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An Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2018

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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 NL Shelf. It represents a proxy for thermal Snow 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.

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 Snow Crab.

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

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

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

NAFO: Northwest Atlantic Fisheries Organization (Divisions).

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

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

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

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

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

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

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

Primiparous female: First-time mating spawning female crab.

Recruitment: 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.

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.

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 using a variety of metrics. Data from multi-species bottom trawl surveys conducted during fall in Divs. 2HJ3KLNO and spring in Divs. 3LNO and Subdiv. 3Ps are examined to provide information on trends in biomass, recruitment, production, and mortality over the time series. Multi-species trawl survey indices are compared with other relevant indices toward inferring changes in resource status for 2019 and beyond. These other indices are derived utilizing data from harvester logbooks, at-sea observers, the dockside monitoring program (DMP), and inshore and offshore trap surveys, as well as oceanographic surveys. Snow Crab landings remained near 50,000 t from 2007 to 2015 but have since steadily declined to a two-decade low of 27,700 t in 2018. Overall effort remained at approximately 3.5 to 4.5 million trap hauls per year over that time. Overall catch per unit effort (CPUE) was at a time-series low in 2018. Despite modest increases in the past two years, the trawl survey exploitable biomass index has remained at its lowest level for the past four years. Meanwhile, the trap survey index has declined by nearly 60% in the last two years to a time-series low. Despite modest increases in some divisions in the past two years, overall recruitment into the exploitable biomass will remain low in most divisions in 2019. Total mortality in exploitable Snow Crab is estimated to be near time-series' averages in most divisions. It has declined from very high levels in most divisions during the past two years, with the exception of Division (Div.) 3K, where it remains at a time-series high. Exploitation rate indices were at or near time-series highs in most divisions in 2017. In 2018, exploitation rates subsequently increased to a new high in Div. 3L Inshore, remained high in Divs. 2HJ3KLNO, and declined to be near or below long-term average levels in Divs. 3Ps and 4R3Pn. Elements of the Precautionary Approach Framework presented in this assessment are tentative. Limit Reference Points defining the critical zone have been established by a peer-reviewed Science process, but Upper Stock Reference lines defining the cautious and healthy zones remain under development. In 2019, most divisions are projected to fall within the cautious zone of the proposed Precautionary Approach Framework. Div. 3L Inshore would be in the critical zone. These projections assume status-quo landings. The thermal habitat index (defined as the areal extent of <2°C bottom water) has returned to near-average conditions in all divisions in recent years. Broad-scale climate indices appear favourable for improved recruitment to occur in most major areas of the stock range over the next few years. Ecosystem conditions in the NL Bioregion are indicative of an overall low productivity at the lower trophic levels (phytoplankton and zooplankton) in recent years with changes in zooplankton community structure potentially impacting the transfer of energy to higher trophic levels. A sharp decline in male size-at-maturity (i.e., terminal molt size) in most Assessment Divisions (ADs) in recent years will dampen short-term prospects for recruitment into the Snow Crab exploitable biomass.

INTRODUCTION

This document assesses the status of the Snow Crab (*Chionoecetes opilio*) resource surrounding Newfoundland and Labrador (NL) in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2HJ3KLNOP4R (Figure 1, Figure 2). The information presented follows from a formal scientific assessment and regional peer-review process conducted during late February 2019 that focused on identifying changes in the exploitable biomass of Snow Crab available to the fishery.

SPECIES BIOLOGY

Snow Crab are sexually dimorphic, with males normally achieving larger sizes than females. The Snow Crab life cycle features a spring hatching followed by a planktonic larval period that involves several stages before settlement. Benthic juveniles of both sexes molt multiple times each year but molt frequency slows with growth. Females cease molting after sexual maturity is achieved at approximately 40–75 mm carapace width (CW). Sexually mature, adolescent males generally molt annually until their terminal molt, when they develop enlarged claws (becoming adults) that likely enhance their competitive ability in mating dynamics. Males molt to adulthood at any size greater than approximately 40 mm CW.

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 (Divs. 2J3K4R and Subdiv. 3Pn) and at slightly older ages in cold areas (Divs. 3LNO and Subdiv. 3Ps), reflecting less frequent molts at low temperatures (Dawe et al. 2012). Adult legal-sized males remain new-shelled with low meat yield throughout the remainder of the year of their terminal molt. They are not likely to contribute to the fishery until the following year when their shells are fully hardened and full of meat. Males may live a maximum of 6–8 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 ontogeny are associated with increased survey biomass and fishery catch per unit effort (CPUE) indices several years later (Marcello et al. 2012; Mullowney et al. 2017). While growth rates are affected by temperature, with younger age-at-recruitment and typically larger sizes occurring in warm regimes, the over-riding positive effect of cold water on early survival appears stronger than the negative effect on size-at-terminal molt and highest productivity occurs in cold areas.

Along the NL Shelf, cold and most productive conditions are generally found in shallow to intermediate depth areas (Colbourne et al. 2016; Mullowney et al. 2017). Historically, the most productive fisheries have been associated with shallow to intermediate-depth plateaus and slope edges of offshore banks and within inshore bays. Snow Crab typically undertake ontogenetic movements from shallow cold areas with hard substrates during early ontogeny to warmer deep areas typically featuring softer substrate as they grow (Mullowney et al. 2018a). Largest males are most commonly distributed on mud or mud/sand, while small Snow Crab are more common on harder substrates. Some Snow Crab also undertake an upslope migration in winter or spring for mating and/or molting (Mullowney et al. 2018a).

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

Snow Crab in NL are part of a larger stock in Canadian Atlantic waters, ranging from southern Labrador to the Scotian Shelf (Puebla et al. 2008). However, movements of individuals within the stock are thought to be limited, so assessments are conducted at the NAFO Division level (Figure 2), with inshore and offshore portions of divisions separated where applicable and some divisions combined. Accordingly, Assessment Divisions (ADs) differ from both the 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.

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 was 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 collapses in the early 1990s. During 1982 to 1987, there were major declines of the 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 fishery during the expansion years led to the development of the many quota-controlled areas, with approximately 3,500 active license holders participating in the fishery in the mid-2000s. Resource declines and rationalization measures have led to reduced participation in recent years. The fishery is now prosecuted by several offshore and inshore fleet sectors with approximately 2,200 enterprise allocations in 2018.

In the late 1980s, quota control was initiated in all CMAs of each division. Current management measures include trap limits, individual quotas, spatial and temporal closures within divisions, and differing seasons. Mandatory use of the electronic vessel monitoring system (VMS) was fully implemented in offshore fleets 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 Snow Crab to escape. Under-sized and soft-shelled Snow 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 in recent years and is now primarily prosecuted during spring and summer. The fishery can be delayed in northern divisions (Divs. 2HJ3K) due to ice conditions 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. A protocol was initiated in 2004 that results in closure of localized areas (10 x 7 na. mi.) when the percentage of soft-shelled Snow Crab within the legal-sized catch exceeds 20%. The closure threshold was reduced to 15% for Assessment Division 3LNO in 2009–10 and grids have been partitioned into quarters in some inshore areas in recent years.

Landings for Divs. 2HJ3KLNOP4R historically peaked at 69,100 t in 1999. In recent years, landings peaked at 53,500 t in 2009 and have since gradually declined to 27,700 t in 2018. ADs 3L Inshore and particularly 3LNO Offshore have accounted for a steadily increasing percentage of the catch, from about half in 2009 to 80% in recent years. However, resource and fishery declines are now occurring in these important ADs.

METHODOLOGY

MULTI-SPECIES TRAWL SURVEY DATA

Data on total catch numbers and weights were derived from depth-stratified multi-species bottom trawl surveys. These surveys were conducted during fall in Northwest Atlantic Fisheries Organization (NAFO) Divisions 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 each year from 1996 to 1999, bi-annually from 2004 to 2008, and annually from 2010 to 2018. Sampling of Snow Crab during spring Subdiv. 3Ps surveys began in 1996 and in Divs. 3LNO in 1999.

The survey trawl was changed to a Campelen 1800 shrimp trawl in 1995. This trawl proved to be more efficient in capturing Snow 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. 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 (unpublished data). 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.

Prior to 2015, survey abundance and biomass indices were calculated using STRAP (Smith and Somerton 1981), with a set of core strata invoked from 2009 to 2014 due to attrition of survey coverage in deepest and fringe areas of the inshore and offshore over time. However, in recent years Ogive Mapping (Ogmap) (Evans 2000) has been used as the spatial expansion platform for biomass and abundance estimation (Figure 3). Due to the greater flexibility of Ogmap to extrapolate across poorly sampled areas, it was no longer necessary to restrict trawl survey data inclusion to core strata.

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

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

1. **Soft-shelled:** Crab that recently molted, have a high water content, and are not retained in the fishery. There is no fouling of the carapace or legs or presence of barnacles, leeches, leech egg cases, or other epibionts.
2. **New-shelled:** Crab that molted in spring of the current year, have a low or partial meat yield throughout most of the fishing season, and are generally not retained in the fishery. Negligible fouling of the carapace and legs and slight presence of epibionts is typical.
3. **Intermediate-shelled:** Crab that last molted in the previous year and are fully recruited to the fishery throughout the current fishing season. Shells are full of meat and moderate fouling of carapace and legs is typical. There can be a moderate to well established presence of epibionts.
4. **Old-shelled:** Crab that last molted at least two years before sampling. Shells and legs are often heavily fouled and blackness around joints may be visible. There is often a well-established presence of barnacles, leeches and leech eggs, and other epibionts.

5. **Very old-shelled:** Crab that last molted and been available to the fishery for a long duration (i.e., ≥4 years). Carapace and legs are turning black, particularly around joints, and the shell is losing rigidity. There is often a well-established presence of epibionts.

Males were also sampled for chela (claw) height (*CH*, 0.1 mm). Males develop enlarged chelae when they undergo their terminal molt, which may occur at any size larger than approximately 40 mm CW. Therefore, only males with small chelae will continue to molt and subsequently recruit to the fishery. To standardize data capture, only the right chelae of males were measured. A model which separated males into two 'clouds' based on the relationship between 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 Snow Crab under-taking terminal molt in any given year (becoming a morphometrically mature male or sexually mature female) were identified. The analysis was limited to Snow 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:

$$logit(M_i) = \alpha + f_{1k}(CW_i) + f_{2k}(Year_i) + f_{3k}(CW_i * Year_i) + a_i + \epsilon_i$$

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

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

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.

Unstandardized biomass and abundance estimates from trawl surveys were computed using Ogmap (Evans 2000). A nonparametric estimate was made of the probability distribution for trawl catch (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. Biomass and abundance estimates were calculated for the abundance of small (<50 mm CW) Snow Crab, the abundances of mature females and pre-recruit males, and the biomass of exploitable males. For spring surveys, the indices represent abundances or biomasses for the immediately upcoming (or on-going) fishery, whereas for fall (post-season) surveys they represent biomass for the fishery in the following calendar year.

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

We examined annual changes in abundance indices of recruits and residual Snow Crab in the exploitable biomass, in-part to evaluate the internal consistency of the data series. Snow 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 Snow Crab. In the absence of fishery effects or other source(s) of error, including subjectivity in shell age classification, we would expect annual changes in biomass to first be seen in recruits and to subsequently occur in residual Snow Crab.

Pre-recruit biomass and abundance indices were calculated based on all adolescent (small-clawed) males with 65–94 mm CW captured in the surveys. Theoretically, we would expect pre-recruits 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., 2018) that undergoes a terminal molt to exploitable size in the subsequent winter or spring (i.e., 2019) would be identified as a recruit into the exploitable biomass in the 2019 survey(s), and should begin contributing to the fishery in 2020. 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 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 large adolescent males in cold areas (Dawe et al. 2012). Along with compromising the ability to track Snow Crab from the pre-recruit to recruit and residual biomass stages, the annually variable proportion of skip-molters complicates the ability to assess shell condition in pre-recruits.

The biomass indices derived through Ogmap were calculated from raw survey data. However, it is known that catchability of Snow Crab by the survey trawl (i.e., trawl efficiency) is much lower than 1 (Dawe et al. 2010a) and that raw survey biomass estimates are greatly underestimated 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:

$$đ = \sum_{y=2000}^{2018} (Ty/Dy \ * 1/n)$$

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 remain interpreted as relative indices.

The spatial distributions of mature females, pre-recruit and exploitable males, and small Snow Crab (<50 mm CW), were mapped and examined using catch rates for each survey set.

Catchability of Snow Crab by the Campelen trawl varies with size. It is highest in largest Snow Crab (Dawe et al. 2010a). It also varies with the diurnal cycle, being highest at night (Benoît and

Cadigan 2014, 2016). Further, it differs across survey vessels, being higher on the Canadian Coast Guard research vessels *Teleost* and *Alfred Needler* than the *Wilfred Templeman* (Benoît and Cadigan 2014, 2016). However, exploratory analyses showed conversions to account for time and vessel made negligible difference in scaling raw biomass indices to standardized estimates, with trends in unstandardized trawl survey biomass estimates similar in all combination of conversions, thus no conversions were applied prior to re-scaling exploitable biomass through fishery depletion conversions.

To examine size compositions of both sexes, Snow 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 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 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, 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 AD 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 2019. For provision of advice, exploitation rate indices based on smoothed two-period average biomass indices were calculated. This smoother was applied to account for annually variable survey performance and the possibility of ‘year effects’ in biomass estimates, a feature typically raised during annual assessments.

Relative size-specific proportions of adult male Snow Crab in the survey population were examined to qualitatively investigate fishing effects. For this analysis, Snow 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-shelled Snow Crab in the population was inferred as representing the relative effects of fishing. The analysis was more explicitly refined to compare the percentage of adult male Snow Crab 75–95 mm CW versus 96–115 mm CW that were either old or very-old shelled, with reduced percentages in the larger group inferred to represent relative fishing mortality.

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, Snow 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.

Finally, total annual mortality rates in any given year (A_t) were calculated based on stage-specific biomass indices of exploitable Snow 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 two-year moving average total mortality rate index was calculated for each AD to smooth annual variability.

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. The dataset is normally incomplete in the current year (Figure 4), resulting from a time lag associated with compiling data from the most recent fishery, thus the most recent point estimates are considered preliminary.

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 days (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 produced negatively-skewed distributions in some cases. Finally, the model is weighted by consistency of fishing (i.e., cumulative number of years fished within 10’ x 10’ cells). This model was used to predict average annual CPUE by averaging set-specific predicted values (as well as 95% lower and upper confidence estimates) for each AD and year:

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

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

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

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

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

CPUE is used as an index of biomass, but it is recognized that it can be biased by unaccounting for factors stemming from variation in fishing practices such as 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 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 and trap survey based biomass estimates and fishery discards.

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 (5-day increment) CPUEs were plotted for individual ADs and CMAs within each AD for a 6-year timespan to assess fishery performance over a prolonged continuous timescale. The 5-day estimates were fit with least squares loess regression curves to visually depict changes occurring in the fishery over time.

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

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 5-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 day 200 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, with the forecasted intercept used to calculate the beginning of the season biomass:

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

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

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

where,

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

pot_cum = cumulative number of pots

year_AD = factor variable combining AD and year

A limitation associated with biomass estimation based on depletion methods is that a resource must be depleted for the method to work. Four years were omitted from analysis based on anomalous biomass estimates reflecting lack of depletion (AD 3LNO Offshore in 2010 and 2011, and AD 4R3Pn in 2002 and 2006). 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 1994–2018. There were no surveys in these bays in 2001, and no survey was conducted in Notre Dame Bay in 2009 and 2011. The surveys have consistently occurred in late August to mid-September and occupy five of the depth strata developed for multi-species trawl surveys in the NL.

In AD 3L Inshore, long-term trap surveys within Bonavista Bay (CMA 5A) and Conception Bay (CMA 6B) have occurred from 1979 to 2018. 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. 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 since 2007. This survey occupies three depth strata encompassing the entire vertical distribution of the bay.

All surveys follow a random 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 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.

For each survey series, catch rate indices of legal-sized Snow 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. A pre-recruit catch rate index, defined as kg/trap of adolescent males 65–94 mm CW was derived from small-mesh traps, and mortality was inferred from levels of BCD observed in these surveys.

Catches of exploitable males from the inshore DFO trap surveys were also combined with data from the Collaborative Post-Season (CPS) trap survey to estimate exploitable biomass.

COLLABORATIVE POST-SEASON TRAP SURVEYS

Data were examined from industry-DFO CPS trap surveys in all ADs (Figure 8, Figure 9). These surveys were initiated in 2003 and have occurred each year following the fishery, typically beginning in early September and ending in November. They are conducted by Snow Crab harvesters accompanied by at-sea observers and focus on commercial (i.e., deep) fishing grounds within individual CMAs. Thus, being at localized spatial scales, these surveys cover a narrower depth range than the multi-species trawl surveys in the offshore or the DFO trap surveys in select inshore CMAs.

Survey stations are fixed and generally follow a grid pattern, with a maximum station spacing of 10' x 10' (nautical miles). At each station, six (inshore) or ten (offshore) commercial (133–140 mm mesh) traps are set in a fleet. Biological sampling of male Snow Crab is conducted by observers at-sea from a single large-mesh trap at each station. Sampling includes determination of CW, shell condition (soft, new, old), leg loss, and presence of BCD. Small-mesh traps have been haphazardly included at some stations to collect information on females and pre-recruit males. Biological sampling of males from small-mesh traps includes determination of chela height. As per all other surveys, females are sampled from small-mesh traps for the same morphometrics as males, with examination of the abdomen used rather than chela height to determine maturity. Until 2016, catches from small-mesh traps were returned to shore and sampled by Technicians at DFO in St. John's. However, in the past three years at-sea observers measured the contents of the small-mesh traps. This has been associated with increased use of small-mesh traps in the survey.

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 do not adequately sample small Snow Crab in some areas because the survey design focuses near-exclusively on capturing exploitable Snow Crab and has 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 2016–2018 surveys (Figure 8, Figure 9). Overall, more than half of the stations had a small-mesh trap in 2018. More small-mesh traps will be added into the survey in forthcoming years, with a goal of having a small-mesh trap included at every station by 2020. Further, the CPS survey has been transitioning to a partly random stratified design over the past couple years. In 2018, approximately 50% of survey stations were random while 50% remained 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 toward encompassing a more representative depiction of all population components into the assessment.

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 Snow Crab by shell condition from large-mesh pots and size frequency distributions from large and small-mesh pots. The definition of core stations was established in 2018 to account for changing distribution in occupied sets over time. The definition of core stations was defined as those sampled in seven of the last ten years, as of 2017. Consistent with analyses from DFO trap surveys and observer data, large-mesh pot size frequency distributions examined abundance by shell condition while small-mesh pot size frequency distributions examined abundance by maturity. 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 research 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 65–4 mm CW adolescent males) was also derived from small-mesh pots 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 Snow Crab within CMA boundaries. Spatial expansion of survey catch rates into biomass within polygons is 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), Brethes 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 stratification scheme represents the actual distribution of the stock, 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 DFO inshore trap surveys described above also used in the analysis. The incorporation of all surveys using similar techniques was thought to improve the reliability of the results due to the inclusion of more data.

OBSERVER CATCH-EFFORT AND AT-SEA SAMPLING DATA

At-sea sampling data by observers have been collected since 1999. For each trip, observers sampled entire trap catches of males for CW (mm) and shell condition. Overall levels of sampling have been generally highest in AD 3LNO Offshore (Figure 10). 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 aging conducted by observers. Like the three stage assessment of shell ages used in the CPS survey, observers only classify Snow Crab as soft-, new-, and old-shelled. First, the total catch rate of legal-sized Snow Crab by shell condition for each AD was calculated as an index of exploitable biomass from the fishery. Similarly, size frequency distributions of catch rates of male Snow 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.

Observer sampling data formed the basis for estimating fishery discards. Total discard rates as well as the percentage of the catch discarded in the fishery were examined, with under-sized (<95 mm CW) and soft-shelled Snow 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. The response variable was the ratio of discarded to total catch. Fixed effects were time (5-day bins) and soak times (days) and random intercepts for time in year*CMA groupings were included. As per the CPUE standardization model, the spatial CMA term accounts for the multiple management areas within each AD.

$$W_{discard,t,y,D} = Binom(W_{caught,t,y,D}, p_{t,y,D})$$

$$logit(p_{t,y,D}) = \alpha_{Discard,y,D} + \beta_{Day,y,D} \cdot Day_{t,y,D} + \beta_{Soak} \cdot Soak_{t,y,D}$$

$$\alpha_{Discard,y,D} = N(\bar{\alpha}_{Discard}, \sigma_{\alpha}^2)$$

$$\mathrm{B}_{Day,y,D} = N(\bar{\beta}_{Day}, \sigma_{Day}^2)$$

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 Snow Crab captured in the fishery were also constructed and examined for each AD. Soft-shelled Snow Crab prevalence is interpreted as both an index of mortality and wastage because it is assumed that the majority of Snow 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 Snow Crab (i.e., most competitive) and a high discard rate of soft-shelled Snow Crab, it would be inferred that recruitment prospects for the forthcoming fishery are favourable. However, a high incidence of soft-shelled Snow 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 (10 x 7 na. mi.) when the percentage of soft-shelled Snow Crab reached 20% of the observed catch. The closure threshold was reduced to 15% for AD 3LNO Offshore and 3L Inshore in 2009–2010.

ECOSYSTEM INDICES

A lagged index of the North Atlantic Oscillation (NAO) was compared with the exploitable biomass index from each AD to assess the effect of climate on future exploitable biomass. The NAO reflects the relative strength of atmospheric pressure at sea level between dominant centres in the western (Icelanic Low) and eastern (Azores High) north Atlantic. NAO forcing affects the strength and distribution of wind and storm patterns. Under high NAO, arctic northwesteriles prevail and the NL shelf experiences overall cold conditions which propogate through the system via responses such as cold sea temperatures and heavy sea ice. The NAO index data were obtained from the National Oceanographic and Atmospheric Association (NOAA) of the United States website. The NAO index used herein is a smoothed 3-period centred moving average of the annual NAO, which is calculated by averaging monthly values each year. For all ADs, a 7-year lag was applied to the NAO index prior to conducting cross correlations and comparisons with biomass. Seven years was chosen to represent the approximate time it would take for the influence of climate to be observed in the exploitable biomass.

The centred 7-year lagged NAO index (standardized over the time series) and the exploitation rate index were used as explanatory variables in a linear model investigating the effects of these two drivers on biomass. The response variable was the 2-year moving average exploitable biomass index. The model was run independently for each AD.

Thermal habitat indices in each AD were qualitatively examined to assess ecosystem production potential. The thermal habitat indices were calculated as the percentage of the surveyed area covered by water <2°C. In ADs 3LNO Offshore and 3Ps, preferred spring bottom temperatures were used whereas only fall temperature data were available for ADs 2HJ and 3K. The thermal habitat index from AD 4R3Pn came from summer trawl surveys. Spring temperature indices are preferred because they are more closely associated with critical life history events in Snow Crab such as mating and molting.

Indices of predation on Snow Crab were available for previous years, but not in 2018. Estimates of Snow Crab consumed by predators were generated by combining three sources of information: biomass estimates for predators, estimations of total food consumption by unit of biomass for those predators, and fractionation of that consumption using diet compositions to define the proportion of Snow Crab in the diet. As each step involved assumptions and generalizations the resulting index is not absolute but intended to generate a plausible envelope for the order of magnitude for consumption.

Among all fish species recorded in DFO multi-species trawl surveys, only those belonging to the piscivores and large benthivores functional groups were considered Snow Crab predators due to gape limitation of smaller fishes. The total biomass of predators was approximated from multi-species 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 three approaches:

1. A bioenergetic-allometric consumer-resource modelling framework, which is based on empirical allometric scaling relationships (Yodzis and Innes 1992).
2. A multivariate statistical model (Palomares and Pauly 1989).
3. By assuming daily rations as a percent fraction of body weight. We assumed two daily ration scenarios of 1% and 2% based on typical literature reports (Macdonald and Waiwood 1987, Richter et al. 2004).

Strictly speaking, these approaches estimate 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 rates.

Data on diet composition is only available for a few recent years and for a small subset of Snow Crab predators (American plaice – *Hippoglossoides platessoides*, Atlantic cod – *Gadus morhua*, and turbot – *Reinhardtius hippoglossoides*). Estimates of the overall fraction of Snow Crab in their diets, as well as relative contributions of these species to the overall biomass of the Snow Crab predator assemblage, were used to approximate the fraction of Snow Crab consumed by all piscivore and large benthivore fishes. Since these predator species are a major component of the biomass of the corresponding fish functional groups, using their diets to represent the functional groups is a reasonable proxy, but the assumption of a constant diet composition in the earlier part of the time series (where we lack diet composition information) is a less robust (but unavoidable) assumption. Point estimates of absolute consumption of Snow Crab by all piscivore and large benthivore fishes were presented along with a predation mortality index (predation estimate / total survey biomass).

PRECAUTIONARY APPROACH

In June 2018, a Precautionary Approach (PA) framework for NL Snow Crab passed the CSAS peer-review process (Mullowney et al. 2018b). The PA and decision-making framework is based on three key metrics of stock health:

1. CPUE.
2. Discards.
3. Proportion of females with full egg clutches.

Limit reference points (LRP), as set by the peer-review process, were identified as CPUE = 5 kg/trap, discards = 20%, and proportion of females with full egg clutches = 0.6. Upper stock reference (USR) points have not been established by fisheries management, so the provisional USR proposed during the CSAS process are presented in this document.

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

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

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

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

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 Snow Crab in previous year.

AD = Assessment Division

Both the CPUE and discard predictive models project ahead 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.

No formal harvest control rules (HCR) have been developed for the fishery. However, the overarching application of the framework is that the stock is considered to be in the lowest of the three metrics examined. 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.

RESULTS AND DISCUSSION

BROAD-SCALE TRENDS: DIVISIONS 2HJ3KLNOPS4R

Fishery

Landings for Divs. 2HJ3KLNOP4R increased steadily from 1989 to peak at 69,100 t in 1999, largely due to expansion of the fishery to offshore areas. They decreased by 20% to 55,400 t in 2000 and changed little until they decreased to 44,000 t in 2005, primarily due to a sharp decrease in Div. 3K. In recent years, landings remained near 50,000 t from 2007 to 2015, but have since steadily declined to a two-decade low of 27,700 t in 2018 (Figure 12). Most of the landings are from ADs 3K and 3LNO (3LNO Offshore and 3L Inshore combined), but during the past three years, AD 3LNO has accounted for a steadily decreasing percentage of the landings. In AD 2HJ, landings have remained near 1,700 t for the past five years (Figure 13). In AD 3K, landings have remained relatively low for the past three years (6,000 t in 2018). In AD 3L Inshore, landings declined by 56% from a time-series high in 2015 to 3,700 t in 2018. The 2018 landings were 16% below the TAC. In AD 3LNO Offshore, landings declined by 43% from 2016 to 14,000 t in 2018 because of reductions in the TAC, to the lowest level in two decades. In AD 3Ps, landings increased from decadal lows to 1,900 t in 2018, exceeding the TAC, which was set at 1,792 t. Finally, in AD 4R3Pn, landings have steadily declined since a recent peak in 2013 and were 250 t in 2018.

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. In 2018, median fishing weeks ranged late-April in AD 4R3Pn to mid-June in AD 2HJ. The last regular (excluding a fall experimental fishery) fishery was completed in AD 3K by late August. AD 3Ps exhibited notable declines in the timing of median fishing day and the end of the fishery in 2018. 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). Overall effort remained at approximately 3.5 to 4.5 million trap hauls per year over that time. 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 Div. 2H virtually abandoned in the past five years. 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 has been maintained near a two-decade low for the past six years, with about 1.0 to 1.1 million trap hauls occurring each year. In AD 3LNO Offshore, effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level since then, at an estimated 1.5 to 2.5 million trap hauls per annum. In AD 3L Inshore, effort nearly doubled from 2013 to 2017, when it reached a historical high of 1.0 million trap hauls. In 2018, effort remained near a time-series high. In AD 3Ps, effort has declined by 60% since 2014 to be near its lowest level in two decades. Finally, in AD 4R3Pn, effort has remained at a low level relative to other ADs, with about 150,000 trap hauls per year occurring for the past eight years.

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. Throughout the past 25 years, CPUE (kg/trap) has shown a great deal of variability both across and within ADs, except in AD 4R3Pn where it has remained relatively constant and low relative to other ADs (Figure 17). Overall, the fishery performed poorly in 2018, with CPUE in most ADs at or near historical lows. In AD 2HJ, CPUE has remained near the decadal average in recent years (Fig. 17). In AD 3K, it increased in 2018 from a time-series low in 2017, but remains below the time-series average. In AD 3L Inshore, CPUE has declined by 68% since 2013 to below 5 kg/trap, its lowest level in the time-series. In AD 3LNO Offshore, CPUE most recently peaked near a time-series high in 2013 and has since declined by 49% to its lowest level since 1992. In AD 3Ps, CPUE increased from time-series lows in 2016 and 2017 to more than 5 kg/trap in 2018. Finally, in AD 4R3Pn, CPUE has declined since 2013 to below the long-term average.

There has been considerable spatial contraction of high fishery CPUE (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. Although high catch rates (>15 kg/trap) remain in northern offshore portions of AD 3LNO Offshore, several areas had notable declines in recent years. For example, catch rates along the Div. 3N slope edge decreased markedly in the past five years, while localized aggregations of effort in shallow portions of the western Grand Bank have performed relatively poorly since 2010. AD 3L Inshore has shown dramatic declines in CPUE throughout most fished areas in the past three years. In AD 2HJ, the Cartwright and Hawke Channels have near-exclusively become the two areas of fishing activity. In AD 3K, very few areas had experienced high catch rates in 2017, but increased catch rates were notable in offshore areas in 2018. In AD 3Ps, the decline in fishery CPUE had been both precipitous and broad-based from 2010 to 2017, but in 2018, all major fishing areas in AD 3Ps had improved catch rates. In AD 4R3Pn, catch rates in the offshore have been perpetually low, while all inshore bays yield catch rates in the order of 0–10 kg/trap.

Observer 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 Snow Crab decreased dramatically in 2016 and 2017. In 2018, the presence of both soft-shelled Snow Crab and residual Snow Crab in the fishery increased in AD 2HJ (Figure 18, Figure 19, Figure 20). The AD 3K fishery has observed overall catch rates of both residual Snow Crab and recruits at a consistent low level since 2008. In ADs 3LNO Offshore and 3L Inshore, the compilation of recruitment and the residual biomass (old-shelled Snow Crab) have been gradually eroding for the last four years to be at time-series lows. 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.

Overall, the combination of landings and spatial patterns 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 and greatly improving in AD 3Ps, with most other areas performing fairly poorly.

Biomass

The fishery has strongly depleted the exploitable biomass in all ADs in recent years (Figure 21, Figure 22). With the exception of ADs 3Ps and 2HJ, in 2018, end of season catch rates remained among the lowest observed levels.

In AD 2HJ, depletion rates have been relatively consistent for the last four years (Figure 23). In AD 3K, the fishery began at relatively high catch rates, but it quickly and precipitously depleted the biomass (Figure 24). In AD 3LNO Offshore, there had been only slight depletion of the biomass up to removals of about 25,000 t from 2010 to 2014, but the rate of depletion has accelerated in recent years (Figure 25). In AD 3L Inshore, there was little depletion evident from 2011 to 2013, but deteriorated since, to the extent that the 2018 fishery began and ended at its lowest levels in the time-series, with drastic depletion throughout the season (Figure 26). In AD 3Ps, rapid depletion under minimal removals occurred in 2016 and 2017, but minimal depletion was noted in 2018, with start and end catch rates near the highest recorded in several years (Figure 27). Finally, in AD 4R3Pn, the 2017 and 2018 linear regression slope was extremely steep, indicative of a rapid depletion of the biomass (Figure 28).

Overall point estimates of biomass from the fishery were at or near time-series lows in all ADs (with the exception of AD 2HJ) in 2018 (Figure 29), with a broad-based scenario of the fishery becoming an increasingly dominant factor contributing to reduced exploitable biomass.

Multi-species trawl surveys indicate that the exploitable biomass was highest at the start of the survey series (1995–1998) (Figure 30). It declined from the late 1990s to 2003 and then varied without trend until 2013. From 2013 to 2016, the exploitable biomass declined by 80%. Despite modest increases in 2017 and 2018, the trawl survey exploitable biomass index has remained at its lowest observed level for the past four years. Meanwhile, the trap survey index has declined by nearly 60% in the last two years to a time-series low (Figure 30) and overall fishery CPUE remained at a two-decade low in 2018. The overall low biomass reflects diminishing contributions of recruitment, to historical low levels in recent years, but more strongly reflects the elimination of virtually all the residual biomass in most areas.

The overall low exploitable biomass level is coupled with concentration into localized areas in all ADs (Figure 31, Figure 32). In 2018, the majority of trawl survey tows captured no exploitable Snow Crab, with densest concentrations found in offshore mid-latitude areas. Fringe areas of all ADs have been virtually void of exploitable Snow Crab in recent years.

Despite broad-based spatial contraction of the biomass in recent years, there were subtle signs of some localized improvements in some ADs in 2018. Particularly noteworthy are the increased survey catch rates in the northern portion of AD 3K and the southern portion of 2HJ. Further, in AD 3LNO Offshore the 2018 fall trawl survey showed a higher density of moderate catches throughout the northern and eastern portions of Div. 3L. The spring survey in AD 3Ps also captured a broader spatial signal of exploitable Snow Crab biomass in 2018 relative to recent years.

The overall patterns of prolonged deterioration and modest improvements seen in trawl surveys during 2017 and 2018, generally reflect those seen in trap surveys. With the exception of AD 3Ps, trap surveys showed considerable and continued spatial contraction in high catch rates of exploitable Snow Crab wherever conducted (Figure 6, Figure 8). After two years without CPS survey coverage in most areas of AD 3Ps, there has been strong signs of recovery in catch rates of exploitable Snow Crab from the trap survey throughout most of the AD during the last two years. Higher catch rates of exploitable Snow Crab from the DFO surveys were also noted in inshore areas of AD 3K (Figure 6). Nonetheless, overall, among all survey series, with the exception of AD 3Ps, there is a coherent depiction of an overall depleted exploitable biomass featuring some localized strong aggregations of Snow Crab.

Overall trends in trawl and trap survey exploitable biomass indices reflect variability among ADs (Figure 33, Figure 34). In AD 2HJ, the exploitable biomass index has changed little during the past 15 years (Figure 33, Figure 34). A modest increase in 2018 reflects an increase in residual biomass. Despite consistency across the two surveys, stock status interpretation is compromised by incomplete trap surveys during the past two years. The 2017 and 2018 point estimates from the CPS trap survey in AD 2HJ (Figure 34) 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, despite localized improvements, the post-season trawl and trap survey exploitable biomass indices have remained near time-series lows for the past five years. In AD 3L Inshore, the exploitable biomass is severely depleted. The post-season trap survey exploitable biomass index remained near a time-series low in 2018. In AD 3LNO Offshore, the trawl-derived exploitable biomass index showed a modest increase in 2018, but both it and the trap-derived exploitable biomass index remain at or near time-series' lows. In AD 3Ps, the in-season trawl survey exploitable biomass index was at a time-series low in 2016, but has improved during the past two years. The post-season trap survey index suggests an increase in the exploitable biomass throughout the major fishing grounds. Finally, in AD 4R3Pn, the exploitable biomass is severely depleted, with few residual Snow Crab in the population. The trap survey exploitable biomass index most recently peaked in 2012 and declined to a time-series low in 2017. The index increased slightly in 2018, reflecting localized improvements.

Although almost 50% of the sampling locations were randomly identified in 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 index closely agrees with fishery CPUE in each AD, reflecting the occupation of like grounds with like gear. The concentrated distribution on strongest aggregations of biomass in the CPS survey and fishery creates the potential for hyper-stability 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 35, Figure 36). This lag between measuring signals of change in biomass between data sources likely reflects the inclusion of marginal grounds in the trawl survey, where signals of change 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.

Trap saturation is an important concept for managers and harvesters to understand resource status (Mullowney et al. 2018b). Hyper-stable CPUE in trap-based biomass indices constitutes a mechanism that masks changes in stock size and should be examined in future research initiatives.

Collectively, the three survey and fishery metrics are consistent in showing an exploitable biomass that remains at or near historic lows in all ADs, except AD 3Ps. The index with the most predictive power (the trawl survey) suggests that notwithstanding potential for localized improvements within some ADs, no major improvements are likely in the 2019 fishery.

Recruitment

Overall recruitment into the exploitable biomass has been very low in recent years and survey data suggest recruitment available to the 2019 fishery will remain low in most ADs. This is particularly evident by the low biomass of new-shelled Snow Crab in trawl surveys (Figure 30, Figure 33). The recent declines of recruitment into the exploitable biomass were anticipated and reflect a prolonged lack of stock productivity (Mullowney et al. 2014).

In AD 2HJ, recruitment into the exploitable biomass has changed little during the past 15 years (Figure 33). The 2018 trawl and trap surveys suggest recruitment will remain unchanged in 2019 (Figure 33, Figure 37). This suggests little change in fishery prospects for 2019. In AD 3K, the post-season trawl and trap survey indices of recruitment into the exploitable biomass have remained near time-series lows for the past five years, suggesting little prospects for improvements in the fishery in 2019. In AD 3LNO Offshore, recruitment into the exploitable biomass has been at or near time-series lows in both the trawl and trap surveys in the past three years, but increased slightly in 2018. This suggests slightly better prospects for the 2019 fishery. In AD 3Ps, recruitment into the exploitable biomass was near a decadal high in 2018, with the exception of Fortune Bay. The marked improvement in recruitment into the AD 3Ps exploitable biomass strongly suggests the 2019 fishery should perform well.

For ADs where no trawl surveys occur, in AD 3L Inshore recruitment into the exploitable biomass steadily declined to a time-series low in 2017 and recruitment indices from DFO and CPS trap surveys remained near their lowest levels in 2018 (Figure 37). This suggests a continuation of a depleted exploitable biomass and a poor performing fishery in AD 3L in 2019. In AD 4R3Pn, recruitment into the exploitable biomass was low from 2014 to 2017, but survey data from 2018 suggest localized improvements may occur in 2019 (Figure 37).

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 33, Figure 38). In reality however, the proportion of the 65–94 mm CW adolescents measured by these surveys that reach the exploitable biomass depends on several factors including mortality and the size at which Snow Crab terminally molt. The overall abundance of pre-recruits in the stock has remained at or near its lowest observed level of eight consecutive years. This largely reflects trends in the largest AD (3LNO Offshore). Nonetheless, both surveys are suggesting the potential for localized improvements of recruitment into the exploitable biomass in forthcoming years (Figure 39). Most notably, in AD 3Ps the survey data of pre-recruit abundance suggest short-term prospects are positive relative to the recent 2013-16 low period (Figure 33, Figure 38). Spatially, the distribution of pre-recruit Snow Crab appears concentrated on the major fishing grounds of the AD (Figure 40). Further potential for localized improvements of recruitment are suggested by increased abundance of pre-recruits in the trap surveys in AD 3L Inshore, AD 3LNO Offshore, and AD 4R3Pn. The scenario of low or depleted exploitable biomass levels in each these ADs coupled with increased potential of recruitment into the biomass suggests soft-shelled crab incidence may be high in the fishery in these areas over the next couple of years if measures to ensure efficient transition of these Snow Crab into the exploitable biomass are not taken.

The relatively low abundance of small Snow Crab since the early 2000s (Figure 30, Figure 41, Figure 42, Figure 43), suggest overall weak recruitment potential in the long term relative to levels experienced in the mid- to late-1990s. The pulse of small Snow Crab that emerged in the trawl surveys in 2013–2014 (Figure 30) was largely localized to ADs 2HJ and 3K (Figure 41). Slight increases in the abundance of small Snow Crab in the population in 2017 were most pronounced in ADs 3K and 3LNO Offshore (Figure 41). Although from resource limitations it appears this fishery will inevitably be reduced in scale moving forward, as recent abundances of small Snow Crab are generally not nearly as large as historic pulses, other factors being equal, they could contribute to a modest fishery in the long term. For example, the spring trawl surveys showed a relatively high level of small Snow Crab in AD 3Ps in 2010 (Figure 41). That strong signal is almost certainly associated with marked improvements in new-shelled recruits in 2017 and 2018 (Figure 33). Unfortunately, there has been a relatively steady-state broad distribution of low catch magnitude for small Snow Crab in AD 3Ps for the past seven years (Figure 41), inferring weak prospects after the currently emerging pulse of recruitment benefits the biomass and fishery in the next few years. Whether or not the coincidental spike in small Snow Crab abundance seen in the 2010 AD 3LNO trawl survey will make significant contributions to the exploitable biomass in that AD remains to be seen (Figure 41). Neither the trawl nor trap surveys have yet measured a significant improvement of recruitment into the exploitable biomass in AD 3LNO Offshore.

Females

The management regime of the NL Snow Crab stocks (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 41). Despite this variability, like most other components of the population, the relative abundance of mature females has remained near times-series lows in most ADs (with the exception of AD 2HJ) for about the past seven years.

The spatial distribution pattern observed in recent years is typical of a dominant shallow water presence of mature females (Figure 44, Figure 45). For example, relatively high abundance is 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 (Figure 44). 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 45). These shallow areas, where the majority of reproduction occurs, are typically very cold. Mullowney et al. (2018a) recently described winter and spring breeding migrations of female and male Snow 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 survey trawl throughout the time-series could reflect their small size. This corresponds with a ‘trough’ in size frequency distributions from the Campelen trawl (Figure 46, Figure 47), 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 2008–2009 in the trawl survey (Figure 41).

There are no clear stock-recruitment relationships evident in this stock and 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 high abundance of 15-25 mm CW crab (males and females) observed in all ADs in the 2001–2002 surveys would have likely been 2–3 years of age (Sainte-Marie et al.1995) and been produced from the relatively low levels of abundance of mature females that occurred in 1998–2000 in all ADs. Similarly, the present pulse of smallest Snow Crab of about the same size in AD would have been produced from apparently low mature female abundance levels seen during recent years. Further research into the effects of female abundance and their contribution to stock productivity is necessary.

Environment

Overall, virtually all population components are at low levels in all ADs (Figure 46, Figure 47), but some ADs are showing modest signs of improvements. This suggests that the stock had been in an overall unproductive state for much of the past decade, but conditions may have been improving in recent years. Bottom temperature has been shown to act positively on size and negatively on abundance in regulating stock productivity and ultimately biomass. Low 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). However, recruitment is more strongly affected by the positive effects of a cold regime on year class production (Dawe et al. 2008; Marcello et al. 2012) than it is by the negative effects of a cold regime on size-at-terminal molt.

Cold conditions during early ontogeny have been associated with the production of strong year classes and subsequent strong recruitment in this and globally important Snow Crab resources (Boudreau et al. 2011; Marcello et al. 2012; Mullowney et al. 2014; Émond et al. 2015). In the Eastern Bering Sea and Northern Gulf of St. Lawrence (Marcello et al. 2012; Émond et al. 2015), climate data have been directly linked to survey-based indices of small Snow Crab abundance. In NL, a similar linkage has been established between bottom temperature and subsequent fishery CPUE (Mullowney et al. 2017), which is used as a proxy in lieu of small Snow Crab abundance from trawl surveys due to poor or inconsistent capture by the Campelen trawl (Marcello et al. 2012).

Despite spatiotemporal differences across ADs in the time necessary for temperature to affect future biomass, an overall consistent phenomenon in the NL Snow Crab resource is that cold conditions are beneficial to future biomass (Mullowney et al. 2017). The species is uniquely adapted to thrive in some of the coldest bottom temperature conditions on earth, with high temperature regions not suitable for survival or habitation. Indeed, the recent (modest) emergent pulse of small Snow Crab observed in many areas of the NL shelf has been associated with generally cooling oceanographic conditions in recent years (Colbourne et al. 2016), with the areal coverage of cold bottom water increasing in all ADs, except AD 3Ps, since record warm conditions in 2010–2011 (Figure 48, Figure 49).

The Snow Crab thermal habitat index (defined as the areal extent of <2°C bottom water) has returned to near-average conditions in all ADs in recent years (Figure 49). Although a return to cooler conditions in recent years is positive because it appears to have promoted the emergence of a modest pulse of small Snow Crab, expectations for the future should be tempered as climatic conditions are still relatively warm (Colbourne et al. 2016). The ocean climate indices have varied considerably over the past decade, introducing uncertainty beyond the short term, but the overall trend is warming. Present '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-late-1990s originated (Mullowney et al. 2014). Long-term abundance may heavily hinge on the extent to which the recent cooling 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 NAO (North Atlantic Oscillation [atmospheric forcing index]) was demonstrated. In its application to ocean climate phenomena, the NAO is essentially a proxy multivariate climate index. Although the association of NAO and future biomass is consistent with a linkage between cold conditions and high stock productivity (as high NAO produces cold conditions along the NL shelf), it could be that other associated climatic factors such as sea ice, bloom strength, water mixing, food availability, or predator field dynamics, affect Snow Crab survival during early ontogeny. Notwithstanding an incomplete understanding of the mechanisms associated with climatic forcing, the 3-year centered moving average annual NAO index (lagged by 7 years) was strongly correlated with exploitable biomass indices in each AD (Figure 50). The lagged NAO analysis predicts that the exploitable biomass should enter into a recovery phase over the next few years, to levels near average for the biomass time series in each AD (Figure 50).

It is unclear if or by how much potential forthcoming climate-predicted improvements to the exploitable biomass 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 (now current) 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, including the biggest areas of supply (see forthcoming section on mortality). Until the past few years, following a regime shift (Buren et al. 2014) culminating in a collapse of most of the finfish community in the late 1980s and early 1990s, 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, 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 below for details) can only serve to reduce the proportion of animals progressing through size and dampen forthcoming recruitment.

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 51) 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 with the exception of 2HJ, drastic declines in the presence of snow crab in finfish stomachs were observed in all ADs in 2017. 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 Snow Crab now outgrowing sizes able to be consumed by most predators (i.e., <40 mm CW) (Chabot et al. 2008), as inferred by increases in pre-recruit indices in 2017. Important differences are evident in magnitude of predation mortality across ADs, with ADs 3K and 3Ps having predation levels much higher than other areas.

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 in decline, increased top-down controls in the forms of predation and fishing are likely now (or will become) more important in regulating the resource than historically. If this is the case, and top-down forcings become dominant, the strength of linkages with bottom-up forcing (i.e., NAO) would be expected to diminish moving forward. The confluence of current events including climate-predicted improvements, exceptionally high exploitation rates, modest recovery and now decline of many finfish stocks, and low population density at all sizes (Figure 46), creates a great situation for studying the relative importance of various resource drivers on population dynamics in Snow Crab.

Mortality

The overall trajectory of most focal population components has been a prolonged decline of abundance indices for two decades in all ADs (Figure 52). The downward trajectory of recruitment into the exploitable biomass opposes total mortality rates gradually increasing in the exploitable component of the population until 2018. Total mortality in exploitable Snow Crab was very high in all ADs during 2015–2016 (Figure 53). In AD 2HJ, total mortality remained high in 2017, but declined slightly in 2018. In AD 3K, total mortality in exploitable Snow Crab has remained at its highest level during the past four years (>75%). In AD 3LNO Offshore, total mortality declined from its highest observed level in 2016 to a relatively low level in 2018. Finally, in AD 3Ps, total mortality in exploitable Snow Crab has varied considerably throughout the times series but was low in 2018. The high variability in the total mortality index in AD 3Ps likely reflects the shell condition-based methodology, with a spring survey potentially compromising the efficacy of 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. Bitter Crab Disease (BCD) is one important source of consistently measured natural mortality in the population. BCD has been observed, based on macroscopic observations of Snow Crab captured in the fall trawl surveys, at generally low levels throughout NAFO Divs. 2J3LNO from 1995 to 2018 (Figure 54). The prevalence and distribution of this parasitic infection 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 Snow Crab (Mullowney et al. 2011).

BCD, which is fatal to crab, occurs primarily in new-shelled crab of both sexes and appears to be commonly acquired during molting (Dawe 2002). Although the macroscopic analyses used to classify Snow 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 recent 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 (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 54). BCD is normally most prevalent in AD 3K. In 2018, levels of BCD were more than 10% in >94 mm CW Snow Crab. This represents three consecutive years of relatively high levels of BCD in fairly large size classes 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 Snow Crab. This sustained pulse of BCD likely reflected progression of the recruitment pulse detected in the trawl surveys as 20–30 mm CW Snow Crab in 2001–2003 (Figure 46, Figure 47, Figure 52), which was subsequently tracked as pre-recruits in surveys from 2008 to 2010 (Figure 52).

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

Beyond direct removals from the system, the fishery also imposes mortality on Snow Crab through discarding. Snow 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; Urban 2015). Soft-shelled 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 recent study in the Bering Sea, Urban (2015) predicted only approximately 5% mortality on discarded Snow Crab, a value much less than previously thought. 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 Snow 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-shelled 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 low biomass.

The current situation in ADs 3K and 3L Inshore is particularly concerning, where discard levels are very high at approximately 35 and 40% in the ADs, respectively (Figure 55). In AD 3L Inshore, this represents a substantial increase in discards compared to 2017, when discards represented less than 20% of the observed catch. At-sea observer sampling data suggest that the discards in AD 3K are comprised of a combination of soft-shelled and under-sized Snow Crab, while the bulk of discards in AD 3L Inshore are under-sized, old-shelled crab (Figure 56).

Discard levels in the fishery are negatively related to the relative strength of the ratio of exploitable to pre-recruit biomass indices and CPUE (Figure 57) (Mullowney et al. 2018b). This likely reflects competition for baited pots, with the catchability of less competitive Snow Crab (both under-sized and soft-shelled) increasing when the exploitable biomass is relatively low. The relatively low level of residual biomass at all sizes in all ADs in recent years is concerning, given it is generally associated with low CPUE and high levels of discards in the fishery. Modest increases in recruitment potential in some ADs, coupled with a low residual biomass, suggests that wastage of soft-shelled pre-recruits could be problematic in the fishery in the next few years and potential gains could be quickly diminished if aggressive harvest strategies persist. Mortality of both soft-shelled and under-sized males can be minimized by maintaining a relatively high level of residual biomass and, for soft-shelled crab in particular, may be further reduced by fishing early in the spring before they are capable of entering traps.

