021* | West Point | 592 | 0.557 | 11 | 19.18 | 0.57 |
| *2022* | West Point | 540 | 0.325 | 18 | 32.35 | 0.55 |
| *2023* | West Point | 394 | 2.409 | 4 | 8.70 | 0.47 |

| Year | Area | n (logs) | q | C (t) | $B_0$ (t) | Ê |
|---|---|---|---|---|---|---|
| 2017 | Pictou | 372 | 0.038 | 6 | 120.45 | 0.05 |
| *2018* | Pictou | 390 | -0.131 | 6 | -33.39 | -0.19 |
| 2019 | Pictou | 388 | -0.099 | 3 | -45.63 | -0.06 |
| 2020 | Pictou | 702 | -0.008 | 5 | -581.81 | -0.01 |
| *2021* | Pictou | 611 | 0.266 | 5 | 25.26 | 0.20 |
| *2022* | Pictou | 410 | -0.111 | 8 | -58.69 | -0.14 |
| *2023* | Pictou | 512 | 0.089 | 4 | 71.59 | 0.06 |

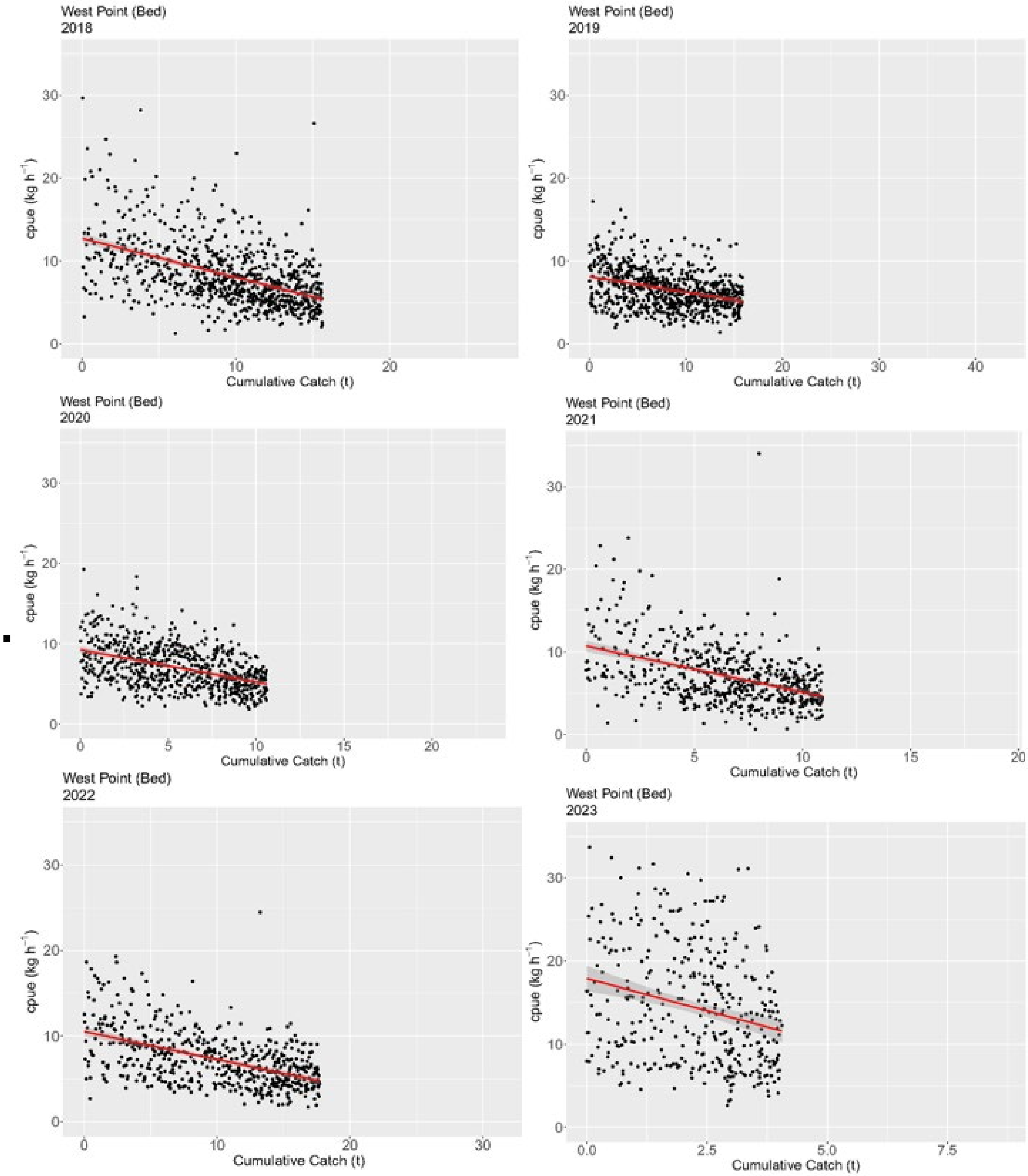



*Figure A3-a. Plot of daily catch rates against the cumulative catch of scallops and the best-fit line of the Leslie depletion model for the West Point bed data as defined by the survey bed stratum for each year from 2018 to 2023.*

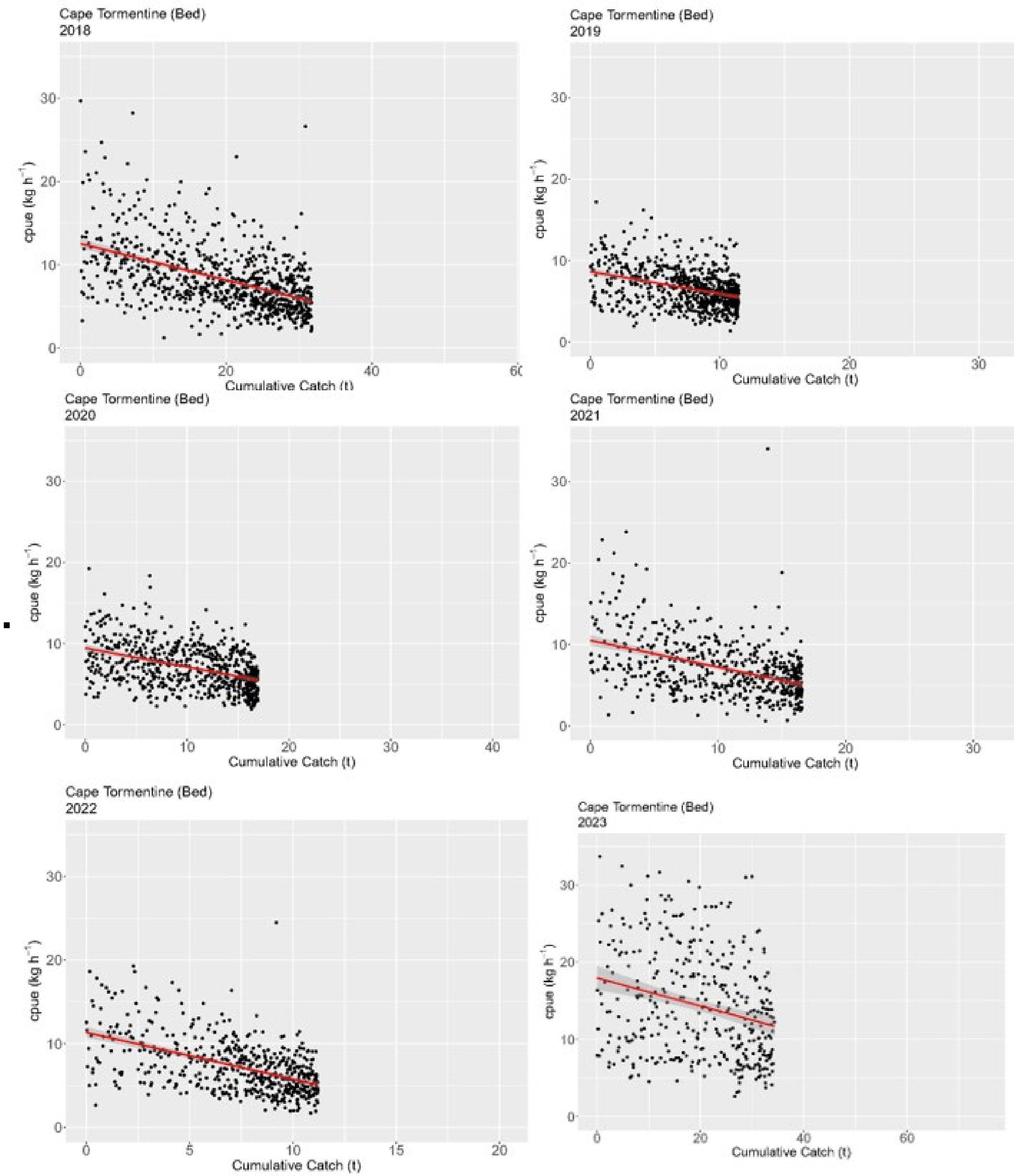



*Figure A3-b. Plot of daily catch rates against the cumulative catch of scallops and the best-fit line of the Leslie depletion model for the Cape Tormentine bed data as defined by the survey bed stratum for each year from 2018 to 2023.*

