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An Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2020

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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. Third party verification of fishery 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.

Habitat index: Areal extent of cold (<2°C) bottom water in shallow areas commonly associated with early-life stages of 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 a year ago. Carapace lightly fouled and meat content high.

Legal-size: ≥95 mm carapace width male crab.

LRP: Limit Reference Point. Marks the boundary between the cautious and critical zones in the Precautionary Approach Framework.

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 65–94 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 crab.

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

Residual biomass: Intermediate- and old-shelled male 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 crab 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), and oceanographic surveys are used to inform trends in biomass, recruitment, production, and mortality over the time series. Due to the COVID-19 pandemic, there was no spring multispecies trawl survey and at-sea observer coverage was very poor in 2020. Snow Crab landings declined to a 25-year low of 26,400 tonnes (t) in 2019, but increased slightly to 29,100 t in 2020. Fishing effort decreased to under 2.5 million trap hauls per year in 2020, the lowest level in two decades. Overall fishery catch per unit effort (CPUE) was at a time-series low in 2018, but returned to near the time-series average in 2020. There have been modest increases in the trawl exploitable biomass index over the past three to four years and the index was nearing the time-series average in 2020. Meanwhile, the trap survey exploitable biomass index declined by nearly 60% in 2017 and 2018 to a time-series low. This index has increased during the past two years, but remains below the time-series average. Overall recruitment into the exploitable biomass increased in 2020, nearing the time-series average. Total mortality in exploitable crab has decreased in all ADs in recent years, but remains highest in AD 2HJ and lowest in AD 3LNO Offshore. Exploitation rate indices (ERIs) were near time-series lows in all ADs in 2020, except AD 2HJ, where it remained high at around 50%. Elements of the Precautionary Approach (PA) Framework presented in this assessment are tentative. Limit Reference Points (LRPs) have been established by a peer-reviewed Science process, but Upper Stock References (USRs) and Harvest Control Rules (HCRs) remain under development. In 2021, with status quo landings, all ADs are projected to be above the LRPs of the PA Framework. There are indications that several ecosystem-related factors may be encouraging both short- and long-term growth of the stock, including cool bottom water temperatures in previous years (2012–17) and a slight decline in predation in most areas. Furthermore, there are signals of increased abundances of pre-recruit and small-sized crab, indicating a positive outlook for the next two to four years if fishing pressure levels allow the crab to recruit into the exploitable biomass. A sharp decline in male size-at-maturity (i.e., terminal molt size) in most ADs in recent years, and persisting in ADs 2HJ and 3K in 2020, could dampen short-term prospects for recruitment into the 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 2021 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 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 each year, but molt frequency slows as crab grow. 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). 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 to mate. 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. 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- life stages are associated with increased survey biomass and fishery catch per unit effort (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. Despite apparent positive benefits of warm conditions for growth via higher molt frequency and molt increments, Mullowney and Baker (2021) showed that along the NL shelf overall size-at-maturity has been highest in cold AD 3LNO Offshore during the past 25 years, suggesting high population density in cold conditions was the dominant determinant of terminal size.

Along the NL Shelf, cold and most productive conditions are generally found in shallow to intermediate depth areas (Cyr et al. 2021; Baker et al. 2021). 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 life stages 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 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).

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, long distance movements of individuals within the stock are thought to be limited, so assessments are conducted at the AD level whereby some NAFO Divisions (Figure 1) are separated into inshore and offshore portions where applicable and some divisions combined. Accordingly, Assessment Divisions 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. Le Corre et al. (2020) recently 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 the potential that unclosed population units are examined at the AD-scale and a disconnect between management (CMA) 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. During 1982 to 1987, there were major declines of the Snow Crab resource in traditional 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 2,350 license holders representing three dominant fleet sectors in 2020.

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. Under-sized 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 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 crabs 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 2020, landings increased slightly to 29,100 t. While ADs 3LNO Offshore and 3L Inshore combined account for the majority of the catch (61% in 2020), an increasing percentage has been coming from AD 3Ps in the last three 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 (post-season) survey has occurred annually in all but Div. 2H where it was executed annually 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 spring survey did not take place in 2020 due to the COVID-19 pandemic.

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.

The catchability of the survey trawl for Snow Crab differs by season and area. 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 occurs. The catchability of Snow Crab by the Campelen trawl also varies with crab size and diurnal cycle, being highest on large crab (Dawe et al. 2010a), and at night (Benoît and Cadigan 2014; 2016). Further, it differs among 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 of day 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 degrees latitude in Div. 2H are omitted because of consistently low capture of crab in this area 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), individual weight (if crab condition allowed), 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 many years (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 chela height (*CH*) and carapace width (*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 under-taking terminal molt (becoming a morphometrically mature male or sexually mature female) in any given year were identified. The analysis was limited to crab that had either just molted (were 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 (Figure 3). 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 (≥95 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 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., 2019) that undergoes a terminal molt to exploitable size in the subsequent winter or spring (i.e., 2020) would be identified as a recruit into the exploitable biomass in the 2020 survey(s) and should begin contributing to the fishery in 2021. 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 less 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 reality using conversion factors developed through fishery depletion regression analysis on catch rate data from logbooks. Further details on this method are provided in the logbooks methods section. These depletion conversion factors (đ) represented the median difference between logbook and survey-based biomass estimates in each AD over the time series:

$$đ = \sum_{y=2000}^{2020} (Ty/Dy * 1/n)$$

where,

- *T* = raw exploitable biomass estimates from Ogmap
- *D* = depletion biomass estimates from logbooks
- *y* = year beginning in 2000
- *n* = number of years in the analysis

Standardized biomass indices were calculated as T / đ. Although closer to reality, these standardized biomass estimates are not absolute and are interpreted as relative indices.

The spatial distributions of mature females, pre-recruit and exploitable males, and small crab (<50 mm CW), 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 intervals. 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 over-estimated (Baker et al. 2021), exploitation rate indices likely slightly under-estimate 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 exploitable 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 all 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 in any given year (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} = recruitment (shell conditions soft, new)

B_{old} = residual (shell conditions intermediate, old, very old)

t = denotes survey year

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

There was no spring trawl survey in AD 3Ps in 2020, therefore the trap survey data (see Collaborative Post-Season Trap Survey section) were primarily used to interpret exploitable biomass trends. However, to display the overall trawl exploitable biomass index trends, an estimate for the AD 3Ps trawl exploitable biomass index was derived by exploring the relationship between trap and trawl exploitable biomass indices from 2004–19. The equation of this trend line was used to calculate an estimate for the 2020 trawl exploitable biomass index from the 2020 trap exploitable biomass index in AD 3Ps.

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 4), resulting from a time lag associated with compiling data from the most recent fishery, thus the terminal points are considered preliminary.

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 trap hauls) 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. 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, mesh size, bait type, bait quantity, bait jars, 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 depletion model conversion factors (đ) 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,

$lnCPUE$ = natural log of fishery catch per unit effort (kg/trap)

pot_cum = 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 centred three-period moving average was used to smooth annual logbook-based biomass estimates prior to making comparisons for survey biomass conversion.

INSHORE DFO TRAP SURVEYS

Data were available from inshore trap surveys in ADs 3K, 3L Inshore, and 3Ps (Figure 5, Figure 6, Figure 7). In AD 3K, surveys were carried out in White Bay (CMA 3B), Green Bay (CMA 3C), and Notre Dame Bay (CMA 3D) during 1994–2020. There were no surveys in these bays in 2001, no survey was conducted in Notre Dame Bay in 2009 and 2011, and no survey was conducted in White Bay in 2019. The surveys 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 2020. 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. Meanwhile, 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. There was no survey in St. Mary’s Bay in 2020 due to the COVID-19 pandemic. 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 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 early June from 2007 to 2019. There was no survey in Fortune Bay in 2020 due to the COVID-19 pandemic. This survey 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 chela height, weight (if crab condition allows), 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 chela height 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 Collaborative Post-Season (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 8, Figure 9). 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 chela height, 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 ages 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 Collaborative Post-Season (CPS) trap survey to estimate exploitable biomass.

COLLABORATIVE POST-SEASON TRAP SURVEY

Data were examined from an industry-DFO Collaborative Post-season (CPS) trap survey in all ADs (Figure 8, Figure 9). These surveys were initiated in 2003 and have occurred each year following the fishery, typically beginning in late August/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 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 in 2020 sampling expanded to include two large-mesh traps. Sampling includes determination of CW, shell condition (soft, new, old), 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. 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 2016–20 surveys (Figure 9). Overall, more than 60% of the stations had a small-mesh trap in 2020. More small-mesh traps will be added into the survey in forthcoming years until every station is occupied by one small-mesh trap.

Despite ongoing changes to the survey design most analyses remain virtually unchanged for the present assessment. Only core stations were used to develop catch rate indices of legal-sized crab by shell condition from large-mesh traps and size frequency distributions from large- and small-mesh traps. The definition of core stations has seen slight changes in recent years to account for changing distribution in occupied stations over time. In the previous assessment, core stations were identified as those stations sampled in seven of the last 10 years, as of 2019. However, the present assessment defined core stations as those established as fixed stations in the new survey design in 2018. These 650 stations will be the core stations moving forward. 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 only a three-stage scale of soft, new, and old-shelled. A pre-recruit catch rate index (defined as kg/trap of 65–94 mm CW adolescent males) was also derived from small-mesh traps deployed at core stations.

The stratification scheme used for biomass estimation for this survey (Figure 3) closely conforms to the footprint of the fishery, and by extension, the assumed distribution of dense aggregations of exploitable crab within CMA boundaries. Spatial expansion of survey catch rates into biomass within polygons 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, as well as the extent to which the spatially biased stratification scheme represents the actual distribution of the resource, biomass estimates developed from this survey remain as indices and are assessed in a relative sense.

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 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 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.

Overall, due to changes occurring within the CPS survey, biomass estimation from trap surveys is currently in a period of transition within the stock assessment time series. Within the next few years as a time series is generated, it is anticipated all stations from CPS surveys will be utilized alongside the more localized DFO and TJFB trap surveys to extrapolate representative catch rates over a broad spatial footprint (similar to the trawl surveys) to estimate biomass indices.

OBSERVER CATCH-EFFORT AND AT-SEA SAMPLING DATA

In 2020, at-sea observer sampling was particularly low and unrepresentative of the fishery activity due to the COVID-19 pandemic. At-sea observers prioritized larger vessels to be able maximize sampling and area covered, while limiting movements and contacts between vessels. Larger vessels tend to stay at sea for longer and some fish in multiple areas. This strategy was not successful in obtaining representative at-sea sampling and resulted in no sampling in ADs 2HJ and 4R3Pn, and very little sampling in ADs 3L Inshore and 3Ps. Even ADs that did receive at-sea observer coverage in 2020 had reduced sampling (Figure 10). In light of these data deficiencies, the various catch rate indices and analyses on discards traditionally presented in the stock assessment were not conducted. However, results from the previous stock assessment are presented to investigate time-series trends.

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 10, Figure 11). Sampling has been consistently low in inshore CMAs and virtually absent throughout ADs 2HJ and 4R3Pn in recent years. 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, or 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, binned to 3-mm CW intervals, 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.

Observer sampling data form the basis for estimating fishery discards. Total discard rates as well as the percentage of the catch discarded in the fishery were examined, with under-sized (<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-shelled crab captured in the fishery were also constructed and examined for each AD. Soft-shelled crab prevalence is interpreted as an index of both 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-shelled crab in the catch during a period of low residual biomass would not lead to the same inference and would be indicative of wastage.

Along with biological sampling to inform the stock assessment, observer data also form the basis of the soft-shell protocol. This management tool was implemented in 2004 to close specific small fishing areas offshore (10 x 7 nM) and inshore (5 x 3.5 nM) when the percentage of soft-shelled crab reaches 20% of the observed catch. The closure threshold was reduced to 15% for ADs 3LNO Offshore and 3L Inshore in 2009–10. This protocol was compromised in 2020 due to the reduced and unrepresentative at-sea observer sampling.

ECOSYSTEM INDICES

Fall bottom temperature climatological maps and fall 2020 observations and anomalies were determined using the methodology described and presented in Cyr and Galbraith (2021). There were no spring data for 2020 as there was no spring trawl or Atlantic Zonal Monitoring Program (AZMP) surveys in spring 2020 due to the COVID-19 pandemic. The changes in thermal habitat indices in each AD were examined to qualitatively assess Snow Crab productivity potential. The rationale being that increases in thermal habitat index indicate increases in potential Snow Crab habitat, and it is assumed that this improved habitat availability would accordingly increase Snow Crab productivity potential. The thermal habitat index was not updated for ADs 3Ps and 4R3Pn in 2020 due to a lack of data. The thermal habitat indices were calculated as the percentage of the surveyed area covered by water with a bottom temperature of <2°C. The thermal habitat index from AD 4R3Pn comes from summer trawl surveys conducted by DFO Quebec region. 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 for the present 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 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. 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 crab during early-mid life stages. The broad-scale system-level effects of these climate modes propagate through a number of ecosystem processes including ecosystem food production and thermal habitat regimes.

Estimates of 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 crab in the diet. As each step involved 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 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. We assumed two daily ration scenarios of 1% and 2% based on the typical range of values from literature reports (Macdonald and Waiwood 1987; Adams and Breck 1990).

Strictly speaking, 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.

Data on diet composition is only available for a few recent years and for a small subset of crab predators (American plaice [*Hippoglossoides platessoides*], cod [*Gadus morhua*], and turbot [*Reinhardtius hippoglossoides*]). Estimates of the overall fraction of crab in their diets, as well as relative contributions of these species to the overall biomass of the crab predator assemblage, were used to approximate the fraction of 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 crab survey biomass).

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 Newfoundland and Labrador Snow Crab, based on the best scientific information available. DFO Science proposed a PA Framework for the NL Snow Crab resource and fishery (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. The PA and decision-making framework is based on three key metrics of stock health:

1. predicted CPUE,
2. predicted discards, and
3. proportion of females with full egg clutches.

LRPs, as set by the peer-review process, were identified as predicted CPUE = 5 kg/trap, predicted discards = 20%, and proportion of females with full egg clutches = 0.6.

Predicted 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 = Exploitation rate index, based on 2-period biomass index.

CBI = Combined biomass index from trawl and trap surveys in previous year (i.e., an average of the trawl and trap survey biomass indices and scaled within AD).

$NAO7$ = 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:

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

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

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

where,

$wCPUE$ = cell-weighted catch per unit effort (with the number of years a 5'x 5' cell was occupied was used as the weighting factor)

$medFD$ = median fishing day based on effort (i.e., pots)

EP = ratio of exploitable to pre-recruit crab in previous year.

AD = 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 very poor observer coverage in 2020, there was not a 2020 observed point. To determine an estimate for the observed discards point, a reference fleet of vessels from the commercial logbook data was identified. 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 2020 at-sea observer % discards and the reference fleet 2020 % discards was calculated to determine the 2020 % discards observed point on the PA Framework figure. This value is 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. The observed discards estimate for AD 2HJ was 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, 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, In prep[1]). Following this process, a working group was reestablished to bring forward a series of recommendations to DFO on the USRs and HCRs, but no formal recommendations had been made by the time of the stock assessment. Accordingly, USRs are not presented in this assessment and the overarching HCR for the framework is not defined, meaning an AD is not projected to be in a zone, rather individual metrics are either above or below the associated LRP.

RESULTS AND DISCUSSION

BROAD-SCALE TRENDS: DIVISIONS 2HJ3KLNOP4R

Fishery

Landings in 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 2020, landings increased slightly to 29,100 t (Figure 12). Until recently, AD 3LNO Offshore accounted for a steadily increasing proportion of the landings from the NL region, however, in the last three years, ADs 3K and 3Ps have accounted for a steadily increasing percentage of the landings.

In AD 2HJ, landings remained near 1,700 t from 2012 to 2019, however landings decreased to 1,300 t in 2020 (Figure 13). In AD 3K, landings have remained below 6,000 t for the past four years, but increased in 2020 to 6,500 t. In AD 3L Inshore, landings declined by 67% from a time-series high in 2015 to a time-series low of 2,750 t in 2019. The landings increased slightly in 2020 and the TAC was fully taken. In AD 3LNO Offshore, landings declined by 48% from 2016 to 2019 because of reductions in the TAC, to the lowest level in two decades (less than 13,000 t). The landings increased to near 15,000 t in 2020. In AD 3Ps, landings increased from decadal lows of less than 1,200 t in 2016–17 to around 3,200 t in 2020. In AD 4R3Pn, landings have steadily declined since a recent peak in 2013 and were 167 t in 2020, the lowest in the time series and 36% below the TAC.

Fishery timing transitioned from summer-fall to spring-summer throughout the 2000s in most ADs (Figure 14). 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 2020, the start of the season was delayed due to the COVID-19 pandemic. In 2020, median fishing weeks ranged from late-May in ADs 3K, 3Ps, and 4R3Pn to mid-June in AD 2HJ. 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 15). Since then, overall effort remained at approximately

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[1] DFO. In prep. Proceedings of the Regional Peer Review of an Alternate Precautionary Approach Framework for Snow Crab in Newfoundland and Labrador. DFO Can. Sci. Advis. Sec. Proceed. Ser.

3.5 to 4.5 million trap hauls per year, but decreased to under 2.5 million trap hauls in 2020, the lowest level in over two decades. Spatially, the distribution of fishing has remained relatively broad-based, but there have been significant changes in some ADs in recent years (Figure 16).

In the north, effort in the northernmost portion of AD 2HJ has gradually dissipated since 2011, with NAFO Div. 2H virtually abandoned since then. Effort in AD 2HJ has remained at a consistent low level, about 200,000 trap hauls per year, in recent years. In AD 3K, effort decreased to a 25-year low in 2019, with about 600,00 trap hauls, but increased slightly in 2020. Effort has contracted primarily into the Funk Island Deep and areas west. The furthest offshore portions of this AD appear to have been abandoned. In AD 3L Inshore, effort nearly doubled from 2013 to 2017, when it reached a historical high of near 1 million trap hauls. In 2020, effort decreased to a 25-year low of just over 300,000 trap hauls. In AD 3LNO Offshore, effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level since then, at around 1.5 to 2.5 million trap hauls per annum. However, effort decreased to around 1 million trap hauls in the last two years. Effort along the NAFO Div. 3N edge has been decreasing in recent years, with very low fishing activity in 2020. In AD 3Ps, effort has declined by 75% since 2014 to be near its lowest level in 25 years. Finally, in AD 4R3Pn, effort has remained at a low level relative to other ADs and decreased to an over 25-year low in 2020, with about 22,000 trap hauls.

Fishery CPUE tends to lag behind survey biomass trends by 1–2 years in all ADs, thus the fishery is typically delayed in reflecting stock status, indicative of hyperstability in the CPUE index. Throughout the past 25 years, CPUE (kg/trap) has shown a great deal of variability both across and within ADs (Figure 17).

Overall, the fishery performed poorly in 2017 and 2018, with CPUE at a historical low. In 2020, the overall CPUE increased back to time-series average levels. In AD 2HJ, standardized CPUE declined to the lowest level since 2012 in 2020 (Figure 17). In AD 3K, standardized CPUE increased in 2019 from a time-series low in 2017 and remained around the same level in 2020; near the time-series average. In AD 3L Inshore, standardized CPUE declined to a time-series low in 2018 to below 5 kg/trap, but increased to near 9 kg/trap in 2020. In AD 3LNO Offshore, standardized CPUE most recently peaked near a time-series high in 2013 and declined to its lowest level since 1992 in 2018. Standardized CPUE has increased in the last two years, nearing time-series average levels. In AD 3Ps, standardized CPUE increased from time-series lows in 2016 and 2017 to near a time-series high in 2020, at 16 kg/trap. In AD 4R3Pn, standardized CPUE has increased to a time-series high of over 7 kg/trap in 2020.

In recent years there has been considerable spatial contraction of high levels of fishery CPUE; however, increases were seen in some areas in 2020 (Figure 16). Fishery CPUE is typically highest in AD 3LNO Offshore as well as portions of AD 3L Inshore, adjacent to the southeast portion of the island of Newfoundland and extending east across the Grand Bank. There were notable declines in catch rates from 2017 to 2019 in this area, however, high catch rates (15–25 kg/trap) were evident in most offshore areas of Div. 3L in 2020. There has been contraction of fishing effort along the tail of the Grand Bank and there have been decreasing catch rates along the Div. 3N slope edge for the past six years. Areas of AD 3L Inshore (CMAs 6B, 6C and 9A) which showed dramatic declines in CPUE from 2017 to 2019, showed improvements in 2020. In AD 2HJ, the Cartwright and Hawke Channels have near-exclusively become the two areas of fishing activity. In AD 3K there has been considerable spatial contraction with very little fishing taking place in the offshore areas east of the Funk Island Deep in the last three years. However, the areas where fishing occurred in this AD have experienced increasing catch rates in the last three years. 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. In AD 4R3Pn, catch rates in the offshore have been perpetually low and effort in 2019 and 2020 was particularly sparse. Effort in 2020 was focused in CMAs 12C and 12EF.

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 two years in most ADs except for AD 2HJ.

Observer data on shell composition are used to infer dynamics of recruitment into the biomass. These data indicate that although the improvement in fishery CPUE in AD 2HJ in 2015 was predominately due to an increase in recruitment into the exploitable biomass, the proportion and magnitude of new-shelled crab decreased dramatically in 2016 and 2017. In 2018, the presence of both soft-shelled crab and residual crab in the fishery increased, but there was a large decrease in residual crab in 2019 (Figure 18, Figure 19, Figure 20). However, the level of observer sampling was very low in AD 2HJ in 2018 and it is likely the increase in 2018 is not a true representation of catch rates and composition that year. 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 2019. In ADs 3LNO Offshore and 3L Inshore, the compilation of recruitment and the residual biomass (old-shelled crab) were at a time-series low in 2018, however, slight increases in recruits were observed in both ADs in 2019. 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.

Biomass

The fishery had strongly depleted the exploitable biomass in all ADs in recent years (Figure 21, Figure 22). There were improvements in end of season catch rates in most ADs in 2020. The end of season catch rate in AD 3Ps was particularly high, nearing 10 kg/trap (Figure 22). There were much higher start of season catch rates than previous years in ADs 3L Inshore, 3Ps, and 4R3Pn.

In AD 2HJ, depletion rates were relatively consistent from 2014 to 2018, however, there was much quicker depletion in 2019 and 2020, with an end-of-season catch rate the lowest in seven years (Figure 23). This is particularly disconcerting given the contraction of the fishery back into the two dominant centres of the Hawke and Cartwright Channels. In AD 3K, the 2020 fishery began at the highest catch rates since 2008, but it quickly and precipitously depleted the biomass (Figure 24). However, the end-of-season catch rates in 2019 and 2020 were the highest since 2014. 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 25). However, in 2020 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 in recent years (Figure 26). In 2020, the start-of-season catch rate was higher than the previous three years and the end-of-season catch rate was the highest since 2015. In AD 3Ps, rapid depletion under minimal removals occurred in 2017, however minimal depletion was noted in 2018 and 2019 (Figure 27). In 2020, the start- and end-of-season catch rates were the highest in the last twenty years. Finally, in AD 4R3Pn, the 2017–20 linear regression slopes were extremely steep, indicative of a rapid depletion of the biomass (Figure 28). However, the start-of-season catch rate in 2020 was the highest in the last five years. Overall point estimates of biomass calculated from fishery depletion regressions were at or near time-series lows in all ADs in 2020 (Figure 29), with the exception of AD 3Ps.

Multispecies trawl surveys indicate that the overall exploitable biomass was highest at the start of the survey series (1995–98) (Figure 30). The index declined from the late 1990s to 2003 and then varied without trend until 2013. From 2013 to 2016, the exploitable biomass declined by 80%. 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 overall trawl exploitable biomass index includes the estimation for AD 3Ps calculated based on the relationship between trap and trawl exploitable biomass index (Figure 31). Meanwhile, the trap survey index declined by nearly 60% in 2017 and 2018 to a time-series low. It has increased in the past two years but remains below the time-series average (Figure 30). The low in exploitable biomass in recent years reflected diminishing contributions of recruitment, to time-series low levels, but concomitantly and more strongly reflected the elimination of virtually all the residual biomass in some areas. In 2020, there were increases in the residual biomass, however the exploitable biomass is still dominated by recruits.

The overall low exploitable biomass level in recent years was coupled with concentration of exploitable crab into localized areas in all ADs (Figure 32, Figure 33). However, despite this contraction, there were signs of some localized improvements in the last two years. Particularly noteworthy are the increased survey catch rates throughout the northern and eastern portions of Div. 3L in the fall survey in the last two years 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. The overall patterns of prolonged deterioration followed by modest improvements seen in trawl surveys from 2017 to 2020 are generally reflected by patterns seen in trap surveys (Figure 30). It is expected that with the CPS survey undergoing a transition in survey design in recent years, more holistic trends in spatial distribution of population components including the exploitable biomass will be more apparent as the time series builds.

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 exploitable biomass index has changed little during the past decade; however, the trawl exploitable biomass index decreased slightly in 2020 and persistently consists of very low residual biomass. Despite consistency across the two surveys, stock status interpretation is compromised by incomplete trap surveys in recent years and reduced coverage of the fall multispecies trawl survey in 2019. The 2017–19 point estimates from the CPS trap survey in AD 2HJ are considered incomplete due to incomplete and improperly collected data; 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 greatly in 2020 to near time-series high levels. This large increase is not reflected in the trap survey, which shows a modest increase from the 2018 low level. In AD 3L Inshore, the trap survey exploitable biomass index has increased slightly in the last two years, but remained below the time-series average in 2020. 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 and/or 2020 in the bays surveyed (Figure 6). In AD 3LNO Offshore, the trawl exploitable biomass index has increased in the last three years from time-series lows in 2016–17 (Figure 34). The trap exploitable biomass index has also shown an increase in the last two to three years, but remains well below the time-series average (Figure 35). In AD 3Ps, the trap exploitable biomass index showed further increases in 2020, nearing time-series high levels. In AD 4R3Pn, the trap exploitable biomass index has increased over the past 2 to 3 years to around the time-series average.

Although almost 50% of the sampling locations have been randomly determined since 2018, the past spatially restricted coverage of the CPS trap survey's core stations essentially measured the exploitable biomass on primary fishing grounds and constituted an analog of fishery CPUE. Accordingly, the CPS exploitable biomass index closely agrees with fishery CPUE, reflecting the occupation of like grounds with like gear (Figure 36). The concentrated distribution on strongest aggregations of exploitable biomass in the CPS survey and fishery creates 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 or fishery (Figure 36, 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. Further, the trawl survey is also not subjected to gear saturation, as occurs in crab traps. Differences in spatial representativeness and gear catchabilities across surveys and the fishery lead to trap CPUE signals temporally lagging behind trawl survey indices and exhibiting overall little dynamic range in catch rates when biomass is high. This can be particularly problematic when a resource is declining and underscores the importance of establishing and maintaining well-designed surveys for this resource assessment.

Collectively, the three survey and fishery metrics are consistent in showing an exploitable biomass that has shown improvements in the last two to three years. The index with most predictive power (the trawl survey) suggests potential for improvements within most ADs and consequently the fishery of 2021.

Recruitment

Overall recruitment into the exploitable biomass increased in 2020, nearing the time-series average (Figure 30). In most ADs, the exploitable biomass is presently dominated by incoming recruits (Figure 34).

In AD 2HJ, recruitment into the exploitable biomass has changed little during the majority of the time series (Figure 34). The 2020 trawl survey suggests recruitment will remain unchanged in 2021 which suggests little change in fishery prospects for 2021. In AD 3K, the post-season trawl and trap survey indices of recruitment into the exploitable biomass showed increases in 2020 (Figure 34, Figure 38), suggesting potential for improvement in the fishery in 2021. In AD 3LNO Offshore, the post-season trawl and trap survey indices of recruitment into the exploitable biomass showed increases in 2020, suggesting potential for improvement in the fishery in 2021.

For ADs where no trawl surveys occur, trap-derived indices are used. In AD 3L Inshore recruitment into the exploitable biomass steadily declined to a time-series low in 2017 (Figure 38). While recruitment has been at an increased level for the past three years, it remains below the time-series average level. In AD 3Ps, recruitment into the exploitable biomass declined slightly in 2020, but remains near time-series high levels. This suggests continued improvements in the fishery in 2021. In AD 4R3Pn, recruitment into the exploitable biomass was low from 2014 to 2017, but increased to a time-series high in 2019. Recruitment decreased slightly in 2020, but remains near a time-series high level, suggesting potential improvements in the fishery in 2021.

Survey and environmental data collectively suggest modest increases in recruitment could occur in some ADs over the next two to four years. Pre-recruit abundance indices for trawl and trap surveys provide an index of recruitment prospects for the next two to four years (Figure 30,

Figure 34, Figure 39). In reality 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 overall abundance of pre-recruits in the trawl surveys increased to above the time-series average in 2020 and was at a decadal high level (Figure 30), however this does not include any data from AD 3Ps, as there was no trawl survey in 2020. 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 40, Figure 41). Both surveys are suggesting the potential for localized improvements of recruitment into the exploitable biomass in forthcoming years. While there have been decreases or little change in the pre-recruit abundance indices from trap surveys in most ADs in 2020, these indices remain near high levels. In ADs where exploitable biomass levels remain low and there is an increased potential of recruitment into the biomass, a scenario of increased soft-shell crab incidence may occur in the fishery over the next couple of years if measures to ensure efficient transition of these crab into the exploitable biomass are not taken.

The relatively low abundance of small crab (<50 mm CW) since the early 2000s (Figure 30, Figure 42), may suggest overall weak recruitment potential in the long term relative to levels experienced in the mid- to late-1990s. However, the overall abundance index of small crab has been near a decadal high in the last two years, and does not include any data from AD 3Ps for 2020. The pulse of small crab that emerged in the trawl surveys in 2013–2014 (Figure 30) was largely localized to ADs 2HJ and 3K (Figure 42). 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 42) that is almost certainly associated with marked improvements in new-shelled recruits in 2017–19 in that AD (Figure 34). Unfortunately, there has been a relatively steady-state broad distribution of low catch magnitude of these small crab in AD 3Ps for the past eight years (Figure 42), although no updated data for 2020 were available, inferring weak prospects after the currently emerging pulse of recruitment benefits the exploitable biomass and fishery over the next few years. The spike in small crab abundance seen in the 2010 AD 3LNO Offshore survey is likely beginning to contribute to the exploitable biomass in that AD in the last couple years (Figure 42, Figure 34). The distribution of small crab has not contracted in recent years to the same extent seen in exploitable crab (Figure 43, Figure 44), 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 stocks) 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 30), it has overall been variable throughout the time series in all ADs (Figure 42). Despite this variability, the relative abundance of mature females has increased overall in the last two years; however, this trend has not been seen in AD 2HJ and the data for 2020 does not include AD 3Ps. The time series of mature female abundance has been particularly variable in AD 2HJ and there have been low abundance indices, 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 45), indicated by large error bars around the estimate (Figure 42).

The spatial distribution pattern observed in recent years is typical of a dominant shallow water presence of mature females (Figure 45, Figure 46). 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 45). 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 46). 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 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 47, Figure 48), 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 42).

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 47) 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 30). Similarly, the present pulse of small crab of about the same size in ADs 3K and 3LNO Offshore would have been produced from apparently low mature female abundance levels seen during recent years. 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 47, Figure 48), 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 two years. Bottom temperature has been shown to relate positively on size and negatively on abundance in regulating stock productivity and ultimately biomass. 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. 2021). 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.

Fall bottom temperatures were generally warmer in 2020 than the 1980–2010 reference period (Figure 49), and have been for the last three years. For those areas with updated data, the Snow Crab thermal habitat index (defined as the areal extent of <2°C bottom water) declined in recent years (Figure 50), indicating warming conditions. There are no updated data for ADs 3Ps, 4R, and spring 3LNO Offshore. 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 (Cyr et al. 2021). 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.

Bottom temperature may not be the only climatic factor important for Snow Crab productivity. A strong association of exploitable biomass with lagged AO and SO was demonstrated (Figure 51). 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, 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 51), but then decrease to around average time series levels. However, 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.

It is unclear if or by how much potential forthcoming 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. This 'test' of stock drivers is currently occurring, with exploitation rate indices being allowed to increase to exceptionally high levels in some ADs in recent years. 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 forcing from heavy exploitation and predation have increased in importance. Notwithstanding incomplete resolution on the extent to which high exploitation rates will affect forthcoming recovery, the recent reductions in size-at-maturity in males (see size-at-maturity section) can only serve to reduce the proportion of animals growing and dampen forthcoming recruitment. If quota decisions follow CPUE more closely than survey biomass, in a relative sense, the lagged signal of CPUE in reflecting stock size promotes over-exploitation when the biomass is in decline and under-exploitation when the biomass increases. 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 can undoubtedly interfere with 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 in recent years (Figure 52), as temperate finfish populations responded positively to warming (DFO 2014a; Rose and Rowe 2015; Pedersen et al. 2017). Predation mortality on Snow Crab increased from the late 2000s to 2016 in most ADs, but drastic declines were observed in all ADs in recent years, with the exception of AD 2HJ. These dramatic declines in relative predation levels are likely the result of a combination of recent declines in predatory fish abundance, 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 in recent years. Given that the regulating effect of predation is thought to be most important on small to intermediate-sized crab (Chabot et al. 2008), a delay would be expected between the time the predation mortality index decreases and crab become available to the fishery. A decline in predation mortality coupled with now decreased fisheries exploitation rates and increasing pre-recruit abundance indices in most ADs 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. Important differences are evident in overall magnitude of predation mortality across ADs, with ADs 3K and 3Ps having predation levels much higher than other areas. Considering that the rebuilding of groundfish biomass appears to have stalled (DFO 2022a; DFO 2022b), the declines in predation pressure could potentially improve the prospects for Snow Crab in the coming years.

Although impacts of increased predation on the fishery in most areas would be expected to be minimal at present, as the ‘missing’ crab would not yet be of exploitable size, with the Snow Crab resource at low levels in recent years increased top-down controls in the forms of predation and fishing may be more important in regulating the resource than historically. If this is the case, and top-down forcing becomes dominant, the strength of linkages with bottom-up forcing (i.e., NAO) would be expected to diminish moving forward. Conversely, if quotas continue to more closely follow CPUE than stock biomass, and do not increase as fast as biomass increases, fisheries exploitation rates could become low, which would likely enable coupling with environmental regulators to be maintained.

With respect to overall ecosystem productivity, ecosystem conditions in the NL Bioregion are indicative of a low productivity state. Total community biomass levels remain much lower than prior to the collapse in the early-1990s. The concerns of low ecosystem productivity extend into the bases of the food-web, with changes in zooplankton community structure (fewer large energy-rich and more small less energy-rich copepods) as well as changes in seasonality (weaker spring and stronger summer and fall zooplankton signals) which may impact the quality and timing of transfer of energy to higher trophic levels.

Mortality

Until the last two to three 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 53). 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 54). There are no indices of total mortality for ADs 3L Inshore and 4R3Pn as this calculation relies on trawl survey data.

In AD 2HJ, total mortality increased in 2020 and remains highest in this AD (Figure 54). In AD 3K, total mortality was at its highest level from 2016 to 2018 but has declined greatly in the last two 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. In AD 3LNO Offshore, total mortality declined from its highest observed level in 2016 to a time-series low in 2019. There was an increase in total mortality in 2020 due to the increase in residual crab in 2019, but a return to the exploitable biomass dominated by recruits in 2020. Finally, there is no updated mortality index for AD 3Ps due to the absence of a spring trawl survey in 2020. Total mortality in exploitable crab has varied considerably throughout the time series in this AD, and the three-year moving average remained low in 2019. 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.

Recent trends in total mortality are more closely aligned with fisheries mortality than known and quantified sources of natural mortality. BCD is one important source of consistently measured natural mortality in the population. BCD has been observed, based on macroscopic observations of crab captured in the fall trawl surveys, at generally low levels throughout NAFO Divs. 2J3KLNOPs from 1995 to 2020 (Figure 55). The prevalence and distribution of this parasitic affliction 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% have occurred for 60–75 mm CW crab in 2015 and 2016 (Figure 55). BCD is normally most prevalent in AD 3K, however, in 2020, BCD was not detected in the fall trawl survey in any of the size classes. Recent years had seen levels of BCD of more than 10% in sizes >94 mm CW in AD 3K. 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 47, Figure 48), which was subsequently tracked as pre-recruits in surveys from 2008 to 2010 (Figure 53).

The most reliable size group of crab assessed for the impact of BCD on the crab 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.

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 under-sized or legal-sized soft-shelled 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 Tamelen 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 explicitly knowing 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, particularly in light of recent low biomass.

There has been particular concern in recent years for ADs 2HJ and 3L Inshore, where discard levels have been very high at approximately 40% of the catch (Figure 56). 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 under-sized, old-shelled crab (Figure 57). 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.

Discard levels in the fishery are negatively related to CPUE (Figure 58) (Mullowney et al. 2018b). This likely reflects competition for baited pots, with the catchability of less competitive crab (both under-sized and soft-shelled) increasing when the exploitable biomass is relatively low. Modest increases in recruitment potential in some ADs, coupled with a low residual biomass in recent years, suggest that wastage of soft-shelled pre-recruits could be problematic in the fishery in the next few years in some ADs, and potential gains could be quickly diminished if aggressive harvest strategies in the form of high exploitation rates persist.

Prevalence of soft-shelled, legal-sized 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-shelled 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-shelled immediate pre-recruits, even during peak soft-shell periods (Mullowney et al. 2021).

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 clearly not an effective conservation tool to safeguard against handling mortality in this fishery and should be re-examined.

Soft-shell incidence has featured relatively prominently in the observed catch in ADs 2HJ and 3K in recent years (Figure 57). This was associated with generally low and declining recruitment and exploitable biomass. Measures should be taken not only to reduce soft-shell encounters, but to better quantify prevalence of soft-shelled crab in the fishery and afford better protection to incoming recruitment.

Trends in total mortality generally reflect those of fishing-induced mortality, as measured by exploitation rate indices. ADs currently experiencing notable recovery in the exploitable biomass (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 (2HJ) are associated with persistent high total mortality and exploitation rates (Figure 54). 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 59).

In AD 2HJ, the exploitation rate index declined to near the time-series average in 2020 (Figure 54). This was due to a TAC reduction in 2020 along with the full TAC not being caught in CMA 2JN. Under status quo removals in 2021 the exploitation rate index would increase to near the time-series high level. The exploitation rate index averaged 64% during the last five years in this AD. In AD 3K, the exploitation rate index declined from a decadal high in 2017 to a time-series low in 2020. Under status quo removals in 2021 the exploitation rate index would further decrease. In AD 3LNO Offshore, the exploitation rate index increased by a factor of five from 2014 to 2017, but decreased to below the time-series average in 2020. The exploitation rate index would further decline with status quo removals in 2021.

There are no trawl-based biomass indices available in ADs 3L Inshore and 4R3Pn from which to calculate exploitation rate indices. Accordingly, the shorter time series of trap surveys are used as the basis (Figure 60). The trap-based exploitable biomass index is also used for AD 3Ps as the trawl survey takes place within season, as opposed to post-season as in the other ADs. In AD 3L Inshore, the overall trap survey-derived exploitation rate index increased to its highest observed level in 2018 but decreased to near time-series low levels in 2020. Status quo removals would decrease the exploitation rate index to a time-series low in 2021. In AD 3Ps, the trap survey-derived exploitation rate index increased slightly in 2019, but decreased to a time-series low in 2020. Under status quo removals in 2021, the exploitation rate index would decline further. In AD 4R3Pn, the trap survey-derived exploitation rate index declined to a time-series low in 2020. Status quo removals in 2021 would maintain the exploitation rate index at a similar level.

Recent exploitation rate indices in the NL Snow Crab fishery are overall very high relative to other major fisheries for the species in Atlantic Canada and Alaska. 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 under-estimated) estimates of fishing exploitation rates are routinely >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 61). 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 over-fishing, 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 if this heavy exploitation is sustained. Large hard-shell males are the prime breeders and likely serve to introduce sufficient intraspecifc 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 managemement 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 where exploitable biomass is low and exploitation rates remain high and suggests poor prospects of resource recovery for 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.

However, in contrast to AD 2HJ, improved signals of recruitment potential (Figure 61, Figure 62, Figure 63) as well as decreasing exploitation rates (Figure 54, Figure 60) in most other ADs should result in forthcoming gains if fisheries-induced mortality is not excessive in the next few 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 but AD 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 (Figure 64). However, all ADs have shown increases in male size-at-maturity from the recent low points. In ADs 2HJ and 3K, the male size-at-maturity is still lower than historical low periods. These results suggest that any improvements in recruitment potential could be significantly dampened, unless 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 promotes 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 effect 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 2021, assuming status quo removals, CPUE is predicted to be above the LRP in all ADs (Figure 65). However, the predicted CPUE for 2021 is very close to the LRP for AD 2HJ, at 5.3 kg/trap.

Discards levels, assuming status quo removals, were predicted to be above the LRP in all ADs for 2021 (Figure 65).

To monitor reproductive health, an index of egg clutches of females is used (Figure 65). 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 2020, all ADs were above the LRP for egg clutches; however, there is no 2020 point for AD 3Ps as a spring trawl survey was not conducted in 2020.

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 ensures 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. 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, but no formal recommendations have been made at this point and therefore cannot be implemented in the 2021 fishery. Accordingly, USRs are not presented in this assessment and the overarching HCR for the framework, including rules pertinent to addressing the relative importance of each metric in overall stock status assessment, is not defined. Therefore, in the current assessment an AD is not projected to be in a zone, rather individual metrics are either above or below the associated LRP. Thus, in 2021, all ADs are projected to be above the LRPs for each stock status metric in the PA Framework. These projections assume status quo landings.

ASSESSMENT DIVISION 2HJ

Fishery

The AD 2HJ fishery occurs in offshore regions of central and southern Labrador in CMAs 1 and 2 (Figure 1, Figure 16). CMA 1 is often referred to as N5440 or 2JN and CMA 2 is often referred to as S5440 or 2JS. The bathymetry of the region is characterized by a series of shallow water offshore banks separated by deep channels (Figure 2). The Cartwright and Hawke Channels, the two dominant fishing grounds, extend to depths of 750 m, although the fishery tends to avoid the deepest portions of the channels. The bottom water temperature in these two deep channels is warmer than the surrounding shallow banks.

In relative terms, the AD 2HJ fishery is one of the smallest fisheries for Snow Crab in NL, with the exception of AD 4R3Pn (Figure 12). There have been exploratory fisheries in Div. 2H since the mid-1990s and a commercial TAC was first established in 2008. The fishery in Div. 2H is small relative to Div. 2J and the history of commercial fishing in Div. 2J is longer, extending back into the early 1980s.

In AD 2HJ, landings remained near 1,700 t from 2014 to 2019, but declined to around 1,400 t in 2020 (Figure 13). Effort declined to its lowest level in decades (about 140,000 trap hauls per year) in 2013 and has since remained around 200,000 trap hauls per year (Figure 15). To a large degree, the shortfalls in achieving the TAC in 2011–13 and 2020 reflect events in the northernmost fishing grounds of CMA 1 (i.e., 2JN) (Figure A1. 1), with the southern CMA consistently fully or near fully subscribing its quota. Although poor fishing in the northern area is a contributing factor (Figure 16), it also reflects a management decision by industry stakeholders to leave 15% of the annual TAC unharvested in CMA 1 from 2014 to 2018 to promote conservation measures (Figure A1. 1). This measure was stopped in 2019, however the TAC was still not fully taken in this CMA in the last two years.

Logbook return rates in AD 2HJ have been variable throughout the time series and tend to be slower than in most of the other ADs, however only approximately 58% of landings were accounted for in the logbook dataset for this assessment, compared to the 70% in previous years (Figure 4). Some of this delay may have been due to COVID-19 restrictions. Incomplete datasets create uncertainty in calculating and interpreting logbook CPUE. Adding to uncertainty in assessing fishery performance in this AD is that observer coverage is routinely low (Figure 10).

Standardized CPUE declined to below the time-series average in 2020 (Figure 17), reflecting decreases in standardized CPUE in both CMAs (Figure A1. 2). Weekly CPUE trends are normally highest during the early portion of the season and tend to decline sharply throughout the fishery (Figure 22). This reflects depletion of the resource. The typical seasonal depletion pattern occurred in both CMAs for the past five years (Figure A1. 3). The initial catch rates in the northern CMA have declined for the past four years and there was little replenishment of the resource between 2019 and 2020. This indicates declining recruitment into the fishery, however low logbook returns may influence trends seen in the logbook data for 2020. As well, there was an influx of newer, less experienced vessels participating in the fishery from 2JN in 2020 that may have influenced early catch rate trends.

Spatially, there has been a reduction in the areal coverage of the fishery since 2011 (Figure 16). It has contracted into the Cartwright and Hawke Channels, with the northernmost fishing grounds of Div. 2H virtually abandoned. Along with contraction from the north, effort no longer extends into the farthest offshore areas and the slope edge. The abandonment of northernmost fishing grounds also 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.

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 1 more clearly showing signals of resource depletion in the fisheries data, even in the historically best-performing fishing grounds of the Cartwright Channel.

Size distributions from at-sea sampling by observers during the fishery suggest that two recent recruitment pulses benefitted the fishery during 2007–09 and 2012–15 (Figure 20). This can be seen by an increase in abundance of soft- and new-shelled legal-sized crab during those periods. There was no observer data in 2020, however in 2019, there was virtually no old-shelled legal-sized crab in the observed catch, indicating a decline in the residual biomass and reflecting trends in CMA 2 where observer sampling occurred (Figure A1. 4).

Discards in the fishery were very high in 2019, with around 40% of the catch discarded (Figure 56), and the majority of these discards soft-shelled (Figure 57). Observer sampling suggests that the recruitment pulse that recently benefitted the fishery was subjected to relatively high levels of fishing mortality in the form of soft-shell prevalence and discarding in the mid- to late- portions of the 2011, 2012, and 2014 fisheries (Figure A1. 5). Weekly levels of soft-shell in the catch typically exceeded 20% after late June during those years, as occurred in 2019.

Total mortality in exploitable crab had been at its highest level in recent years, but the three-year moving average for the last three years has been relatively lower (Figure 54). The trend in total mortality has reflected that of fishing mortality in recent years (Figure 54).

The exploitation rate index returned to the long-term average in 2020 (Figure 54), however the TAC was not fully subscribed. Status quo removals (91% of 2020 TAC) in 2021 would increase the exploitation rate index. A lower exploitation rate would be required to promote recovery of the exploitable biomass. All inferences from fishery data are that caution is warranted in the 2021 fishery.

Surveys

The exploitable biomass indices have changed little during the past decade (Figure 34, Figure 35), with the exception of a 2014 spike in the trawl index. However, the trawl exploitable biomass index decreased slightly in 2020. The trap-based exploitable biomass estimates in 2017, 2018, and 2019 are considered highly uncertain and should be viewed with caution, particularly in CMA 2 (S5440) (Figure A1. 6). The 2017–19 trap surveys omitted a large proportion of core stations and in the 2018 trap survey shell conditions were identified inaccurately in CMA 2 (S5440) (Figure 8). There was reduced coverage of the fall multispecies trawl survey in 2019 and consequently the 2019 trawl exploitable biomass index was likely an overestimation. However, the spatially-broad trawl survey has captured very few exploitable crab outside the Cartwright and Hawke Channels during the past decade (Figure 32).

Recruitment into the exploitable biomass was low throughout the 2000s relative to the high levels of the late 1990s. It has changed little during the past two decades with the exception of a 2014 spike (Figure 34), and the 2020 surveys suggest recruitment will remain unchanged in 2021 (Figure 34, Figure 38). Interestingly, a high level of recruitment into the biomass in the northern area during 2013 (Figure A1. 7, Figure A1. 9) preceded the high level of recruitment seen in the trap survey in the southern area in 2014 (Figure A1. 8, Figure A1. 10). While recruitment has increased in 2020 from the last complete survey in 2016 in the southern area, the trend in recruitment in the years in between is unknown (Figure A1. 8).

In 2018, a modest increase in residual crab (Figure 34), no prior increase in recruits in 2017 (Figure 34), the general location of the new residual crab within the deep channel extending from AD 3K to southern AD 2HJ (St. Anthony Basin) (Figure 32), and the lack of increase in residual crab in 2018 following an increase in recruits in 2017 in AD 3K (Figure 34), indicated a possibility that recruits from AD 3K had moved into southern portions of AD 2HJ as residual crab. This does not appear to be the case in the two years since as the residual crab were found in the northern portion of AD 3K where they are usually recorded in the surveys

(Figure 32). This situation highlights the difficulties is assessing a stock based on delineations (ADs and CMAs) that are not set based on biological criteria as much as resource management considerations.

Looking at prospects beyond 2021, the pre-recruit abundance index has been relatively low in recent years, with a slight increase in 2020 (Figure 34). The modest 2014 spike in pre-recruits in the trawl survey appeared to be associated with the progression of a mode of crab into legal-size in small-mesh traps from the Torngat survey in CMA 1 (2JN) during 2015 (Figure A1. 11). There has been an increase in small adolescent crab in the small-mesh traps from the Torngat survey in the last two years, however, this mode has not been maintained to the same level into the larger sizes in the small-mesh traps in 2020 nor appeared in the large-mesh traps in that survey. Trends in pre-recruits from small-mesh traps in the southern area cannot be determined due to the incomplete surveys from 2017 to 2019 (Figure A1. 12). The slight increase in the trawl survey pre-recruitment index suggests the potential for some small improvements in two to four years if the crab survive and do not terminally molt smaller than commercial size.

Long-term recruitment prospects appeared to improve from 2013 to 2016. The abundance of small crab (<50 mm CW) in the population was higher than it had been for roughly a decade, but the abundance of small crab has returned to lower levels in recent years (Figure 42). These smallest crab in the trawl survey have consistently been captured in shallow areas, on top of the Hamilton Bank and adjacent nearshore plateaus (Figure 43). The persistently low signal of small crab in the survey trawl prior to 2013 suggests no improvements are likely before the most recent emergent mode of small crab contributes to the fishery. The high consumption level of Snow Crab by large predators in 2016 and 2017 (Figure 52), as well as a spike in BCD prevalence in 60–75 mm CW crab (Figure 55), is consistent with tracking these crab through ontogeny, although neither survey has yet to capture them in high abundance as pre-recruits (Figure 34, Figure 39). Other factors being equal, this promising signal of small crab abundance should start contributing to pre-recruit or exploitable indices in the near future if any remnant portions of the pulse remain as adolescent males in the population.

Size-at-terminal molt in males has precipitously declined in recent years, indicating dampened short-term recruitment prospects into the exploitable biomass (Figure 64). An increase was seen in male size-at-terminal molt in the last few years, however, the maturation of 50% of males remains well below exploitable size (i.e., 62–76 mm CW since 2015). It is unknown if this trend will continue, but it should be monitored closely moving forward.

The proposed PA indicates that with status quo removals stock status would be projected to be above the LRPs in 2021 (Figure 65).

Overall, key resource indicators suggest there has been a prolonged period of low resource available to the fishery, with both the pre-recruit and exploitable biomass near their lowest observed levels for the past six years. If this pattern holds, the fishery performance would be expected to remain similar in 2021.

ASSESSMENT DIVISION 3K

Fishery

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 (Figure 49).

Within the AD there are six CMAs (Figure 1). The effort distribution in Green Bay (CMA 3C), Notre Dame Bay (CMA 3D), and the offshore (CMA 4) forms a continuum stretching from the shallow nearshore waters of Green Bay (i.e., 200–300 m) into the deeper trenches of Notre Dame Bay (i.e., 300–400 m) and the Funk Island Deep in the offshore (i.e., 400–500 m) (Figure 16). White Bay (CMA 3B) is a deep (i.e., 400–500 m) fjord protected at the mouth by a shallow sill (i.e., 200–300 m) that forms the basis of a relatively discrete pocket of fishing effort. There are two distinct pockets of effort in CMA 3A, one concentrated near the mouth of White Bay in the south and another in an easterly extension of the management area that stretches into the offshore at depths of approximately 200–300 m. Finally, CMA 3BC is relatively shallow (i.e., 200–300 m) and bathymetric features are similar to the offshore and southern portions of CMA 3A. Effort within CMA 3BC essentially forms a western extension of the offshore fishery.

Landings have remained relatively low for the past five years, although there have been small increases in the last two years (Figure 13). This reflects patterns in the offshore (CMA 4) and CMA 3D, the two largest CMAs in terms of fishery scale (Figure A2. 1). In these two dominant areas, TACs and landings have been at or near their lowest levels in a decade in recent years. In 2020, the TAC increased in all CMAs, except CMA 3A which has had the same TAC for the last five years. The TAC has not been reached in this CMA for the last seven years. Effort increased slightly in 2020 in AD 3K, but remained near a two-decade low (Figure 15).

Standardized CPUE has increased in the last three years from a time-series low in 2017, to around the time-series average (Figure 17), however the increase was very slight in 2020. Increases in standardized CPUE were seen in most CMAs, however, catch rates remained unchanged in CMA 3D and slightly decreased in CMA 4 in 2020 (Figure A2. 2).

It should be noted that in 2017 evidence was presented that the CPUE calculated in AD 3K may have been too low in recent years. This reflects harvester error in filling out logbooks upon implementation of a fishery rationalization program whereby harvesters are able to combine quota allocations to a single vessel. With respect to reporting catches, requirements for the partnerships entail splitting the catch among both license holders. However, it has been reported that some harvesters were reporting the full amount of effort (pot hauls) in their logbooks in association with half the catch. The extent of the issue was unclear; 25–30% of the fleet has been fishing under such arrangements from 2014 to 2017, with the fraction of those mistakenly over-reporting effort in their catch logs unknown. It is also unknown how many harvesters corrected this issue in 2018; therefore, causing an artificial low CPUE followed by an artificial increase in their CPUE in 2018.

Spatially, the fishery data are reflecting a constricting of fishing activity primarily into the Funk Island Deep area and inshore bays, with much of the offshore fringe areas not fished in the last three years (Figure 16).

In 2020, the fishery CPUE declined throughout the season in all CMAs (Figure A2. 3), reflecting resource depletion. This depletion was pronounced in all CMAs, except in CMA 3A where start-of-season catch rates were lower than the rest of the CMAs and therefore the decrease was less pronounced. There has been replenishment of the resource between seasons in all CMAs, with much higher start-of-season catch rates in 2020 than previous years in CMAs 3C and 4. In 2020, CMA 4 also experienced much lower end-of-season catch rates than the previous year.

Discards in the fishery decreased in 2019 to around 20% discarded (Figure 56). Observer sampling during the fishery showed catch rates of new-shelled and/or soft-shelled crab starting to increase in all CMAs in 2017, with the exception of CMA 4 (Figure A2. 4). With the exception of CMA 3D in 2018, these trends have continued over the last two years resulting in increased catch rates of new-shelled crab in all CMAs in 2019. As well, there was an increase in soft-shelled crab in CMA 3BC.

In 2018 and 2019, the catches observed in CMAs 3A and 3B were dominated by new-shelled recruits, in sharp contrast to the previous years which were dominated by old-shelled crab, indicating a new recruitment pulse (Figure A2. 4). A large increase in catch rates of all three shell conditions was observed in 2019 in CMA 3BC. In 2019, a knife-edge effect emerged in CMA 3A, indicating strong fishing pressure on the resource in this area.

Improvements in recruitment in Green Bay (CMA 3C) and neighbouring Notre Dame Bay (CMA 3D) started to emerge in 2016 in the observer sampling (Figure A2. 4). From about 2009 to 2013 the overall magnitude of catch rates of most sizes of crab showed a steady decline as the size frequency distribution became platykurtic, particularly in CMA 3D. Beginning in approximately 2014, a notable change in shape of the observed population occurred in this CMA as the primary size mode became centered near legal-size and the distribution became right-skewed. In Green Bay (CMA 3C), size frequency distributions from observer sampling suggested a persistent high exploitation rate, evident by a sharp ‘knife-edge’ effect at legal-size from 2009 to 2017. However, in 2018 and 2019, the knife-edge effect was not evident in Green Bay, with high frequencies of crab larger than legal size evident.

In the offshore (CMA 4 plus small contributions from CMAs 3A and 3BC), observer sampling showed a gradually dissipating exploitable biomass since 2009, with progressive depreciation in catch rates of legal-sized crab until 2017 (Figure A2. 4). In 2018, and even more so 2019, observer catch rates of recruits and residuals increased in CMA 4.

Soft-shell crab incidence in the catch is a perpetual issue in AD 3K (Figure A2. 5). In general, a large portion of discards in this AD are attributable to soft-shell crab (Figure 57). However, the majority of discarded crab were represented by undersized crab in 2018 and 2019. Soft-shell incidence tends to increase as the season progresses, with the fishery consistently experiencing soft-shell percentages exceeding 20% by about the end of May in most years since 2005 (Figure A2. 5). This persistently high incidence of soft-shelled crab in the catch is thought to reflect, at least in-part, a depleted residual biomass. 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.

Total mortality in exploitable crab was at its highest levels (>75%) from 2016 to 2018 (Figure 54), however, it decreased dramatically in the last two years. This is thought to partially be a result of the movement of crab back into AD 3K in 2019 from AD 2HJ in 2018 (see Mortality section above for more details). This would result in more residuals than recruits from the previous year which affects the calculation of the total mortality index. The exploitation rate index has declined from a decadal high in 2017 (Figure 54). Under status quo removals in 2021 the exploitation rate index would decrease to a time-series low.

Surveys

Both the trawl and trap surveys have seen increases in the exploitable biomass in the last two years, however, the trawl survey exploitable biomass has increased significantly over the last two years (Figure 34), while there has only been a slight increase in the trap survey (Figure 35, Figure A2. 6). This discrepancy in trends between the trawl and trap survey is beyond the expected lag in response of trap surveys to changes in stock size.

Similar to AD 2HJ, exploitable males in AD 3K are generally found deep, predominately at fringe areas of the Funk Island Deep and St. Anthony Basin, with few exploitable crab captured in the farthest offshore areas (Figure 32). In 2018, a portion of the crab that is generally found within AD 3K in the St. Anthony Basin, appeared to have moved north and was centered in AD 2HJ; however, catches in 2019 and 2020 showed a return to the more typical distribution of crab in AD 3K. The exploitable biomass has consisted largely of incoming recruits throughout the time series (~50–75%), however there was an increase in residual crab in 2019 and 2020 from previous low levels (Figure 34). Trap survey catch rates of residual crab remained relatively unchanged in all CMAs in 2020. (Figure A2. 7).

The overall CPS survey catch rates in AD 3K have increased from the time-series low in the last two years, with the increase in 2020 due to recruits (Figure 38). The overall increase in recruits was primarily driven by trends in CMAs 3D and 4 (Figure A2. 7). The Inshore DFO trap survey results are generally consistent with the CPS survey results (Figure A2. 8, Figure A2. 9). In White Bay (CMA 3B), an unusually high abundance of recruitment was seen throughout the bay in 2012 (Figure A2. 7), and has been increasing again in the last two years. It is noteworthy that the best comparison with the CPS survey is made with the 201–300 m and 301–400 m strata from the Inshore DFO trap survey, which constitute the majority of the area, with the deepest stratum very small and generally beyond depths where the fishery occurs (Figure A2. 8). However, this deepest strata also showed increased recruits in 2020. Recruitment in Green Bay (CMA 3C) has been variable over the CPS time series with alternating increases and decreases over the last five years (Figure A2. 7), however this variability has not been as strong in the Inshore DFO trap surveys (Figure A2. 9). Interestingly, unlike the CPS survey which exhibited abrupt increases in recruitment in CMA 3C in 2017 and 2019, the Inshore DFO survey measured these improvements in CMA 3D, specifically in the deeper confines of it (Figure A2. 7, Figure A2. 9). Such spatial inconsistencies between areas likely reflect non-conformance of CMA boundaries to bathymetry and population structure, with the two areas almost certainly being intrinsically connected.

Size frequency distributions from large-mesh pots in the CPS survey show increased levels of new-shelled crab across a broad size range in CMAs 3B, 3BC, 3D, and 4 in 2020 (Figure A2. 10). The pulse of small new-shelled crab in CMA 3A in 2019 was not apparent in 2020, with very little crab caught in the large-mesh traps in this CMA in 2020. There were almost exclusively old-shelled crab caught in CMA 3BC in 2019 and a large proportion of those caught in 2020 were also old-shelled. Overall numbers per trap increased in 2020 in CMA 4, where catch numbers have been very low since 2012.

Looking beyond 2021, there were mixed signals between the trawl and trap pre-recruit abundance indices in 2020 with an increase in the trawl surveys and a decrease in the trap surveys (Figure 34, Figure 39), however both indices remain slightly above time-series average levels. This suggests there may be improvements in the short term (2–4 years).

Small-mesh trap usage by the CPS survey has been sporadic in many of the CMAs throughout the time series (Figure A2. 11). Only Green Bay (CMA 3C) and the offshore (CMA 4) have been consistently covered, however, there has been expansion in small-mesh trap coverage in the last couple years with all CMAs now having some small-mesh trap data. There have been stronger signals of adolescent crab in most CMAs in the last two years. While small-mesh trap use has been very patchy in CMA 3BC, in 2019 there were large catches of very small adolescent crab, which was also seen in CMA 4. This strong signal of adolescents diminished in CMA 4 in 2020.

Small-mesh traps in the Inshore DFO trap surveys show a dramatic decline in the catches of small adolescents and adults in White Bay (CMA 3B) from 2008 to present (Figure A2. 12), with a very small hint of potential increased recruitment in the middle (301–400 m) and deepest (401–500 m) strata in 2018 and 2020. The surveys tracked a mode of adolescent males across years and depths, beginning at about 47 mm CW in the shallowest stratum in CMA 3A/White Bay in 2005 to pre-recruit-sized crab with modes of about 75–85 mm CW in the two deeper strata in 2011 and 2012. The deep progression over time reflects the ontogenetic migration of Snow Crab in this area (Mullowney et al. 2011). This recruitment pulse led to the large exploitable biomass experienced from 2012 to 2014. Another very small pulse of adolescents was detected at about 47 mm CW in the shallowest stratum in 2015, which may have started to appear as pre-recruits in the 301–400 m depth stratum in 2018. The pulse is not apparent in the small-mesh trap data in 2020.

Small-mesh traps in the Inshore DFO trap surveys show an increase in adolescent crab in Green Bay (CMA 3C) and Notre Dame Bay (CMA 3D) was apparent in 2018 and has remained since then (Figure A2. 13). This trend is not as apparent in the CPS survey in CMA 3C (Figure A2. 11). Collectively, these surveys provide evidence to suggest the potential for modest increased long-term recruitment prospects for the exploitable biomass and fishery. However, a large proportion of crab appear to be terminally molting smaller than exploitable size, so the extent to which this potential recruitment is realized in the fishery is likely diminished and remains unclear.

Long-term recruitment prospects have improved in recent years with increased abundance of small crab in the trawl survey in 2019 and 2020 (Figure 42). The strong pulse of pre-recruits currently observed in the trawl survey most likely emerged from the relatively strong pulse of small crab captured during 2014. The spike in small crab abundance seen in the survey in 2014 was also seen in AD 2HJ, however, there has not been a corresponding spike observed in 2HJ in 2019–20.

BCD incidence levels generally represent another metric of recruitment potential via the density dependence attributes of the disease in reflecting the relative abundance of small to mid-sized crab (Mullowney et al. 2011). For example, the progression of a spike in BCD in the shallow stratum of White Bay in 2005 through to the mid-depth stratum in 2006 and finally into the deepest stratum in 2007 (Figure A2. 14) reflected the high abundance of crab in the pseudo-cohort of adolescents ranging from about 45 to 75 mm CW. This led to the record high exploitable biomass in 2012 that persisted until about 2014. The previous ‘cycle’ of BCD in White Bay from 1996 to 1999 preceded the relatively high exploitable biomass experienced from about 2002 to 2007. The percent of new-shelled males with BCD most recently peaked in 2016 and was relatively high again in 2018 and 2020. Observed BCD incidence levels have been highly variable in Green Bay (CMA 3C) and Notre Dame Bay (CMA 3D) over the time series and were near average in 2020, with between 10–15% of new-shelled males having BCD (Figure A2. 14).

There were signals inferring improvement in long-term recruitment prospects in 2019 and 2020. However, expectations must be tempered and also examined in-light of recent declines in size-at-maturity (Figure 64). Although not to the extent seen in AD 2HJ, size-at-terminal molt in males has precipitously declined in recent years, suggesting potentially dampened short-term recruitment prospects into the exploitable biomass. A slight increase was seen in male size-at-terminal molt in the last three years, however, the maturation of 50% of males remains well below exploitable size (i.e., 77–87 mm CW since 2015). Trends in male size-at-terminal molt should be monitored closely moving forward, with an anticipation for increases to potentially occur if or when modes of pre-recruits begin to more fully progress through exploitable crab sizes.

The proposed PA indicates that with status quo removals stock status would be projected to be above the LRPs in 2021 (Figure 65).

Caution is encouraged in making decisions on the resource at the CMA level in this AD as they could affect biological functioning. Information presented herein shows that many broad-scale resource trends are consistent throughout the AD. Although specific aspects of spatial connectivity (such as migration routes) are not well understood, of potential concern is that excessive fishing in one CMA could directly affect adjacent areas. Similarly, cautious actions in a given CMA have the potential to benefit adjacent areas. Broad-scale spatial stratification by size is evident in Snow Crab populations in the northern portions of the NL shelf, including Division 3K (Dawe and Colbourne 2002). Among other connectivity processes, large-scale ontogenetic migrations extending beyond CMA boundary lines knowingly occur in this AD (Mullowney et al. 2018a), following a dominant west-east downslope trajectory from the shallow nearshore plateaus toward the warm waters of the Funk Island Deep and St. Anthony Basin as crab grow.

ASSESSMENT DIVISION 3L INSHORE

Fishery

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. 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). All but CMAs 6C and 8A are further sub-divided into inner and outer management areas, but those finer-scale areas are not considered in the assessment.

All the bays in this AD feature deep holes in their central interior portions. Bonavista and Trinity Bays are open at their mouths; thus the deep water inner portions are continuous with the offshore bathymetry. In contrast, Conception and particularly St. Mary's Bays feature shallow sills at their mouths. The bathymetry in the areas east of the Avalon Peninsula encompassing CMAs 6C and 8A is dominated by the Avalon Channel, a deep-water trough through which the southerly flowing cold inner branch of the Labrador Current passes (Figure 2). Overall, the bottom water in these areas is cold (Figure 49).

Overall, landings declined by 67% from a time-series high in 2015 to a time-series low of 2,750 t in 2019 (Figure 13). In 2020, the landings increased slightly, and the TAC was fully taken. In 2020 there were TAC increases (CMAs 5A and 6A), decreases (CMAs 6B and 6C), and TACs that remained unchanged (CMAs 8A and 9A) and TACs were fully or near fully subscribed in all CMAs (Figure A3. 1). Effort oscillated without trend in this AD from 2005 to 2015 (Figure 15). There was a time-series high in 2017 of close to 1 million trap hauls per year, however declined to a two-decade low of around 300,000 trap hauls in 2020.

Overall standardized CPUE has increased in the last two years from the lowest level in the time series (<5 kg/trap) in 2018 (Figure 17). There were strong declines starting around 2014 leading to near time-series lows in all CMAs in 2018 (Figure A3. 2). However, improvements have been seen in all CMAs over the last two years, with catch rates at or over 10 kg/trap in CMAs 5A, 8A, and 9A. In CMAs 6B and 6C, catch rates have improved from the time-series lows in 2018–19, but are still near historical lows.

Strong depletion of the resource during the 2020 fishery was evident in all CMAs except 8A, however the start-of-season catch rates were higher than the previous end-of-season catch rates indicating replenishment of the resource between seasons (Figure A3. 3). A pattern of annual stepwise decreases in CPUE has occurred in CMAs 6B, 6C, and 9A in recent years, with start-of-year catch rates similar to end-of-season catch rates from the preceding years. This indicates relatively poor recruitment after the fishery is complete. However, start-of-season catch rates were much higher in these CMAs in 2020.

Observer data up to 2019 has shown a general lack of renewal in the exploitable biomass. In-season catch monitoring data show that the catches consisted almost exclusively of old-shelled crab (Figure 18), with low incidence of new-shelled crab in the AD as a whole and within most CMAs (Figure A3. 4). Very low numbers of new-shelled crab were observed in all CMAs, with the exception of Southern Avalon (CMA 8A), where almost all of the observed crab were new-shelled. In 2017, large increases in new-shelled crab were observed in Northeast Avalon (CMA 6C) and Southern Avalon (CMA 8A) across all size ranges. However, the discrepancies of these trends with other data sources (e.g., CPS data) and the lack of pulses in 2018, indicate these data were likely misidentified shell categories. Another year of data will be necessary to determine if this is the case for CMA 8A in 2019.

Discards in the fishery have been very high in 2018 and 2019, with over 40% discarded (Figure 56). The majority of these discards were old-shelled undersized males (Figure 57). Observed weekly soft-shell encounters remained relatively low in AD 3L Inshore from 2012 to 2016 (Figure A3. 5). However, in 2017, for the first time in seven years, a relatively large pulse of soft-shelled crab was observed near the end of the season. In 2018 and 2019, soft-shelled crab were observed throughout the season. This is likely indicative of a low residual biomass.

Biomass declines have been greatly outpacing adjustments to removals with quotas non-prohibitive in several CMAs in recent years. The overall trap survey-derived exploitation rate index increased in 2013 and remained at its highest observed level until 2018 (Figure 60). It has greatly declined in the last two years to near time-series lows. Status quo removals would decrease the exploitation rate to time-series low levels in 2021. 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.

Surveys

The exploitable biomass has been very low in this AD. The post-season trap survey exploitable biomass index has increased slightly in the last two years, but remains near the time-series low (Figure 35). In all CMAs, the exploitable biomass index has been at its lowest observed level in recent years, however slight increases were seen in all CMAs in the past two years (Figure A3. 6).

The low biomass is largely a result of declining recruitment renewal since 2010, sequentially followed by a decline in residual crab in 2014 (Figure 38). Overall recruitment into the exploitable biomass steadily declined from 2014 to a time-series low in 2017, with the catch rate index at 1 kg/trap. Although modest increases in recruitment were observed in some CMAs in the last three years, recruitment indices from Inshore DFO and CPS trap surveys remained near low levels in many CMAs (Figure A3. 7, Figure A3. 8, Figure A3. 9, Figure A3. 10, Figure A3. 11). In general, resource renewal has been low, and any gains are likely to be moderate in 2021.

In the CPS survey in Bonavista Bay (CMA 5A), there was a sharp reduction of new-shelled legal-sized crab in the catch from about 10 kg/trap in 2011 to 4 kg/trap in 2013 and has remained near this low level since (Figure A3. 7). There was a further decline in recruitment in this survey in 2020. This decline in 2020 was also seen in the deep stratum (275–366 m) in the Inshore DFO trap survey, however recruitment has been a lot more variable in this time-series (Figure A3. 8). The deeper strata of the Inshore DFO trap survey corresponds well with area and depths covered by most of the core stations in the CPS survey in this bay. The CPS survey has seen increases in the residual crab in Bonavista Bay in the last two years which was also tracked in the Inshore DFO trap survey. Both surveys are consistent in showing the modest improvements in exploitable crab over the last few years in this CMA, which may result in modest improvements for the 2021 fishery.

In Trinity Bay (CMA 6A), recruitment has been variable throughout the time series, but the CPS survey showed the abundance of new-shelled legal-sized crab plummeted in 2015 to approximately 1 kg/trap and remained at that level for two years (Figure A3. 7). There was a drop in recruitment in 2019, from the increase to near long-term average in 2018, but a small increase again in 2020. The drop in recruitment in 2015 was reflected in the Inshore DFO trap surveys within the shallow (93–183 m) and deep (367–549 m) strata (Figure A3. 9). Meanwhile, the increase in recruitment in the 2018 CPS surveys was observed in the middle strata (184–366 m) in the Inshore DFO trap surveys. An increase in recruitment was seen in the Inshore DFO trap survey in the shallowest strata in 2019 that was not reflected in the CPS survey. Catch rates of residual crab in the CPS survey increased in 2019, but decreased again in 2020. This increase in 2019 was also seen in the Inshore DFO trap survey in the middle strata (184–366 m). Again, both surveys are consistent in showing the overall relative abundance of exploitable crab was near a historical low in 2016–17 and started increasing in 2018. No major changes in exploitable biomass available to the 2021 fishery is expected in this CMA.

In Conception Bay (CMA 6B), catch rates of legal-sized new-shelled crab were at time-series lows (<1 kg/trap) from 2016 to 2018 (Figure A3. 7, Figure A3. 10). The CPS survey in this CMA was considered incomplete in 2019 because the inner portion of the bay was not surveyed (Figure 8), however there were very slight increases in recruits in both depth strata in the Inshore DFO trap survey in 2019 (Figure A3. 10). Dramatic declines in residual crab were also observed in CMA 6B in both the CPS and Inshore DFO trap surveys during that time (Figure A3. 7, Figure A3. 10). Both surveys showed an alarming rate of decline in overall relative abundance of exploitable crab from 2014 to 2018. In 2020, increases in recruits and residual crab were seen in Conception Bay, particularly in the Inshore DFO trap survey. There were very dramatic increases in recruits in both depth strata in 2020, with catch rates nearing 15 kg/trap in the deepest stratum. With such a significant increase in recruits, improvements in the 2021 fishery would be expected.

In the Northeast Avalon (CMA 6C), the recruitment index of new-shelled legal-sized crab fluctuated at 3–6 kg/trap between 2011 and 2015, but catch rates of recruits declined to a time-series low in 2017, near 0 kg/trap (Figure A3. 7). Catch rates of recruits remained at this low level until an increase in 2020 to near the time-series high. A small increase in residual crab was seen in the Northeast Avalon in 2019 that was maintained in 2020, however remains near the time-series low levels. With the increase in recruits, there may be some small improvements in the 2021 fishery.

In the Southern Avalon (CMA 8A), the recruitment index of new-shelled legal-sized crab fluctuated at 3–6 kg/trap between 2011 and 2015, but catch rates of recruits declined to a time-series low in 2017, near 0 kg/trap (Figure A3. 7). After two years of slight improvements, the catch rates of recruits declined again in 2020 to near time-series low. However, the catch rates of residual crab increased to near the time-series high in 2020 from the low levels seen in 2015–18. No major improvements in exploitable biomass available to the 2021 fishery is expected in this CMA.

St. Mary's Bay (CMA 9A) experienced a prolonged and steady decline in catch rates of recruits from 2010–17, with both surveys showing the index of new-shelled legal-sized crab at time-series lows in 2017 (Figure A3. 7, Figure A3. 11). In 2019, catch rates of recruits in both the Inshore DFO trap survey and CPS survey increased to at or near time-series highs, however the catch rates of residuals declined to a time-series low. There was no Inshore DFO trap survey in 2020 due to COVID-19 global pandemic disruptions, however the CPS survey showed a decline in recruits to near time-series low, but an increase in residuals in 2020. No major changes in exploitable biomass available to the 2021 fishery is expected in this CMA.

Overall, the prolonged decline in recruitment throughout the AD manifested into low catch rates of old-shelled residual crab in 2017 and 2018. This is evident in size frequency distributions from large-mesh traps in the CPS surveys, with the abundance of legal-sized crab eroding to very low levels in all areas in recent years (Figure A3. 12). However, there have been some improvements in recruitment in all CMAs in the last one to three years. With the increase in residual crab over legal size in CMAs 5A, 8A, and 9A, and an incoming pulse of new-shelled recruits in CMAs 6A, 6B, and 6C, there may be some improvements expected in 2021 in the AD.

The overall trap pre-recruit abundance index for the AD was at its lowest level in a decade in 2015, but has increased to a time-series high in 2020 (Figure 39). Small-mesh traps from the CPS surveys showed modest increases in adolescent crab in all CMAs starting in 2017 and progressively increasing (Figure A3. 13). In St. Mary's Bay (CMA 9A), a particularly large pulse of adolescent crab with a mode ~63 mm was observed in 2018 and 2019, but was not apparent in 2020.

Small-mesh trap size frequency distributions from the Inshore DFO trap survey in Bonavista Bay (CMA 5A) show increases in pre-recruit adolescents in all depth strata in 2019, that was particularly maintained in the middle stratum in 2020 (Figure A3. 14). The signal of pre-recruits from Trinity Bay (CMA 6A) started showing small improvements in 2017 that increased in 2018 and continued into 2020, with the relative abundance of pre-recruits the highest in the survey time series in the last three years (Figure A3. 15). The Inshore DFO trap survey in Conception Bay (CMA 6B) captured virtually no pre-recruit adolescents in any strata from 2011 to 2017, however modest levels of adolescent males were observed over a broad range of size categories less than exploitable size in 2018 to 2020 (Figure A3. 16). While the Inshore DFO trap survey recorded catches in small-mesh traps dominated by adults, the CPS survey recorded a more even composition of adults and adolescents (Figure A3. 13). The St. Mary's Bay (CMA 9A) survey captured a relatively large pulse of adolescent crab (<95 mm CW) in the deepest stratum in 2018, which was maintained in 2019. As well, there were adolescent crab captured in the shallow stratum in 2019, the most in that stratum for the time series (Figure A3. 17).

The incidence of BCD provides a signal of the relative strength of the density of small and intermediate-sized crab and associated recruitment prospects. In Bonavista Bay there was some incidence of BCD in 2017–18 and again in 2020 in the deepest strata, however it remains at a low level (Figure A3. 18). BCD incidence has been nil in Trinity Bay for most of the time series, however there was a spike in BCD in the deepest stratum (367–549 m) in 2019 and slight increases in 2020 at all depths. After five years of almost no incidence, there were increases in BCD incidence in Conception Bay in 2020, indicative of the high density of recruits seen in the Inshore DFO trap survey.

