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Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2021

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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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GLOSSARY

AD: Assessment Division.

CIL: Cold Intermediate Layer. A body of <0°C water that sits intermediate in the water column and covers shallow areas of the Newfoundland and Labrador (NL) Shelf. It represents a proxy for thermal crab habitat.

CMA: Crab Management Area.

CPS Survey: Collaborative (Industry-DFO) Post-season Trap Survey.

CPUE: Catch per unit of effort.

CW: Carapace width (mm).

DFO: Fisheries and Oceans Canada.

DMP: Dockside Monitoring Program. Provides independent third party verification of landings.

EBI: Exploitable biomass index.

ERI: Exploitation rate index. Landings of the current year divided by the exploitable biomass index of the most recent survey.

Exploitable biomass: Biomass of ≥95 mm carapace width male Snow Crab.

HCR: Harvest Control Rules. Pre-agreed harvest rates and management actions required in each zone or steps within a zone of the Precautionary Approach Framework.

Intermediate-shelled: Molted over one year ago. Carapace lightly fouled and meat content high.

Legal-size: ≥95 mm carapace width male Snow Crab.

Multiparous female: A mature female that has spawned multiple times.

NAFO: Northwest Atlantic Fisheries Organization (Divisions).

NAO: North Atlantic Oscillation. A broad-scale climate forcing defined as sea level atmospheric pressure differences between two dominant east-west centers in the North Atlantic.

New-shelled: Molted within the past year. Carapace becoming rigid and still generally clean. Low meat content.

Ogmap: Ogive mapping assessment approach. A spatial expansion method for survey catch rate data used to estimate biomass or abundance.

Old-shelled: Molted two or more years ago. Carapace moderately to heavily fouled and meat content high.

Ontogenetic movements: Net-movements undertaken over the course of life, generally from shallow to deep areas prior to terminal molt.

Precautionary Approach (PA): In fisheries management, being cautious when scientific knowledge is uncertain, and not using the absence of adequate scientific information as a reason to postpone action or failure to take action to avoid serious harm to fish stocks or their ecosystem.

Pre-recruit male: Male crab with 65–94 mm carapace width that is adolescent (not terminally molted) and is expected to contribute to the exploitable biomass after another 1–2 molts.

Pre-recruit abundance: Abundance of 65–95 mm carapace width adolescent males expected to contribute to the exploitable biomass and fishery over the next 2–4 years.

Primiparous female: First-time mating spawning female Snow Crab.

Recruit: A new-shelled exploitable male Snow Crab (first year in exploitable biomass).

Residual biomass: Intermediate- and old-shelled male Snow Crab in the exploitable biomass.

Seasonal migration: A migration undertaken during spring, generally from deep to shallow areas, for either mating or molting.

Size-at-maturity: The carapace width at which a crab undergoes terminal molt into morphometric maturity (adulthood).

Skip-molter: A crab that does not undergo a molt in a given year. Identified as an intermediate- or old-shelled adolescent male or pre-pubescent female.

Soft-shelled: Recently molted with a carapace that is very pliable. Shell filled with water and virtually no meat content.

Stratum: A unit of ocean bottom defined by depth used as the basis for survey design and spatial expansion of catch rates in biomass estimation.

TAC: Total allowable catch (quota).

Terminally-molted: A crab having undertaken its final molt as indicated by enlarged claws for males or enlarged ovaries for females.

URR: Upper Removal Reference. The maximum acceptable removal rate for the stock in the Precautionary Approach Framework.

USR: Upper Stock Reference Point. Marks the boundary between the healthy and cautious zones in the Precautionary Approach Framework.

Very-old-shelled: Molted several years (i.e., ≥4 years) ago. Carapace heavily fouled and turning black.

VMS: Vessel monitoring system.

ABSTRACT

The status of the Snow Crab (*Chionoecetes opilio*) resource surrounding Newfoundland and Labrador (NL) in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2HJ3KLNOP4R is assessed at the Assessment Division (AD) level using a variety of metrics. Data from multispecies bottom trawl surveys, inshore and offshore trap surveys, harvester logbooks, at-sea observers, the Dockside Monitoring Program (DMP), as well as oceanographic surveys are used to inform trends in biomass, recruitment, production, and mortality over the time series. There was no spring or fall multispecies trawl survey in AD 3LNO Offshore in 2021 and there was reduced coverage in the fall trawl survey in ADs 2HJ and 3K. Analyses were undertaken to investigate the impact of reduced coverage in 2HJ3K, and comparative modelling was conducted to investigate exploitable biomass estimates for AD 3LNO Offshore in the absence of trawl survey data. Snow Crab landings declined to a 25-year low of 26,400 tonnes (t) in 2019, but have increased since to around 38,000 t in 2021, while effort increased slightly to near 3 million trap hauls. Overall fishery catch per unit effort (CPUE) was at a time-series low in 2018 but has greatly increased since then and was above the time-series average level in 2021. The overall exploitable biomass has increased in both trawl and trap surveys during the past four years from historic lows. However, this increase has not been seen in AD 2HJ. Total mortality in exploitable crab has decreased in all ADs in recent years. It remains highest in AD 2HJ. There is no updated total mortality estimate for AD 3LNO Offshore in 2021. Exploitation rate indices (ERI) were near time-series lows in all ADs in 2021, except AD 2HJ. With status quo removals in 2022, ERI is expected to decrease or remain low in all ADs, except 2HJ, where it would be over 60%. Elements of the Precautionary Approach (PA) Framework presented at the time of this assessment were tentative. Limit Reference Points (LRPs) have been established by a peer-reviewed Science process, but Upper Stock References (USRs) and Harvest Control Rules (HCRs) remained under development at the time of the assessment. In 2022, with status-quo removals, all ADs are projected to be in the healthy zone of the provisional PA Framework, except AD 2HJ, which is projected to be in the cautious zone. Pre-recruit abundance indices suggest favourable prospects for recruitment into the exploitable biomass over the next two to four years, however multiple streams of evidence suggest further improvements may be limited. A sharp decline in male size-at-maturity (i.e., terminal molt size) occurred in most ADs in recent years, and persisted in AD 2HJ in 2021, which could dampen short-term prospects for recruitment into the Snow Crab exploitable biomass.

INTRODUCTION

This document assesses the status of the Snow Crab (*Chionoecetes opilio*) resource surrounding Newfoundland and Labrador (NL) in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2HJ3KLNOP4R (Figure 1, Figure 2). The information presented follows from a formal scientific assessment and regional peer-review process conducted in February 2022 that focused on identifying changes in the exploitable biomass of Snow Crab available to the fishery.

SPECIES BIOLOGY

Snow Crab are sexually dimorphic, with males normally achieving larger sizes than females. The Snow Crab life cycle features a spring hatching followed by a planktonic larval period that involves several stages before settlement. Small benthic stages of both sexes molt multiple times annually, but molt frequency slows as crab grow (Comeau et al. 1998). Females cease molting during their ninth or tenth molt at the same time sexual maturity is achieved at approximately 40–75 mm carapace width (CW) (Alunno-Bruscia and Sainte-Marie 1998). Males enter puberty at their eighth or ninth molt and during this sexually mature adolescent stage will generally continue to molt near-annually until their terminal molt, when they develop enlarged claws (becoming adults) that likely enhance their competitive ability in mating dynamics. Males can molt to adulthood at any size greater than approximately 40 mm CW, but terminal molt typically occurs after 10 to 13 molts over a size range spanning about 55–135 mm CW (Sainte-Marie et al. 1995).

The minimum legal size in the NL Snow Crab fishery is 95 mm CW and therefore females are excluded from the fishery and a portion of adult males remain available for reproduction. Age is not determined, but Snow Crab are believed to recruit to the fishery at 8–10 years of age in warm areas (i.e., Divs. 2J3K4R) and at slightly older ages in cold areas (i.e., Divs. 3LNO and Subdivision [Subdiv.] 3Ps), reflecting less frequent molts (skip-molting) at low temperatures (Dawe et al. 2012). However, population density also affects molt frequency with more frequent molting (lower incidence of terminal molt at small size) under high-density conditions, at least in males (Mullowney and Baker 2021). Adult legal-sized males remain soft- or new-shelled with less than full meat yield for almost a year following their terminal molt. Crab are commonly believed to be more susceptible to handling mortality when in this soft-shell condition. Following their terminal molt, they are not likely to efficiently contribute to the fishery (i.e., render maximum meat yield) until the following year when their shells are fully hardened and full of meat. Males may live a maximum of six to eight years as adults after the terminal molt (Fonseca et al. 2008).

Snow Crab typically inhabit a narrow range of temperatures, and variation in temperature has a profound effect on production, early survival, and subsequent recruitment to fisheries (Foyle et al. 1989; Dawe et al. 2008; Marcello et al. 2012). Cold conditions during early- to mid-ontogeny are associated with increased survey biomass and fishery CPUE indices several years later (Marcello et al. 2012; Baker et al. 2021). While growth rates are positively affected by temperature, with overall higher molt frequency and molt increments occurring in warm regimes, the overriding positive effect of cold water on early- to mid-life stages appears stronger than the dampening effects on growth rates, with highest productivity occurring in cold areas.

Along the NL Shelf, cold and most productive conditions for Snow Crab are generally found at shallow to intermediate depths (Baker et al. 2021; Cyr et al. 2022). Historically, the most productive fisheries have been associated with intermediate-depth slope edges of offshore banks and inshore bays. Snow Crab typically undertake ontogenetic movements from shallow cold areas with hard substrates during early ontogeny to warmer deep areas featuring softer substrate as they grow (Mullowney et al. 2018a). Largest males are most commonly distributed on mud or mud/sand, while small Snow Crab are more common on harder substrates. Some Snow Crab also undertake an upslope migration in winter or spring for mating and/or molting (Mullowney et al. 2018a).

The Snow Crab diet includes fish, clams, polychaete worms, brittle stars, shrimp, Snow Crab, and other crustaceans (Squires and Dawe 2003). Predators of Snow Crab include various groundfish, seals, and other Snow Crab.

Snow Crab in NL are part of a larger genetic stock unit in Canadian Atlantic waters, ranging from southern Labrador to the Scotian Shelf (Puebla et al. 2008). However, large movements of individuals within the stock are thought to be limited, therefore assessments are conducted at the AD level whereby some NAFO Divisions (Figure 1) are separated into inshore and offshore portions were applicable and some divisions combined. Accordingly, ADs differ from both NAFO Divisions, and the small spatial scale Crab Management Areas (CMAs) used to manage the fishery. The spatial scale of the assessment approach accommodates different types and amounts of available information among ADs and better conforms with broad-scale resource status indicators than the CMAs, which have no biological basis. While the assessment does not consider processes at the CMA level, partition by CMA is of utility and interest to managers and industry and therefore some CMA-level results are included in the Appendices. Crab movements across divisional boundaries may affect survey indices resulting in uncertainties in distributions and the extent to which modes of growth progression can be followed from one year to the next. In the 2019 Snow Crab assessment, there was evidence presented of a large redistribution of exploitable crab out of AD 3K and into AD 2HJ during the previous year and back into AD 3K the following year. This situation highlights the difficulties in assessing a stock based on delineations (ADs and CMAs) that are not set based on biological criteria as much as resource management considerations. Le Corre et al. (2020) modelled downstream flow of Northern Shrimp (*Pandalus borealis*) larvae from northern source areas (including Divs. 2HJ) to southern sink areas (Divs. 3KL) in conjunction with the Labrador Current, highlighting connectivity processes in this ecosystem. With respect to Snow Crab, this may suggest a disconnect between management (CMA), assessment (AD), and biological scales.

FISHERY

The NL Snow Crab fishery began in Trinity Bay (CMA 6A) in 1967. Initially, Snow Crab were taken as gillnet by-catch, but within several years a directed trap fishery developed in inshore areas along the northeast coast of Divs. 3KL. Until the early 1980s, the fishery was prosecuted by approximately 50 vessels limited to 800 traps each. In 1981, fishing became restricted to the NAFO Division adjacent to where the license holder resided. The fishery expanded throughout all areas of the province from the 1970s to 2000s, especially following groundfish stock and fishery collapses in the early 1990s. Between 1982 and 1987, there were major declines of the Snow Crab resource in traditional fishing areas in Divs. 3K and 3L, while new fisheries started in Div. 2J, Subdiv. 3Ps, and offshore Div. 3K. A Snow Crab fishery began in Div. 4R in 1993. Management of the increasingly diverse and complex fishery during the expansion years led to progressive development and refinement of the many quota-controlled areas (CMAs), with approximately 3,500 active license holders representing various vessel-size fleet sectors participating in the fishery in the mid-2000s. Resource declines and rationalization measures have led to reduced participation during the past decade. The fishery is now prosecuted by around 2,300 license holders representing three dominant fleet sectors in 2021.

The fishery typically spans from the fringes of the Makkovik Bank off central Labrador in the north to the far offshore slope edges of the Grand Bank in Divs. 3LNO in the south, to near the border of Quebec in the westernmost portions of Div. 4R. The AD 2HJ fishery occurs in offshore regions of central and southern Labrador (Figure 1). The bathymetry of the region is characterized by a series of shallow water offshore banks separated by deep channels (Figure 2). The bottom water temperature in the two dominant fishing grounds in these channels is warmer than the surrounding shallow banks. The AD 3K fishery occurs off the northeast coast of Newfoundland predominately within a network of deep trenches located between nearshore shallow water plateaus and the Funk Island Bank in the offshore (i.e., St. Anthony Basin and Funk Island Deep) (Figure 2). Bottom temperatures are cooler in the shallow nearshore areas and the Funk Island Bank and warmer in the Funk Island Deep area. The AD 3L Inshore fishery occurs in coastal bays and near-to-shore regions within 25 nM of headlands off the east coast of Newfoundland, which are overall characterized by cold bottom water. It incorporates Bonavista Bay (CMA 5A), Trinity Bay (CMA 6A), Conception Bay (CMA 6B), Northeast (NE) Avalon (CMA 6C), Southern Avalon (CMA 8A), and St. Mary's Bay (CMA 9A) (Figure 1). The AD 3LNO Offshore fishery occurs on and surrounding the Grand Bank off Newfoundland's southeast coast (Figure 2) and is a massive, shallow, cold, and productive environment for Snow Crab. Virtually the entire AD consists of cold bottom temperatures, with the exception of the shallow Southeast Shoal and the deep edges of the Grand Bank. The AD 3Ps fishery occurs off the south coast of Newfoundland (Figure 1). Relative to other ADs along the NL continental shelves, AD 3Ps is shallow. The shallow areas of the AD, where the bulk of the fishery occurs, are cold, but temperatures increase abruptly at the slope edges. The AD 4R3Pn fishery occurs along the west and southwest coasts of Newfoundland in and adjacent to the Gulf of St. Lawrence (Figure 1). The bathymetry off the west coast is characterized by a shallow water nearshore plateau that borders the deep Esquiman Channel, while the bathymetry off the south coast is characterized by the presence of the Burgeo Bank (Figure 2). Bottom temperatures in this AD are the warmest along the NL shelf.

In the late 1980s, quota control was initiated in all CMAs of each NAFO Division. Current management measures include trap limits, individual quotas, spatial and temporal closures within divisions, and differing seasons. Annual management decisions are formed following a consultation and recommendation process with harvester groups and other industry stakeholders. Mandatory use of the electronic vessel monitoring system (VMS) was fully implemented in mid-shore and offshore fleet sectors in 2004 to ensure compliance with regulations regarding area fished. The fishery is prosecuted using conical baited traps set in long-lines ('fleets'), typically with a trap spacing of approximately 45 m. The minimum legal mesh size is 135 mm to allow small crab to escape. Undersized and soft-shelled crab that are captured in traps are returned to the sea and an unknown proportion of those die.

The fishery was traditionally prosecuted during summer and fall, but has become earlier during the past decade and is now primarily prosecuted during spring and summer. The fishery can be delayed in northern NAFO Divisions (Divs. 2HJ3K) due to ice conditions or fleet preferences in some years. The fishery can also be delayed (or extended) for other reasons such as price disputes or difficulties in capturing quotas. Late fishing seasons are often associated with a high incidence of soft-shelled immediate pre-recruits in the catch, particularly under high fisheries exploitation rates (Mullowney et al. 2021). A soft-shell protocol for at-sea observers was initiated in 2004 to protect soft-shelled immediate pre-recruits from handling mortality by closing localized areas (70 nM^2 grids in the offshore and 18 nM^2 grids in inshore areas of ADs 3L Inshore, 3K, 3Ps, and 4R3Pn) for the remainder of the season when a threshold level of 20% of the legal-sized catch is reached. That threshold has since been reduced to 15% in ADs 3LNO Offshore and 3L Inshore and grids have been partitioned into quarters in some inshore areas in recent years. It became evident during 2010–12 that this protocol, as implemented, is not effective in controlling handling mortality. Among other issues, this reflects very low observer coverage to monitor thousands of grid cells. Approximately <0.1–0.2% of the catch has been sampled in recent years. Beyond coverage capacity, there has been failure to invoke the protocol even when it was clear that the level of soft-shelled crab had exceeded the threshold, due to small sample sizes of measurements within a given cell associated with low fishery catch rates in recent years (DFO 2020).

Landings for Divs. 2HJ3KLNOP4R historically peaked at 69,100 t in 1999. In recent years, landings peaked at 53,500 t in 2009 and declined to a 25-year low of 26,400 t in 2019. In 2021, landings increased to 38,000 t. While ADs 3LNO Offshore and 3L Inshore combined account for the majority of the catch (63% in 2021), an increasing percentage has been coming from AD 3Ps in the last four years.

METHODOLOGY

MULTISPECIES TRAWL SURVEY DATA

Data on total catch numbers and weights were derived from depth-stratified multispecies bottom trawl surveys. These surveys were conducted during fall in NAFO Divs. 2HJ3KLNO and spring in Divs. 3LNO and Subdiv. 3Ps. The fall survey has occurred annually in all but Div. 2H where it was executed each year from 1996 to 1999, bi-annually from 2004 to 2008, and annually from 2010 to present. Sampling of Snow Crab during spring Subdiv. 3Ps surveys began in 1996 and in Divs. 3LNO in 1999.

The survey trawl was changed to a Campelen 1800 shrimp trawl in 1995. This trawl proved to be more efficient in capturing crab than the previously used Engels 145 Hi-rise groundfish trawl that featured larger footgear. Therefore, the trawl survey time series for Snow Crab starts in 1995.

The catchability of the survey trawl for Snow Crab is known to be low, particularly at smallest sizes, but even at largest sizes retention efficiency is below 100% (Dawe et al. 2010a). Trawl efficiency is also affected by substrate type, depth, diurnal cycle, and season (Dawe et al. 2010a; Benoît and Cadigan 2014; 2016). Catch efficiency is lower and more variable on hard (typically shallow) substrates than on soft (typically deep) substrates, and higher during dark periods when crab appear most active. Based on comparative data from Divs. 3LNO, where both a spring and fall survey occurs, fall trawl surveys are deemed to have a higher catchability for Snow Crab. Spring surveys are considered less reliable because some population components are believed to be relatively poorly sampled during this time, when mating and molting typically occur. Further, it differs across survey vessels, being higher on the Canadian Coast Guard research vessels Teleost and Alfred Needler than the Wilfred Templeman, which was in use until 2008 (Benoît and Cadigan 2014; 2016). Previous exploratory analyses have shown that conversions to account for time and vessel make negligible difference in scaling raw exploitable biomass indices to standardized estimates. This is because time-series trends within any given AD hold in all combinations of catchability conversions, and the effect size of any given vessel or area-specific conversion is small relative to a subsequent re-scaling adjustment applied to survey exploitable biomass estimates through a comparison with biomass estimates derived through fishery depletion estimations. Accordingly, no vessel or area-specific conversions were applied prior to re-scaling survey exploitable biomasses in this assessment but for some qualitative analyses a vessel conversion factor was applied to the raw data collected from the Wilfred Templeman to aid in interpretation of trends.

Data north of 56°N in Div. 2H are omitted because of consistently low capture of crab farther north and sporadic frequency of survey coverage in Div. 2H throughout the time series. The 2006 spring survey in AD 3Ps was incomplete and omitted.

Snow Crab catches from each survey set were sorted, weighed, and counted by sex. Catches were sampled in their entirety or sub-sampled by sex. Sampling of individual crab of both sexes included determination of carapace width (mm) and shell condition. Shell condition was assigned one of five categories:

1. soft-shelled – Crab that recently molted, have a high water content, and are not retained in the fishery. There is no fouling of the carapace or legs or presence of barnacles, leeches, leech egg cases, or other epibionts.
2. new-shelled – Crab that molted in spring of the current year, have a low or partial meat yield throughout most of the fishing season, and are generally not retained in the fishery. Negligible fouling of the carapace and legs and slight presence of epibionts is typical.
3. intermediate-shelled – Crab that last molted in the previous year and are fully recruited to the fishery throughout the current fishing season. Shells are full of meat and moderate fouling of carapace and legs is typical. There can be a moderate to well-established presence of epibionts.
4. old-shelled – Crab that last molted at least two years before sampling. Shells and legs are often heavily fouled and blackness around joints may be visible. There is often a well-established presence of barnacles, leeches, and leech eggs, and other epibionts.
5. very old-shelled – Crab that last molted and been available to the fishery for a long duration (i.e., ≥4 years). Carapace and legs are turning black, particularly around joints, and the shell is losing rigidity. There is often a well-established presence of epibionts.

Males were also sampled for chela (claw) height (*CH*, 0.1 mm). Males develop enlarged chelae when they undergo their terminal molt, which may occur at any size larger than approximately 40 mm CW. Therefore, only males with small chelae will continue to molt and subsequently recruit to the fishery. To standardize data capture, only the right chelae of males were measured. A model which separated males into two ‘clouds’ based on the relationship between CH and CW was applied (Dawe et al. 1997) to classify each individual as either adult (‘large-clawed’) (above the modelled line) or adolescent (‘small-clawed’) (below the modelled line). This model is defined as the following:

$$CH = 0.0806 * CW^{1.1999}$$

Maturity status was determined for females based on visual examination of the abdominal flap (small = immature, enlarged = mature) and the relative fullness and stage of egg clutches and development were subjectively assessed.

An index of size-at-maturity in both males and females was developed based on trawl survey data. For this analysis, proportions of crab undertaking terminal molt in any given year (becoming a morphometrically mature male or sexually mature female) were identified. The analysis was limited to crab that had either just molted (i.e., new-soft or new-shelled) or skip-molted (were adolescent male in intermediate or older-shelled condition or immature female in intermediate or older-shelled condition) to focus on the most recent molting outcomes with size-specific proportions of molt-type outcomes (terminal molt versus other [=adolescent/immature molt or skip-molt]) estimated in a binomial generalized additive mixed model (GAMM) defined as:

$$logit(M_i) = \beta_o + f_1(CW_i) + f_2(Year_i) + te(CW_i * Year_i) + a_i + \epsilon_i$$

$$a_i \sim N(0, \sigma^2_{AD,Year})$$

$$\epsilon_i \sim N(0, \sigma^2_{error})$$

where, M_i represents the category of terminally molted or non-terminally molted for an individual of a given CW, in a given AD and year, βo is the intercept, fj are unique smooth function of both year and CW estimated using a thin-plate smoothing spline for each AD, and te denotes a tensor-interaction spline. a_i denotes an interactive random effect of AD and year, and ϵ_i is error. The model was run separately for males and females.

The size at which 50% of the crab were predicted to undertake their final maturity molt in any given year was used for assessment of the analysis.

Ogive Mapping (Ogmap) (Evans et al. 2000) was used as the spatial expansion platform for biomass and abundance estimation. A nonparametric estimate was made of the probability distribution for trawl catch (unstandardized biomass or numbers) at any point in the area to be assessed (Figure 3). Total biomass or abundance was computed as the integral over the area of the mean value of the distribution. Confidence bounds were computed by bootstrap resampling from the distribution field. Abundance estimates were calculated for small (<50 mm CW) crab, mature females, and pre-recruit males, and biomass estimates were calculated for exploitable males. For spring surveys, the indices represent abundances or biomasses for the immediately upcoming (or on-going) fishery, whereas for fall (post-season) surveys they represent biomass for the fishery in the following calendar year.

The exploitable biomass index was calculated from the survey catch of legal-sized (>94 mm CW) males, regardless of shell condition or claw size. The exploitable biomass index generated from spring survey data includes a component of soft- or new-shelled males that would not actually be retained by the fishery in the immediate year, but would be fully recruited to the fishery in the following year.

Annual changes in biomass indices of recruits and residual crab in the exploitable biomass were examined. Crab captured as soft- or new-shelled in the current survey represent recruitment into the exploitable biomass, while the residual biomass is comprised of intermediate to very old-shelled crab. In the absence of fishery effects or other source(s) of error, including subjectivity in shell age classification, annual changes in biomass would be expected to first be seen in recruits and to subsequently occur in residual crab.

The pre-recruit abundance index was calculated based on all adolescent (small-clawed) males with 65–94 mm CW captured in the surveys. Theoretically, pre-recruits would be expected to begin contributing to the exploitable biomass in the following one to three years and to the fishery in the following two to four years. A pre-recruit captured in either the present spring or fall survey (i.e., 2020) that undergoes a terminal molt to exploitable size in the subsequent winter or spring (i.e., 2021) would be identified as a recruit into the exploitable biomass in the 2021 survey(s), and should begin contributing to the fishery in 2022. However, a portion of pre-recruits would molt but remain adolescent, which would further delay their contribution to the exploitable biomass and fishery by a year. The issue of transition rate of crab into the fishery is further complicated by the presence of skip-molting, whereby not all identified pre-recruits will molt in the following winter or spring and their arrival into the exploitable biomass and fishery would be delayed even further. Skip-molting is most common in mid-large adolescent males in cold areas (Dawe et al. 2012) and under high population density conditions, whereby skip-molting is more common than terminally-molting for crab not undergoing a regular molt in any given year (Mullowney and Baker 2021).

The exploitable biomass indices derived through Ogmap were calculated from unstandardized raw survey data. However, it is known that catchability of crab by the survey trawl (i.e., trawl efficiency) is lower than 1, even for the most efficiently captured large males (Dawe et al. 2010a), and that raw survey biomass estimates are underestimated to variable extents across ADs relative to reality (Mullowney et al. 2017). Accordingly, the raw exploitable biomass estimates were scaled to values closer to true exploitable biomass using catchability scalars developed through fishery Delury depletion regression analysis on catch rate data from logbooks. Further details on this method are provided in the Fishery Logbook Data methods section. These depletion catchability scalars (S) represented the median difference between logbook and survey-based exploitable biomass estimates in each AD over the time series:

$$S = \sum_{y=2000}^{2021} (Ty/Dy * 1/n)$$

where, T is raw exploitable biomass estimates from Ogmap, D is depletion biomass estimates from logbooks, y is year beginning in 2000, and n is number of years in the analysis.

A constant S was applied to the trawl time series for each AD, calculated as the median. Standardized biomass indices were calculated as T / S. Although closer to reality, these standardized biomass estimates are not absolute and remain interpreted as relative indices. The Delury fisheries depletion biomass estimates are applicable to the beginning of the season (spring), therefore a one-year lag was applied to survey estimates in Divs. 2HJ3KLNO in calculating the annual scalars, as these surveys occur in the fall.

The spatial distributions of mature females, pre-recruit and exploitable males, and small crab were mapped and examined using catch rates for each survey set.

To examine demographic size compositions of both sexes, crab were grouped by maturity and partitioned into 3-mm CW bins. A square root of mean numbers per tow for each maturity-size grouping was plotted. A square root transformation was applied simply for visual aid because trawl size frequency distributions often exhibit a ‘trough’ pattern, with crab ranging from 30 to 70 mm CW poorly represented in the sample population. In relative terms, the square root transformation visually dampens the magnitude of the dominant modes of smallest and largest crab and elevates the magnitude of the sparsely captured intermediate-sized groups of crab.

An annual exploitation rate index (ERI) for each AD was calculated as the ratio of dockside-monitored landings to the most recent depletion-adjusted exploitable biomass index. As exploitable biomass indices are not absolute, neither are exploitation rate indices. Given evidence to suggest biomass is slightly overestimated (Baker et al. 2021), exploitation rate indices likely slightly underestimate absolute harvest rate. Nonetheless, long-term trends in exploitation rate indices provide a useful indication of trends of relative effects from fishing. In ADs 3L Inshore and 4R3Pn, where no trawl surveys occur, exploitation rate indices were based on landings in relation to exploitable biomass estimates from trap surveys. The exploitation rate index for trap surveys was also examined for AD 3Ps since the spring trawl surveys do not have the ability to forecast the biomass available in the following calendar year. For provision of advice, exploitation rate indices based on smoothed two-period average biomass indices were calculated. This smoother was applied to account for annually variable survey performance and the possibility of ‘year effects’ in biomass estimates, a feature typically raised during annual assessments.

Relative size-specific proportions of adult male crab in the survey population were examined to qualitatively investigate fishing effects. For this analysis, crab were partitioned into 3-mm CW and two-year survey bins, with shell condition proportions plotted. A low level of intermediate to very old-shell crab in the population was inferred as representing the relative effects of fishing.

Occurrence of advanced stages of Bitter Crab Disease (BCD), a fatal affliction and source of natural mortality, was noted in both sexes based on macroscopic examination in trawl surveys. In cases of unclear external characteristics, crab were dissected and classified based on observation of the hemolymph (i.e., ‘blood’). Observation of cloudy or milky hemolymph supported the classification of such specimens as infected.

Total annual mortality rates (A_t) were calculated based on stage-specific biomass indices of exploitable crab:

$$A_t = 1 - \frac{B_{old_t}}{\left(B_{new_{t-1}} + B_{old_{t-1}}\right)}$$

where, B_{new} is recruitment (shell conditions soft, new), B_{old} is residual (shell conditions intermediate, old, very old), and t denotes survey year.

A three-year moving average total mortality rate index was calculated for each AD to smooth annual variability.

Due to vessel disruptions, there was no trawl survey in AD 3LNO Offshore and reduced coverage in ADs 2HJ and 3K in 2021 (Figure 4) and consequently no updated trawl exploitable biomass index for AD 3LNO Offshore. In an attempt to determine the impacts of the reduced coverage on the exploitable biomass estimates in ADs 2HJ and 3K, 25 test datasets were generated mimicking the 2021 coverage/strata for the time series. The unadjusted exploitable biomass estimates of these 25 test datasets were compared to the unadjusted exploitable biomass estimates produced for the time series in the previous assessment.

To address the missing trawl survey in AD 3LNO Offshore, a comparative analysis of seven biomass estimation approaches was performed to estimate the 2021 trawl survey exploitable biomass index for that AD. The first model estimated exploitable biomass based on a predictor variable of a three-year cumulative sum of pre-recruit abundance from fall trawl surveys. The second model inferred the rate of increase in 3LNO Offshore exploitable biomass was similar to the adjacent two ADs (3K and 3Ps) using biomass from those two ADs from 2016–21 as predictor variables. The third model used lagged inputs of the Arctic Oscillation (5 to 7 years) and the El-Niño Southern Oscillation (4 to 6 years) as predictor variables. The fourth model used climate predictor variables focused on birth and settlement stages, with predictor variables of the Arctic Oscillation and sea ice extent along the NL shelf lagged at 11 years and 12 years, respectively. This approach predicted the lowest level of biomass among the suite of models. The first four models were generalized additive models (GAMs) with gaussian family distributions and identity link functions and acceptable fits were based on overall residual fits, low autocorrelation of the residuals, and intuitive shapes of marginal effects. The fifth model explored was a mass balance model based on calculating a beginning of the season biomass for 2021 from a Delury depletion model fit to weekly fisheries catch rate data (see Fishery Logbook Data methods section for further details on Delury depletion). The 2021 fishery landings were subsequently deducted from this beginning of season biomass estimate and a growth parameter to account for recruitment into the biomass was added, which was defined as the slope of a linear regression fit to the pre-recruit abundance of the previous three years multiplied by the Delury estimate of beginning of season biomass. The sum of these three mass balance elements was subsequently adjusted with a natural survival estimator of 0.8 to produce the biomass estimate. The sixth model explored was a surplus production model in continuous time (“SPiCT” [Pedersen and Berg 2017; Pedersen et al. 2021]), which used both the time series of trawl survey biomass data (1995–2021) and the Collaborative Post-Season (CPS) trap survey biomass data (2018–21) to predict biomass. The seventh approach was the 2021 CPS survey biomass estimate calculated through spatial expansion of survey catch rates with Ogmap and rescaled with a time series catchability adjustment based on Delury depletion biomass estimations. This estimate was ultimately chosen to represent the 2021 trawl survey biomass index value because it is an actual measurement of the population and is consistently supported by similar estimates in the broad suite of inferential prediction models (Table 1).

FISHERY LOGBOOK DATA

Data on commercial catch (kg) and fishing effort (number of trap hauls) were obtained from vessel logbooks. These data were compiled by the Statistics Division, Policy and Economics Branch, NL Region of DFO. Return of complete and accurate fishing logbooks is a condition of license in this fishery. Logbook return rates are calculated as the percentage of the fishery landings accounted for in the logbook data in comparison to landings recorded by the DMP. The dataset is normally most incomplete in the current assessment year (Figure 5), resulting from a time lag associated with compiling data from the most recent fishery, thus the terminal points are considered preliminary. In most years, the logbooks account for between 85–95% of the landings at the time of the assessment in all ADs, except 4R3Pn which typically has lower returns. The reliability of the logbook data can be suspect with respect to effort (i.e., under-reporting) and areas fished. However, logbook data provide the broadest coverage and therefore the most representative fishery performance index.

Trends in the timing of the fishery over the time series were investigated by plotting the fishery start and end weeks, the median week of the fishery, and the lower and upper quantiles depicting 25–75% completion of the fishery.

Because the logbook dataset is incomplete, annual fishing effort (number of traps) within any given AD was estimated based on annual dockside monitored landings (kg) divided by unstandardized CPUE (kg/trap).

Standardized logbook CPUE (kg/trap) was calculated by year and AD, as well as by CMA. Annual fishery CPUE estimates are standardized for time and space using a linear mixed model (LMM). In this model, *y* indicates a given year, *t* indicates a given day, and *D* indicates a given AD. α terms indicate intercepts, β terms indicate coefficients for specific covariates, the ϵ term indicates unmodelled error around predicted CPUE, and σ^2 terms indicate variances on random effects or the error term. The model regresses the response variable of square-root transformed CPUE (catch/trap haul) from individual observations (normally on a per set basis) against fixed effects of time, binned in 5-day intervals ($\overline{\beta_{Day}}$) and gear soak time, measured in hours (β_{Soak}). Random effects were used to model square-root CPUE: calendar day*year*AD*CMA groupings. The model has a random intercept for CMA within AD within year and a random slope for scaled day, so that the relationship between day and square-root CPUE is allowed to vary by year: AD: CMA. The AD: CMA parameter accounts for spatial variation across multiple management areas within any AD. The positively-skewed response variable was square-root transformed to normalize it, as stronger transformations such as logarithms were found to produce negatively-skewed distributions in some cases. Finally, the model is weighted by consistency of fishing (i.e., cumulative number of years fished within 10’ x 10’ cells). This model was used to predict average annual CPUE by averaging set-specific predicted values (as well as 95% lower and upper confidence estimates) for each AD and year.

$$\sqrt{CPUE_{y,t,D}} = \alpha_{y,D} + \beta_{Day,y,D} \cdot Day_{y,t,D} + \beta_{Soak} \cdot Soak_{y,t,D} + \epsilon_{y,t,D}$$

$$\alpha_{y,D} \sim N(\mu, {\sigma^2}_{intercept})$$

$$\beta_{Day,y,D} \sim N(\overline{\beta_{Day}}, {\sigma^2}_{Day})$$

$$\epsilon_{y,t,D} \sim N(0, \frac{{\sigma^2}_{error}}{effort})$$

Late season data (November and December) were omitted because of their sporadic presence in the dataset. Entries of CPUE equal to 0 were also removed because it was unclear if they represented real catch rates or other practices such as dumping traps once quotas were subscribed.

CPUE is used as an index of latent biomass, but it is recognized that it can be biased by unaccounted for factors stemming from variation in fishing practices such as soak time, trap mesh size, bait type, bait quantity, bait quality, bait jars, high-grading, gear spacing, artificial lighting, and presence or absence of escape mechanisms. One factor supporting the interpretation of CPUE as an index of relative latent biomass is the consistent broad-spatial coverage of the fishery each year generated by the numerous CMAs. CPUE was directly compared and related to other indices of biomass and associated relevant indices, including trawl survey exploitable biomass estimates, fishery discards, and exploitation rates.

Standardized annual logbook CPUEs were mapped in 10’ x 10’ (nautical minutes) cells, encompassing the entire fishery distribution each year, and used to qualitatively assess spatial fishery performance within each AD. Further, time-binned (five-day increment) CPUEs were plotted for individual ADs and CMAs within each AD for a six-year timespan to assess fishery performance over a prolonged continuous timescale. The five-day estimates were fit with least squares loess regression curves to visually depict changes occurring in the fishery over time.

Logbook data were used to adjust for survey-based exploitable biomass underestimates through catch rate Delury depletion model scalars (S) in each AD. The depletion analysis used five-day unstandardized CPUEs in each AD beginning in the year 1999. Prior data were omitted due to less evidence of strong seasonal depletion in the fishery, with rapid expansion and substantial increases in removals occurring throughout the 1990s to a peak in 1999. To estimate biomass, 5-day CPUEs were natural log transformed and regressed on cumulative pots. Catch data associated with the first and last 5% of the effort (measured by number of pots) and data later than July in any given AD and year were omitted to control for small sample size effects potentially associated with atypical fishing practices such as high levels of searching at the beginning of the season, dumping of excess catches near the end of the season, or recruitment of exploitable males at the end of season. A linear mixed model was fit to log-catch rate versus cumulative effort (i.e., number of pots) data by AD and year, with the forecasted intercept used to calculate the beginning of the season biomass:

$$lnCPUE_i = \alpha + pot\_cum_i + a_i + \epsilon_i$$

$$\epsilon_i \sim N(0, \sigma^2_{error})$$

where, $lnCPUE$ is the natural log of fishery catch per unit effort (kg/trap), and pot_cum is the cumulative number of pots.

A limitation associated with biomass estimation based on depletion methods is that a resource must be depleted for the method to work. For example, no depletion occurred in catch rates during the fishery in AD 3Ps during the 2019 season and a usable depletion-based biomass estimate could not be calculated. To account for other variability resulting from sporadic depletion patterns, a centered three-period moving average was used to smooth annual logbook-based biomass estimates prior to making comparisons for survey biomass scaling.

INSHORE DFO TRAP SURVEYS

Data were available from inshore DFO trap surveys in ADs 3K, 3L Inshore, and 3Ps (Figure 6, Figure 7, Figure 8). In AD 3K, surveys were carried out in White Bay (CMA 3B), Green Bay (CMA 3C), and Notre Dame Bay (CMA 3D) during 1994–2021 and have consistently occurred in late August to mid-September and occupy five of the depth strata developed for multispecies trawl surveys. In AD 3L Inshore, long-term trap surveys within Bonavista Bay (CMA 5A) and Conception Bay (CMA 6B) have occurred from 1979 to 2021. Historically, the Bonavista and Conception Bay surveys covered only the deepest stratum in each bay where the fishery was concentrated. However, shallower strata have been occupied in the surveys since 2013. Depth stratified surveys have been conducted in Trinity Bay (CMA 6A) and St. Mary's Bay (CMA 9A) since 2013, covering virtually the entire vertical distribution of each bay. The Bonavista Bay surveys occur during late July each year, the Trinity Bay surveys have occurred during early August, the St. Mary's Bay surveys have occurred during early to mid-June, and the Conception Bay surveys have occurred during late September or early October. In AD 3Ps, a trap survey has been conducted in Fortune Bay (CMA 11E) during late May to early June from 2007 to 2021 and occupies three depth strata encompassing the entire vertical distribution of the bay.

All surveys follow a depth-stratified survey design with set locations randomly distributed within each stratum, and stratum-specific set allocations weighted by area. All surveys utilize large-mesh (commercial [135 mm]) and small-mesh (27 mm) traps intermittently placed within each 'fleet' of gear, with traps spaced approximately 45 m (i.e., 25 fathoms) apart. Each fleet includes six baited traps, with two additional end traps not baited. Squid (*Illex* spp.) hung on skivers is attached to the inner entry cone of each trap for bait, with approximately 2–3 pounds of squid on each skiver. Although soak times are intended to be standardized to 24–48 hours, weather and other factors can affect the surveys and soak times are ultimately variable. Biological sampling is conducted at-sea from all traps at each station. Sampling of males includes determination of CW, shell condition (same categories as trawl survey), determination of CH, and presence of BCD. As per the trawl surveys, females are sampled from small-mesh traps for the same morphometrics as males, with examination of the abdomen rather than CH used to determine maturity, and the relative fullness and stage of egg clutches estimated.

For each survey series, catch rate indices of legal-sized crab by shell condition from large-mesh traps (i.e., comparable to fishery index) and size frequency distributions of males by maturity status from small-mesh traps were produced for assessment. Mortality was inferred from levels of BCD observed in new-shelled males from these surveys.

Catches of exploitable males were also combined with data from the CPS trap survey to estimate exploitable biomass.

TORNGAT JOINT FISHERIES BOARD POST-SEASON TRAP SURVEY

Data were examined from a collaborative trap survey between the Torngat Joint Fisheries Board (TJFB) and DFO which takes place in CMA 1 (N5440) in AD 2HJ (Figure 9, Figure 10). This survey was initiated in 2013 and has occurred each year from late August to early September. The survey is conducted by TJFB technicians onboard a commercial vessel and consists of 20 fixed stations. At each station, nine commercial (133–140 mm mesh) and two small-mesh traps are set in a fleet. Prior to 2017, the fleets consisted of ten commercial and one small-mesh trap. Biological sampling is conducted at-sea from all traps at each station. Sampling of males includes determination of CW, shell condition (soft, new, or old), determination of CH, leg loss, and presence of BCD. Females are sampled from small-mesh traps as per protocols on the Inshore DFO Trap surveys.

Catch rate indices of legal-sized crab by shell condition and size frequency distributions by shell condition from large-mesh traps, and size frequency distributions by maturity from small-mesh traps were produced for assessment. All analyses were limited to males, with sizes partitioned into 3-mm CW bins. However, unlike the five-stage assessment of shell condition used on DFO surveys, this survey uses a three-stage scale of soft, new, and old-shelled.

Catches of exploitable males were also combined with data from the CPS trap survey to estimate exploitable biomass.

COLLABORATIVE POST-SEASON TRAP SURVEY

Data were examined from an industry-DFO CPS trap survey in all ADs (Figure 9, Figure 10). These surveys were initiated in 2003 and have occurred each year following the fishery, typically beginning in late August or early September, and ending in November. They are conducted by Snow Crab harvesters accompanied by at-sea observers and historically focused on commercial (i.e., deep) fishing grounds within individual CMAs. Thus, at localized spatial scales these surveys are more vertically-limited than the multispecies trawl surveys in the offshore or the Inshore DFO trap surveys in select inshore CMAs. The CPS trap survey began transitioning to a partly random stratified design in 2017. Since 2018, approximately 50% of survey stations are randomly allocated while 50% remain fixed (systematically chosen from existing core stations). The changes were invoked to increase both vertical and horizontal coverage in areas beyond prime commercial fishing grounds to encompass a more representative depiction of all population components in the assessment.

Historical survey stations generally followed a grid pattern, with a maximum station spacing of 10’ x 10’ (nautical miles), while newer randomized stations follow no systematic spatial design. At each station, six (inshore) or ten (offshore) commercial (133–140 mm mesh) traps are set in a fleet. Biological sampling of male crab is conducted by observers at-sea from a single large-mesh trap at each station, however, starting in 2020, sampling expanded to include two large-mesh traps. Sampling includes determination of CW, shell condition (soft, new, old), determination of CH, leg loss, and presence of BCD. Small-mesh traps have been included on sampling fleets after trap # 3 at some stations to collect information on females and pre-recruit males. Inshore stations with a small-mesh trap use a fleet of seven traps and offshore stations with a small-mesh trap use a fleet of eleven traps. Sampling of males is the same as those from the large-mesh traps and females are sampled as per protocols on the trawl and Inshore DFO trap surveys. Until 2016, catches from small-mesh traps were returned to shore and sampled by technicians at DFO in St. John’s. However, since 2016 at-sea observers have measured the contents of the small-mesh traps. This has been associated with increased use of small-mesh traps in the survey. Observers are required to measure 75 males and 25 females caught in the small-mesh traps and count any extra crab caught.

Stemming from the temporal and spatial inconsistencies and limitations in the distribution of small-mesh traps, indices are not available for all areas in all years. Furthermore, small-mesh traps have not adequately sampled small crab in some areas because the survey design focused near-exclusively on capturing exploitable crab and had limited sampling in shallow water, which tends to be associated with small-crab distribution in many areas. To address concerns about the limited utility of small-mesh traps in the survey, more small-mesh traps were incorporated in the 2016–21 surveys (Figure 10). Overall, more than 85% of the completed stations had a small-mesh trap in 2021. More small-mesh traps will be added into the survey in forthcoming years until every station is occupied by one small-mesh trap.

Historically, a set of core stations was selected from this survey for calculating assessment indices from large- and small-mesh traps. However, in the present assessment a comparative index from all stations was calculated and presented. This new time series was used to infer trends from the trap surveys. Furthermore, a stratification scheme conforming to the limited historic survey footprint that was used for estimating biomass indices from this survey in the past was abandoned this year in accordance with the broader spatial distribution of the survey in recent years that allowed spatial expansion of survey catch rates over the majority of the continental shelf area (Figure 3). Catch rate indices of legal-sized crab by shell condition from large-mesh traps, large-mesh trap size frequency distributions by shell condition, and small-mesh trap size frequency distributions by maturity were produced for assessment. All analyses were limited to males, with sizes partitioned into 3-mm CW bins. However, unlike the five-stage assessment of shell ages used on DFO surveys, this survey uses a three-stage scale of soft, new, and old-shelled. Catch rate indices of pre-recruits (kg/trap of 65–94 mm CW adolescent males), small crab (number/trap of crab less than 50 mm CW), and mature females (number per trap) was also derived from small-mesh traps.

Spatial expansion of survey catch rates into biomass was conducted using a modified version of Ogmap (‘Ogtrap’). Ogtrap utilizes the same vertex points as Ogmap (Figure 3) to integrate catch rates over any given spatial area. The input parameter of trawl swept area in Ogmap has been altered to conform to the effective fishing area of a crab trap, with the value set at 0.01 km^2. This effective fishing area parameter represents an intermediate value from estimates reported by Miller 1977, Brêthes et al. 1985, and Dawe et al. 1993. Nonetheless, because uncertainties remain regarding the accuracy of the effective fishing area parameter, biomass estimates developed from this survey remain as indices and are assessed in a relative sense.

As with the trawl survey exploitable biomass estimates, the trap survey exploitable biomass indices derived through Ogtrap were scaled using catchability scalars developed through fishery depletion regression analysis on catch rate data from logbooks. Further details on this method are provided in the Fishery Logbook Data methods section. The trap survey scalars were previously calculated using the same method as the trawl survey, however, in the current assessment the *S* applied to the time series was calculated using linear regressions rather than a time-series median. This change in methodology was due to the change in the CPS trap survey design and the incorporation of stations covering a much larger area which resulted in a temporal shift in the calculated annual scalars associated with broadening survey coverage. The use of linear regressions normalized the error structure of survey catchability around a central tendency during this shifting period of areal survey coverage. The Delury fisheries depletion biomass estimates are applicable to the beginning of the season (spring), therefore a one-year lag was applied to most survey estimates in calculating the annual catchability scalars, as most surveys occur in late-summer or fall.

As a result of the historical lack of small-mesh traps in the survey and the targeting of deep commercial Snow Crab grounds by the previous survey design, biomass estimation was limited to exploitable-sized males from large-mesh traps. However, biomass estimation in some areas was not exclusive to CPS trap survey data, with data from the Inshore DFO trap surveys and TJFB post-season trap survey also used in the analysis. The incorporation of all surveys using similar techniques was thought to improve the reliability of the results due to the inclusion of more data.

OBSERVER CATCH-EFFORT AND AT-SEA SAMPLING DATA

At-sea sampling data by observers have been collected since 1999. For each trip, observers sampled entire catches of males for CW (mm) and shell condition for as many traps as time allowed. Overall levels of sampling have been generally highest in AD 3LNO Offshore (Figure 11, Figure 12) and consistently low in inshore CMAs. Overall, at-sea observer coverage has decreased in recent years, with a precipitous decline in the number of trips observed per year. Considering the increase in total allowable catch (TAC) in the last two years, this has resulted in a reduction in the percentage of landings observed. Sampling was particularly low in 2020 due to the COVID-19 pandemic, however, it remained low in ADs 3L Inshore, 3Ps, and 4R3Pn in 2021. Consequently, these three ADs were excluded from most at-sea observer analyses for 2021. Various catch rate indices were developed from shell condition staging conducted by observers. Like the three-stage assessment of shell ages used in the post-season surveys, observers classify crab as soft, new, and old-shelled. The total catch rate of legal-sized crab by shell condition for each AD was calculated as an index of in-season exploitable biomass from the fishery. Similarly, size frequency distributions of catch rates of male crab by shell condition and size, in 3-mm CW bins, were constructed to interpret the composition of the catch. Size frequency distributions were presented and examined at both the AD and CMA level where data were sufficient. Relative proportions of legal-sized crab by shell condition throughout the fishing season were also examined. For this analysis, crab were partitioned into five-day increments with shell condition proportions plotted. This analysis provides a depiction of the timing of sampling throughout the fishing season and whether comparisons between years are representative.

At-sea observer sampling data formed the basis for estimating fishery discards. Total discard rates as well as the percentage of the catch discarded in the fishery were examined, with undersized (<95 mm CW) and soft-shelled crab measured during commercial fishing activities deemed to be discarded. A generalized linear mixed model (gLMM) was used to standardize discard percentages. The binomial model with a logit link function regressed raw data from observations of discarded weights from individual fishing sets:

$$logit\ (p_i) = \beta_0 + Day + Soak + \gamma_i$$

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

$$E(Y_i) = p_i \times n_i$$

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

where, Y_i is the weight of discarded Snow Crab observed in each fishing set in a particular AD, CMA, day, and year, n_i is the total number of Snow Crab observed in each fishing set in a particular AD, CMA, day, and year, β_0 is the intercept, Day is the calendar day when the fishing set occurred, $Soak$ is the soak time (hours) of the fishing set, and γ_i is a random intercept for soak time in each combination of AD, CMA, and year. As per the CPUE standardization model, the spatial CMA term accounts for the multiple management areas within each AD.

Annual percentages of discards were related to fishery CPUE, with both indices standardized to mean=0 and standard deviation=1, to assess the relationship between the two variables. Bubble plots of weekly catch rates and percentages of soft-shell crab captured in the fishery were also constructed and examined for each AD. Soft-shell crab prevalence is interpreted as both an index of mortality and wastage because it is assumed that the majority of crab discarded as soft-shell die. Soft-shell prevalence can also be used to infer the relative strength of recruitment potential for forthcoming fisheries. For example, under the scenario of high catch rates of large residual crab (i.e., most competitive) and a high discard rate of soft-shell crab, it would be inferred that recruitment prospects for the forthcoming fishery are favourable. However, a high incidence of soft-shell crab in the catch during a period of low residual biomass would not lead to the same inference and would be indicative of wastage.

ECOSYSTEM INDICES

Spring and fall bottom temperature climatological maps and spring and fall 2021 observations and anomalies were determined using the methodology described and presented in Cyr and Galbraith (2021). There were no data for Divs. 3LNO in 2021 or Subdiv. 3Ps in 2020 as there were no trawl or Atlantic Zonal Monitoring Program (AZMP) surveys in those areas in those years. Spring temperature indices are preferred because they are more closely associated with critical life history events in Snow Crab such as mating and molting.

Atmospheric forcing has been associated with latent biomass in major global Snow Crab stocks. Exploratory work in the previous assessment demonstrated latent biomass correlations with winter-spring indices of several climate modes including the Pacific Decadal Oscillation (PDO), the El-Niño Southern Oscillation (SO), the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO). A variety of models were explored to explain latent biomass with the following model used to make short-term projections of exploitable biomass for the aggregate 2HJ3KLNOP NL Snow Crab stock:

$$tBIO \sim s(AO567) + s(SO456)$$

where, *tBIO* represents trawl-derived exploitable biomass plus landings, to account for all exploitable males in the population, $AO567$ represents a mean value of December to March values of the Arctic Oscillation from five to seven years ago, and the $SO456$ represents a mean value of December to March values of the El-Niño Southern Oscillation from four to six years ago. The s term denotes a thin-plate smoothing spline. The model assumed a normal family distribution and default identity link function and was selected among a suite of candidate models based on adjusted r-square (0.71) and deviance explained (73.4%) statistics. This model was not updated in 2021 due to the absence of trawl data for 3LNO Offshore.

The exact mechanisms by which these climate oscillations affect future biomass are unknown, but the winter-spring seasonality of the effects, and the four to seven year periodicity of the lagged effects suggests they are important in regulating survival and growth of Snow Crab during early-mid ontogeny. The broad-scale system-level effects of these climate modes propagate through a number of ecosystem processes including food production and thermal habitat regimes.

Estimates of Snow Crab consumed by fish predators were generated by combining three sources of information: biomass estimates for fish predators, estimations of total food consumption by unit of biomass for those predators, and fractionation of that consumption using diet compositions to define the proportion of Snow Crab in the diet. As each step involves assumptions and generalizations, the resulting index is not a precise estimate of consumption, but intended to generate a plausible envelope for the order of magnitude for consumption.

Among all fish species recorded in DFO multispecies trawl surveys, only those belonging to the piscivores and large benthivores functional groups were considered Snow Crab predators due to gape limitation of smaller fishes and the available evidence from stomach contents. The total biomass of fish predators was approximated from multispecies trawl survey biomass estimates, assuming the sample populations reflect fish community composition. However, as species-specific estimates were not corrected for gear catchability they likely reflect minimal estimates of predator biomass.

Estimation of consumption rates per unit of biomass were derived using two separate approaches:

1. Allometric methods. Two different models were used: a) bioenergetic-allometric consumer-resource modelling framework, based on empirical allometric scaling relationships (Yodzis and Innes 1992), and b) an allometric framework derived from growth principles based on the von Bertalanffy equation and rationale (Wiff and Roa-Ureta 2008).
2. Daily ration. These estimates are based on assuming daily consumption as a percent fraction of body weight. Two daily ration scenarios of 1% and 2% were assumed based on the typical range of values from literature reports (Macdonald and Waiwood 1987; Adams and Breck 1990).

To be precise, these approaches estimate average food requirements, not actual food consumption. The implicit assumption is that all predators achieve their food requirements. Using these alternative estimates of consumption rates together allows the development of a plausible envelope for consumption that likely contains the actual consumption rate.

Diet composition data are only available for a few recent years and for a small subset of Snow Crab predators (American Plaice [*Hippoglossoides platessoides*], Atlantic Cod [*Gadus morhua*], and Greenland Halibut [*Reinhardtius hippoglossoides*]). Estimates of the overall fraction of Snow Crab in their diets, as well as relative contributions of these species to the overall biomass of the Snow Crab predator assemblage, were used to approximate the fraction of Snow Crab consumed by all piscivore and large benthivore fishes. Since these predator species are a major component of the biomass of the corresponding fish functional groups, using their diets to represent the functional groups is a reasonable proxy, but the assumption of a constant diet composition in the earlier part of the time series (where there is a lack of diet composition information) is a less robust (but unavoidable) assumption. Estimates of absolute consumption of Snow Crab by all piscivore and large benthivore fishes were presented as the median (point estimate) and range from all consumption models considered, along with a predation mortality index (predation estimate / total Snow Crab survey biomass). Predation mortality indices should be interpreted with caution as it is calculated using total Snow Crab biomass, however the influence of predation is exerted primarily on small-sized crab.

PRECAUTIONARY APPROACH

In June 2018, DFO Science held a CSAS Regional Peer Review process to develop a Precautionary Approach (PA) Framework for Snow Crab in the NL Region. The key objective of the meeting was to define Limit Reference Points (LRPs) consistent with the PA for NL Snow Crab, based on the best scientific information available. DFO Science proposed a PA Framework for the NL Snow Crab resource and fishery that was based on three key metrics of stock health:

1. predicted CPUE (pCPUE),
2. predicted discards (pDiscards), and
3. proportion of females with full egg clutches (Mullowney et al. 2018b)

The adopted parts of the framework include the LRPs, differentiating the Critical from Cautious Zones, and the Upper Removal Reference (URR). Harvest Control Rules (HCRs) and Upper Stock References (USRs) have been proposed but not adopted into the framework at the time of this assessment. LRPs, as set by the peer-review process, were identified as pCPUE = 5 kg/trap, pDiscards = 20%, and proportion of females with full egg clutches = 0.6.

Predicted CPUE (CPUE) was estimated based on the following generalized additive mixed model:

$$CPUE_i = \alpha + f_{1k}(ERI_i) + f_{2k}(CBI_i) + f_{3k}(NAO7_i) + a_i + \zeta_i + \epsilon_i$$

$$a_i \sim N(0, \sigma^2_{AD})$$

$$\zeta_i \sim N(0, \sigma^2_{year})$$

$$\epsilon_i \sim N(0, \sigma^2_{error})$$

where, *ERI* is the exploitation rate index, based on 2-period exploitable biomass index, *CBI* is the combined exploitable biomass index from trawl and trap surveys in the previous year (i.e., an average of the trawl and trap survey biomass indices and scaled within AD), and *NAO7* is the centered, lagged by 6–8 years index of annual NAO, calculated as annual mean NAO based on monthly data values before centering the 3-year average.

Predicted discards (DIS) were estimated based on the following generalized additive mixed model:

$$DIS_i = \alpha + f_{1k}(wCPUE_i) + f_{2k}(medFD_i) + f_{3k}(EP_i) + a_i + \epsilon_i$$

$$a_i \sim N(0, \sigma_{AD}^2)$$

$$\epsilon_i \sim N(0, \sigma_{error}^2)$$

where, *wCPUE* is cell-weighted CPUE (with the number of years a 5’x 5’ cell was occupied used as the weighting factor), *medFD* is median fishing day based on effort (i.e., pots), *EP* is the ratio of exploitable to pre-recruit crab in the previous year, and *AD* is Assessment Division.

While the model-predicted discards estimate is used in the PA Framework in relation to the LRP, the observed points are also plotted. Due to the particularly poor at-sea observer coverage in 2020 and 2021 there were no observed points presented for these years. To determine an estimate for the observed discards point, a reference fleet of vessels from the commercial logbook data was identified in 2020. The percentage of Snow Crab catch discarded per year per AD was calculated for vessels that had discards reported in seven out of the last 10 years (2010–19). These annual AD % discards were correlated against the annual at-sea observer AD predicted discards from 2010 to 2019 from the previous stock assessment. A vessel was included in the reference fleet if its logbook-recorded discards were not significantly different from the at-sea observer predicted discards for a given AD (p-value <0.05) and the correlation coefficient was ≥70%. The mean of the at-sea observer % discards and the reference fleet % discards for each year was calculated to determine the % discards observed point on the PA Framework figure. This value was not used to determine the status of the PA metric in relation to the LRP; the predicted value was used which was not affected by the reduced at-sea observer coverage in 2020 and 2021. The observed discards estimates for AD 2HJ were particularly poor because there were very few vessels in the logbook data that correlated strongly with the at-sea observer data.

Both the CPUE and discard predictive models project one year based on scenarios of various exploitation rates in the forthcoming fishery.

As presented in Mullowney et al. (2018b), egg clutches are calculated directly (as a 2-year moving average) from survey results.

For CPUE and discards metrics, provision of advice on stock status zone is intended to be based on projected outcomes based on status-quo exploitation rates, while for the egg clutch metric (where no projections are possible) it is based on the current year’s data.

In early-2020, industry representatives submitted an alternative PA Framework for Snow Crab to be reviewed. Following peer review in September 2020, this alternate PA Framework was not accepted and the DFO Science LRPs remained in place (DFO 2023). A working group was reestablished to bring forward a series of recommendations to DFO on the USRs and HCRs. Discussions have been productive, and progress is ongoing, however the HCRs were not finalized by the time of the stock assessment. A scoring system has been developed to incorporate the stock status of the three metrics into one stock health score (Mullowney and Baker 2023).

RESULTS AND DISCUSSION

BROAD-SCALE TRENDS: DIVISIONS 2HJ3KLNOP4R

Fishery

Landings for Divs. 2HJ3KLNOP4R increased steadily from 1989 to peak at 69,100 t in 1999, largely due to expansion of the fishery to offshore areas. They decreased by 20% to 55,400 t in 2000 and changed little until they decreased to 44,000 t in 2005, primarily due to a sharp decrease in AD 3K. In recent years, landings remained near 50,000 t from 2007 to 2015, but steadily declined to a 25-year low of 26,400 t in 2019. In 2021, landings increased to around 38,000 t (Figure 13).

In AD 2HJ, landings remained near 1,700 t from 2014–19, however landings decreased to around 1,200 t in 2021 (Figure 14). In AD 3K, landings remained between 5,500 and 6,000 t from 2016 to 2019, but increased in the last two years to around 7,500 t in 2021. In AD 3L Inshore, landings declined by 67% from a time-series high in 2015 to a low of 2,750 t in 2019. Landings have increased in the last two years to around 3,700 t in 2021. In AD 3LNO Offshore, landings declined by 48% from 2016 to less than 13,000 t in 2019 because of reductions in the TAC, to the lowest level in two decades. The landings increased in the last two years to over 20,000 t in 2021. In AD 3Ps, landings increased from a time-series low of around 1,200 t in 2017 to around 5,000 t in 2021. In AD 4R3Pn, landings declined by 81% from a recent peak in 2013 to a time-series low of 167 t in 2020. Landings increased slightly in 2021 to near 300 t.

Fishery timing transitioned from summer-fall to spring-summer throughout the 2000s in most ADs (Figure 15). In recent years, the fishery generally begins in early April for all but AD 2HJ, where it usually starts in early to mid-May due to ice cover in the spring. In 2021, median fishing weeks ranged from mid-April in AD 4R3Pn, early to mid-May in ADs 3Ps and 3K, and late-May to early June in ADs 2HJ, 3L Inshore, and 3LNO Offshore. The large end-of-season spike in AD 3K in 2017 reflects a fall meat yield project that occurred during November.

Fishing effort, as indicated by estimated trap hauls, increased by a factor of five throughout the 1990s as the fishery grew (Figure 16). Overall effort remained at approximately 3.5 to 4.5 million trap hauls per year over that time period, but decreased to under 2.5 million trap hauls in 2020, the lowest level in over two decades. Effort increased to near 3 million trap hauls in 2021. Spatially, the distribution of fishing has remained relatively broad-based, but there have been significant changes in some ADs in recent years (Figure 17). In the north, effort in the northernmost portion of AD 2HJ has gradually dissipated since 2011, with NAFO Div. 2H virtually abandoned since then and the Cartwright and Hawke Channels have near-exclusively become the two areas of fishing activity. The abandonment of northernmost fishing grounds reflects both resource shortages and a regulation change after the 2012 fishery whereby vessels previously restricted to Div. 2H were allowed access to the northern portion of the Cartwright Channel, inside Div. 2J, at the southernmost portion of CMA 1. Effort in AD 2HJ has remained moderately consistent, at around 200,000 trap hauls per year, in recent years (Figure 16). In AD 3K, effort decreased to a 25-year low in 2019, with about 600,000 trap hauls, and has remained near this level in the last two years. Effort has contracted primarily into the Funk Island Deep and areas west, with the furthest offshore portions of this AD appearing to have been abandoned. In AD 3L Inshore, effort reached a historical high of near 1 million trap hauls in 2017, but quickly decreased to a time-series low in 2020, with just over 300,000 trap hauls. Effort remained near this level in 2021. In AD 3LNO Offshore, effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level of about 1.5–2 million trap hauls per year until decreasing to approximately 1 million trap hauls in 2019 and 2020. Effort increased to about 1.4 million trap hauls in 2021. A substantial reduction in fishing effort was seen in CMA 3N200 in the last three years, with virtually no activity along the very tail of the Grand Bank. In AD 3Ps, effort reached a 25-year low in 2020, but increased in 2021 to near 300,000 trap hauls. In AD 4R3Pn, effort has remained at a low level relative to other ADs and decreased to an over 25-year low in 2020. Effort has been low in recent years with fewer than 100,000 trap hauls per year and is restricted to a few CMAs. There has been a substantial reduction in fishing activity in the offshore area (CMA OS8) of this AD and fishing is primarily focused in CMAs 12C, 12D, 12E, and 12F.

Fishery CPUE tends to lag behind survey biomass trends by one to two years in most ADs, thus the fishery is typically delayed in reflecting stock status, indicative of hyperstability in the CPUE index. Throughout the past 25 years, CPUE has shown a great deal of variability both across and within ADs (Figure 18). From 2015 to 2018, there was considerable spatial contraction of fishing activity associated with high levels of fishery CPUE; however, increases have been seen in many areas in the last three years (Figure 17). Fishery CPUE is typically highest in NAFO Div. 3L; however, in recent years, ADs 3K and 3Ps have also had high levels of fishery CPUE.

Overall, the fishery performed poorly in 2017 and 2018, with standardized CPUE at a historical low (Figure 19). In 2021, the overall standardized CPUE increased to above the time-series average. In AD 2HJ, at about 6 kg/trap, standardized CPUE was below the time-series average in 2021 (Figure 18). The coupling of reduced or stable fishery catch rates with contraction of the fishery back into the core areas of known concentrations of exploitable biomass is indicative of hyperstability occurring in the CPUE index in this AD, and in particular the southern portion of it, with the northernmost CMA more clearly showing signals of resource depletion in the fisheries data, even in the historically best-performing fishing grounds of the Cartwright Channel. In AD 3K, standardized CPUE increased from a time-series low of 5 kg/trap in 2017 to above the time-series average exceeding 10 kg/trap in 2021. In AD 3L Inshore standardized CPUE was near the time-series average level of about 11 kg/trap in 2021 and areas which showed dramatic declines in CPUE from 2017 to 2019 showed improvements in the last two years. In AD 3LNO Offshore, standardized CPUE was near the time-series average level of about 14 kg/trap in 2021. In AD 3Ps, the decline in fishery CPUE had been both precipitous and broad-based from 2010 to 2017, but all major fishing areas have had improved catch rates since then. The standardized CPUE at 16 kg/trap was near the time-series high in 2021. Finally, in AD 4R3Pn, standardized CPUE remained at a time-series high of 7 kg/trap in 2021.

Overall, the combination of landings, spatial patterns, and spatial distribution of catch rates from the various sources of fishery data suggest the fishery remains strongest in an aggregated area along the northern Grand Bank in AD 3LNO Offshore, with improvements in the last three years in most ADs except for AD 2HJ.

At-sea observer data on shell composition are used to infer dynamics of recruitment into the biomass. Observer coverage has been poor in recent years and was too low in all ADs in 2020, and in ADs 3L Inshore, 3Ps, and 4R3Pn in 2021 to be used to infer trends in the stock assessment. In AD 2HJ, the observer data indicates the proportion and magnitude of new-shelled crab decreased dramatically in 2016 and 2017. In 2018, the presence of both soft-shell crab and residual crab in the fishery increased, but there was a large decrease in residual crab in 2019 (Figure 20, Figure 21). However, the level of observer sampling was very low in AD 2HJ in 2018 and it is likely that the increase in 2018 is not a true representation of catch rates and composition that year. The observer data in 2021 showed a catch composition dominated by residuals. The AD 3K fishery has observed overall catch rates of both residual crab and recruits at a consistent low level since 2008, however, increases were observed in both 2019 and 2021. The observed catch composition has been fairly consistent throughout most of the time series. In ADs 3L Inshore and 3LNO Offshore, the compilation of recruit and residual crab were at a time-series low in 2018, however, slight increases in recruits were observed in both ADs in 2019 and in AD 3LNO Offshore in 2021. In AD 3Ps, both the recruitment and residual components of the biomass observed in the fishery decreased by more than half from 2011 to 2017. In 2018, a sharp increase in the observed catch rates of recruits occurred, indicating a strong recruitment pulse entering the system, followed by an increase in residuals in 2019. Observer coverage was extremely low in AD 4R3Pn in 2019 and the catch rates and composition are very likely not representative of the resource in that AD.

The fishery had strongly depleted the exploitable biomass in all ADs in recent years (Figure 22, Figure 23). There were improvements in end-of-season catch rates in all ADs except 2HJ in the last three years, with end-of-season catch rates particularly high in ADs 3Ps and 3LNO Offshore, near 10 kg/trap. In AD 2HJ, depletion rates were relatively consistent from 2014 to 2018, however, there was much quicker depletion in the last three years (Figure 24). This is particularly concerning given the contraction of the fishery back into the two dominant centres of the Hawke and Cartwright Channels. In AD 3K, the fishery began at relatively high catch rates, but has quickly and precipitously depleted the biomass in recent years (Figure 25). In AD 3L Inshore, there was little depletion evident from 2011 to 2013, but depletion has occurred since, to the extent that the 2019 fishery began near its lowest level and ended at its lowest level in the time series, with precipitous depletion throughout the season (Figure 26). However, in 2020 and 2021 the end-of-season catch rates were much higher than the previous three years. In AD 3LNO Offshore, there had been only slight depletion of the biomass from 2010 to 2014, but the rate of depletion has accelerated since then (Figure 27). In 2020 and 2021, the start-of-season catch rates were higher than the previous three years and the end-of-season catch rate in 2021 was the highest since 2015 (Figure 23). In AD 3Ps, rapid depletion under minimal removals occurred in 2016 and 2017, however minimal depletion has been seen since (Figure 28). In 2021, the start- and end-of-season catch rates were the highest in the last twenty years (Figure 23). In AD 4R3Pn, the 2017–20 linear regression slopes were extremely steep, indicative of a rapid depletion of the biomass (Figure 29). In 2021, the catch rates appeared variable throughout the season with no indication of depletion. The relatively consistent within-year depletion in most years across ADs allowed for the calculation of Delury-based exploitable biomass estimates that could be used as scaling factors (Figure 30), as described in the Methodology section.

Biomass

Multispecies trawl surveys indicate that the overall exploitable biomass index was highest at the start of the survey series (1995–98) (Figure 31). The index declined from a peak near 400 kt in the late-1990s to about 150 kt in 2003 and then varied without trend until 2013. From 2013 to 2016, the exploitable biomass declined by 80% to a historical low of about 33 kt. Modest increases have been observed in the trawl survey exploitable biomass index over the past three to four years, and the exploitable biomass index was nearing the time-series average in 2020. The trawl survey did not take place in AD 3LNO Offshore in 2021, therefore the stock-level trawl exploitable biomass index was not updated. However, the redesign of the CPS trap survey and subsequent incorporation of stations over a much larger area has resulted in the trap survey exploitable biomass index becoming more temporally in-line with the trawl survey exploitable biomass index, rather than lagging behind the trawl trends as was evident with the previous survey design. The two surveys are now measuring approximately the same grounds at approximately the same time. Therefore, the trap survey exploitable biomass index was used exclusively for stock-level exploitable biomass trends in 2021. This index has also shown an increasing trend in exploitable biomass (Figure 31).

The overall low exploitable biomass level in recent years was coupled with concentration of exploitable crab into localized areas in all ADs. However, despite this contraction, there were signs of some localized improvements in the last two years (Figure 32, Figure 33). Particularly noteworthy are the increased survey catch rates throughout the northern and eastern portions of Div. 3L in the fall survey in 2019 and 2020 and the eastern portion of Div. 3L in the 2019 spring survey. As well, the fall and spring surveys of 2019 and fall survey of 2020 showed notable catches of exploitable crab along the eastern edge of Div. 3N, where there have not been signs of exploitable crab since 2015.

Overall trends in trawl and trap survey exploitable biomass indices mask spatiotemporal variability among ADs (Figure 34, Figure 35), as well as potential confounding factors occurring within any given area. In AD 2HJ, the trawl exploitable biomass index remained low, and the trap exploitable biomass index decreased in 2021. Due to the reduced trawl coverage in AD 2HJ in 2021, the trawl exploitable biomass index may be overestimated in 2021 (Figure 36). Despite consistency across the two time series, stock status interpretation has been compromised in recent years by incomplete trap surveys from 2017–19 and reduced coverage of the fall multispecies trawl surveys in 2019 and 2021. The 2017–19 point estimates from the trap time series in AD 2HJ are considered incomplete due to incomplete and improperly collected data in the CPS trap survey those years; large proportions of data were not collected properly and therefore unavailable for analyses and many core stations were not surveyed. In AD 3K, the trawl exploitable biomass index increased over the last three years to near time-series high levels (Figure 34). Unlike AD 2HJ, simulations of the effect of reduced survey coverage in recent years was not directionally consistent (Figure 36). Increases in the trap exploitable biomass index were also seen in the last three years in this AD (Figure 35). In AD 3L Inshore, the trap exploitable biomass index increased over the last three years, but remained below the time-series average in 2021 (Figure 35). There were signs of improvements in this AD in the Inshore DFO trap surveys in 2019 and 2020, with spatial expansion of high catch rates in 2019–21 in the bays surveyed (Figure 7). In AD 3LNO Offshore, both the trawl and trap exploitable biomass indices increased from time-series lows in 2016–18 (Figure 34, Figure 35); however, there was no trawl survey in this AD in 2021, therefore the trap time series was used to infer trends. The trap exploitable biomass index increased in 2021. In AD 3Ps, the exploitable biomass index increased in 2021 to a decadal high in both the trawl and trap time series (Figure 34, Figure 35). In AD 4R3Pn, the trap exploitable biomass index increased over the past three years to near time-series highs (Figure 35).

Although almost 50% of the sampling locations have been randomly determined since 2018, the past spatially restricted coverage of the CPS trap survey core stations essentially measured the exploitable biomass on primary fishing grounds and constituted an analog of fishery CPUE. The concentrated distribution on strongest aggregations of exploitable biomass in the CPS trap survey and fishery created the potential for hyperstability in indices derived from both sources. The spatially all-encompassing trawl survey generally detects changes in the biomass prior to them being detected in the CPS trap survey core stations (Pantin et al. 2022) or fishery (Figure 37). This lag between measuring signals of change in biomass among metrics likely reflects the inclusion of marginal grounds in the trawl survey, where, operating under an assumption of some degree of density dependent regulation, signals of change in stock size would be expected to occur first. The inclusion of the random stations since 2018 in the current stock assessment has shifted the CPS trap survey to a distribution more similar to that of the trawl survey.

Collectively, the survey and fishery metrics are consistent in showing an exploitable biomass that has shown improvements in the last three to four years.

Recruitment

In most ADs, the exploitable biomass was dominated by incoming recruits (Figure 34). In AD 2HJ, recruitment into the exploitable biomass changed little during the majority of the time series. The 2021 trawl survey indicates recruitment will remain unchanged in 2022, suggesting little change in fishery prospects for 2022. In AD 3K, the trawl and trap indices of recruitment into the exploitable biomass showed increases in 2021 (Figure 34, Figure 38), suggesting potential for improvement in the fishery in 2022. The exploitable biomass has consisted largely of incoming recruits throughout the time series (~50–75%), however there has been an increase in the proportion of residual crab in the last three years from previous low levels. In AD 3LNO Offshore, recruitment into the exploitable biomass was at or near time-series lows in both trawl and trap time series from 2015 to 2017, but has increased in the last four years. The trap index of recruitment into the exploitable biomass increased slightly in 2021, suggesting potential for improvement in the fishery in 2022. In AD 3Ps, the decline in exploitable biomass to a low in 2016 and the subsequent increase in 2017 reflects trends in recruitment. Overall recruitment into the exploitable biomass had been at its lowest observed level in the trawl survey, but started increasing in 2017. With gaps in both the trawl and trap time series, overall trends can be interpreted, but year to year changes can be missed. There were mixed signals between the trawl and trap time series in terms of composition of exploitable biomass, with declines in the catch rates of recruits in the trap time series in 2021 not observed in the trawl time series.

For ADs where no trawl surveys occur, the trap-derived indices are solely used. In AD 3L Inshore, recruitment into the exploitable biomass steadily declined to a time-series low in 2017. While recruitment has been at an increased level for the past four years, it remains below the time-series average (Figure 38). In AD 4R3Pn, recruitment into the exploitable biomass was low from 2014 to 2017, but increased to a time-series high in 2021, suggesting potential improvements in the fishery in 2022. In recent years the exploitable biomass has been dominated by recruits.

Looking at prospects beyond 2022, pre-recruit abundance indices for trawl and trap surveys provide an index of recruitment prospects for the next two to four years (Figure 39, Figure 40, Figure 41). However, the proportion and rate of the 65–94 mm CW adolescents measured by these surveys that reach exploitable biomass depends on several factors including mortality, skip-molting incidence, and the size at which crab terminally molt. The distribution of pre-recruit crab follows that of exploitable crab closely and changes seen in exploitable crab distribution is reflected in the pre-recruits as well (Figure 42, Figure 43). Recent trends in pre-recruit indices from trawl and trap surveys suggest potential for improvements of recruitment into the exploitable biomass in forthcoming years (Figure 40, Figure 41). However, pre-recruit catch rates from the trap surveys have declined in the last two years in most ADs, suggesting they may have peaked (Figure 41). In AD 2HJ, the pre-recruit abundance index has been relatively low in recent years, with a slight increase in 2020 and decline in 2021 (Figure 40). A similar trend has been seen in the last two years in the pre-recruit catch rates from the trap surveys (Figure 41). There were mixed signals between the trawl and trap pre-recruit abundance indices in recent years in ADs 3K, 3LNO Offshore, and 3Ps, with an increase in the trawl surveys and a decrease in the trap surveys (Figure 40, Figure 41), however both indices showed increases in AD 3K in 2021 and the trawl index could not be updated for AD 3LNO Offshore for 2021. The overall trap pre-recruit abundance index for AD 3L Inshore reached a time-series high in 2019–20 (Figure 41). In 2021, the catch rates of pre-recruits decreased, however remains high for the time series. In AD 4R3Pn, the trap pre-recruit abundance index decreased slightly in 2021 from a relative high period in recent years.