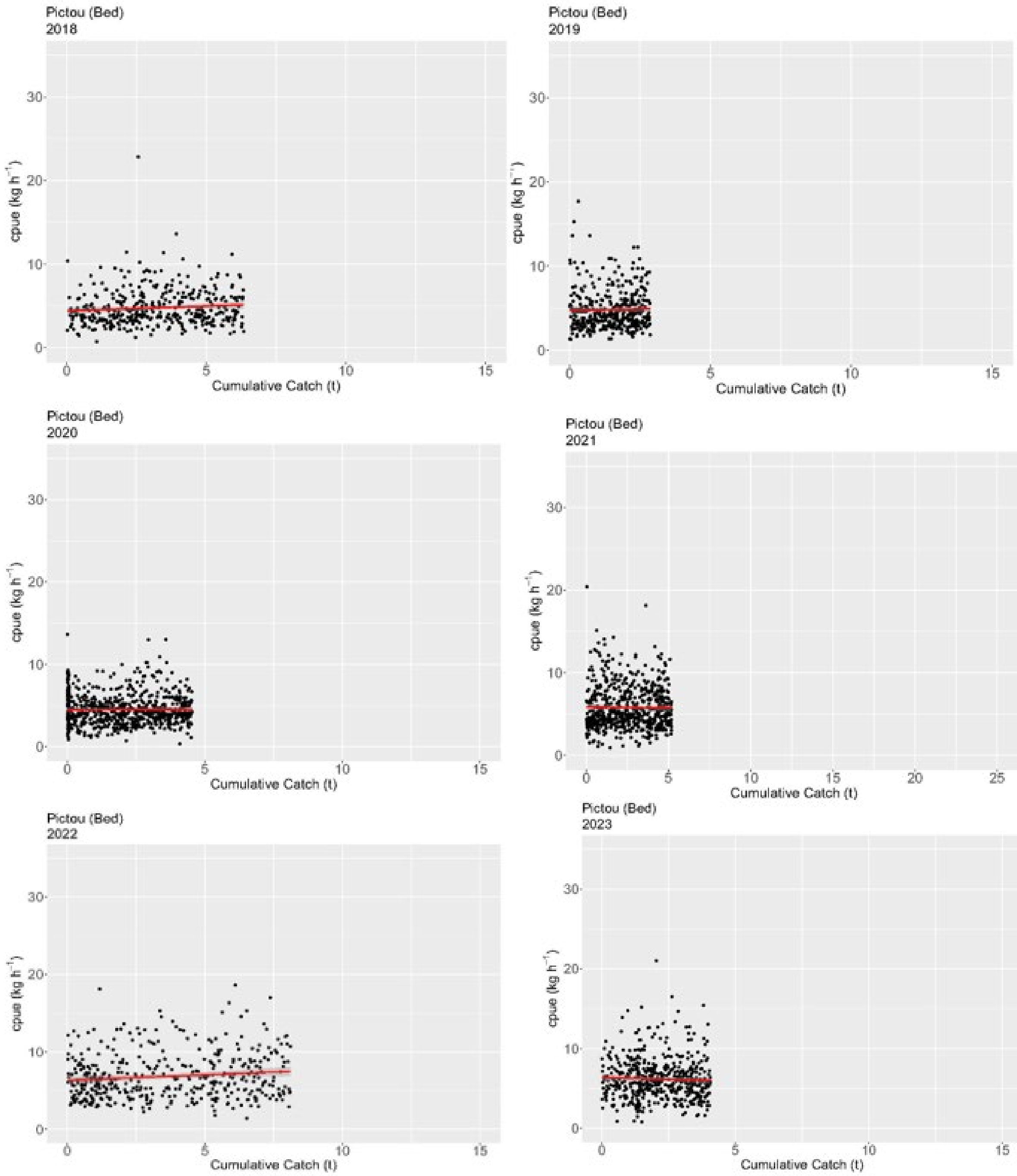



*Figure A3-c. Plot of daily catch rates against the cumulative catch of scallops and the best-fit line of the Leslie depletion model for the Pictou bed data as defined by the survey bed stratum for each year from 2018 to 2023. Note that only the 2021 model was model was statistically significant.*

## A.4. APPENDIX

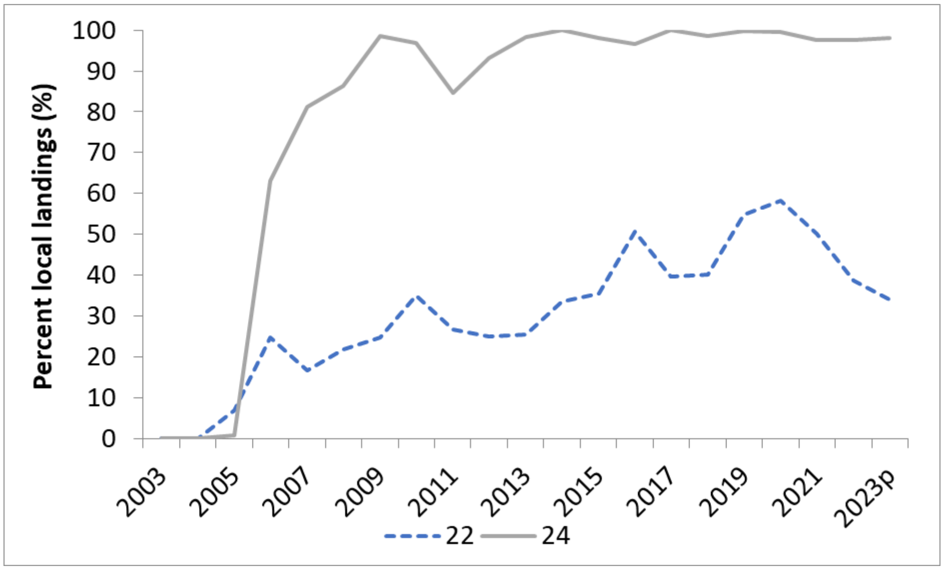



*Figure A4. Percent of commercial scallop landings that are from local buyers (buyer code 9997), in Scallop Fishing Areas (SFA) 22 (dotted line) and 24 (solid line).*

## A.5. APPENDIX

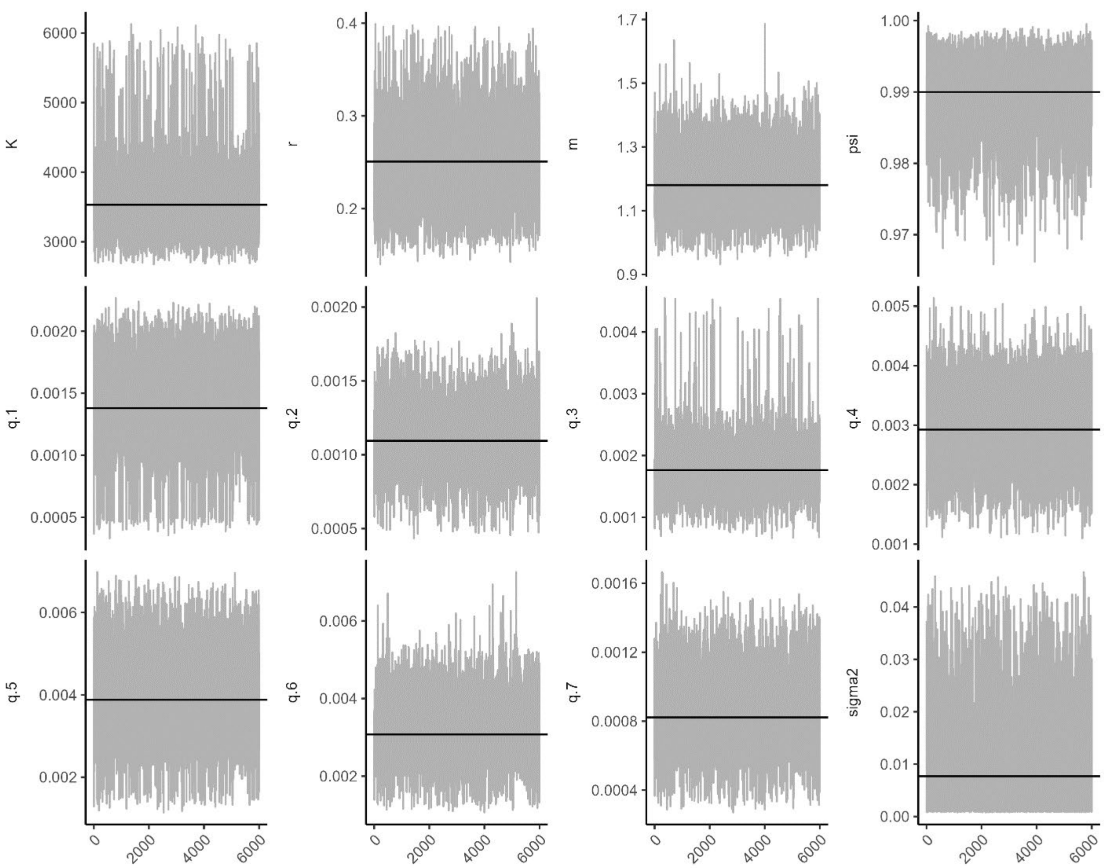



*Figure A5-a. Key model parameter estimates across MCMC replicates for the updated JABBA model three MCMC chains.*

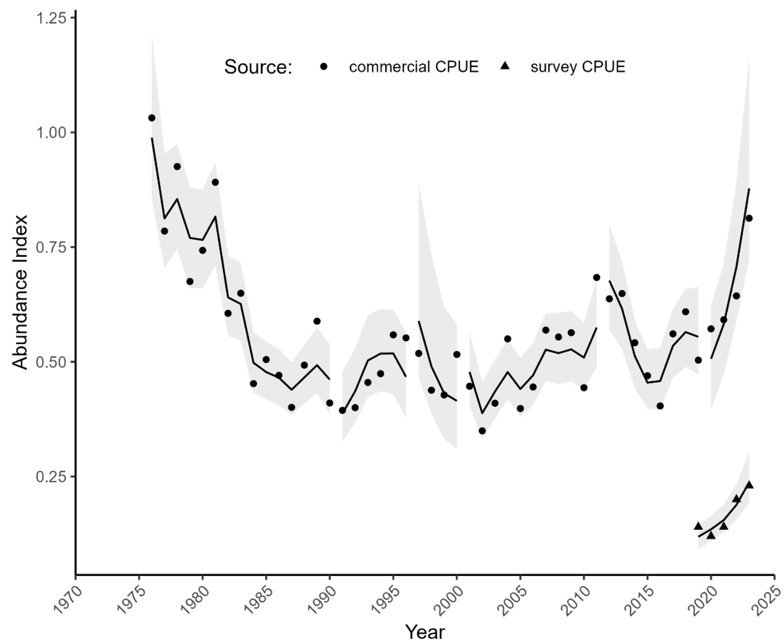



*Figure A5-b. Residuals from the log transformed observed and predicted CPUE indices from both fishery dependent and independent abundance indices.*