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 two years. In the short-term beyond 2021 there are some emerging pulses of pre-recruits in the population that could lead to improvements in the fishery within a few years in some CMAs, and therefore localized improvements in overall biomass available to the fishery could occur within the next two years. However, expectations of potential for improvements in the short term should be tempered, particularly if discard levels are not lowered and exploitation rates return to the high levels of recent years.

The proposed PA indicates that with status quo removals stock status would be projected to be above the LRPs in 2021 (Figure 65).

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, with most CMAs rebounding from the recent time-series lows. It is unknown how broad-scale forthcoming improvements beyond 2021, 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

Fishery

The AD 3LNO Offshore fishery occurs on and surrounding the Grand Bank off Newfoundland's southeast coast (Figure 16). It is a massive, shallow, cold, and productive environment for Snow Crab that encompasses CMAs Nearshore (NS), Midshore (MS), Midshore Extended (MSex or MSX), 3L Extended (3Lex or 3LX), 3L Extended in 3N (3Lex3N), 3L Extended in 3O (3Lex3O), 8B, 3L Outside 200 Miles (3L200), 3N Outside 200 Miles (3N200), and 3O Outside 200 Miles (3O200) (Figure 1). Like other ADs, the numerous management areas have no biological basis and serve to differentiate fishing grounds among a large number of vessels in several fleet sectors. Virtually the entire AD consists of cold bottom temperatures, with the exception of the Southeast Shoal and the deep edges of the Grand Bank (Figure 49).

The fishing pattern normally forms a continuum extending from inshore bays of eastern Newfoundland into dense masses of effort in CMAs NS and MS, then extends farther east in a thin band along the northern Grand Bank from the MSex to 3L200 (Figure 16). The continuum ends after wrapping around the deep slope edge of Div. 3N in CMA 3N200. Discrete pockets of effort also occur in small bathymetric intrusions on the shallow northwestern portion of the Grand Bank in CMA 8B.

Overall, landings increased gradually since 2009 to a historical high of 28,750 t in 2015 (Figure 13). Landings were the lowest level in two decades in 2019 due to reductions in the TAC, but increased in 2020 to 14,839 t. The TAC has not been fully taken in CMA 8B since 2009 or in CMA 3N200 since 2011 (Figure A4. 1). Effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level until decreasing in 2019 (Figure 15). Effort was at its lowest level in over 20 years in 2020 at just over 1 million trap hauls.

Overall, standardized CPUE most recently peaked near a time-series high in 2013 and declined by 49% in 2018 to its lowest level since 1992 (Figure 17). There were increases in 2019 and 2020 to near time-series average levels. Substantial declines have occurred in all CMAs in recent years, however increases have also been seen in all CMAs in 2019 and/or 2020 (Figure A4. 2). The largest increases have been seen in CMAs 3L200, 8B, and NS in the last two years. Catch rates remain just above 5 kg/trap in CMA 3N200 in 2020.

Spatially, the fishery data are reflecting a situation where fishing remained relatively strong along the central northern Grand Bank, but depreciated substantially in fringe areas of the deep slope edges and in the discrete patches of effort in the central and western portions of the Bank (Figure 16). A substantial reduction in fishing effort was seen in CMA 3N200 in 2019 and 2020.

A pattern of annual stepwise decreases in CPUE has occurred in CMAs 3L200, 3Lex, 3N200, MS, MSex, and NS in recent years, with start-of-season catch rates similar to end-of-season catch rates from the preceding years (Figure A4. 3). This indicates relatively poor recruitment after the fishery is complete. However, in 2019 and particularly 2020, start-of-season catch rates were much improved in all CMAs, except CMA MS, indicating replenishment between fishing seasons. For the last two years catch rates have been maintained throughout the season in CMA MS.

The shape, magnitude, and shell composition of size distributions from at-sea sampling by observers changed considerably from 2008 to 2018 (Figure 18, Figure 19, Figure 20). The mode of the size distributions abruptly shifted left to approximately 92–98 mm CW in 2008–09, followed by a marked increase in the magnitude of new-shelled crab in the population during 2010–12, while the primary mode gradually moved to larger sizes. Since then, the overall magnitude of the distributions has been gradually decreasing due in large part to diminishing contributions from new-shelled crab, and the primary mode returned to 115 mm CW in 2017. These observer data clearly depict a prolonged period of strong recruitment contributing to the exploitable biomass from about 2008 to 2012, and subsequently a resource not being renewed at a high rate and gradually being eroded. The shape and shell composition of size distributions changed in 2019 to reflect a similar trend to that seen in 2010–11, with a mode of 101–104 mm CW and an increase in new-shelled crab. In 2019, the improvements in recruitment were observed during the fishery in all CMAs except 3N200 (Figure A4. 4).

Discards in the fishery remained low in 2019, with 20% or less throughout the time series (Figure 56). The majority of these discards were undersized males (both old and new-shelled) (Figure 57). Historically, there had to be high levels of soft-shell crab in the population, 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. However, the presence of a progressively depleting residual biomass and the virtual lack of soft-shell crab in the catch from 2013 to 2017, reflected a low level of soft-shell crab in the population and the broad-scale dissipation of recruitment (Figure A4. 5). However, in 2018 and 2019, small increases in soft-shell crab were observed in the latter half of the fishery.

Total mortality declined from its highest observed level in 2016 to its lowest level in 2019, however there was an increase in 2020 (Figure 54). The exploitation rate index increased by a factor of five from 2014 to 2017, but decreased back to time-series average levels in 2019 and 2020. The exploitation rate index would further decline with status quo removals in 2021.

Surveys

The trawl survey exploitable biomass index, which covers the entire AD, precipitously declined by about 75% from 2013 to 2016, but has been increasing since (Figure 34). The trap-derived exploitable biomass index has also been increasing over the last three years, but remains near the time-series low (Figure 35). All surveyed CMAs were at historical lows for trap-derived exploitable biomass in 2018, but have seen increases in the last two years (Figure A4. 6). Many surveyed CMAs remained at or near historical low catch rates of residual crab (old-shelled, legal-sized crab) in 2019 and 2020, with only CMA 3Lex showing an increase (Figure A4. 7).

Both the trawl and trap surveys show considerable spatial contraction in high catch rates of exploitable crab in recent years (Figure 8, Figure 32, Figure 33). The trawl survey index of exploitable biomass shows the resource has become increasingly localized into portions of Div. 3L; the majority of survey trawls in Divs. 3N and 3O caught no exploitable crab for the last six years, with catches particularly absent from the 3O slope edge and the Tail of the Grand Bank. However, catches of exploitable crab were seen along the slope edge of Div. 3N in the spring and fall surveys in 2019 and in the fall survey in 2020 (Figure 32, Figure 33). The CPS trap survey has shown the distribution of exploitable crab becoming contracted in the northern portion of the Grand Bank (Figure 8), however, modest signs of improvement have been seen in the last three years in the Whale Deep (in the northern portion of Div. 3O), in the last two years in the northern portion (particularly the Nose) of the Grand Bank, and in 2020 along the 3N slope edge. The CPS trap survey, where core stations do not cover fringe and marginal areas and intensively targets the MS and particularly the MSex CMAs (where fishery catch rates are the highest in the province), continues to show low levels of exploitable biomass that were noted in the trawl survey two years ago. The spatial differences in coverage of the two surveys largely account for the delayed signal in the trend of exploitable biomass indices derived from the two surveys and highlight deficiencies in the CPS survey design with respect to its ability to detect changes in the resource in a hyper-stable catch rate scenario. Once random stations are incorporated into the assessment of CPS data, some of these deficiencies may be resolved. Nevertheless, the recorded spatial contraction and lower exploitable biomass index reflected in the CPS trap survey indicates that prime fishing grounds in AD 3LNO Offshore have been experiencing declines in exploitable biomass previously signaled in the trawl survey.

Overall recruitment into the exploitable biomass was at or near time-series lows in both the trawl and trap surveys from 2015 to 2017, but has increased significantly in the last three years (Figure 34, Figure 38). This trend is most evident in CMAs 3Lex and MS (Figure A4. 7). Since 2013, the catch in the large-mesh traps has been dominated by old-shelled crab, however, in the last two years the catches have shown an increase in new-shelled crab in most CMAs (Figure A4. 8).

CPS trap survey size frequency distributions show the movement of a recruitment pulse in CMAs 3Lex, MS, MSex, and NS advancing as the primary mode from sub-legal size in 2009–10 to about 115 mm CW in 2015–17 (Figure A4. 8). An increase in recruitment has been observed in these CMAs starting in 2019, with the mode centered around legal size. Catch rates have improved in most CMAs, with a particularly large increase in 3Lex in the last two years, after very low catch rates in 2018. Recruitment prospects are positive based on the increases seen in the last two years, indicating potential increases in the exploitable biomass in 2021. However, catches in the large-mesh traps in CMAs 3L200 and 3N200 are composed primarily of old-shelled crab centered above legal size in 2020.

The trawl survey pre-recruit abundance index steadily declined since 2009 to its lowest level from 2014–16 (Figure 34). This index has been steadily increasing since then. The largest aggregations of pre-recruit catches were found throughout Div. 3L, and the southeast edge of the Grand Bank in Div. 3N (Figure 40, Figure 41). The CPS pre-recruit index has increased since 2017 to near time-series highs in 2018–20 (Figure 39), with increases primarily in CMAs 3Lex, MS, MSex, and NS (Figure A4. 9). The small-mesh traps indicate potential for localized improvements in these CMAs in the next few years, with large catches of adolescent crab centered around 75 mm CW. The pulse of adolescent crab in CMA 8B, which first appeared in the small-mesh traps in 2012 and can be seen centered around progressively larger sizes, appears to have dissipated in 2019 and 2020. However, the leading tail of this pulse could have led to the increase in CPUE in the fishery in this CMA in the last two years (Figure A4. 2). A small pulse of adolescents ranging from 60 mm to legal size was seen in CMA NS in 2020, of which there has been very few adolescents caught in the small-mesh traps in the CMA in the last 10 years.

Relative to the 1995–2003 period, few small crab have been captured by the trawl survey during the past decade (Figure 42). The strong pulse of pre-recruits observed in the survey from 2008 to 2010 most likely emerged from the relatively strong pulse of small crab captured during 2001–03. The small spike in small crab abundance seen in the survey in 2010 was also seen in AD 3Ps. There has been a lack of sustained strong pulses of small crab in the survey since the early 2000s, however there were small signals of small crabs in 2017 and again in 2019–20 that may indicate future improvements if sustained.

Size-at-terminal molt in males has oscillated throughout the time series and the maturation of 50% of males has been just below exploitable size for the last few years (Figure 64). It is unknown if this trend will continue, but trends should be monitored closely moving forward.

The proposed PA indicates that with status quo removals stock status would be projected to be above the LRPs in 2021 (Figure 65).

This AD essentially constitutes the heart 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

Fishery

The AD 3Ps fishery occurs off the south coast of Newfoundland (Figure 1, Figure 16). In the inshore, it predominately occurs within the confines of two major bays: Fortune Bay (CMA 11E) and Placentia Bay (CMA 10A). While the land and bathymetrical features partition Fortune Bay as relatively discrete from the remainder of the AD, Placentia Bay forms a continuum with the expansive offshore. Historically, most major aggregations of Snow Crab have been found in a deep-water trough (i.e., maximum 275 m depth) extending out of Placentia Bay and into the Halibut Channel in CMA 10B (Figure 2). In terms of scale, the fisheries in all other management areas of the AD are small compared to CMAs 10A and 10B. Like other ADs, there is little scientific basis for the numerous CMAs and fishery and resource trends among CMAs are often synchronous.

Relative to other ADs along the NL continental shelves, AD 3Ps is shallow. The tops of the two major offshore banks, the St. Pierre Bank in the west and the Green Bank in the east (Figure 2), are both shallower than 100 m depth and the intersecting Halibut Channel is less than 200 m depth throughout. These shallow areas of the AD, where the bulk of the fishery occurs (Figure 16), are cold, but temperatures increase abruptly at the slope edges (Figure 49).

Landings declined from a recent peak of 6,700 t in 2011 to a time-series low of 1,200 t in 2017 (Figure 13). Landings have increased since then to about 3,200 t in 2020. Increased landings were consistent across CMAs, with the exception of CMA 11W, which saw decreased landings in 2020 and only one third of the TAC was taken (Figure A5. 1). Effort declined in 2020 to the lowest level in over 20 years (Figure 15). The larger fisheries in CMAs 10A and 10B play a particularly strong role in influencing the overall trends observed in the AD.

Standardized fishery CPUE increased from time-series low levels in 2016 and 2017 to nearing time-series high levels in 2020 at around 16 kg/trap (Figure 17). CPUE in CMAs 10A, 10B and 11S improved from particularly large and precipitous declines in previous years, and CMA 11E also showed signs of improvement (Figure A5. 2). CPUE declined in CMA 11W from the time-series high in recent years. In 2016 and 2017, fishery catch rates in all CMAs (with the exception of CMA 11W) began below or near 5 kg/trap (Figure A5. 3), however, the start-of-season and end-of-season CPUE levels were higher than observed in the previous three years in 2018–20. Start-of-season catch rates were particularly high in CMAs 10A, 10B, and 11S in 2020. CPUE in CMA 11E has shown no depletion throughout the season in the last three years, and instead, increased as the season progressed. Standardized CPUE has been very variable throughout the season in CMA 11W in recent years.

For those areas with observer sampling in 2019 (CMAs 10B, 11E, and 11S), in-season data were consistent with the logbook data in depicting an improving fishery in recent years in CMAs 10B and 11S, and low catch rates in CMA 11E (Figure A5. 2, Figure A5. 4). The large increase in new-shelled crab observed in CMA 10B in 2018 was much smaller in 2019, with the catches less dominated by recruits. As well, the large pulse of recruits observed in Fortune Bay (CMA 11E) in 2018 was not observed in the catches in 2019. The high catch rates in Fortune Bay in 2018 were based on very few traps sampled, and is likely not representative of the catches that year.

Discards comprised half the catch in 2016 and 2017, but declined sharply in 2018 and 2019 to near time-series lows (Figure 56). In the past decade, the majority of discards were under-sized old-shelled crab, a high proportion of which were likely terminally molted adults (Figure 57). After an extended time with few soft-shell crab reported in the catch, soft-shell occurrences became more prominent from 2014 to 2017, but decreased in 2018 and 2019 (Figure A5. 5). In 2017, levels of soft-shell crab in the catch increased throughout the duration of the fishery. This was followed by a recruitment pulse of exploitable crab in 2018 (Figure 34). The greatly reduced proportion of discards in the catch in 2018 and 2019 is attributed to the increase in available exploitable crab that outcompete small or soft-shelled crab at a trap. A continuation of current measures is recommended to re-establish a strong residual biomass to continue to help minimize discards.

Previous large quota reductions, followed by an increase in exploitable biomass resulted in the exploitation rate index being at a low level in recent years and status quo removals would result in a further reduction of the overall exploitation rate index to a time-series low in 2021 (Figure 60), consistent across all CMAs (Figure A5. 6).

Overall, fisheries data are suggesting a recovery phase is occurring for the fishery in this AD and current low exploitation rates are likely to help bolster forthcoming improvements.

Surveys

The DFO multispecies trawl survey did not take place in AD 3Ps in 2020 due to COVID-19 global pandemic disruptions. The in-season trawl survey exploitable biomass index was at a time-series low in 2016, but has improved since then (Figure 34). In the absence of updated trawl data, the relationship between the trawl exploitable biomass index and the CPS trap exploitable biomass index was examined to estimate a conceivable trawl exploitable biomass index for 2020 (Figure 31). This estimate suggested a slight increase in exploitable biomass index in 2020. The post-season trap survey index shows an increase in the exploitable biomass index throughout most of the AD, near the time-series high (Figure 35, Figure A5. 6). The CPS trap survey was not or only partially conducted in most areas in 2015 and 2016 because of poor resource status (Figure 8). Therefore, no biomass indices were available from that survey for Placentia Bay or Halibut Channel in those years. The observed increase in exploitable biomass is attributed to increased survey catch rates of residual crab in CMAs 10A and 11S and the maintenance of high levels of residual and recruit crab observed in CMA 10B (Figure A5. 7). The Inshore DFO trap survey in Fortune Bay (CMA 11E) also did not take place in 2020 due to COVID-19 global pandemic disruptions, however in 2019, total catch rates of exploitable crab were very low in all strata, reflecting the same trends as the CPS survey in that CMA (Figure A5. 8).

On the broad-scale, the residual biomass in AD 3Ps, represented by intermediate- to old-shelled legal-sized crab, began to decline after 2010, but significantly increased in 2018 and has remained near that level (Figure 34). 2018 was the first year since 2011 that the trawl survey captured any relatively large catches of exploitable crab anywhere in the AD (Figure 33). The large catches of exploitable crab were found in CMAs 10A and 10B in 2019, with virtually no crab caught in the other CMAs in the spring trawl survey. This trend was observed in the CPS trap survey in 2020 with all catches greater than 5 kg/trap reported in CMAs 10A and 10B (Figure 8).

Size frequency distributions from the CPS survey showed substantial declines in catch rates of legal-sized old-shelled crab in all occupied CMAs from about 2010 to 2014 (Figure A5. 9). The ability to define short-term prospects was compromised by the abandonment of the CPS survey in most areas in 2015 and 2016 and it is difficult to determine at which point prior to 2017 declining trends started to reverse. However, since 2017, the CPS trap survey observed substantial catch rates of legal-sized new-shelled and old-shelled crab in CMAs 10A and 10B. There was a small signal of catches of new- and old-shelled crab in the large-mesh traps in CMAs 11E and 11S in 2020. This level of catch has not been observed in this survey since 2013 (noting the absence of complete surveys in 2015 and 2016). The CPS survey has not been completed in CMA 11W since 2012.

The decline in exploitable biomass to a low in 2016 and the subsequent increase in 2017 reflect trends in recruitment. Overall recruitment into the exploitable biomass had been at its lowest observed level in recent years, but started increasing in 2017 (Figure 34, Figure 38). Recruitment into the exploitable biomass was at a time-series high in 2019, which was driven by CMAs 10A and 10B (Figure A5. 7). There was a slight decrease in recruits in 2020, but remained near time-series high levels. There was a significant improvement in the pre-recruit abundance index in 2018 (with high variability based on two very large catches), but a decrease in 2019 (Figure 34, Figure 39). However, the 2019 pre-recruit abundance index level was still a decadal high suggesting short-term prospects have improved significantly from the recent 2013–16 low period. The same trends of increasing trawl pre-recruit index have also been seen in the CPS pre-recruit abundance index (Figure 39).

The small-mesh traps from the CPS survey indicate potential for localized improvements in CMAs 10A and 10B in the next few years (particularly CMA 10B), with large catches of adolescent crab along a wide range of sizes since 2017 (Figure A5. 10). However, the pulse of adolescents appears to have diminished in 2020, some of which may have grown to be caught in the large-mesh traps. Prospects for Fortune Bay (CMA 11E) remain relatively low, with very little sign of significant recruitment prospects in the next two to four years based on 2019 catches (Figure 41, Figure A5. 10, Figure A5. 11). Small-mesh traps from the Inshore DFO trap survey in Fortune Bay have captured virtually no adolescent crab of any size for the past six years, however there was a very small signal seen in 2019 (Figure A5. 11).

The 2018 recruitment pulse likely corresponds with the presence of a relatively large mode of small crab in the trawl survey from 2009 to 2011 (Figure 42, Figure 53). The prior major prolonged pulse of crab of this size occurred from 2003 to 2005. Subsequently, the pre-recruit biomass index increased to a very high level in 2009, a lag period of four to six years from detection of small crab in the survey. In extension, the exploitable biomass index was high from 2009–11. The delayed arrival of the 2009–11 pulse of small crab to recruitment was likely partially a result of a significant skip-molting event that occurred in AD 3Ps in 2012 and 2013.

Size-at-terminal molt in males has oscillated dramatically throughout the time series (Figure 64). There is no clear trend in male size-at-terminal molt in this AD, however trends should still be monitored closely moving forward.

The proposed PA indicates that with status quo removals stock status would be projected to be above the LRPs in 2021 (Figure 65).

Overall, prospects in AD 3Ps are favourable. The resource appears to be recovering, with marked improvements in major stock status signals. The low exploitation rates in 2017 and 2018 are not thought to be inconsequential to this improvement. It is anticipated that if harvest rates remain relatively controlled in the coming years, that an improved fishery can be sustained beyond 2021.

ASSESSMENT DIVISION 4R3PN

Fishery

The AD 4R3Pn fishery occurs along the west and southwest coasts of Newfoundland in and adjacent to the Gulf of St. Lawrence. The area encompasses nine CMAs (Figure 1). The offshore CMA OS8 is separated from the numerous inshore CMAs by a line 8 nm from headlands of the shoreline. There is little fishing activity in the southwestern CMAs 12A and 12B and the largest scale fishery occurs in Bay St. George (CMA 12C).

The bathymetry off the west coast is characterized by a shallow water nearshore plateau that borders the deep Esquiman Channel (Figure 2). The bathymetry off the south coast is characterized by the presence of the Burgeo Bank extending through CMA 12A into NAFO Subdiv. 3Pn. Bottom temperatures in this AD are the warmest along the NL shelf (Figure 49), and it is comparatively unproductive for Snow Crab. Fishery CPUE is consistently low compared to other ADs (Figure 17) and the fishery has historically tended to be opportunistic in nature, with harvesters choosing to prosecute it when commercial quantities of Snow Crab are believed to be present.

Overall landings recently peaked at 900 t in 2013, but have steadily declined to a time-series low of 167 t in 2020 (Figure 13). These trends are not consistent across the AD, with increased TAC and landings in CMAs 12C, 12E, and 12F in 2020 (Figure A6. 1). Effort has remained at a fairly low level (~100,000 trap hauls) since 2012, and declined to near time-series low level of around 22,000 trap hauls in 2020 (Figure 15). CMA 12G was closed to fishing in 2020 upon the request of industry representatives.

Logbook return rates in AD 4R3Pn have been variable throughout the time series and tend to be slower than in most of the other ADs, however only approximately 37% of landings were available in the logbook dataset for this assessment (Figure 4). Some of this delay may have been due to COVID-19 restrictions. Incomplete datasets create uncertainty in calculating and interpreting logbook CPUE.

Standardized CPUE has been low throughout the time series relative to most other ADs; however, it increased to a time-series high in 2020 to around 7 kg/trap (Figure 17). This primarily reflects trends of increased CPUE in 2020 in CMAs 12C, 12D, and 12E (Figure A6. 2).

A pattern of annual stepwise decreases in CPUE occurred in most CMAs from 2015 to 2018, with start-of-season catch rates similar to end-of-season catch rates from the preceding years (Figure A6. 3). This indicates relatively poor recruitment after the fishery is complete. However, in 2019 and 2020, start-of-season catch rates were somewhat improved in most CMAs, indicating some replenishment between fishing seasons. In 2020, this was seen primarily in CMAs 12C, 12D, and 12E.

Fishery observer coverage in AD 4R3Pn has been extremely poor (Figure A6. 4) with data only collected in CMAs 12E and 12F in 2019. The limited data showed an exploitable biomass dominated by recruits with very few crab under legal size. Discards levels have been low in this AD in recent years (Figure 56) and mostly consist of undersized crab (Figure 57). Overall, more common incidences of soft-shelled catches were evident in 2016 and 2017, but absent in the limited observed catch in 2018 and 2019 (Figure A6. 5).

The overall exploitation rate index declined to the lowest levels in the time series in 2020 (Figure 60) reflecting trends in the major fishing areas for which there is data (Figure A6. 6). Status quo removals in 2021 would maintain the same level of exploitation rate index.

Surveys

Exploitable biomass index has been low throughout the time series relative to most other ADs (Figure 35) with low levels of residual crab in the population (Figure 38). The trap survey exploitable biomass index most recently peaked in 2012 and declined to a time-series low in 2017–18 (Figure 35). However, there have been increases in the exploitable biomass since, which have been greatest in CMAs 12C and 12EF (Figure A6. 6). Overall total catch rates in 2020 declined from the high of 2019, however, are higher than the low of around 1 kg/trap observed during the 2017 survey (Figure 38). Residual crab catch rates remain very low.

The abrupt increase in the exploitable biomass index in 2011 (Figure 38) was associated with sharp increases in recruitment (new-shelled legal-sized crab) in Bay St. George (CMA 12C), and the Inner and Outer Bay of Islands (CMAs 12F and 12E), and an increasing trend in Bonne Bay (CMA 12G) (Figure A6. 7). Recruitment into the exploitable biomass was low from 2014 to 2017, but survey data from 2018 to 2019 showed localized improvements, particularly in CMAs 12C and 12EF. There was a decrease in the catch rates of recruits in 2020, however, it remains at a high level for the time series.

Size frequency distributions from large-mesh traps from the CPS survey showed an influx of recruitment into the exploitable biomass in most CMAs during 2010–12 that dissipated up until 2018 (Figure A6. 8). A large recruitment pulse nearing exploitable size was observed in Bay of Islands (CMA 12EF) in 2018 and continued into larger sizes in 2019 and 2020, to a degree. After five years with virtually no signs of recruitment, there was a signal of recruitment into the exploitable biomass in Bay St. George (CMA 12C) in 2018–20. For the first time since 2013, there were catches of recruits in CMA 12G in 2019, and a much larger pulse in 2020. Small-mesh trap size frequency distributions tracked approaching modes of adolescent males quite well from 2008 to 2010, immediately preceding the improvements in recruitment into the biomass (Figure A6. 9). The signal of short-term recruitment prospects (i.e., >75 mm CW adolescents) from these traps has been improving in recent years in some CMAs, with a pulse of small crab centered near 55 mm CW that emerged in CMA 12EF in 2016 and continues to show a positive, strong signal moving toward exploitable size. A modest increase in small crab centered near 70–80 mm was observed in CMA 12C from 2017–19, which may be the recruits now seen in the large-mesh traps in the last couple years. A signal of small crab centered around 70–80 mm was also observed in CMA 12G in 2020. These trends indicate the possibility of localized improvements in one to two years.

Overall, the exploitable biomass has shown improvements in the last three years, however there are few residual crab. Poor monitoring coverage throughout this AD, particularly outside the main fishing areas of CMAs 12C, 12EF, and 12G, results in large uncertainty in the biomass estimates provided in 2020 and predictions for 2021. Caution is warranted when developing conclusions from these estimates. This AD is not included in the proposed PA due to ongoing data deficiencies.

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FIGURES

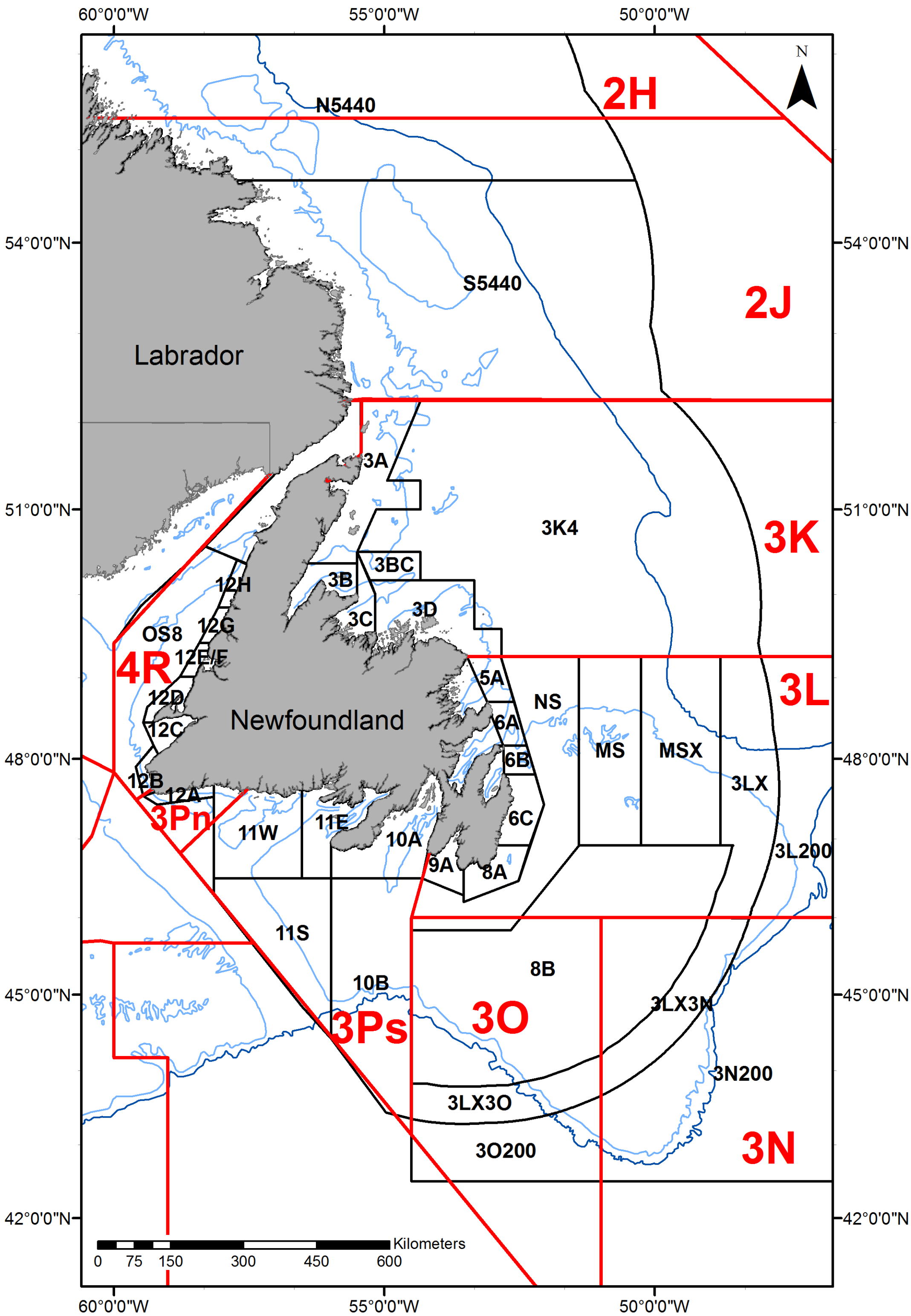

Figure 1. North Atlantic Fisheries Organization (NAFO) Divisions (red lines) and Newfoundland and Labrador Snow Crab Management Areas (CMAs) (black lines).

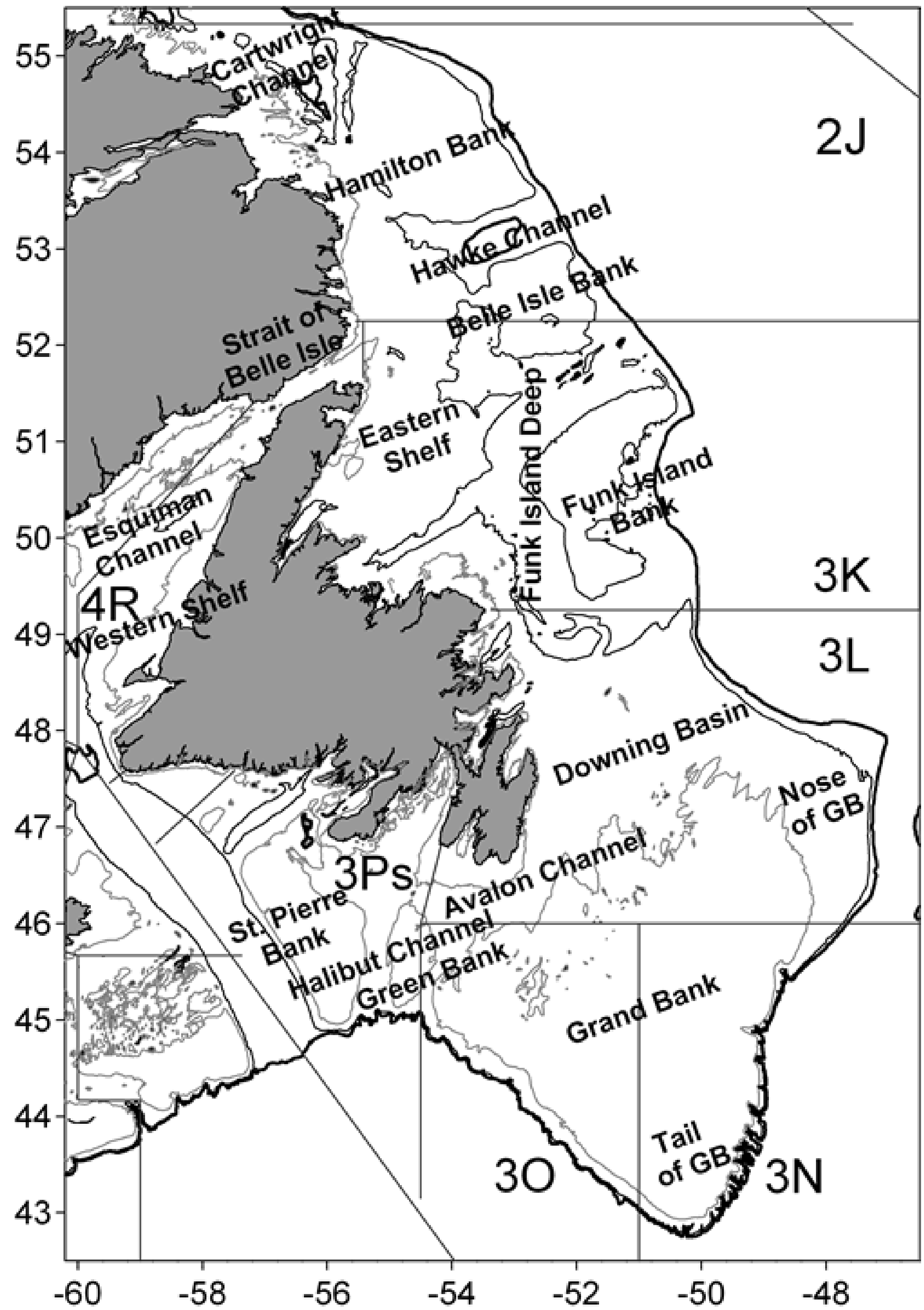

Figure 2. Map of Newfoundland and Labrador Continental Shelf showing place names, bathymetrical features, and NAFO Divisions.

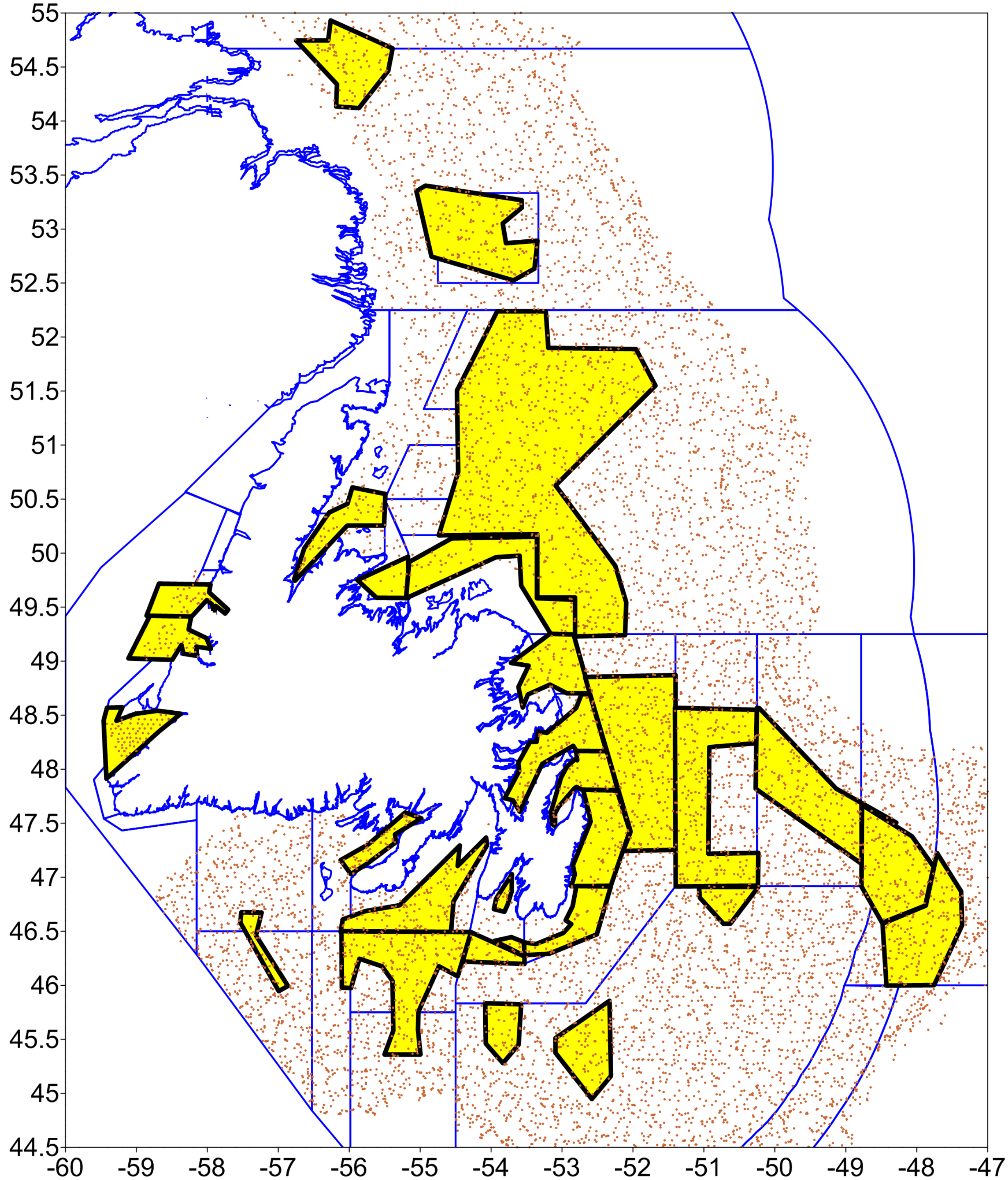

Figure 3. Map of Ogmap vertices (red dots) and strata developed for biomass estimation from Inshore DFO and CPS trap surveys (yellow polygons).

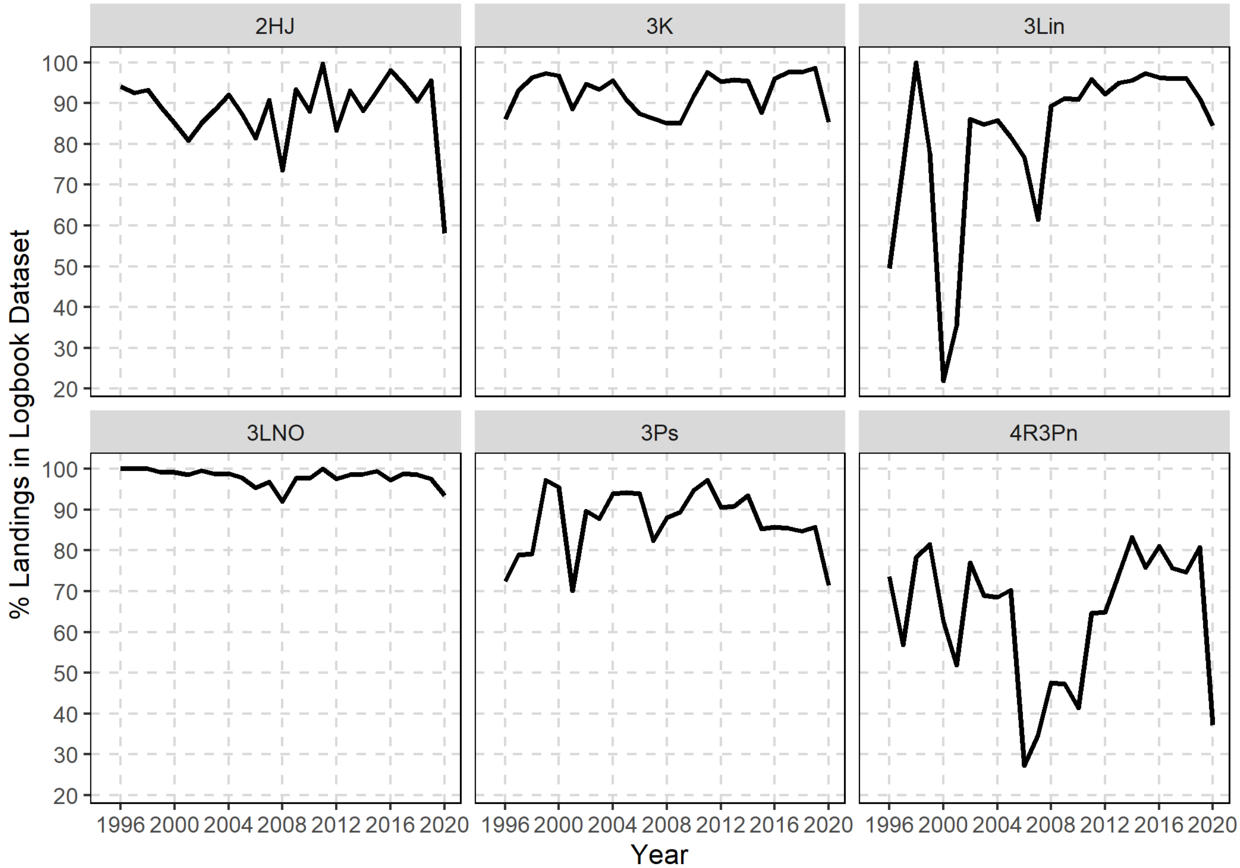

Figure 4. Logbook return rates by Assessment Division and year (1995–2020).

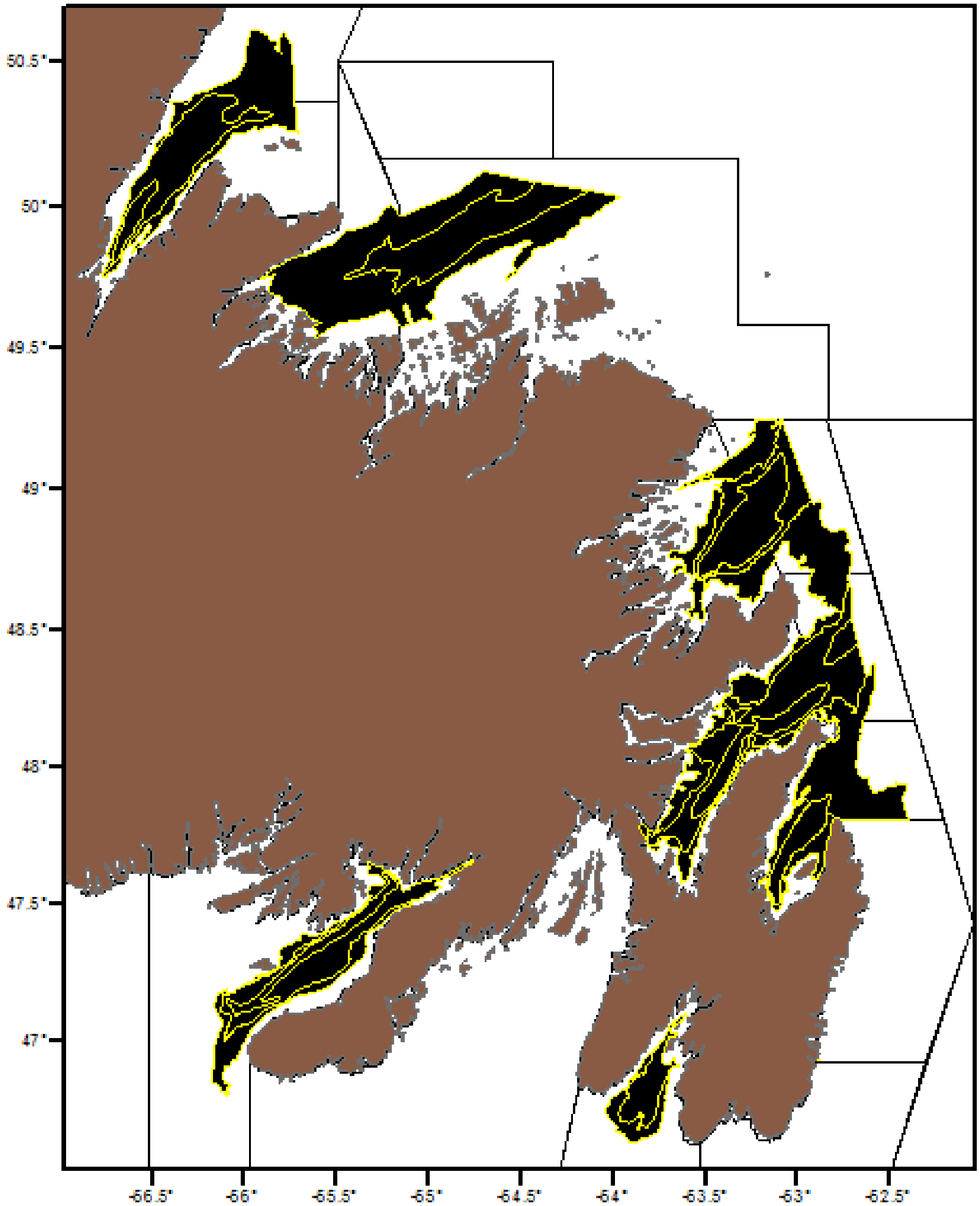

Figure 5. Strata occupied during Inshore DFO trap surveys.

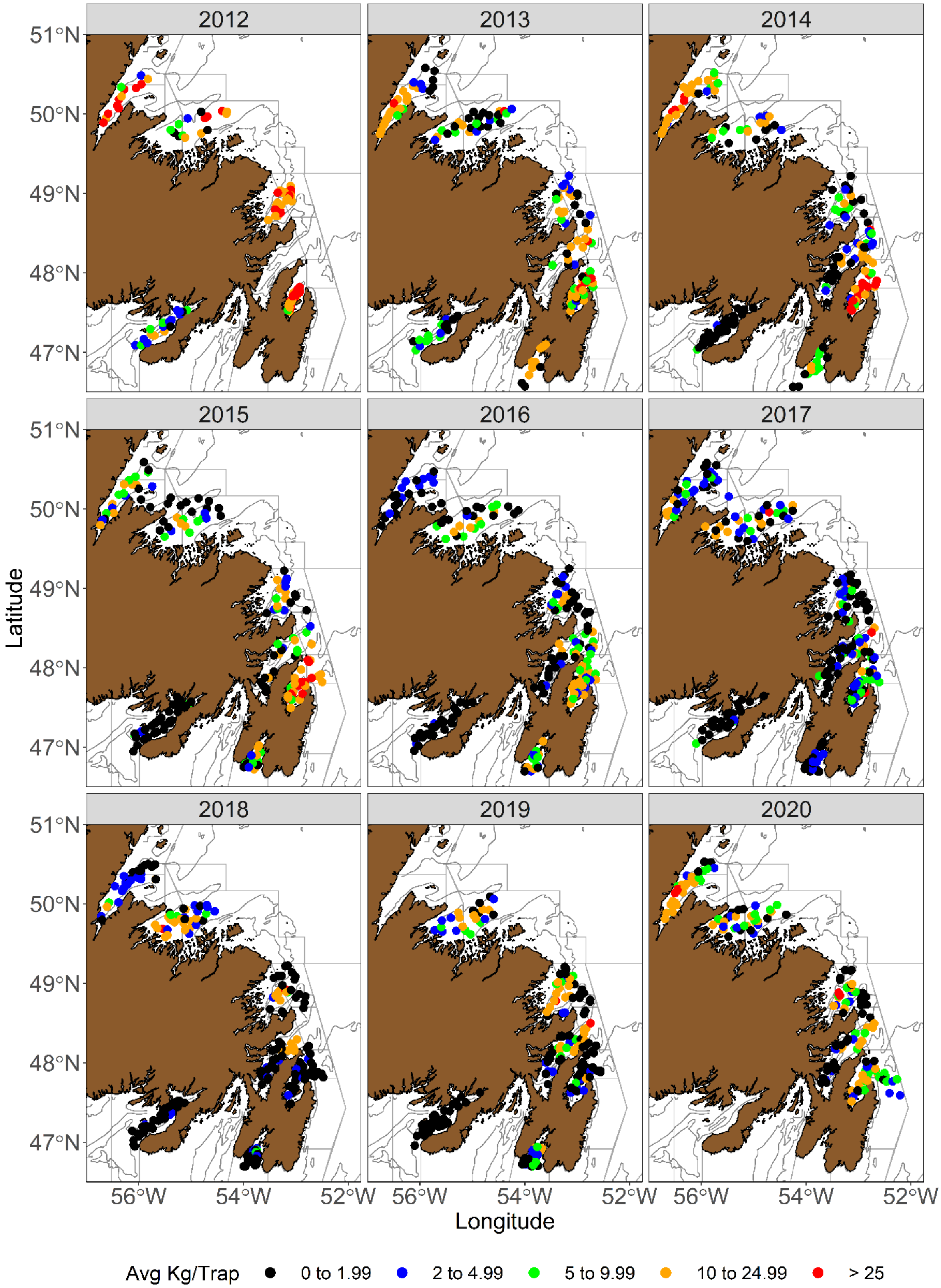

Figure 6. Location of set positions and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the Inshore DFO trap surveys (2012–20).

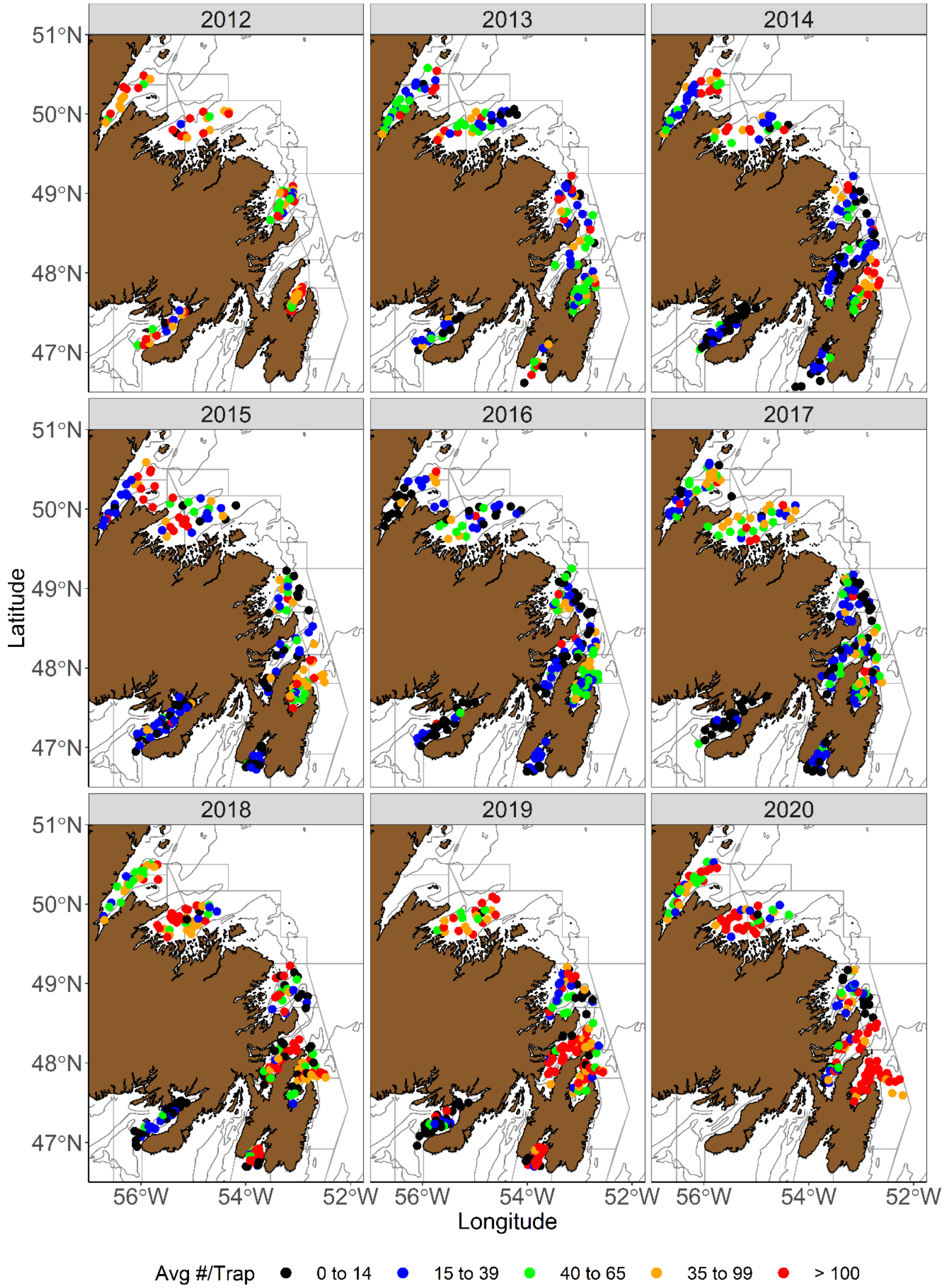

Figure 7. Location of set positions and CPUE (#/trap) of all Snow Crab in small-mesh traps from the Inshore DFO trap surveys (2012–20).

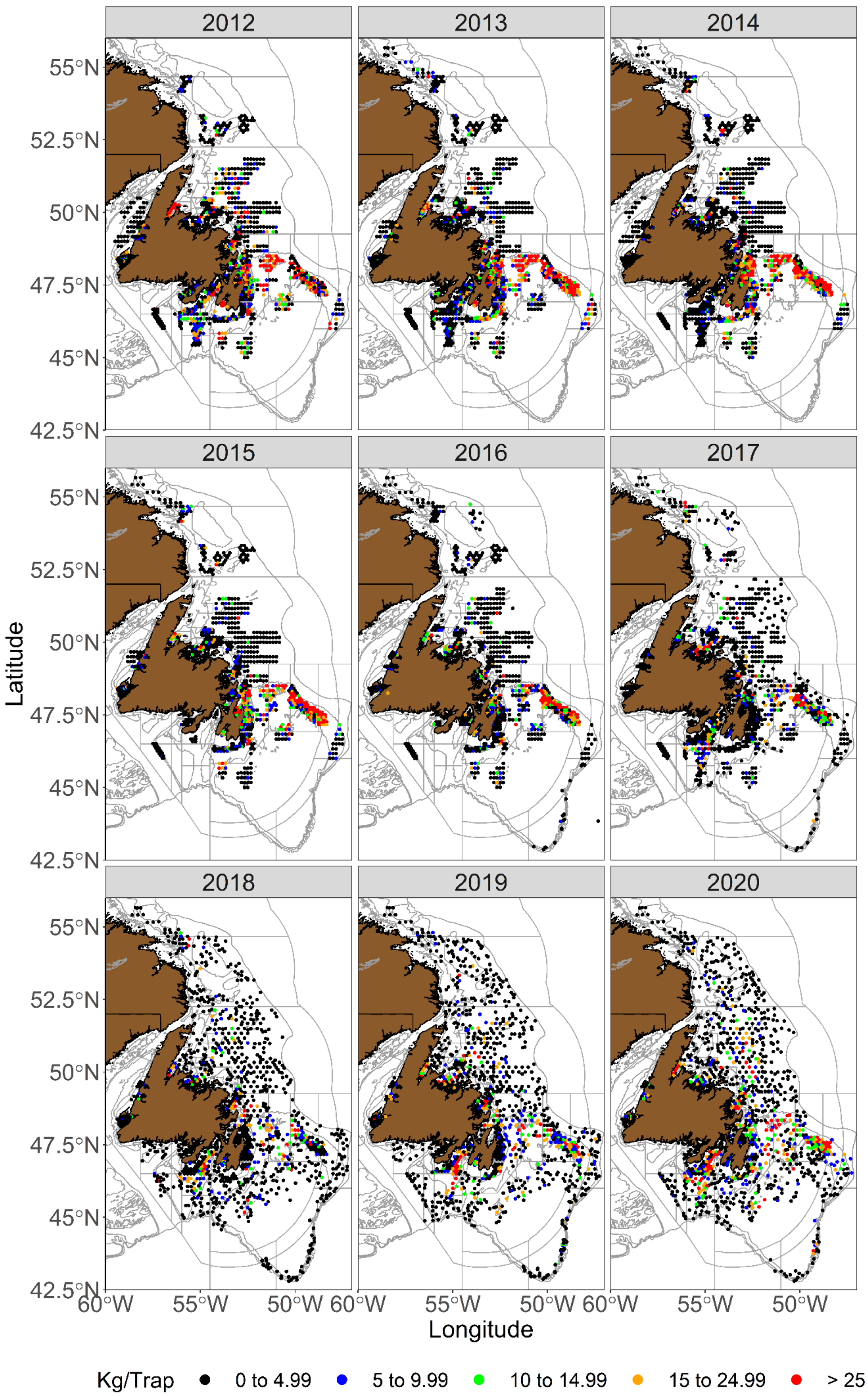

Figure 8. Location of set locations and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the Collaborative Post-Season (CPS) trap survey (2012–20) and Torngat Joint Fisheries Secretariat trap survey (2013–20).

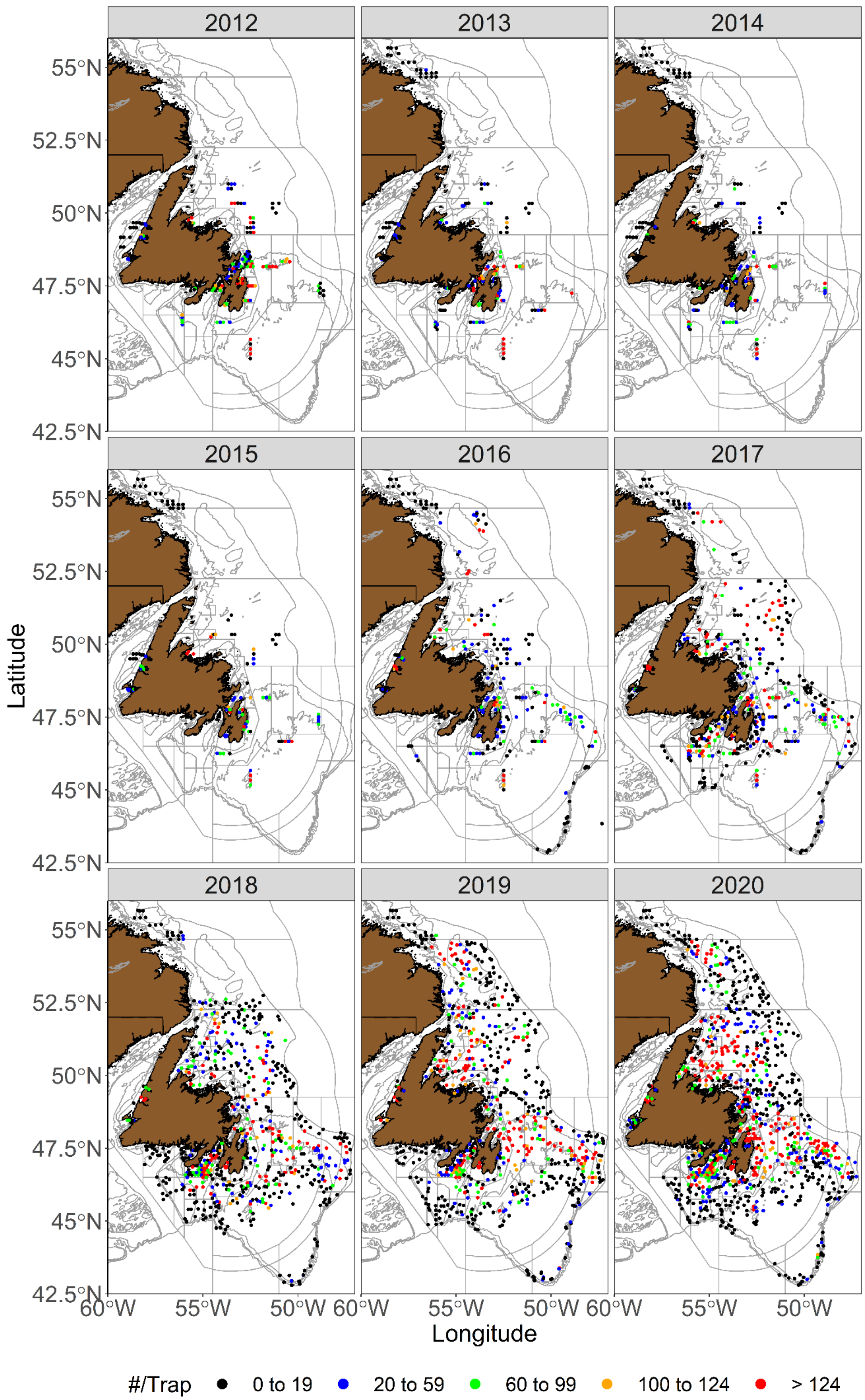

Figure 9. Location of set locations and CPUE (#/trap) of Snow Crab in small-mesh traps from the CPS trap survey (2012–20) and Torngat Joint Fisheries Secretariat trap survey (2013–20).

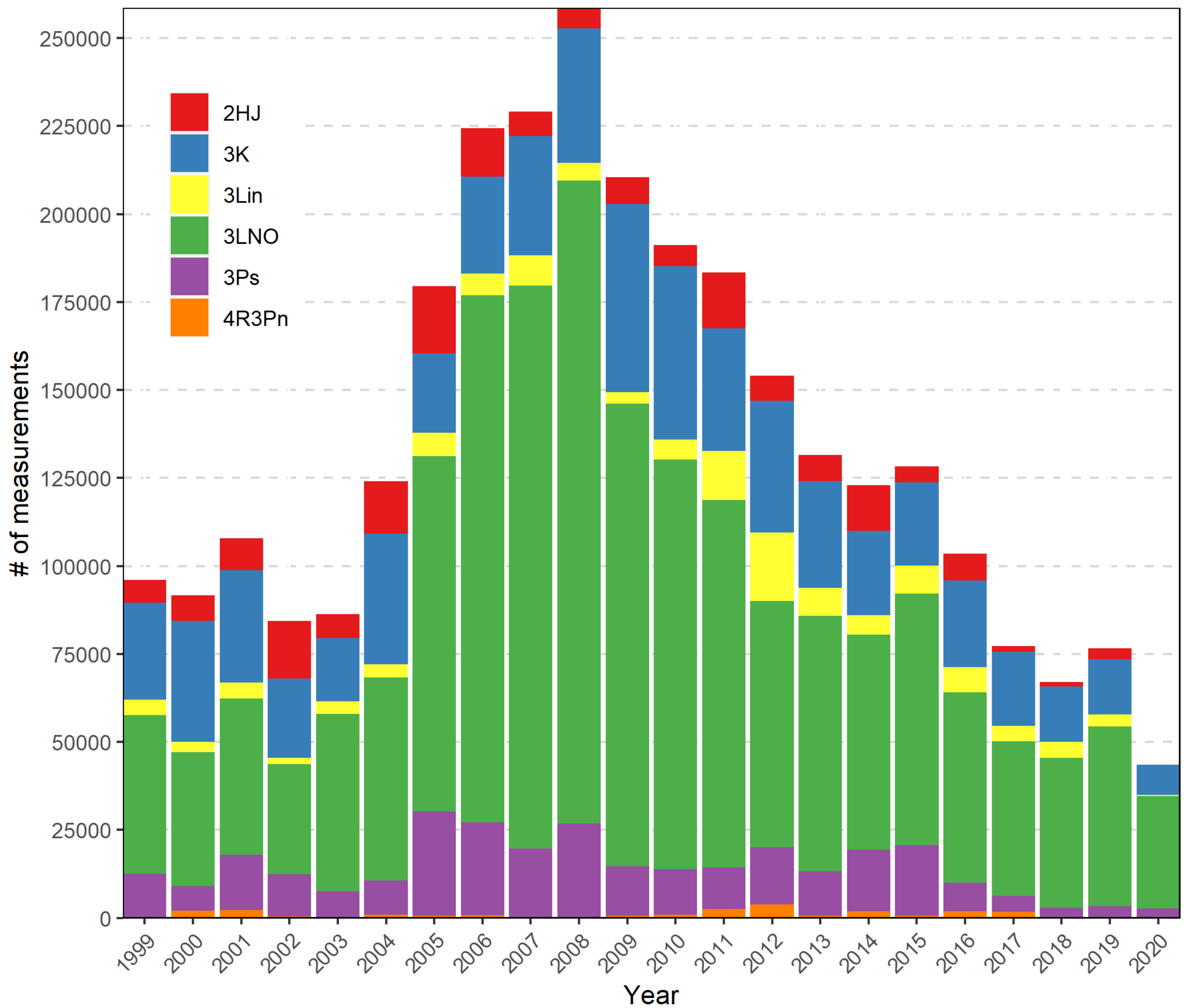

Figure 10. Annual at-sea observer sampling by Assessment Division (1999–2020).

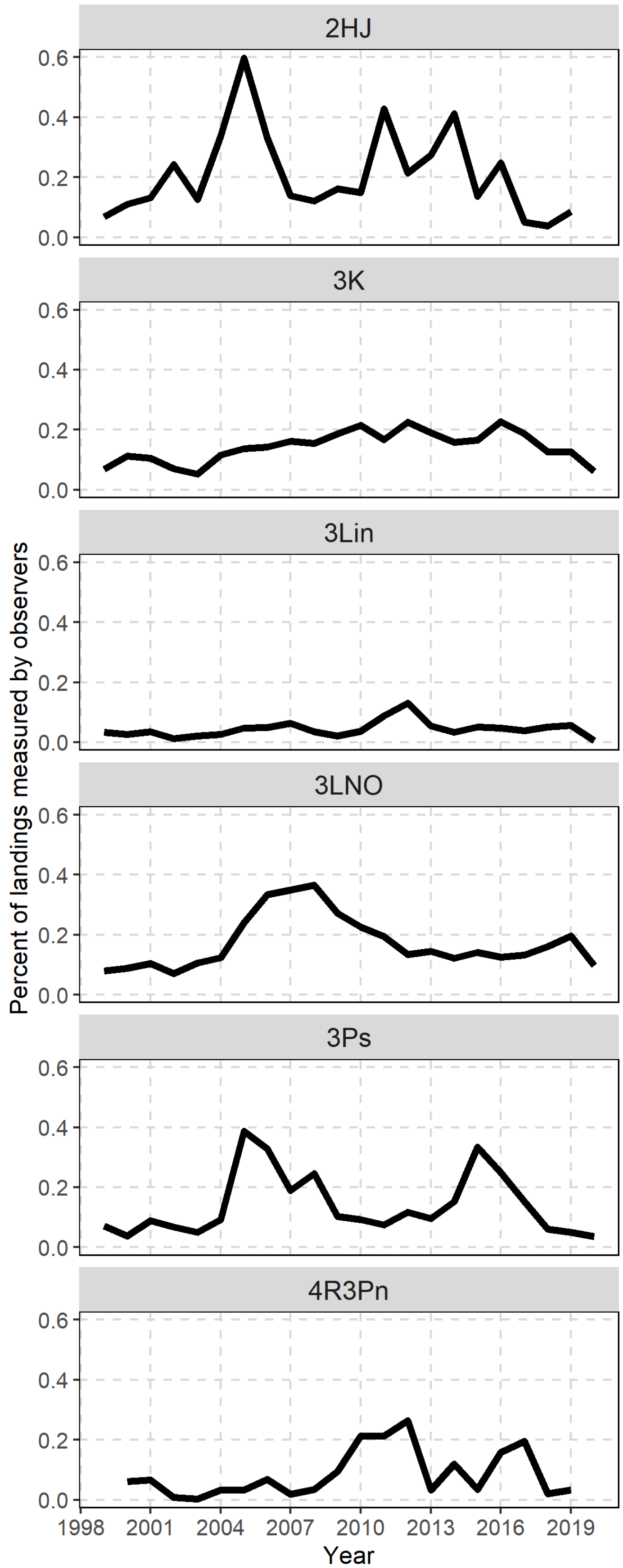

Figure 11. Percent of landings with annual observer sampling by Assessment Division (1999–2020).

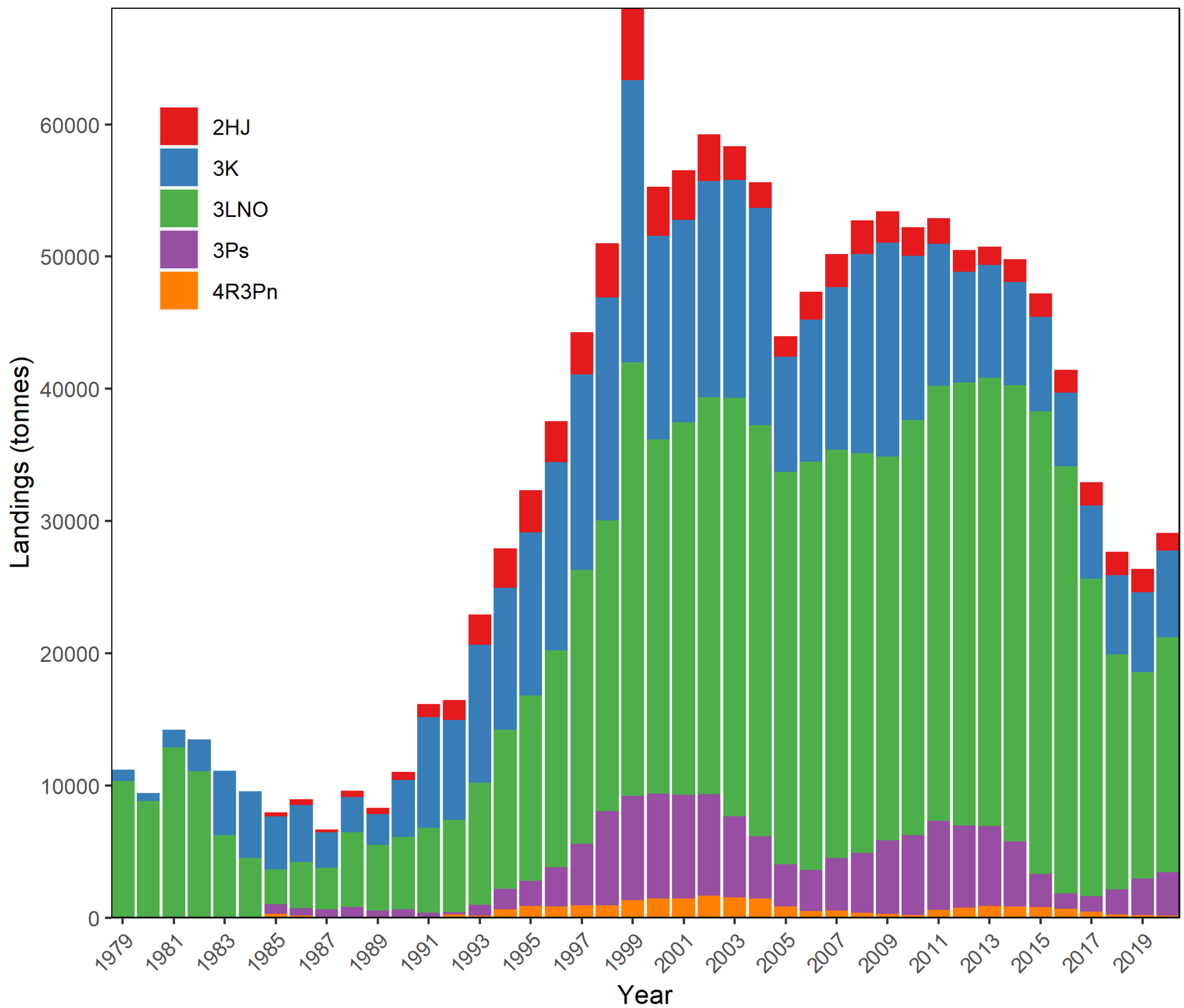

Figure 12. Annual landings (tonnes) of Snow Crab by Assessment Division (3LNO = 3LNO Offshore + 3L Inshore) (1979–2020).

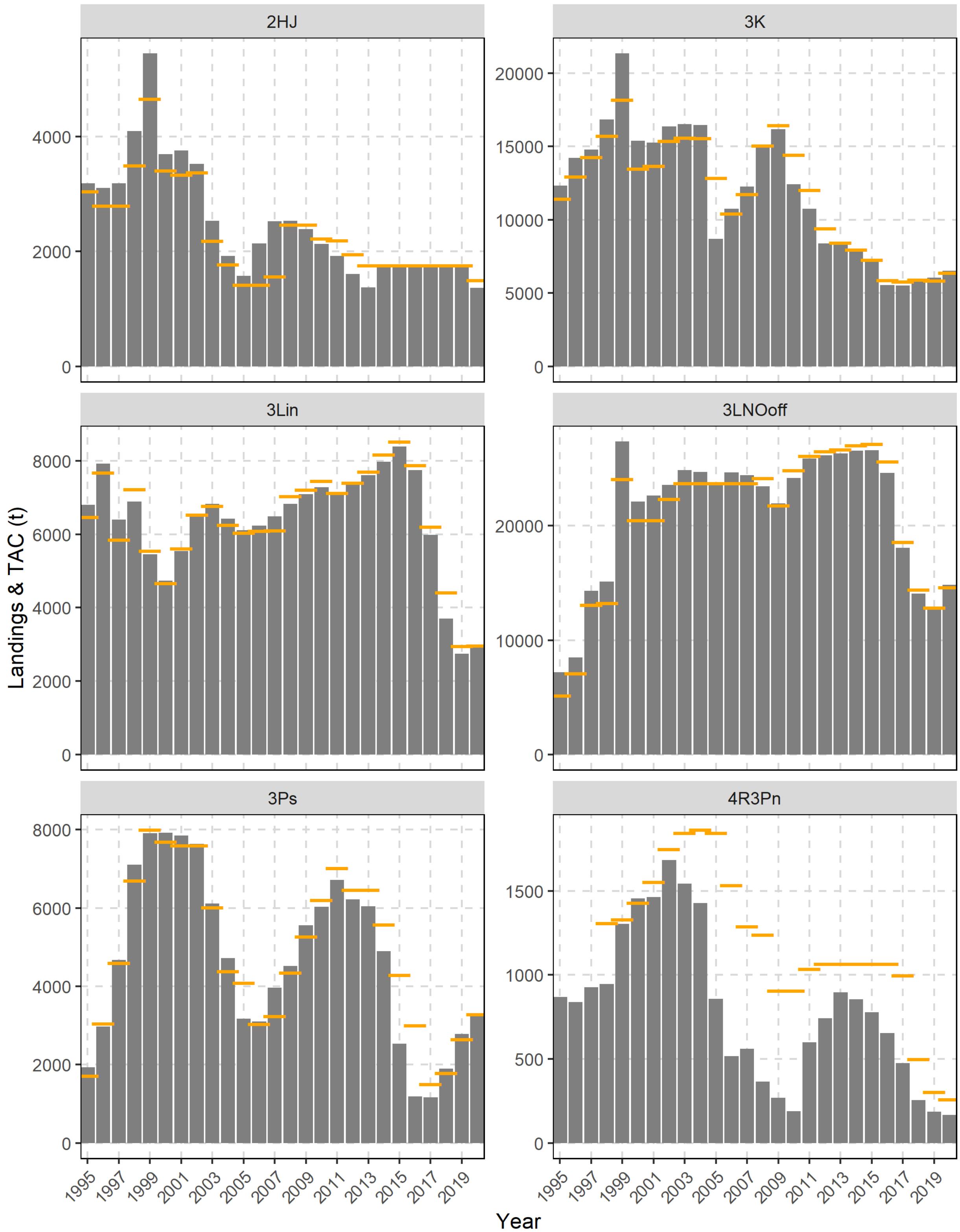

Figure 13. Annual landings (t) of Snow Crab and total allowable catch (TAC) by Assessment Division (1995–2020).

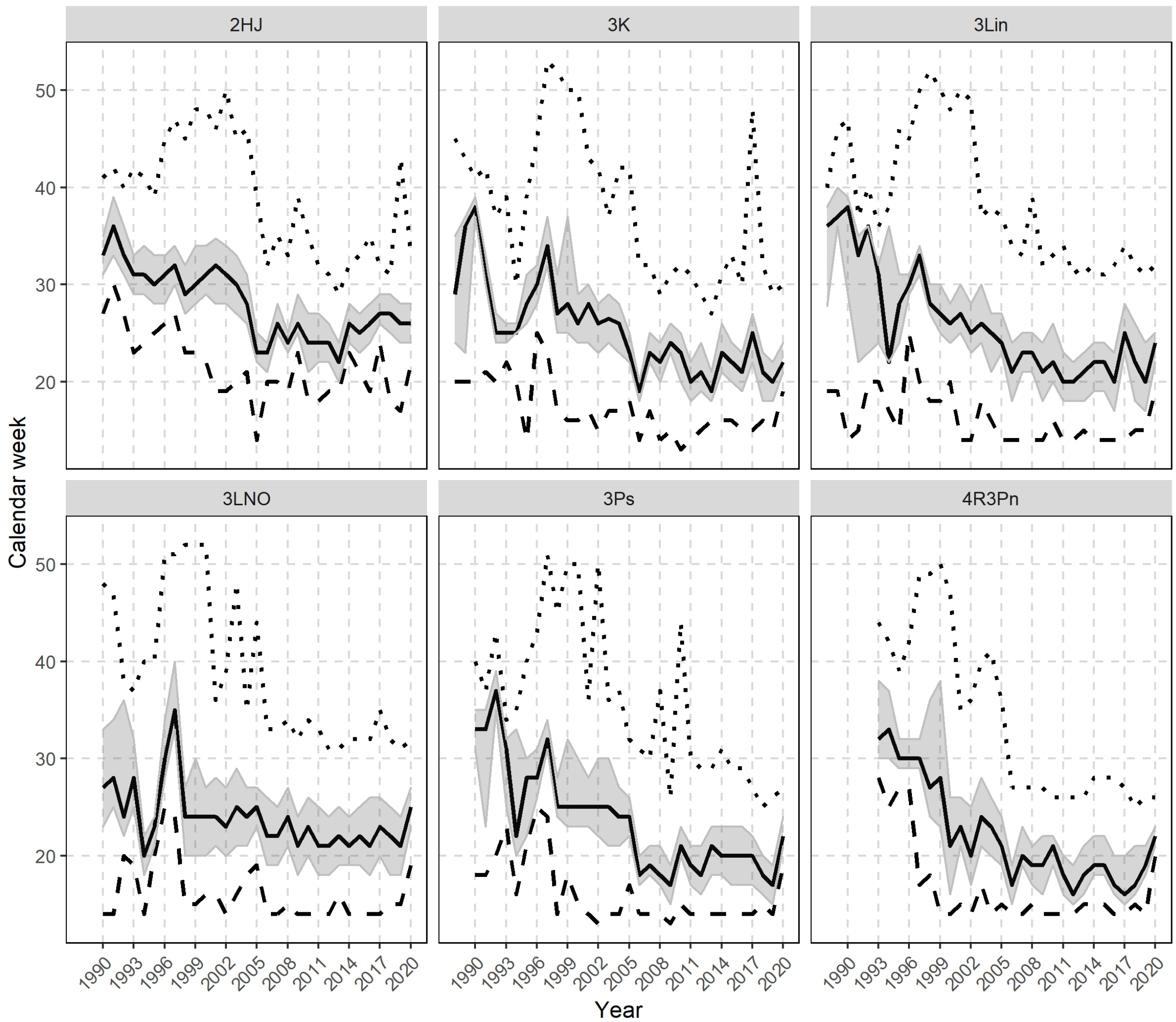

Figure 14. Trends in timing of the fishery by Assessment Division. Solid line = median timing of fishery, dashed line = start of fishery, dotted line = end of fishery, and shaded area = fishery 25–75% complete.