Looking at long-term recruitment prospects, the relatively low abundance of small crab (<50 mm CW) since the early 2000s (Figure 44), may suggest overall weak recruitment potential in the long term relative to levels experienced in the mid- to late-1990s. The pulse of small crab that emerged in the trawl surveys in 2013–14 was largely localized to ADs 2HJ and 3K (Figure 45). Slight increases in the abundance of small crab in the population in 2017 and more so in 2019–20 were most pronounced in ADs 3K and 3LNO Offshore. Recent abundance levels of small crab are generally not nearly as large as historic pulses. For example, the spring trawl surveys showed a relatively high level of small crab in AD 3Ps in 2010 (Figure 45) that is almost certainly associated with marked improvements in new-shelled recruits in 2017–19 in that AD (Figure 34). There had been a relatively steady-state broad distribution of low catch magnitude of small crab in AD 3Ps from 2013 to 2019 (Figure 45) inferring weak prospects after the currently emerging pulse of recruitment benefits the exploitable biomass and fishery over the next few years, however, this index increased slightly in 2021. The spike in small crab abundance seen in the 2010 AD 3LNO Offshore trawl survey is likely beginning to contribute to the exploitable biomass in that AD in the last few years (Figure 34, Figure 45). The recent improvements in small-mesh trap coverage in the CPS trap survey result in a short time series for inferring temporal trends in small crab abundance. The catch rates of these small crab show similar results to the trawl survey, with increases in ADs 2HJ, 3LNO Offshore, and 3Ps, and a decline in AD 3K (Figure 46). Trap data also show an increase in the catch rates in AD 4R3Pn and a decrease in AD 3L Inshore. The distribution of small crab has not contracted in recent years to the same extent seen in exploitable crab (Figure 47, Figure 48), with small crab still caught in most of the same areas despite generally lower catch magnitudes relative to the early part of the time series.

Females

The management regime of the NL (and most other commercially harvested) Snow Crab stock restricts all females and a large proportion of breeding males from exploitation. The fishery targets only the largest males, which constitute a small fraction of the overall population. A management strategy of maintaining a sufficient residual biomass of largest males, coupled with the ability of sub-legal-sized adolescent and adult males to successfully copulate and breed, is thought to safeguard reproductive capacity in the stock.

Although the relative abundance of mature females was generally highest in the mid-1990s (Figure 49), it has overall been variable throughout the time series in all ADs (Figure 45). The time series of mature female abundance has been particularly variable in AD 2HJ and there have been low abundance estimates, such as in 2020, 2015, and 2011. Careful monitoring of this trend, particularly in light of the declines in male size-at-terminal molt in this AD (see size-at-maturity section) will be important moving forward as this could have serious implications for reproductive potential in AD 2HJ and potentially other ADs considering upstream/downstream population connectivity. There was a particularly dramatic increase in the abundance index of mature females in AD 3K in 2020, however, this was due to a small number of tows with very large catches (Figure 50), indicated by large error bars around the estimate (Figure 45). The overall spatial distribution pattern observed in recent years is typical of a dominant shallow water presence of mature females (Figure 50, Figure 51). For example, relatively high abundance was consistently found on top of the Hamilton Bank and nearshore plateaus in AD 2HJ, in the shallow western portions of AD 3K, and along the shallow northern Grand Bank in AD 3LNO Offshore (Figure 50). AD 3Ps is overall the shallowest of all ADs, with females typically concentrated in the central portions of the division near the fringes of the St. Pierre and Green Banks (Figure 51). These shallow areas, where the majority of reproduction occurs, are typically very cold. Mullowney et al. (2018a) described winter and spring breeding migrations of female and male crab into shallow water along offshore parts of the NL shelf, a behavior known to occur in some inshore bays for decades.

The recent improvements in small-mesh trap coverage in the CPS trap survey result in a short time series for inferring temporal trends in mature female abundance. There have been declines in the catch rates of mature females in ADs 3L Inshore and 4R3Pn in recent years, while the recent trends have been variable in the other ADs (Figure 52).

The sporadic capture of females by the trawl survey throughout the time series could reflect their small size. This corresponds with a ‘trough’ in size frequency distributions from the Campelen trawl (Figure 53, Figure 54), and assumed poor catchability. However, variability in annual abundance indices could also reflect demographic changes in this component of the population. ‘Cyclic’ pulses of female abundance have been described in other areas, including the Northern Gulf of St. Lawrence (Sainte-Marie 1993; Sainte-Marie et al. 1996). For example, some chronological pulses of relatively high abundance of mature females are evident in the data, such as during 2008–09 in the trawl survey (Figure 49).

It is unknown to what extent mature female abundance influences future recruitment. Interestingly, historically, some of the largest recruitment pulses observed in the stock have been born from periods of low mature female abundance. For example, the 15–25 mm CW crab observed in the 2001–02 surveys (Figure 53) would have almost certainly been 2–3 years of age (Sainte-Marie et al. 1995) and therefore produced from the relatively low abundance levels of mature females that occurred in 1998–2000 (Figure 49). Further research into the importance of female abundance in regulating stock productivity is required.

Environment

Overall, virtually all population components were at low levels in all ADs in recent years (Figure 53, Figure 54), however some ADs are showing improvements. This suggests that the stock had been in an overall unproductive state for much of the past decade, but productivity may have been improving in the last three years. Cold bottom temperatures appear to promote terminal molt at small sizes in Snow Crab, resulting in relatively low recruitment and yield-per-crab from a given year class (Dawe et al. 2012). This outcome appears particularly applicable under low population densities of large males (Mullowney and Baker 2021). However, recruitment is more strongly affected by the positive effects of cold environmental conditions on year class production (Dawe et al. 2008; Marcello et al. 2012) than it is by the negative effects of cold conditions on size-at-terminal molt. This is consistent with positive benefits of cold conditions in promoting early- to mid-life survival and subsequently increased densities of crab in the population. Cold bottom temperature conditions have been experienced between the mid-1980s and the mid-1990s, and from about 2012 to 2017 (Cyr et al. 2022). The recent (modest) emergent pulse of small crab observed in many areas of the NL shelf has been associated with generally cooling oceanographic conditions in those recent years.

Spring and fall bottom temperatures have been generally warmer in the last four years than the 1991–2020 reference period (Figure 55, Figure 56). It was particularly warm in 2021, with the NL Climate Index (Cyr and Galbraith 2021) indicating it was one of the top three warmest years in the 70+ year time series (Cyr et al. 2022). Although a return to cooler conditions in recent years (2012–17) is positive because it appears to have promoted the emergence of a modest pulse of small crab, expectations for the future should be tempered as climatic conditions are still relatively warm. The ocean climate indices have varied considerably over the past decade, introducing uncertainty beyond the short term, but the overall trend is warming. Recent ‘cold’ bottom conditions are not as spatially or temporally expansive as they were in the late 1980s and early 1990s, from which the highest exploitable biomass levels in the mid- to late 1990s originated (Mullowney et al. 2014). Long-term abundance may heavily hinge on the extent to which the recent warming conditions are sustained, although it is unclear how environmental, anthropogenic, or other factors such as predation will affect the survival and progression of recruitment pulses throughout life.

A strong association of exploitable biomass with lagged Arctic Oscillation (AO) and El Niño Southern Oscillation (SO) has also been demonstrated (Figure 57). Although the association of these indices and future biomass is consistent with a linkage between cold conditions and high stock productivity (e.g., positive AO and NAO generally leads to cold conditions along the NL shelf), other climatic factors such as sea ice, bloom strength and timing, water mixing, food availability, or predator field dynamics may affect Snow Crab survival during early ontogeny. The lagged AO and SO analysis predicts that the exploitable biomass should continue to increase in the short-term, above average levels for the biomass time series (Figure 57), but then decrease to around time-series average levels. However, as mentioned above, the recent positive NAO phase (i.e., relatively strong for most of 2013–20) did not translate into bottom conditions as cold as observed in the early 1990s which were associated with the highest levels of small crab ever recorded. There is much uncertainty about the reliability of qualitatively relating recent climate events to long-term recruitment potential. Strong direct linkages of future biomass to climate forcings such as the NAO (Colbourne et al. 2011) could fail if additional factors such as excessive fishing or high predation affect recruitment and yield. Moreover, under anthropogenic climate change, there is uncertainty regarding whether such long-term oscillations will persist as they have in the past or how they will interact with additional forcings.

It is unclear if, or by how much, potential climate-predicted improvements will be affected by the fishery. In a review of stock drivers, Mullowney et al. (2014) warned that the fishery had the potential to take stronger control of stock productivity dynamics if exploitation rates were allowed to elevate during the predicted low biomass phase. Until the past few years, following a regime shift culminating in a collapse of most of the finfish community in the late-1980s and early-1990s (Buren et al. 2014), the Snow Crab resource appears to have largely been under bottom-up control, in association with low exploitation rates in the largest areas of abundance (i.e., AD 3LNO Offshore). However, recent assessments have highlighted that other factors such as top-down control from heavy exploitation and predation have increased in importance. In the most recent two years, substantially decreased fisheries exploitation rates have been associated with current improvements in the exploitable biomass index. Recent high exploitation rates across all ADs are a direct result of quota reductions not matching the scale of biomass declines, and unintended consequences such as reductions in size-at-maturity in males (see size-at-maturity section) can undoubtedly interfere with the environmental regulation of the resource.

Besides exerting a direct impact on early-life survival, climate shifts could affect Snow Crab productivity via other routes such as predation. A general prolonged shift toward warmer conditions throughout the 2000s appears to have affected the Snow Crab resource in the form of increased predation (Figure 58), as temperate finfish populations responded positively to warming (DFO 2014a; Rose and Rowe 2015; Pedersen et al. 2017). While the predation mortality index remained among the highest in recent years, there have been declines from the peaks of 2016-18 (Figure 58). The predation mortality index remained among the highest levels in 2J3K and 3LNO, but declined to its lowest value in over 25 years in 3Ps. Within 2J3K, predation mortality was substantially higher in 2J than in 3K. These declines in relative predation levels are likely the result of a combination of recent declines in predatory fish abundance during the colder mid-2010s, as well as the most recent pulse of small crab now outgrowing sizes consumed by most predators (i.e., <40 mm CW) (Chabot et al. 2008), as inferred by increases in some pre-recruit indices. The regulating effect of predation is thought to be most important on small to intermediate-sized crab, thus, a delay would be expected between decreases in the predation mortality index and recruitment into the exploitable biomass. In most ADs in recent years, a decline in predation mortality coupled with current decreased fisheries exploitation rates and increased pre-recruit abundance indices indicates a positive outlook in the next two to four years, if fishing pressure levels remain low enough to allow the crab to continue to recruit into the exploitable biomass.

With respect to overall ecosystem productivity, ecosystem conditions in the NL bioregion are indicative of a low productivity state. Total fish biomass levels remain much lower than prior to the finfish collapse in the early 1990s, however some ecosystem indicators (biomass trends and stomach content weights) appear to be improving in recent years. Improvements extend into the bases of the food-web, with a return to more average conditions in zooplankton community structure in recent years, which may have a positive impact on energy transfer to higher trophic levels.

Mortality

Until the last few years, the overall trajectory of most focal population components had been a prolonged decline of abundance or biomass indices for two decades in all ADs (Figure 59). The downward trajectory of recruitment into the exploitable biomass opposed total mortality rates gradually increasing in the exploitable component of the population until 2018. Total mortality in exploitable crab was very high in all ADs during 2015–17 (Figure 60). There are no indices of total mortality for ADs 3L Inshore and 4R3Pn as this calculation relies on trawl survey data.

In AD 2HJ, the total mortality index increased in 2020 and 2021 and remains highest in this AD (Figure 60). The trend in total mortality has reflected that of fishing mortality in recent years. In AD 3K, the total mortality index was at its highest levels (>75%) from 2016 to 2018, but has declined greatly in the last three years. The recent trends in total mortality indices in ADs 2HJ and 3K are likely influenced by crab movements across the divisional boundary. In the 2019 assessment (Baker et al. 2021), evidence was presented suggesting the possibility that recruits from AD 3K moved into southern portions of AD 2HJ as residual crab in 2018. In 2019, there were no indications that this persisted and therefore the calculation of total mortality based on present residual crab and previous recruits and residuals indicated a very low total mortality in AD 3K. Such issues have the potential to affect stock status interpretations and indicate the stock may be assessed at inappropriate spatial scales. The total mortality index was not calculated for AD 3LNO Offshore in 2021 due to the absence of a trawl survey in that AD, however, it has been low since the peak in 2016. The total mortality index of exploitable crab has varied considerably throughout the time series in AD 3Ps and was low in 2021. The high variability in the total mortality index in AD 3Ps likely reflects the shell condition-based methodology, with a spring survey potentially affecting the subjective shell condition classifications.

Natural Mortality

Bitter Crab Disease (BCD) is one important source of consistently measured natural mortality in the population. BCD has been observed, based on macroscopic observations of Snow Crab captured in the trawl surveys, at generally low levels throughout NAFO Divs. 2J3KLNOPs from 1995 to 2021 (Figure 61). The prevalence and distribution of BCD throughout the NL Shelf has been described in detail by Dawe (2002) and appears related to circulation features (Dawe et al. 2010b) and the density of small crab (Mullowney et al. 2011).

BCD, which is fatal to crab, occurs primarily in new-shelled crab of both sexes and is most commonly acquired during molting (Dawe 2002). Although the macroscopic analyses used to classify crab as infected are known to underestimate true prevalence, and trawl survey sample populations show lower levels of BCD than trap survey sample populations, a study using advanced polymerase chain reaction (PCR) techniques on specimens collected since the mid-2000s to identify infections has shown trends closely reflect the visually observed patterns seen throughout the region (DFO, unpublished data).

Spatially, the disease has tended to follow a pattern of being most prominent in shallow nearshore areas of the continental shelf with a virtual absence in deeper areas farther offshore. BCD has been consistently low in fall trawl surveys in AD 2HJ, although two consecutive years of prevalence exceeding 10% occurred for 60–75 mm CW crab in 2015 and 2016 (Figure 61). BCD is normally most prevalent in AD 3K. Recent years had seen levels of BCD of more than 10% in sizes >94 mm CW in AD 3K; however, BCD prevalence was restricted to the usual smaller sizes of crab in the 2021 survey. BCD is normally uncommon in AD 3LNO Offshore, but a prolonged pulse of relatively high incidence was observed in this AD from approximately 2001 to 2006, most prominent in 40–59 mm CW crab. This sustained pulse of BCD likely reflected progression of the recruitment pulse detected in the trawl surveys as 20–30 mm CW crab in 2001–03 (Figure 53), which was subsequently tracked as pre-recruits in surveys from 2008 to 2010 (Figure 40).

The most reliable size group of Snow Crab assessed for the impact of BCD on the population is the 40–59 mm CW size group, with these small to mid-sized animals commonly visibly infected (Mullowney et al. 2011). Overall, the relatively low level of BCD observed in this size group in recent years is positive because it suggests this source of natural mortality is killing fewer small crab than historically. However, it is also negative because it suggests a decreased density of these animals, representing future fishery prospects. This index will be important to monitor as presently emerging pulses of small crab reach sizes commonly associated with BCD infection.

Fishing Mortality

Beyond direct removals of crab from the system, the fishery also imposes mortality on Snow Crab through discarding. Crab that are caught and released as undersized or legal-sized soft-shell males are subject to multiple stresses and have unknown survival rates. Time out of water, air temperature, water temperature, wind speed, sunlight, shell hardness, and crab size may all influence the mortality level on discarded Snow Crab (Miller 1977; Dufour et al. 1997; Grant 2003; van Taemelen 2005; Urban 2015). Soft-shell crab are likely subject to more damage and mortality than hard-shelled crab. Poor handling practices, such as prolonged exposure on deck and dropping or throwing crab, induces limb loss and also leads to increased mortality levels associated with catching and discarding crab (Grant 2003).

In a study in the Bering Sea, Urban (2015) predicted only about 5% mortality on discarded Snow Crab. This estimate is virtually identical to the estimate of Grant (2003) in NL for Snow Crab subjected to best handling practices, specifically in the form of minimal dropping distances and exposure time on deck. However, Grant (2003) showed that mortality rates increased substantially under poor handling practices. It must be noted that both studies featured predominately hard-shelled crab and both authors cautioned that unobserved latent mortality was unaccounted for in their studies. Despite not knowing absolute discard mortality rates, minimizing fisheries-induced mortality and wastage of crab not retained in the fishery (particularly most vulnerable soft-shell pre-recruits which are suspected to experience higher rates of discard mortality) is a best advised practice for the NL Snow Crab fishery.

There was particular concern in recent years for ADs 2HJ and 3L Inshore, where discard levels were very high at approximately 40% of the catch in 2019 (Figure 62). At-sea observer sampling data suggest that the discards in AD 2HJ have been comprised of mostly legal-sized soft-shell crab, while the bulk of discards in AD 3L Inshore have been undersized, old-shelled crab (Figure 63). Accordingly, relative levels of resource wastage in the form of discard mortality are likely highest in the AD 2HJ fishery, assuming survival is lowest in soft-shell crab. Trends in discards composition are not available for all ADs in 2020 and ADs 3L Inshore, 3Ps, and 4R3Pn in 2021 due to poor at-sea observer coverage. In 2021, discard levels declined in ADs 2HJ and 3K, and remained near the same level in AD 3LNO Offshore (Figure 62). Soft-shell incidence has featured relatively prominently in the observed catch in ADs 2HJ and 3K throughout the time series and was associated with generally low and declining recruitment and exploitable biomass. However, in 2021 the majority of discarded crab in AD 3K were represented by undersized hard-shelled crab, while soft-shell crab composed the majority of discards in AD 2HJ. In AD 3LNO Offshore, the majority of discards are also composed of undersized hard-shelled crab. Historically, there had to be higher levels of soft-shell crab in the population in this area, as the resource was consistently productive and strong recruitment occurred each year. The historic situation likely reflects imposition of an efficient harvest that maintained a strong residual biomass that prohibited persistent high levels of soft-shell crab from emerging as a major concern in the fishery through trap competition.

Measures should be taken not only to reduce soft-shell encounters overall, but to better quantify prevalence of soft-shell crab in the fishery and afford better protection to incoming recruitment. A high incidence of soft-shell crab in the catch ultimately reflects inefficiency in resource extraction. It is wastage that occurs on pre-recruits and constitutes an opportunity cost to the future fishery as well as a biological loss to future reproductive potential.

Prevalence of legal-sized soft-shell males in the fishery is affected by fishery timing and exploitable biomass level. From a biological perspective, the optimal time to harvest Snow Crab to avoid soft-shell individuals in the catch is winter. However, in the absence of an ability to conduct a winter fishery, mortality on soft-shell males can be minimized by fishing early in spring before recently-molted crabs are capable of climbing into traps. It can be further reduced by maintaining a relatively high exploitable biomass level, thereby maintaining strong competition for baited traps and low catchability of less-competitive soft-shell immediate pre-recruits, even during peak soft-shell periods (Mullowney et al. 2021). Discard levels in the fishery are generally negatively related to CPUE, suggesting that maintaining a high fishery CPUE is a good management strategy to avoid high discarding (Figure 64) (Mullowney et al. 2018b).

Overall, the many shortcomings of the soft-shell protocol (described in the fishery introduction section) undermine its intent of safeguarding against handling mortality in the fishery. As it has been and continues to be invoked, the soft-shell protocol can serve as a basis to enable and prolong fishing on soft-shell crab under the auspice of conservation rather than preventing mortality to soft-shell crab. The soft-shell protocol as currently invoked is not an effective conservation tool to safeguard against handling mortality in this fishery and should be reexamined.

Trends in total mortality generally reflect those of fishing-induced mortality, as measured by ERIs. ADs currently experiencing notable recovery in the exploitable biomass (i.e., 3K, 3LNO Offshore) are associated with reduced total mortality rates and associated reductions in exploitation rates, while ADs remaining at low levels with little signs of recovery (i.e., 2HJ) are associated with persistent high total mortality and exploitation rates (Figure 60). Evidence suggests that reducing exploitation rates constitutes an effective strategy toward promoting recovery of the exploitable biomass. This is further bolstered by the presence of stronger residual components to the exploitable biomass in less heavily exploited areas. Generally, maintaining high catch rates is a good management strategy to avoid high discarding (Figure 65).

In AD 2HJ, the ERI increased in 2021 (Figure 60). Under status quo removals in 2022 the ERI would further increase to over 60% of the exploitable biomass index. In AD 3K, the ERI declined from a decadal high in 2017 to a time-series low in 2021. Under status quo removals in 2022 the ERI would further decrease. In AD 3LNO Offshore, the ERI increased by a factor of five from

2014–17, but declined to below the time-series average in 2021. The ERI would remain near this level with status quo removals in 2022. The trawl-derived ERI is usually used in this calculation in AD 3LNO Offshore, however the trap-derived estimate was used for 2021 in the time series in the absence of trawl data.

There are no trawl-derived exploitable biomass indices available in ADs 3L Inshore and 4R3Pn from which to calculate ERIs. Accordingly, the shorter time series of trap surveys are used as the basis (Figure 66). The trap-derived exploitable biomass index is also used for AD 3Ps as the trawl survey takes place within season, as opposed to the post-season as in the other ADs. In AD 3L Inshore, the trap-derived ERI increased in 2013 and remained at its highest observed level until 2018 but decreased to near time-series low levels in 2021. Status quo removals would decrease the ERI to a time-series low in 2022. The consequences of such high exploitation in recent years are unknown, but the potential for biological harm to the resource through fishing elevates as exploitation reaches and becomes sustained at such high levels. In AD 3Ps, the trap-derived ERI increased slightly in 2021. Under status quo removals in 2022, the ERI would decline to a time-series low. In AD 4R3Pn, the trap-derived ERI increased to over 60% in 2021; however, with status quo removals in 2022, the ERI would decrease.

In the NL Snow Crab fishery ERIs are overall very high relative to other major fisheries for the species in Atlantic Canada and Alaska, particularly the high ERIs seen in most ADs in the late-2010s and maintained in AD 2HJ. For example, exploitation rates above 45% are not permitted under the PA frameworks used to manage the Snow Crab fishery in the southern Gulf of St. Lawrence, even when the biomass is extremely high (DFO 2014b). In NL, conservative (i.e., likely underestimated) estimates of fishing exploitation rates have routinely been >50% and have been as high as 80% in some ADs in some years. Of particular note, the lack of old-shell crab in the biomass, even at largest sizes associated with terminally molted animals, is concerning (Figure 67). The virtual absence of large old-shell males in the population is not typical of the population structure for other fished Snow Crab populations globally. The strategy of exploiting heavily and near-wholly relying on incoming recruitment each year is risky with respect to the possibility of unforeseen events to affect recruitment. Moreover, experience has shown that areas with low residual biomasses are generally associated with wasteful practices and recruitment overfishing, with soft-shell prevalence and discard rates generally high in the presence of high exploitation and low residual biomass.

Beyond promoting risk and wastage in the fishery, high exploitation rates greatly increase the potential for negative biological outcomes in the population. There has been an inability for fisheries to take quotas in some ADs in recent years. Accordingly, in several areas it is possible for fisheries to capture almost all available exploitable males in a given year. The strategy of removing most large males from the population could have serious consequences such as sperm limitation in females or changes in growth patterns or maturation sizes. Large hard-shelled males are the prime breeders and likely serve to introduce sufficient intraspecific competition in the population to promote large size-at-terminal molt. As in many animal populations, large competitive males serve to maintain reproductive integrity as well as physically structure population demographics. The outcomes of the scenario of rendering the population virtually void of large males in some areas will be important to continue to monitor from biological and management advice perspectives. Overall, the scenario of a low exploitable biomass coupled with high exploitation rates suggests a relatively low likelihood of any appreciable long-term gains in some ADs. This scenario is most apparent in AD 2HJ. This situation of heavy exploitation leading to severe depletion of large males that is being maintained in AD 2HJ is further exacerbated by surplus mortality on soft-shell pre-recruits, as their capture incidence often scales as a function of ERI (Mullowney et al. 2021), thus further compromising recovery potential. A lower exploitation rate would be required to promote recovery of the exploitable biomass.

In contrast to AD 2HJ, improved signals of recruitment potential (Figure 68, Figure 69) as well as decreasing exploitation rates (Figure 60, Figure 66) in most other ADs should result in forthcoming gains if fisheries-induced mortality is not excessive in the forthcoming years. Biologically, recent works have verified that it is safest to maintain a high residual biomass component of the exploitable male population if biological harm through fishing is to be avoided (Mullowney and Baker 2021) and recruitment overfishing minimized (Mullowney et al. 2021). All ADs except 2HJ have begun to better adhere to these principles in recent years.

Size-at-maturity

A sharp decline in male size-at-maturity (i.e., size-at-terminal molt) occurred in all major ADs around 2015–17, but increases have been occurring since (Figure 70). However, in AD 2HJ, the male size-at-maturity is still much lower than historical low periods and is well below exploitable size (i.e., 62–76 mm CW since 2015). These results suggest that any improvements in recruitment potential could be significantly dampened, unless male size-at-maturity recovers to previous levels.

Recent research found that the pronounced shift in male size-at-maturity in AD 2HJ was a consequence of a concomitant combination of cold conditions and low density of large males (Mullowney and Baker 2021). This study shows that low densities of large males promote a small terminal molt size and consequently high exploitation can affect molting dynamics. While temperature also affects molting and growth dynamics, this study asserts that other factors interact with temperature to regulate molting, as this shift has not been seen in female size-at-maturity under the same environmental conditions or under similar or more extreme historical cold periods. The emergence or potential reversal of this phenomenon will be important to monitor moving forward as persistent decreased size-at-maturity would negatively impact stock and subsequently fishery productivity. The potential for these changes to affect reproductive success is possible; the mating behaviors of Snow Crab rely on large males and small females. Trends in size-at-maturity should continue to be monitored closely.

Precautionary Approach

In 2022, assuming status-quo removals, CPUE is predicted to be in the Healthy Zone in all ADs, except AD 2HJ, where the predicted CPUE for 2022 is very close to the LRP in the Cautious Zone (Figure 71).

Discards levels, assuming status-quo removals, is predicted to be in the Healthy Zone in ADs 3K and 3LNO Offshore, and in the Cautious Zone in ADs 2HJ, 3L Inshore, and 3Ps for 2022 (Figure 71).

To monitor reproductive health, an index of egg clutches of females is used (Figure 71). Data from both the fall and spring surveys throughout Divs. 2HJ3KLNOPs show that in nearly all years the vast majority (i.e., >80%) of mature females are carrying full clutches of viable eggs. In 2021, all ADs were in the Healthy Zone for egg clutches; however, with no 2021 point for AD 3LNO Offshore trawl survey, the 2021 CPS index value was used as a substitute.

Mature females store sperm and can produce multiple clutches of eggs from a single mating season (Sainte-Marie 1993). The ability of males to mate multiple females and of females to store sperm ensure that a large portion of mature females should have full-egg clutches. Although it is believed that per capita fecundity can be impacted by excessive fishery exploitation of males, it has not been persistently observed to date in NL Snow Crab. However, some notable exceptions have occurred in the clutch fullness index in all ADs. Low percentages of clutch fullness were observed in AD 2HJ in 2006 and 2007, in AD 3K in 2015, in AD 3LNO Offshore in 2013 (note uncertainty in 2014 due to incomplete survey) and in AD 3Ps in 2014–16 (Figure 71). With no broad-scale prolonged periods of low clutch fullness presently, the overall evidence suggests that the species may maintain a high level of reproductive resiliency to historic levels of fishery exploitation. To benefit management by assessing the extent to which high exploitation rates can be sustained before unwanted changes or harm is caused to the resource, investigations into possible top-down fishery effects in light of current high exploitation rates on males in most ADs are warranted. This includes more in-depth monitoring of female insemination levels.

In early-2020, members of the harvesting sector submitted an alternative PA Framework for Snow Crab to be reviewed. Following peer review, this alternate PA Framework was not accepted and the DFO Science LRPs remained in place. A working group was reestablished to bring forward a series of recommendations to DFO on the USRs and HCRs. Discussions have been productive, and progress is ongoing, but the HCRs had not been finalized by the time of the assessment. A scoring system has been developed to incorporate the stock status of the three metrics into one stock health score (Figure 72). In 2022, all ADs are projected to be in the Healthy Zone in the provisional PA Framework, except AD 2HJ which is projected to be in the Cautious Zone (Figure 73). These projections assume status quo landings. Recent and ongoing data deficiencies resulted in the exclusion of AD 4R3Pn in the provisional PA Framework.

CONCLUSIONS

Assessment Division 2HJ

Overall, key resource indicators suggest there has been a prolonged period of low resource available to the fishery, with both the exploitable biomass and recruitment indices near their lowest observed levels for many years. The ERI has been high throughout most of the time series relative to other ADs within NL, as well as other fished Snow Crab stocks globally. Status quo removals in 2022 would further increase the ERI to above 60% of the exploitable biomass. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Cautious Zone in 2022. In addition to low residual biomass and high fishing pressure, there have been declines in the male size-at-terminal molt and mature female abundance index in AD 2HJ. These declines are very concerning and could dampen recruitment if a higher proportion of males reach their terminal molt below exploitable size and declines in mature females result in lower egg production.

Assessment Division 3K

Overall, prospects in AD 3K are favourable. The exploitable biomass index increased over the last three years and was dominated by recruits, suggesting improvements in the coming year. Total mortality of exploitable crab has declined in recent years. The ERI has been high throughout most of the time series relative to other ADs within NL, as well as other fished Snow Crab stocks globally, but has been at a much lower level since 2020. Status quo removals in 2022 would maintain the ERI at the time-series low. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2022.

Assessment Division 3L Inshore

Overall, virtually all data are coherent and consistent in showing a broad-scale depleted exploitable biomass in recent years, that has been showing some improvements over the last three years. Recruitment has remained steady for the last four years, above the low in 2017.

There have been some emerging pulses of pre-recruits in the population that could lead to improvements in the fishery within a few years and therefore localized improvements in overall biomass available to the fishery could occur within the next two to four years. The overall ERI has declined from recent high levels to a more moderate level of exploitation. Status quo removals in 2022 would reduce the ERI to a time-series low. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2022.

There has been considerable spatiotemporal variability in stock status among the CMAs throughout the time series, however this appears to have diminished in the most recent years. It is unknown how broad-scale forthcoming improvements beyond 2022, if they become manifest, may be, as movement and density-dependent regulation dynamics are relatively poorly understood both among the CMAs within the AD as well as in association with neighbouring ADs.

Assessment Division 3LNO Offshore

Overall, prospects in AD 3LNO Offshore are favourable. There have been an increasing trend in the exploitable biomass index in both the trawl and trap surveys in the last three to four years. There has been low total mortality in recent years, however this was not updated in 2021. While there may be improvements coming in the AD in the short-term, trap survey pre-recruit indices have decreased in the last two years and there was no updated pre-recruit information from the trawl survey to inform trends. This AD had a period of high ERI from 2014–17, but the ERI declined significantly in the last four years. Status quo removals in 2022 would further reduce the ERI. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2022.

This AD constitutes the bulk of the NL Snow Crab stock; it drives virtually all overall stock trends. The AD functions as a broad-scale biological unit and numerous arbitrary CMA lines and associated CMA-specific management decisions may affect its biological functioning. Crab movements are known to extend across CMA boundaries (Mullowney et al. 2018a) and key resource trends are clearly broad scale.

Assessment Division 3Ps

Overall, prospects in AD 3Ps are favourable. The exploitable biomass index increased in 2021 to a decadal high. The low exploitation rates in 2017 and 2018 are not thought to be inconsequential to this improvement. There may be improvements coming in the AD, with increases in recruitment and pre-recruitment indices in the trawl survey indicating improvements in the short-term, but the level of improvements from these indices in two to four years is uncertain. The pre-recruit index in the trap survey has shown a declining trend in the last three years. The ERI declined in 2021 and status quo removals in 2022 would maintain the ERI at this low level. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2022.

Assessment Division 4R3Pn

The exploitable biomass index increased over the past three years and was dominated by recruits, suggesting improvements in the coming year. The overall ERI increased in 2021, however with status quo removals in 2022, the ERI would decline to near time-series lows. Poor monitoring coverage throughout this AD, particularly outside the main fishing areas of CMAs 12C and 12EF, results in large uncertainty in the biomass estimates provided in 2021 and predictions for 2022. Caution is warranted when developing conclusions from these estimates as it does not represent the entire stock area in this AD. Recent and ongoing data deficiencies do not allow inclusion of this AD into the provisional PA Framework.

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TABLES

Table 1. Exploitable biomass estimates for AD 3LNO Offshore from seven models to fill missing 2021 value in the trawl time series.

Model Approach	Exploitable Biomass Estimate (kt)
1 – Pre-recruits model	135.4
2 – 3K and 3Ps model	120.2
3 – Arctic Oscillation/Southern Oscillation growth model	119.2
4 – Arctic Oscillation/sea ice extent birth model	78.3
5 – Mass balance model	134.3
6 – SPiCT surplus production model	123.9
7 – CPS index	121.8

FIGURES

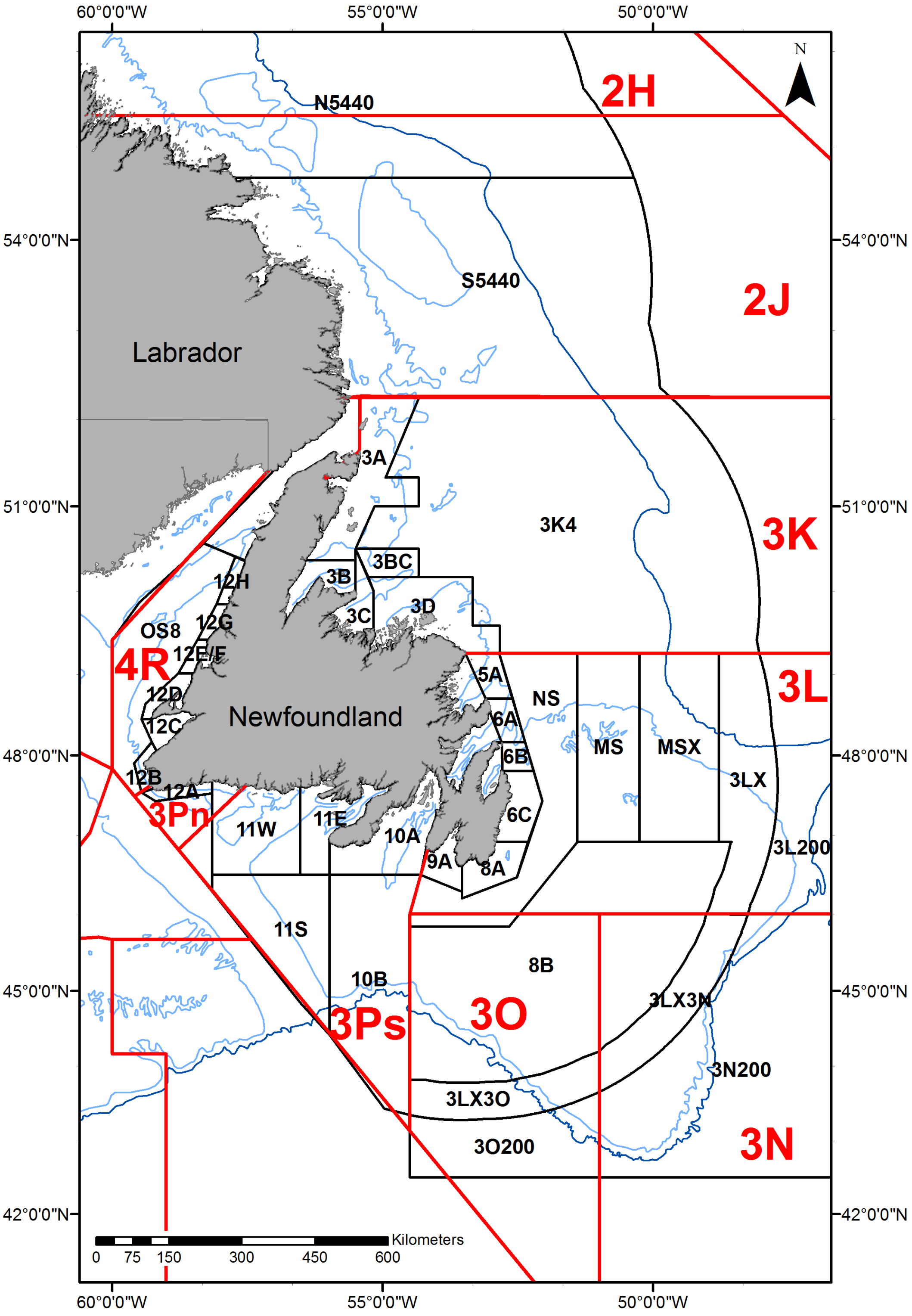


Figure 1. North Atlantic Fisheries Organization (NAFO) Divisions (red lines) and Newfoundland and Labrador Snow Crab Management Areas (CMAs) (black lines).

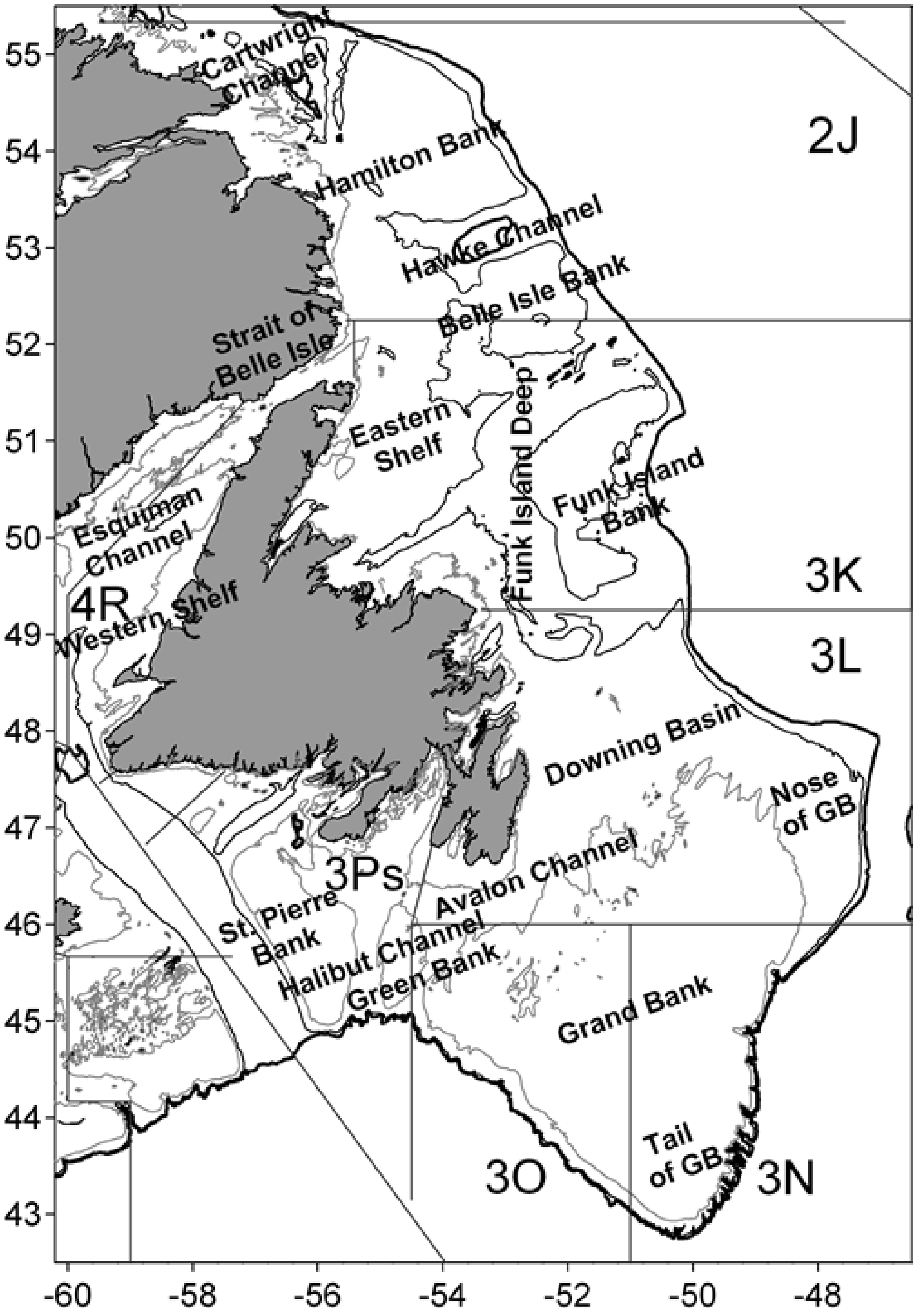


Figure 2. Map of Newfoundland and Labrador Continental Shelf showing place names, bathymetrical features, and NAFO Divisions.

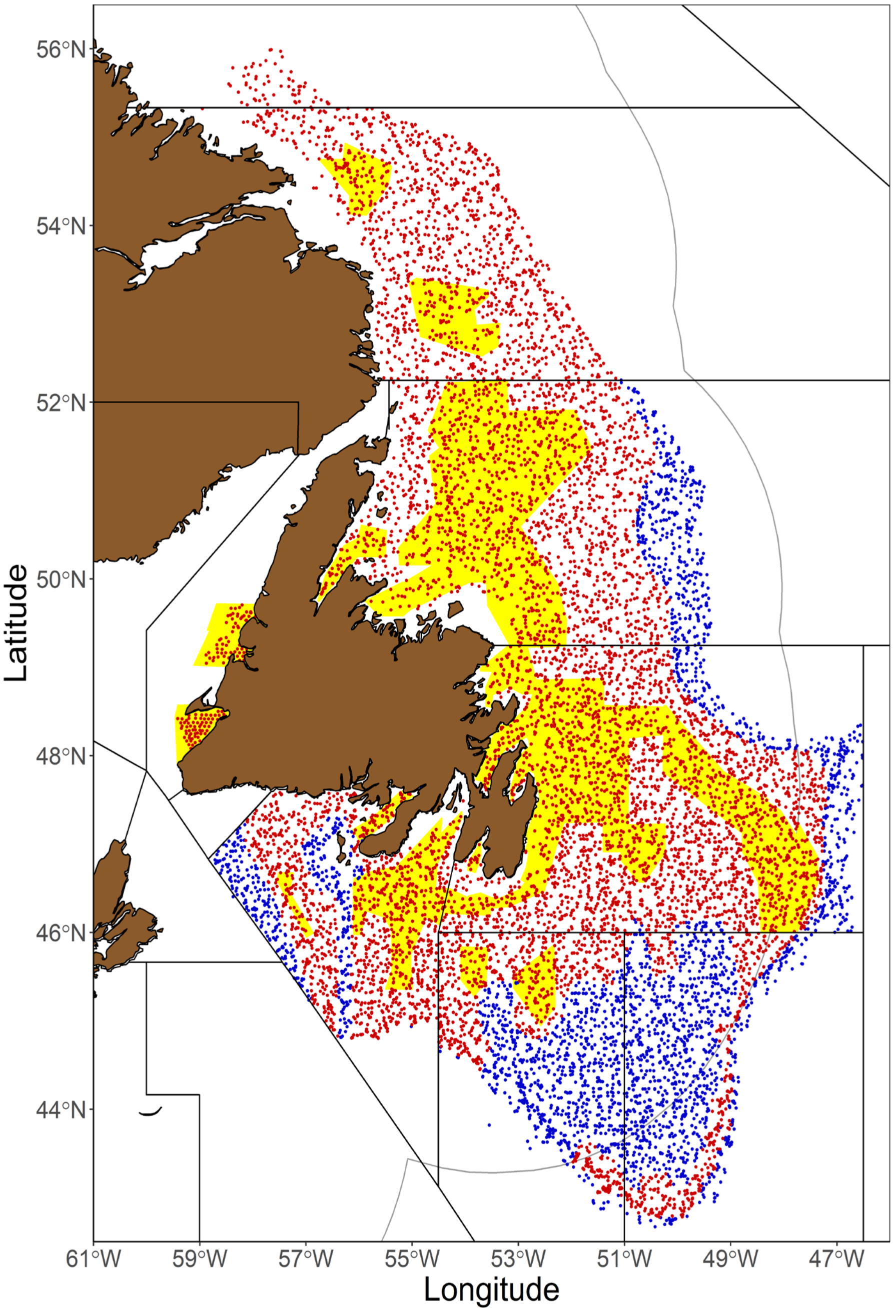


Figure 3. Map of Ogmap vertices (red + blue points) used for biomass and abundance estimation from trawl survey data, and Ogtrap vertices (red points) and Ogtrap strata (yellow polygons) for biomass estimation for all stations and core stations, respectively, from the DFO, CPS, and Torngat trap surveys.

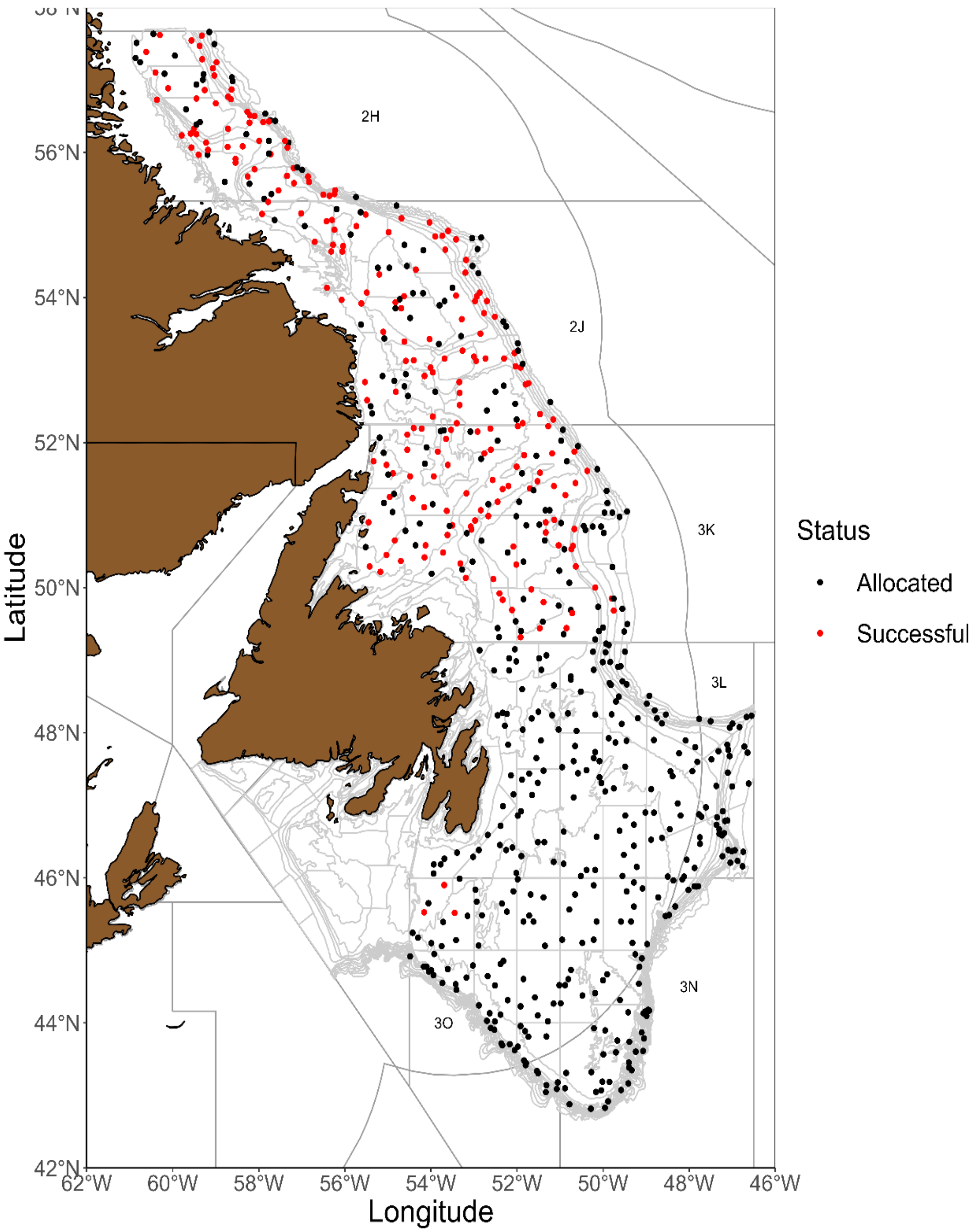


Figure 4. Set allocation (black) and successful sets (red) from the 2021 DFO fall multispecies trawl survey.

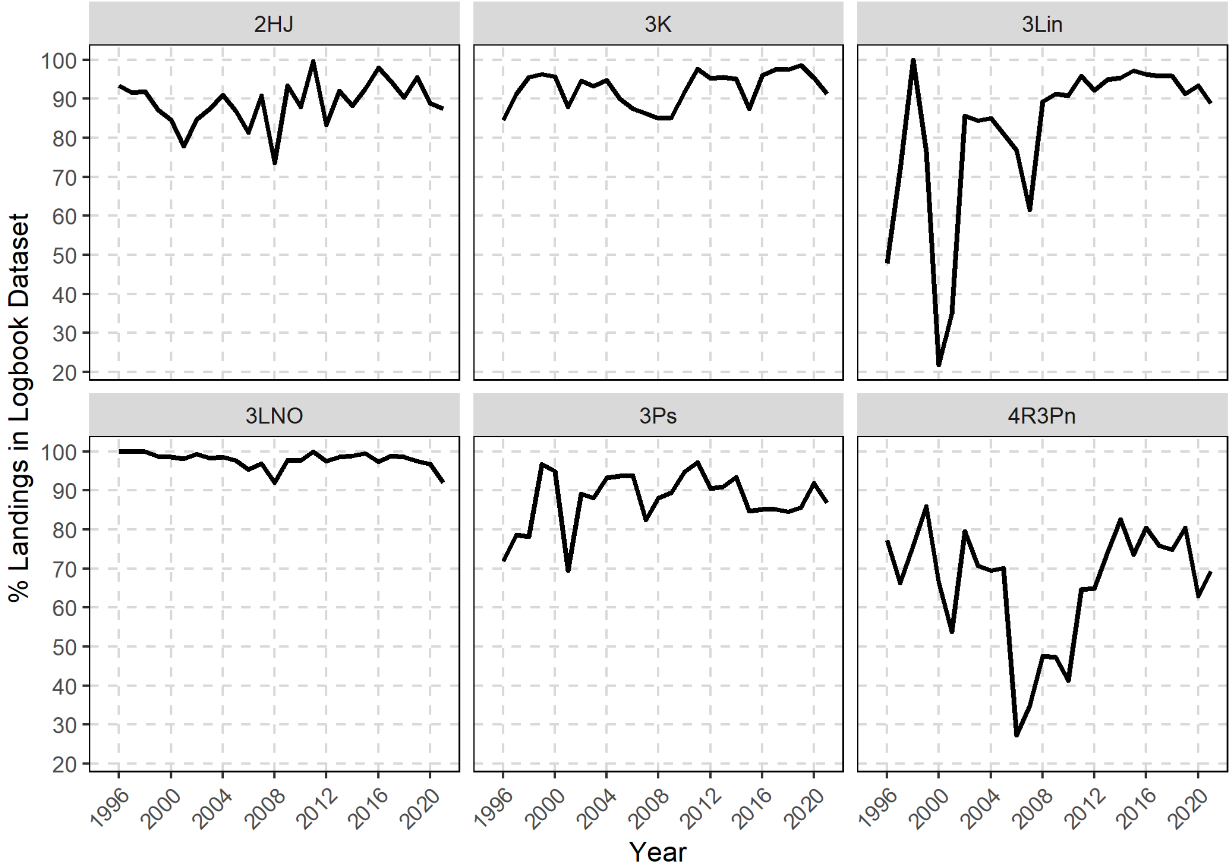


Figure 5. Logbook return rates by Assessment Division and year (1995–2021).

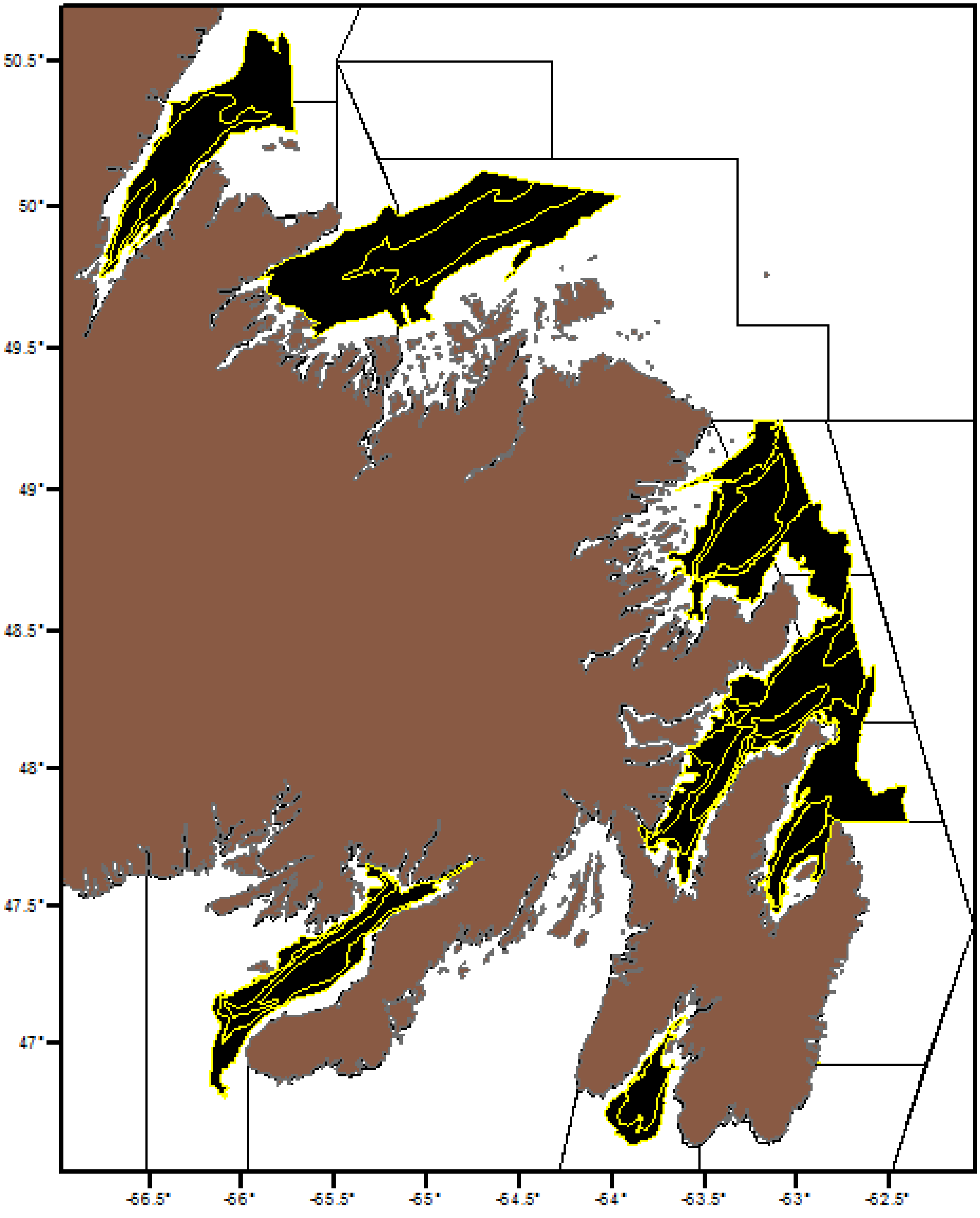


Figure 6. Strata occupied during Inshore DFO trap surveys.

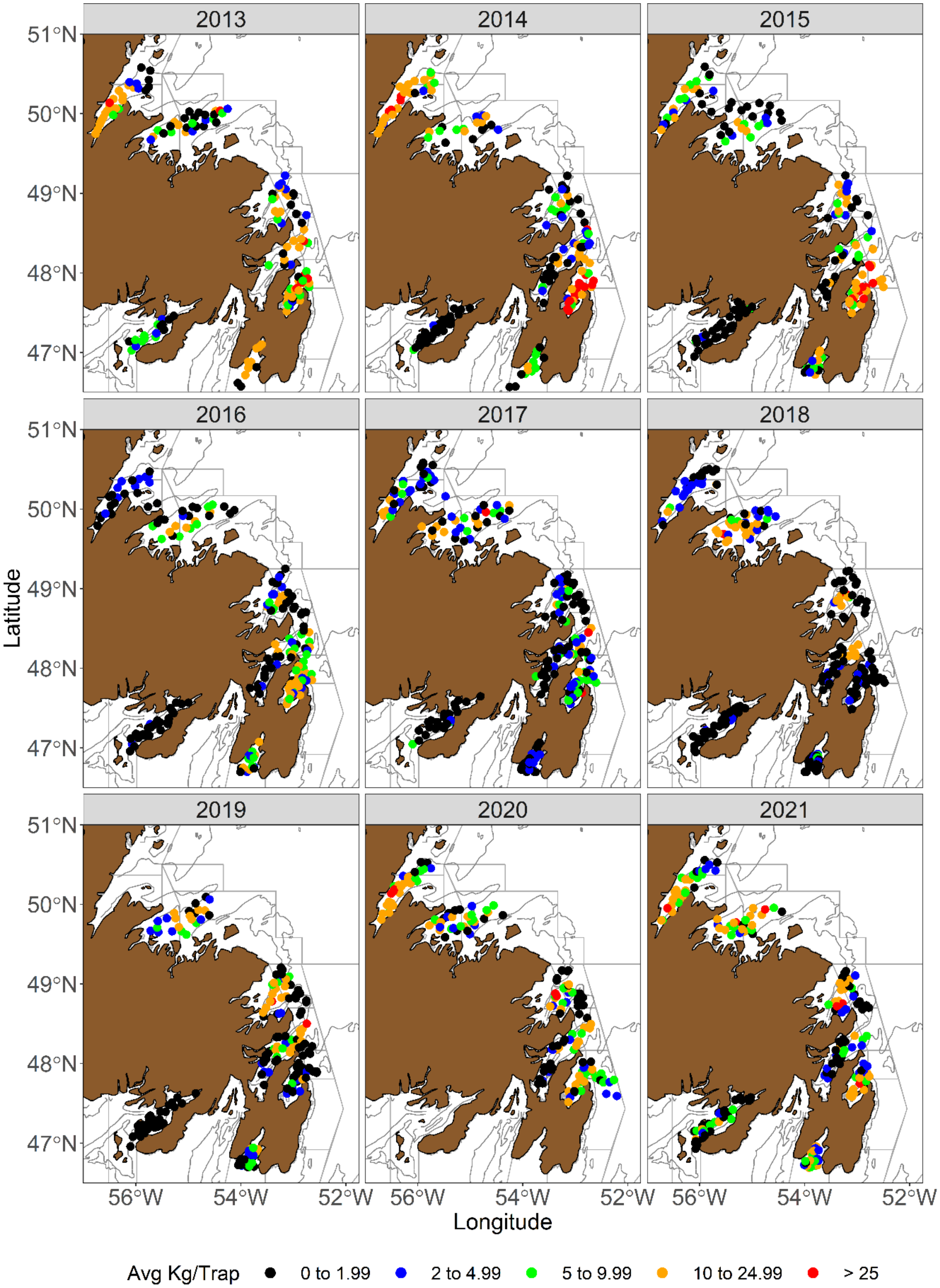


Figure 7. Location of set positions and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the Inshore DFO trap surveys (2013–21).

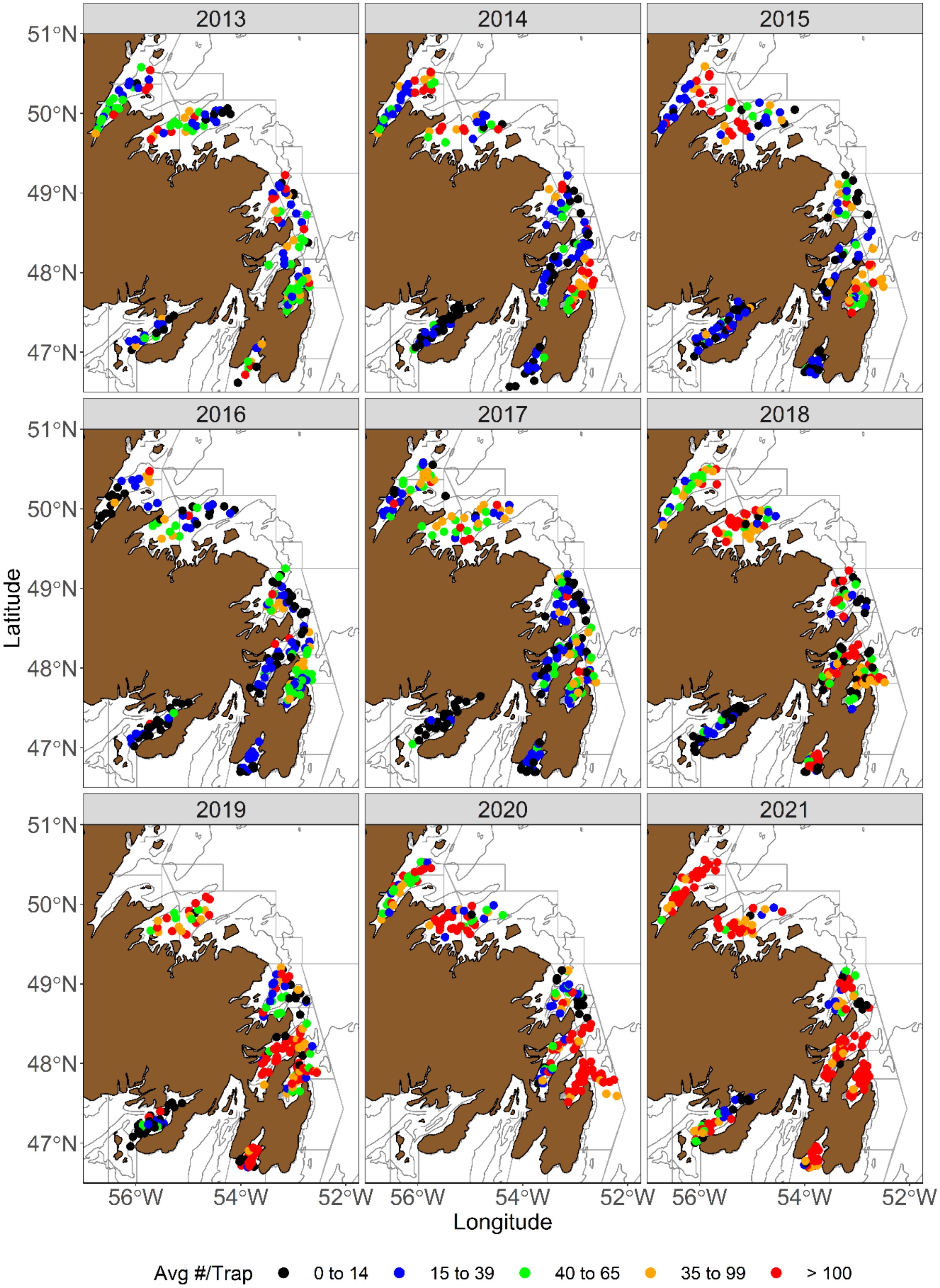


Figure 8. Location of set positions and CPUE (#/trap) of all Snow Crab in small-mesh traps from the Inshore DFO trap surveys (2013–21).

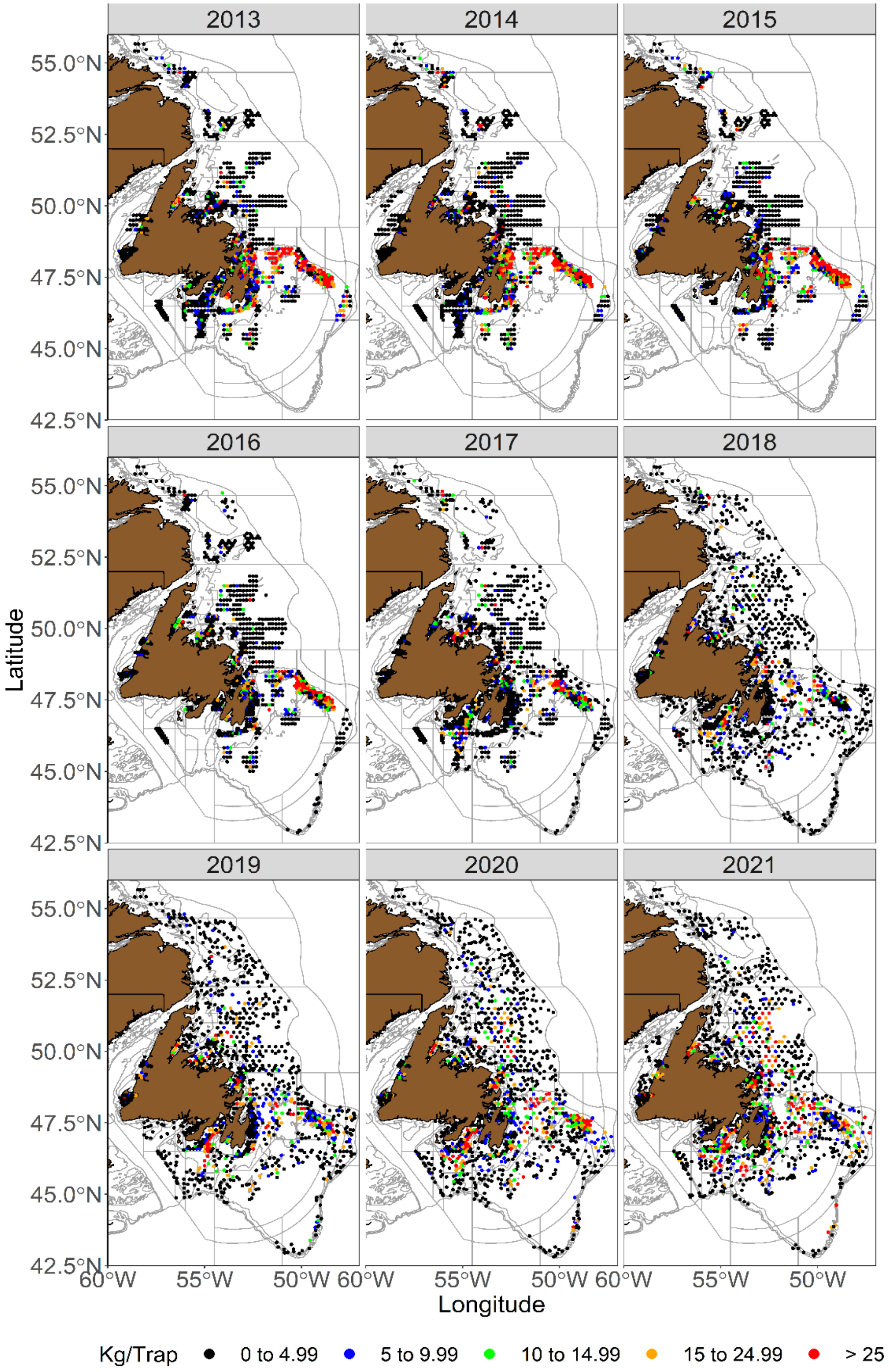


Figure 9. Location of set locations and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the Collaborative Post-Season (CPS) trap survey and Torngat Joint Fisheries Board trap survey (2013–21).

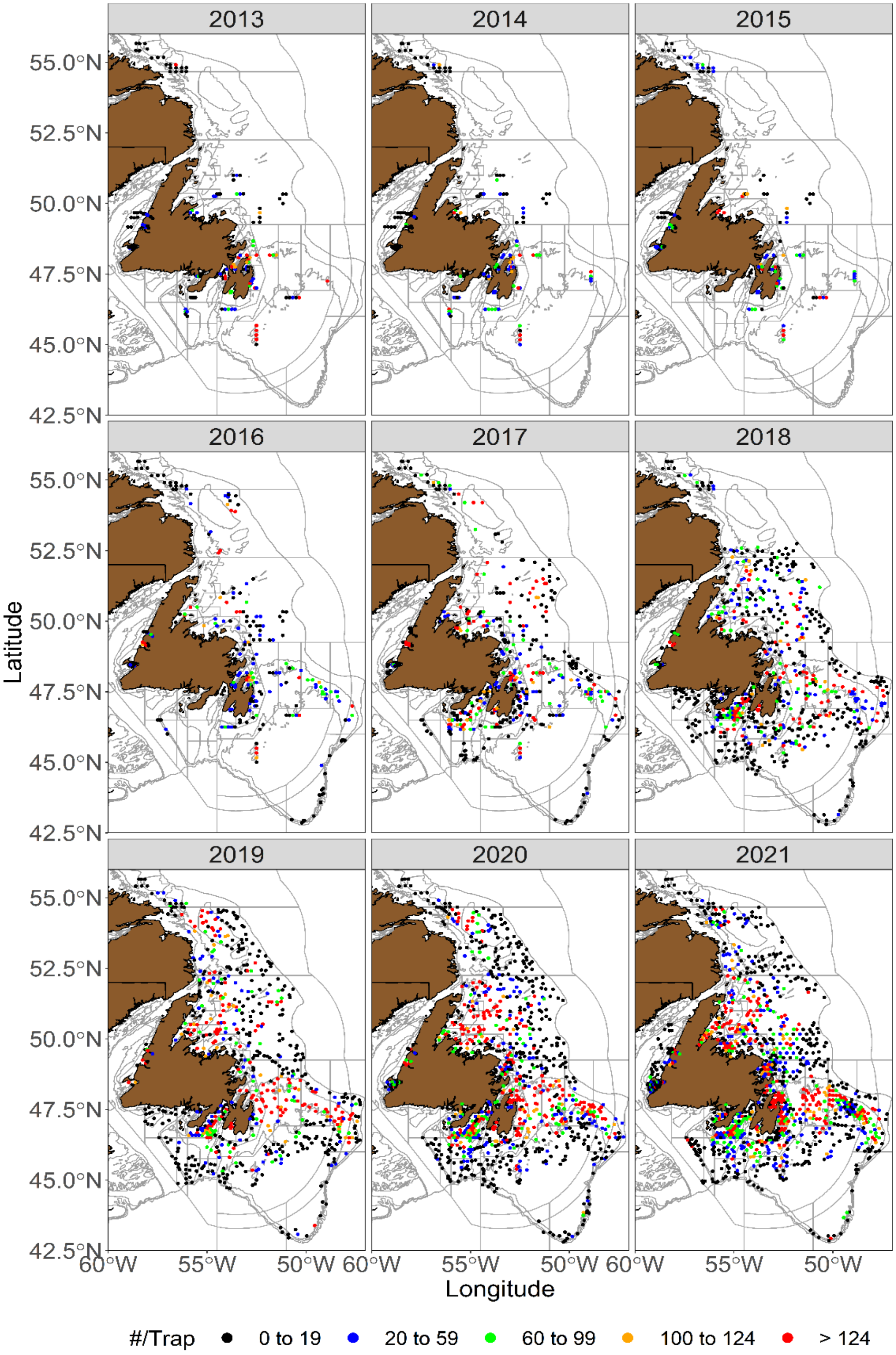


Figure 10. Location of set locations and CPUE (#/trap) of Snow Crab in small-mesh traps from the Collaborative Post-Season (CPS) trap survey and Torngat Joint Fisheries Board trap survey (2013–21).

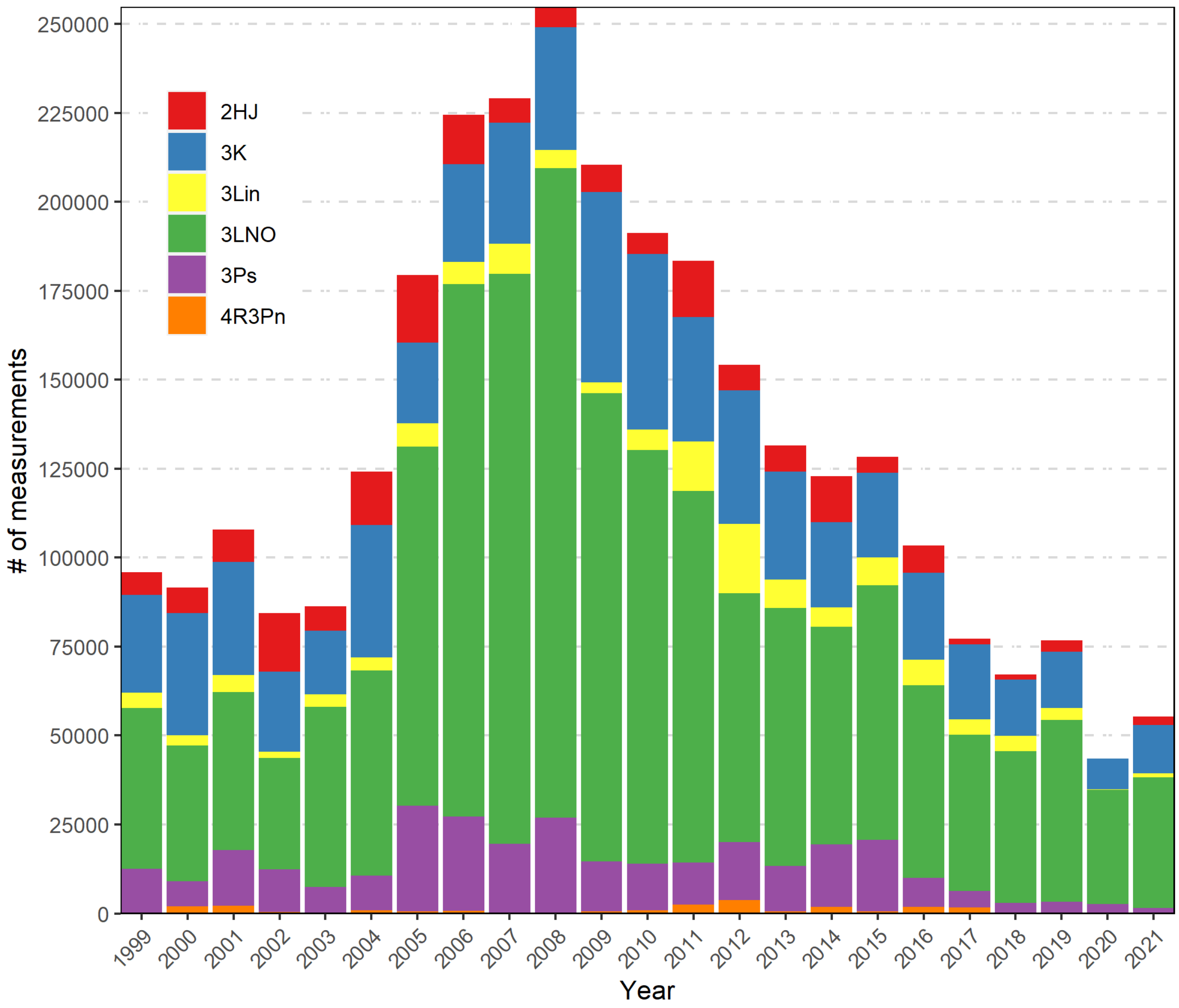


Figure 11. Annual at-sea observer sampling by Assessment Division (1999–2021).

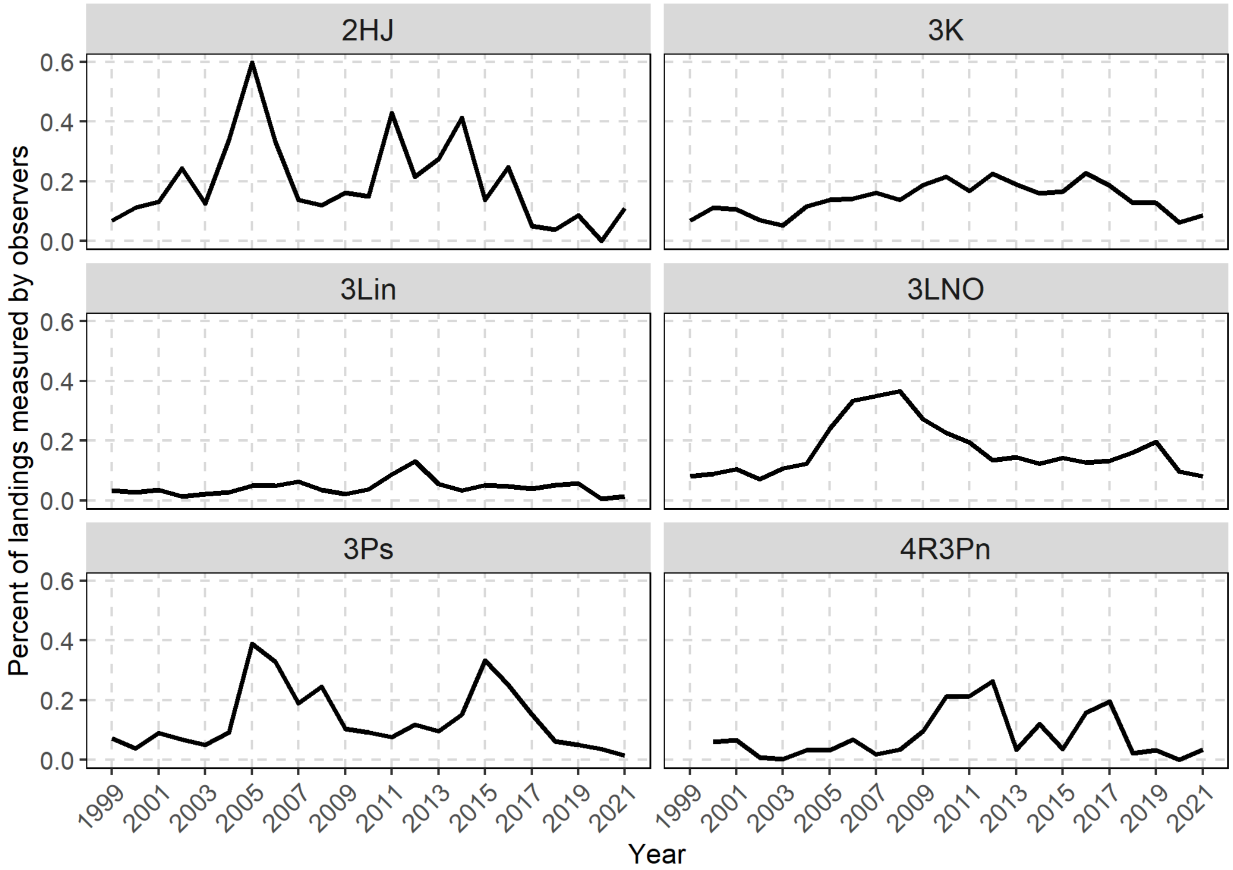


Figure 12. Percent of landings with annual at-sea observer sampling by Assessment Division (1999–2021).