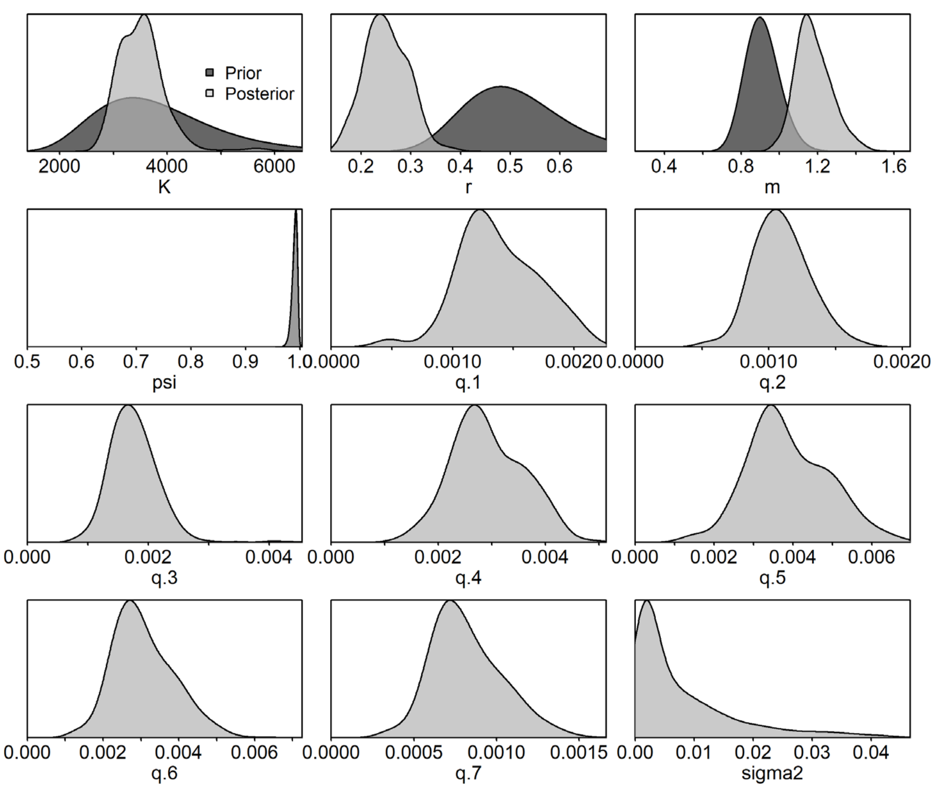



*Figure A5-c. Posterior and prior parameter distributions for carrying capacity (K), intrinsic growth rate (r) and shape (m), from the updated JABBA model fit to sea scallop from the core area of the sGSL.*

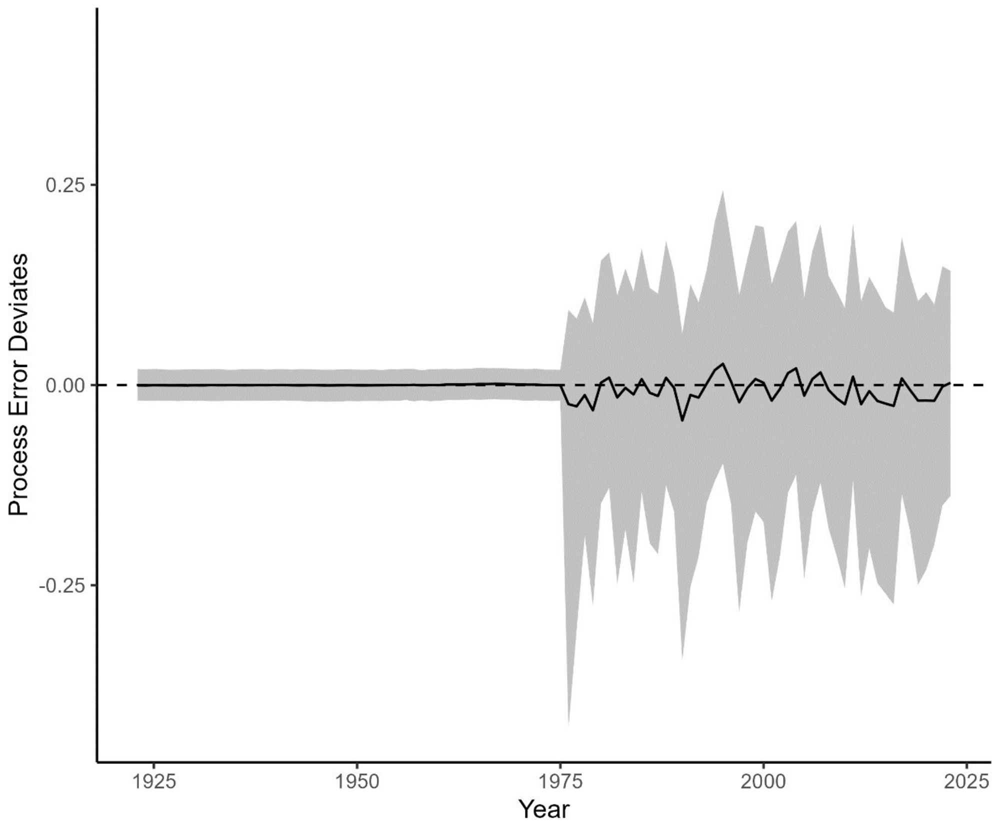



*Figure A5-d. Process error deviates for the updated JABBA model.*

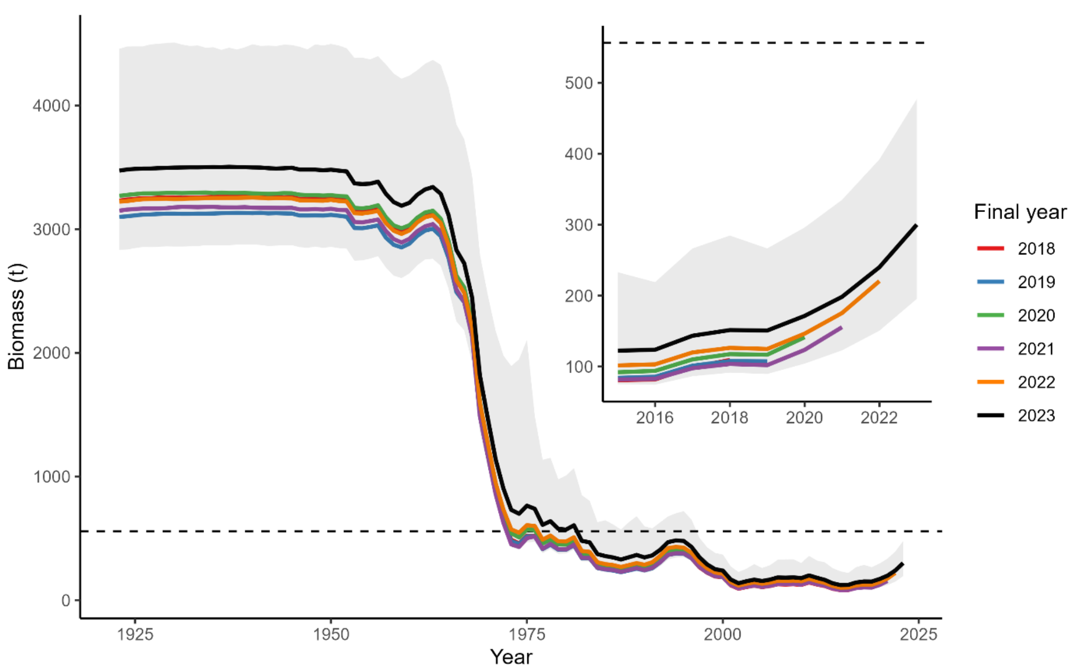



*Figure A5-e. Biomass estimates from a retrospective analysis with the updated JABBA model fit.*