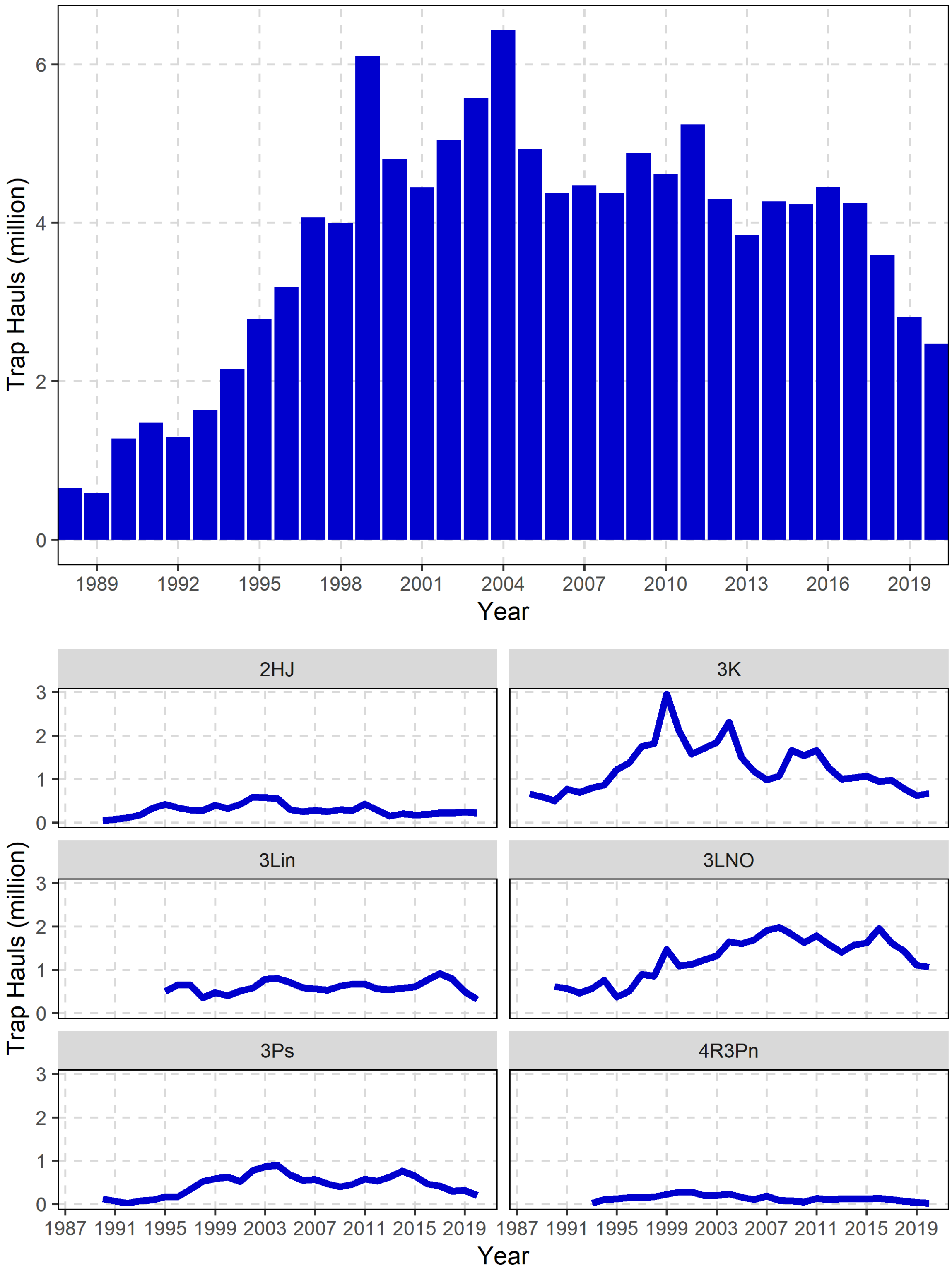

Figure 15. Estimated effort (number of trap hauls) in total (top) and by Assessment Division (bottom), by year (1988–2020).

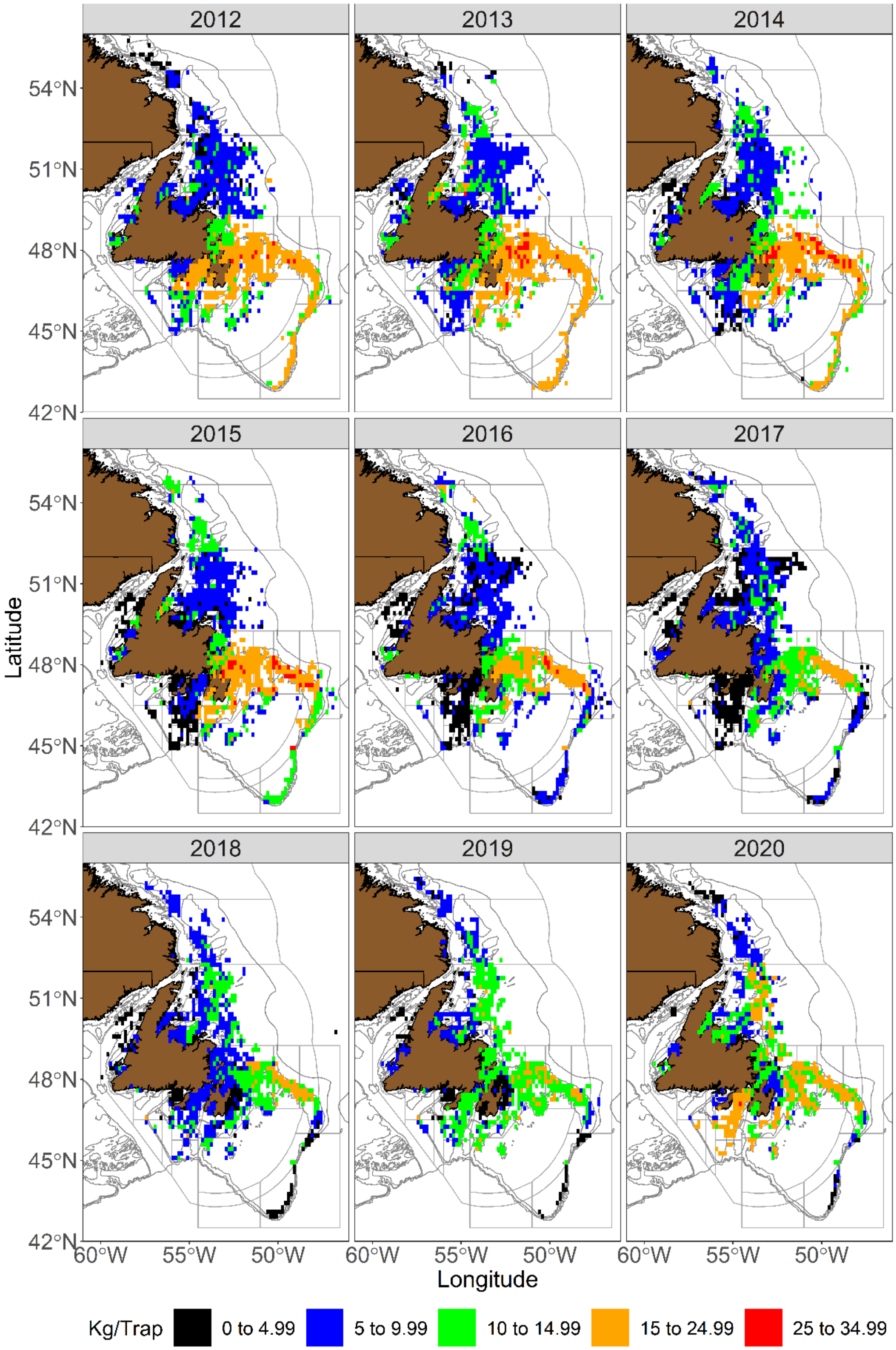

Figure 16. Locations of fishery sets and catch rates (kg/trap) from logbooks (2012–20).

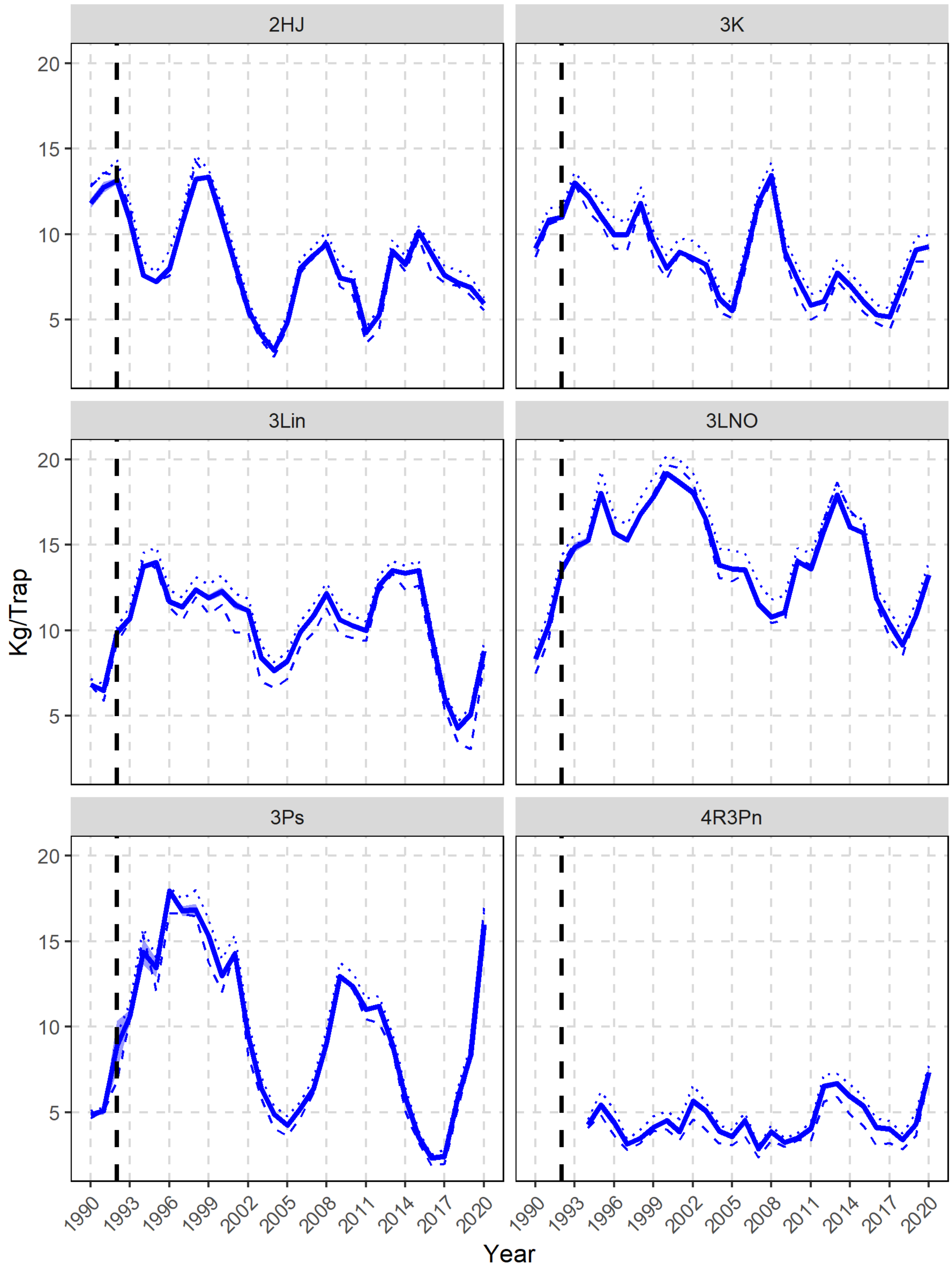

Figure 17. Standardized CPUE (kg/trap) by Assessment Division. Solid line is average predicted CPUE, shaded band is 95% confidence interval, dotted line represents average raw CPUE, and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

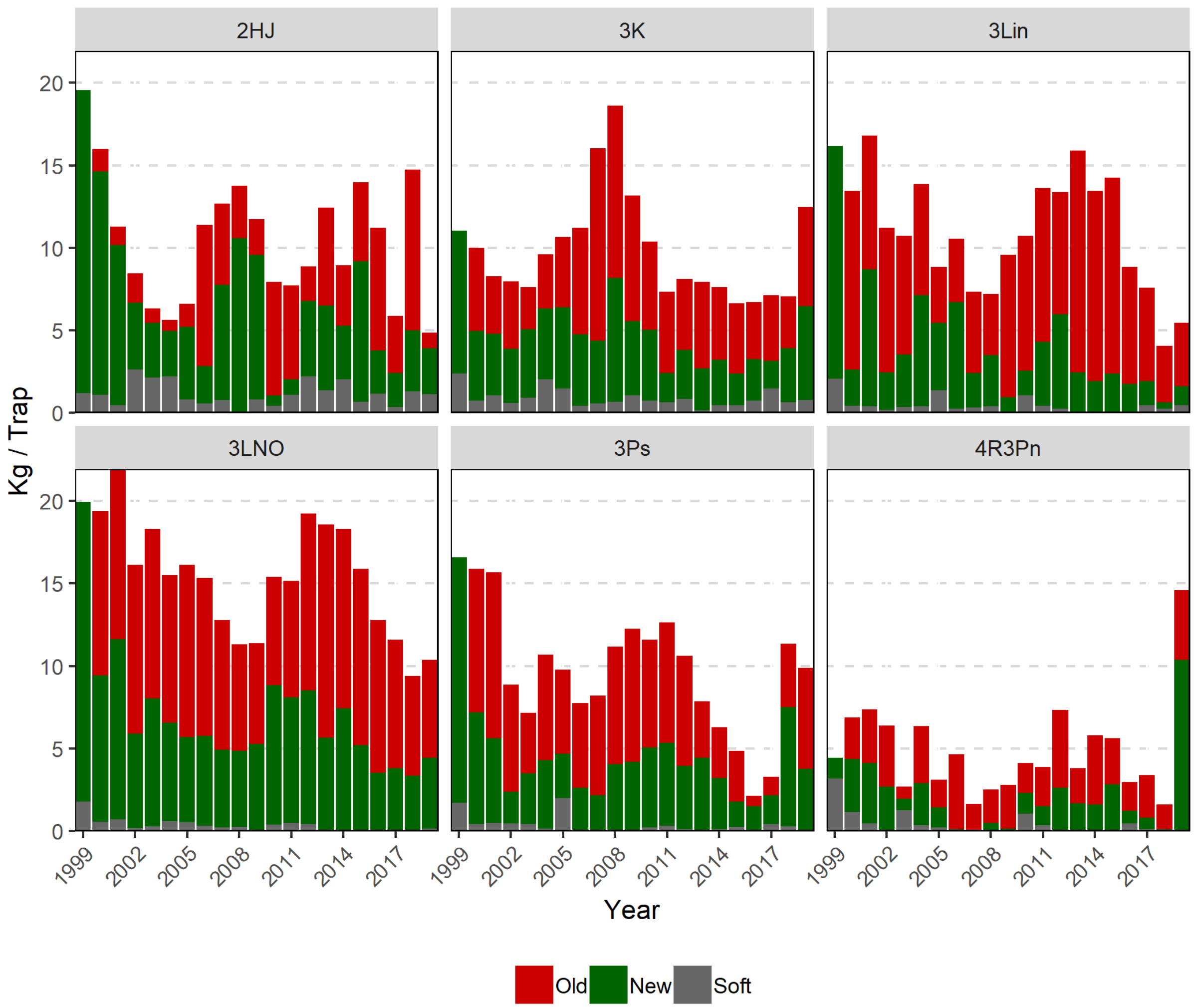

Figure 18. Trends in catch rates (kg/trap) of legal-sized Snow Crab by shell condition from observer at-sea sampling by Assessment Division (1999–2019). Note: Not updated for 2020.

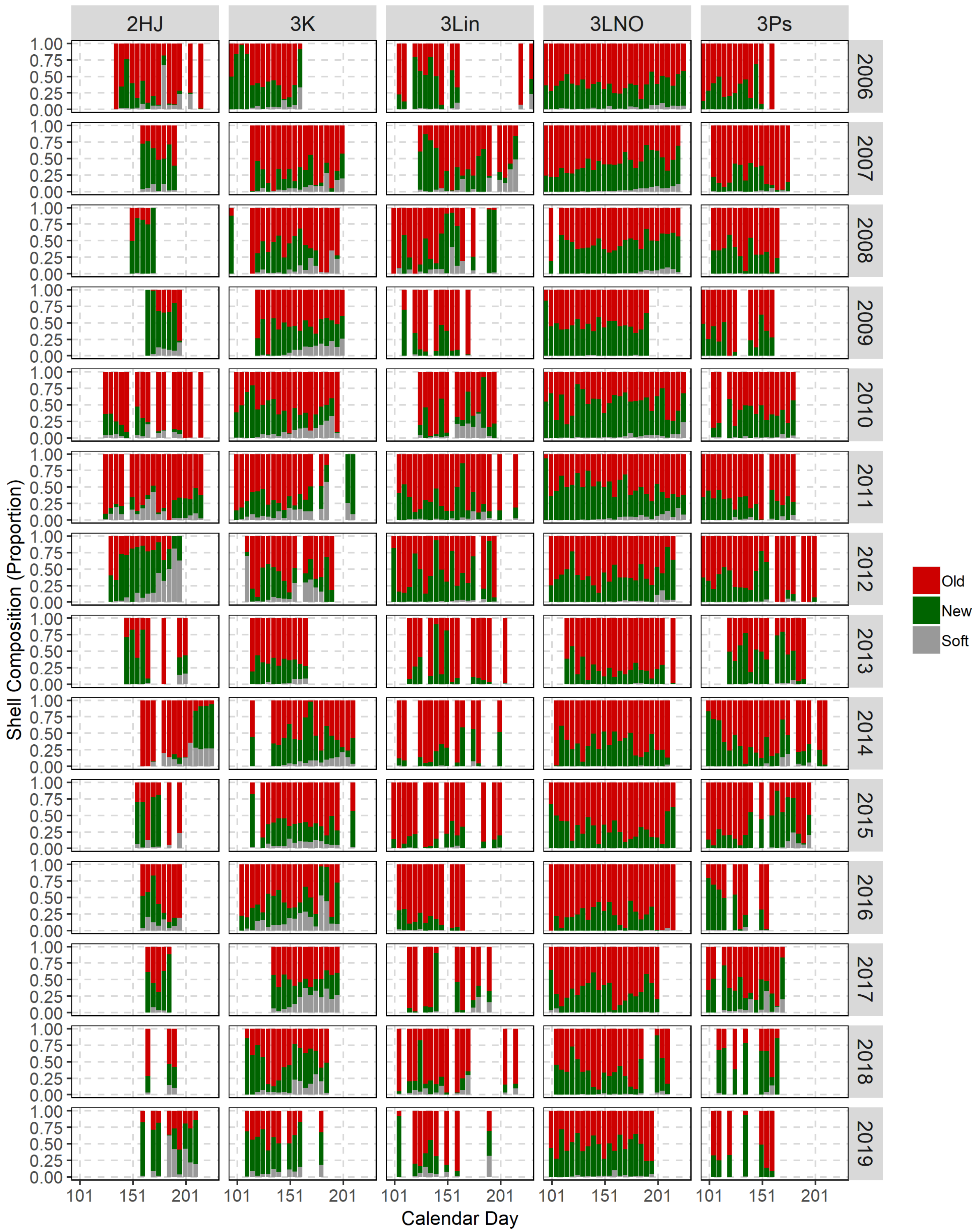

Figure 19. Proportion of legal-sized Snow Crab by shell condition from observer at-sea sampling throughout fishing season (binned in 5-day increments) by Assessment Division (2006–19). Note: Not updated for 2020.

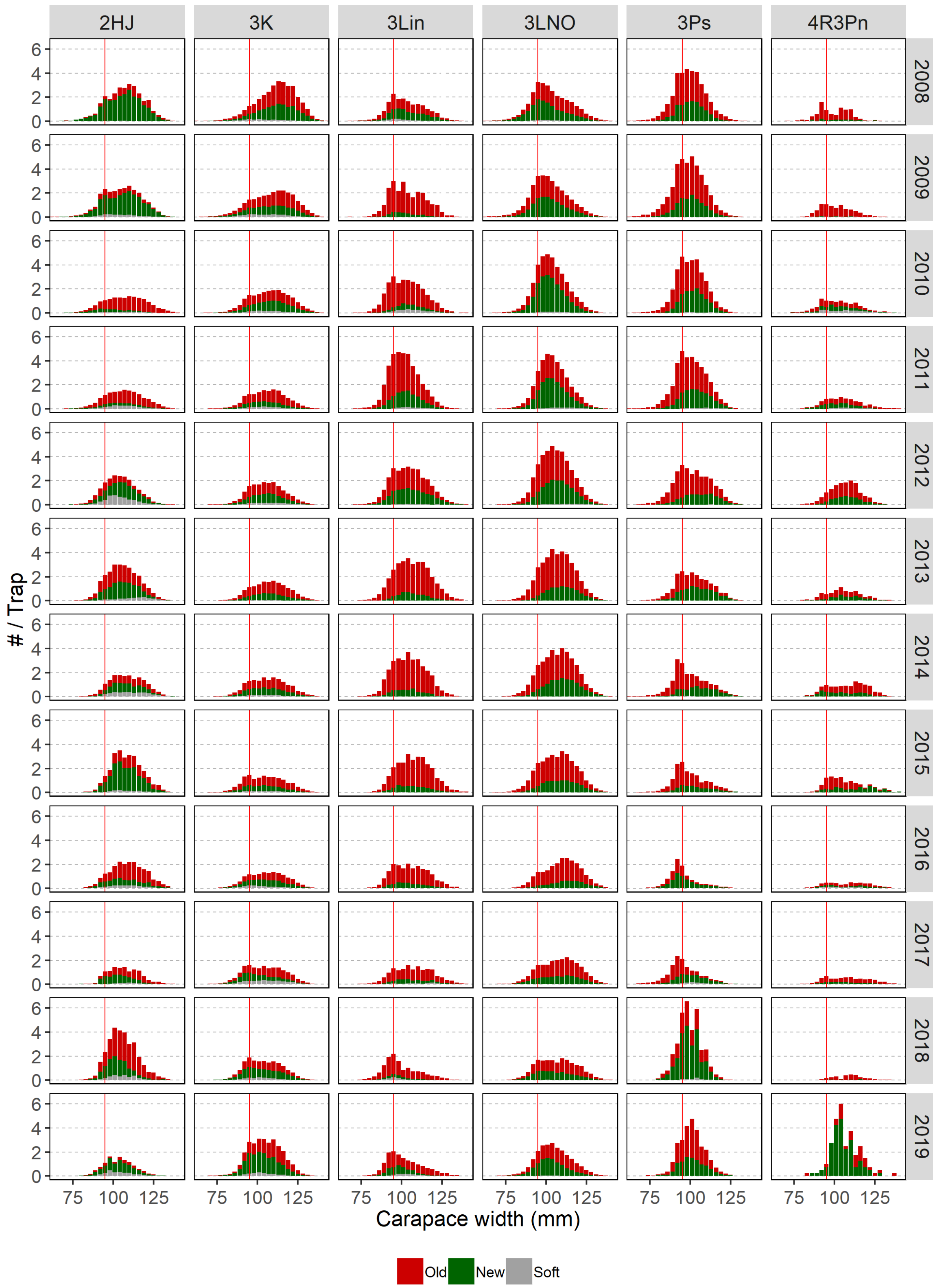

Figure 20. Catch rates (#/trap) of male Snow Crab based on carapace width distributions by shell condition from observer at-sea sampling in each Assessment Division (2008–19). The red vertical line indicates the minimum legal size. Note: Not updated for 2020.

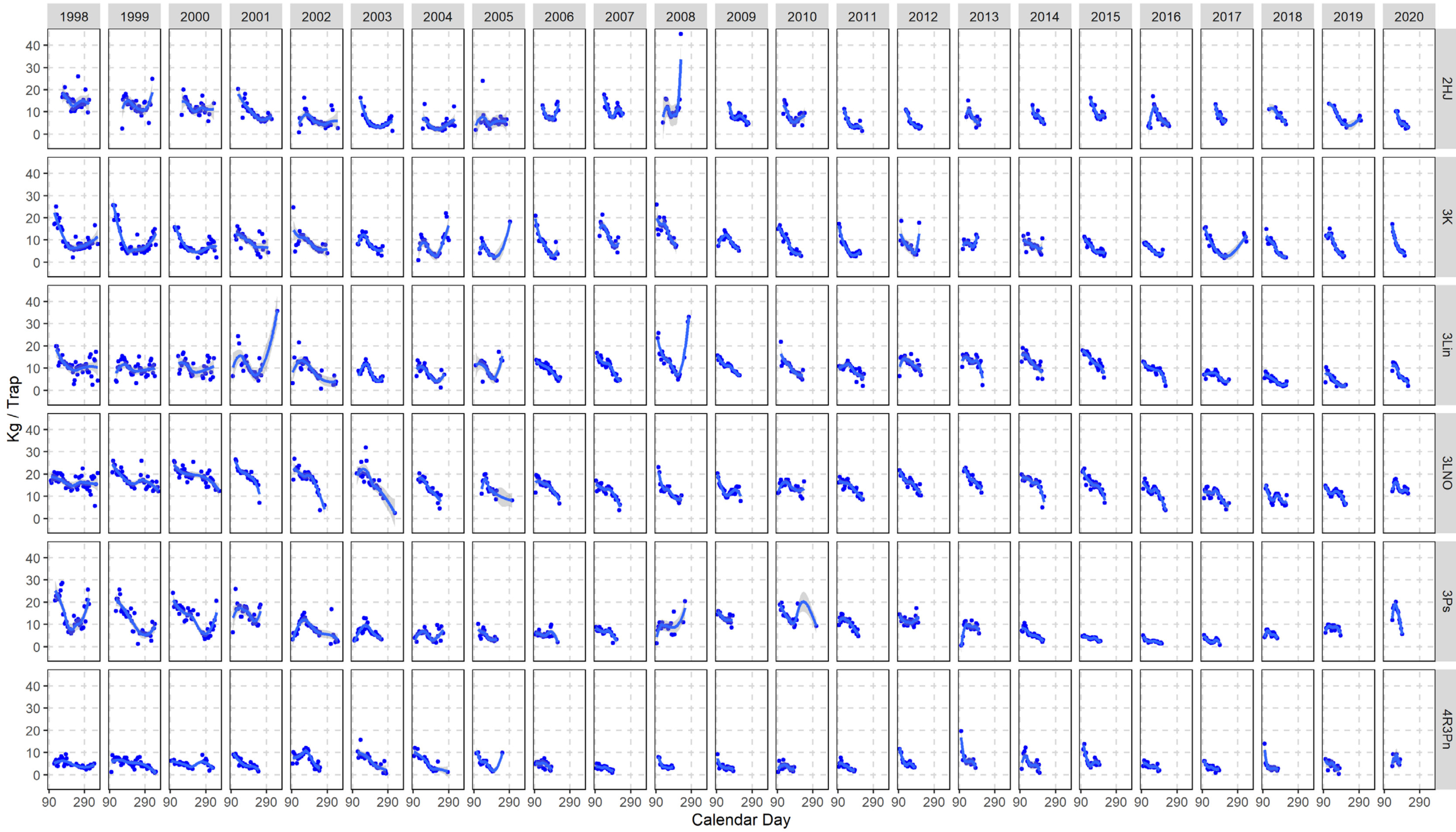

Figure 21. Unstandardized CPUE (kg/trap) throughout the season (calendar day) in each Assessment Division (1998–2020), derived from logbooks. Points denote mean CPUE in 5-day increments and trend lines are loess regression curves.

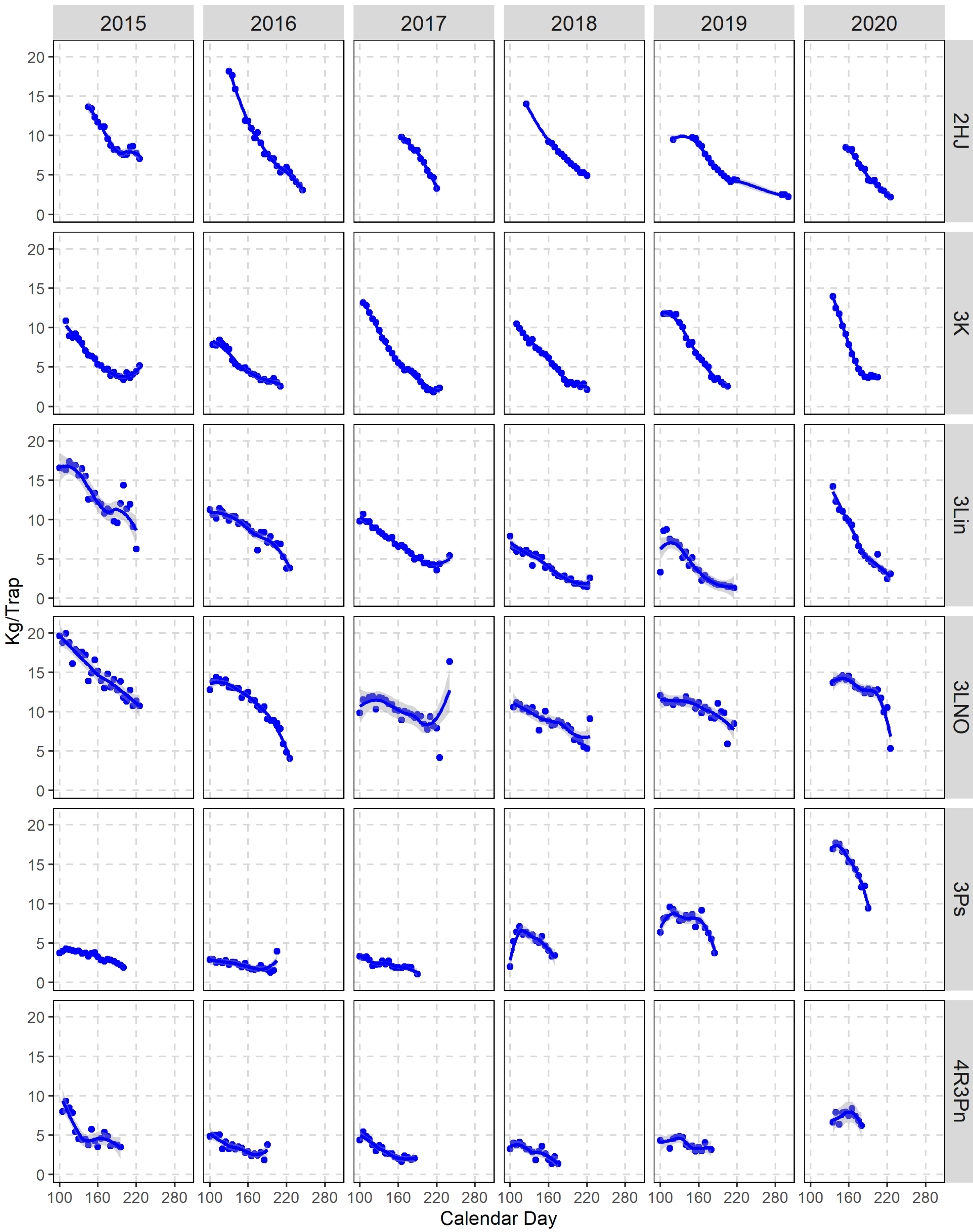

Figure 22. Standardized CPUE (kg/trap) of Snow crab throughout the season (calendar day) in each Assessment Division (2015–20), derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

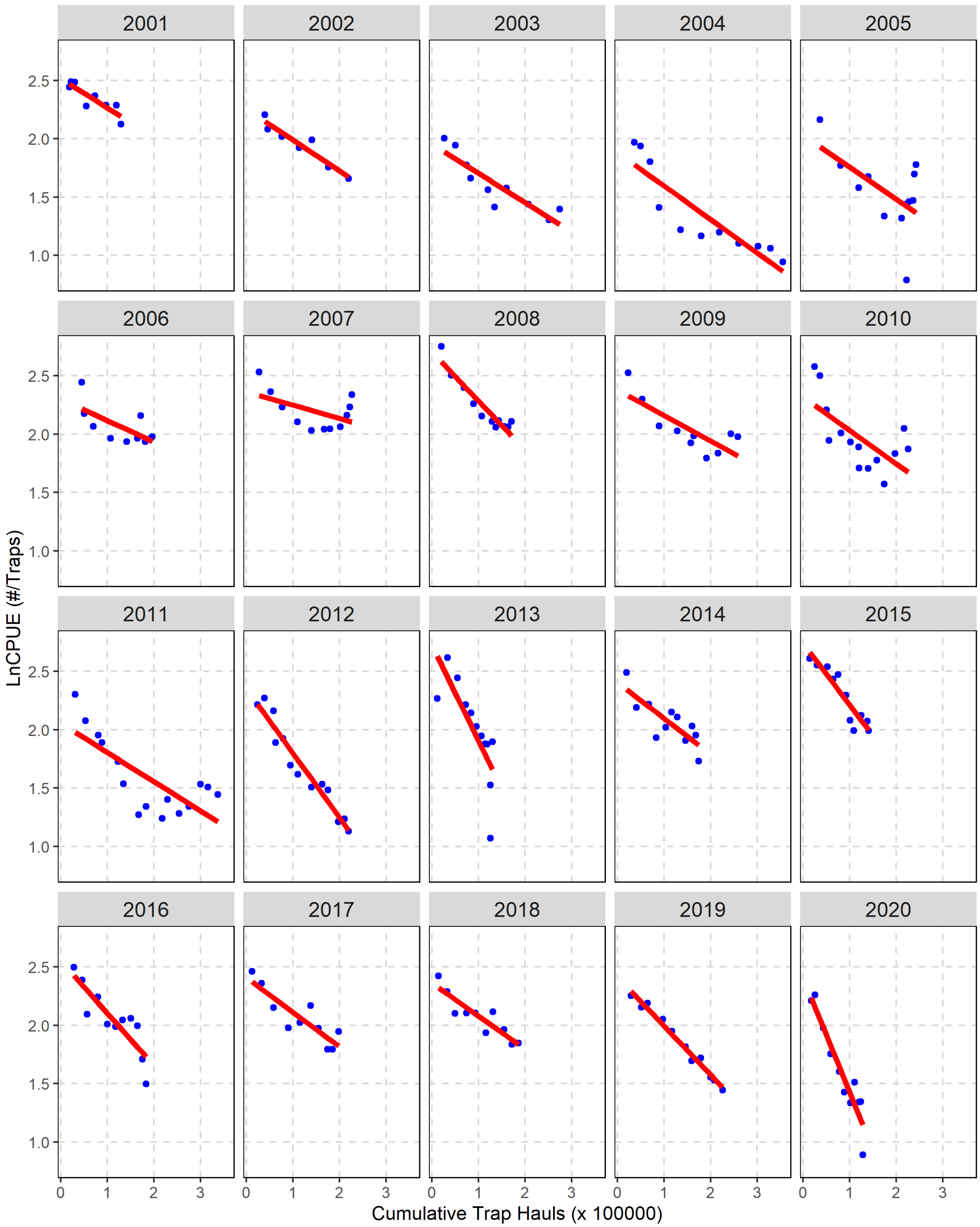

Figure 23. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 2HJ (2001–20). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

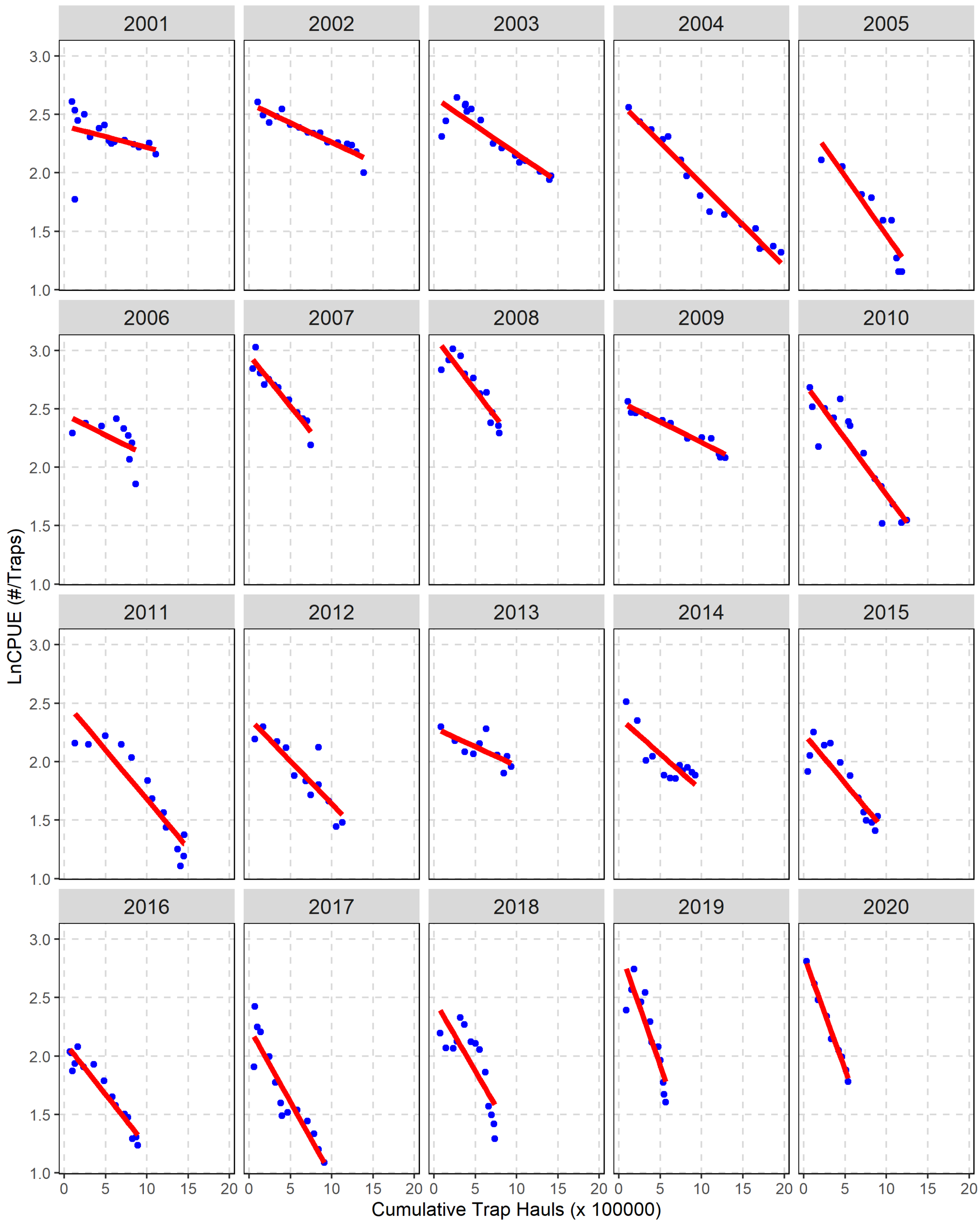

Figure 24. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3K (2001–20). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

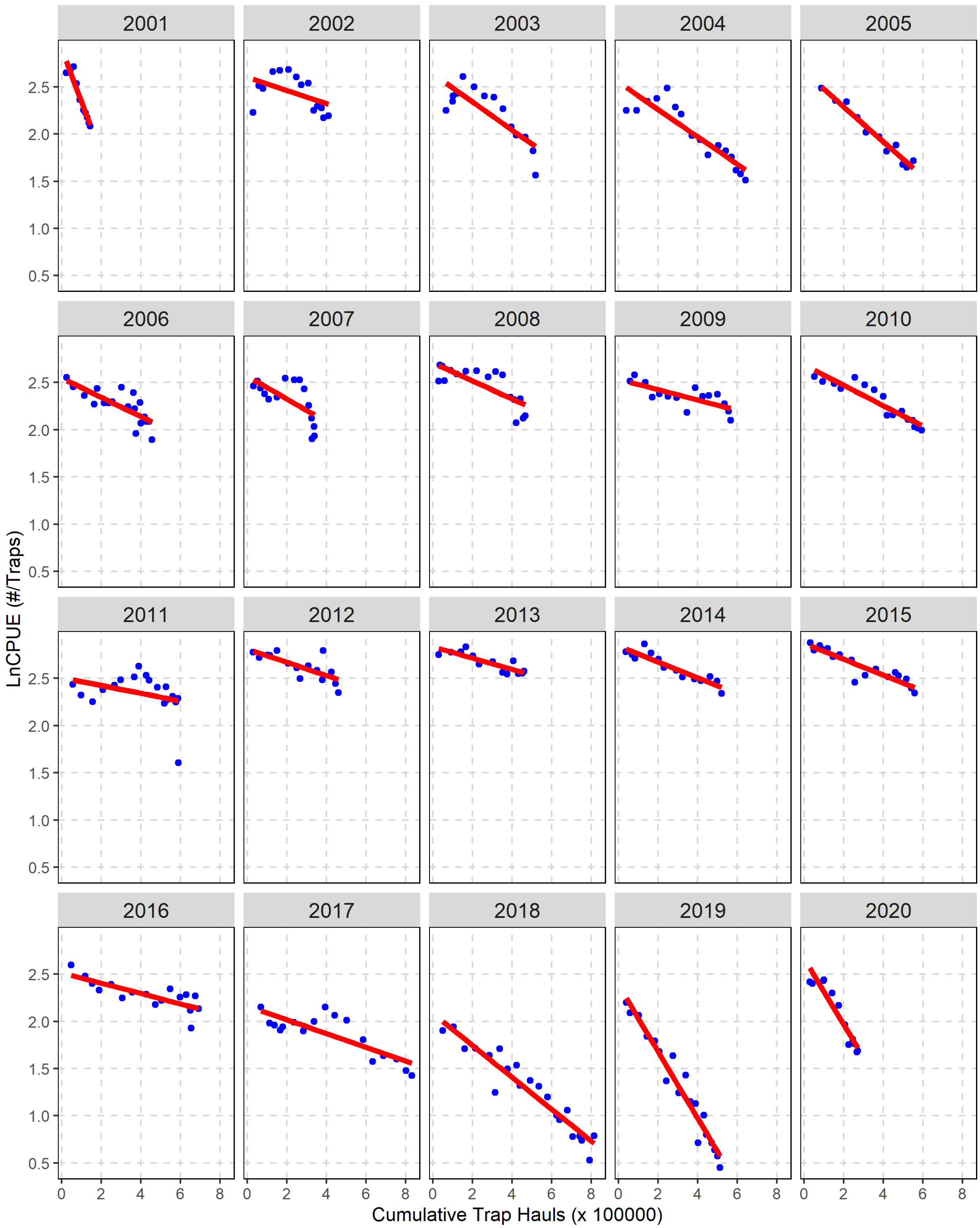

Figure 25. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3L Inshore (2001–20). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

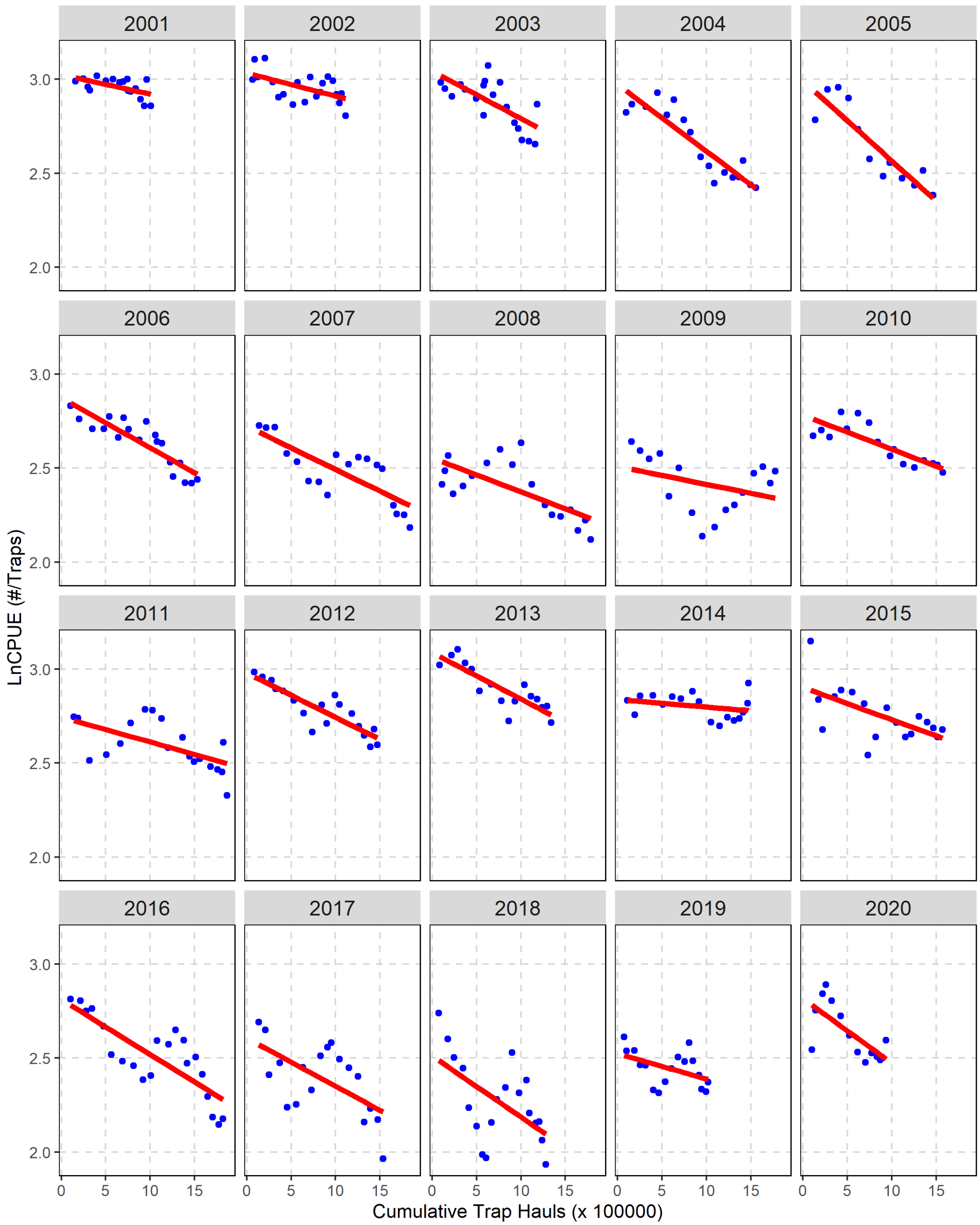

Figure 26. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3LNO Offshore (2001–20). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

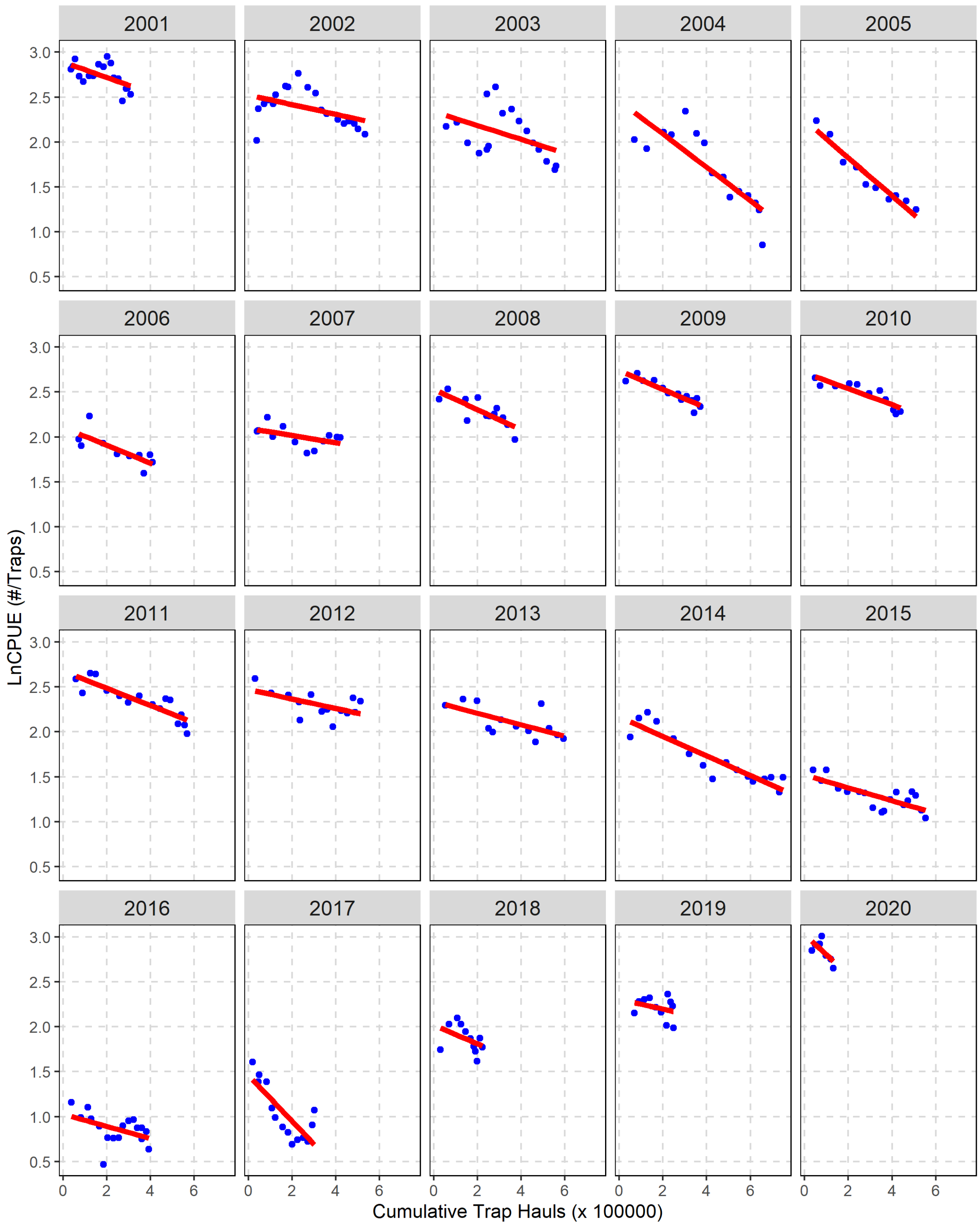

Figure 27. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3Ps (2001–20). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

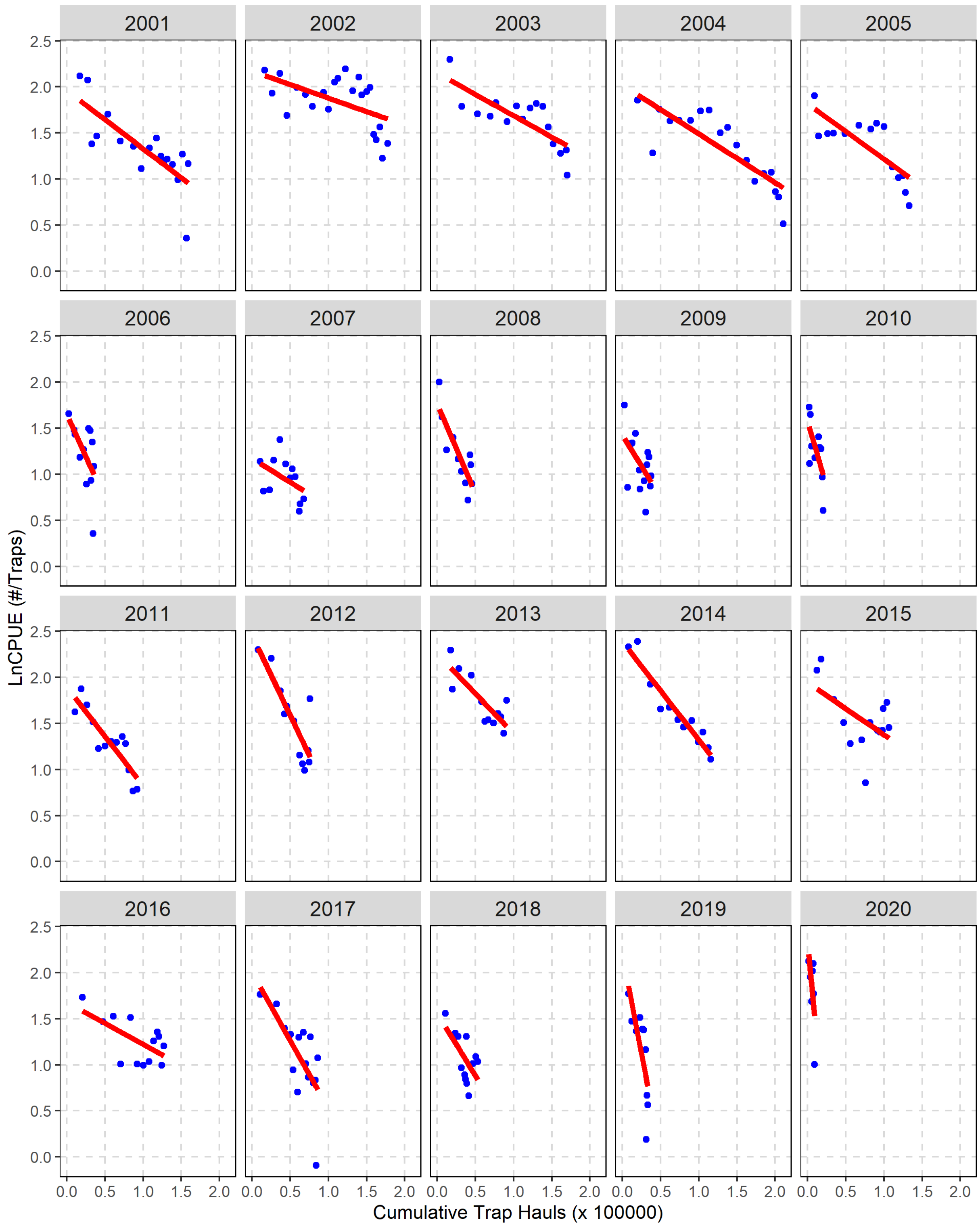

Figure 28. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 4R3Pn (2001–20). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

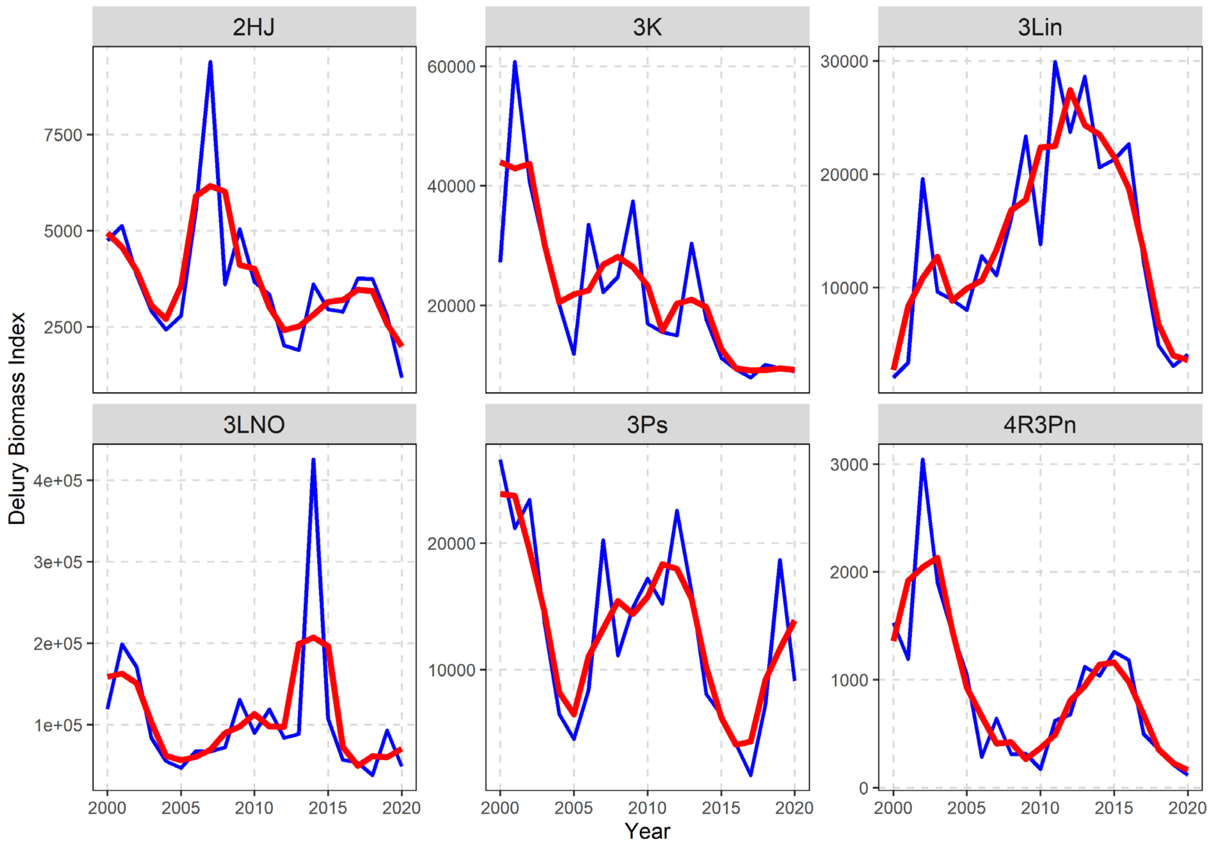

Figure 29. Fishery depletion model biomass estimates of exploitable Snow Crab (t) from logbooks (blue) and 3-year centered moving averages (red) in each Assessment Division.

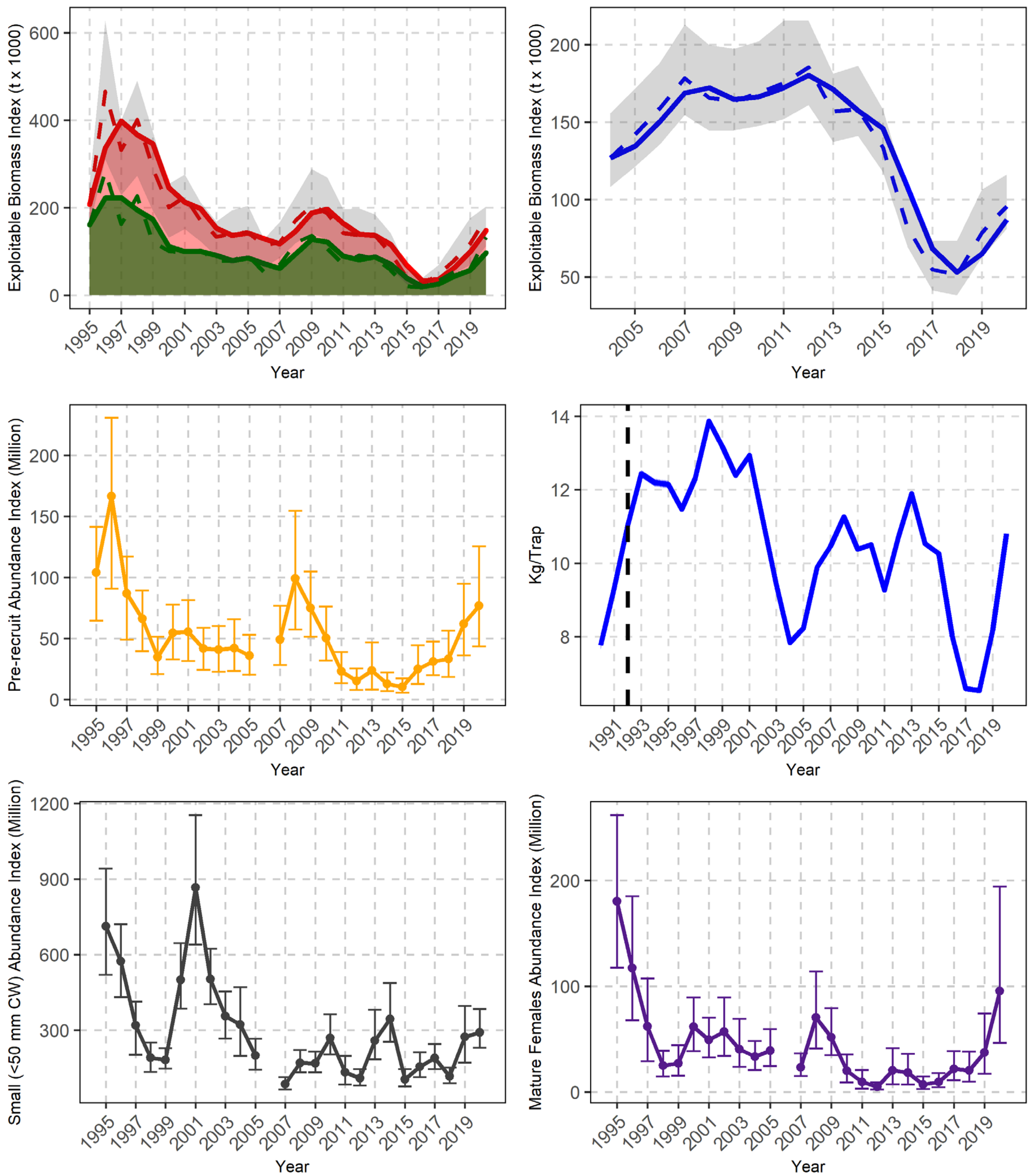

*Figure 30. Summary of Snow crab stock status in Assessment Divisions 2HJ3KLNOP4R: Top-left: Annual exploitable biomass index (t *1,000) by shell condition (1995–2020) based on trawl surveys. Shaded area is 2-year moving average of biomass and dashed line is annual estimate (red = residuals, green = recruits). Grey band is 95% confidence intervals of annual estimate. Top-right: Annual trap survey-based exploitable biomass index (t*1,000) (2004–20). Solid line is 2-year moving average, dashed line is annual estimate, and grey band is 95% confidence intervals of annual estimate. Middle-left: Annual pre-recruit abundance index (# million) from trawl surveys (1995–2020). Note: does not include AD 3Ps for 2020. Middle-right: Fishery CPUE (1990–2020). Bottom-left: Annual abundance index (# million) of small crab (<50 mm carapace width) from trawl surveys (1995–2020). Note: does not include AD 3Ps for 2020. Bottom-right: Annual abundance index (# million) of mature female crab from trawl surveys (1995–2020). Note: does not include AD 3Ps for 2020.*

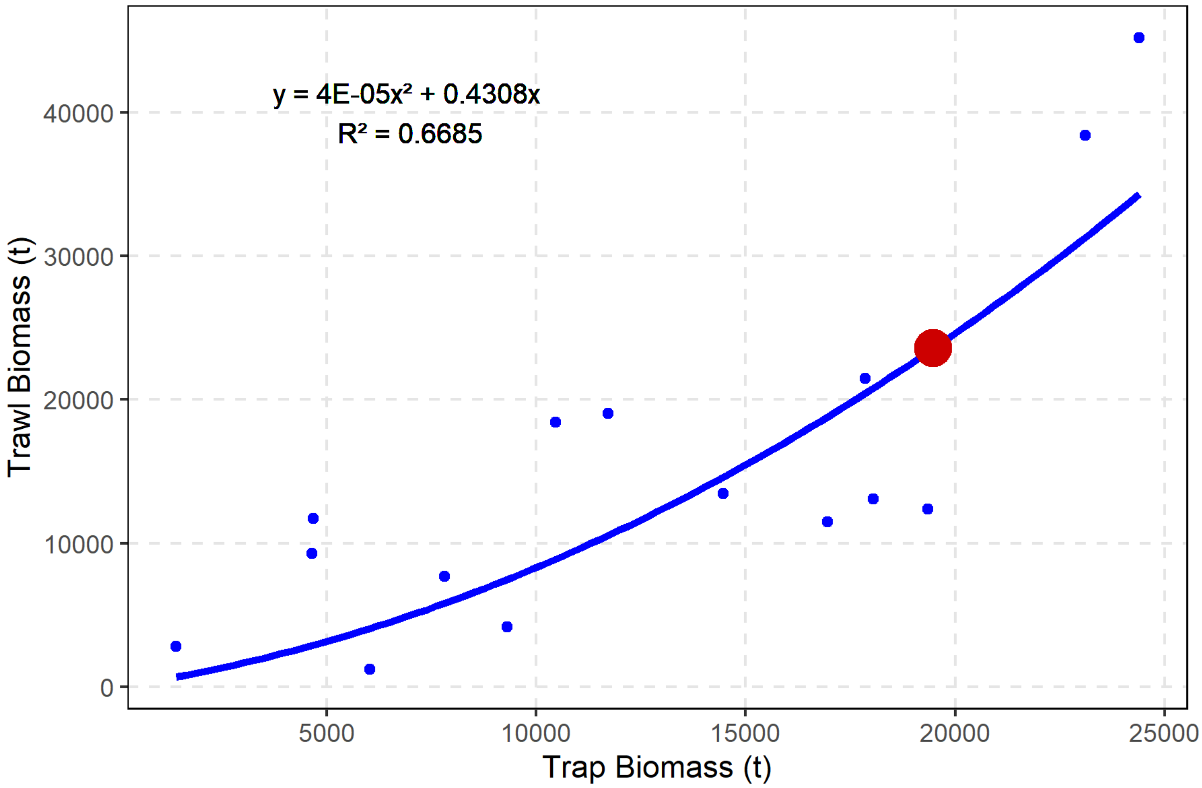

Figure 31. Relationship between trawl and trap exploitable biomass indices used for estimating 2020 trawl exploitable biomass in AD 3Ps using data from 2004–19. The red circle represents the estimated 2020 value.

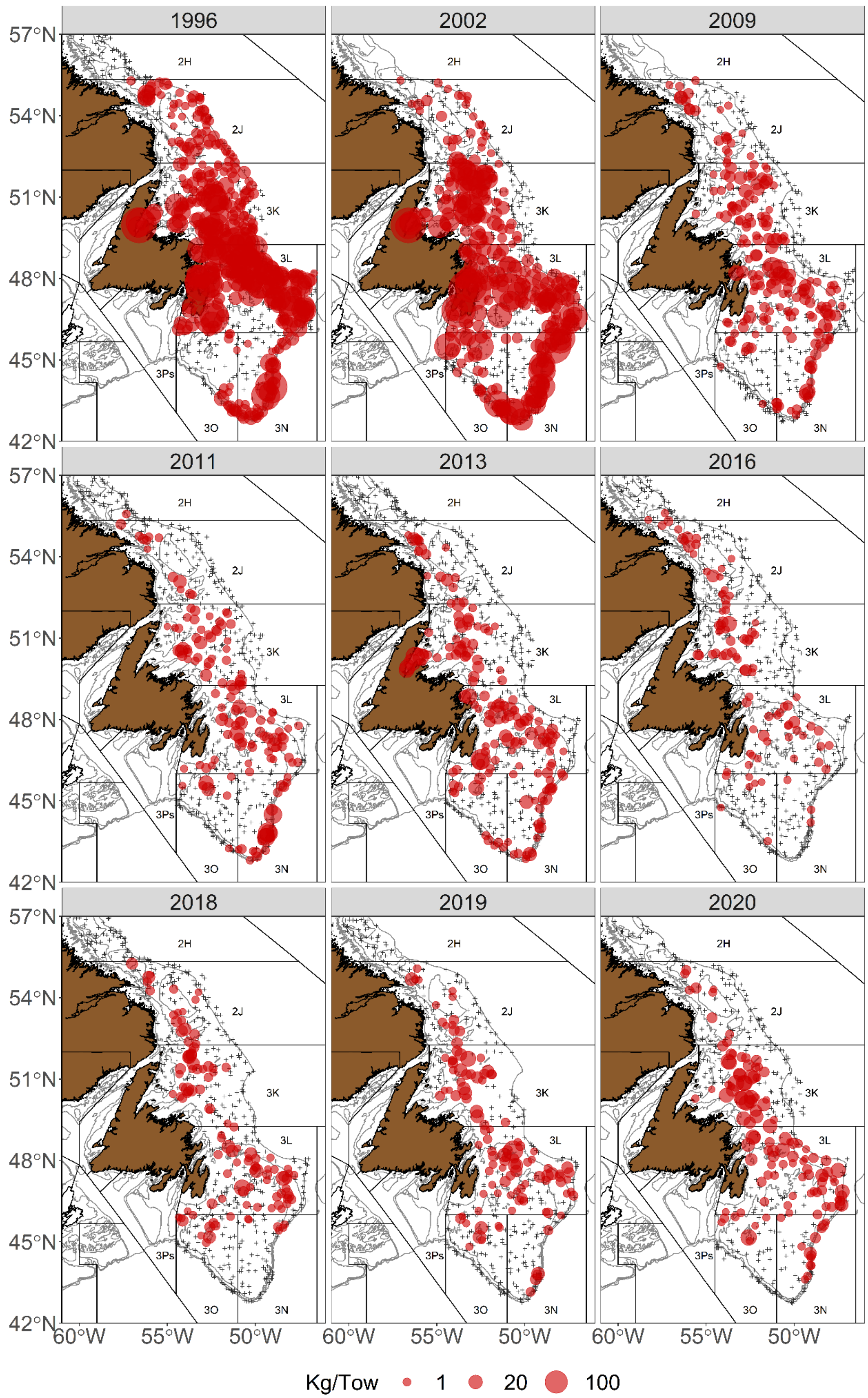

Figure 32. Distribution of exploitable males (kg/tow) from Assessment Divisions 2HJ3KLNO fall trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2017–20. Data standardized by vessel.

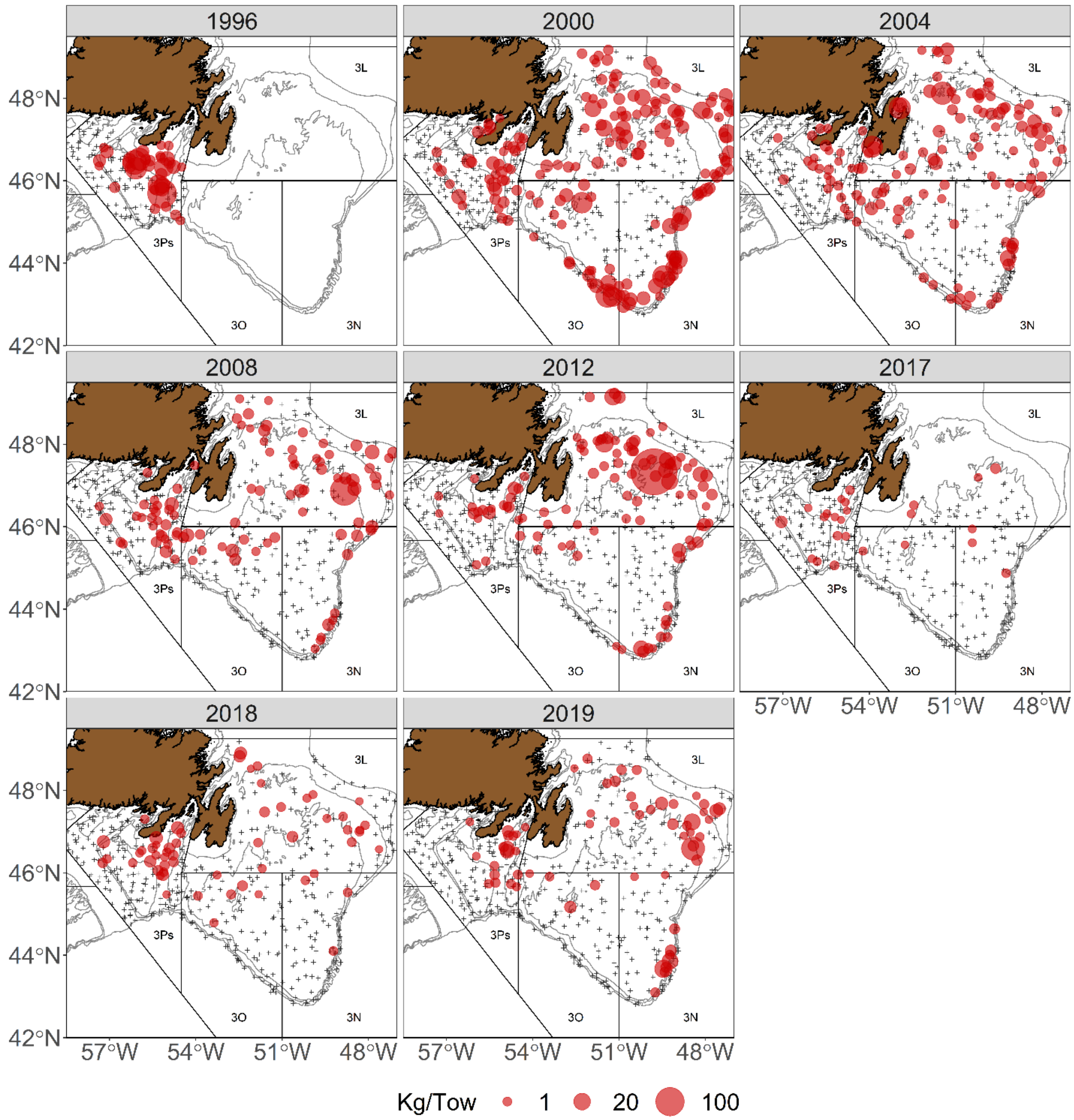

Figure 33. Distribution of exploitable males (kg/tow) from Assessment Divisions 3LNOPs spring trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2017–19. Data standardized by vessel.