The soft-shell protocol was introduced in 2005 to protect soft-shelled immediate pre-recruits from handling mortality by closing localized areas for the remainder of the season when a threshold level of 20% of the legal-sized catch is reached (based on only observed catch). That threshold has since been reduced to 15% in ADs 3LNO Offshore and AD 3L Inshore. However, it has become evident that the protocol as implemented is ineffective in controlling handling mortality. Limited observer coverage is a central limiting factor affecting the efficacy of the soft-shell protocol. Approximately 1–3% of fishery landings have been observed in any given AD in recent years. This corresponds with about 0.1–0.3% of the catch being sampled (Figure 11). This observer coverage level is available to monitor thousands of grids. For example, there are about 650 grid cells in the offshore portion of AD 3K alone. Moreover, the 7 x 10 nautical mile grids in inshore areas have been further divided in quarters in recent years. In addition, high sample sizes required to invoke closure compromises the ability to monitor the few cells that get observed.

Beyond issues relating to too many grids and too little observer coverage, historic application of the protocol has been problematic from a conservation perspective. Insufficient monitoring leads to a decision to treat unobserved grids (the majority) as if they were below the closure threshold. Further, in the few grids that do get observed, a failure to invoke closures when only moderate sample sizes can be obtained due to low fishery catch rates, even when it was clear that the level of soft-shelled Snow Crab exceeded the threshold, has historically compromised the efficacy of the protocol. Overall, such shortcomings undermine the intent of the protocol and it can serve as a basis to enable and prolong fisheries under the auspice of conservation rather than prevent mortality to soft-shelled Snow Crab.

Soft-shell incidence has featured relatively prominently in the observed catch in ADs 2HJ and 3K in recent years (Figure 56). This is 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 Snow Crab in the fishery and afford better protection to incoming recruitment if and when the situation improves.

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 (3LNO Offshore, 3Ps) 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, 3K) are associated with persistent high total mortality and exploitation rates. 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.

In AD 2HJ, the exploitation rate index has been above the long-term average for the past three years (Figure 53). Status quo removals in 2019 would decrease the exploitation rate index, but it would remain at a relatively high level. In AD 3K, the exploitation rate index declined from a decadal high to near time-series average levels in 2018. Under status quo removals in 2019 the exploitation rate index would be unchanged (Figure 53). In AD 3LNO Offshore, the exploitation rate index increased by a factor of five from 2014 to 2017, and remained high in 2018. The exploitation rate index would decline to near the long-term average with status quo removals in 2019 (Figure 53). In AD 3Ps, the exploitation rate index was near its lowest observed level in the time series in 2018. Projections are hampered because the survey is conducted in the spring, but status quo removals and exploitable biomass would result in the exploitation rate index being near a time-series low in 2019 (Figure 53). Since these projections have limited applicability, the exploitation rate index from trap surveys was also reviewed. This trend also projects record-low exploitation rates under status quo landings in 2019 (Figure 58). 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. In AD 3L Inshore, the overall trap survey-derived exploitation rate index has increased since 2013 and remained at its highest observed level in 2018. Status quo removals would maintain the exploitation rate at a time-series high in 2019. In AD 4R3Pn, the overall exploitation rate index declined to below the long-term average in 2018. Status quo removals in 2019 would result in little change to the exploitation rate index.

Current 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 Precautionary Approach 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 can be as high as 80% in some ADs in some years. Of particular note, the lack of old-shelled Snow Crab in the biomass, even at largest sizes associated with terminally molted animals, is concerning. The virtual absence of large old-shelled 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-entirely relying on incoming recruitment each year is risky with respect to the possibility of unforeseen events to affect recruitment. Moreover, our experiences have shown that areas with low residual biomasses are generally associated with wasteful fisheries, 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 heavy exploitation is sustained. Large hard-shelled males are the prime breeders and likely serve to introduce sufficient intraspecific competition in the population to promote large size at terminal molt. As in many animal populations, large competitive males serve to maintain reproductive integrity as well as physically structure population demographics. The outcomes of the unfolding scenario of rendering the population virtually void of large males in some areas will be important to monitor from biological and management advice perspectives.

Overall, the scenario of a depleted exploitable biomass coupled with generally high exploitation rates suggests a relatively low likelihood of any appreciable long-term gains to be gleaned from the modestly improved signals of recruitment potential (Figure 60, Figure 61, Figure 62). The trade-offs of a one versus multi-year extraction strategy, particularly in respect to a lack of residual Snow Crab in the population, should be considered. Biologically, it is advised to invoke strategies to restore the residual biomass component of the population, as there is potential for biological harm to occur if total mortality continues to near-fully deplete the exploitable biomass each year.

Size-at-maturity

Size-at-maturity of male Snow Crab has recently declined substantially in all ADs (Figure 63), with 2/3 of males maturing well below exploitable size (i.e. 60–70 mm CW). These results indicate that any improvements in recruitment potential could be significantly dampened, unless size-at-maturity recovers to previous levels. Concurrently, the size-at-maturity for females appears to be increasing in all ADs in recent years. The consequences of these changes remain unknown, but the potential for these changes to affect reproductive success is possible; the mating behaviors of Snow Crab rely on large males and small females. Trends in this size-at-maturity should continue to be monitored closely and research initiatives developed to better understand the underlying cause of these changes.

Precautionary approach

Mature females store sperm and can produce multiple clutches of eggs from a single mating season (Sainte-Marie 1993). To monitor reproductive health, an index of egg clutches of females is used (Figure 64). Data from both the fall and spring surveys throughout NAFO 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 2018, all ADs, with the exception of AD 2HJ were in the healthy zone for egg clutches; AD 2HJ was in the cautious zone (Figure 64).

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. In 2017 and 2018, AD 2HJ showed an appreciable decrease in the percent of females with full egg clutches, to a level of about 80%. Low percentages of clutch fullness in previous years were also observed in AD 2HJ in 2006 and 2007, and recent low levels have been observed in AD 3LNO Offshore in 2013 (note uncertainty in 2014 due to incomplete survey) and in AD 3K in 2015. 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.

Discards levels were predicted to be within the proposed cautious zone for all ADs in 2019, with the exception of AD 3L inshore, where they were considered in the critical zone (Figure 64). High discard rates coincide with low residual biomass and represent wastage in the fishery.

In 2019, CPUE is predicted to be in the Cautious Zone in all other ADs (Figure 64). The predicted CPUE in ADs 3K and 3L Inshore dropped to extremely low levels and remains close to the lower reference point. In contrast, the CPUE in AD 3Ps is predicted to substantially increase in 2019, but remains in the proposed cautious zone.

Together, the metrics indicate that all ADs, except AD 3L Inshore are in the proposed cautious zone, while AD 3L Inshore is in the critical zone (Figure 64). The Precautionary Approach and harvest control rules remain in development and therefore cannot be implemented in the management of the 2019 fishery.

ASSESSMENT DIVISION 2HJ

Fishery

The AD 2HJ fishery occurs in offshore regions of central and southern Labrador in CMAs 1 and 2 (Figure 2, 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 1). 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. 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 fishing in Div. 2J is longer, extending back into the early 1980s.

Landings in AD 2HJ have remained at 1,700 t for the past four years (Figure 13). Effort was substantially reduced in 2011 and has since remained at its lowest level (~200,000 trap hauls per year) in two decades (Figure 15). The shortfalls in achieving the TAC in 2011–2013 and 2016 reflect events in the northernmost fishing grounds of CMA 1 (i.e. 2JN) (Figure A1.1), while the southern CMA consistently 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 in recent years to promote conservation measures (Figure A1.1).

Logbook return rates in AD 2HJ have been relatively consistent with other ADs, but only approximately 70% of landings data were accounted for in the logbook dataset for this assessment (Figure 4). 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 11).

CPUE has remained near the decadal average in recent years (Figure 17), reflecting trends throughout the AD (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 two years, potentially showing declining recruitment into the fishery; however, end-of-season catch rates in 2018 were higher than the previous two years (Figure A1.3).

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.

Size distributions from at-sea sampling by observers during the fishery suggest that two recent recruitment pulses benefitted the fishery during 2007–2009 and 2012–2015 (Figure 20). This can be seen by an increase in abundance of soft- and new-shelled legal-sized Snow Crab during those periods. In 2018, the observed catch of old-shelled and soft-shelled Snow Crab across the size distribution seemed to increase (Figure 20), reflecting trends in CMA 2 where observer sampling occurred (Figure A1.4).

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. However, minimal soft-shell catches have been observed in the past four years.

Total mortality of exploitable Snow Crab had been at its highest level in recent years, but declined slightly in 2018 (Figure 53). The trend in total mortality has reflected that of fishing mortality in recent years (Figure 53), however, in 2018 exploitation rate index remained high while total mortality declined. The drop in total mortality could be caused a potential immigration of large Snow Crab from AD 3K into southern areas of AD 2HJ (see below for more details).

The exploitation rate index has been above the long-term average for the past three years. Status quo removals in 2019 would decrease the exploitation rate index, but it would remain at a relatively high level. 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 2019 fishery.

Surveys

Both the trawl and trap-based exploitable biomass indices have changed little during the past 15 years, with the exception of a 2014 spike in the trawl index (Figure 33). A modest increase in 2018 reflects an increase in residual biomass (Figure 33). However, the trap-based biomass estimates in 2017 and 2018 are considered highly uncertain and should be viewed with caution (Figure 34), particularly in CMA 2 (Figure A1.6). The 2017 trap survey omitted a relatively large proportion of core stations and the 2018 trap survey omitted a large portion of core stations and shell conditions were identified inaccurately in CMA 2 (Figure 8). However, the spatially-broad trawl survey has captured very few exploitable Snow Crab outside the Cartwright and Hawke Channels during the past decade (Figure 31).

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 15 years with the exception of a 2014 spike (Figure 33), and the 2018 trawl and trap surveys suggest recruitment will remain unchanged in 2019. Interestingly, a high level of recruitment into the biomass in the northern area during 2013 (Figure A1.6) preceded the high level of recruitment seen in the trap survey in the southern area in 2014 (Figure A1.7, Figure A1.8). The shell conditions were identified incorrectly in the majority of stations in 2018 and therefore the levels of recruits versus residual Snow Crab from large-mesh pots could not be accurately estimated this year (Figure A.17, Figure A1.8).

The combination of a modest increase in residual Snow Crab in 2018, no prior increase in recruits in 2017 (Figure 33), the general location of the new residual Snow Crab within the deep channel extending from AD 3K to southern AD 2HJ (St. Anthony Basin) (Figure 31), and the lack of increase in residual Snow Crab in 2018 following an increase in recruits in 2017 in AD 3K (Figure 33) indicates the possibility that recruits from AD 3K may have moved into southern portions of AD 2HJ as residual Snow Crab. Therefore, caution should be used when recommending quotas based on this modest increase.

Looking at prospects beyond 2019, the pre-recruit biomass index has been relatively low in recent years and was at or near its lowest level for the last four years (Figure 33). The modest 2014 spike in pre-recruits in the trawl survey appeared to be associated with the progression of a mode of Snow Crab into legal-size in small-mesh traps from the Torngat survey in CMA 1 (2JN) during 2015 (Figure A1.10). However, like the trawl survey, there is no strong indication of an imminent influx of pre-recruits seen in the Torngat survey small-mesh trap data in the most recent three years.

Long-term recruitment prospects appeared to improve from 2013 to 2016. The abundance of small Snow Crab (15–25 mm CW) in the population was higher than it had been for roughly a decade, but in 2017 and 2018 the abundance of small Snow Crab was near average levels (Figure 41). These smallest Snow Crab in the trawl survey have consistently been captured in shallow areas, on top of the Hamilton Bank and adjacent nearshore plateaus (Figure 42). The persistently low signal of small Snow Crab in the trawl survey prior to 2013 suggests no improvements are likely before the most recent emergent mode of small Snow Crab contributes to the fishery. The high consumption level of Snow Crab by large predators in 2016 and 2017 (Figure 51), as well as a spike in BCD prevalence in 60–75 mm CW Snow Crab in 2015 and 2016 (Figure 54), is consistent with tracking these Snow Crab through ontogeny, although neither survey has yet to capture them in high abundance as pre-recruits (Figure 33). Other factors being equal, this promising signal of small Snow Crab abundance should start contributing to pre-recruit indices in the near future.

Size-at-terminal molt in males has precipitously declined in recent years, suggesting potentially dampened short-term recruitment prospects into the exploitable biomass (Figure 63).

The proposed Precautionary Approach indicates that stock status would be in the provisional cautious zone in 2019 (Figure 64). Egg clutches, discards, and CPUE were all within the proposed cautious zones.

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 four years. If this pattern holds, the fishery performance would be expected to remain similar in 2019. A lower exploitation rate would be required to promote recovery of the exploitable biomass.

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). Within the Assessment Division there are six CMAs (Figure 2). 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 1). 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 (Figure 16). 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 three 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 levels are at or near their lowest levels in a decade. In 2018, the TACs within the CMAs remained unchanged or increased slightly. The TAC has not been reached for the last three years in CMAs 3A and 3BC. At below a million traps hauls a year, overall effort reached a two-decade low in 2018 (Figure 15).

Standardized CPUE increased in 2018 from a time-series low in 2017, but remains below the times-series average (Figure 17), reflecting trends in most management areas (Figure A2.2). An exception to the recent overall trend occurs in Green Bay (CMA 3C), where CPUE has oscillated throughout the time series. Interestingly, most CMAs have shown a quasi-cyclical pattern in CPUE. In CMAs 3A, 3BC, and 4 (i.e., the offshore areas) the most recent peak occurred in 2013 and catch rates have since been on a steep three-year decline, were at or near historical lows in 2017, and increased slightly in 2018. The oscillating pattern in CMAs 3C and 3D is slightly out of phase with the offshore, with modest increases occurring in 2017. Nonetheless, in general, the fishery has performed relatively poorly throughout most of the AD in recent years, but showed modest signs of improvement in 2018.

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 years, 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. However, it is noteworthy that there is very little difference in trap survey (forthcoming) versus logbook catch rates.

In 2018, the fishery CPUE declined throughout the season in every CMA (Figure A2.3), reflecting resource depletion. This depletion was pronounced in every CMA, but CMAs 3A and 3B had very low late season catch rates, below 2 kg/trap.

Observer sampling during the fishery showed increasing catch rates of new-shelled and/or soft-shelled Snow Crab in all CMAs in 2017, with the exception of CMA 4. In 2018, the catch rates of new-shelled and soft-shelled Snow Crab declined slightly again (but remained relatively high compared to the past decade), except in CMA 4, where an increase was observed (Figure A2.4). The emergence of a recruitment pulse into the White Bay (CMA 3B) fishery, likely beginning in 2012, followed an anomalous event in 2010 whereby the fishery was closed prematurely due to a high level of soft-shell in the catch (the early closure was initiated by harvesters). Only half the TAC was subscribed in that year and catch rates were atypically low. Such proactive action appears to have benefitted the White Bay fishery, with catch rates in this area higher than most other portions of the AD for the subsequent five years (Figure A2.2). However, as seen in an eroding size frequency distribution (Figure A2.4) and steep decline in fishery CPUE in the past three years (Figure A2.2), benefits gleaned from that recruitment event now appear over.

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 (Figure A2.4). However, in 2018, the knife-edge effect was not evident in Green Bay. In 2018, a knife-edge effect emerged in White Bay (CMA 3B), indicating strong fishing pressure on the resource in this area.

An increase in recruitment that appeared to be entering the exploitable biomass in Green Bay (CMA 3C) and neighbouring Notre Dame Bay (CMA 3D) in 2018, appears to be mostly complete (Figure A2.4). The improving situation in the exploitable biomass began three years ago. From about 2009 to 2013 the overall magnitude of catch rates of most sizes of Snow Crab showed a steady decline as the size frequency distribution became platykurtic. Beginning in approximately 2014, a notable change in population distribution occurred as the primary size mode became centered near legal-size and the distribution became right-skewed. However, in 2018, the catch rates across size categories in these CMAs declined.

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 Snow Crab until 2017. In 2018, observer catch rates of recruits increased in CMA 4.

Soft-shelled Snow Crab incidence in the catch is a perpetual issue in AD 3K (Figure A2.5). In general, the bulk of discards in this AD are attributable to soft-shelled Snow Crab (Figure 56). However, the majority of discarded Snow Crab were represented by undersized Snow Crab in 2018. 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. 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-shelled 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 Snow Crab has remained at its highest levels (>75%) during the past four years (Figure 53). The exploitation rate index declined from a decadal high to near time-series average levels in 2018. Under status quo removals in 2019 the exploitation rate index would remain relatively unchanged. CMAs 3B, 3D, and 4 would have trap survey-based exploitation rate indices near or at time-series highs (Figure A2.6).

Surveys

Despite localized improvements, the post-season trawl and trap survey exploitable biomass indices have remained near time-series lows for the past five years (Figure 33, Figure 34). This trend is consistent throughout the AD, with the exception of Green Bay (CMA 3C), where trap-based exploitable biomass appears to be increasing in recent years (Figure A2.6). 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 Snow Crab captured in the farthest offshore areas (Figure 31). In 2018, the pocket of Snow Crab that is generally found within AD 3K in the St. Anthony Basin (north-central portion of AD 3K), appeared to have moved north and was centered in AD 2HJ. The exploitable biomass has consisted largely of incoming recruits throughout the time-series (50–75%), with few old-shelled Snow Crab (Figure 33). This suggests high mortality of large adult male Snow Crab.

Despite localized improvements, the post-season trawl and trap survey indices of recruitment into the exploitable biomass have remained near time-series lows for the past five years (Figure 33, Figure 34). Although modest increases in recruitment were observed in most CMAs in 2017, in 2018 recruitment indices from the post-season trap survey dropped back to near time-series lows in all CMAs, except White Bay (CMA 3B), where recruitment showed a modest increase

(Figure A2.7). The overall CPS survey catch rates in AD 3K remain relatively low (<5 kg/trap) (Figure 37). The DFO trap survey results are generally consistent with the CPS survey results. In White Bay, an unusually high abundance of recruitment was seen throughout the bay in 2012 (Figure A2.7), but catch rates have since declined to near or below 5 kg/trap. It is noteworthy that the best comparison with the CPS survey is made with the 201–300m and 301–400m strata, which constitute the majority of the area, with the deepest stratum very small and generally beyond depths where the fishery occurs (Figure A2.8). Nonetheless, the DFO survey typically finds large soft-shelled pre-recruits in this deep hole, thus the improved signal in 2017 and 2018 could reflect increased recruitment potential for 2018. Interestingly, unlike the CPS survey which exhibited an abrupt increase in CMA 3C in 2016 and 2017, the DFO survey measured the improvement in CMA 3D, specifically in the deepest confines of it (Figure A2.9). In 2018, a modest increase in recruits was observed in the DFO trap survey in both 3C and 3D, but a significant decrease in recruits was observed in the deepest stratum of 3D. Such spatial inconsistencies between areas likely reflects non-conformance of CMA boundaries to bathymetry and population structure, with the two areas almost certainly being intrinsically connected. The results indicate that although modest increases in recruitment were observed in 2017, recruitment returned to low levels again in 2018.

Size frequency distributions from large-mesh pots in the CPS survey show increased levels of new- and soft-shelled Snow Crab across a broad size range in all CMAs, except CMA 4 and 3D in 2017 (Figure A2.10). In 2018, the catch rates were returned to relatively low levels in all CMAs, except 3B, where they continued to increase, but overall numbers per trap remained relatively low for the time-series. Looking beyond 2019, both the trawl and trap pre-recruit abundance indices increased in 2016 from historical lows (Figure 33, Figure 38), but then both decreased in 2017 and again in 2018. Pre-recruit potential appears to be returning to near its lowest observed levels seen during 2012–2015.

Small-mesh trap usage by the CPS survey has been sporadic or non-existent in most CMAs throughout the time-series (Figure A2.11). Only Green Bay (CMA 3C) and the offshore (CMA 4) have been consistently covered. Overall catch rates had been consistently high in Green Bay until 2018, but the overwhelming majority of Snow Crab were terminally molted below legal-size in all but 2017 (Figure A2.11).

Small-mesh traps in the DFO surveys show a depleted biomass in all areas of White Bay (CMA 3B) (Figure A2.12), with a very small hint of potential increased recruitment in the middle (301–400 m) stratum in 2018. The surveys tracked a mode of adolescents 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 animals 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 high exploitable biomass experienced from 2012 to 2014. Although another very small pulse of adolescents was detected at about 47 mm CW in the shallowest stratum in 2015, there has been no strong signal of pre-recruit Snow Crab in the population since 2012 and expectations are that the exploitable biomass and fishery in 3A/White Bay will remain relatively stable in the next couple of years.

An emerging pulse of small Snow Crab in Green Bay seen in the CPS survey (Figure A2.11) in 2017 was not clear in small-mesh pot data from the DFO trap survey in 2017 (Figure A2.13). However, in 2018, an increase in terminally-molted Snow Crab below exploitable size (mode CW ~75 mm) is easily recognized in the DFO trap survey data. A small, modest increase in catch rates of adolescent Snow Crab throughout a wide size range below exploitable size is also evident. 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 Snow 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.

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 Snow Crab in the pseudo-cohort of adolescents ranging from about 45–75 mm CW. This led to the record high exploitable biomass in 2012 that persisted until about 2014. The previous pulse of BCD in White Bay from 1996 to 1999 preceded the relatively high exploitable biomass experienced from about 2002 to 2007. While the percent of new-shelled males with BCD most recently peaked in 2016 and was relatively high again in 2018 (Figure A2.14), the increase is evident in the largest size categories (CW > 76 mm) (Figure 54). This unusual trend means that a relatively high proportion of large males (many of which are exploitable size) have been subjected to BCD and died during the last three years. This is most likely contributing to the high total mortality observed in AD 3K (Figure 53).

Despite several inferences of improving long-term recruitment prospects in 2017, the inferences appear somewhat weaker in 2018. Expectations must be tempered and also examined in-light of recent declines in size-at-maturity.

Size-at-terminal molt in males has precipitously declined in recent years, suggesting potentially dampened short-term recruitment prospects into the exploitable biomass (Figure 63).

The proposed Precautionary Approach indicates that stock status would be in the provisional cautious zone in 2019 (Figure 64). Discards and CPUE were within the proposed cautious zones, while the proportion of females with full egg clutches was considered healthy.

Caution is encouraged in making decisions on the resource at the CMA level in this AD as they could affect biological functioning. Most information presented herein shows that 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 Snow 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 Avalon (CMA 6C), Southern Avalon (CMA 8A), and St. Mary's Bay (CMA 9A) (Figure 2). 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 (Figure 2). 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 here is cold (Figure 48) and most of the area is characterized by productive Snow Crab grounds.

Overall, landings declined by 56% from a time-series high in 2015 to 3,700 t in 2018. In 2018, the landings were 16% below the TAC (Figure 13). In 2017 and again in 2018, the TACs decreased in all CMAs, resulting in subsequent declines in landings (Figure A3.1). The reduced TAC was not reached in all CMAs, except CMA 5A. Effort had oscillated without trend from 2005 to 2015, but has nearly doubled since 2013 to a time-series high in 2018 (Figure 15).

Overall standardized CPUE has declined by 68% since 2013 to below 5 kg/trap, its lowest level in the time series (Figure 17). There have been strong recent declines in every CMA, with many now at or near time-series lows (Figure A3.2). Although recent catch rate declines have been substantial in all CMAs, particularly precipitous declines in CPUE have occurred in Conception Bay (CMA 6B), Northeast Avalon (CMA 6C), Southern Avalon (CMA 8A), and St. Mary's Bay (CMA 9A) during the past two to three years (Figure A3.2).

Strong depletion of the resource during the 2018 fishery was evident in all areas (Figure A3.3). Fishery CPUEs ended at or near historical lows (<5 kg/trap) in all CMAs. Conception Bay (CMA 6B), Northeast Avalon (CMA 6C), Southern Avalon (CMA 8A), and St. Mary's Bay (CMA 9A) had particularly alarming low end-of-season catch rates (~1 kg/trap), suggesting a near-fully depleted biomass. Within most CMAs, the start-of-season fishery CPUEs in 2018 were equivalent to or below the end-of-season CPUEs of 2017. This indicates the resource experienced little to no recruitment between fisheries, consistent with emerging patterns of strong resource depletion through fishing.

Observer data show a general lack of renewal in the exploitable biomass. In-season catch monitoring data show that the catches consisted almost exclusively of old-shelled Snow Crab (Figure 20), with extremely low incidence of new-shelled Snow Crab in the AD as a whole and within most CMAs (Figure A3.4). In 2018, knife-edge trends at exploitable size (indicating strong exploitation pressure) have emerged in the AD, reflecting trends in Northeast Avalon (CMA 6C), Southern Avalon (CMA 8A), and St. Mary's Bay (CMA 9A). New-shelled Snow Crab were virtually absent in all CMAs, with the exception of Northeast Avalon (CMA 8A), where very few new-shelled Snow Crab were observed. In 2017, large increases in new-shelled Snow Crab were observed in NE 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. In general, with the absence of a large recruitment event in 2019, these data suggest further dissipation of the already depleted exploitable biomass.

Observed weekly soft-shell encounters remained relatively low in AD 3L Inshore from 2012 to 2016. However, in 2017, for the first time in seven years, a relatively large pulse of soft-shelled Snow Crab was observed near the end of season (Figure A3.5). In 2018, soft-shelled Snow Crab were observed throughout the season. The sustained period of about seven years with little to no soft-shelled Snow Crab observed in the fishery is indicative of recently declining recruitment and with little exception suggests no major improvements in recruitment into the exploitable biomass are expected for 2019.

Biomass declines have been greatly outpacing adjustments to removals. The overall trap survey-derived exploitation rate index has increased since 2013 and remained at its highest observed level in 2018 (Figure 58). Status quo removals would maintain the exploitation rate at a time-series high in 2019. With the exception of Southern Avalon (CMA 8A), under status quo removals, all CMAs would reach or maintain exceptionally high levels of exploitation (Figure A3.6). A small increase in exploitable biomass in Southern Avalon (CMA 8A) in 2018 would result in exploitation rate reducing to near the time-series average under status quo landings. CMAs Conception Bay (CMA 6B), NE Avalon (CMA 6C) and St. Mary's Bay (CMA 9A) would reach highest observed exploitation rates. The consequences of such high exploitation are unknown, but the potential for biological harm to the resource through fishing elevates as exploitation elevates to such high levels. The entire AD can currently be considered overexploited.

Surveys

The exploitable biomass is severely depleted. The post-season trap survey exploitable biomass index remained near a time-series low in 2018 (Figure 34). In all CMAs, the exploitable biomass index has been at its lowest observed level in the past two to three years (Figure A3.6). CMAs 6B and 6C had total catch rates of approximately 1 kg/trap in the 2018 surveys.

The declining biomass is largely a result of declining recruitment renewal since 2010, sequentially followed by a decline in residual Snow Crab since 2014 (Figure 37). 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 very modest increases in recruitment were observed in some CMAs in 2018, recruitment indices from DFO and CPS trap surveys remained near their lowest levels (Figure A3.7). In general, resource renewal has been low and is expected to remain low in 2019.

In the CPS survey in Bonavista Bay (CMA 5A), there was a sharp reduction of new-shelled legal-sized Snow Crab in the catch from about 12 kg/trap in 2011 to 6 kg/trap in 2013. The index has remained near this low level since (Figure A3.7). The DFO survey similarly tracked this decline in recruitment in Bonavista Bay, but showed minor signs of improvement in the recruitment in the deep strata (184–366 m) in 2016 and again in 2018 (Figure A3.8). In 2018, the DFO survey also observed a significant increase in residual Snow Crab in the two deepest strata of Bonavista Bay (Figure A3.8). Both surveys are consistent in showing the relative abundance of exploitable Snow Crab have had very modest improvements, but still near time-series lows in 2018.

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 Snow Crab plummeted in 2015 to approximately 1 kg/trap and remained at that level for two years (Figure A3.7). In 2018, the CPS survey noted an increase in recruitment to near long-term averages. The drop in recruitment in 2015 was reflected in the 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 stratum (184–366 m) in the DFO surveys. Again, both surveys are consistent in showing the overall relative abundance of exploitable Snow Crab was near a historical low in 2017, but increased slightly in 2018.

In Conception Bay (CMA 6B), catch rates of legal-sized new-shelled Snow Crab were at time-series lows (<1 kg/trap) in 2017 and 2018 (Figure A3.7, A3.10). Dramatic declines in residual Snow Crab were also observed in CMA 6B in both the CPS and DFO trap surveys (Figure A3.7, A3.10). Both surveys showed an alarming rate of decline in overall relative abundance of exploitable Snow Crab in recent years, from about 30 kg/trap in 2014 to about 1 kg/trap in 2018.

With the recruitment index near zero, all indications are of an exploitable biomass in a near-fully depleted state in this area. The ability for this area to sustainably maintain any fishery in 2019 is highly unlikely.

In the Northeast Avalon (CMA 6C) and Southern Avalon (CMA 8A), the recruitment index of new-shelled legal-sized Snow Crab fluctuated at 3–6 kg/trap between 2011 and 2015, but catch rates of recruits in both CMAs declined to time-series lows in 2017, near 0 kg/trap (Figure A3.7). In 2018, catch rates of recruits remained at or near time-series lows in both CMAs, however, a very modest increase in recruitment was observed in the Southern Avalon. Like Conception Bay, given that trends in residual Snow Crab catch rates have generally lagged behind those in recruitment, the prognosis for the exploitable biomass available to the 2019 fishery is very poor, particularly in the Northeast Avalon (CMA 6C).

St. Mary's Bay (CMA 9A) has been experiencing a prolonged and steady decline in catch rates of recruits since 2010 and both surveys showed the index of new-shelled legal-sized Snow Crab and residual Snow Crab were at time-series lows in 2017 (Figure A3.7). In 2018, catch rates in the both the DFO survey and CPS survey remained near time-series lows (Figure A3.11). Like virtually all other areas, the exploitable biomass in St. Mary's Bay appears severely depleted and prospects for the 2019 fishery are poor.

Overall, the prolonged decline in recruitment throughout the AD has now manifested into low catch rates of old-shelled residual Snow Crab. This is evident in size frequency distributions from large-mesh traps in the CPS surveys, with the abundance of legal-sized Snow Crab eroding to very low levels in all areas in recent years (Figure A3.12), with only very small hints of any recruitment in CMAs 5A, 6A, and 9A. The overall prognosis for the 2019 fishery is very poor throughout most of the AD and no major improvements in biomass available to the fishery are expected in the short term.

The overall pre-recruit abundance index for the AD was at its lowest level in a decade in 2015, but has since returned to near the decadal average (Figure 38). However, it must be cautioned that this decadal average level of pre-recruits has been associated with the recent prolonged decline in exploitable biomass throughout the AD.

Small-mesh traps from the CPS surveys observed modest increases in adolescent Snow Crab in all CMAs in 2017 and 2018 (Figure A3.13). In St. Mary's Bay (CMA 9A), a particularly large pulse of adolescent Snow Crab with a mode ~63 mm was observed in 2018.

Small-mesh trap size frequency distributions from the DFO surveys in Bonavista Bay (Figure A3.14) suggest that although there are some pre-recruit adolescents remaining in the population in the deepest stratum of the bay, the overall level is below that seen in most years since 2011. The signal of pre-recruits from Trinity Bay improved in 2018, with the relative abundance of pre-recruits the highest in the five year survey time-series (Figure A3.15). The DFO survey in Conception Bay captured virtually no pre-recruit adolescents in any strata from 2011 to 2017, but adolescent males were observed over a broad range of size categories less than exploitable size in 2018 (Figure A3.16). The St. Mary's Bay survey captured a relatively large pulse of adolescent males (<95 mm CW) in the deepest stratum in 2018.

The incidence of BCD, which provides a signal of the relative strength of the density of small and intermediate-sized Snow Crab and associated recruitment prospects, has been virtually nil in Conception Bay for five consecutive years (Figure A3.18).

Overall, the various sources of data are coherent and consistent in showing a broad-scale depleted exploitable biomass in AD 3L Inshore. In the short-term beyond 2019 there are modest inferences of emerging pulses of pre-recruits in the population that could marginally improve 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, the overall scenario of a severely depleted exploitable biomass coupled with low recruitment prospects and high exploitation rates suggests expectations of potential improvements in the short-term must be tempered, particularly if exploitation rates are not better controlled than at present.

Size-at-terminal molt in males has precipitously declined in recent years, suggesting potentially dampened short-term recruitment prospects into the exploitable biomass (Figure 63).

The proposed Precautionary Approach indicates that stock status would be in the critical zone in 2019 (Figure 64). Discards were within the critical zone, CPUE was within the proposed cautious zone and the proportion of females with full egg clutches was considered healthy.

Extremely careful consideration of short-term removal strategies in AD 3L Inshore are advised. The exploitable biomass in most areas is both severely depleted and dominated by old-shelled Snow Crab. Under the current scenario, it is theoretically possible for the fishery to take virtually every large male in the population in some areas. The consequences of near-fully depleting the population of large males are unknown, but biological risks including impacts to stock reproductive capacity are possible.

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), 3L Extended (3Lex), 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 2). 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.

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.

Until recently, this AD has accounted for a steadily increasing proportion of the NL Region landings (Figure 12). Overall, landings increased gradually since 2009 to a historic high of 28,750 t in 2015 (Figure 13). Landings declined by 43% from 2016 to 14,000 t in 2018 because of TAC reductions, to the lowest level in two decades. TACs were reduced in all CMAs in AD 3LNO Offshore in 2017 and 2018, resulting in declined landings (Figure A4.1). CMA 8B has not reached the TAC since 2009, while it has not been taken in CMA 3N200 in the last five years.

Fishing effort increased rapidly from 1992 to the mid-2000s and has oscillated at a similar level since that time (Figure 15), with 1.5 to 2 million trap hauls occurring each year. Overall, standardized CPUE most recently peaked near a time-series high in 2013 and has since declined by 49% to its lowest level since 1992 (Figure 17). Substantial declines have occurred in all management areas in recent years (Figure A4.2), with recent and particularly precipitous declines in CMAs NS, MSex, 3N200, 3L200, and 3Lex. Catch rates are below ~5 kg/trap in CMAs 3L200 and 3N200.

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). More recent reductions in fishery strength are also evident in CMAs NS, MS, and MSex.

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 year 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. In 2018, CMAs 3L200, 3N200, 8B, and NS had end-of-season CPUEs less than 5 kg/trap.

The shape, magnitude, and shell composition of size distributions from at-sea sampling by observers changed considerably from 2008 to 2018 (Figure 20). The mode of the size distributions abruptly shifted left to approximately 92–98 mm CW in 2008–2009, followed by a marked increase in the magnitude of new-shelled Snow Crab in the population during 2010–2012, while the primary mode gradually returned 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 Snow 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. In 2018, the small, localized improvements in recruitment were observed during the fishery in CMAs 3L200, 8B, and MS (Figure A4.4).

Discards in the fishery have been maintained from about 15-20% of the catch throughout the time series (Figure 55). The majority of these discards were consistently old, undersized males (Figure 56). Although not detected through fishery monitoring, historically, levels of soft-shelled Snow Crab in the population were assumed high, as the resource was consistently productive and strong recruitment occurred in most years. The historic situation likely reflects imposition of an efficient harvest that maintained a strong residual biomass that prohibited persistent high levels of soft-shelled Snow Crab from emerging as a major concern in the fishery through trap competition. However, in contrast to the historic situation, the presence of a progressively depleting residual biomass and the virtual lack of soft-shelled Snow Crab in the catch from 2013 to 2017, more likely reflects a low level of soft-shelled Snow Crab in the population as trap competition has is now likely lower, signaling the broad-scale dissipation of recruitment (Figure A4.5). In 2018, small increases in soft-shelled Snow Crab were observed in the last half of the fishery (Figure A4.5).

Total mortality declined from its highest observed level in 2016 to a relatively low level in 2018 (Figure 53). The exploitation rate index increased by a factor of five from 2014 to 2017, and remained high in 2018 (Figure 53). The exploitation rate index would decline to near the long-term average with status quo removals in 2019. However, based on exploitation rates derived from the CPS trap survey, status quo removals in 2019 would cause exploitation rates to increase substantially in all CMAs and reach new time-series highs in all CMAs, except CMA 3L200 (Figure A4.6).

The recent level of fishery exploitation is a major contributor to resource declines, exacerbating reduced levels of recruitment into the biomass. The biological outcomes of promoting a severely depleted population of large males are unknown and will be monitored in the forthcoming years. The present scenario could be of benefit to management moving forward in assessing how heavily a Snow Crab resource can be exploited without invoking serious harm or promoting unwanted outcomes through fishing.

Surveys

The trawl survey exploitable biomass index, which covers the entire AD, has precipitously declined by about 75% from 2013 to 2016. The trawl-derived exploitable biomass index showed a modest increase in 2018, but both it and the trap-derived exploitable biomass index remain at or near time-series' lows (Figure 33, Figure 34). All surveyed management areas were at or near historical lows for exploitable biomass in 2017 and 2018 (Figure A4.6). Most surveyed CMAs were at or near historical low catch rates of residual crab (old-shelled, legal-sized crab) in 2017 and 2018 (Figure A4.7). Particularly dramatic declines in survey catch rates have occurred in the past two to three years in CMAs 3Lex, MS, and MSex.

Both the trawl and trap surveys show considerable spatial contraction in high catch rates of exploitable Snow Crab in recent years (Figure 8, Figure 31). The trawl survey index of exploitable biomass shows the resource has become increasingly localized into portions of NAFO Div. 3L; the majority of survey trawls in NAFO Divs. 3N and 3O caught no exploitable Snow Crab for the last four years and catches that were noted in these divisions were generally recorded near the northern portion of these divisions. Similarly, the CPS trap survey is also showing that the distribution of exploitable Snow Crab is becoming contracted in the northern portion of the Grand Bank (Figure 8). However, in 2018, the Whale Deep exhibited very modest signs of improvement while the high catches in the northern portion of the Grand Bank continued to contract. 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 declines in exploitable biomass that were noted in the trawl survey 1–2 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. Nevertheless, the recorded spatial contraction and reduced biomass index reflected in the CPS trap survey indicates that prime fishing grounds in AD 3LNO are experiencing declines in exploitable biomass previously signaled from the trawl survey.

Overall recruitment into the exploitable biomass has been at or near time-series lows in both the trawl and trap surveys in the past three years, but increased slightly in 2018 (Figure 33, Figure 37). This represents trends in all CMAs (Figure A4.7). Despite low catch rates of new-shelled recruits, the proportion of the catch represented by recruitment modestly increased in all CMAs (Figure A4.8).

CPS survey size frequency distributions indicate that the pulse of recruitment that has recently benefitted CMAs MS, MSex, and NS, which first emerged as small Snow Crab in the traps in 2008 and was captured as soft-shelled pre-recruits in 2009, has now fully made its contribution to the exploitable biomass (Figure A4.8). This is particularly evident by the advancement of the primary mode from sub-legal size in each CMA in 2009–2010 to about 115 mm CW in CMAs MS and MSex in 2015 and 2016. The extent to which the modest increase in recruitment observed in 2018 will contribute to the fishery remains unknown. However, collectively, low catch rates of both recruit and residual Snow Crab in most CMAs indicate an overall depleted resource and a population of Snow Crab on the Grand Bank suffering from a lack of adequate renewal and a depletion of all Snow Crab in the exploitable biomass.

Recruitment prospects remain relatively stable but poor. No major increases in the exploitable biomass are expected in 2019. The trawl survey pre-recruit biomass index steadily declined since 2009 and has been at its lowest level for the past five years (Figure 33). The general decline in pre-recruit Snow Crab is widespread, with a steadily depreciating signal of catches of all magnitudes in the trawl survey throughout the AD since 2009 to a nearly barren state in 2015 and 2016. In 2017 and 2018, there were modest increases in the number of trawl stations catching pre-recruits throughout NAFO Div. 3L and the northern portion of Div. 3O. The CPS pre-recruit index has increased in the last three years (Figure 38). This reflects improvements in CMAs 3L200, 3Lex, 8B and MSex (Figure A4.9).

In the short term, the small-mesh traps indicate potential for localized improvements in CMA 8B and possibly CMA MSex in the next few years (Figure A4.9). The pulse of approaching recruits centered at about 83 mm CW in 2018 could benefit CMA 8B fishery in the near future. However, the leading tail of this pulse should already be benefiting the fishery, but it has not been detected in CPUE (Figure A4.2). Given that the exploitable biomass in this area is very low (Figure A4.6) and that the quota has been nowhere near achievable in recent years (Figure A4.1), there is a strong potential that this approaching mode of pre-recruits is or could be subjected to high soft-shell capture mortality before it can contribute to the fishery if adequate controls to protect it are not employed.

Relative to the 1995–2005 period, few small Snow 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 Snow Crab captured during 2001–2003 (Figure 52). The small spike in small Snow Crab abundance seen in the survey in 2010 was also seen in AD 3Ps (Figure 42). This is consistent with the aforementioned trends from small-mesh traps in the CPS survey that have tracked a mode of small Snow Crab on the western Grand Bank that are currently making contributions to the exploitable biomass. Nonetheless, the lack of any sustained strong pulses of small Snow Crab in the survey since the early 2000s is a major point of concern and strongly suggests that, overall, the AD 3LNO Offshore exploitable biomass may not improve markedly. Other factors beyond climate, such as a high level of predation in the past four years (Figure 51) and the recent exceptionally high fishery exploitation rates (Figure A4.6), suggest a strong potential for top-down interferences to override the climate signal in the forthcoming years.

Size-at-terminal molt in males has precipitously declined in recent years, suggesting potentially dampened short-term recruitment prospects into the exploitable biomass (Figure 63).

The proposed Precautionary Approach indicates that stock status would be in the provisional cautious zone in 2019, as indicated by CPUE and discard projections, with the egg clutch index remaining healthy (Figure 64).

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. Snow Crab movements are known to extend across CMA boundaries (Mullowney et al., 2018a) and key resource trends are clearly broad-scale. It is obvious that the resource decline is progressively and aggressively approaching the concentrations of high biomass in the central portion of the population range. Most information suggests low recruitment into the exploitable biomass has been prolonged and that short-term renewal prospects are relatively poor. The fishery is being enabled to exploit this biologically key AD at exceptionally high levels. Biological outcomes of this practice are unknown but could potentially extend beyond AD 3LNO boundaries.

ASSESSMENT DIVISION 3PS

Fishery

The AD 3Ps fishery occurs off the south coast of Newfoundland (Figure 2, 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. 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 1), 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 48). In spring of 2018, the distribution of bottom water was relatively warm, with virtually the entire shallow water plateau of the continental shelf comprised of water approximately 1–2°C and temperatures exceeding 3°C along the slope edges to the west and south and within Fortune Bay (Figure 48). By the fall of 2018, warm bottom water had encroached over much of the St. Pierre Bank and Fortune Bay.

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). In 2018, the landings increased to 1,900 t and exceeded the TAC which was set at 1,792 t. The previous eight years the TAC had not been taken. Effort has declined by 60% since 2014 to be near its lowest level in two decades (Figure 15). These overall trends in removals and effort reflect a relatively consistent pattern in all CMAs (Figure A5.1). However, 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 more than 5 kg/trap in 2018 (Figure 17). CPUE in CMAs 10A and 10B improved from particularly large and precipitous declines in previous years (Figure A5.2). In 2016 and 2017, the fishery in all CMAs (with the exception of CMA 11W) began below or near 5 kg/trap (Figure A5.3). However, in 2018, the start-of-season and end-of-season CPUE levels were higher than observed in the previous three years. CPUE in CMA 11E showed no depletion throughout the season and instead, increased as the season progressed.

In-season data from observer sampling are consistent with the logbook data in depicting an improving fishery throughout much of the AD (Figure A5.4). A particularly significant increase in new-shelled Snow Crab entering the fishery was observed in Placentia Bay (CMA 10A), but improved catch rates across size categories were also observed CMAs 10B and 11E.

Discards comprised half the catch in 2016 and 2017, but declined sharply in 2018 to be near the long-term average (Figure 55). In the past decade, the majority of discards were under-sized old-shelled Snow Crab, a high proportion of which were likely terminally molted adults (Figure 56). After an extended period of time with few soft-shelled Snow Crab reported in the catch, soft-shell occurrences became more prominent from 2014 to 2017 (Figure A5.5). In 2017, levels of soft-shelled Snow Crab in the catch increased throughout the duration of the fishery. This was followed by a recruitment pulse of exploitable Snow Crab in 2018. The greatly reduced proportion of discards in the catch is attributed to the increase in available exploitable Snow Crab that outcompete, small or soft-shelled Snow 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 near its lowest observed level in the time-series in 2018 and status quo removals would result in the exploitation rate index being near a time-series low in 2019 (Figure 53). This reflects trends in all CMAs (A5.6).

Surveys

The in-season trawl survey exploitable biomass index was at a time-series low in 2016, but has improved during the past two years (Figure 33). The post-season trap survey index suggests an increase in the exploitable biomass throughout the major fishing grounds (Figure 34, 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 biomass is attributed to increased survey catch rates observed in all CMAs surveyed, except Fortune Bay (CMA 11E) (Figure A5.7). In the DFO trap survey in Fortune Bay (CMA 11E), total catch rates of exploitable Snow Crab in the two deepest depth strata increased slightly in 2018 from time-series lows in 2017, while the catch rates in the shallowest strata improved in 2017 but declined slightly in 2018 (Figure A5.8).

On the broad-scale, the residual biomass in AD 3Ps, represented by intermediate- to old-shelled legal-sized Snow Crab, began to decline after 2010, but significantly increased in 2018 (Figure 33). 2018 was the first year since 2011 that the trawl survey captured any relatively large catches of exploitable Snow Crab anywhere in the AD (Figure 32).

Size frequency distributions from the CPS survey showed substantial declines in catch rates of legal-sized old-shelled Snow Crab in all occupied CMAs from about 2010 to 2016 (Figure 61). However, with the exception of Fortune Bay, the CPS trap survey observed substantial catch rates of new-shelled and soft-shelled Snow Crab across a wide size range in 2017, followed by new-shelled and old-shelled Snow Crab in 2018 (Figure A5.9).

The decline in the exploitable biomass and the subsequent increase in 2017 reflect trends in recruitment. Overall recruitment into the exploitable biomass was been at its lowest observed level in recent years, but increased slightly in 2017 (Figure 37). Recruitment into the exploitable biomass was near a decadal high in 2018, with the exception of Fortune Bay. Despite a small decline in recruitment available to the 2019 fishery, survey data of pre-recruit abundance suggest short-term prospects have improved significantly from the recent 2013–2016 low period (Figure 33, Figure A5.10). The distribution of pre-recruit Snow Crab appears concentrated on the major fishing grounds of the division (Figure 40). Prospects for Fortune Bay remain relatively low, with few signs of significant recruitment prospects in the next 2–4 years (Figure 40, Figure A5.11). Small-mesh traps from the DFO survey in Fortune Bay have captured virtually no adolescent Snow Crab of any size for the past six years (Figure A5.11); the few Snow Crab captured were mostly small terminally molted adults.

The 2018 recruitment pulse likely corresponds with the presence of a relatively large mode of small Snow Crab in the trawl survey from 2009 to 2011 (Figure 41, Figure 52). The prior major prolonged pulse of Snow Crab of this size occurred from 2003 to 2005. Subsequently, the pre-recruit biomass index increased to a very high level in 2009 (Figure 52), a lag period of 4–6 years from detection of small Snow Crab in the survey. In extension, the exploitable biomass index was high from 2009–2011. The delayed arrival of the 2009–2011 pulse of small Snow Crab to recruitment was likely the result of a significant skip-molting event that occurred in AD 3Ps in 2012 and 2013. It was shown at the present assessment that in these years nearly all Snow Crab captured during trap and trawl surveys skip-molted.

The ability to define short-term prospects was compromised by the abandonment of the CPS survey in most areas in 2015 and 2016. Reliable resource assessment depends on consistency in surveying. The CPS survey was a harvester-driven initiative and the outcomes of it directly affect the fishing industry. All applicable measures should be taken to ensure this survey does not cease when resource shortages occur. Ultimately, small catches are as informative as large catches.

Unlike other ADs, the size-at-terminal molt of males in AD 3Ps appears to be possibly recovering after precipitously declining in recent years (Figure 63). It is unknown if this trend will continue, but trends should be monitored closely moving forward.

The proposed Precautionary Approach indicates that stock status would be in the provisional cautious zone in 2019 (Figure 64). Discards and CPUE were within the proposed cautious zones, while the proportion of females with full egg clutches was considered healthy.

Overall, prospects in AD 3Ps are presently more favourable than in all other ADs. The resource has not yet recovered, but has improved markedly. The low exploitation rates in 2017 and 2018 are not thought to be inconsequential to this improvement. Most indications suggest that removals could be increased in 2019 with little risk of detrimental impacts to the resource, and it is anticipated that if harvest rates remain relatively controlled in the coming years that an improved fishery can be sustained beyond 2019.

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 2). The offshore CMA OS8 is separated from the numerous inshore CMAs by a line at eight nautical miles 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 1). 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 Assessment Division are the warmest along the NL shelf (Figure 48), 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 increased from a historic low of 190 t in 2010 to 750–900 t in 2013, but have steadily declined since that peak and were 250 t in 2018 (Figure 13), reflecting patterns in most CMAs (Figure A6.1). Landings and TAC declined in every CMA in 2018 (Figure A6.1). Substantial declines in both were particularly notable in Bay St. George (CMA 12C), Bonne Bay (CMA 12G), and Inner and Outer Bay of Islands (CMAs 12E and 12F). Effort has remained at a fairly low level (~150,000 trap hauls) since 2012 (Figure 15). The offshore fishery has been patchily distributed for the past nine years, with pockets of effort occurring along adjacent inshore management area lines (Figure 16).