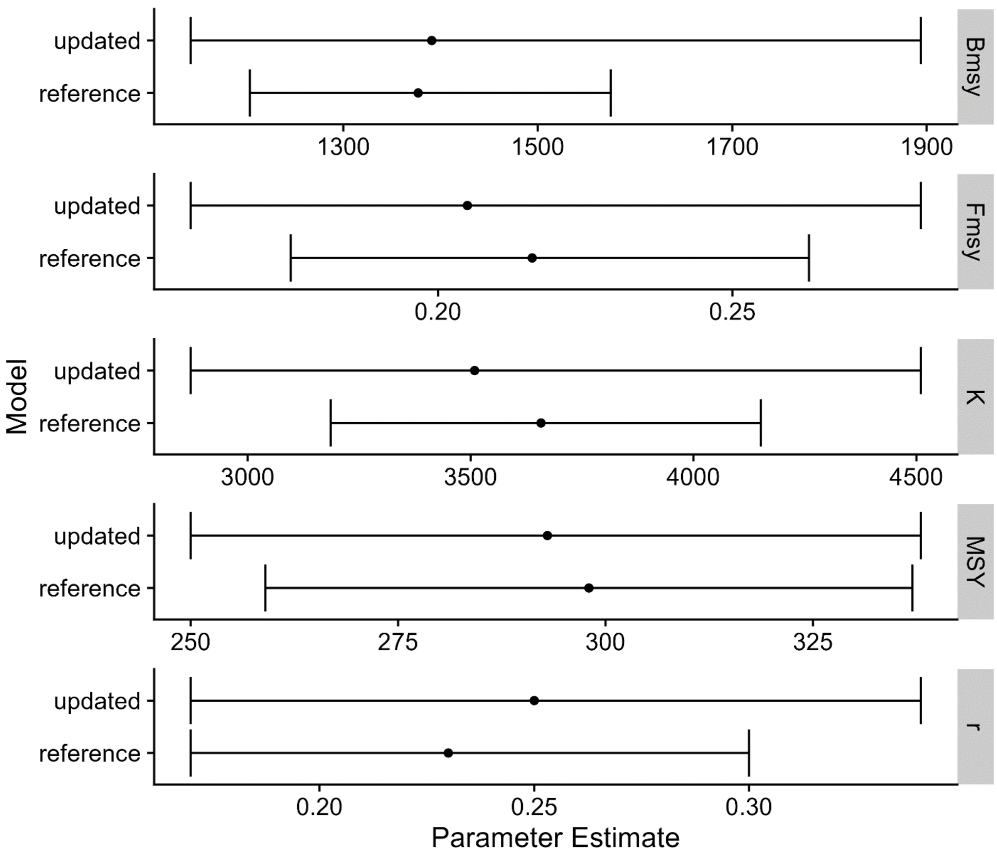



*Figure A5-f. Forest plot comparing reference and updated JABBA model parameter estimates fit to sea scallops data from the core area of the sGSL. Parameter estimates are displayed with their 95% confidence intervals.*

## A.6. APPENDIX

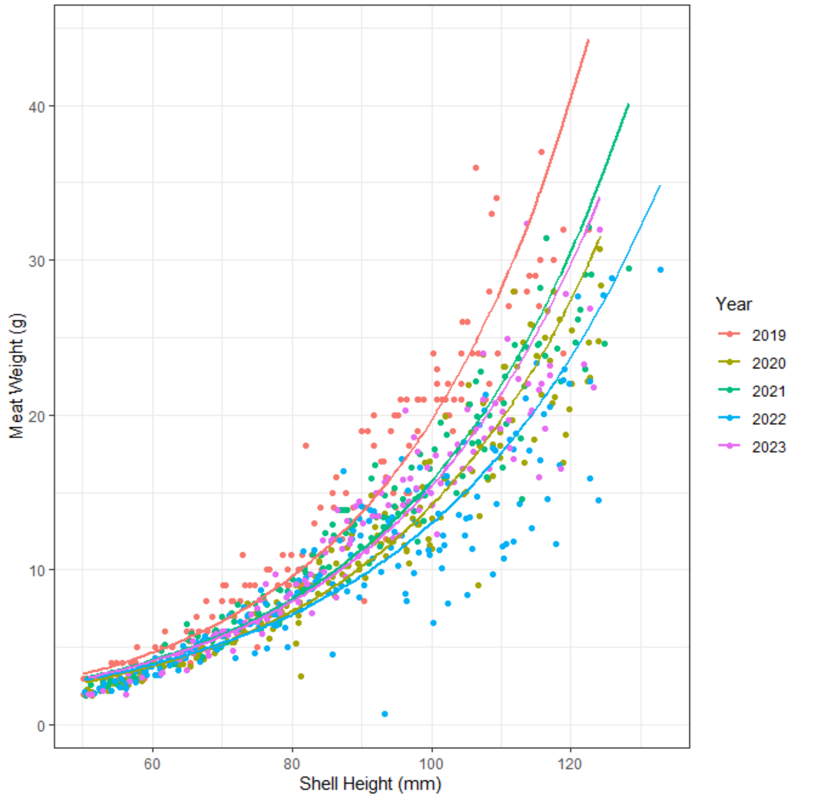



*Figure A6-a. Meat weight shell height relationships from 2019 to 2023 for the West Point bed from the October research surveys.*

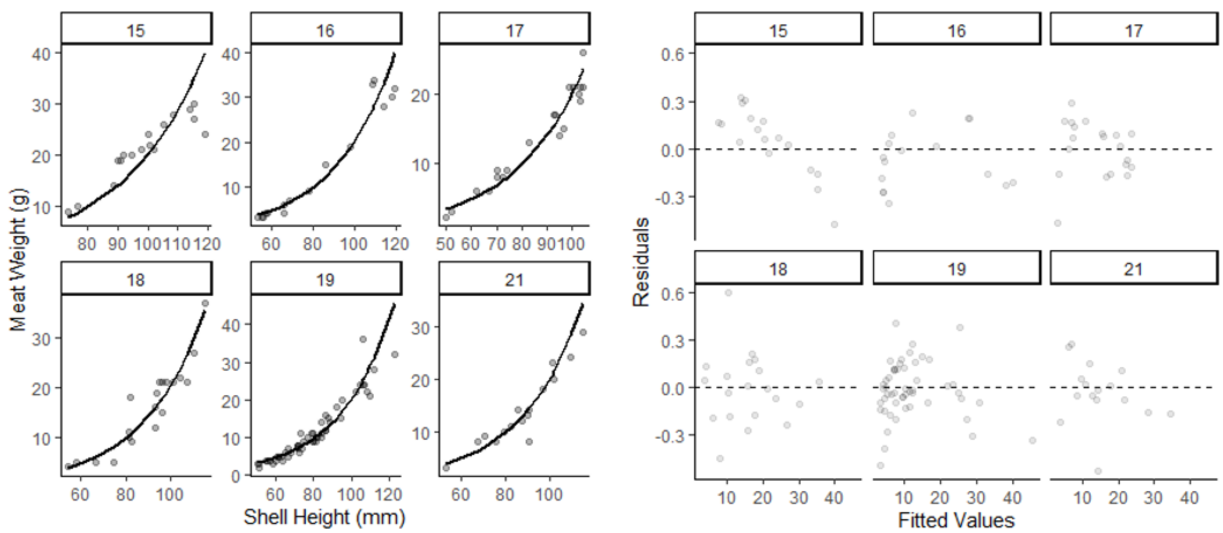



*Figure A6-b. GLMM fit and residual diagnostic plots by tow for the 2019 West Point bed data from the October research survey.*

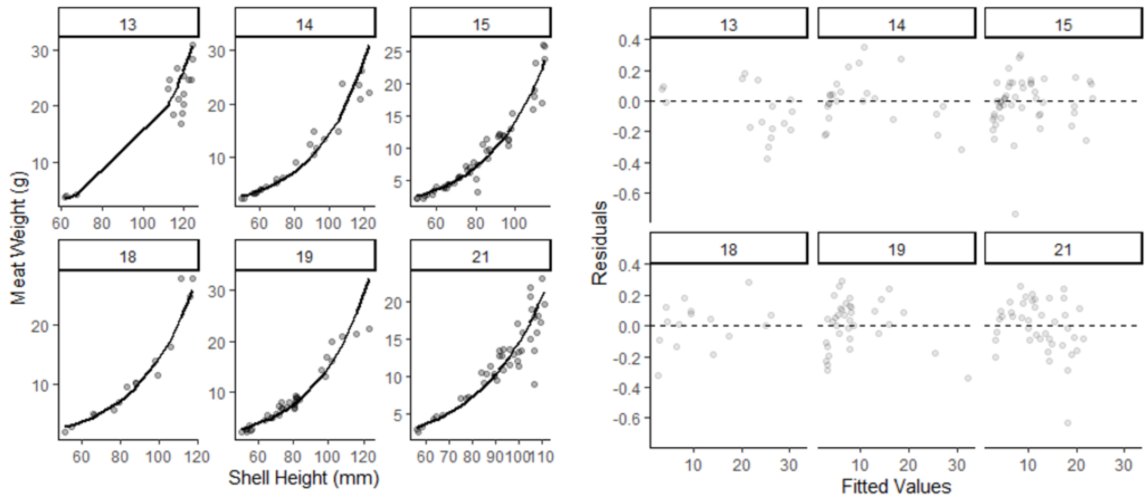



*Figure A6-c. GLMM fit and residual diagnostic plots by tow for the 2020 West Point bed data from the October research survey.*

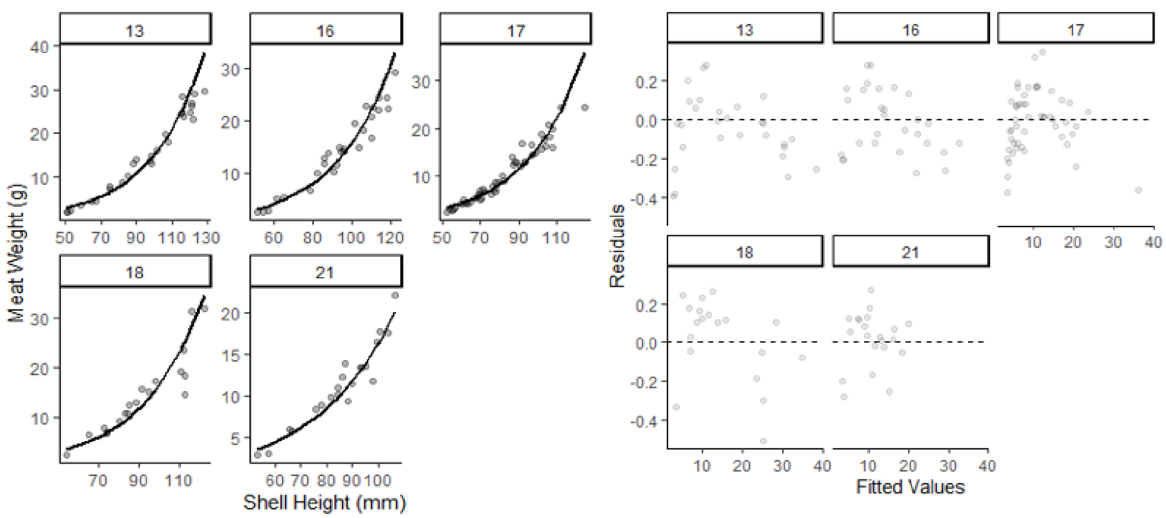



*Figure A6-d. GLMM fit and residual diagnostic plots by tow for the 2021 West Point bed data from the October research survey.*