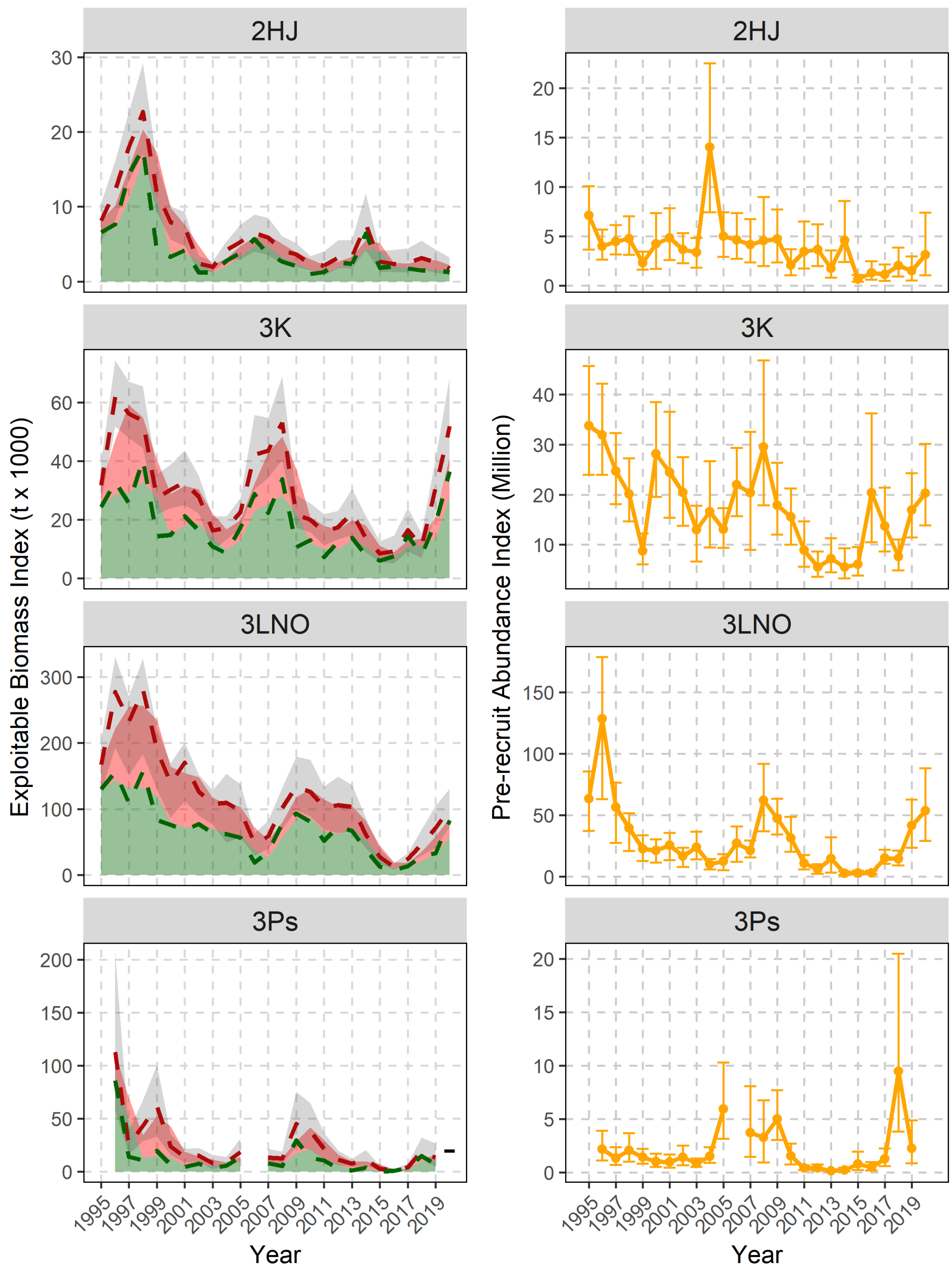

*Figure 34. Left: Trawl survey exploitable biomass indices (t * 1,000) by shell condition and Assessment Division. Soft and new-shell crab represent recruitment (green) and intermediate and old-shell crab represent residual biomass (red). Red and green shaded areas are 2-year moving averages, dashed lines represent annual estimates, and grey band represents 95% confidence interval of the annual estimate. The black dash in AD 3Ps in 2020 represents the exploitable biomass calculated based on the method in Figure 31. Right: Overall trawl survey pre-recruit abundance index (t * million) by Assessment Division.*

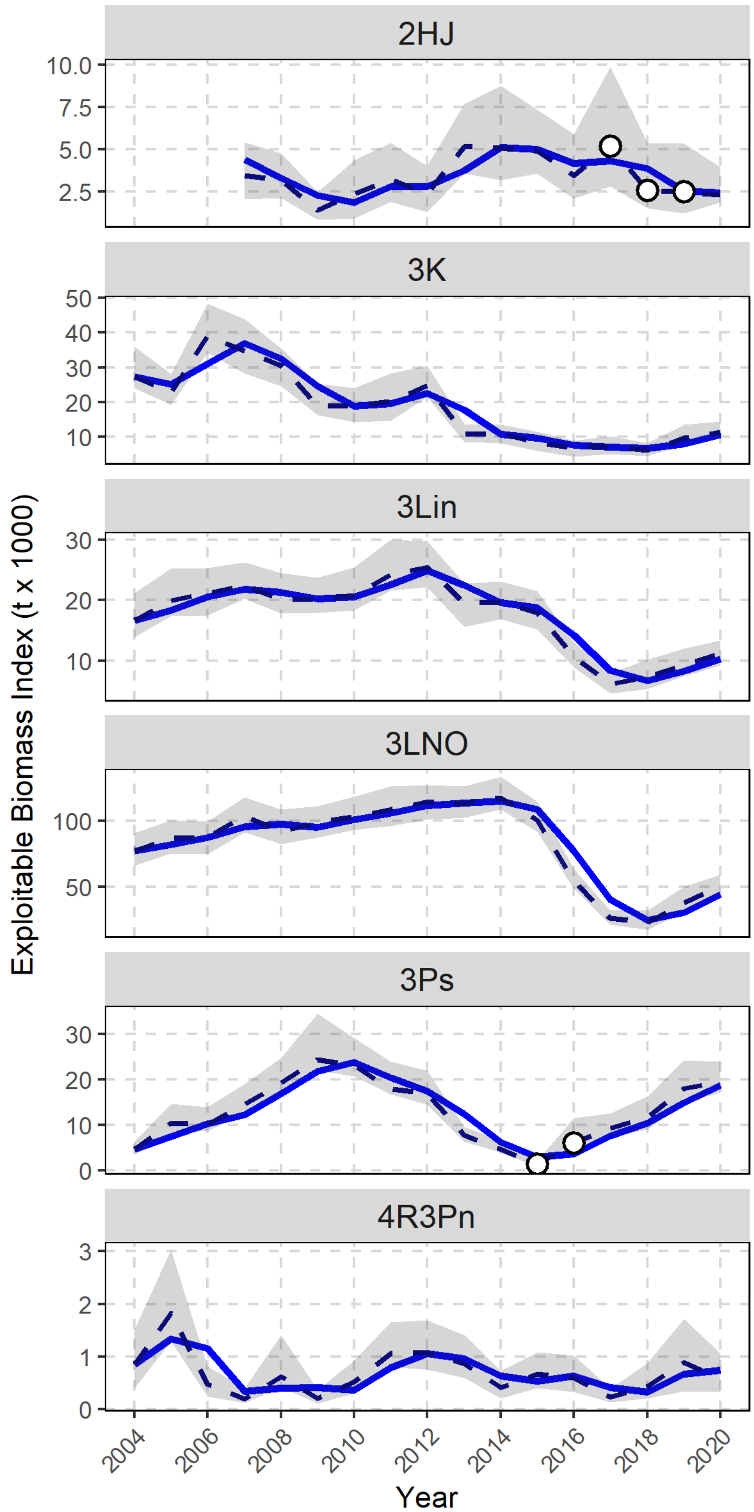

Figure 35. Trap survey-based exploitable biomass index by Assessment Division (2004–20). Solid line represents 2-year moving average, dashed line represents annual estimate, shaded grey band represents the 95% confidence interval of the annual estimate, and open circles represent incomplete surveys.

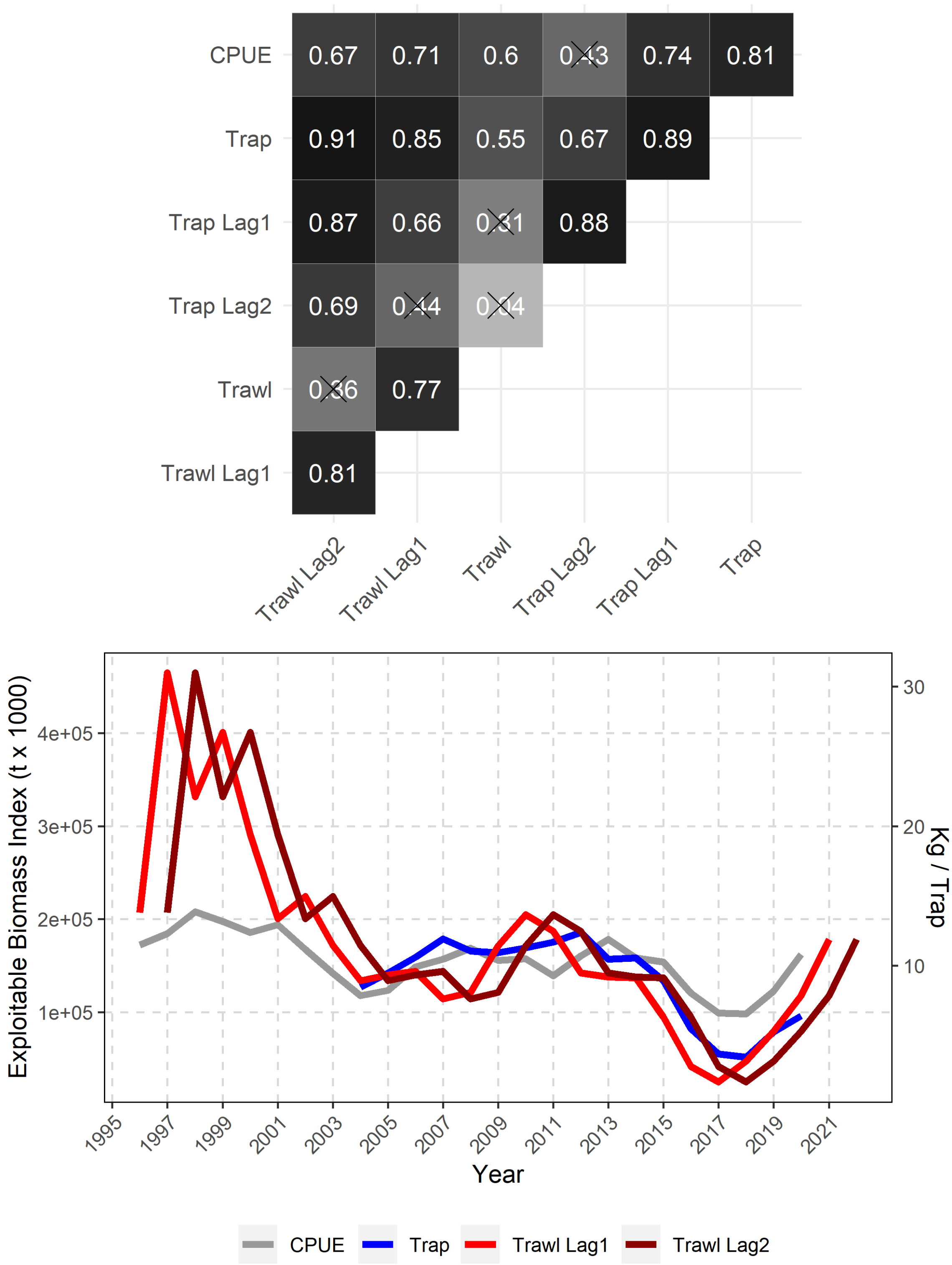

Figure 36. Top: Pearson correlation coefficients of exploitable biomass indices from trawl surveys, trap surveys, and fishery CPUE with lags of none, 1, and 2 years. Bottom: Trends in exploitable biomass indices based on the trawl survey (reds), trap surveys (blue), and fishery CPUE (grey).

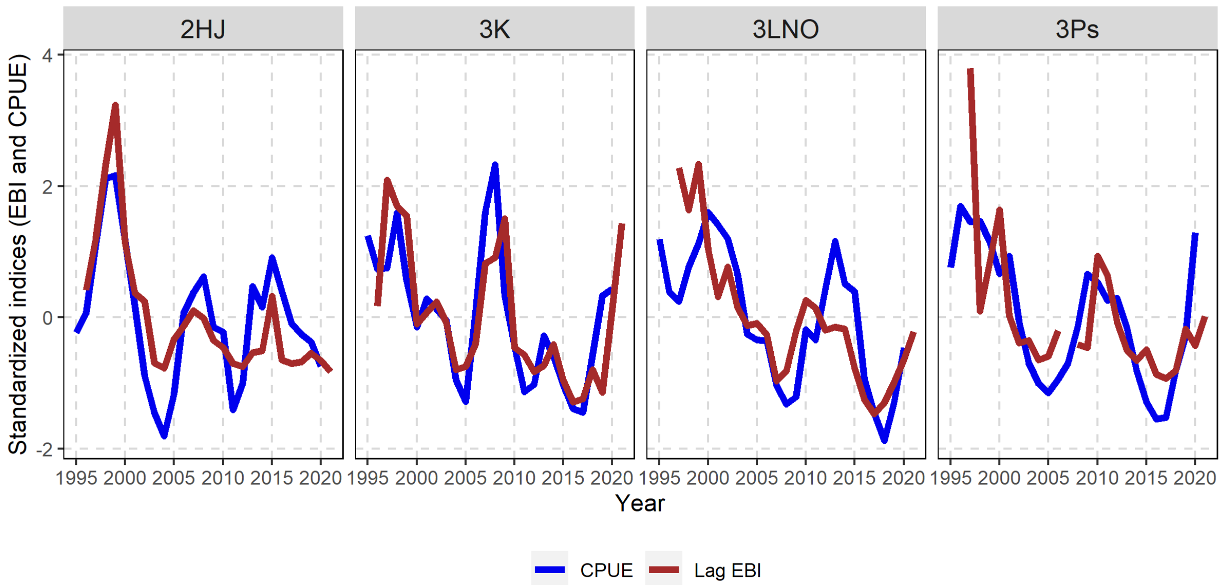

Figure 37. One-year lagged trawl survey exploitable biomass indices versus fishery CPUE by Assessment Division (1995–2020).

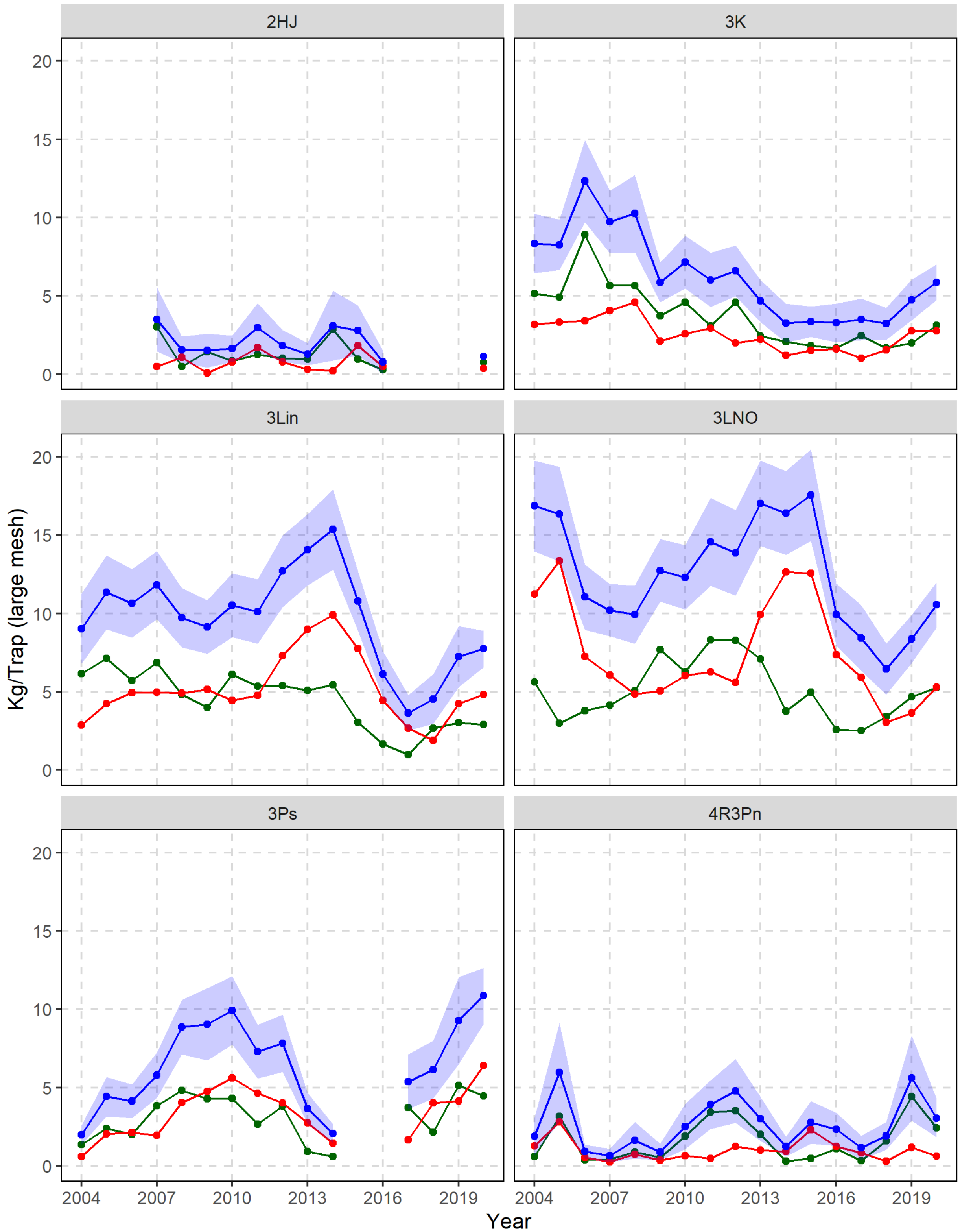

Figure 38. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable crab from core stations in the CPS survey by Assessment Division (2004–20).

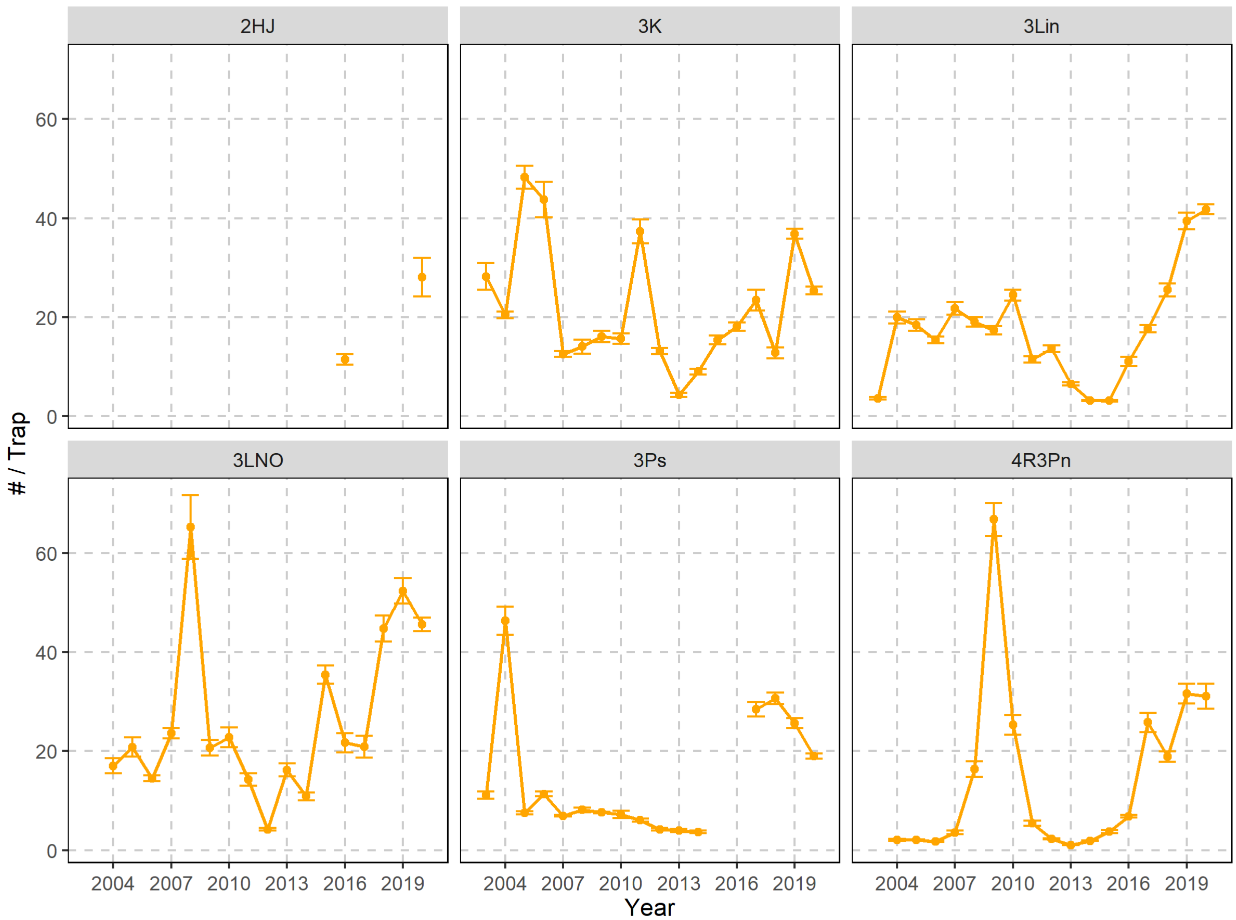

Figure 39. Annual CPUE (#/trap) of pre-recruits from small-mesh traps at core stations in the CPS trap survey by Assessment Division (2004–20).

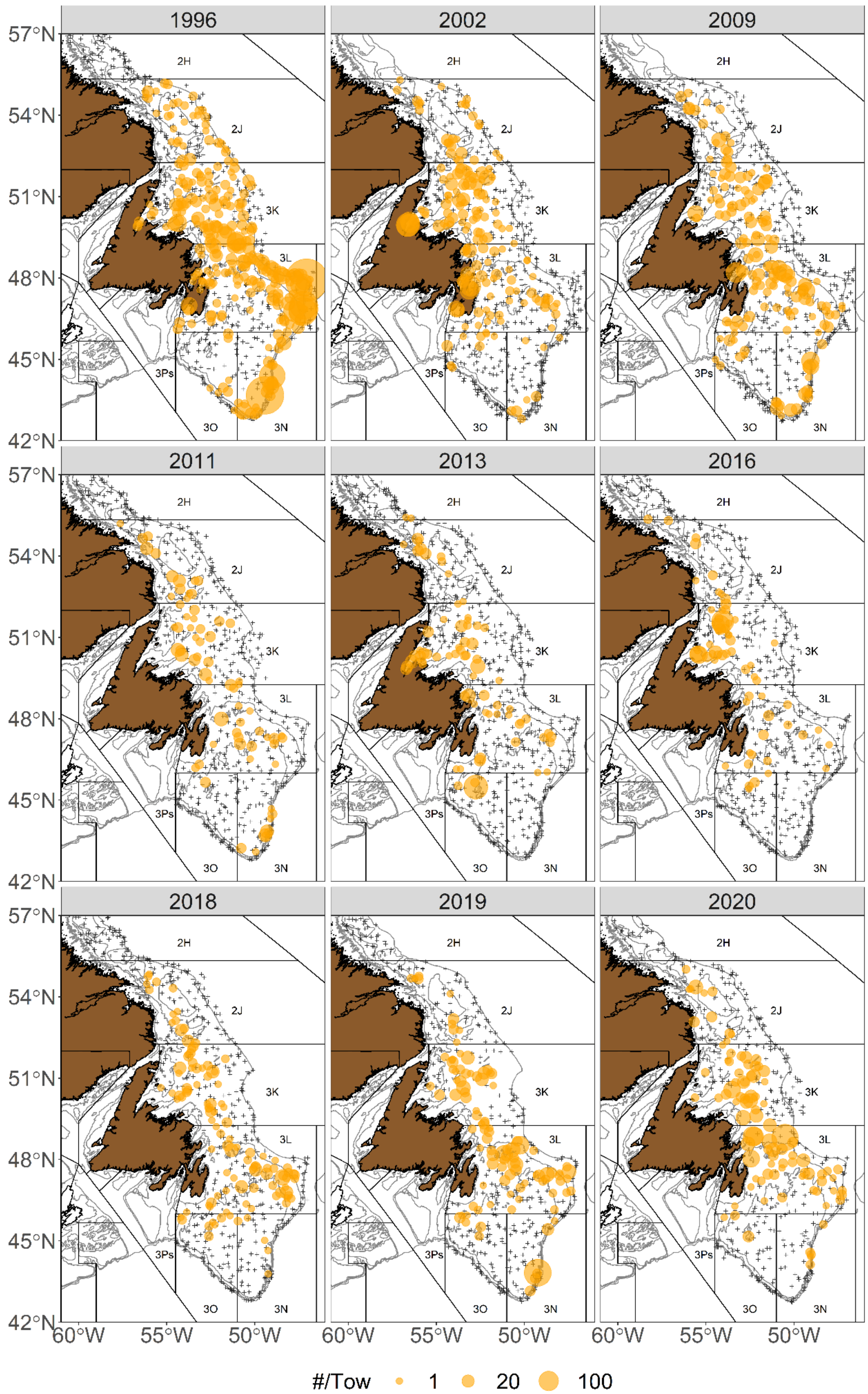

Figure 40. Distribution of pre-recruit males (#/tow) from Assessment Divisions 2HJ3KLNO fall trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016 and 2018–20.

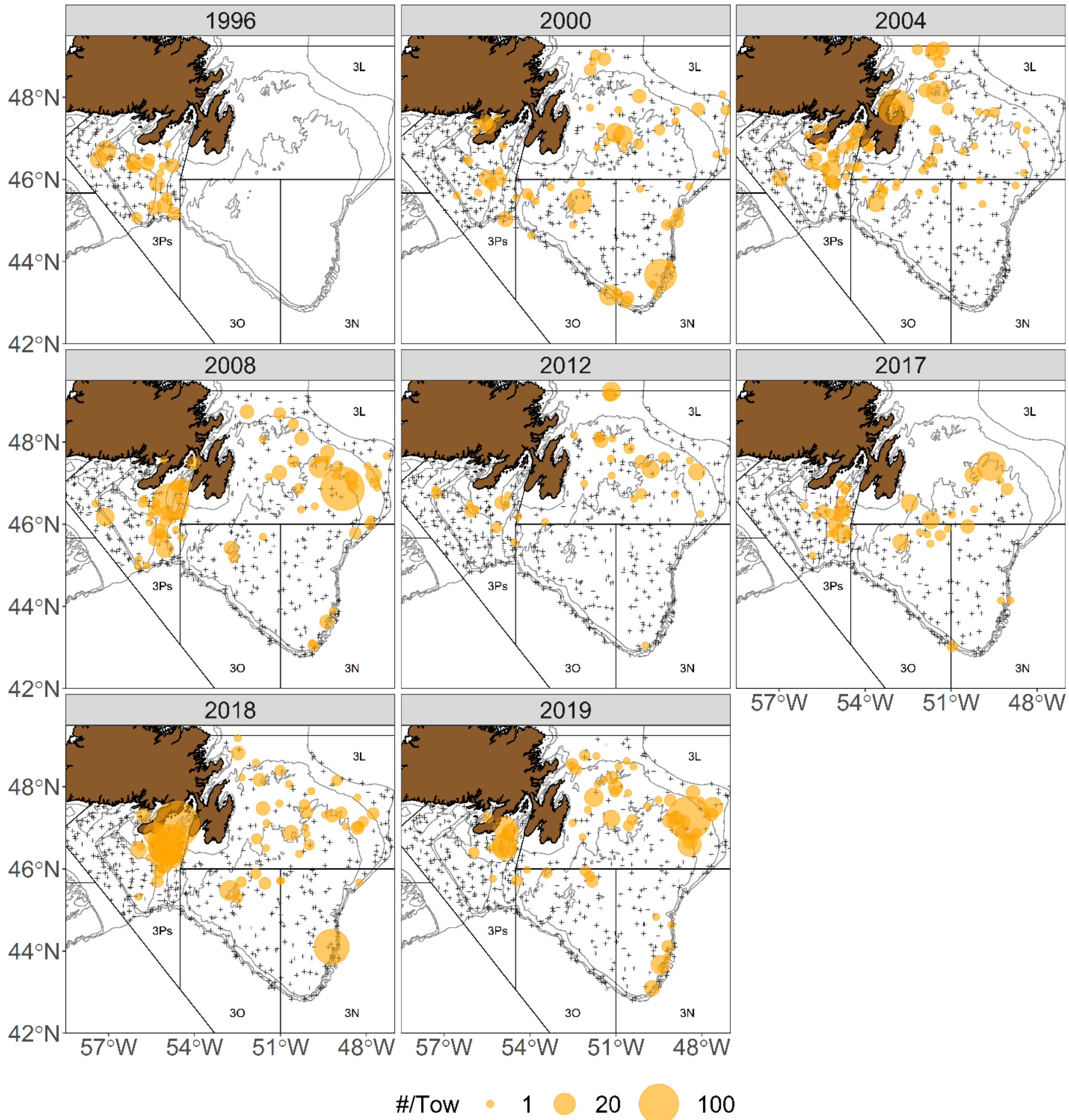

Figure 41. Distribution of pre-recruit males (#/tow) from Assessment Divisions 3LNOPs spring trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2017–19.

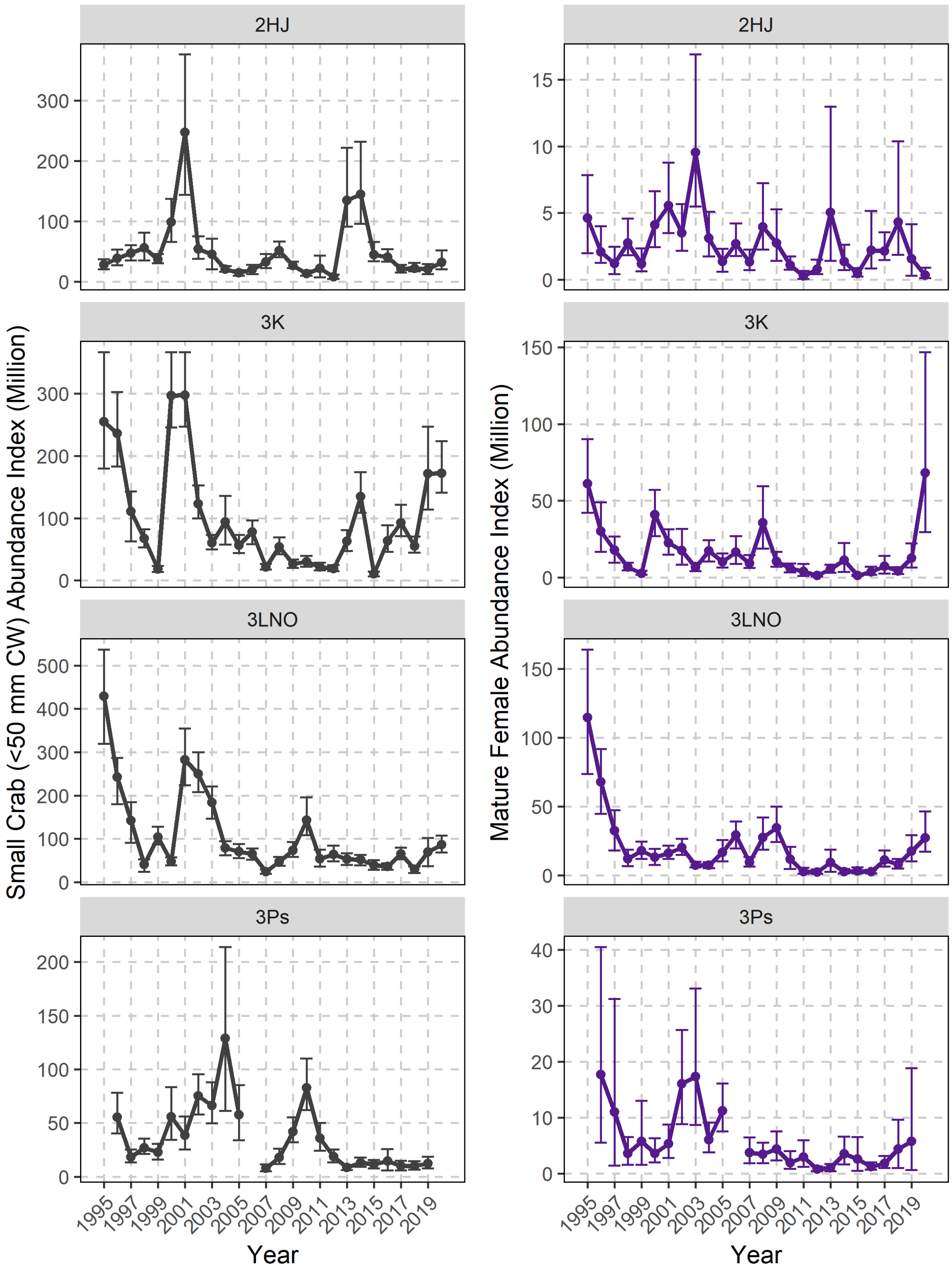

Figure 42. Annual abundance indices (# million) of small crab (<50 mm carapace width) from fall and spring trawl surveys by Assessment Division. Right: Annual abundance indices (# million) of mature female crab from fall and spring trawl surveys by Assessment Division.

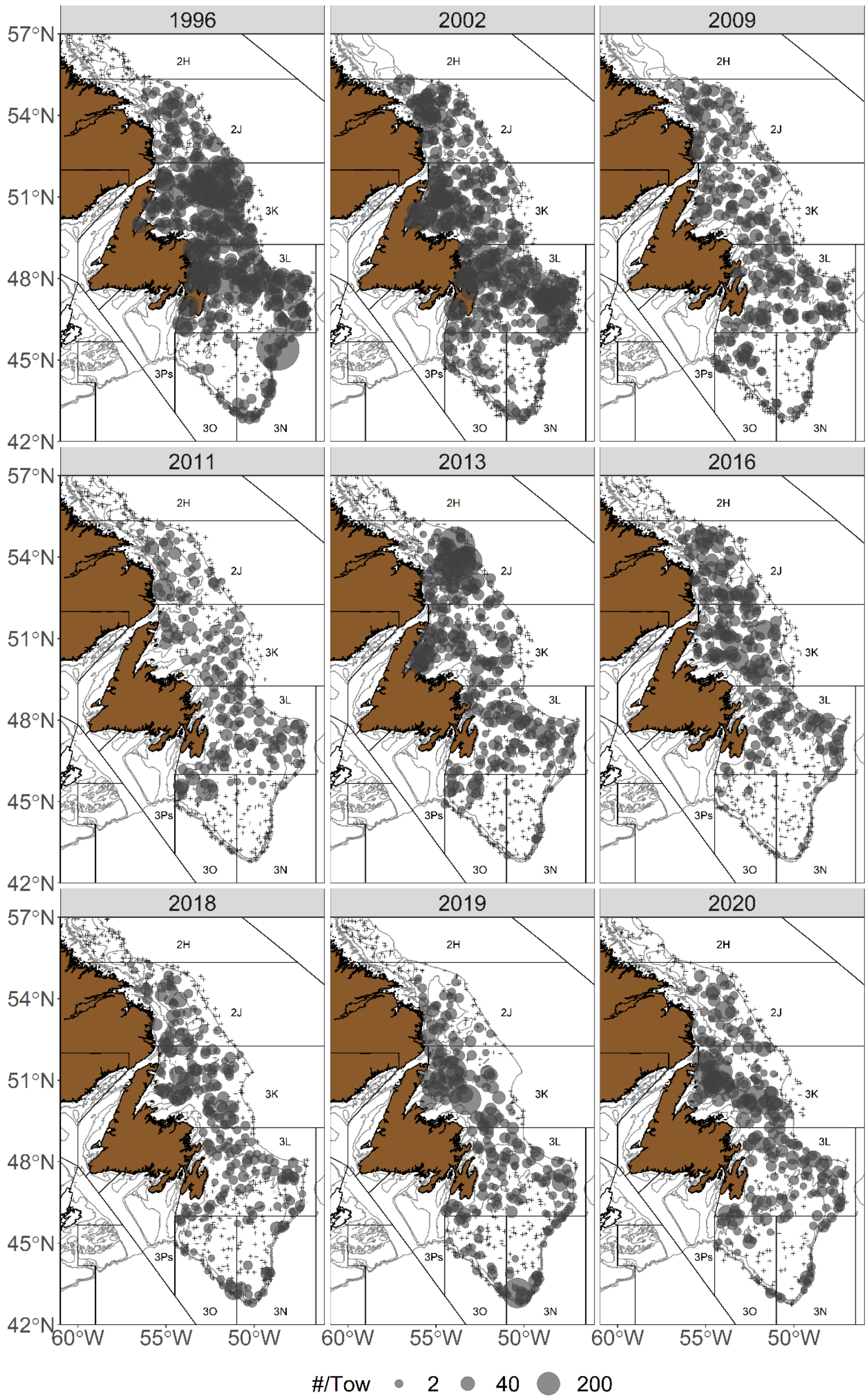

Figure 43. Distribution of small (<50 mm) crab (#/tow) from Assessment Divisions 2HJ3KLNO fall trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016 and 2018–20.

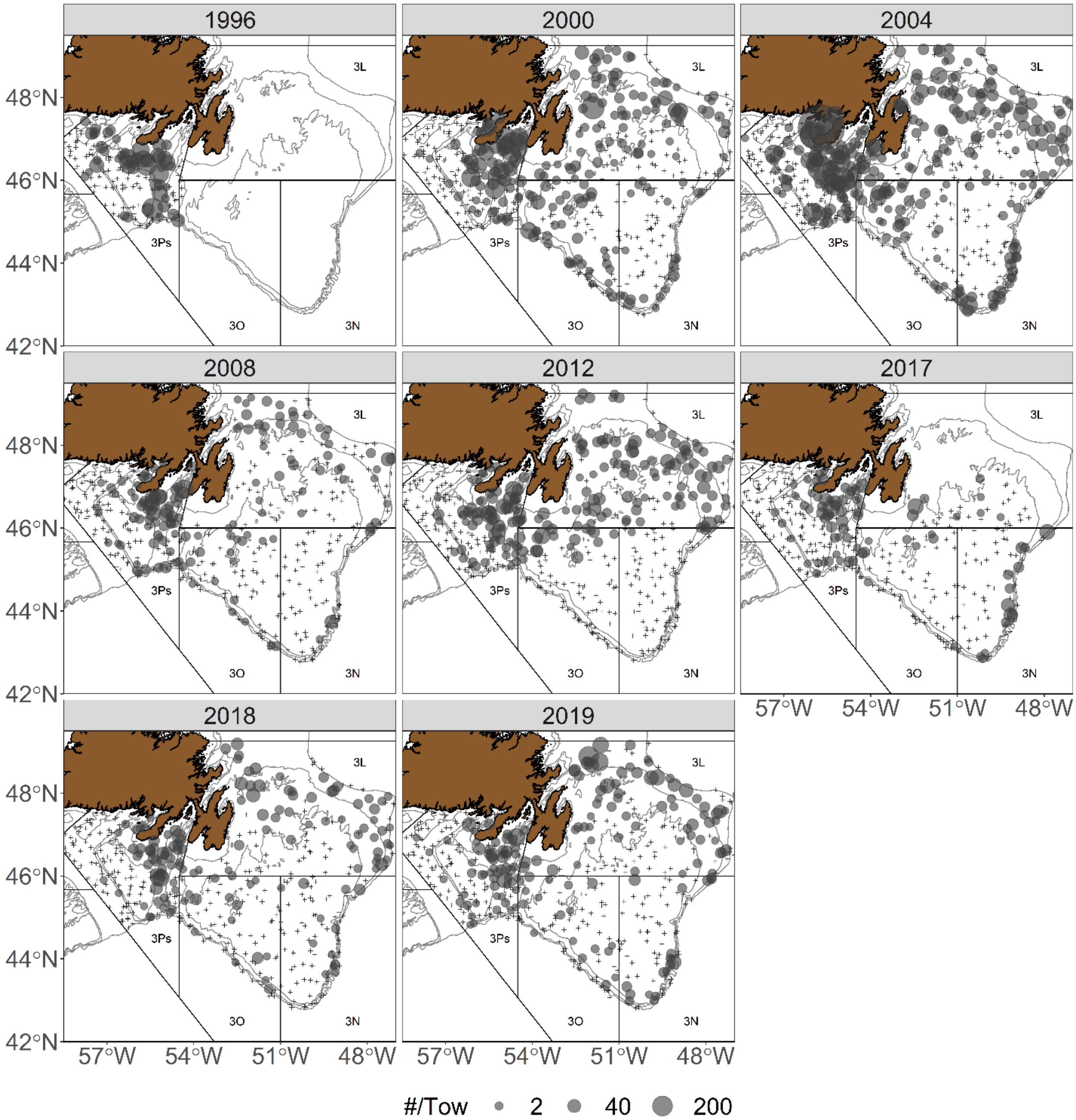

Figure 44. Distribution of small (<50 mm) crab (#/tow) from Assessment Divisions 3LNOPs spring trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2017–19.

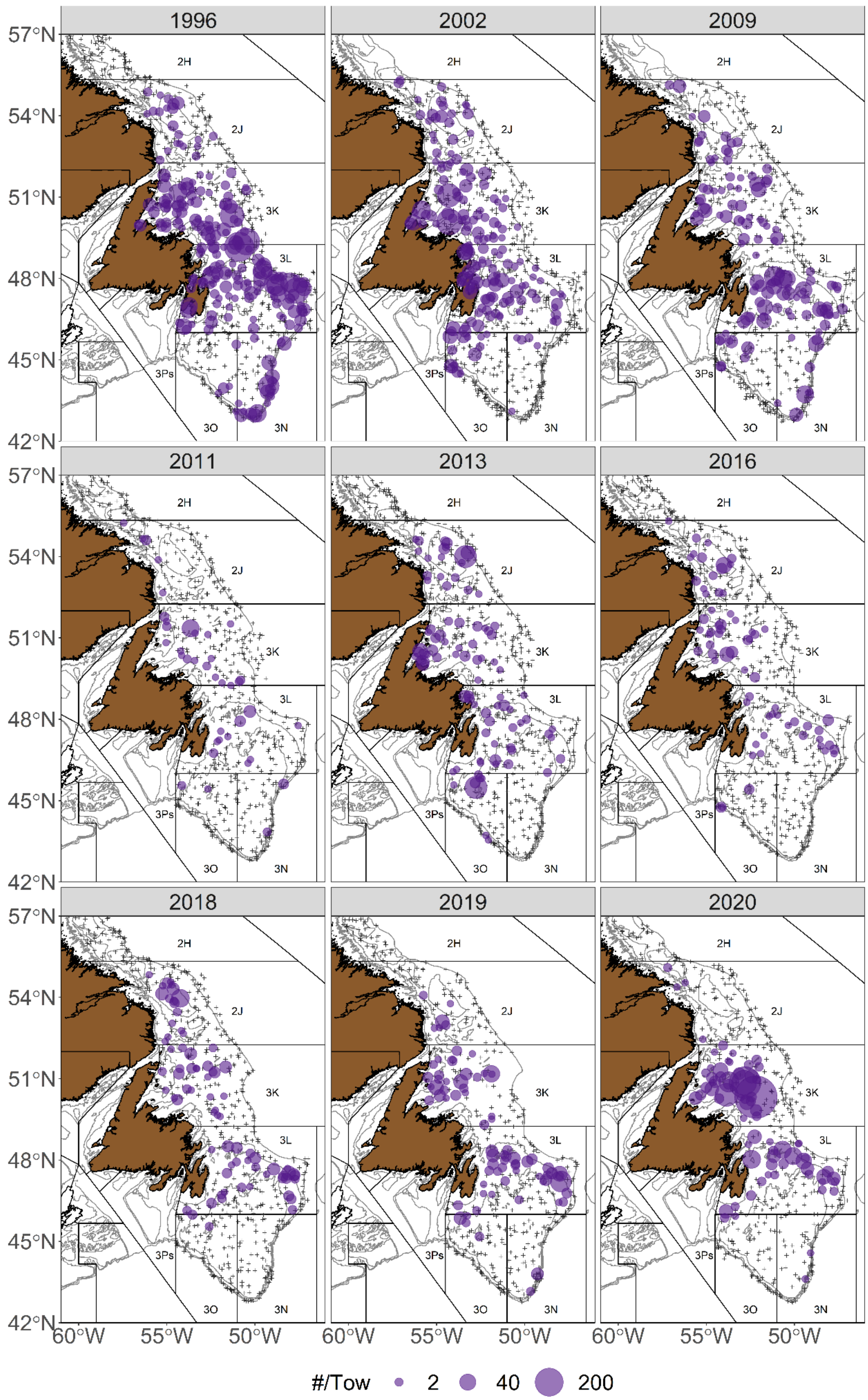

Figure 45. Distribution of mature females (#/tow) from Assessment Divisions 2HJ3KLNO fall trawl surveys in 1996, 2002, 2009, 2011, 2013, 2016 and 2018–20.

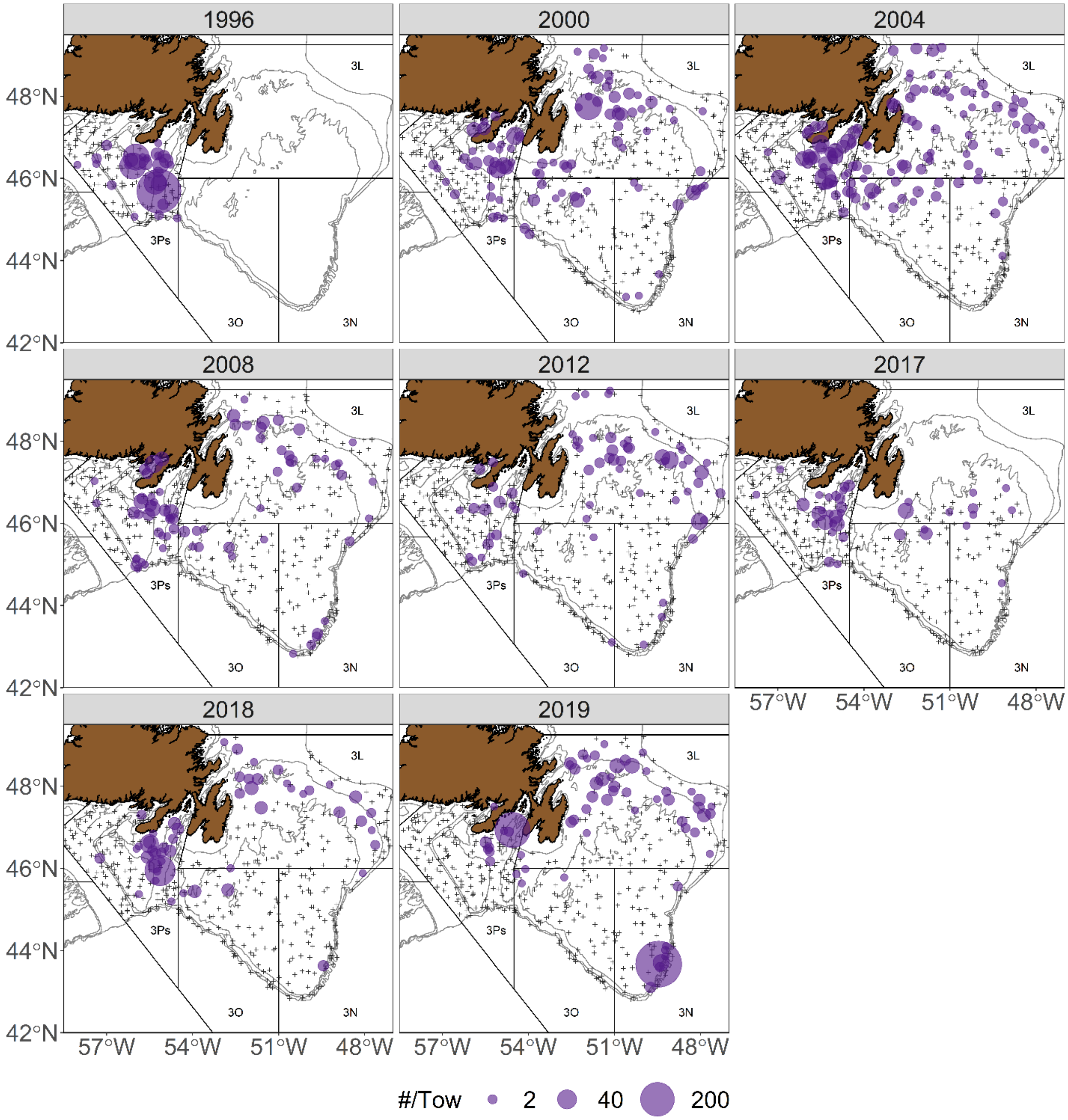

Figure 46. Distribution of mature females (#/tow) from Assessment Divisions 3LNOPs spring trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2017–19.

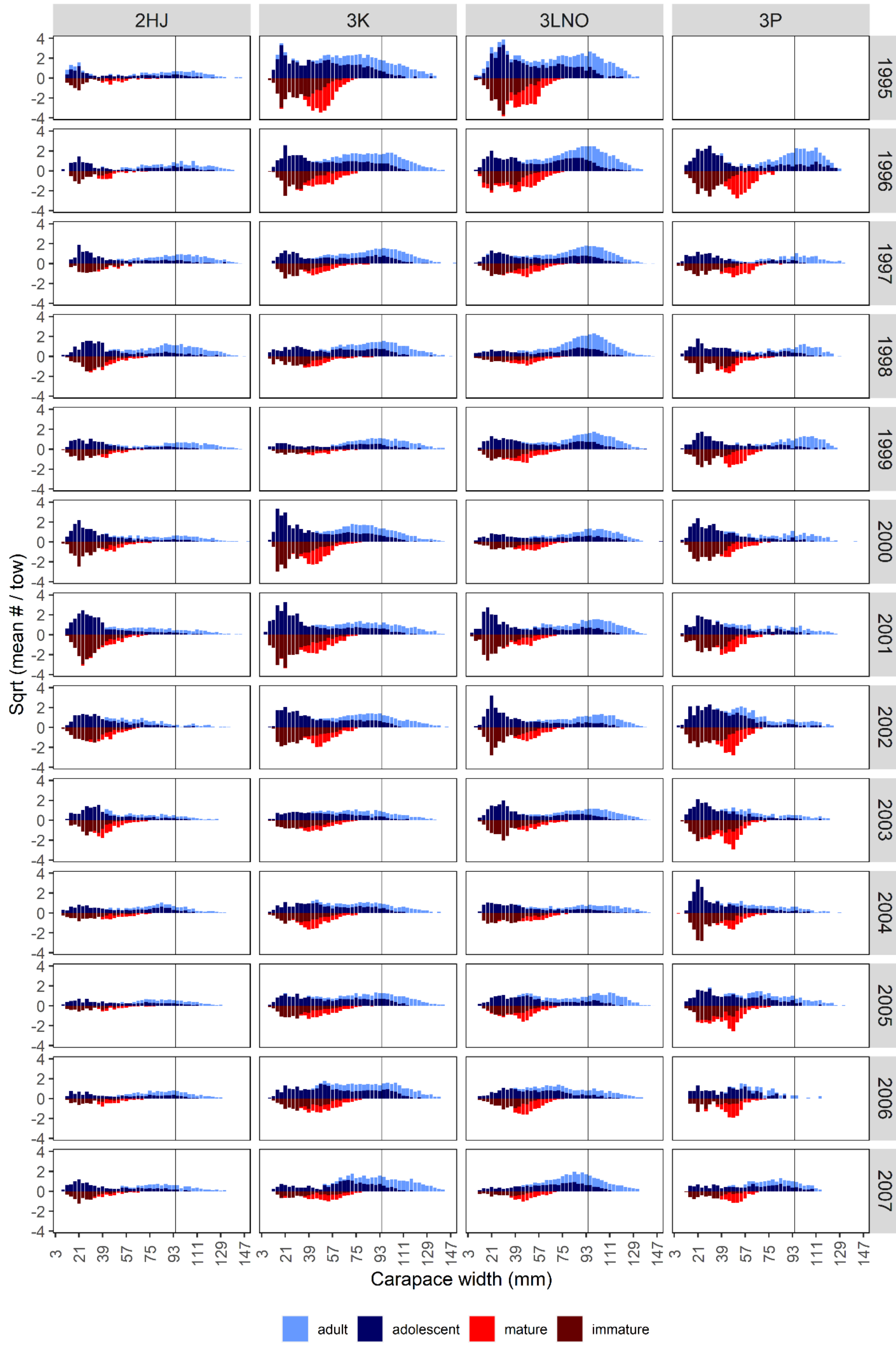

Figure 47. Abundance indices (#/tow) by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (AD 3Ps) and fall (ADs 2HJ, 3K, and 3LNO Offshore) trawl surveys from 1995 to 2007. Information on females, while displayed on the negative y-axis, represent positive abundance indices. Vertical line is legal-size. Data standardized by vessel.

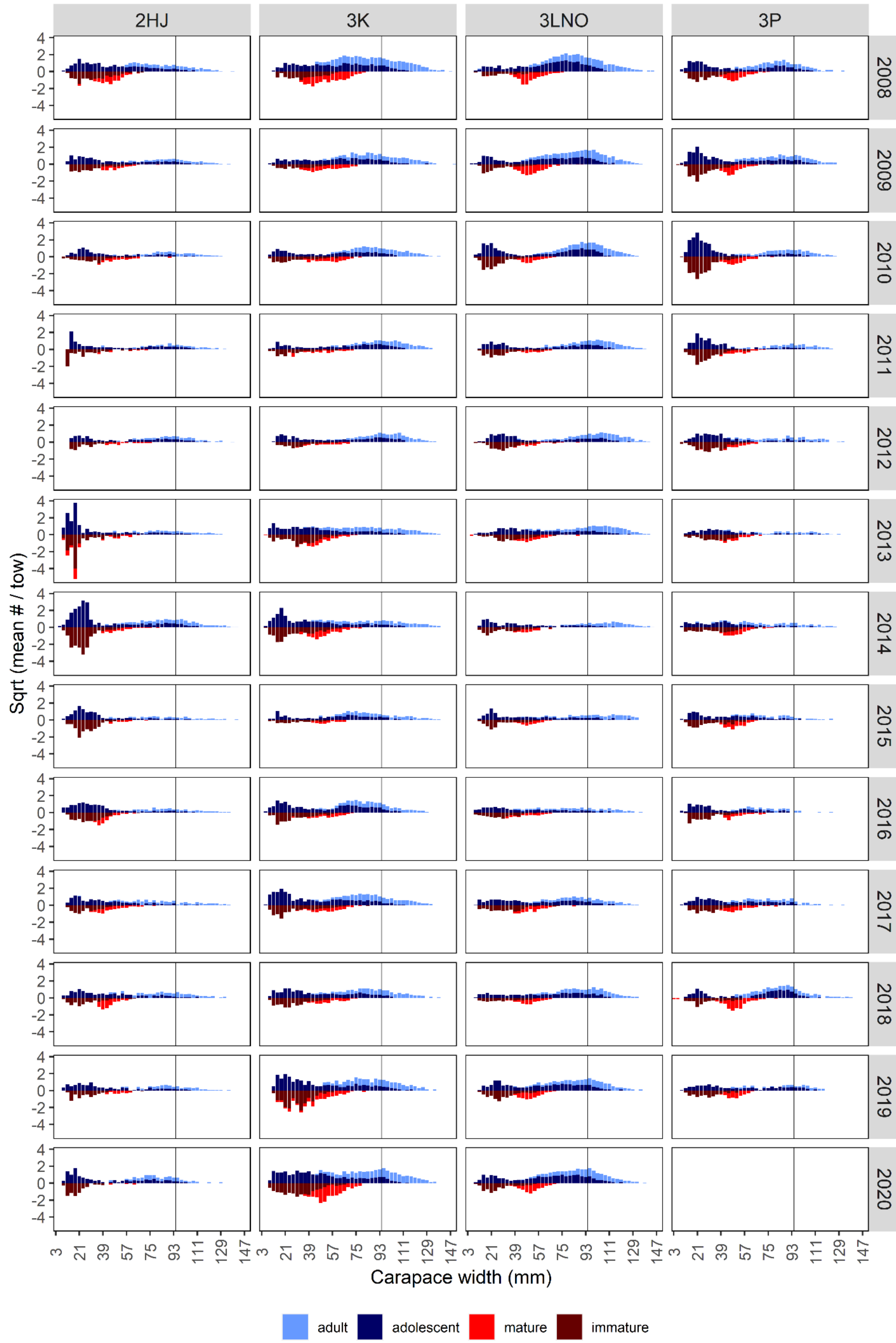

Figure 48. Abundance indices (#/tow) by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (AD 3Ps) and fall (ADs 2HJ, 3K, and 3LNO Offshore) trawl surveys from 2008 to 2020. Information on females, while displayed on the negative y-axis, represent positive abundance indices. Vertical line is legal-size. Data standardized by vessel.

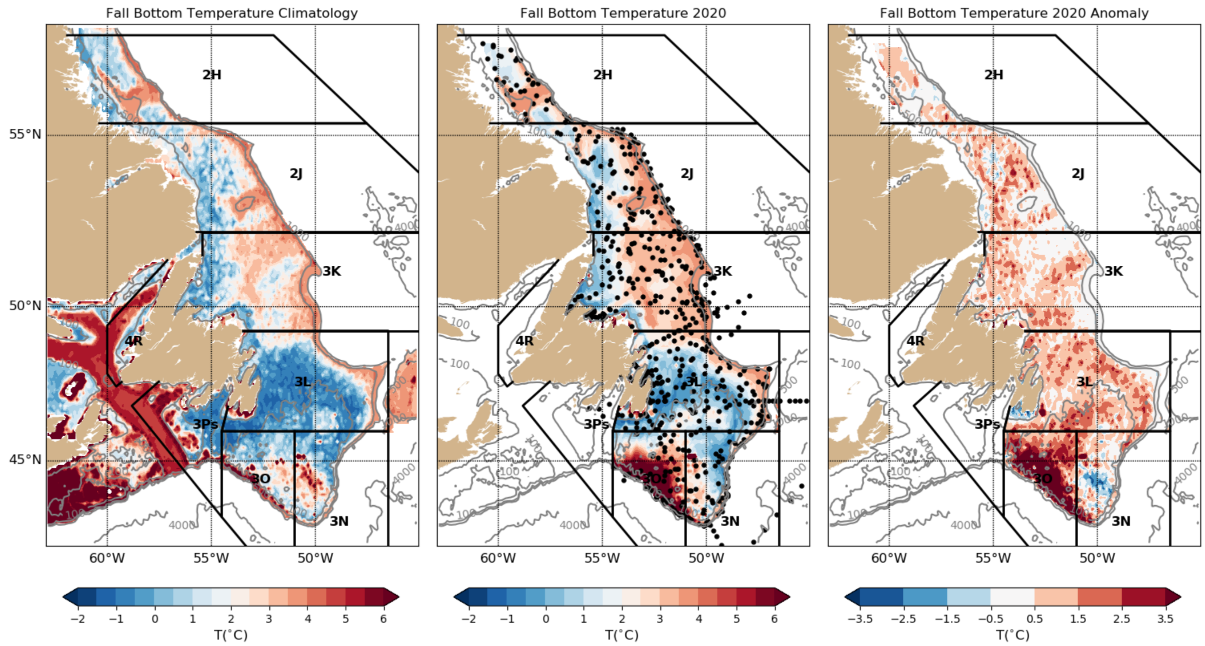

Figure 49. Mean 1981–2010 bottom temperatures (left), 2020 bottom temperatures (middle), and 2020 anomalies (right) in fall along the Newfoundland and Labrador shelf. The location of observations used to derive the temperature field is shown as black points in the middle panel.

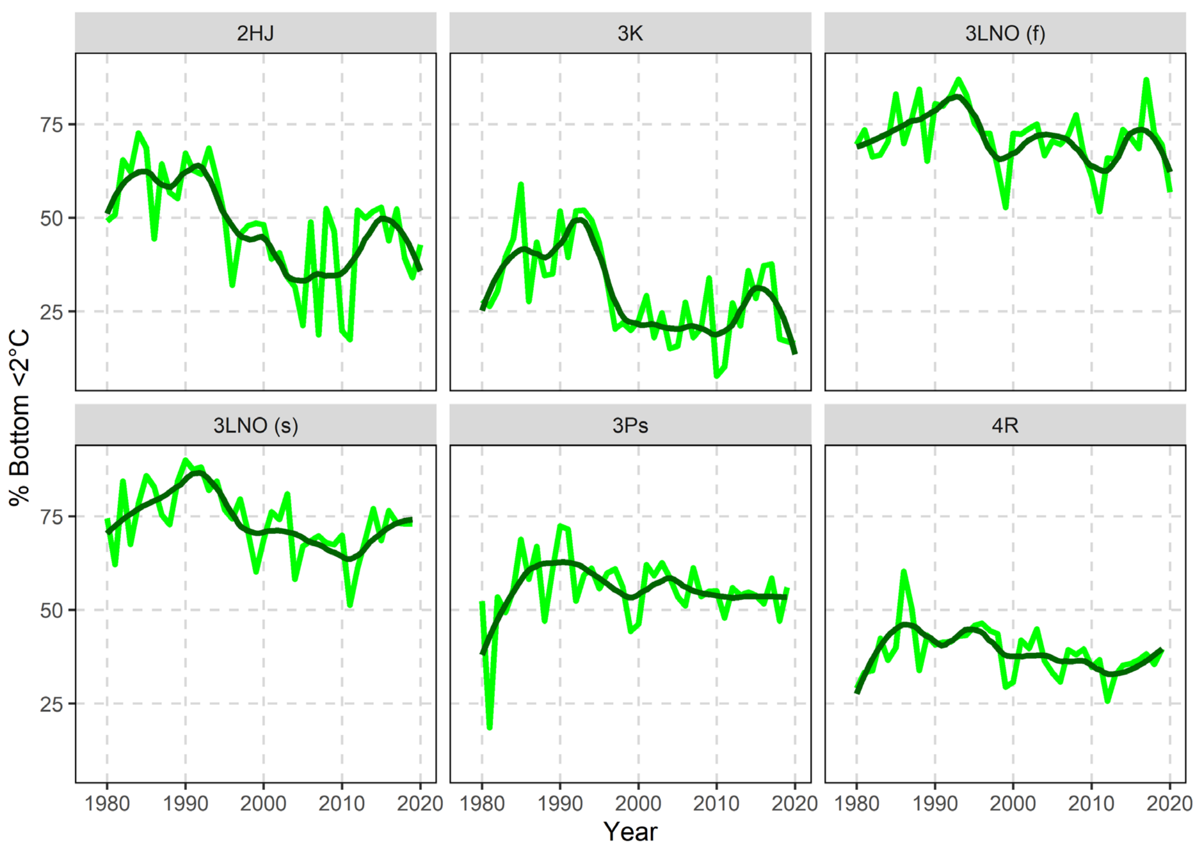

Figure 50. Snow crab thermal habitat indices by Assessment Division and year (1980–2020). f = fall data, s = spring data. Light green lines are annual values and dark green lines are loess regression curves.

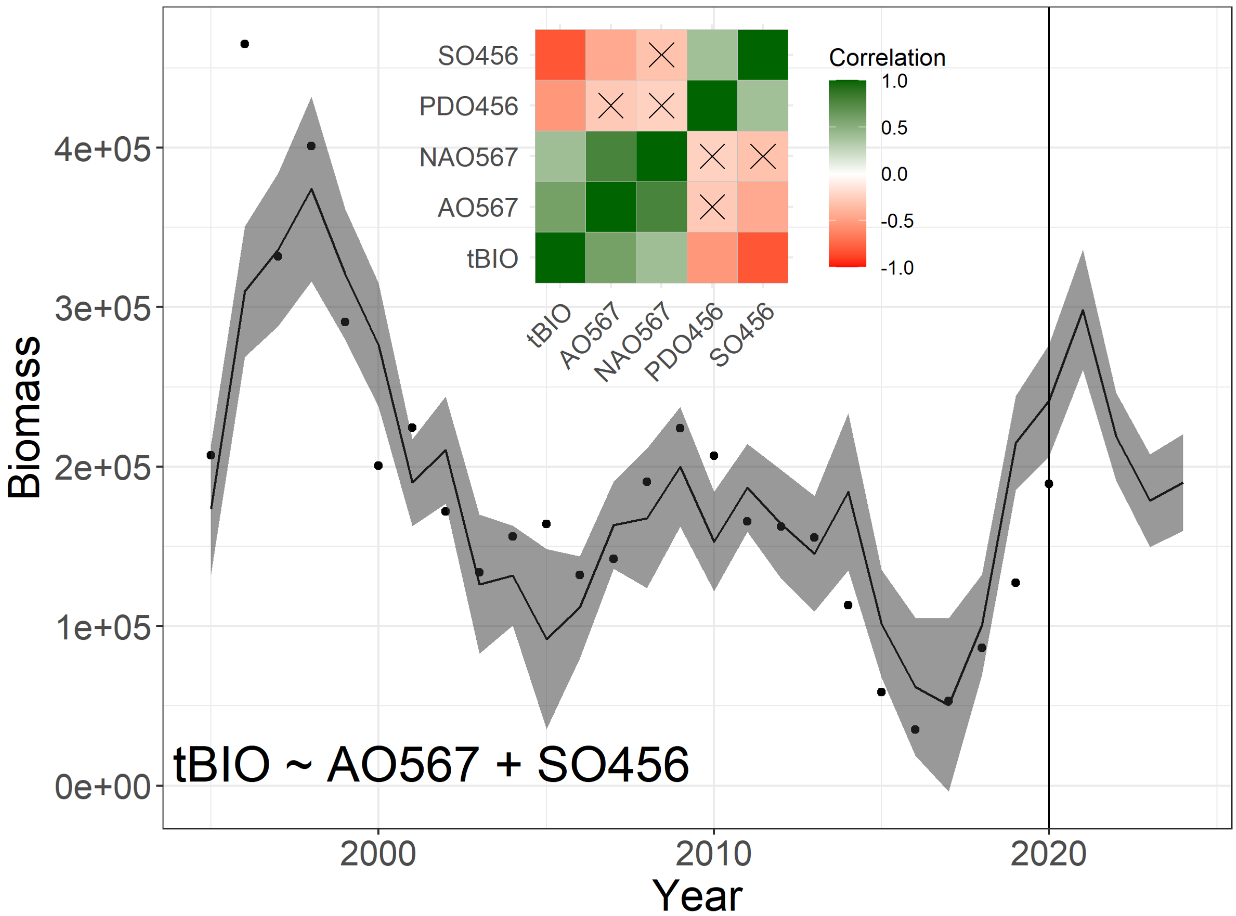

Figure 51. Top: Pearson correlation coefficients of stock-level exploitable biomass index against lagged indices of the Arctic Oscillation (AO), North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), and El Niño-Southern Oscillation (SO). Lagged indices are defined as an average of monthly values over 3 years (e.g., the lagged index of the AO is the average of monthly values from 5 to 7 years ago). Bottom: Stock-level exploitable biomass index in relation to a lagged index of the Arctic Oscillation from 5 to 7 years ago and the El Niño-Southern Oscillation from 4 to 6 years ago. Points are survey exploitable biomass + landings, solid line is the model fit, and the shaded band is the 95% confidence intervals.

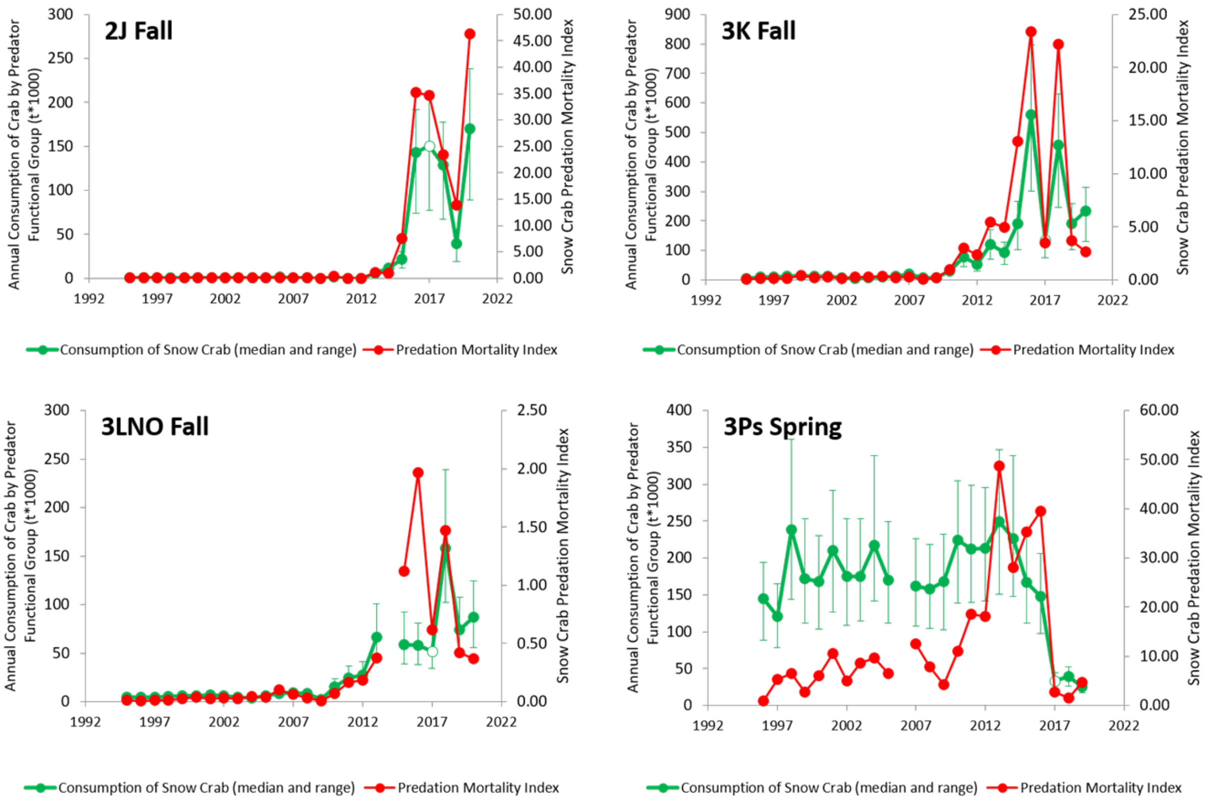

Figure 52. Consumption of Snow Crab by predators and Snow Crab predation mortality index by Ecosystem Production Units (1995–20).

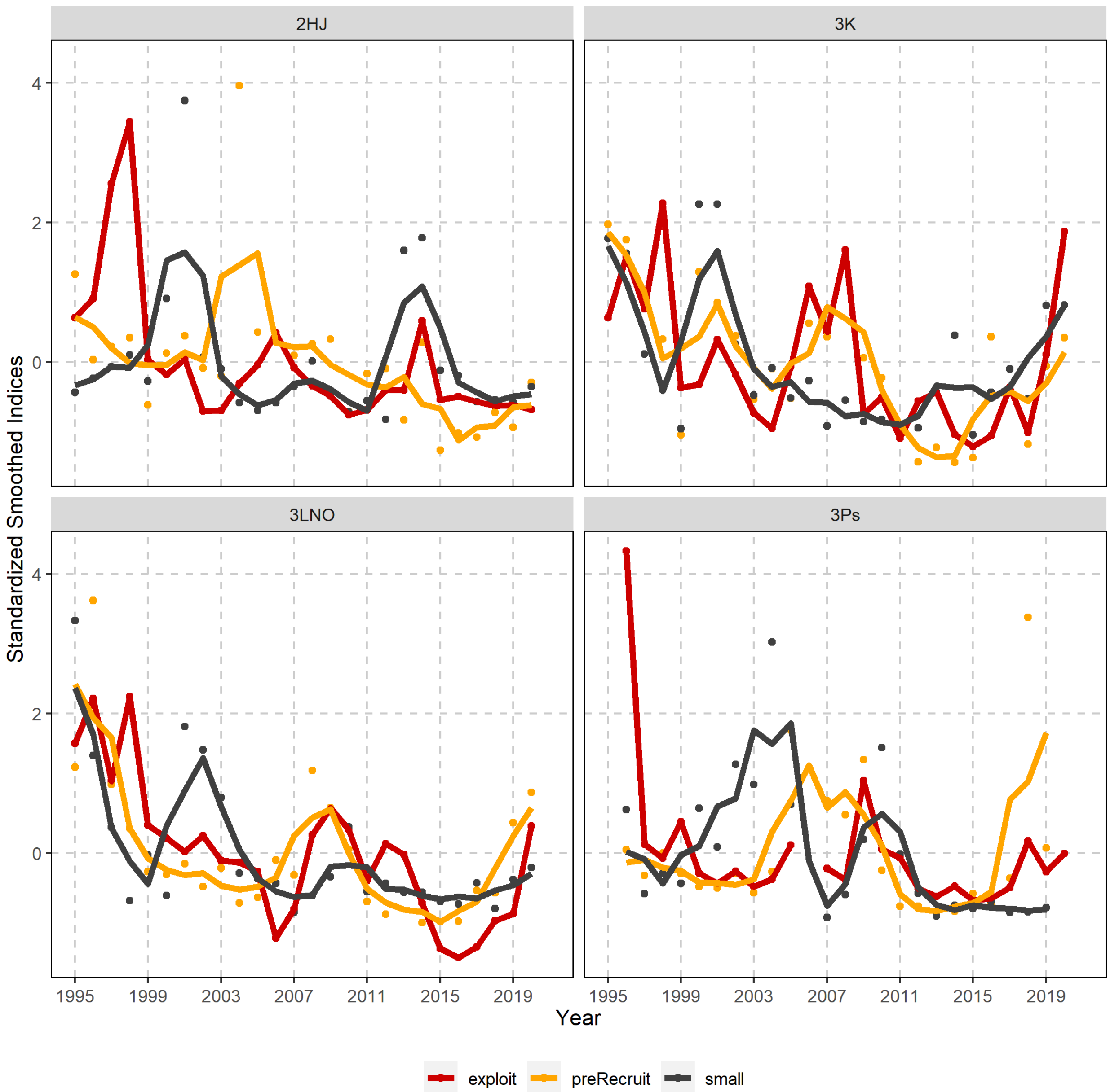

Figure 53. Standardized annual (points) and 3-year centered moving average (solid line) indices of Snow Crab biomass or abundance by Assessment Division: exploitable male crab (red), pre-recruits (orange), and small crab (<50 mm CW) (black).

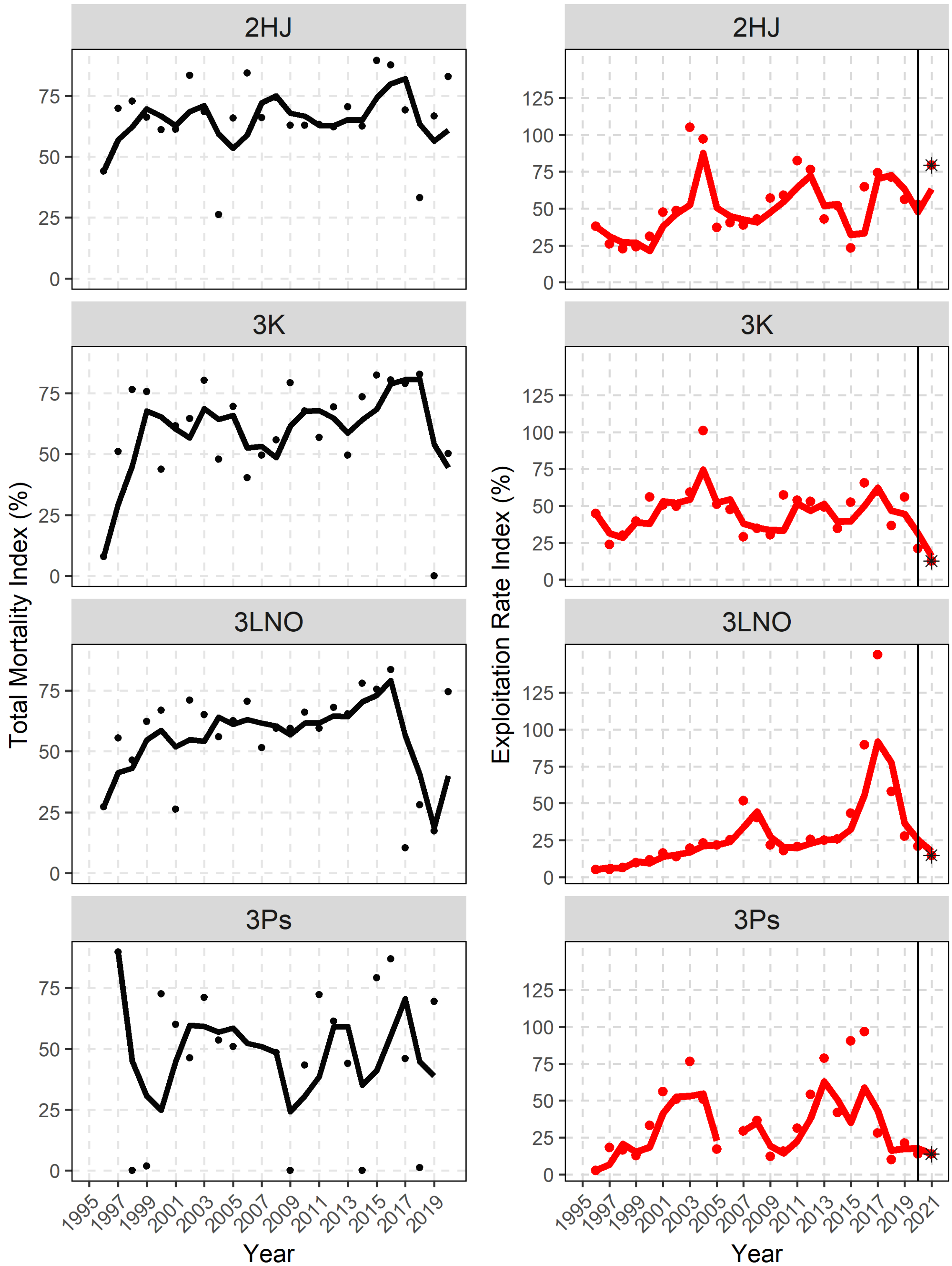

Figure 54. Left: Trends in the annual (points) and 3-year moving average (solid line) total annual mortality index (%) of exploitable crab by Assessment Division. Note if annual mortality index was <0 it was plotted as 0 for presentation. Right: Trends in the trawl-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) by Assessment Division; 2021 points depict projected exploitation rate indices under status quo removals in the 2021 fishery.