Standardized CPUE has been low throughout the time-series relative to most other Assessment Divisions and has declined since 2013 to below the long-term median (Figure 17), reflecting trends throughout all major fishing areas (Figure A6.2). Most CMAs experienced catch rates near time-series highs during 2012–2013, but CPUE has declined to low levels during the past four years in most areas (Figure A6.2).

There appears to be high levels of resource depletion by the fishery in most major fishing areas (Figure A6.3). Strong declines or extremely low CPUEs throughout the season in 2018 are particularly evident in Bay St. George (CMA 12C), Inner and Outer Bay of Islands (CMAs 12E and 12F, Bonne Bay, (CMA 12G), and the offshore (CMA OS8). The depletion plots give an overall suggestion of a broad-scale fishery that has recently declined, but showing localized areas of improvements (e.g., CMA 12H). Fishery observer coverage in AD 4R3Pn remains extremely poor (Figure A6.4), but overall more common incidences of soft-shelled catches were evident in 2016 and 2017, but absent in the limited observed catch in 2018 (Figure A6.5).

The overall exploitation rate index declined to below the long-term average in 2018 (Figure 58), reflecting trends in the major fishing areas (Figure A6.6). Status quo removals in 2019 would result in little change to the exploitation rate index. However, exploitation rate indices would remain relatively high in Bay St. George (CMA 12C) and Bonne Bay (CMA 12G) under status quo removals.

Surveys

The exploitable biomass in AD 4R is severely depleted, with few residual Snow Crab in the population. The trap survey exploitable biomass index most recently peaked in 2012 and declined to a time-series low in 2017 (Figure 34). The index increased slightly in 2018, reflecting localized improvements in CMA 12EF (Figure A6.7). Overall total catch rates were improved from the levels of 1 kg/trap observed during the 2017 survey (Figure 37, Figure A6.7), but residual catch rates remain extremely low (Figure 37).

The abrupt 2011 increase in the exploitable biomass index (Figure 34) was associated with sharp increases in recruitment (new-shelled legal-sized Snow Crab) in Bay St. George (CMA 12C), and the Inner and Outer Bay of Islands (CMAs 12F and 12E), and an increasing phase in Bonne Bay (CMA 12G) (Figure A6.7). Recruitment into the exploitable biomass was low from 2014 to 2017, but survey data from 2018 suggest localized improvements may occur in 2019, particularly in CMA 12EF) (Figure A6.7).

Size frequency distributions from large-mesh traps showed an influx of recruitment into the exploitable biomass in most CMAs during 2010-2012 that has since dissipated (Figure A6.8). However, a large recruitment pulse nearing exploitable size was observed in Bay of Islands (CMA 12EF) in 2018 (Figure A6.8). Small-mesh trap size frequency distributions tracked approaching modes of adolescent males quite well from 2008 to 2010 (Figure A6.9), immediately preceding the improvements in recruitment into the biomass. Although the signal of strong short-term recruitment prospects (i.e., >75 mm CW adolescents) from these traps is now weak, a pulse of small Snow Crab centered near 55 mm CW emerged in the Outer Bay of Islands (CMA 12F) in 2016 and continues to show a positive, strong signal moving toward exploitable size. A very modest increase in small Snow Crab centered near 70–80 mm was also observed in CMA 12C during the 2018 trap survey. These trends indicate the possibility of modest localized improvements in 1–2 years.

The scenario of a low exploitable biomass and CPUE, coupled with an approaching pulse of pre-recruit Snow Crab in CMA 12EF suggests that excessive fishing in 2019 could be detrimental to yield in subsequent years due to associated high soft-shell mortality. A lower exploitation rate index in 2019 would be required to promote recovery of the resource.

Overall, the exploitable biomass is currently severely depleted, with very few residual Snow Crab. Poor monitoring coverage throughout this AD results in large uncertainty in the biomass estimates provided in 2018 and predictions for 2019. Caution is warranted when developing conclusions from these estimates. This AD is not included in the proposed Precautionary Approach due to ongoing data deficiencies.

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FIGURES

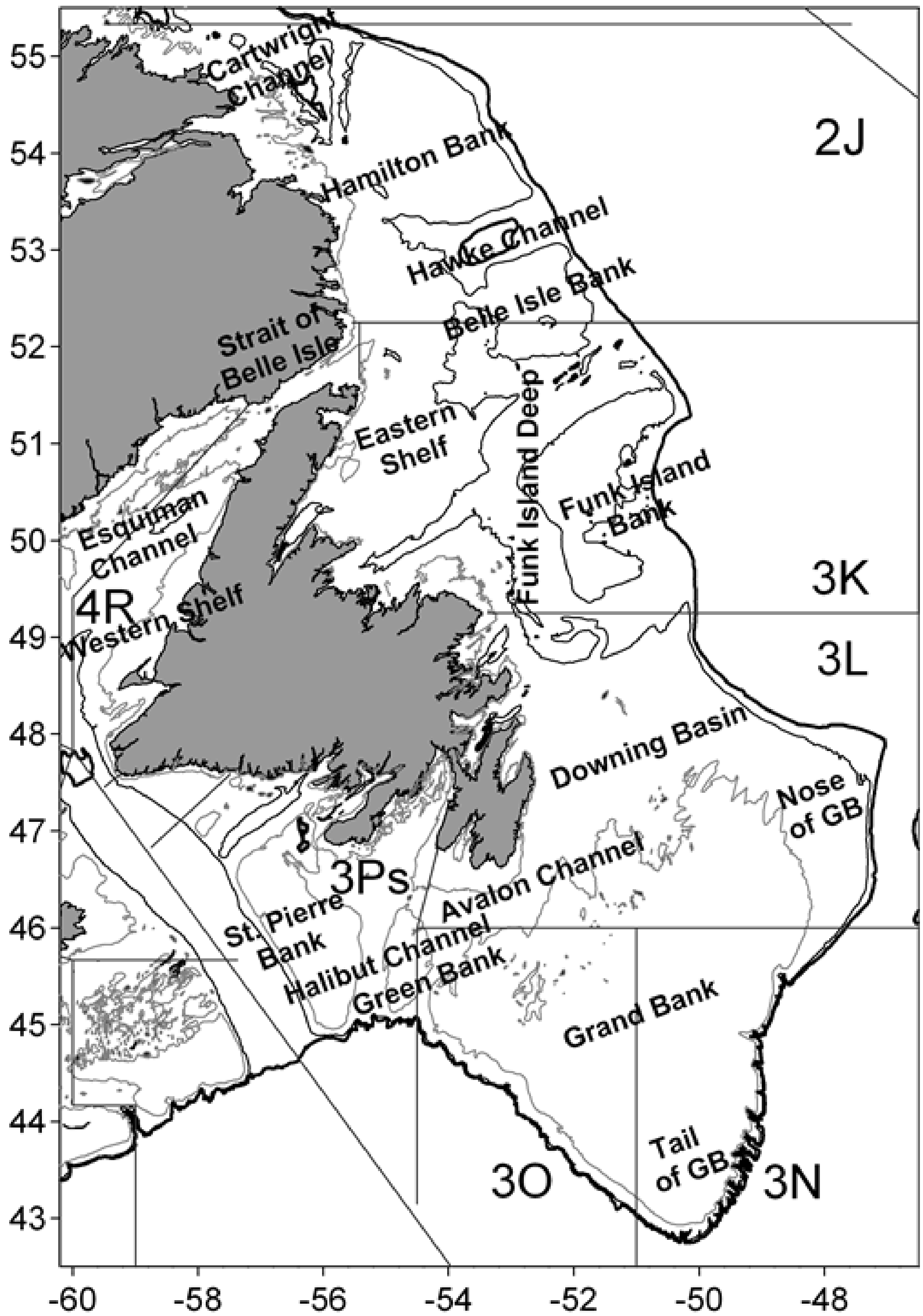

Figure 1. Map of Newfoundland and Labrador Continental Shelf showing place names, bathymetrical features, and Northwest Atlantic Fisheries Organization (NAFO) Divisions.

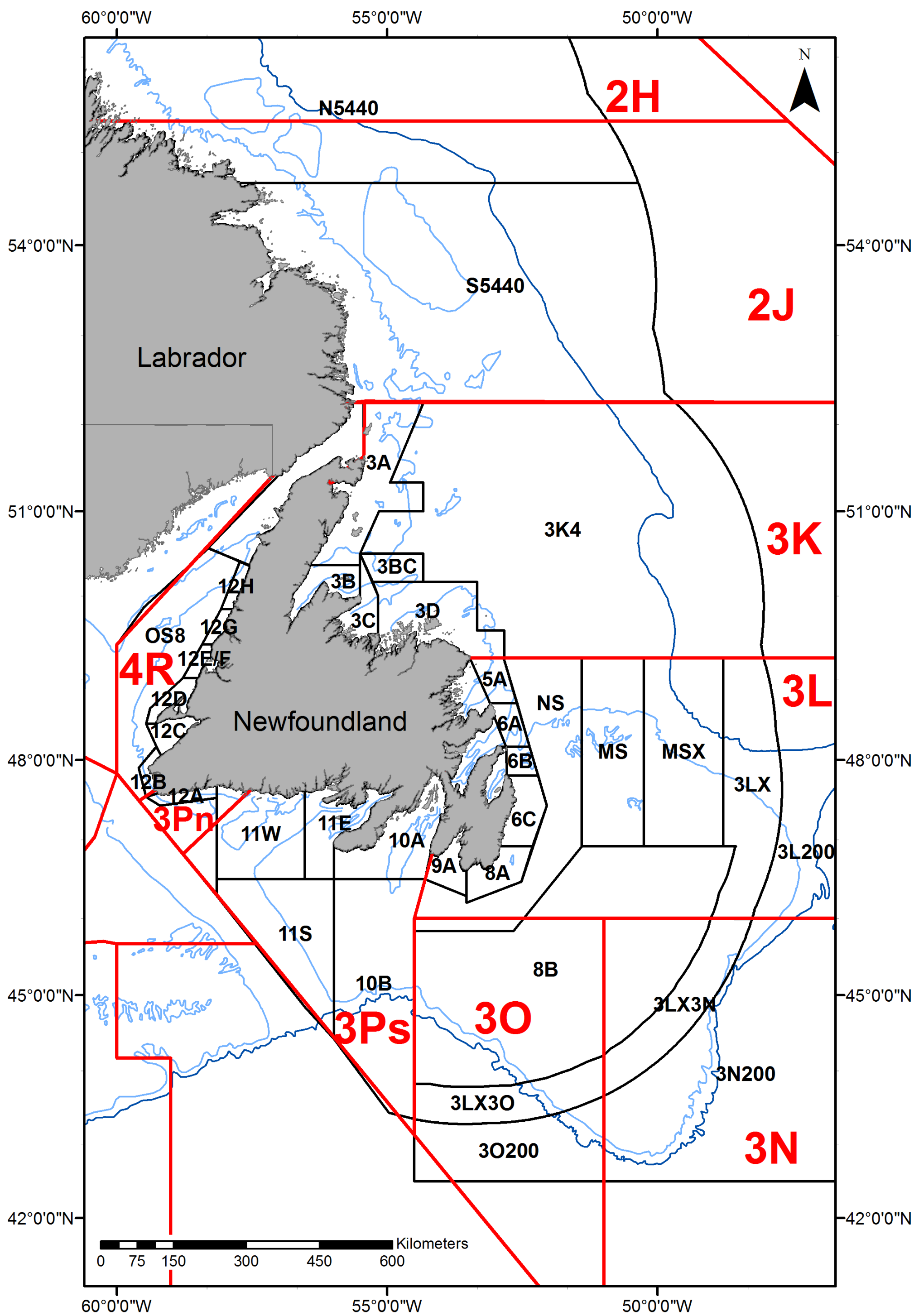

Figure 2. NAFO Divisions (red lines) and Newfoundland and Labrador Snow Crab Management Areas (black lines).

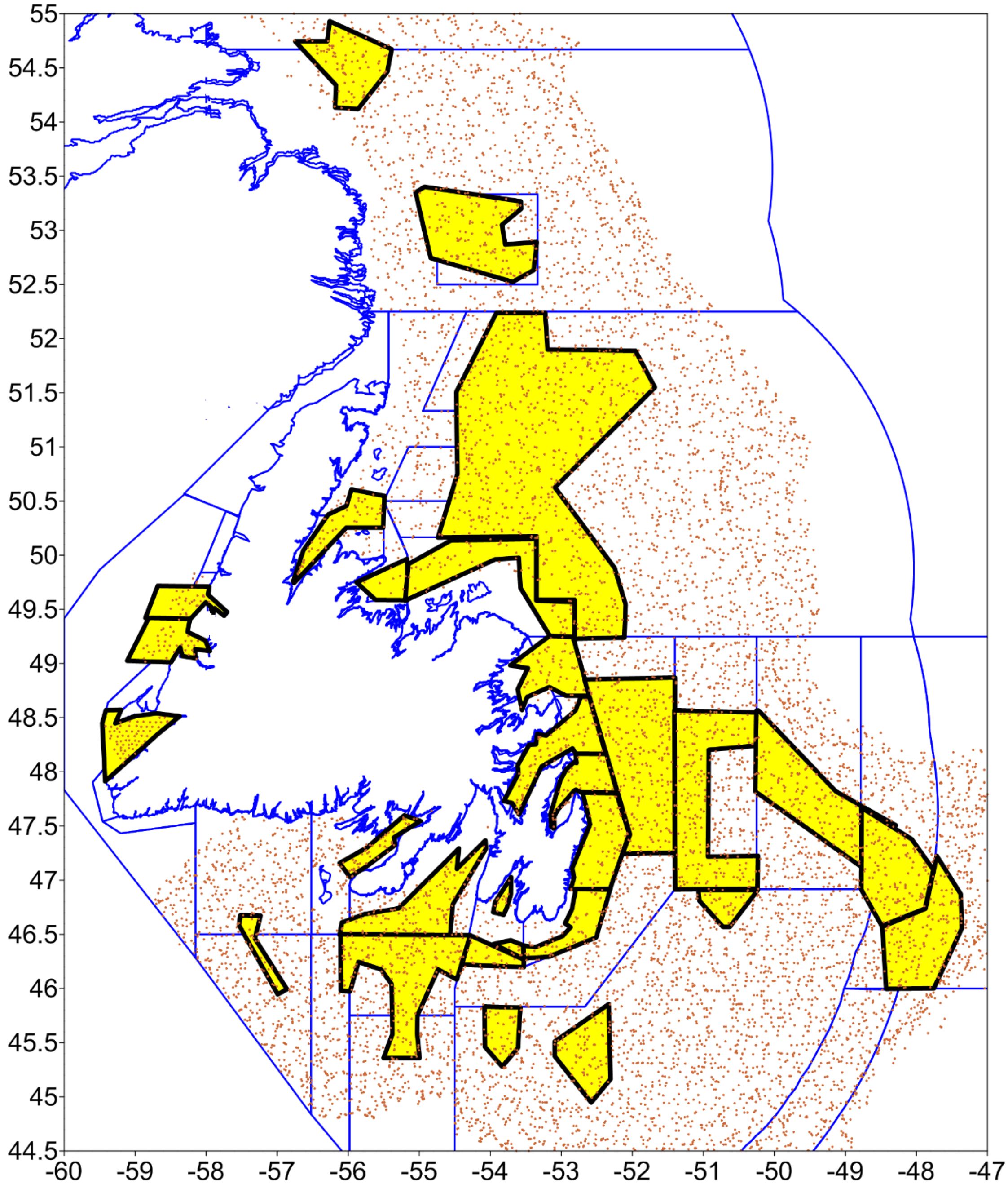

Figure 3. Map of ogmap vertices (red dots) and strata developed for biomass estimation from DFO and CPS trap surveys (yellow polygons).

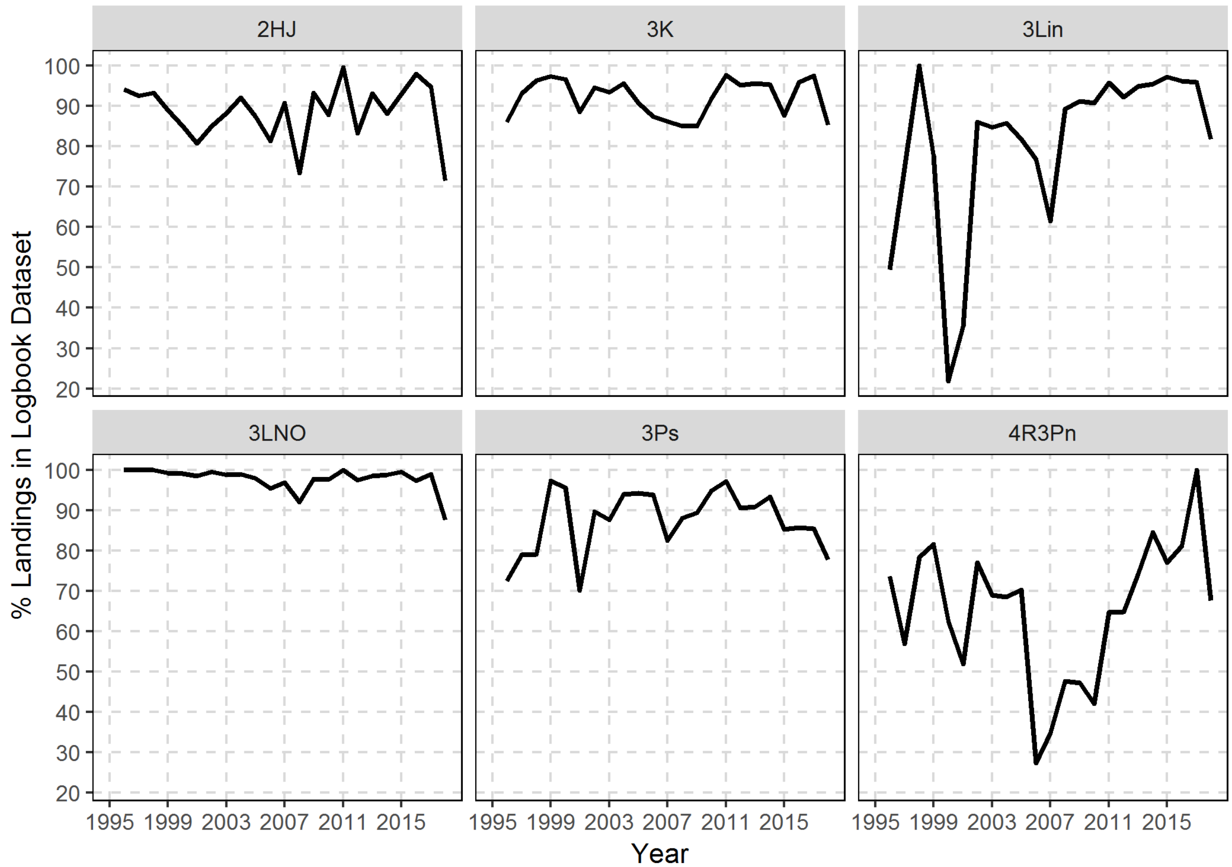

Figure 4. Logbook returns rates by Assessment Division and year (1995-2018).

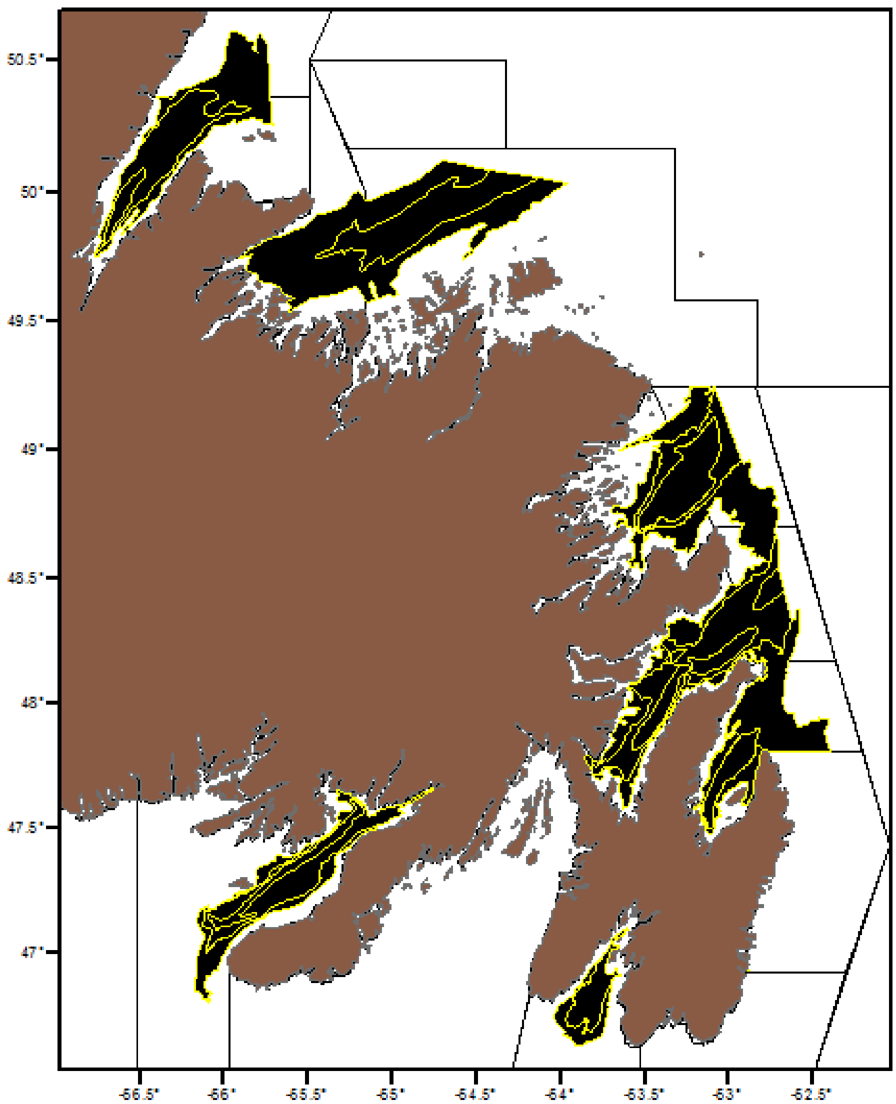

Figure 5. Strata occupied during DFO inshore trap surveys.

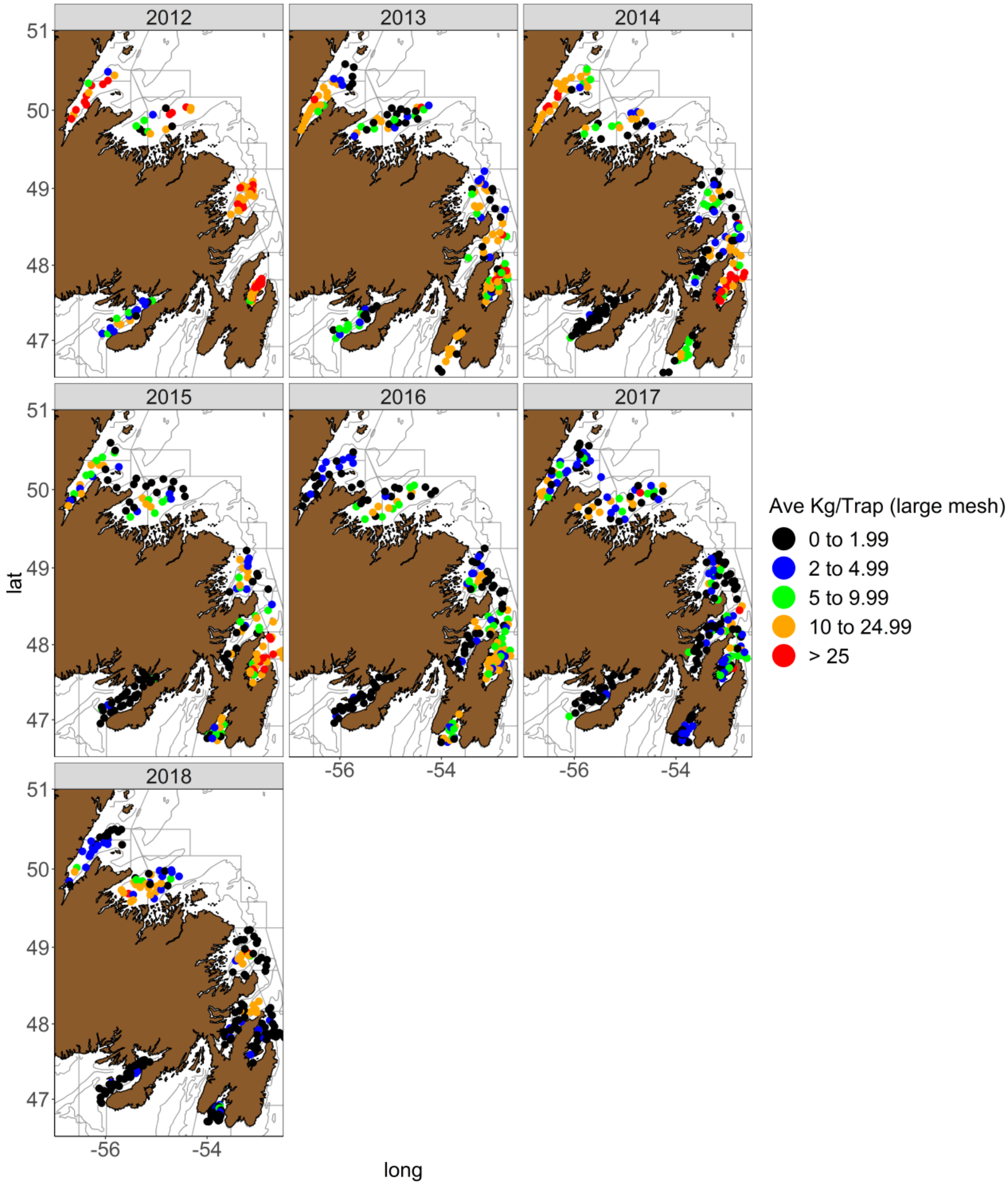

Figure 6. Set positions and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the DFO inshore trap surveys (2012-2018).

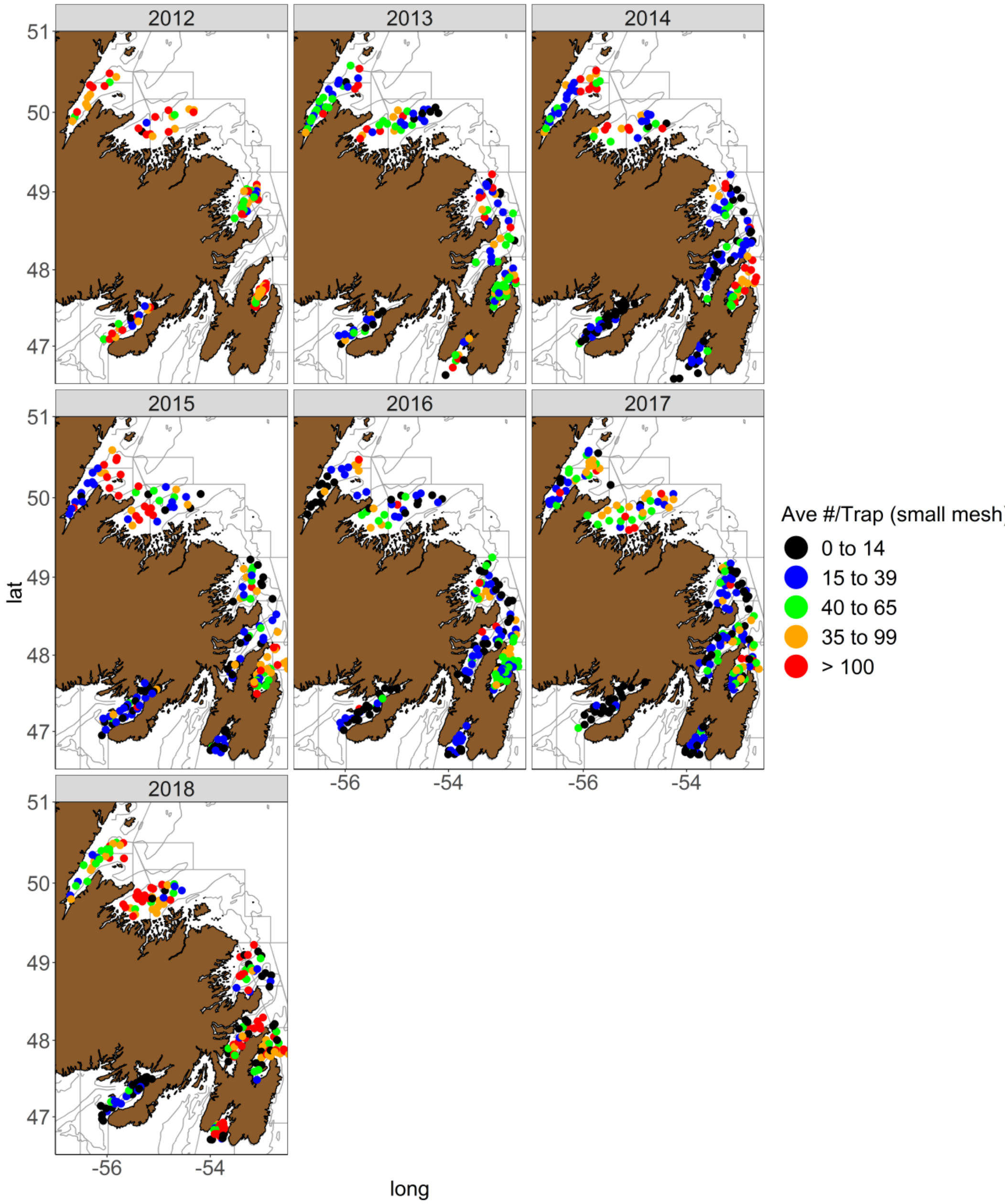

Figure 7. Set positions and CPUE (#/trap) of all Snow Crab in small-mesh traps from the DFO inshore trap surveys (2012-2018).

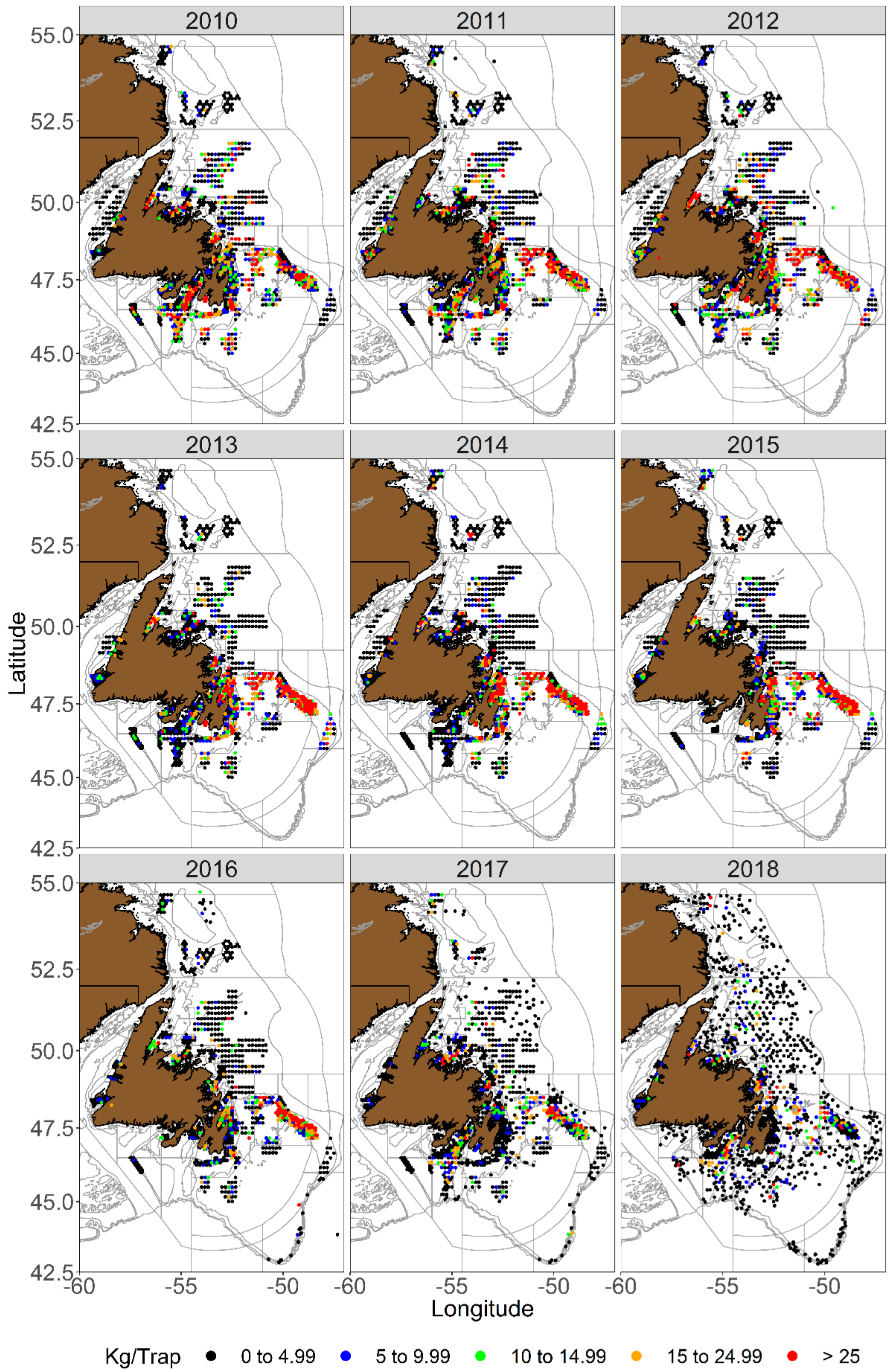

Figure 8. Set locations and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the CPS trap survey (2010-2018).

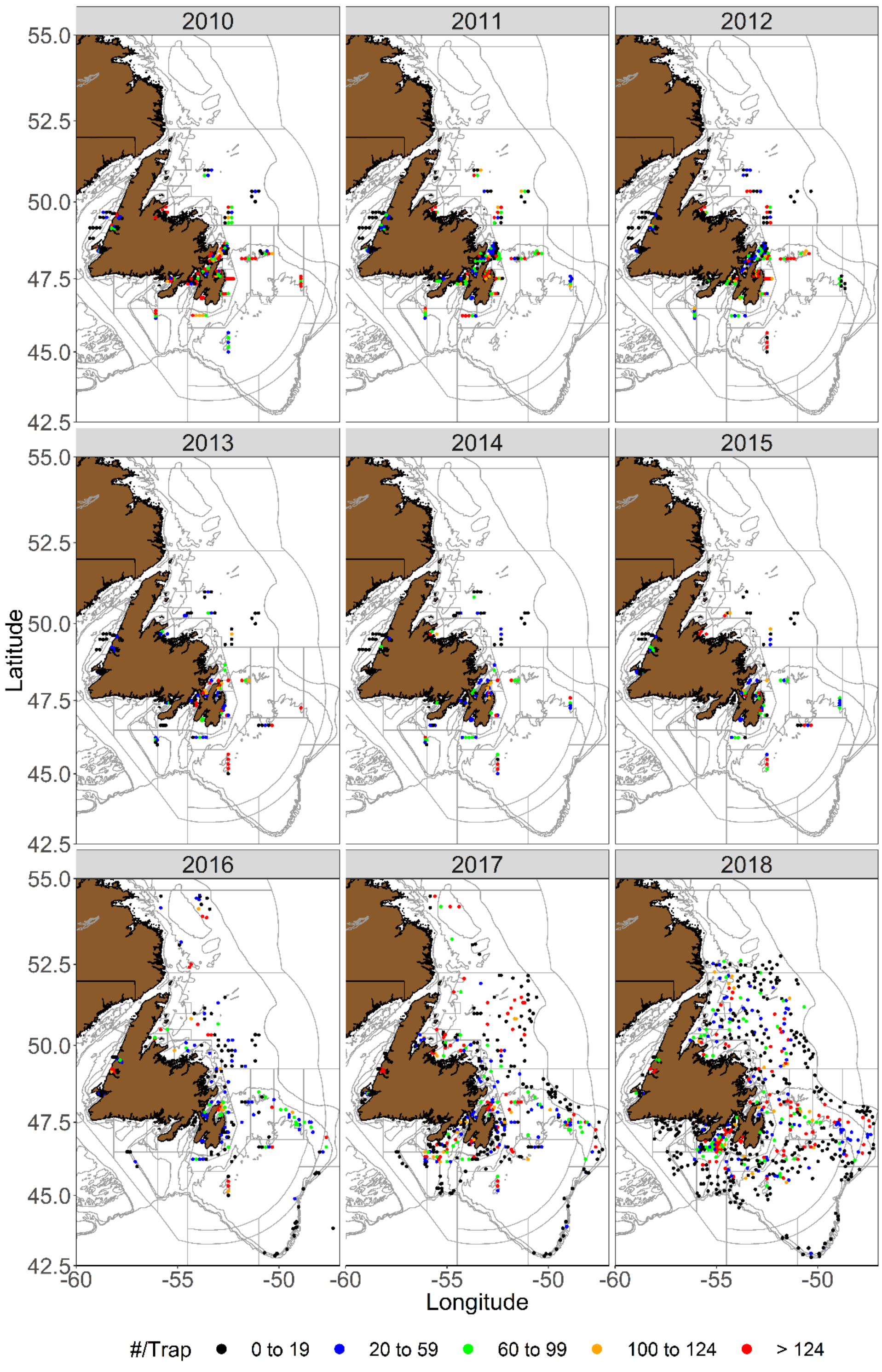

Figure 9. Location of sets and CPUE (#/trap) of Snow Crab in small-mesh traps from the CPS trap survey (2010-2018).

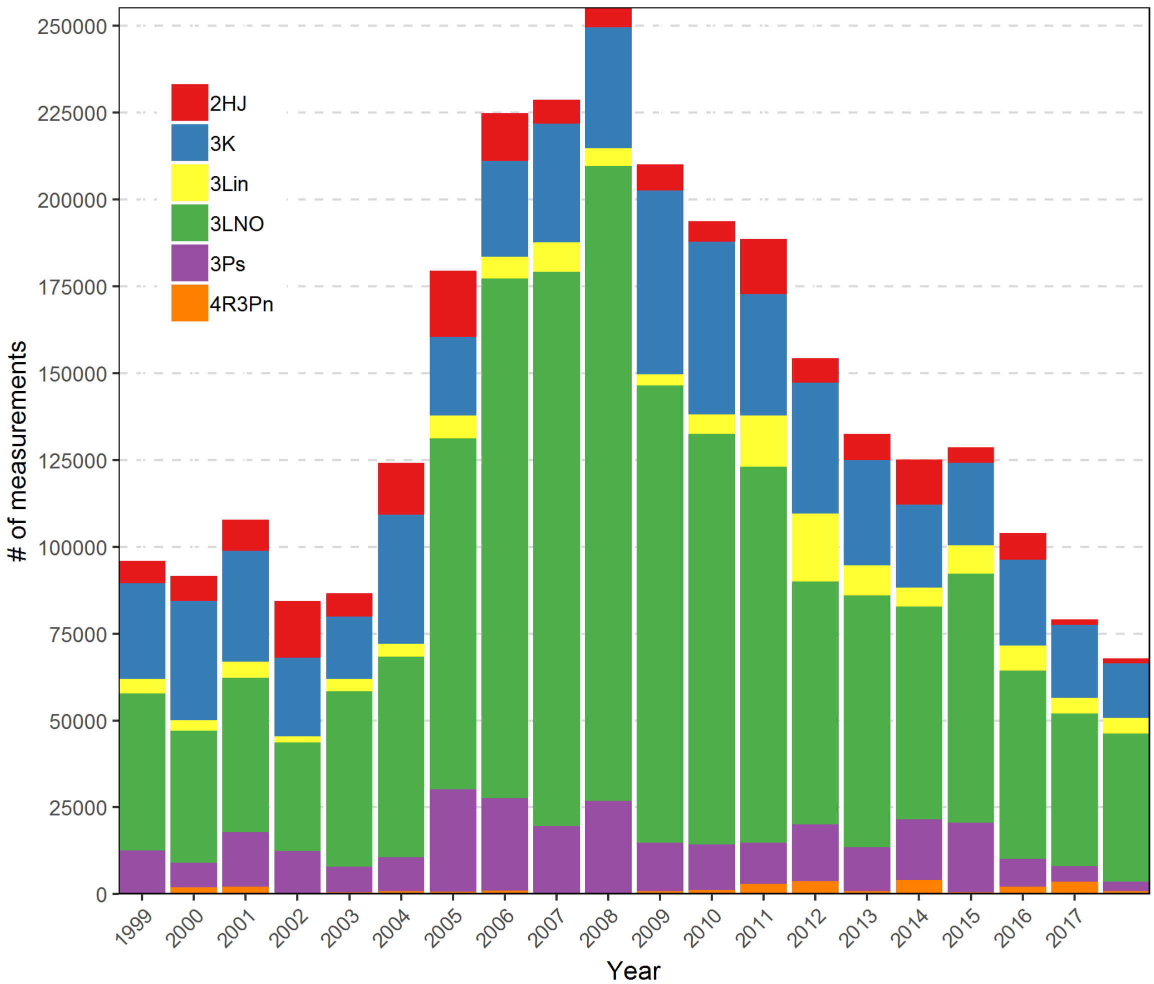

Figure 10. Annual observer sampling by Assessment Division (1999-2018).

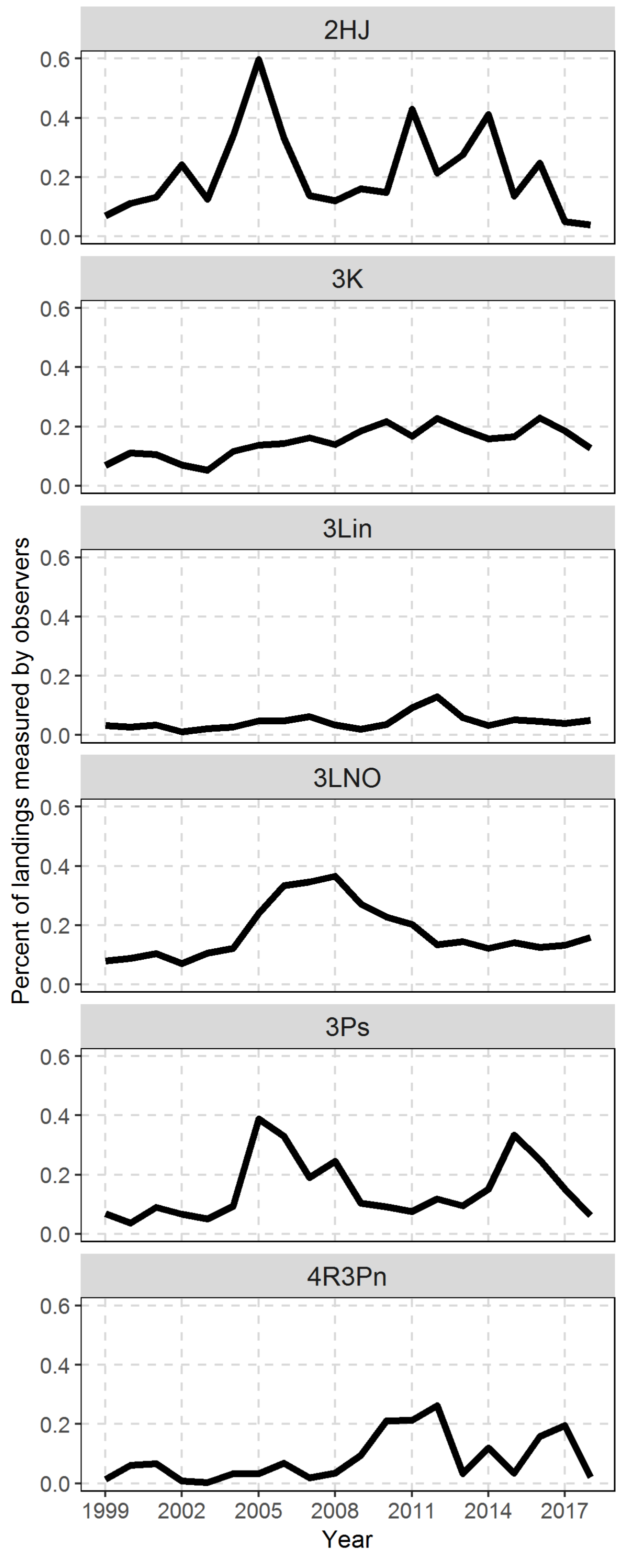

Figure 11. Percent of landings with annual observer sampling by Assessment Division (1999-2018).

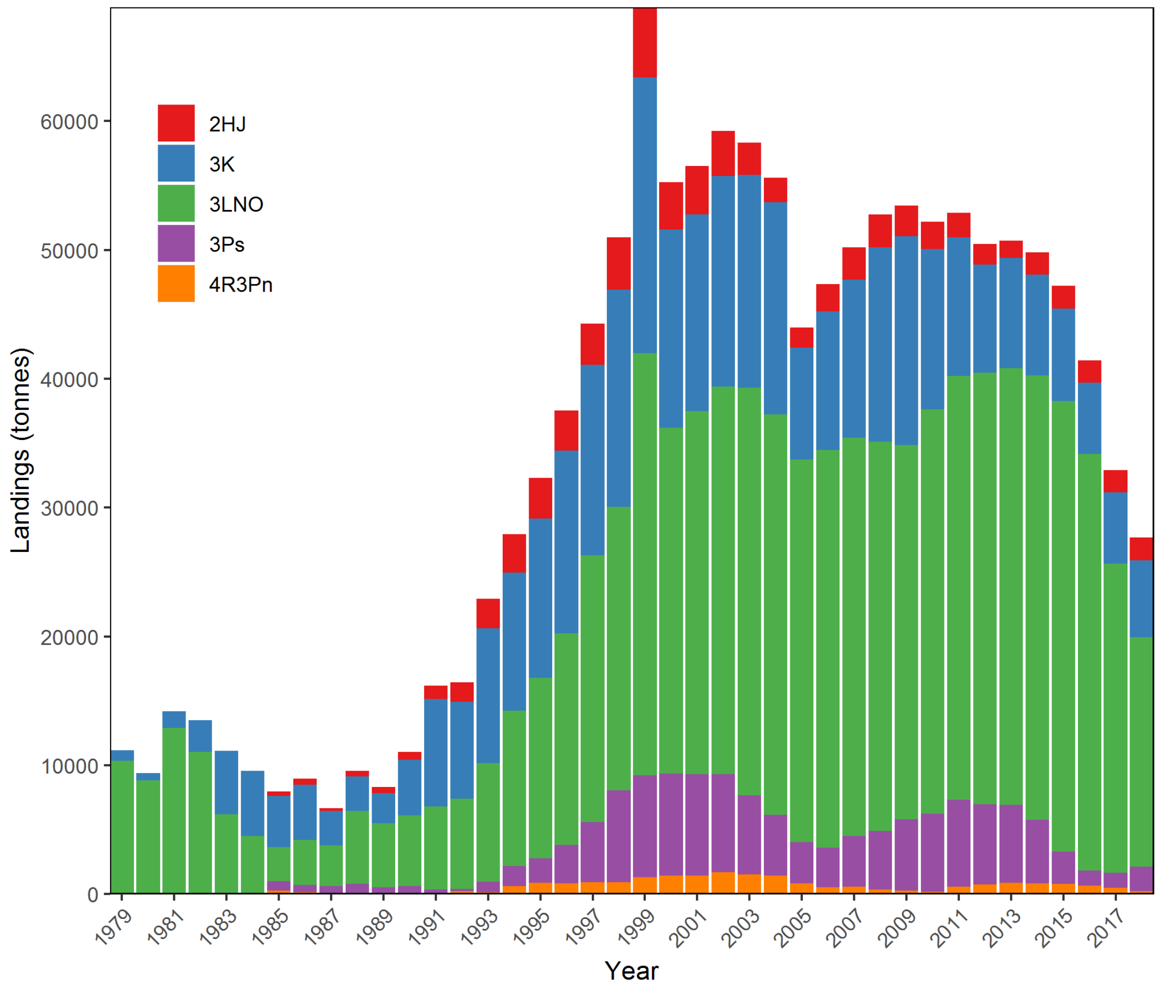

Figure 12. Annual landings (tonnes) of Snow Crab by Assessment Division (1979-2018).