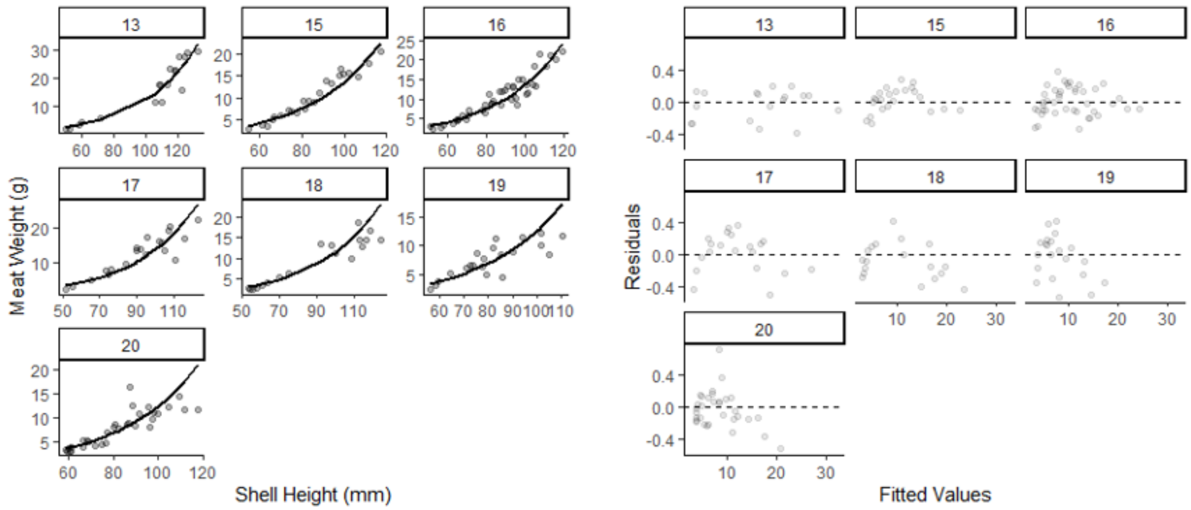



*Figure A6-e. GLMM fit and residual diagnostic plots by tow for the 2022 West Point bed data from the October research survey.*

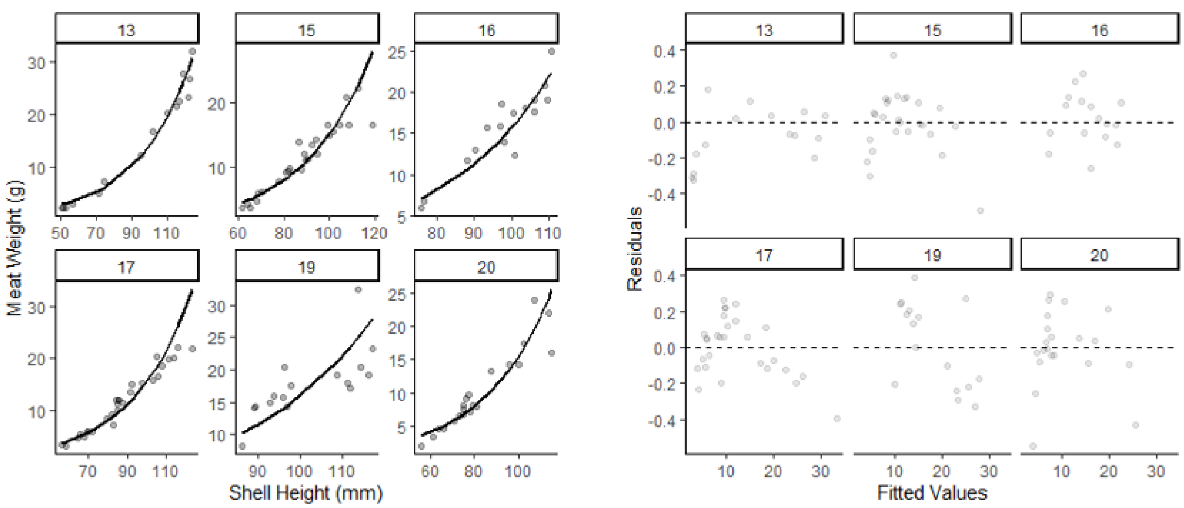



*Figure A6-f. GLMM fit and residual diagnostic plots by tow for the 2023 West Point bed data from the October research survey.*

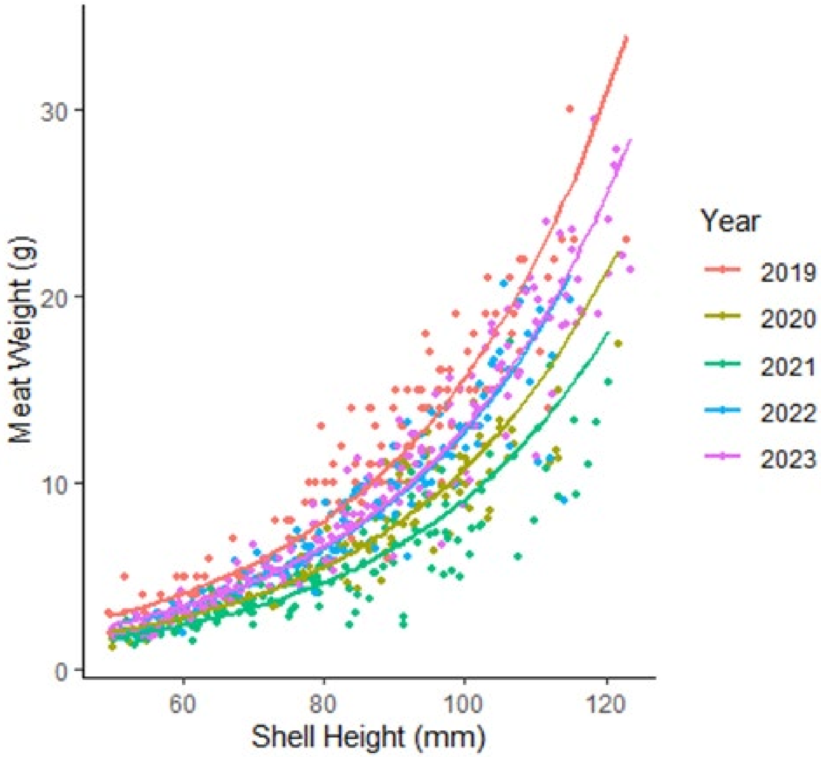



*Figure A6-g. Meat weight shell height relationships from 2019 to 2023 for the Cape Tormentine bed from the October research surveys.*

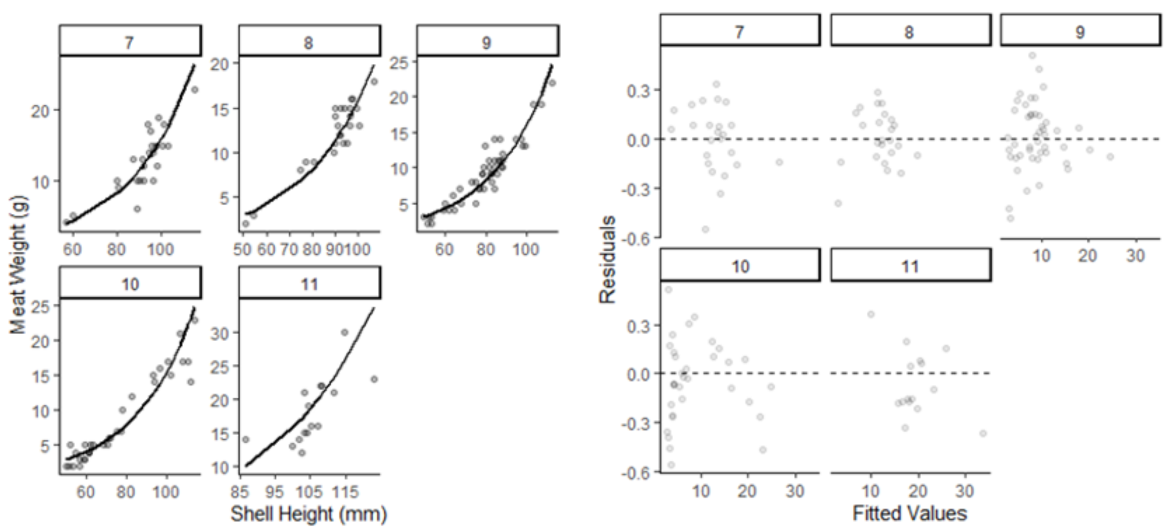



*Figure A6-h. GLMM fit and residual diagnostic plots by tow for the 2019 Cape Tormentine bed data from the October research survey.*