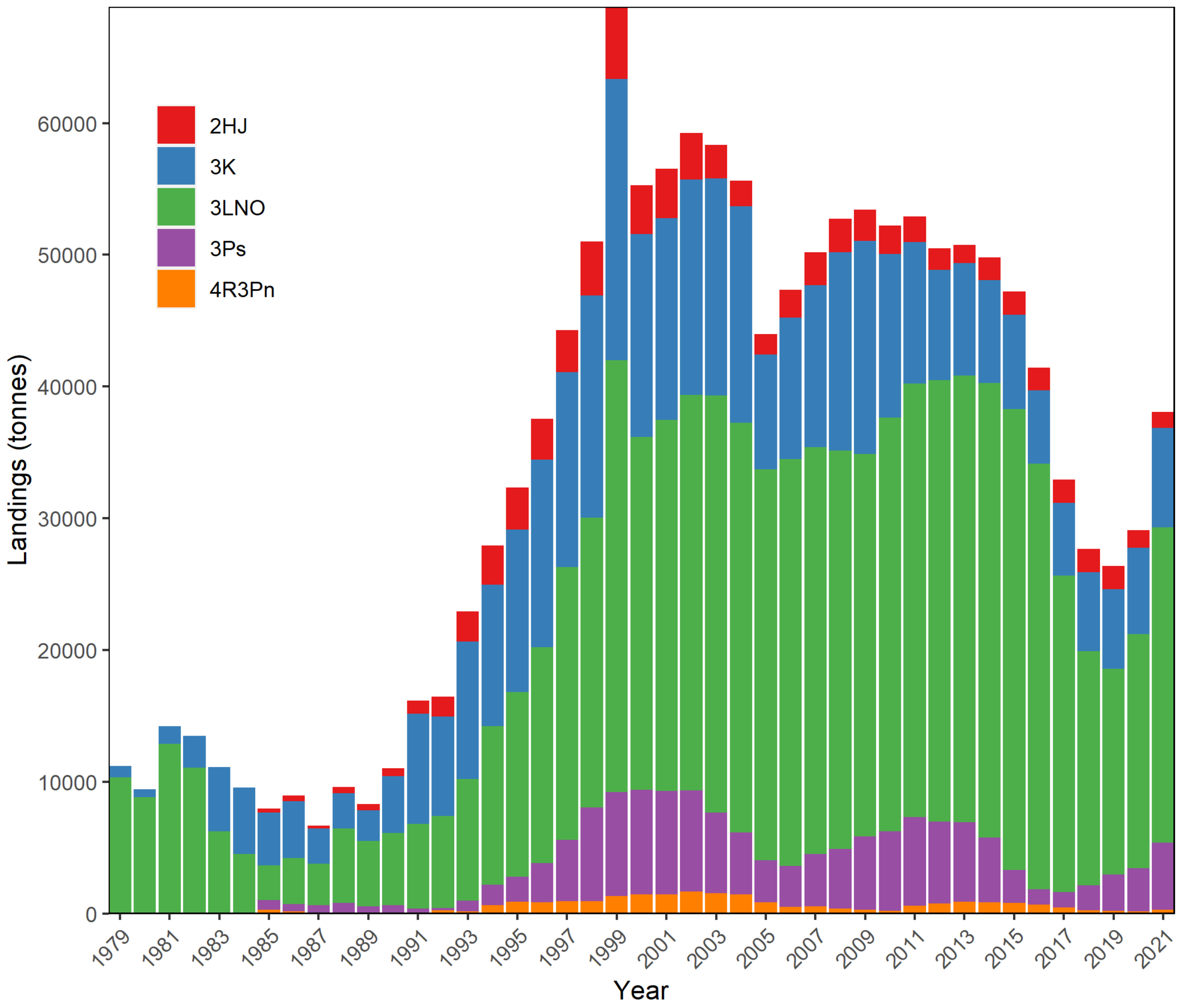


Figure 13. Annual landings (tonnes) of Snow Crab by Assessment Division (3LNO = 3LNO Offshore + 3L Inshore) (1979–2021).

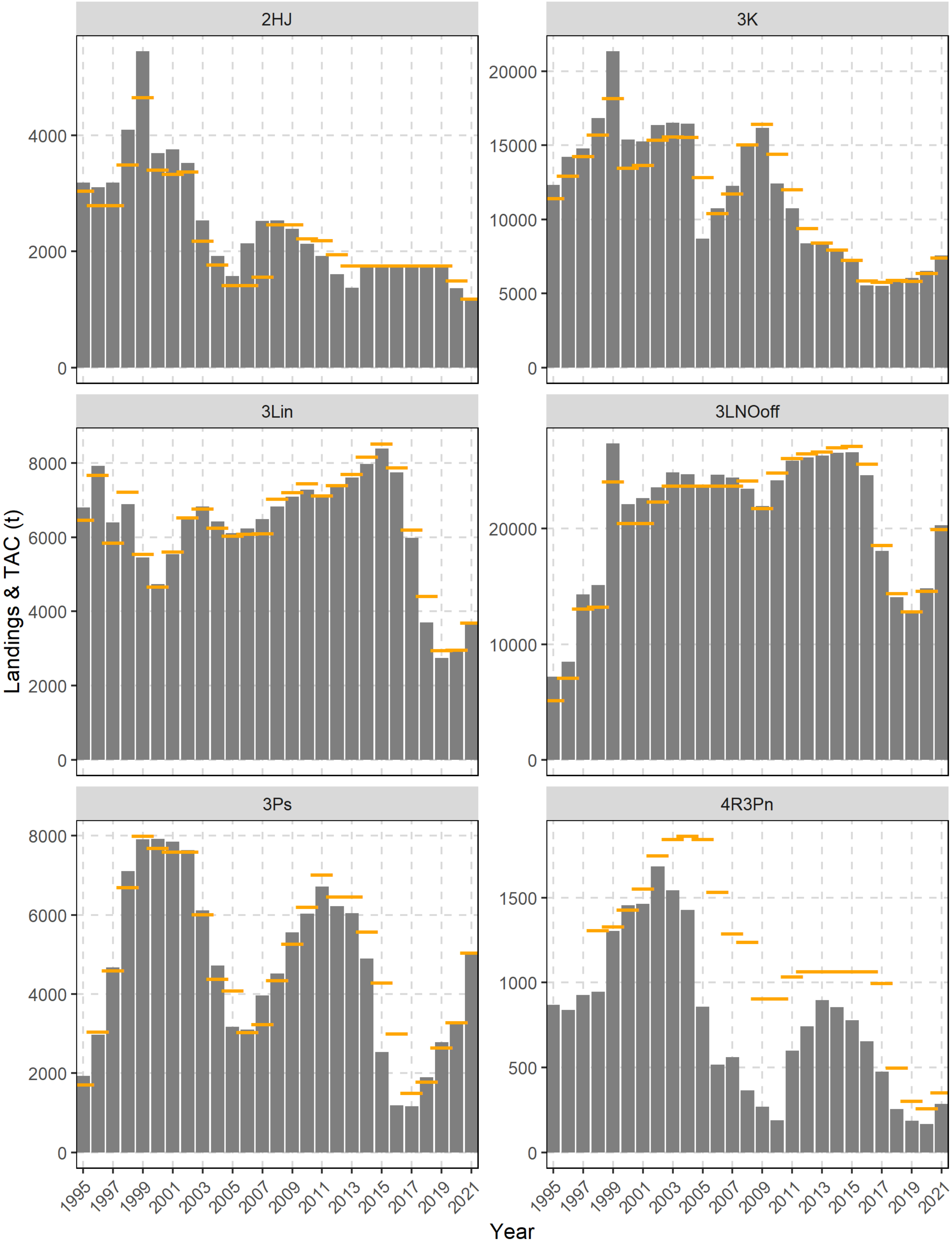


Figure 14. Annual landings (gray bars) and total allowable catch (TAC) (yellow lines) of Snow Crab by Assessment Division (1995–2021).

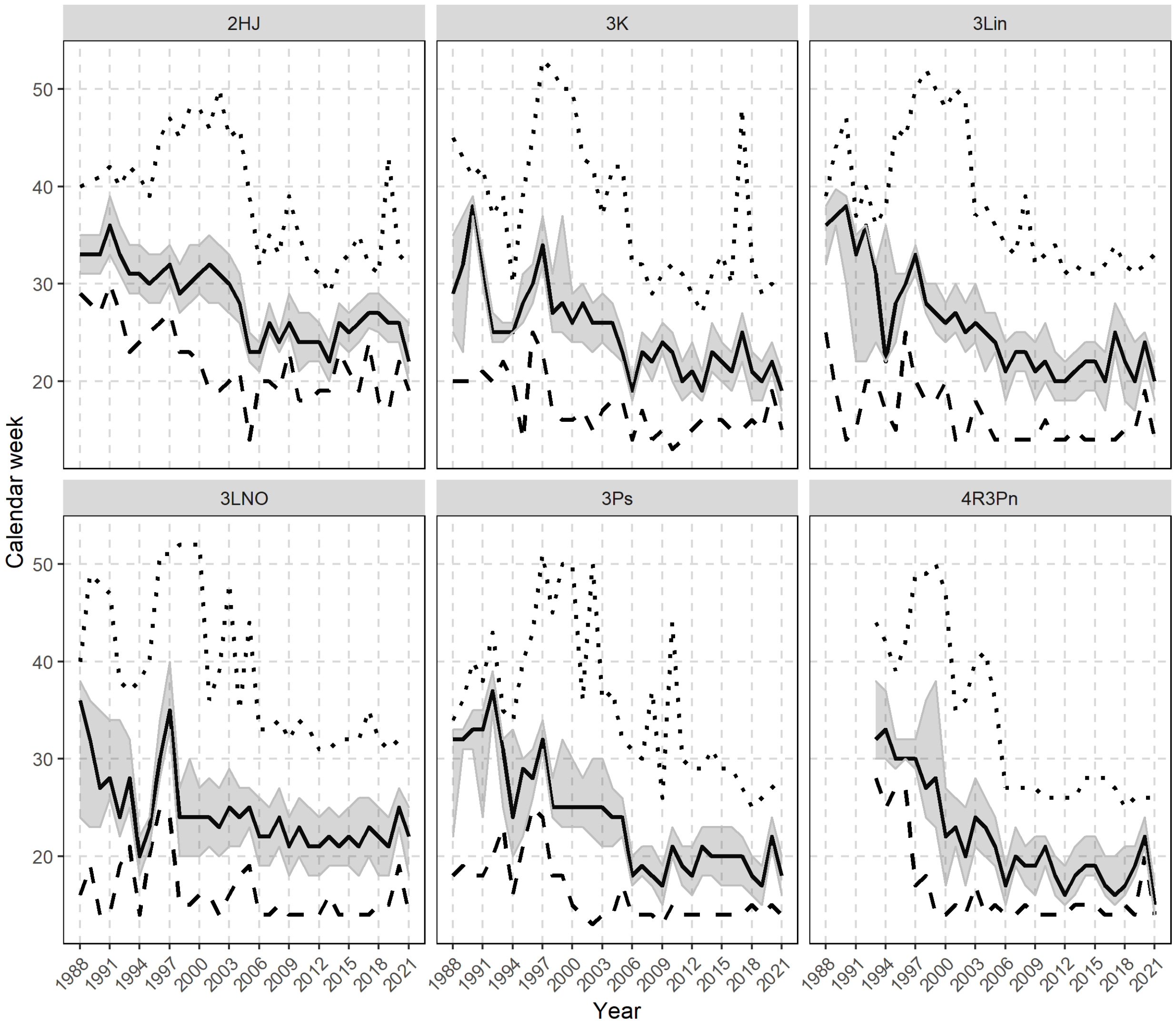


Figure 15. Trends in timing of the fishery by Assessment Division. Solid line = median timing of fishery, dashed line = start of fishery, dotted line = end of fishery, and shaded area = fishery 25–75% complete.

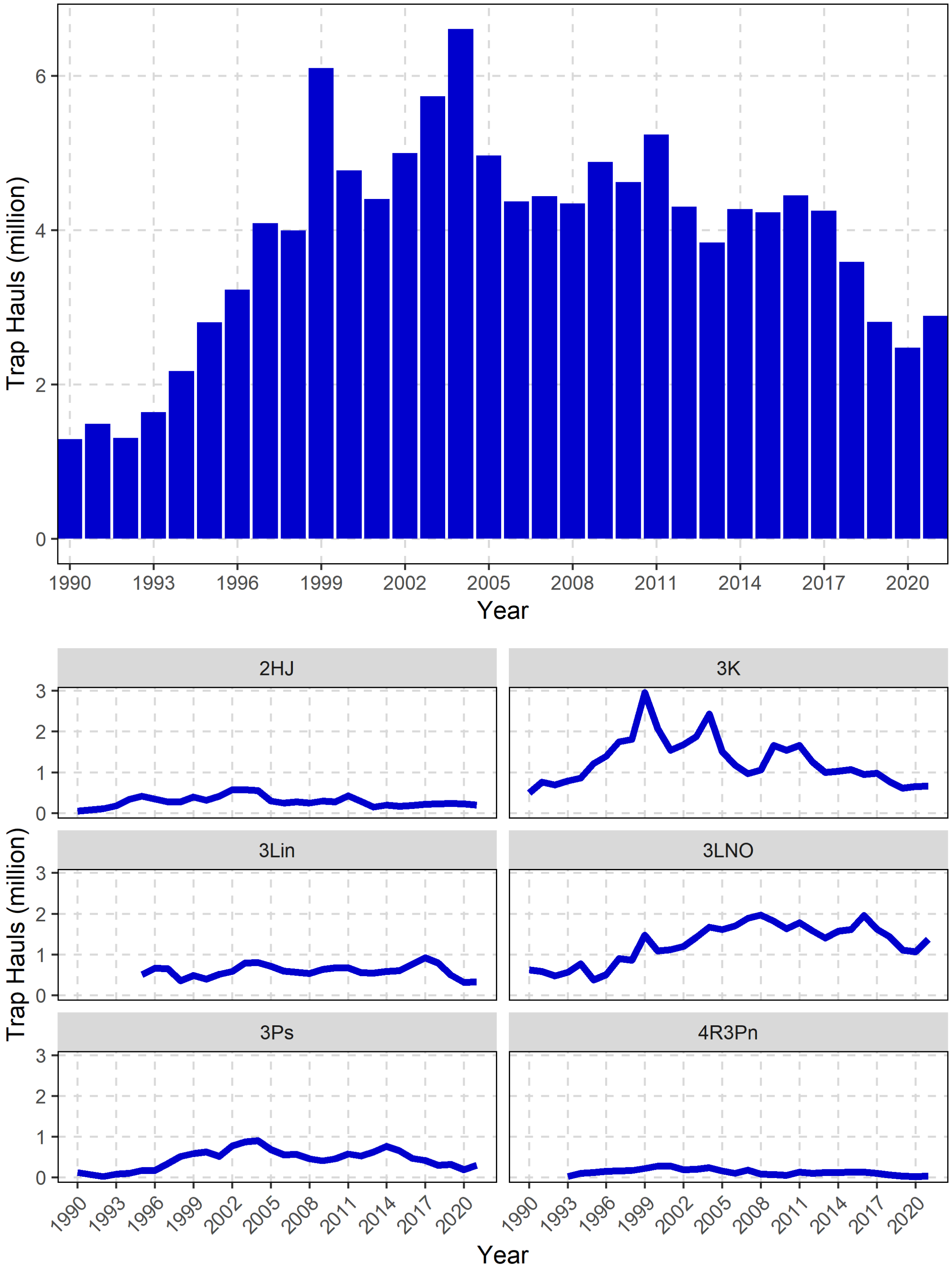


Figure 16. Estimated annual effort (number of trap hauls) for the fishery in Divs. 2HJ3KLNOP4R (top) and by Assessment Division (bottom) (1990–2021). Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

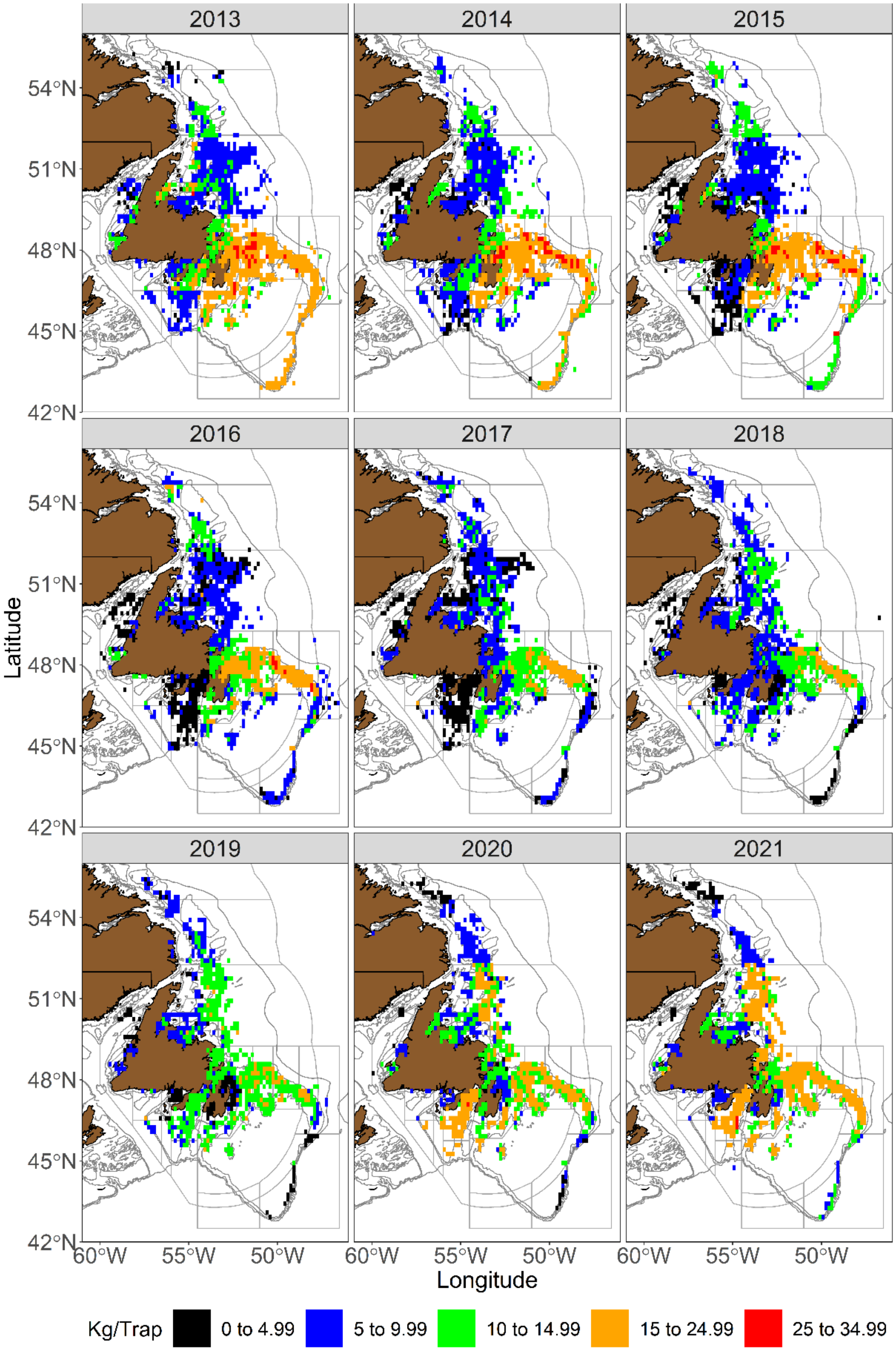


Figure 17. Locations of fishery sets, and Snow Crab catch rates (kg/trap) from fishery logbooks (2013–21). Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

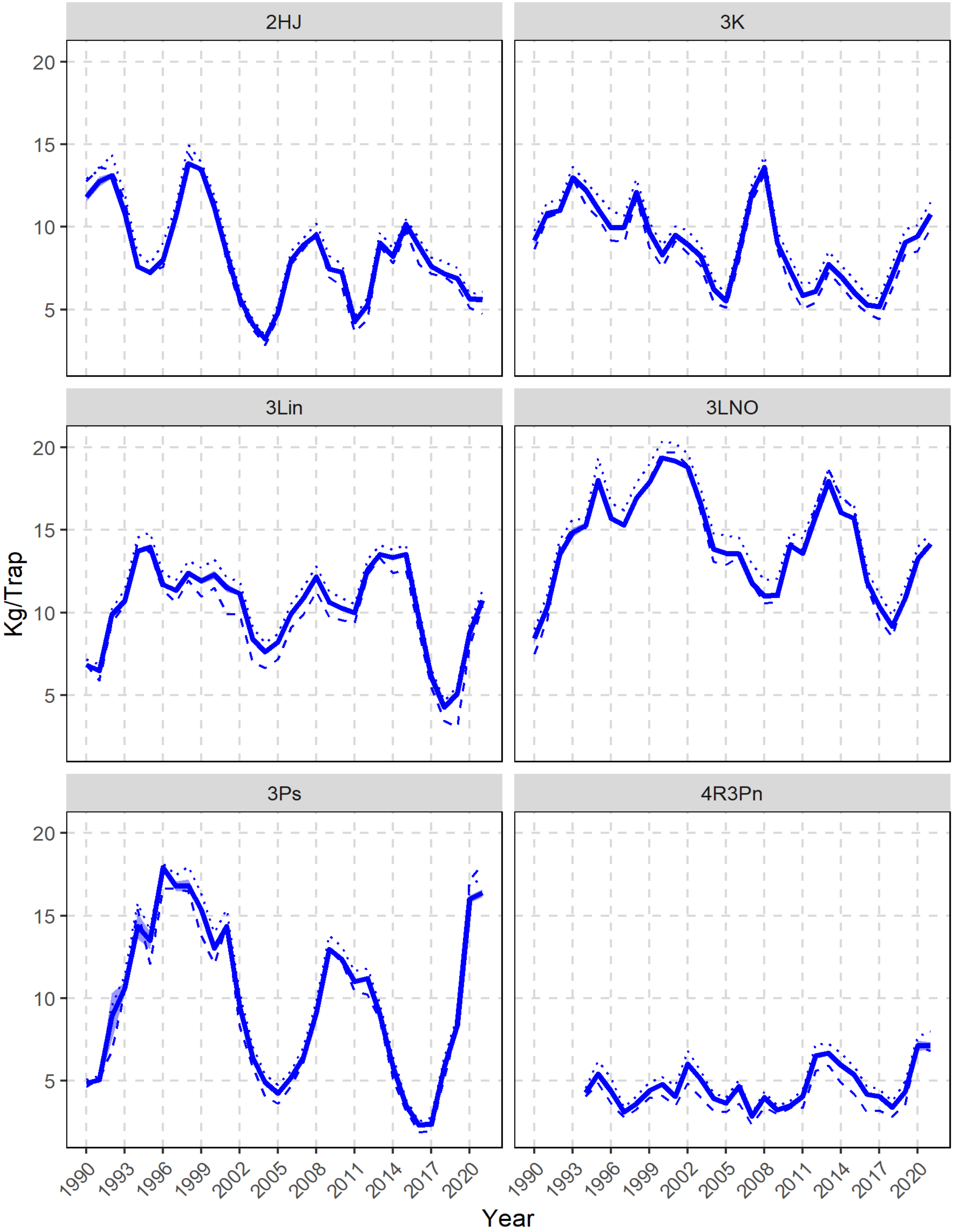


Figure 18. Standardized fishery CPUE (kg/trap) by Assessment Division (1990–2021). Solid line is average standardized CPUE, shaded band is 95% confidence interval, dotted line represents average raw CPUE, and dashed line represents median raw CPUE. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

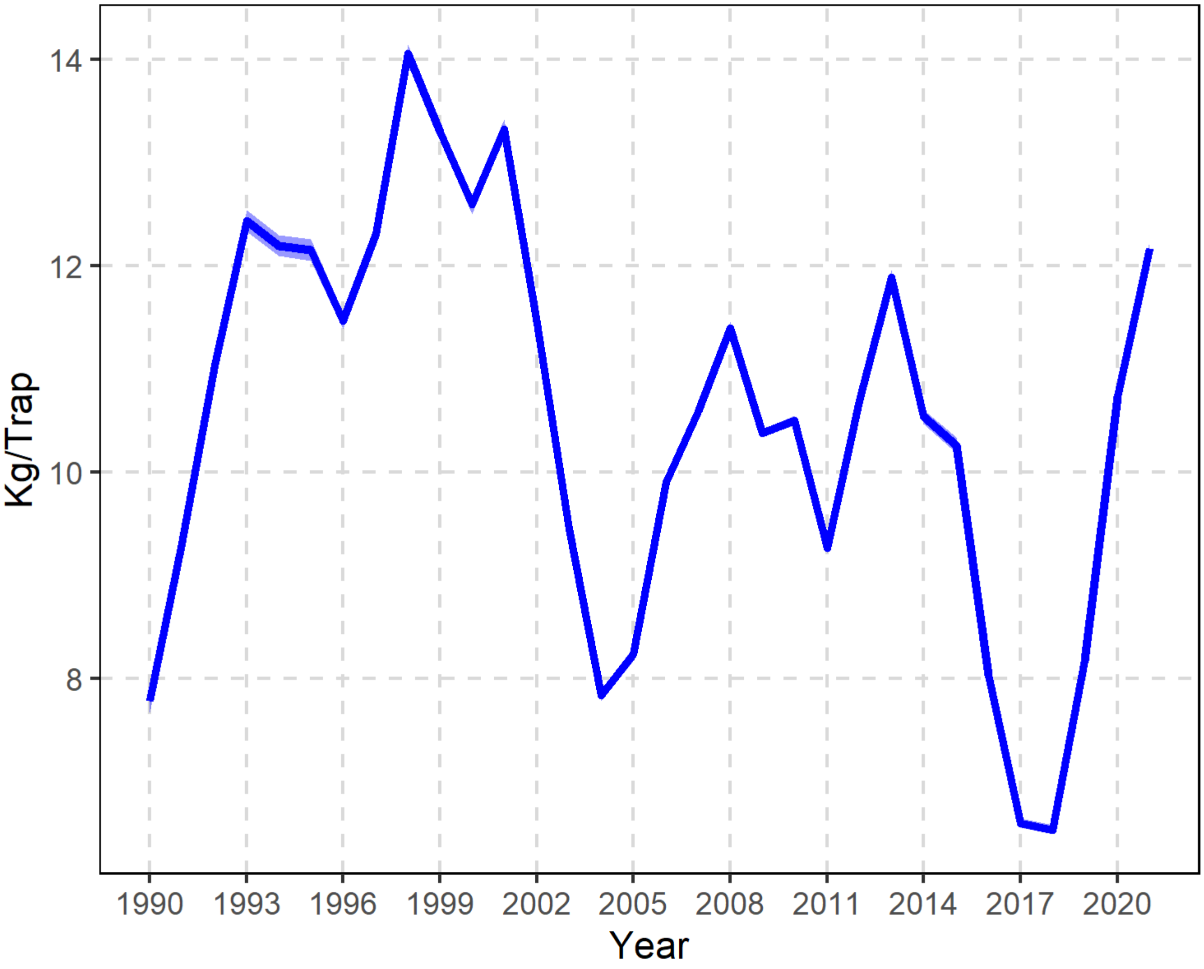


Figure 19. Standardized fishery CPUE (kg/trap) (1990–2021). Solid line is average standardized CPUE, and shaded band is 95% confidence interval. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

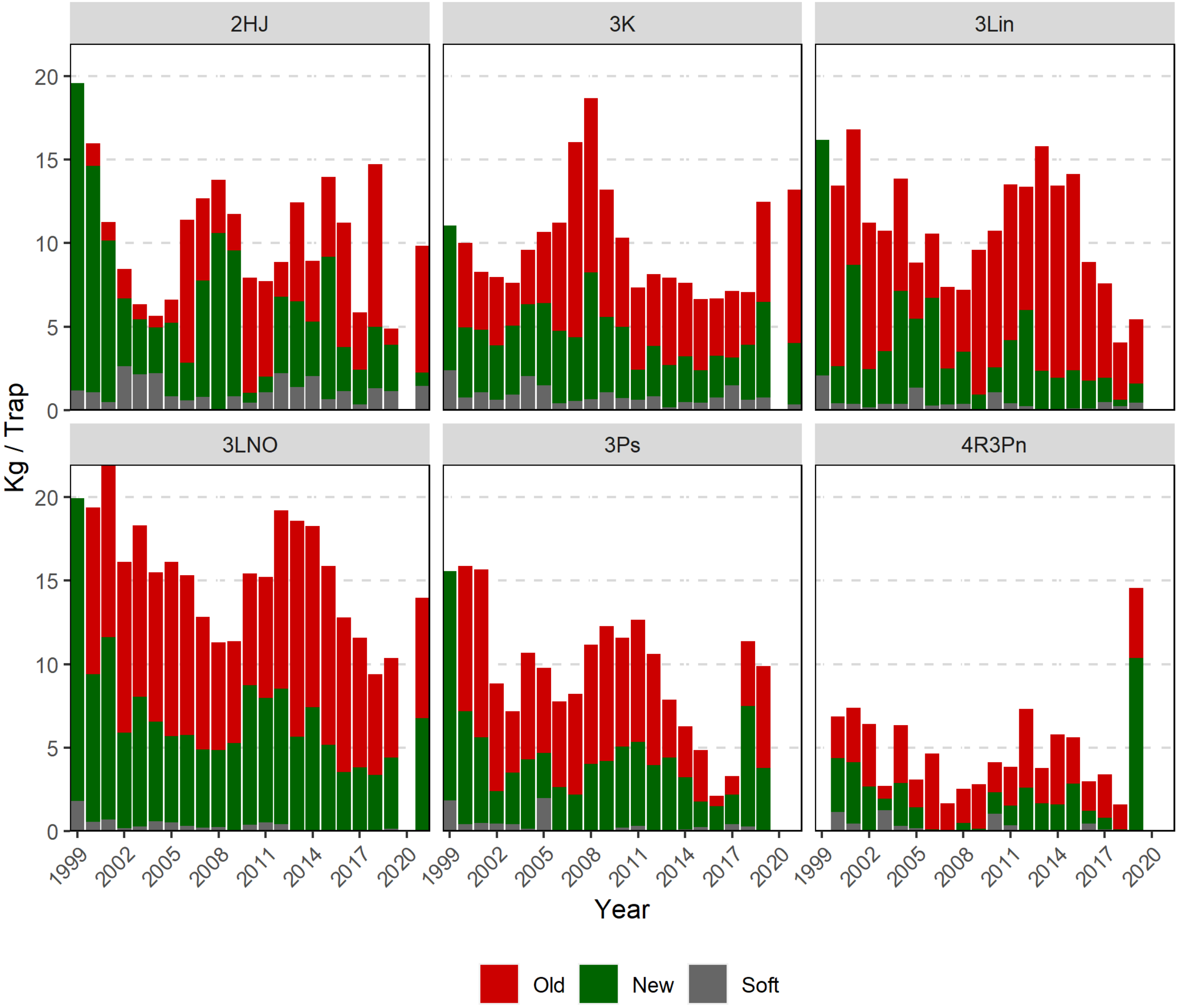


Figure 20. Trends in catch rates (kg/trap) of legal-sized Snow Crab by shell condition from at-sea observer sampling by Assessment Division (1999–2021). Observations excluded for ADs 3L Inshore, 3Ps and 4R3Pn in 2021.

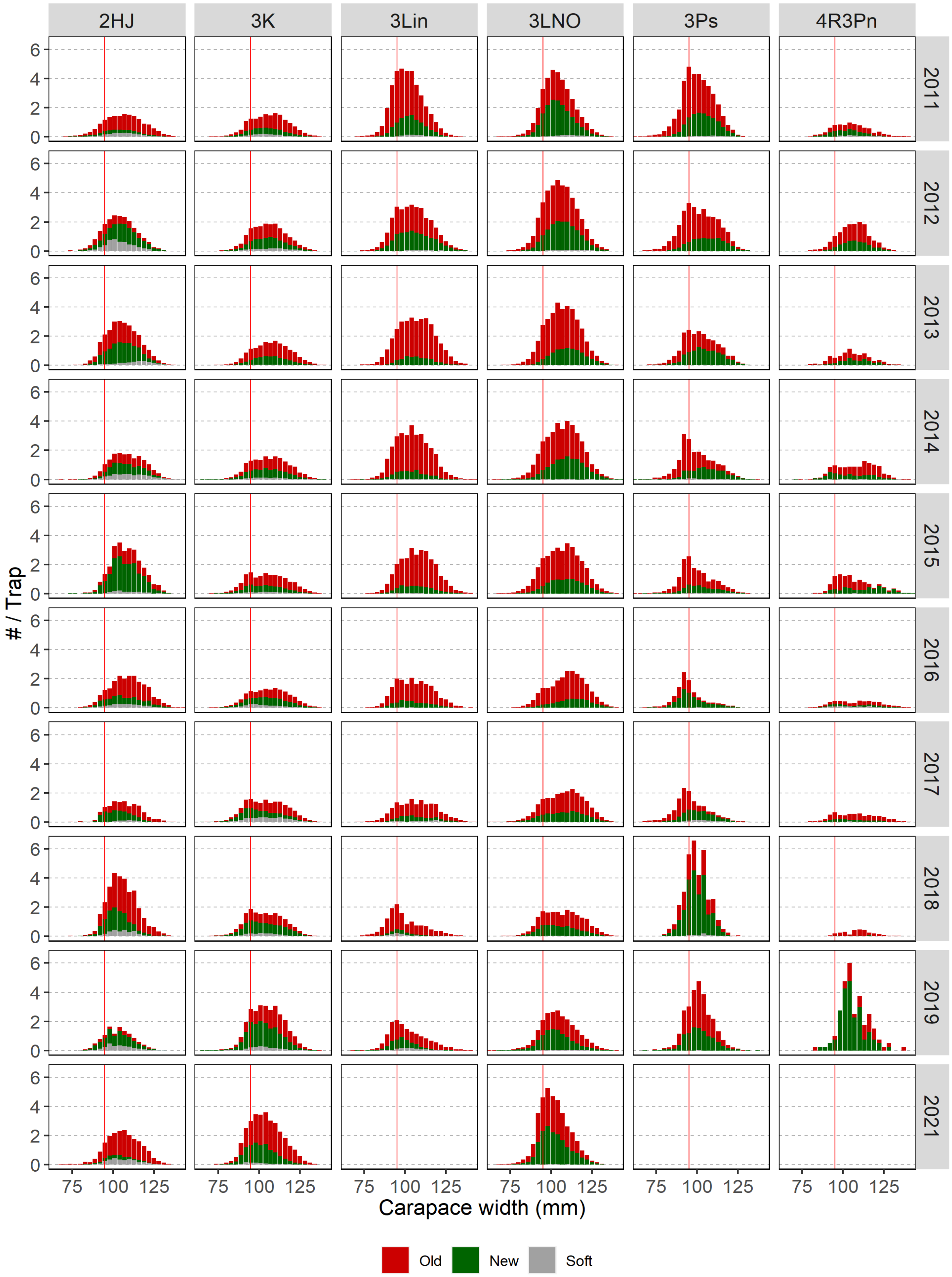


Figure 21. Catch rates (#/trap) based on male carapace width distributions by shell condition from at-sea observer sampling by Assessment Division. The red vertical line indicates the minimum legal size. Observations excluded for ADs 3L Inshore, 3Ps and 4R3Pn in 2021.

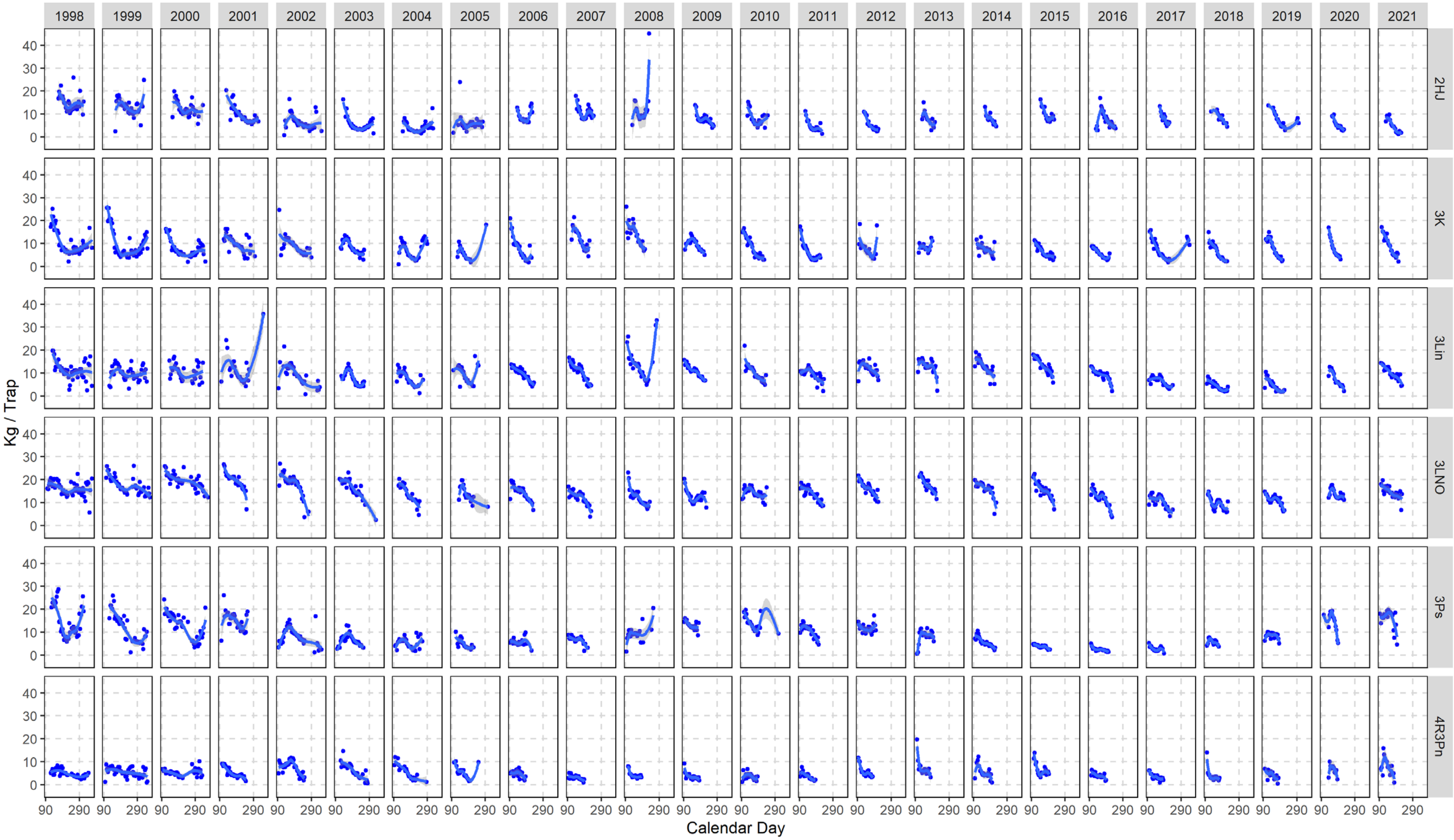


Figure 22. Unstandardized fishery CPUE (kg/trap) throughout the season (calendar day) by Assessment Division (1998–2021). Points denote mean CPUE in 5-day increments and trend lines are loess regression curves. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

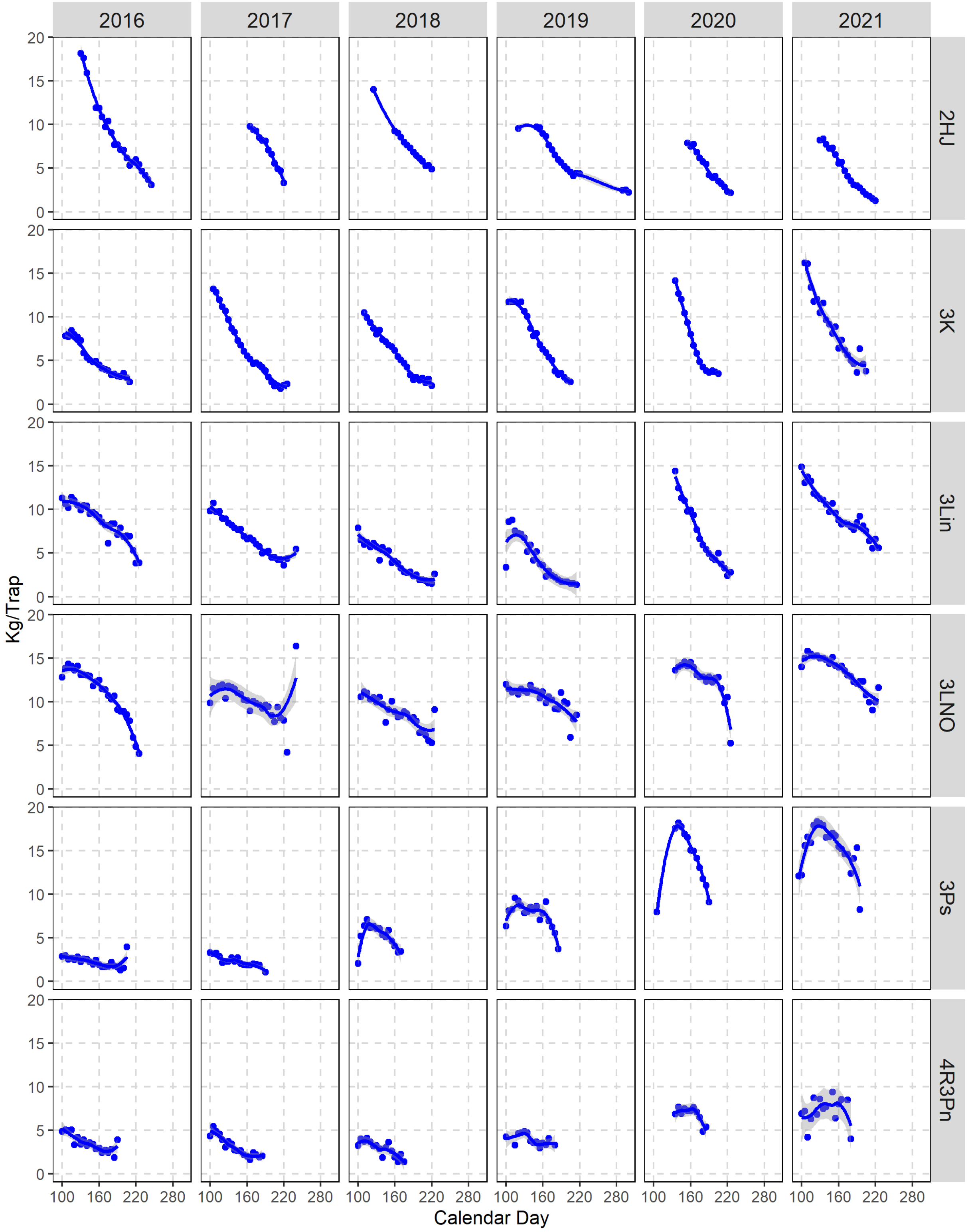


Figure 23. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each Assessment Division (2016–21). Points denote mean CPUE of 5-day increments and trend lines are loess regression curves. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

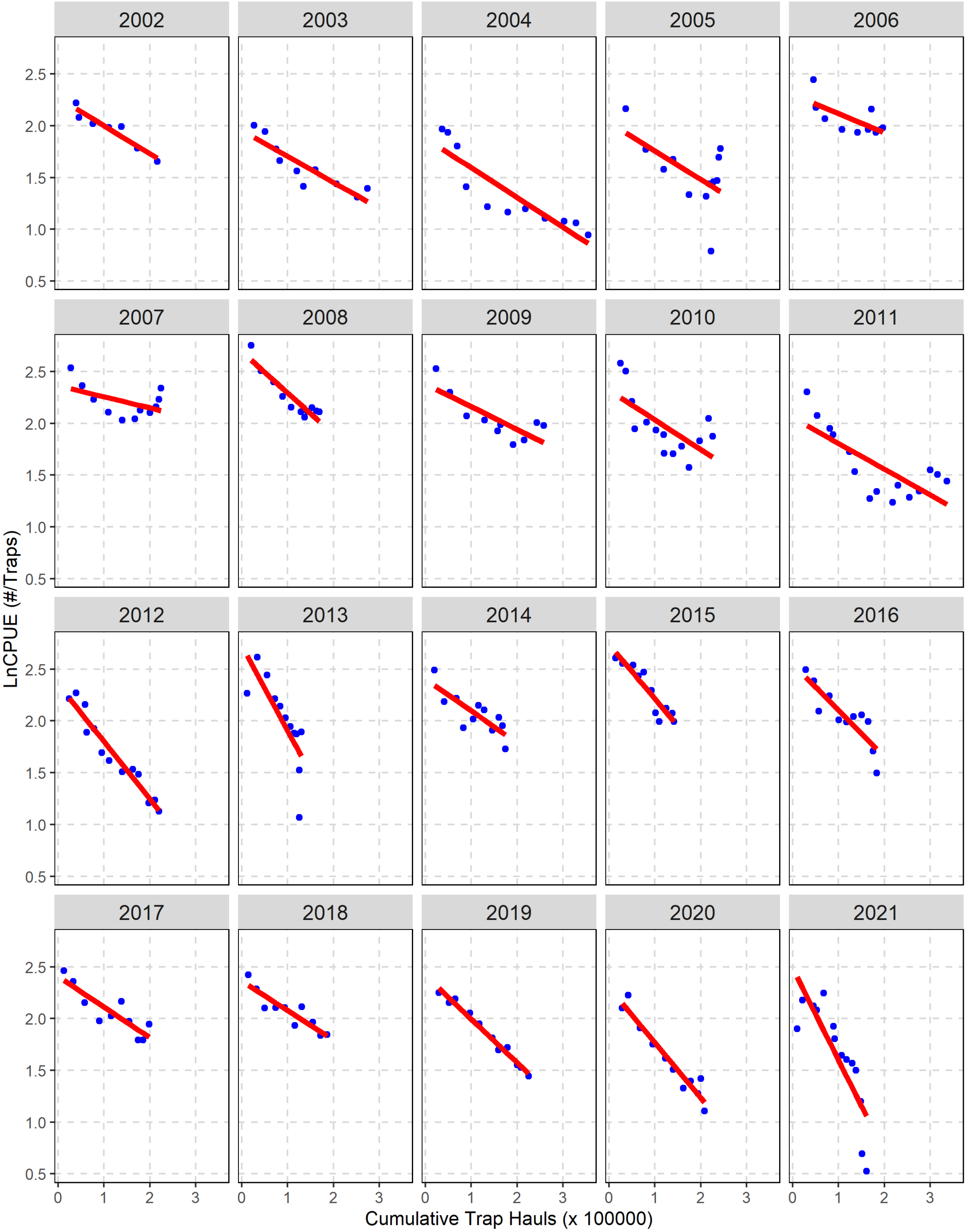


Figure 24. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 2HJ (2002–21). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

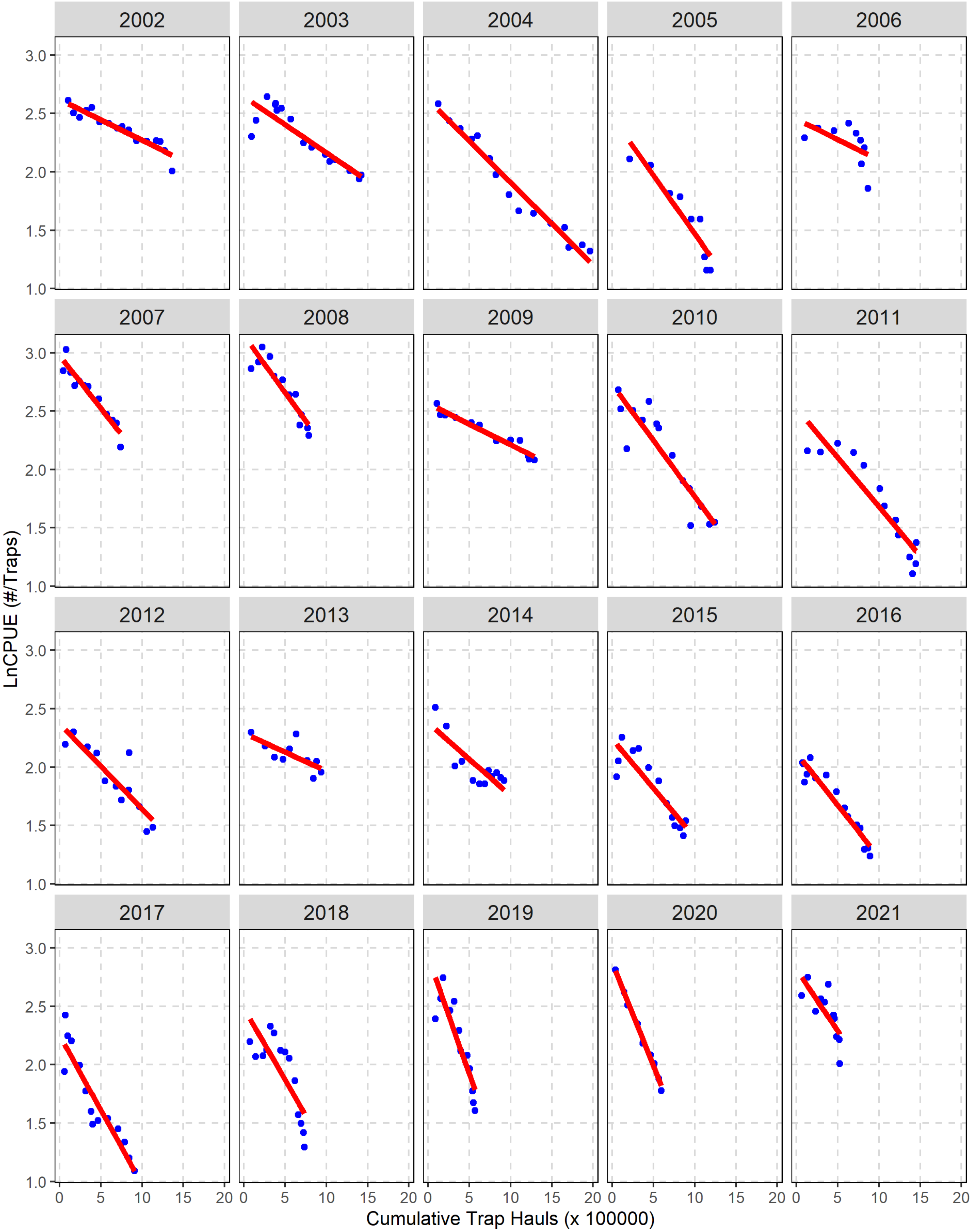


Figure 25. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3K (2002–21). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

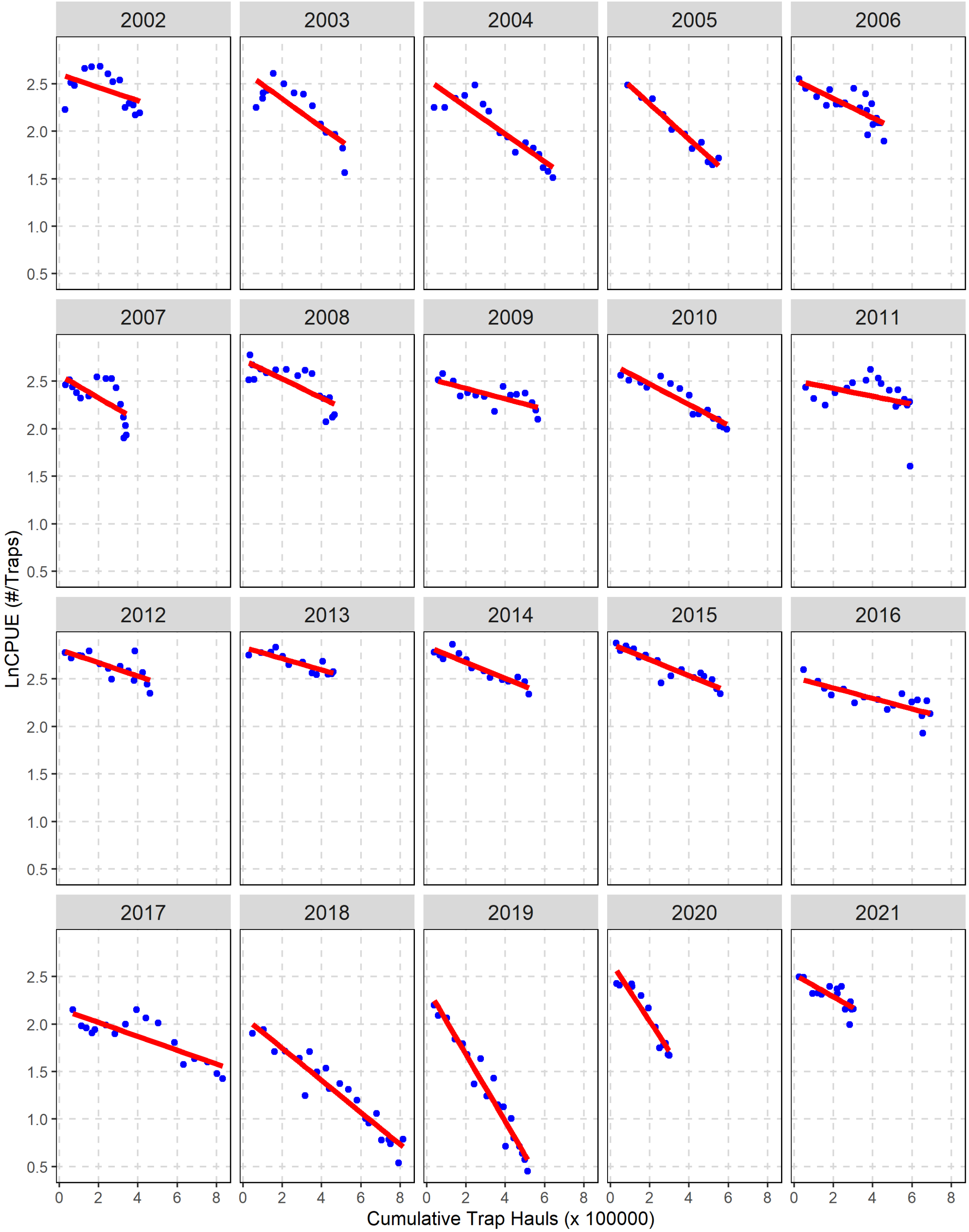


Figure 26. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3L Inshore (2002–21). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

Figure 27. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3LNO Offshore (2002–21). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

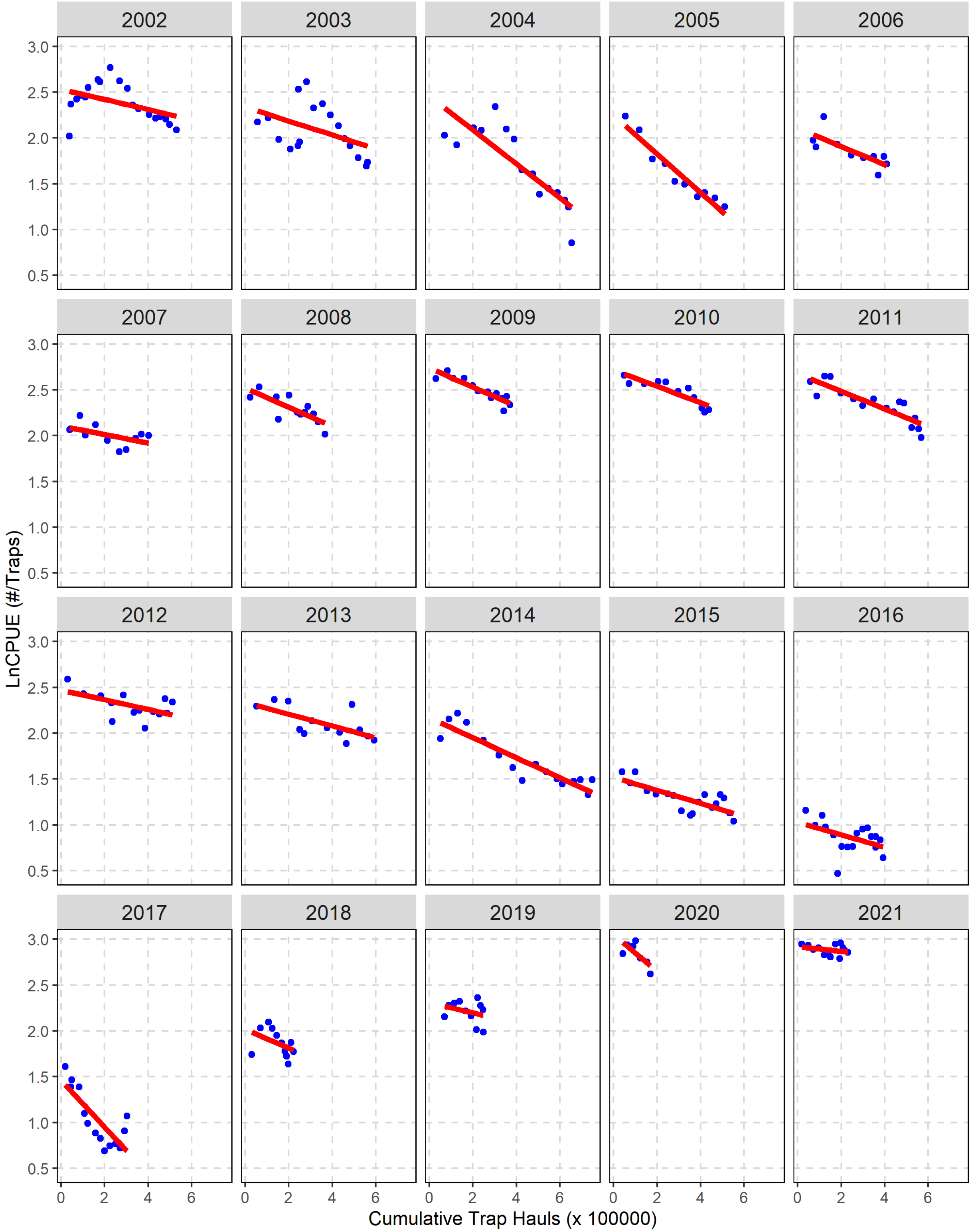


Figure 28. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3Ps (2002–21). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

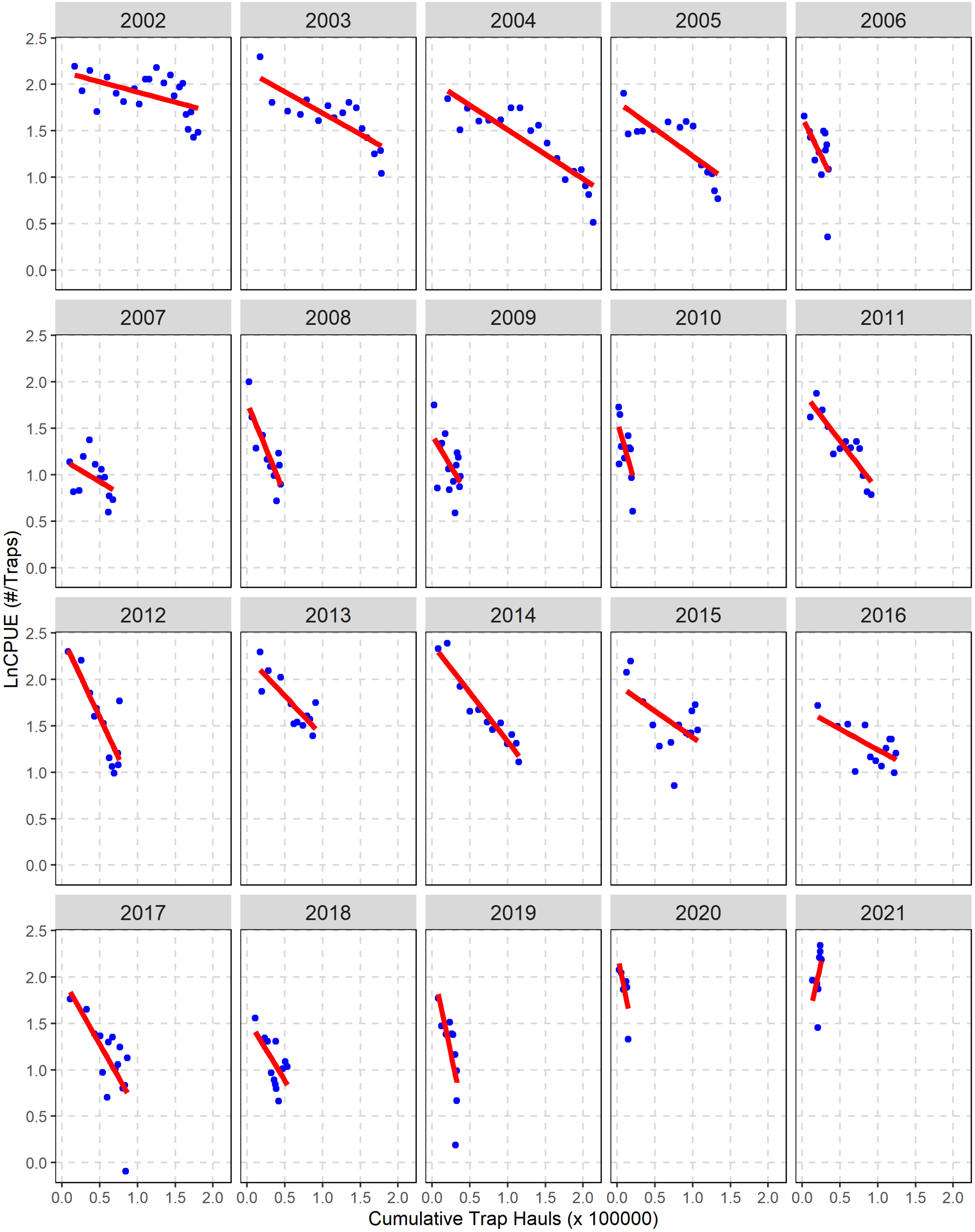


Figure 29. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 4R3Pn (2002–21). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

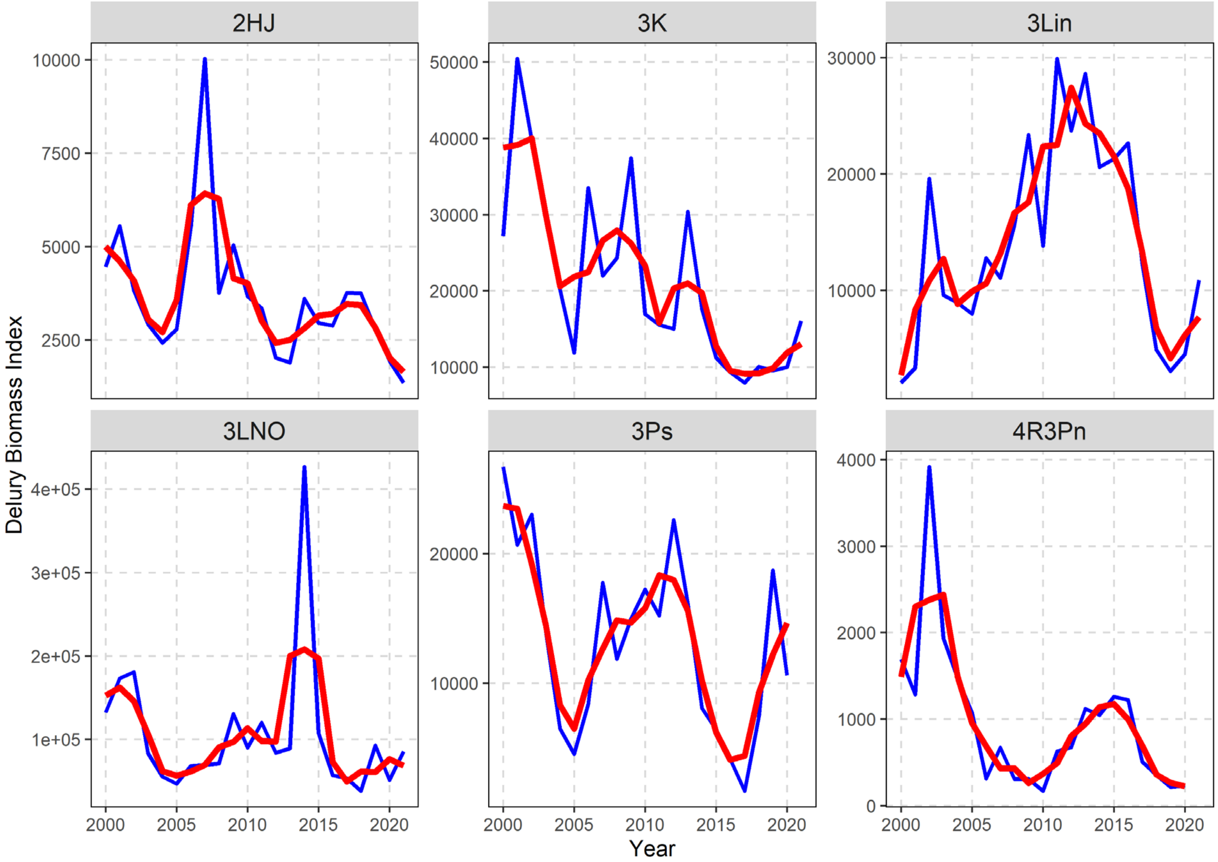


Figure 30. Fishery depletion model biomass estimates of exploitable Snow Crab (t) from logbooks (blue) and 3-year centered moving averages (red) in each Assessment Division.

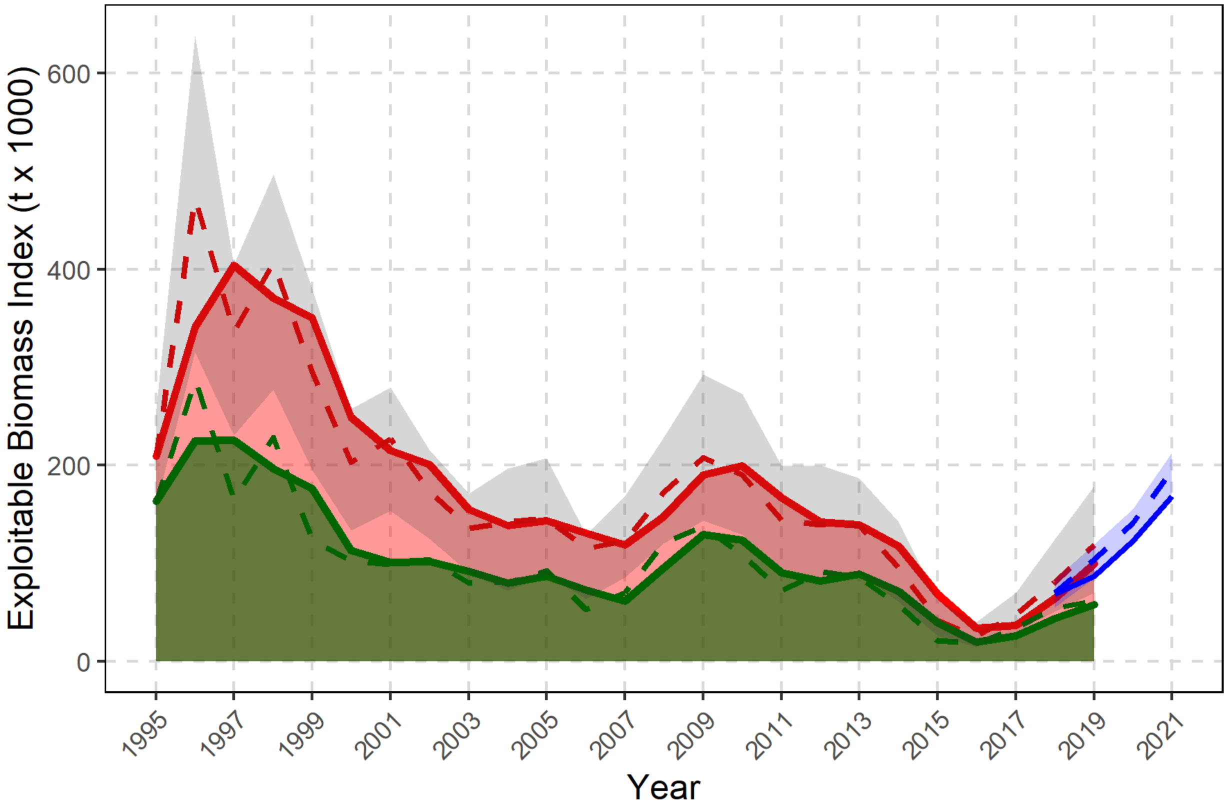


Figure 31. Annual trawl exploitable biomass index by shell condition (red = residuals, green = recruits) (1995–2019) and trap exploitable biomass index (blue) (2018–21). Solid line = 2-year moving average of exploitable biomass, dashed line = annual estimate, and grey or blue band = 95% confidence intervals of annual estimate.

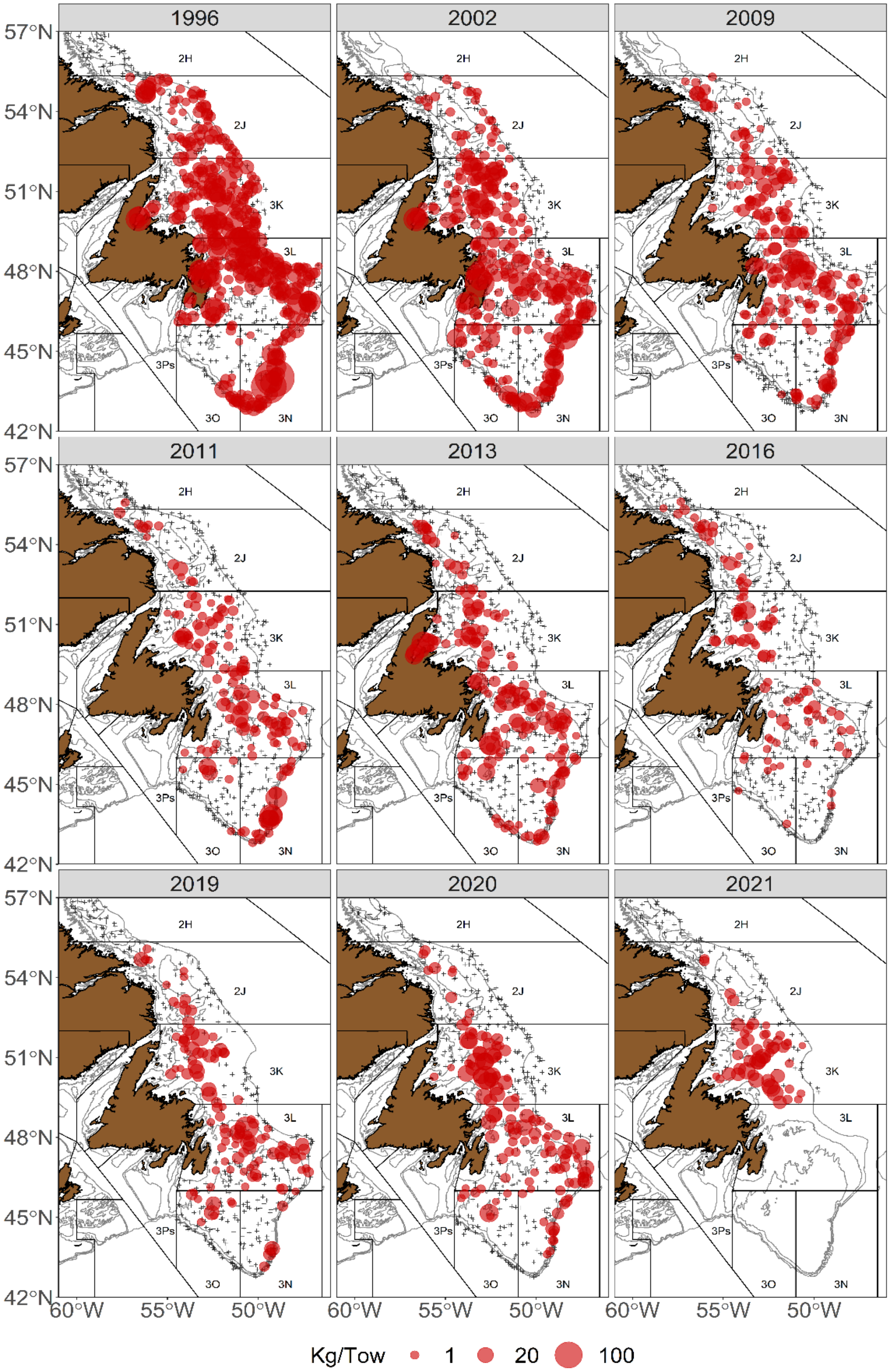


Figure 32. Distribution of exploitable males (kg/tow) from fall trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016 and 2019–21. Data standardized by vessel.

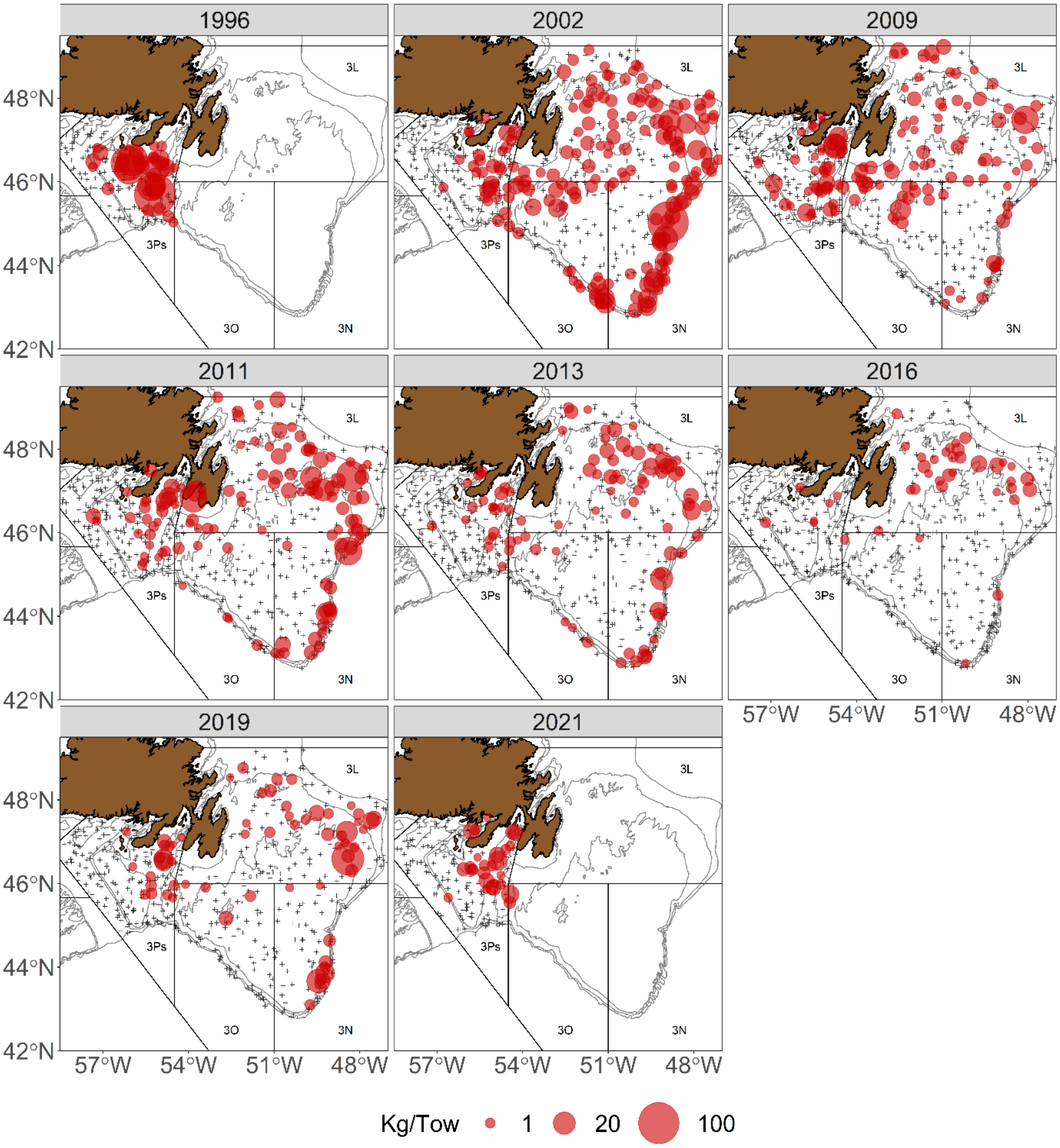


Figure 33. Distribution of exploitable males (kg/tow) from spring trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016, 2019 and 2021. Data standardized by vessel. Note: No survey in 2020.