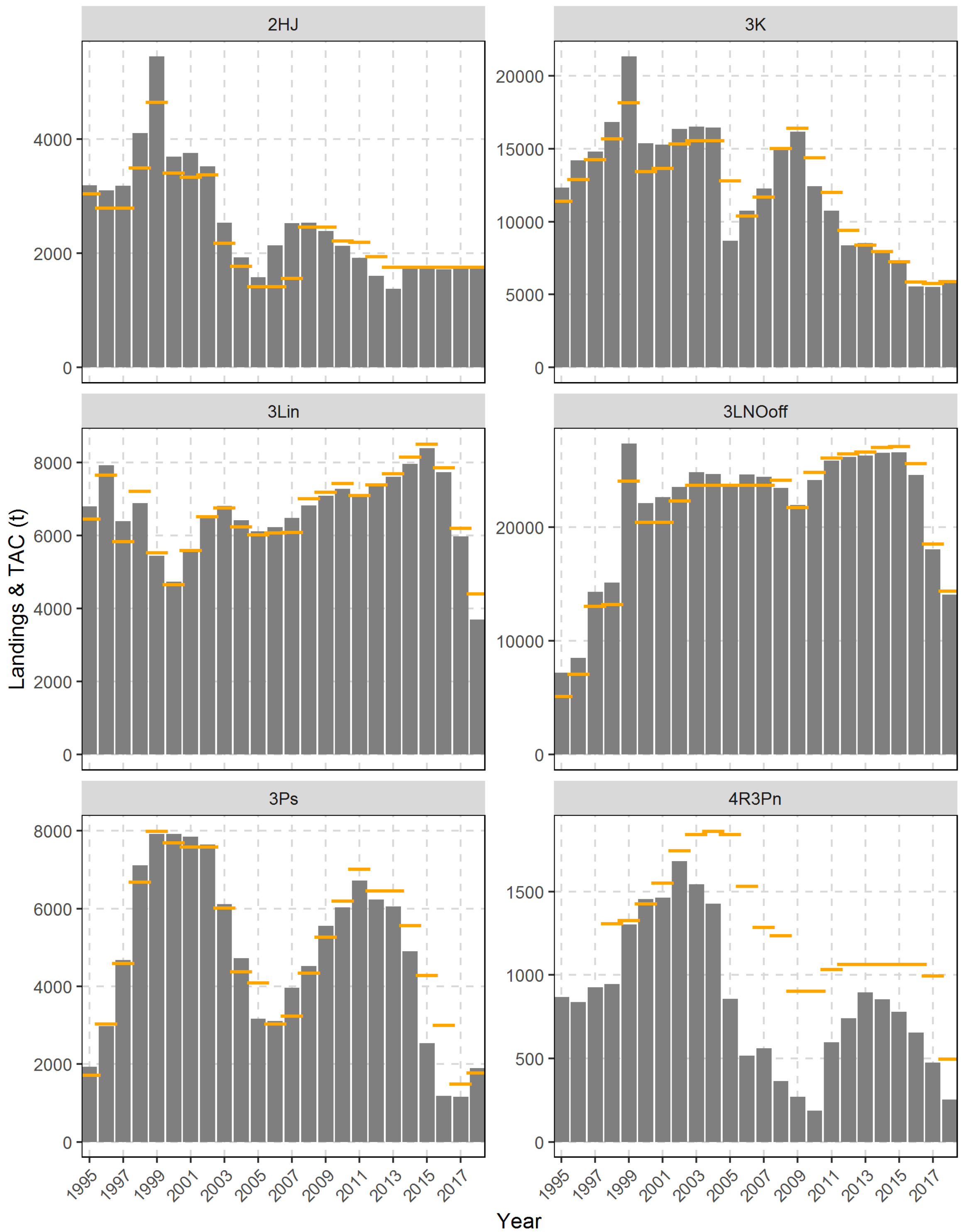

Figure 13. Annual landings (t) of Snow Crab and total allowable catch (TAC) by Assessment Division from 1995 to 2018.

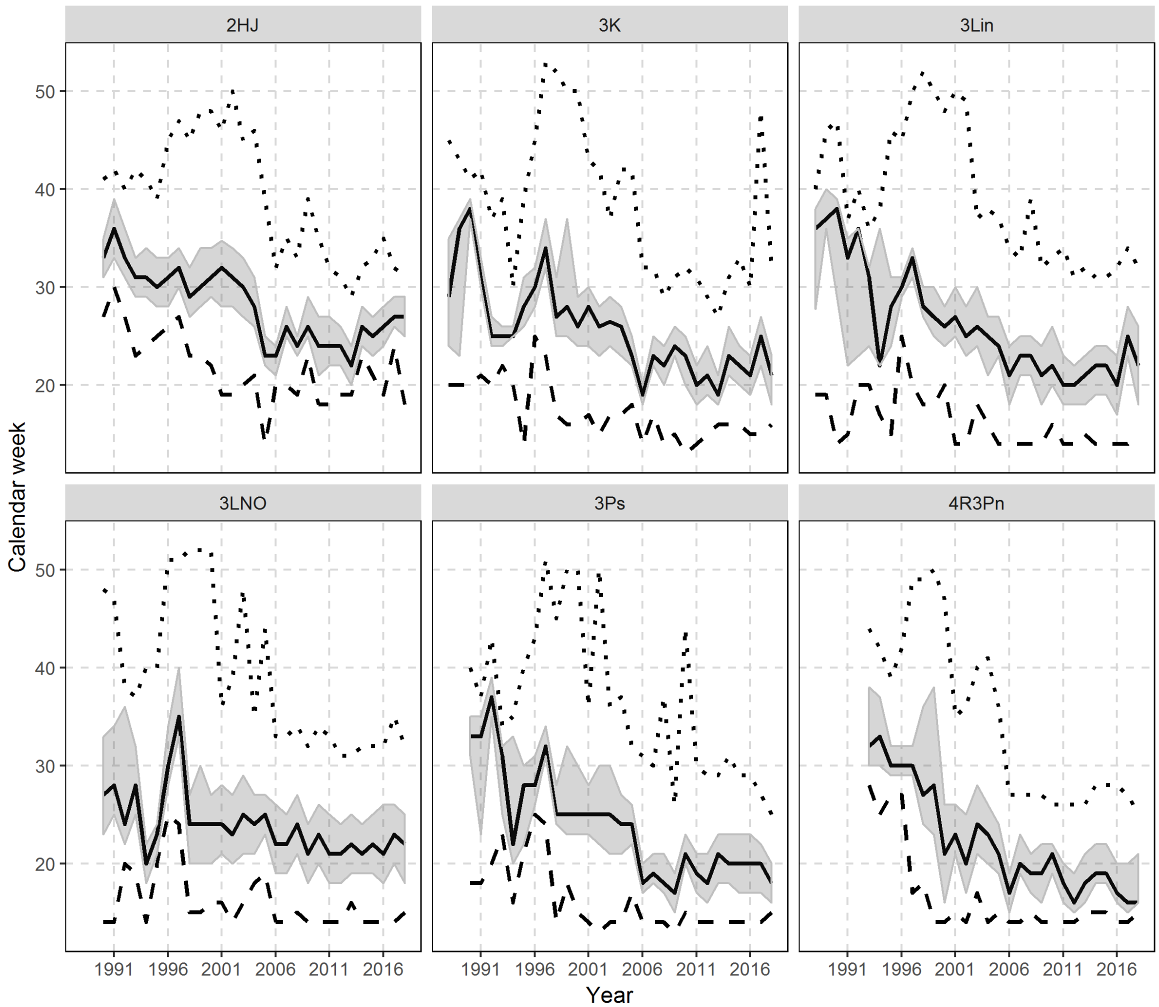

Figure 14. Trends in timing of the fishery by Assessment Division. Solid line = median timing of fishery. Dashed line = start of fishery, Dotted line = end of fishery, Shaded area = fishery 25–75% complete.

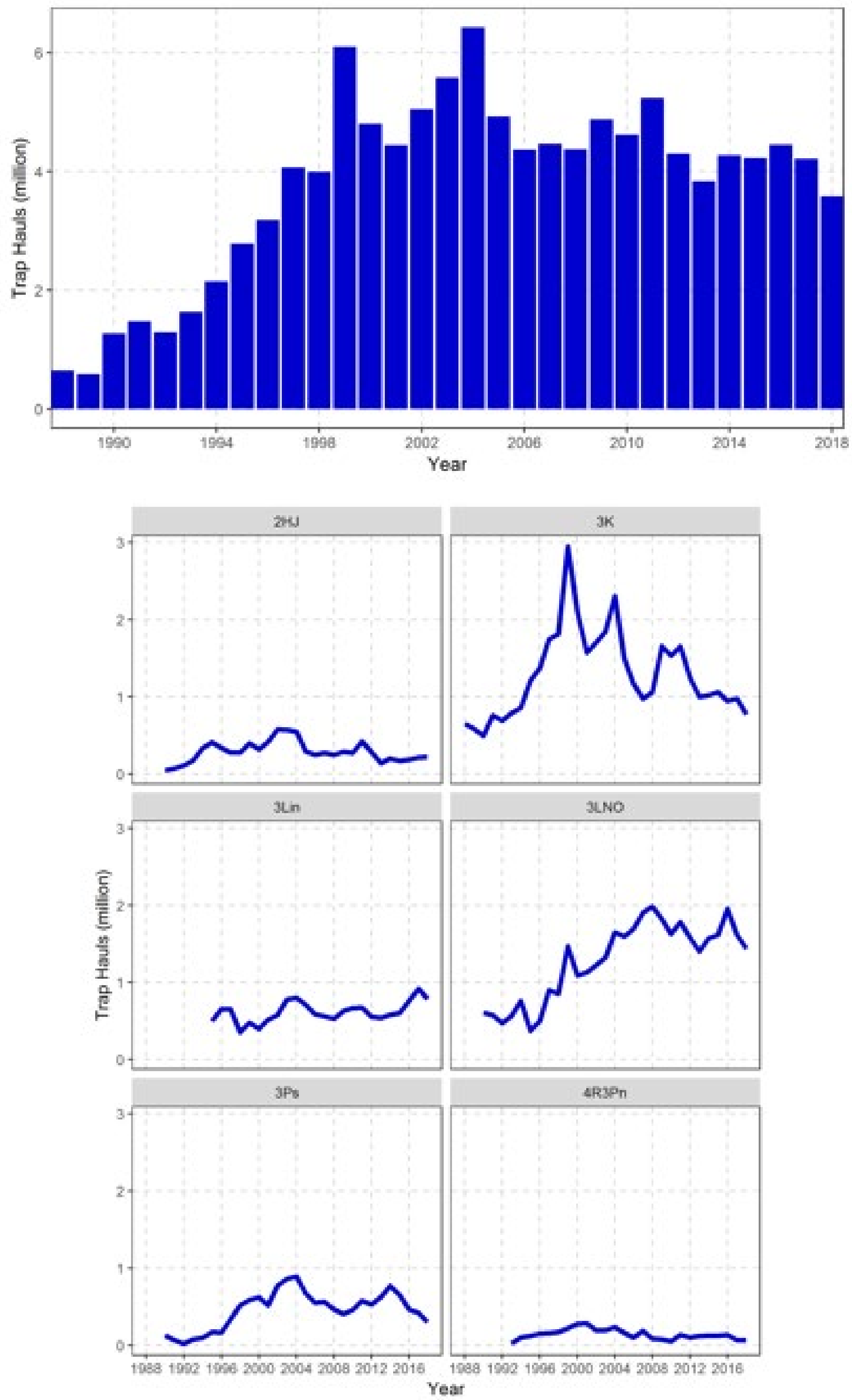

Figure 15. Estimated effort (number of trap hauls) by Assessment Division by year (1988-2018).

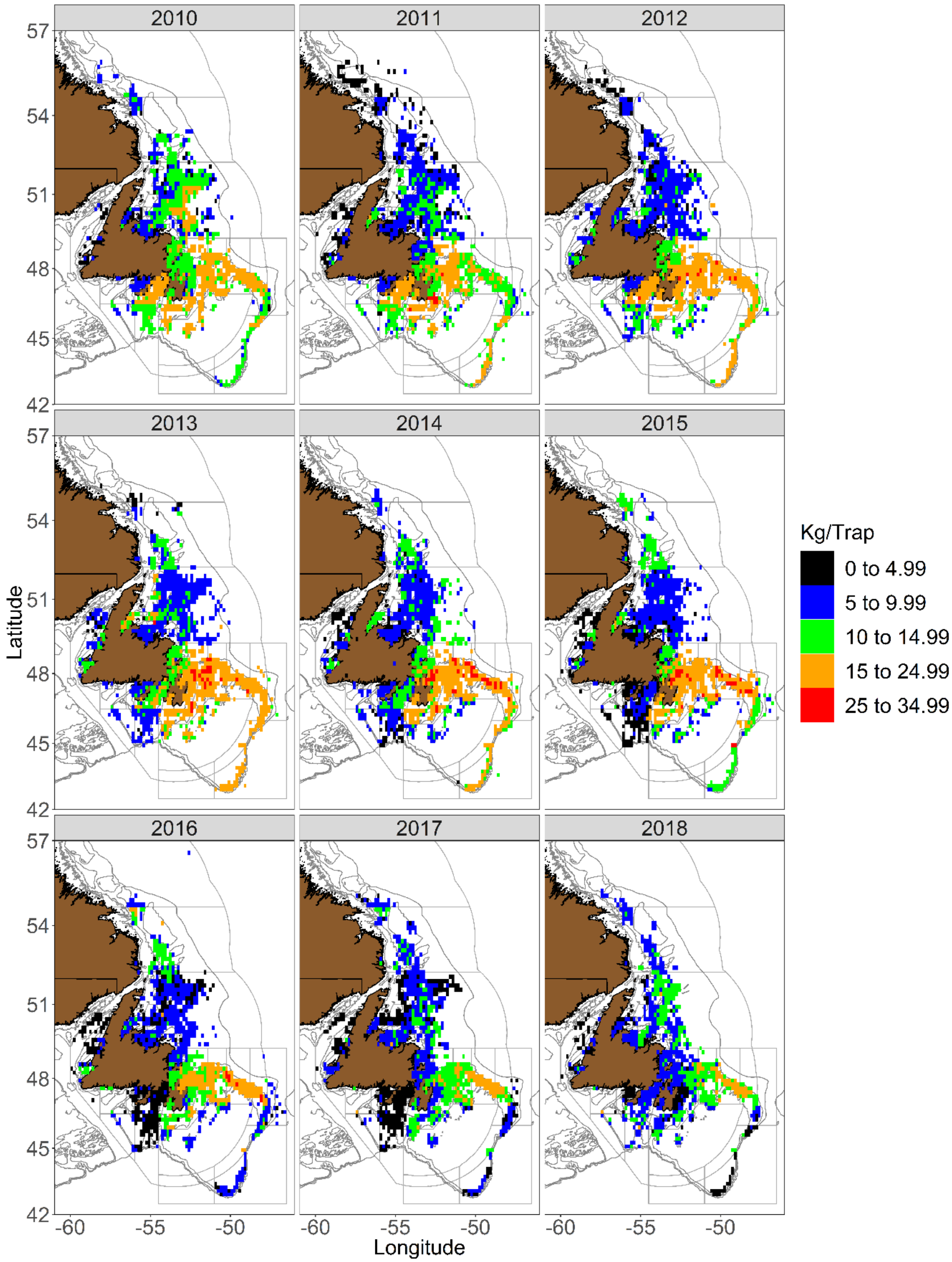

Figure 16. Locations of fishery sets and catch rates (kg/trap) from logbooks (2010-2018).

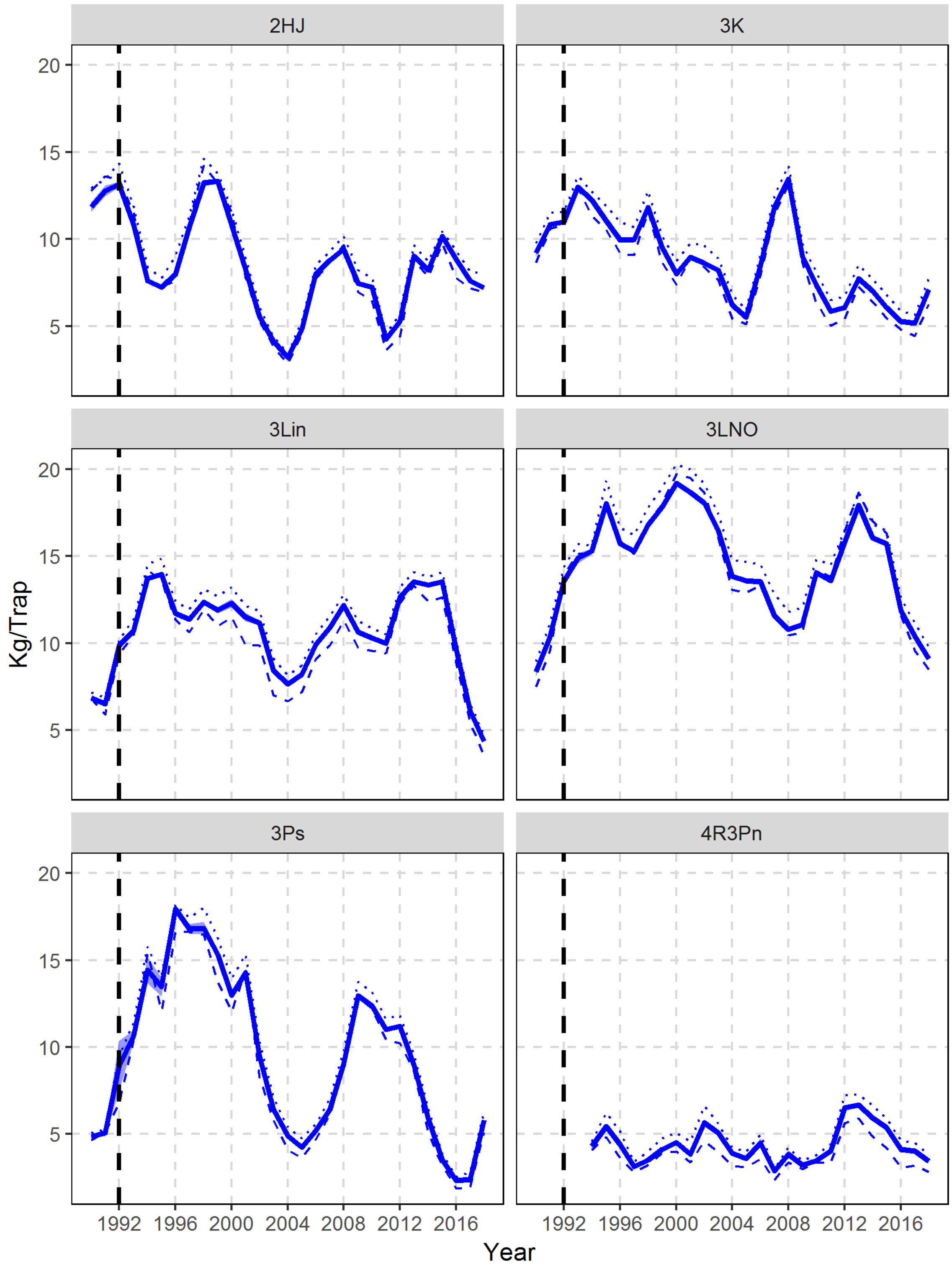

Figure 17. Standardized CPUE (kg/trap) by Assessment Division. Solid line is average predicted CPUE and band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

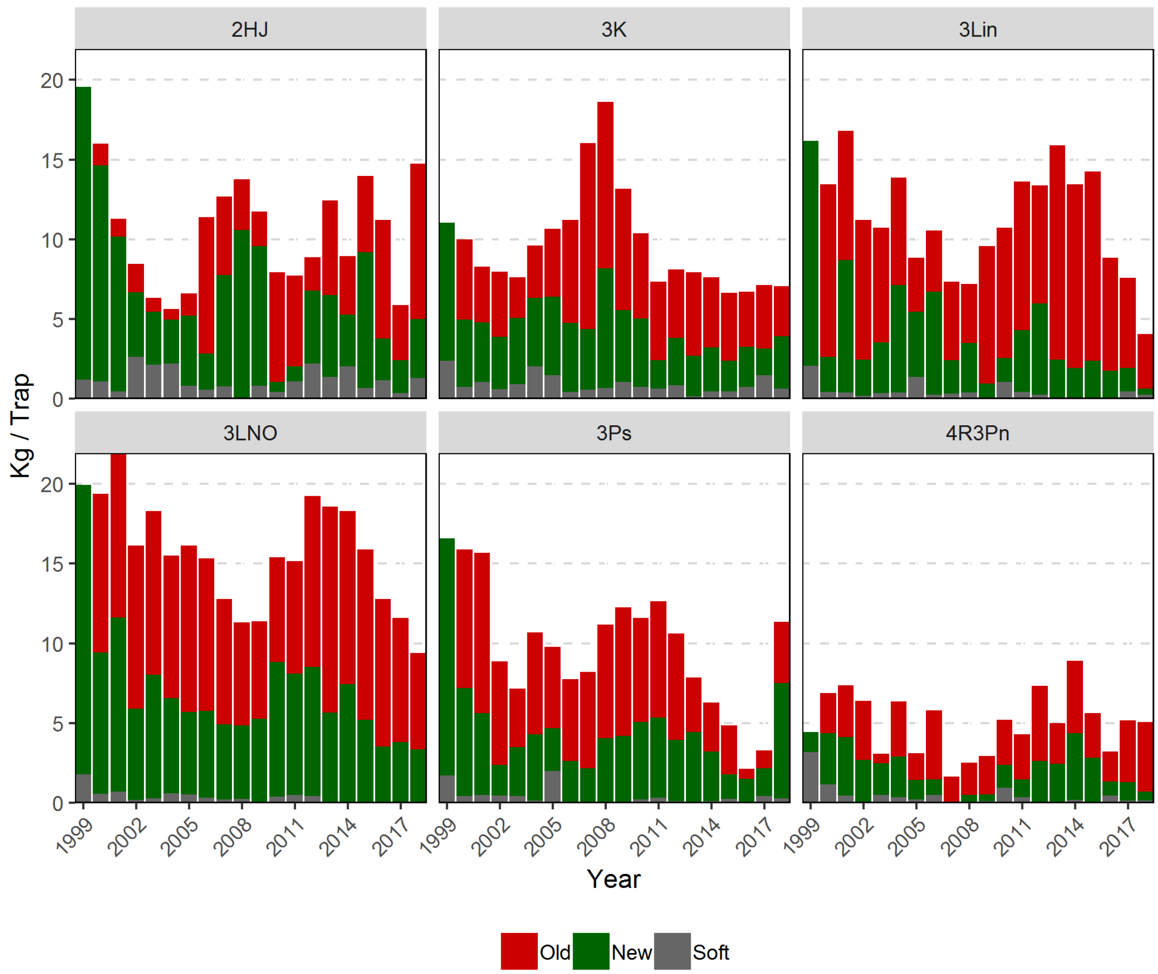

Figure 18. Trends in catch rates (kg/trap) of legal-sized Snow Crab by shell condition from observer at-sea sampling by Assessment Division.

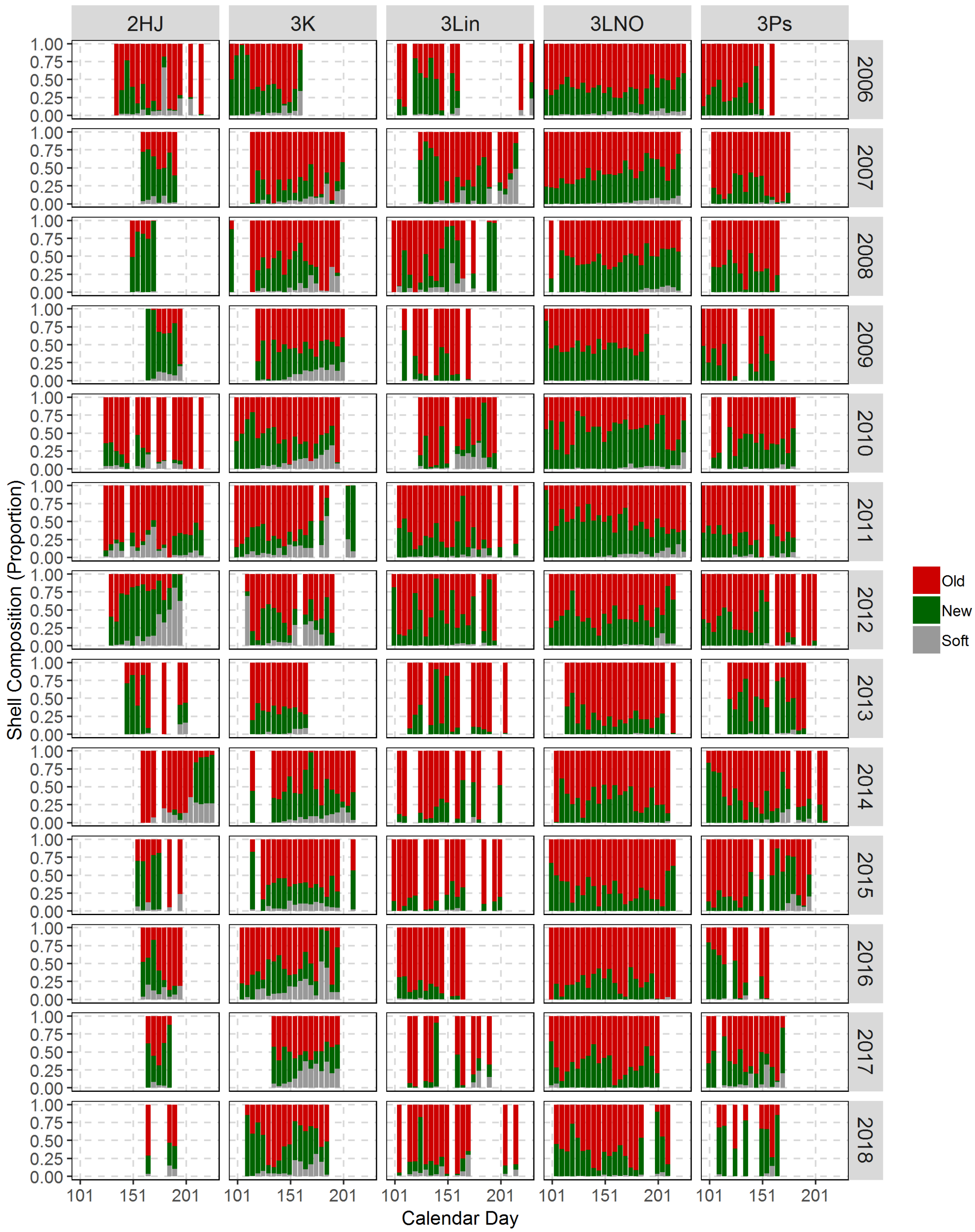

Figure 19. Proportion of legal-sized Snow Crab by shell condition from observer at-sea sampling throughout the fishing season (binned in 5-day increments) by Assessment Division.

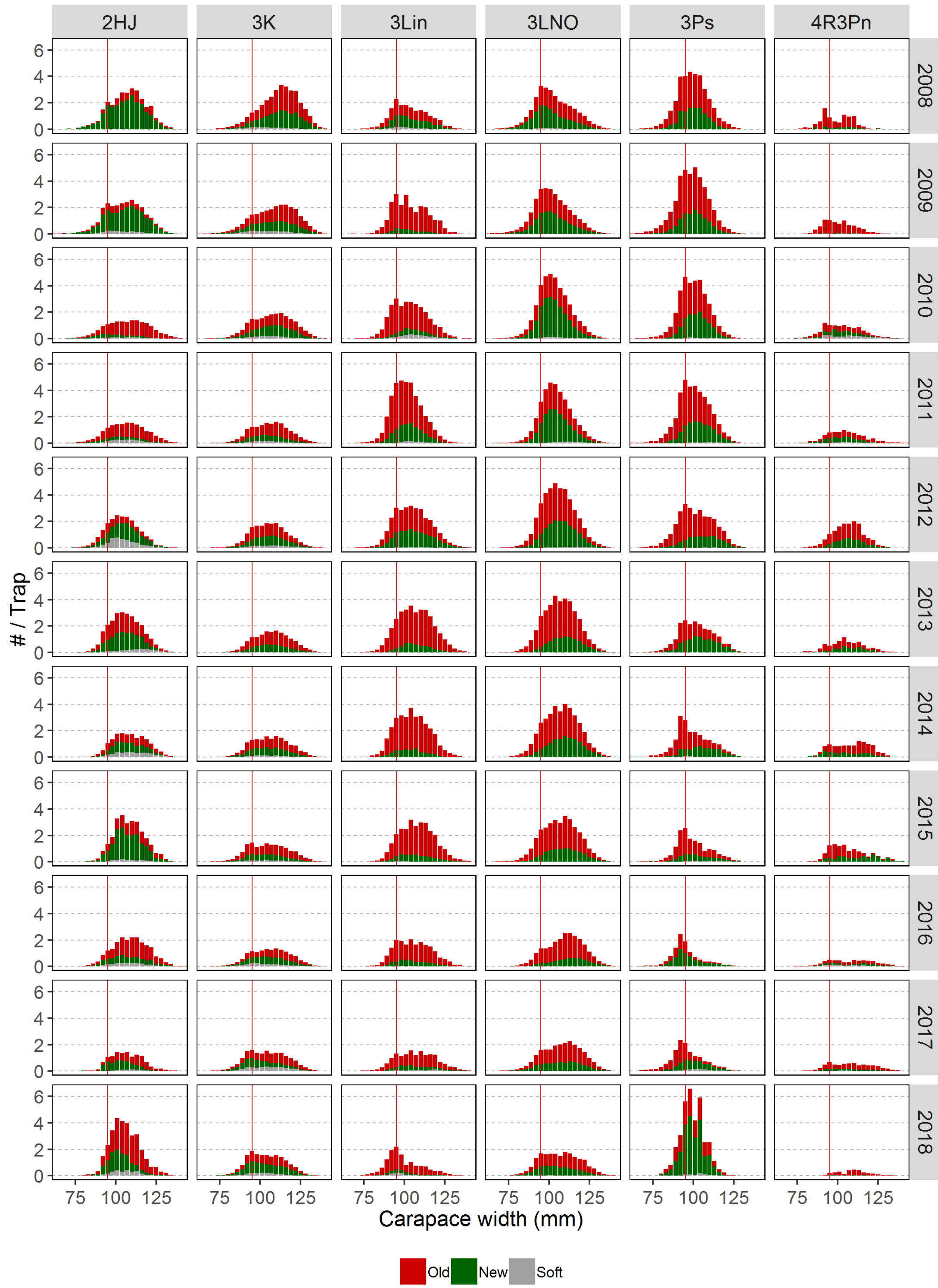

Figure 20. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer sampling in each Assessment Division. The red vertical line indicates the minimum legal size.

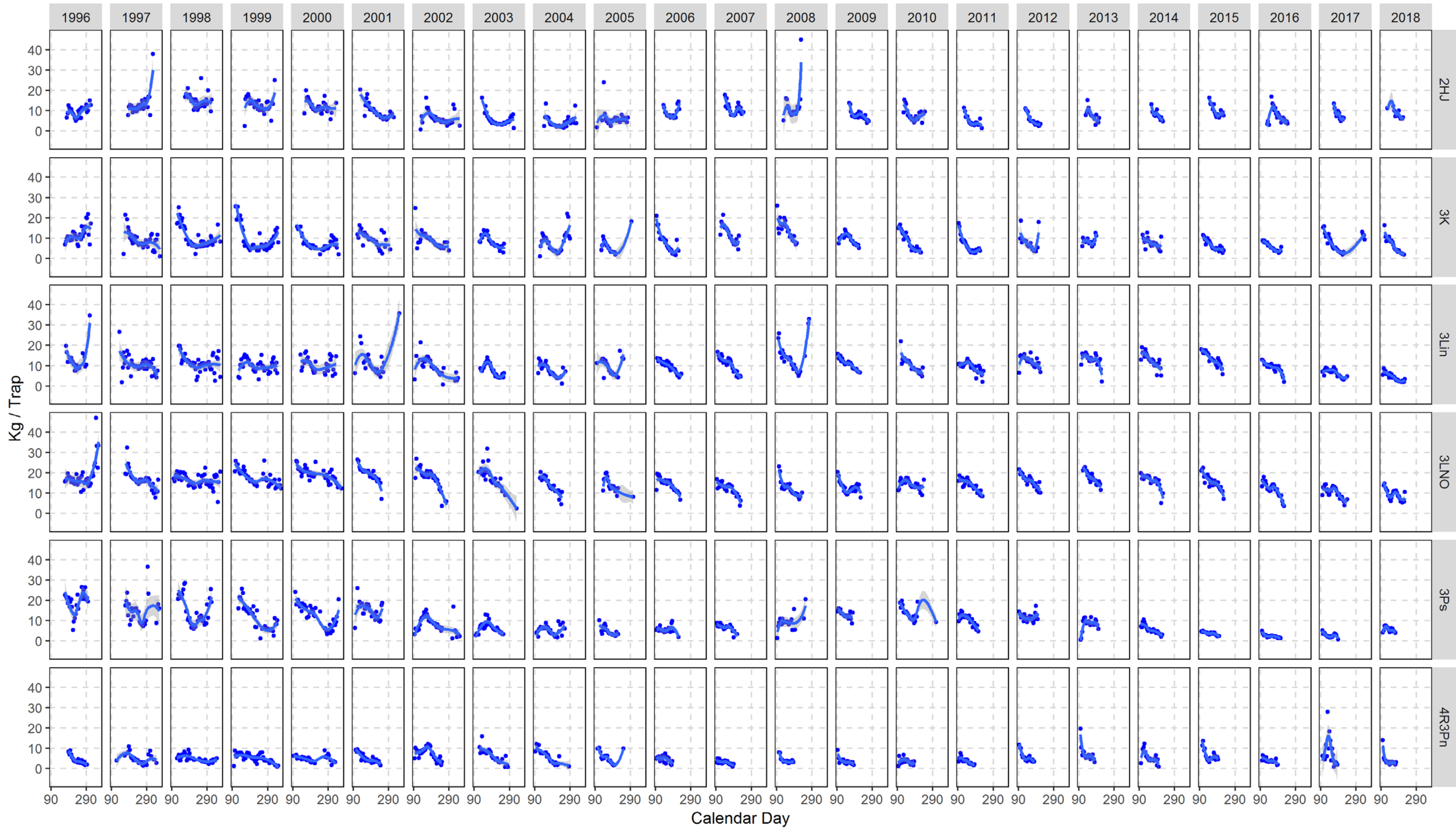

Figure 21. Unstandardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each Assessment Division (1996-2018). Derived from logbooks. Points denote mean CPUE in 5-day increments and trend lines are loess regression curves.

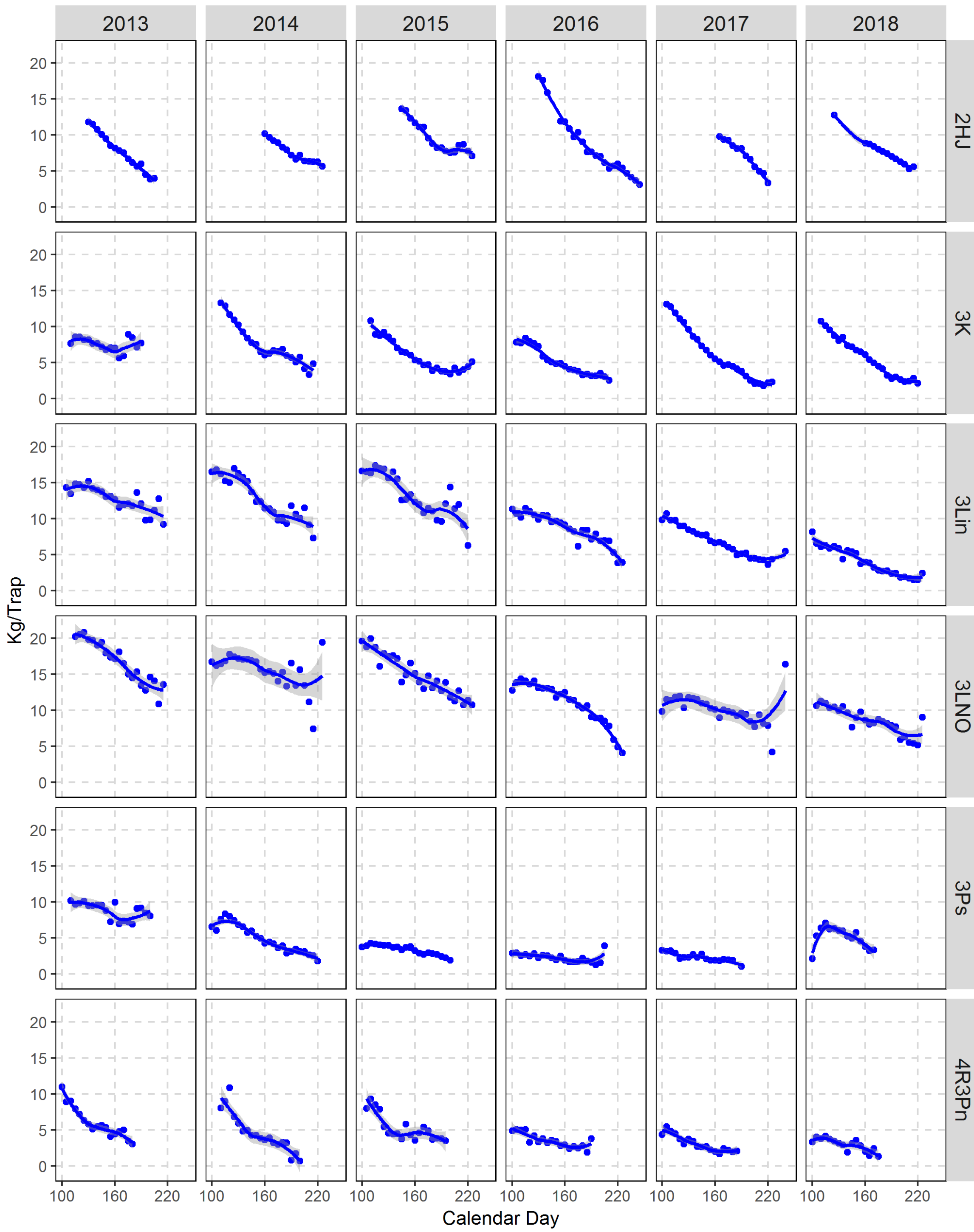

Figure 22. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each Assessment Division (2013-2018). Derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

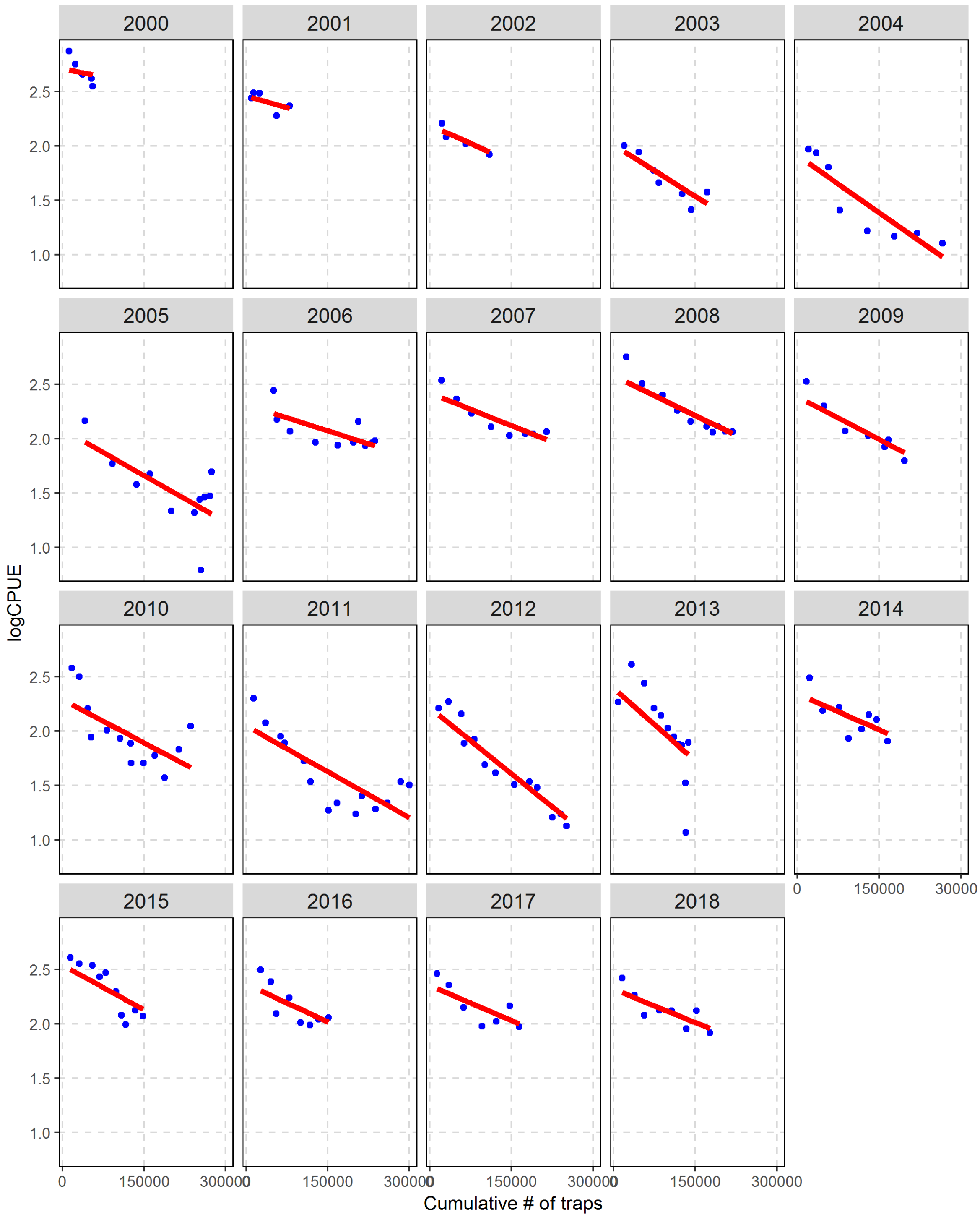

Figure 23. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Divisions 2HJ (2000-2018). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

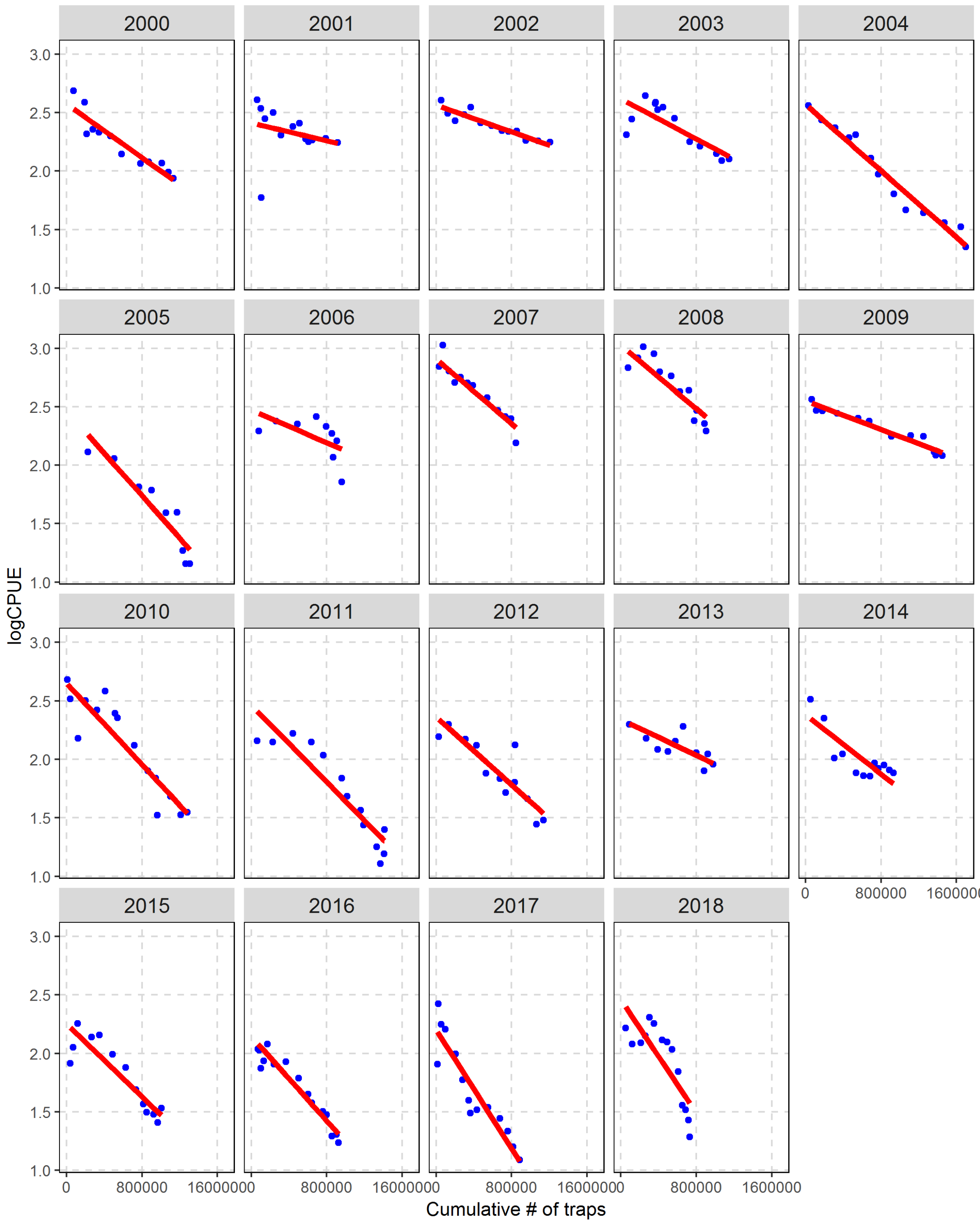

Figure 24. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3K (2000-18). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

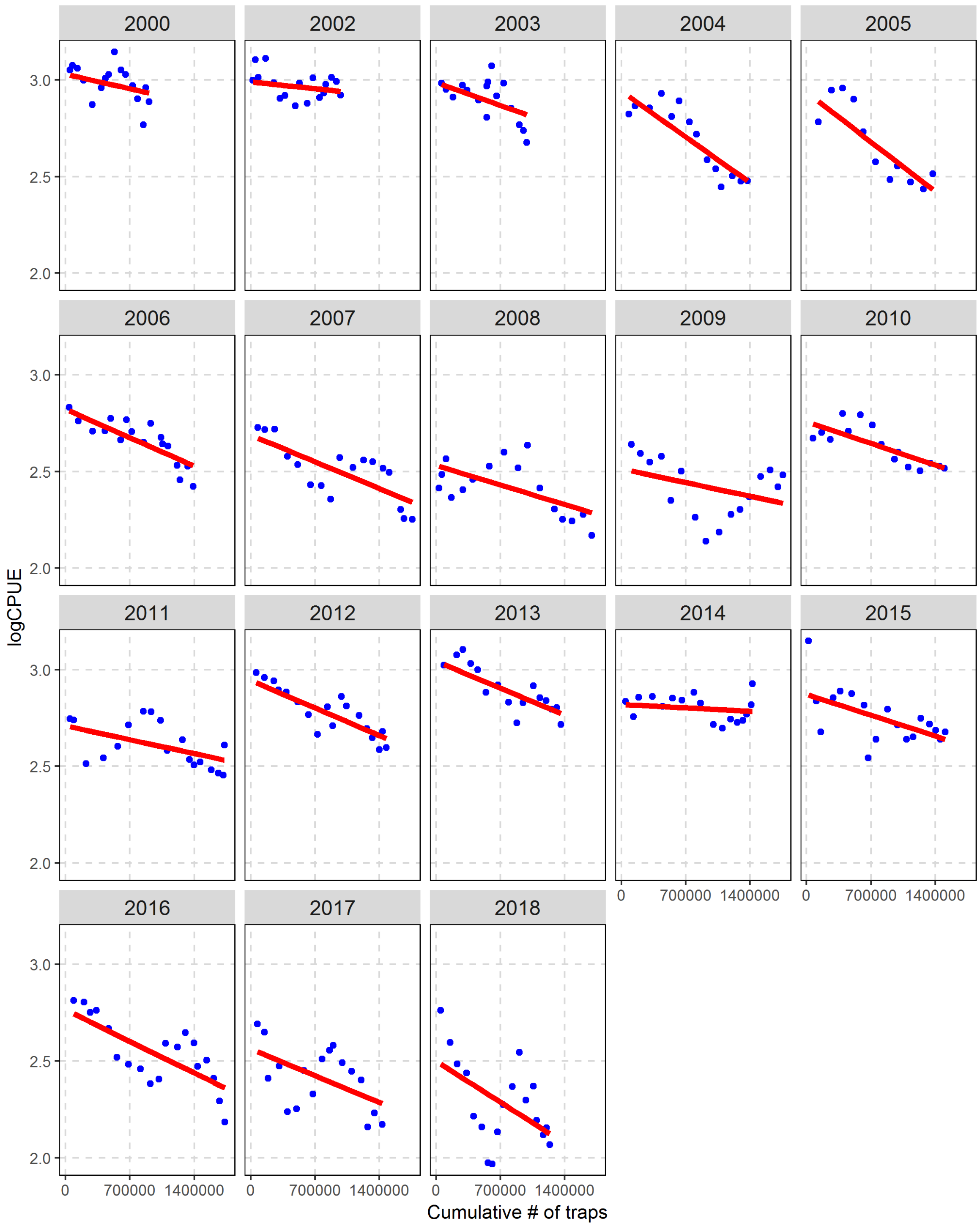

Figure 25. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Divisions 3LNO offshore (2000-18). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