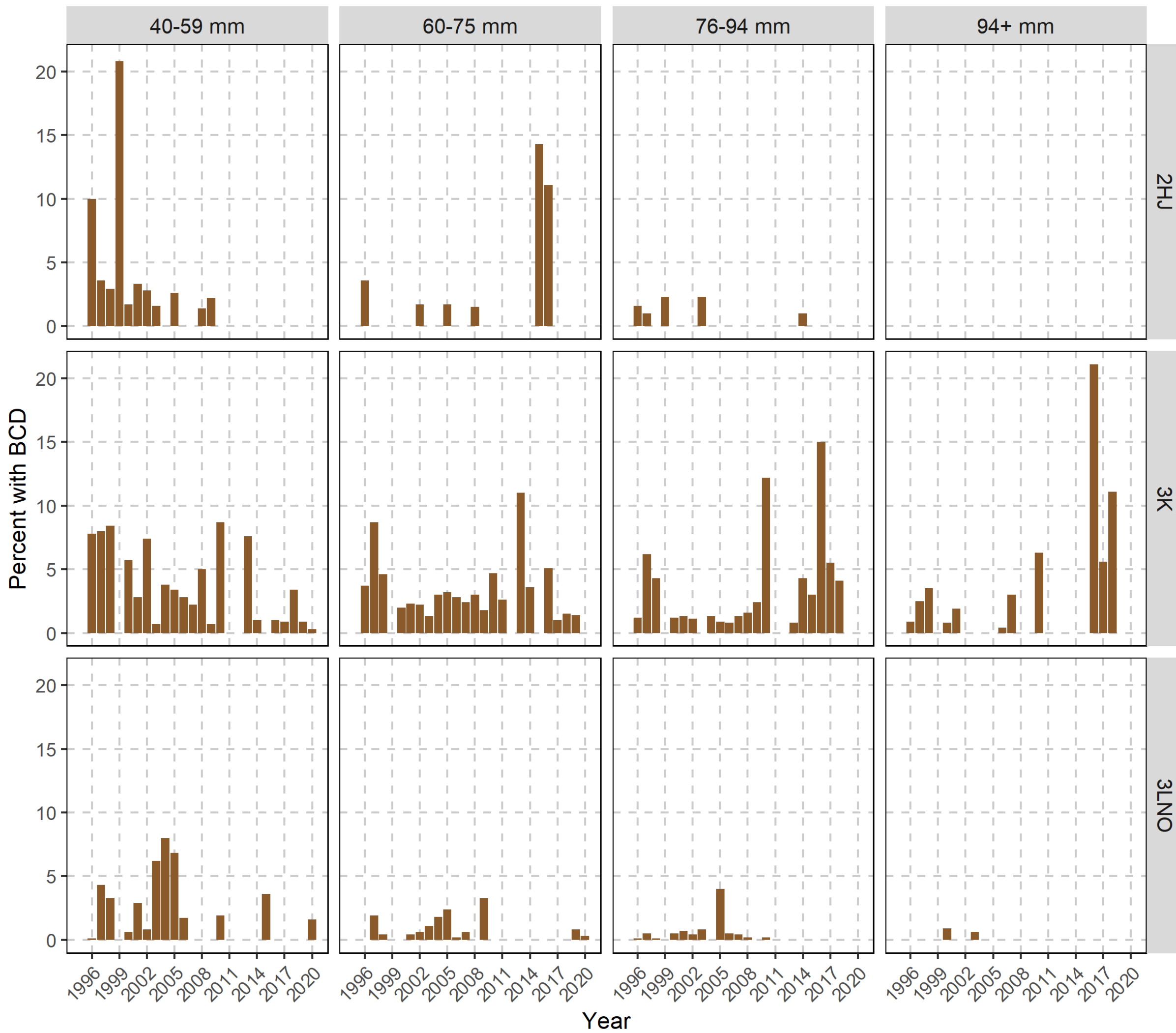

Figure 55. Annual prevalence of Bitter Crab Disease (BCD) from macroscopic observations in new-shelled adolescent male crab in fall trawl surveys by Assessment Division and carapace width (1996–2020).

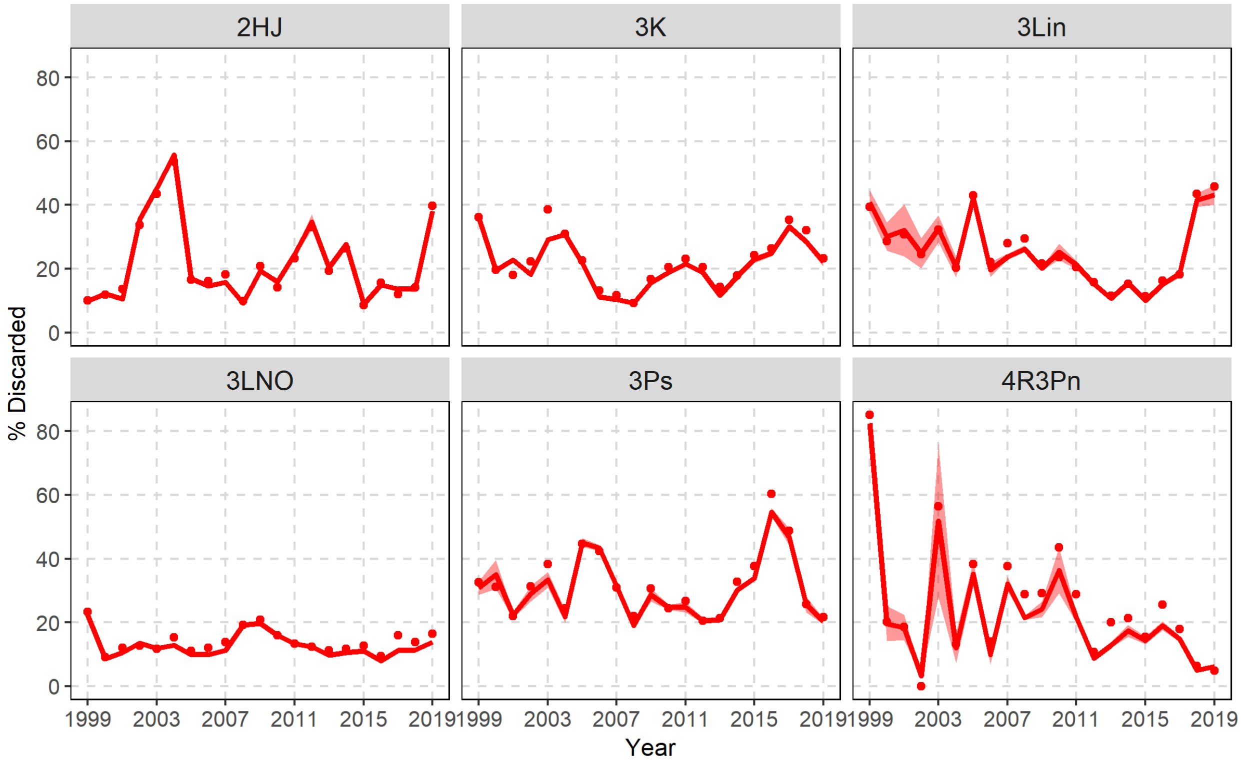

Figure 56. Trends in discards (%) based on raw estimates (points) and standardized values (solid lines). The shaded area represents the 95% confidence interval. Note: Not updated for 2020.

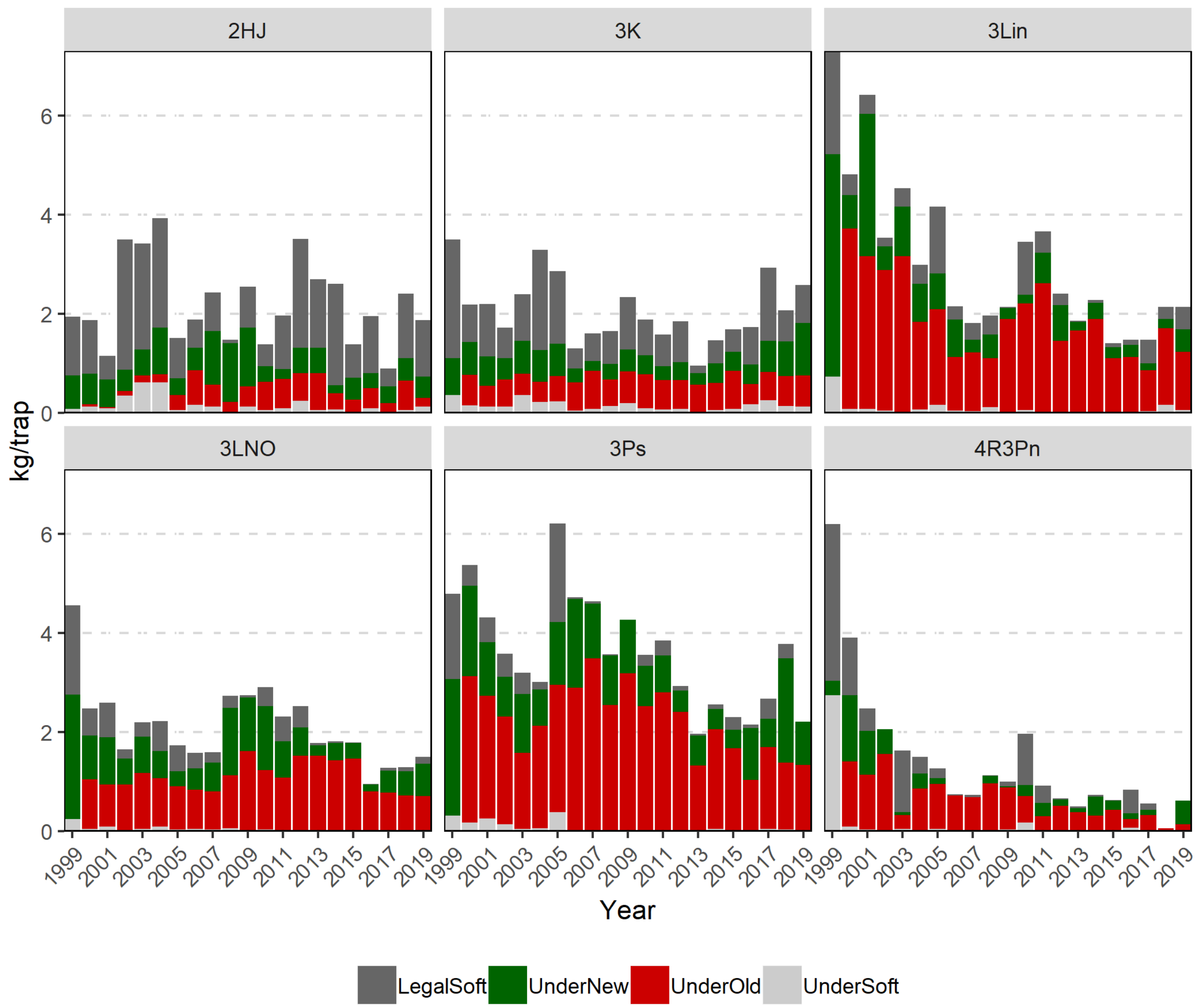

Figure 57. Trends in observed catch rates of discards (kg/trap) based on size and shell condition groups (legal-sized soft-shelled, undersized new-shelled, undersized old-shelled, and undersized soft-shelled) by Assessment Division (1999–2019). Note: Not updated for 2020.

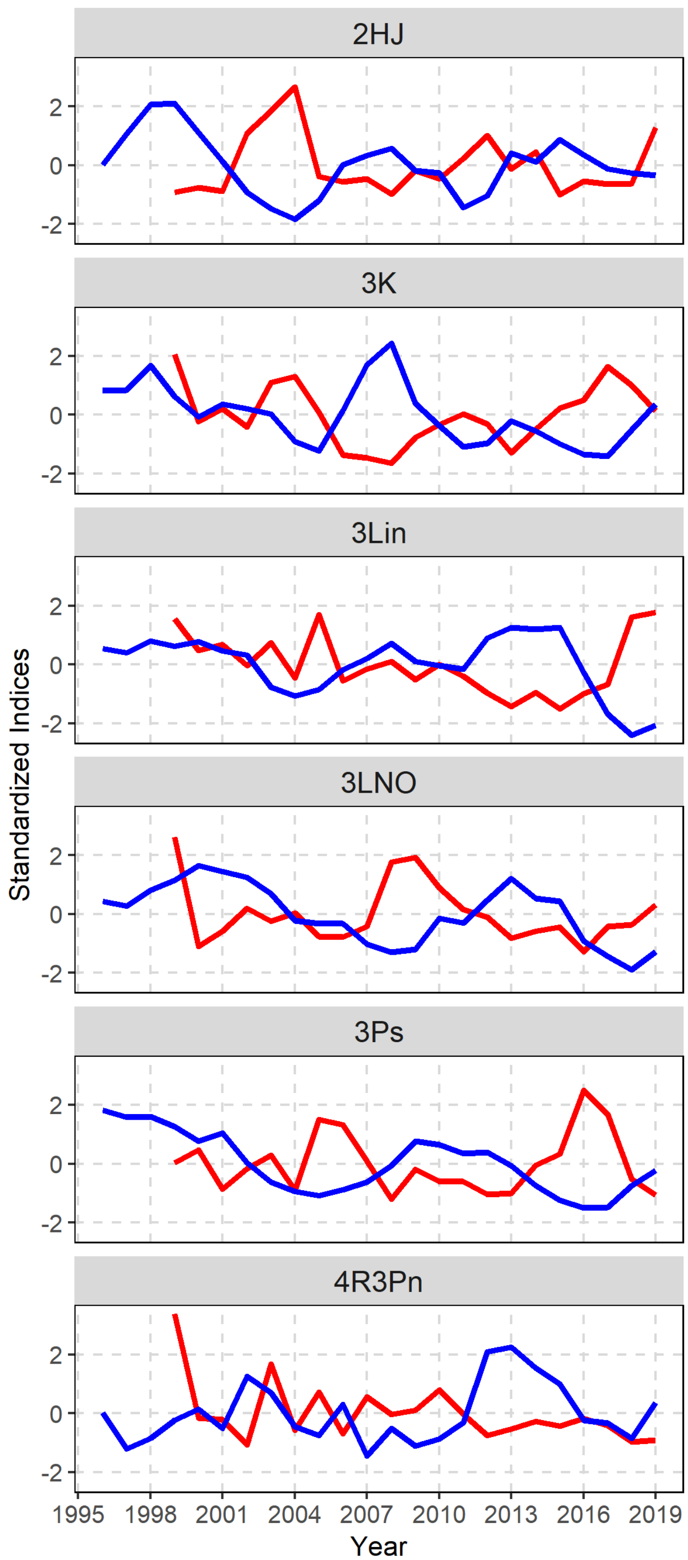

Figure 58. Trends in standardized fishery CPUE (blue) and discard rates (red) by Assessment Division (1996–2019). Note: Not updated for 2020.

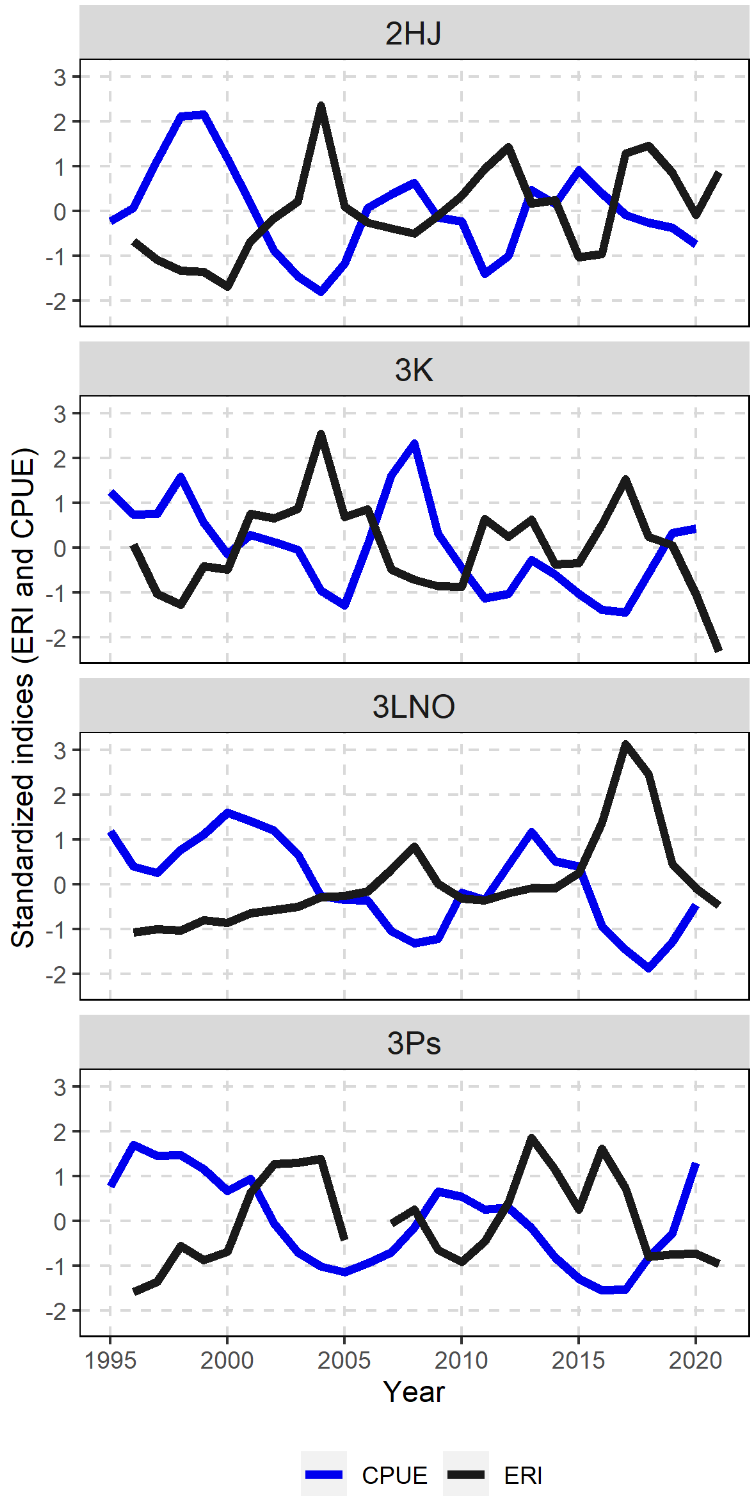

Figure 59. Trends in standardized fishery CPUE (blue) and exploitation rate indices (ERI) (black) by Assessment Division (1995–2020).

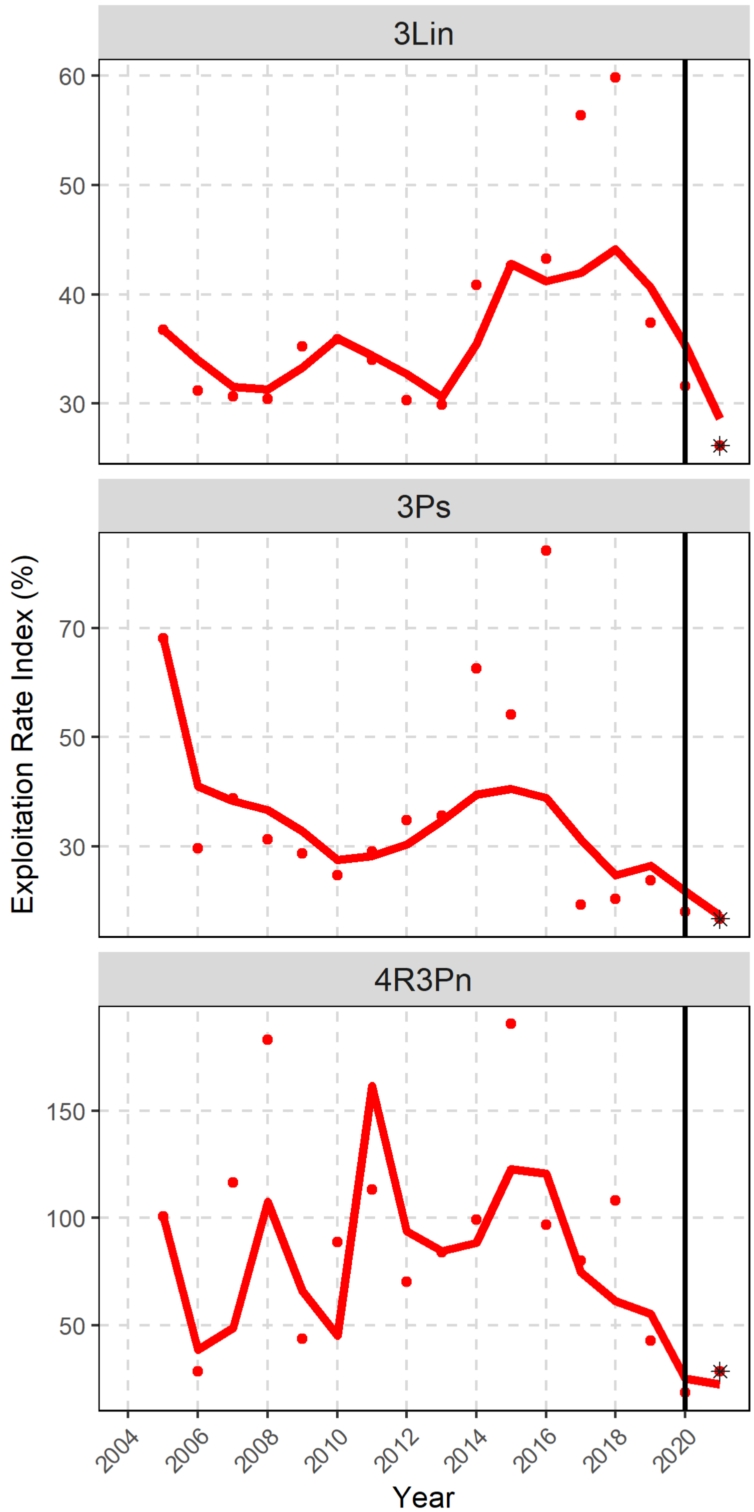

Figure 60. Trends in the trap-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Divisions 3L Inshore, 3Ps, and 4R3Pn; 2021 points depict projected exploitation rate indices under status quo removals in the 2021 fishery.

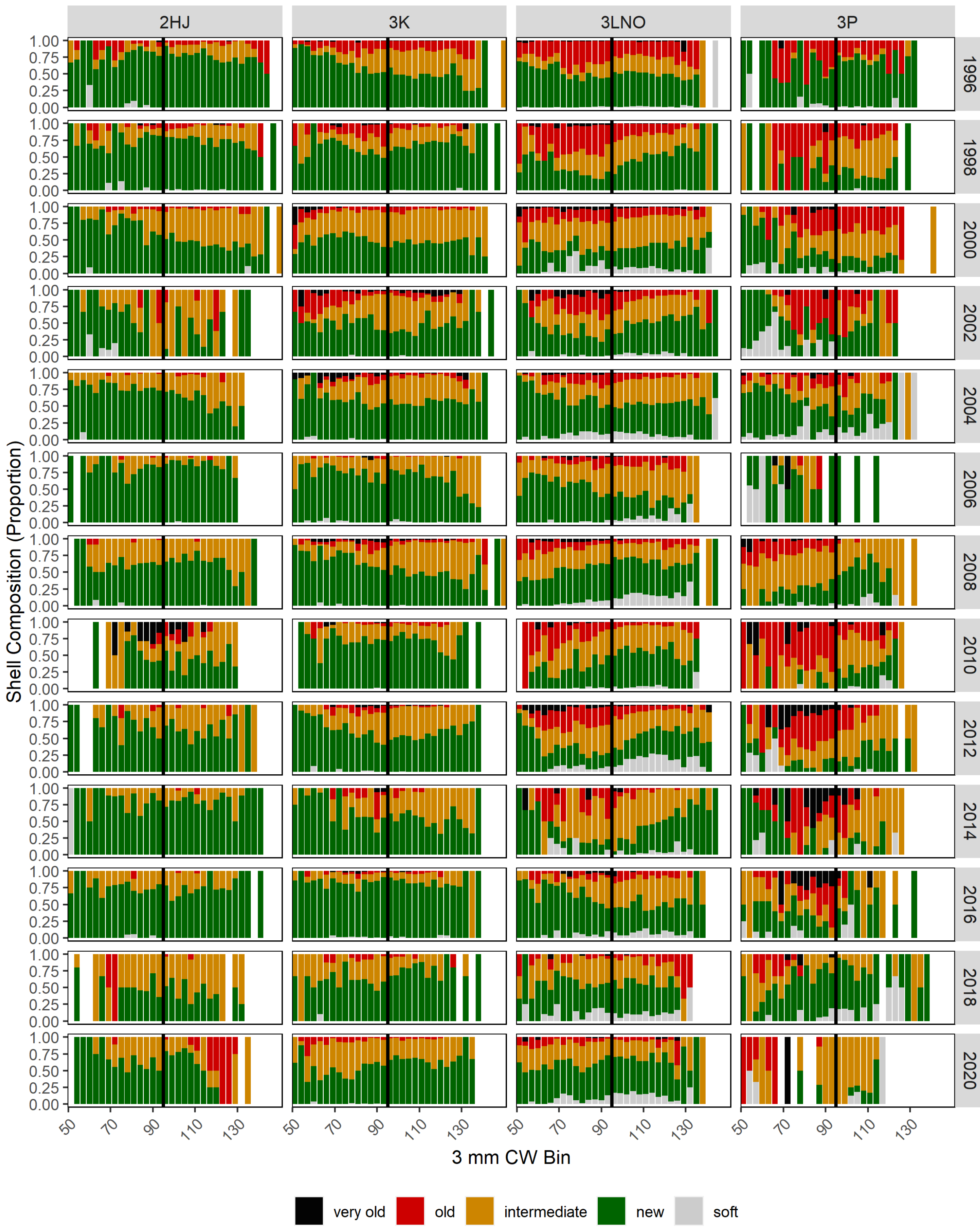

Figure 61. Shell composition (grey = soft shelled, green = new shelled, orange = intermediate shelled, red = old shelled, black = very old shelled) of adult male crab by 3-mm carapace width intervals from trawl surveys since 1995 in each Assessment Division. Years binned to two-year increments (1995 + 1996 = 1996). Vertical black lines depict legal-size.

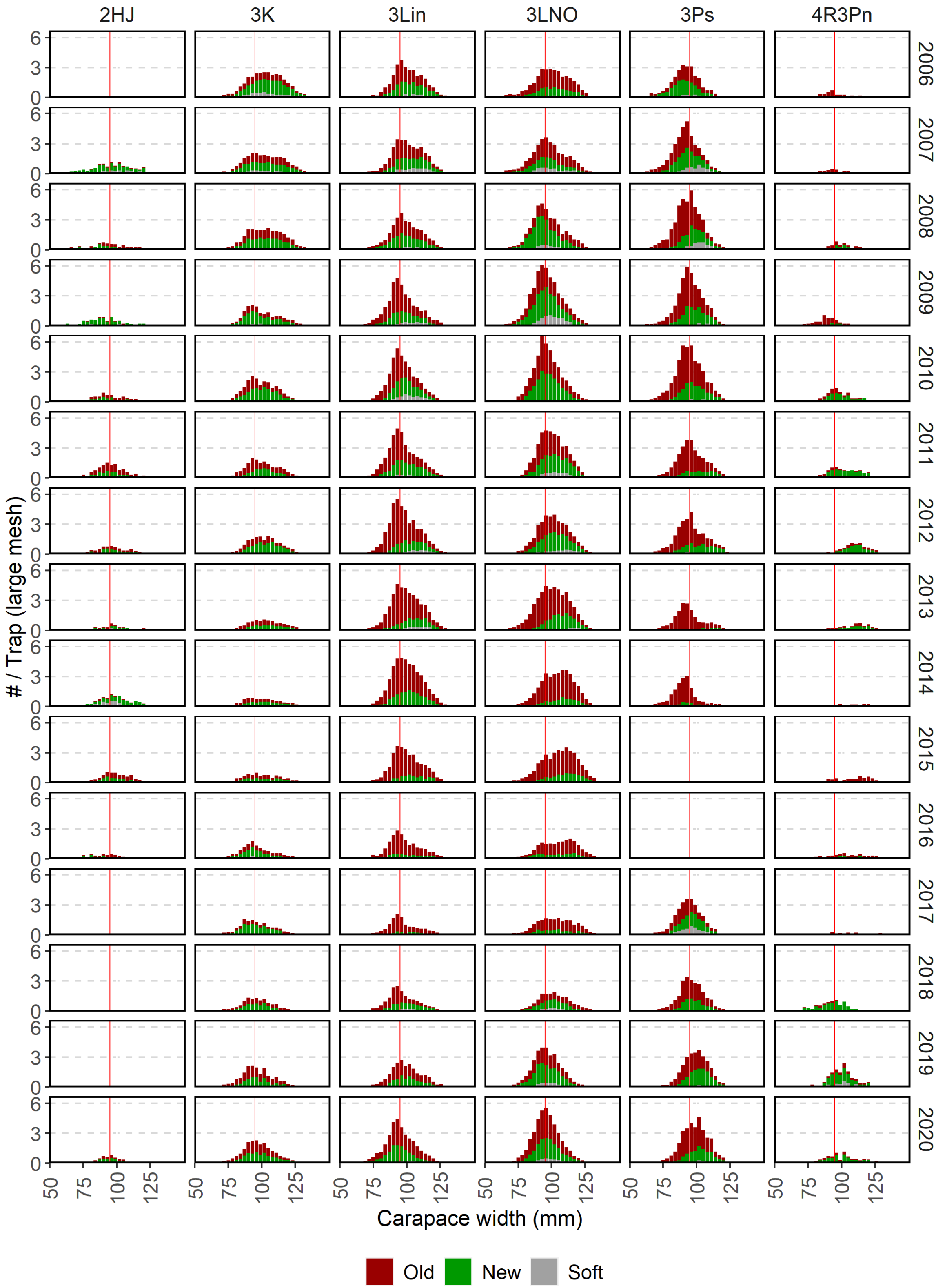

Figure 62. Trends in CPUE (#/trap) by male carapace width distributions and shell condition from large-mesh traps in core stations for the CPS survey by Assessment Division (2006–20). The red vertical line indicates the minimum legal size.

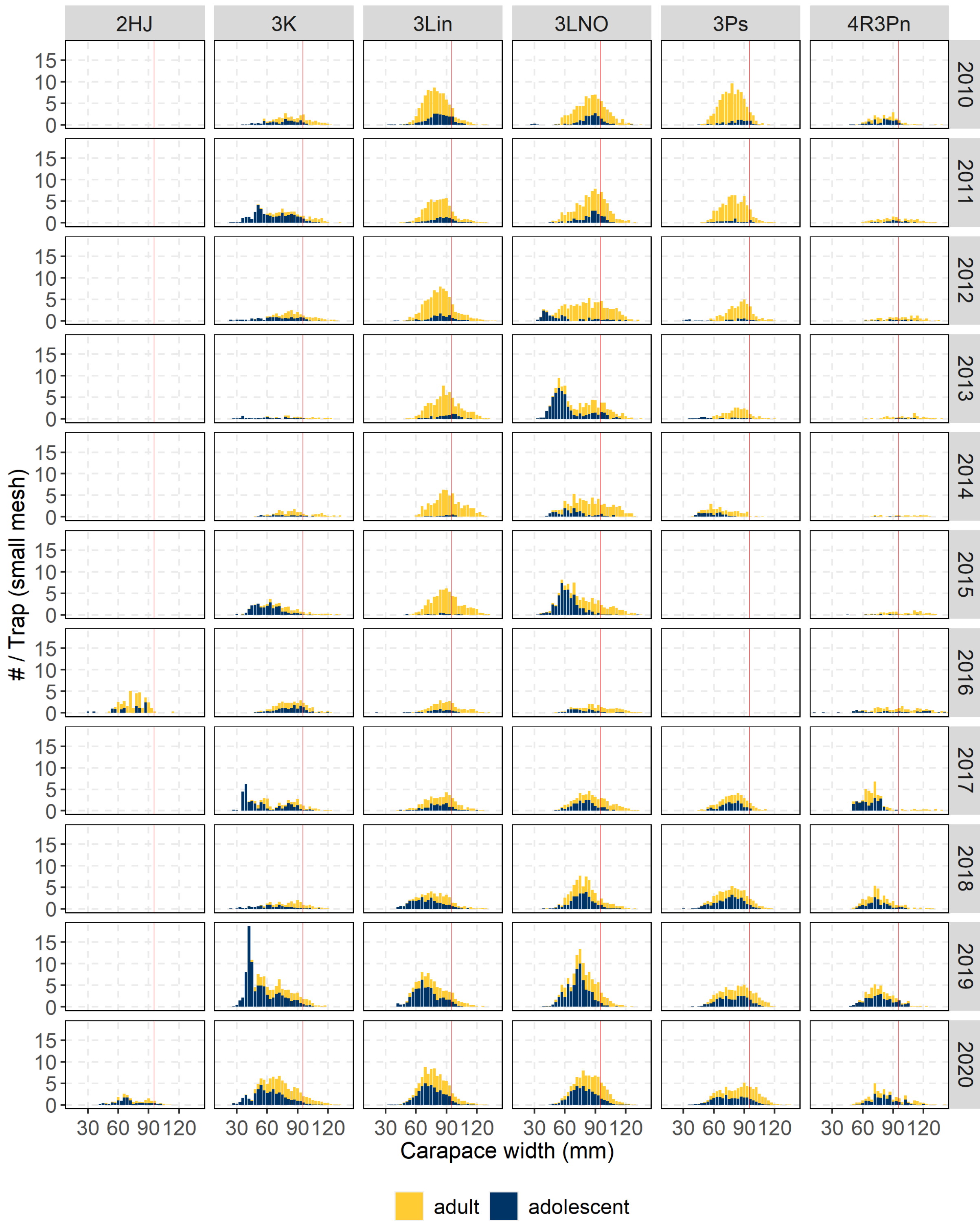

Figure 63. Trends in CPUE (#/trap) by male carapace width distributions and maturity (blue – juveniles and adolescent males, yellow – adult males) from small-mesh traps in core stations from the CPS survey by Assessment Division (2010–20). The red vertical line indicates the minimum legal size.

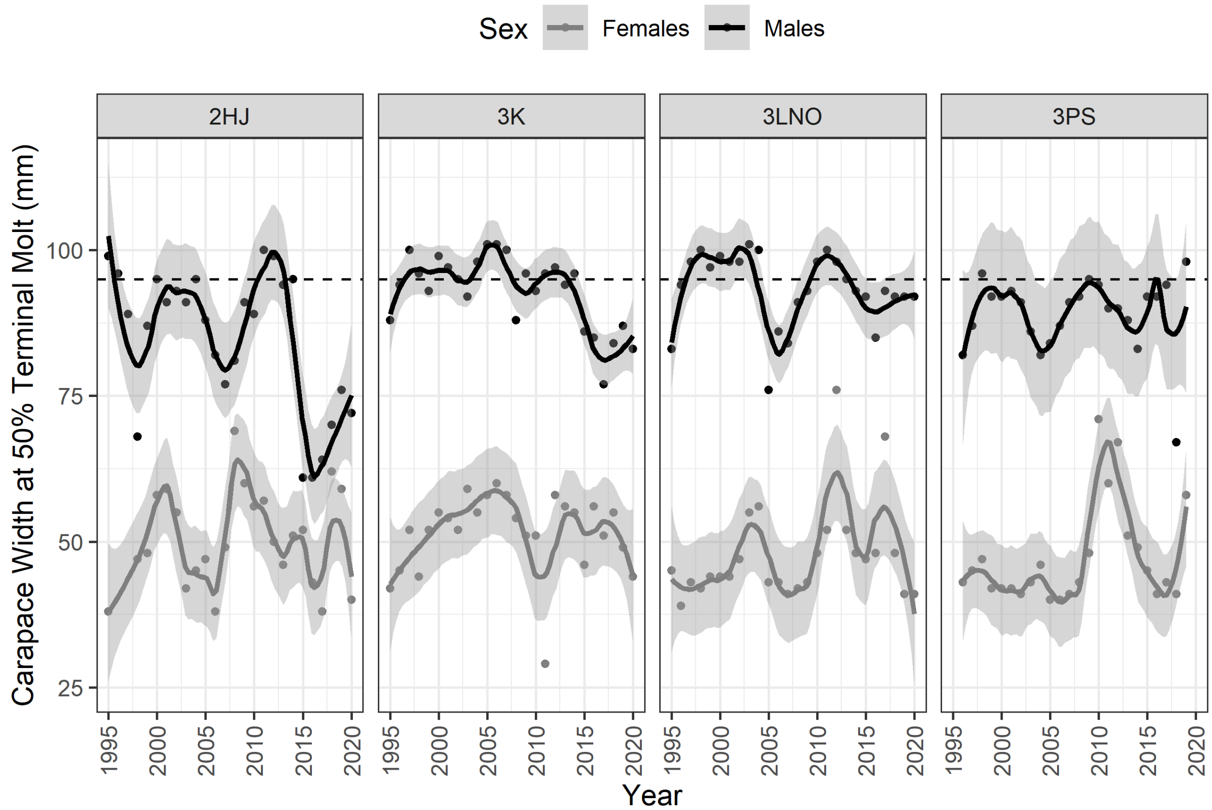

Figure 64. Male (black) and female (grey) size at 50% maturity (terminal molt) in each Assessment Division. Points represent annual estimates from GAM, solid lines represent loess regression curves, and shaded band represents 95% confidence intervals. Horizontal dashed line is minimum legal size.

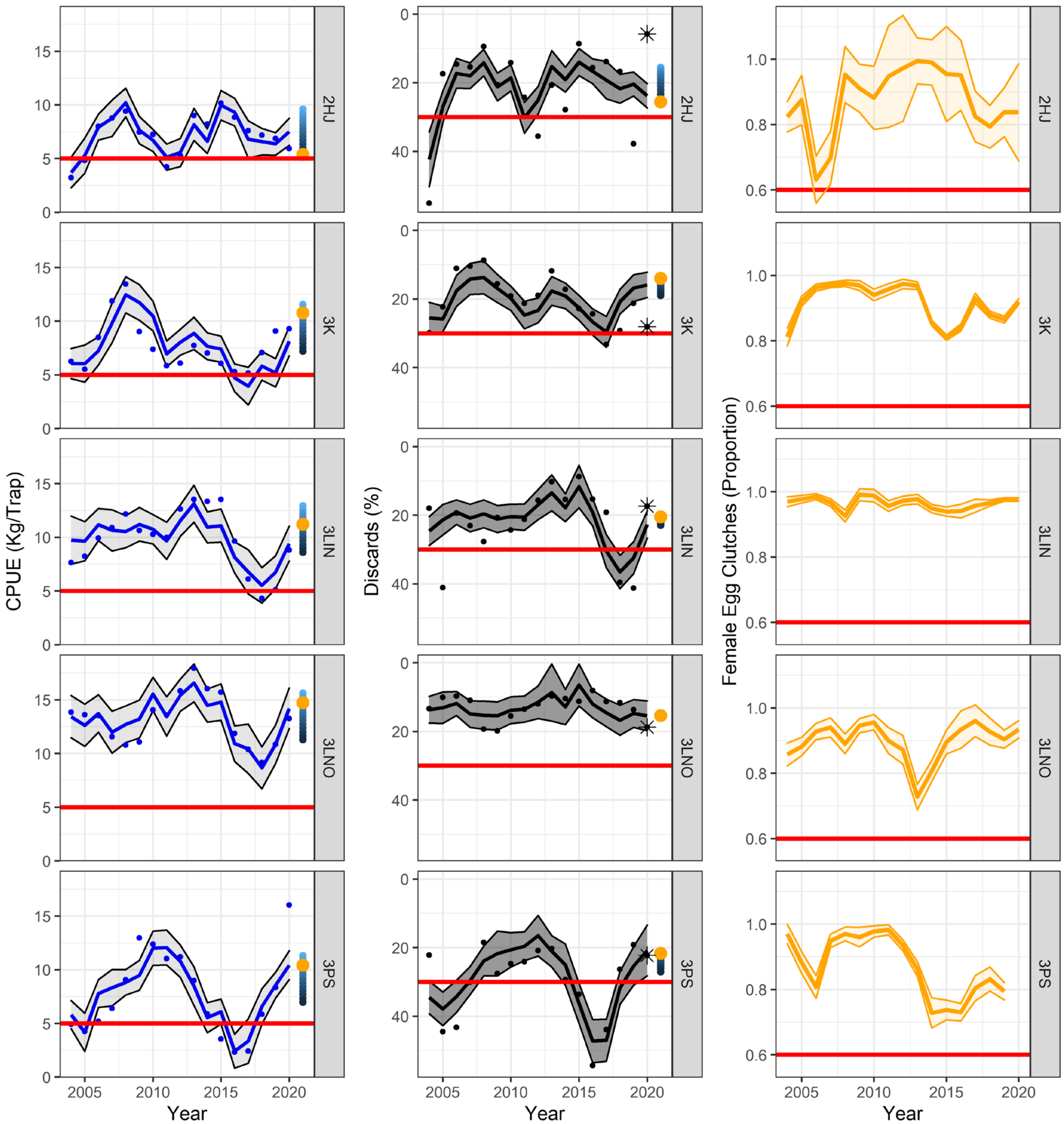

Figure 65. Trends in predicted CPUE (left), predicted % discards (middle), and observed proportion of females with full egg clutch (right) (solid lines), as well as standardized CPUE and % discards (points) in relation to Limit Reference Points (red horizontal lines) for each metric in the proposed Precautionary Approach Framework, by Assessment Division. Shaded areas represent prediction intervals (CPUE and discards) or 1 standard deviation (egg clutches). Stars in % discards panel represent the mean % discards from at-sea observer data and a reference fleet from logbook data. Orange points represent predicted values under status quo landings in the forthcoming fishery. Vertical blue shades in 2021 are the predicted values under varying levels of Exploitation Rate Index (ERI) (light to dark blue: ERI = 0–60%).

APPENDIX 1: ASSESSMENT DIVISION 2HJ DETAILS

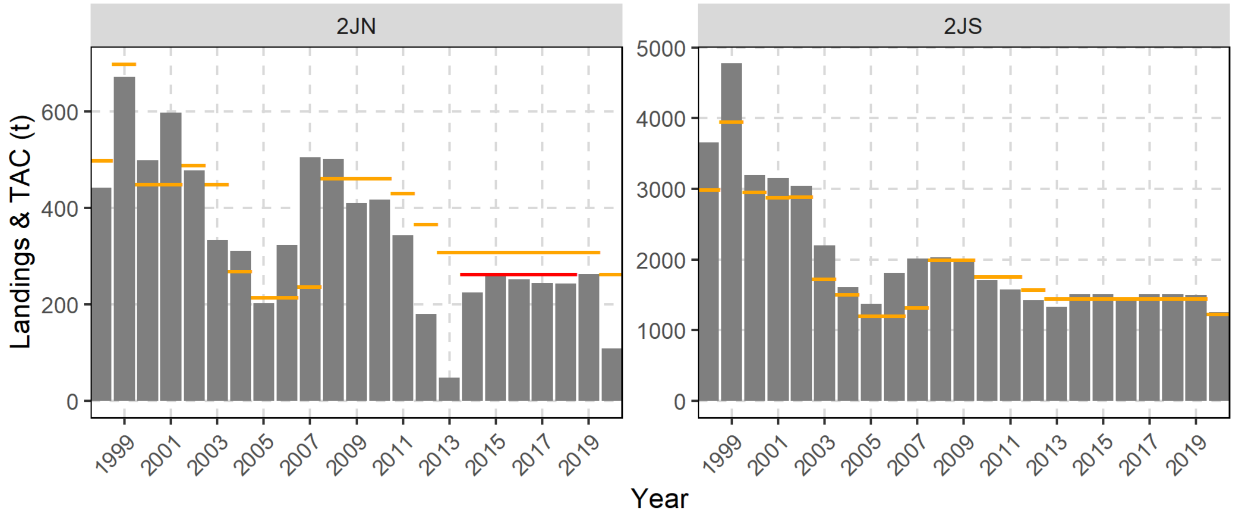

Figure A1. 1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 2HJ (1998–2020). Red dashes are the voluntary TAC (15% reduction of TAC) set by harvesters in 2JN from 2014 to 2018.

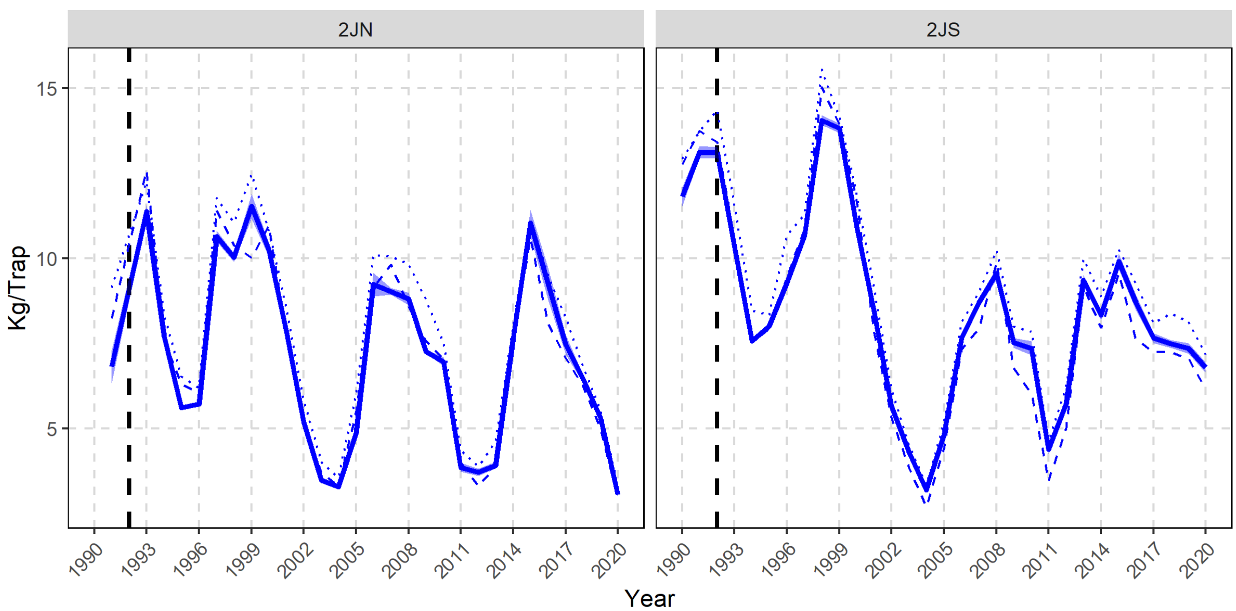

Figure A1. 2. Trends in standardized CPUE (kg/trap) in CMAs within Assessment Division 2HJ. Solid line is average predicted CPUE, shaded band is 95% confidence interval, dotted line represents average raw CPUE, and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

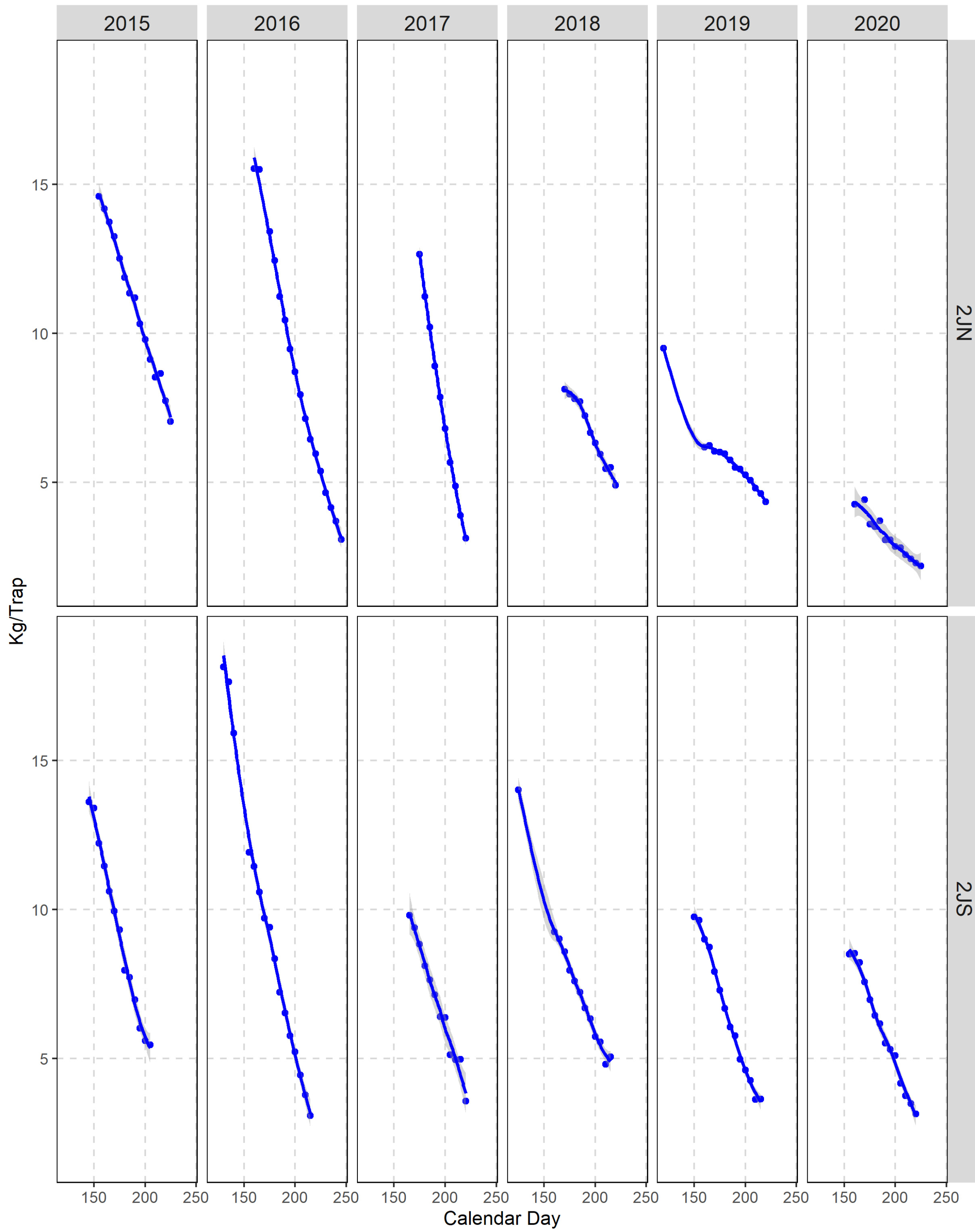

Figure A1. 3. Standardized CPUE (kg/trap) throughout the season (calendar day) in Assessment Division 2HJ (2015–20), derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

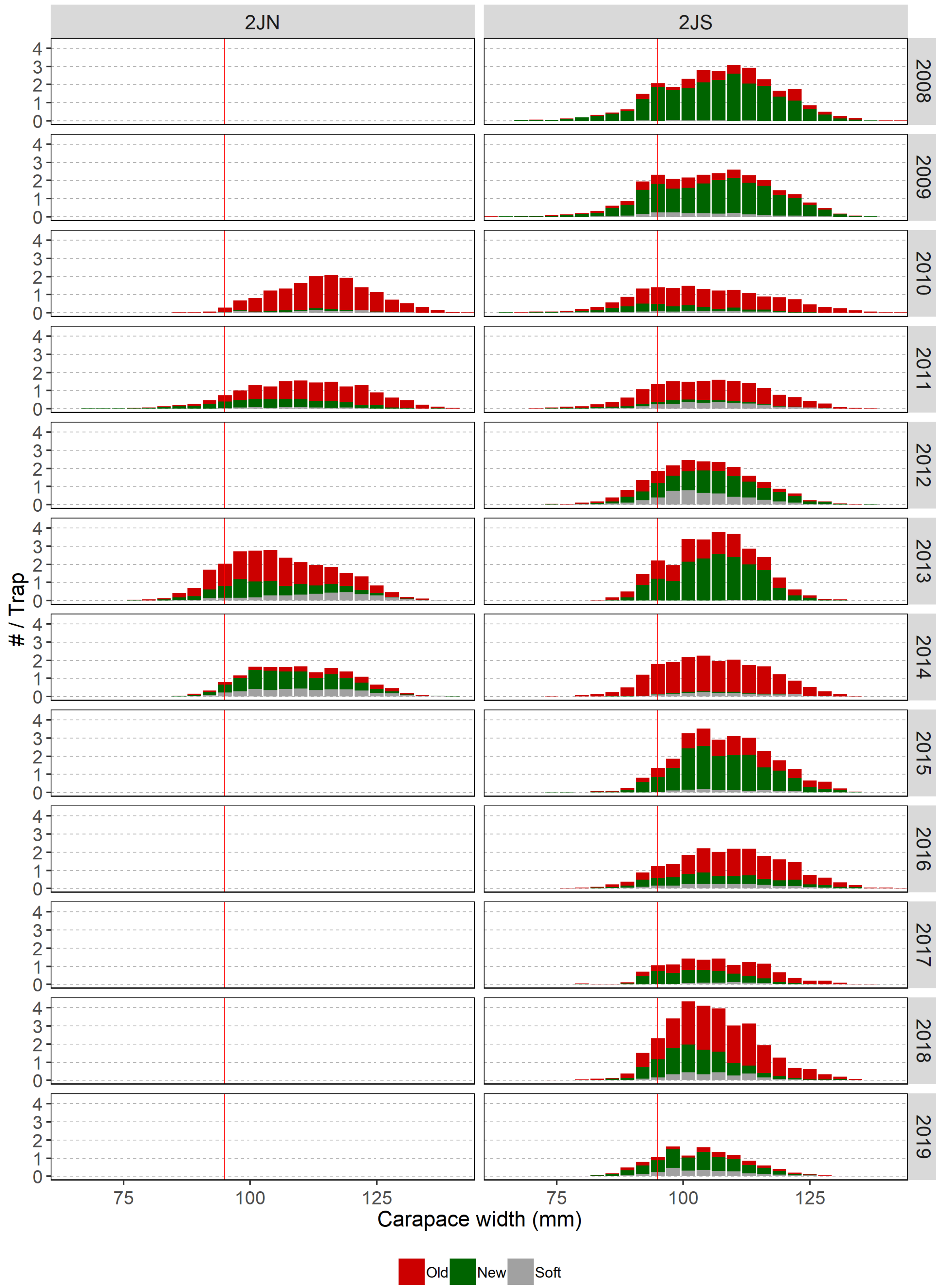

Figure A1. 4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each Crab Management Area in Assessment Division 2HJ (2008–19). The red vertical line indicates the minimum legal size. Note: Not updated for 2020.

Figure A1. 5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Crab Management Areas within Assessment Division 2HJ (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates. Note: Not updated for 2020.

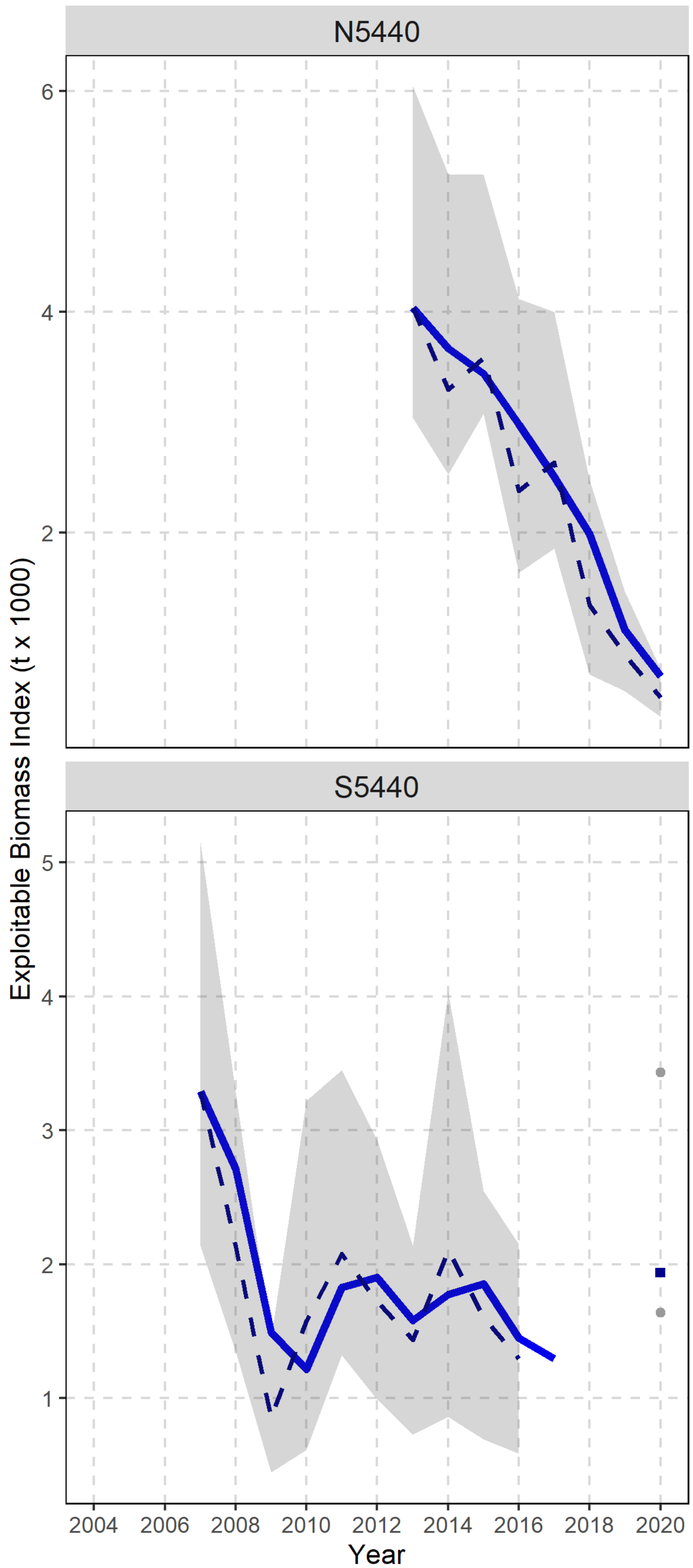

Figure A1. 6. Annual trap-based exploitable biomass index (t x 1,000). The solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the 95% confidence interval of the annual estimates.

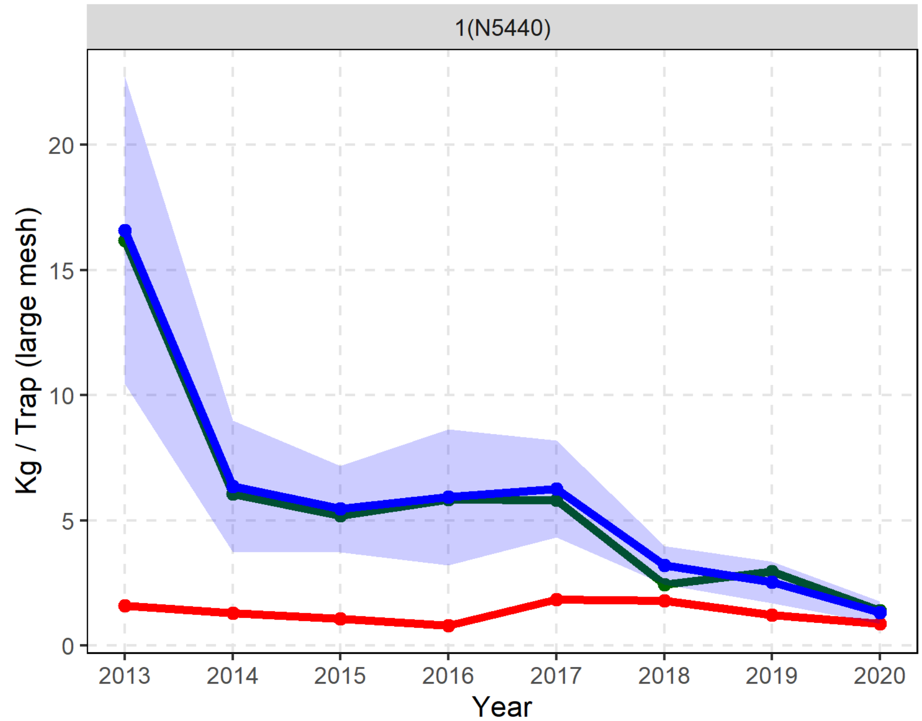

Figure A1. 7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from large-mesh traps in the Torngat Joint Fisheries Secretariat trap survey (2013–20) (CMA 2JN).

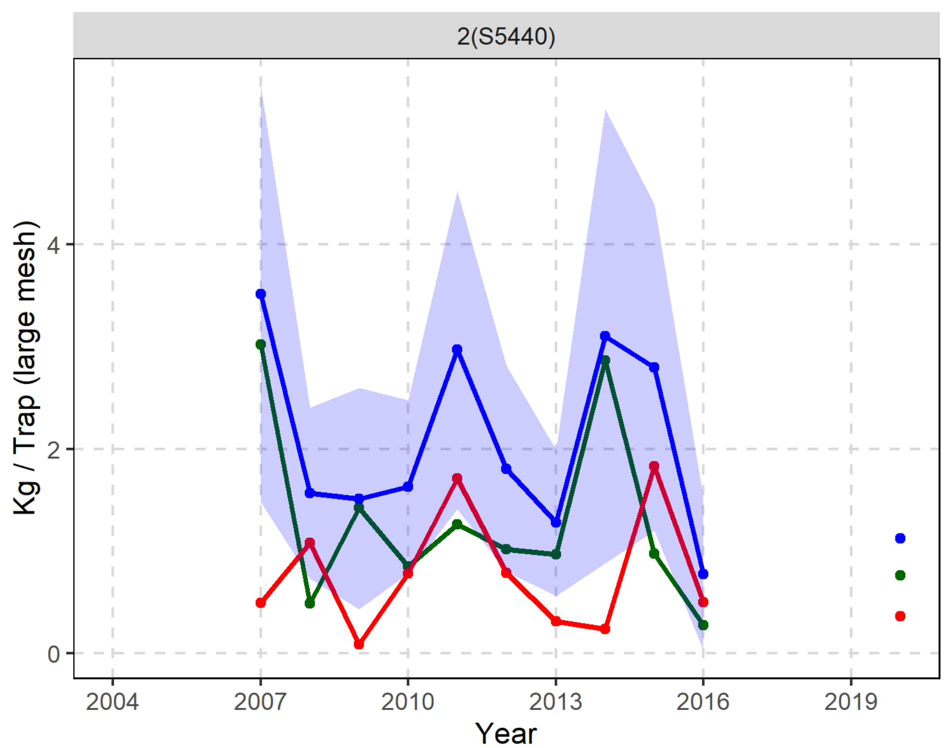

Figure A1. 8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from large-mesh traps at core stations in the CPS trap survey (2007–20) (CMA 2JS).

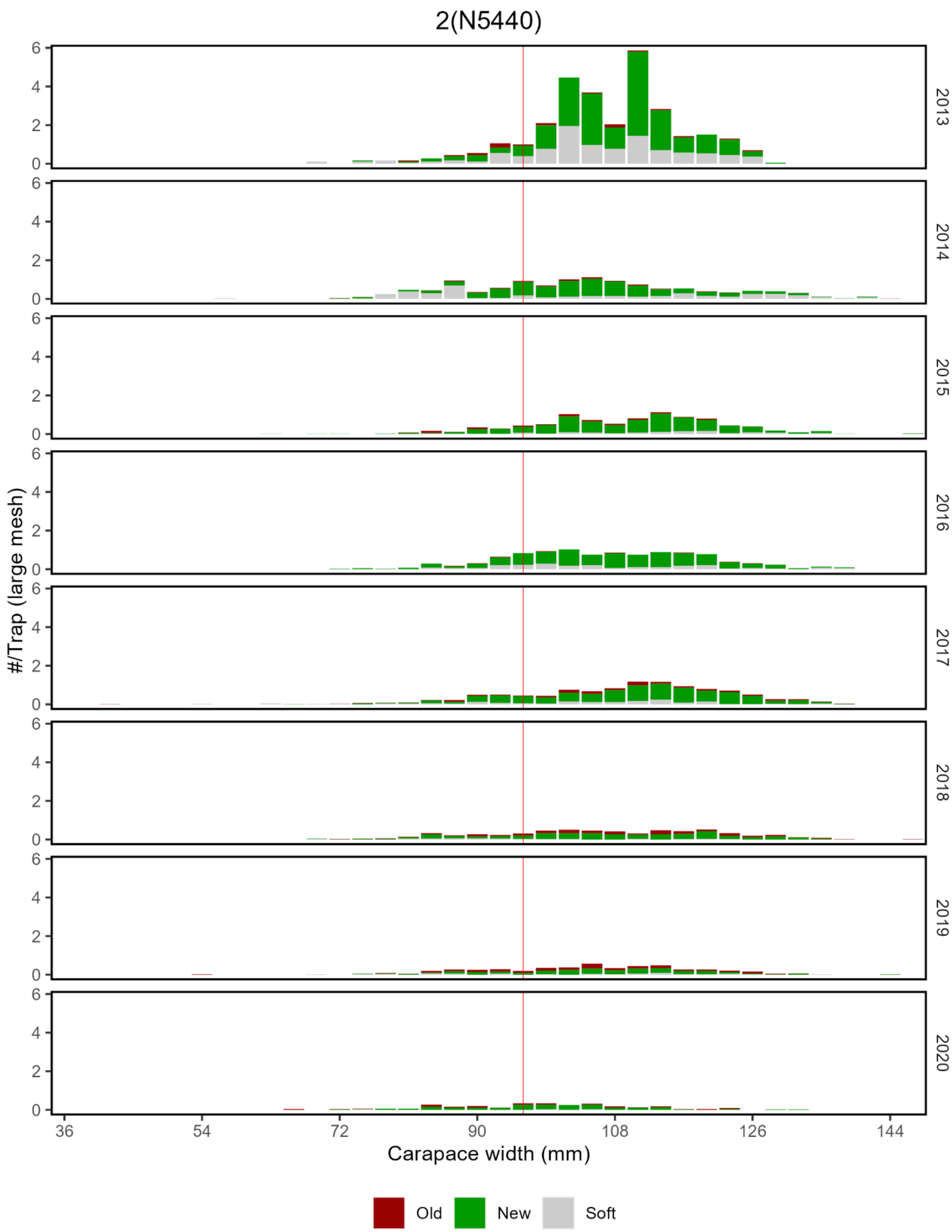

Figure A1. 9. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the Torngat Joint Fisheries Secretariat trap survey in CMA 2JN in Assessment Division 2HJ (2013–20). The red vertical line indicates the minimum legal size.

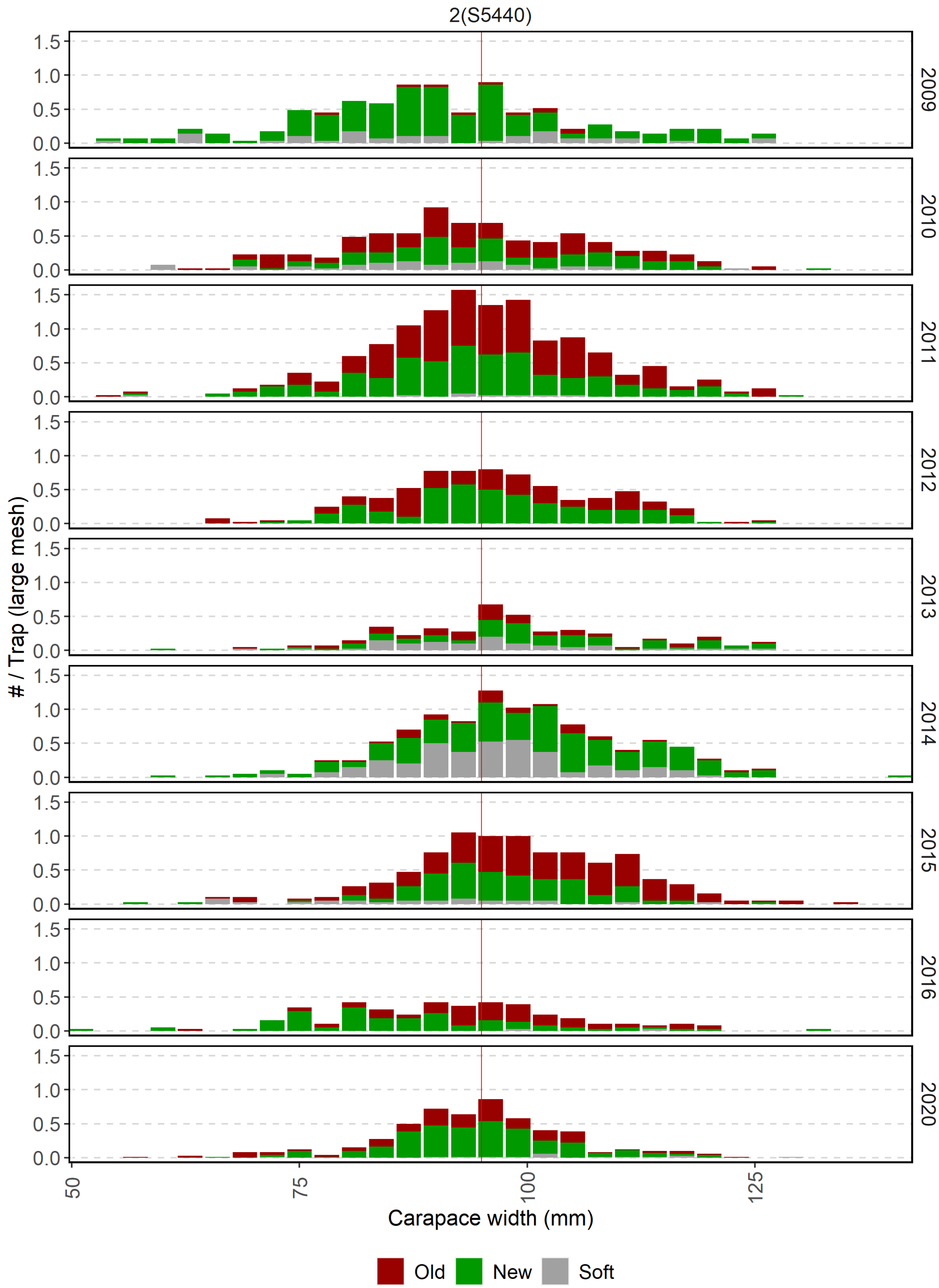

Figure A1. 10. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMA 2JS in Assessment Division 2HJ (2009–20). The red vertical line indicates the minimum legal size.

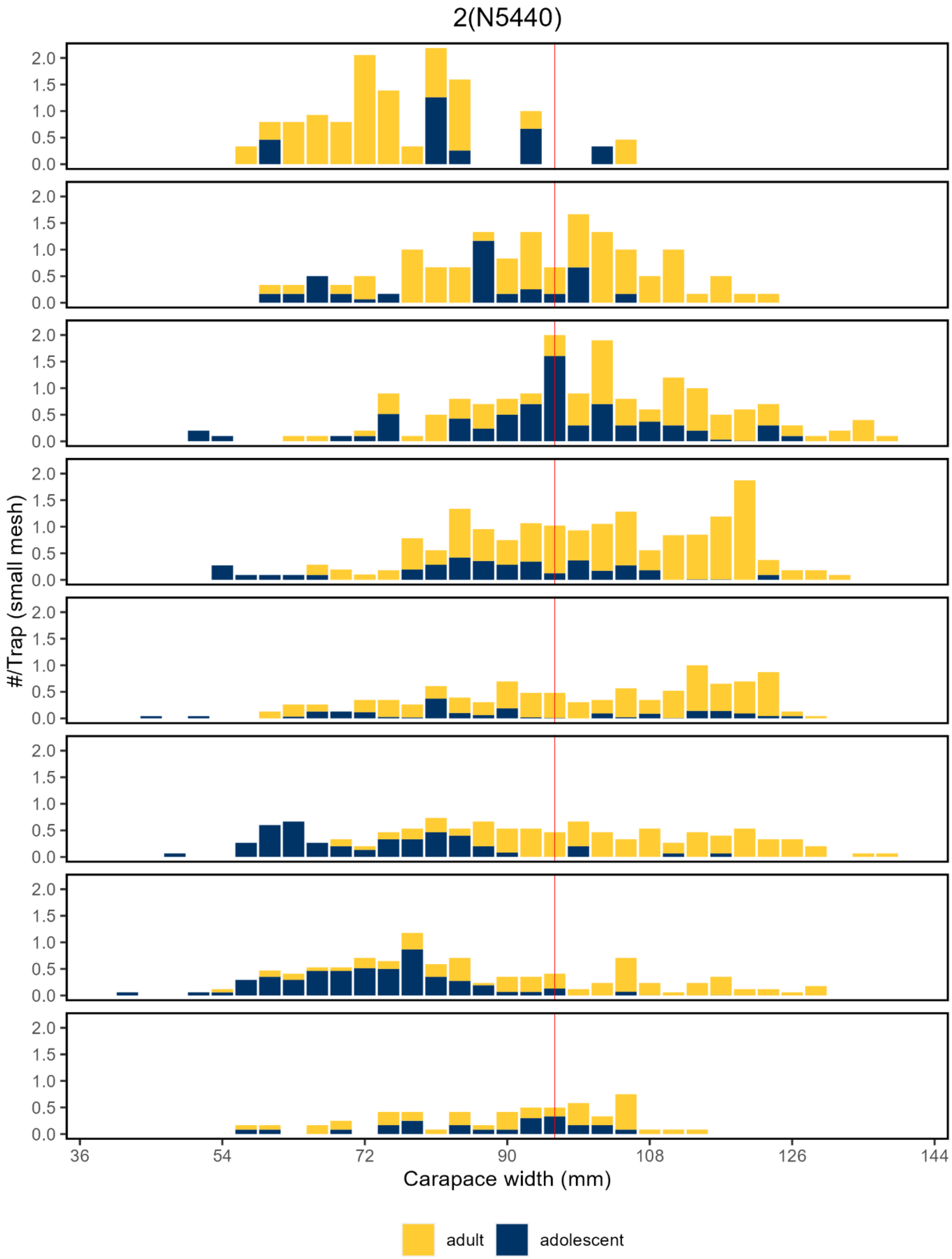

Figure A1. 11. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Torngat Joint Fisheries Secretariat trap survey in CMA 2JN in Assessment Division 2HJ (2013–20). The red vertical line indicates the minimum legal size.

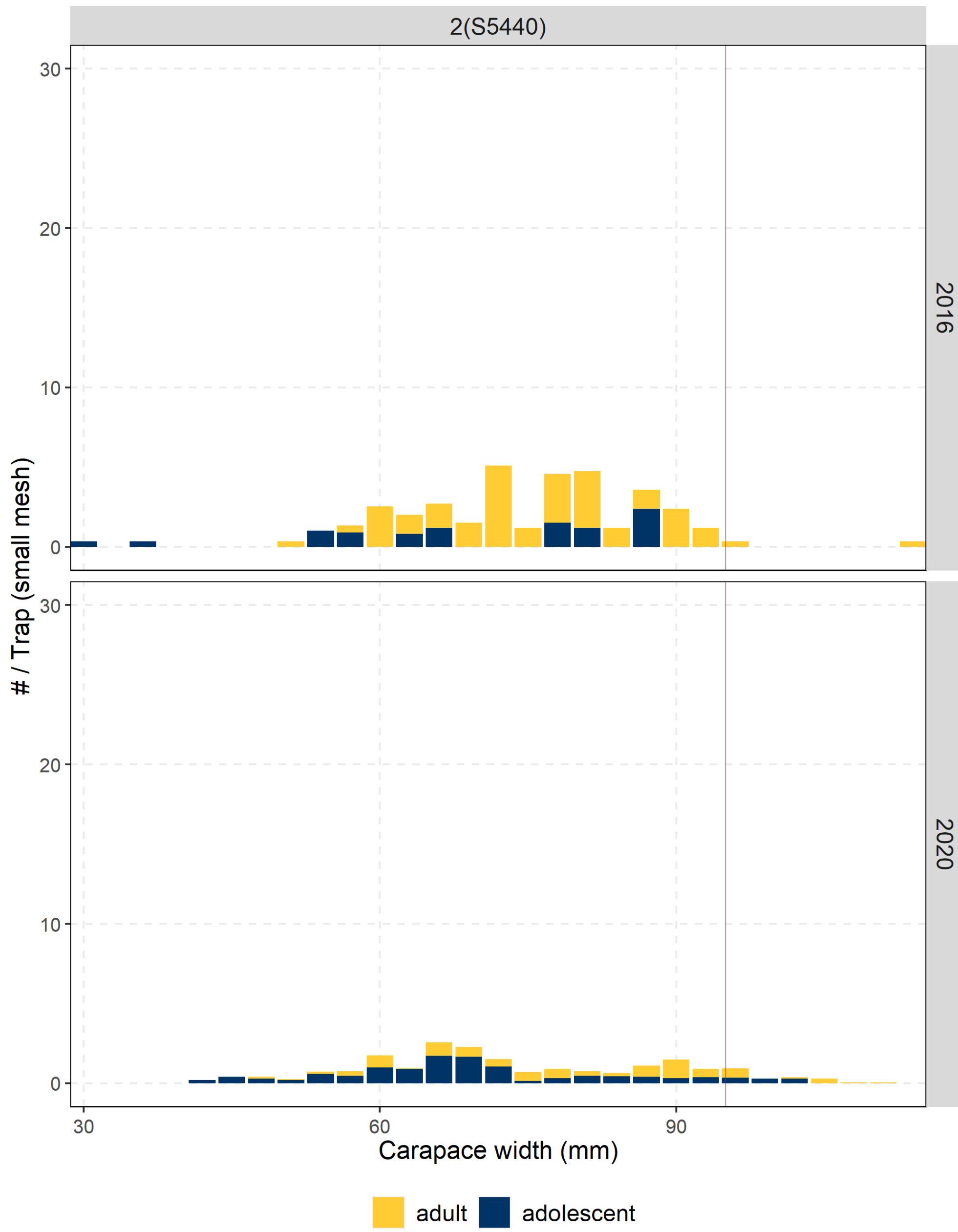

Figure A1. 12. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps at core stations in the CPS trap survey in CMA 2JS in Assessment Division 2HJ (2016 and 2020). The red vertical line indicates the minimum legal size.