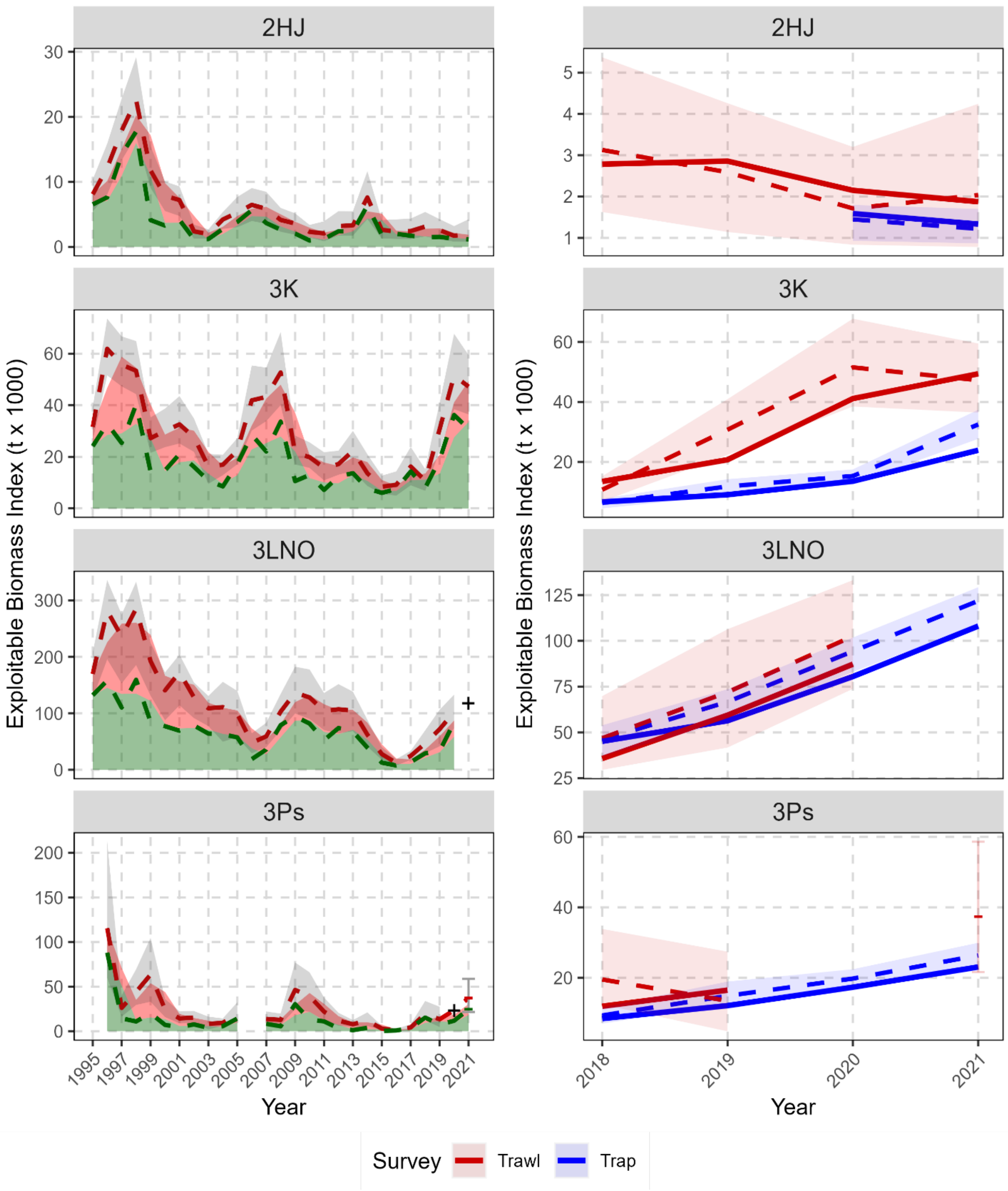


Figure 34. Left: Annual trawl exploitable biomass index by shell condition (red = residuals, green = recruits) and Assessment Division (1995–2021). Solid line = 2-year moving average of exploitable biomass, dashed line = annual estimate, and grey band = 95% confidence intervals of annual estimate. "+" denotes years without a trawl survey where an estimate was calculated from other data sources. Right: Annual trawl (red) and trap (blue) exploitable biomass index by Assessment Division (2018–21). Solid line = 2-year moving average of exploitable biomass, dashed line = annual estimate, and shaded band = 95% confidence intervals of annual estimate.

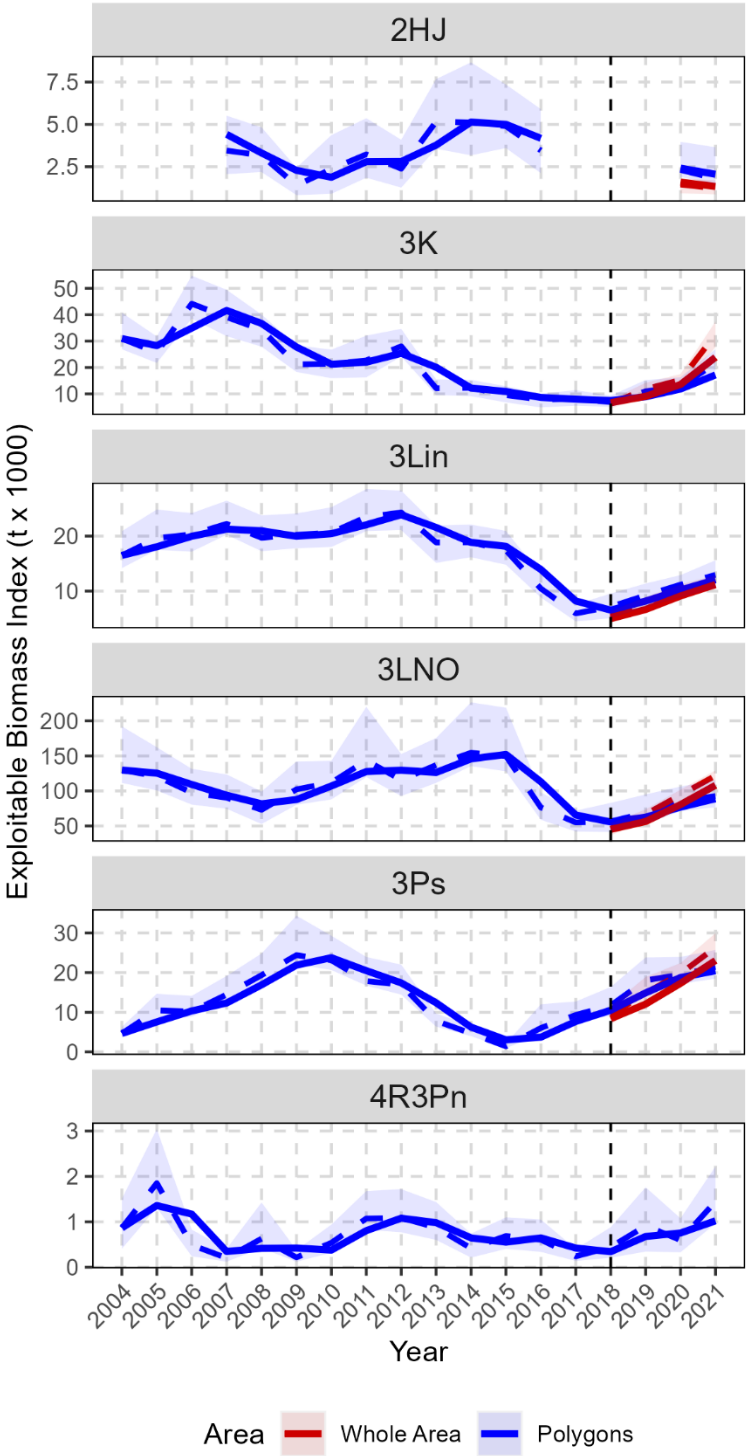


Figure 35. Trap exploitable biomass index by Assessment Division (2004–21). Red series uses all stations of the survey and blue series uses only core stations of the survey. Solid line = 2-year moving average, dashed line = annual estimate, and shaded band = 95% confidence interval of the annual estimate.

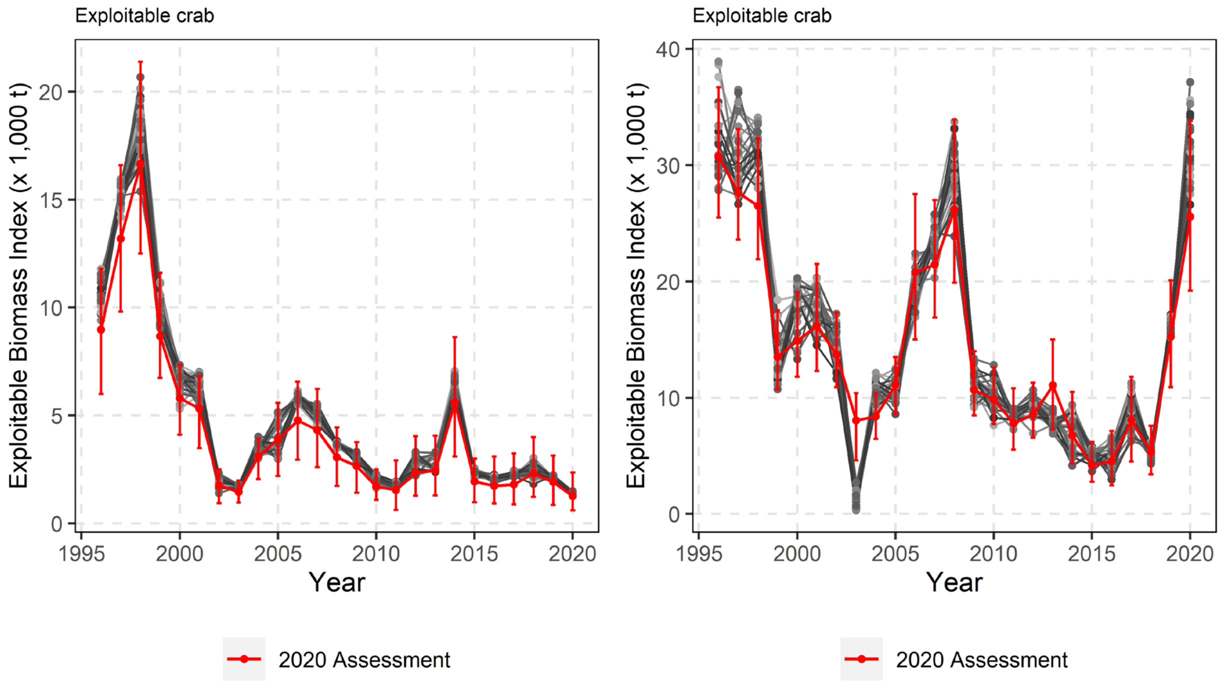


Figure 36. Exploitable biomass estimates for 25 test datasets with 2021 trawl survey coverage (gray lines) and the time-series exploitable biomass estimates presented at the previous stock assessment (red lines) in ADs 2HJ (left) and 3K (right). Exploitable biomass estimates are not Delury-adjusted.

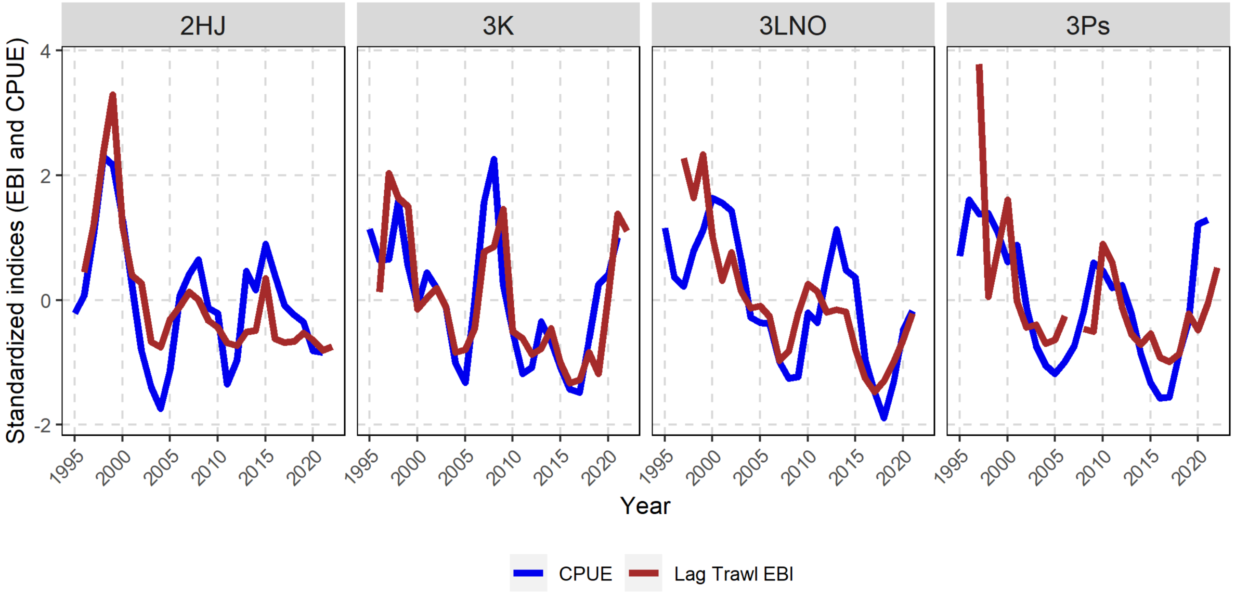


Figure 37. One-year lagged trawl exploitable biomass indices versus fishery CPUE by Assessment Division (1995–2021).

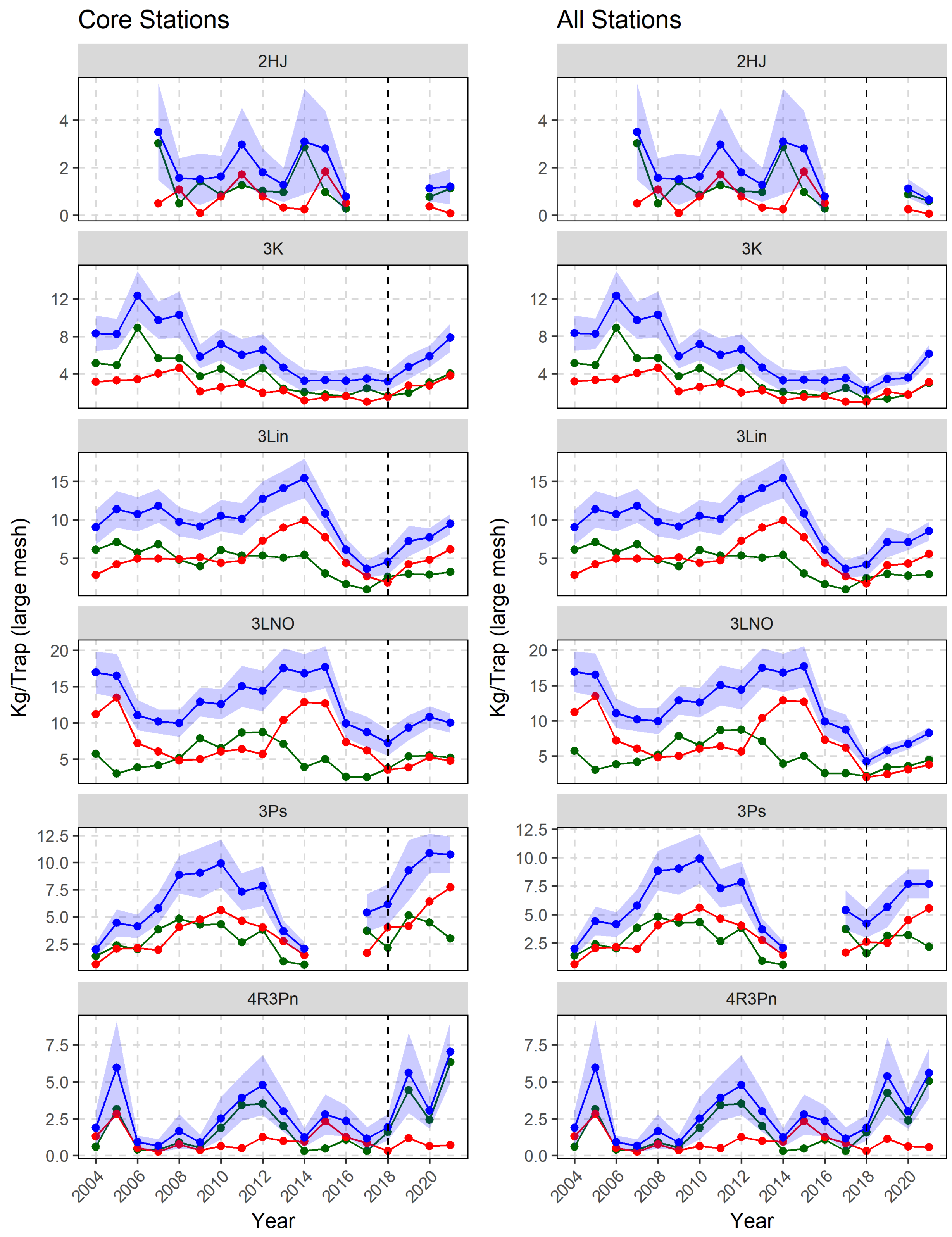


Figure 38. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for legal-sized crab from core stations (left) and all stations (right) in the CPS survey by Assessment Division (2004–21). Shaded area = 95% confidence interval.

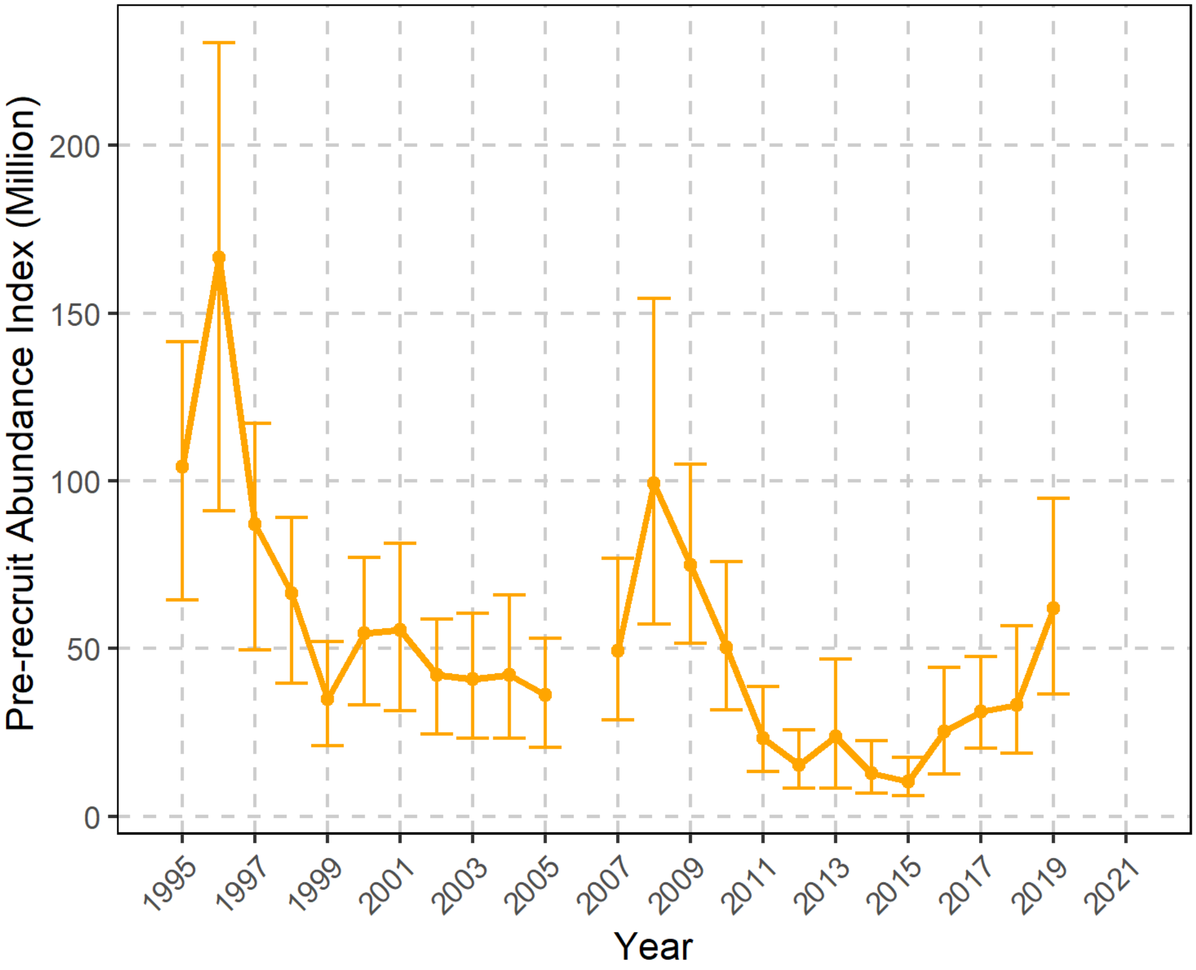


Figure 39. Annual pre-recruit abundance index from trawl surveys (1995–2019).

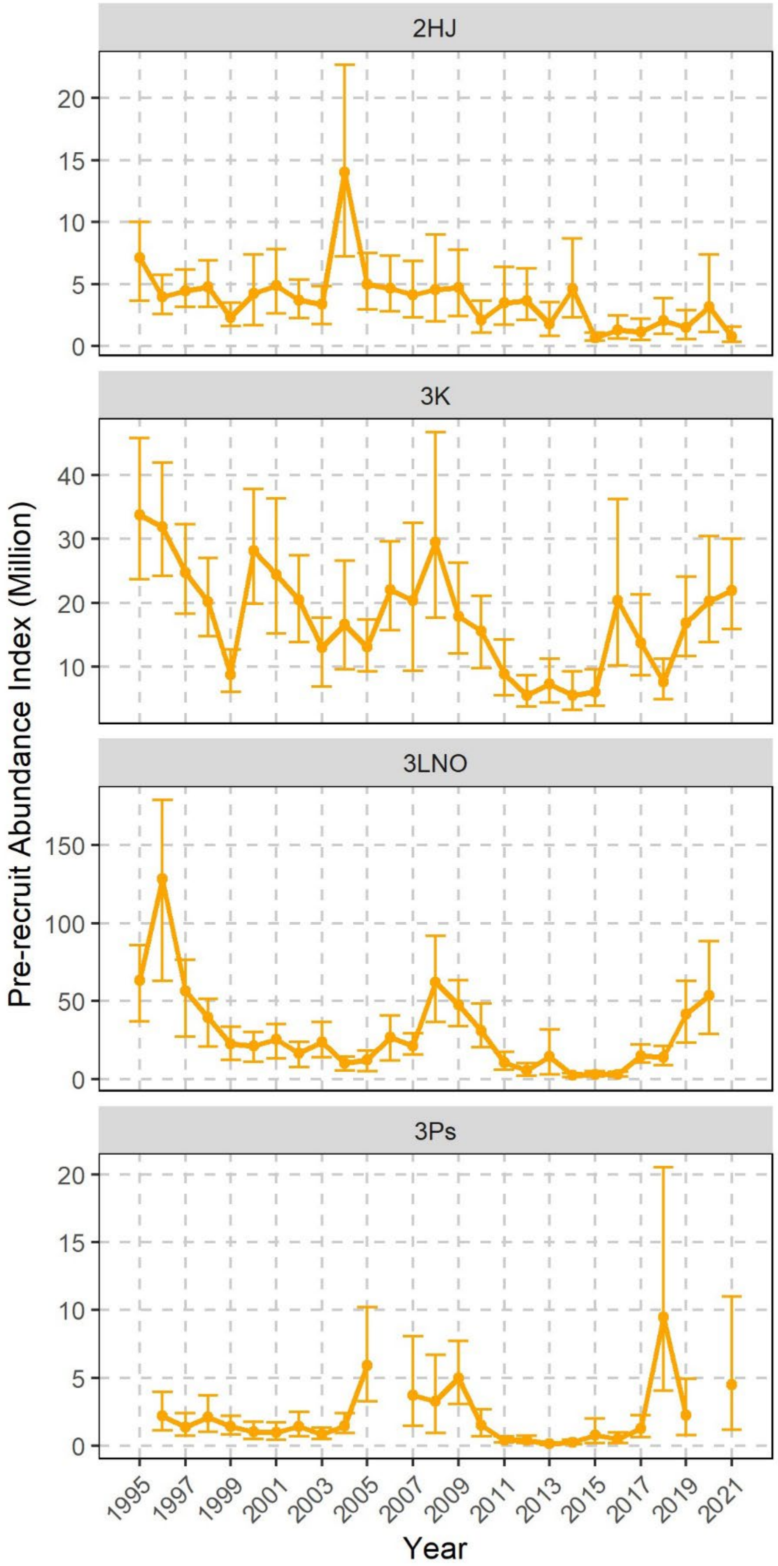


Figure 40. Annual pre-recruit abundance index from trawl surveys by Assessment Division (1995–2021).

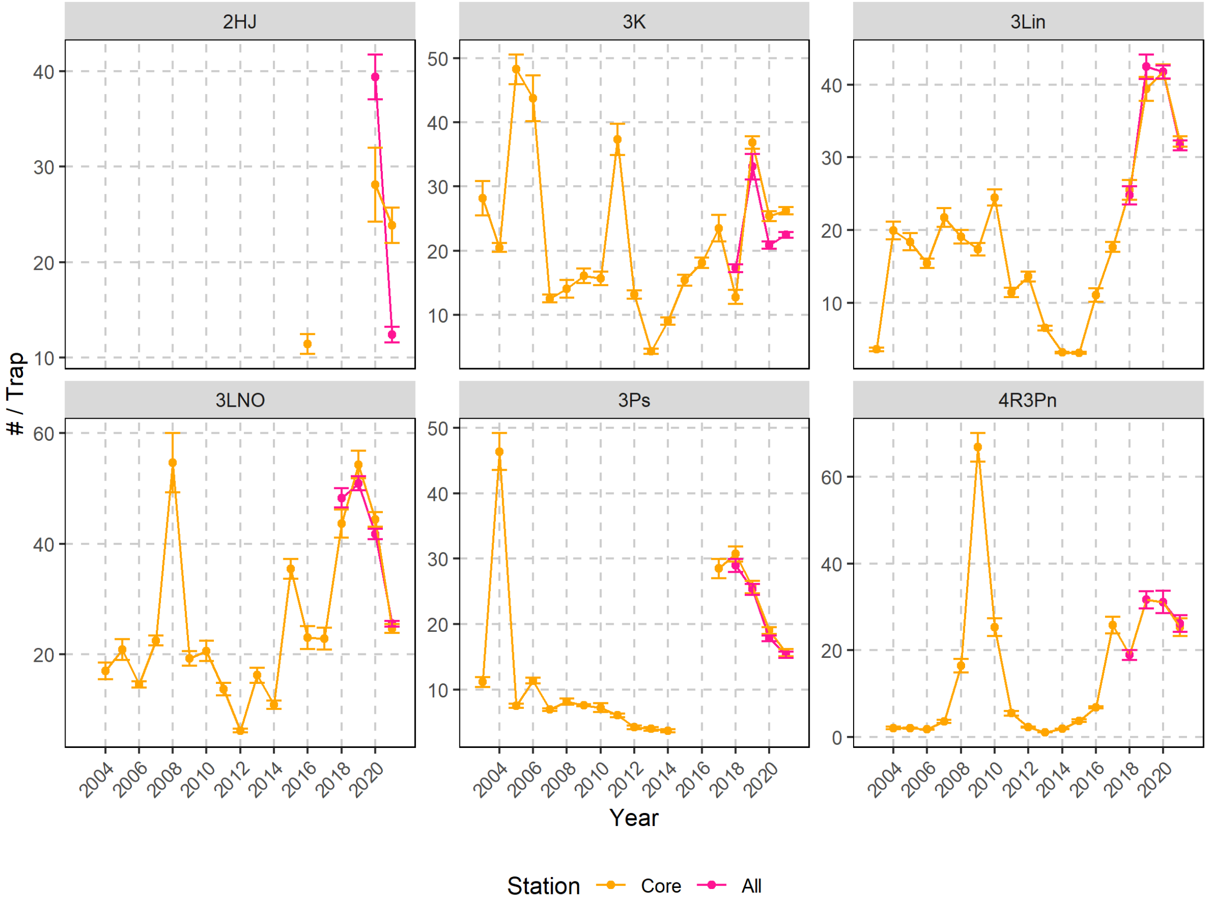


Figure 41. Annual CPUE (#/trap) of pre-recruits from small-mesh traps at core stations (orange) and all stations (pink) in the CPS trap survey by Assessment Division (2004–21).

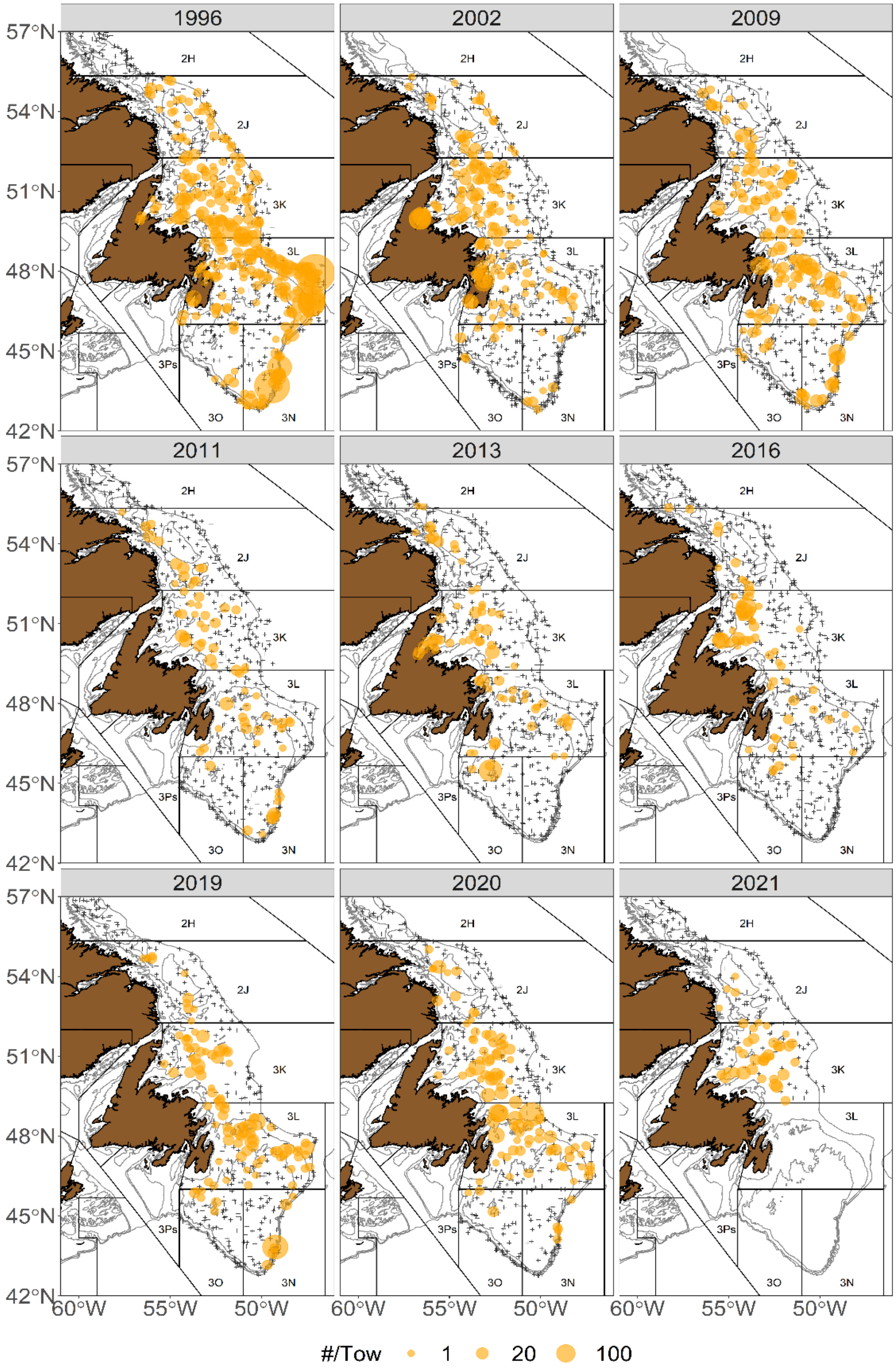


Figure 42. Distribution of pre-recruit males (#/tow) from fall trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016 and 2019–21.

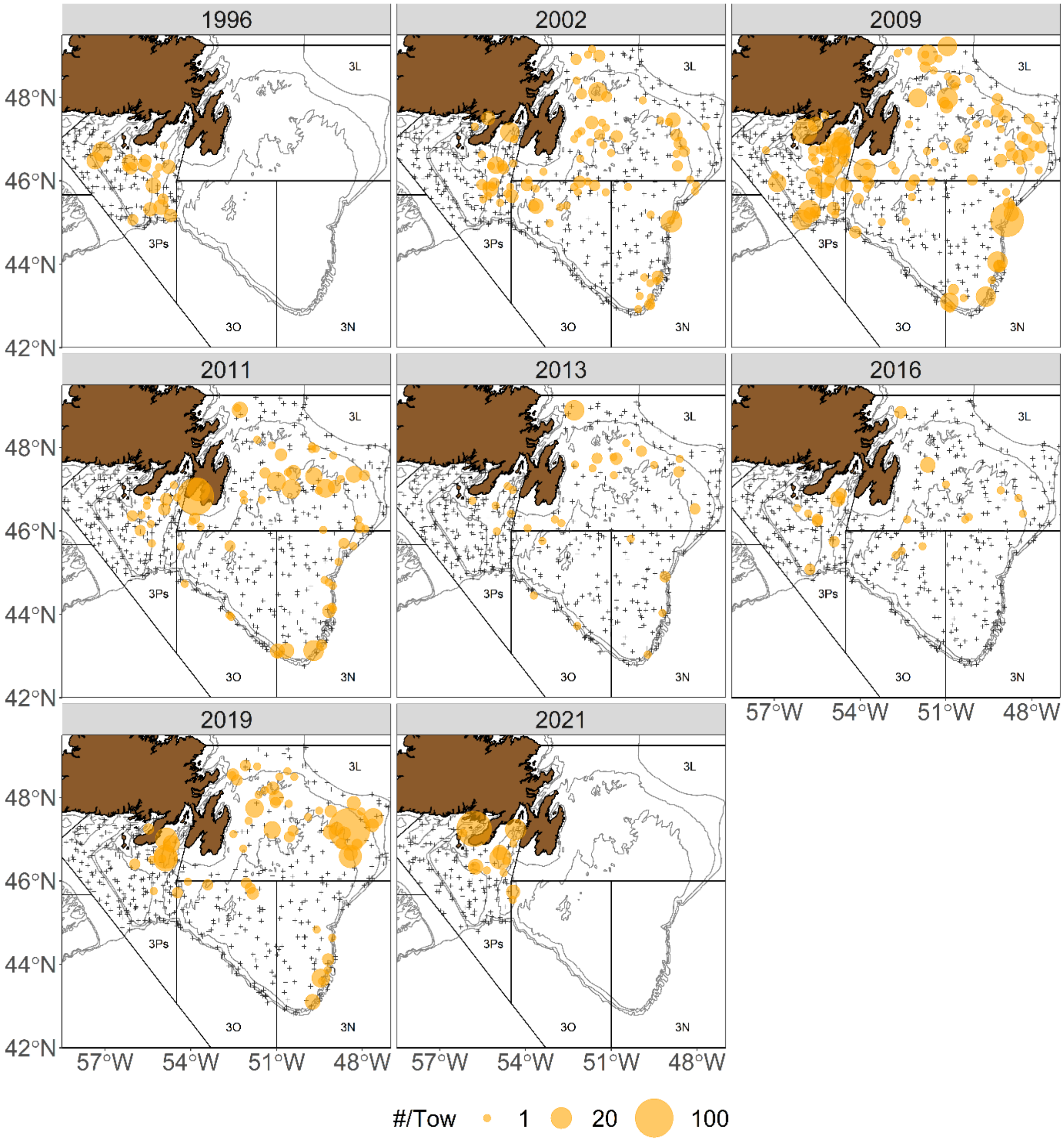


Figure 43. Distribution of pre-recruit males (#/tow) from spring trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016, 2019, and 2021. Note: No survey in 2020.

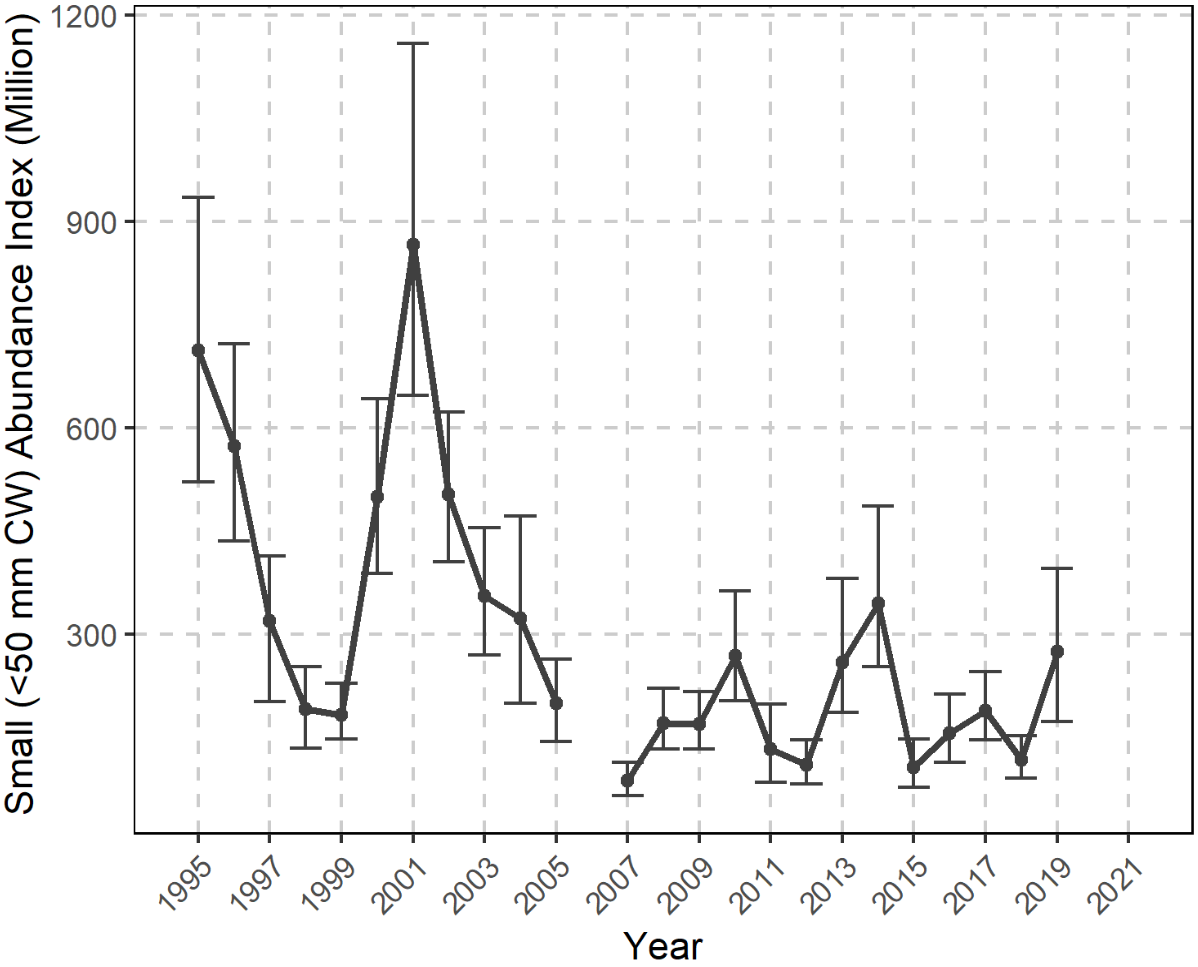


Figure 44. Annual abundance index (# million) of small crab (<50 mm carapace width) from trawl surveys (1995–2019).

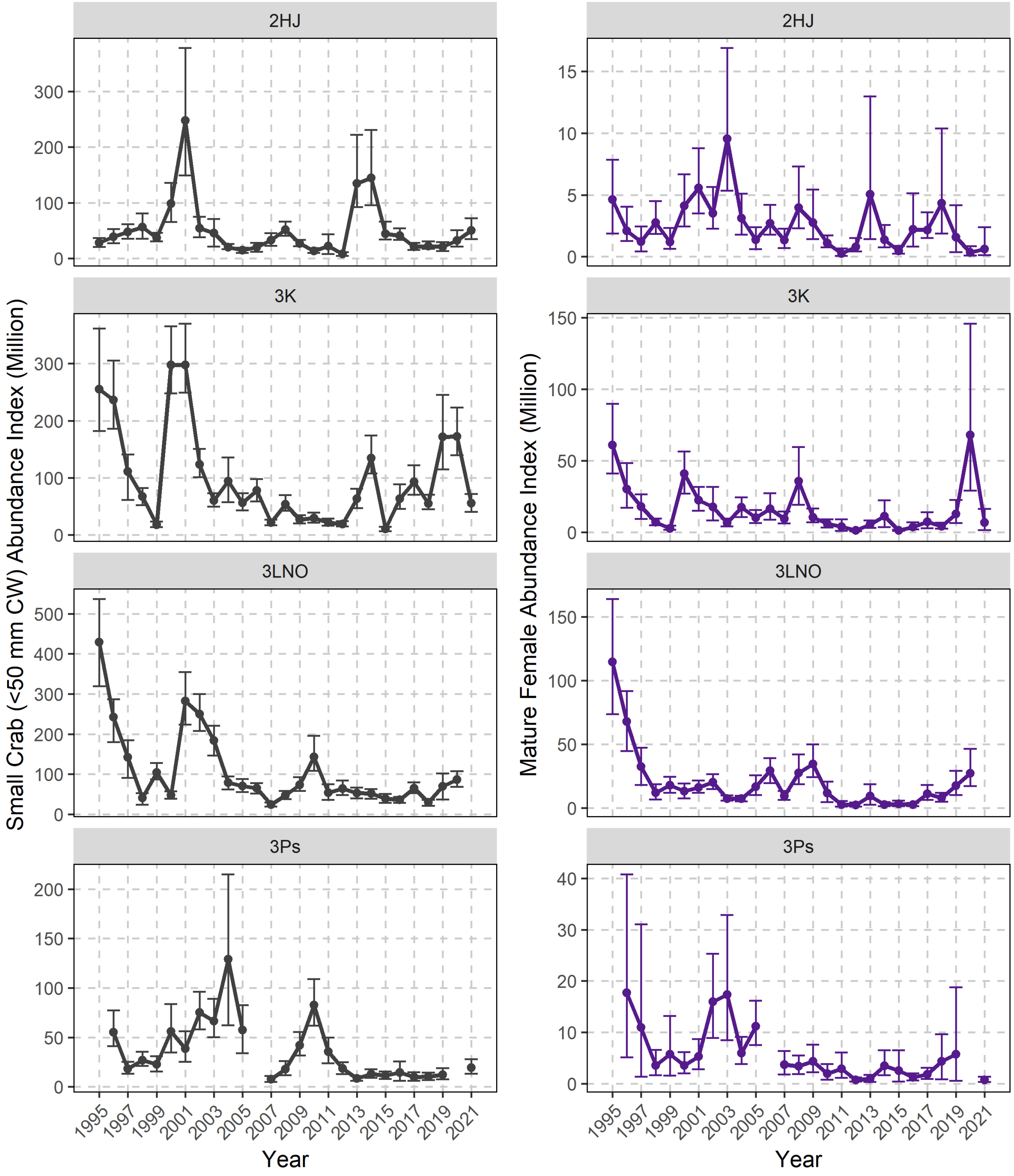


Figure 45. Annual abundance indices (# million) of small crab (< 50 mm carapace width) from trawl surveys by Assessment Division (1995–2021). Right: Annual abundance indices (# million) of mature female crab from trawl surveys by Assessment Division (1995–2021).

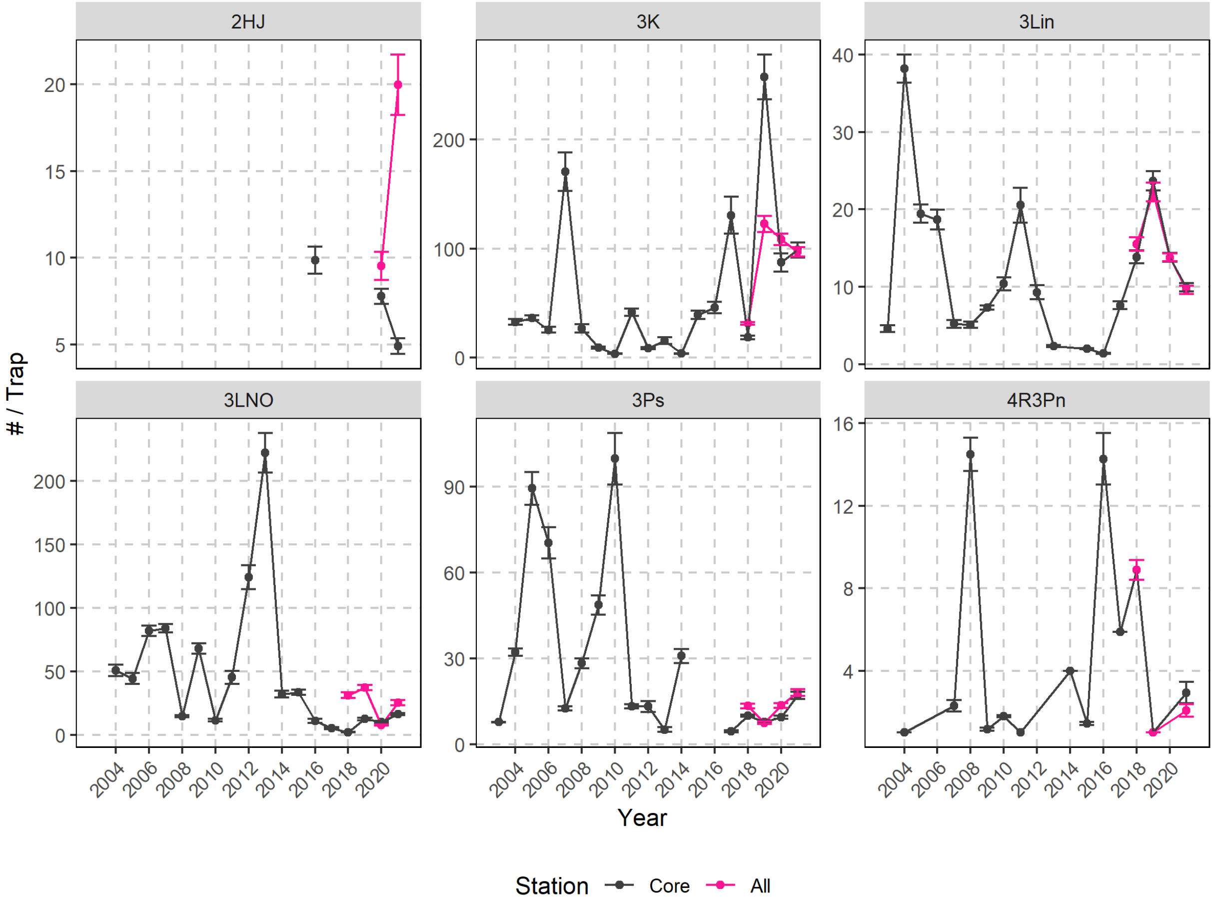


Figure 46. Annual CPUE (#/trap) of small crab from small-mesh traps at core stations (black) and all stations (pink) in the CPS trap survey by Assessment Division (2004–21).

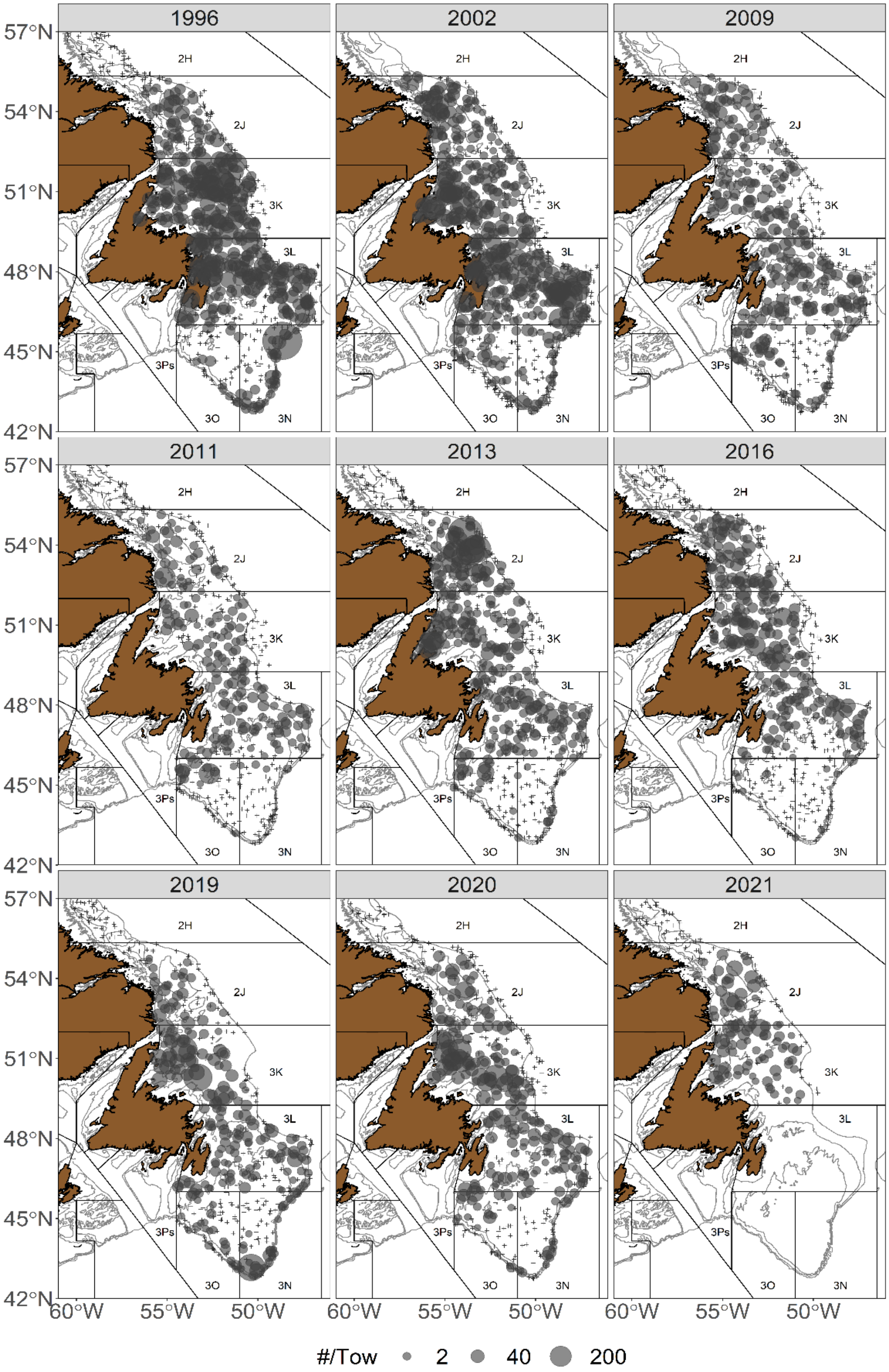


Figure 47. Distribution of small (<50 mm) crab (#/tow) from fall trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016 and 2019–21.

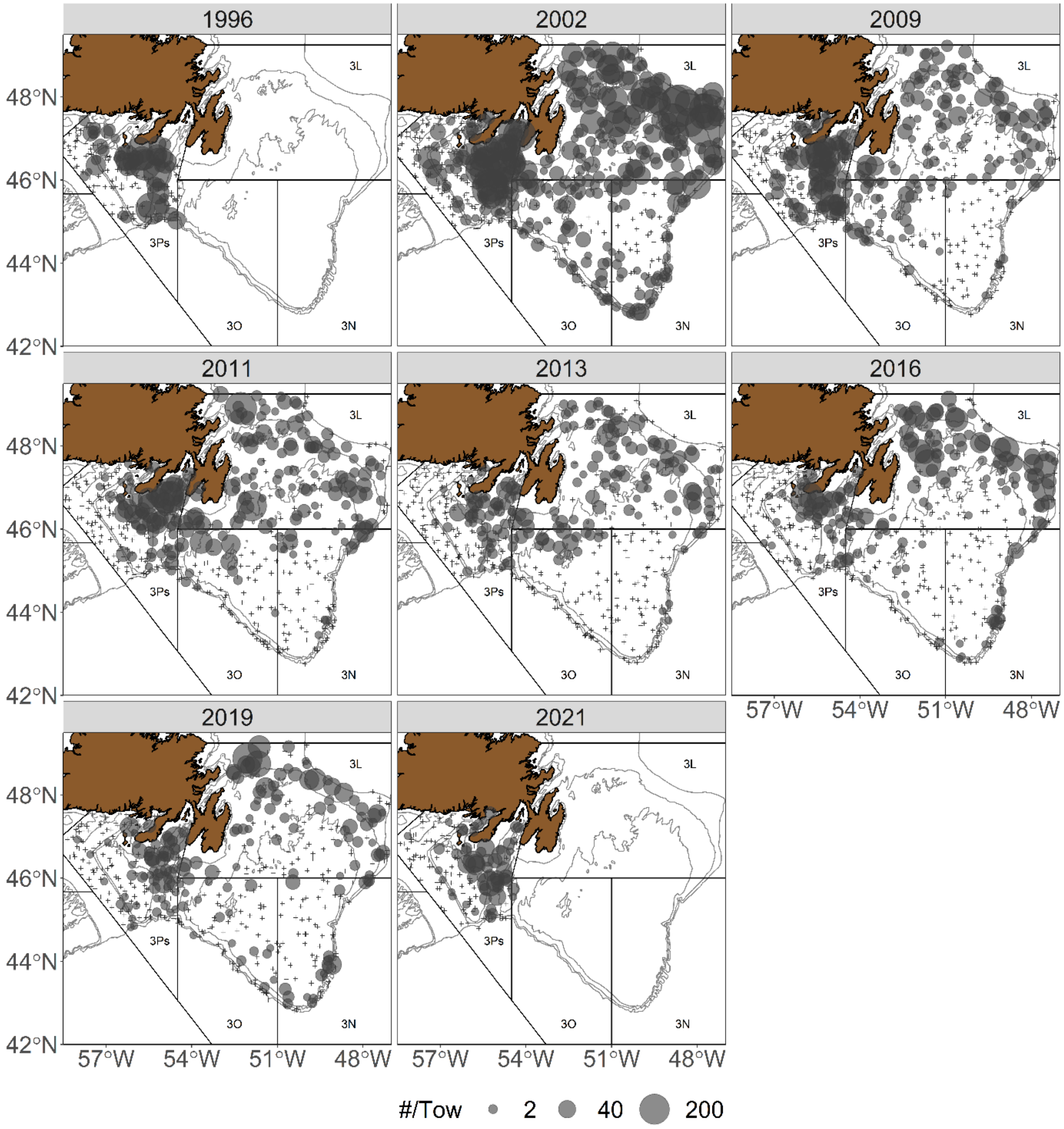


Figure 48. Distribution of small (<50 mm) crab (#/tow) from spring trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016, 2019, and 2021. Note: No survey in 2020.

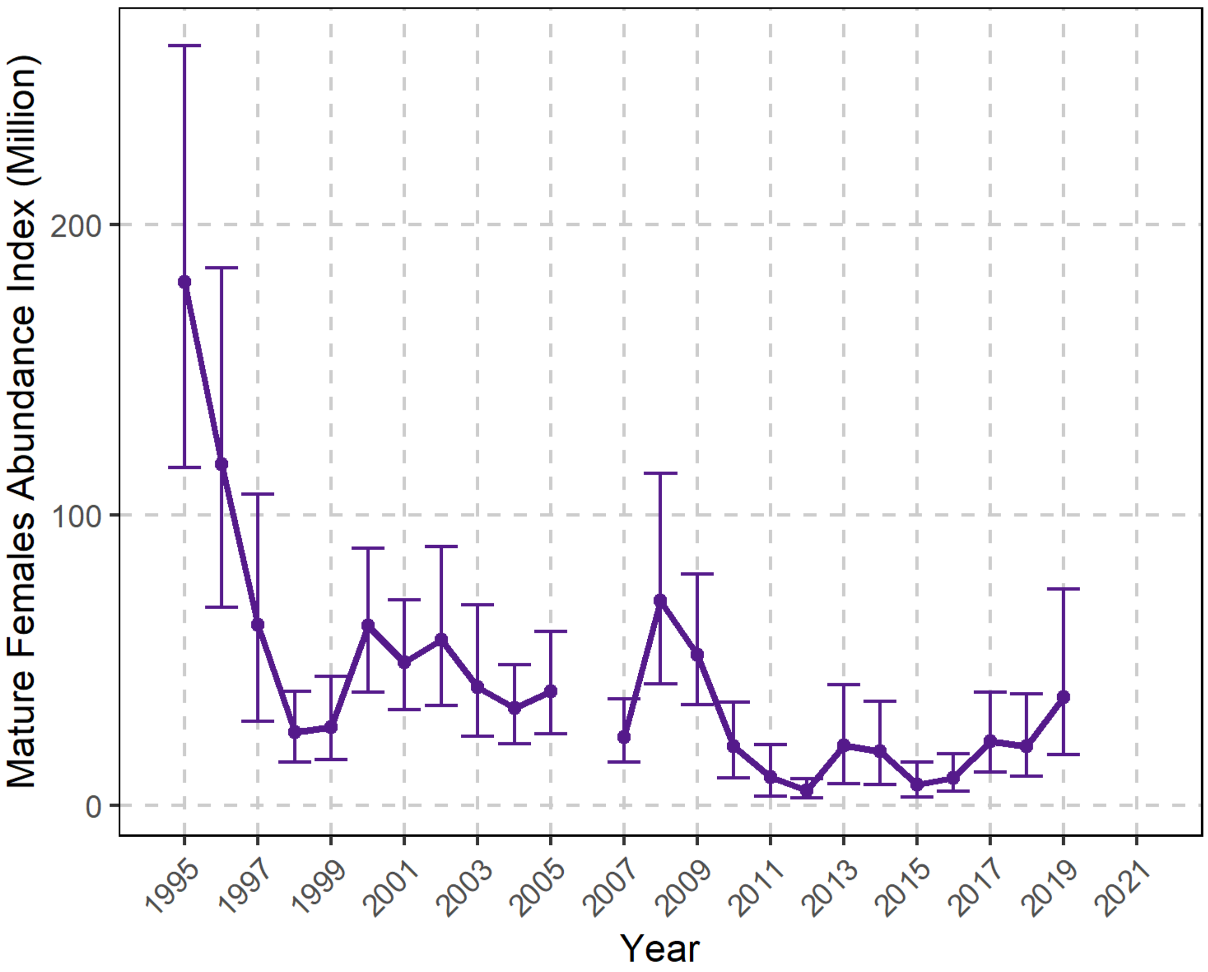


Figure 49. Annual abundance index (# million) of mature female crab from trawl surveys (1995–2019).

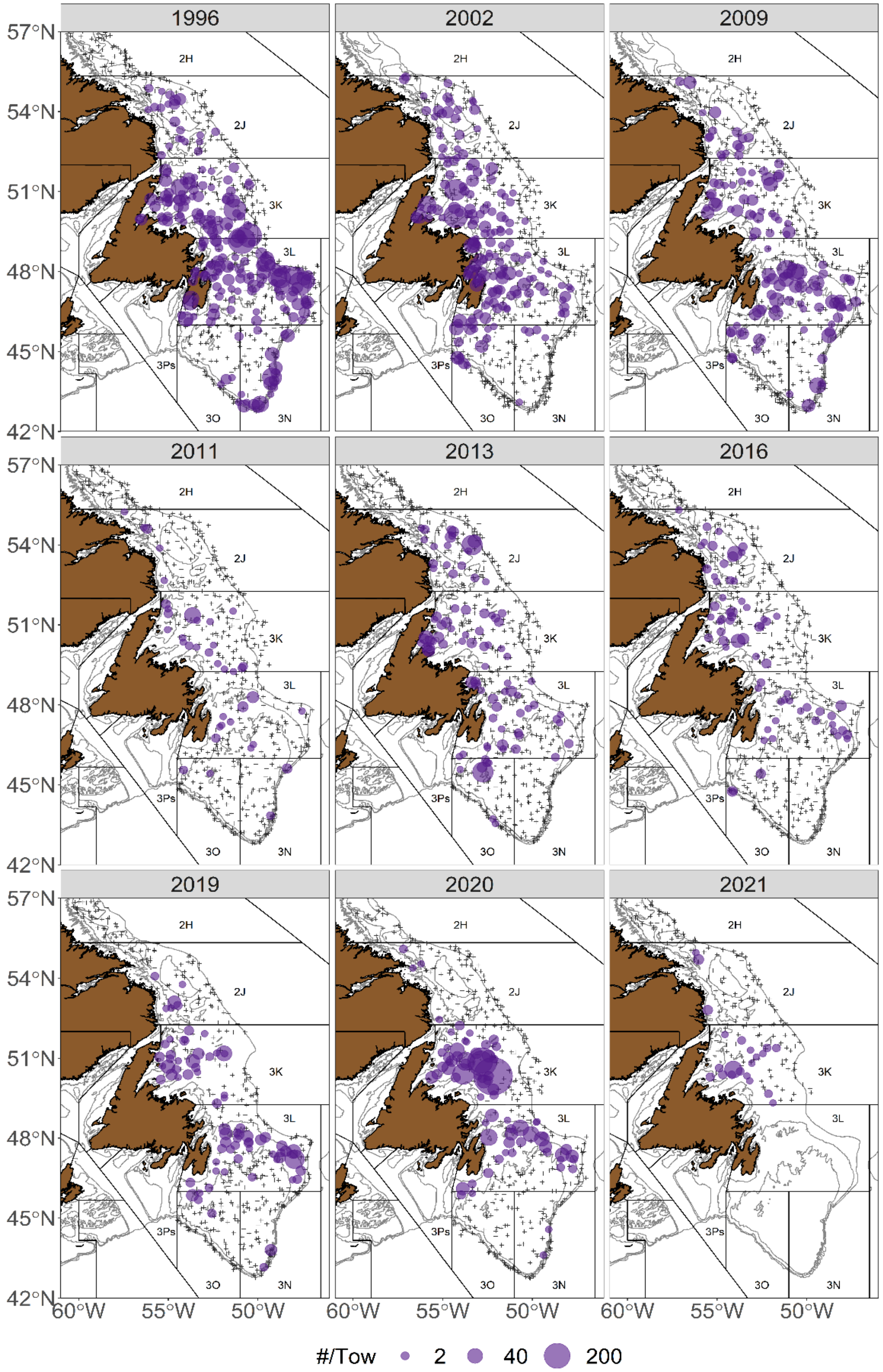


Figure 50. Distribution of mature females (#/tow) from fall trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016 and 2019–21.

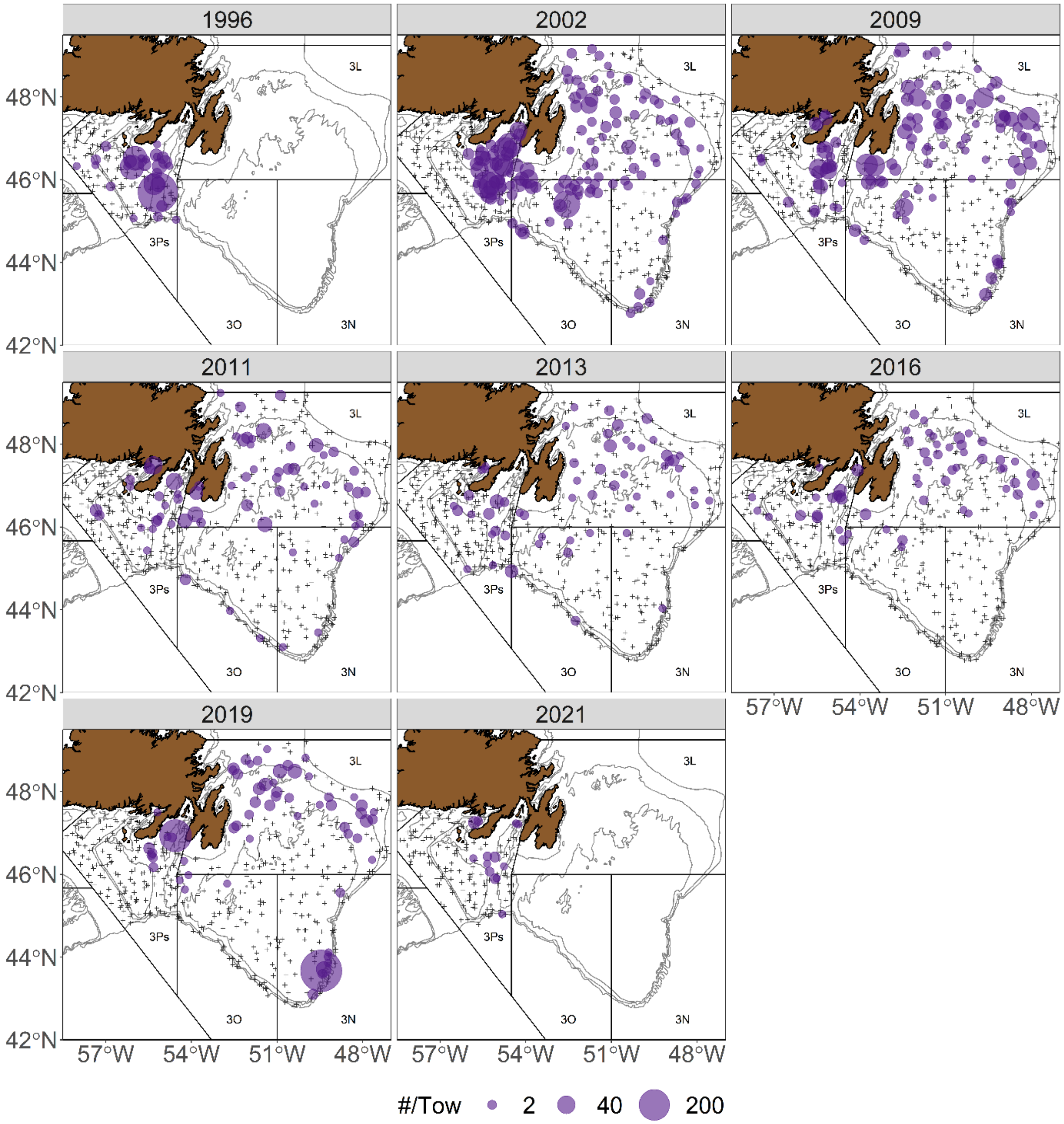


Figure 51. Distribution of mature females (#/tow) from spring trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016, 2019, and 2021. Note: No survey in 2020.

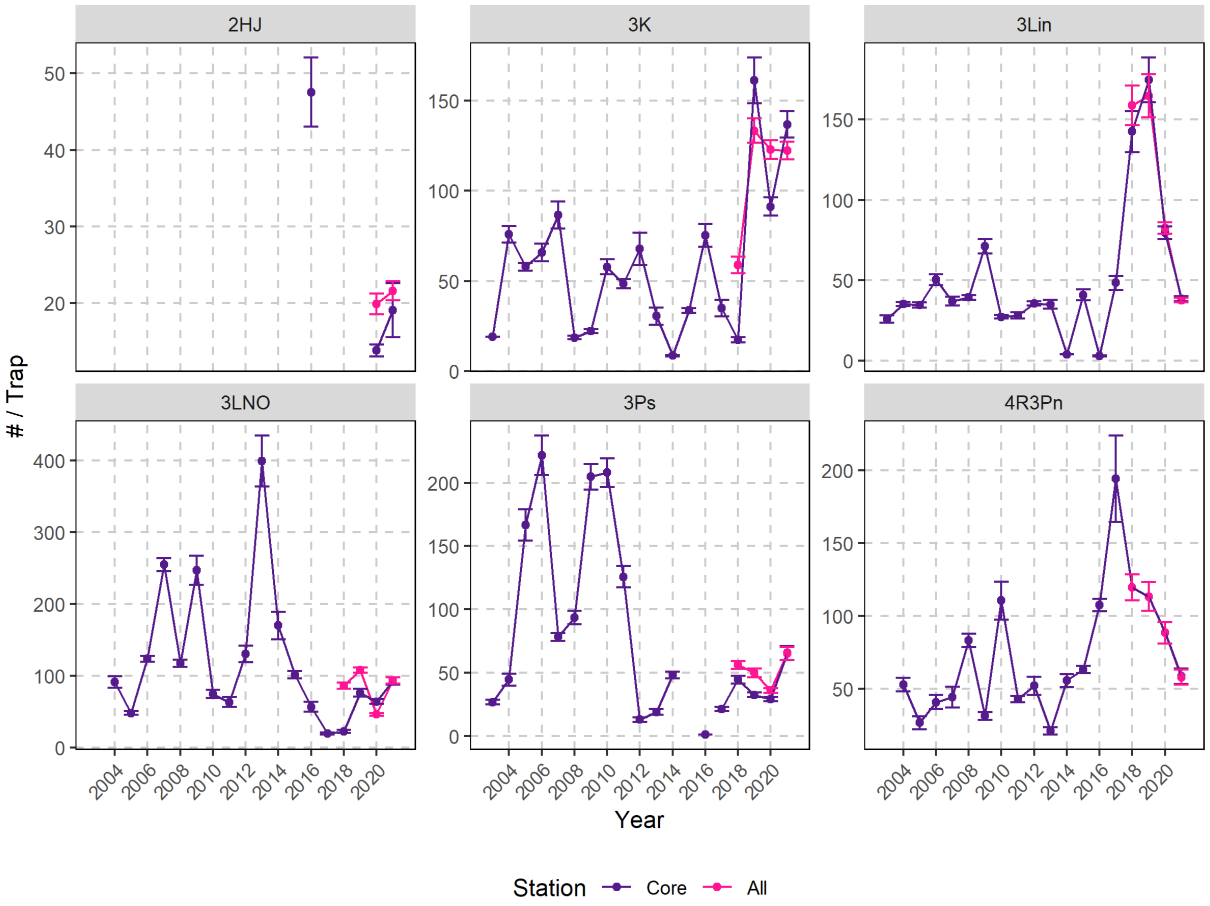


Figure 52. Annual CPUE (#/trap) of mature female crab from small-mesh traps at core stations (purple) and all stations (pink) in the CPS trap survey by Assessment Division (2004–21).

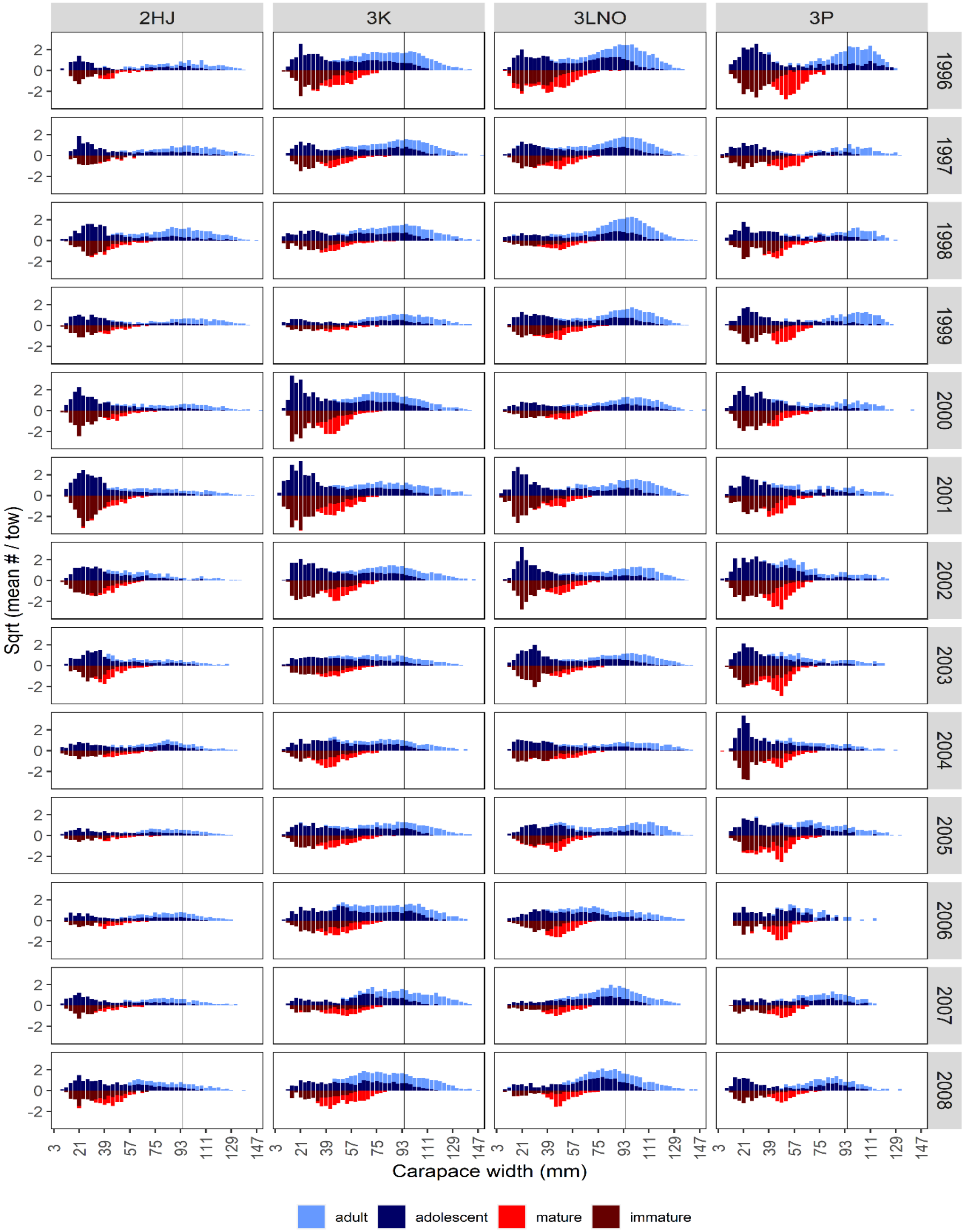


Figure 53. Abundance indices (#/tow) by CW for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (AD 3Ps) and fall (ADs 2HJ, 3K, and 3LNO Offshore) trawl surveys from 1996–2008. Information on females, while displayed on the negative y-axis, represent positive abundance indices. Vertical line is legal-size. Data standardized by vessel.

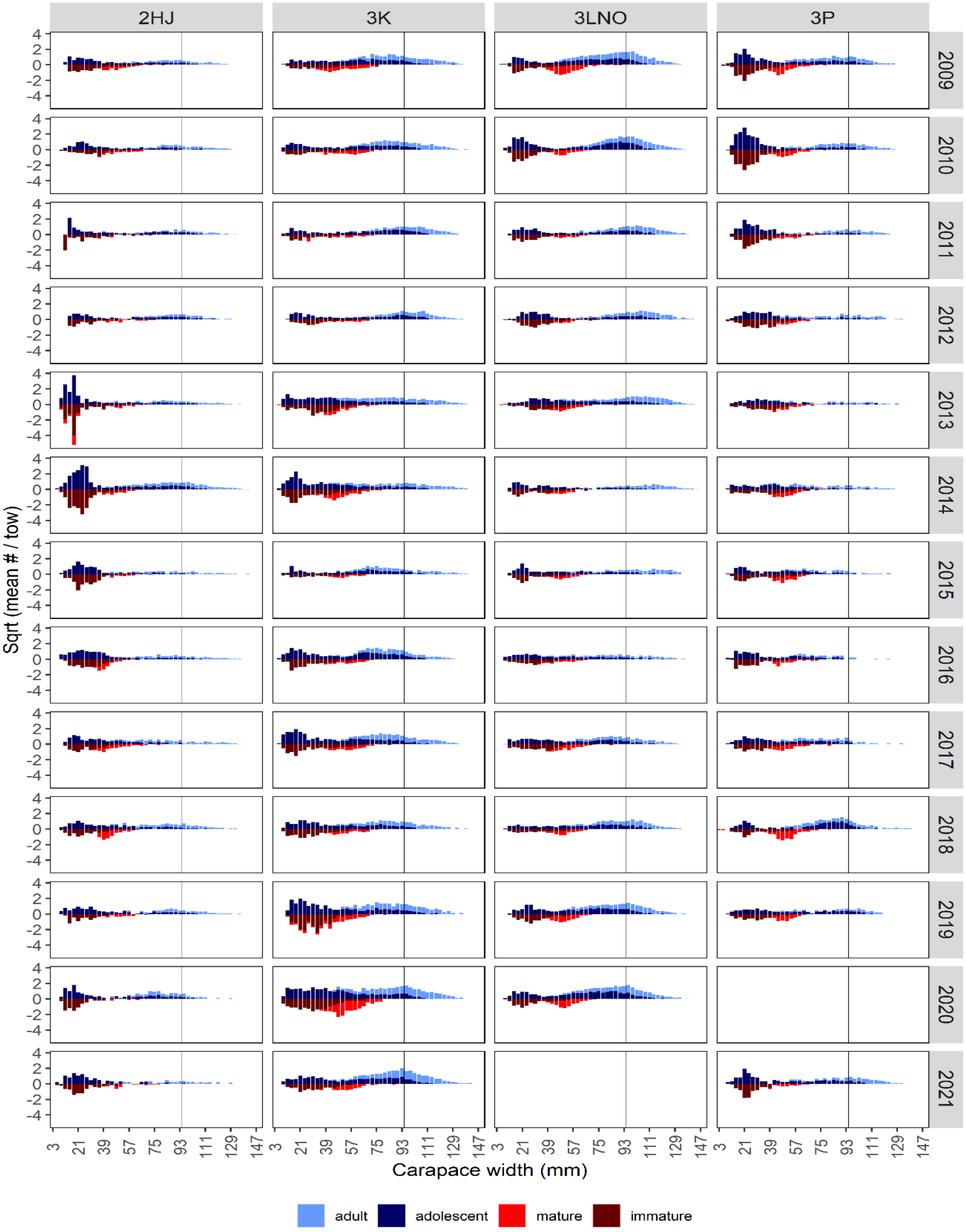


Figure 54. Abundance indices (#/tow) by CW for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (AD 3Ps) and fall (ADs 2HJ, 3K, and 3LNO Offshore) trawl surveys from 2009–21. Information on females, while displayed on the negative y-axis, represent positive abundance indices. Vertical line is legal-size. Data standardized by vessel.