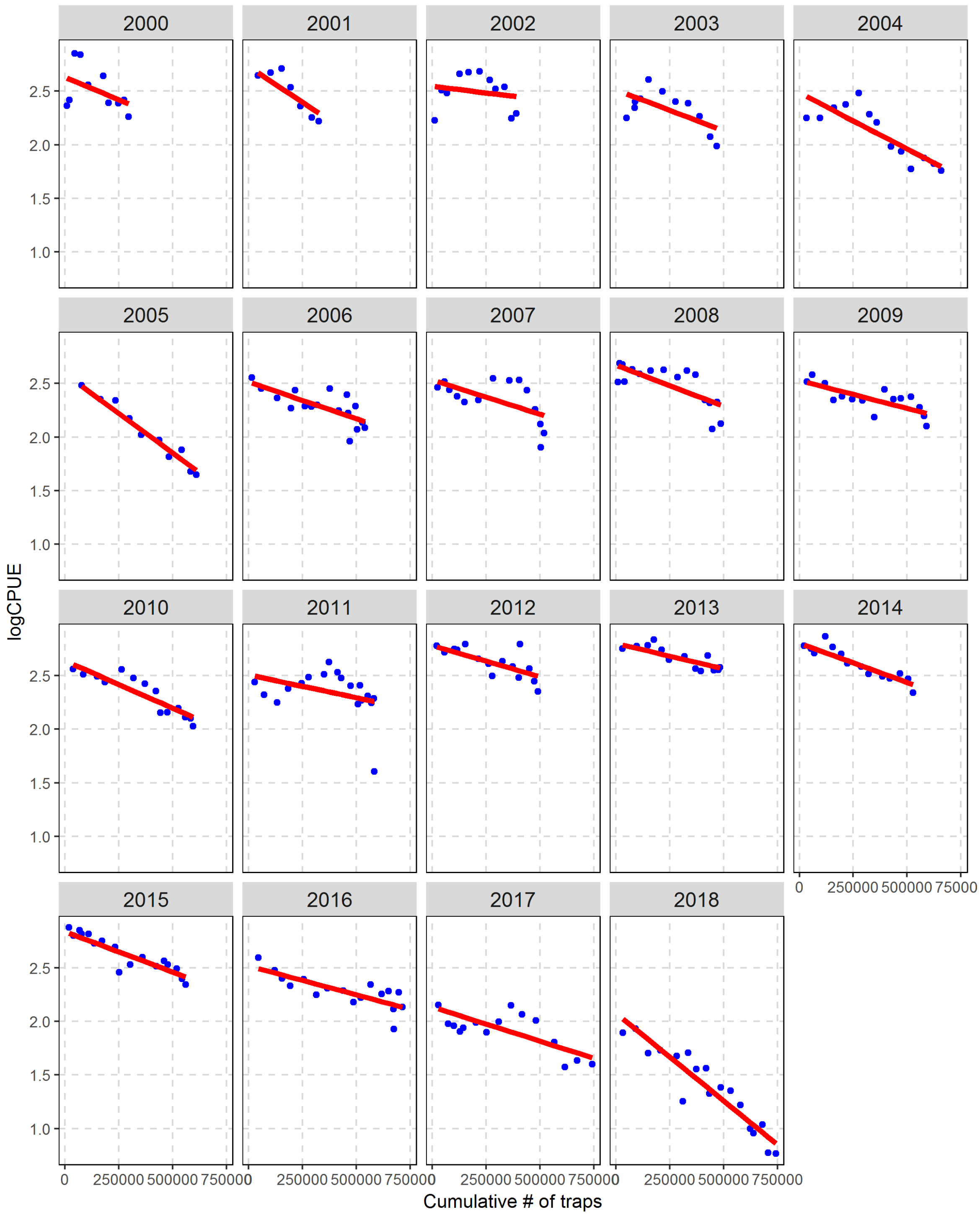

Figure 26. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Division 3L inshore (2000-18). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

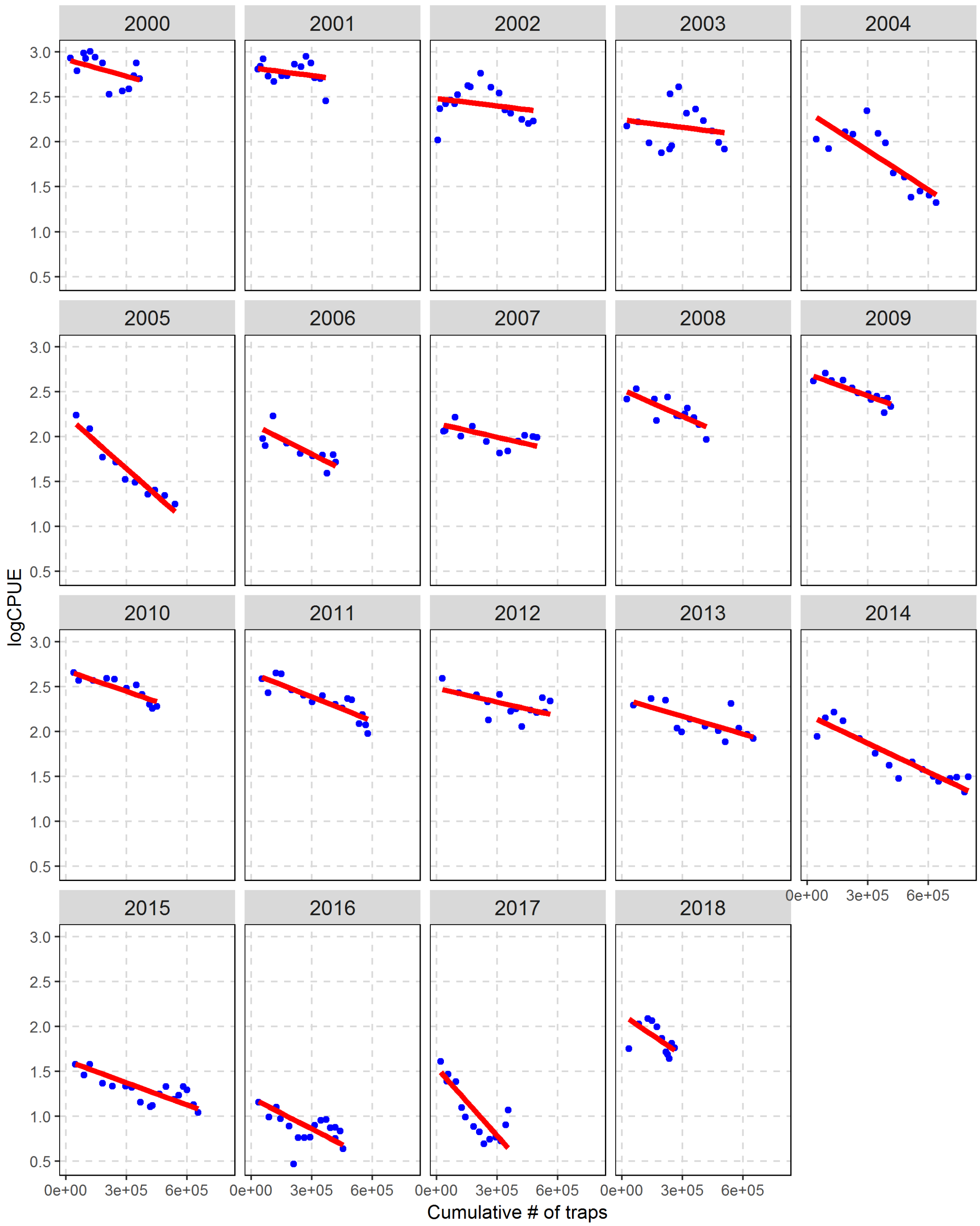

Figure 27. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Subdivision 3Ps (2000-18). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

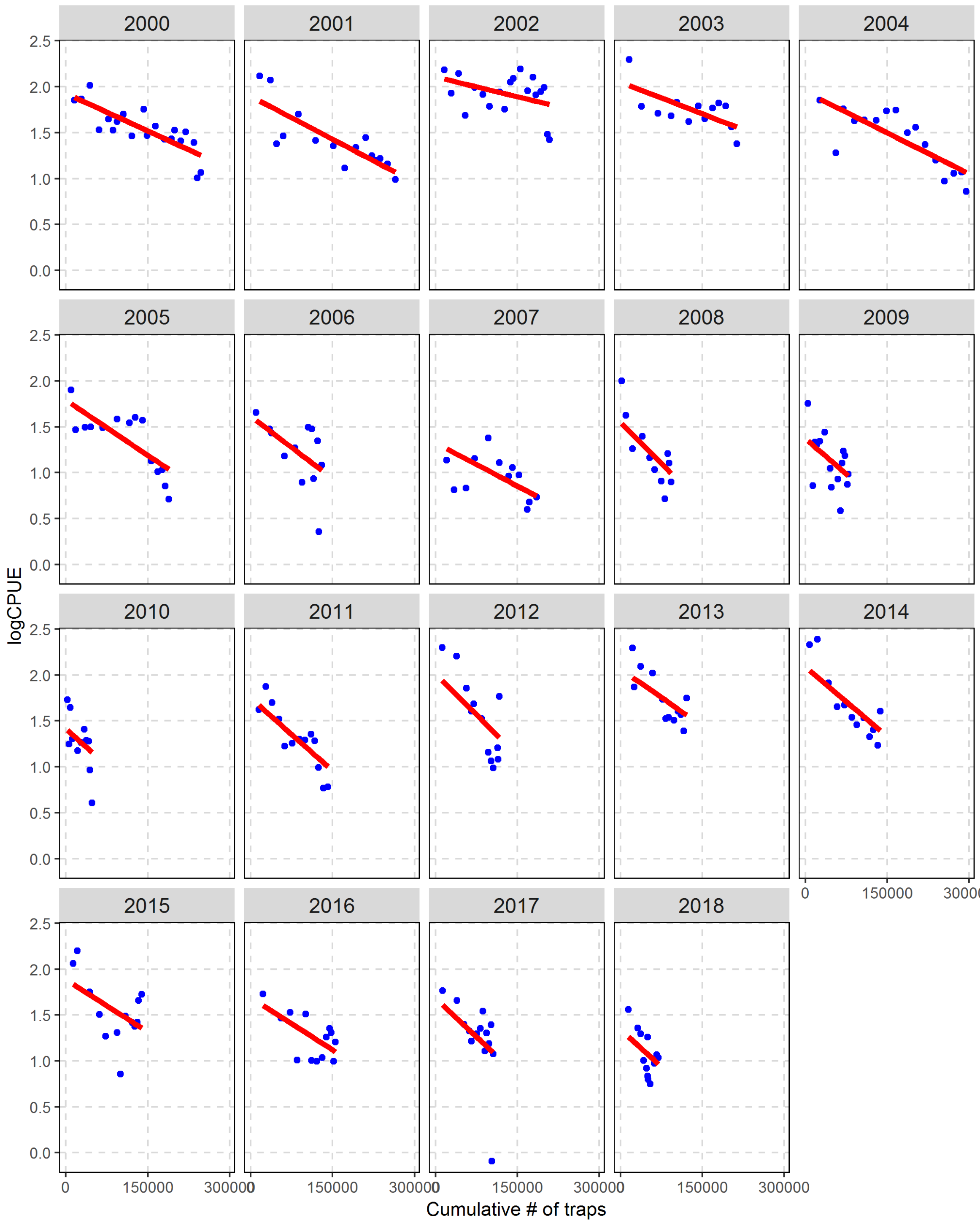

Figure 28. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in Assessment Divisions 4R3Pn (2000-18). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

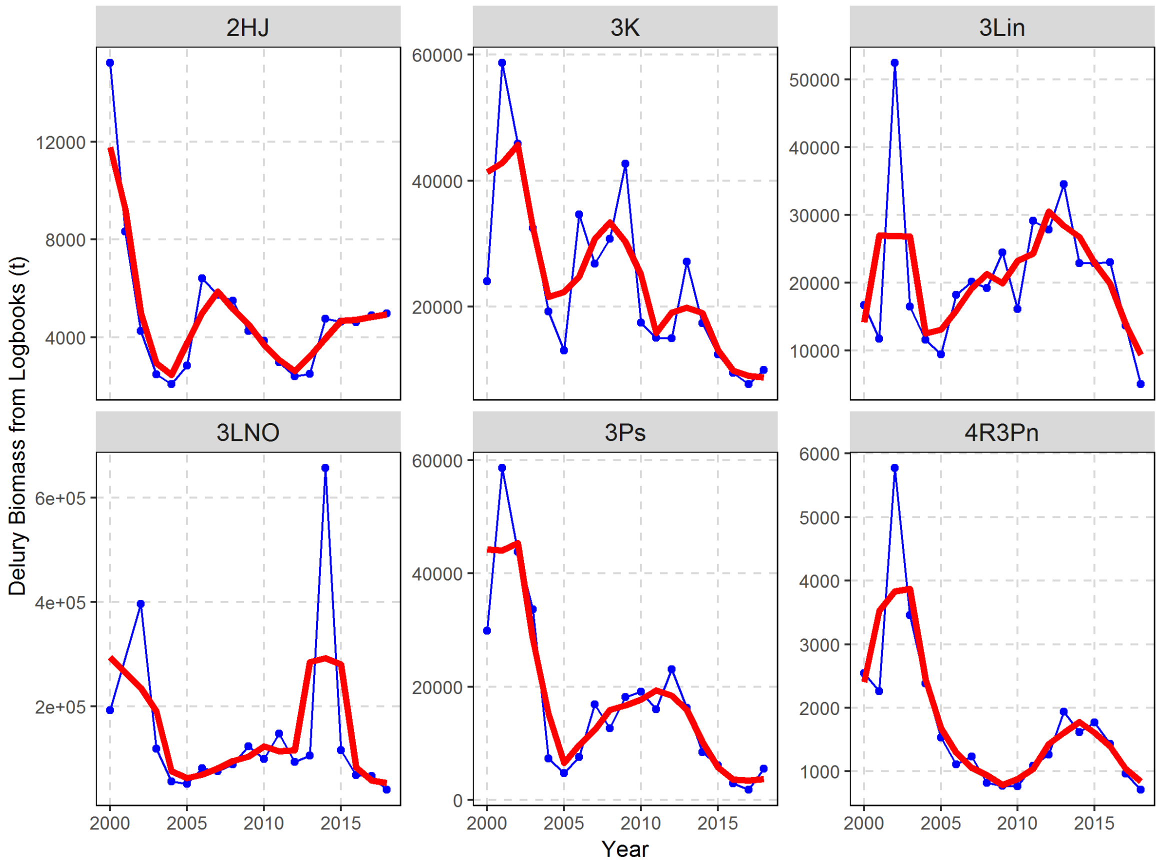

Figure 29. Fishery depletion model biomass estimates of exploitable Snow Crab (t) from logbooks (blue) and 3-year centered moving averages (red) in each Assessment Division.

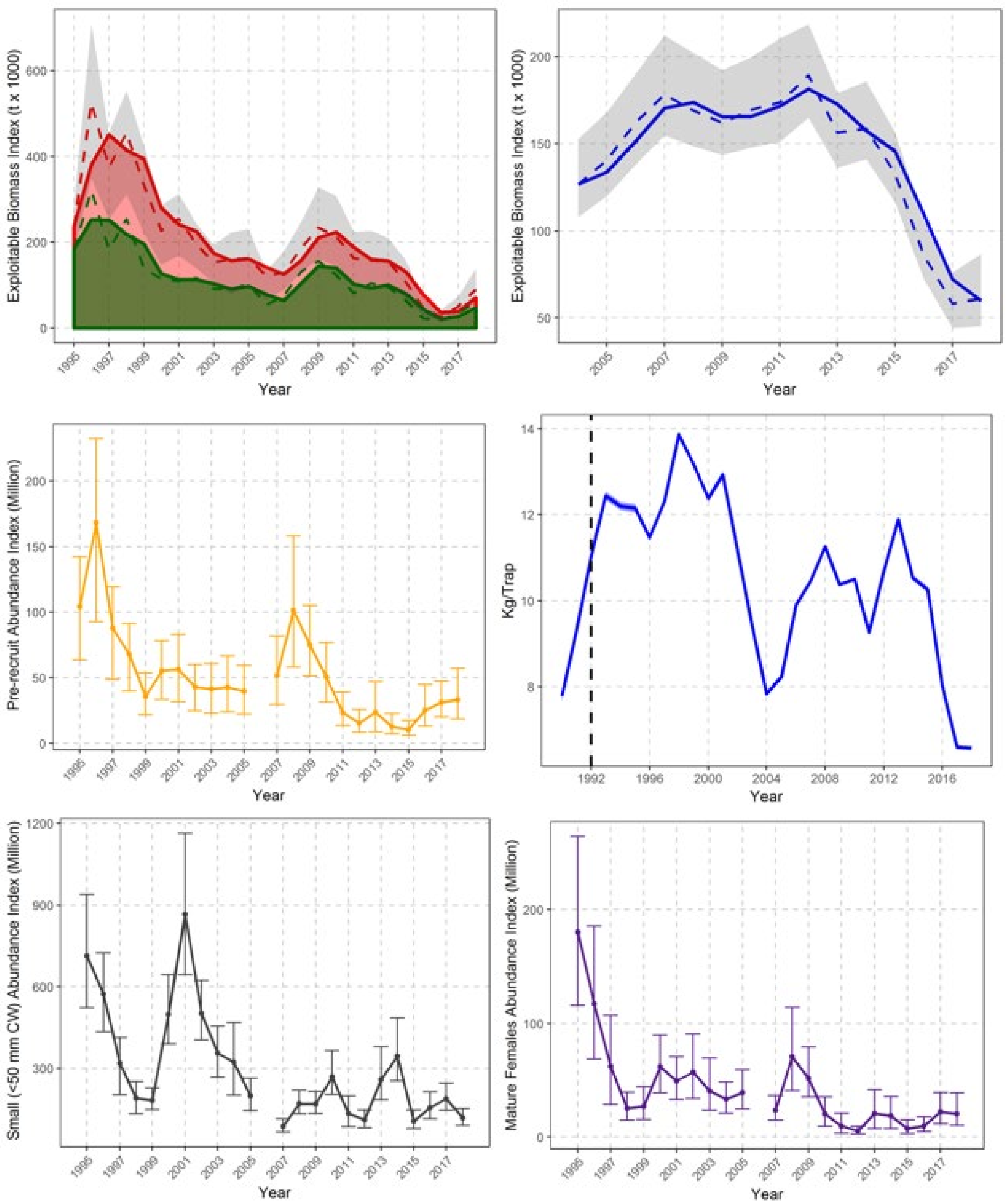

Figure 30. Summary of Snow Crab stock status in Assessment Divisions 2HJ3KLNOP4R: ***Top-left:*** *Annual exploitable biomass index (t *1000) by shell condition (1995-2018) based on trawl surveys. Shaded area is 2-year moving average of biomass and dashed line is annual estimate (red = residuals, green = recruits).* ***Top-right:*** *Trap survey-based exploitable biomass index for Divisions 2HJ3KLNOP4R (t*1000) (2004-18). Solid line is 2-year moving average and dashed line is annual estimate.* ***Middle-left:*** *Pre-recruit index (# million) from trawl surveys (1995-2018).* ***Middle-right:*** *Standardized fishery CPUE for Divisions 2HJ3KLNOP4R (1990-2018).* ***Bottom-left:*** *Annual abundance index (# million) of small Snow Crab (<50 mm carapace width) from trawl surveys (1995-2018).* ***Bottom-right:*** *Annual abundance index (# million) of mature female Snow Crab from trawl surveys (1995-2018).*

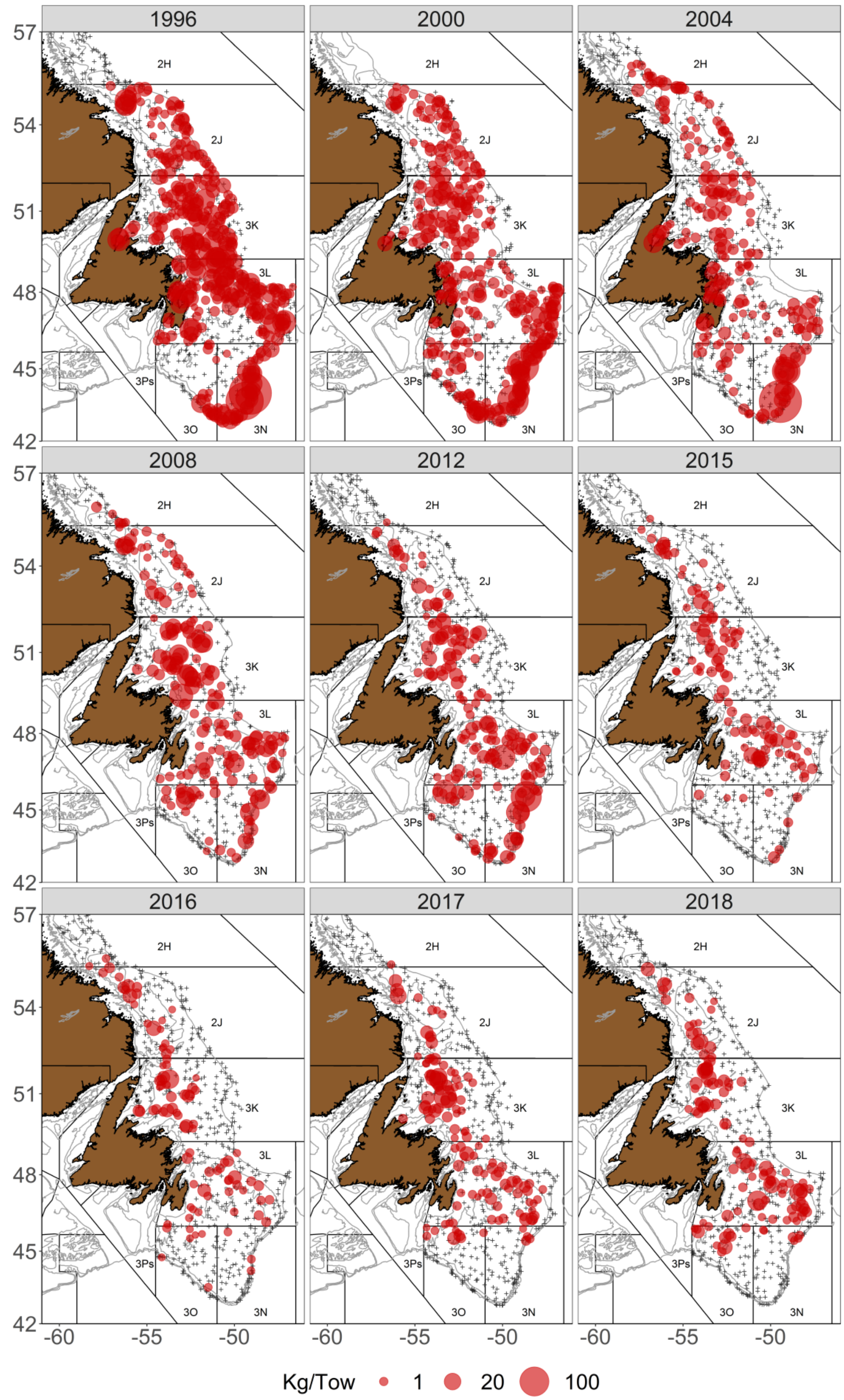

Figure 31. Distribution of exploitable males (kg/tow) from Assessment Divisions 2HJ3KLNO fall bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2015-18. Data standardized by vessel.

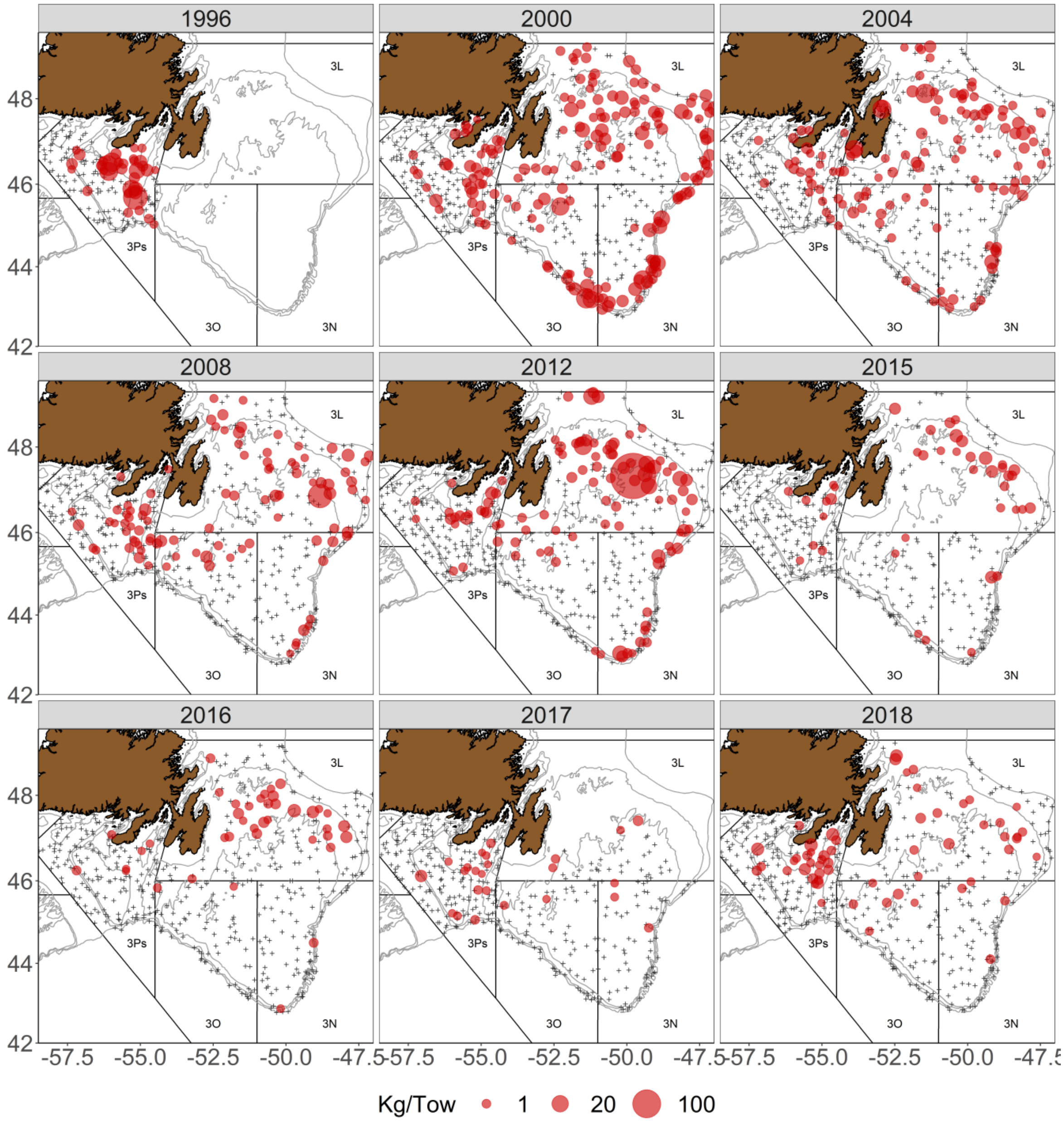

Figure 32. Distribution of exploitable males (kg/tow) from Assessment Divisions 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2015-18. Data standardized by vessel.

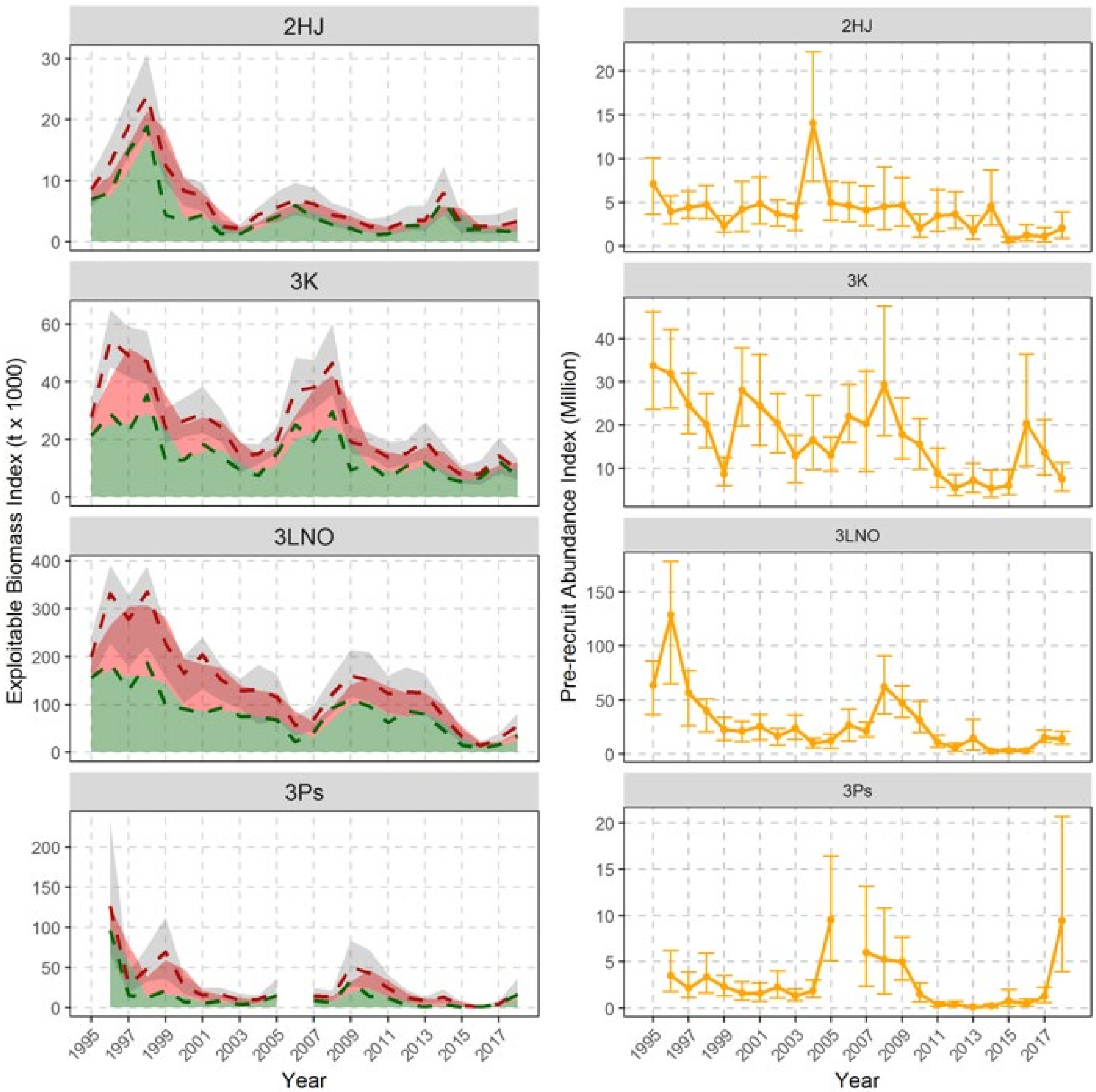

*Figure 33. **Left:** Trawl survey exploitable biomass indices (t * 1000) by shell condition and Assessment Division. Soft and new-shelled Snow Crab represent recruitment (green) and intermediate and old-shelled Snow Crab represent residual biomass (red). Red and green shaded areas are 2-year moving averages and dashed lines represent annual estimates. **Right:** Overall trawl survey pre-recruit biomass index (million) by Assessment Division.*

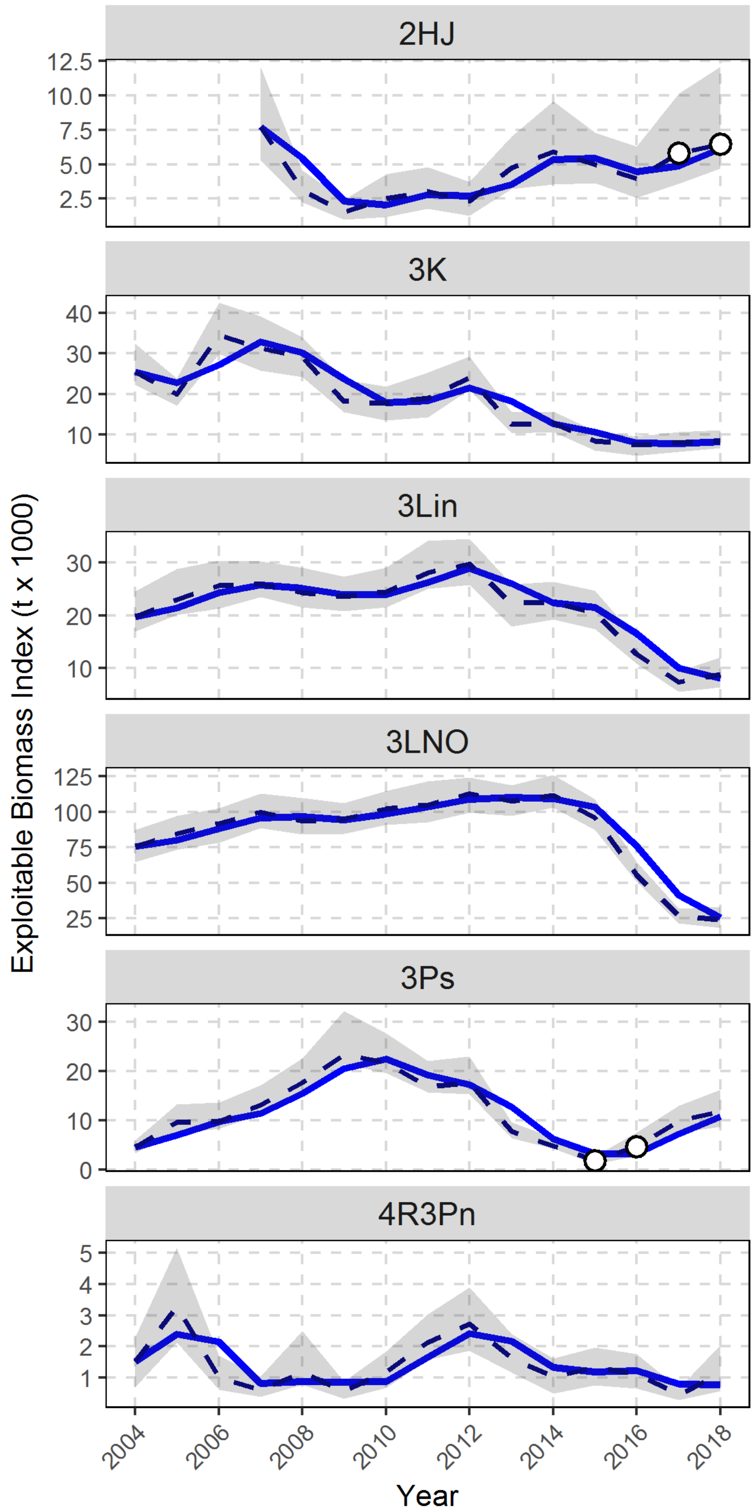

Figure 34. Trap survey-based exploitable biomass index by Assessment Division (2004-18). Solid line represents 2-year moving average and dashed line represents annual estimate. White circles represent years with incomplete survey coverage.

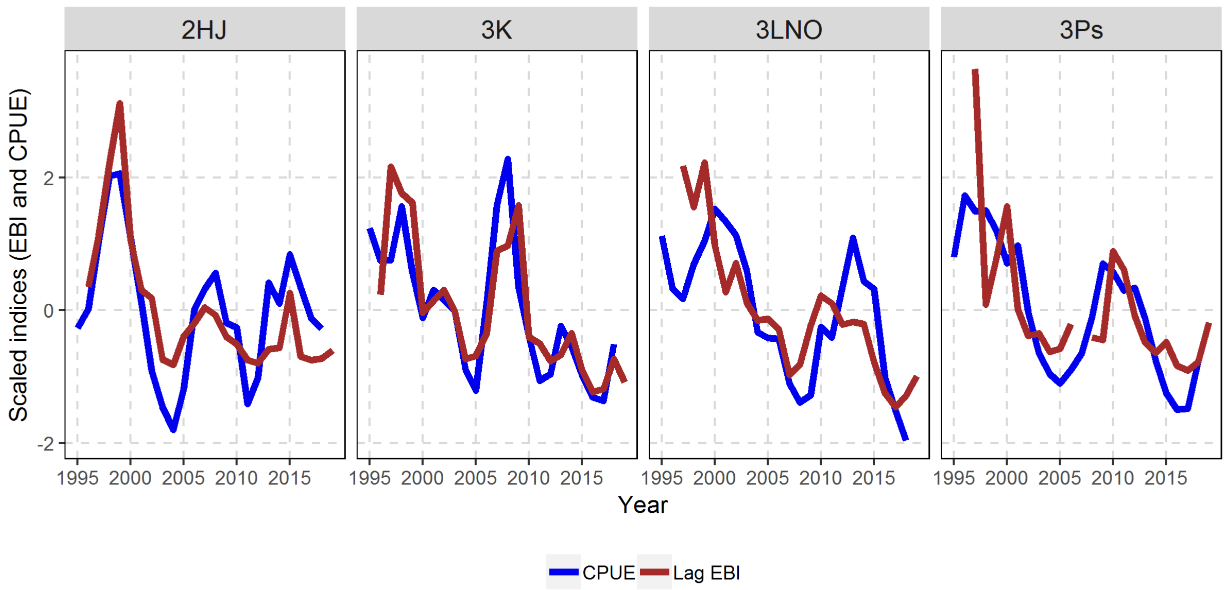

Figure 35. One-year lagged trawl survey exploitable biomass indices versus fishery CPUE by Assessment Division (1995-2018).

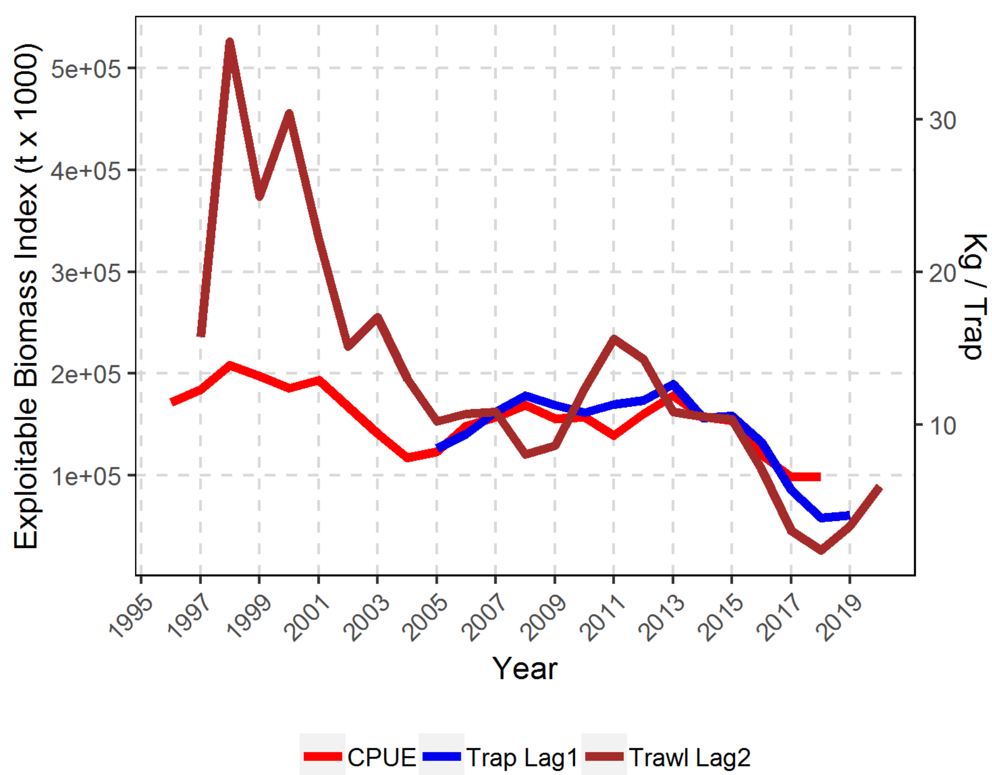

Figure 36. Trends in exploitable Snow Crab abundance indices based on the trawl survey lagged 2 years (brown), trap surveys lagged 1 year (blue), and fishery CPUE (red).

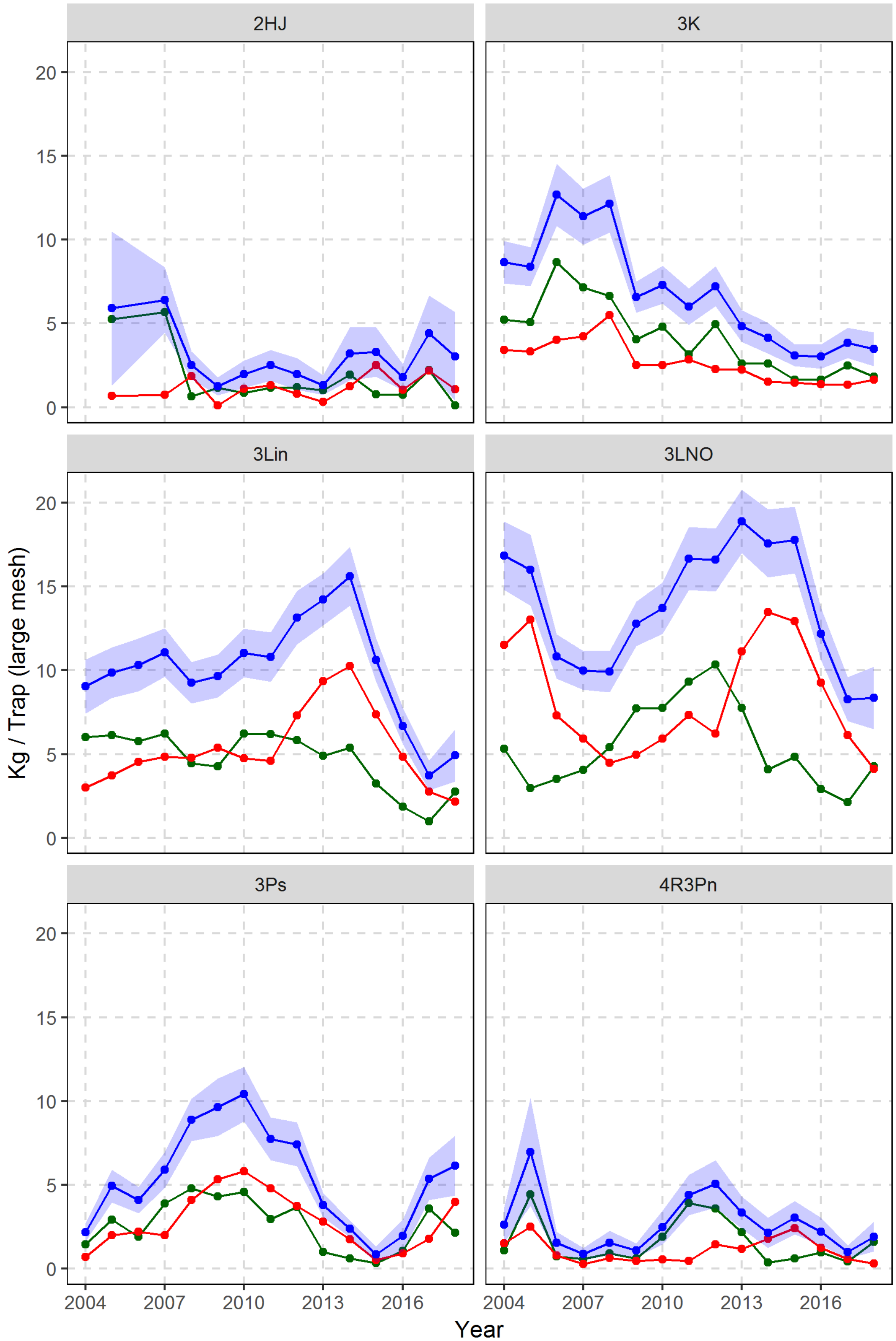

Figure 37. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residual crab, green = recruits) for legal-sized Snow Crab from core stations in the CPS survey in Assessment Divisions (2004-18).

Figure 38. Annual CPUE (#/trap) of pre-recruits from small-mesh traps at core stations in the CPS trap survey by Assessment Division (2004-18).

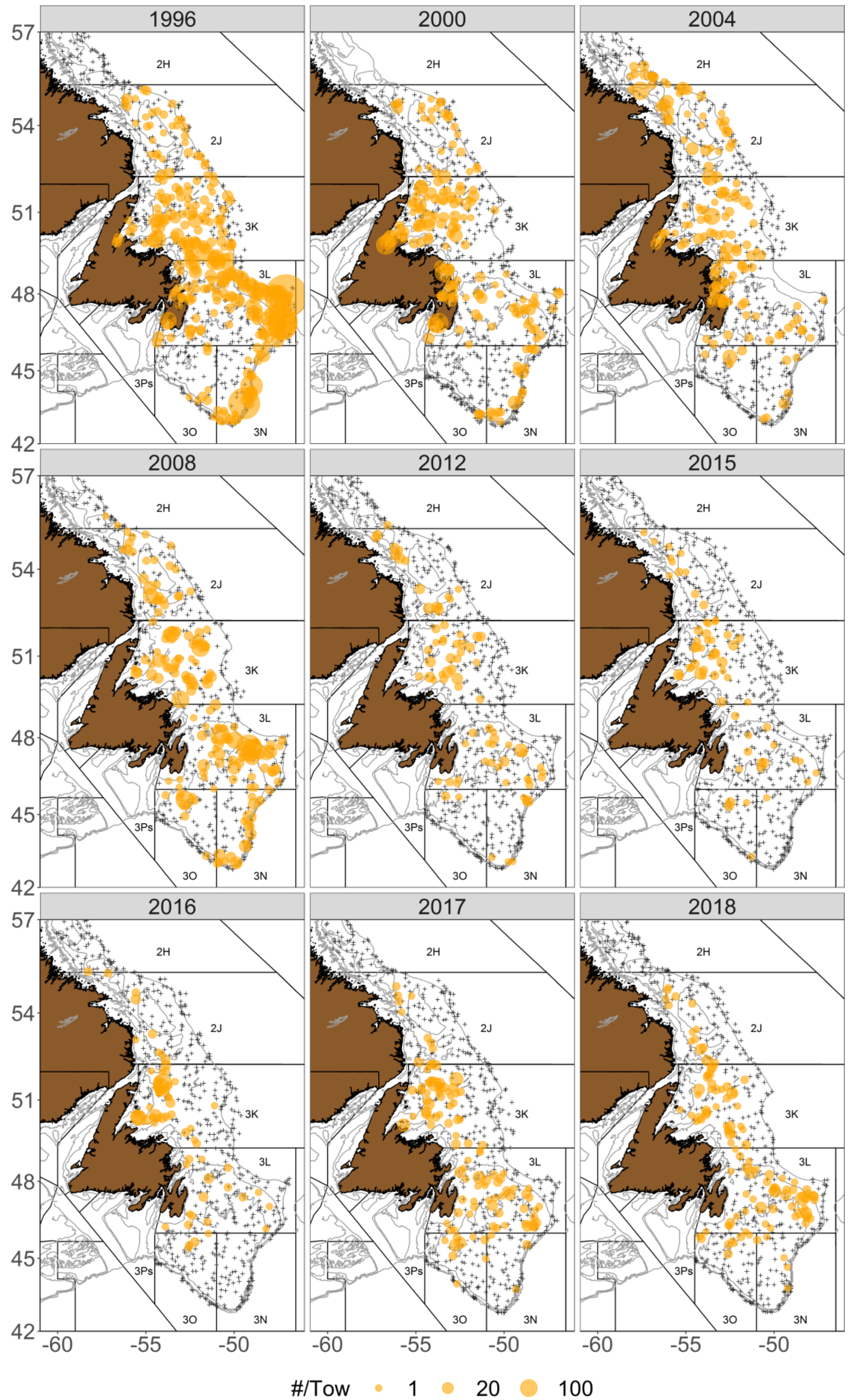

Figure 39. Distribution of pre-recruit males (#/tow) from Assessment Divisions 2HJ3KLNO fall bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2015-18.

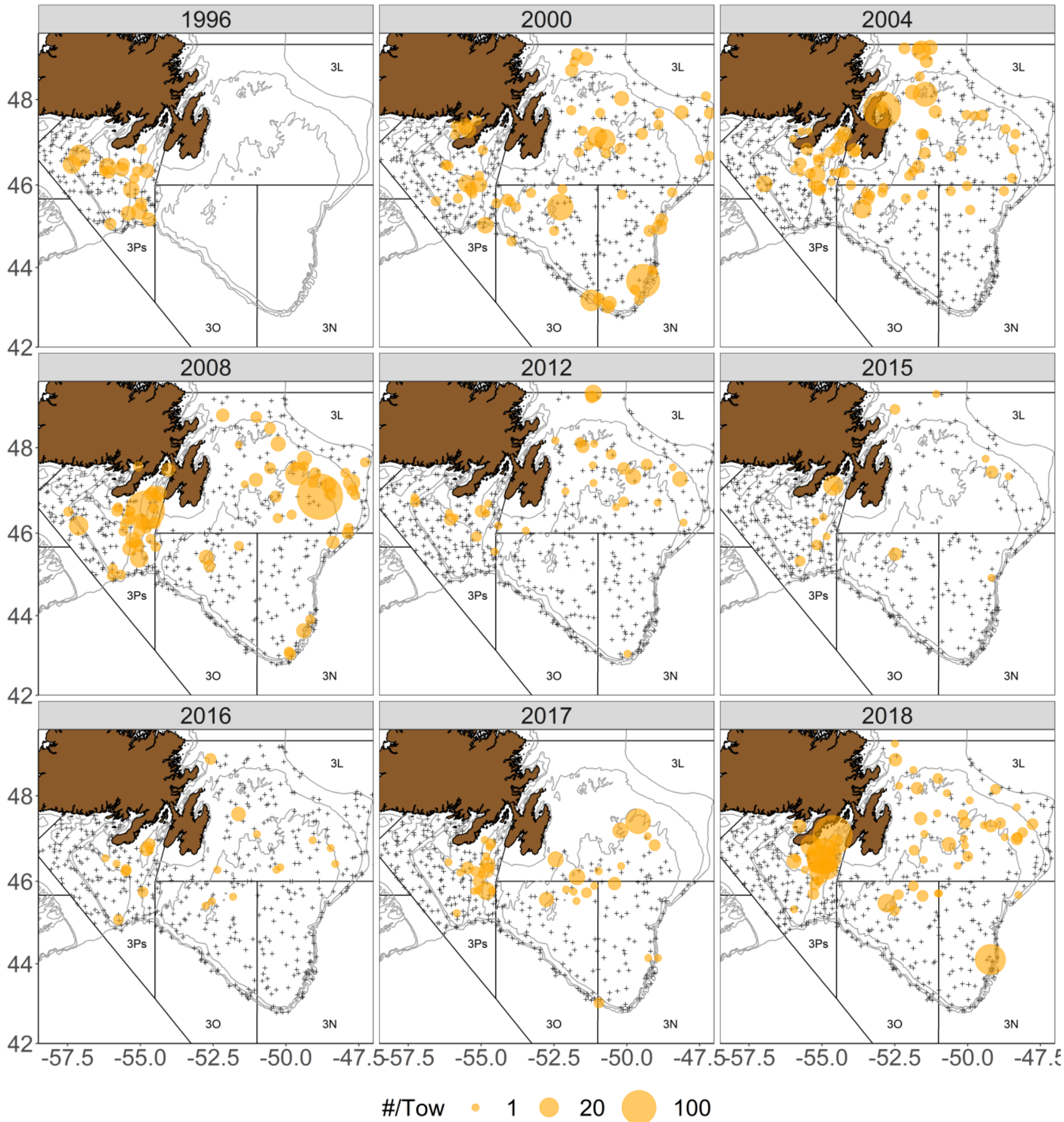

Figure 40. Distribution of pre-recruit males (#/tow) from Assessment Divisions 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2015-18.