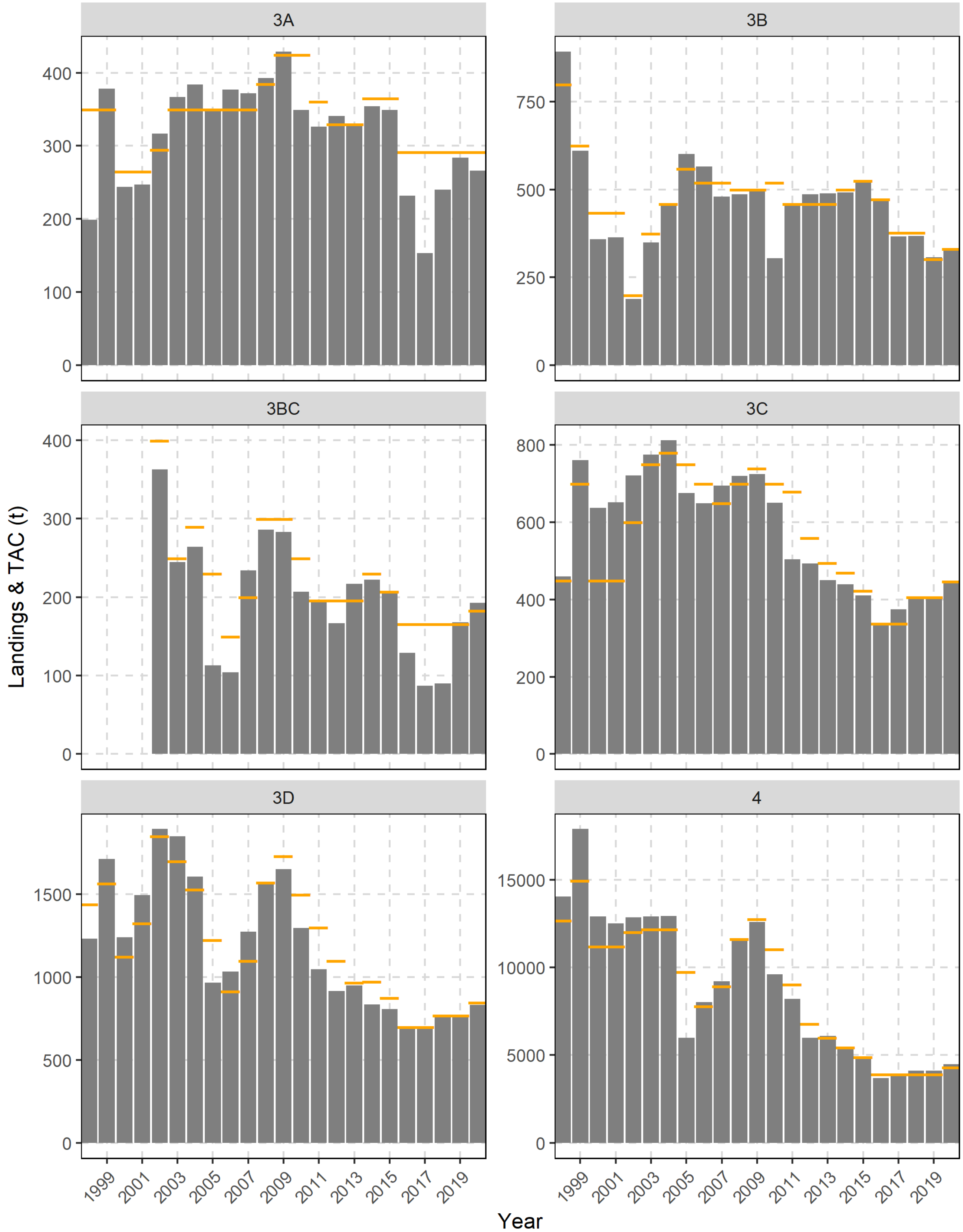

Figure A2. 1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 3K (1998–2020).

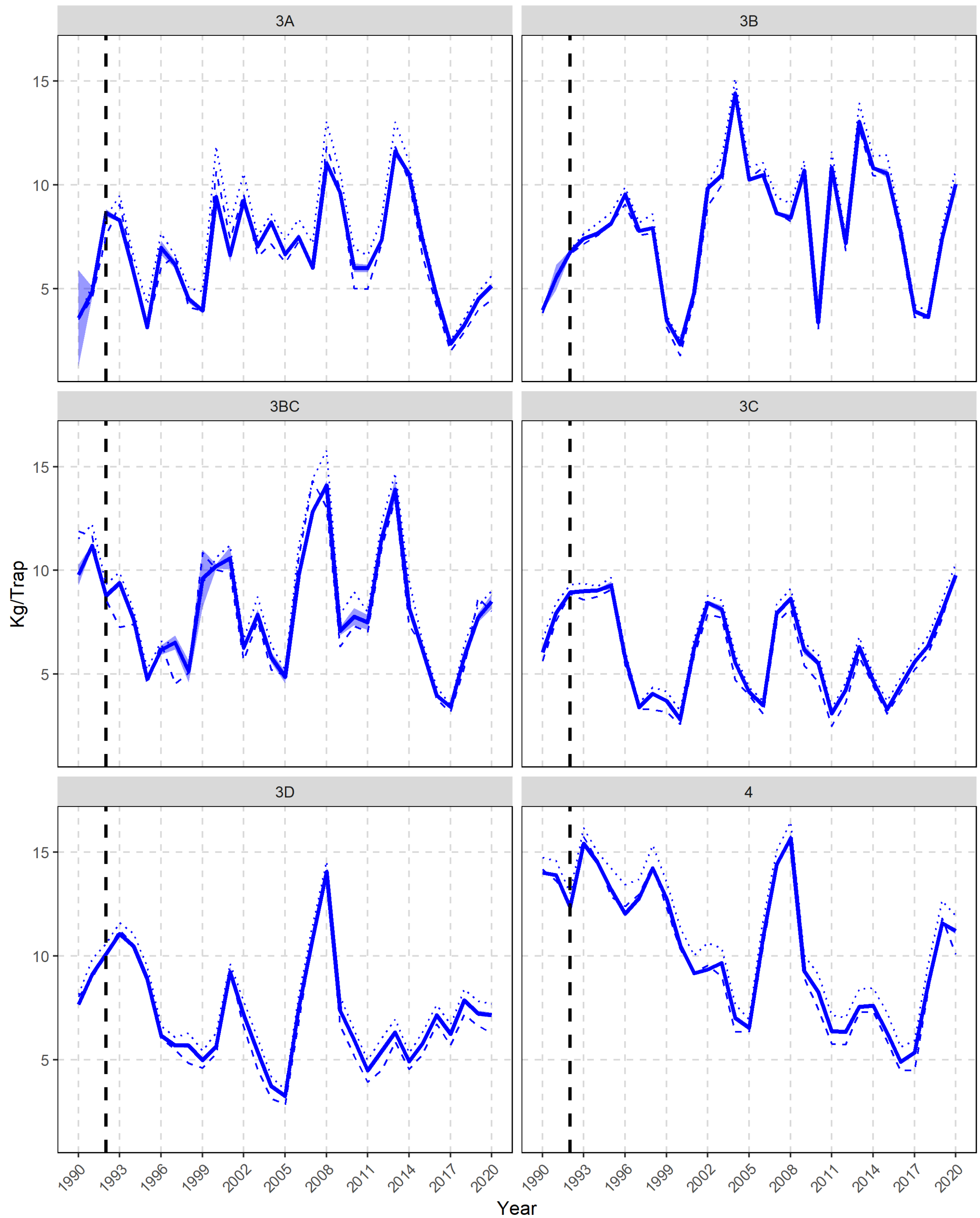

Figure A2. 2. Trends in standardized CPUE (kg/trap) in CMAs within Assessment Division 3K. Solid line is average predicted CPUE, shaded band is 95% confidence interval, dotted line represents average raw CPUE, and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

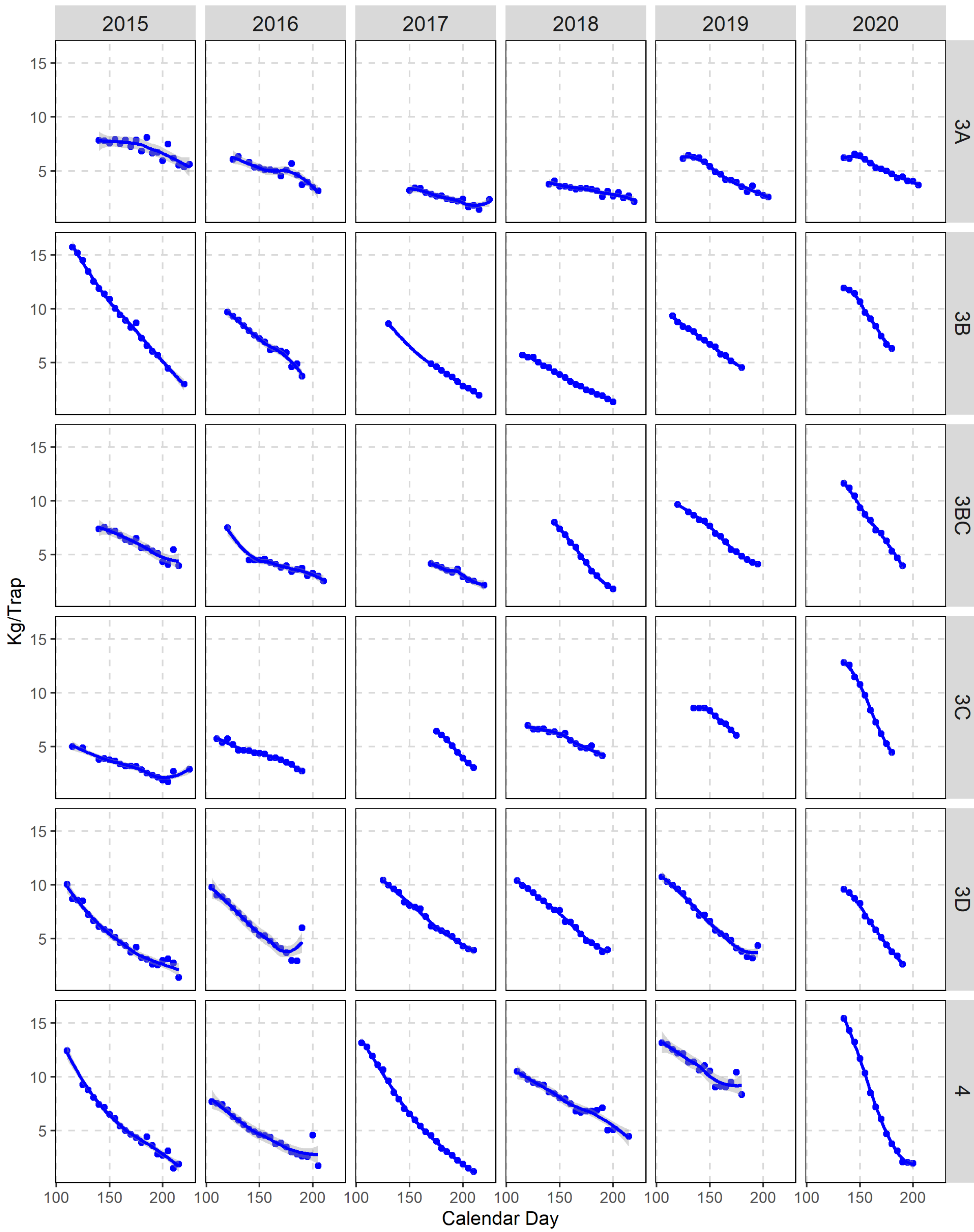

Figure A2. 3. Standardized CPUE (kg/trap) throughout the season (calendar day) in Assessment Division 3K (2015–20), derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

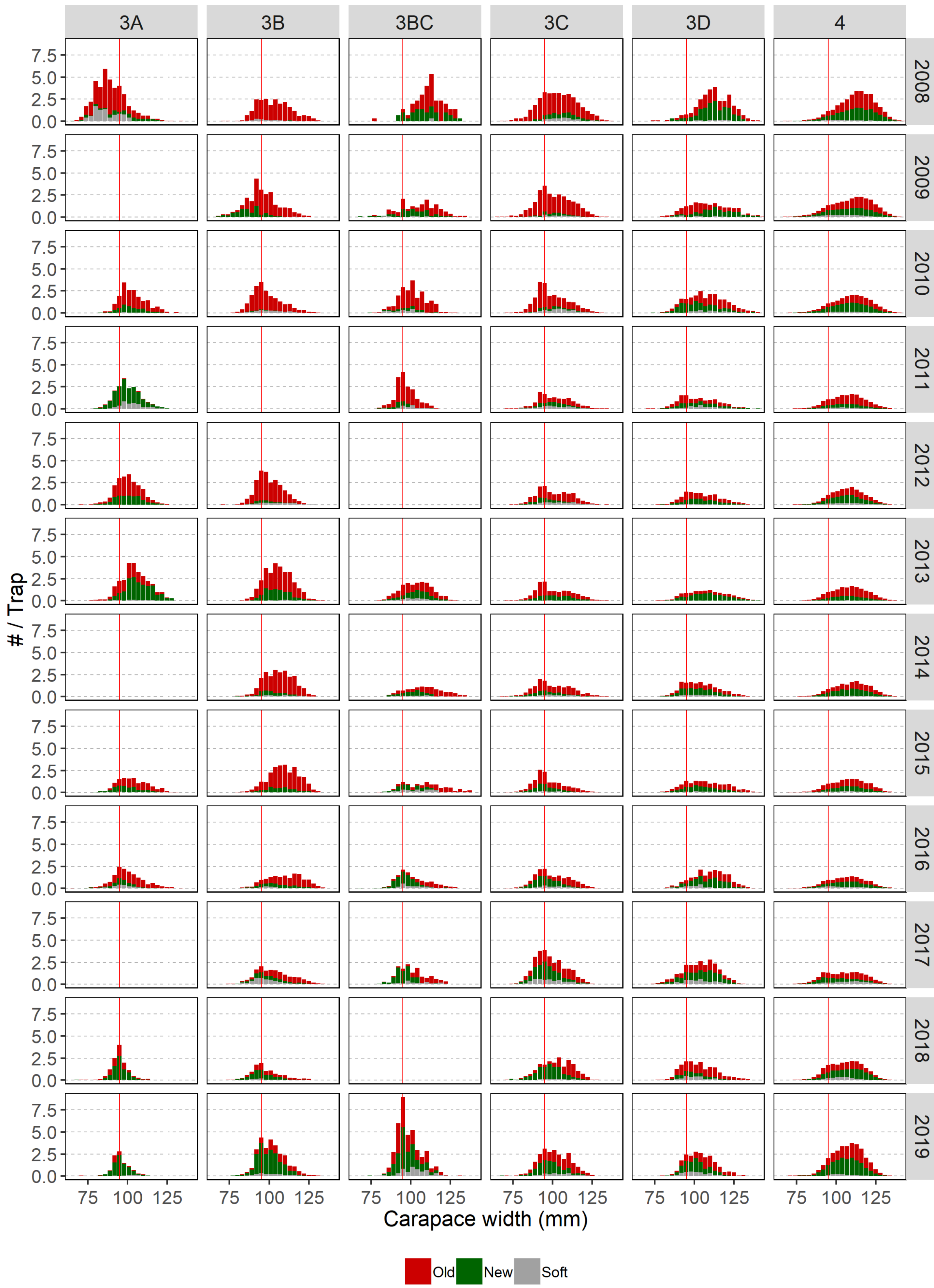

Figure A2. 4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each Crab Management Area in Assessment Division 3K (2008–19). The red vertical line indicates the minimum legal size. Note: Not updated in 2020.

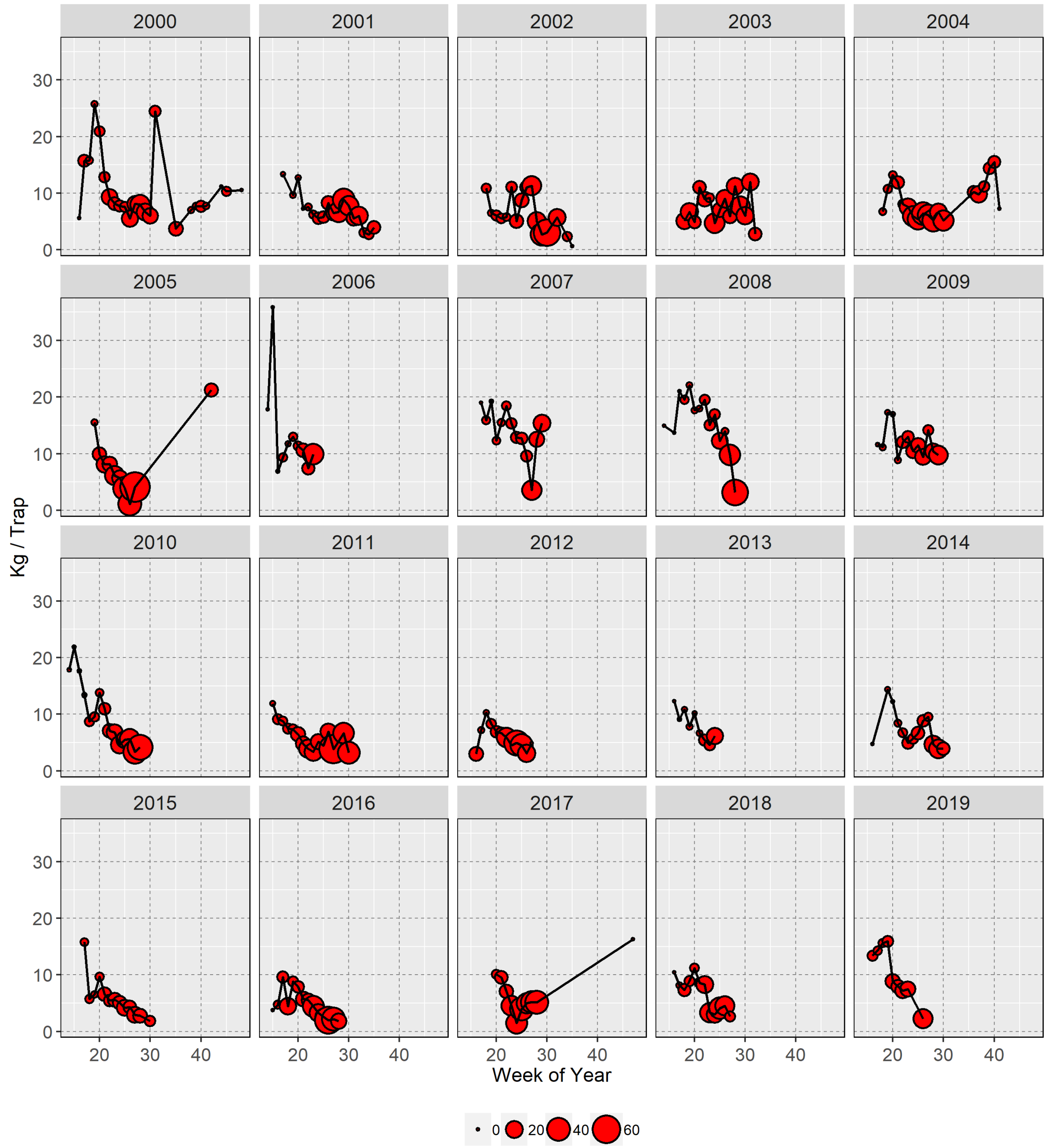

Figure A2. 5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Crab Management Areas within Assessment Division 3K (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates. Note: Not updated in 2020.

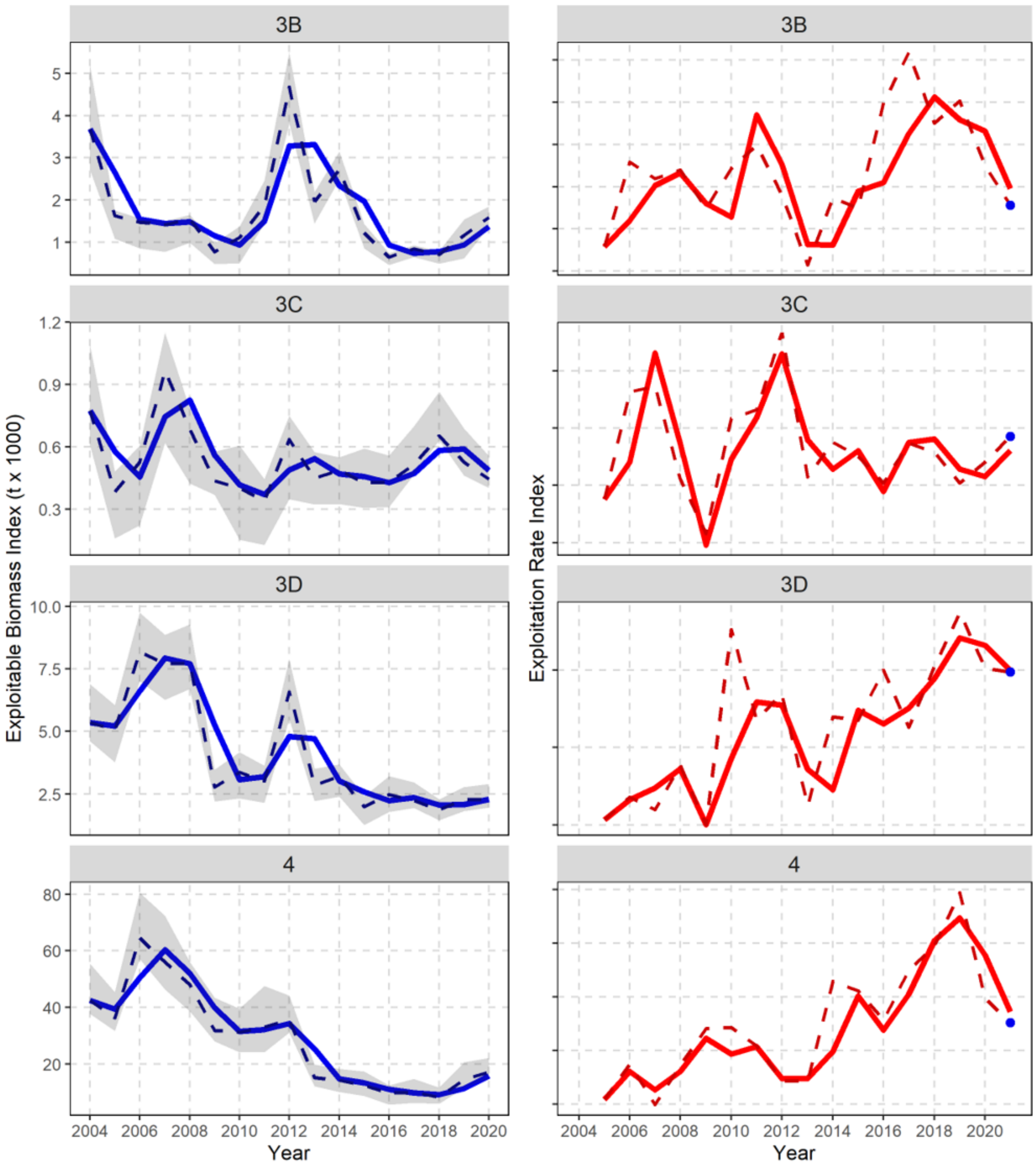

Figure A2. 6. Left: Annual trap-based exploitable biomass index (t x 1,000). The solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the 95% confidence interval of the annual estimates. Right: Trends in the trap-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 3K; 2021 points depict projected exploitation rate indices under status quo removals in the 2021 fishery.

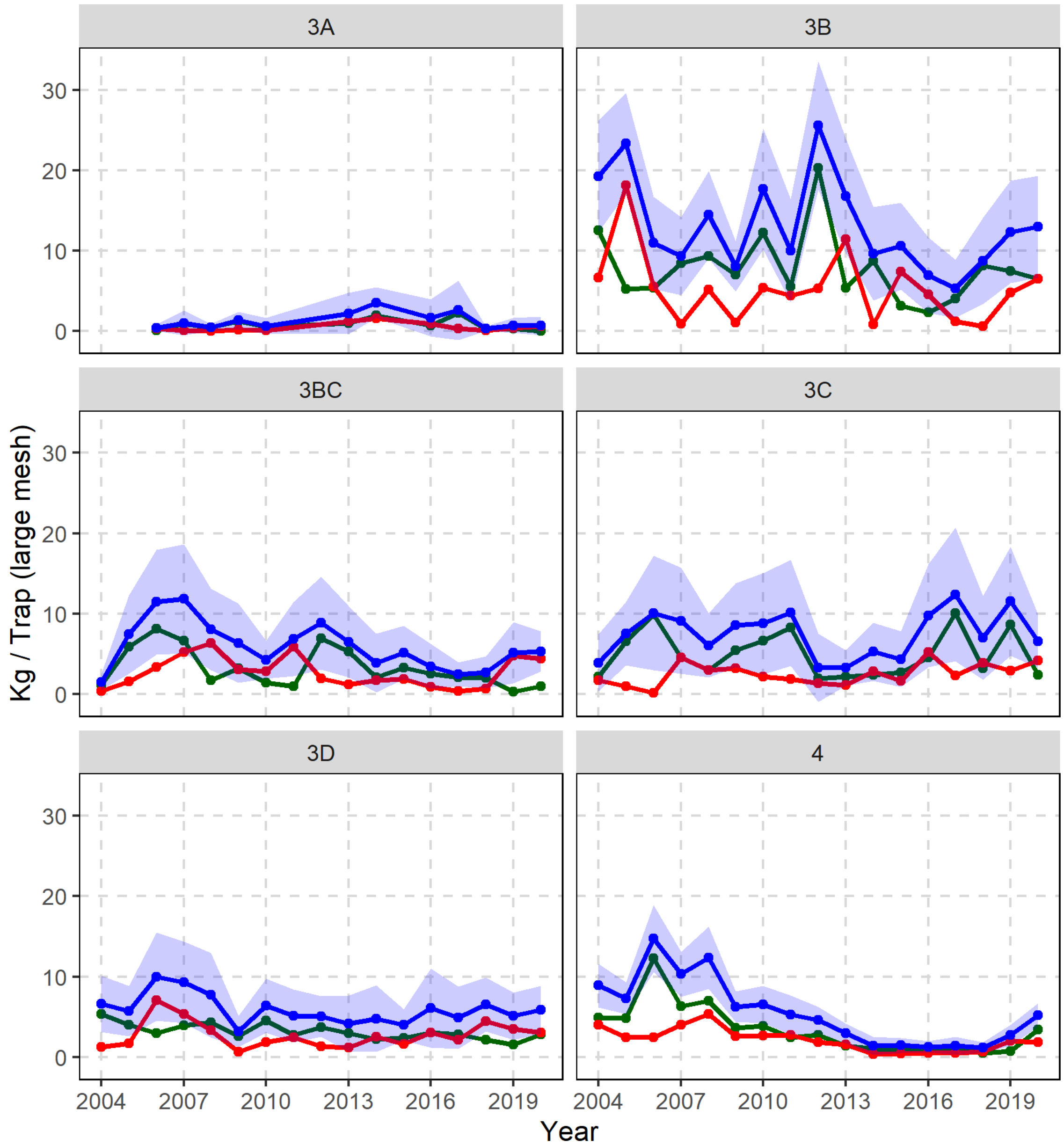

Figure A2. 7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 3K.

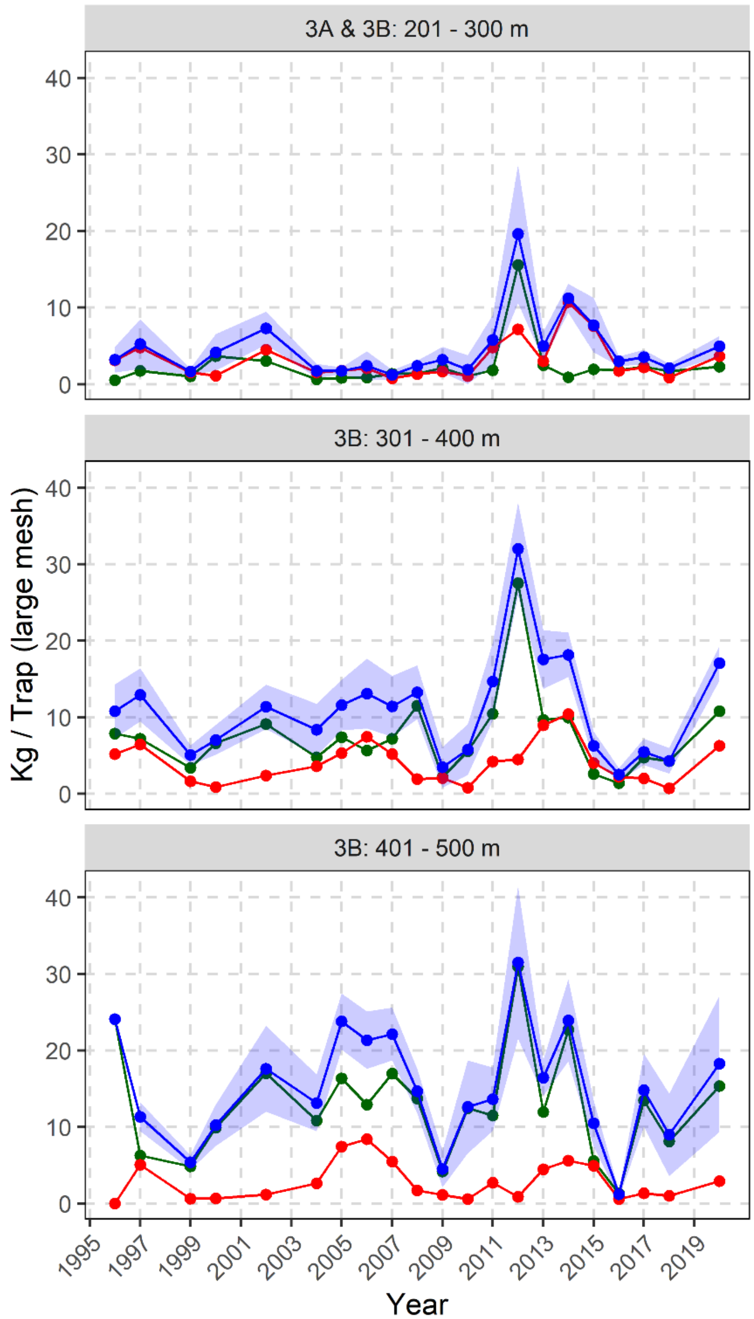

Figure A2. 8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from large-mesh traps in Inshore DFO trap surveys in White Bay (CMAs 3A and 3B).

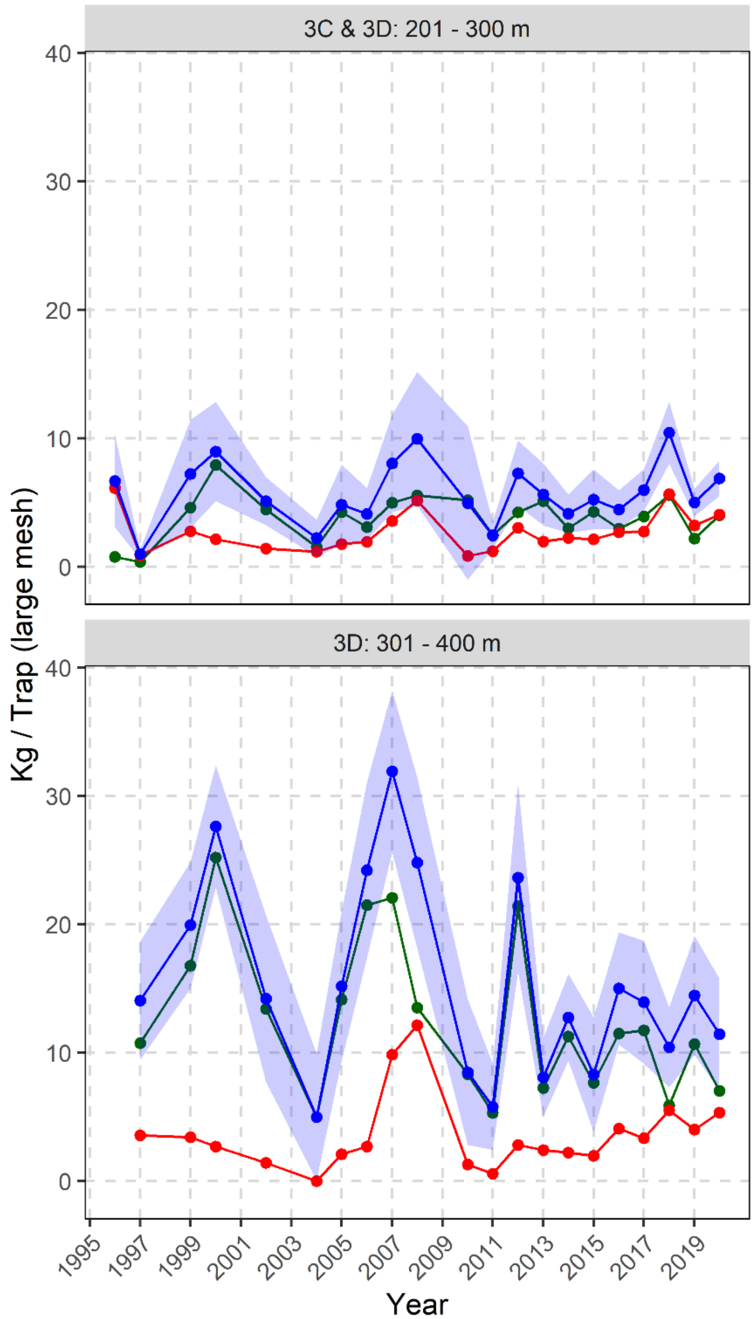

Figure A2. 9. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from large-mesh traps in Inshore DFO trap surveys in Green Bay and Notre Dame Bay (CMAs 3C and 3D).

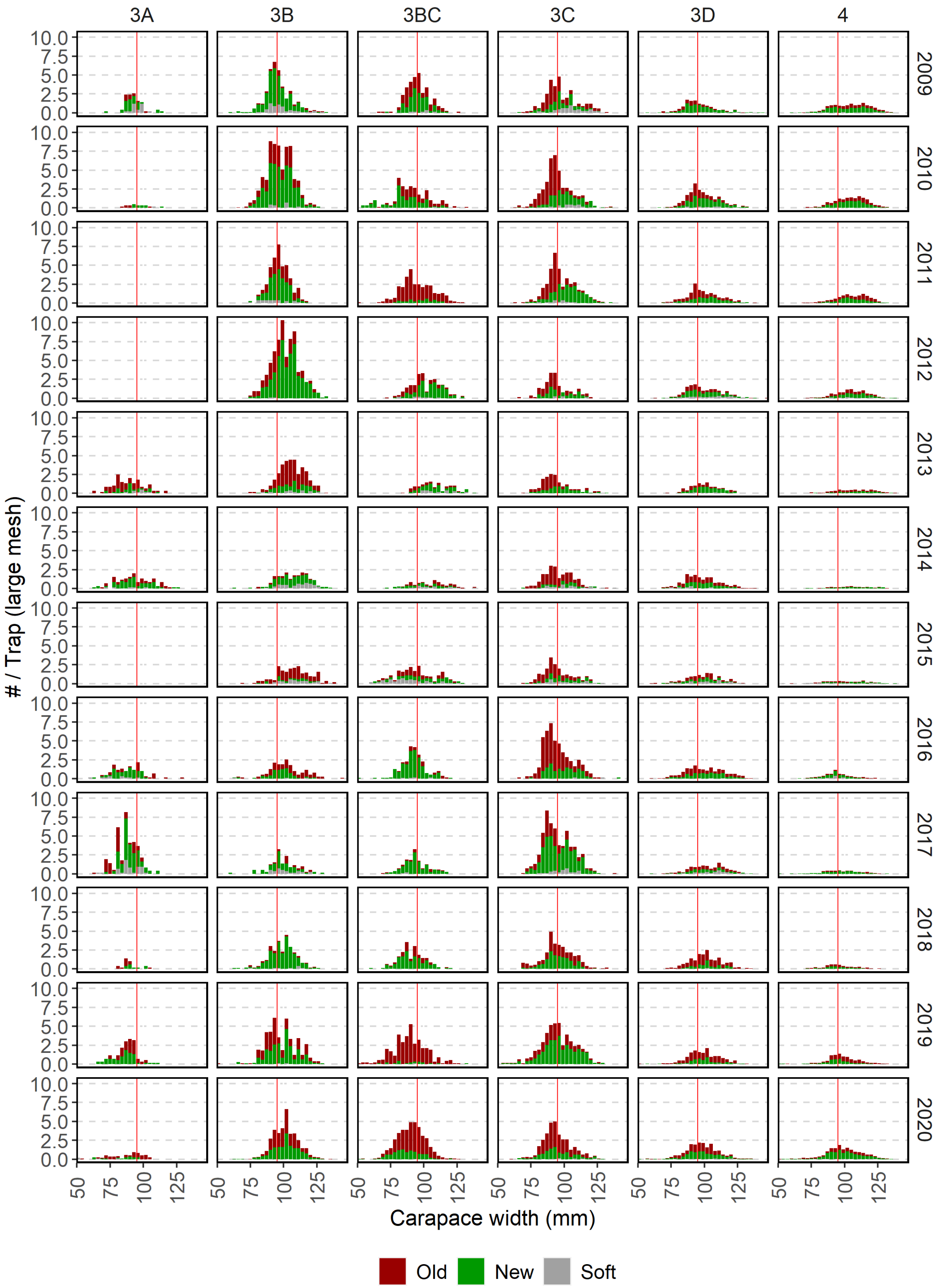

Figure A2. 10. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 3K (2009–20). The red vertical line indicates the minimum legal size.

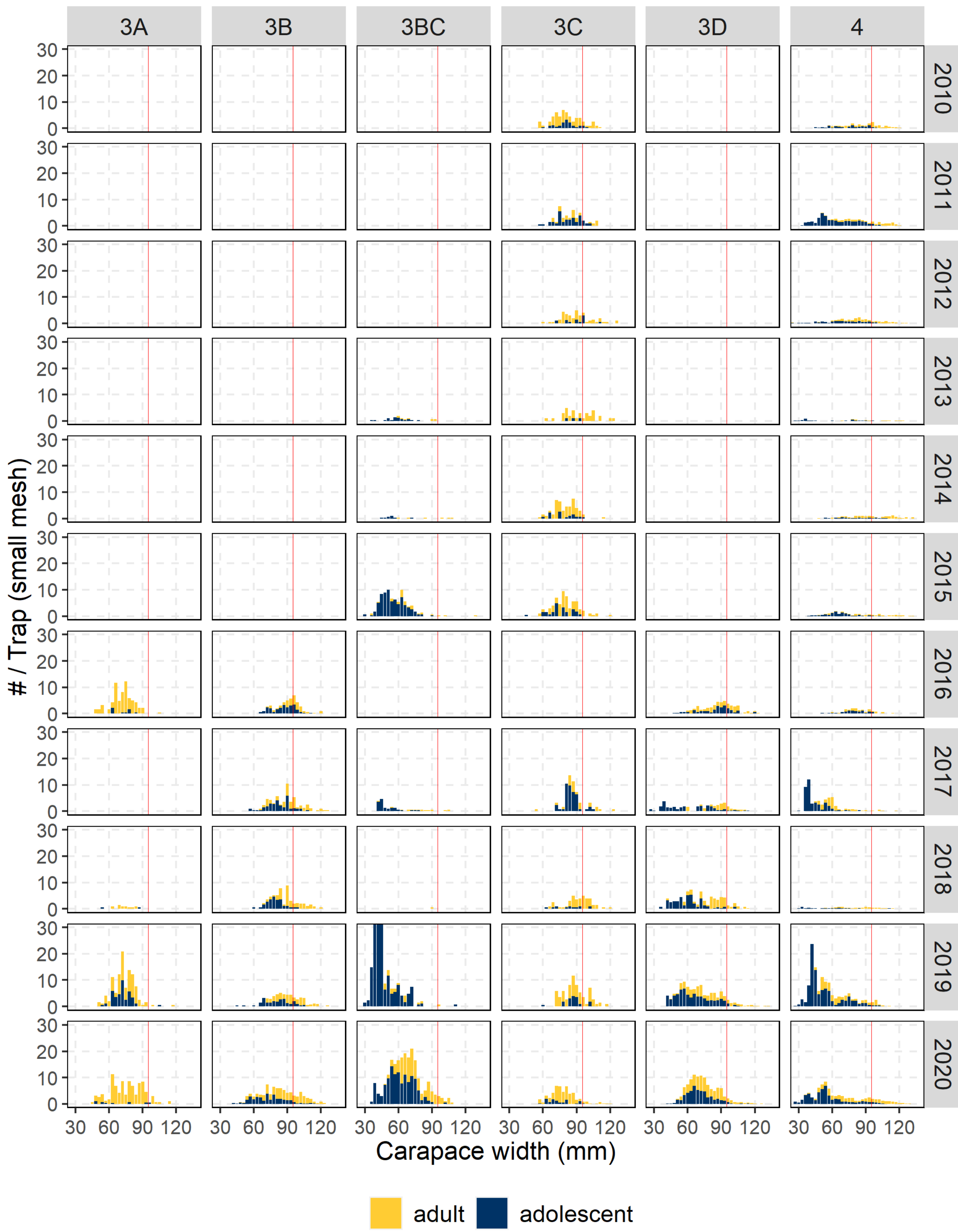

Figure A2. 11. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2010–20) from CMAs in Assessment Division 3K. The red vertical line indicates the minimum legal size.

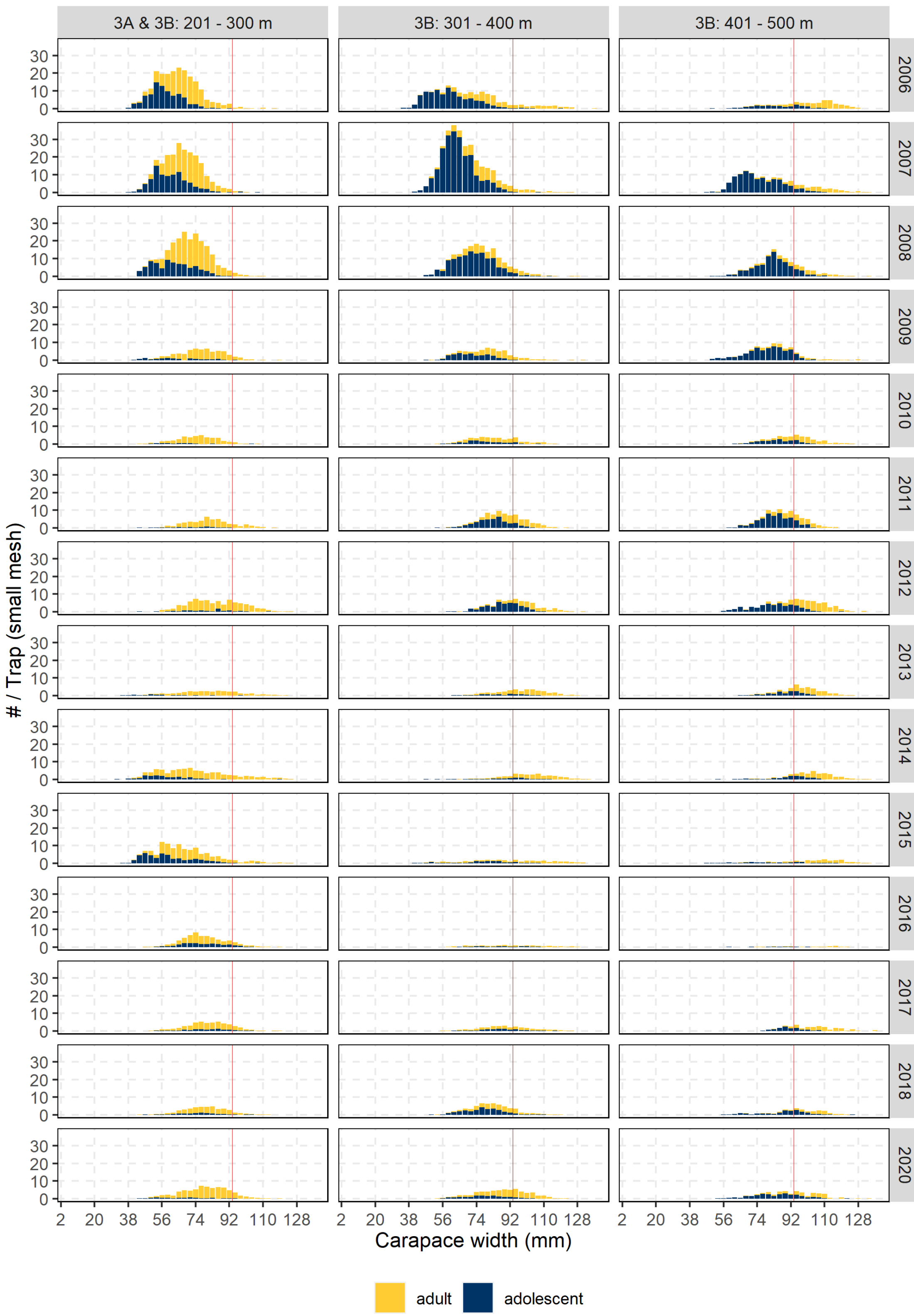

Figure A2. 12. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2006–20) from White Bay (CMAs 3A and 3B). The red vertical line indicates the minimum legal size. Note: no survey in 2019.

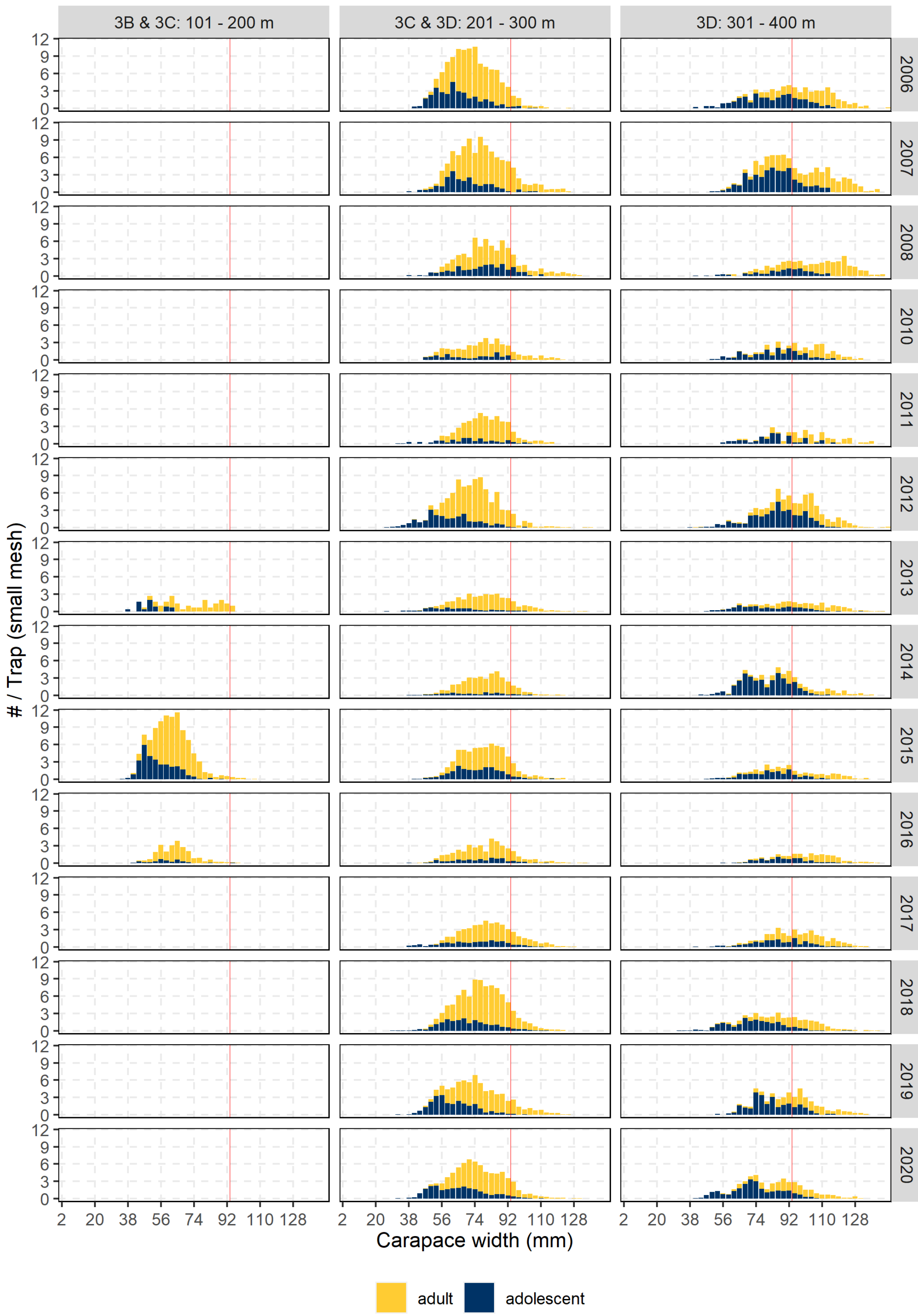

Figure A2. 13. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2006–20) from Green Bay and Notre Dame Bay (CMAs 3B, 3C and 3D). The red vertical line indicates the minimum legal size.

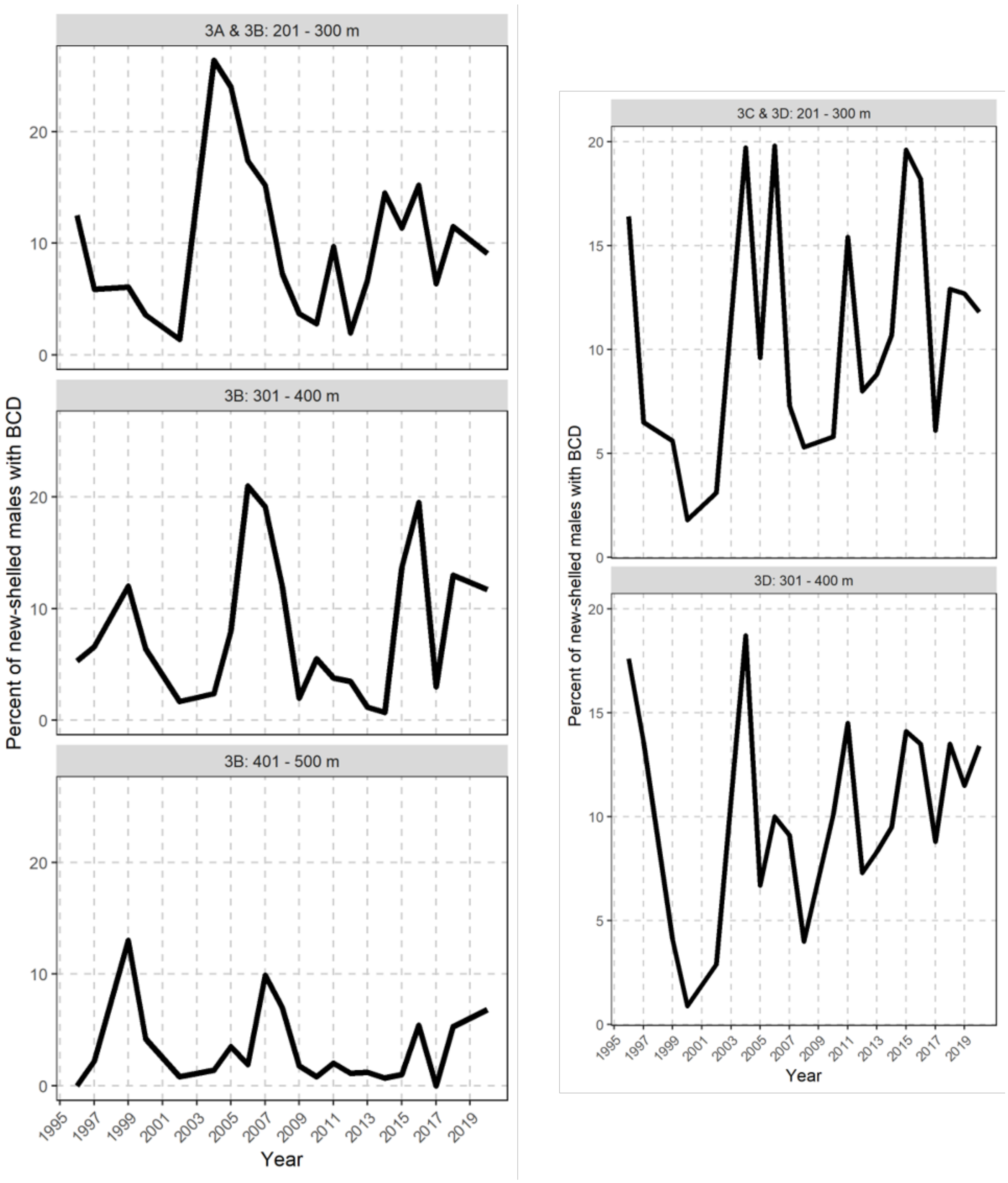

Figure A2. 14. Visually observed percentage of Bitter Crab Disease (BCD) in new-shelled crab from Inshore DFO trap surveys (1996–2020) in White Bay (CMAs 3A and 3B), and Green Bay and Notre Dame Bay (CMAs 3C and 3D).

APPENDIX 3: ASSESSMENT DIVISION 3L INSHORE DETAILS

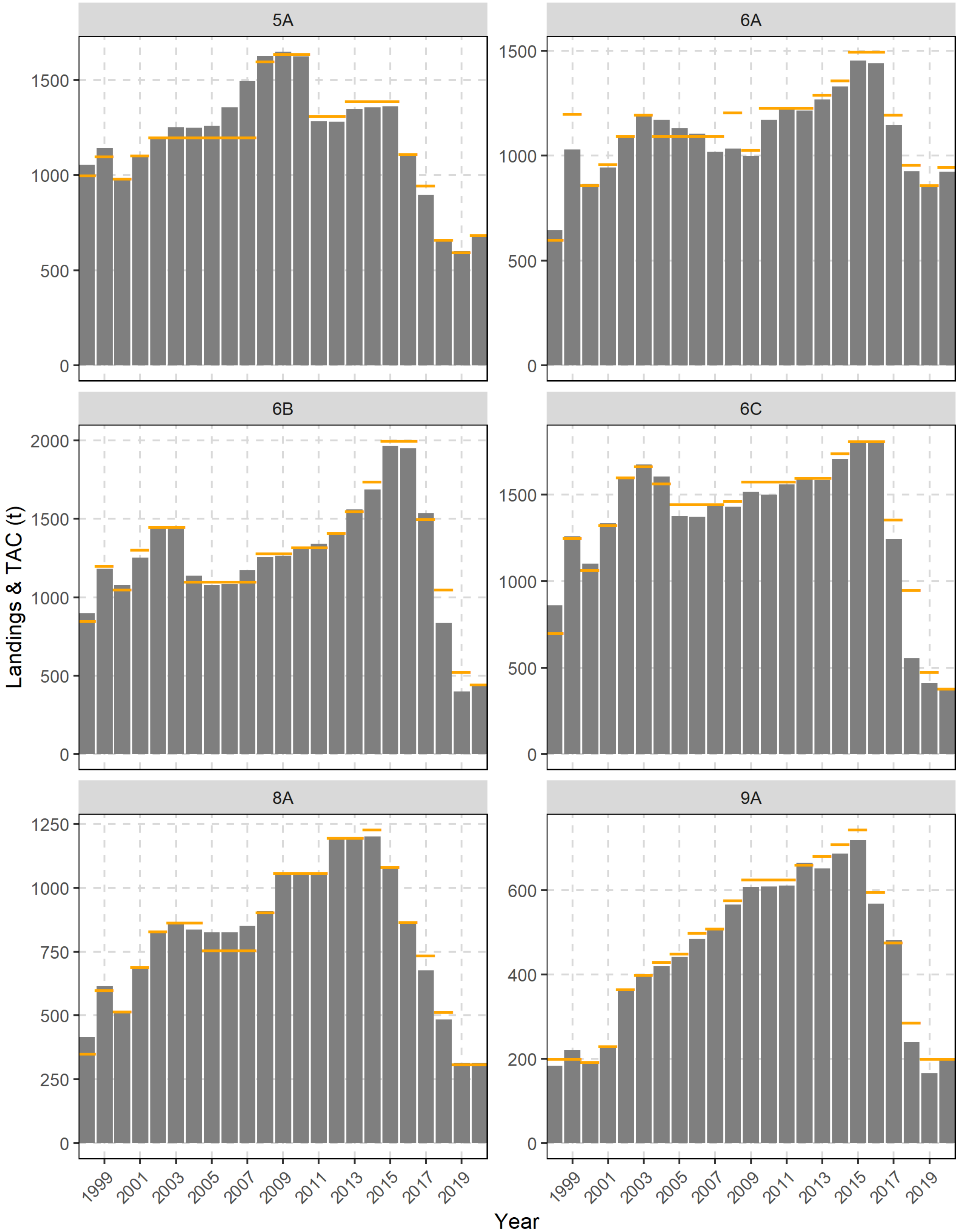

Figure A3. 1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 3L Inshore (1998–2020).

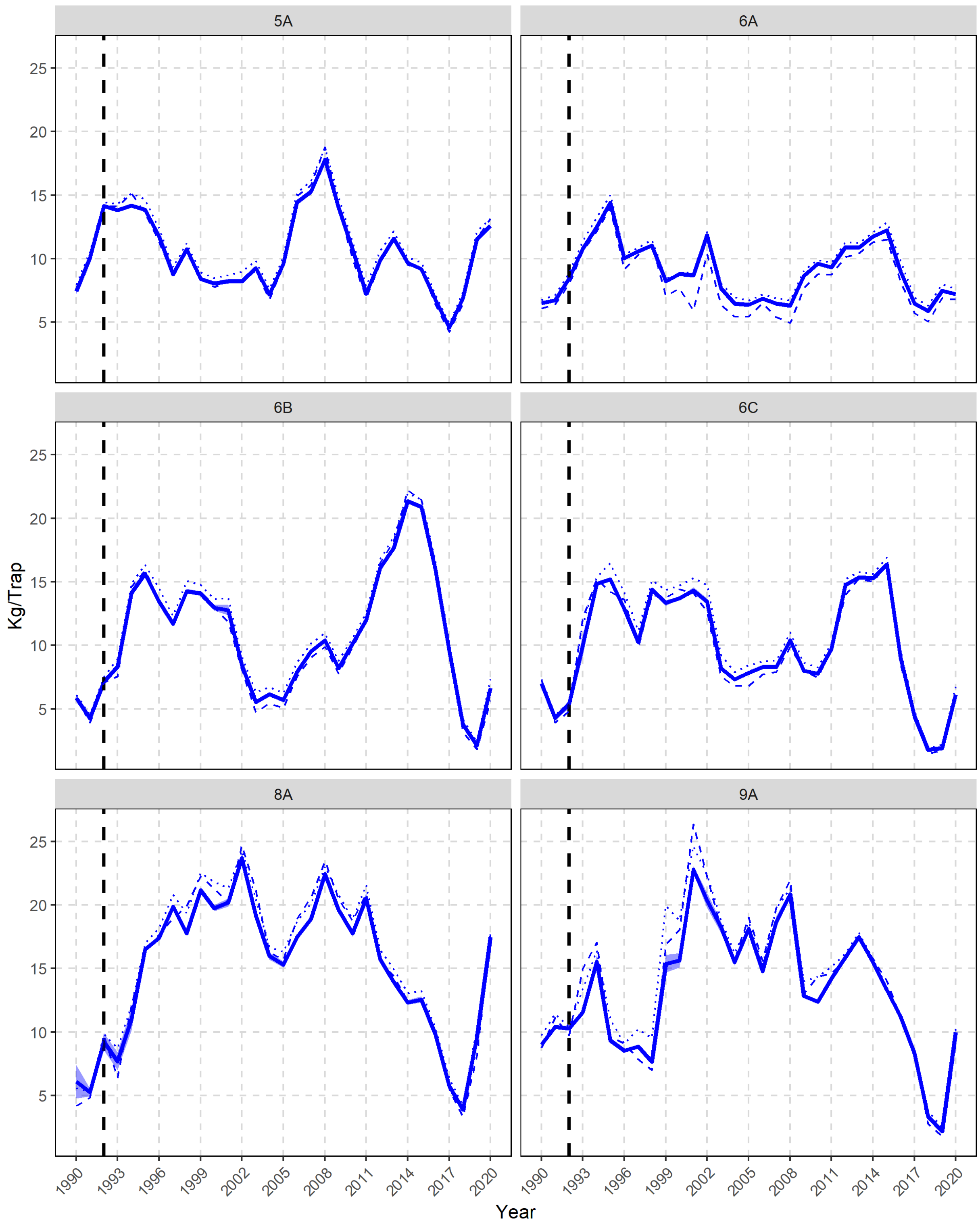

Figure A3. 2. Trends in standardized CPUE (kg/trap) in CMAs within Assessment Division 3L Inshore. Solid line is average predicted CPUE, shaded band is 95% confidence interval, dotted line represents average raw CPUE, and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

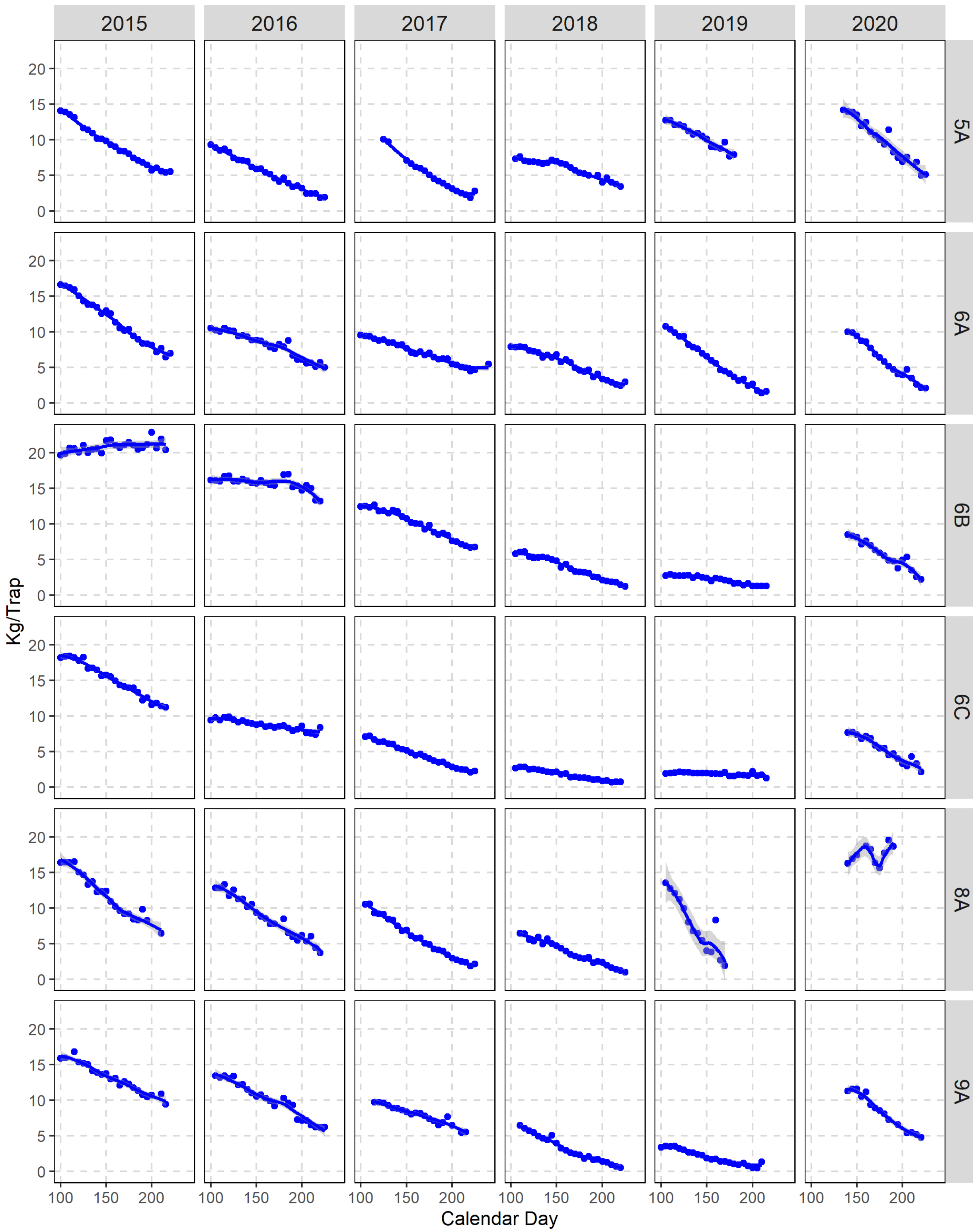

Figure A3. 3. Standardized CPUE (kg/trap) throughout the season (calendar day) in Assessment Division 3L Inshore (2015–20), derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

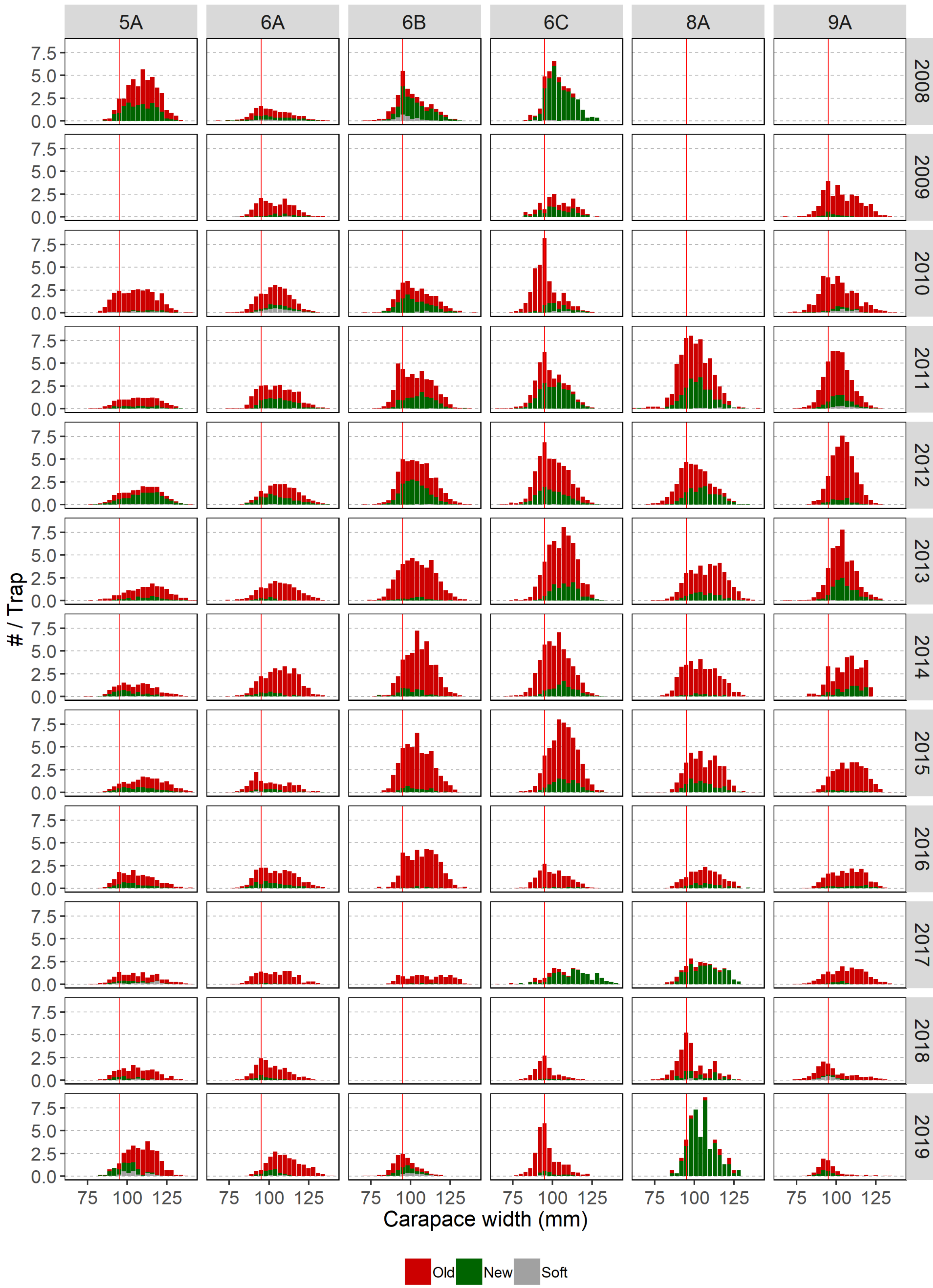

Figure A3. 4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each Crab Management Area in Assessment Division 3L Inshore (2008–19). The red vertical line indicates the minimum legal size. Note: Not updated in 2020.

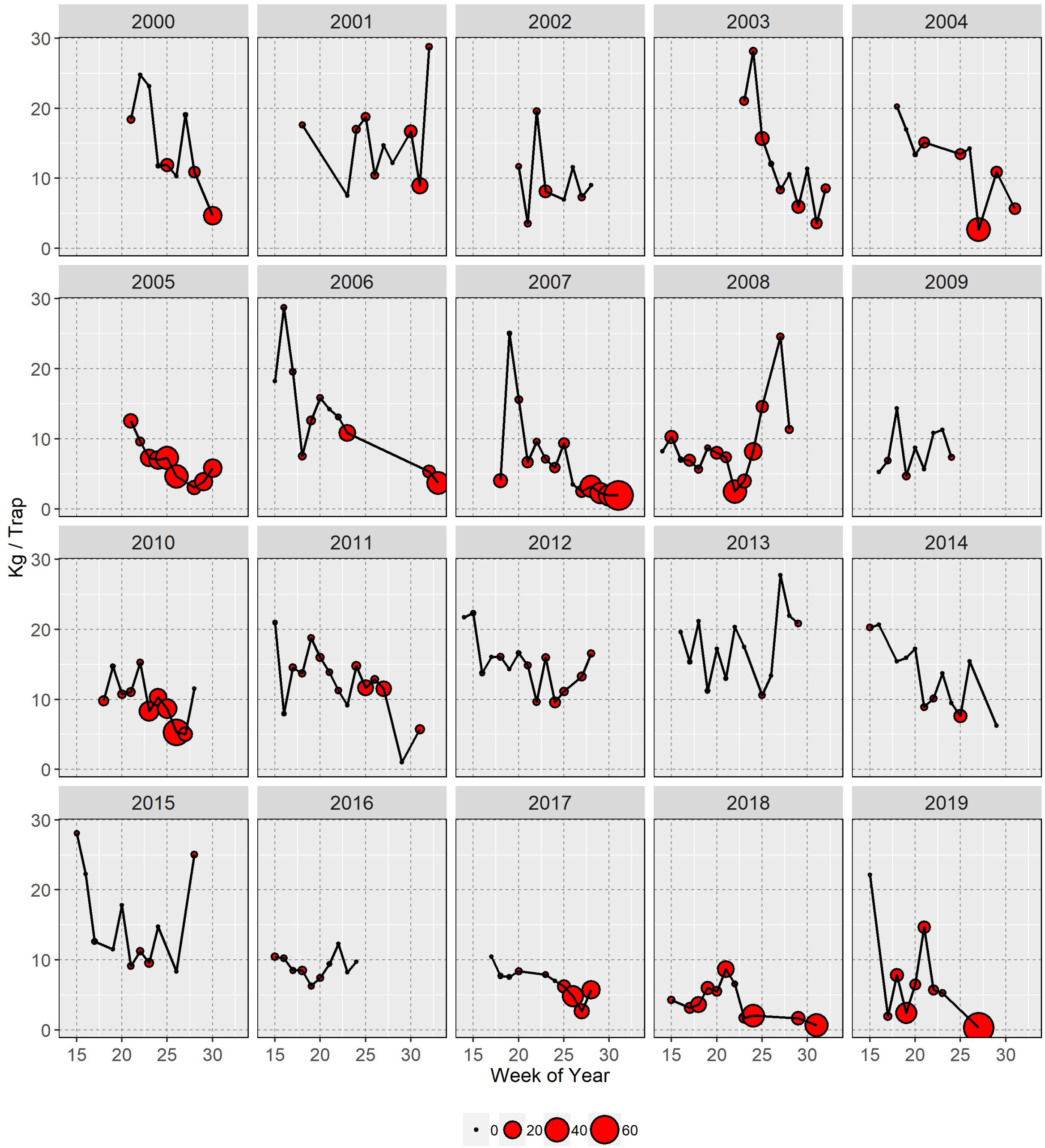

Figure A3. 5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Crab Management Areas within Assessment Division 3L Inshore (1999–2019). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates. Note: Not updated in 2020.

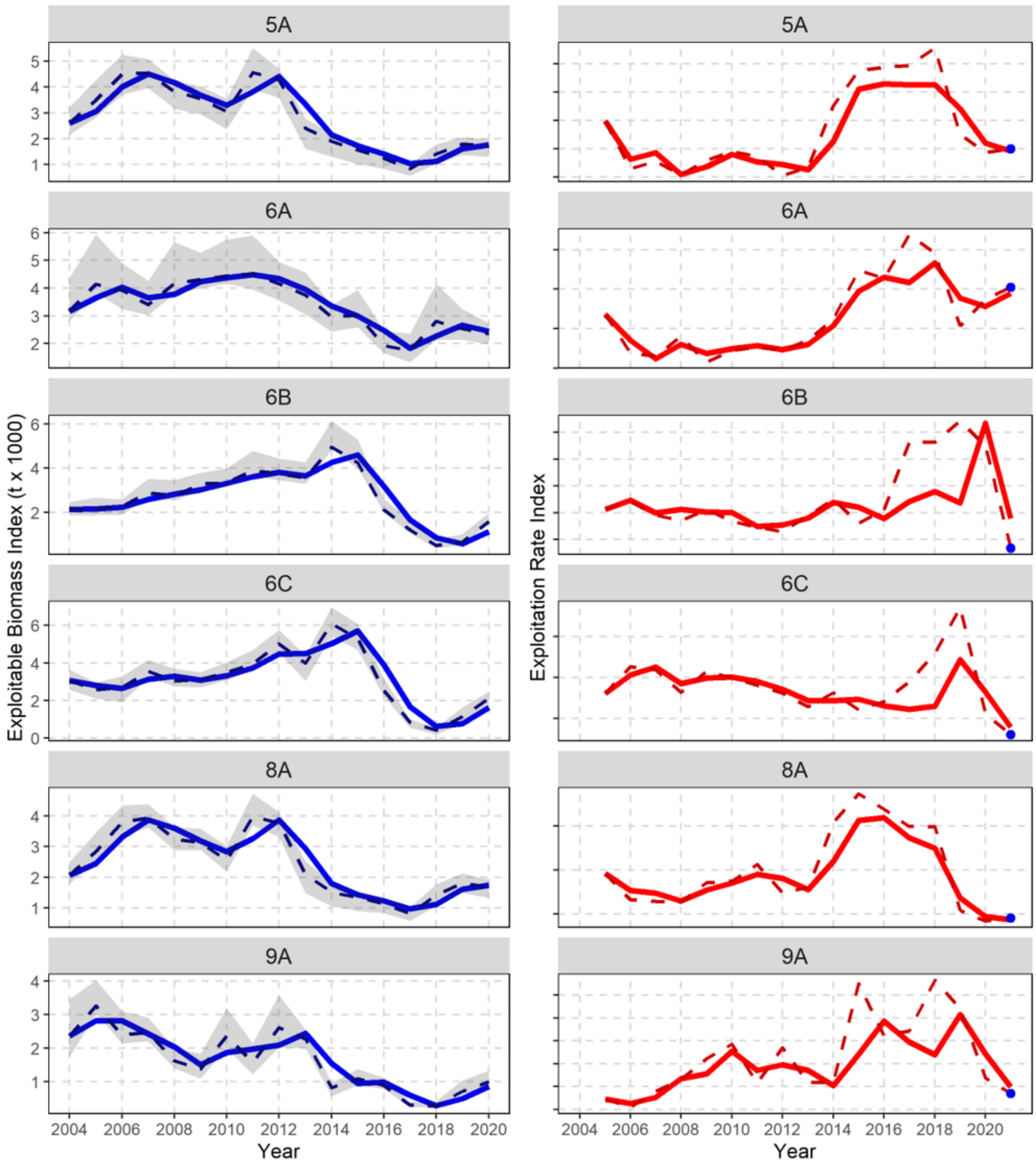

Figure A3. 6. Left: Annual trap-based exploitable biomass index (t x 1,000). The solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the 95% confidence interval of the annual estimates. Right: Trends in the trap-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 3L Inshore; 2021 points depict projected exploitation rate indices under status quo removals in the 2021 fishery.

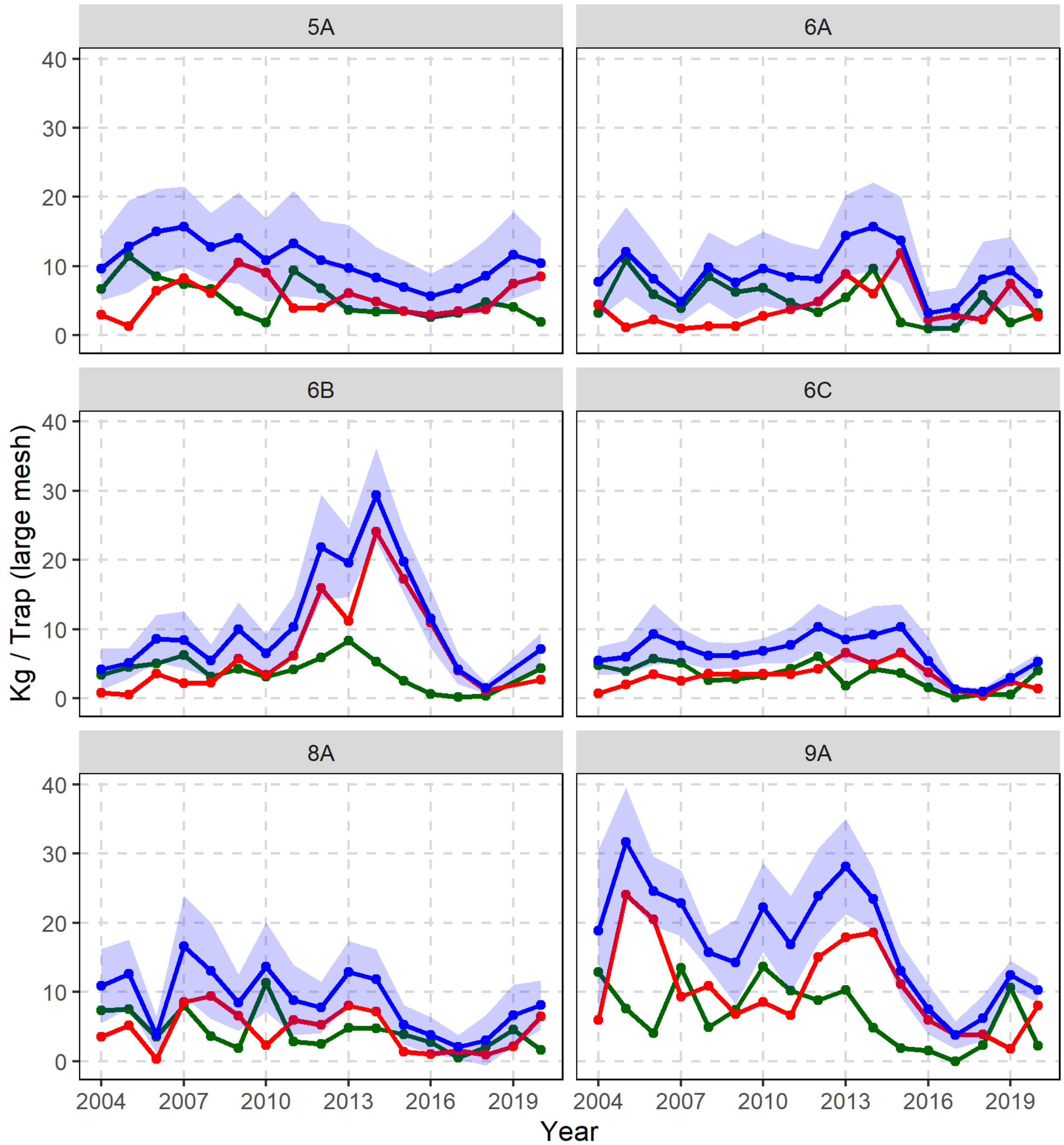

Figure A3. 7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 3L Inshore.