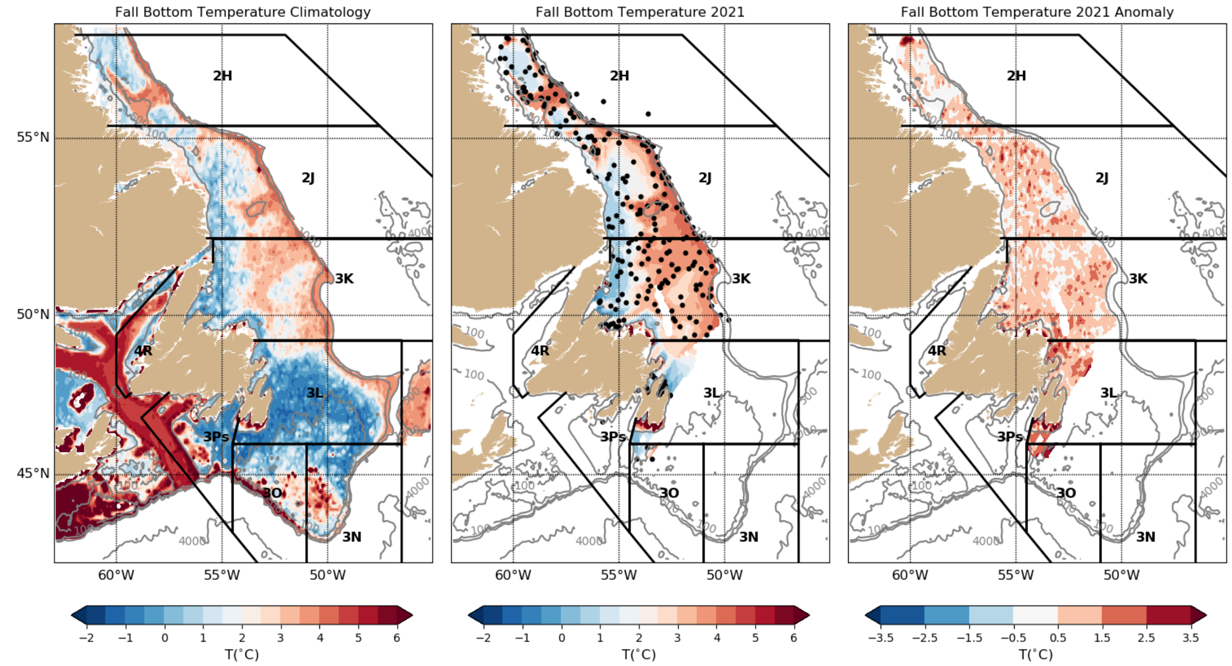


Figure 55. Fall bottom temperatures on the Newfoundland and Labrador shelf averaged over the 1991–2020 climatological period (left panel) and during 2021 (center). Temperature anomalies for 2021 in relation to the climatology is shown in the left panel. Black dots in the center panel indicate the location of the profiles used to calculate the 2021 update (mostly multispecies survey observations).

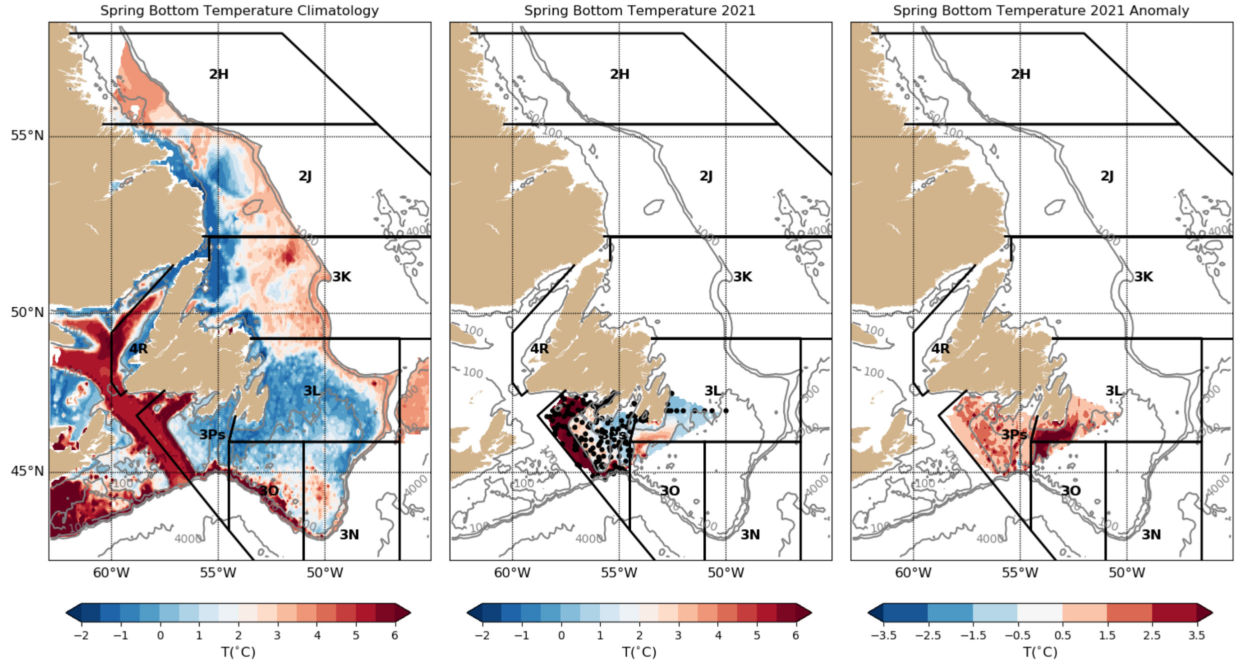


Figure 56. Spring bottom temperatures on the Newfoundland and Labrador shelf averaged over the 1991–2020 climatological period (left panel) and during 2021 (center). Temperature anomalies for 2021 in relation to the climatology is shown in the left panel. Black dots in the center panel indicate the location of the profiles used to calculate the 2021 update (mostly multispecies survey observations).

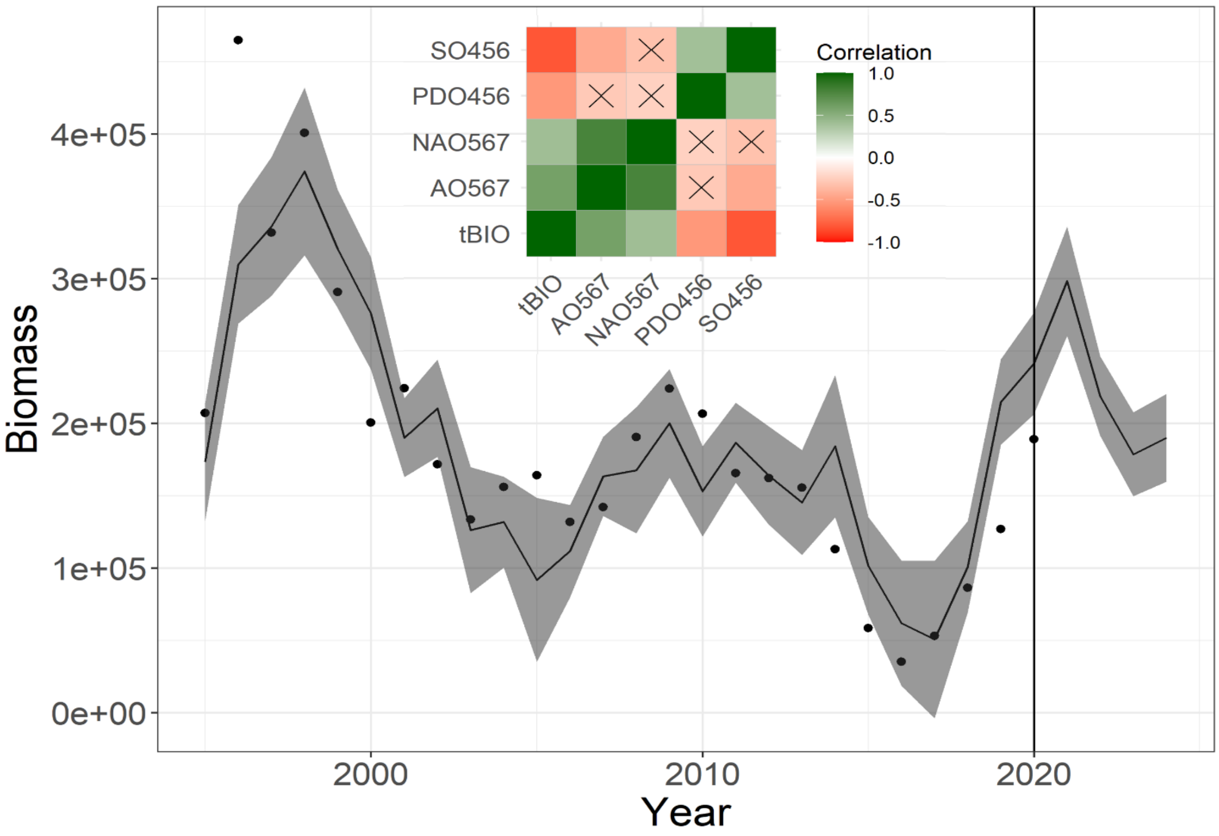


Figure 57. Latent stock-level exploitable biomass index correlations with lagged indices of climate modes (top) and stock-level exploitable biomass index in relation to a lagged index of the Arctic Oscillation from 5–7 years ago and the Southern Oscillation from 4–6 years ago with data from 1995–2020 (bottom). Points = trawl survey exploitable biomass + landings, solid line = model fit, and shaded band = 95% confidence intervals.

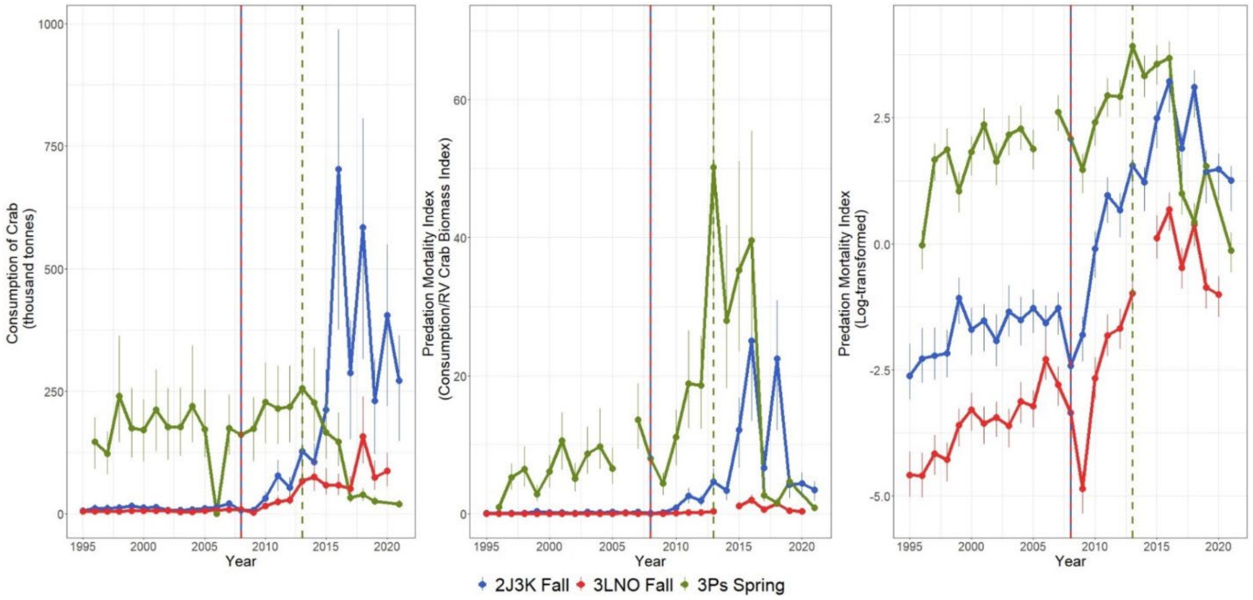


Figure 58. Consumption of Snow Crab by finfish predators (left) and predation mortality index (middle and right) by Ecosystem Production Unit (EPU) and year.

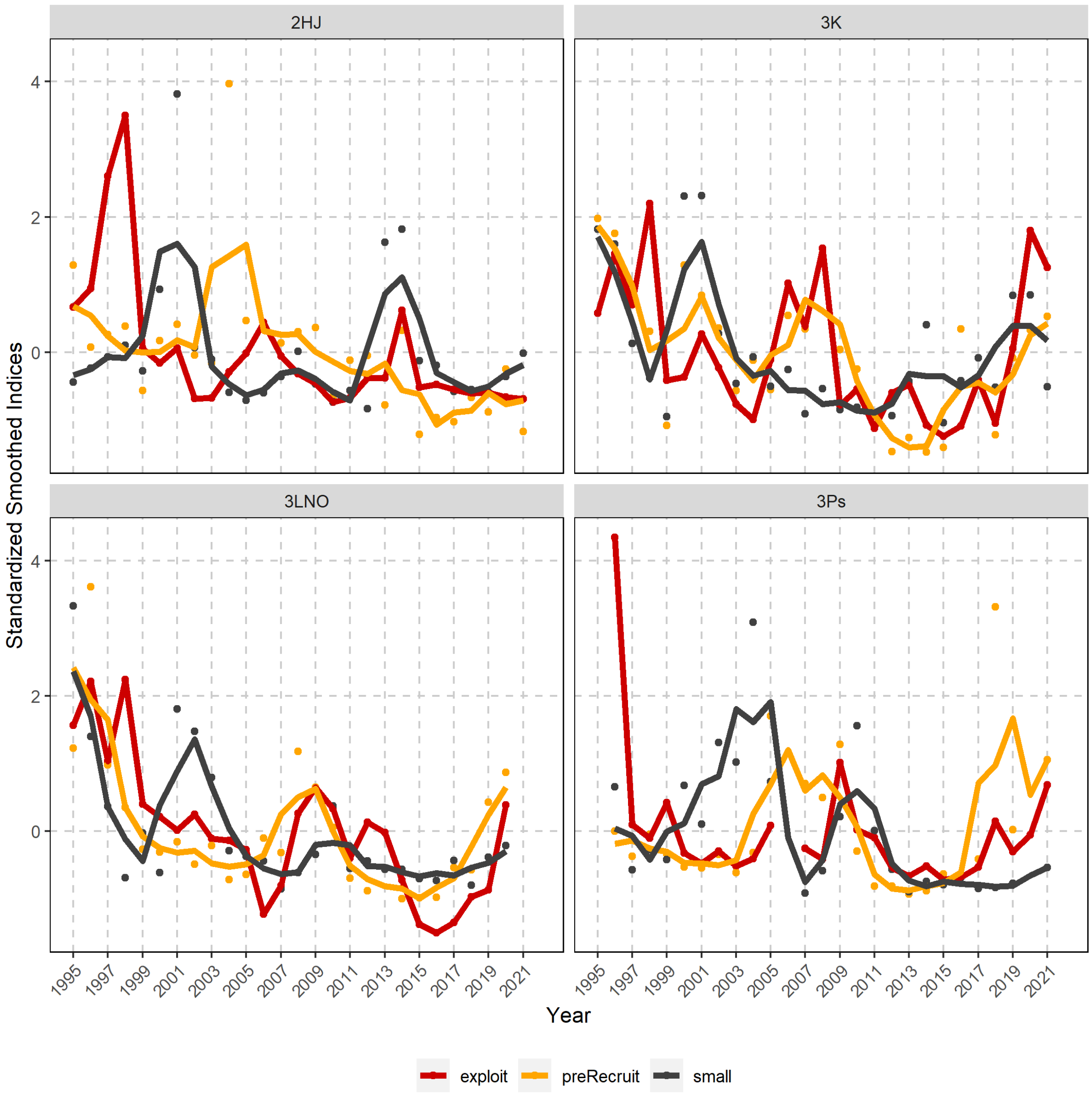


Figure 59. Standardized annual (points) and 3-year centered moving average (solid line) indices of Snow Crab trawl biomass or abundance by Assessment Division: exploitable male crab (red), pre-recruits (orange), and small crab (<50 mm CW) (black).

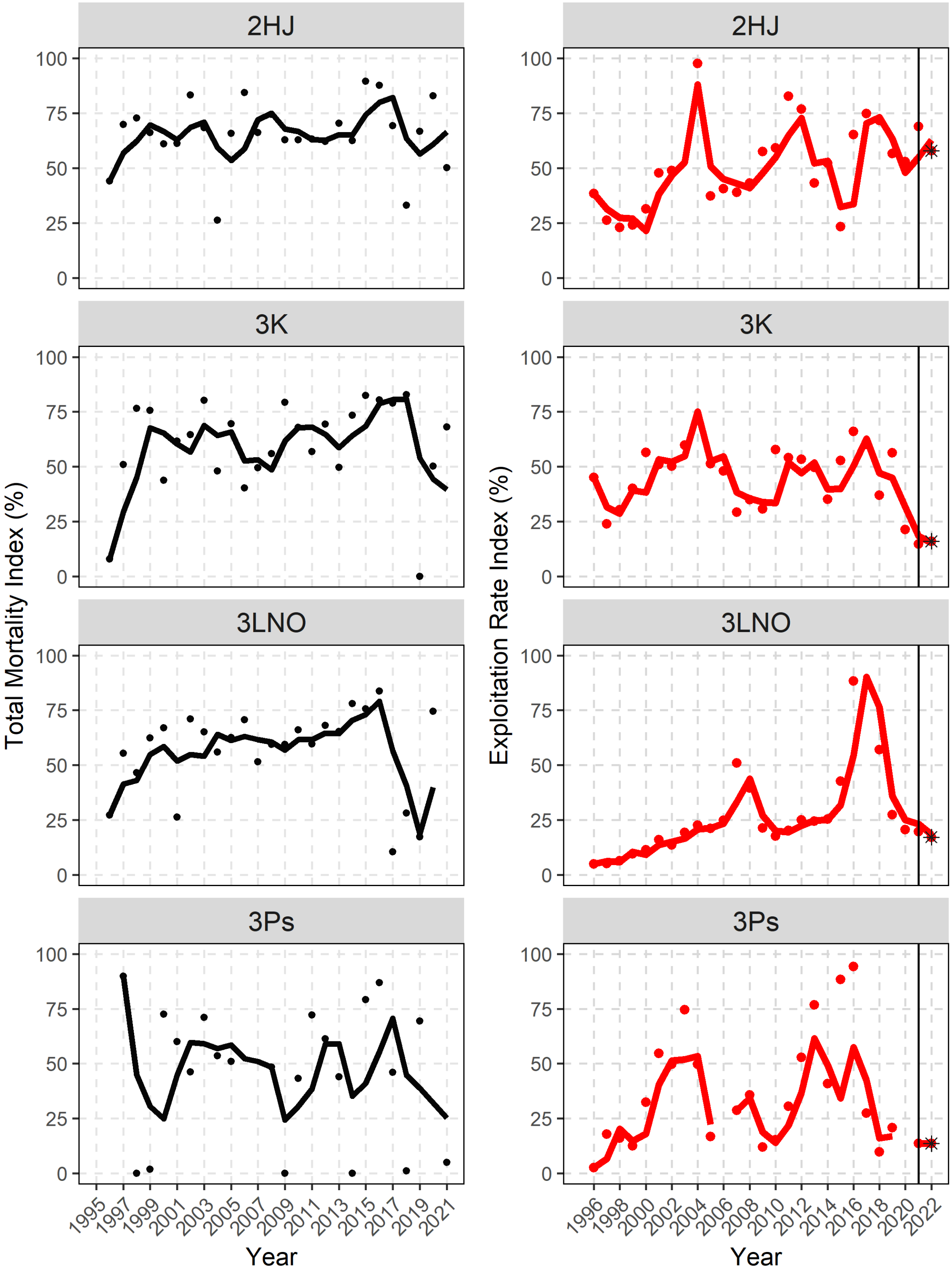


Figure 60. Left: Trends in the annual (points) and 3-year moving average (solid line) total annual mortality index (%) of exploitable crab by Assessment Division. Note if annual mortality index was <0 it was plotted as 0 for presentation. Right: Trends in the trawl-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) by Assessment Division; 2022 points (*) depict projected exploitation rate indices under status quo removals in the 2022 fishery.

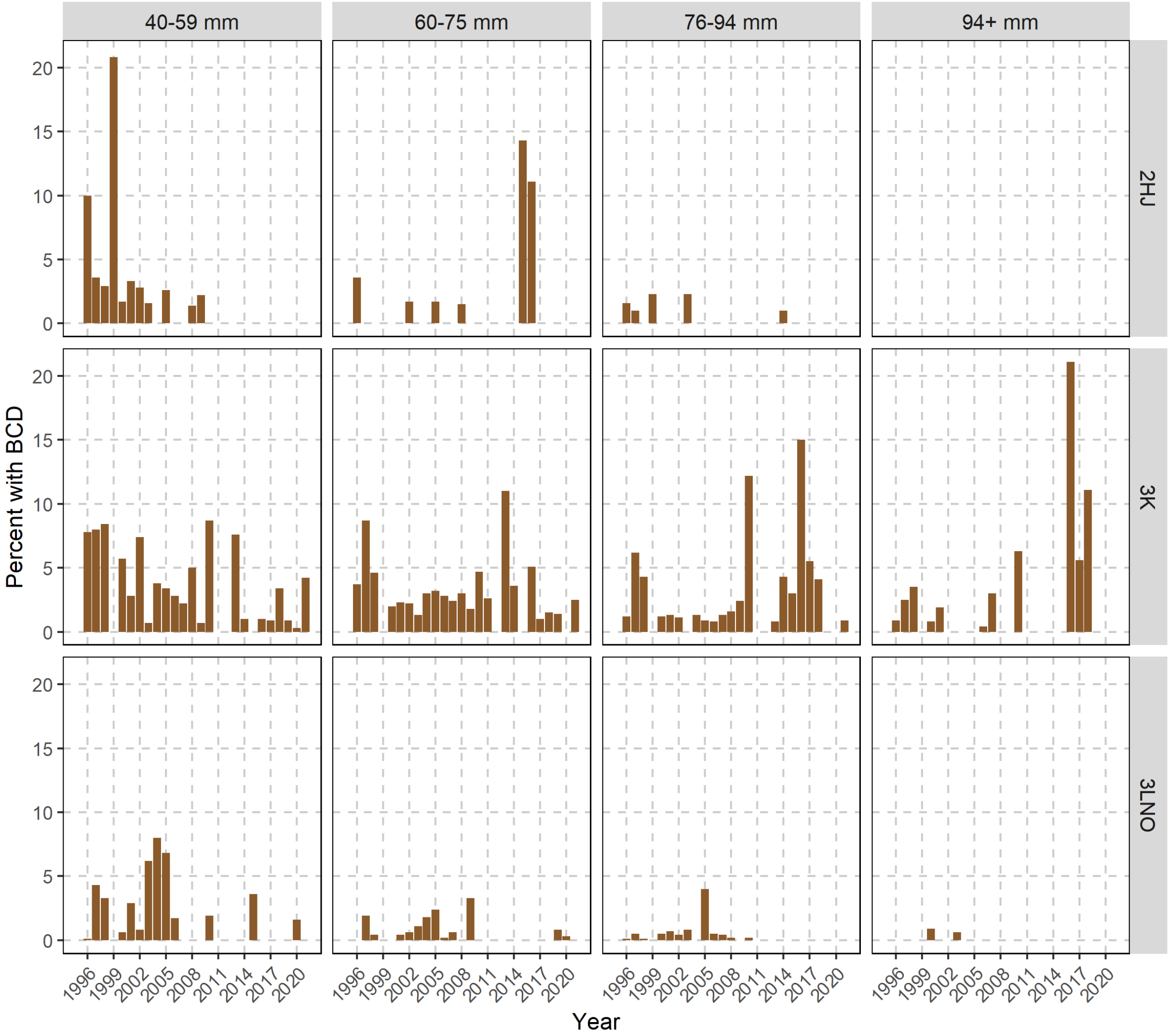


Figure 61. Annual prevalence of Bitter Crab Disease (BCD) from macroscopic observations in new-shelled adolescent male crab in fall trawl surveys by Assessment Division and carapace width (1996–2021).

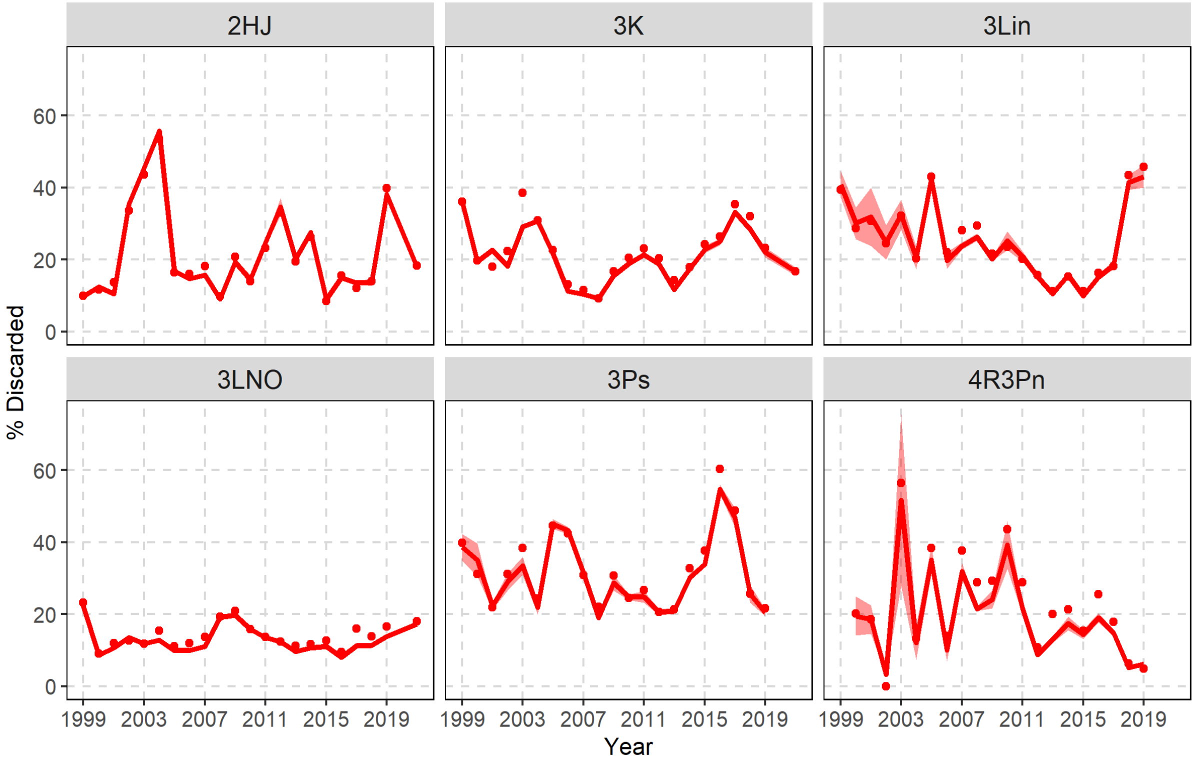


Figure 62. Trends in discards (%) based on raw estimates (points) and standardized values (solid lines). Shaded area = 95% confidence interval.

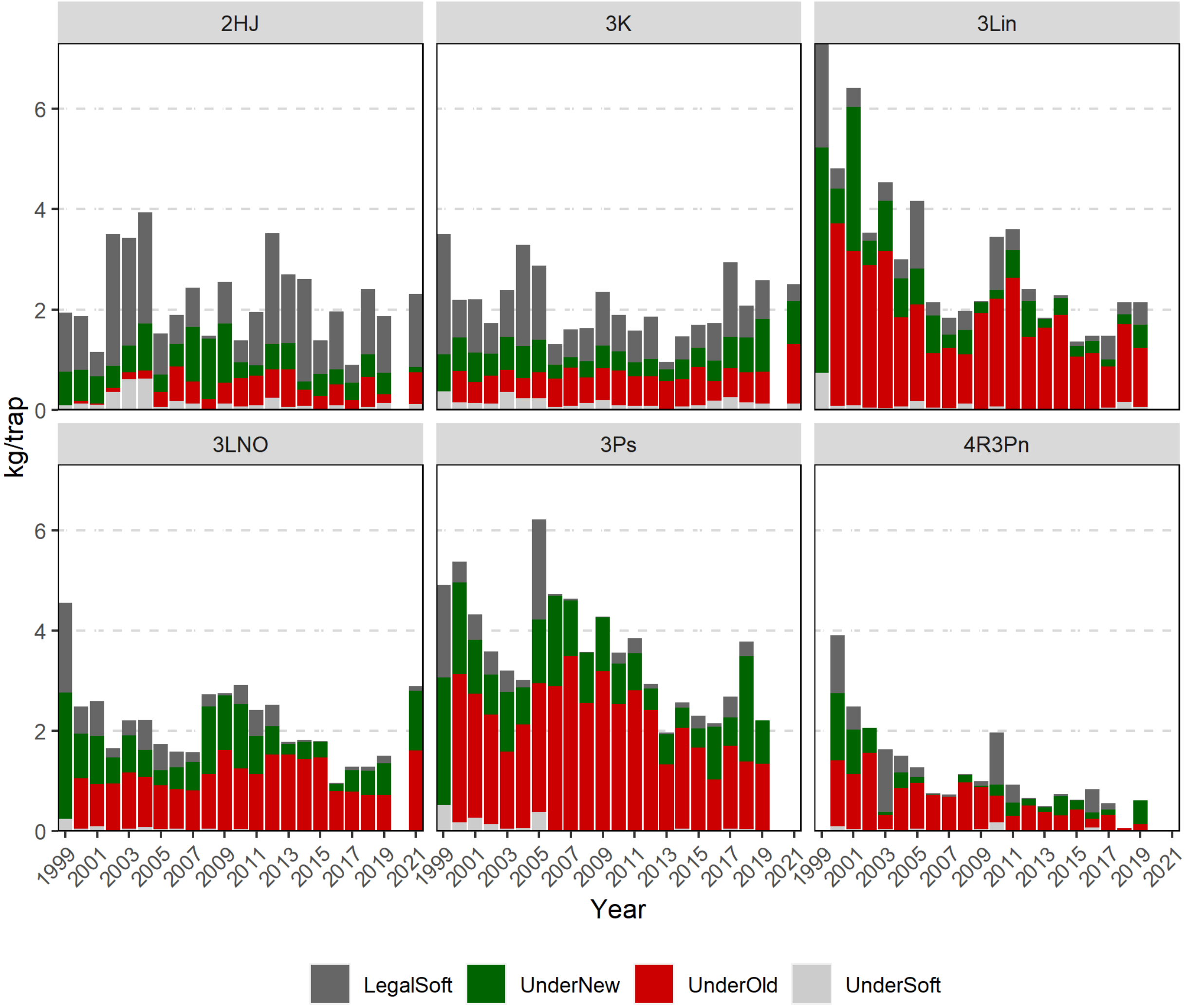


Figure 63. Trends in observed catch rates of discards (kg/trap) based on size and shell condition groups (legal-sized soft-shelled, undersized new-shelled, undersized old-shelled, and undersized soft-shelled discards) by Assessment Division. Observations excluded for ADs 3L Inshore, 3Ps and 4R3Pn in 2021.

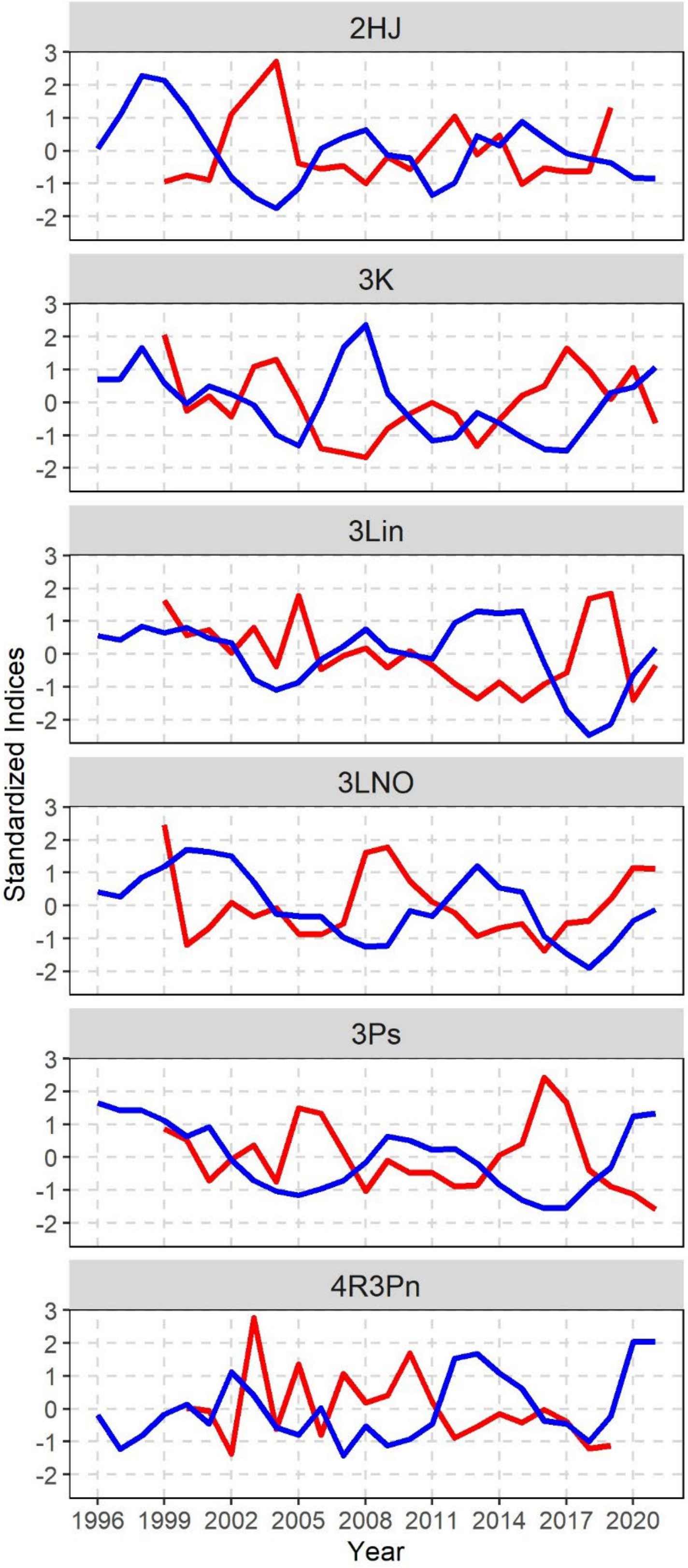


Figure 64. Trends in standardized fishery CPUE (blue) and discard rates (red) by Assessment Division.

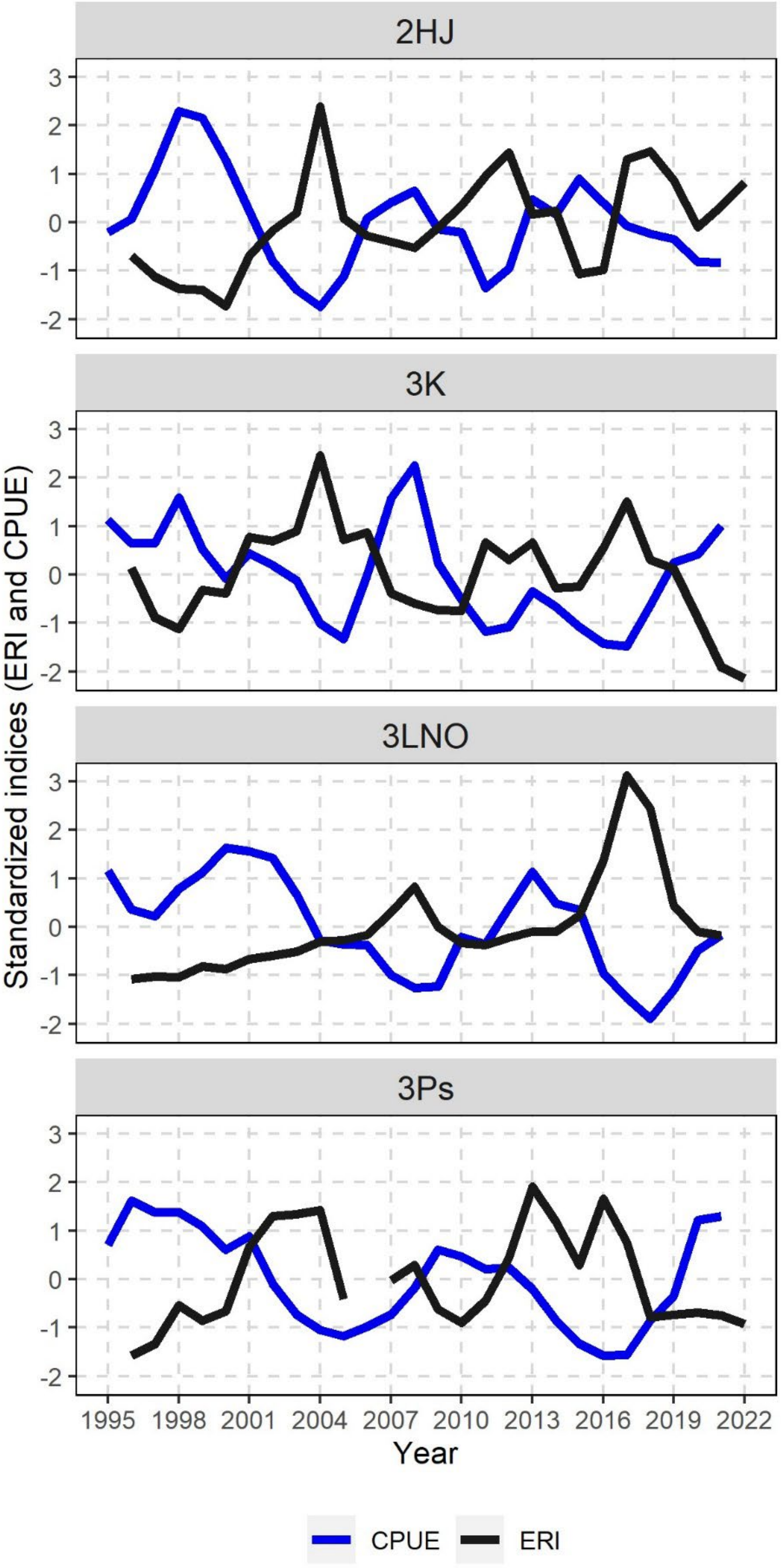


Figure 65. Trends in standardized fishery CPUE (blue) and exploitation rate indices (ERI) (black) by Assessment Division.

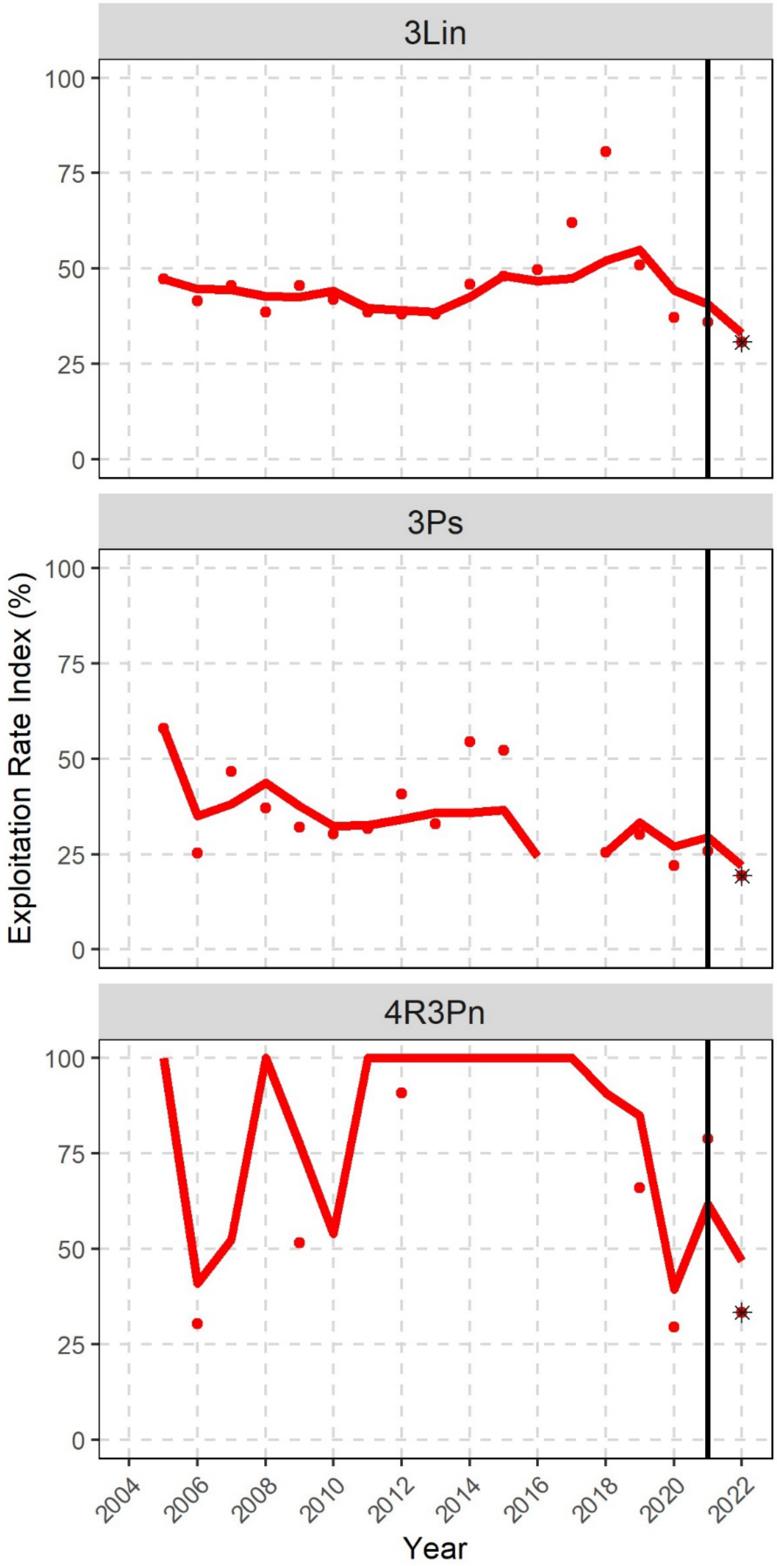


Figure 66. Trends in the trap-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Divisions 3L Inshore, 3Ps, and 4R3Pn; 2022 points (*) depict projected exploitation rate indices under status quo removals in the 2022 fishery.

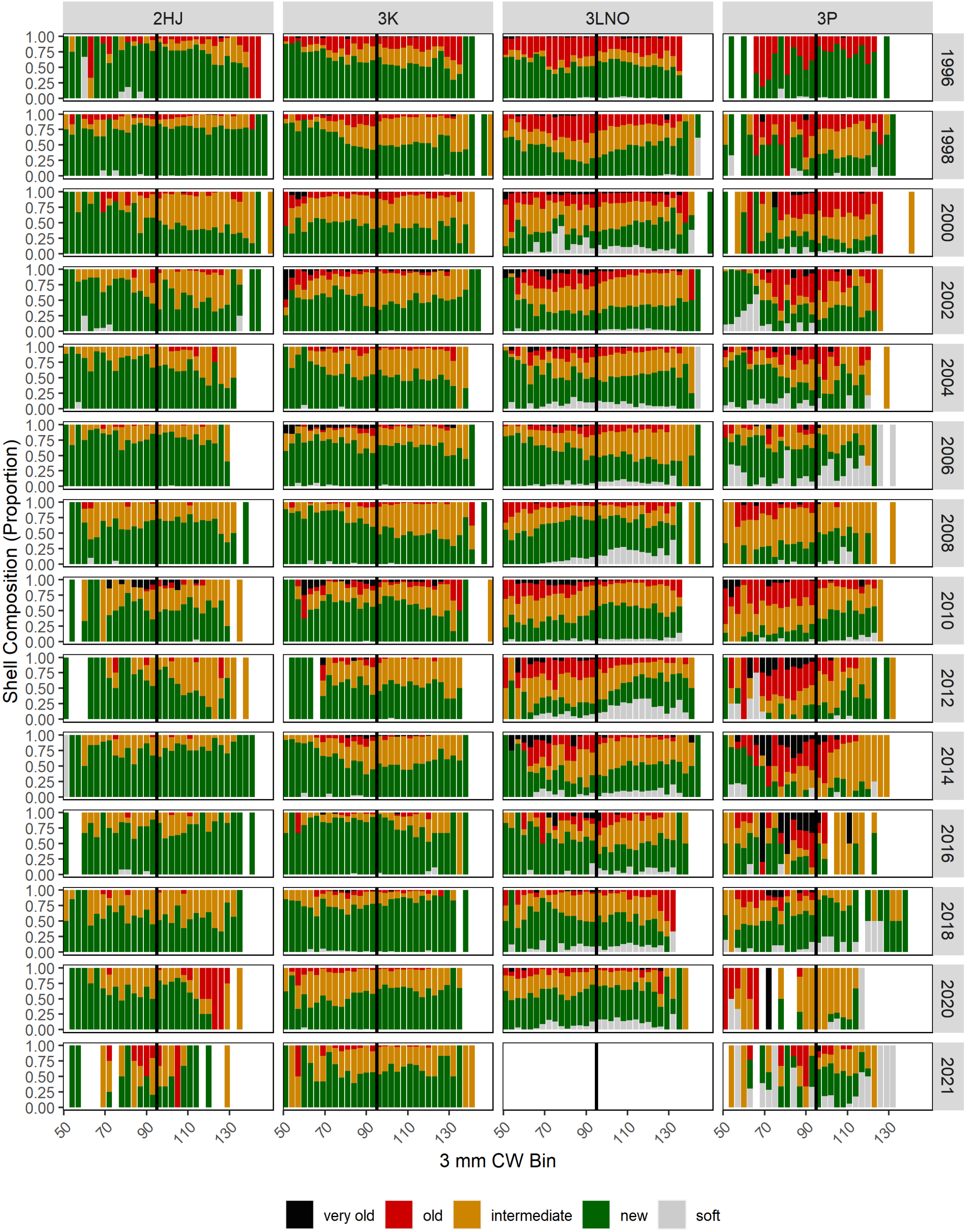


Figure 67. Shell composition (grey = soft-shelled, green = new shelled, orange = intermediate shelled, red = old shelled, black = very old shelled) of adult male crab by 3-mm carapace width intervals from trawl surveys since 1995 in each Assessment Division. Years binned to two-year increments (1995+1996=1996). Vertical black lines depict legal-size. No survey in AD 3Ps in 2006 and 2020, and no survey in AD 3LNO Offshore in 2021.

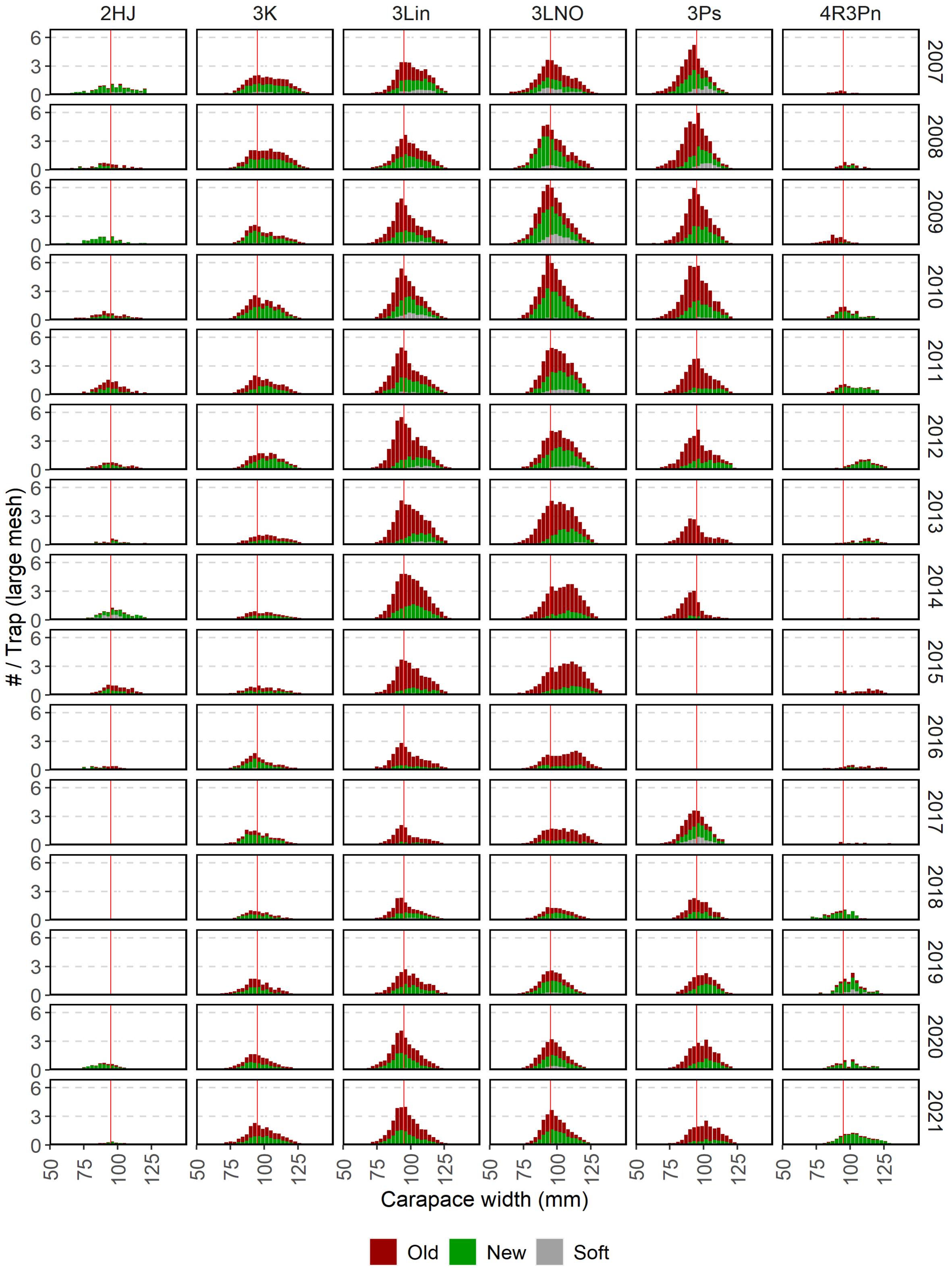


Figure 68. Trends in CPUE (#/trap) by male carapace width distributions and shell condition from large-mesh traps at all stations for the CPS trap survey by Assessment Division (2007–21). The red vertical line indicates the minimum legal size.

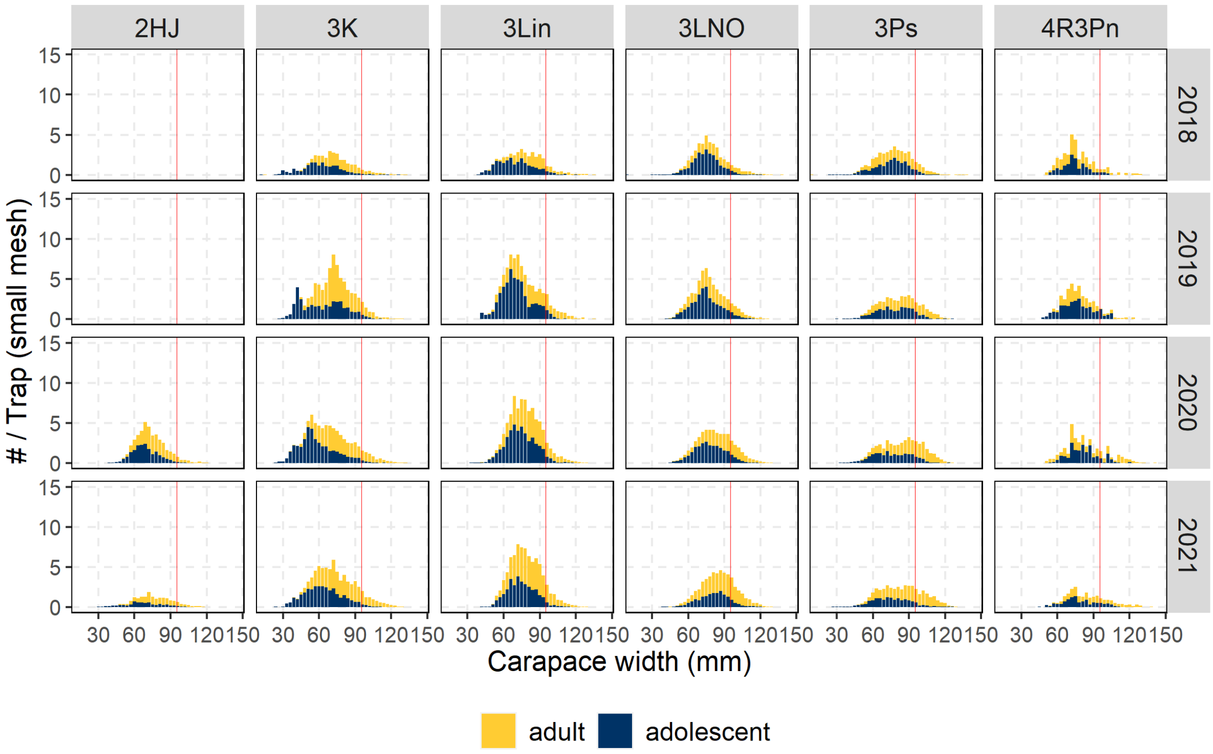


Figure 69. Trends in CPUE (#/trap) by male carapace width distributions and maturity (blue – juveniles and adolescent males, yellow – adult males) from small-mesh traps at all stations from the CPS trap survey by Assessment Division (2018–21). The red vertical line indicates the minimum legal size.

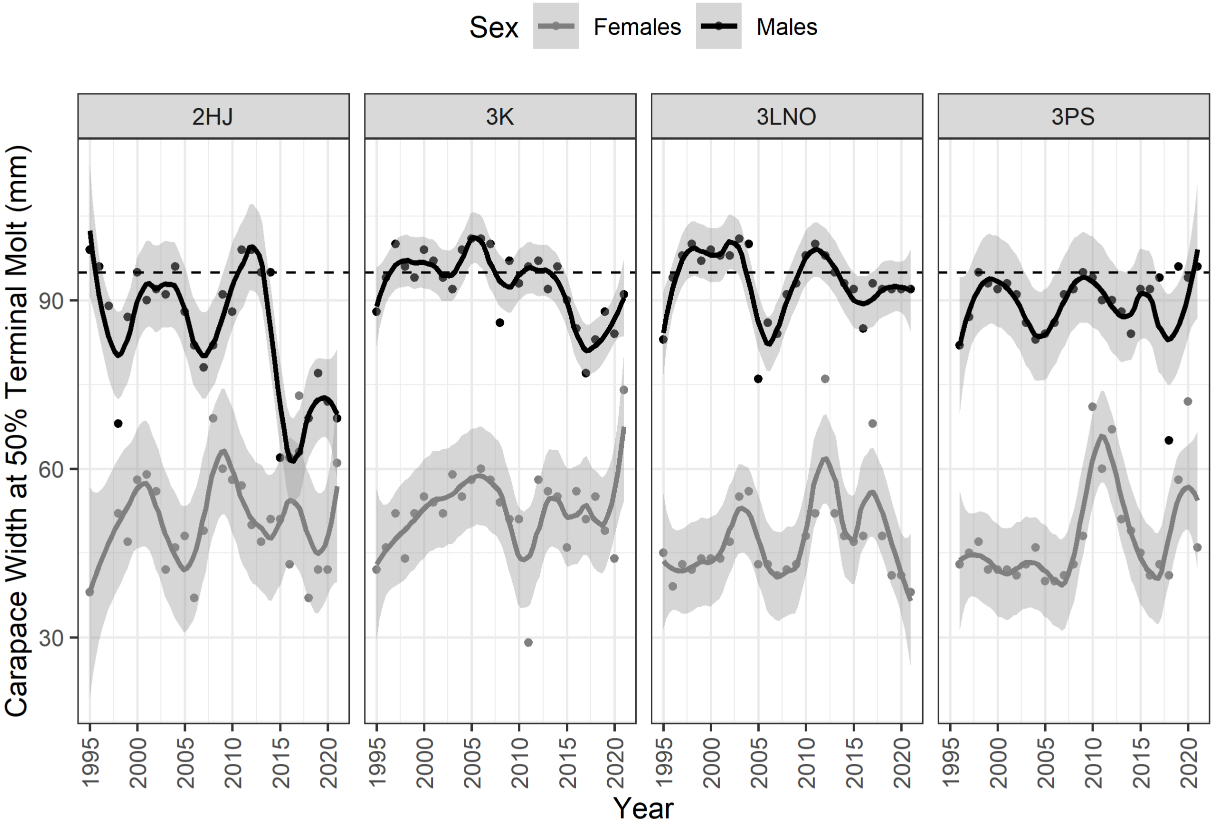


Figure 70. Male (black) and female (grey) size at 50% maturity (terminal molt) by Assessment Division. Points = annual estimates from GAM, solid lines = loess regression curves, shaded band = 95% confidence intervals, and horizontal dashed line = minimum legal size.

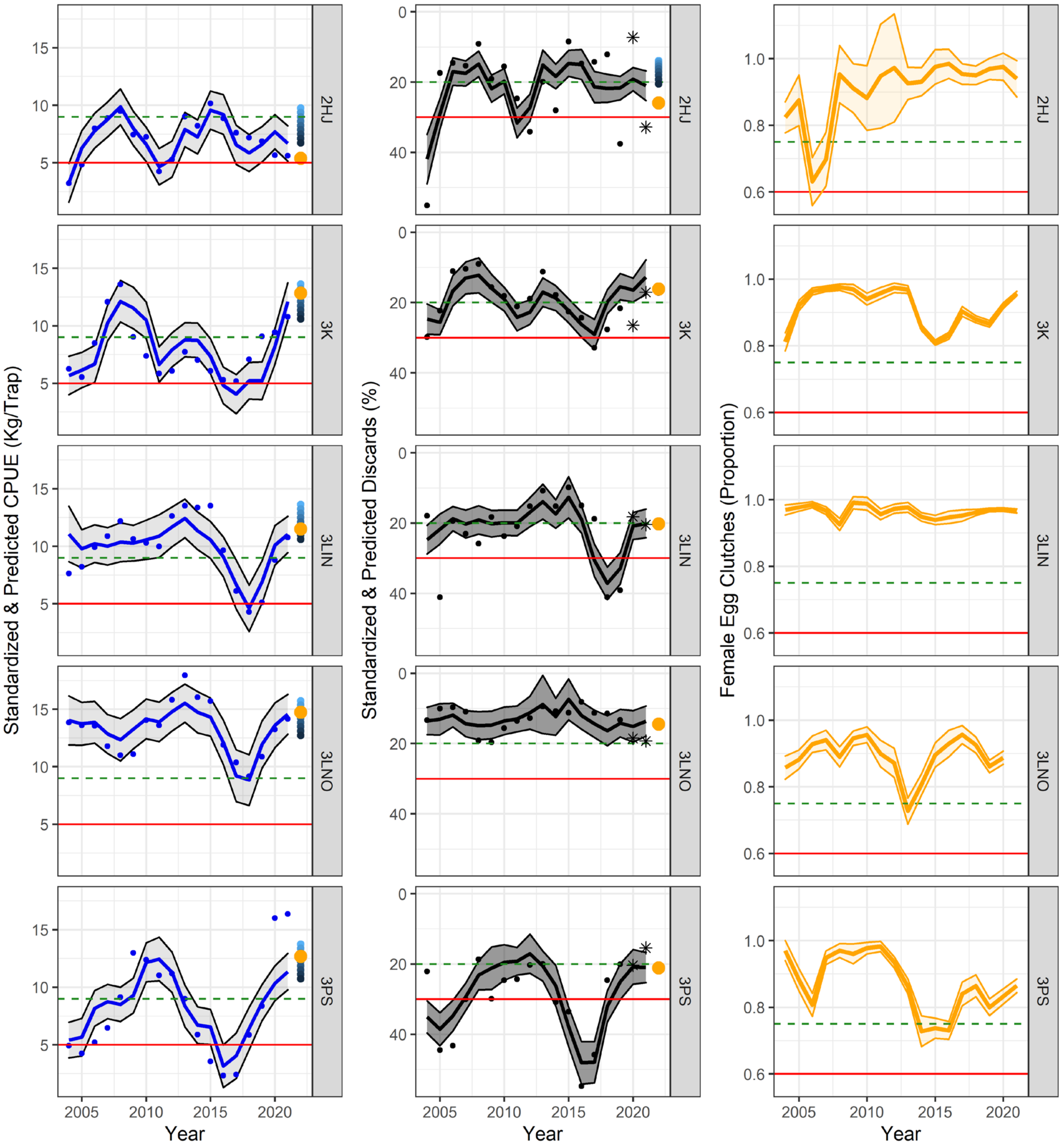
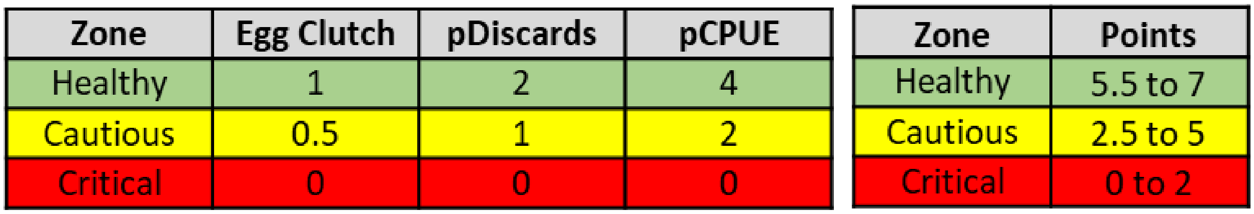


Figure 71. Trends in predicted CPUE (left), predicted % discards (middle), and observed proportion of females with full-egg clutch (right) (solid lines), as well as standardized CPUE and % discards (points) in the provisional Snow Crab Precautionary Approach Framework, by Assessment Division. Shaded areas represent prediction intervals (CPUE and discards) or 1 standard deviation (egg clutches). Orange points represent predicted values under status quo landings in the forthcoming fishery. Vertical blue shades in 2022 are the predicted values under varying levels of Exploitation Rate Index (ERI) (light to dark blue: ERI = 5–45%).



Zone	Egg Clutch	pDiscards	pCPUE
Healthy	1	2	4
Cautious	0.5	1	2
Critical	0	0	0

Zone	Points
Healthy	5.5 to 7
Cautious	2.5 to 5
Critical	0 to 2

Figure 72. Scoring system for determining stock health score from three stock status metrics (Egg Clutch = proportion of females with a full-egg clutch, pDiscards = predicted % discards, and pCPUE = predicted CPUE) in the provisional Snow Crab Precautionary Approach Framework.

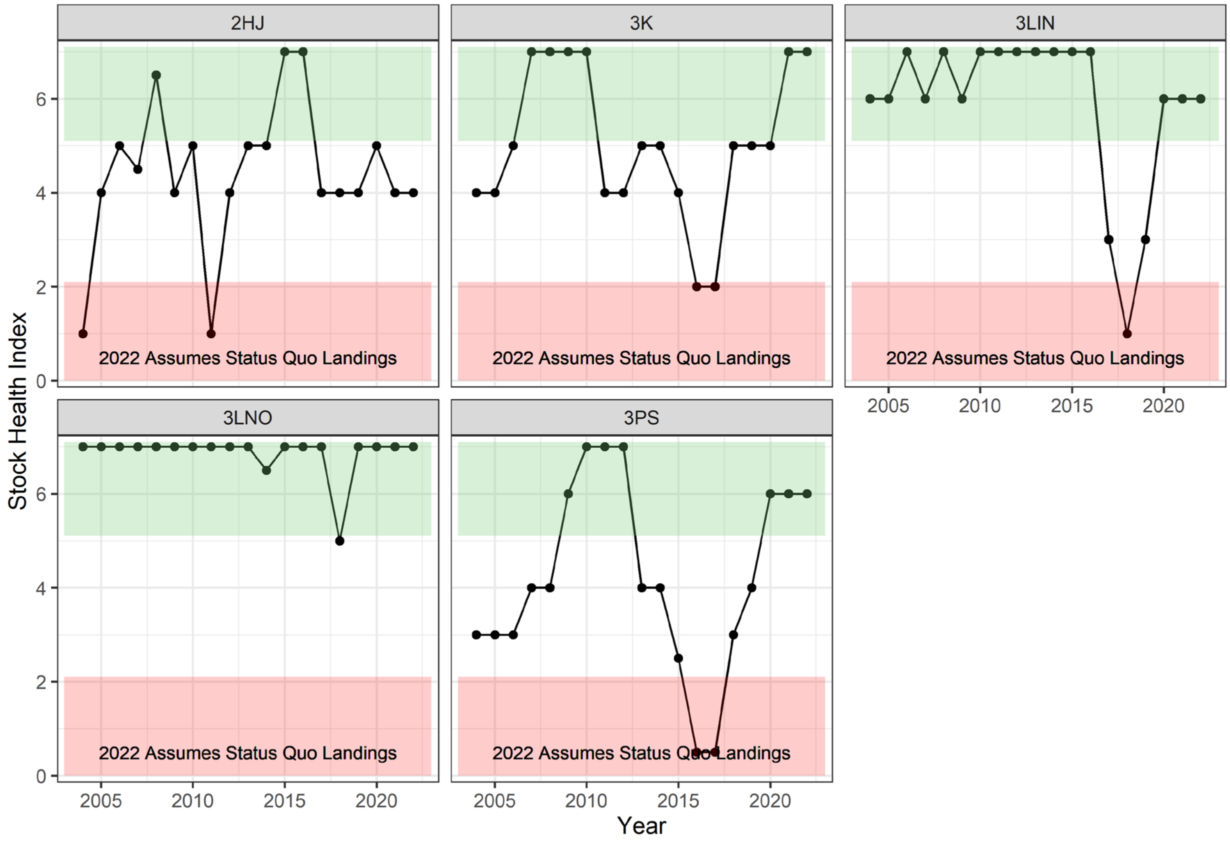


Figure 73. Projected stock status (black point) by Assessment Division in the provisional Snow Crab Precautionary Approach Framework from 2004–22. The green, white, and red shaded areas represent the Healthy, Cautious, and Critical Zones, respectively.

APPENDIX 1: ASSESSMENT DIVISION 2HJ DETAILS

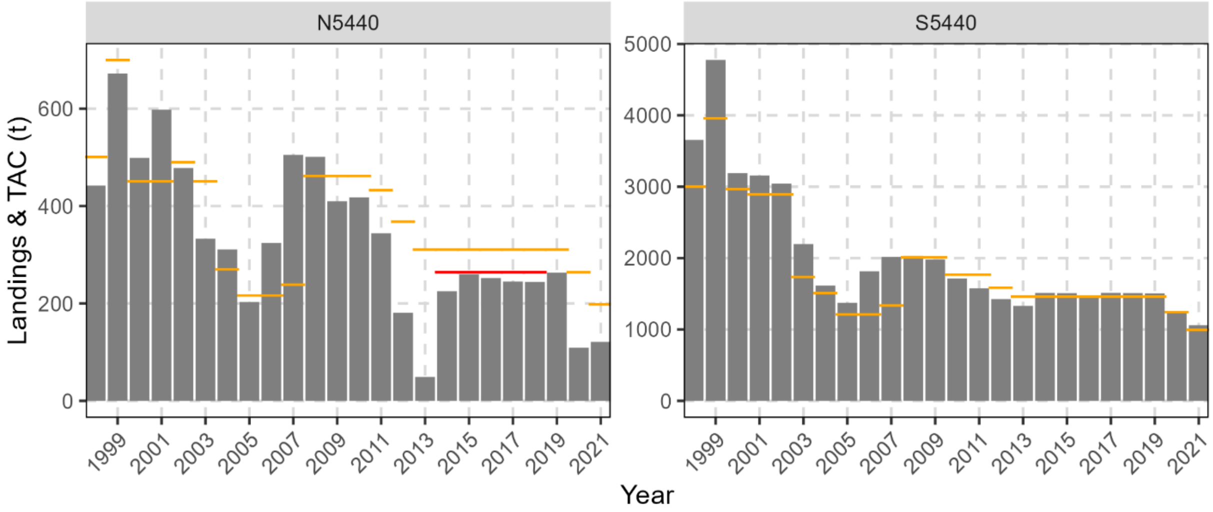


Figure A1.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 2HJ (1998–2021). Red dashes are a voluntary TAC (15% reduction of TAC) set by harvesters in 2JN (N5440) from 2014 to 2018 to promote conservation measures.

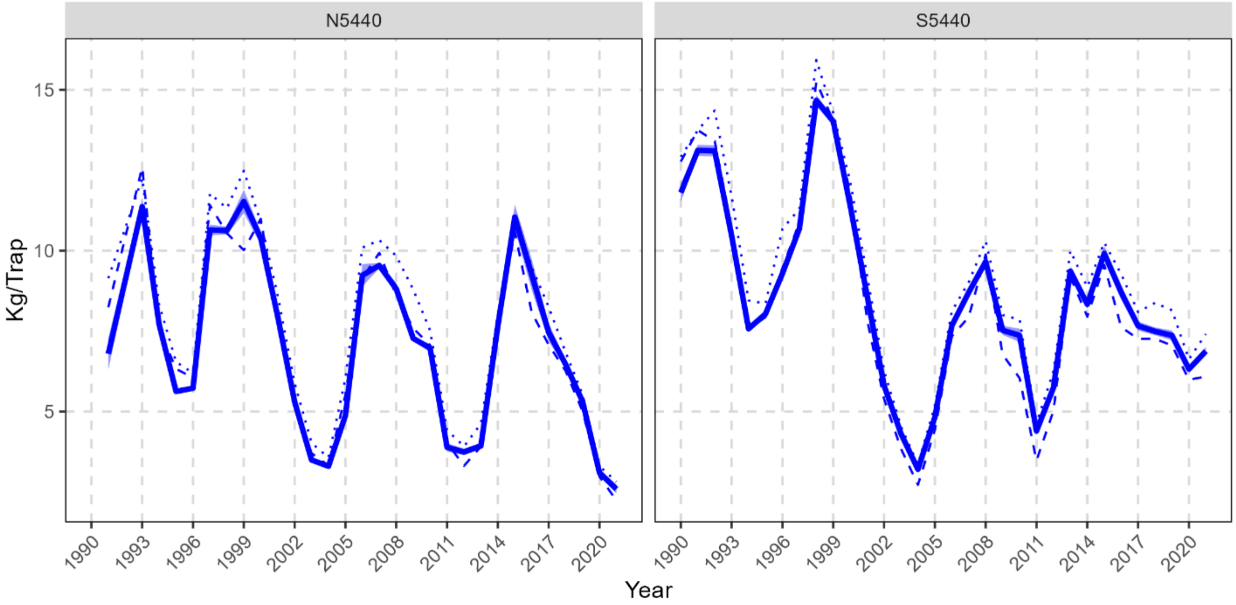


Figure A1.2. Trends in standardized fishery CPUE (kg/trap) in CMAs within Assessment Division 2HJ. Solid line = average predicted CPUE, shaded band = 95% confidence interval, dotted line = average raw CPUE, and dashed line = median raw CPUE. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

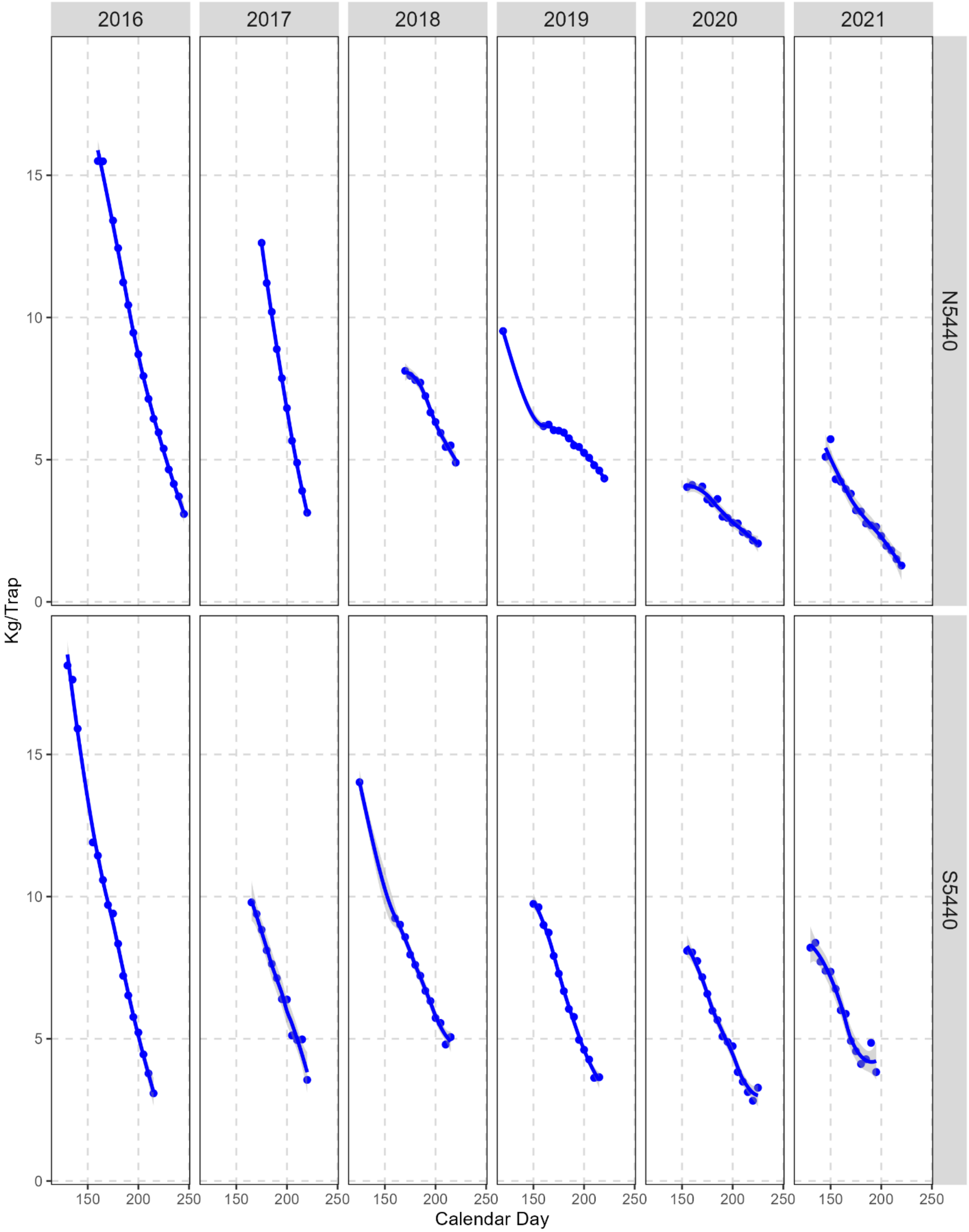


Figure A1.3. Standardized fishery CPUE (kg/trap) throughout the season (calendar day) in CMAs within Assessment Division 2HJ (2016–21). Points = mean CPUE of 5-day increments and trend lines = loess regression curves. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

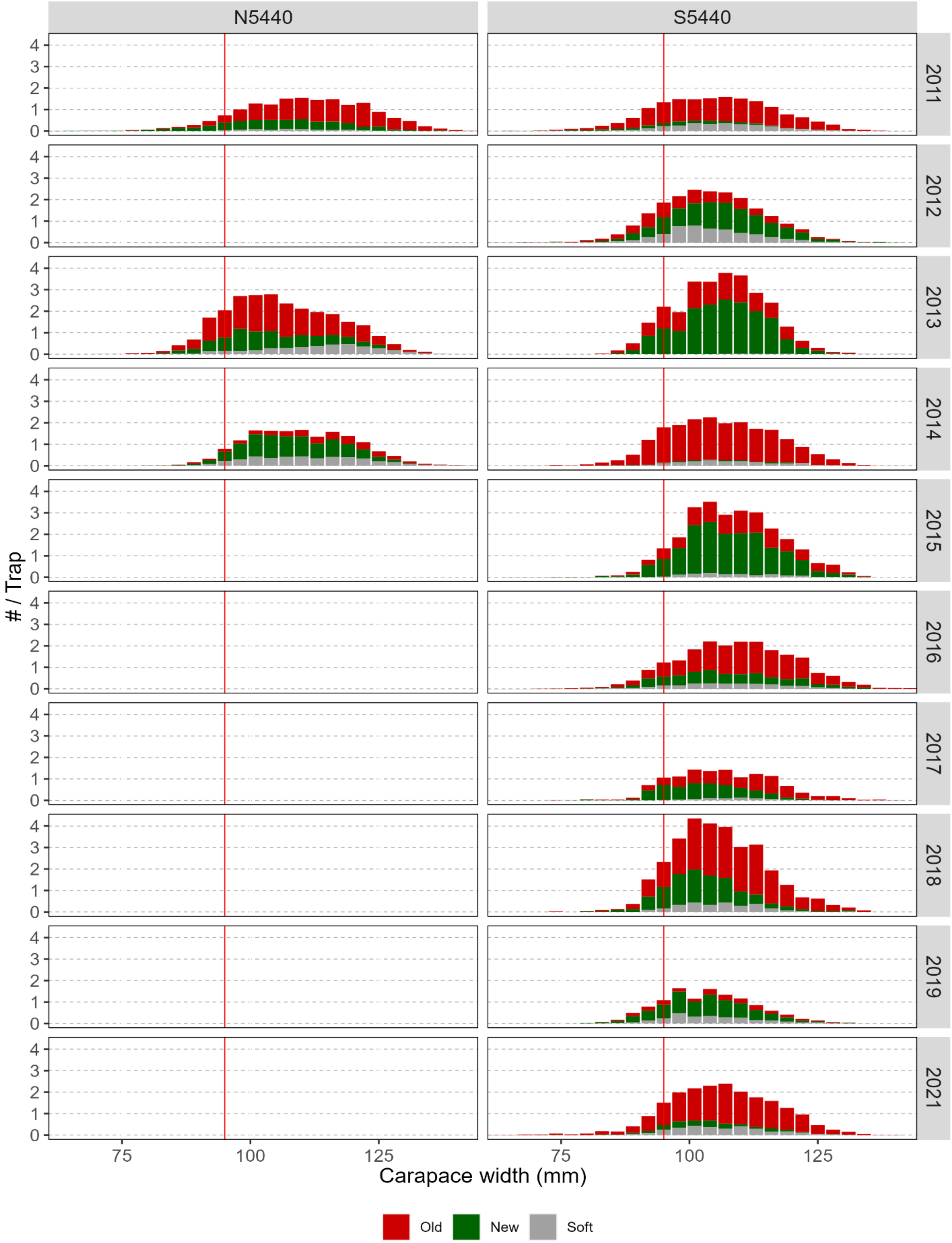


Figure A1.4. Trends in male carapace width distributions by shell condition from at-sea observer sampling in CMAs within Assessment Division 2HJ (2011–21). The red vertical line indicates the minimum legal size.