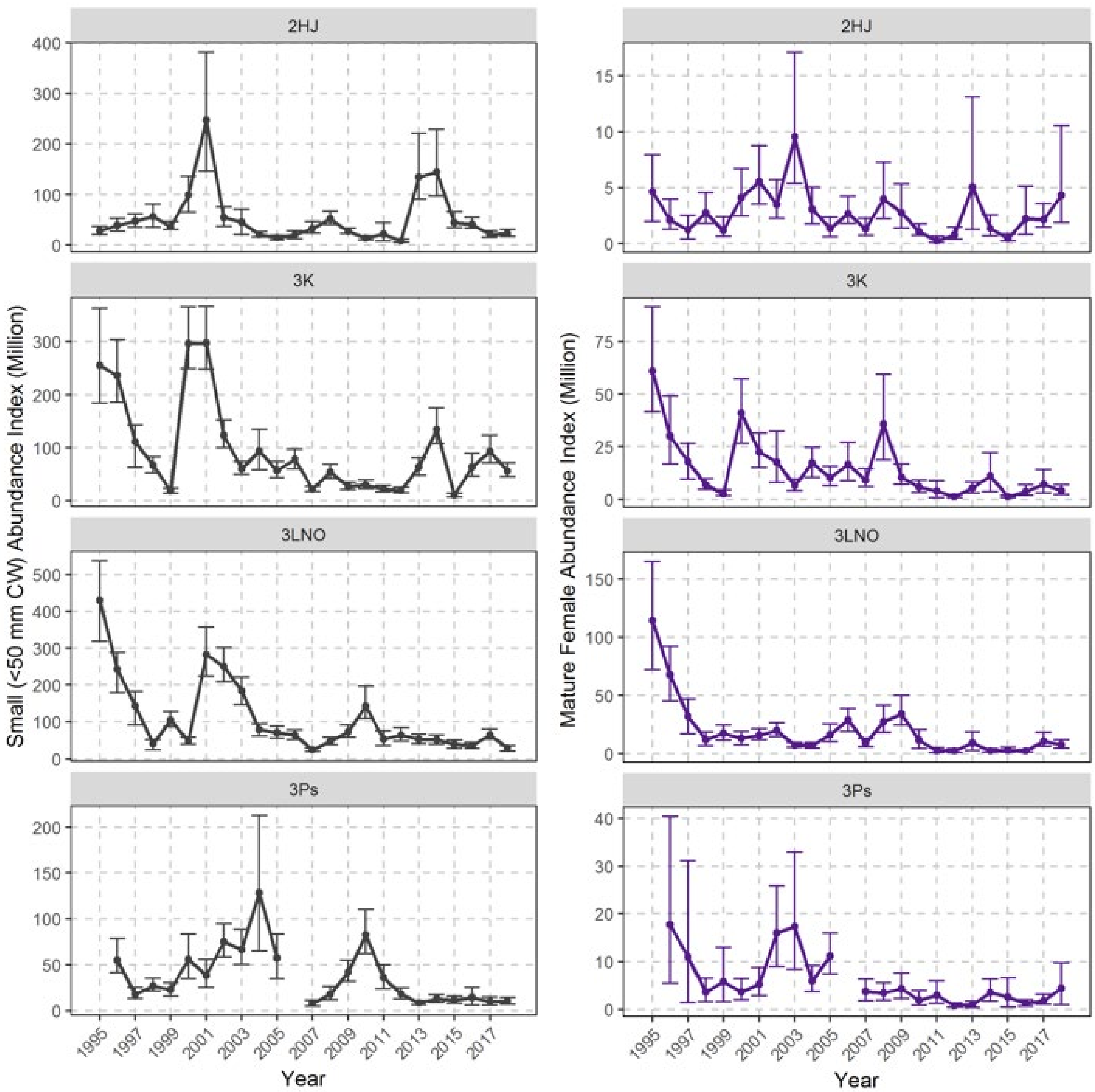

*Figure 41. **Left:** Abundance indices (# million) of small Snow Crab (<50 mm carapace width) from fall and spring trawl surveys by Assessment Division. **Right:** Annual abundance indices (# million) of mature female Snow Crab from fall and spring trawl surveys by Assessment Division.*

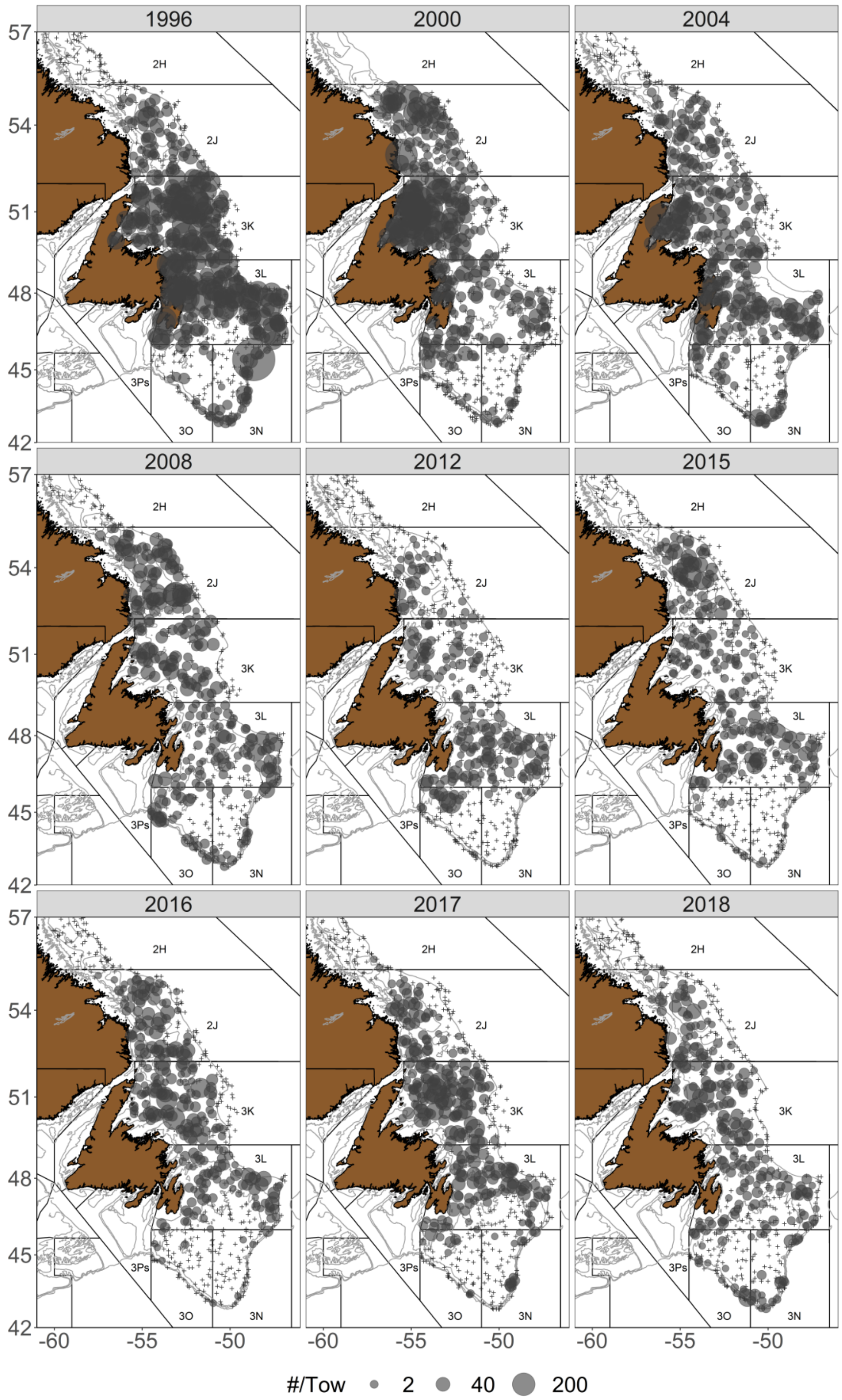

Figure 42. Distribution of small (<50 mm) Snow Crab (#/tow) from Assessment Divisions 2HJ3KLNO fall bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2015-18.

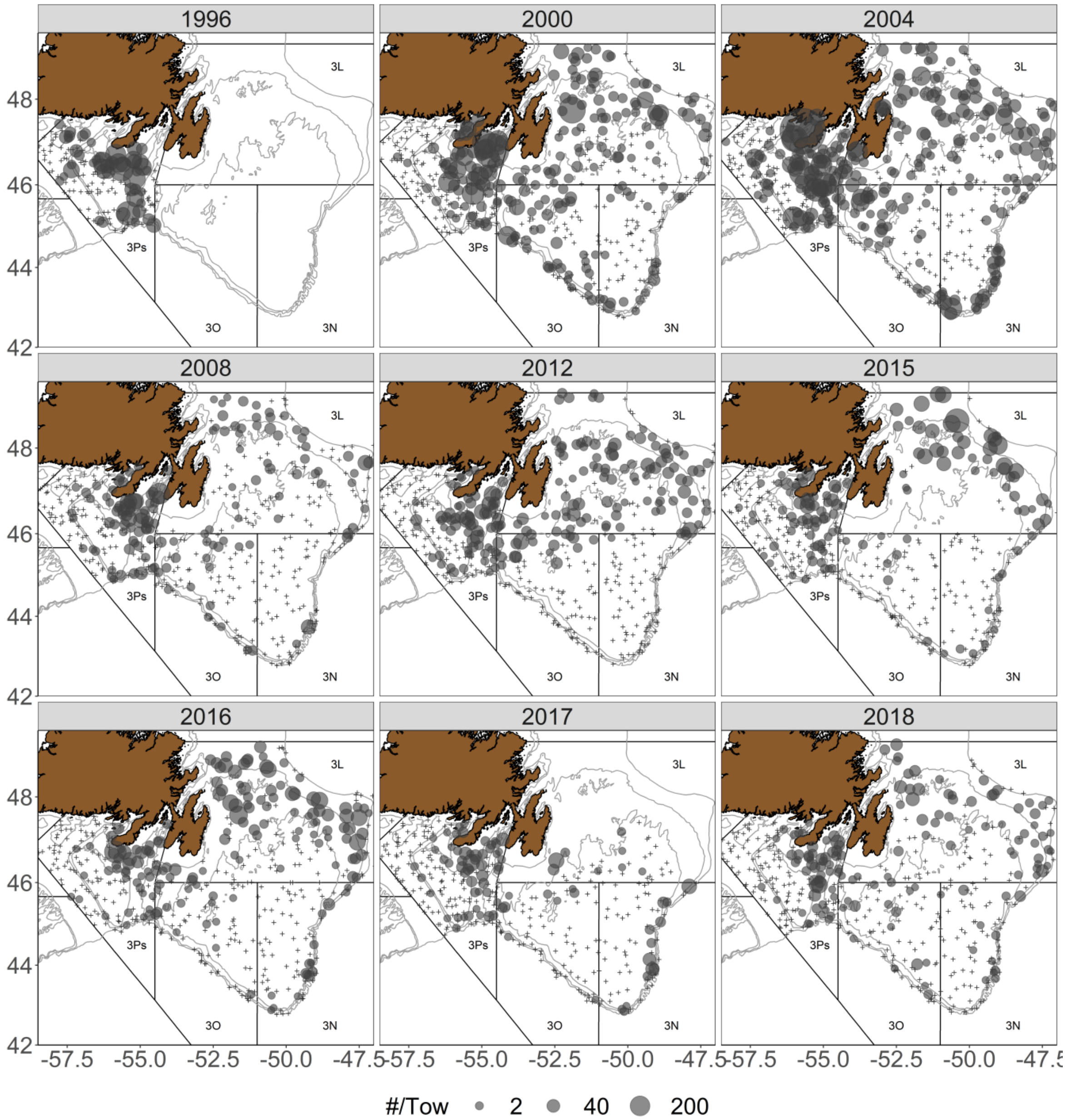

Figure 43. Distribution of small (<50 mm) Snow Crab (#/tow) from Assessment Divisions 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2015-18.

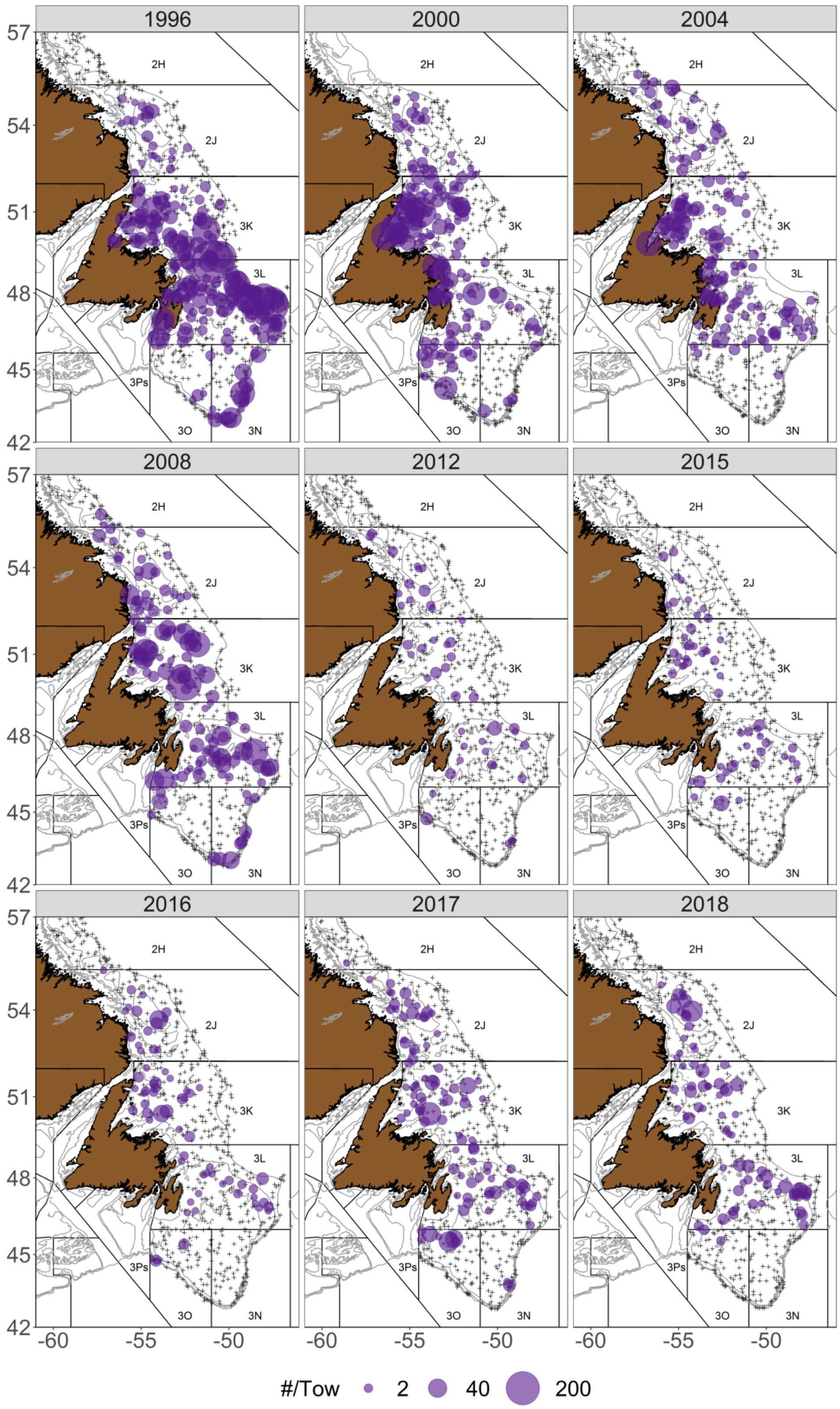

Figure 44. Distribution of mature females (#/tow) from Assessment Divisions 2HJ3KLNO fall bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2015-18.

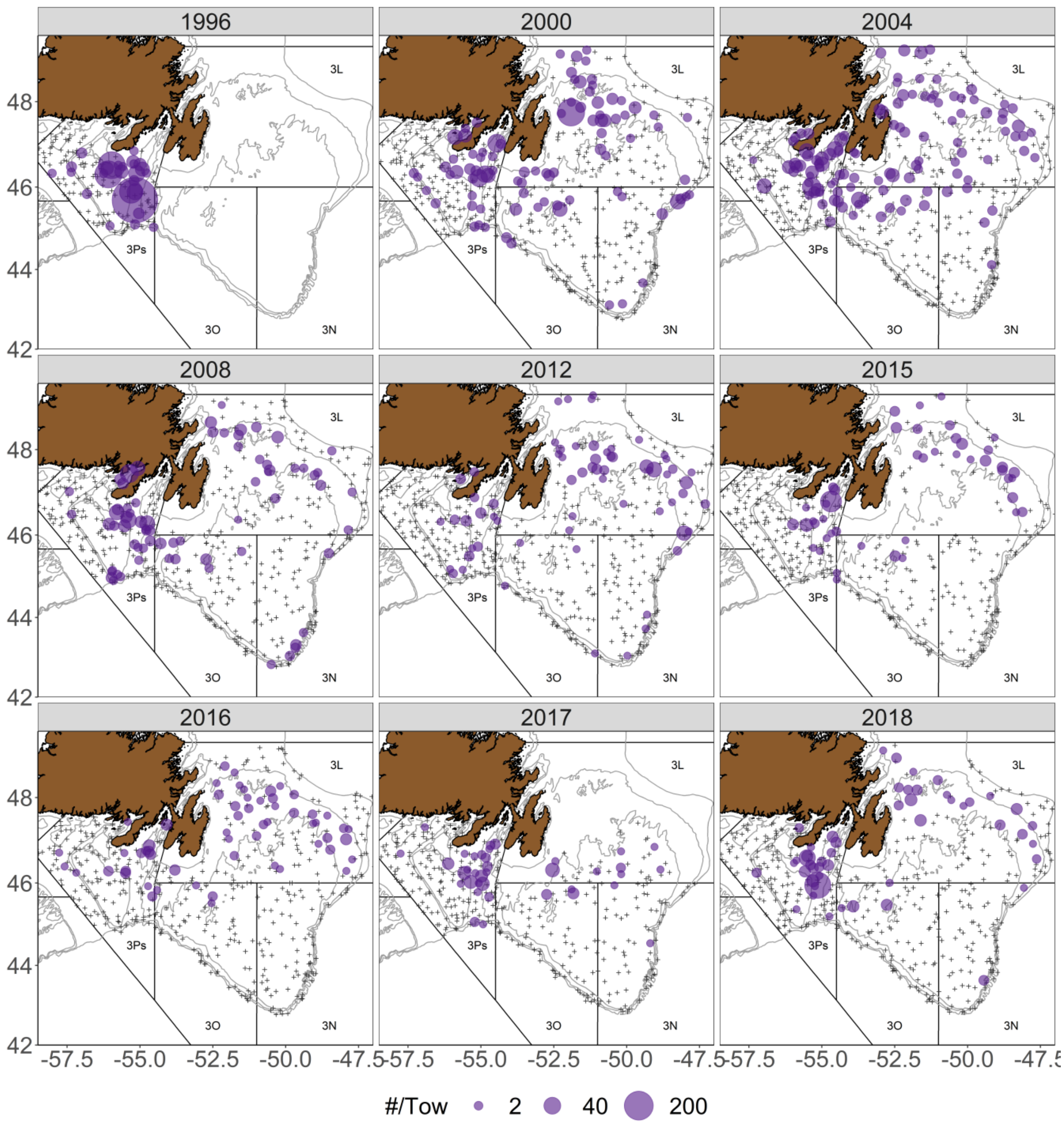

Figure 45. Distribution of mature females (#/tow) from Assessment Divisions 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2015-18.

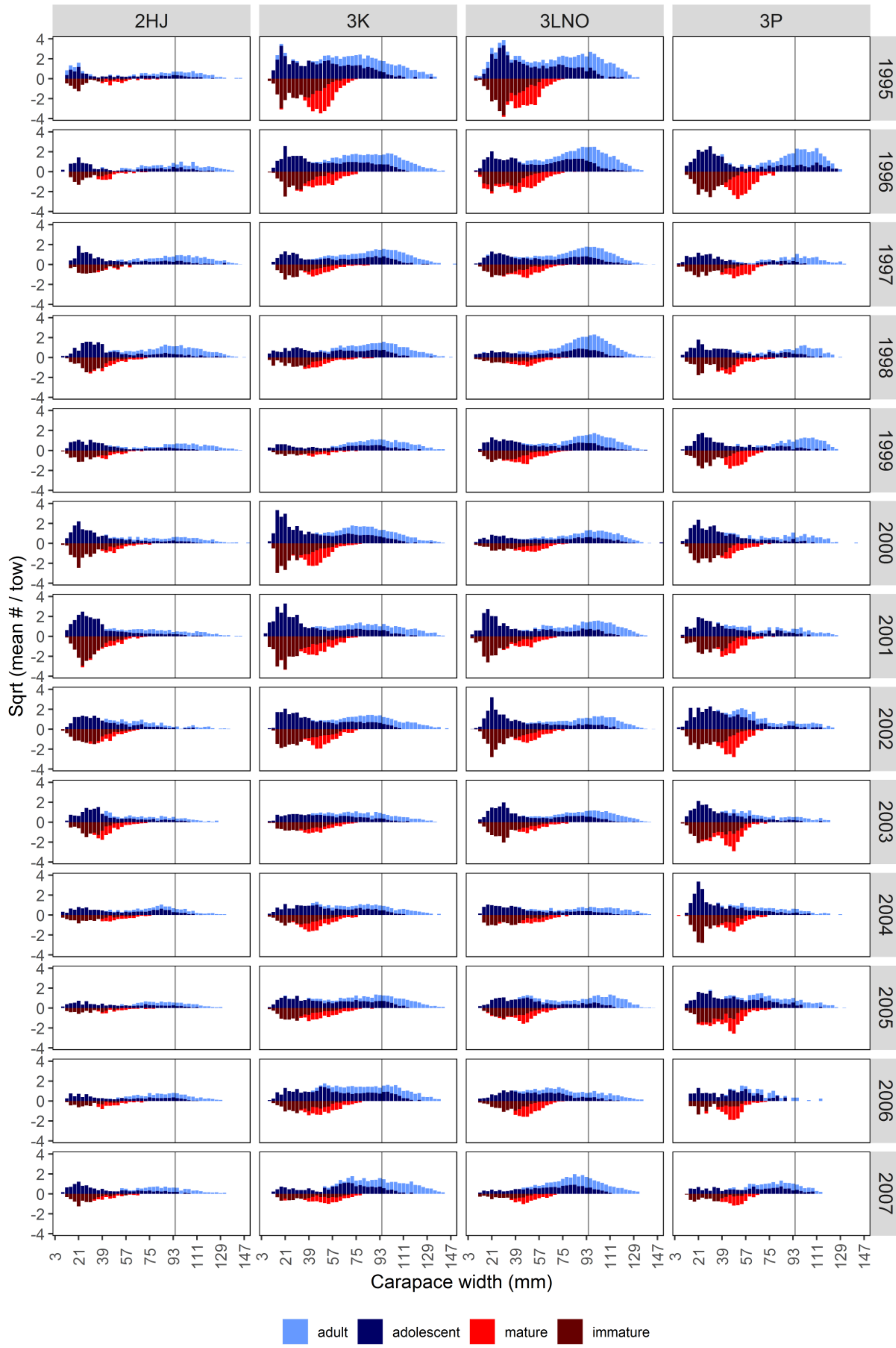

Figure 46. Abundance indices (#/tow) by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (Subdivision 3Ps) and fall (Divisions 2HJ3KLNO) trawl surveys from 1995 to 2007. Vertical line is legal-size. Data standardized by vessel.

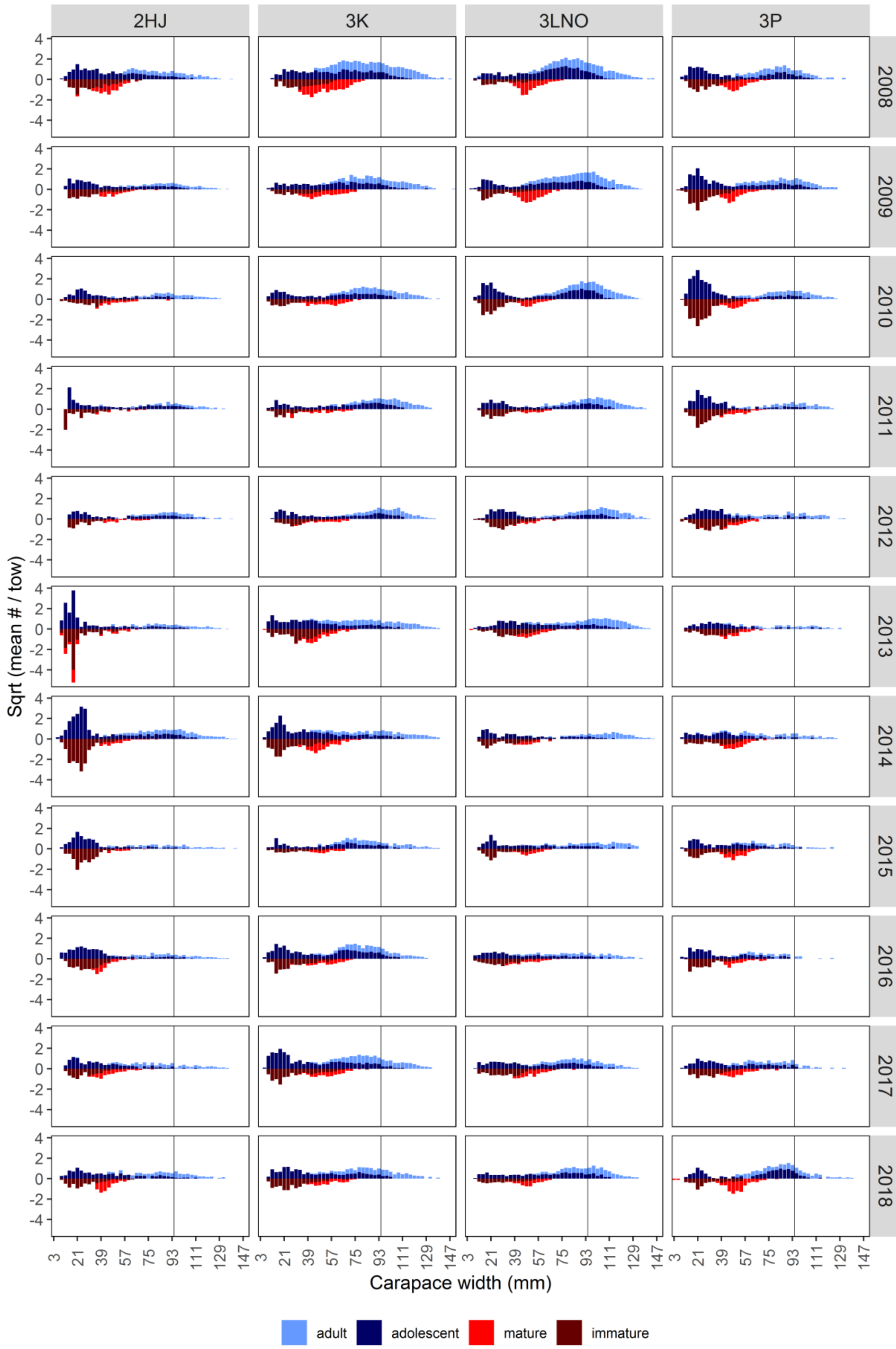

Figure 47. Abundance indices (#/tow) by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (Subdivision 3Ps) and fall (Divisions 2HJ3KLNO) trawl surveys from 2008 to 2018. Vertical line is legal-size. Data standardized by vessel.

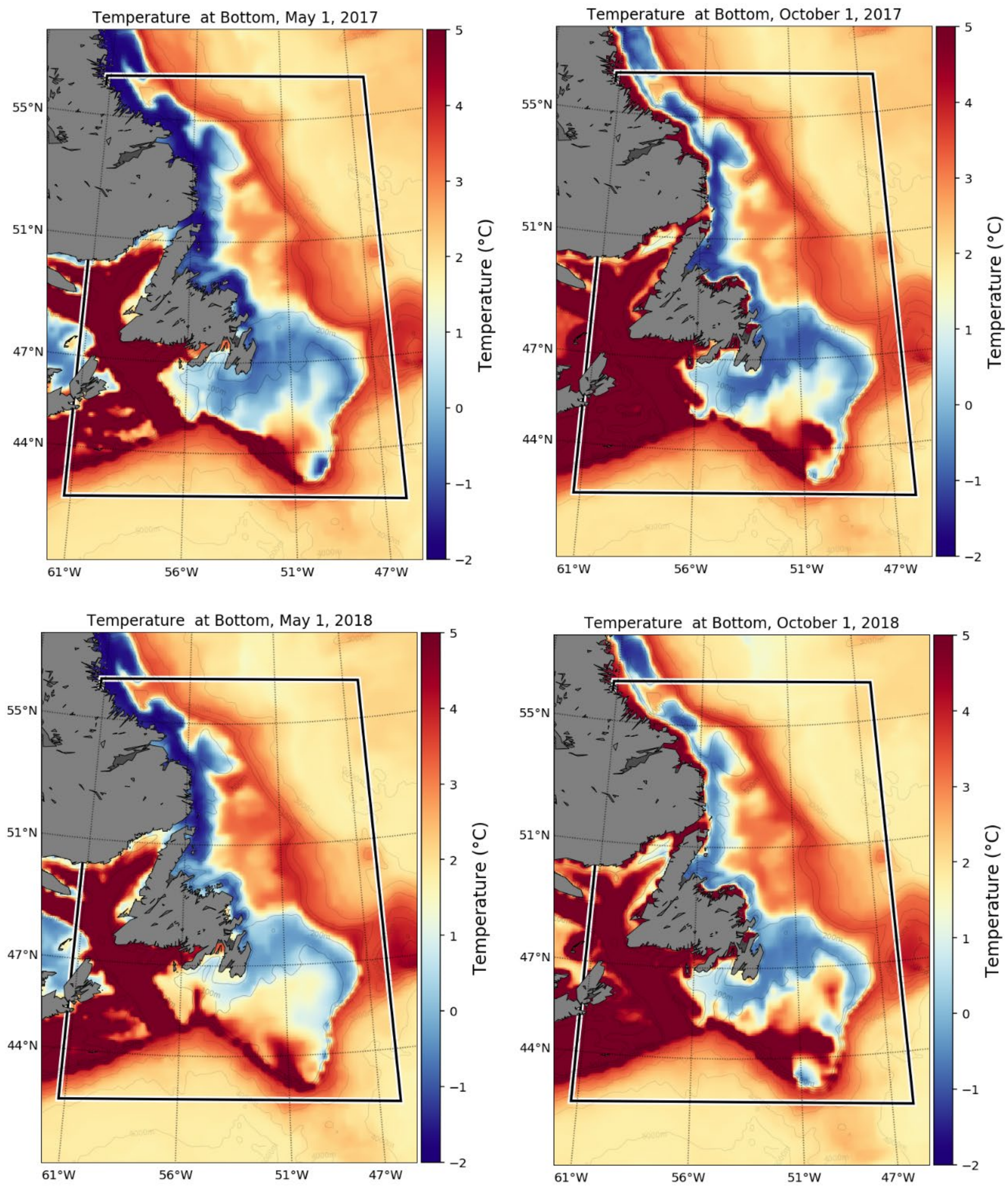

Figure 48. Bottom temperature (°C) off Newfoundland and Labrador in spring (left) and fall (right) during 2017 and 2018. Data taken from DFO Ocean Navigator site using GIOPS database.

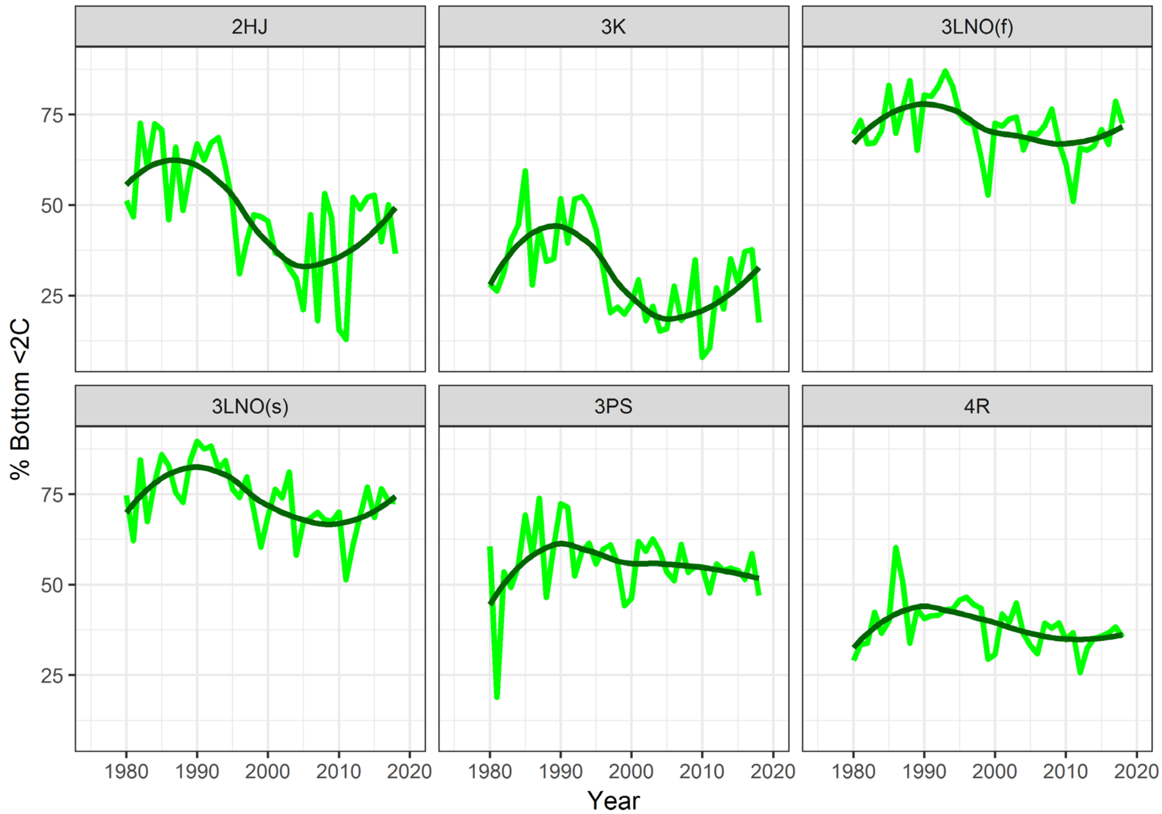

Figure 49. Snow Crab thermal habitat indices by Assessment Division and Year (1980-2018).

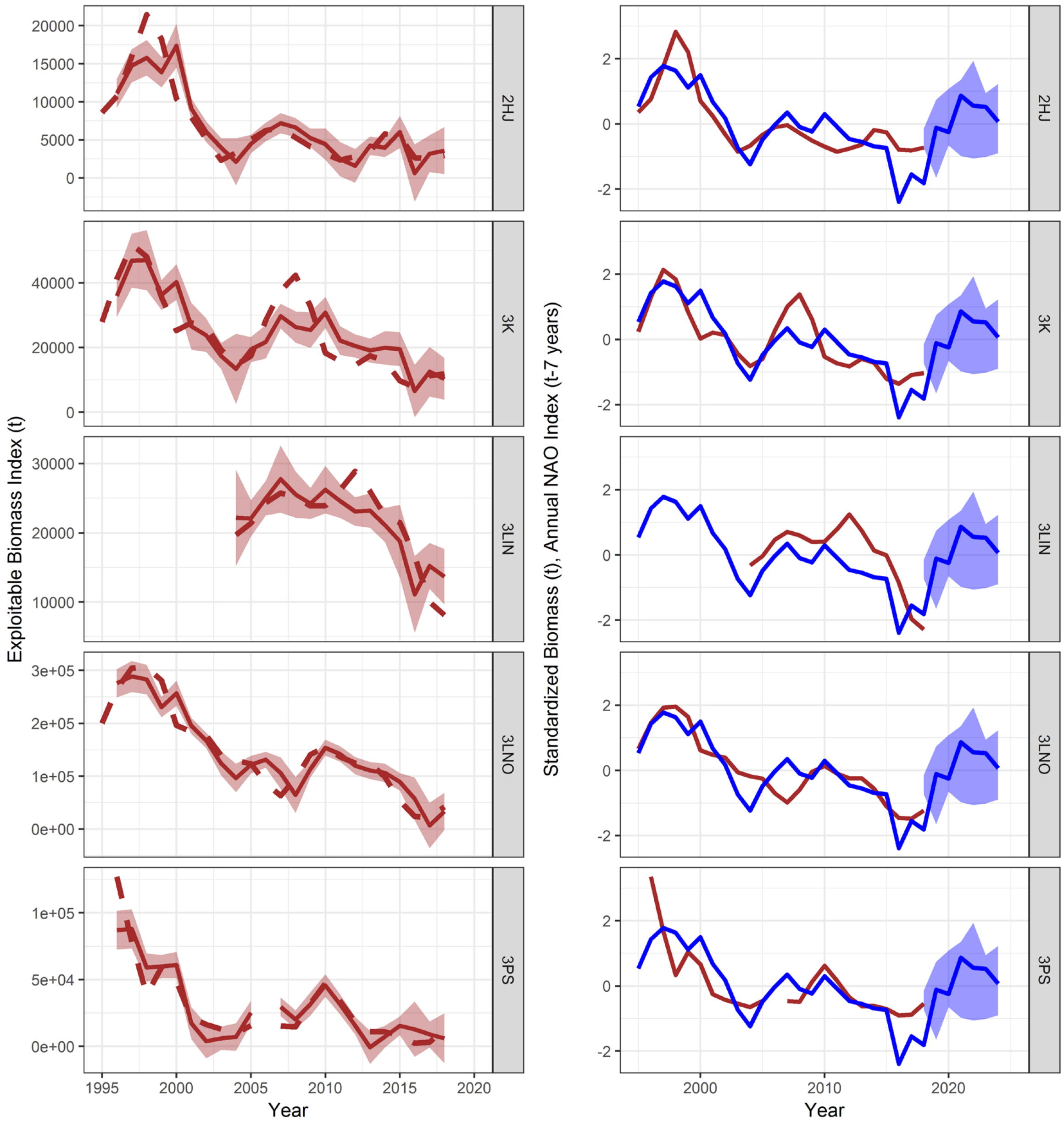

Figure 50. ***Left:*** *Observed biomass (dashed line) and linear model predicted biomass (solid line and CIs) based on 3-year centered moving average NAO lagged seven years and 2-period moving average ERI.* ***Right:*** *Scaled observed biomass vs. annual values ± 1 standard deviation of NAO lagged 7 years.*

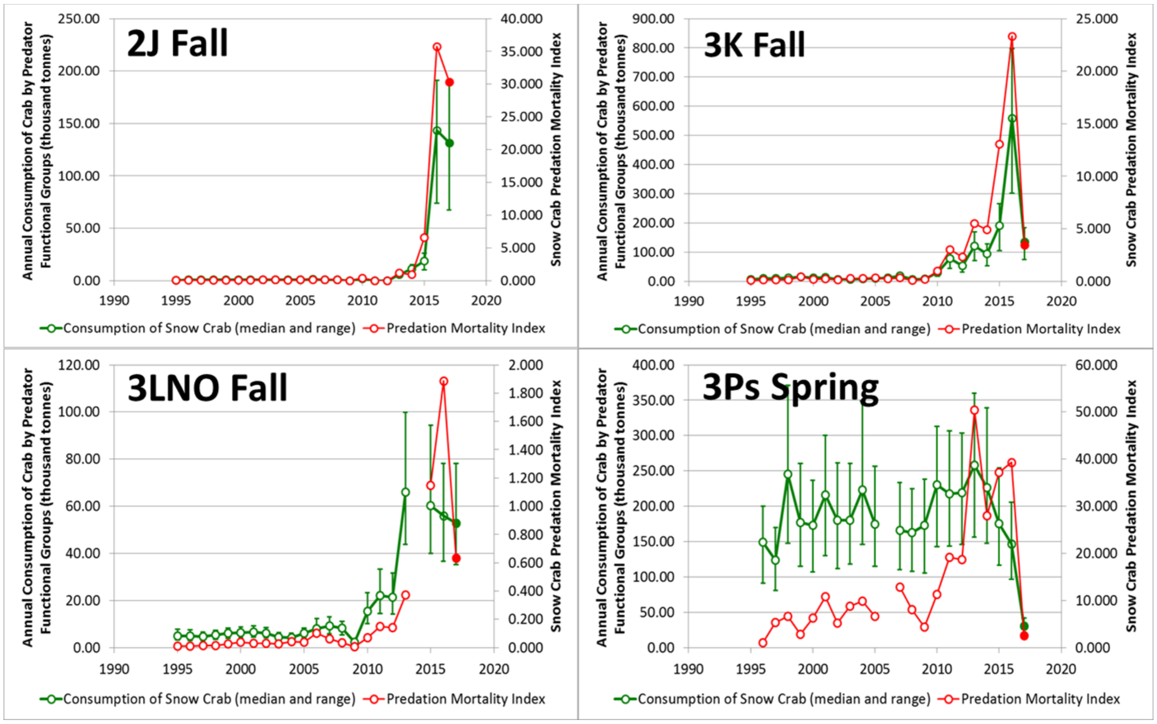

Figure 51. Snow Crab predation mortality indices by Assessment Division and year (1995-2017).

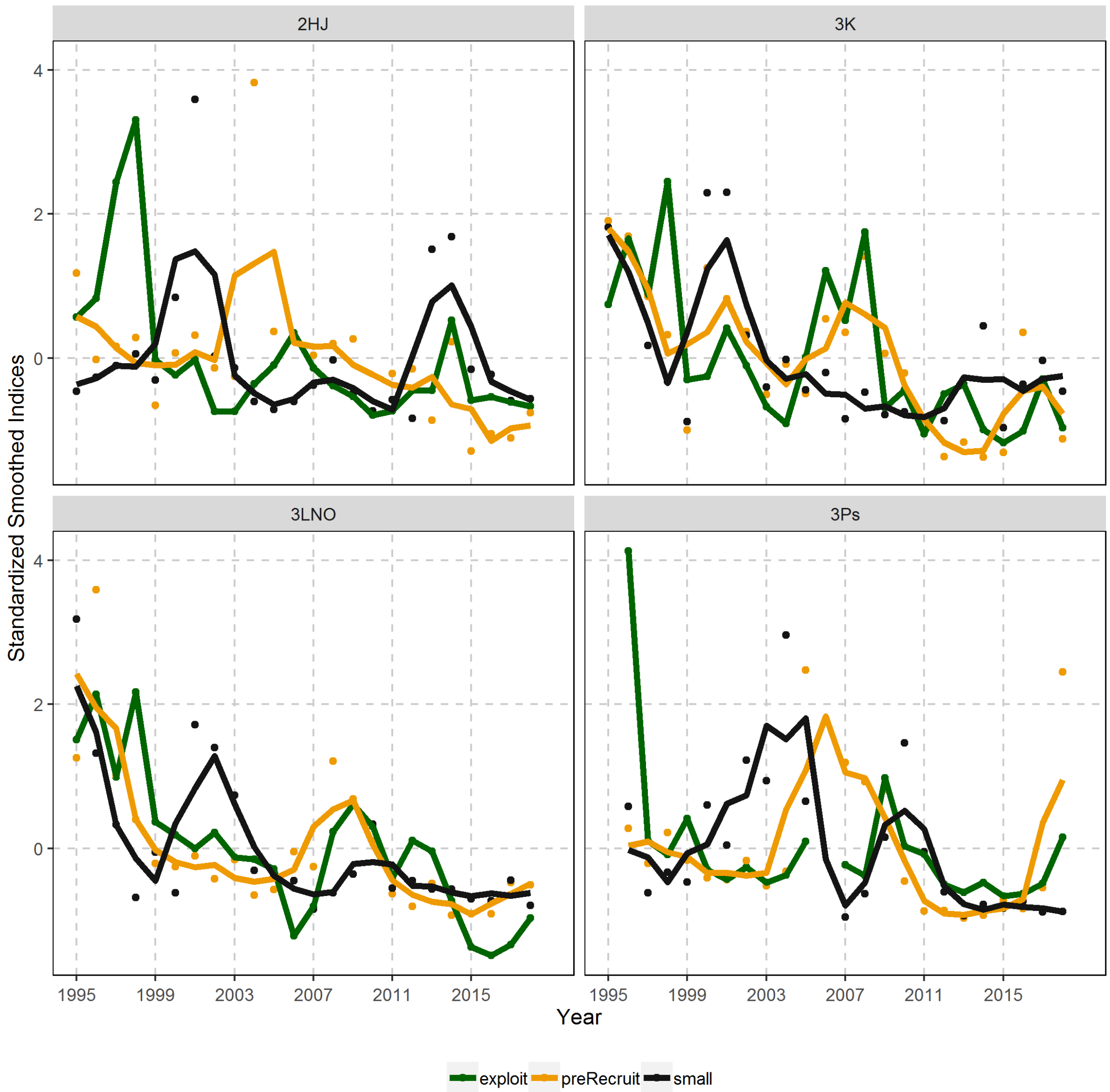

Figure 52. Standardized annual (points) and 3-year centered moving average (solid line) indices of Snow Crab abundance by Assessment Division: Small Snow Crab (black), pre-recruits (orange), and new-shelled (>94 mm) Snow Crab (green).

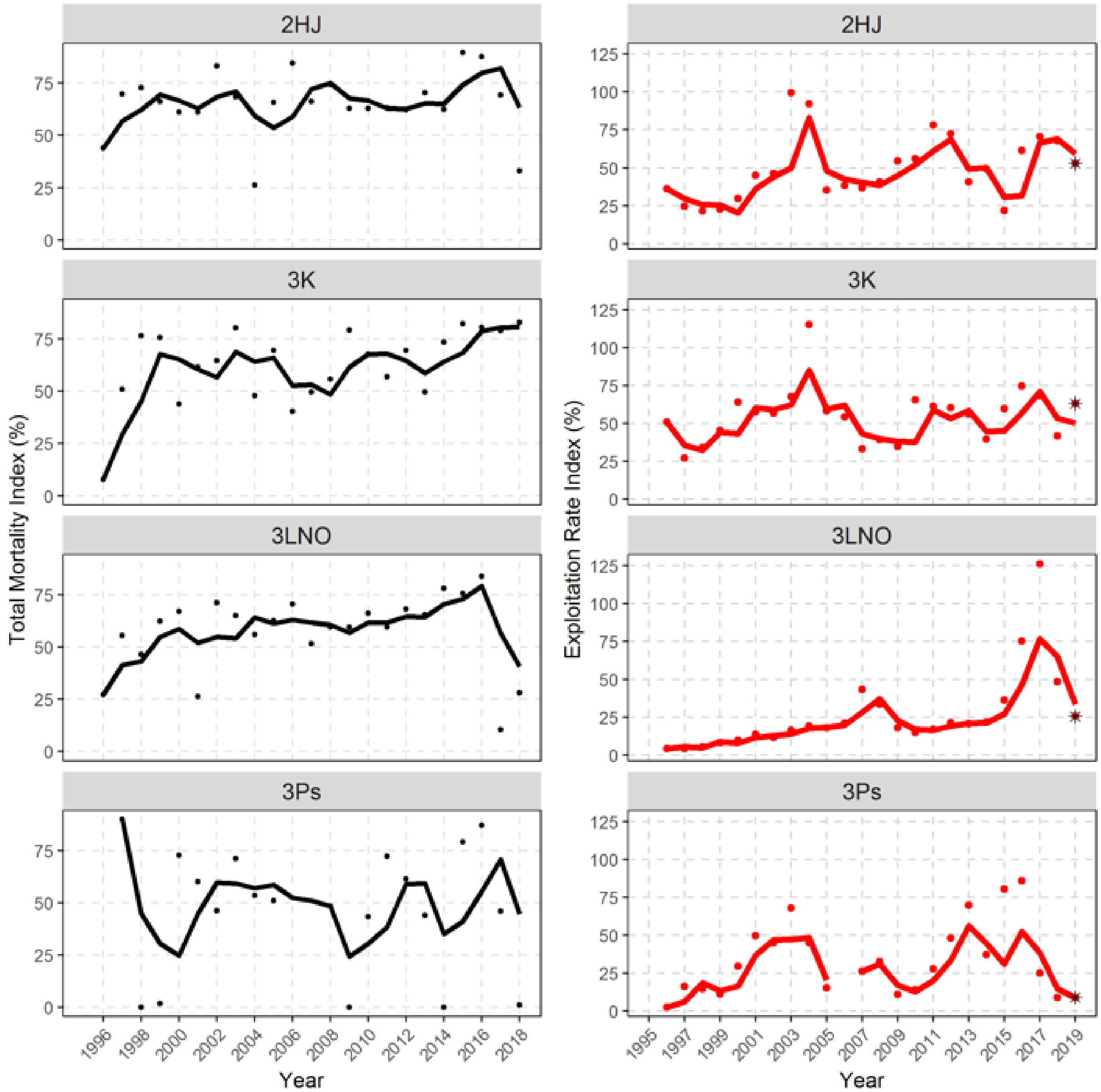

*Figure 53. **Left:** Trends in the annual (points) and 3-year moving average (solid line) total annual mortality index (%) of exploitable Snow Crab by Assessment Division. Note if annual mortality index was <0 it was plotted as 0 for presentation. **Right:** Trends in the annual (points) and 2-year moving average exploitation rate index (solid line) (%) by Assessment Division; 2019 points depict projected exploitation rate indices under status quo removals in the 2019 fishery.*

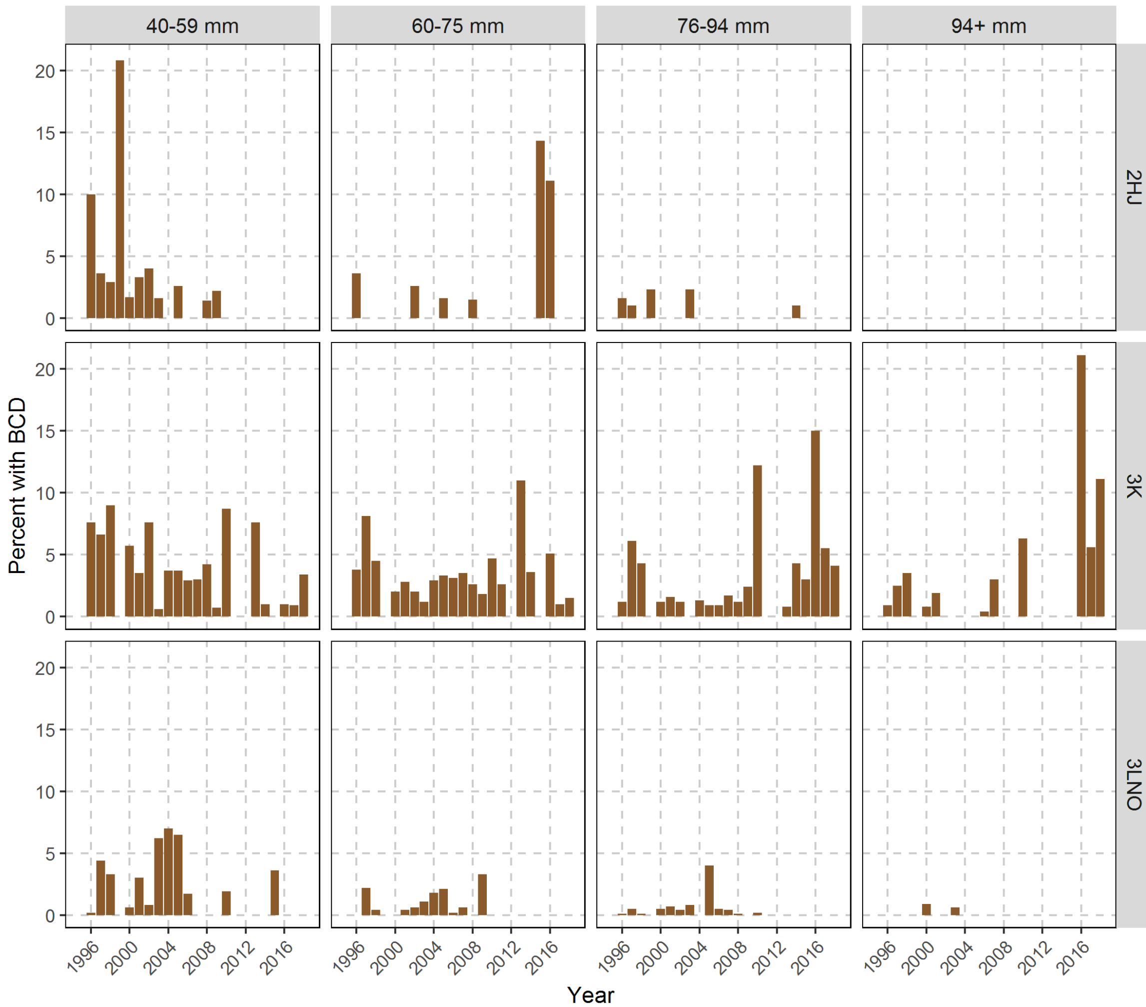

Figure 54. Annual prevalence of Bitter Crab Disease (BCD) from macroscopic observations in new-shelled adolescent male Snow Crab in fall multi-species trawl surveys by Assessment Division and carapace width (1996-2018).