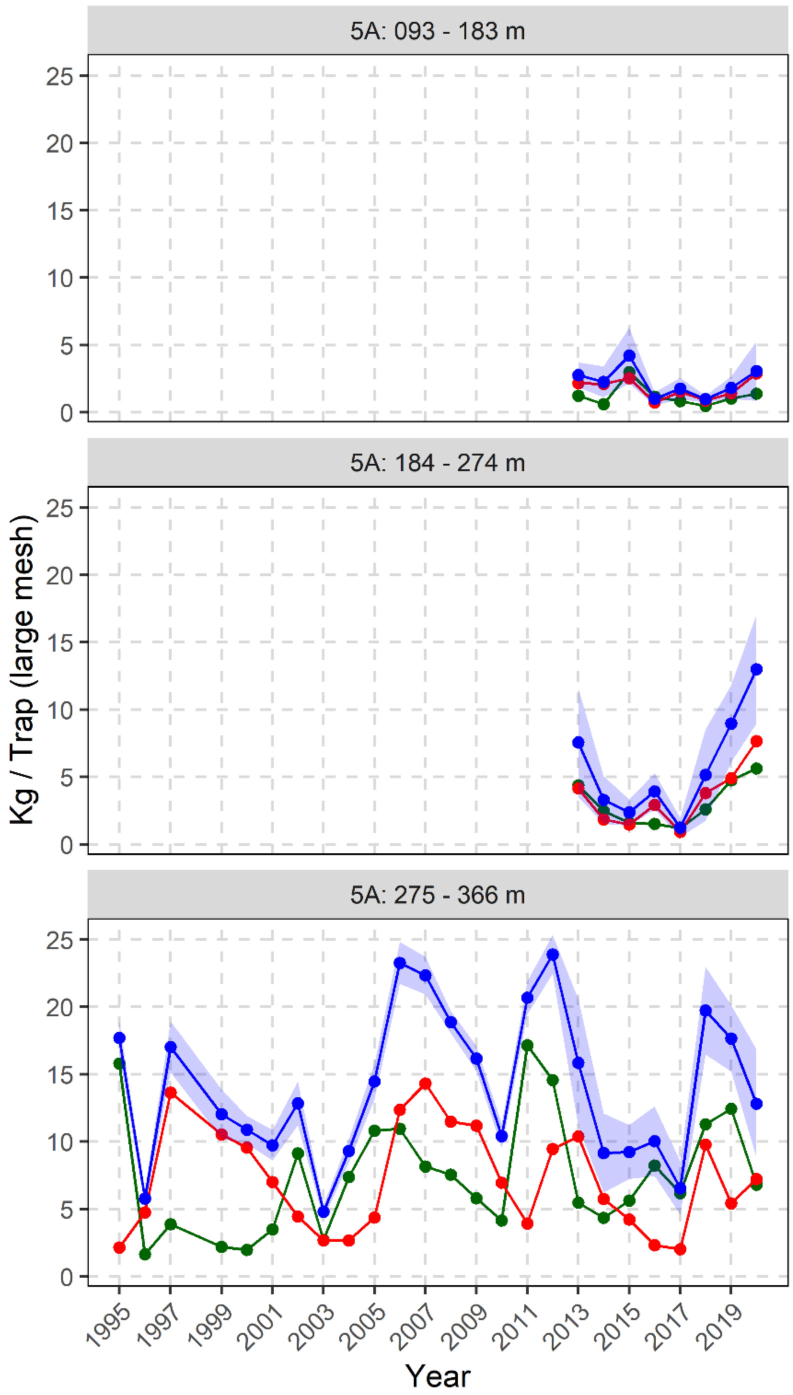

Figure A3. 8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from large-mesh traps in Inshore DFO trap surveys in Bonavista Bay (CMA 5A).

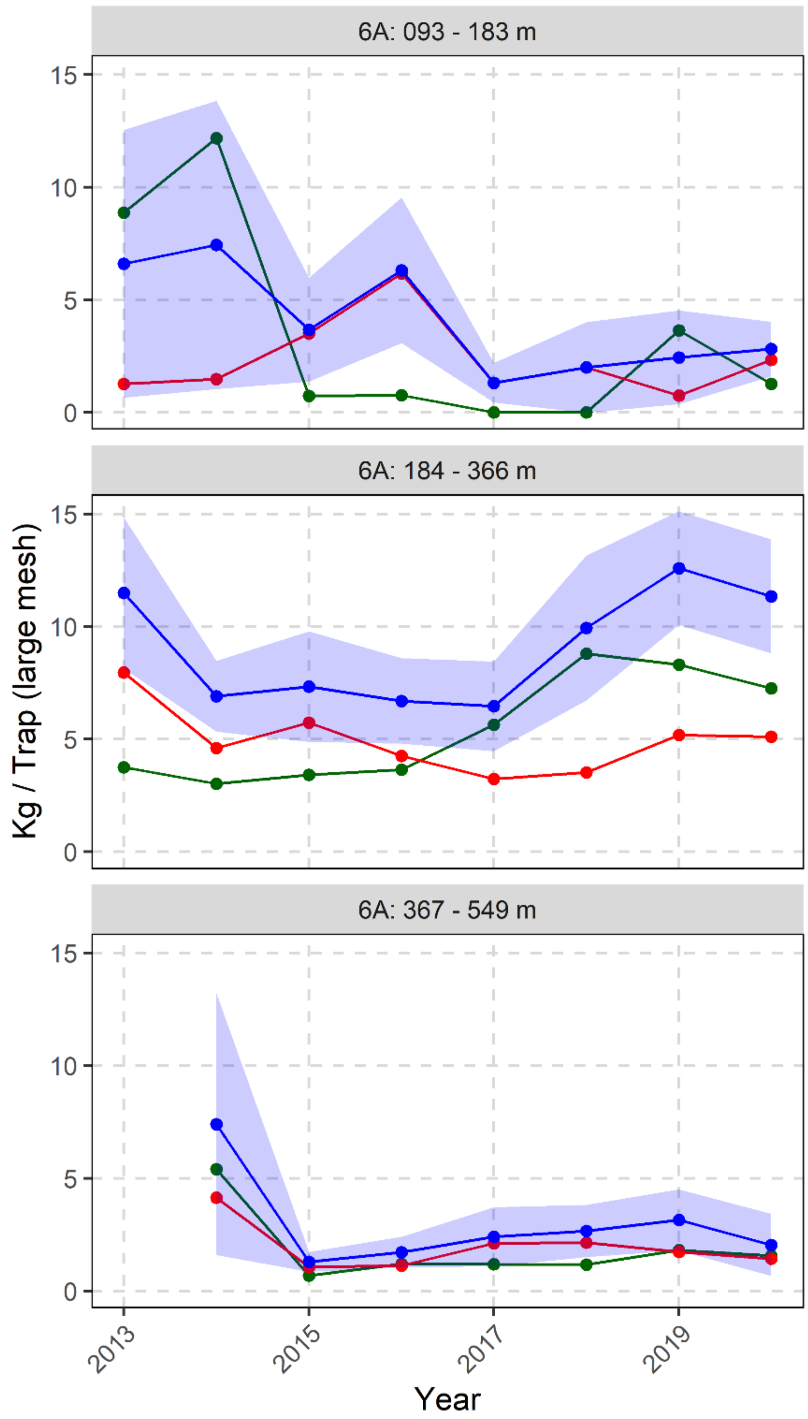

Figure A3. 9. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from large-mesh traps in Inshore DFO trap surveys in Trinity Bay (CMA 6A).

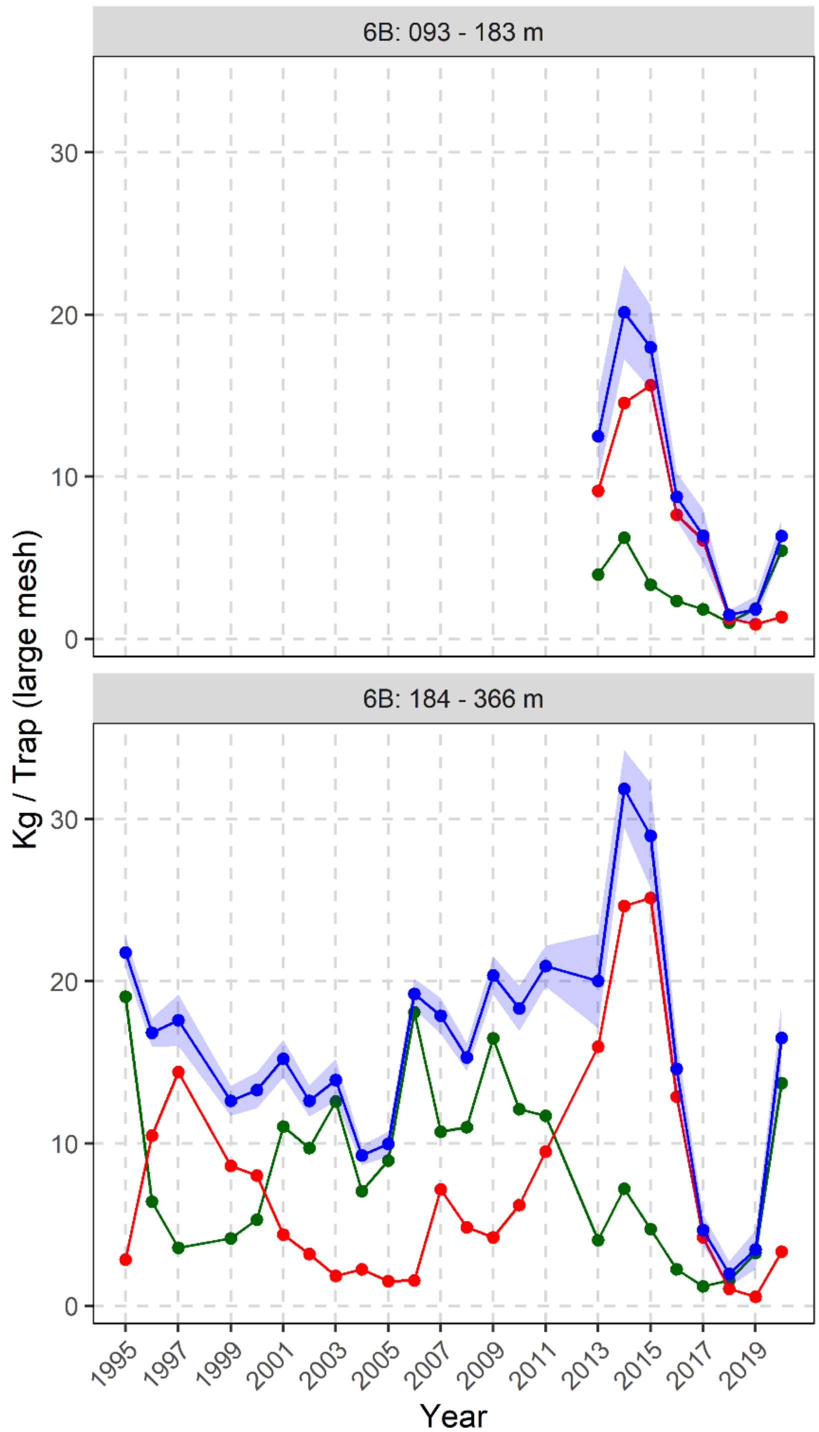

Figure A3. 10. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from large-mesh traps in Inshore DFO trap surveys in Conception Bay (CMA 6B).

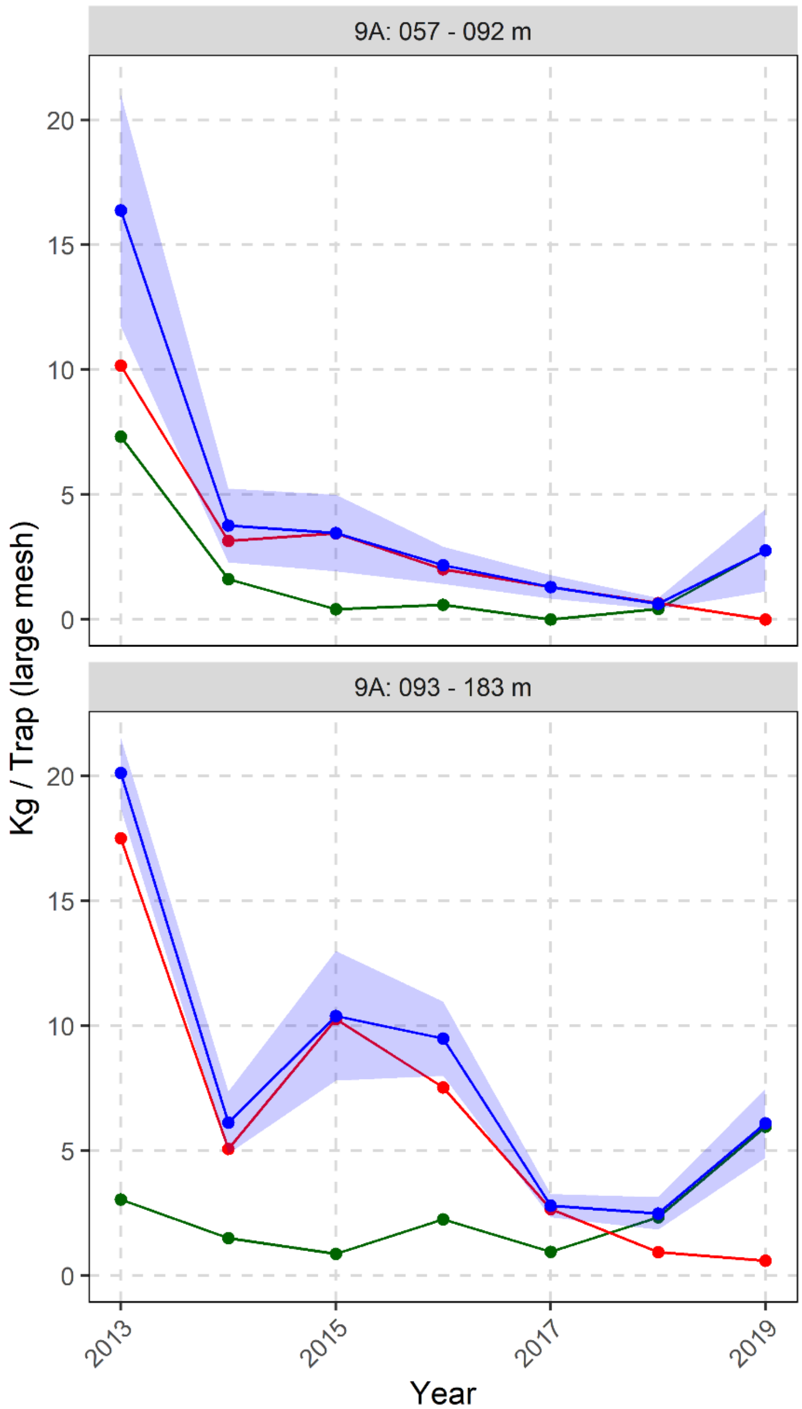

Figure A3. 11. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from large-mesh traps in Inshore DFO trap surveys in St. Mary's Bay (CMA 9A). Note: No survey in St. Mary's Bay in 2020.

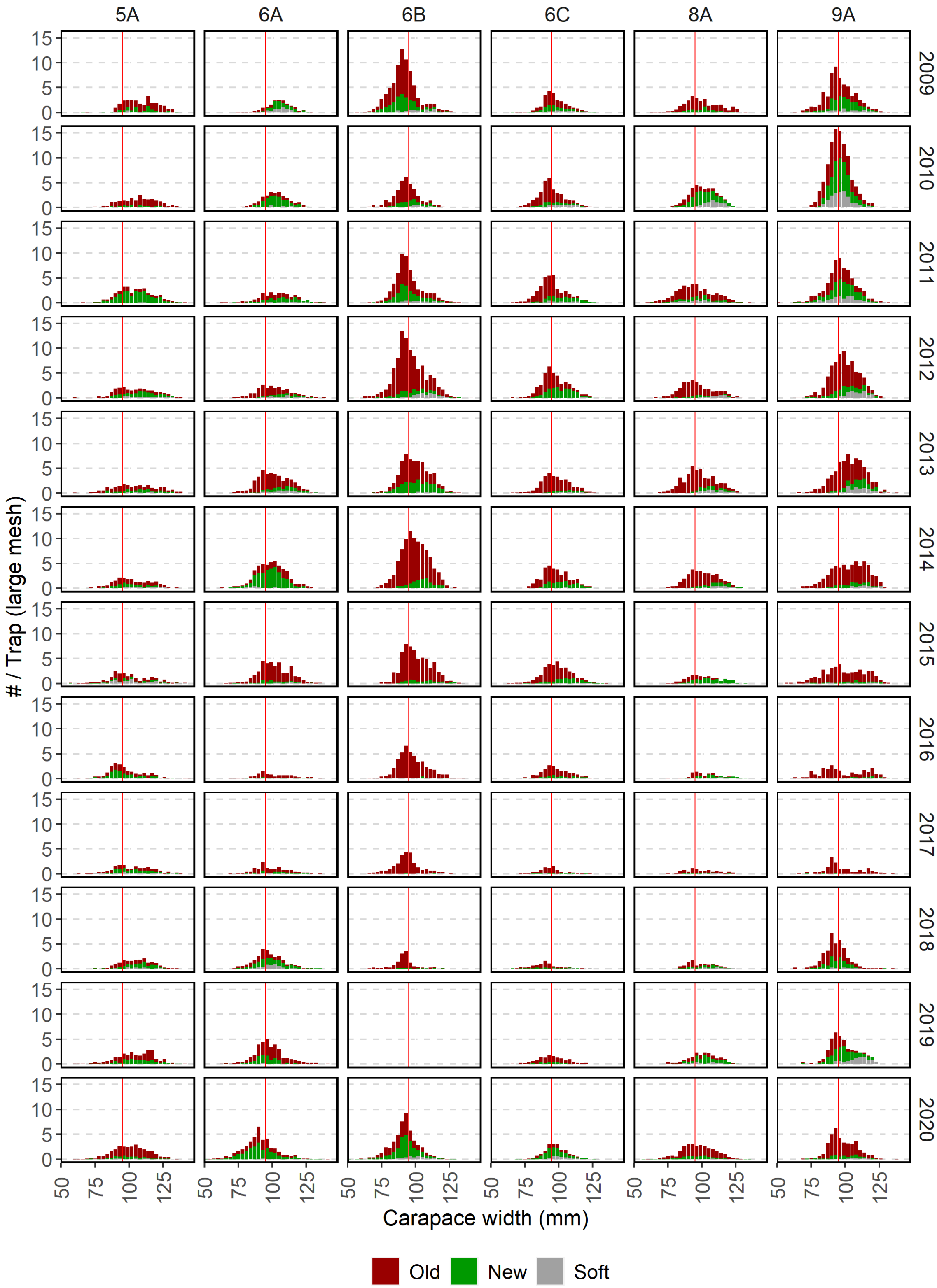

Figure A3. 12. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 3L Inshore (2009–20). The vertical line indicates the minimum legal size.

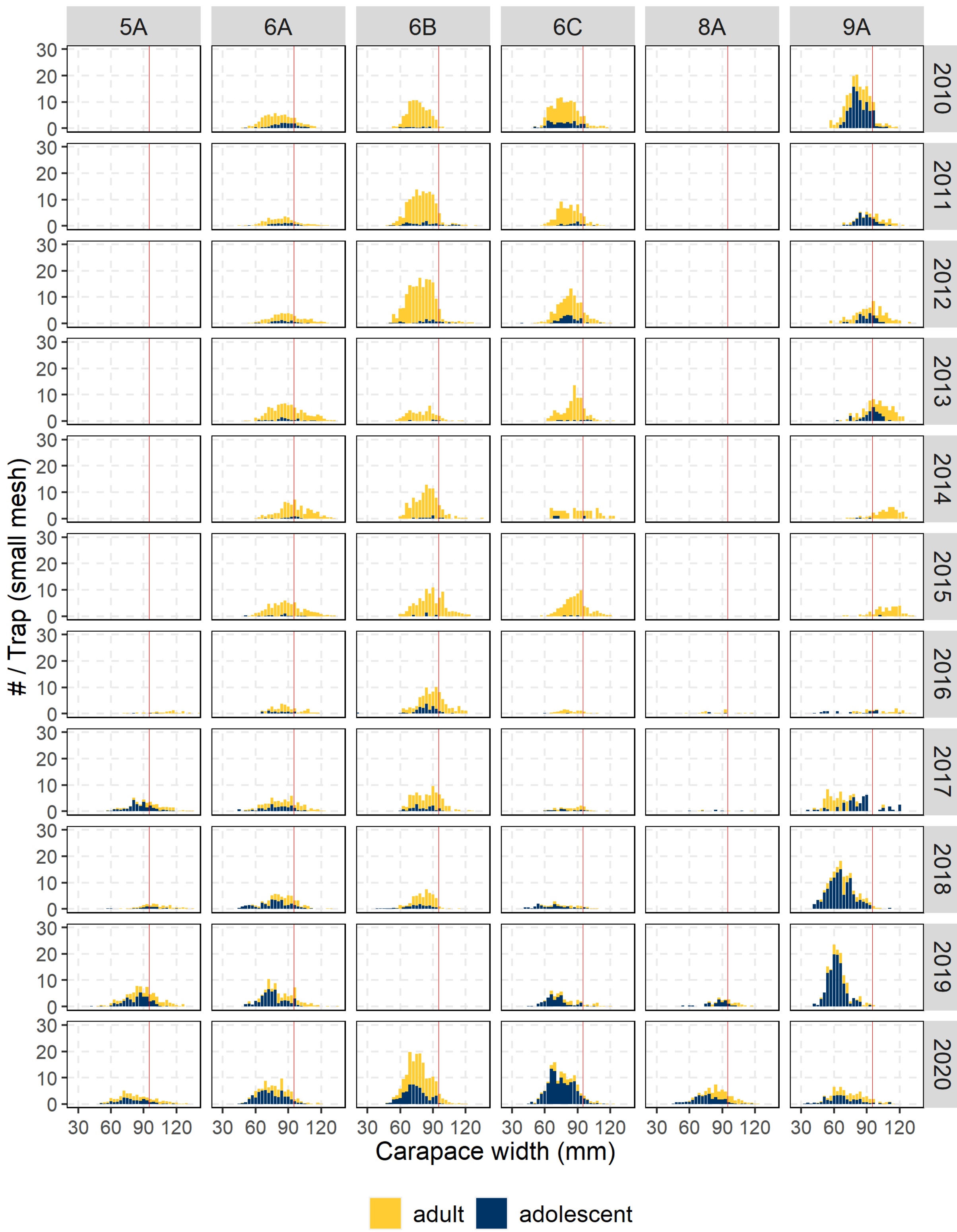

Figure A3. 13. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps at core stations in the CPS trap survey (2010–20) from CMAs in Assessment Division 3L Inshore. The red vertical line indicates the minimum legal size.

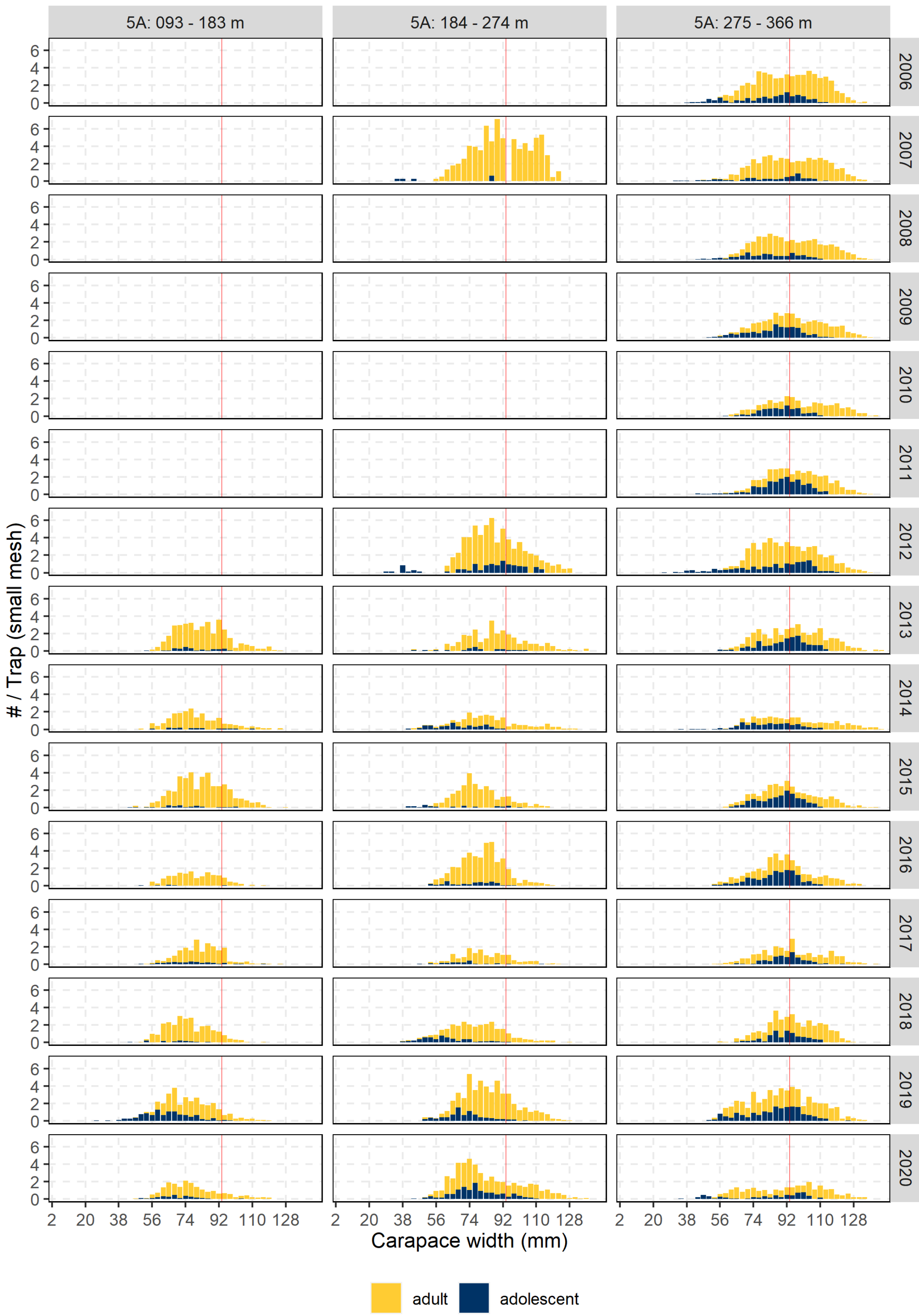

Figure A3. 14. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2006–20) from Bonavista Bay (CMA 5A). The red vertical line indicates the minimum legal size.

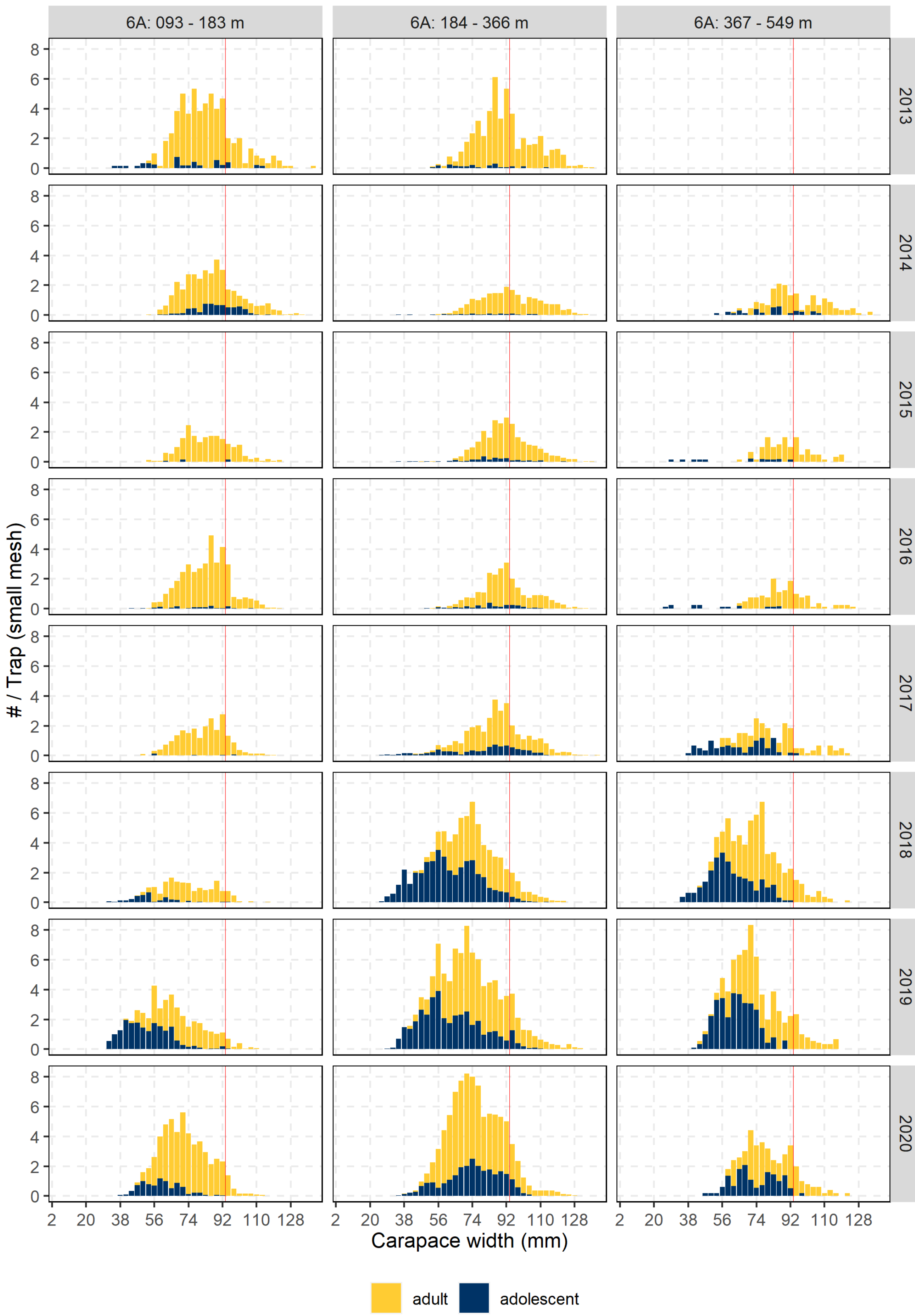

Figure A3. 15. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2013–20) from Trinity Bay (CMA 6A). The red vertical line indicates the minimum legal size.

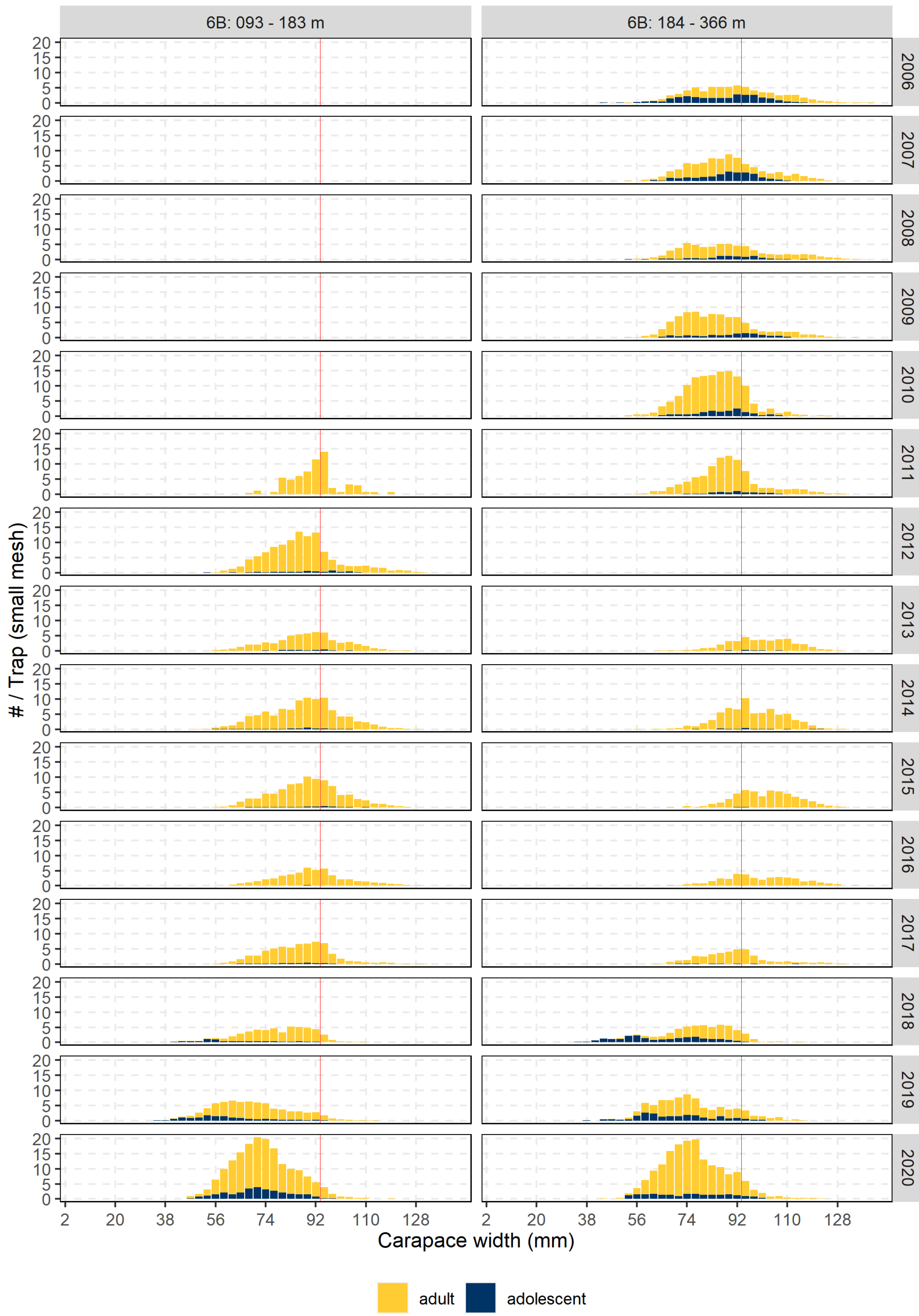

Figure A3. 16. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2006–20) from Conception Bay (CMA 6B). The red vertical line indicates the minimum legal size.

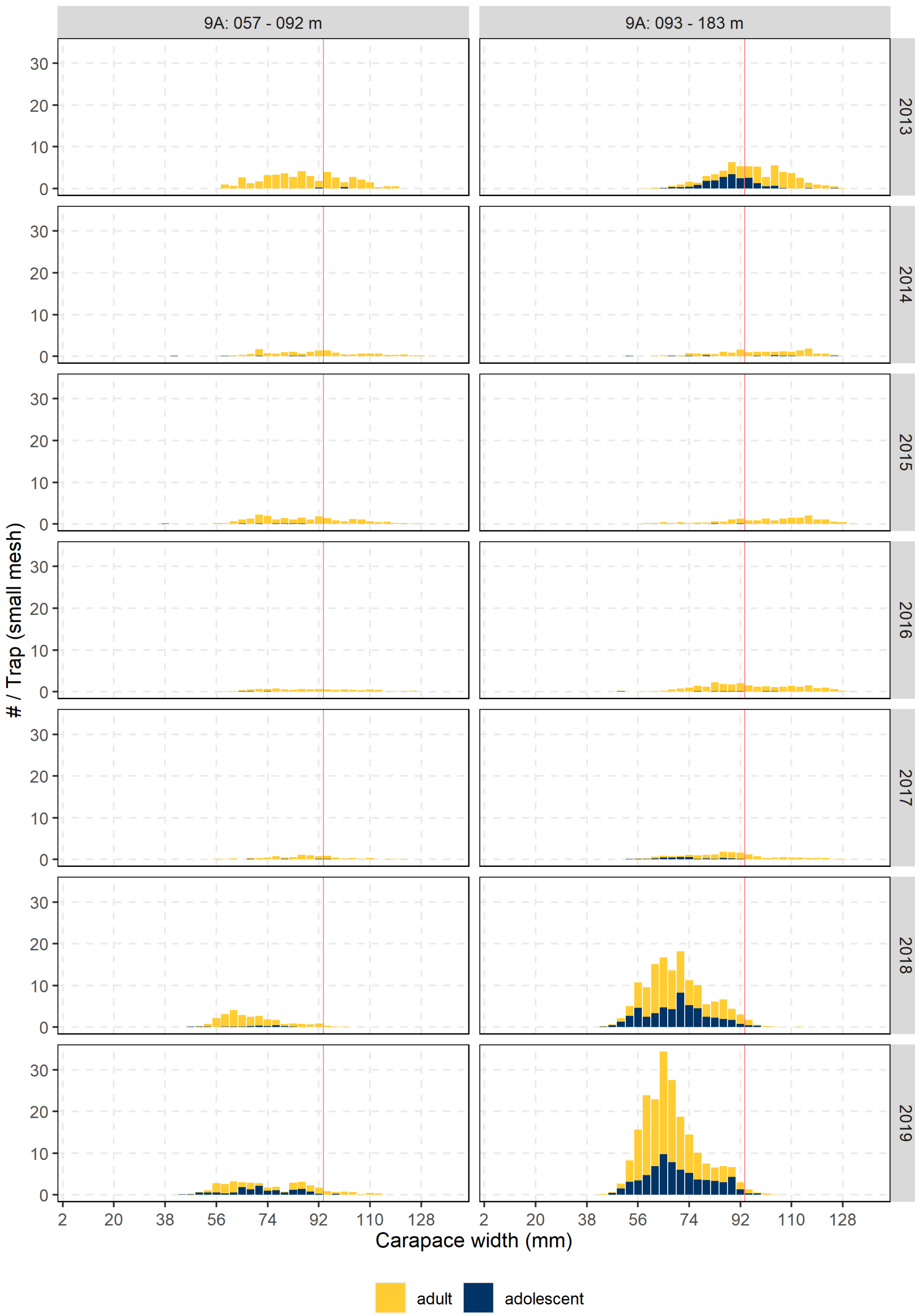

Figure A3. 17. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2013–19) from St. Mary's Bay (CMA 9A). The red vertical line indicates the minimum legal size. Note: No survey in St. Mary's Bay in 2020.

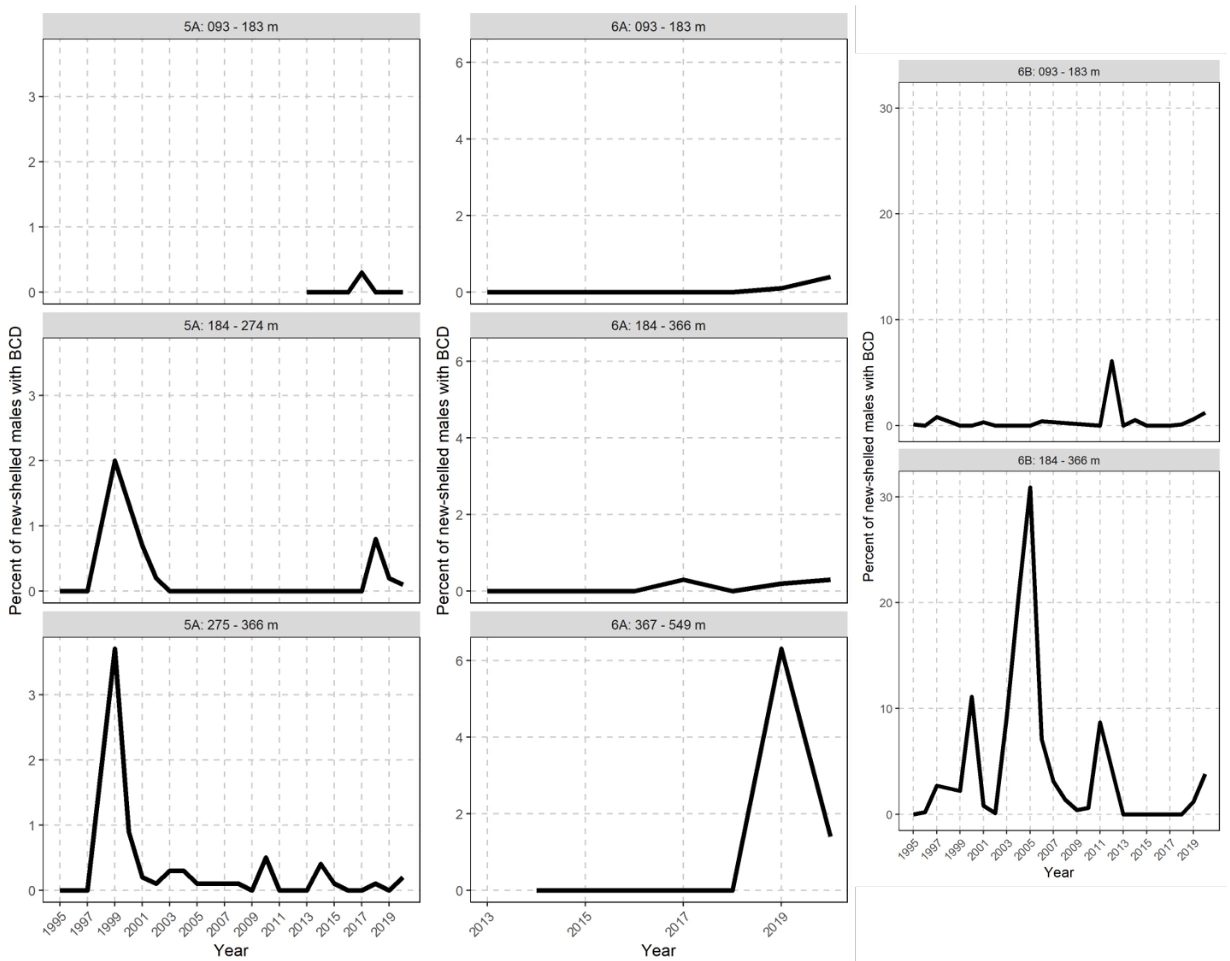

Figure A3. 18. Visually observed percentage of Bitter Crab Disease (BCD) in new-shelled crab from Inshore DFO trap surveys in Bonavista Bay (CMA 5A), Trinity Bay (CMA 6A), and Conception Bay (CMA 6B).

APPENDIX 4: ASSESSMENT DIVISION 3LNO OFFSHORE DETAILS

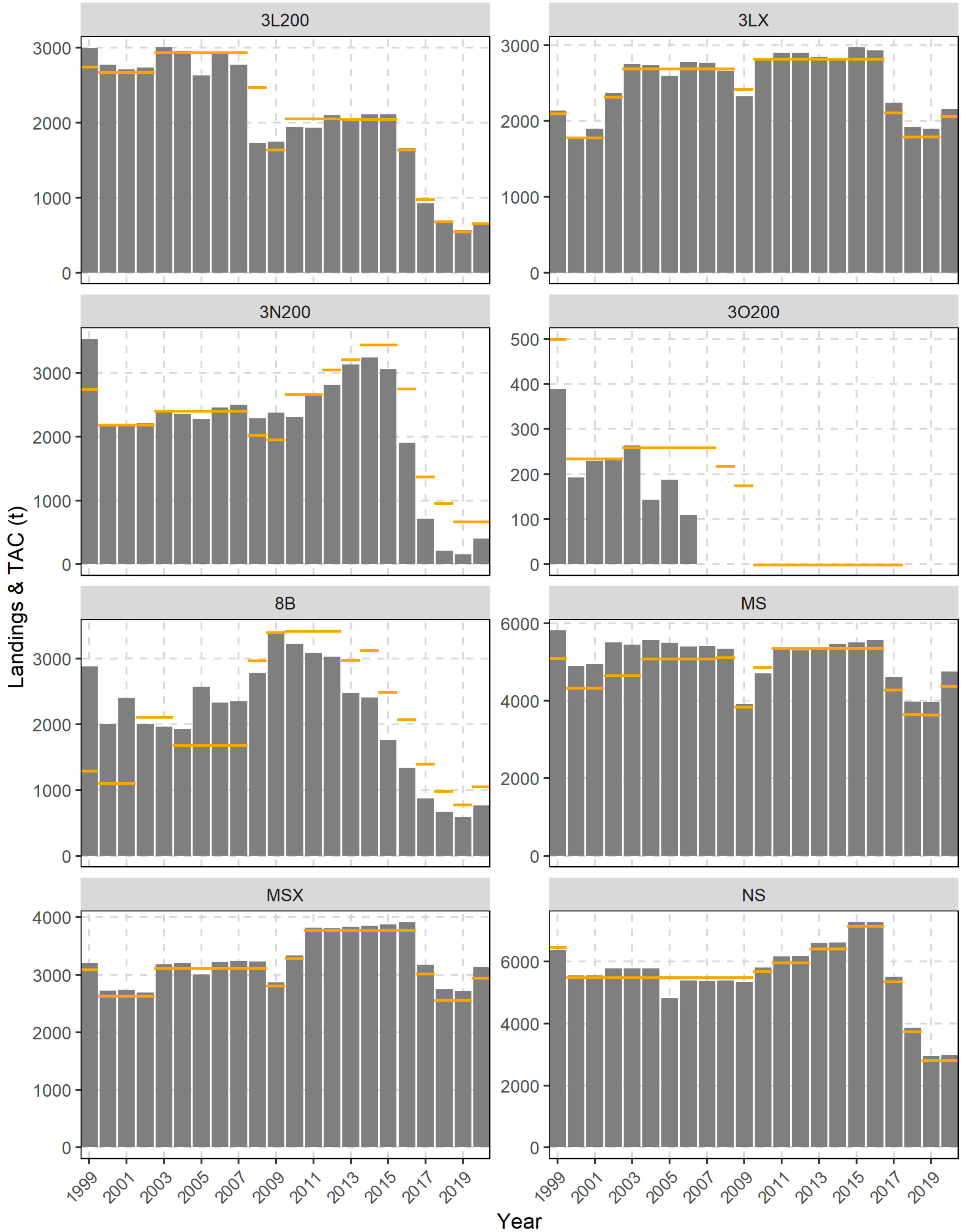

Figure A4. 1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 3LNO Offshore (1999–2020).

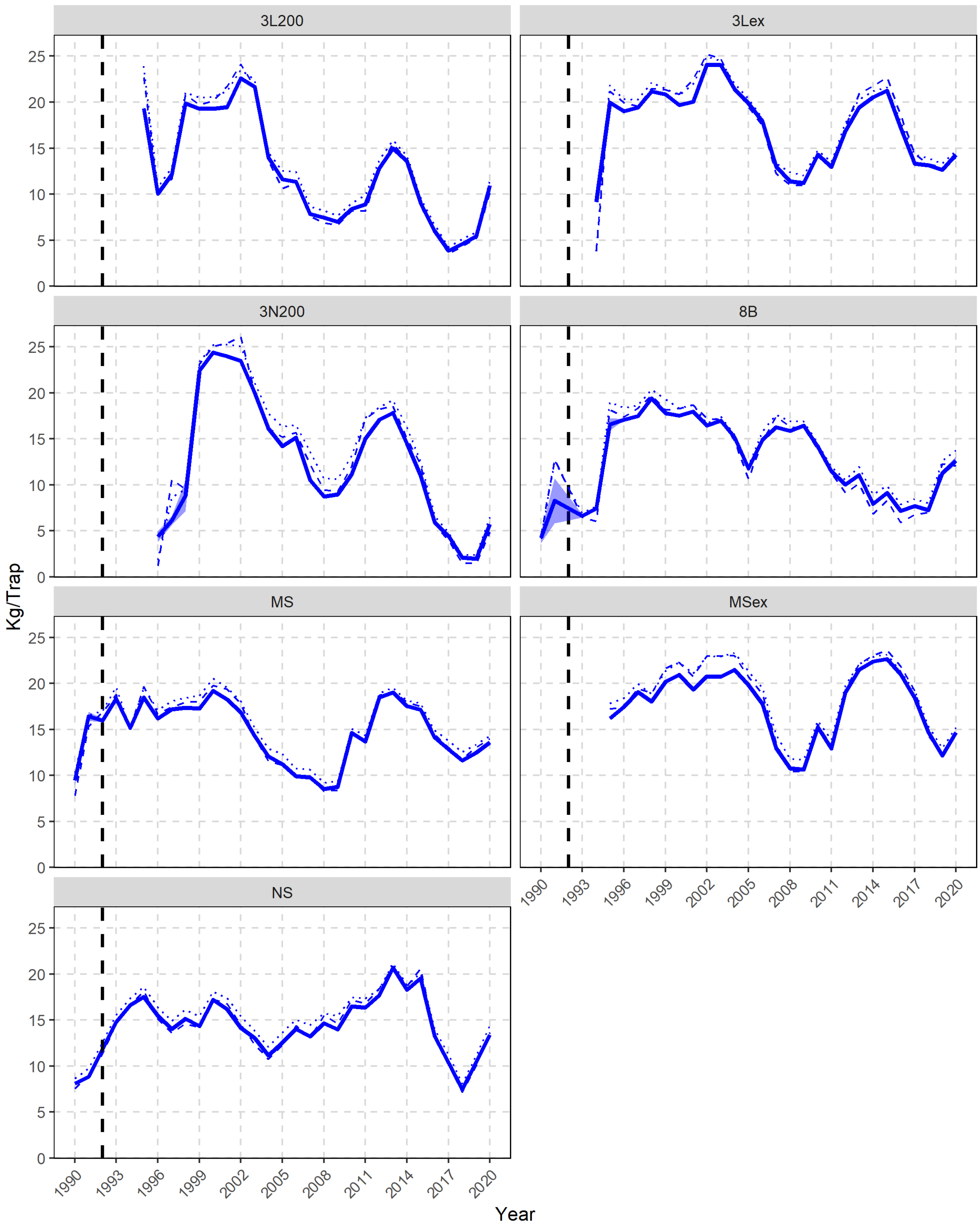

Figure A4. 2. Trends in standardized CPUE (kg/trap) in CMAs within Assessment Division 3LNO Offshore. Solid line is average predicted CPUE, shaded band is 95% confidence interval, dotted line represents average raw CPUE, and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

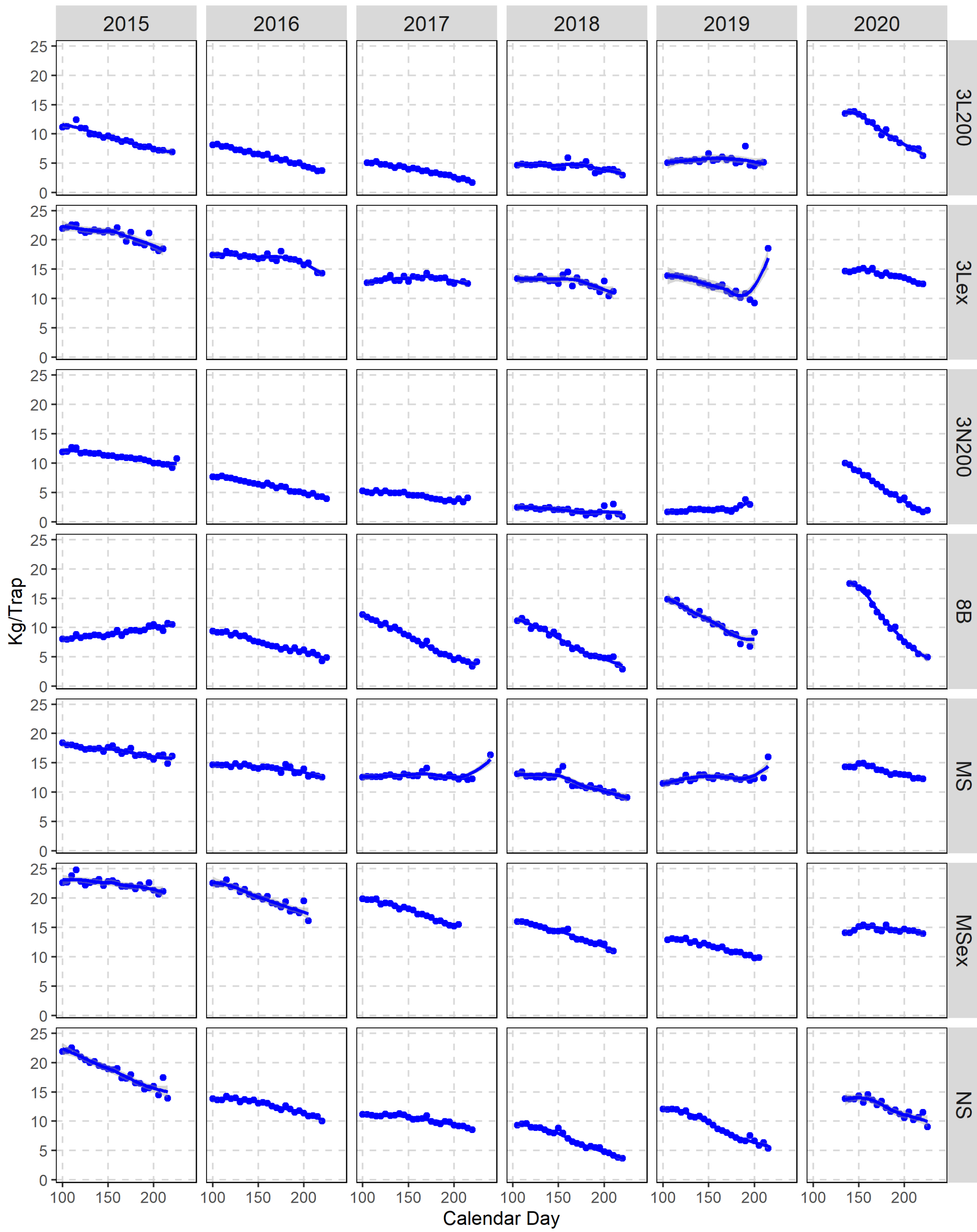

Figure A4. 3. Standardized CPUE (kg/trap) throughout the season (calendar day) in Assessment Division 3LNO Offshore (2015–20), derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

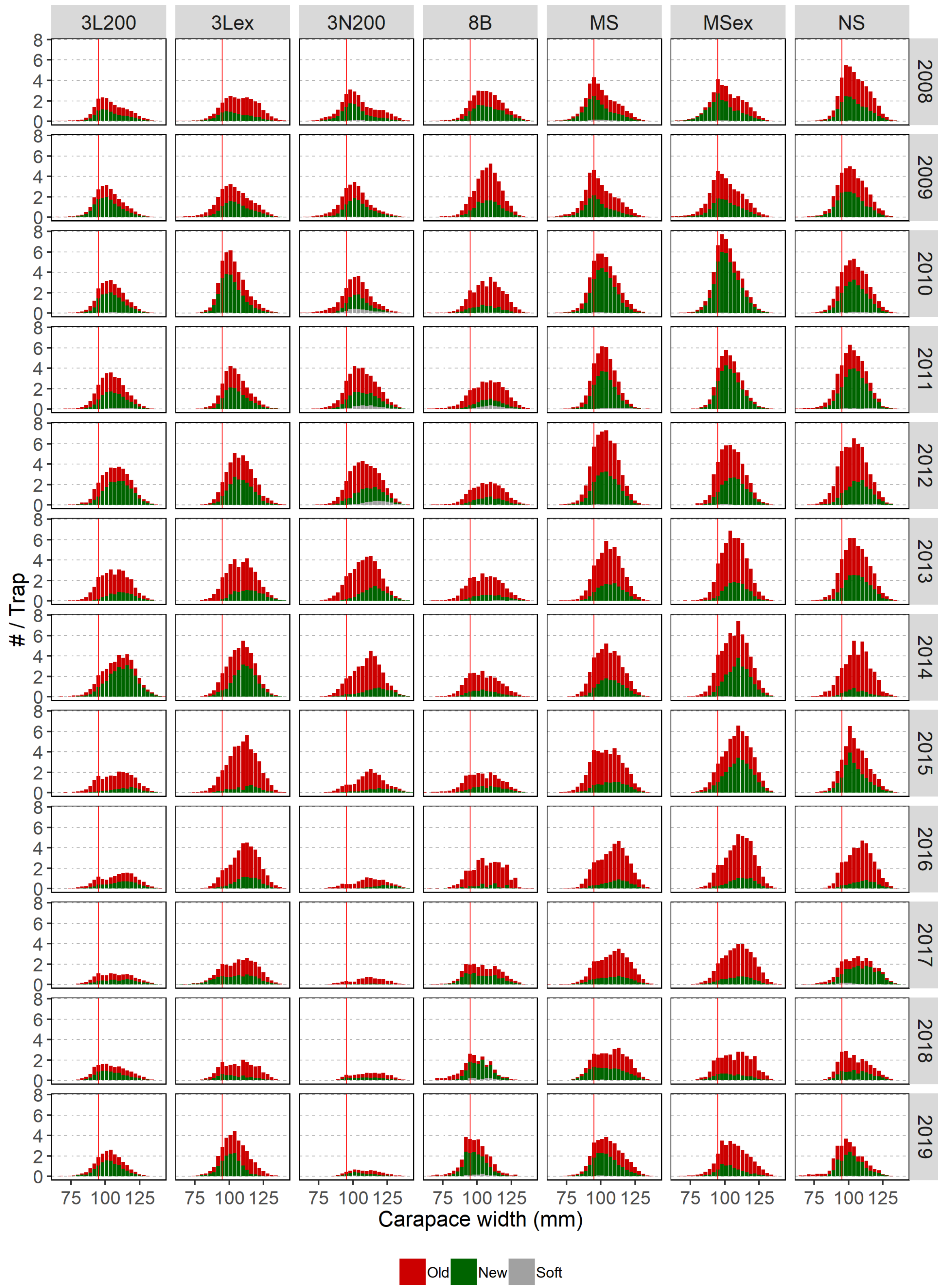

Figure A4. 4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each Crab Management Area in Assessment Division 3LNO Offshore (2008–19). The red vertical line indicates the minimum legal size. Note: Not updated for 2020.

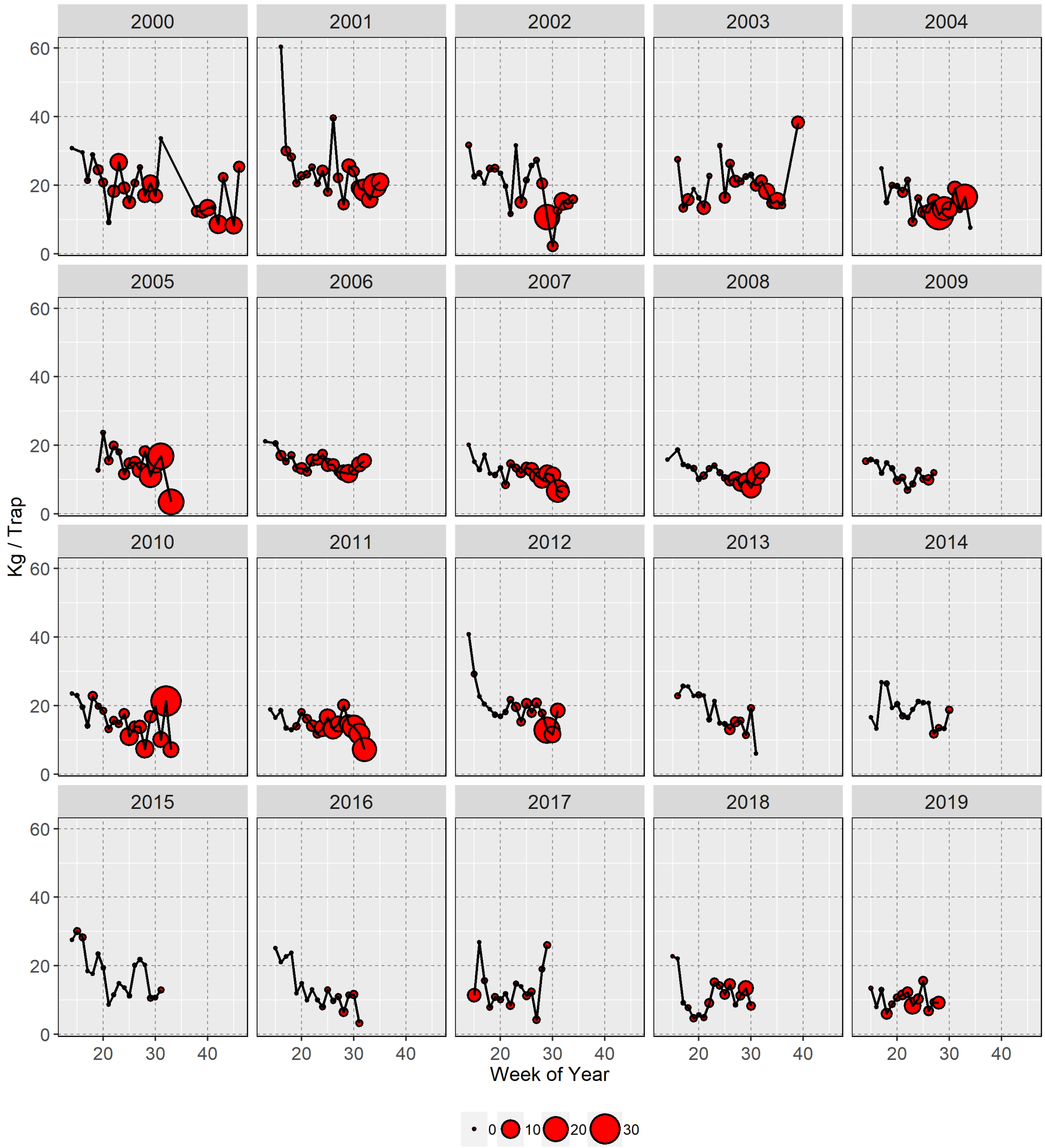

Figure A4. 5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Crab Management Areas within Assessment Division 3LNO Offshore (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates. Note: Not updated in 2020.

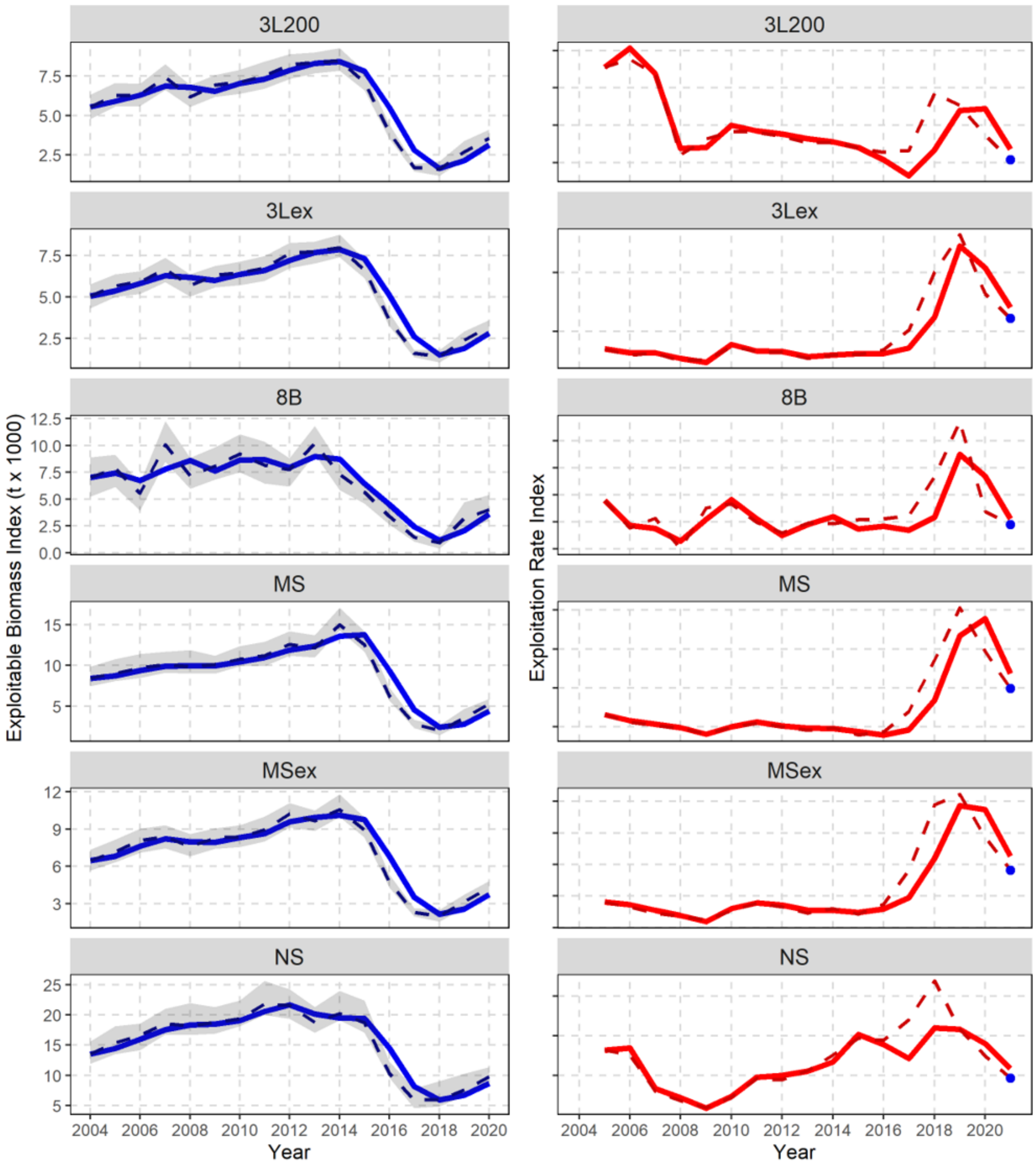

Figure A4. 6. Left: Annual trap-based exploitable biomass index (t x 1,000). The solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the 95% confidence interval of the annual estimates. Right: Trends in the trap-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 3LNO Offshore; 2021 points depict projected exploitation rate indices under status quo removals in the 2021 fishery.

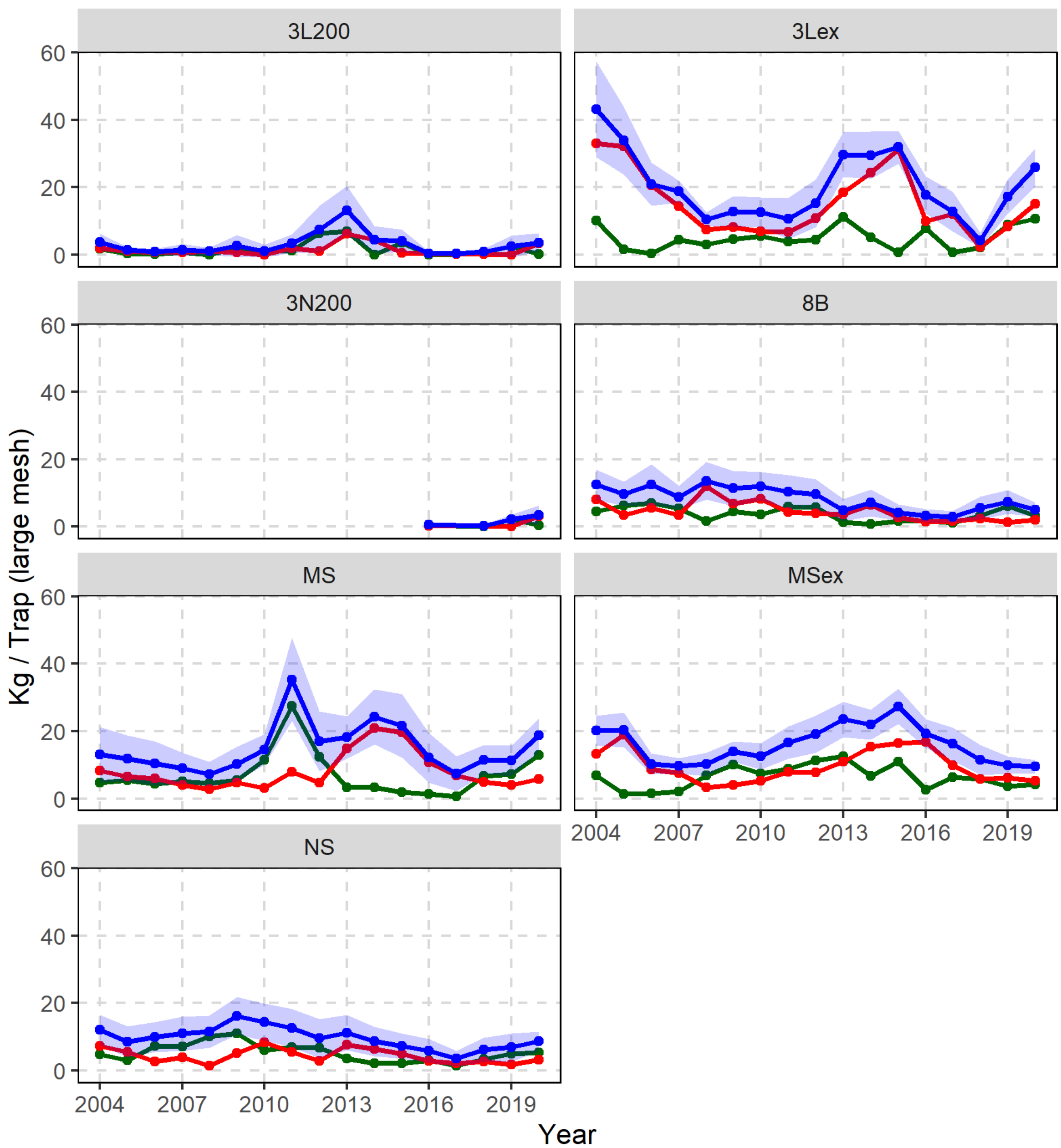

Figure A4. 7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 3LNO Offshore.

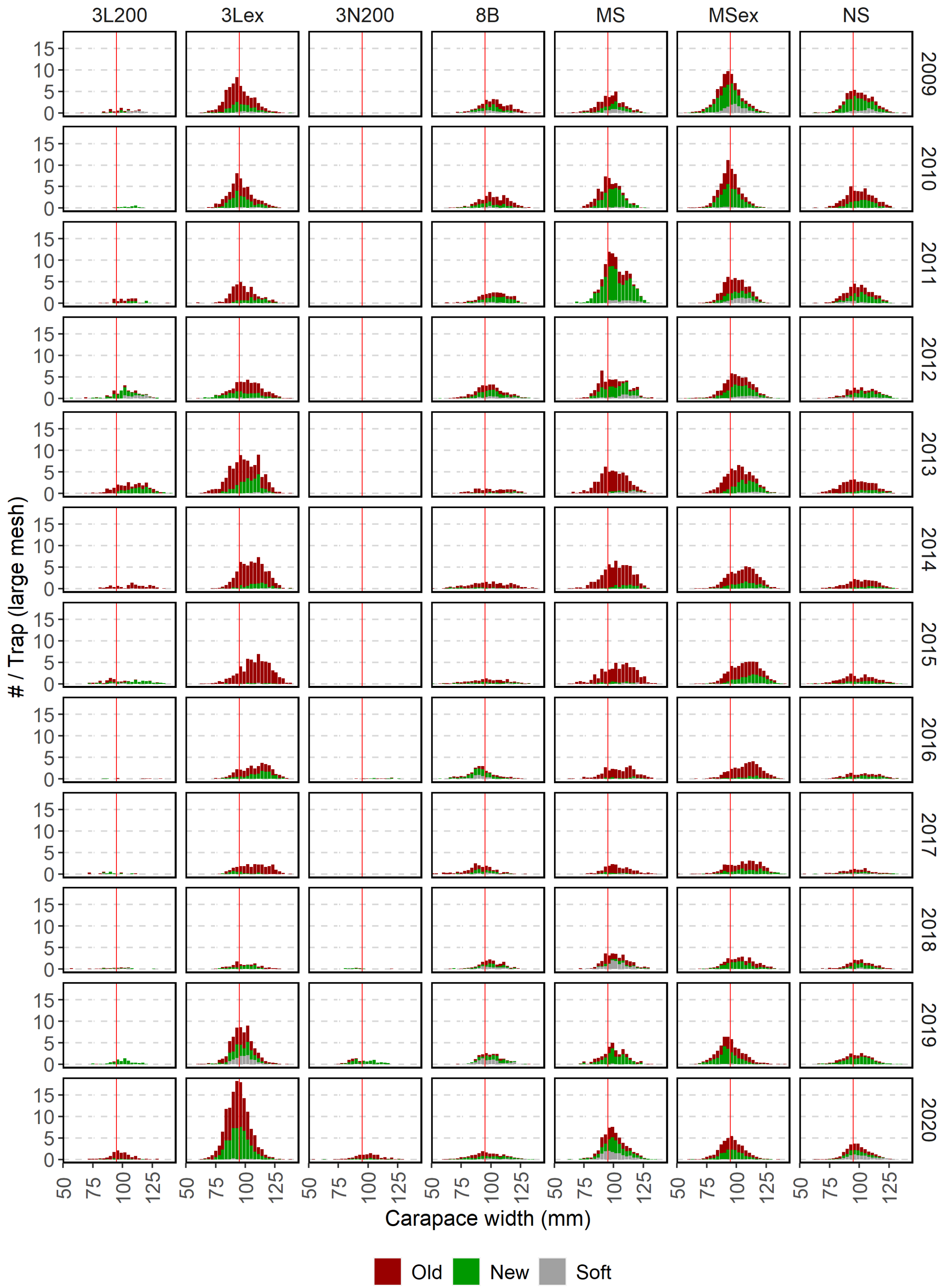

Figure A4. 8. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 3LNO Offshore (2009–20). The red vertical line indicates the minimum legal size.

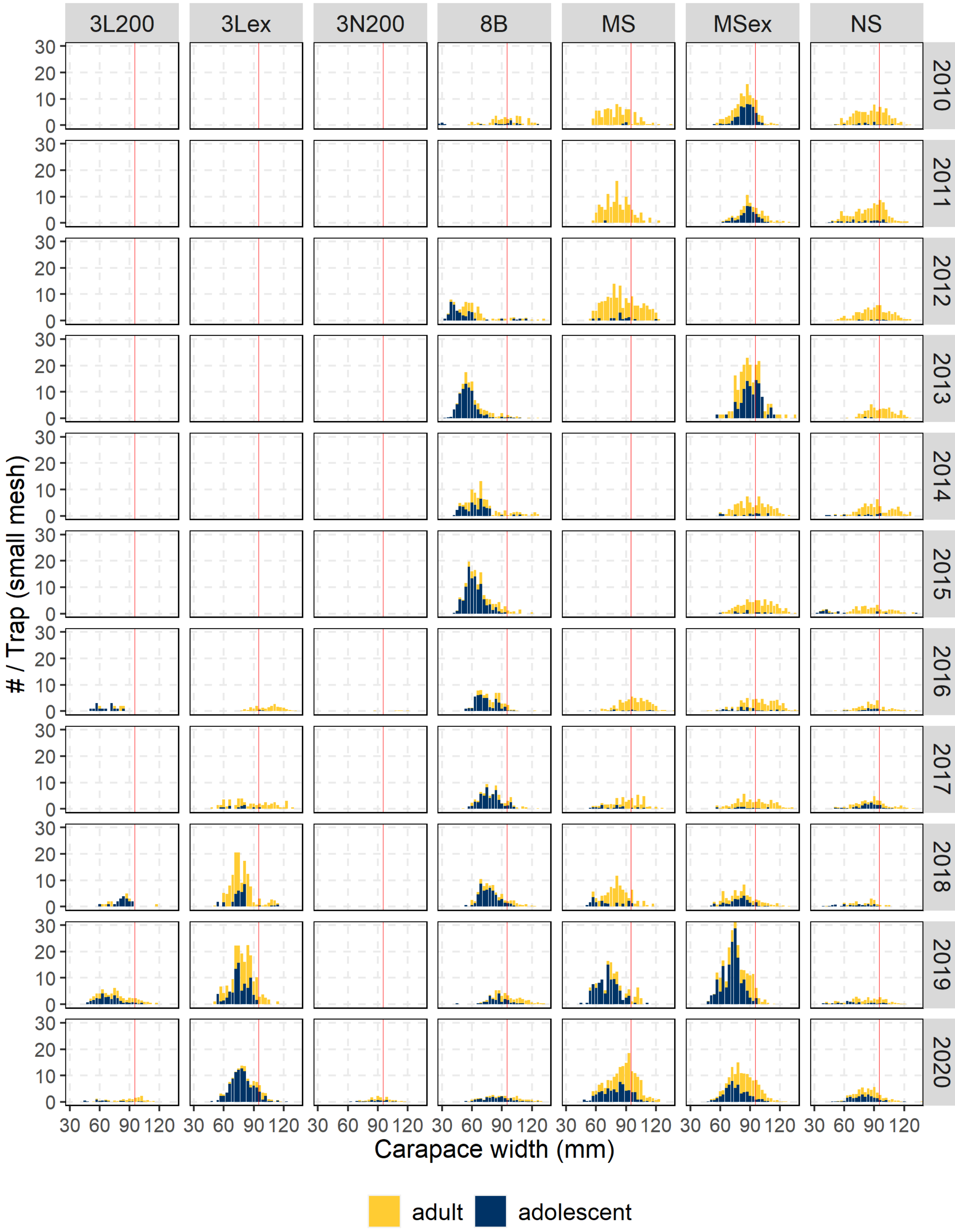

Figure A4. 9. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2010–20) from CMAs in Assessment Division 3LNO Offshore. The red vertical line indicates the minimum legal size.