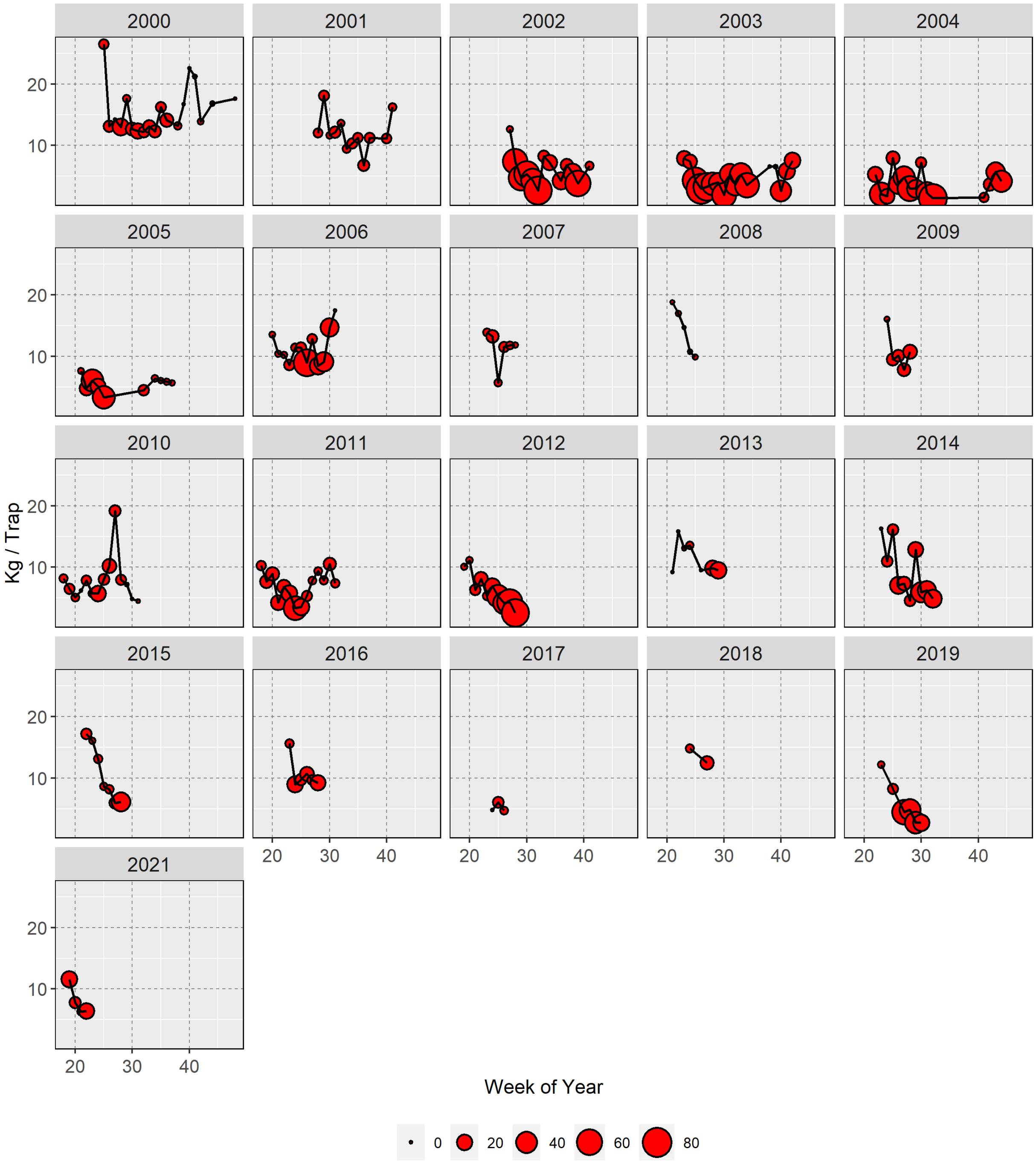


Figure A1.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Assessment Division 2HJ (2000–21). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

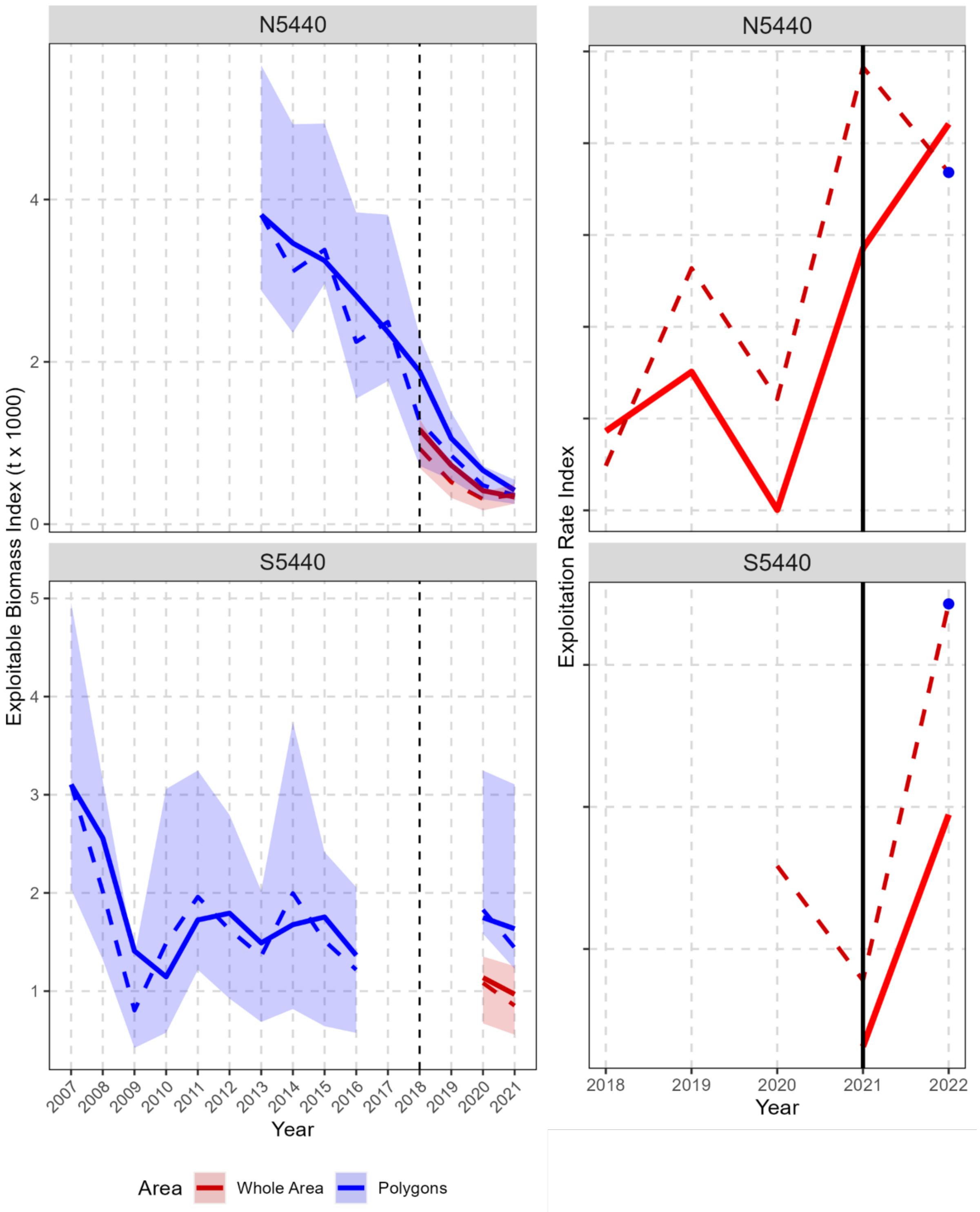


Figure A1.6. Left: Trap exploitable biomass index (2007–21). Red series uses all stations of the survey and blue series uses core stations of the survey. Solid line = 2-year moving average, dashed line = annual estimate, and shaded band = 95% confidence interval of the annual estimate. Right: Trends in the trap-based annual (dashed line) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 2HJ; 2022 points depict projected exploitation rate indices under status quo removals in the 2022 fishery.

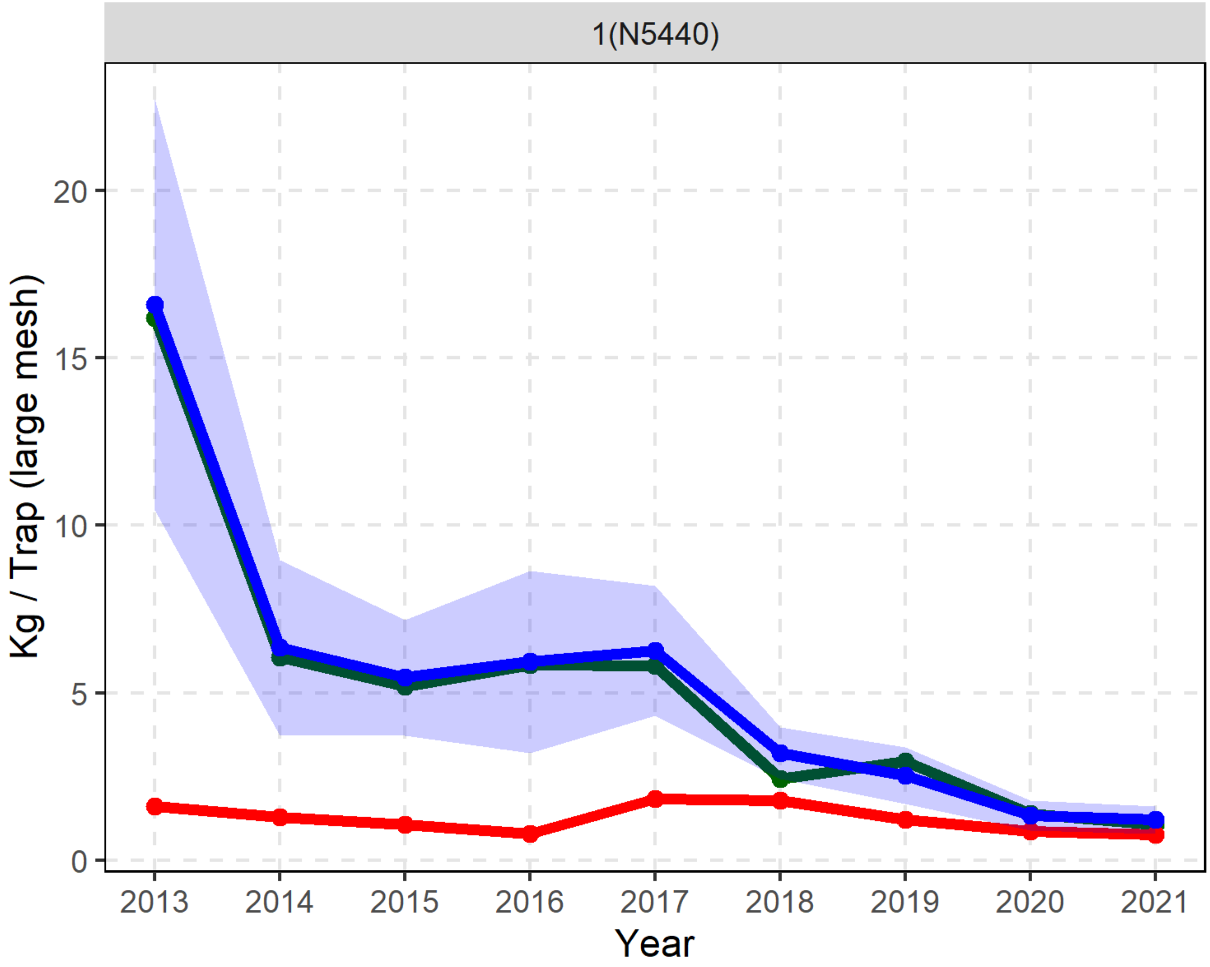


Figure A1.7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from large-mesh traps in the Torngat Joint Fisheries Board trap survey (2013–21) (CMA 1[N5440]).

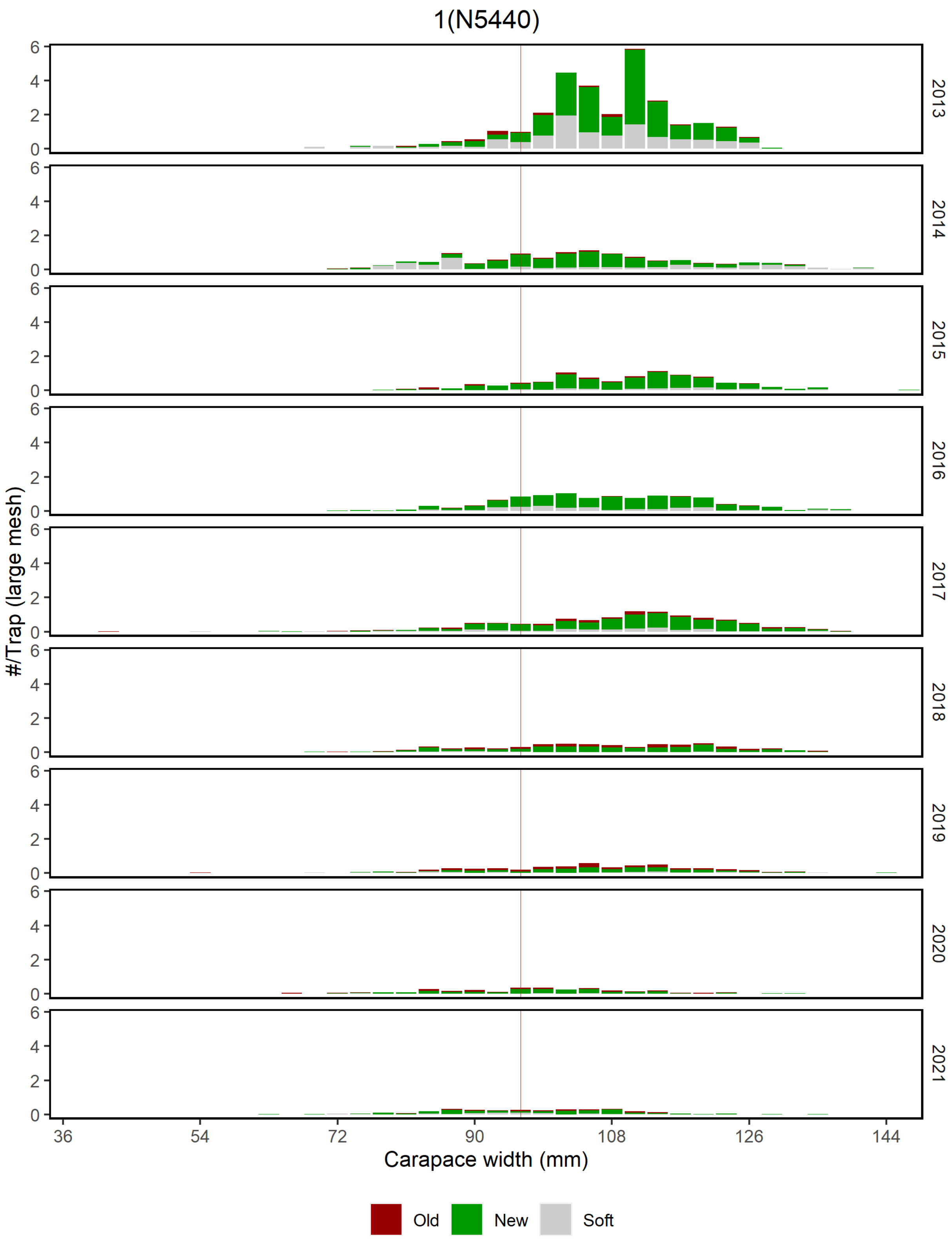


Figure A1.8. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the Torngat Joint Fisheries Board trap survey in CMA 1(N5440) in Assessment Division 2HJ (2013–21). The red vertical line indicates the minimum legal size.

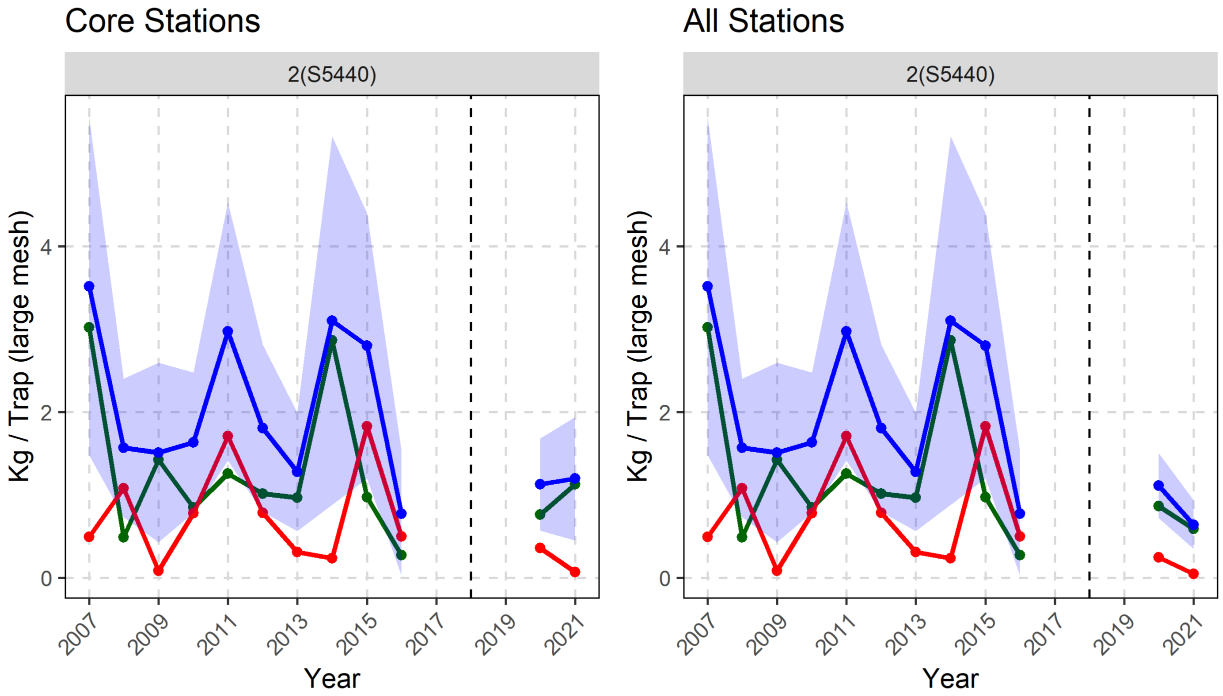


Figure A1.9. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from large-mesh traps at core stations (left) and all stations (right) in the CPS trap survey (2007–21) (CMA 2[S5440]).

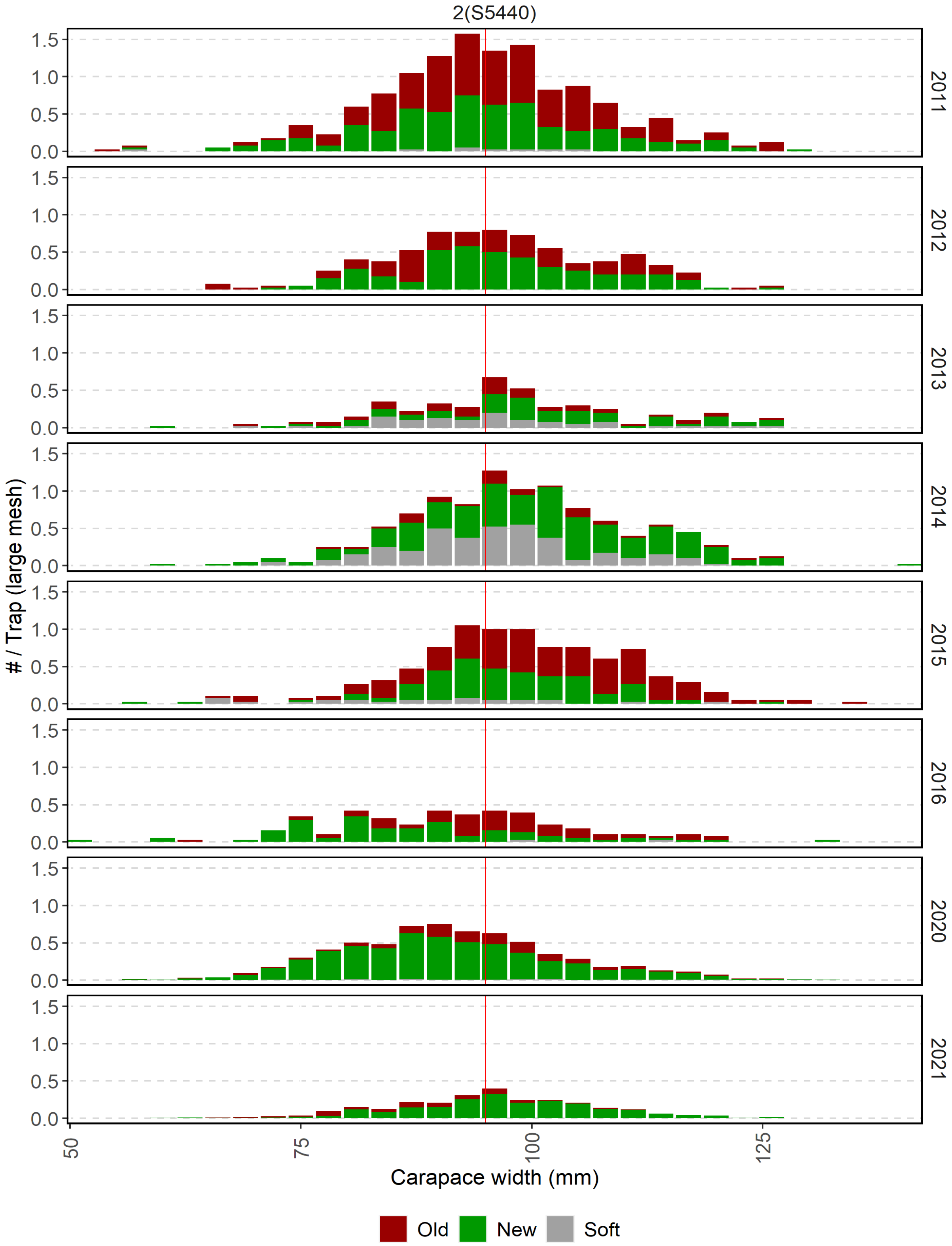


Figure A1.10. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the CPS trap survey in CMA 2(S5440) in Assessment Division 2HJ (2011–21). The red vertical line indicates the minimum legal size.

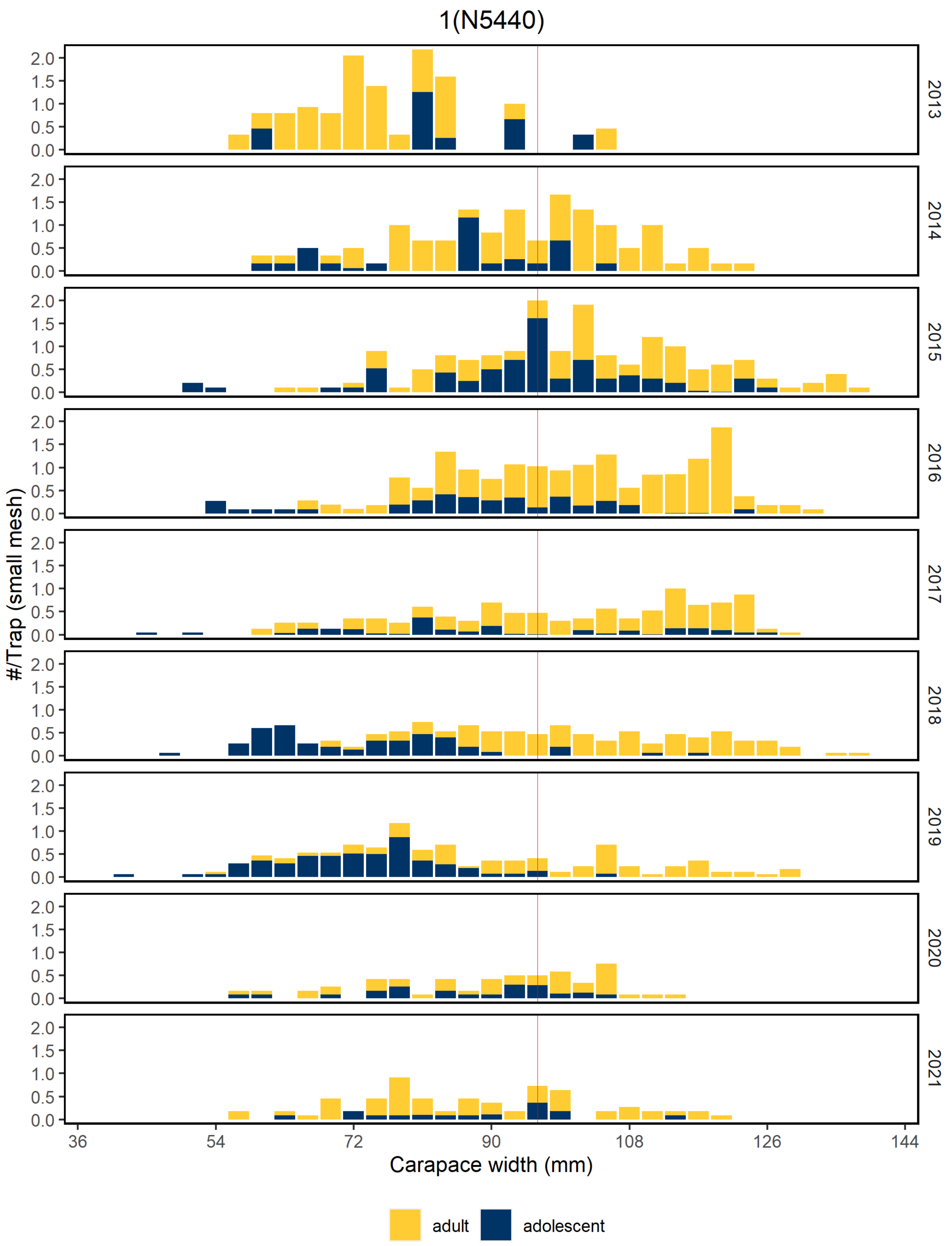


Figure A1.11. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Torngat Joint Fisheries Board trap survey in CMA 1(N5440) in Assessment Division 2HJ (2013–21). The red vertical line indicates the minimum legal size.

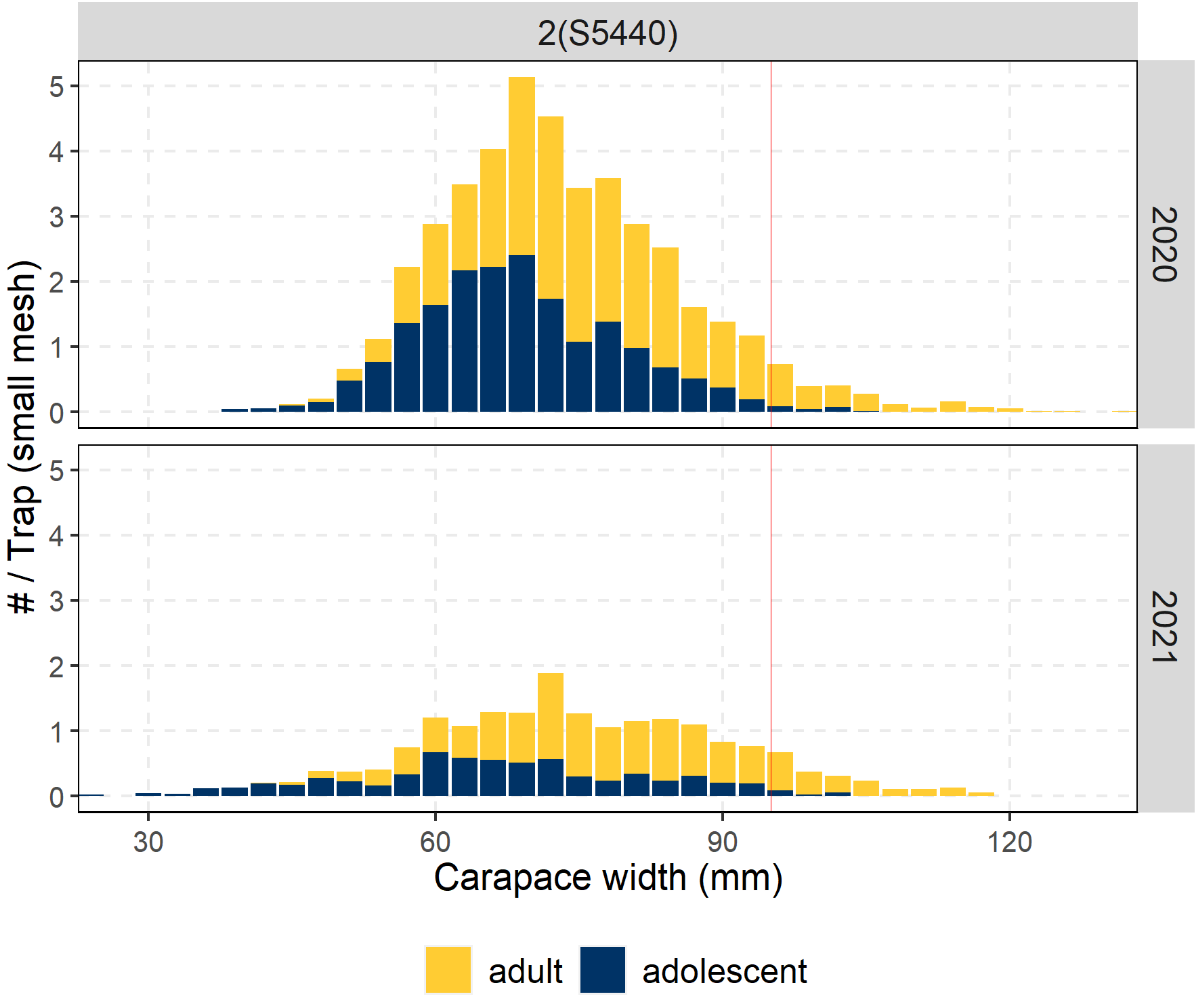


Figure A1.12. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey in CMA 2(S5440) in Assessment Division 2HJ (2020–21). The red vertical line indicates the minimum legal size.

APPENDIX 2: ASSESSMENT DIVISION 3K DETAILS

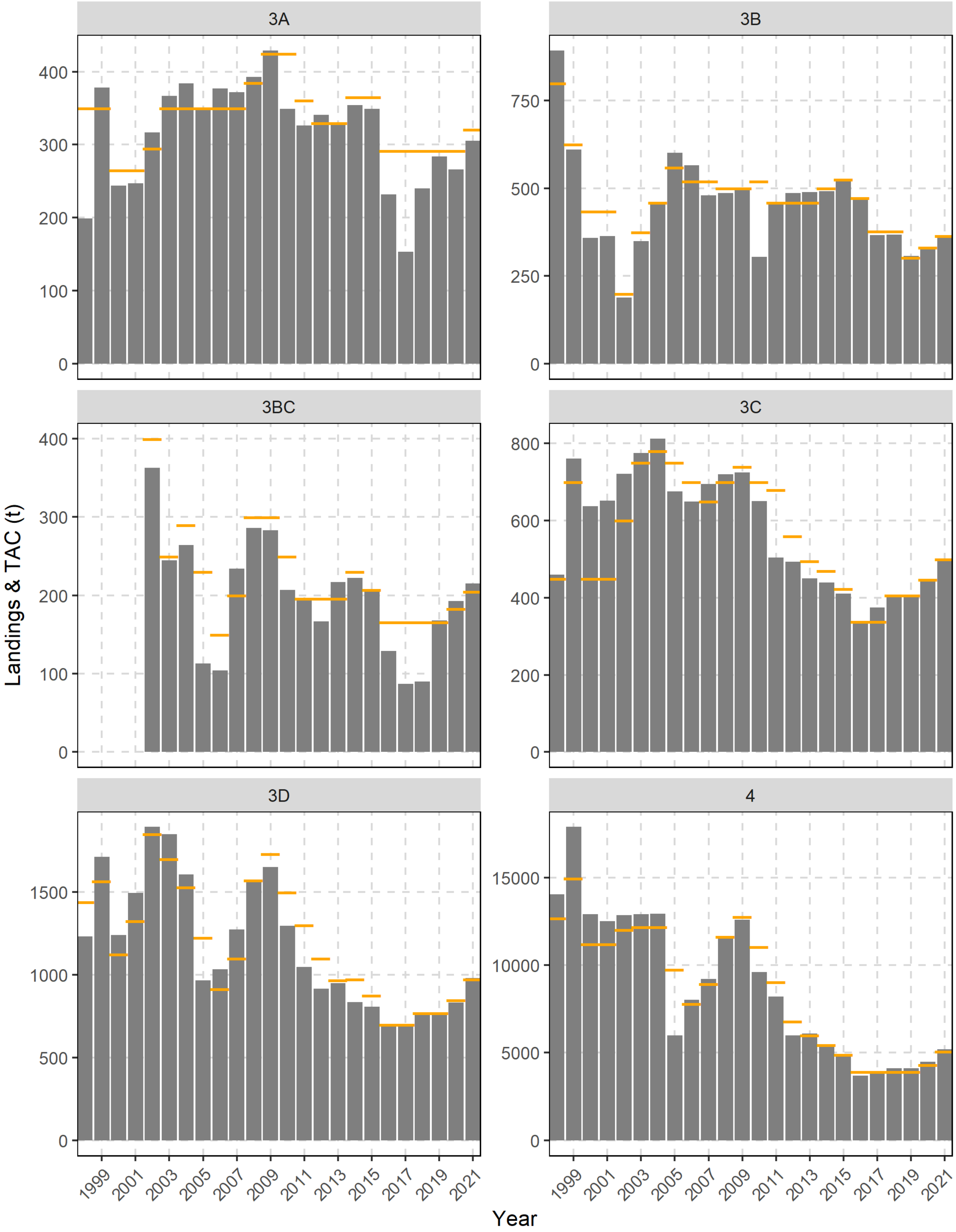


Figure A2.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 3K (1998–2021).

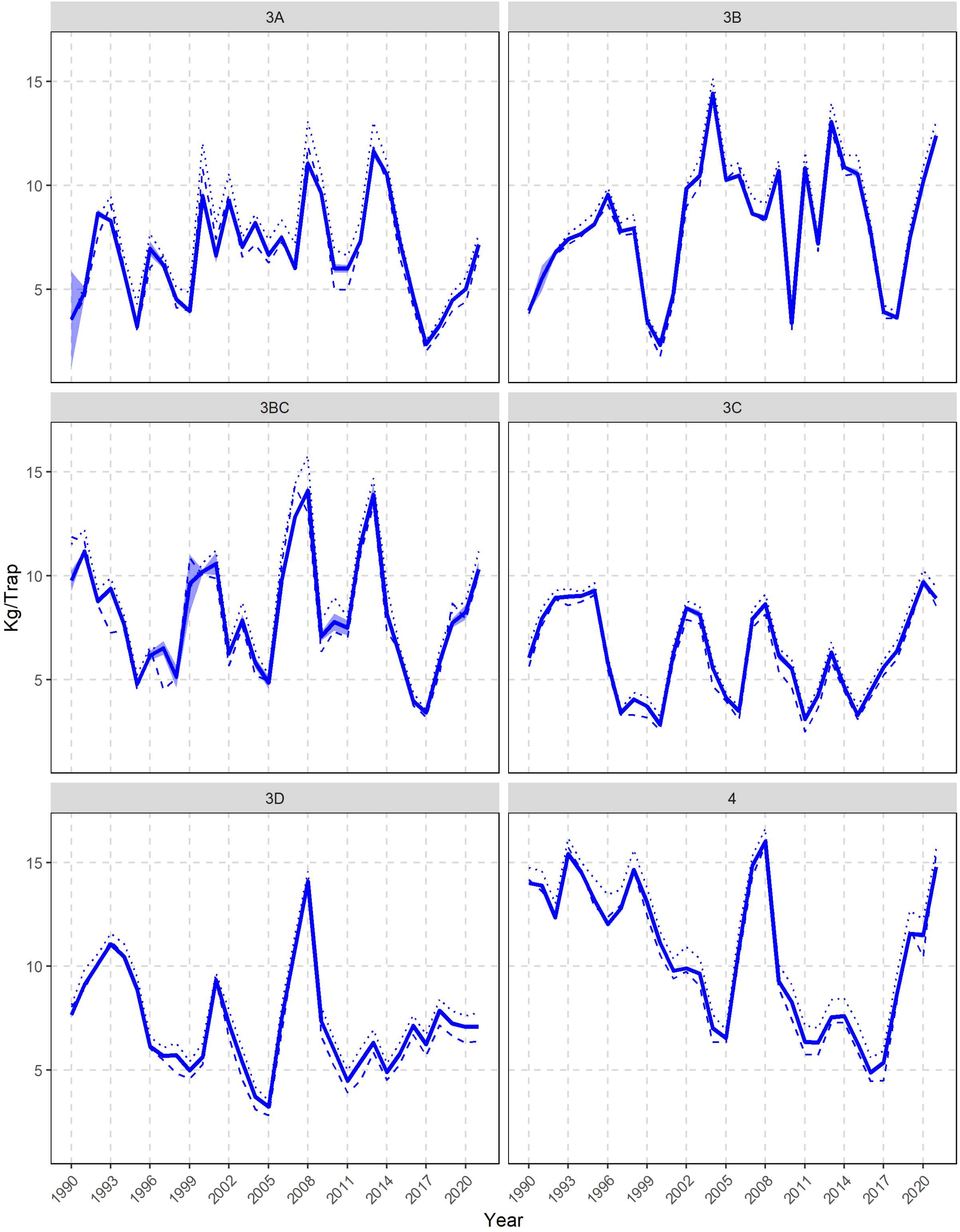


Figure A2.2. Trends in standardized fishery CPUE (kg/trap) in CMAs within Assessment Division 3K. Solid line = average predicted CPUE, shaded band = 95% confidence interval, dotted line = average raw CPUE, and dashed line = median raw CPUE. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

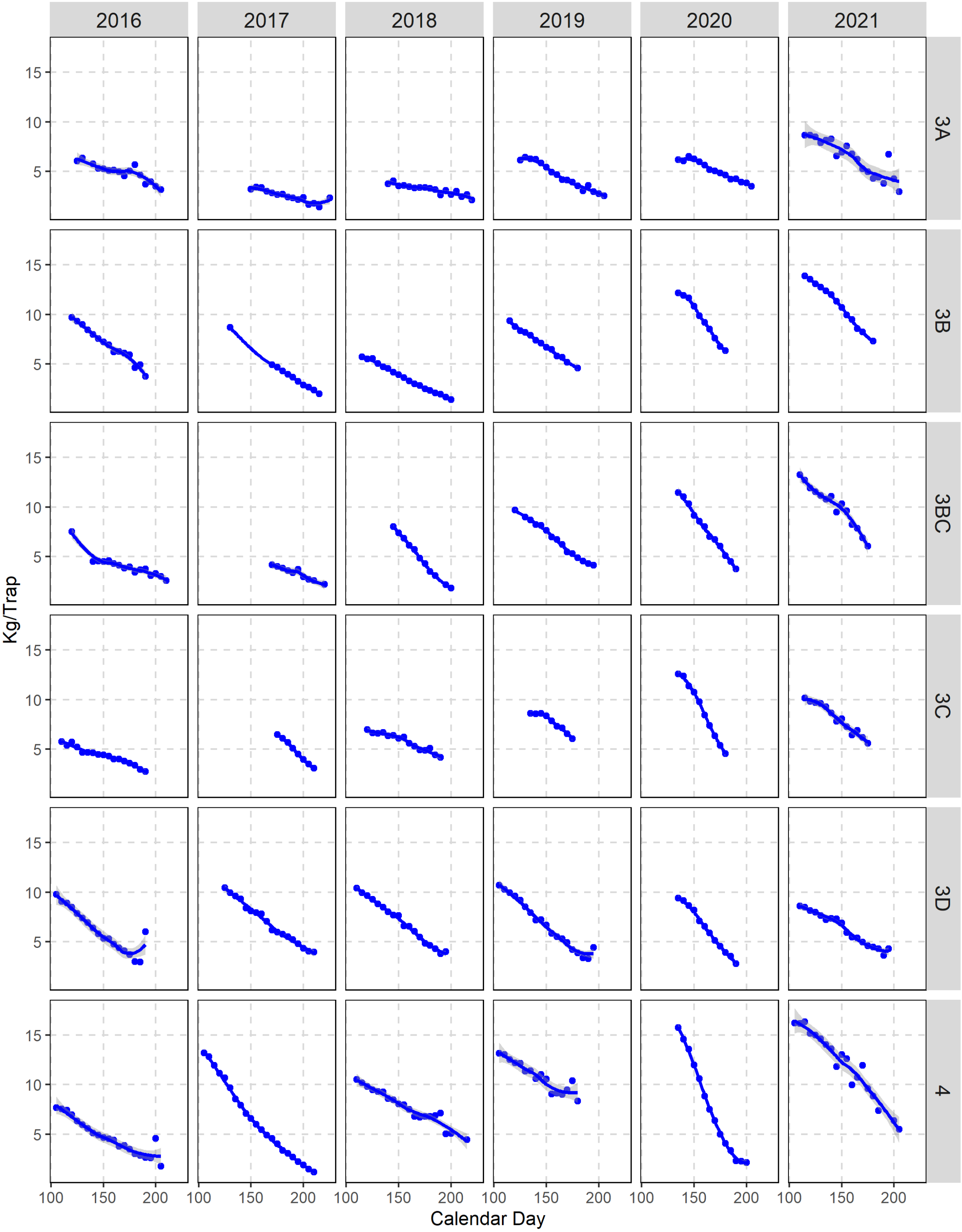


Figure A2.3. Standardized fishery CPUE (kg/trap) throughout the season (calendar day) in CMAs within Assessment Division 3K (2016–21). Points = mean CPUE of 5-day increments and trend lines = loess regression curves. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

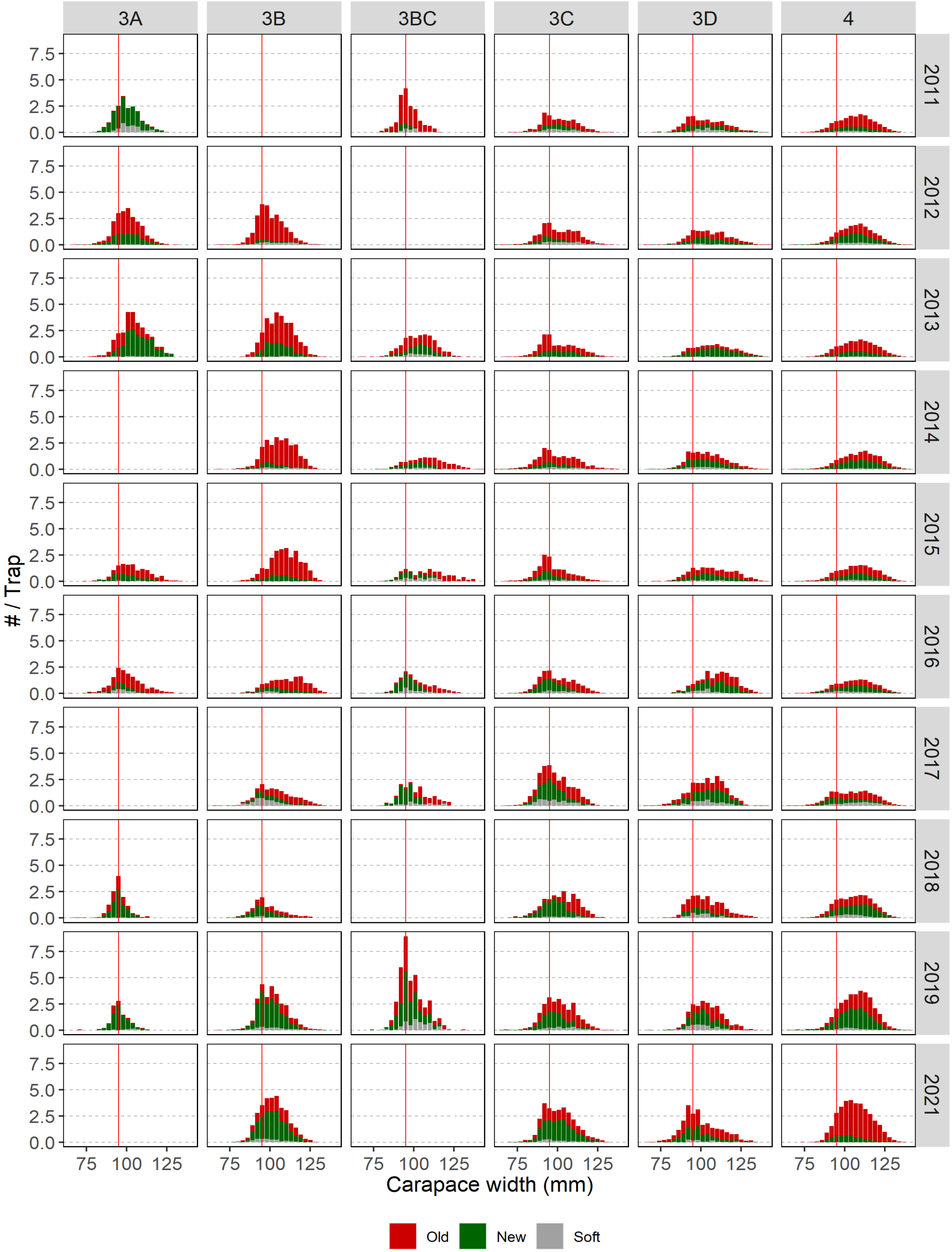


Figure A2.4. Trends in male carapace width distributions by shell condition from at-sea observer sampling in CMAs within Assessment Division 3K (2011–21). The vertical line indicates the minimum legal size.

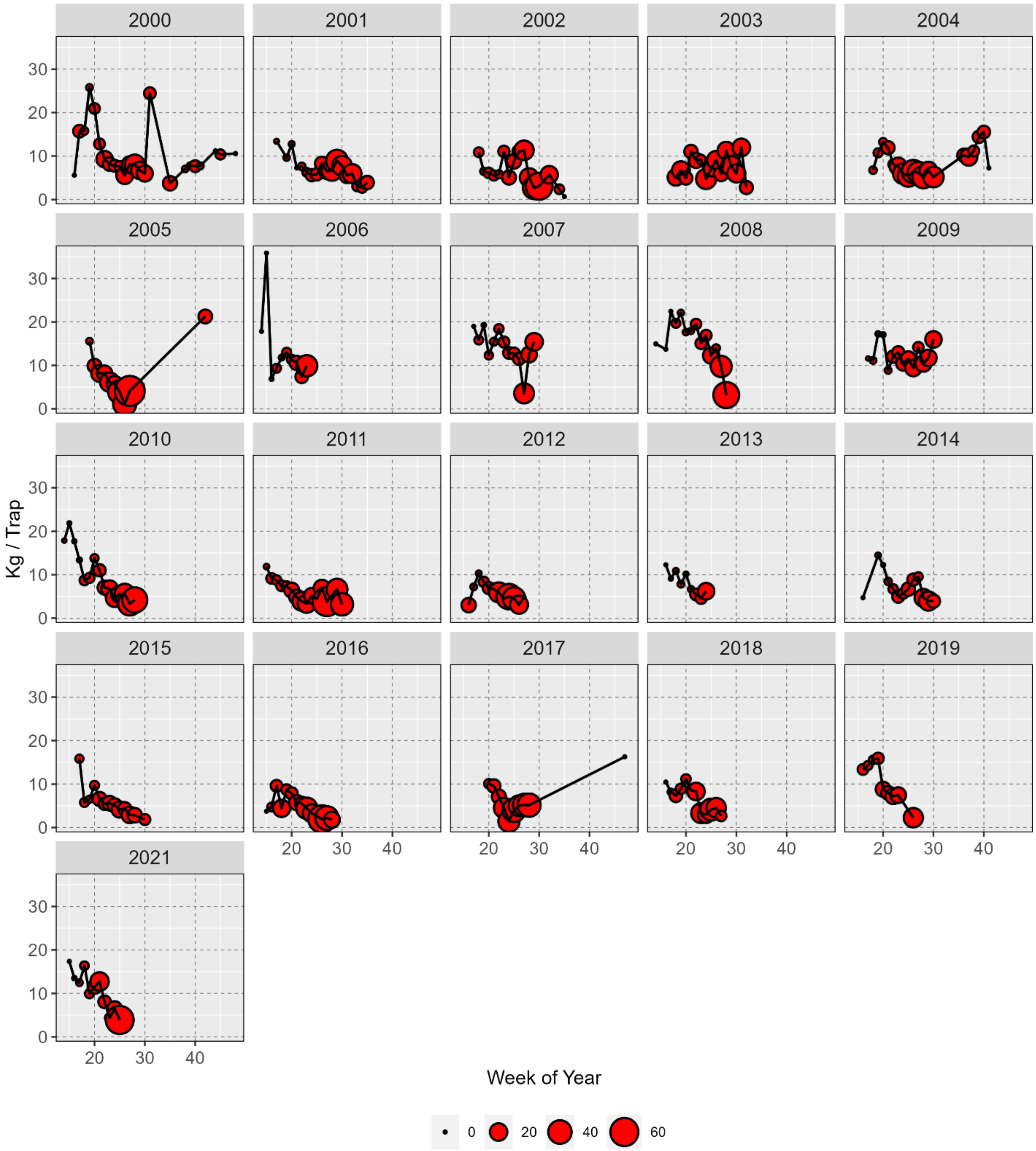


Figure A2.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Assessment Division 3K (2000-21). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

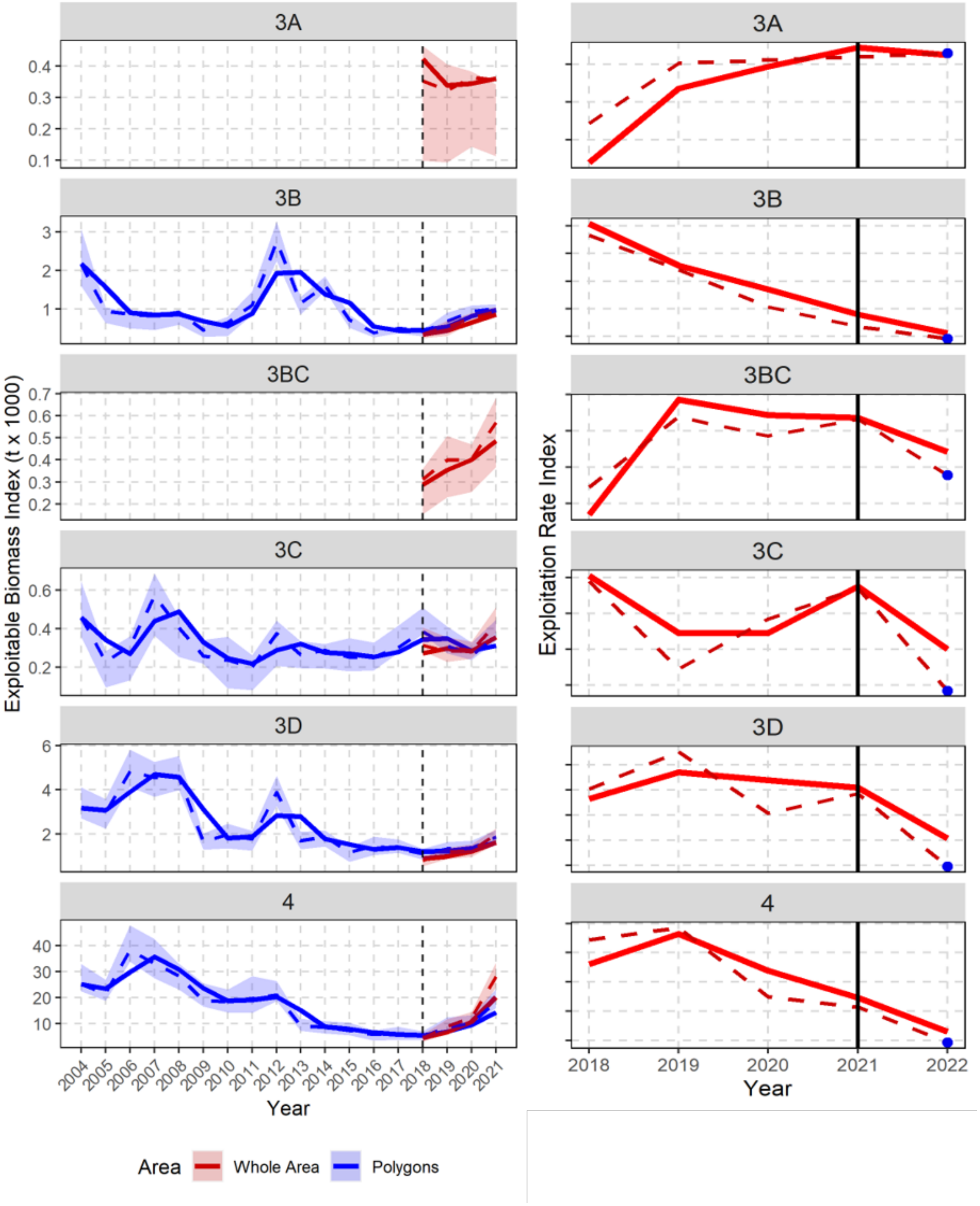


Figure A2.6. Left: Trap exploitable biomass index (2004–21). Red series uses all stations of the survey and blue series uses core stations of the survey. Solid line = 2-year moving average, dashed line = annual estimate, and shaded band = 95% confidence interval of the annual estimate. Right: Trends in the trap-based annual (dashed line) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 3K; 2022 points depict projected exploitation rate indices under status quo removals in the 2022 fishery.

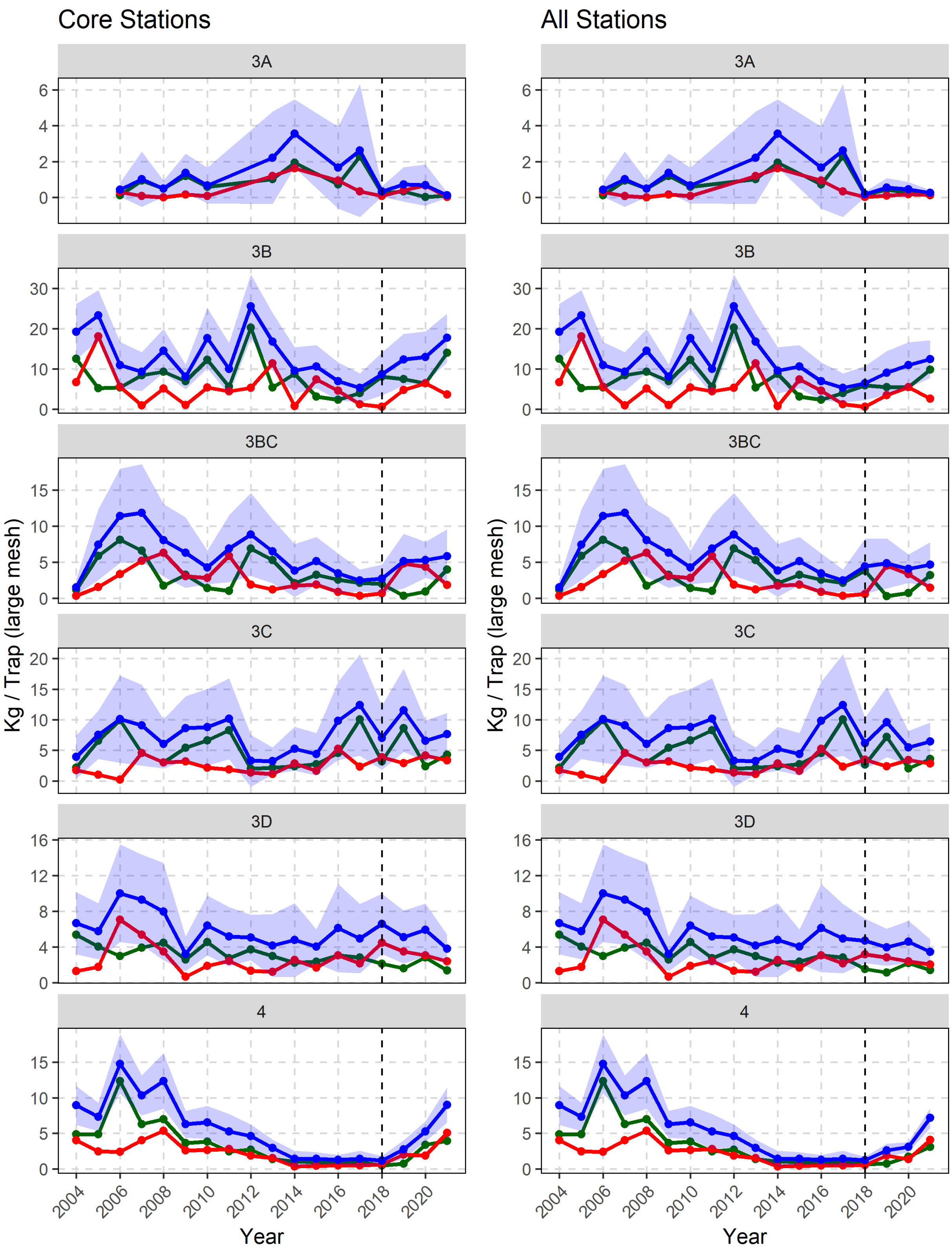


Figure A2.7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations (left) and all stations (right) in the CPS trap survey in CMAs within Assessment Division 3K.

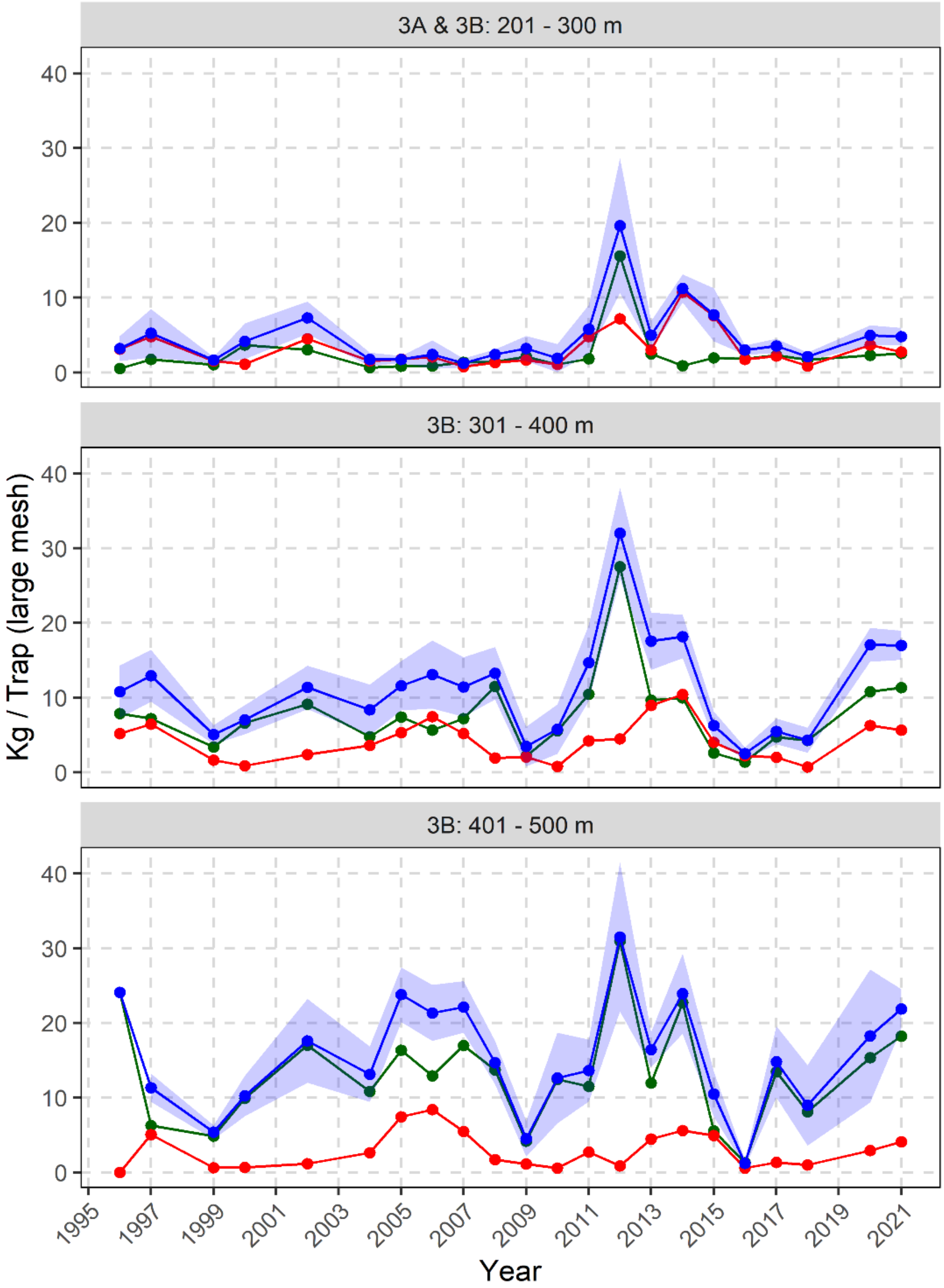


Figure A2.8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps in the Inshore DFO trap surveys in White Bay (CMAs 3A and 3B).

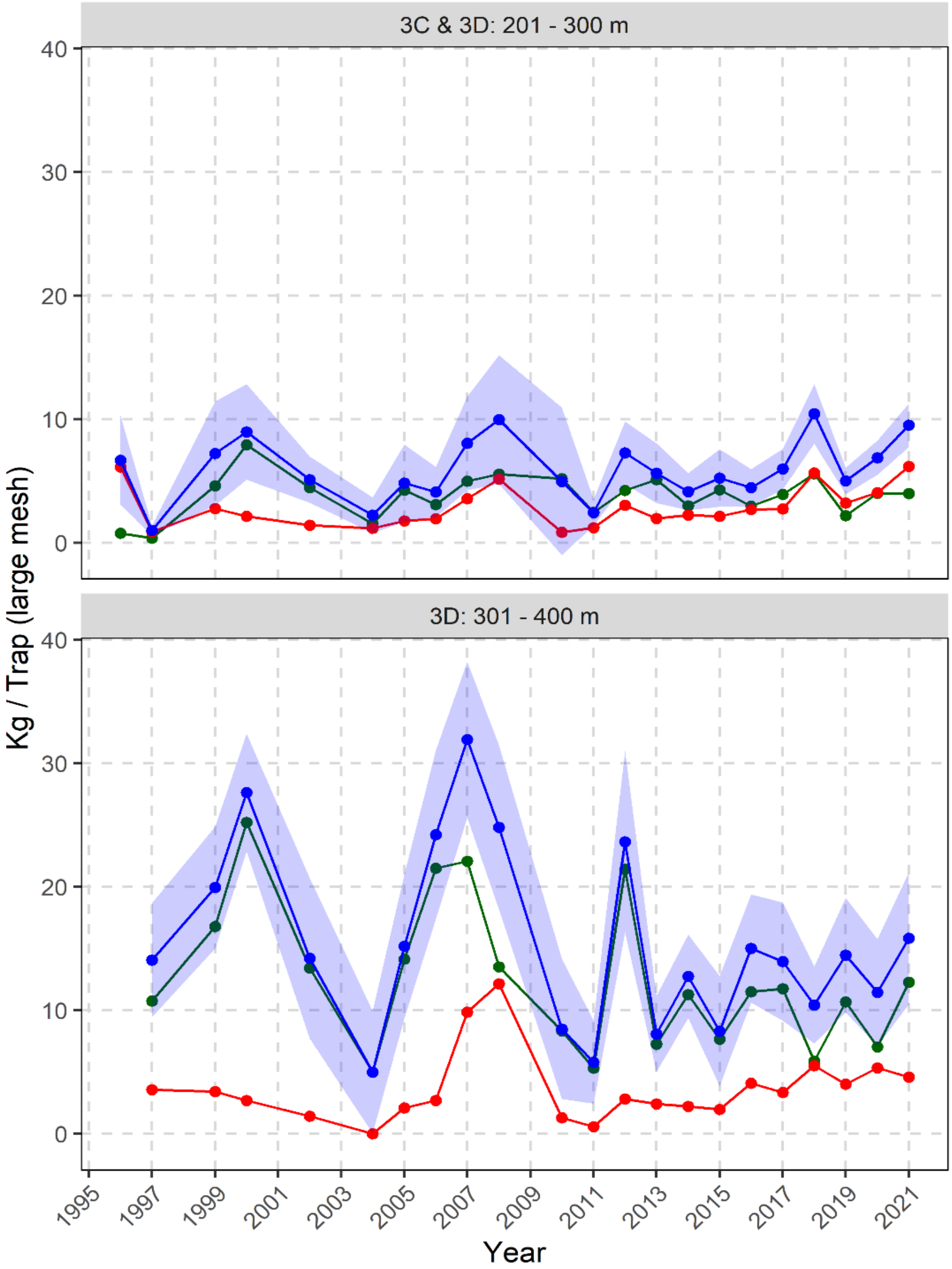


Figure A2.9. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps in the Inshore DFO trap surveys in Green Bay and Notre Dame Bay (CMAs 3C and 3D).

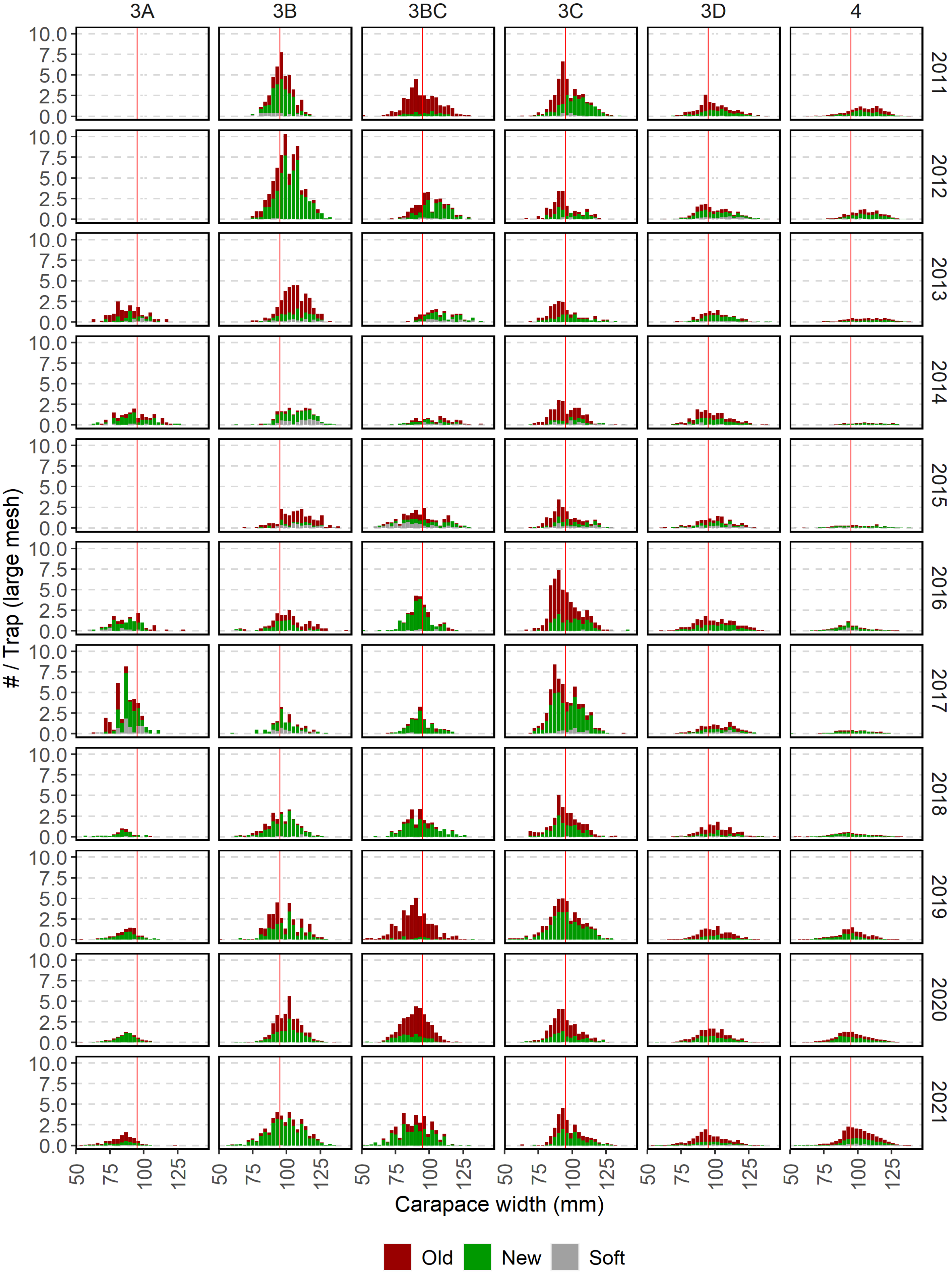


Figure A2.10. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the CPS trap survey in CMAs within Assessment Division 3K (2011–21). The red vertical line indicates the minimum legal size.

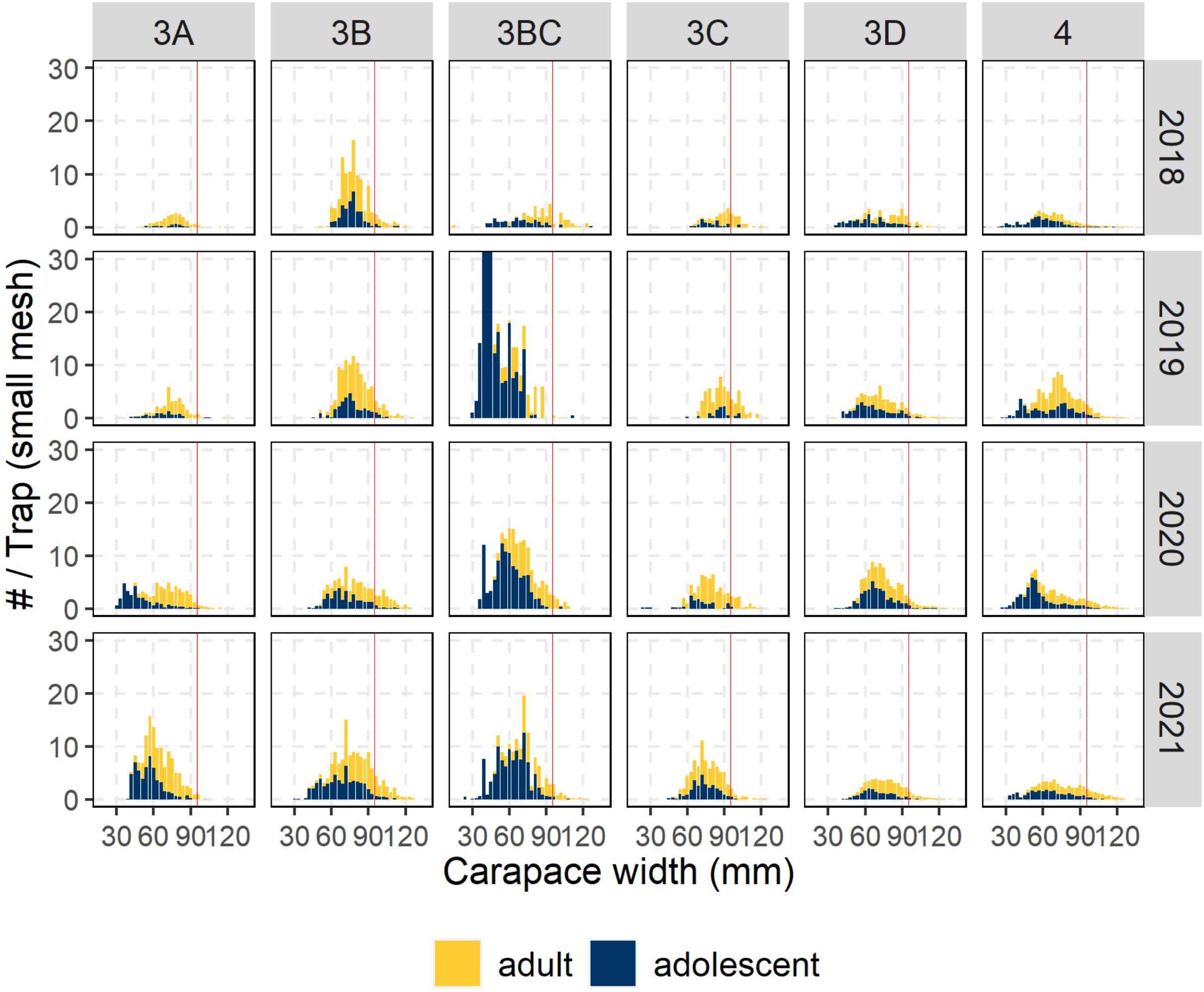


Figure A2.11. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2018–21) from CMAs in Assessment Division 3K. The red vertical line indicates the minimum legal size.

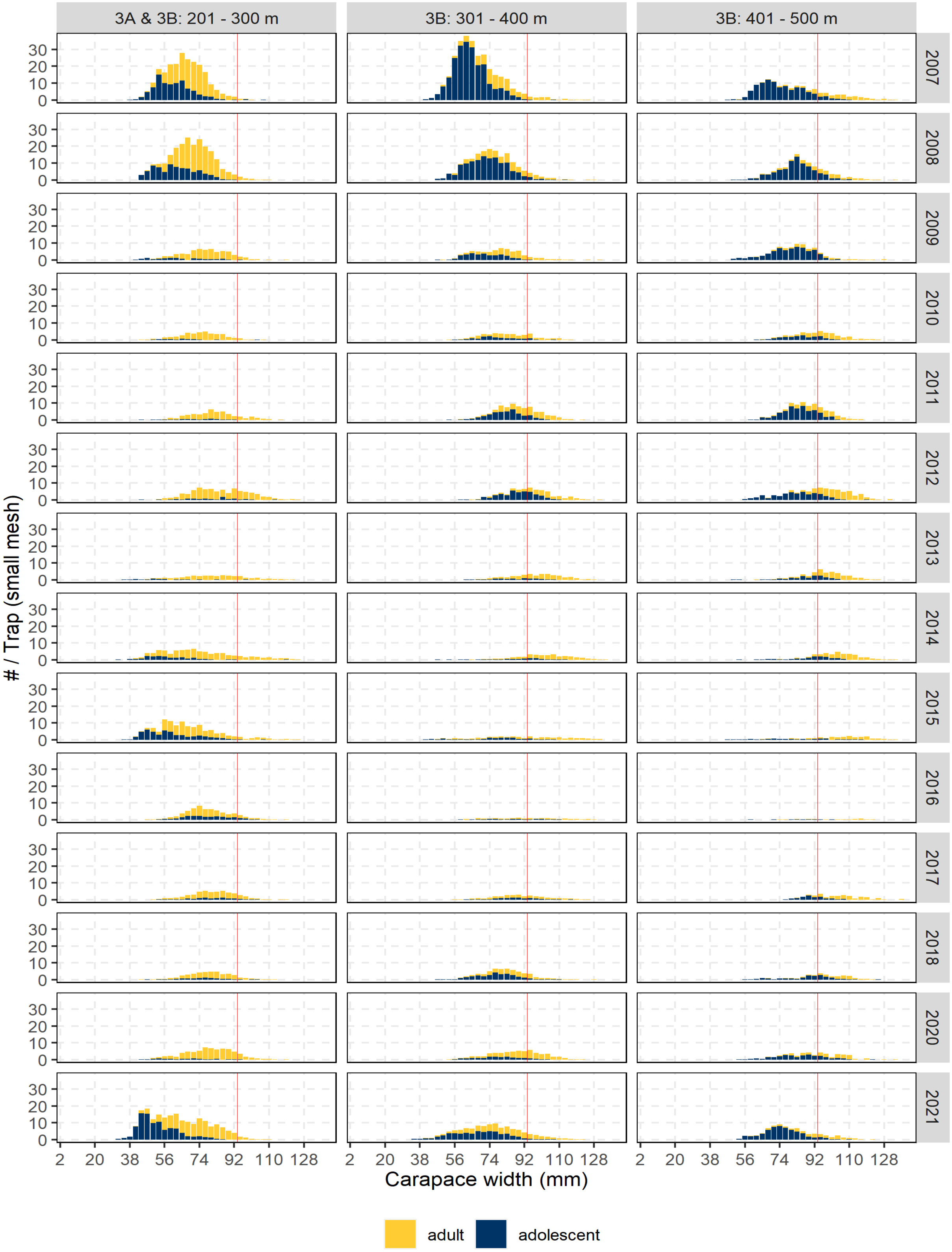


Figure A2.12. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2006–21) from White Bay (CMAs 3A and 3B). The red vertical line indicates the minimum legal size. Note: no survey in 2019.

Figure A2.13. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2007–21) from Green Bay and Notre Dame Bay (CMAs 3B, 3C and 3D). The red vertical line indicates the minimum legal size.