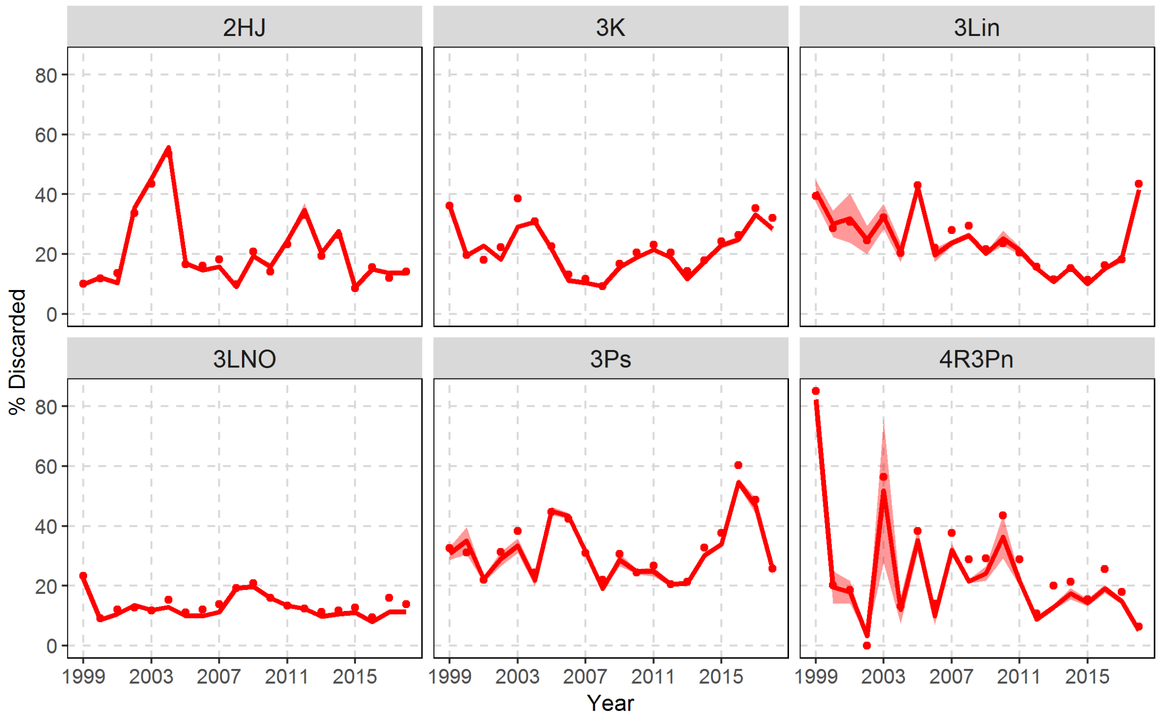

Figure 55. Trends in discards (%) based on raw estimates (points) and standardized values (solid lines). The shaded area represents the 95% confidence interval.

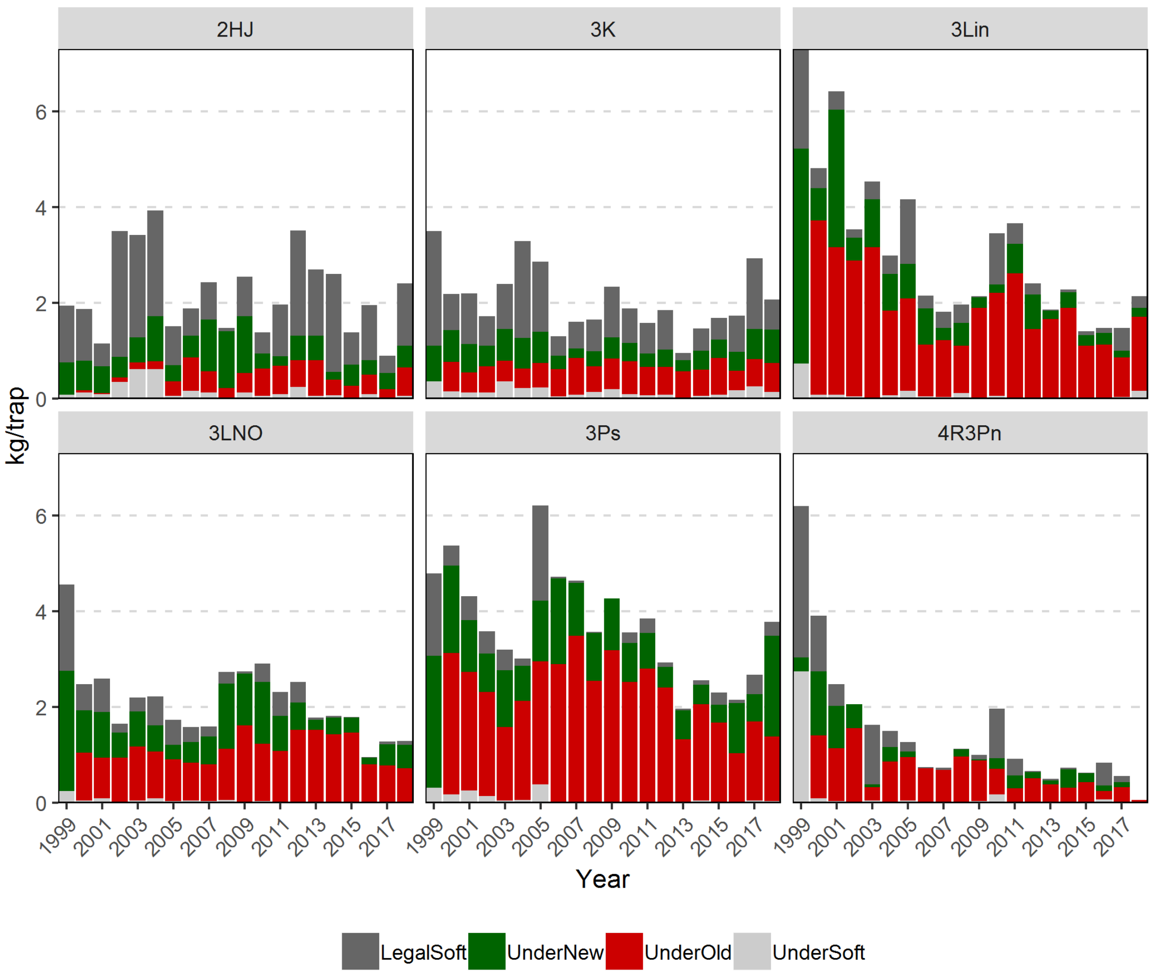

Figure 56. Trends in observed catch rates of discards (kg/trap) based on size and shell condition groups (legal-sized soft-shelled, undersized new-shelled, undersized old-shelled, and undersized soft-shelled discards) by Assessment Division.

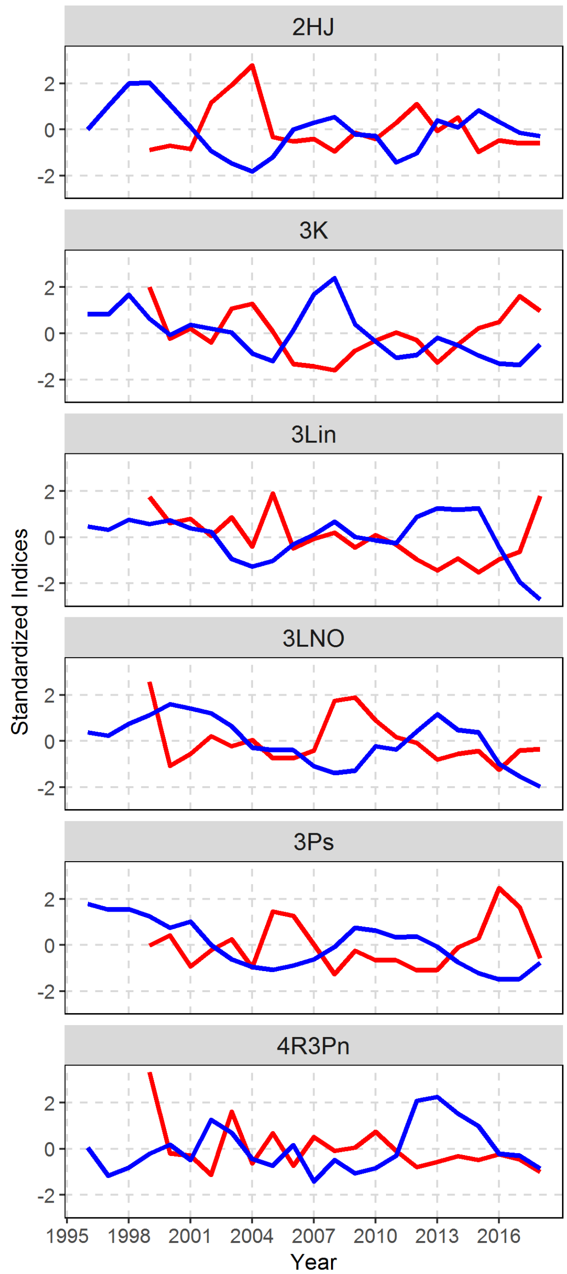

Figure 57.Trends in standardized CPUE (blue) and discard rates (red) by Assessment Division.

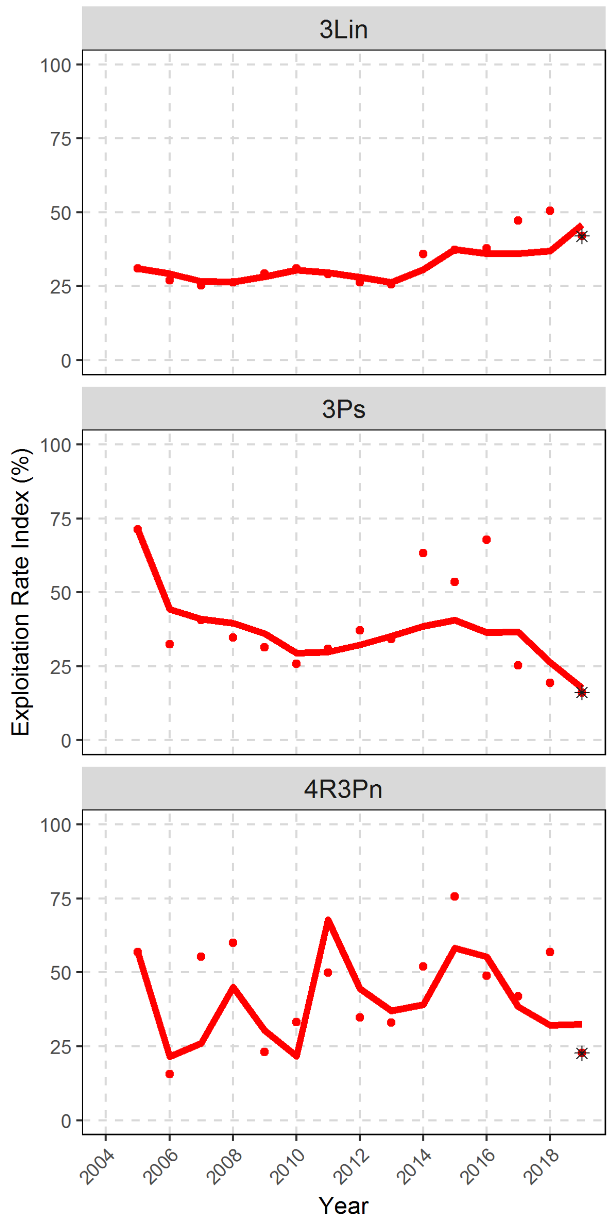

Figure 58. Annual trends in trap survey-based exploitation rate indices (points) and exploitation rate index based on 2-year moving average of exploitable biomass from trap surveys (line) by in Assessment Divisions 3L Inshore, 3Ps, and 4R3Pn. Stars depict projected 2019 exploitation rate indices based on status quo landings in the 2019 fishery.

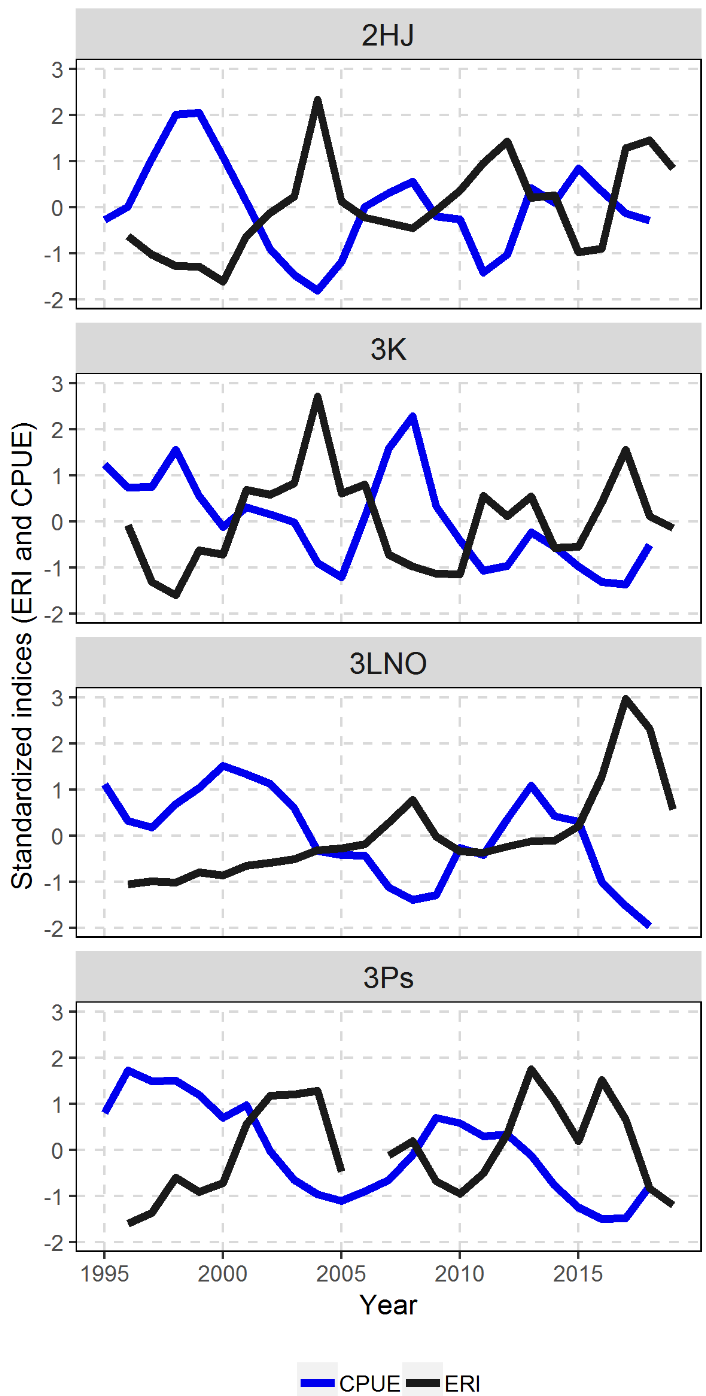

Figure 59. Trends in standardized CPUE (blue) and exploitation rate indices (red) by Assessment Division.

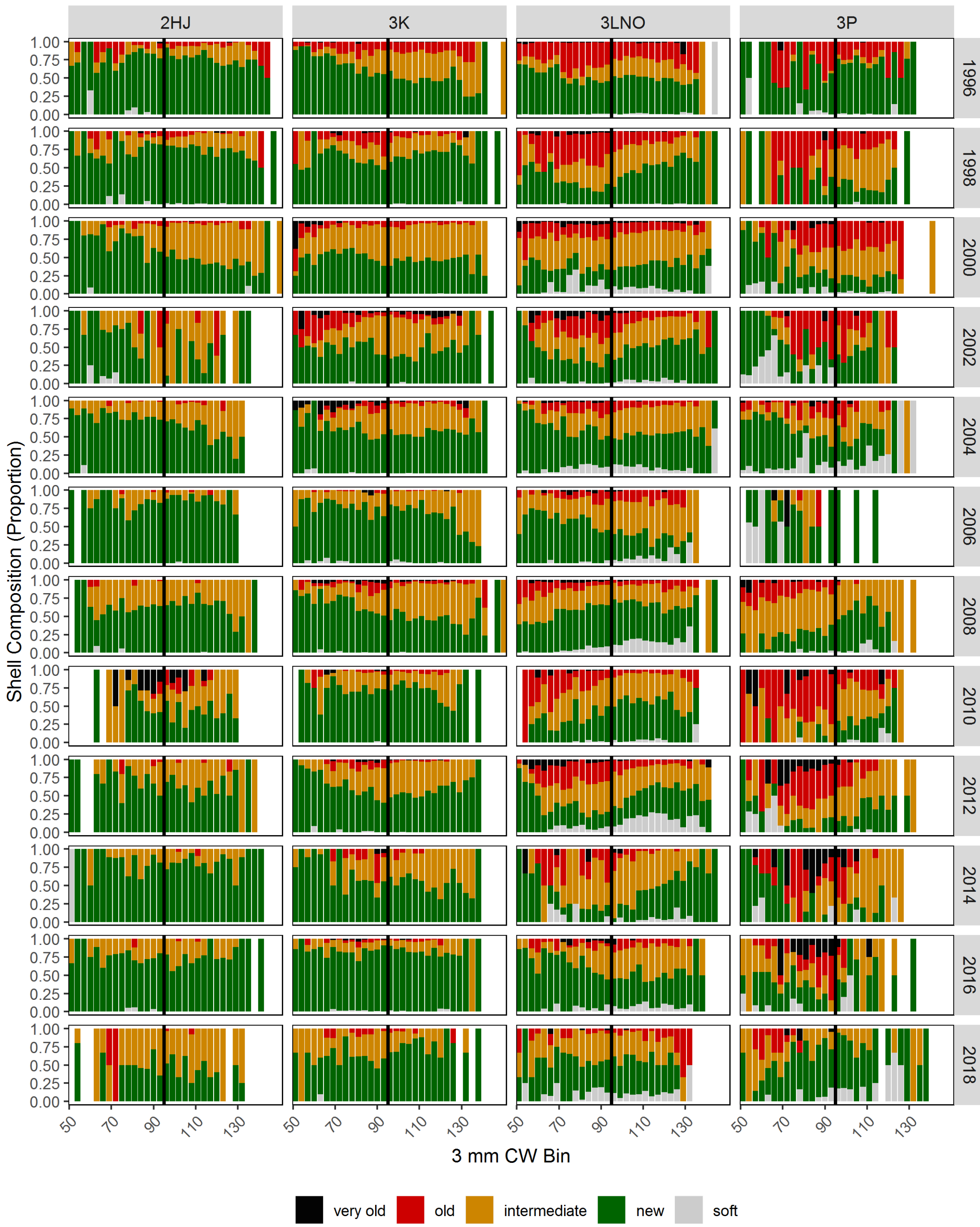

Figure 60. Shell composition of adult male Snow Crab by 3-mm carapace width intervals from multi-species trawl surveys since 1995 in each Assessment Division. Years binned to two year increments (1995+1996=1996). Vertical black lines depict legal-size. (Grey = soft-shelled, green = new-shelled, orange = intermediate-shelled, red = old-shelled, black = very old-shelled).

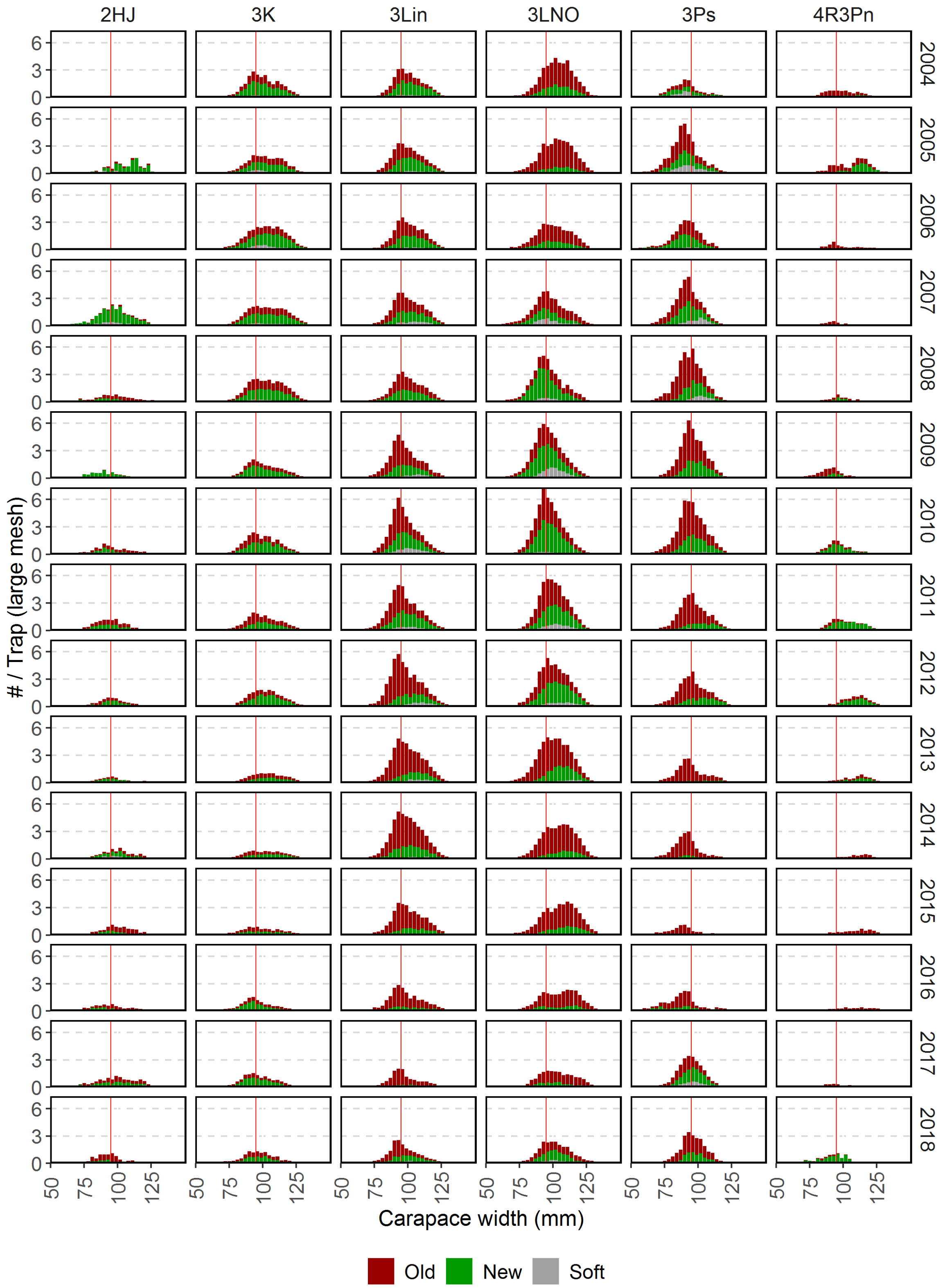

Figure 61. Trends in CPUE (#/trap) by male carapace width distributions and shell condition from large-mesh traps in the CPS survey by Assessment Division (2004-18). The red vertical line indicates the minimum legal size.

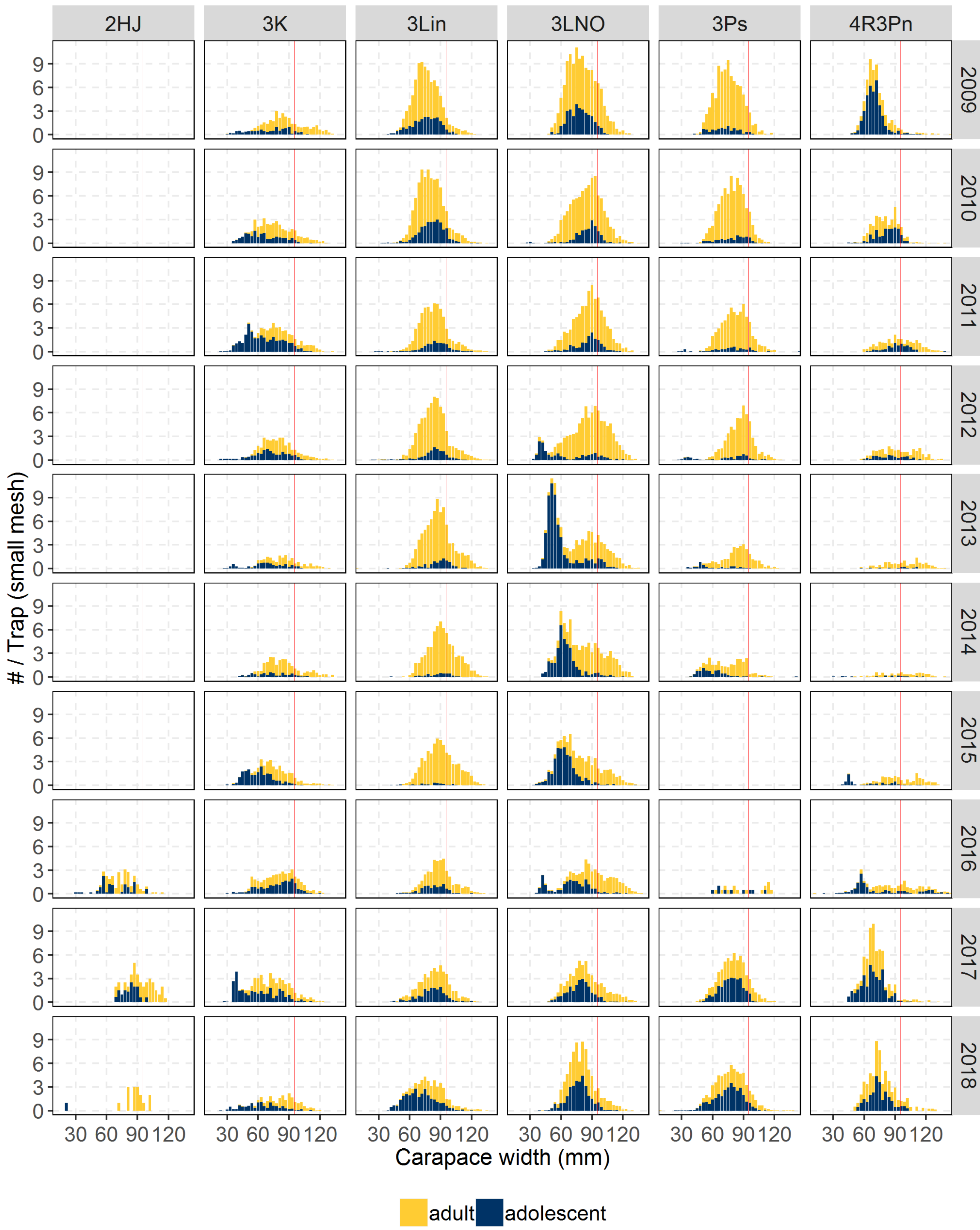

Figure 62. Trends in CPUE (#/trap) by male carapace width distributions and maturity (blue – juvenile and adolescent males, yellow – adult males) from small-mesh traps in core stations from the CPS survey by Assessment Division (2009-18). The red vertical line indicates the minimum legal size.

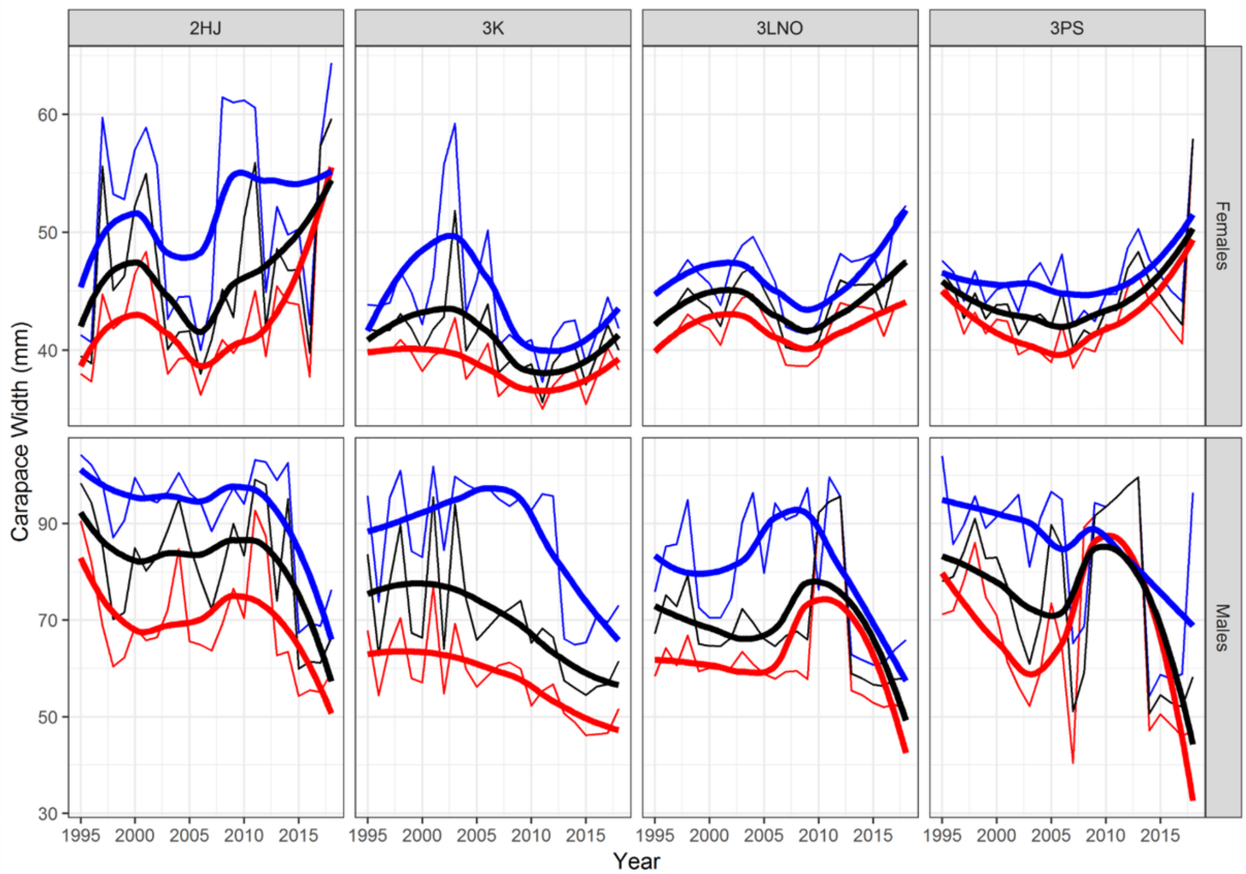

Figure 63. Size of female (top) and male (bottom) 1/3 (red), 50% (black), and 2/3 (blue) size at maturity in each Assessment Division. Thin lines represent annual estimates from GAM. Thick lines represent a smoothed line through annual estimates.

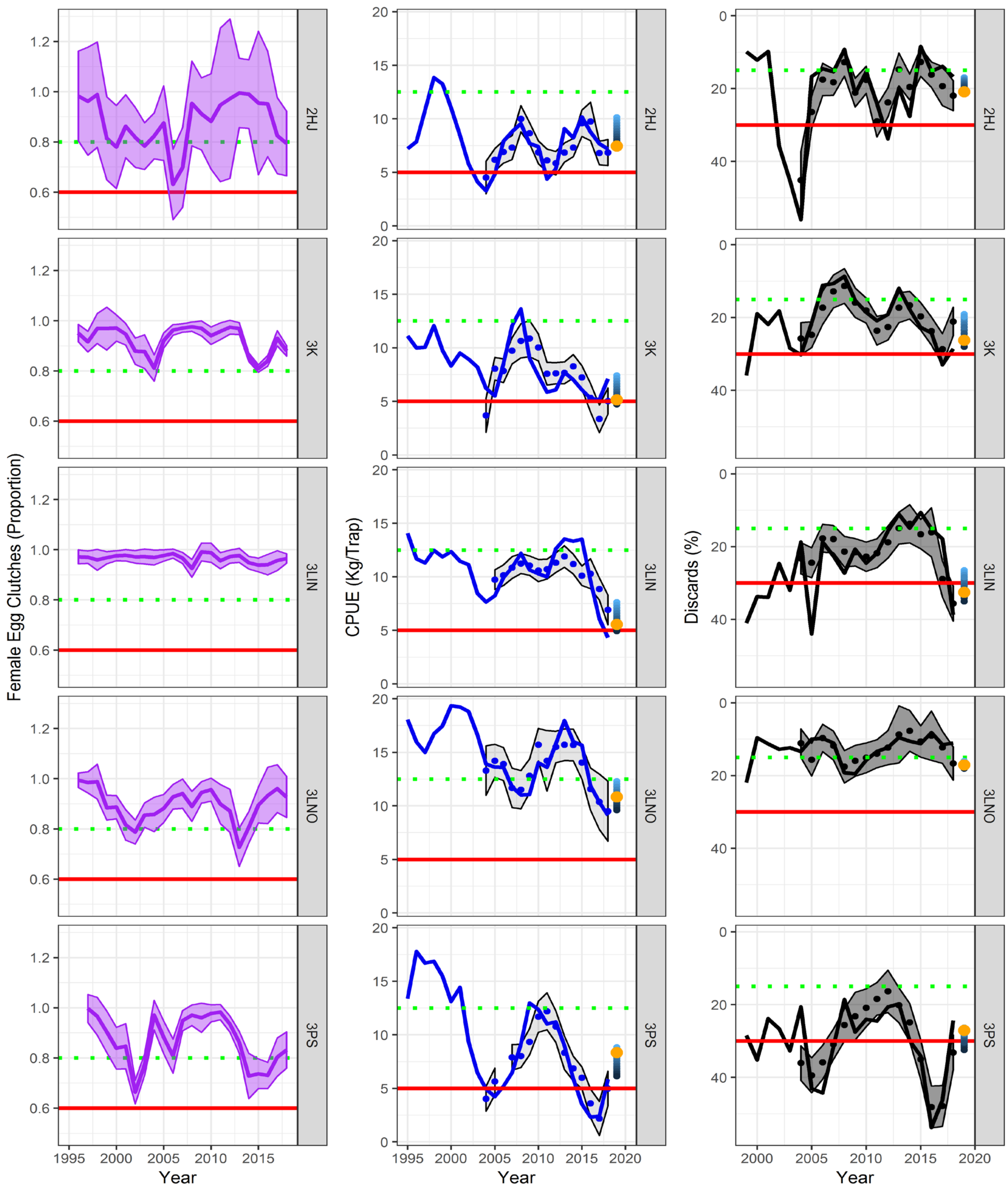

Figure 64.Trends in proportion of females with full egg clutches (left), CPUE (middle), and % discards (right), in relation to proposed Precautionary Approach. Shaded areas represent 95% confidence (egg clutches) or prediction (CPUE and discards) intervals. Points represent predicted values. Solid lines represent standardized annual indices. Orange points represent predicted values under status quo landings. Vertical blue shades in 2019 are the predicted values under varying levels of ERI (light to dark blue: ERI = 0 – 60%). Red line represents limit reference point and green dashed line represents proposed upper stock reference.

APPENDIX 1: ASSESSMENT DIVISION 2HJ DETAILS

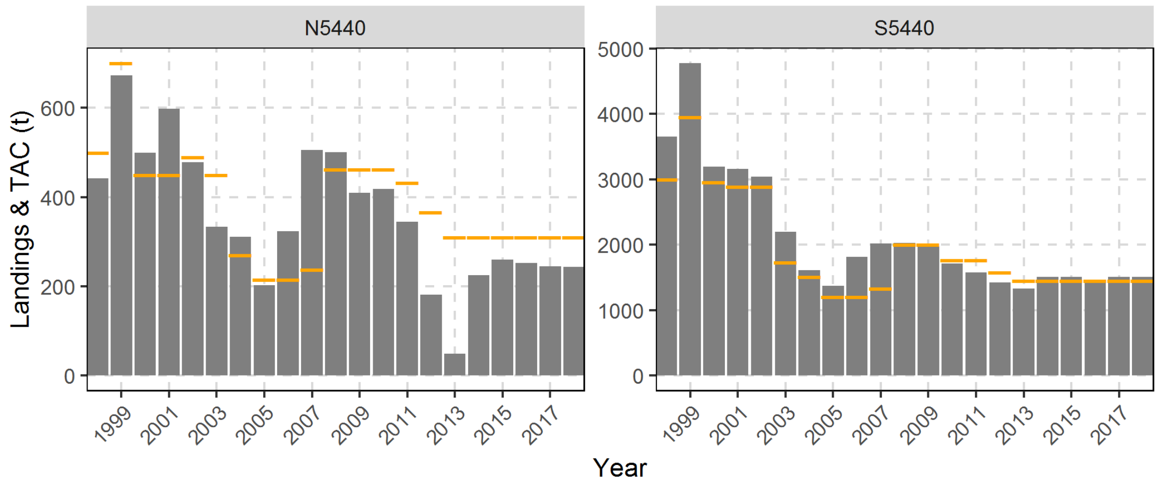

Figure A1.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Divisions 2HJ (1998-2018). Industry stakeholders in N5440 have chosen to not harvest 15% of the TAC in recent years to promote conservation measures.

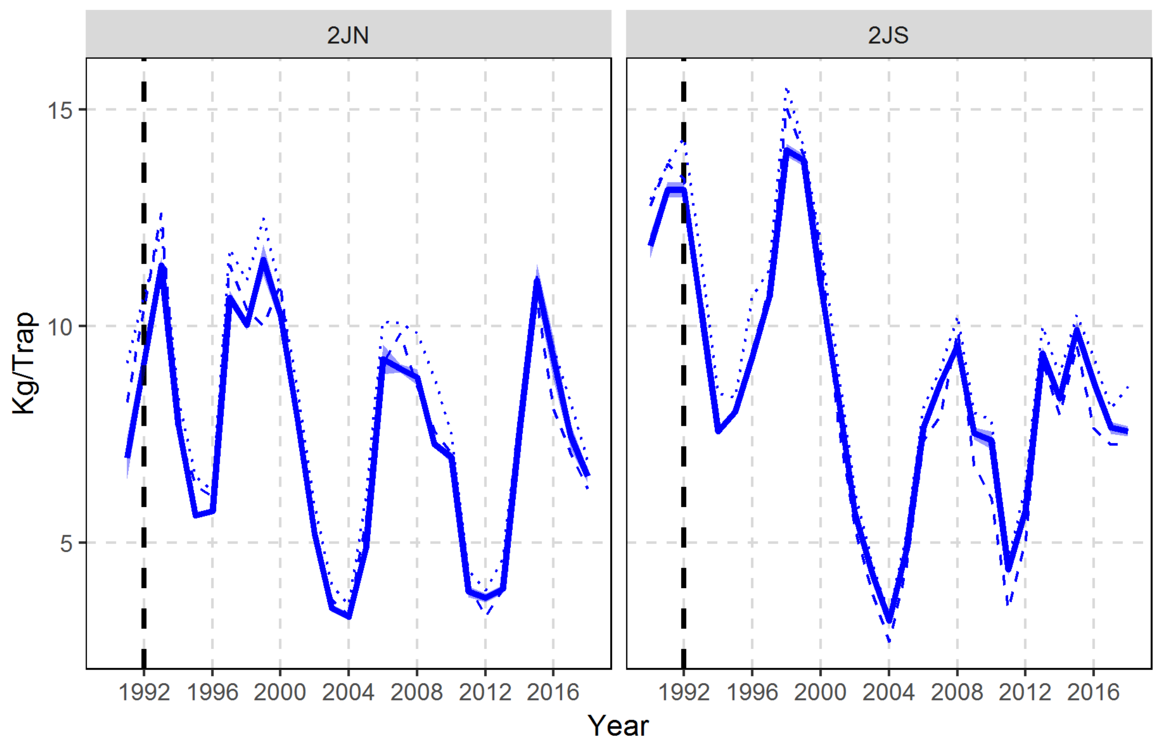

Figure A1.2. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Divisions 2HJ. Solid line is average predicted CPUE and band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents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

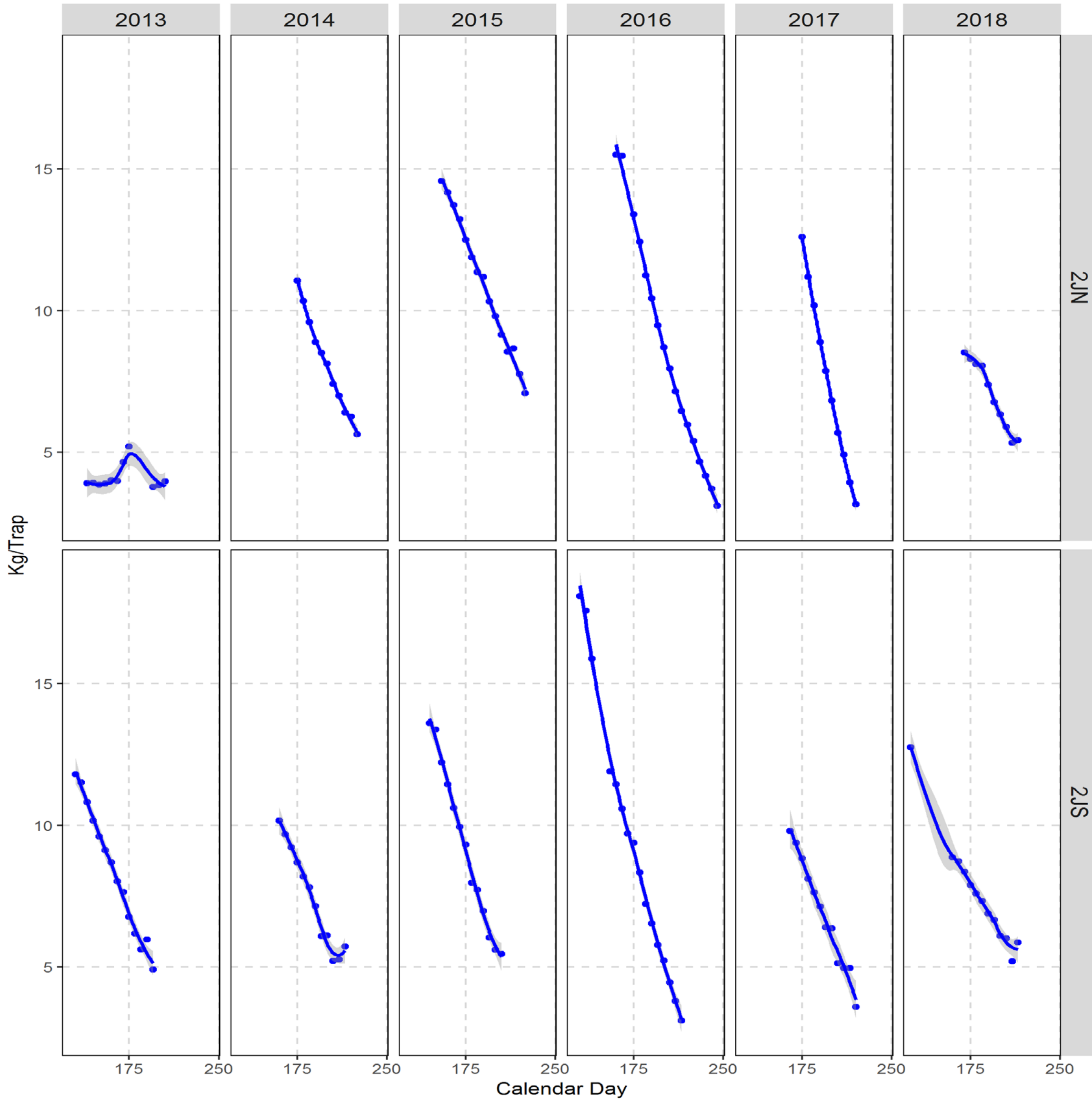

Figure A1.3. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2013-18), by Crab Management Area (CMA) in Assessment Divisions 2HJ.

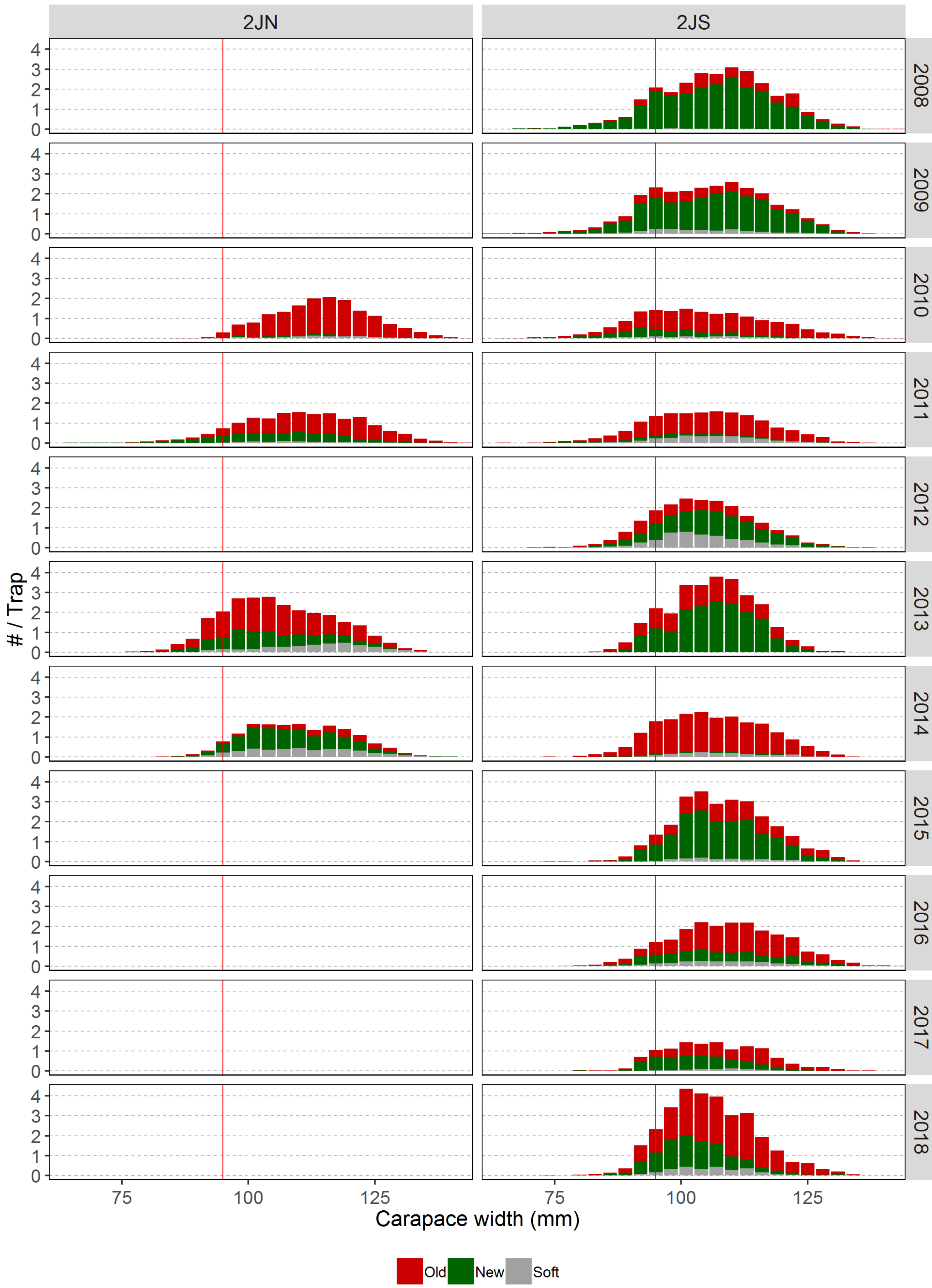

Figure A1.4. Trends in male carapace width distributions by shell condition from observer sampling in Divisions 2HJ (2008-18). The red vertical line indicates the minimum legal size.