APPENDIX 5: ASSESSMENT DIVISION 3PS DETAILS

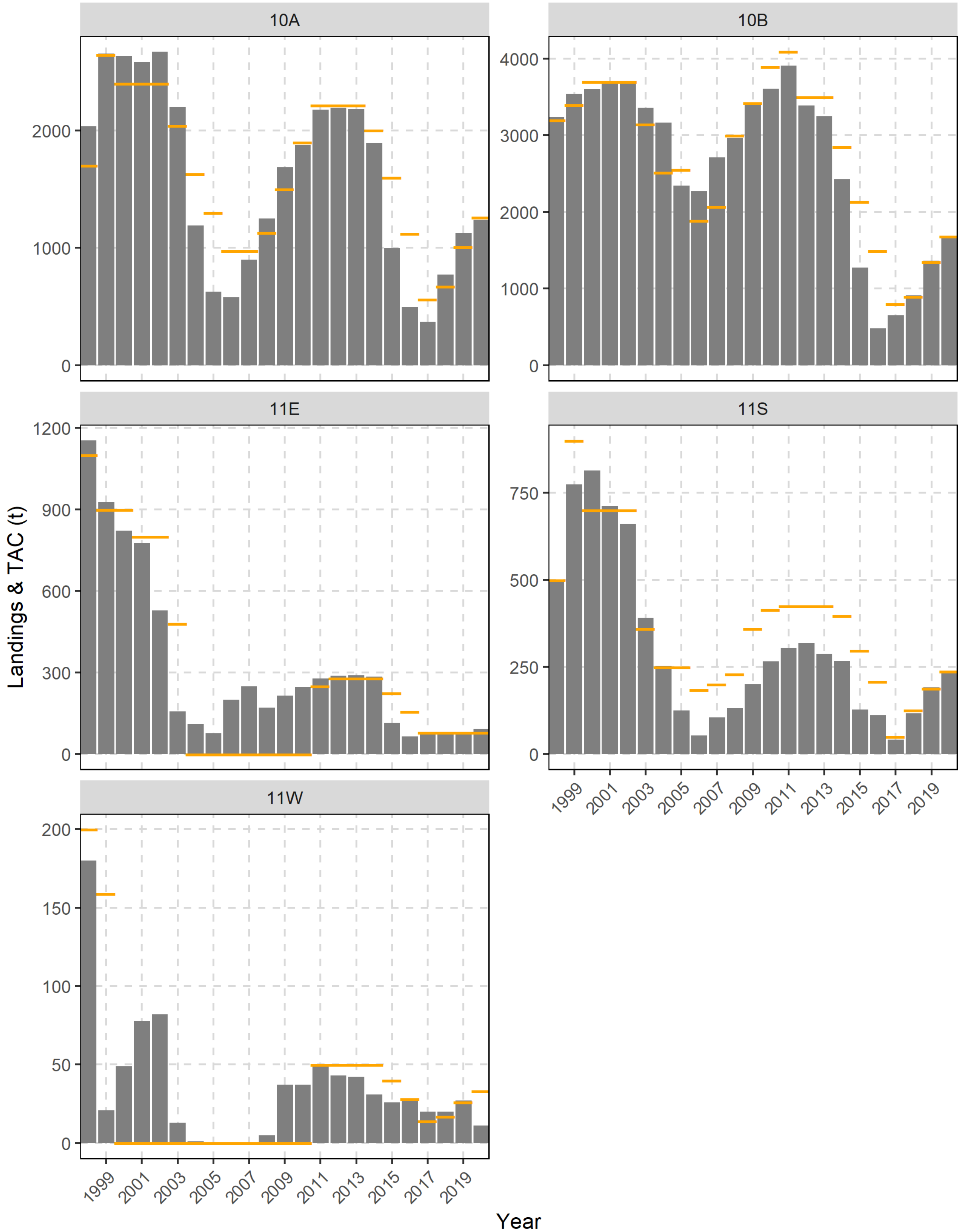

Figure A5. 1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 3Ps (1998–2020).

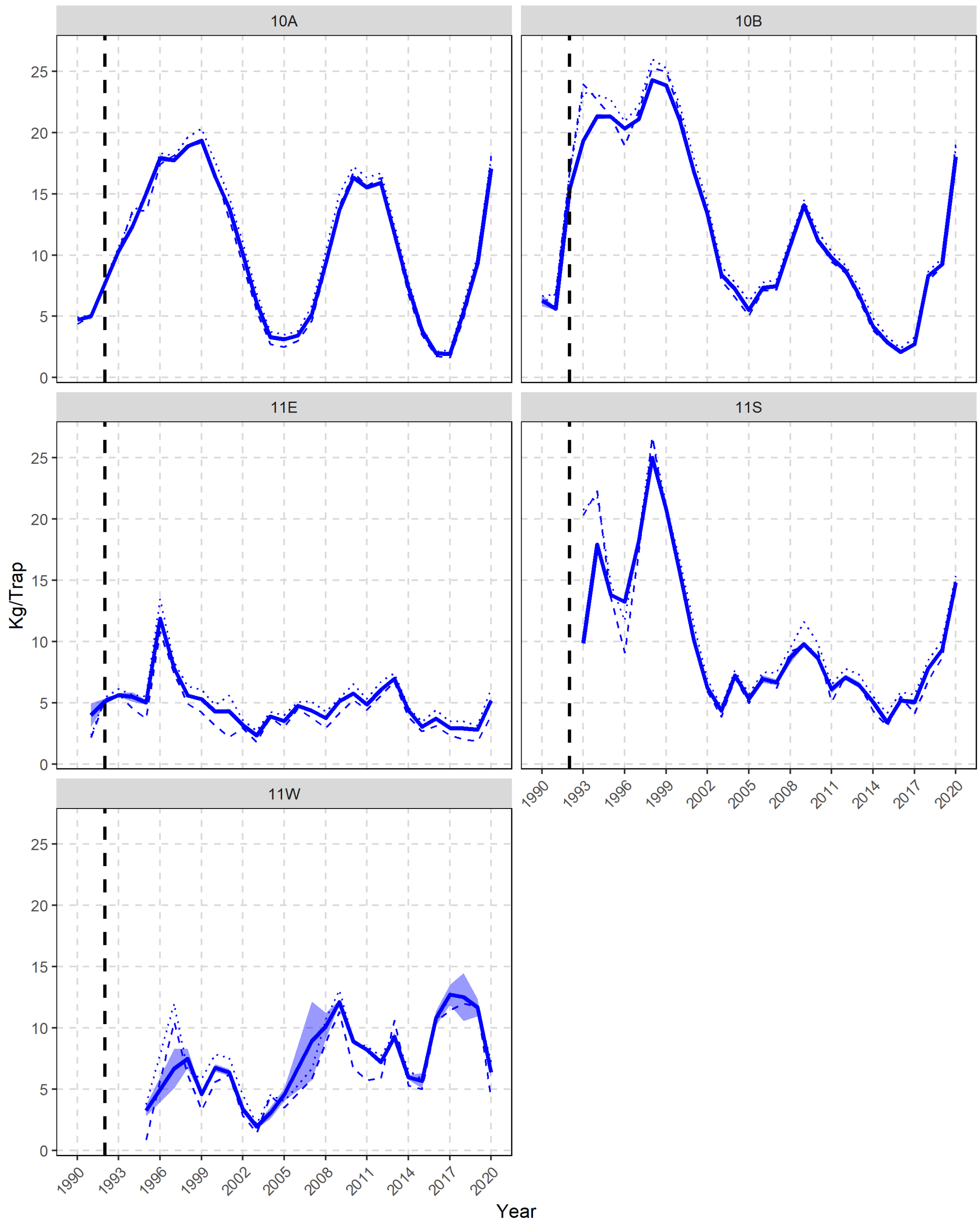

Figure A5. 2. Trends in standardized CPUE (kg/trap) in CMAs within Assessment Division 3Ps. Solid line is average predicted CPUE, shaded band is 95% confidence interval, dotted line represents average raw CPUE, and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

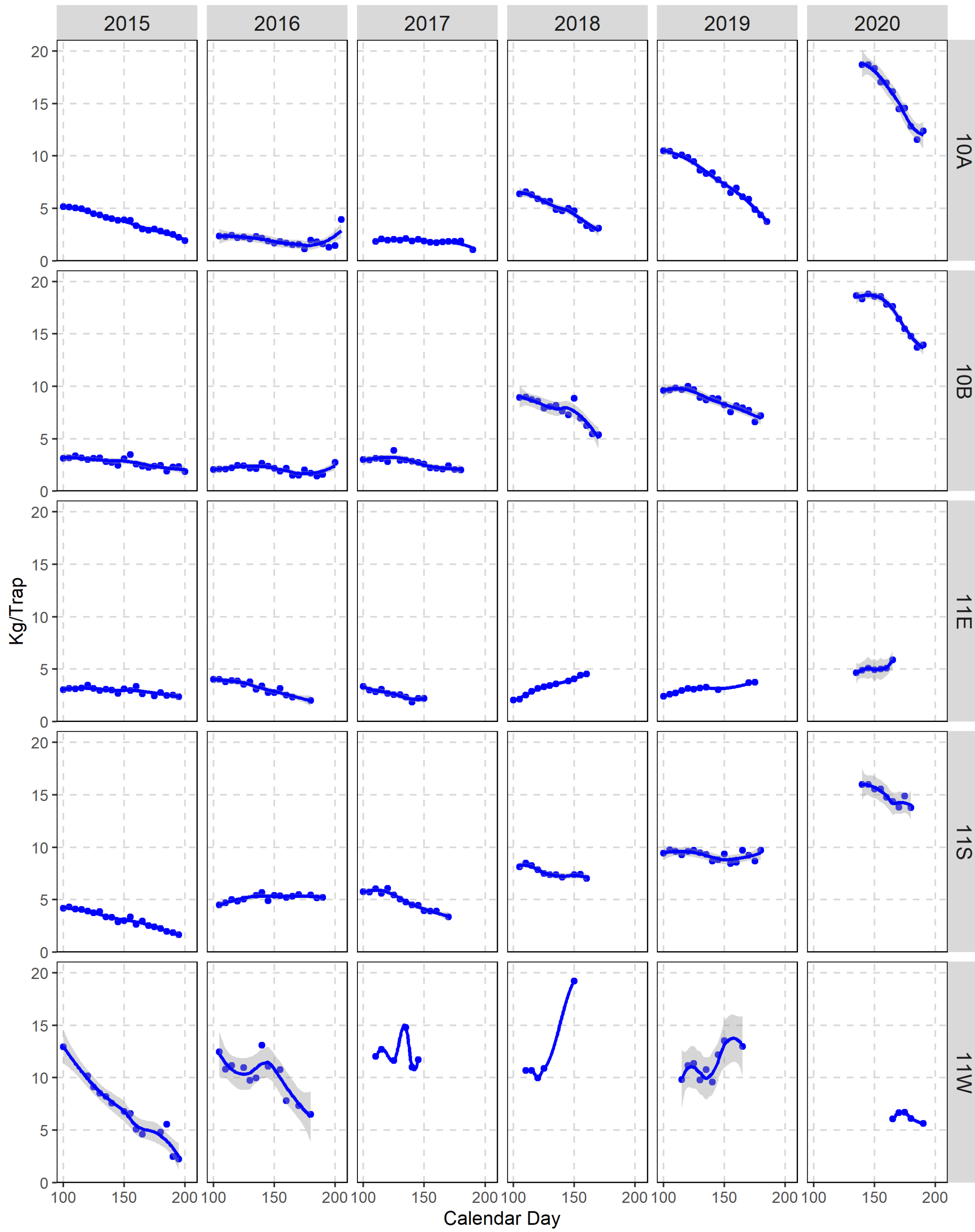

Figure A5. 3. Standardized CPUE (kg/trap) throughout the season (calendar day) in Assessment Division 3Ps (2015–20), derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

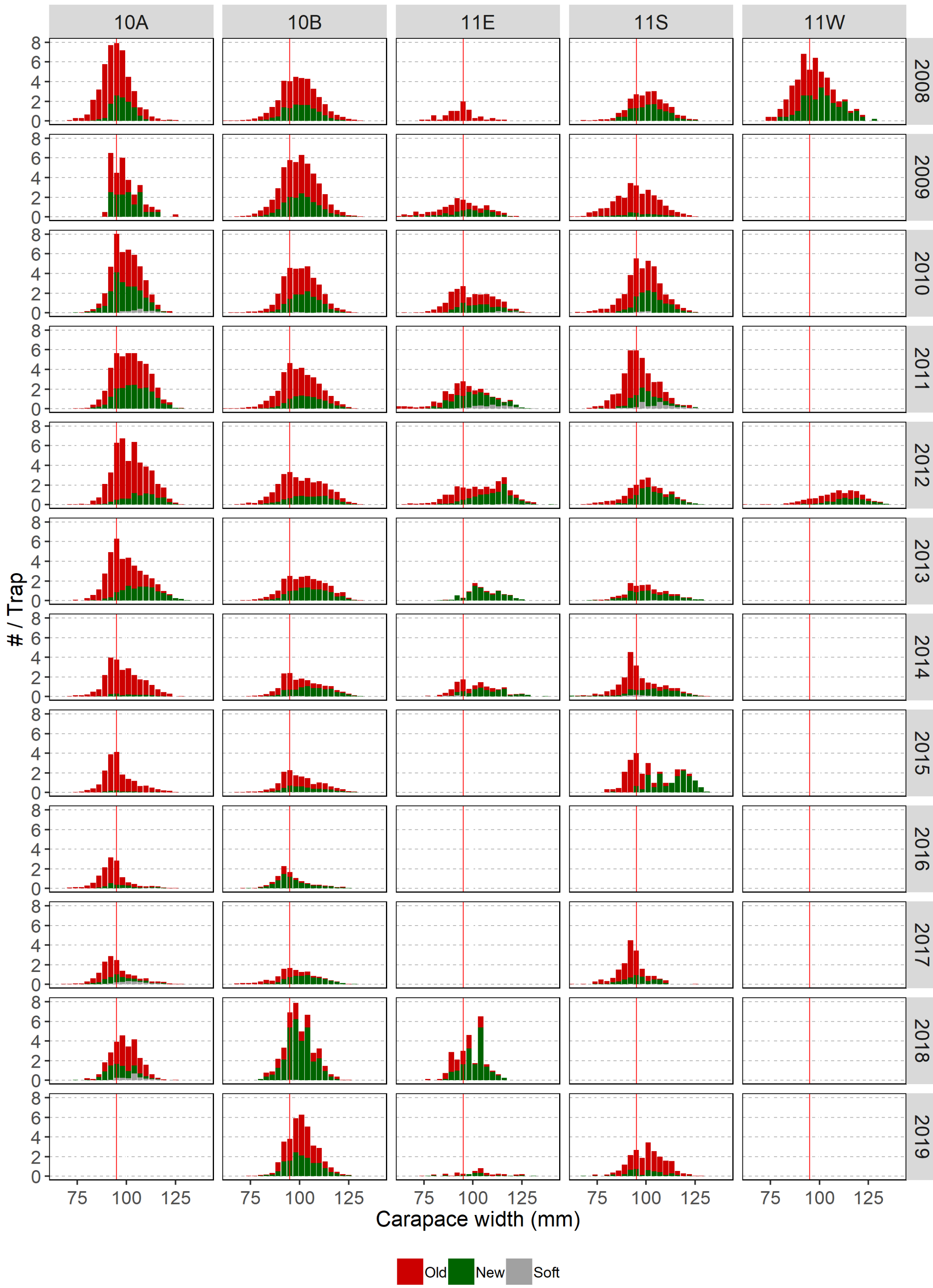

Figure A5. 4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each Crab Management Area in Assessment Division 3Ps (2008–19). The red vertical line indicates the minimum legal size. Note: Not updated in 2020.

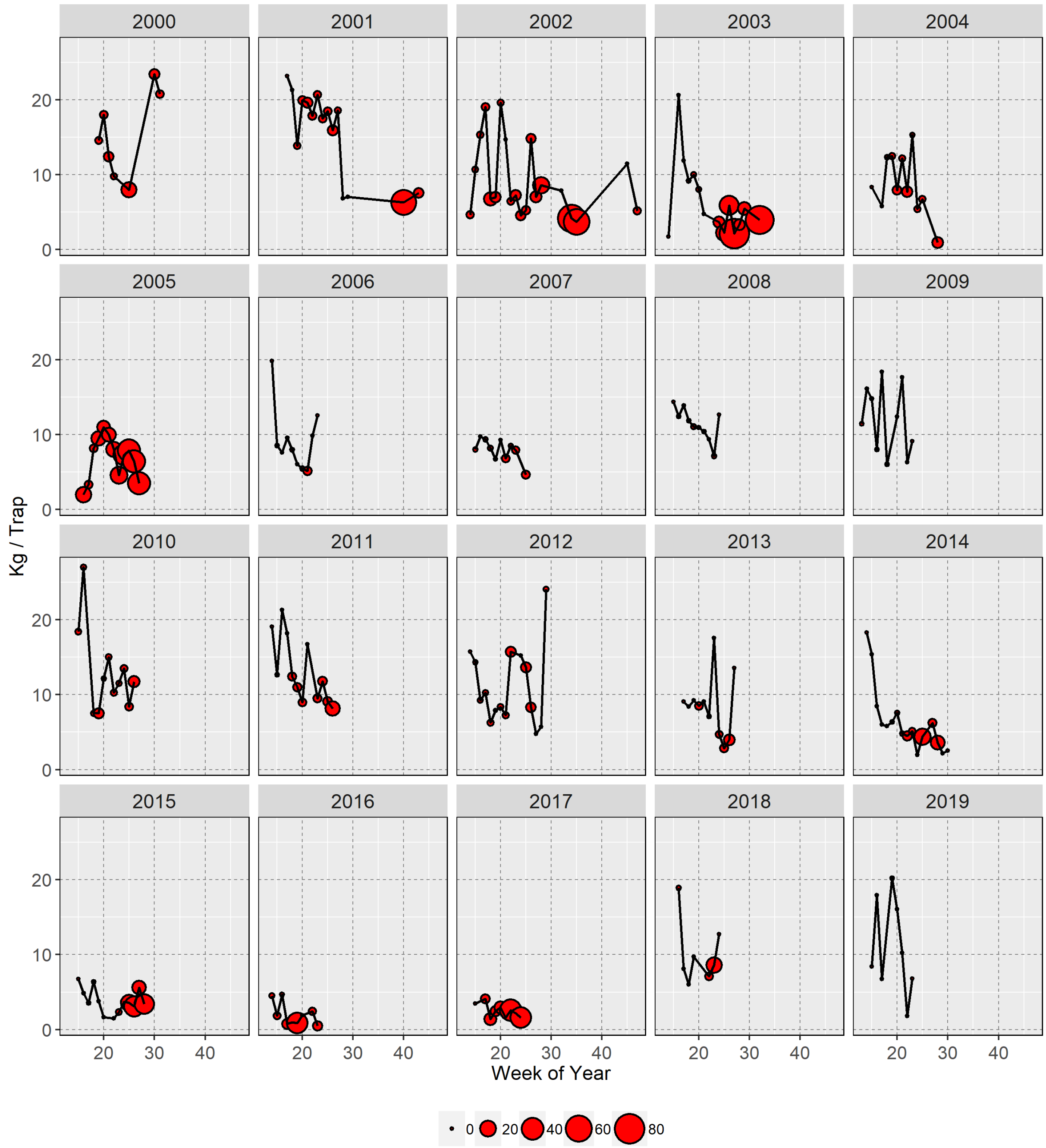

Figure A5. 5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Crab Management Areas within Assessment Division 3Ps (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates. Note: Not updated in 2020.

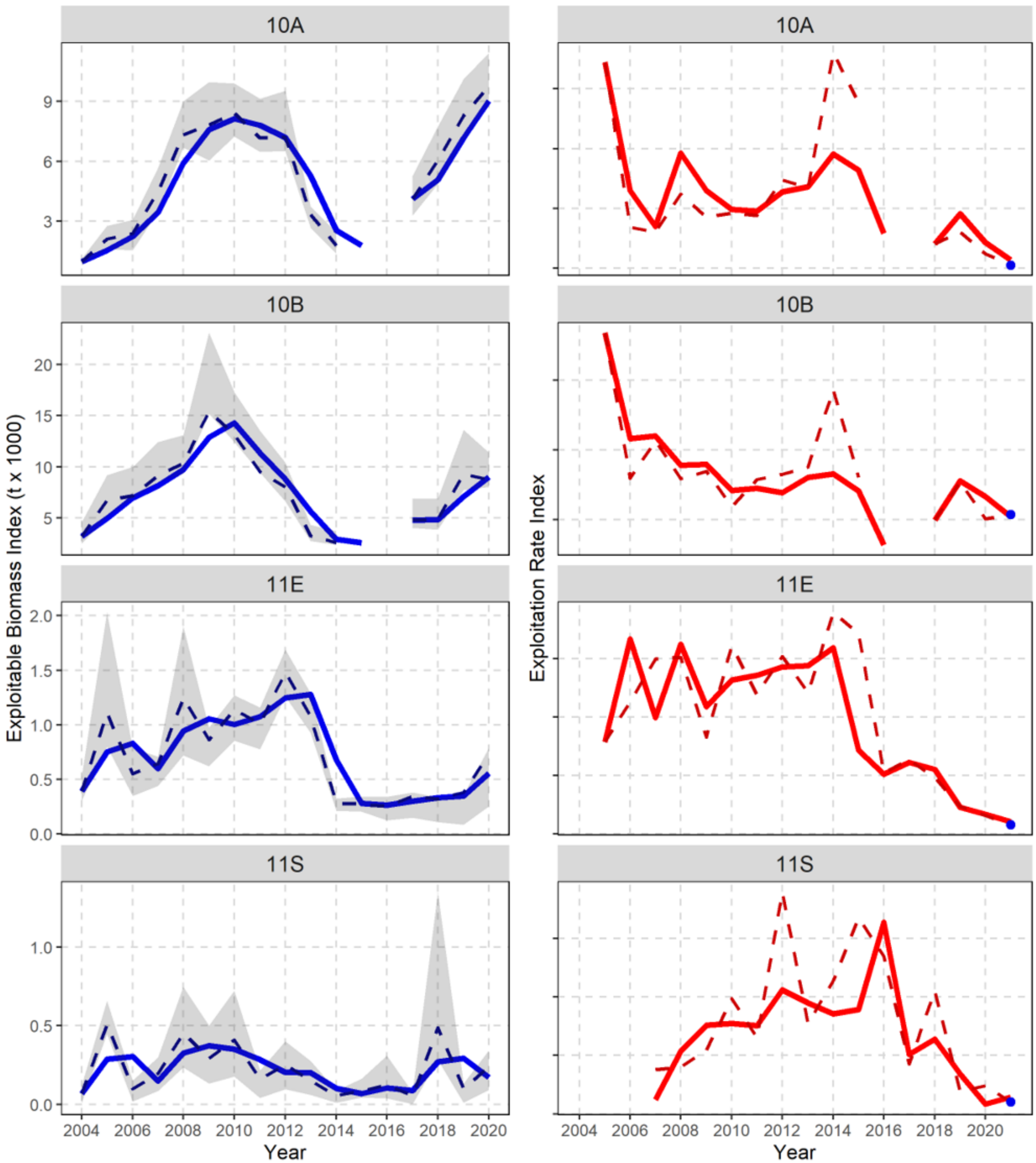

Figure A5. 6. Left: Annual trap-based exploitable biomass index (t x 1,000). The solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the 95% confidence interval of the annual estimates. Right: Trends in the trap-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 3Ps; 2021 points depict projected exploitation rate indices under status quo removals in the 2021 fishery.

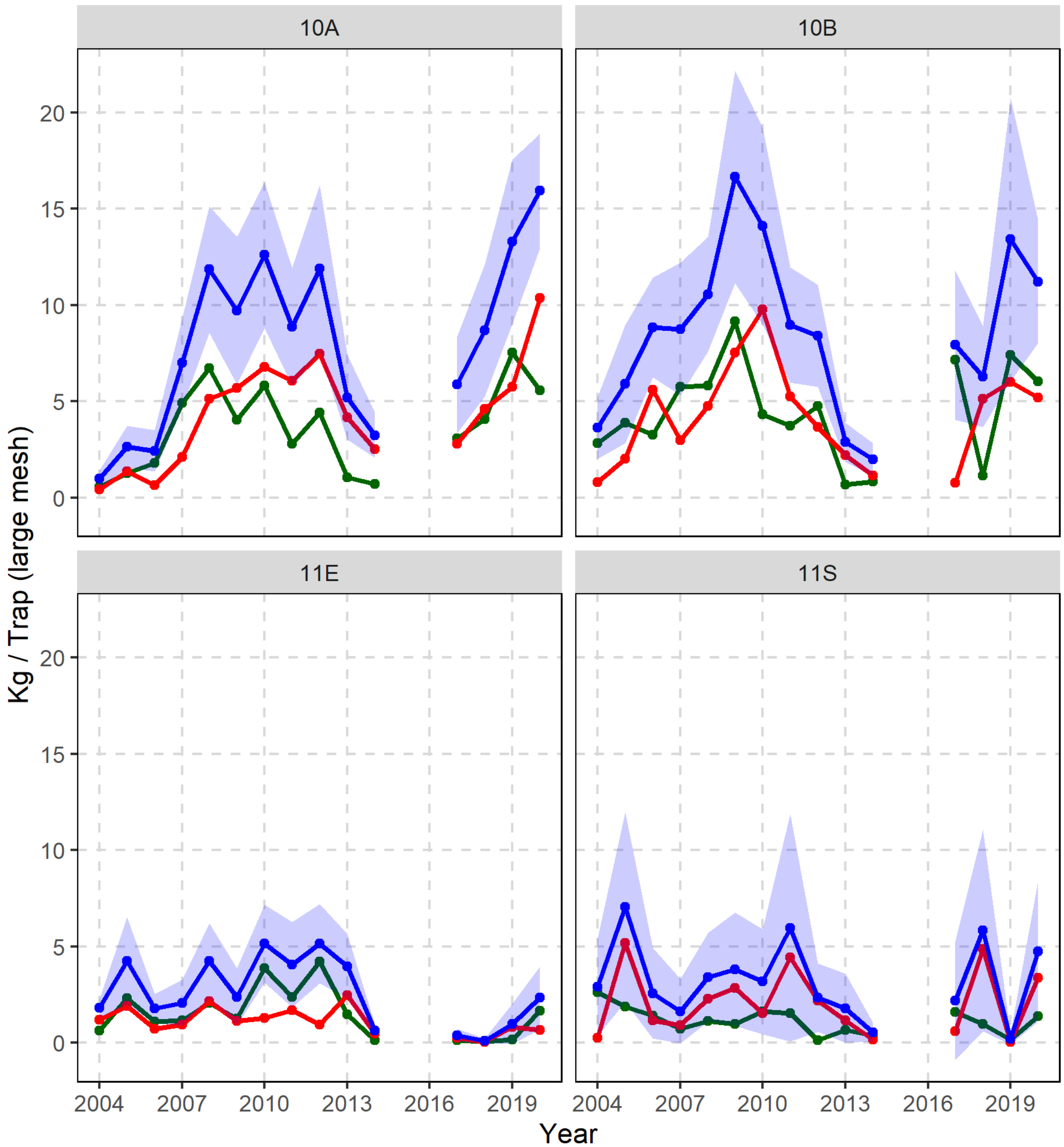

Figure A5. 7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 3Ps.

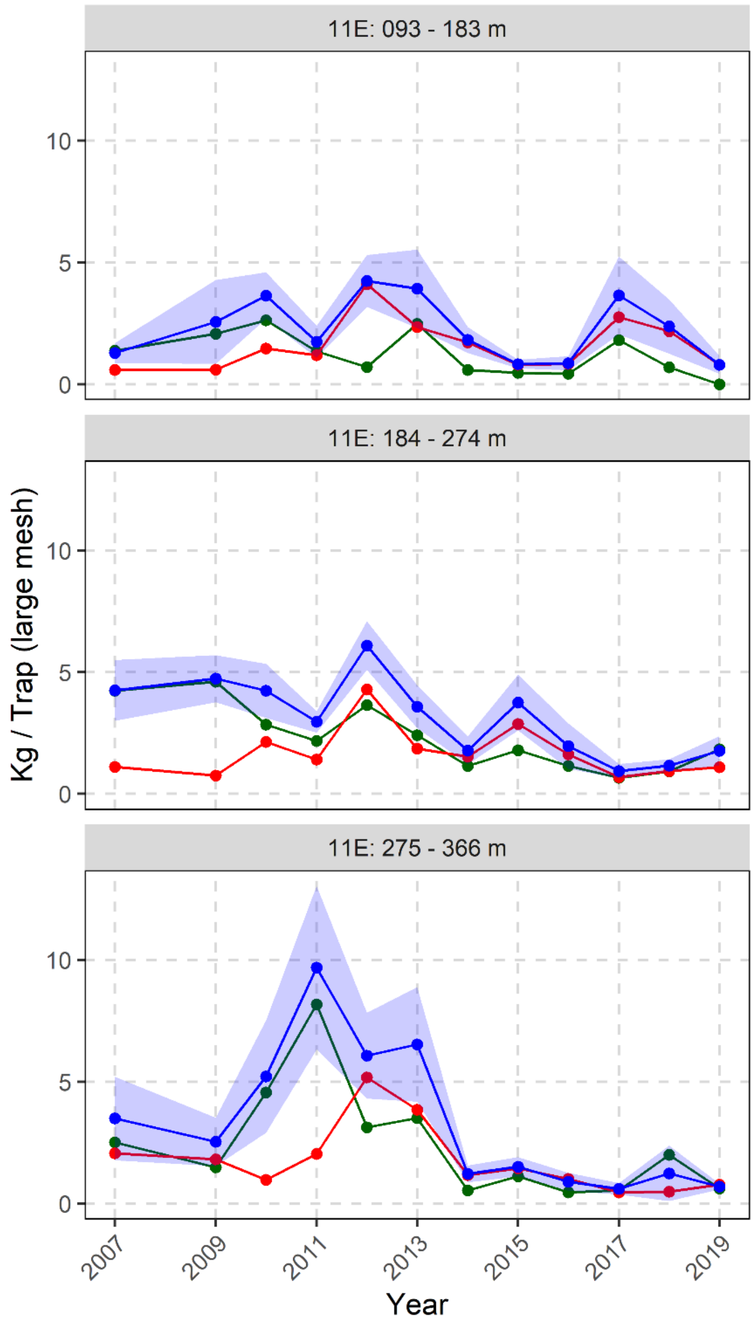

Figure A5. 8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from large-mesh traps in Inshore DFO trap surveys in Fortune Bay (CMA 11E). Note: No survey in Fortune Bay in 2020.

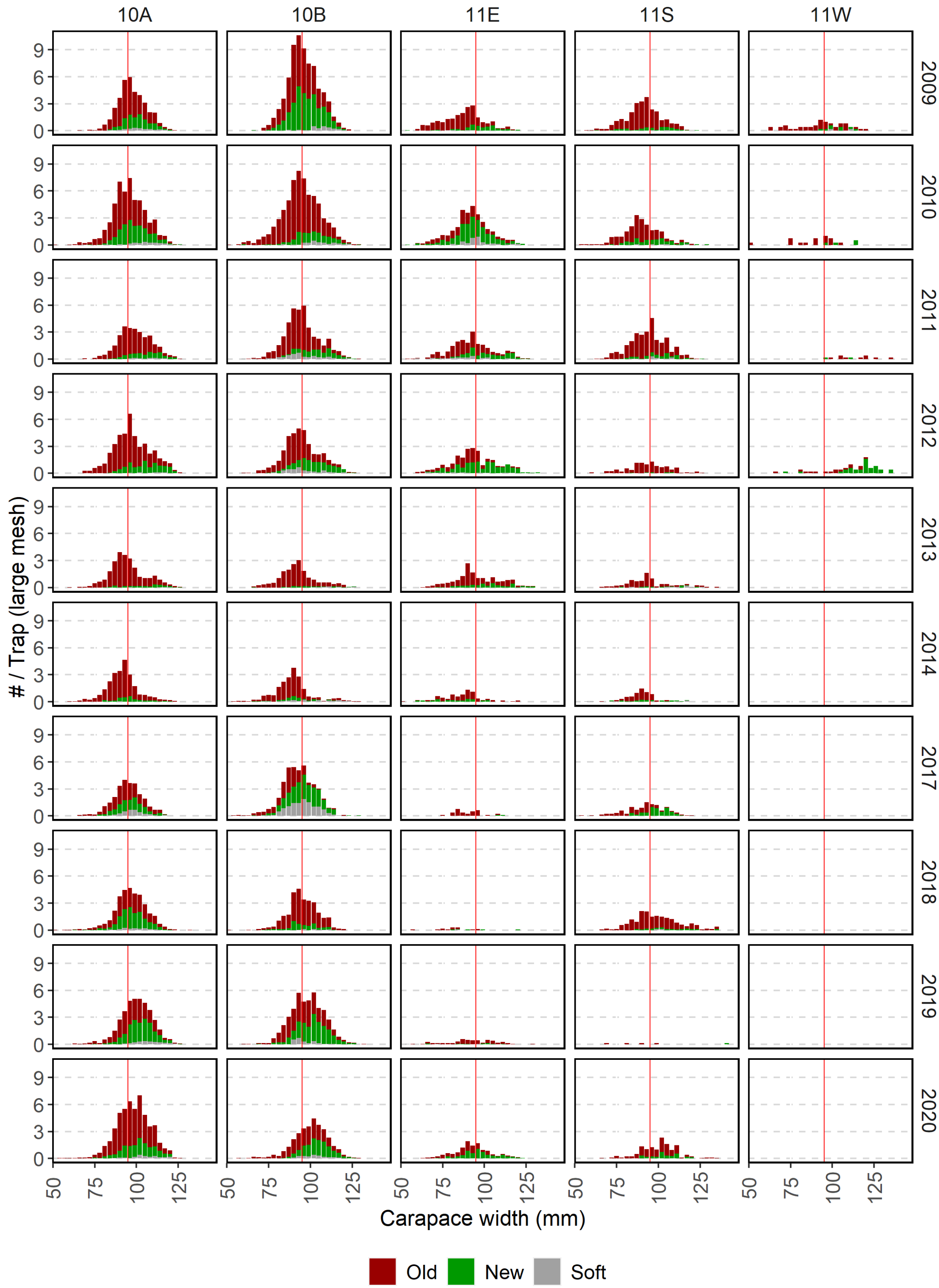

Figure A5. 9. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 3Ps (2009–20). The red vertical line indicates the minimum legal size.

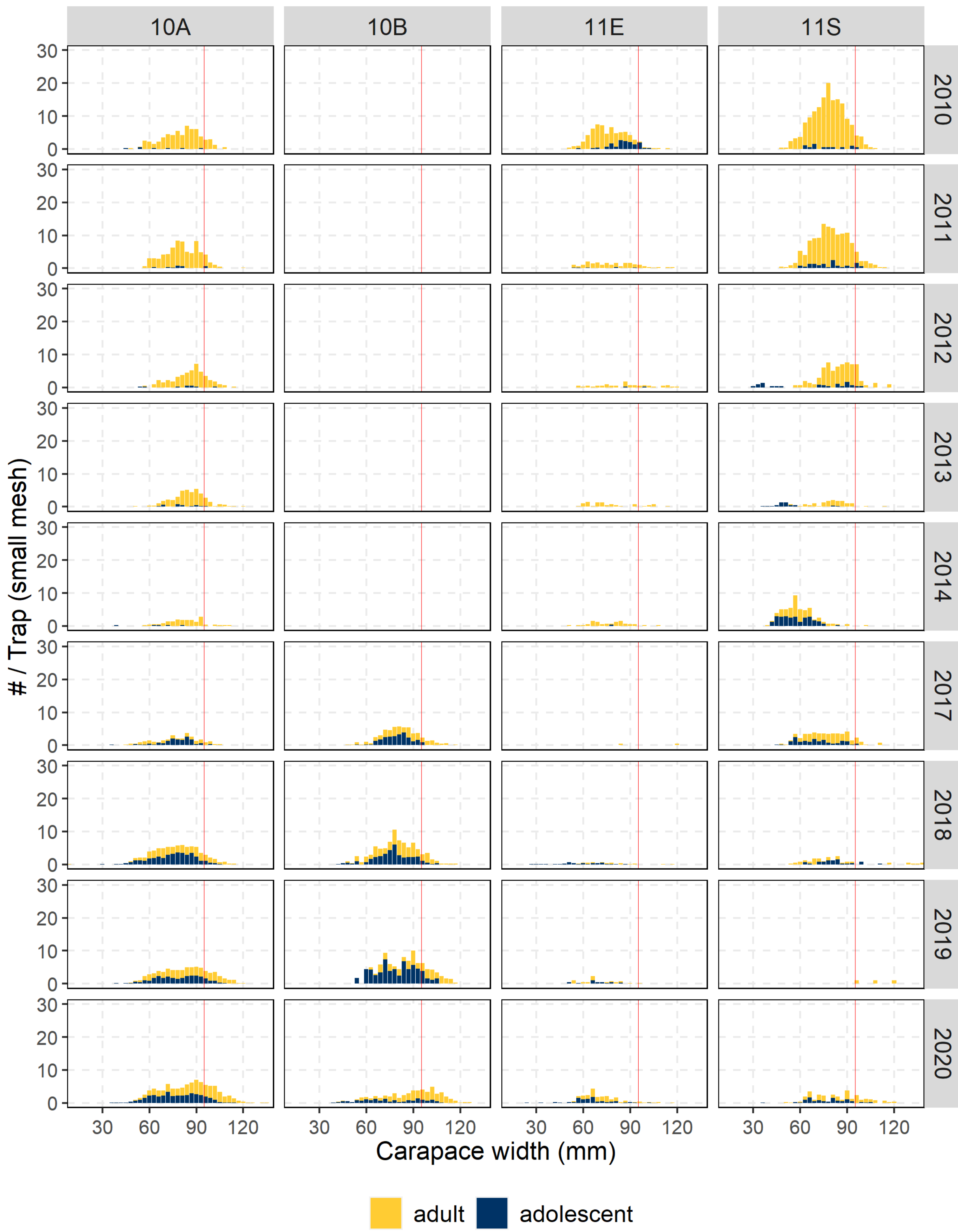

Figure A5. 10. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2010–20) from CMAs in Assessment Division 3Ps. The red vertical line indicates the minimum legal size.

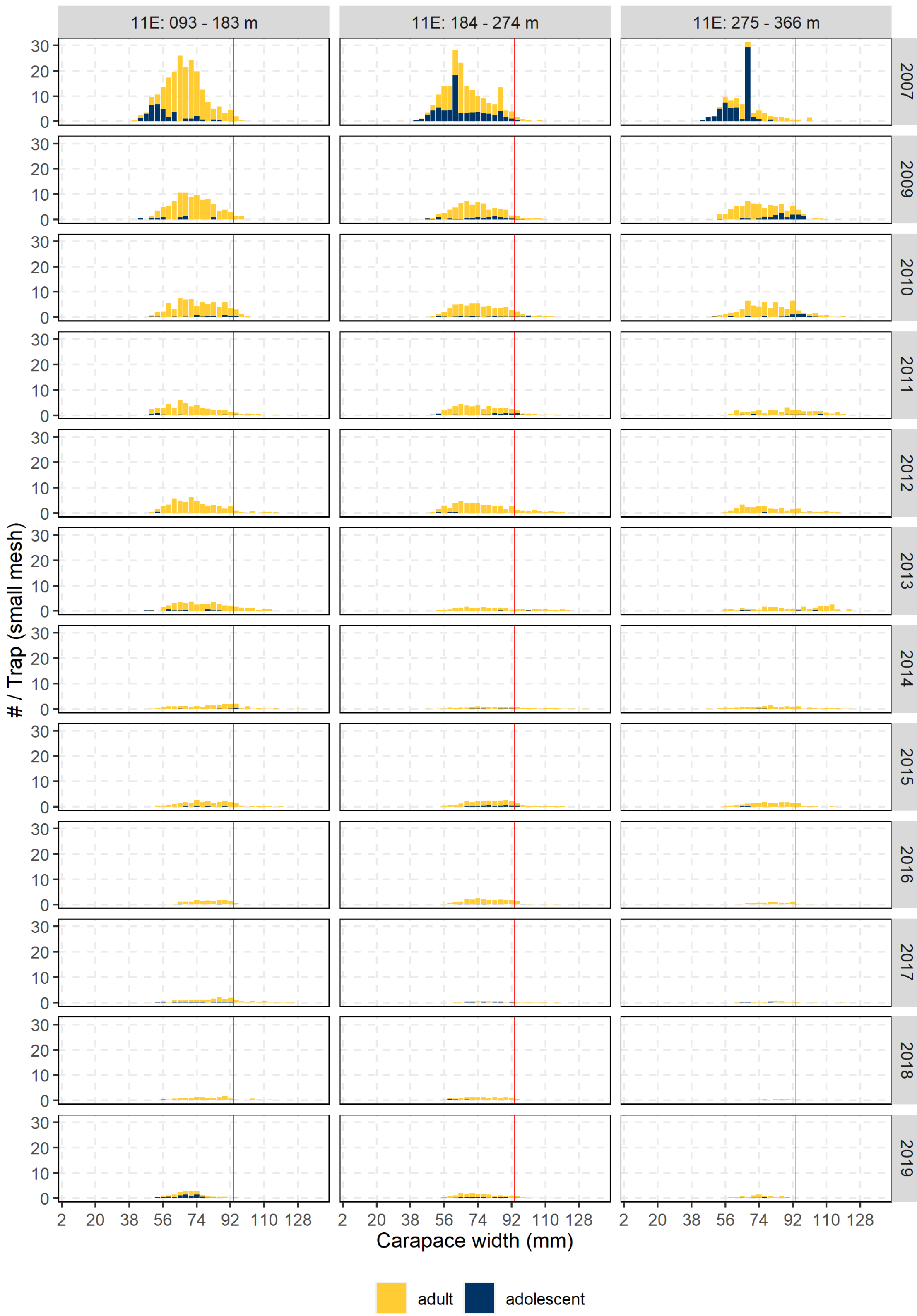

Figure A5. 11. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Inshore DFO trap survey (2007–19) from Fortune Bay (CMA 11E). The red vertical line indicates the minimum legal size. Note: No survey in Fortune Bay in 2020.

APPENDIX 6: ASSESSMENT DIVISION 4R3PN DETAILS

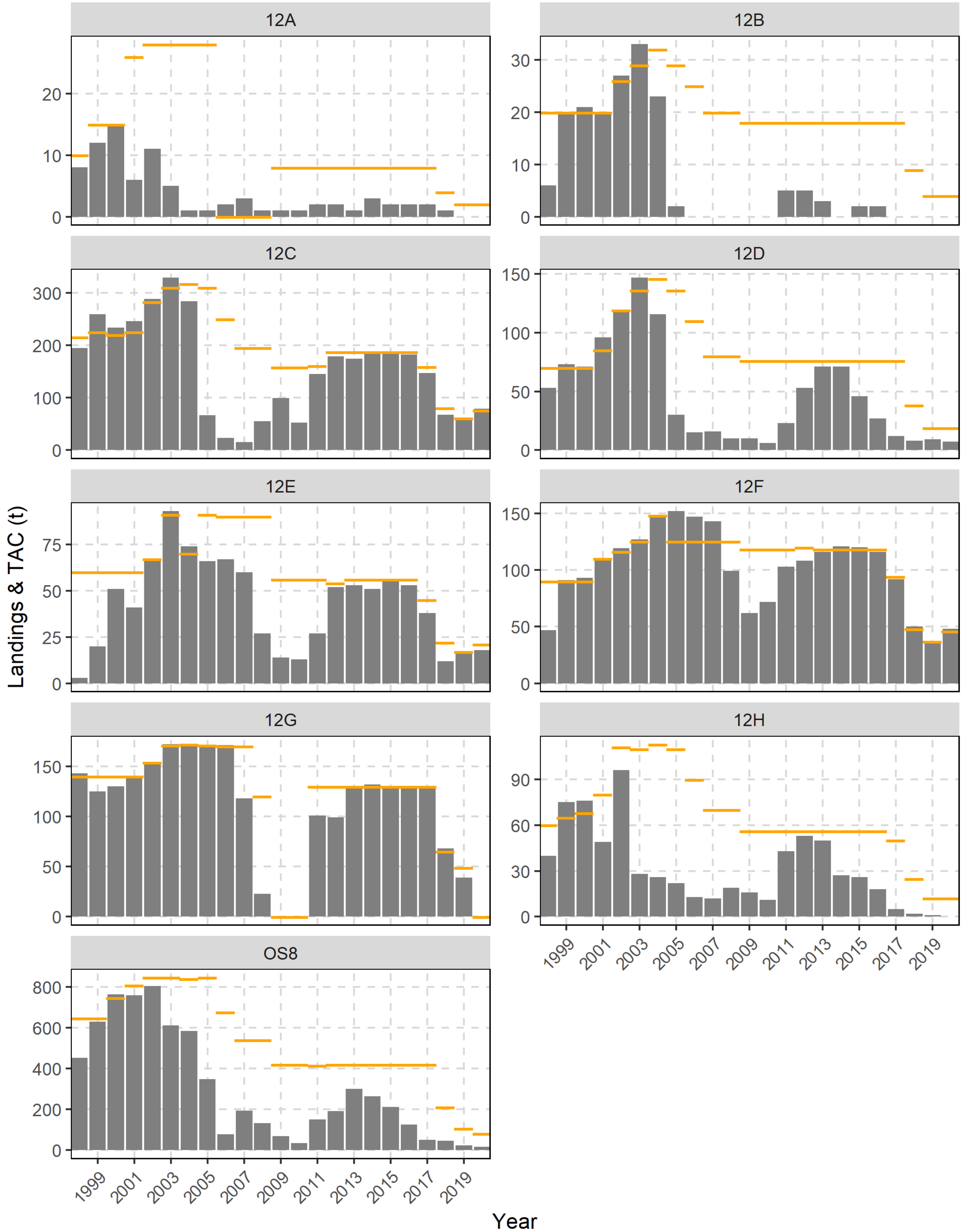

Figure A6. 1. Total Allowable Catch (TAC) (yellow dashes) and landings (grey bars) in CMAs within Assessment Division 4R3Pn (1998–2020).

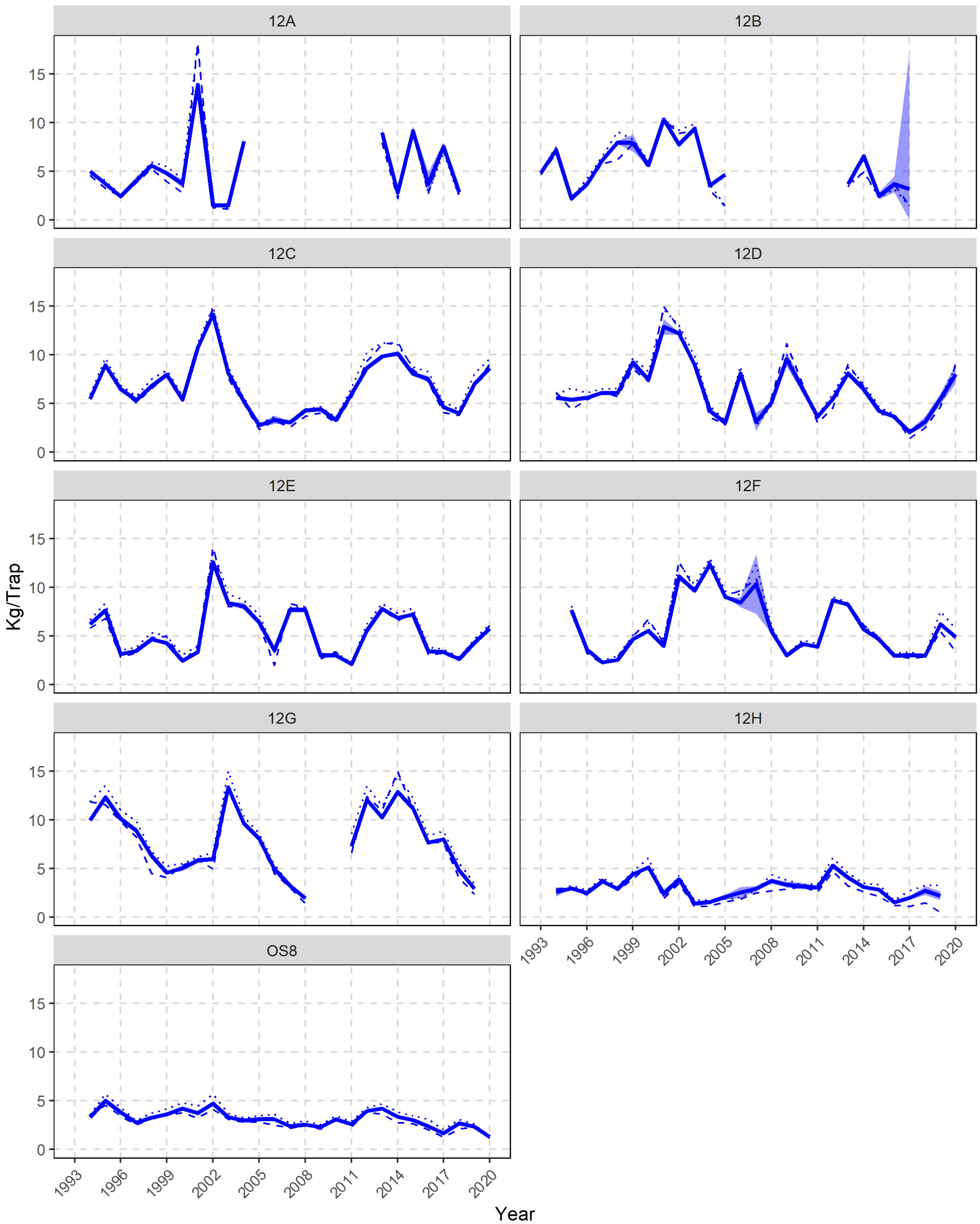

Figure A6. 2. Trends in standardized CPUE (kg/trap) in CMAs within Assessment Division 4R3Pn. Solid line is average predicted CPUE, shaded band is 95% confidence interval, dotted line represents average raw CPUE, and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

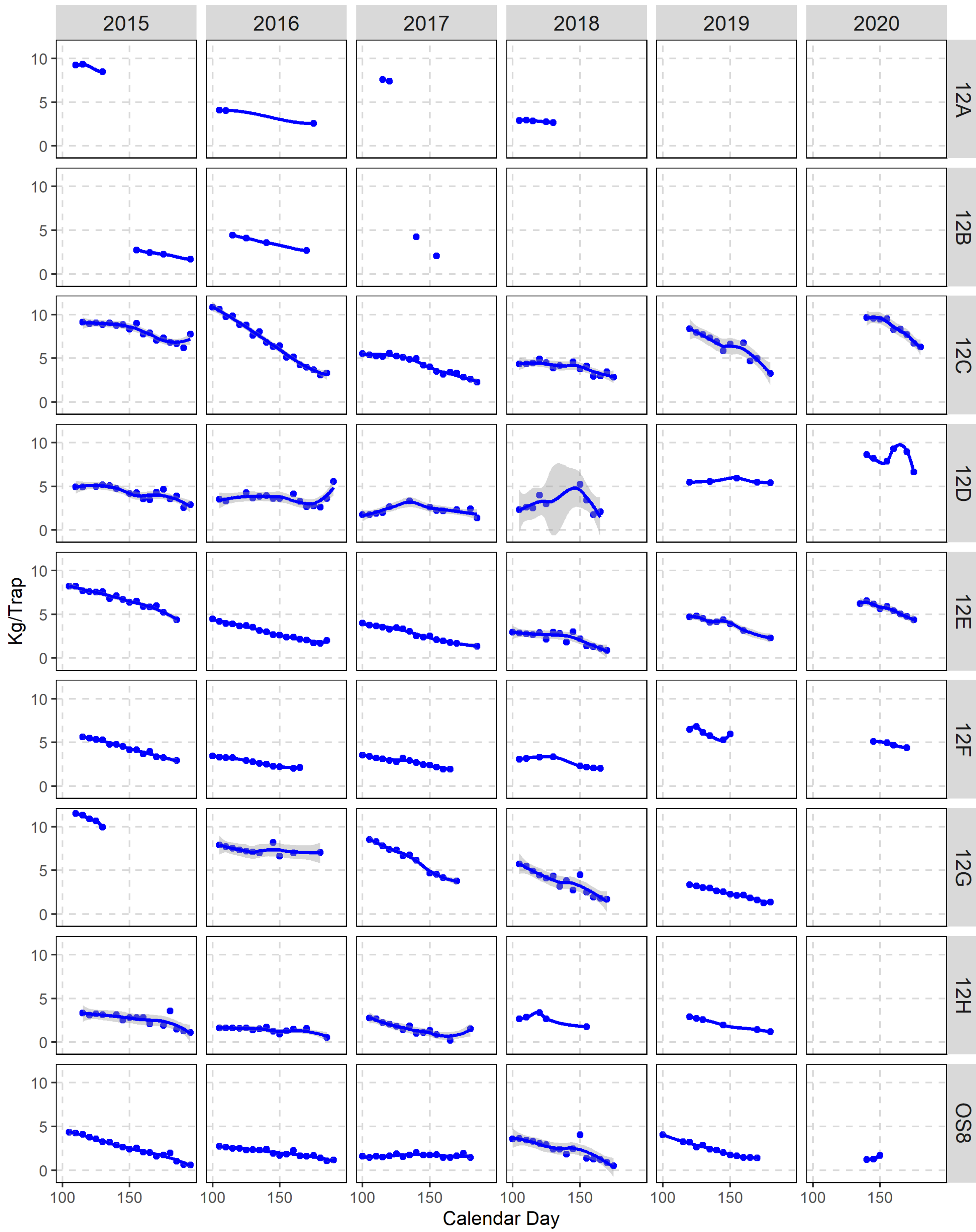

Figure A6. 3. Standardized CPUE (kg/trap) throughout the season (calendar day) in Assessment Division 4R3Pn (2015–20), derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

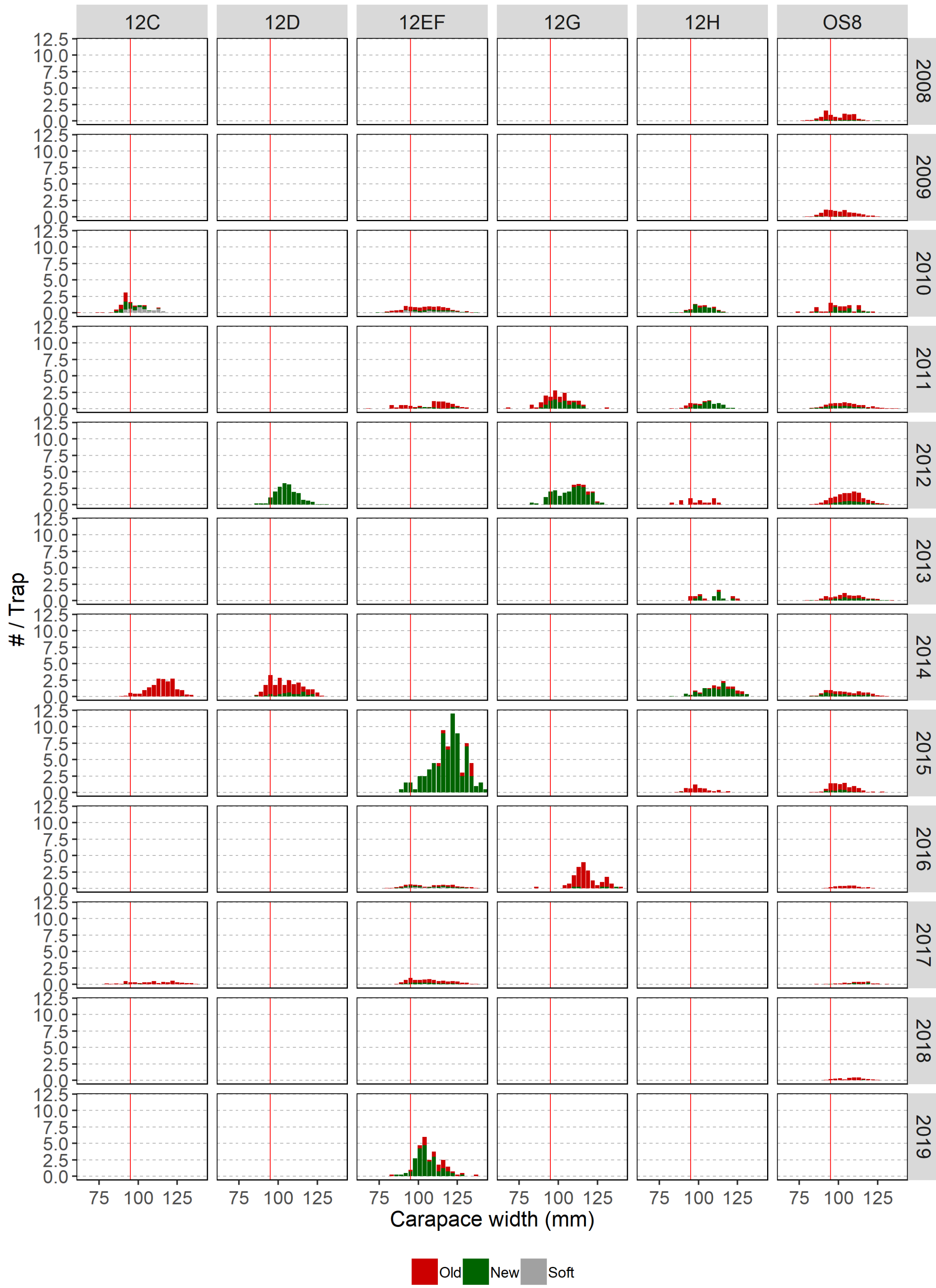

Figure A6. 4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each Crab Management Area in Assessment Division 4R3Pn (2008–19). The red vertical line indicates the minimum legal size. Note: Not updated in 2020.

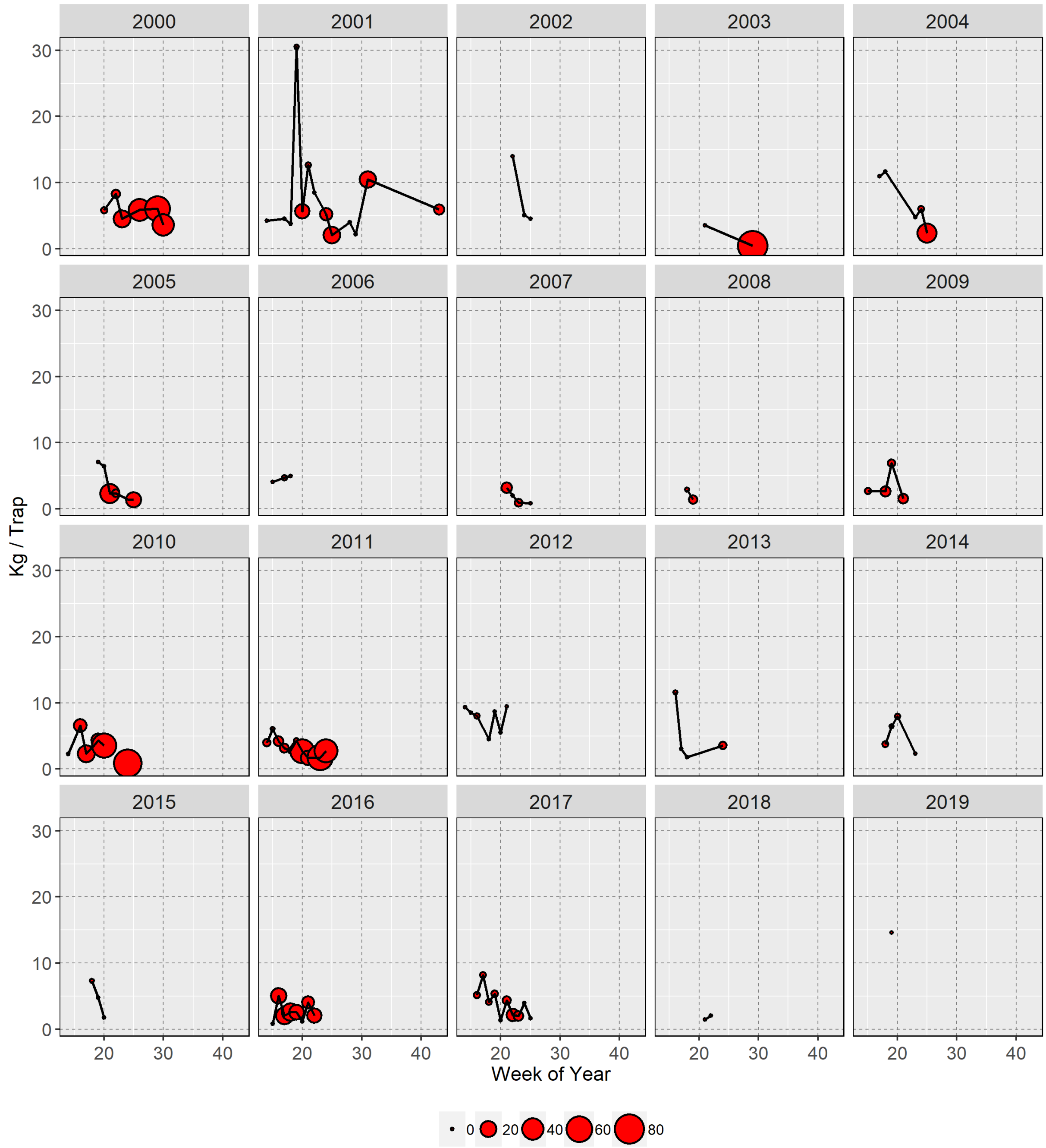

Figure A6. 5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in Crab Management Areas within Assessment Division 4R3Pn (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates. Note: Not updated in 2020.

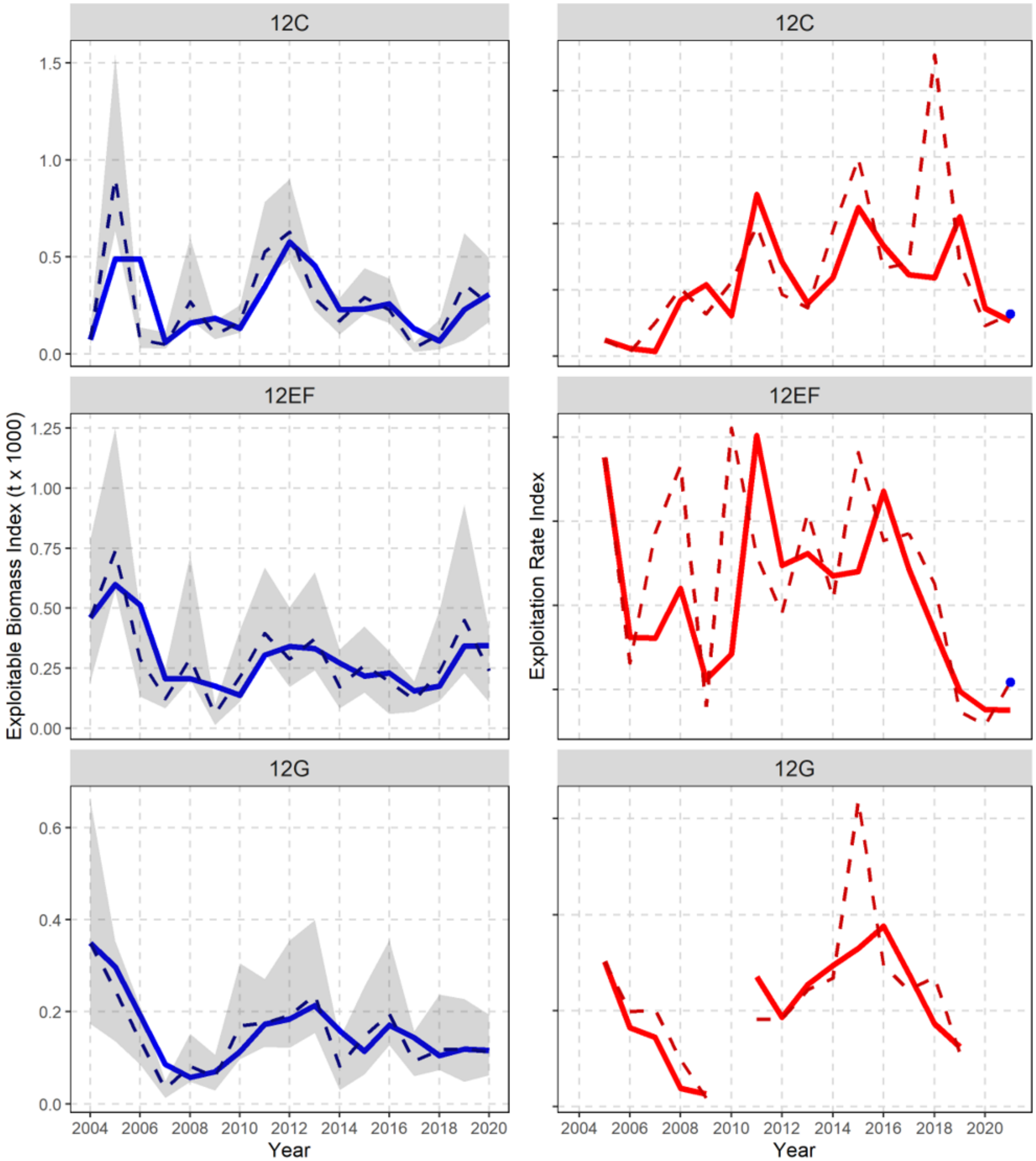

Figure A6. 6. Left: Annual trap-based exploitable biomass index (t x 1,000). The solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the 95% confidence interval of the annual estimates. Right: Trends in the trap-based annual (points) and 2-year moving average (solid line) exploitation rate index (%) in Assessment Division 4R3Pn; 2021 points depict projected exploitation rate indices under status quo removals in the 2021 fishery.

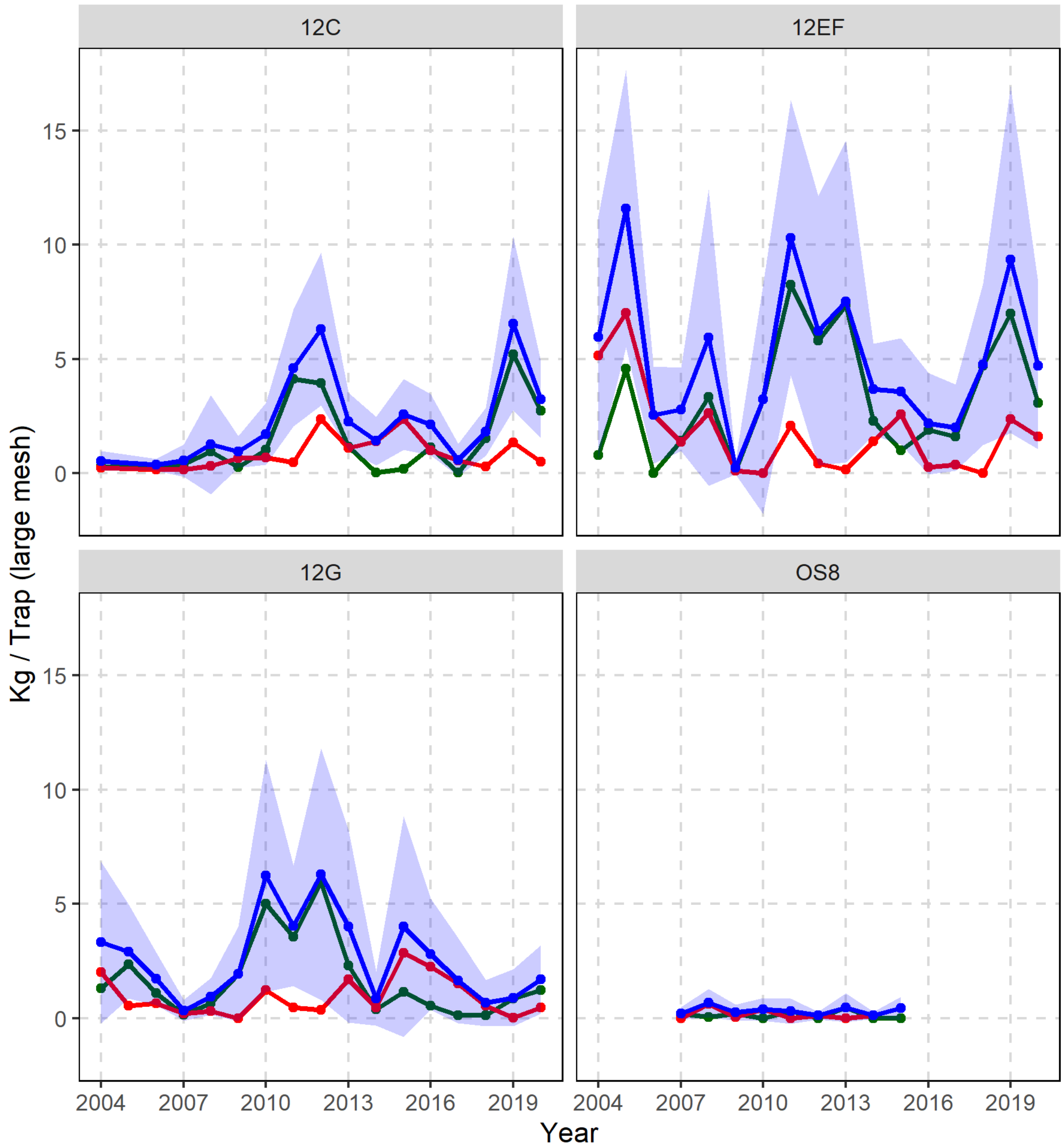

Figure A6. 7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) for legal-sized crab from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 4R3Pn.

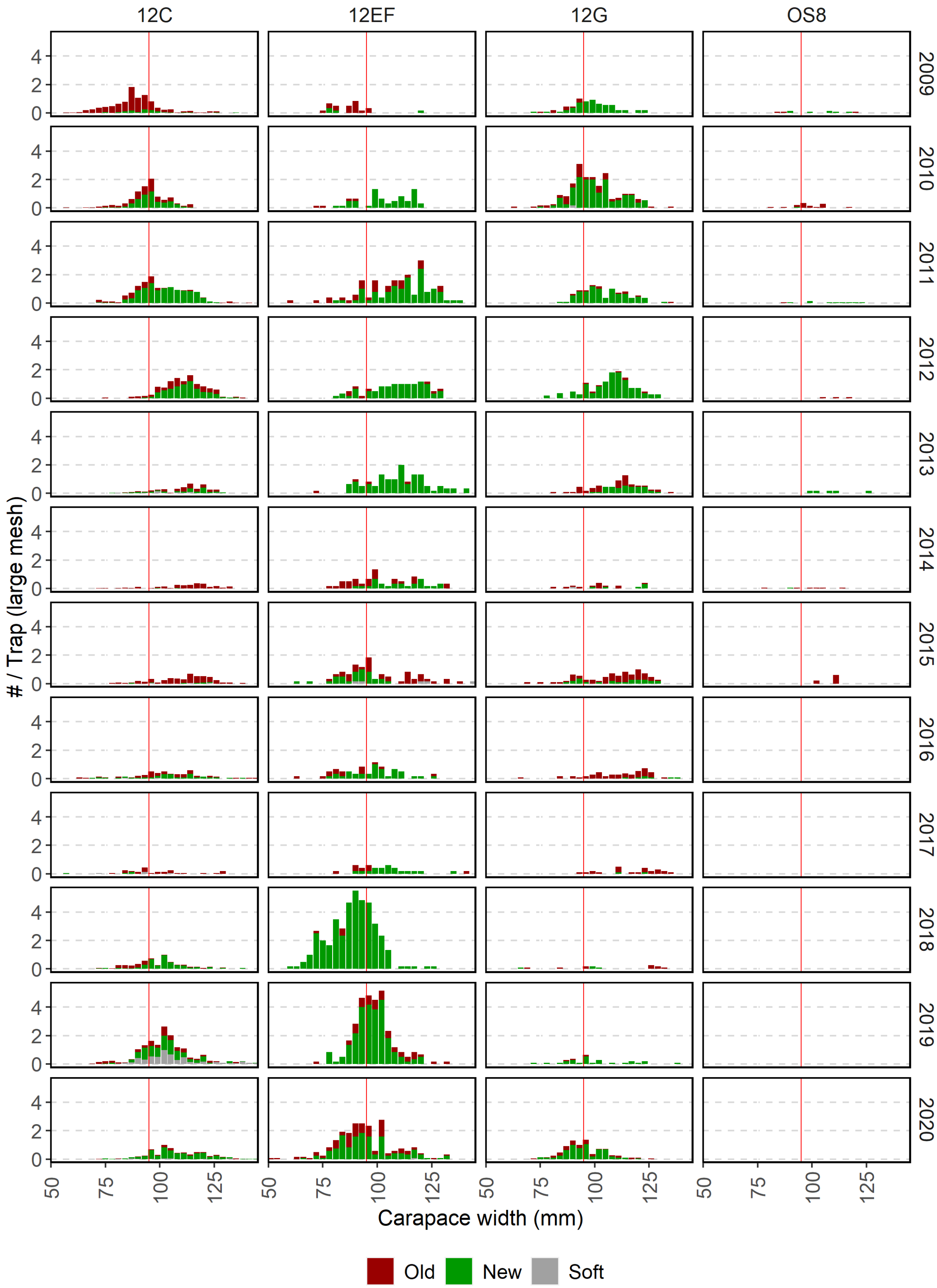

Figure A6. 8. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs within Assessment Division 4R3Pn (2009–20). The red vertical line indicates the minimum legal size.

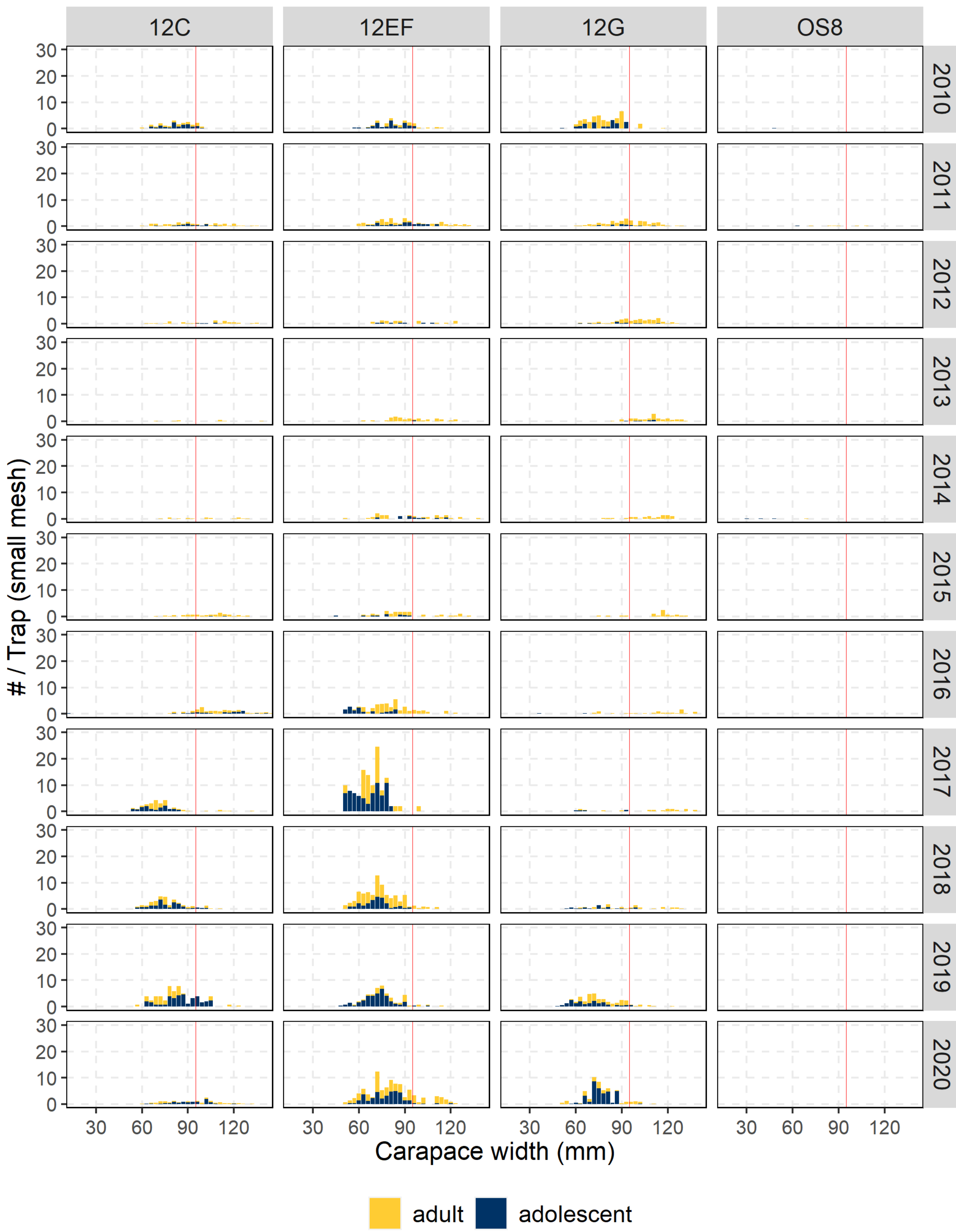

Figure A6. 9. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2010–20) from CMAs in Assessment Division 4R3Pn. The red vertical line indicates the minimum legal size.