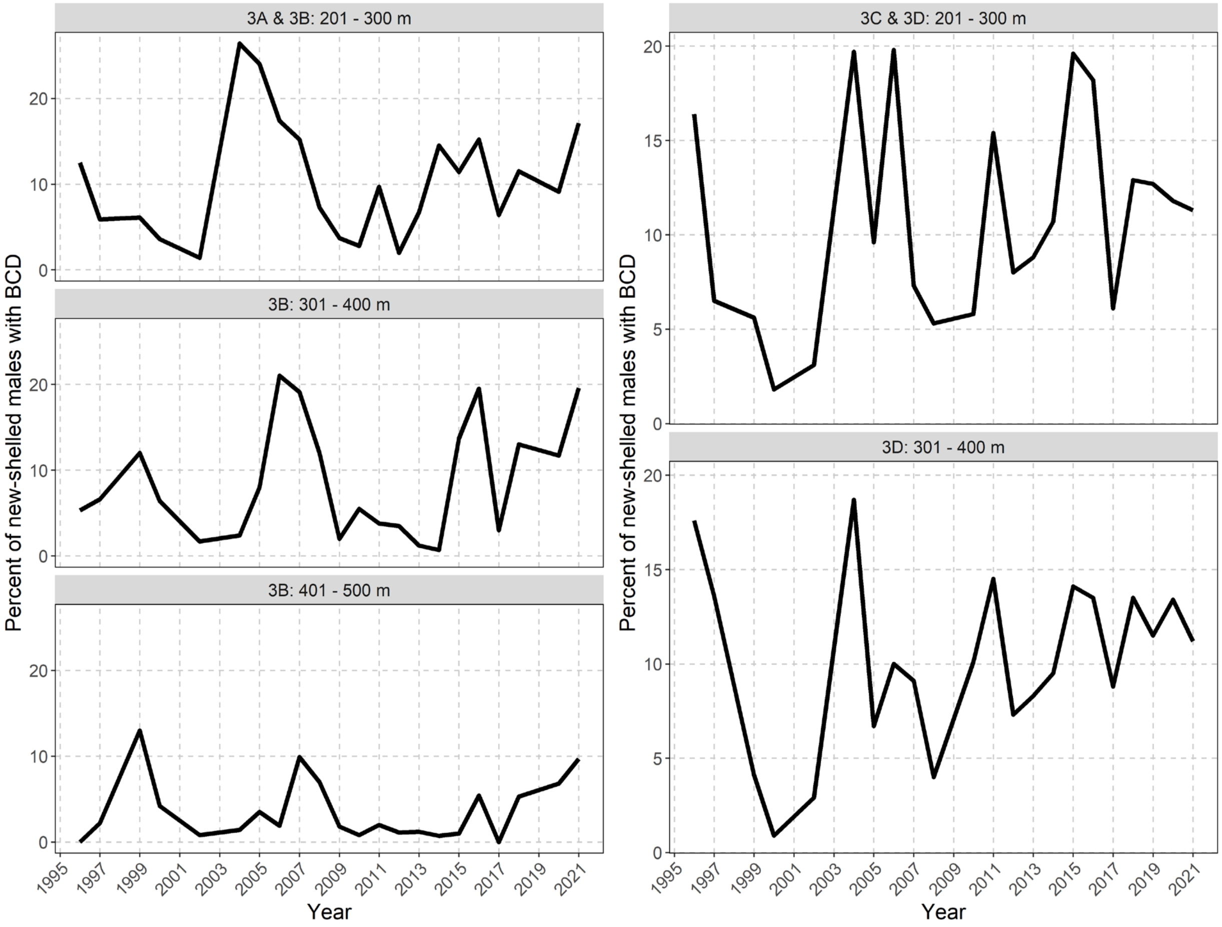


Figure A2.14. Visually observed percentage of Bitter Crab Disease (BCD) in new-shelled crab from Inshore DFO trap surveys (1996–2021) in White Bay (CMAs 3A and 3B), and Green Bay and Notre Dame Bay (CMAs 3C and 3D).

APPENDIX 3: ASSESSMENT DIVISION 3L INSHORE DETAILS

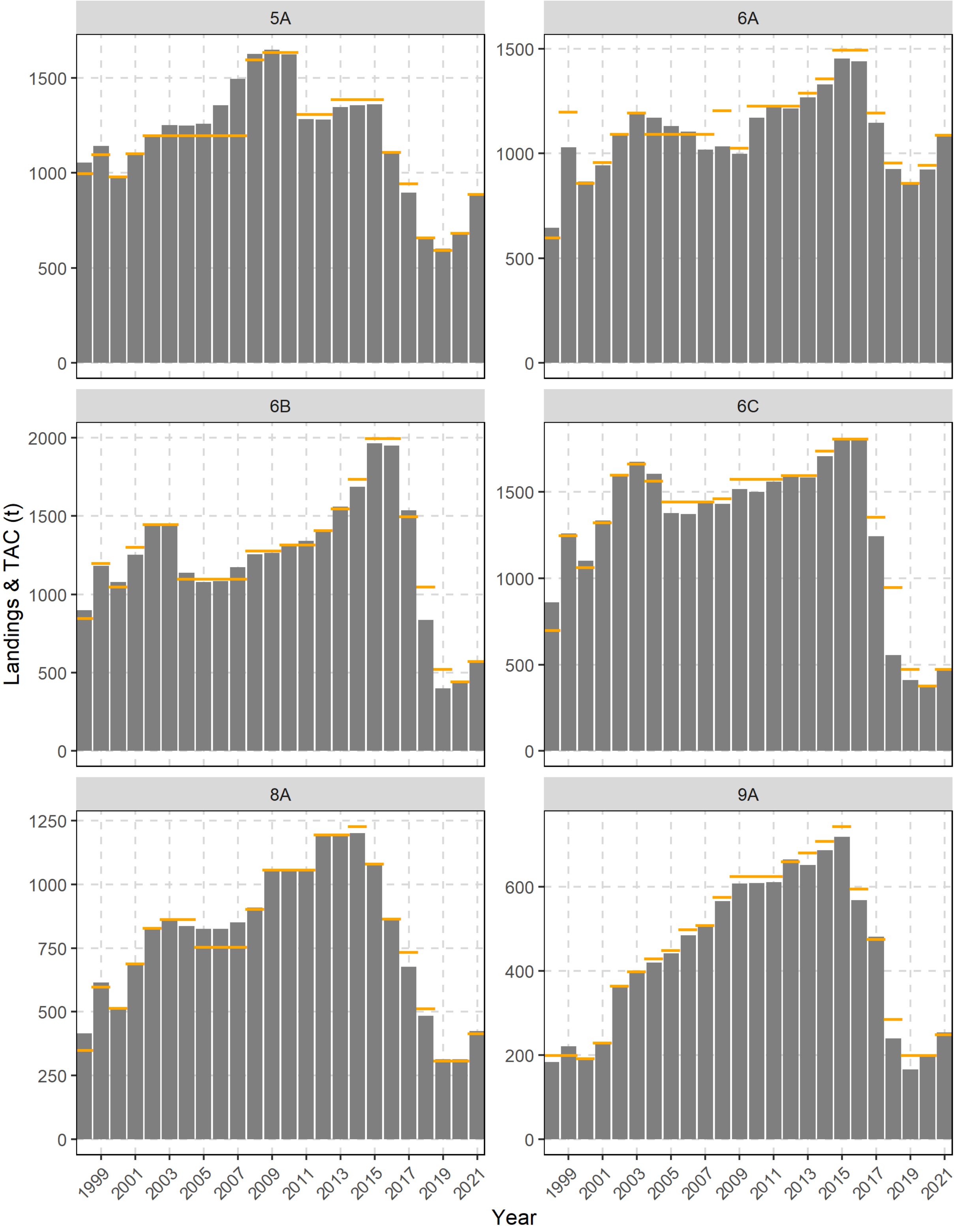


Figure A3.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 3L Inshore (1998–2021).

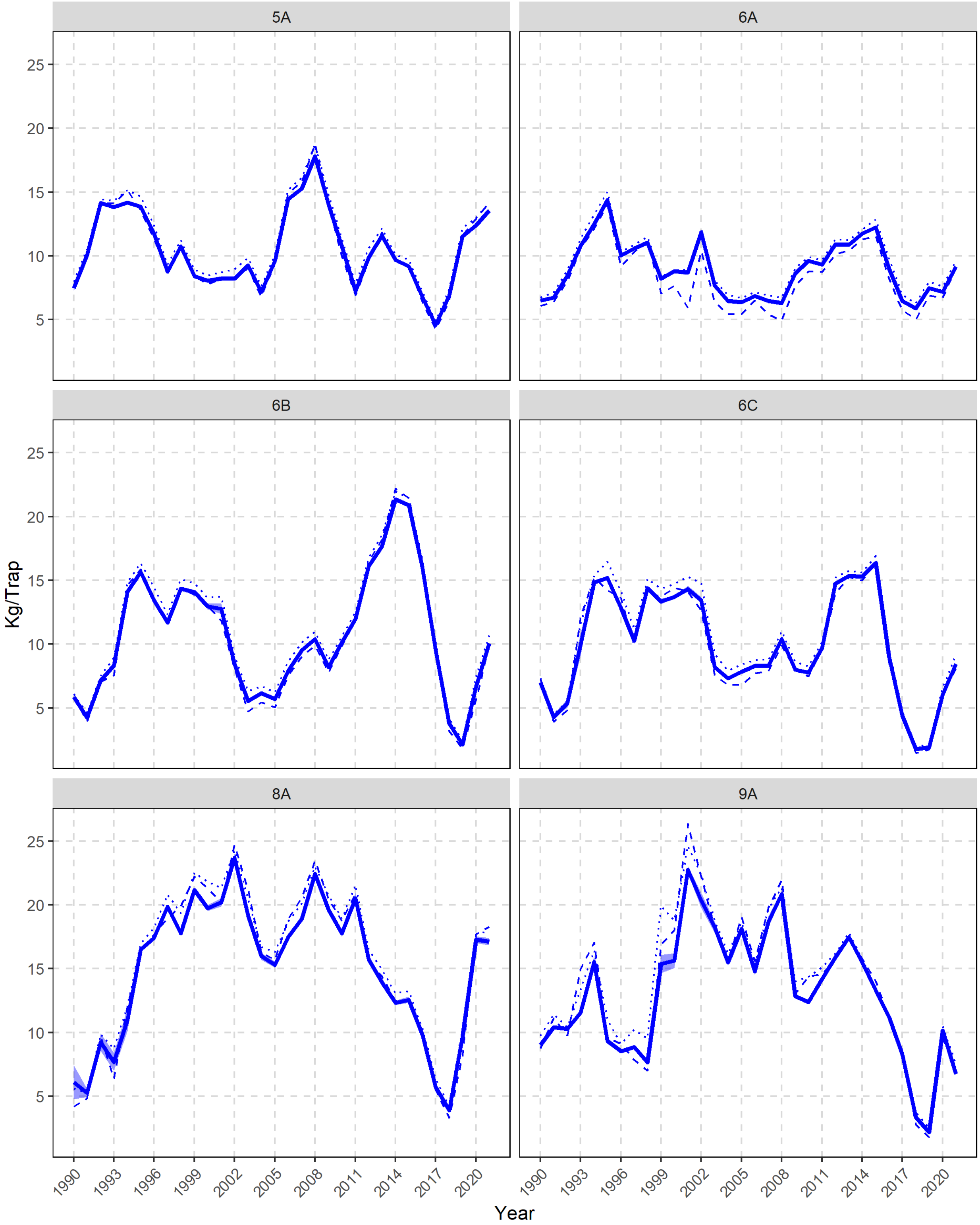


Figure A3.2. Trends in standardized fishery CPUE (kg/trap) in CMAs within Assessment Division 3L Inshore. Solid line = average predicted CPUE, shaded band = 95% confidence interval, dotted line = average raw CPUE, and dashed line = median raw CPUE. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

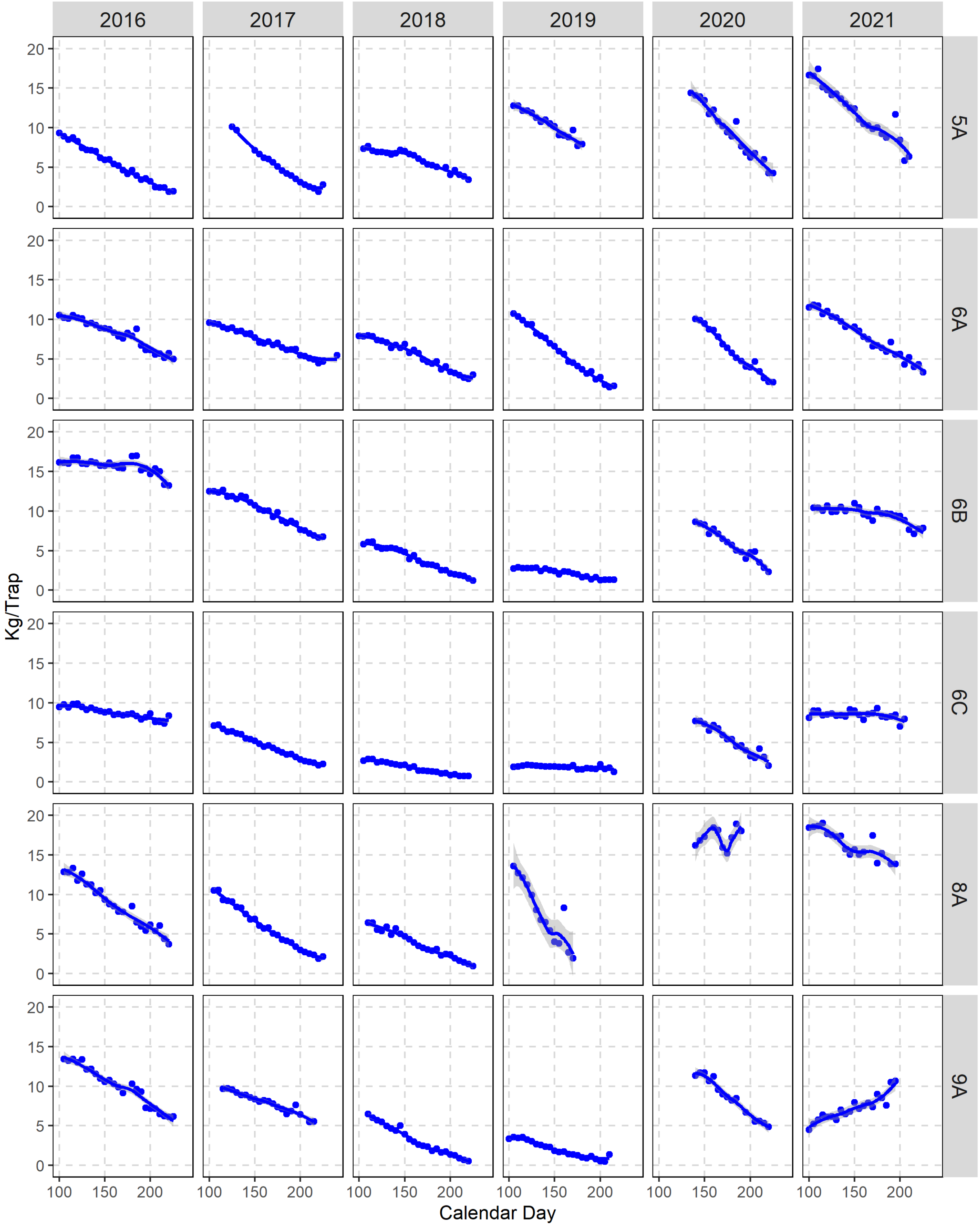


Figure A3.3. Standardized fishery CPUE (kg/trap) throughout the season (calendar day) in CMAs within Assessment Division 3L Inshore (2016–21). Points = mean CPUE of 5-day increments and trend lines = loess regression curves. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

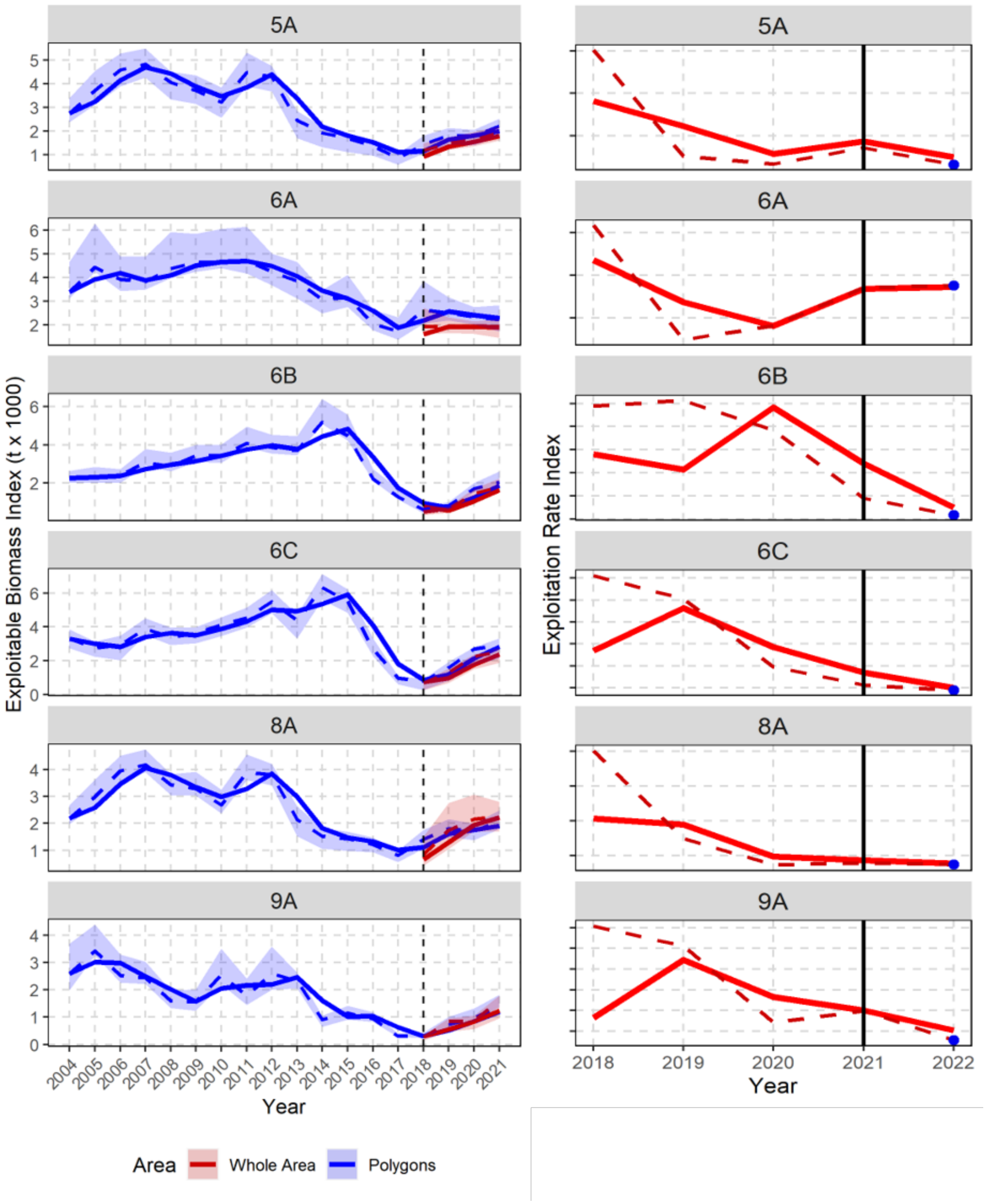


Figure A3.4. Left: Trap exploitable biomass index (2004–21). Red series uses all stations of the survey and blue series uses core stations of the survey. Solid line = 2-year moving average, dashed line = annual estimate, and shaded band = 95% confidence interval of the annual estimate. Right: Trends in the trap-based annual (dashed line) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 3L Inshore; 2022 points depict projected exploitation rate indices under status quo removals in the 2022 fishery.

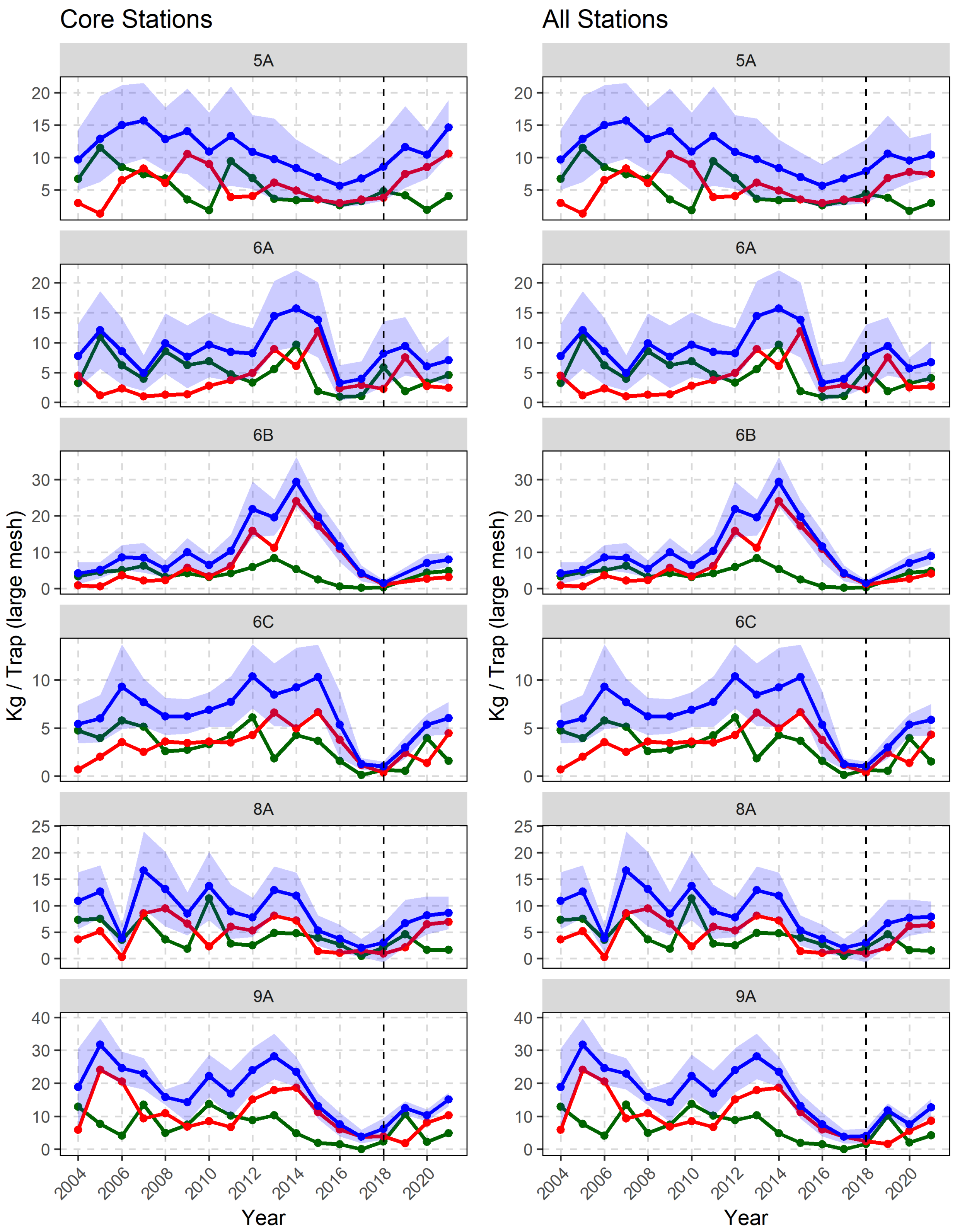


Figure A3.5. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations (left) and all stations (right) in the CPS trap survey in CMAs within Assessment Division 3L Inshore.

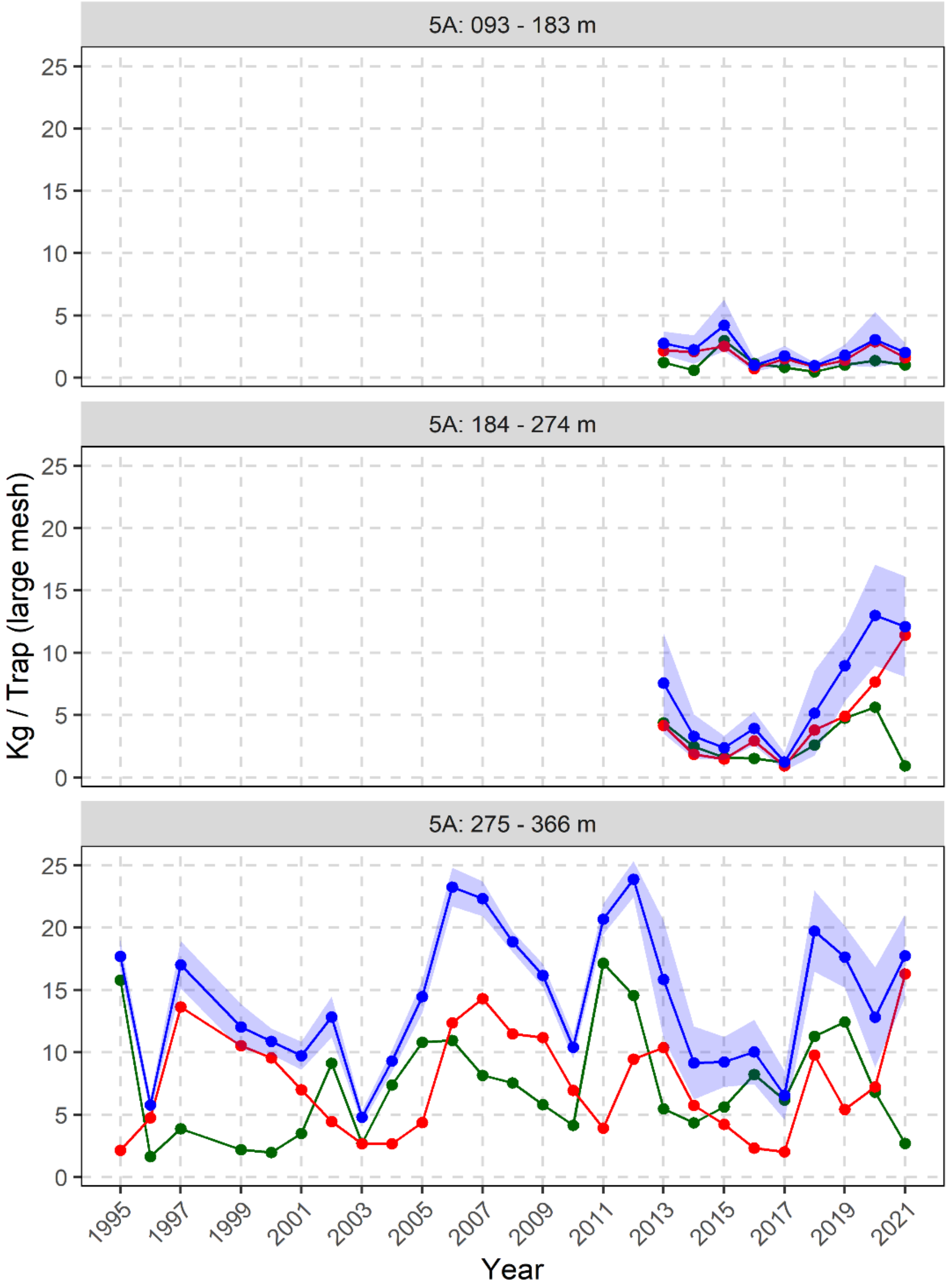


Figure A3.6. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps in the Inshore DFO trap surveys in Bonavista Bay (CMA 5A).

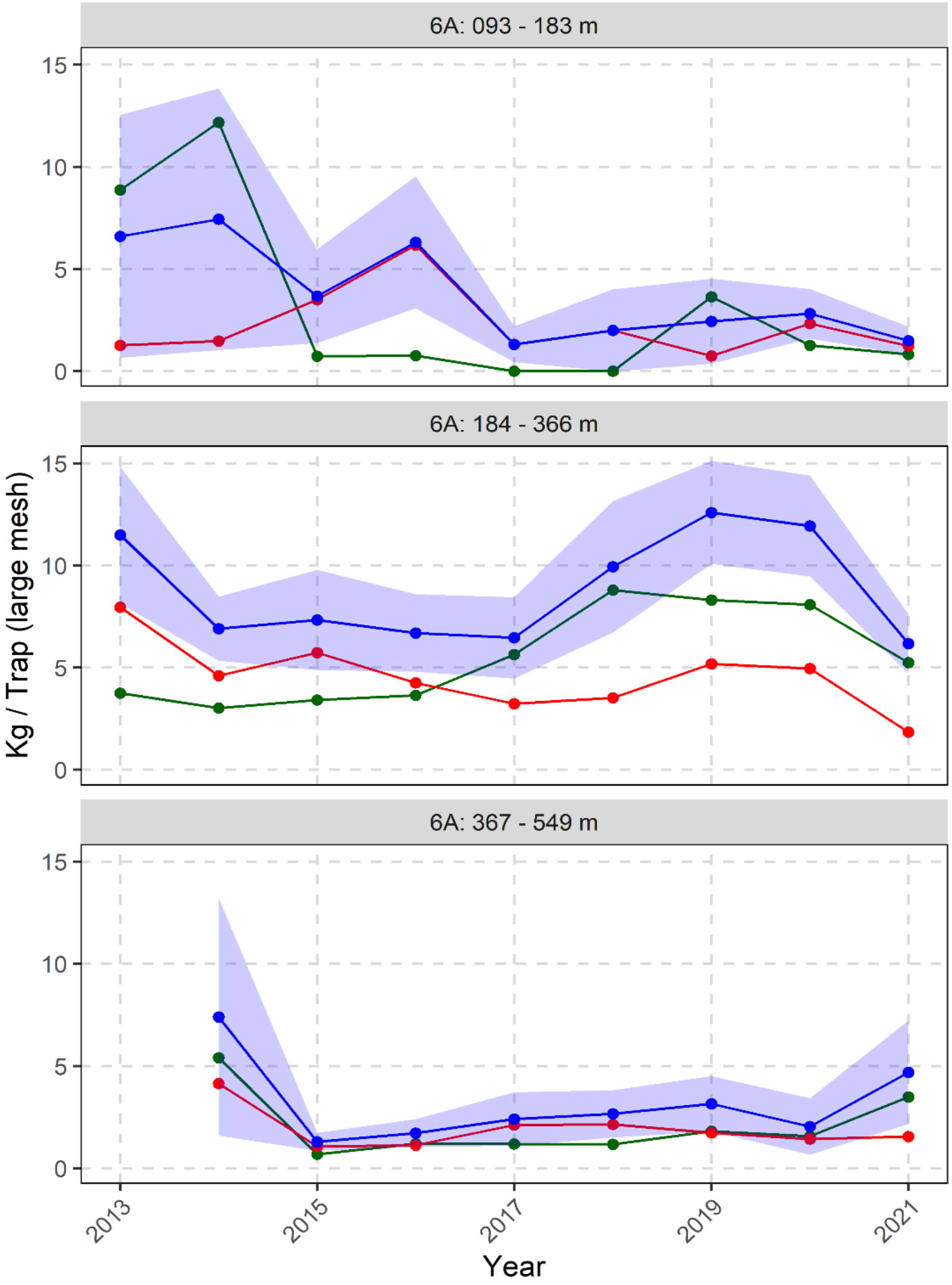


Figure A3.7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps in the Inshore DFO trap surveys in Trinity Bay (CMA 6A).

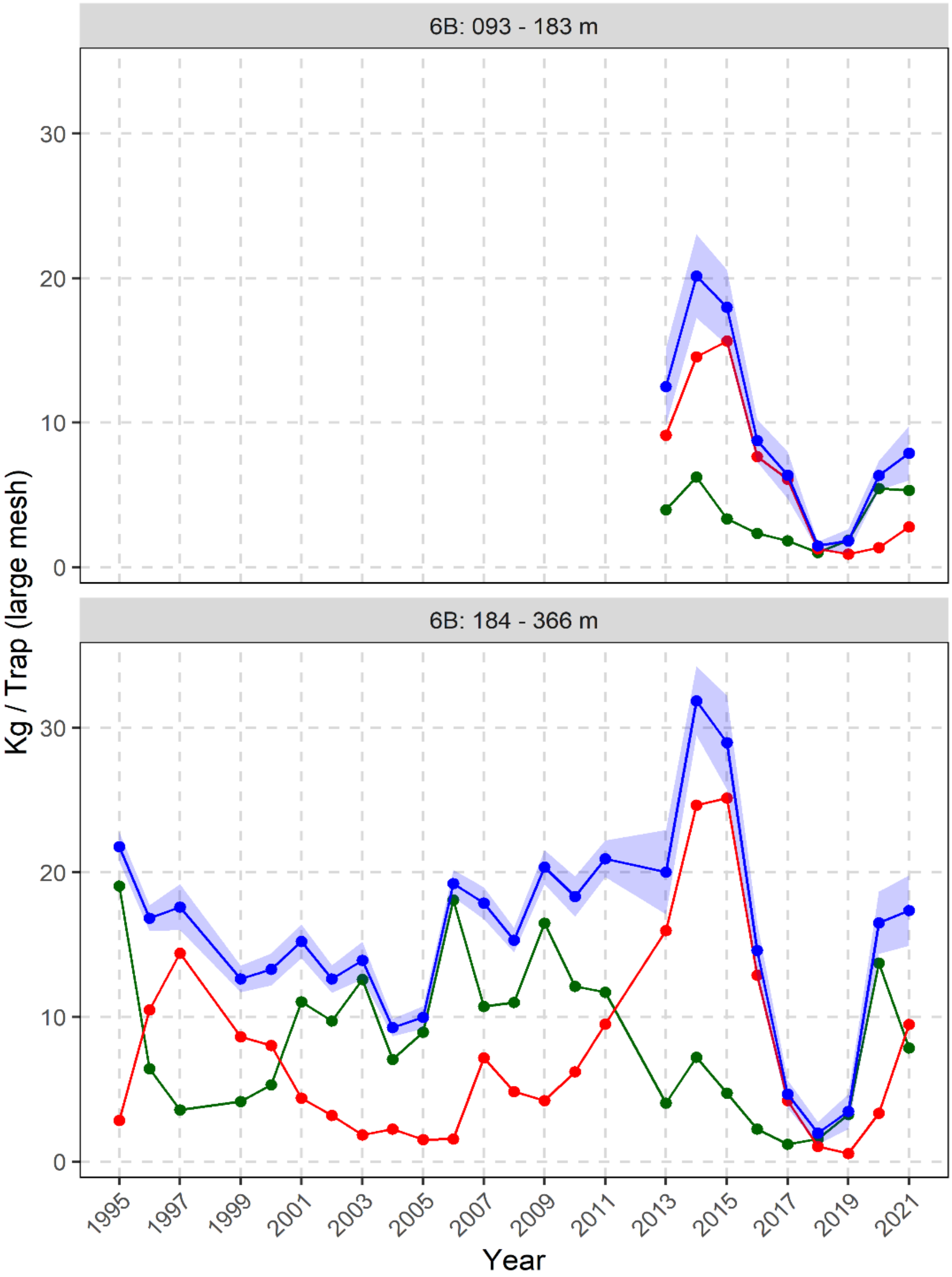


Figure A3.8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps in the Inshore DFO trap surveys in Conception Bay (CMA 6B).

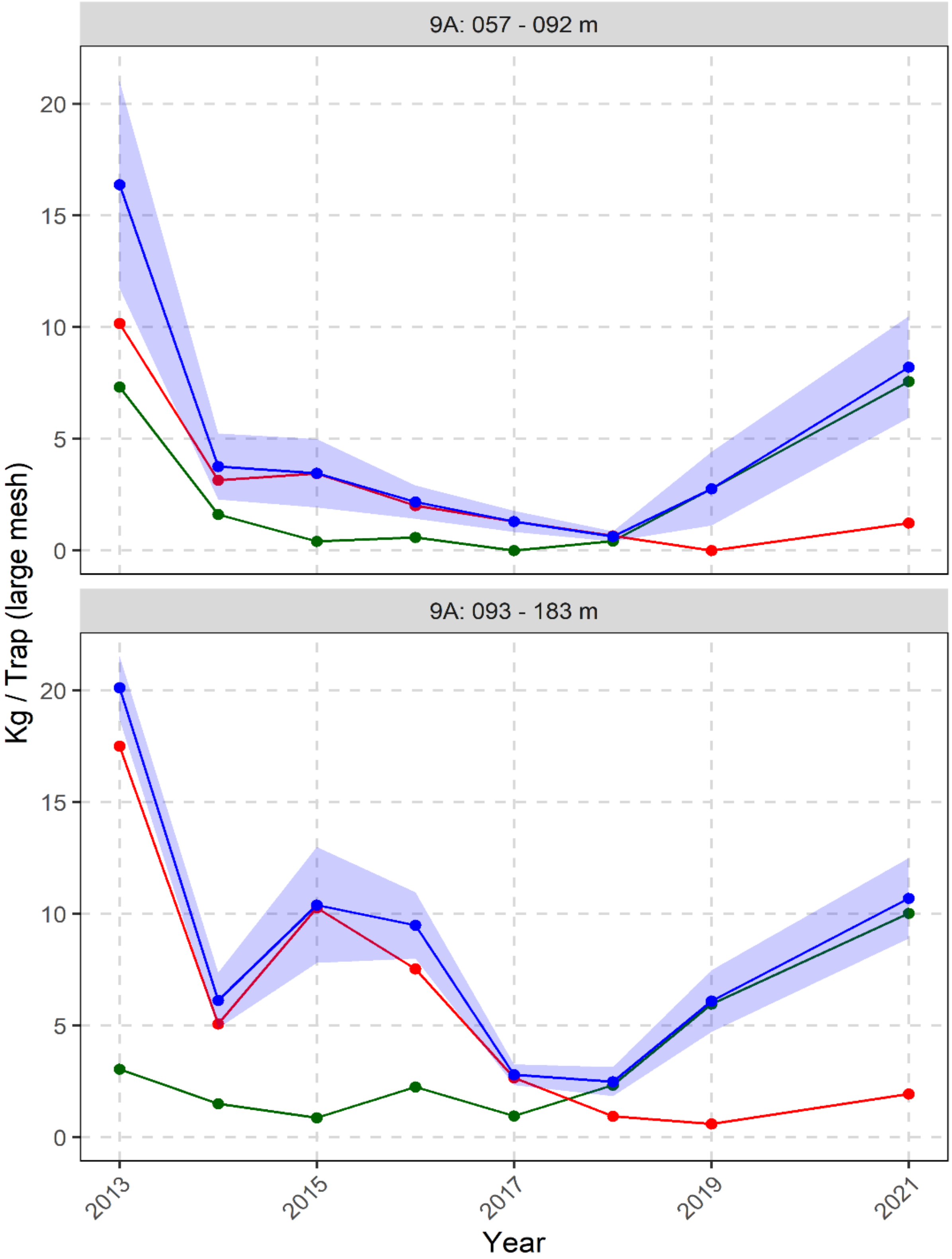


Figure A3.9. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps in the Inshore DFO trap surveys in St. Mary's Bay (CMA 9A). Note: no survey in St. Mary's Bay in 2020.

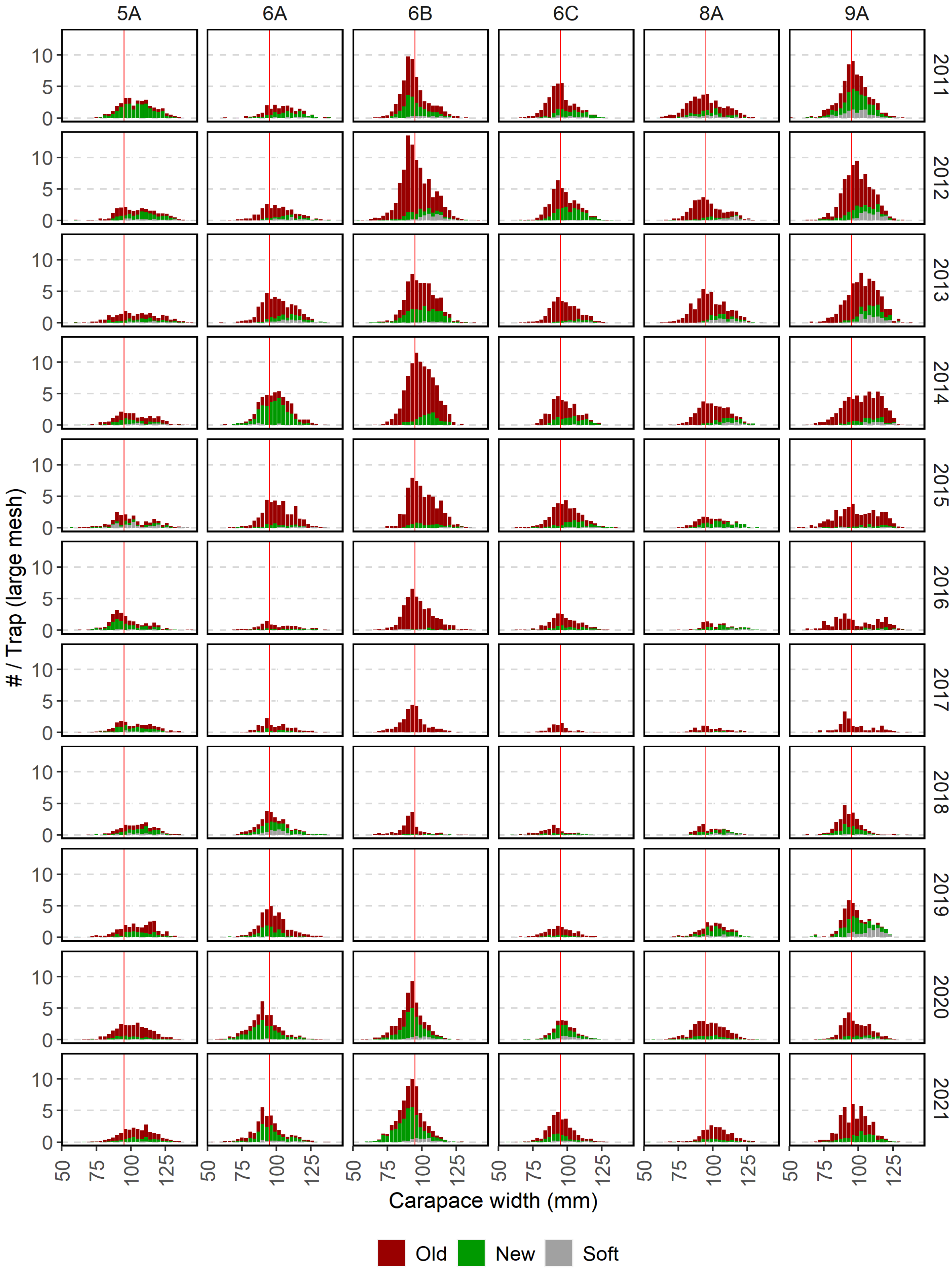


Figure A3.10. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the CPS trap survey in CMAs within Assessment Division 3L Inshore (2011–21). The vertical line indicates the minimum legal size.

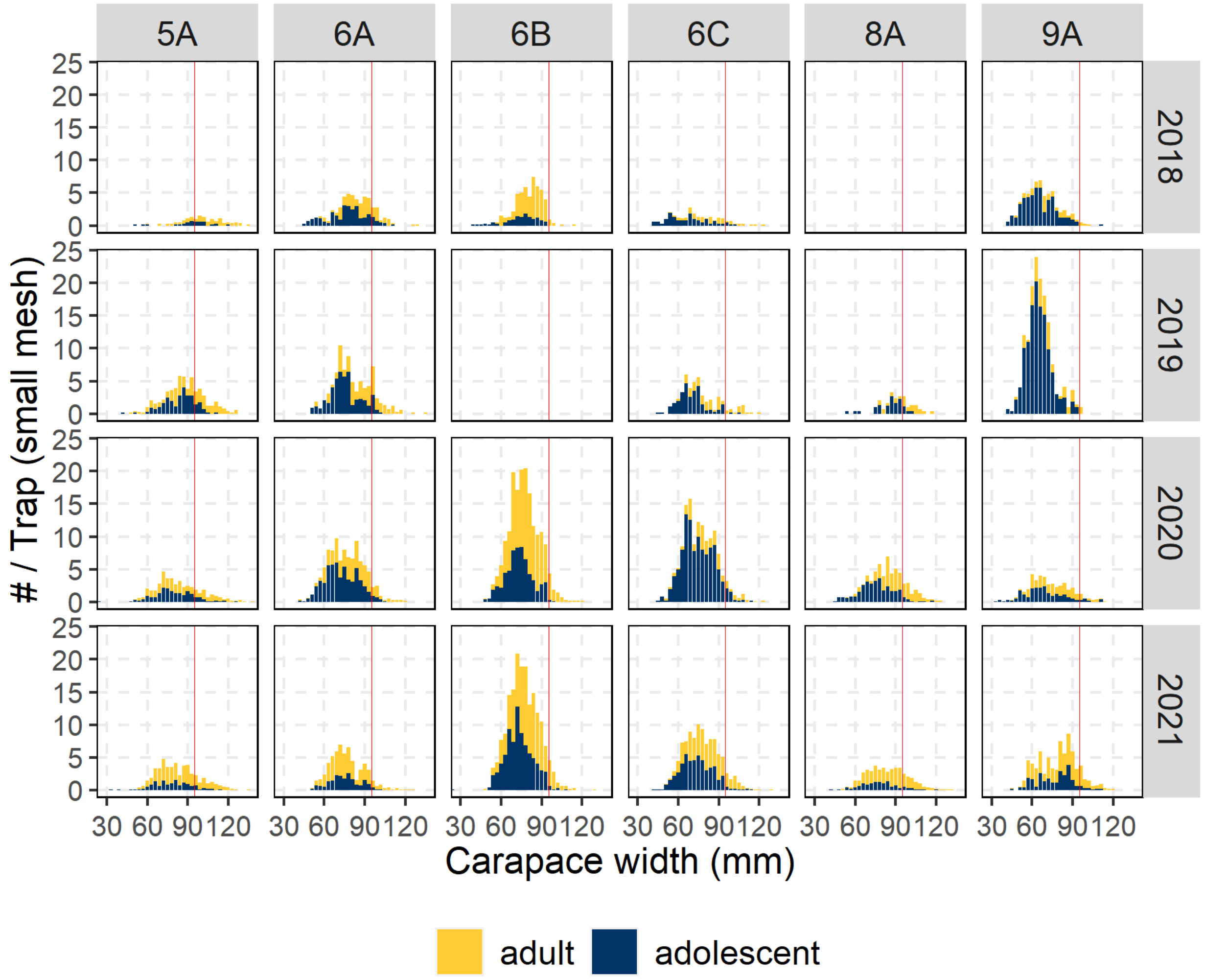


Figure A3.11. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2018–21) from CMAs in Assessment Division 3L Inshore. The red vertical line indicates the minimum legal size.

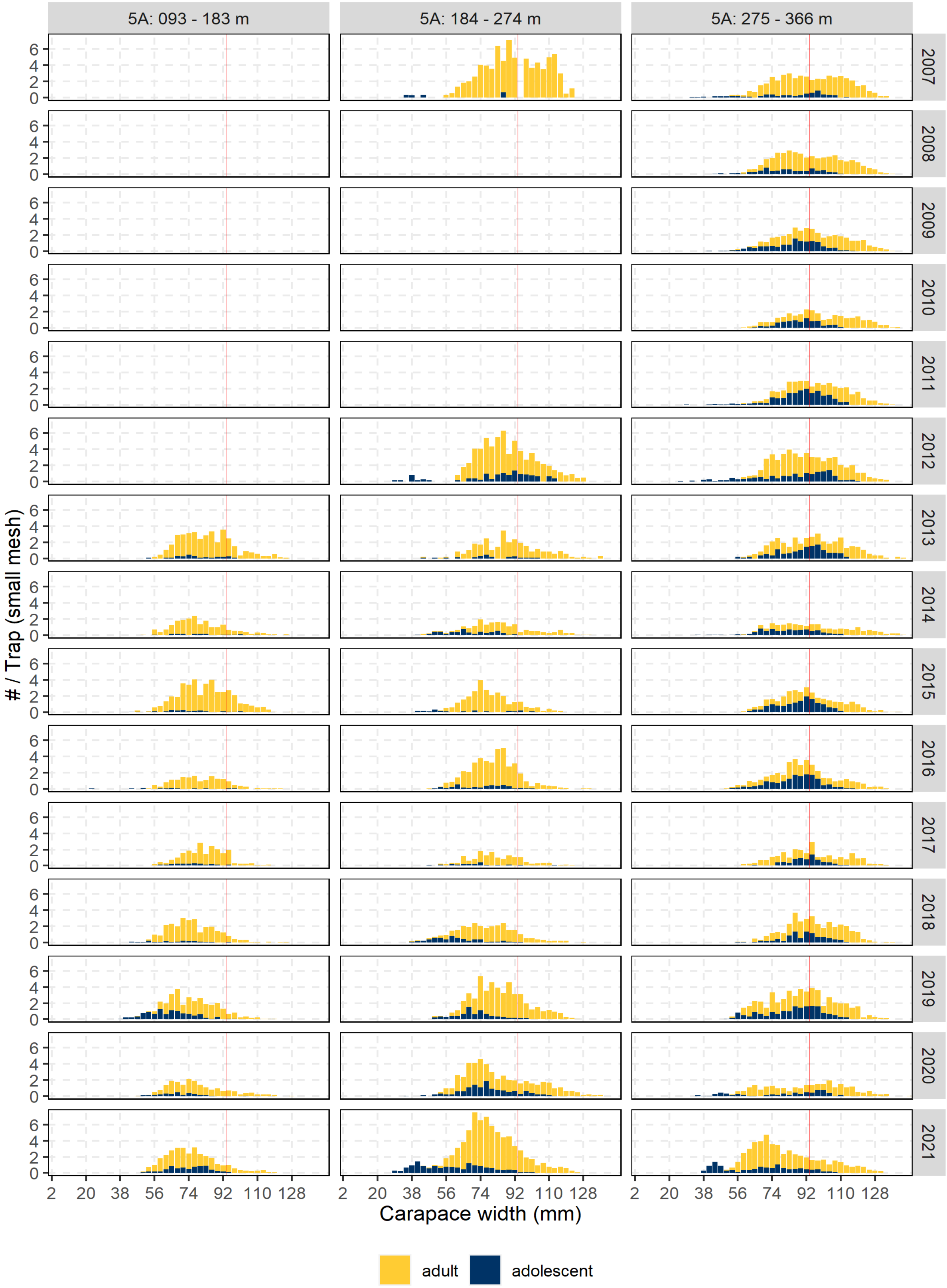


Figure A3.12. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2007–21) in Bonavista Bay (CMA 5A). The red vertical line indicates the minimum legal size.

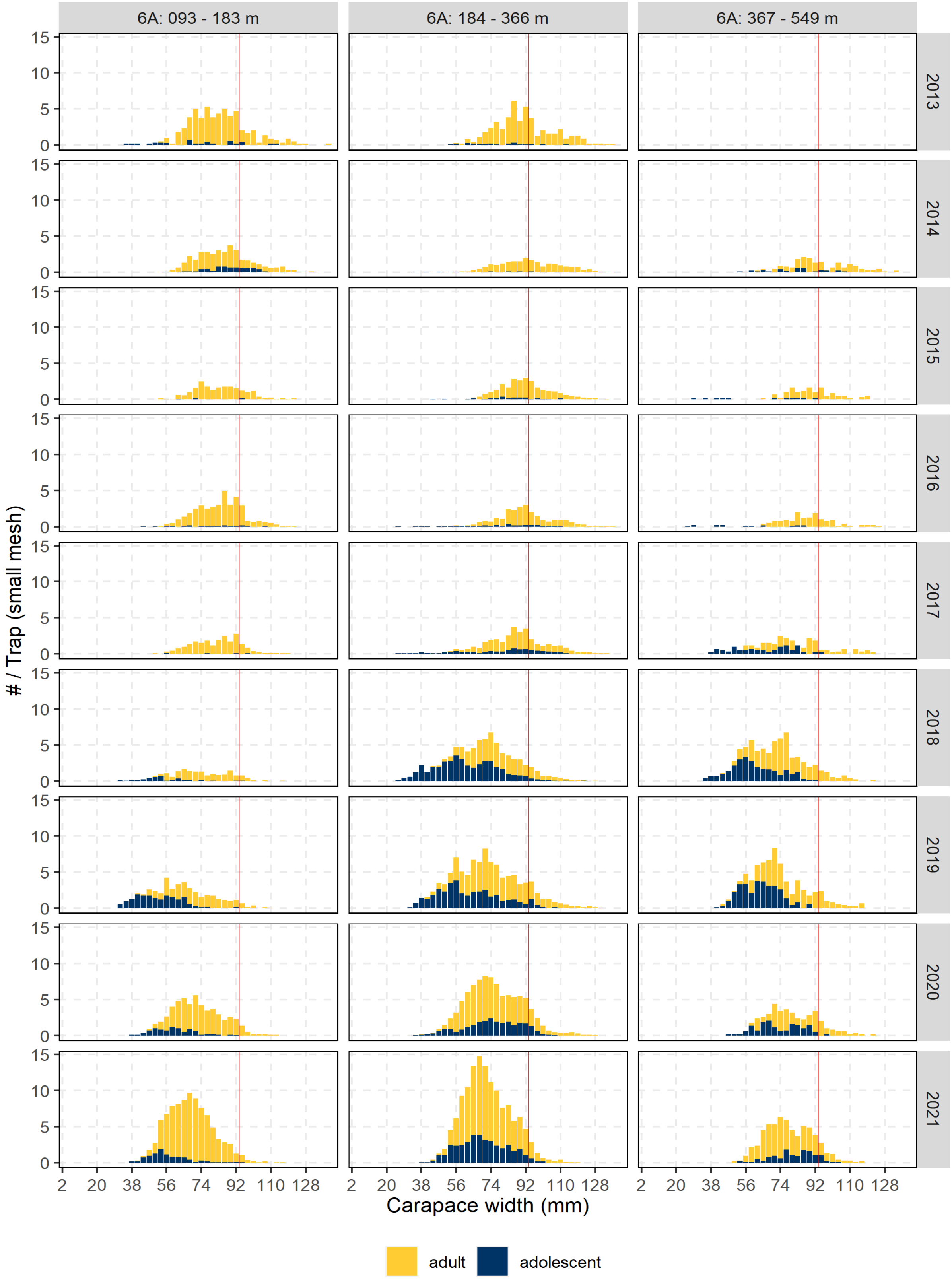


Figure A3.13. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2013–21) in Trinity Bay (CMA 6A). The red vertical line indicates the minimum legal size.

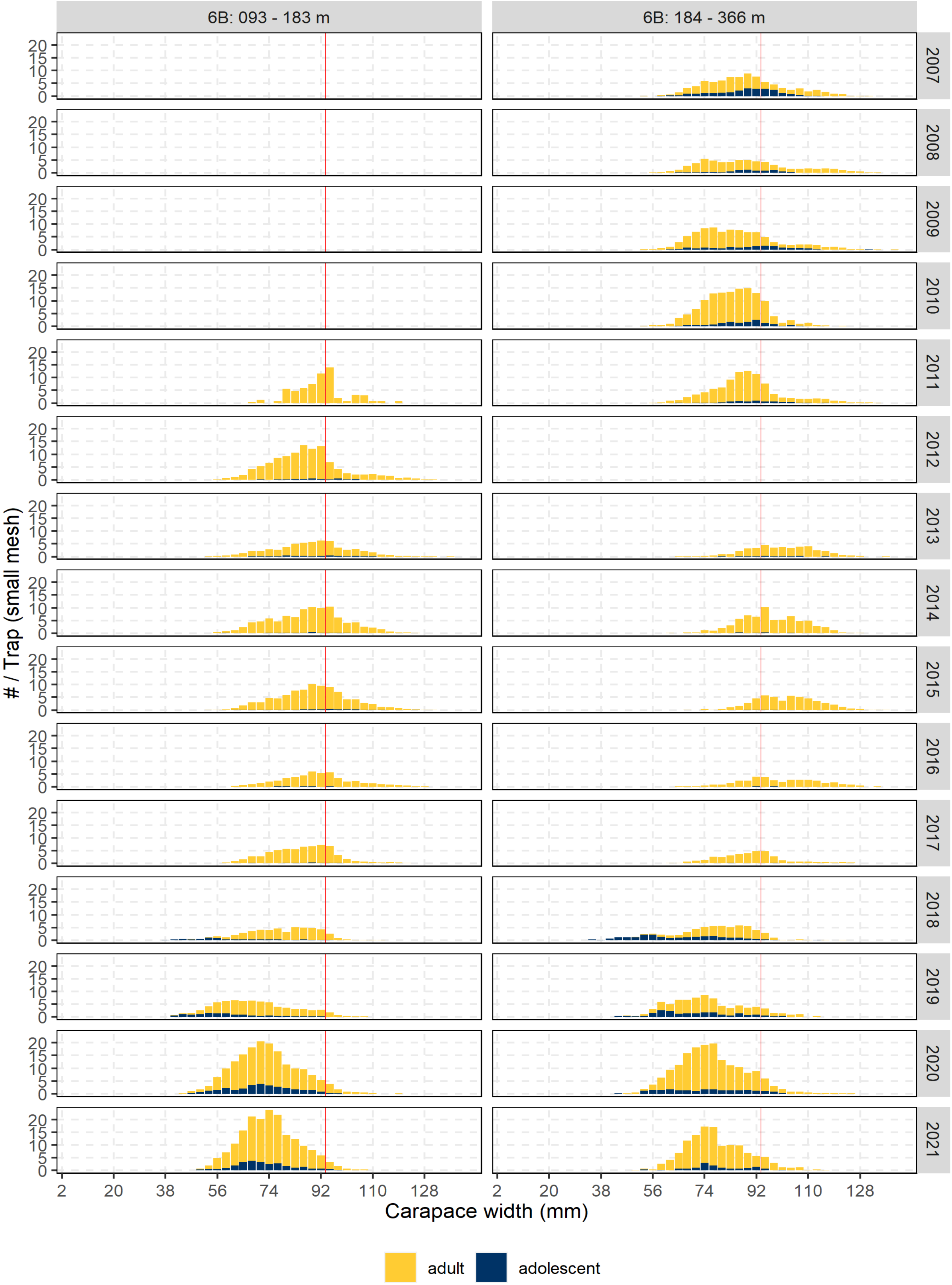


Figure A3.14. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2007–21) in Conception Bay (CMA 6B). The red vertical line indicates the minimum legal size.

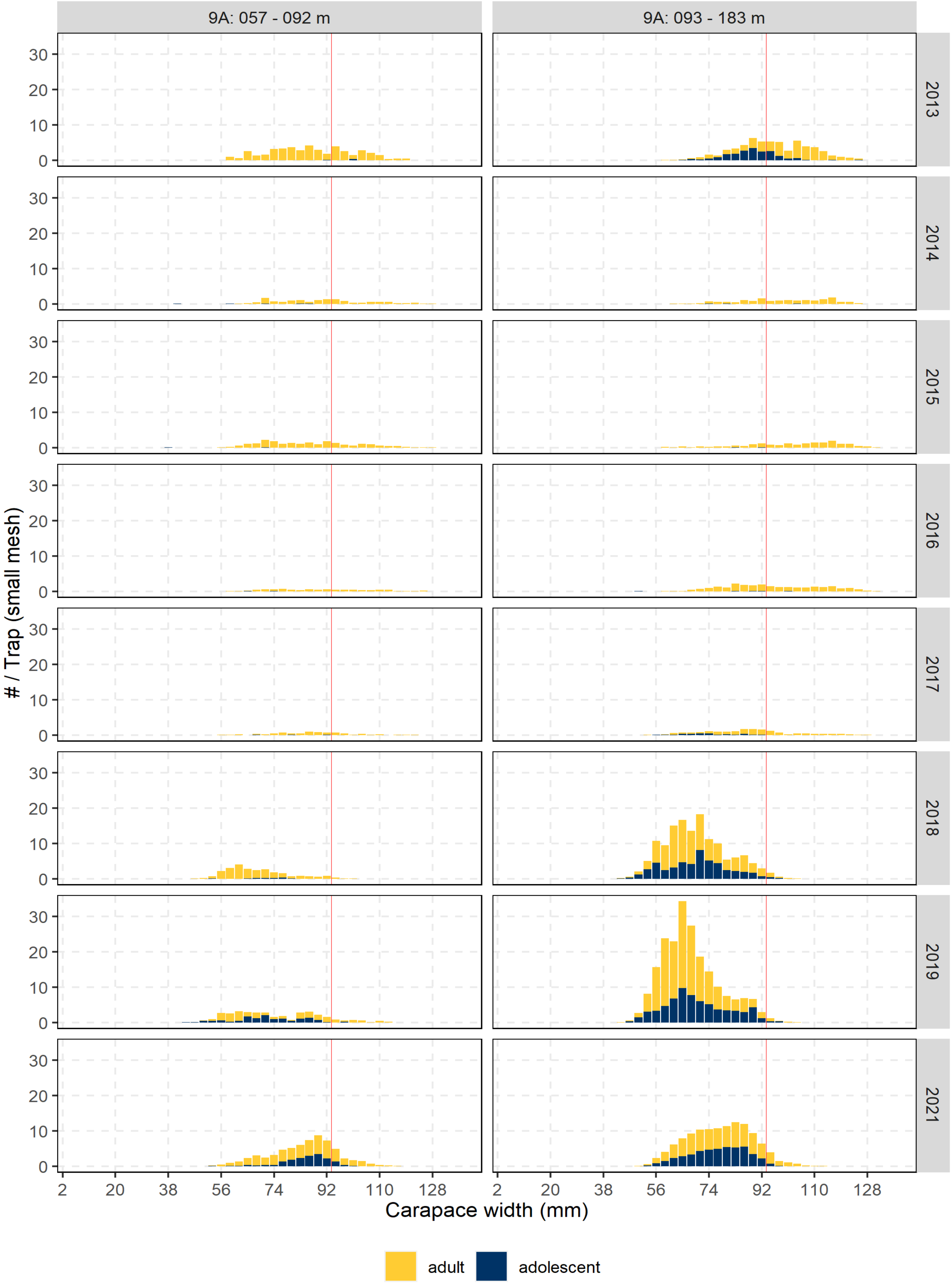


Figure A3.15. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2013–21) in St. Mary's Bay (CMA 9A). The red vertical line indicates the minimum legal size. Note: No survey in St. Mary's Bay in 2020.

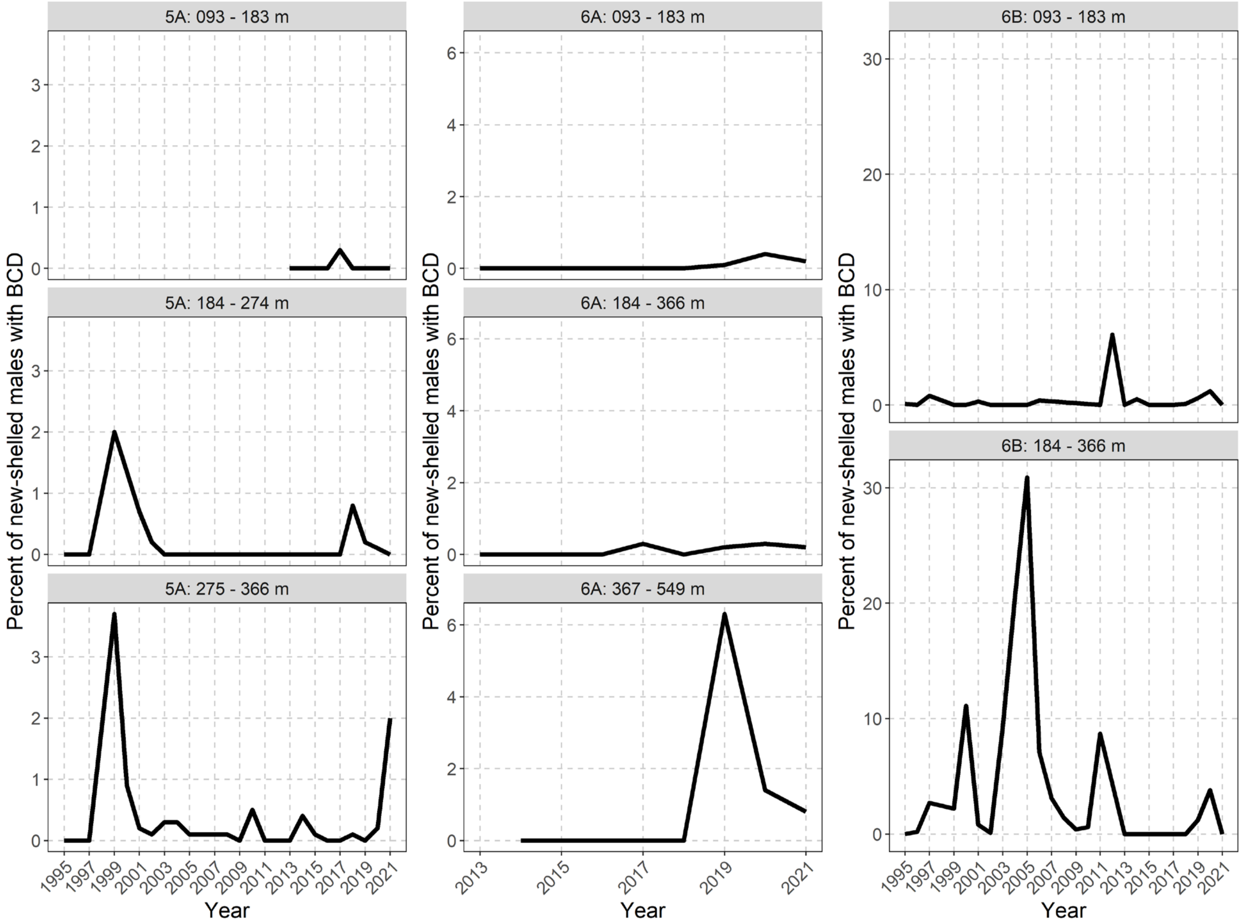


Figure A3.16. Visually observed percentage of Bitter Crab Disease (BCD) in new-shelled crab from Inshore DFO trap surveys (1995–2021) in Bonavista Bay (CMA 5A), Trinity Bay (CMA 6A), and Conception Bay (CMA 6B).

APPENDIX 4: ASSESSMENT DIVISION 3LNO OFFSHORE DETAILS

Figure A4.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 3LNO Offshore (1999–2021).

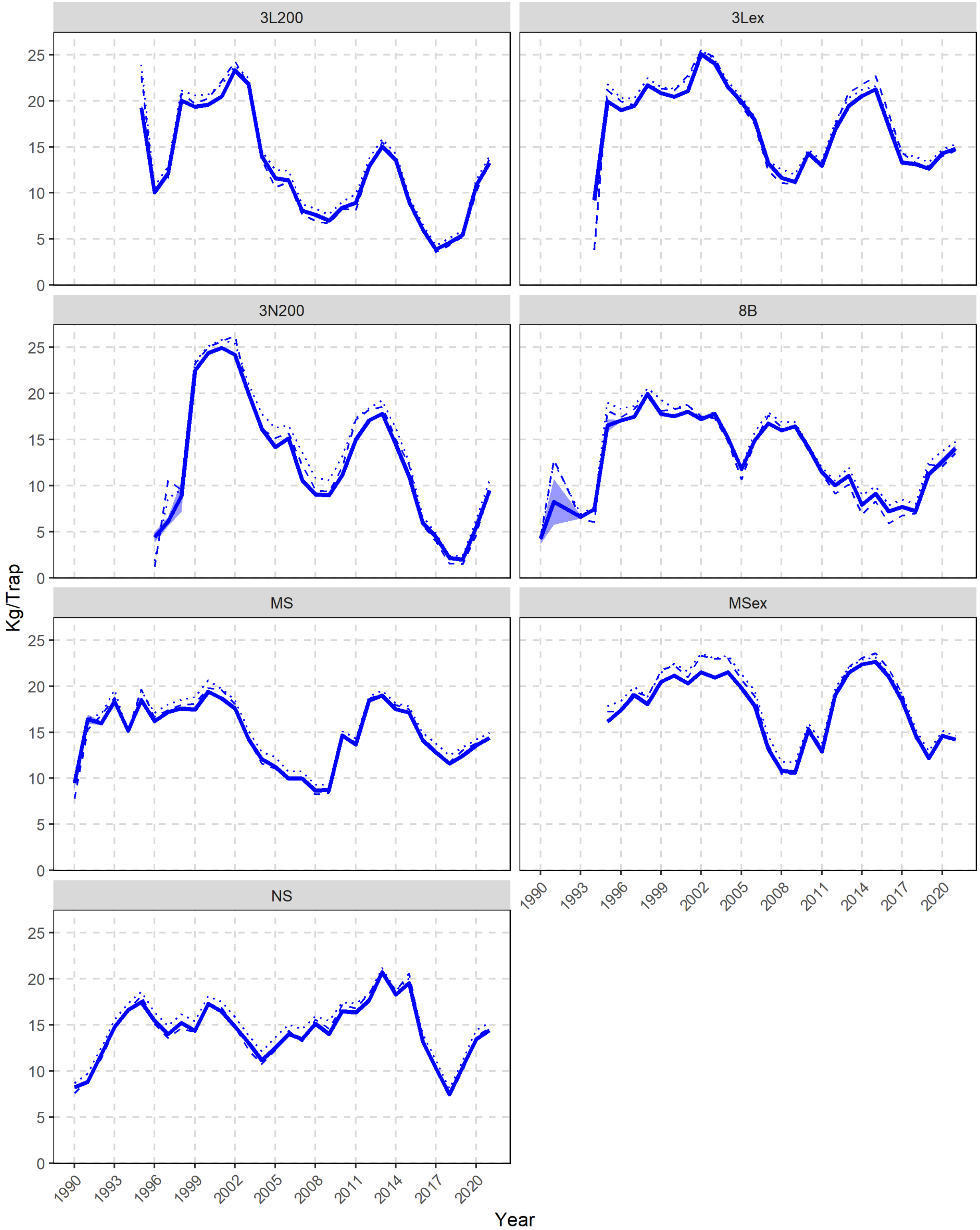


Figure A4.2. Trends in standardized fishery CPUE (kg/trap) in CMAs within Assessment Division 3LNO Offshore. Solid line = average predicted CPUE, shaded band = 95% confidence interval, dotted line = average raw CPUE, and dashed line = median raw CPUE. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

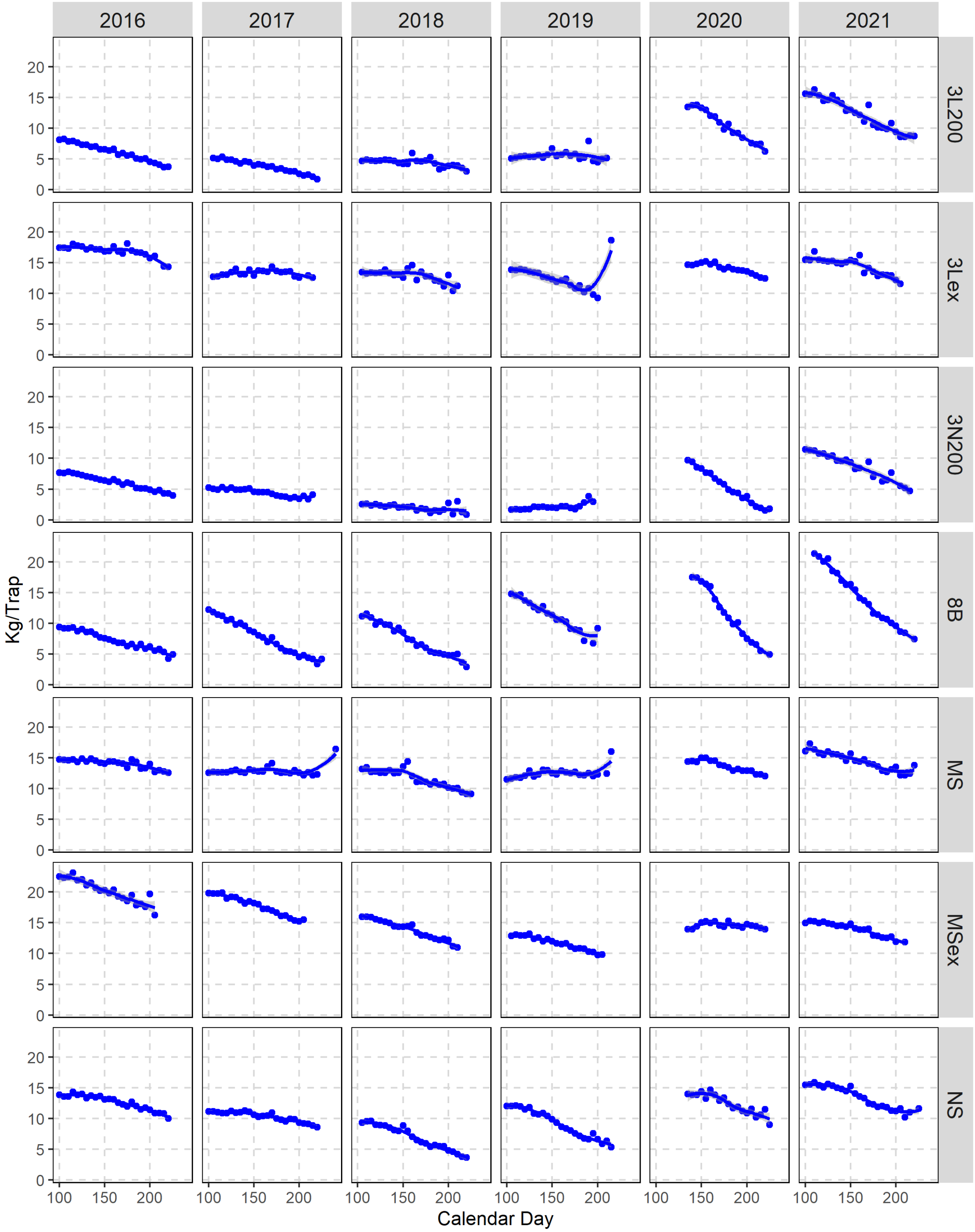


Figure A4.3. Standardized fishery CPUE (kg/trap) throughout the season (calendar day) in CMAs within Assessment Division 3LNO Offshore (2016–21). Points = mean CPUE of 5-day increments and trend lines = loess regression curves. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

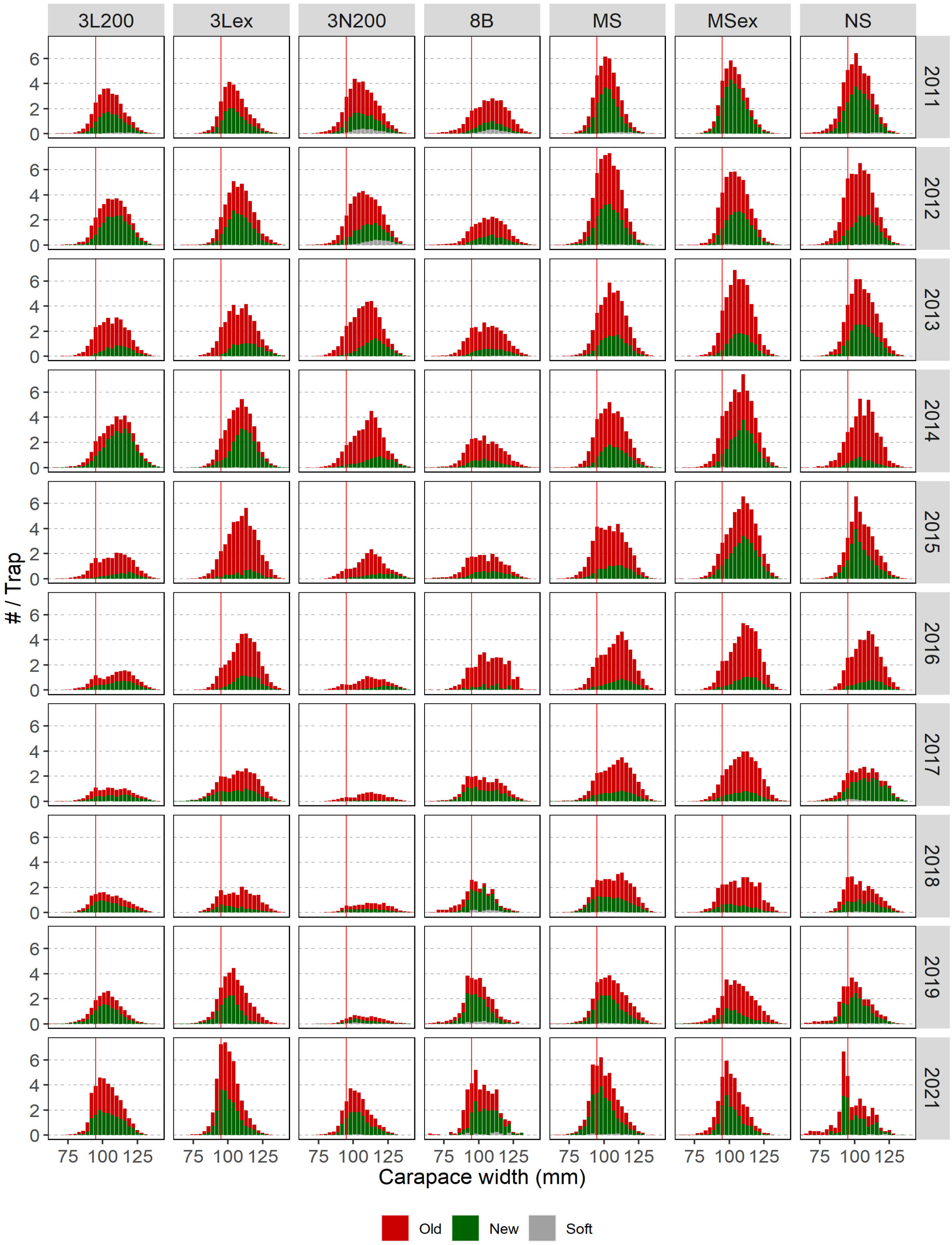


Figure A4.4. Trends in male carapace width distributions by shell condition from at-sea observer sampling in CMAs within Assessment Division 3LNO Offshore (2011–21). The red vertical line indicates the minimum legal size.