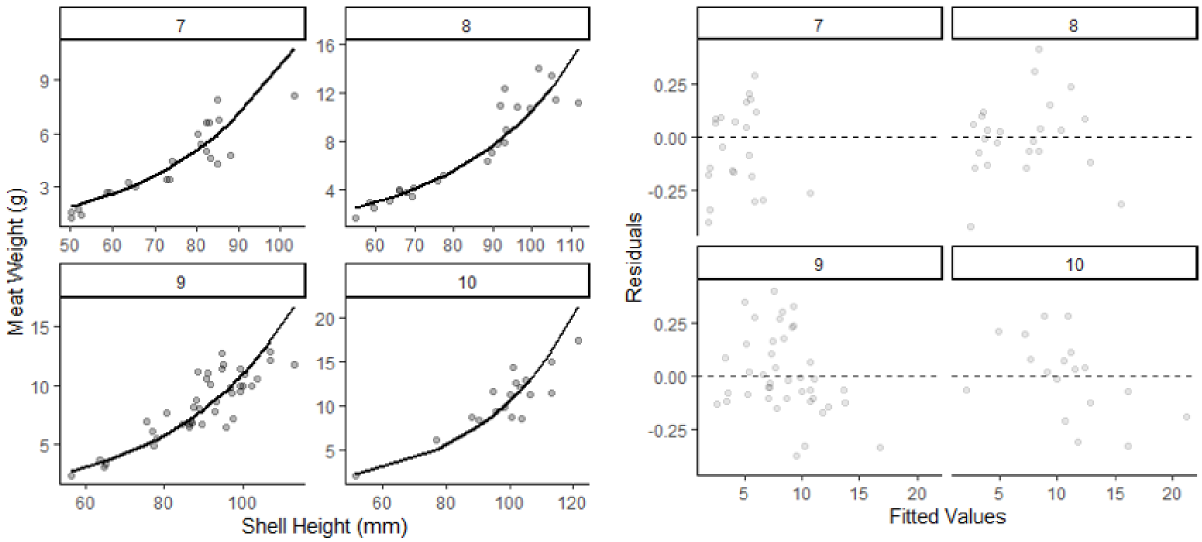



*Figure A6-i. GLMM fit and residual diagnostic plots by tow for the 2020 Cape Tormentine bed data from the October research survey.*

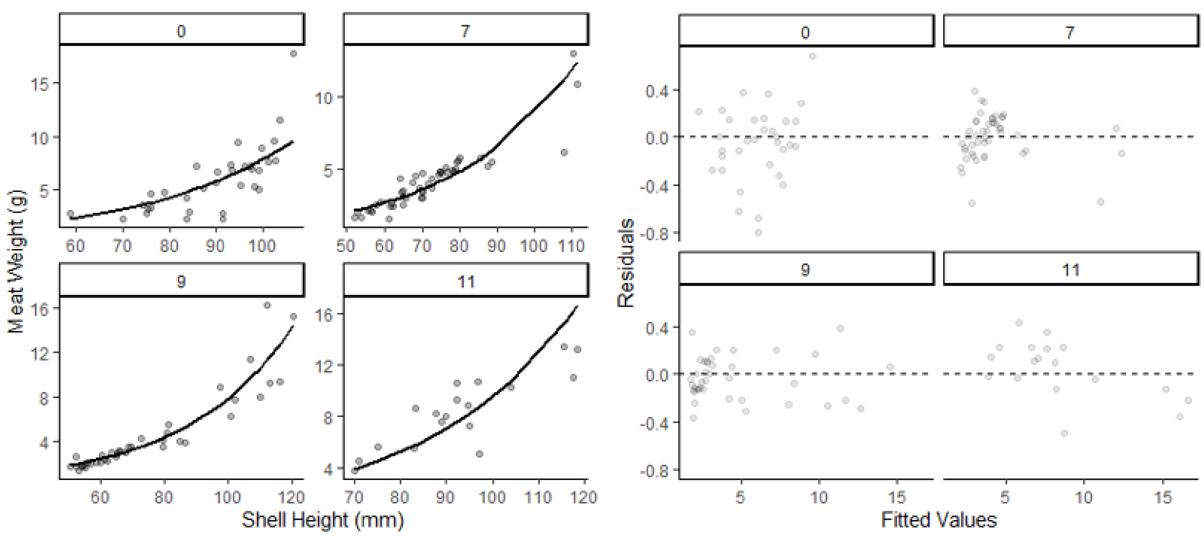



*Figure A6-j. GLMM fit and residual diagnostic plots by tow for the 2021 Cape Tormentine bed data from the October research survey.*

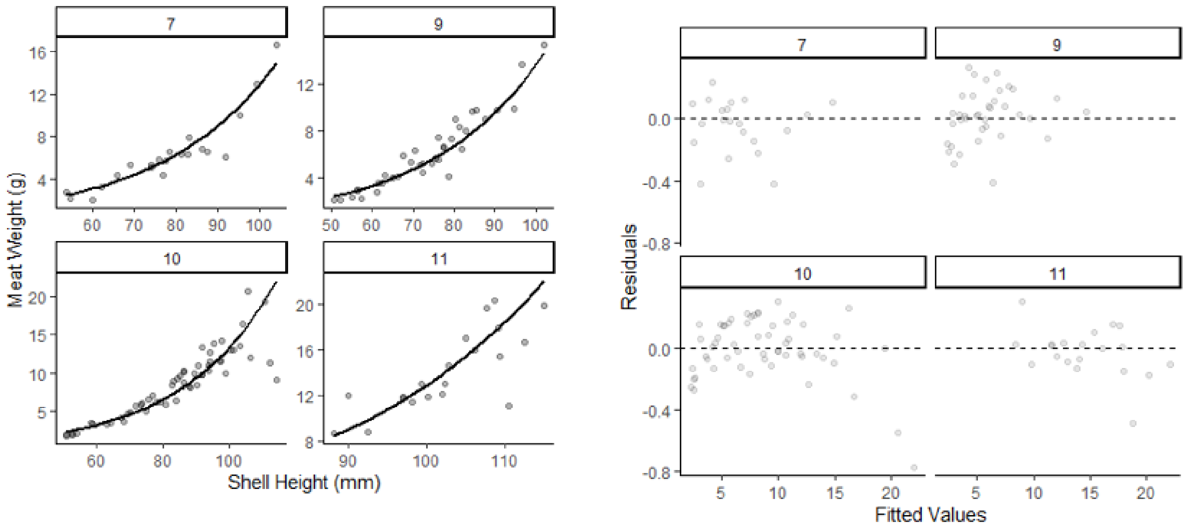



*Figure A6-k. GLMM fit and residual diagnostic plots by tow for the 2022 Cape Tormentine bed data from the October research survey.*

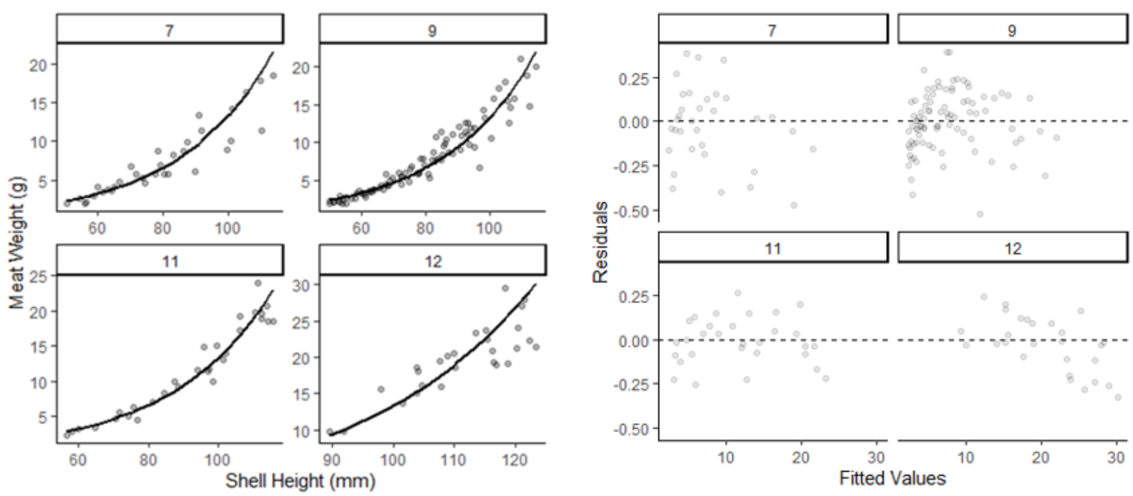



*Figure A6-l. GLMM fit and residual diagnostic plots by tow for the 2023 Cape Tormentine bed data from the October research survey.*

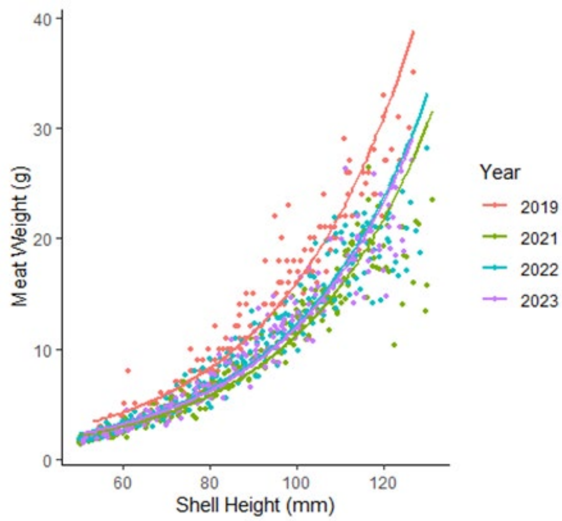



*Figure A6-m. Meat weight shell height relationships from 2019 to 2023 for the Pictou bed data from the October research surveys.*

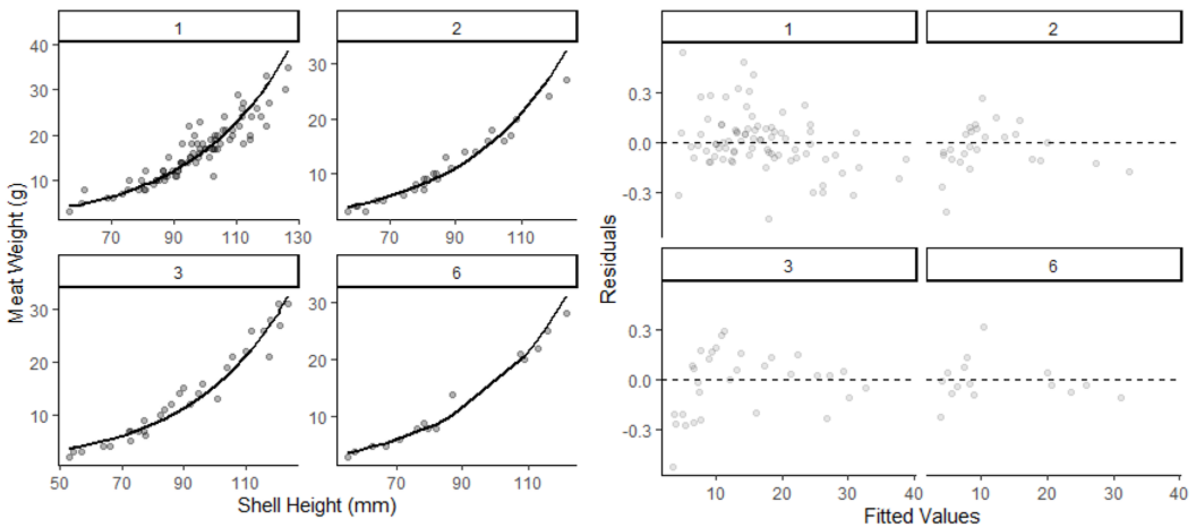



*Figure A6-n. GLMM fit and residual diagnostic plots by tow for the 2019 Pictou bed data from the October research survey.*

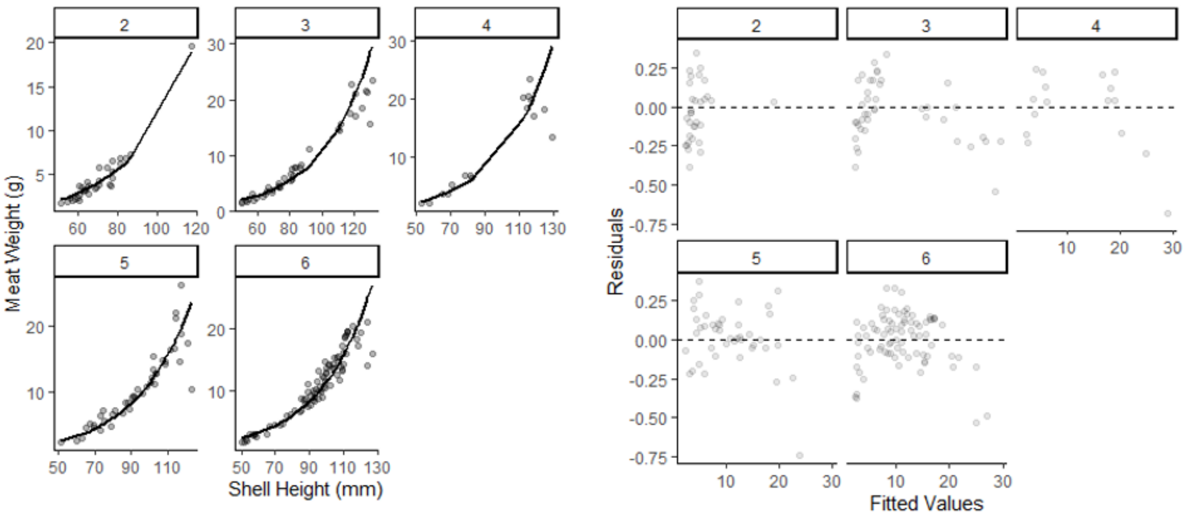



*Figure A6-o. GLMM fit and residual diagnostic plots by tow for the 2021 Pictou bed data from the October research survey.*

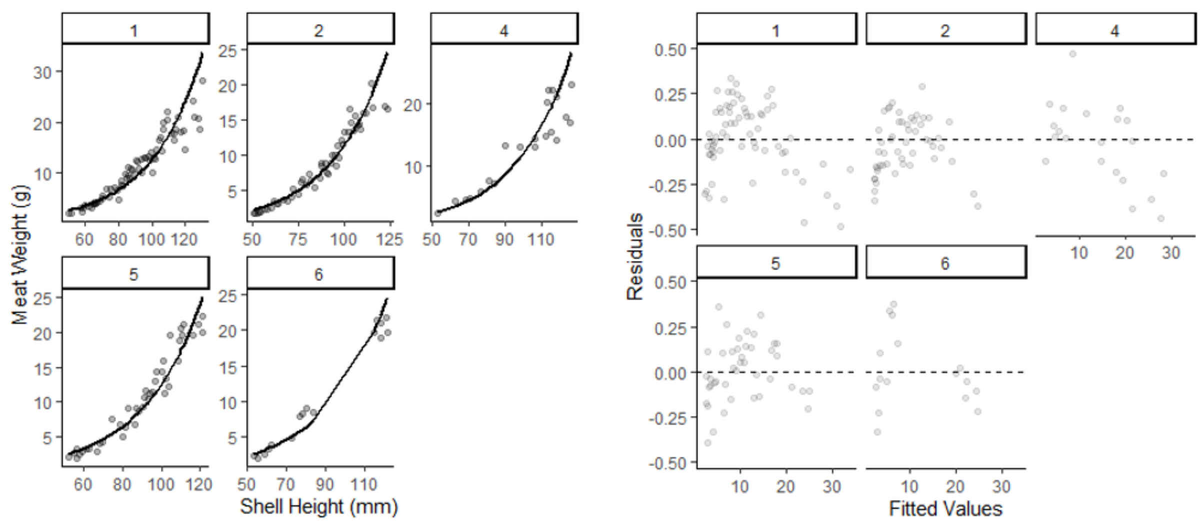



*Figure A6-p. GLMM fit and residual diagnostic plots by tow for the 2022 Pictou bed data from the October research survey.*

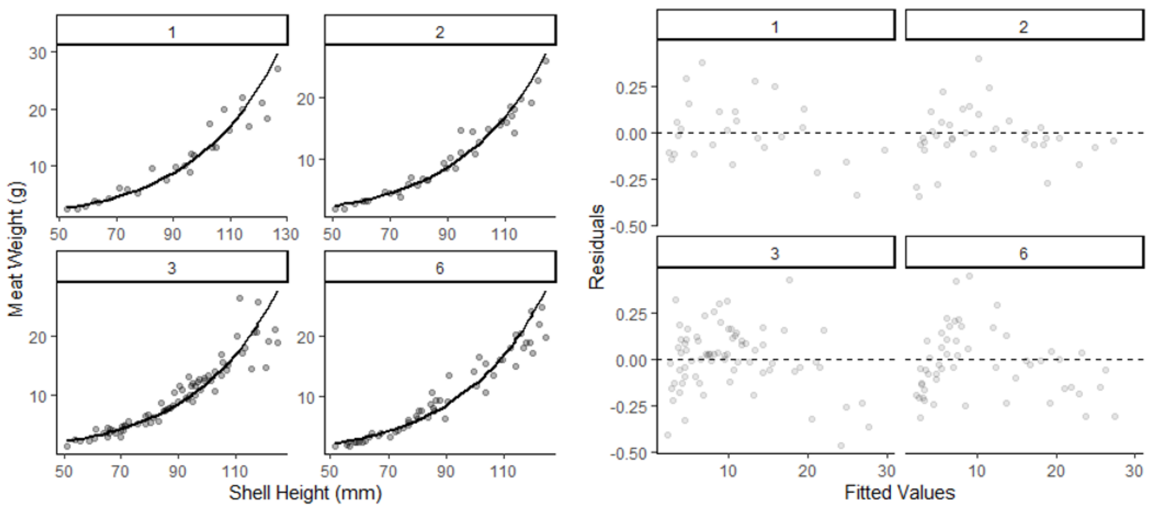



*Figure A6-q. GLMM fit and residual diagnostic plots by tow for the 2023 Pictou bed data from the October research survey.*

## A.7. APPENDIX

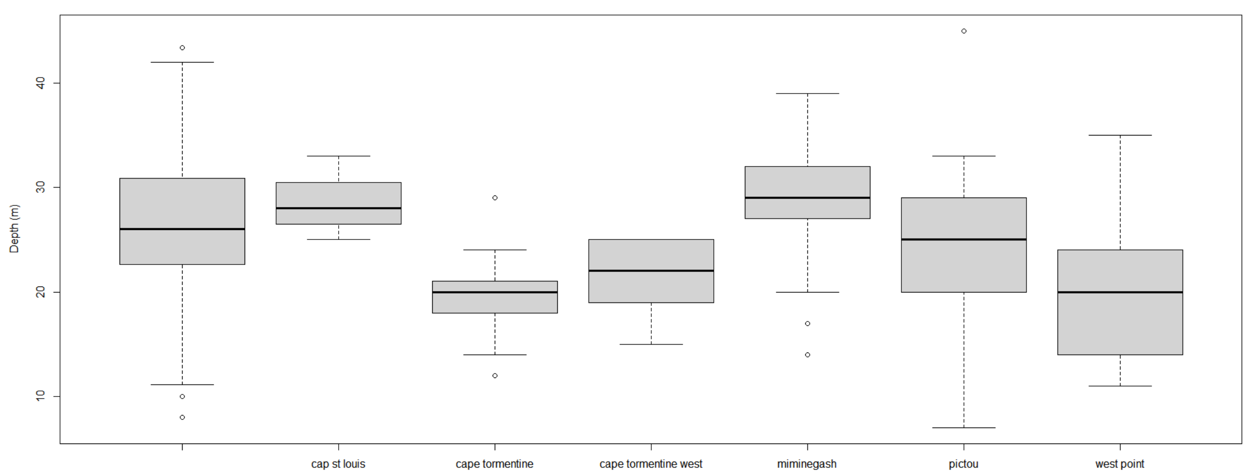



*Figure A7. Boxplot of water depth in meters of survey tows with scallop catch on each bed (Cap St. Louis, Cape Tormentine, Cape Tormentine west, Miminegash, Pictou and West Point; other) over the survey time series (2012 to 2016), in the southern Gulf of St. Lawrence.*