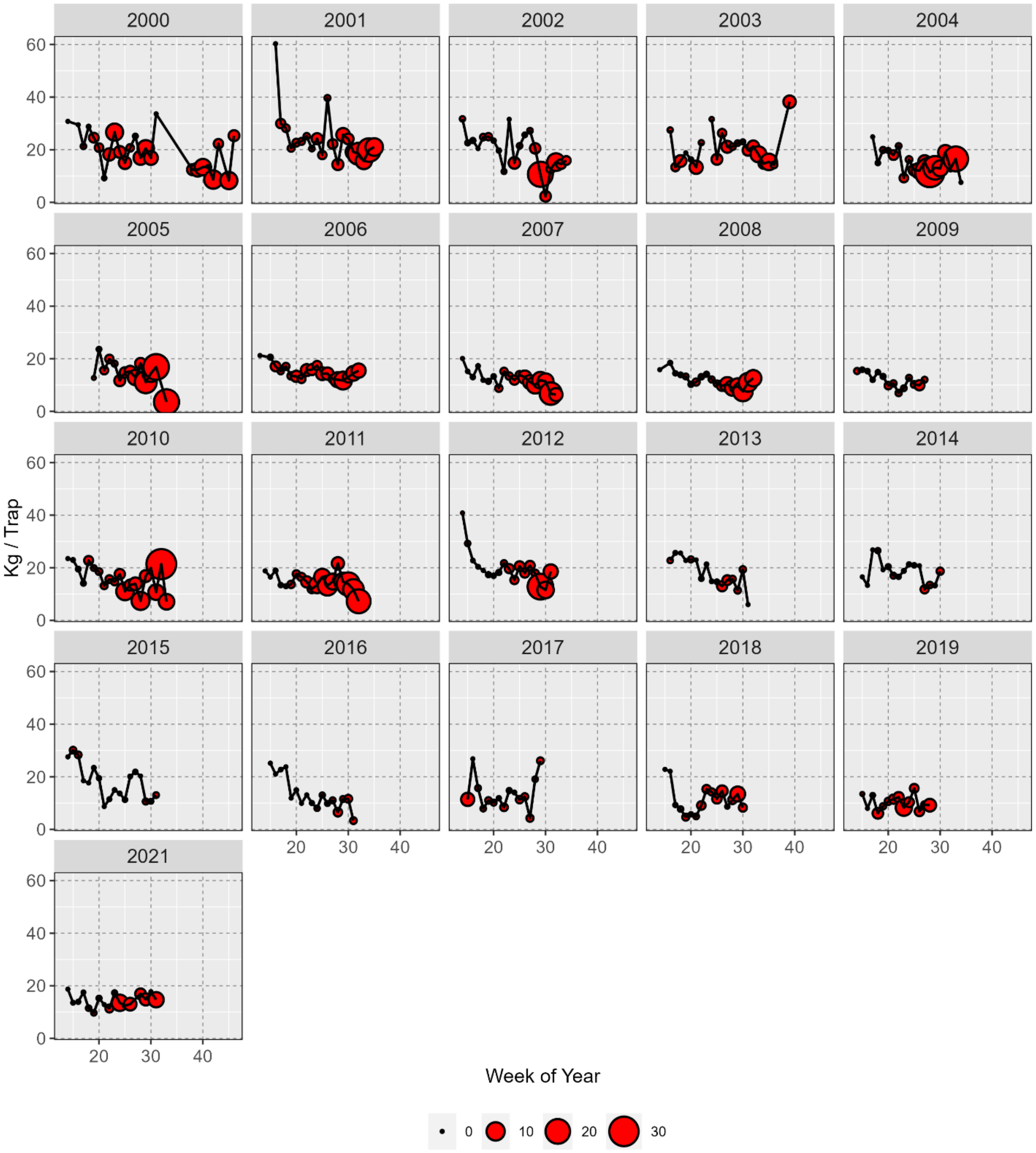


Figure A4.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Assessment Division 3LNO Offshore (2000–21). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

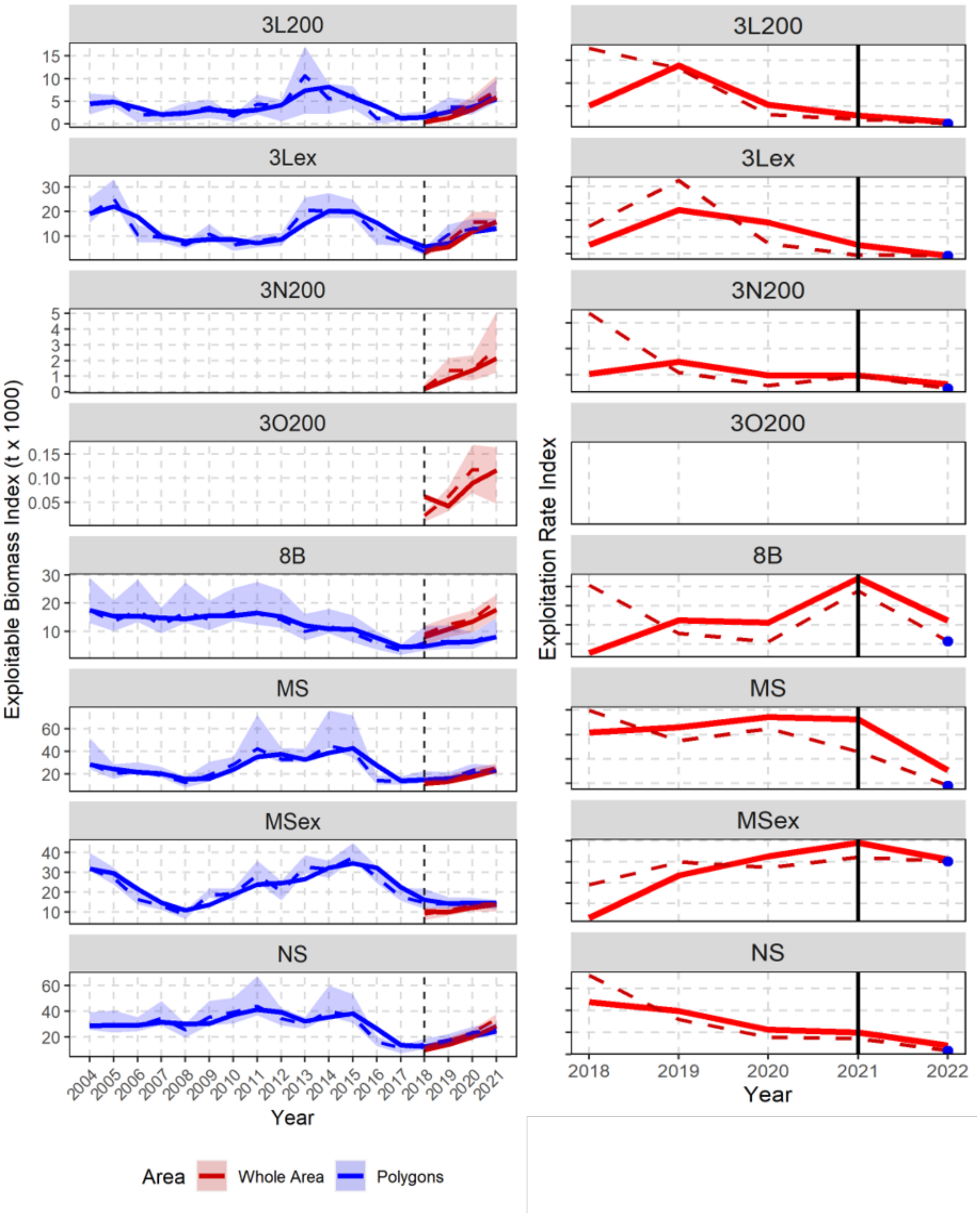


Figure A4.6. Left: Trap exploitable biomass index (2004–21). Red series uses all stations of the survey and blue series uses core stations of the survey. Solid line = 2-year moving average, dashed line = annual estimate, and shaded band = 95% confidence interval of the annual estimate. Right: Trends in the trap-based annual (dashed line) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 3LNO Offshore; 2022 points depict projected exploitation rate indices under status quo removals in the 2022 fishery.

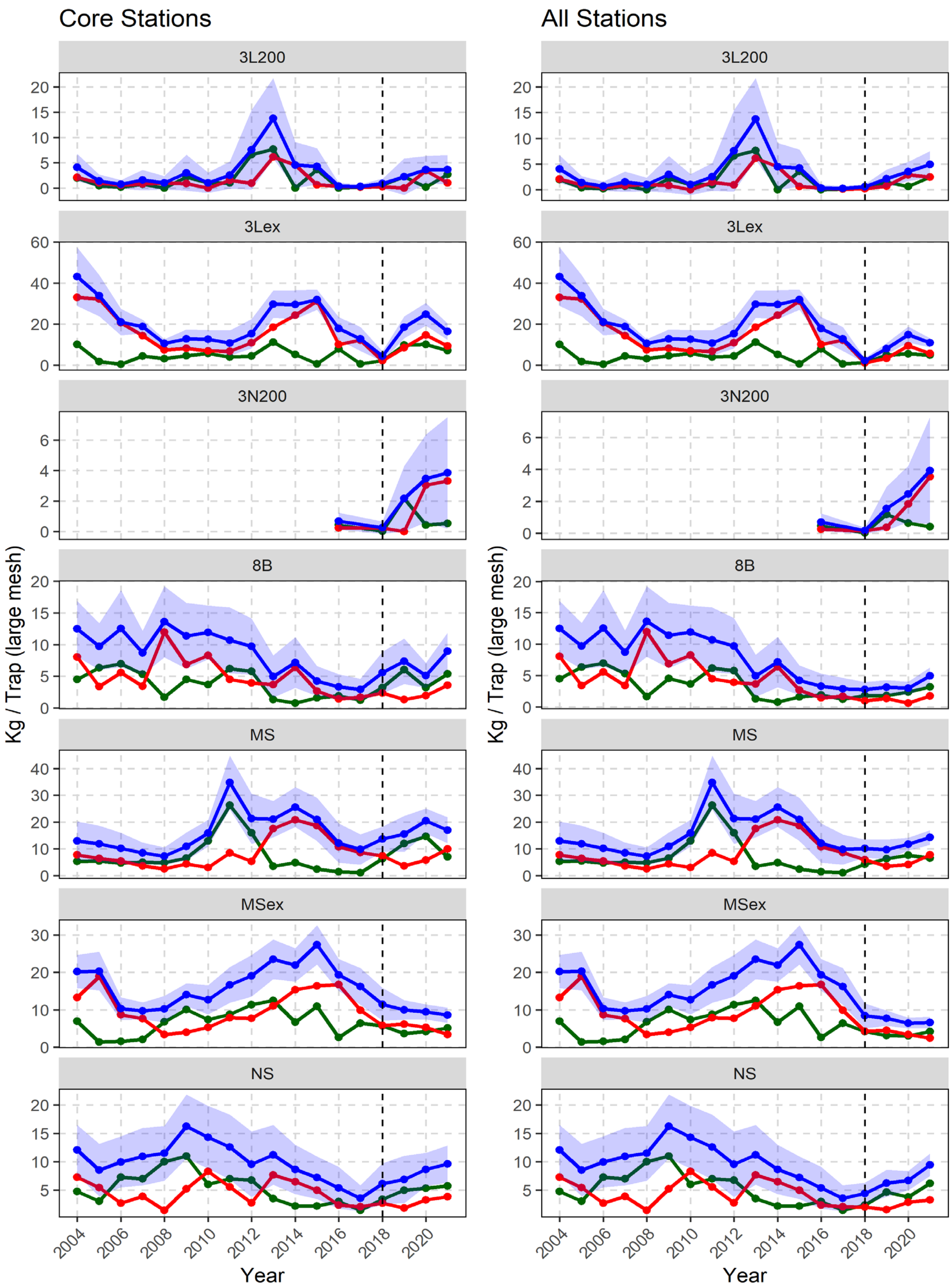


Figure A4.7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations (left) and all stations (right) in the CPS trap survey in CMAs within Assessment Division 3LNO Offshore.

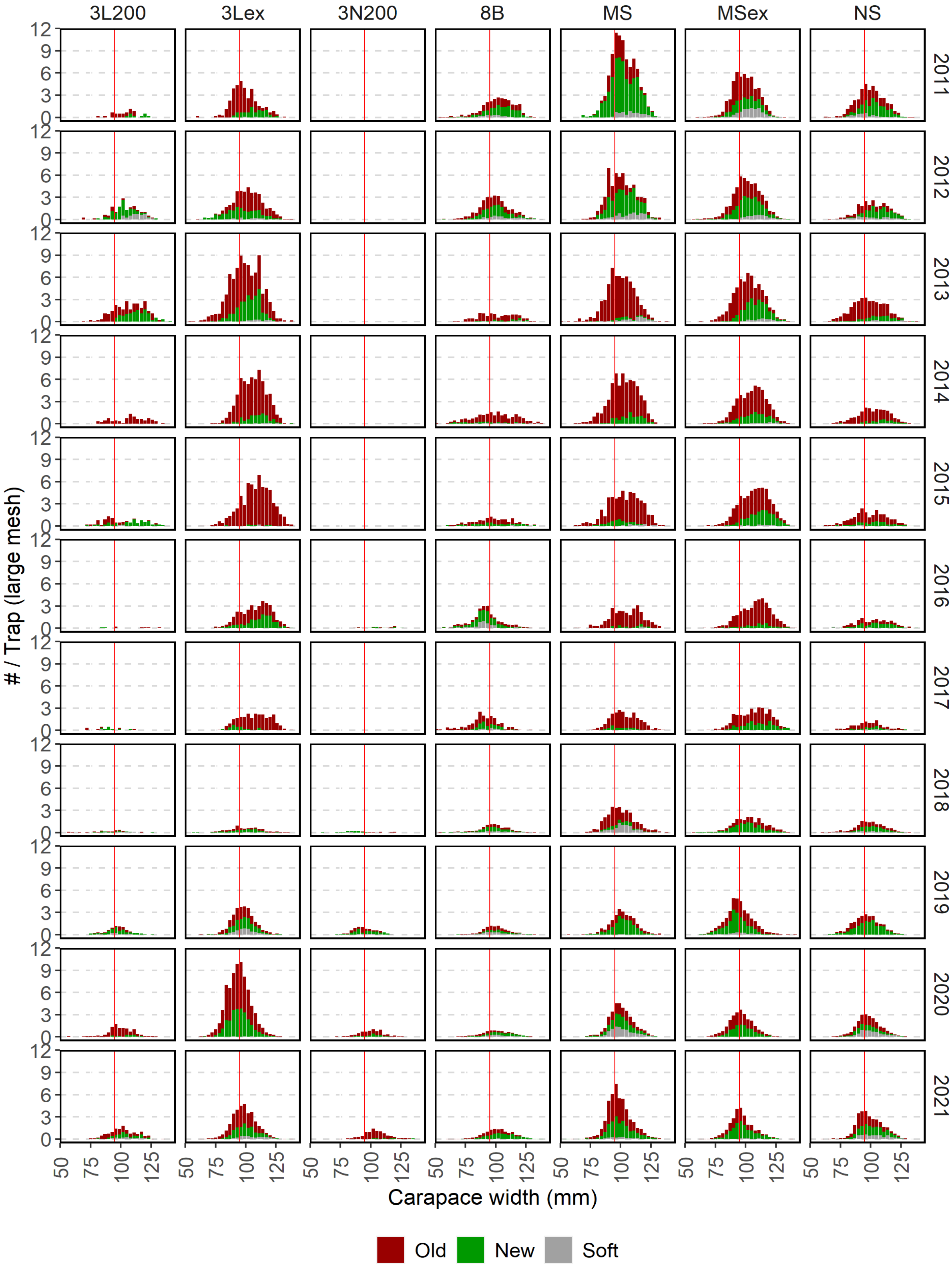


Figure A4.8. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the CPS trap survey in CMAs within Assessment Division 3LNO Offshore (2011–21). The red vertical line indicates the minimum legal size.

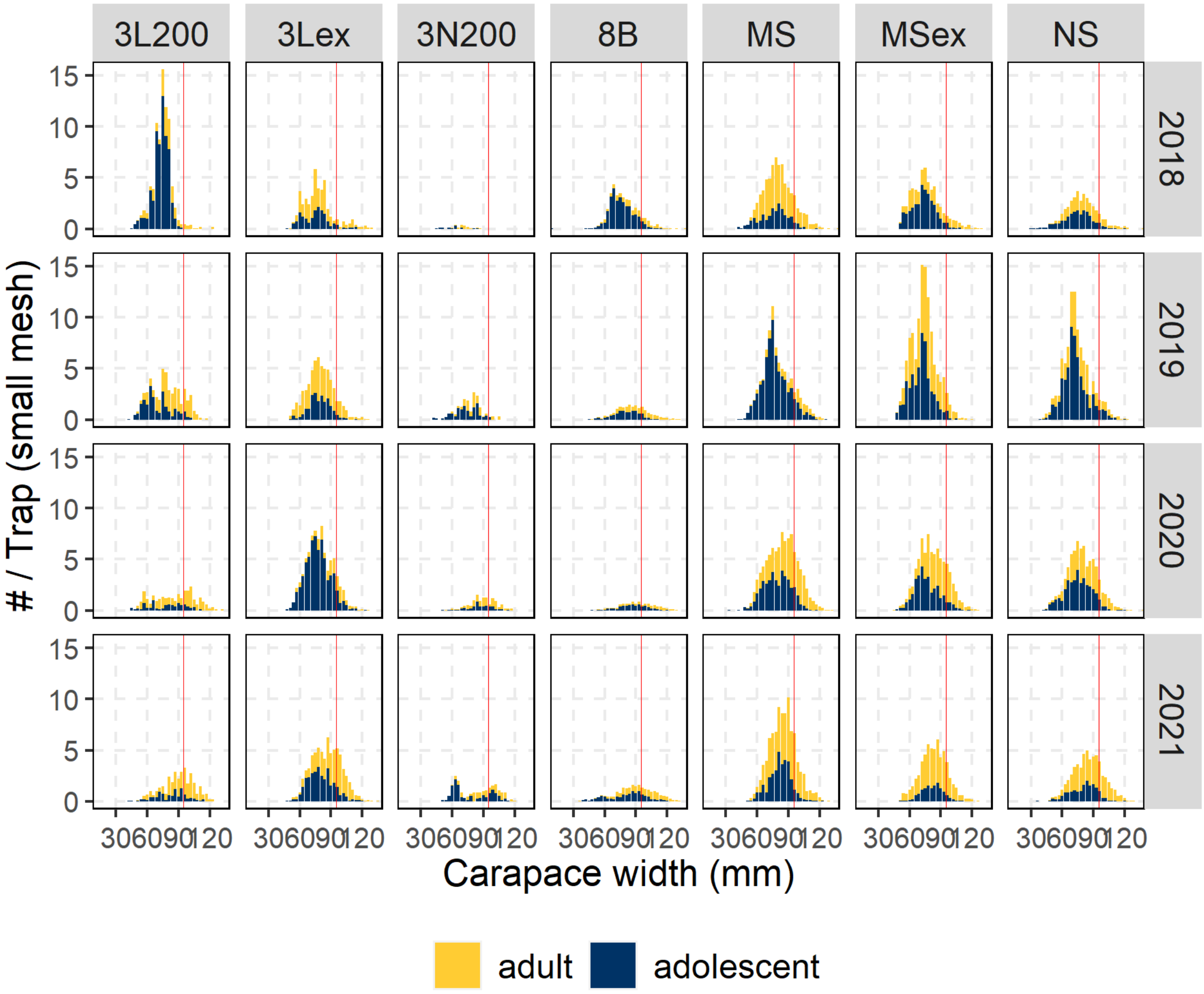


Figure A4.9. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2018–21) from CMAs in Assessment Division 3LNO Offshore. The red vertical line indicates the minimum legal size.

APPENDIX 5: ASSESSMENT DIVISION 3PS DETAILS

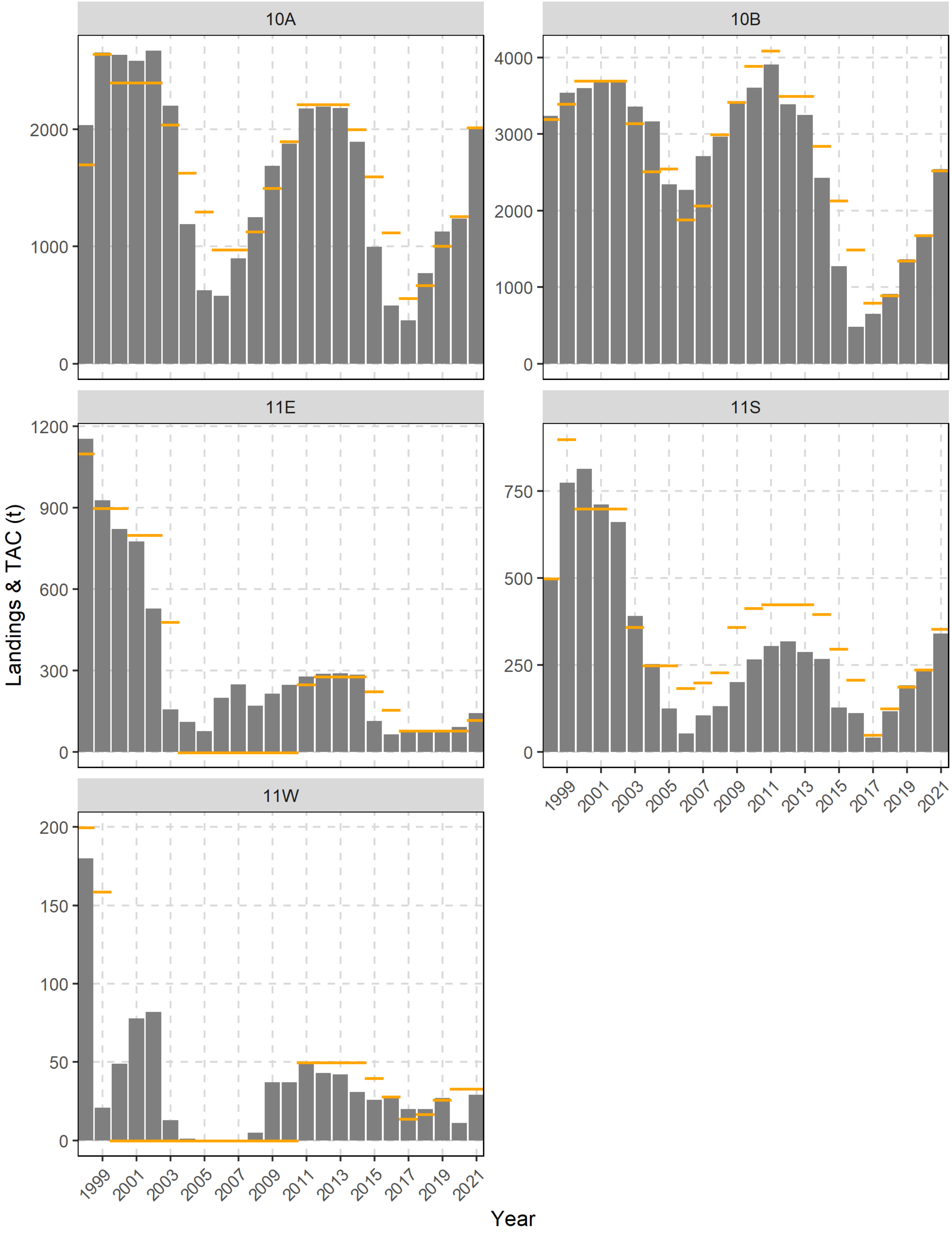


Figure A5.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 3Ps (1998–2021).

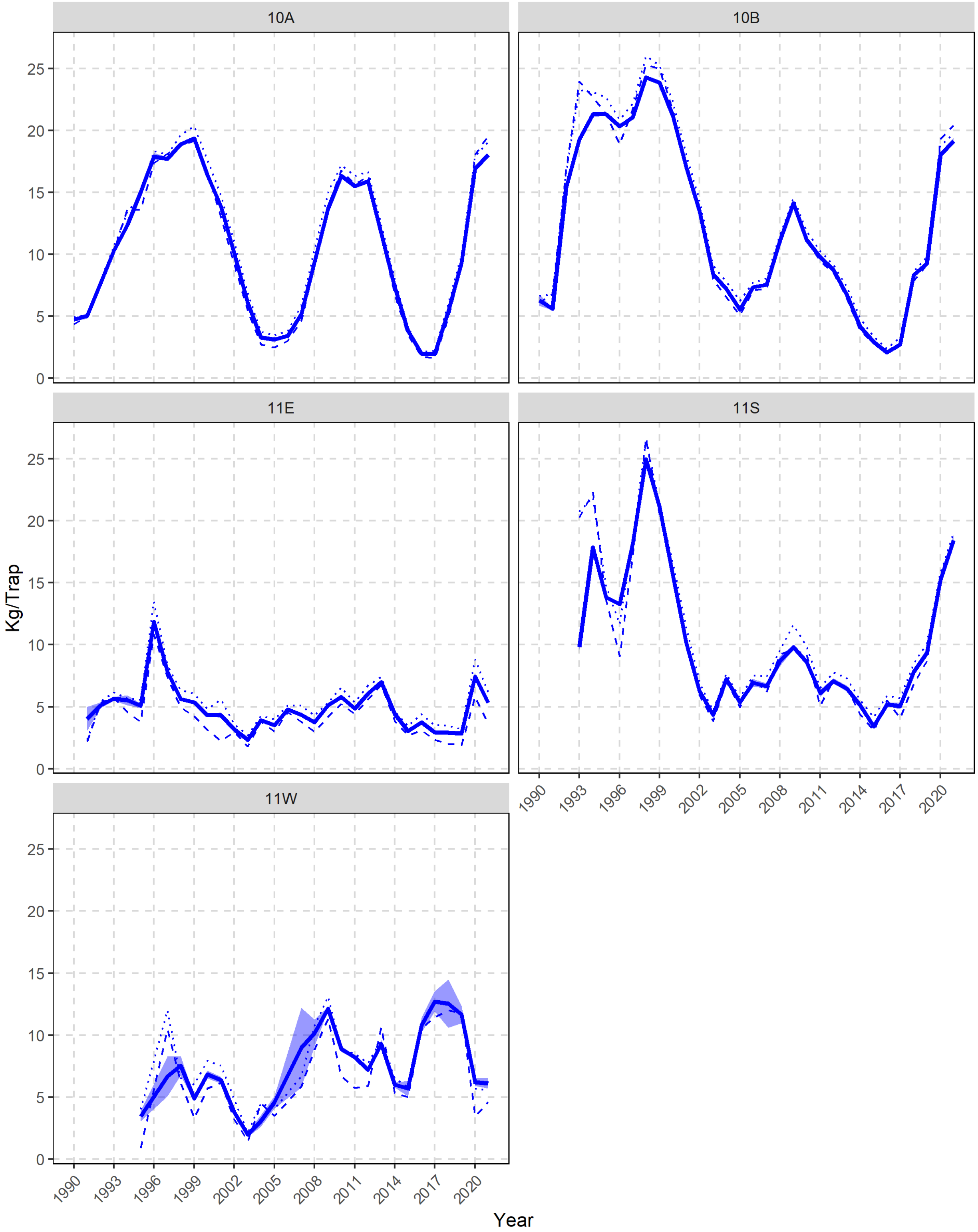


Figure A5.2. Trends in standardized fishery CPUE (kg/trap) in CMAs within Assessment Division 3Ps. Solid line = average predicted CPUE, shaded band = 95% confidence interval, dotted line = average raw CPUE, and dashed line = median raw CPUE. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

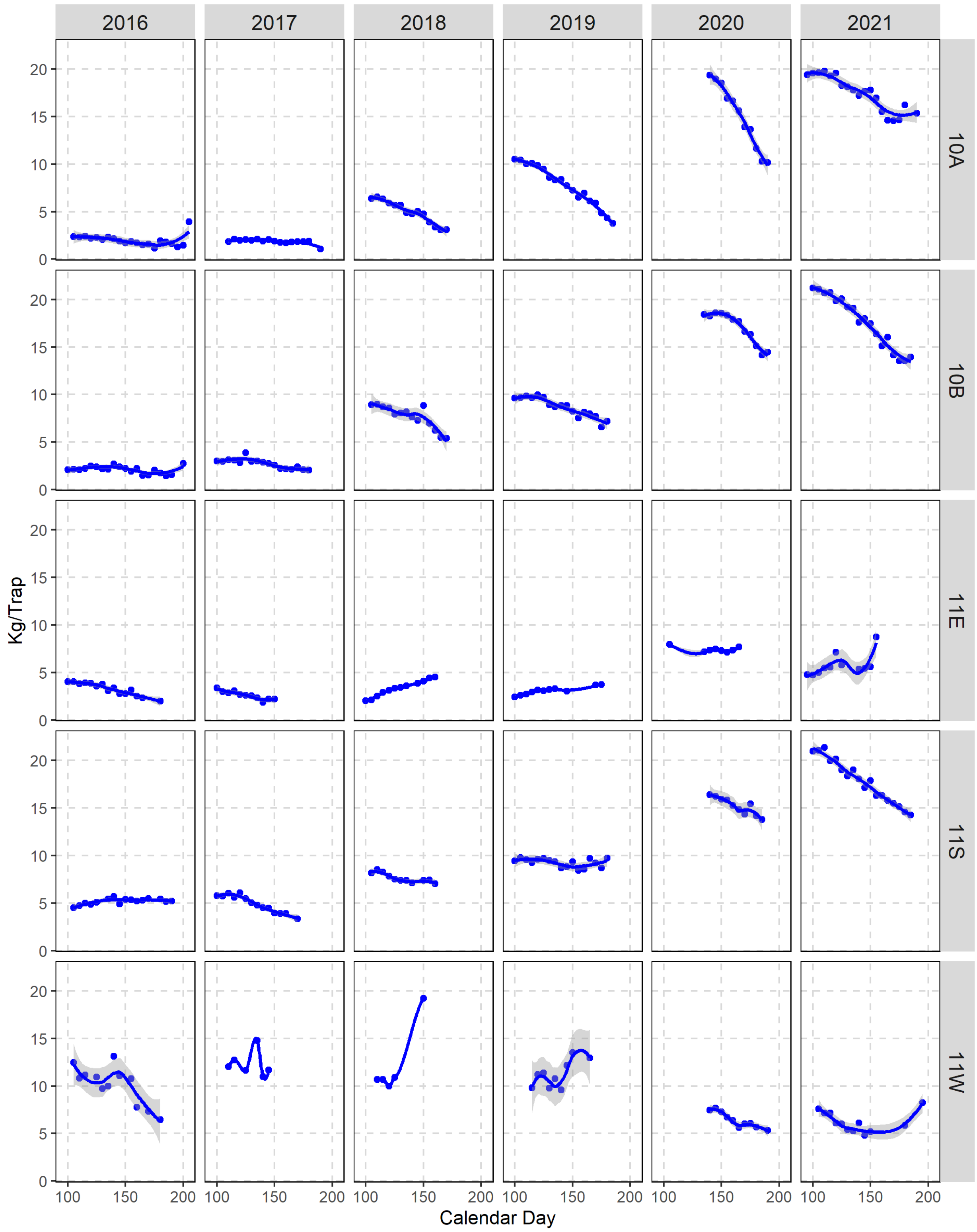


Figure A5.3. Standardized fishery CPUE (kg/trap) throughout the season (calendar day) in CMAs within Assessment Division 3Ps (2016–21). Points = mean CPUE of 5-day increments and trend lines = loess regression curves. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

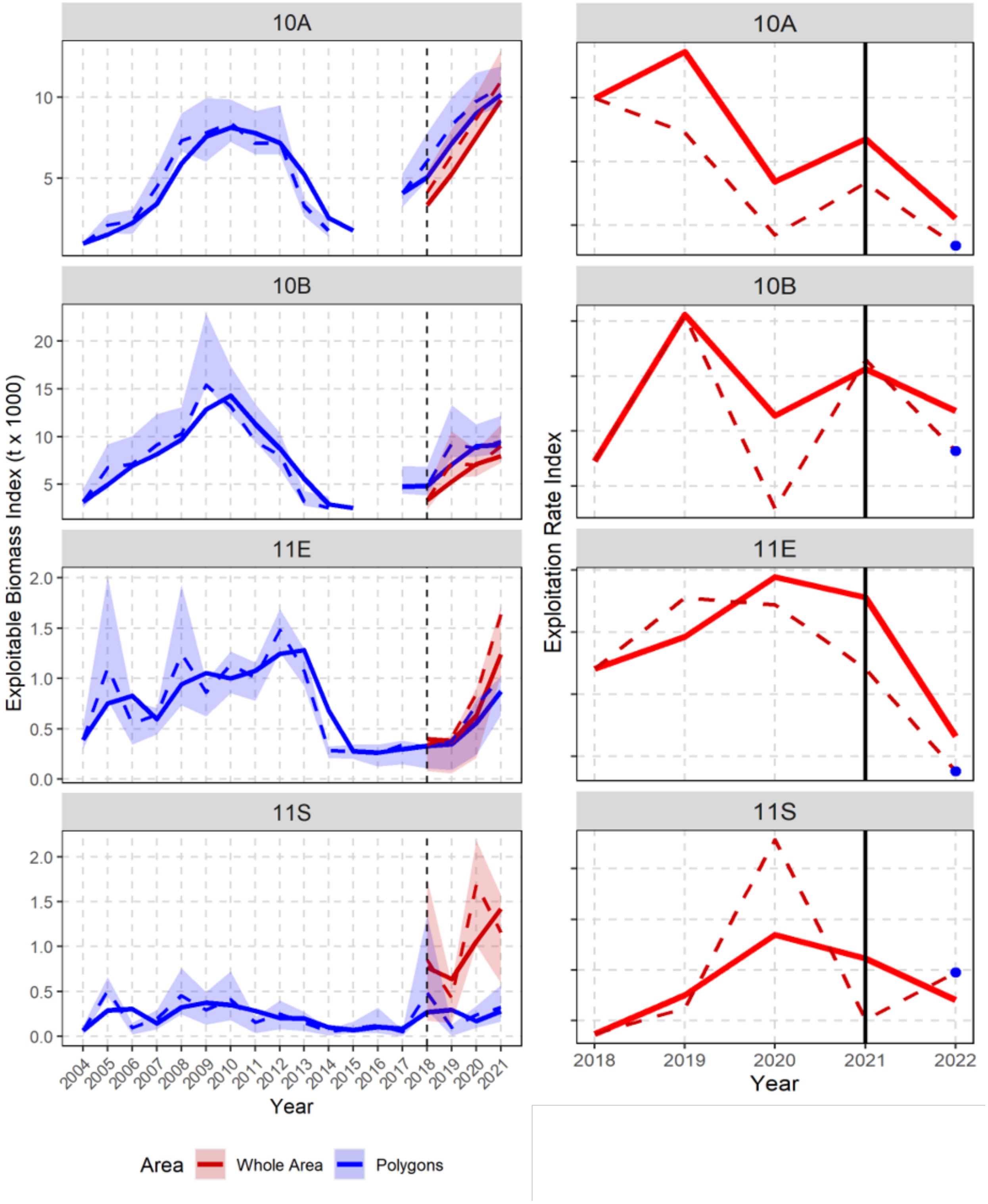


Figure A5.4. Left: Trap exploitable biomass index (2004–21). Red series uses all stations of the survey and blue series uses core stations of the survey. Solid line = 2-year moving average, dashed line = annual estimate, and shaded band = 95% confidence interval of the annual estimate. Right: Trends in the trap-based annual (dashed line) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 3Ps; 2022 points depict projected exploitation rate indices under status quo removals in the 2022 fishery.

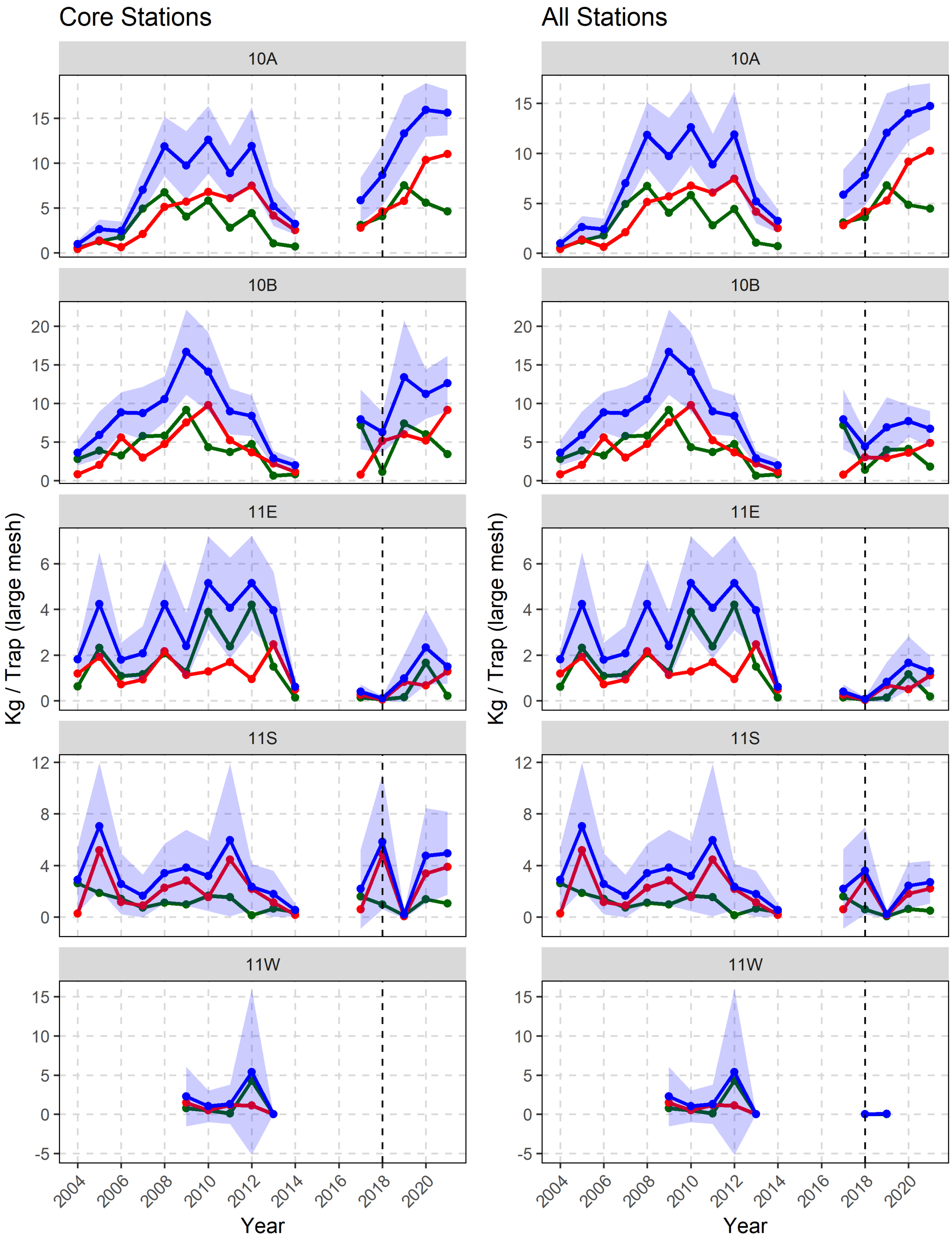


Figure A5.5. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations (left) and all stations (right) in the CPS trap survey in CMAs within Assessment Division 3Ps.

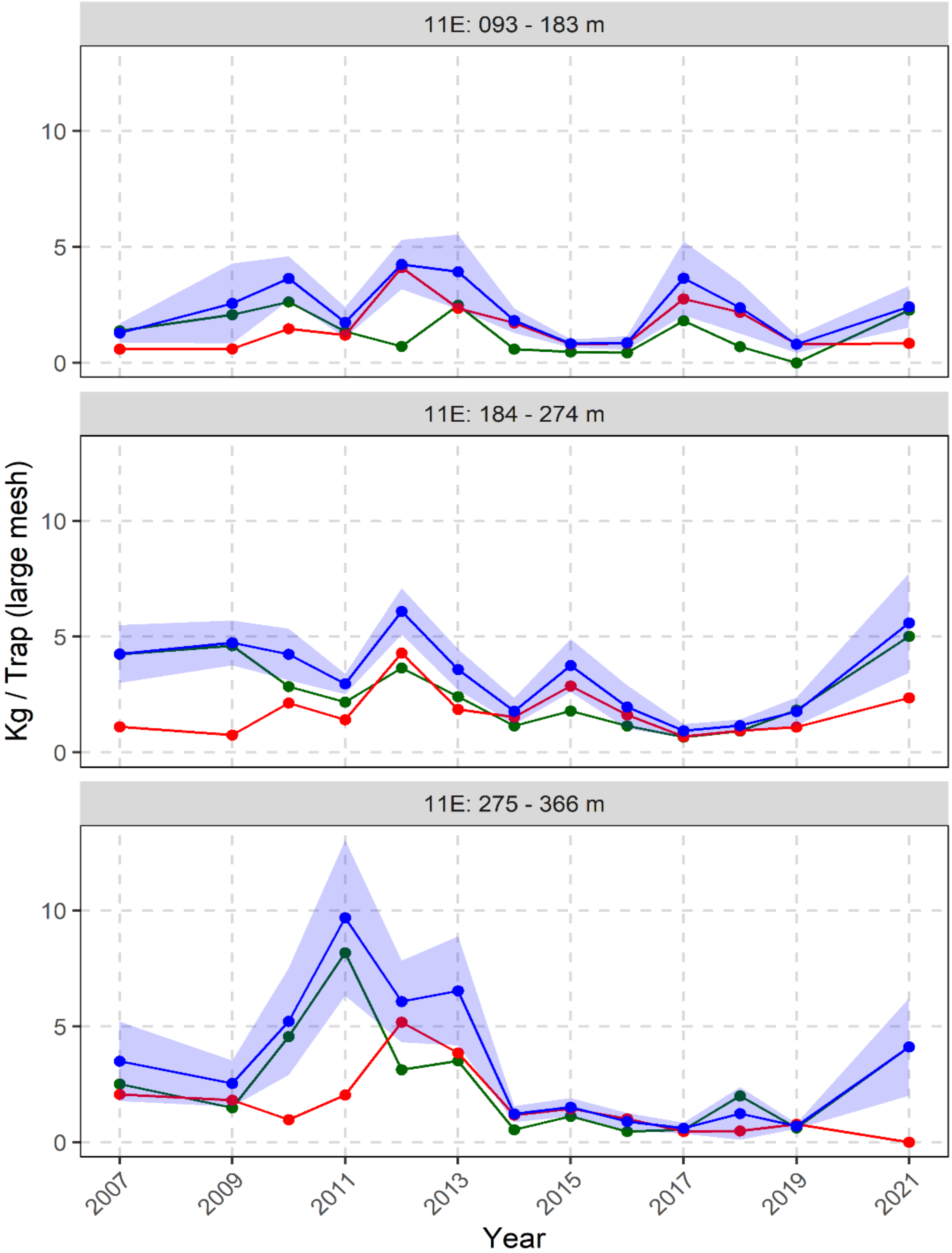


Figure A5.6. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps in the Inshore DFO trap surveys in Fortune Bay (CMA 11E). Note: No survey in Fortune Bay in 2020.

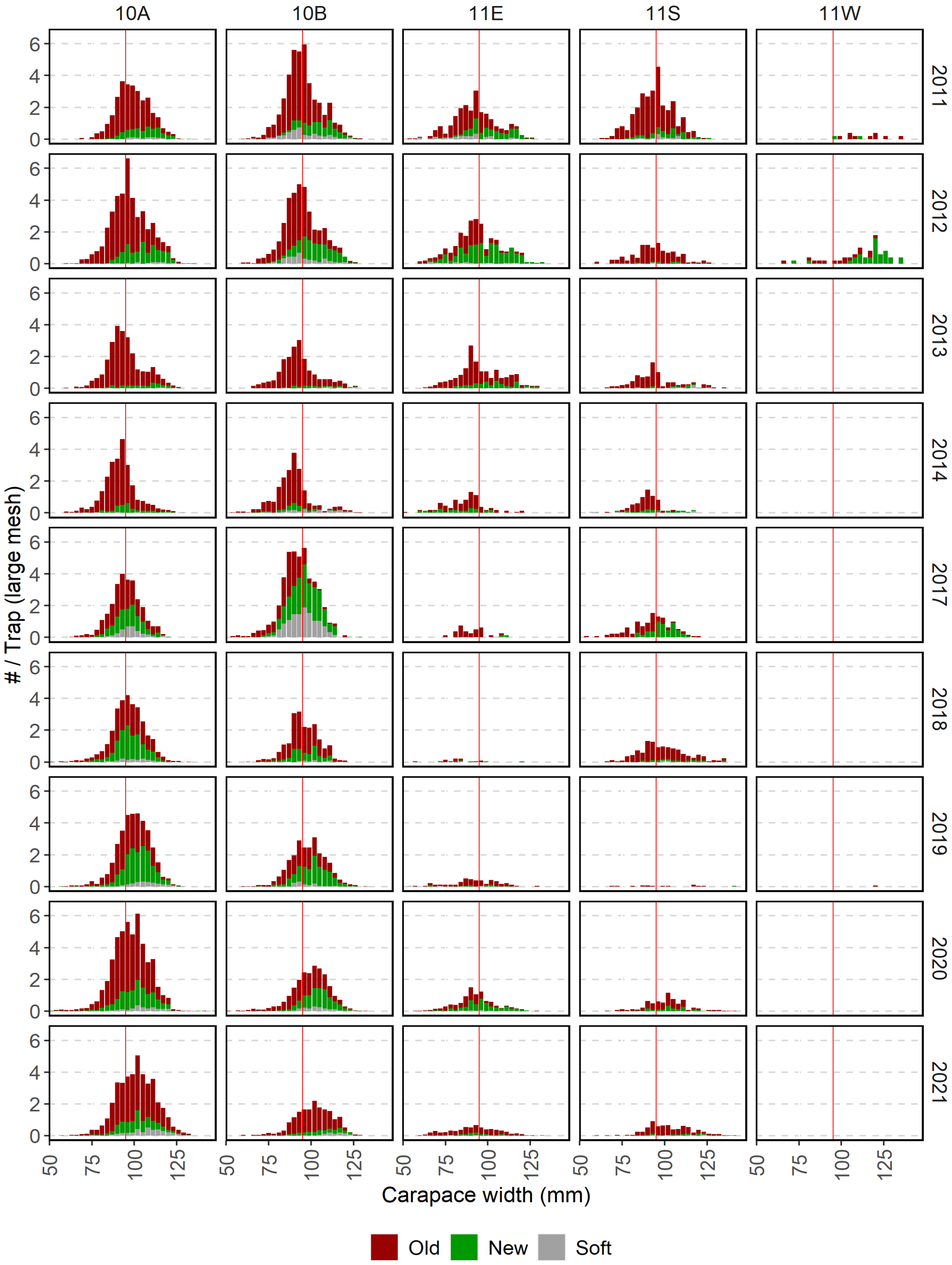


Figure A5.7. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the CPS trap survey in CMAs within Assessment Division 3Ps (2011–21). The red vertical line indicates the minimum legal size.

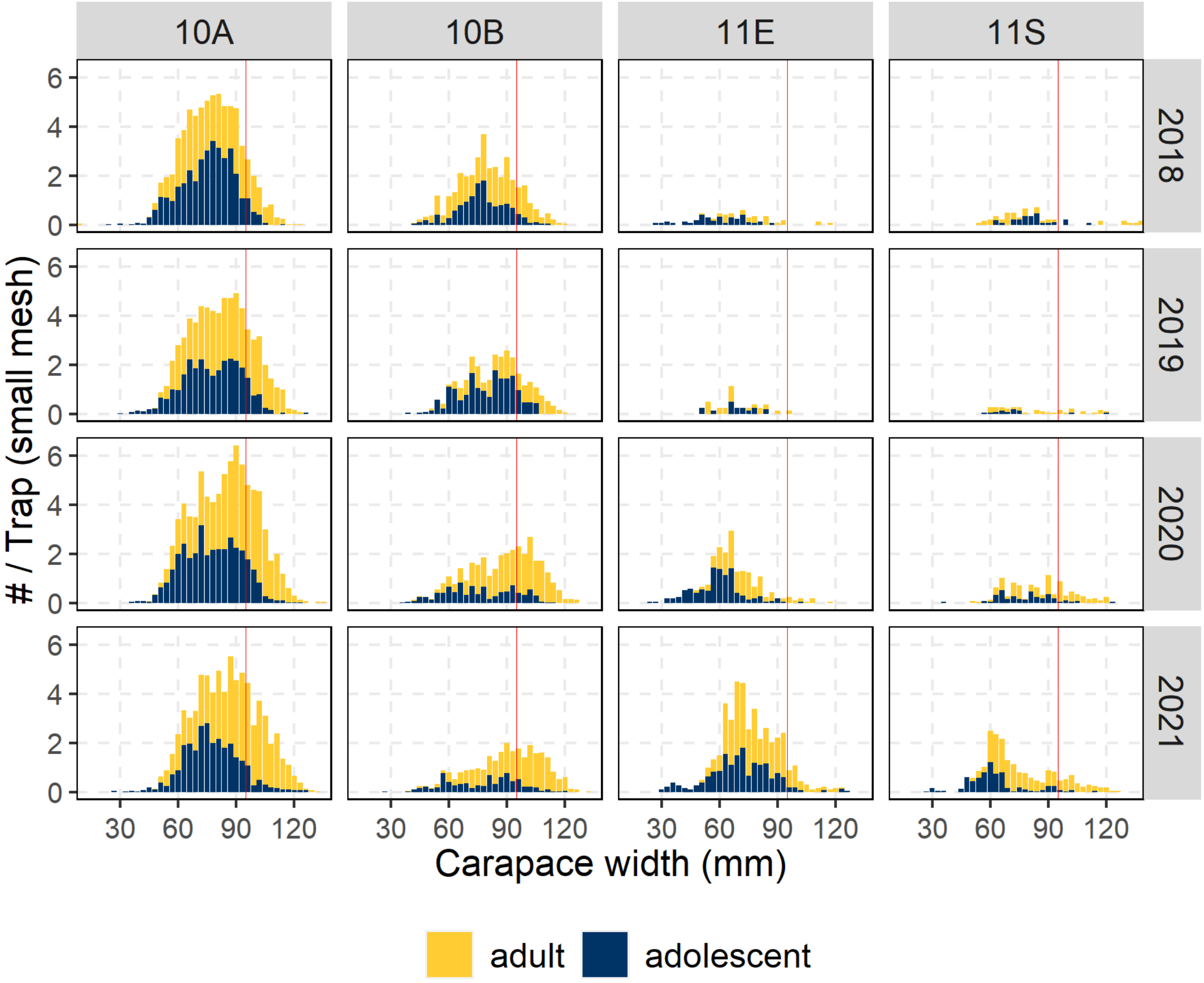


Figure A5.8. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2018–21) from CMAs in Assessment Division 3Ps. The red vertical line indicates the minimum legal size.

Figure A5.9. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap surveys (2007–21) in Fortune Bay (CMA 11E). The red vertical line indicates the minimum legal size. Note: No survey in Fortune Bay in 2008 or 2020.

APPENDIX 6: ASSESSMENT DIVISION 4R3PN DETAILS

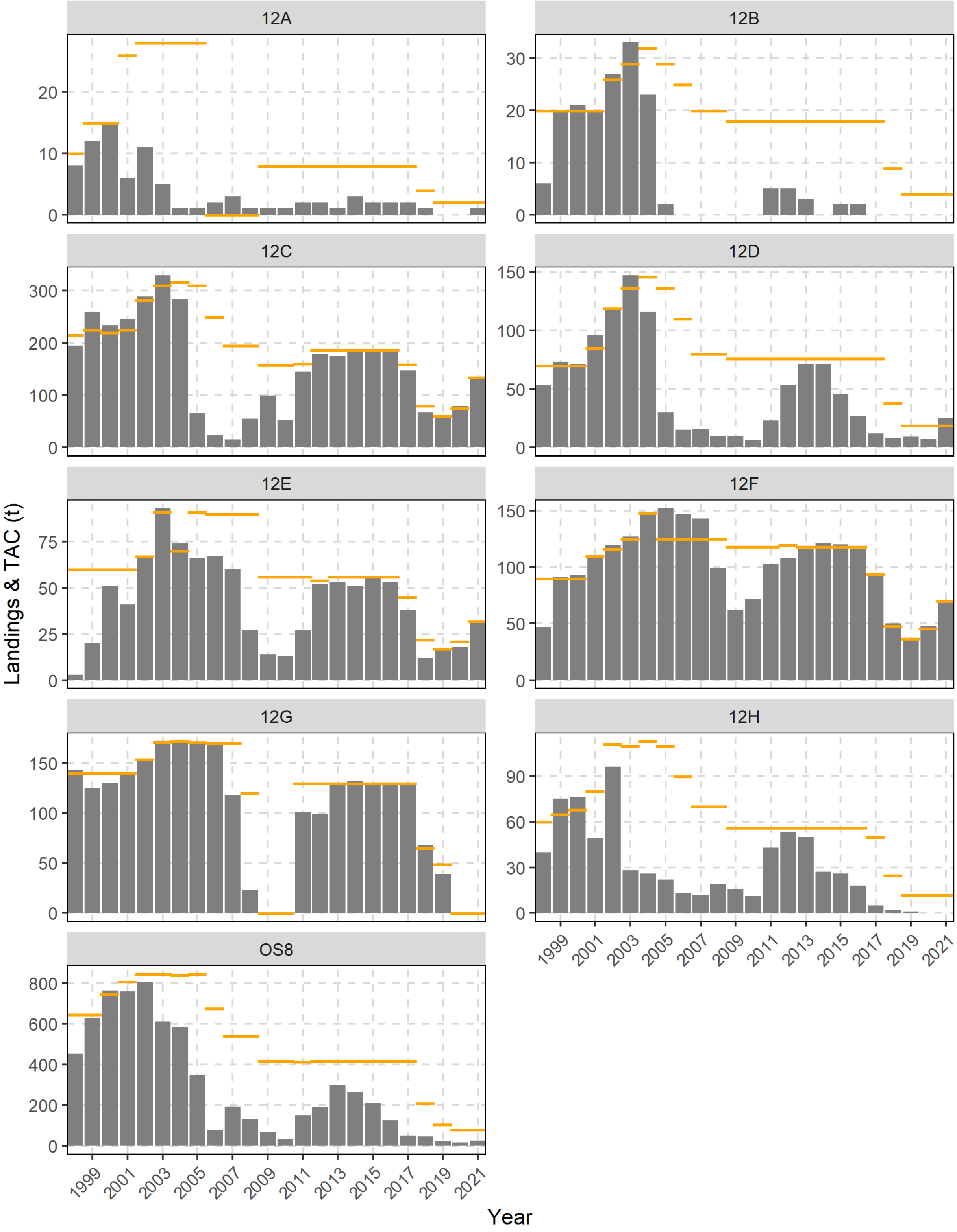


Figure A6.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 4R3Pn (1998–2021).

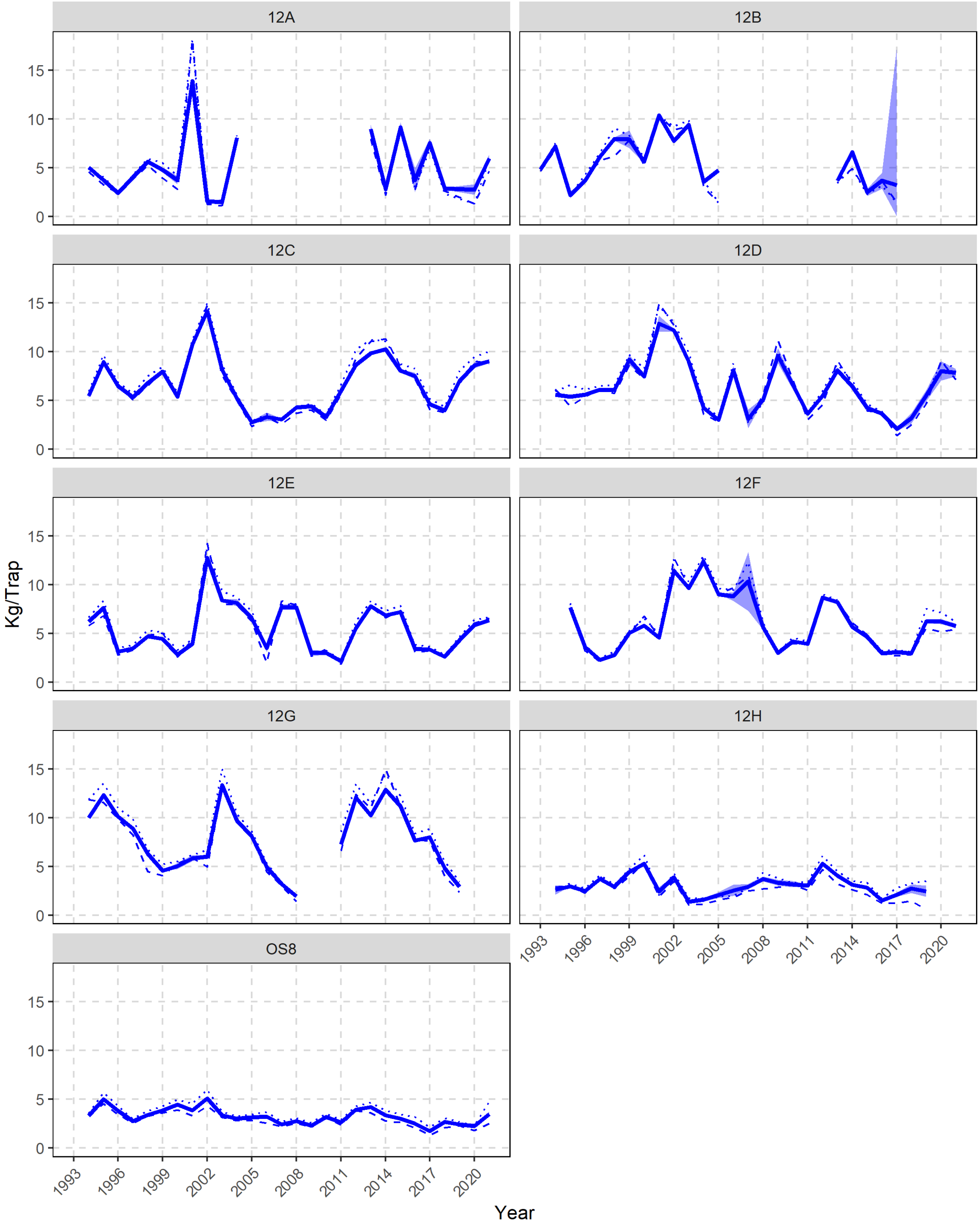


Figure A6.2. Trends in standardized fishery CPUE (kg/trap) in CMAs within Assessment Division 4R3Pn. Solid line = average predicted CPUE, shaded band = 95% confidence interval, dotted line = average raw CPUE, and dashed line = median raw CPUE. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

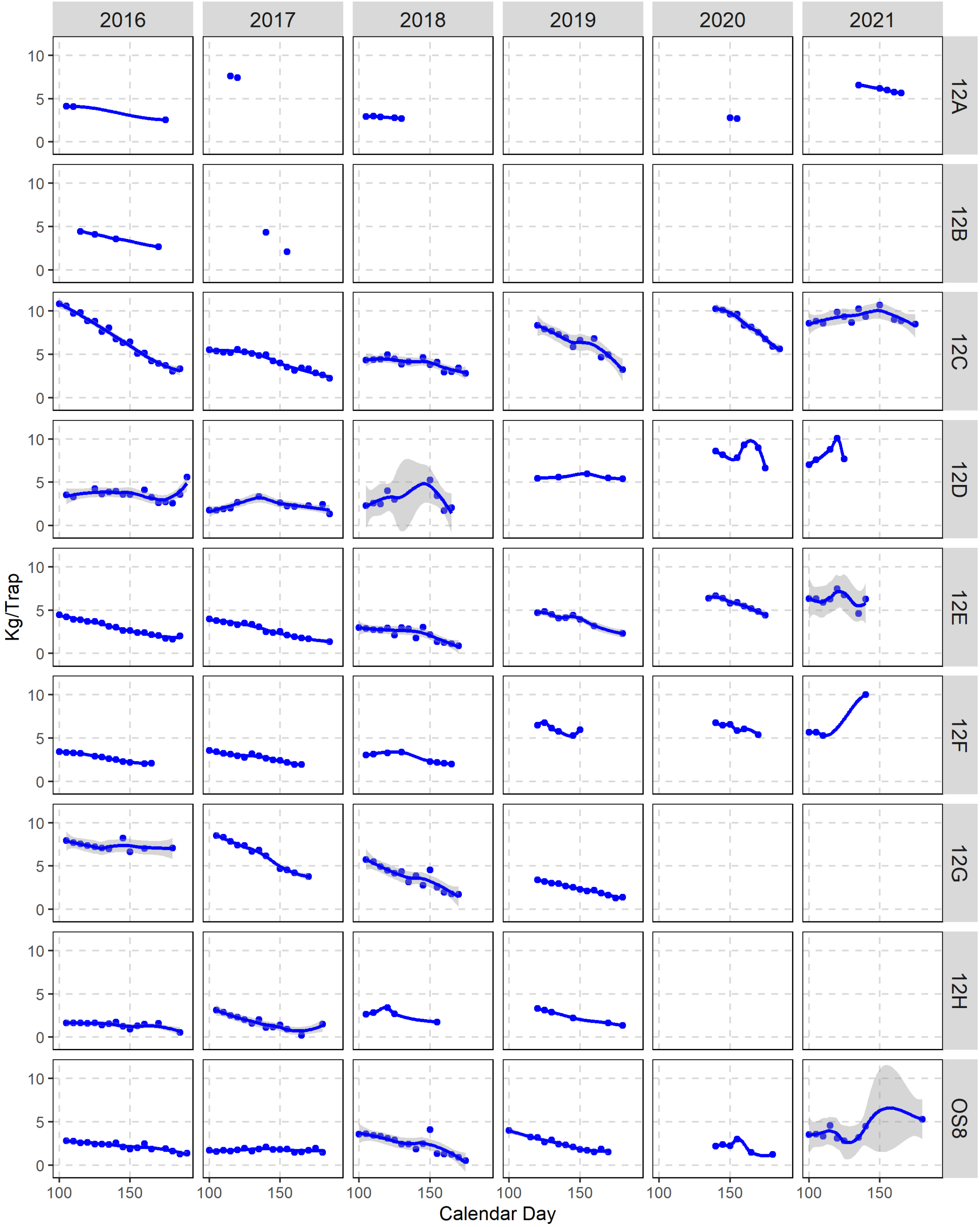


Figure A6.3. Standardized fishery CPUE (kg/trap) throughout the season (calendar day) in CMAs within Assessment Division 4R3Pn (2016–21). Points = mean CPUE of 5-day increments and trend lines = loess regression curves. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

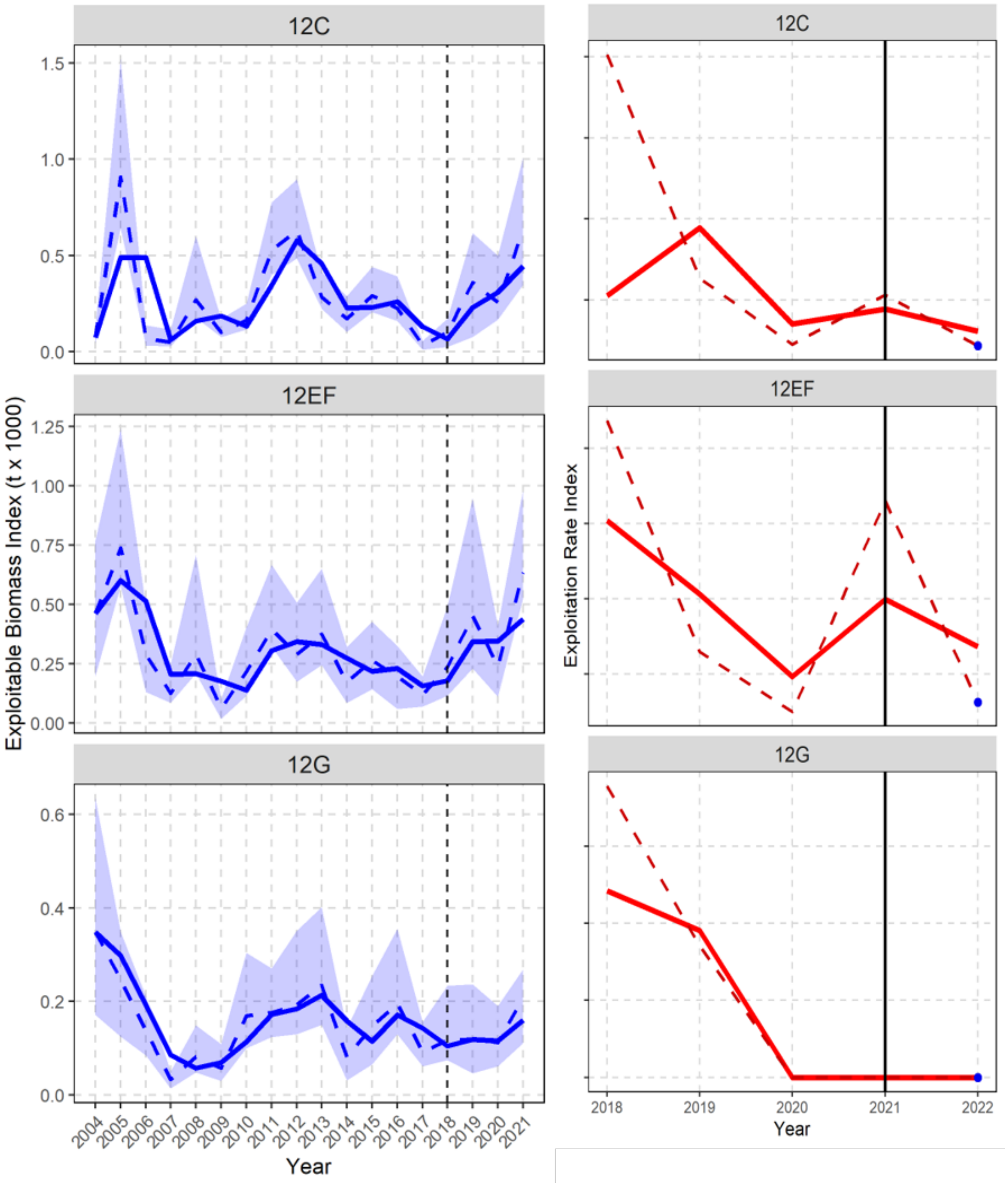


Figure A6.4. Left: Trap exploitable biomass index (2004–21). Solid line = 2-year moving average, dashed line = annual estimate, and shaded band = 95% confidence interval of the annual estimate. Right: Trends in the trap-based annual (dashed line) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 4R3Pn; 2022 points depict projected exploitation rate indices under status quo removals in the 2022 fishery.

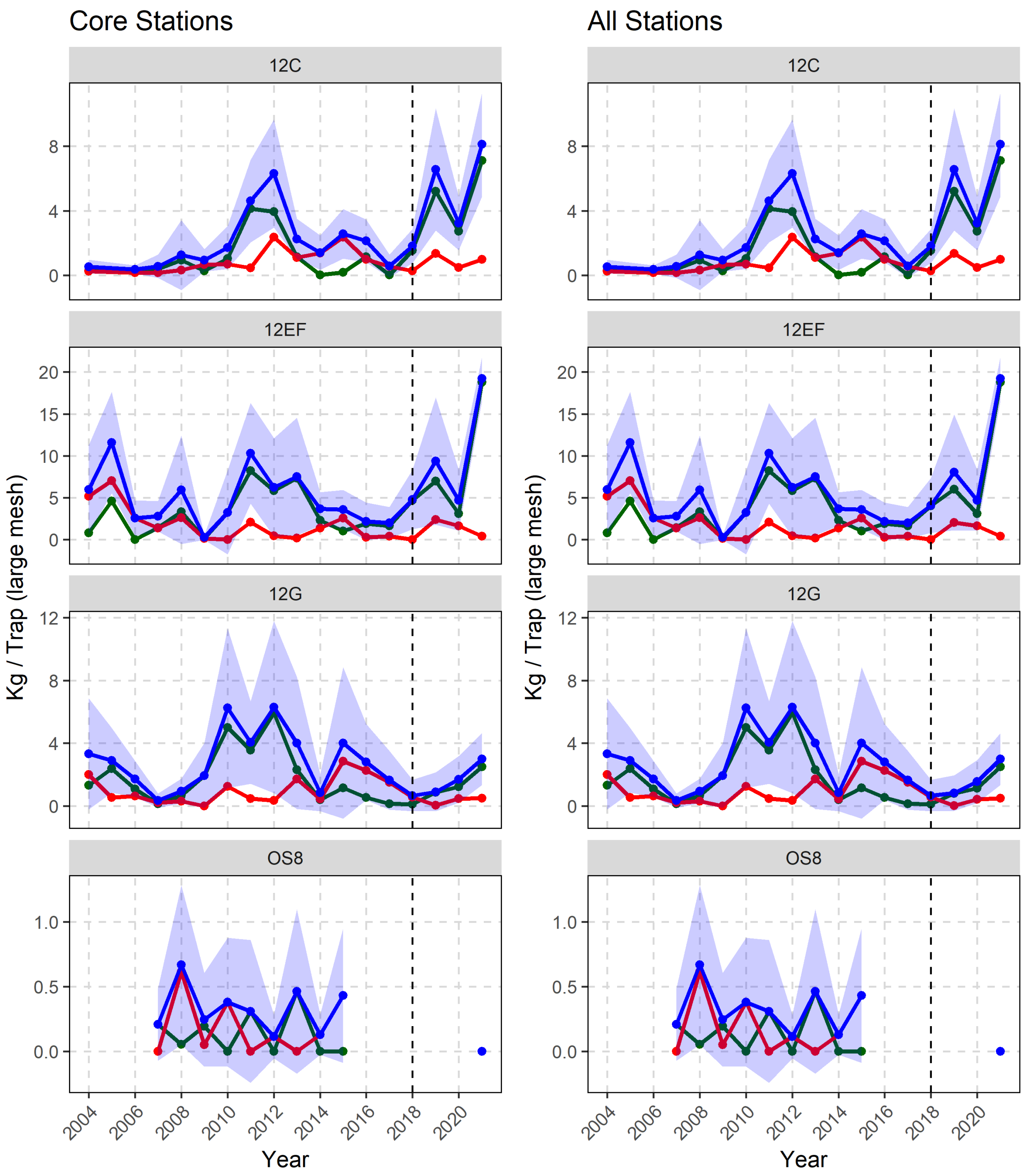


Figure A6.5. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations (left) and all stations (right) in the CPS trap survey in CMAs within Assessment Division 4R3Pn.

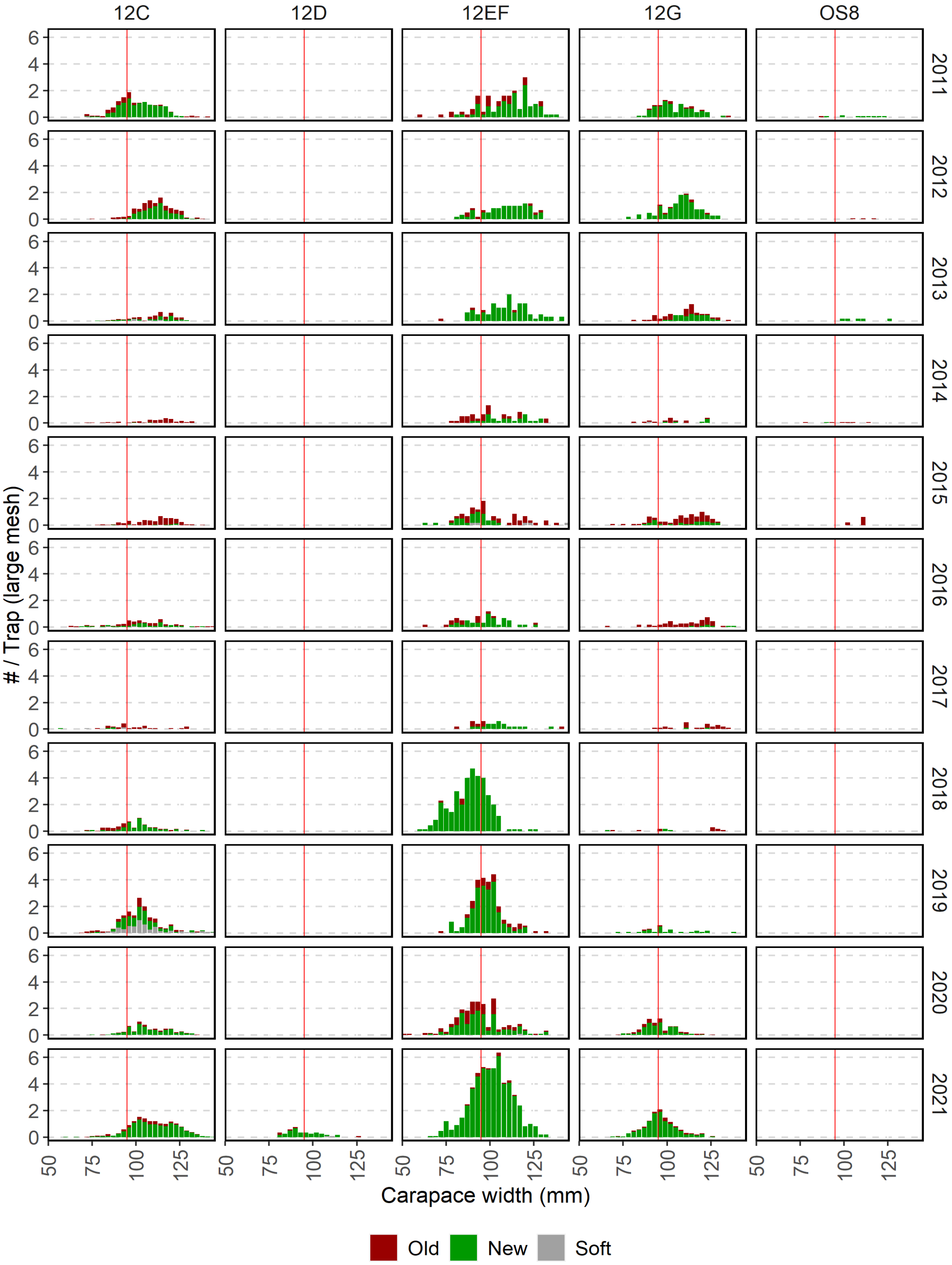


Figure A6.6. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the CPS trap survey in CMAs within Assessment Division 4R3Pn (2011–21). The red vertical line indicates the minimum legal size.

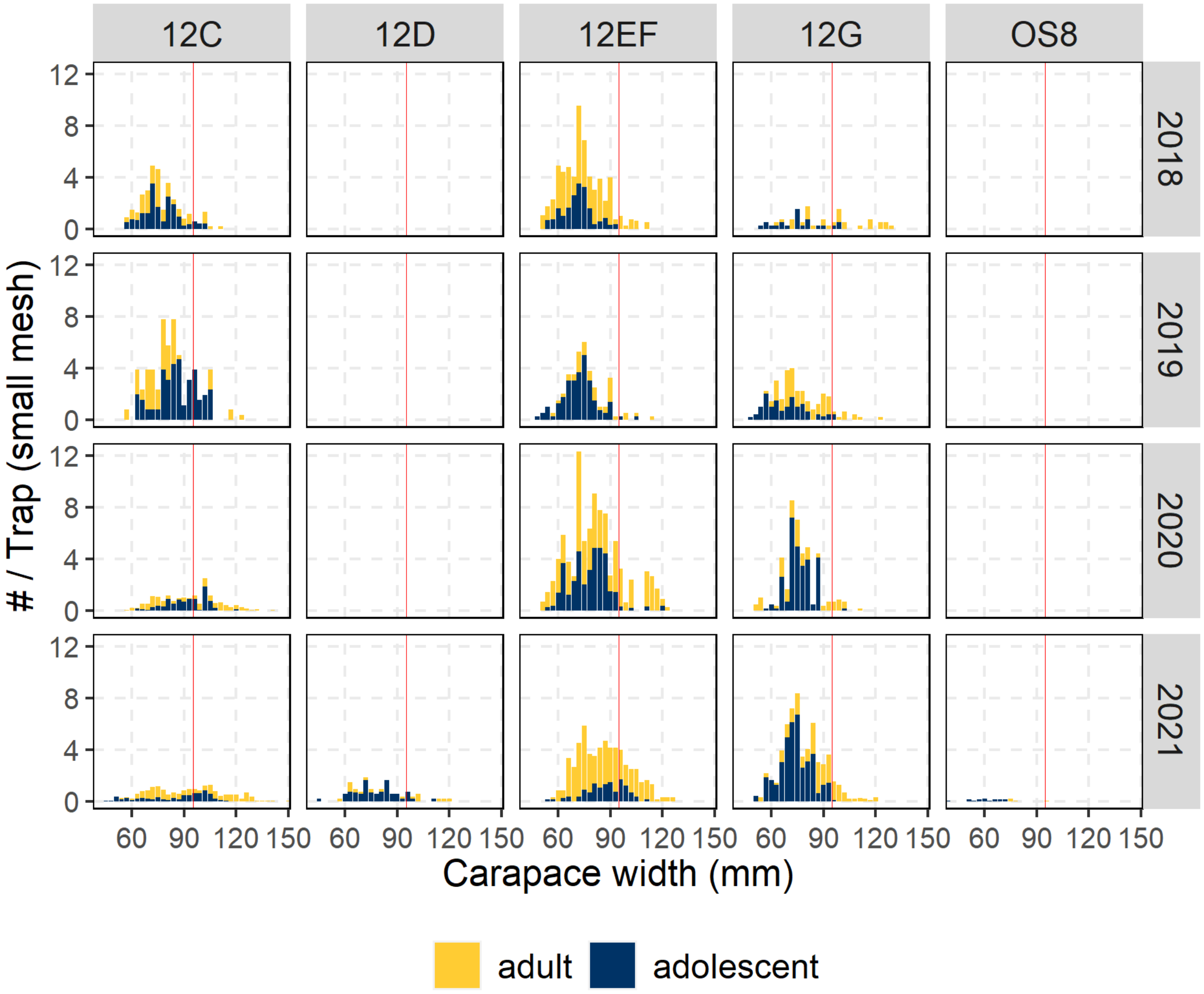


Figure A6.7. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2018–21) from CMAs in Assessment Division 4R3Pn. The red vertical line indicates the minimum legal size.