## A.8. APPENDIX

*Table A8-a. Stratum statistics for the Northumberland scallop surveys conducted in October and in April (year denoted by the letter a) from 2019 to 2023. Stratum (h) name, number of samples ($n_h$), proportion of samples in stratum (Wh), mean and variance of scallop meat weight (g) of scallop ≥ 80 mm per standard tow (657 $m^2$), $\bar{y}_h$ and $s_h$ respectively.*

| Year | Stratum (*h*) | $n_h$ | $W_h$ | $\bar{y}_h$ | $s_h$ | *Biomass estimate (t) for stratum* |
|---|---|---|---|---|---|---|
| 2019 | 1 | 30 | 0.25752 | 161.65 | 26.36 | 33.68 |
| 2019 | 2 | 4 | 0.06391 | 137.42 | 18.66 | 7.11 |
| 2019 | 3 | 18 | 0.17293 | 129.08 | 27.06 | 18.06 |
| 2019 | 4 | 14 | 0.11842 | 74.02 | 26.83 | 7.09 |
| 2019 | 5 | 13 | 0.14662 | 171.81 | 20.7 | 20.38 |
| 2019 | 6 | 20 | 0.2406 | 139.96 | 30.53 | 27.25 |
| 2020 | 1 | 27 | 0.4202 | 189.57 | 33.13 | 39.50 |
| 2020 | 2 | 12 | 0.1043 | 58.71 | 20.93 | 3.04 |
| 2020 | 3 | 19 | 0.2822 | 102.5 | 24.11 | 14.34 |
| 2020 | 4 | 12 | 0.1933 | 49.67 | 28.57 | 4.76 |
| 2021 | 1 | 55 | 0.25752 | 154.06 | 23.45 | 32.10 |
| 2021 | 2 | 17 | 0.06391 | 41.97 | 12.75 | 2.17 |
| 2021 | 3 | 42 | 0.17293 | 166.4 | 23.59 | 23.28 |
| 2021 | 4 | 19 | 0.11842 | 118.3 | 47.77 | 11.33 |
| 2021 | 5 | 32 | 0.14662 | 185.24 | 18.42 | 21.97 |
| 2021 | 6 | 51 | 0.2406 | 133.62 | 17.96 | 26.01 |
| 2022a | 1 | 31 | 0.4202 | 564 | 97.82 | 117.51 |
| 2022a | 2 | 2 | 0.1043 | 269.5 | 168.95 | 13.94 |
| 2022a | 3 | 30 | 0.2822 | 439.4 | 80.98 | 61.48 |
| 2022a | 4 | 14 | 0.1933 | 405 | 129.26 | 38.80 |
| 2022 | 1 | 43 | 0.25752 | 141.8 | 19.91 | 29.54 |

| Year | Stratum ($h$) | $n_h$ | $W_h$ | $\bar{y}_h$ | $s_h$ | *Biomass estimate (t) for stratum* |
|---|---|---|---|---|---|---|
| 2022 | 2 | 10 | 0.06391 | 43.03 | 12.45 | 2.23 |
| 2022 | 3 | 29 | 0.17293 | 253.61 | 52.5 | 35.48 |
| 2022 | 4 | 17 | 0.11842 | 112.29 | 40.82 | 10.76 |
| 2022 | 5 | 20 | 0.14662 | 309.5 | 34.19 | 36.71 |
| 2022 | 6 | 31 | 0.2406 | 240.43 | 33.51 | 46.80 |
| 2023a | 1 | 45 | 0.4202 | 271.5 | 38.76 | 56.57 |
| 2023a | 2 | 8 | 0.1043 | 120.6 | 52.14 | 6.24 |
| 2023a | 3 | 31 | 0.2822 | 708.4 | 203.33 | 99.12 |
| 2023a | 4 | 16 | 0.1933 | 547.9 | 225.32 | 52.50 |
| 2023 | 1 | 46 | 0.25752 | 178.64 | 30.35 | 37.22 |
| 2023 | 2 | 8 | 0.06391 | 37.92 | 18.4 | 1.96 |
| 2023 | 3 | 30 | 0.17293 | 309.25 | 60.4 | 43.27 |
| 2023 | 4 | 17 | 0.11842 | 262.01 | 92.27 | 25.10 |
| 2023 | 5 | 16 | 0.14662 | 305.78 | 41.29 | 36.27 |
| 2023 | 6 | 34 | 0.2406 | 212.91 | 27.28 | 41.45 |

*Table A8-b. Survey results for mean (se) and 95% confidence intervals (CI) for scallop meat weight (g) of scallop ≥ 80 mm per standard tow (657 $m^2$) caught from the 2019 to 2023 October scallop survey and from the 2022a and 2023a April surveys, area surveyed, and the resulting exploitable biomass estimates, the biomass estimate before the fishery ($B_0$) of the three beds, landings ratio (surveyed area:core) and prorated exploitable biomass estimate ($B_0$) for the core area of the Gulf Region (SFA 22 and SFA 24). Note that Pictou bed was not surveyed in 2020 nor in the April (a) surveys, therefore the missing Pictou biomass was estimated from the mean biomass (29 t) of the time series. For the April surveys (a) ctr means biomass controlled for condition.*

| Year | *Survey mean* | *Survey se* | 95% CI lower | 95% CI upper | *Survey area ($km^2$)* | *Biomass estimate (t) for whole survey area* | *$B_0$ (t) for whole survey area , before the fishery* | *Landings ratio* | *Prorated $B_0$ (t) to core area* |
|---|---|---|---|---|---|---|---|---|---|
| 2019 | 140.36 | 11.944 | 116.57 | 164.15 | 454 | 114 | 145 | 0.58 | 251 |
| 2020 | 124.32 | 16.593 | 90.914 | 157.718 | 326 | 62 | 124 | 0.61 | 253 |
| 2021 | 144.45 | 10.568 | 123.5 | 165.4 | 454 | 117 | 149 | 0.60 | 250 |
| 2022 | 199.65 | 14.927 | 170.1 | 229.2 | 454 | 162 | 194 | 0.66 | 295 |
| 2023 | 228.99 | 19.251 | 190.75 | 267.24 | 454 | 185 | 228 | 0.58 | 390 |
| 2022a-ctr | 414.46 | 49.754 | 314.79 | 514.14 | 326 | 205 | 243 | 0.66 | 414 |
| 2023a-ctr | 303.3 | 49.988 | 202.99 | 403.61 | 326 | 150 | 192 | 0.58 | 380 |
| 2022a | 467.39 | 56.09 | 354.3 | 580.5 | 326 | 232 | 261 | 0.66 | 442 |
| 2023a | 432.48 | 74.043 | 283.8 | 581.2 | 326 | 214 | 243 | 0.58 | 467 |

*Table A8-c. Survey results for mean (standard error) and 95% confidence intervals (CI) number of scallops ≥ 80 mm per standard tow (657 m²) caught from the 2019 to 2023 October scallop survey and from the 2022 and 2023 April surveys, the area surveyed and the estimate number of scallop for whole surveyed area and prorated numbers for the core area of the Gulf Region (SFA 22 and SFA 24). Note that Pictou bed was not surveyed in 2020 nor in the April (a) surveys, therefore the missing Pictou biomass was estimated from the mean numbers (5 M) of the time series.*

| Year | *Survey mean* | *Survey se* | 95% CI lower | 95% CI upper | *Survey area (km²)* | *Number of scallop (Millions) for whole survey area* | *Prorated number of commercial core area (M)* |
|---|---|---|---|---|---|---|---|
| 2019 | 8.21 | 0.709 | 6.79 | 9.6 | 454 | 6.64 | 11.46 |
| 2020 | 9.93 | 1.410 | 7.11 | 12.8 | 326 | 4.92 | 15.91 |
| 2021 | 13.76 | 1.207 | 11.3 | 16.2 | 454 | 11.13 | 18.65 |
| 2022 | 16.46 | 1.335 | 13.8 | 19.1 | 454 | 13.32 | 20.30 |
| 2023 | 17.17 | 1.577 | 14.0 | 20.3 | 454 | 13.89 | 23.83 |
| 2022a | 36.76 | 4.774 | 27.2 | 46.3 | 326 | 18.22 | 34.94 |
| 2023a | 22.93 | 4.171 | 14.6 | 31.3 | 326 | 11.37 | 27.57 |

*Table A8-d. Survey results for mean (standard error) and 95% confidence intervals (CI) number of recruit scallop (65−79 mm) per standard tow (657 m²) caught from the 2019 to 2023 October scallop survey and from the 2022 and 2023 April surveys, the area surveyed and the estimate number of scallop for whole surveyed area and prorated numbers for the core area of the Gulf Region (SFA 22 and SFA 24). Note that Pictou bed was not surveyed in 2020 nor in the April (a) surveys, therefore the missing Pictou biomass was estimated from the mean numbers (0.12 M) of the time series.*

| Year | *Survey mean* | *Survey se* | 95% CI lower | 95% CI upper | *Number of scallop (Millions) for whole survey area* | *Prorated number of scallops for core area (M)* |
|---|---|---|---|---|---|---|
| 2019 | 0.24 | 0.071 | 0.1 | 0.4 | 0.19 | 0.33 |
| 2020 | 0.59 | 0.270 | 0.0 | 1.1 | 0.29 | 0.68 |
| 2021 | 1.43 | 0.347 | 0.7 | 2.1 | 1.16 | 1.94 |
| 2022 | 0.54 | 0.157 | 0.2 | 0.9 | 0.44 | 0.67 |
| 2023 | 0.66 | 0.136 | 0.4 | 0.9 | 0.53 | 0.91 |
| 2022a | 3.08 | 1.018 | 1.0 | 5.1 | 1.53 | 2.51 |
| 2023a | 0.32 | 0.097 | 0.1 | 0.5 | 0.16 | 0.47 |