Figure A1.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shelled Snow Crab in the catch in CMAs within the Assessment Divisions 2HJ (1999-2018). Bubble size depicts percentage of soft-shelled Snow Crab and solid line depicts unstandardized observed catch rates.

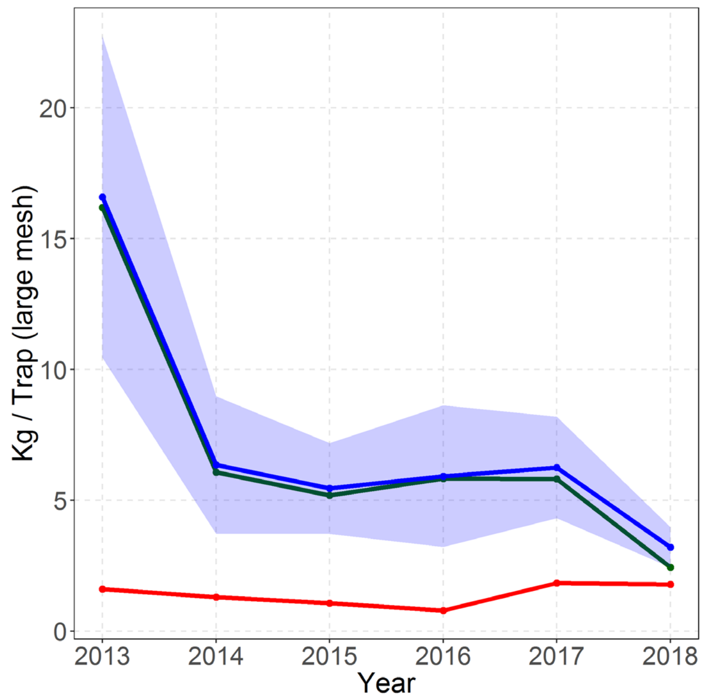

Figure A1.6. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized Snow Crab from the Torngat Joint Fisheries Secretariat survey (2013-18) (CMA 2JN).

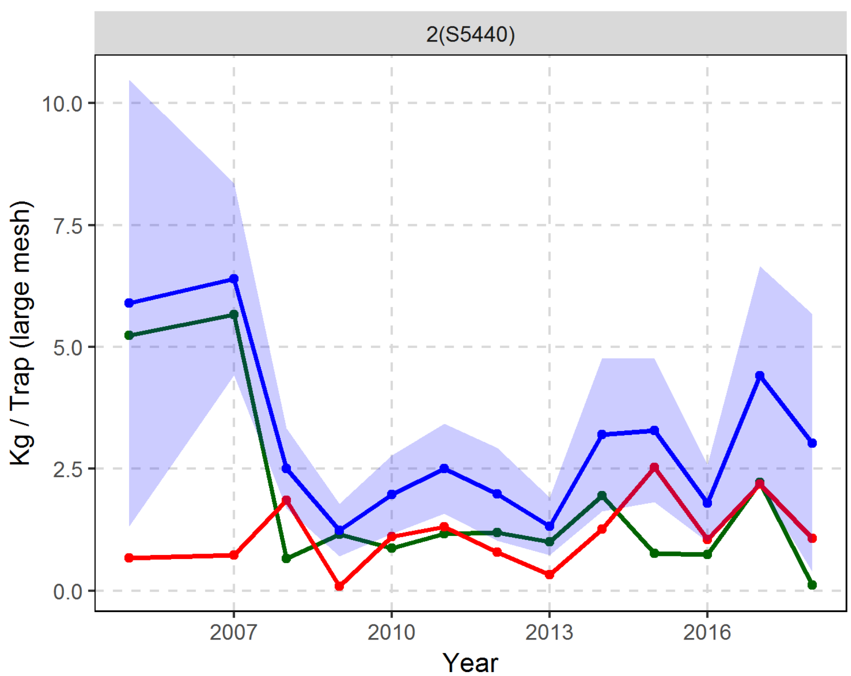

Figure A1.7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized Snow Crab from core stations in the CPS trap survey (CMA 2JS).

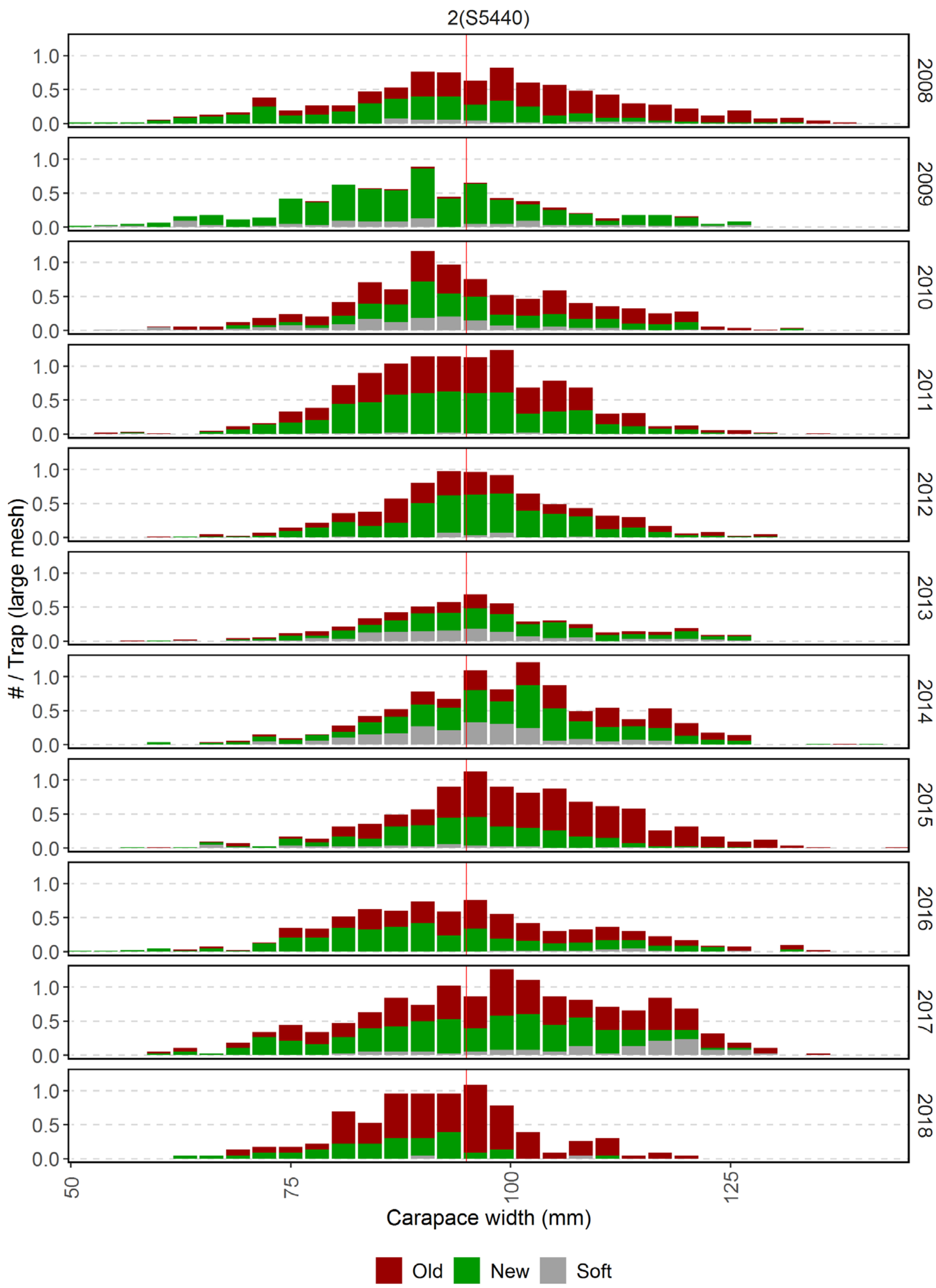

Figure A1.8. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMA 2JS in Assessment Divisions 2HJ (2008-18). The red vertical line indicates the minimum legal size.

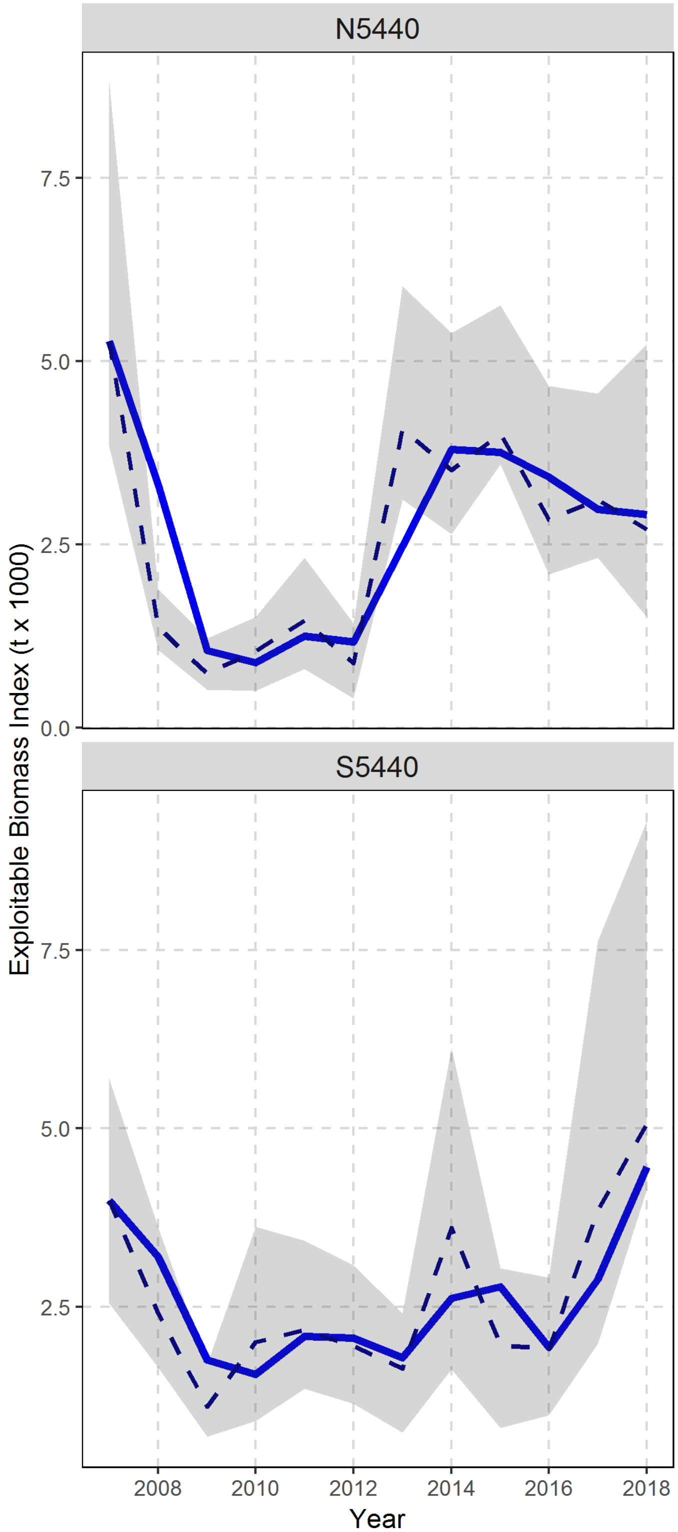

Figure A1.9. ***Left:*** *Annual trap-based exploitable biomass index (t * 1000). The solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the confidence limit of the annual estimates.*

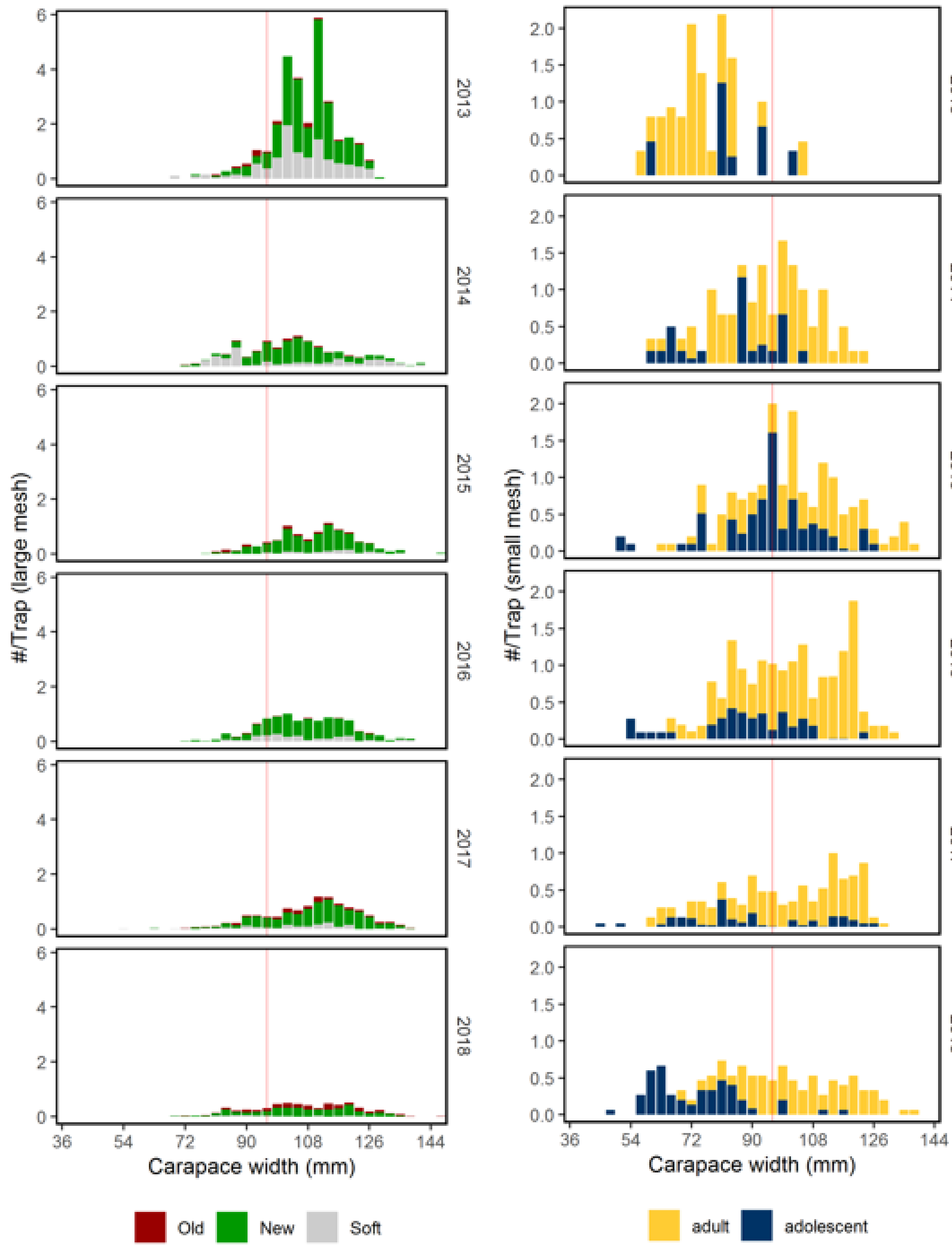

Figure A1.10. ***Left:*** *CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in the Torngat Joint Fisheries Secretariat survey (CMA 2JN) (2013-18).* ***Right:*** *CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Torngat Joint Fisheries Secretariat survey (2013-18). The red vertical line indicates the minimum legal size.*

APPENDIX 2: ASSESSMENT DIVISION 3K DETAILS

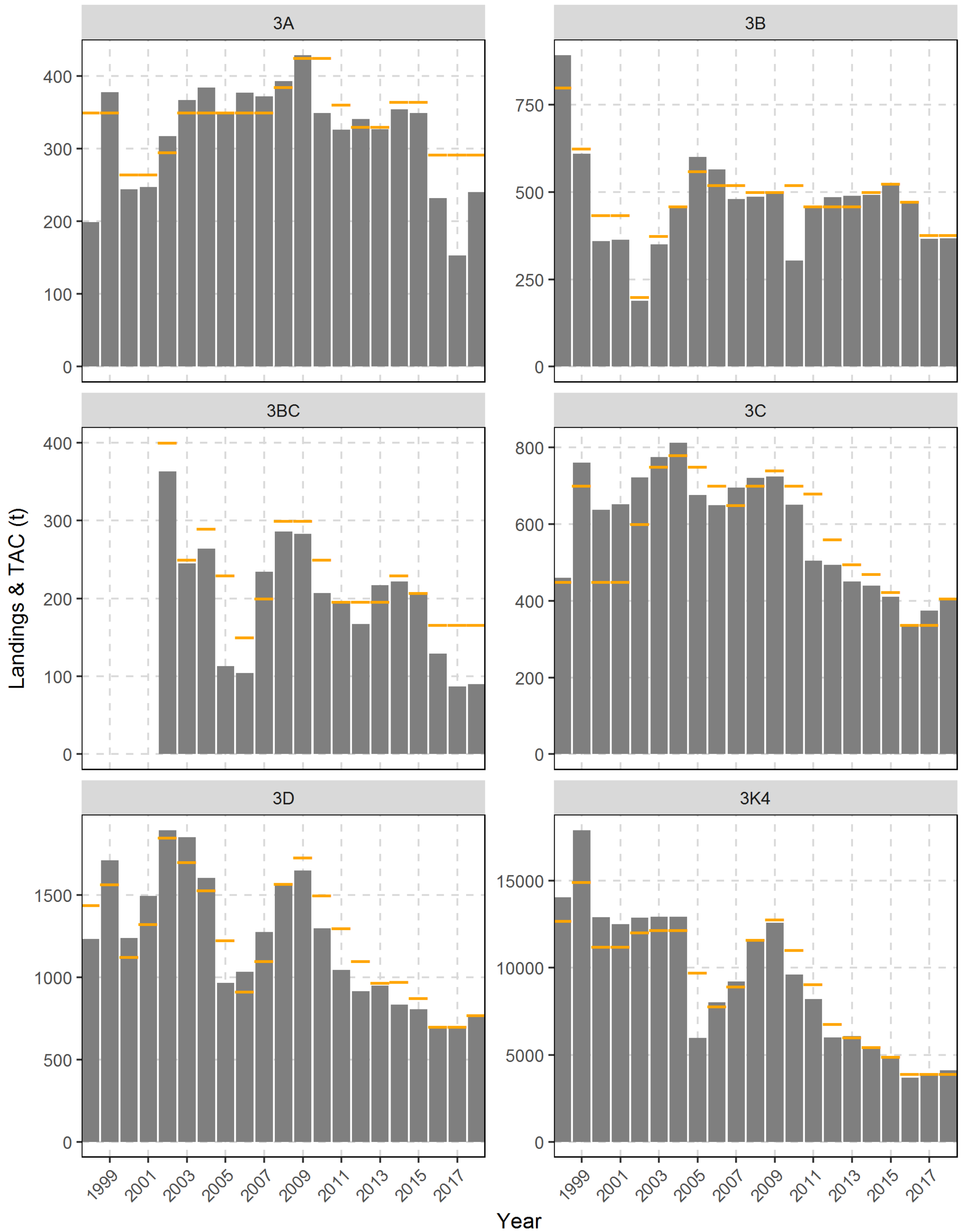

Figure A2.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Division 3K (1998-2018).

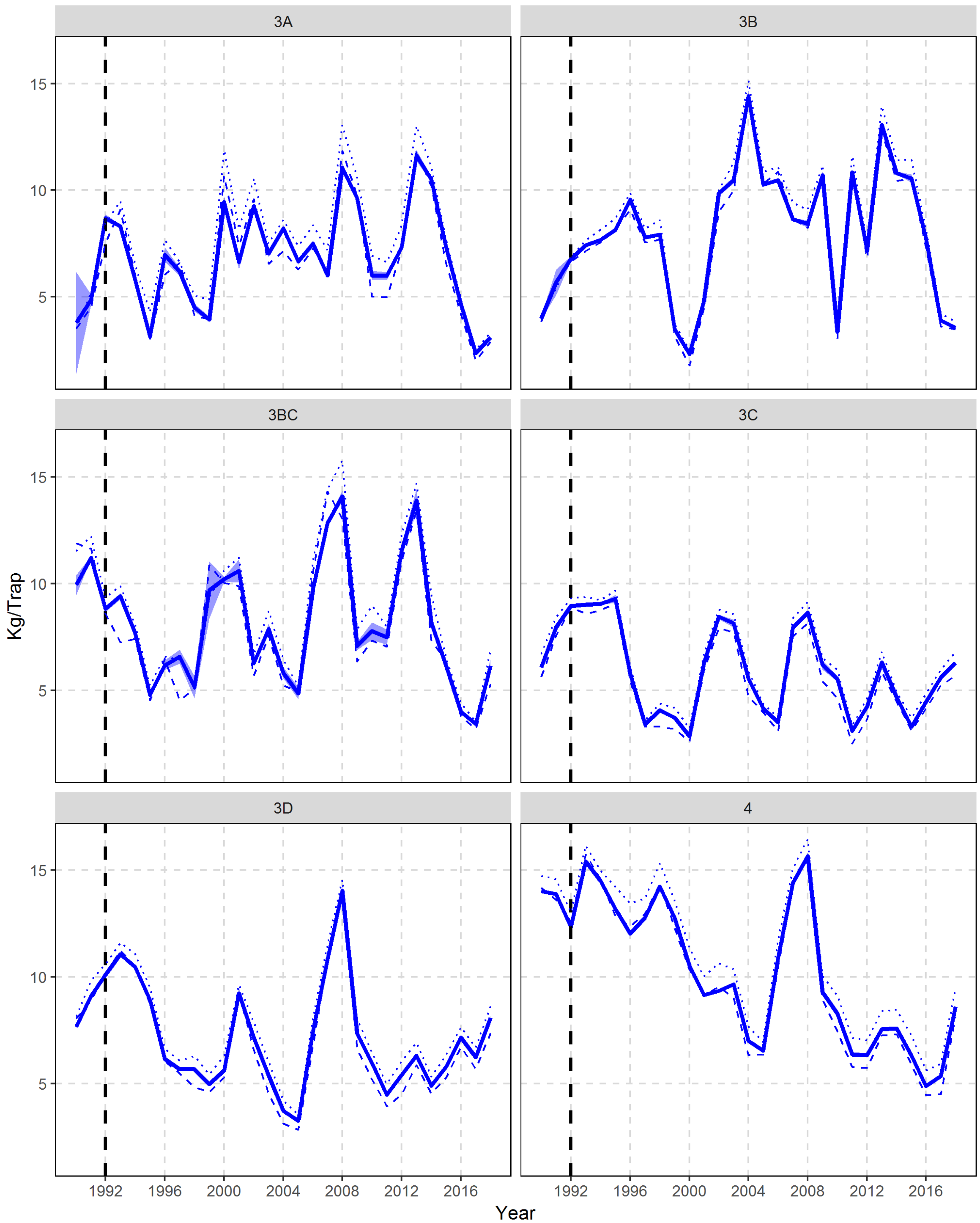

Figure A2.2. Trends in standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Division 3K. Solid line is average predicted CPUE and shaded band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents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

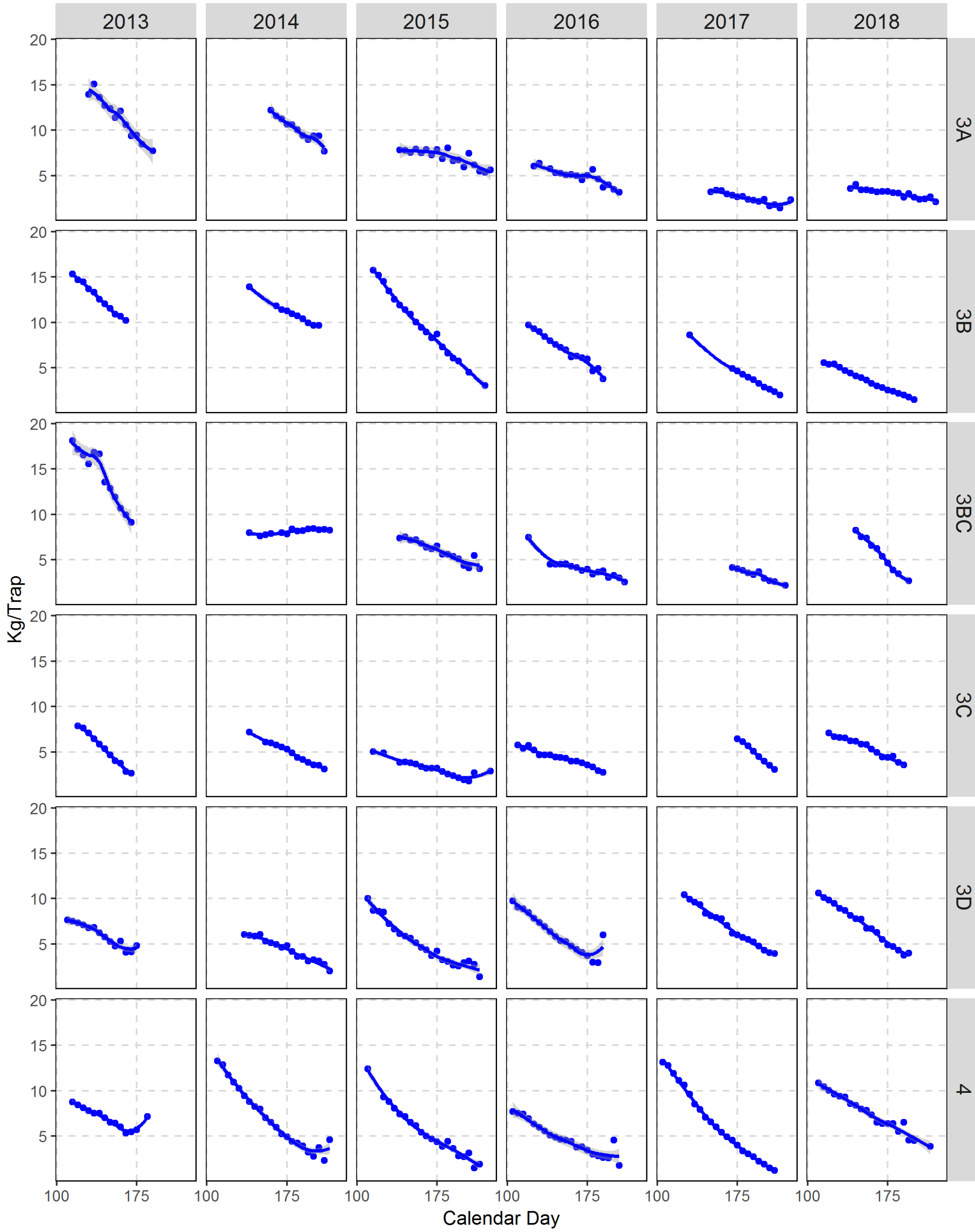

Figure A2.3. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2013-18), by Crab Management Area (CMA) in Assessment Division 3K.

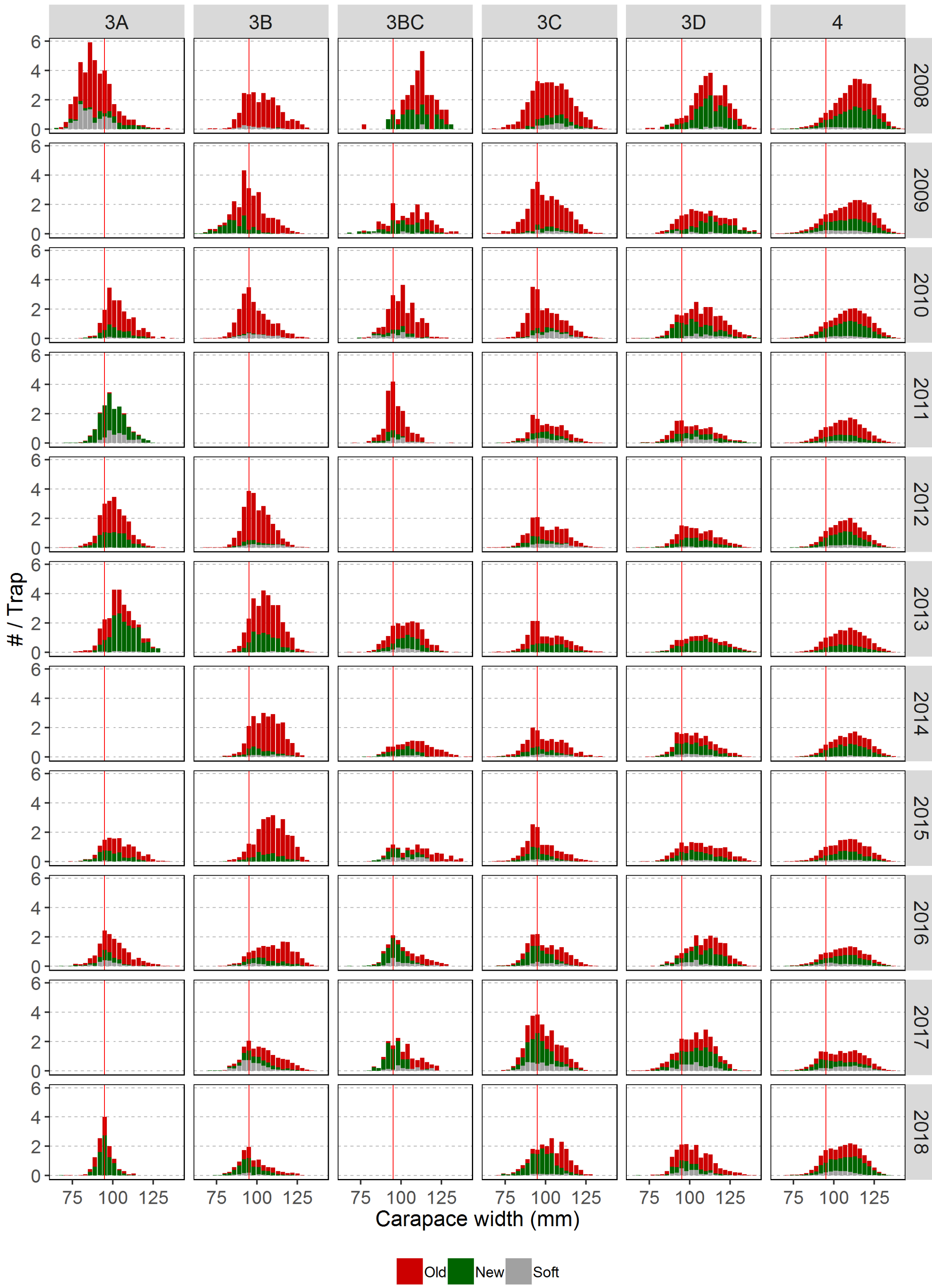

Figure A2.4. Trends in male carapace width distributions by shell condition from observer sampling in Divisions 3K (2008-18). The vertical line indicates the minimum legal size.

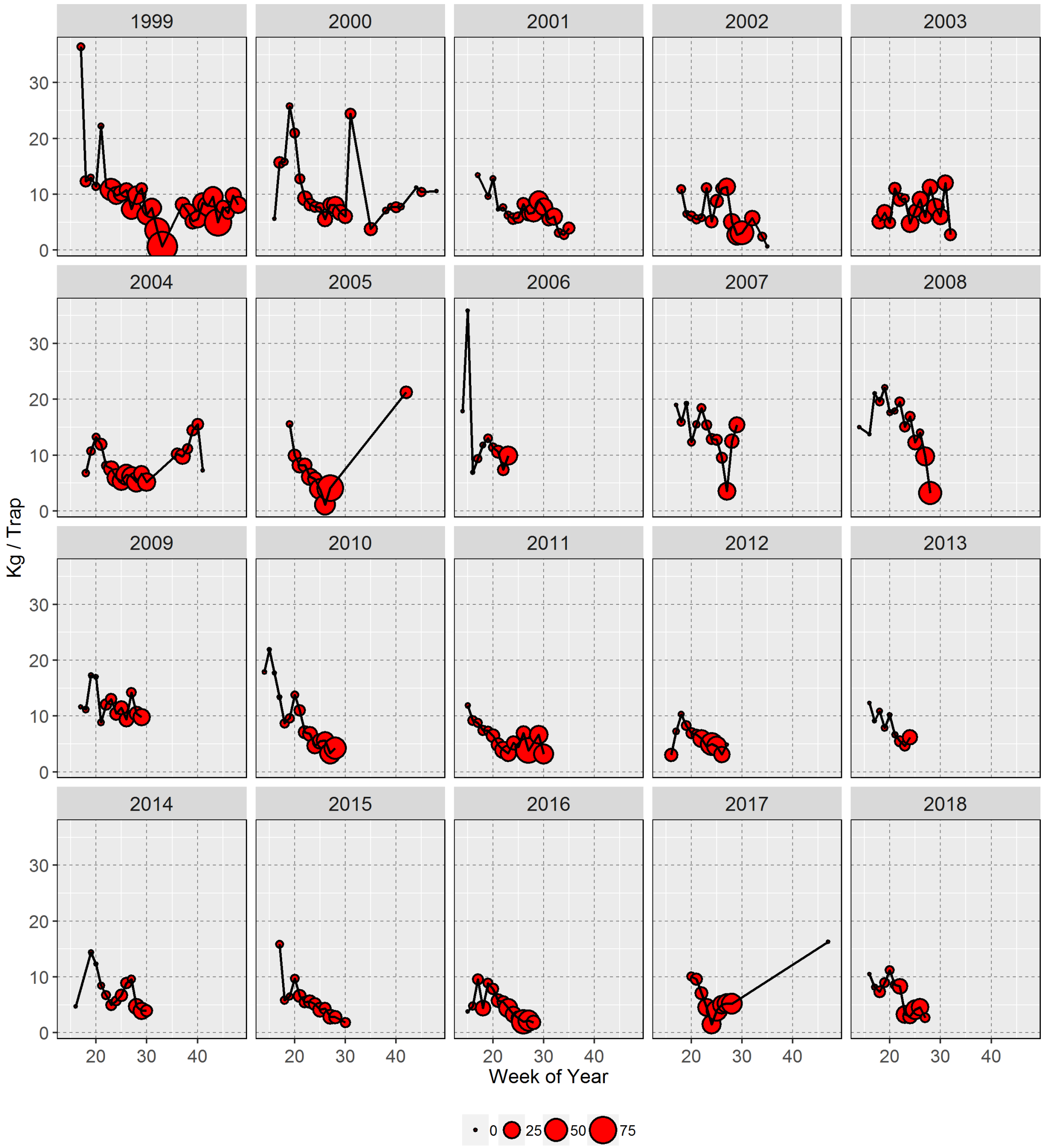

Figure A2.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shelled Snow Crab in the catch in CMAs within the Assessment Division 3K (1999-2018). Bubble size depicts percentage of soft-shelled Snow Crab and solid line depicts unstandardized observed catch rates.

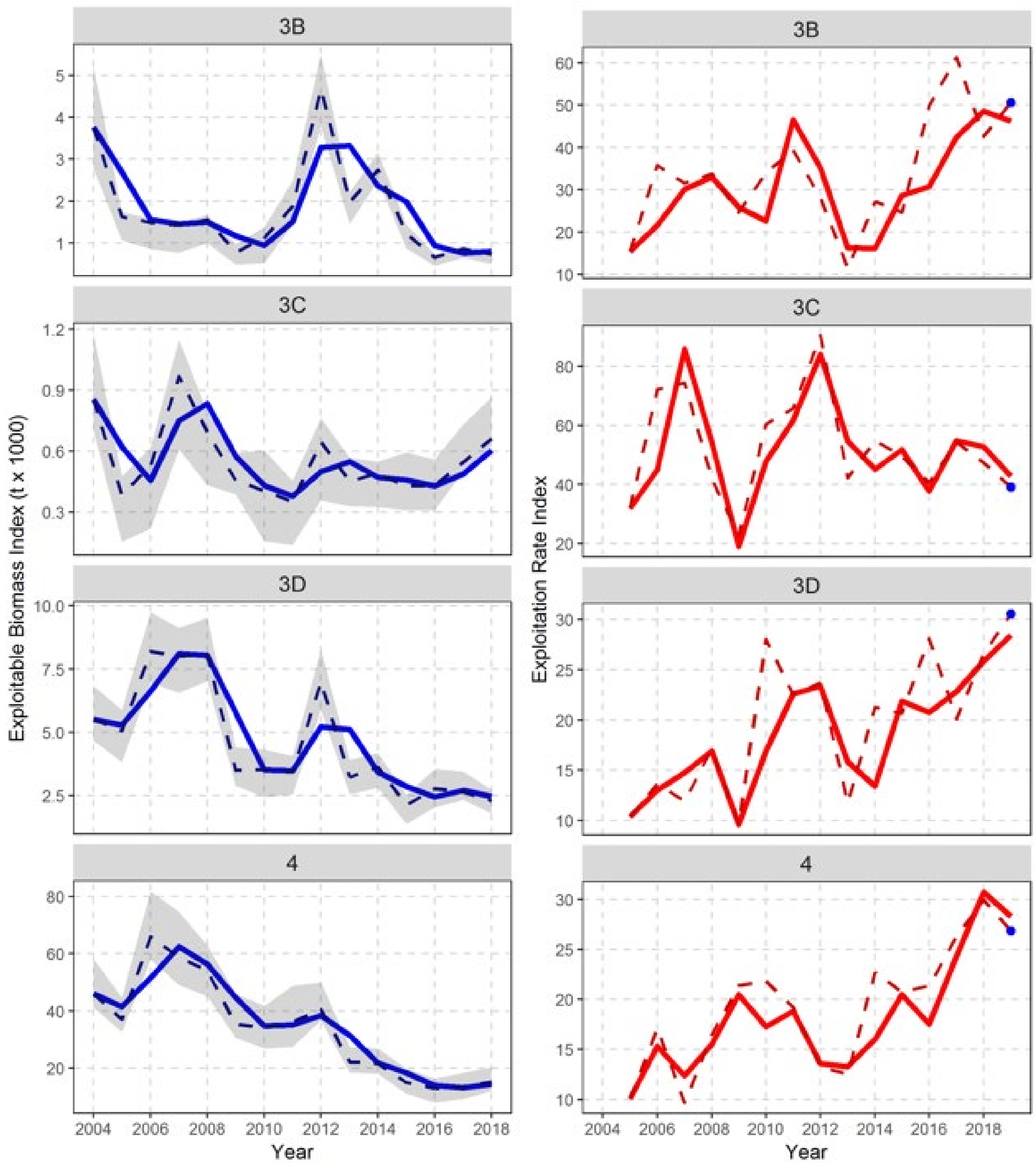

Figure A2.6. ***Left:*** *Annual trap-based exploitable biomass index (t * 1000). The solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the confidence interval of the annual estimates.* ***Right:*** *Trends in the exploitation rate index (ERI) in CMAs within Assessment Division 3K. Solid line represents ERI based on a 2-year moving average of trap-based exploitable biomass and the dashed line represents the trend in annual estimates. The blue point is the annual estimate of ERI in 2019 based on status quo landings.*

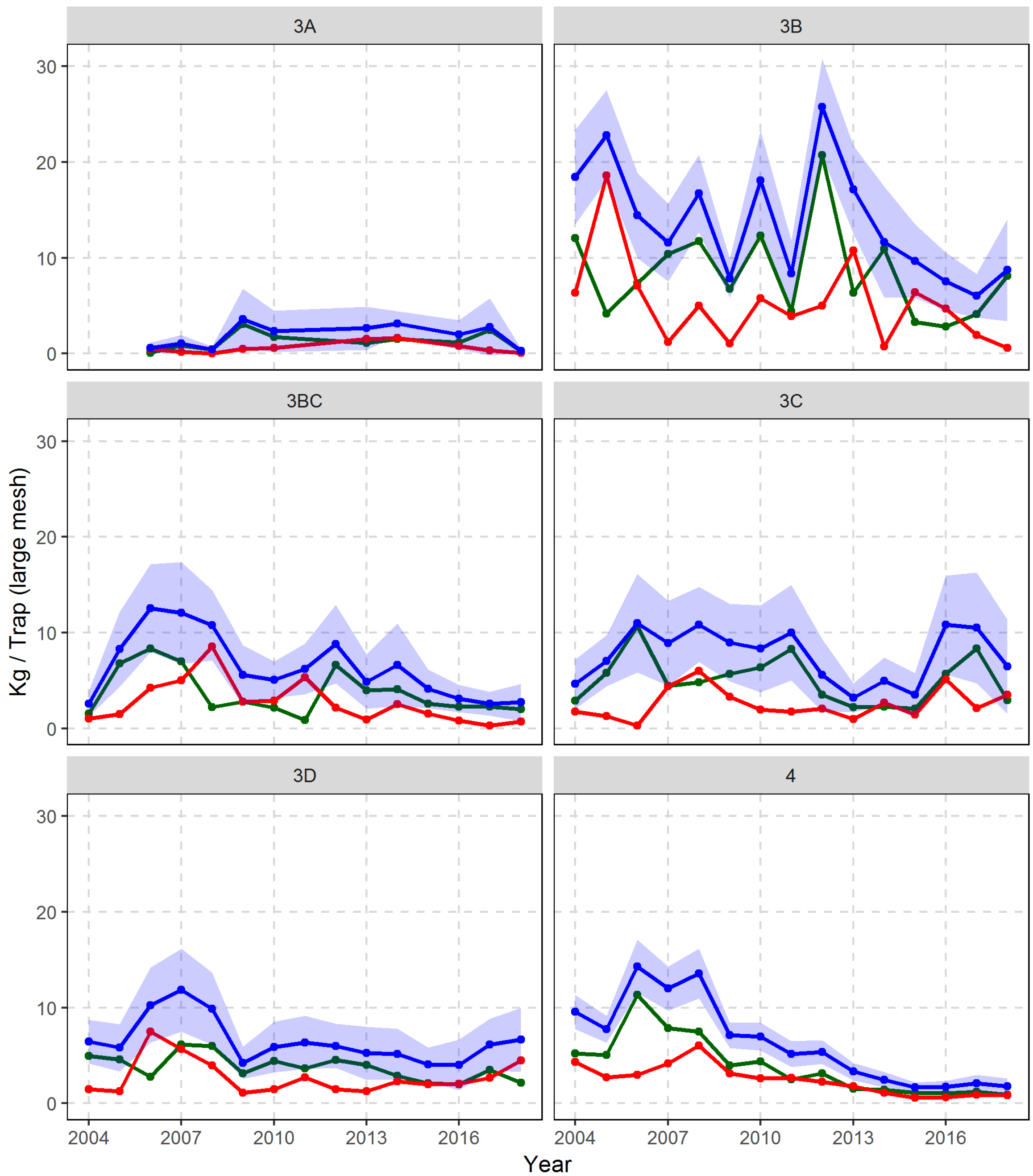

Figure A2.7. Trends in CPUE (kg/trap) by shell condition for legal-sized (recruits = green, residuals = red, all = blue) Snow Crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Division 3K.

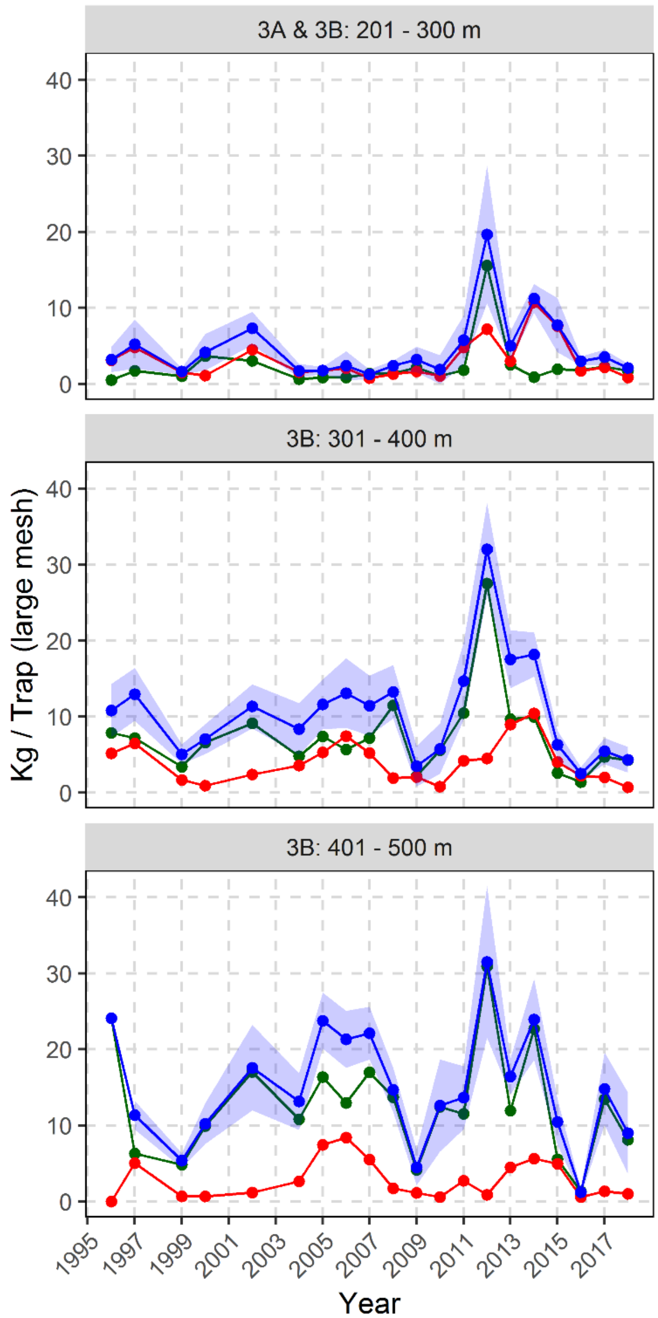

Figure A2.8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized Snow Crab from DFO trap surveys in White Bay (Assessment Division 3K).

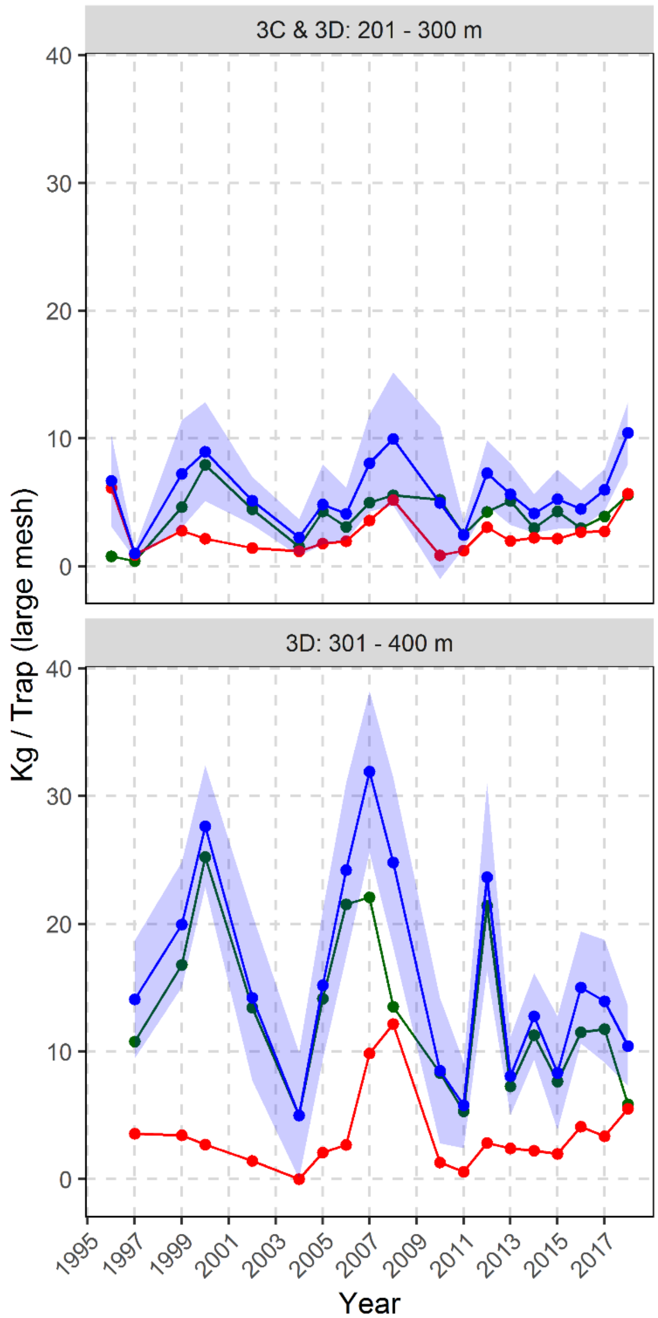

Figure A2.9. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized Snow Crab from DFO trap surveys in Green Bay and Notre Dame Bay (Assessment Division 3K).

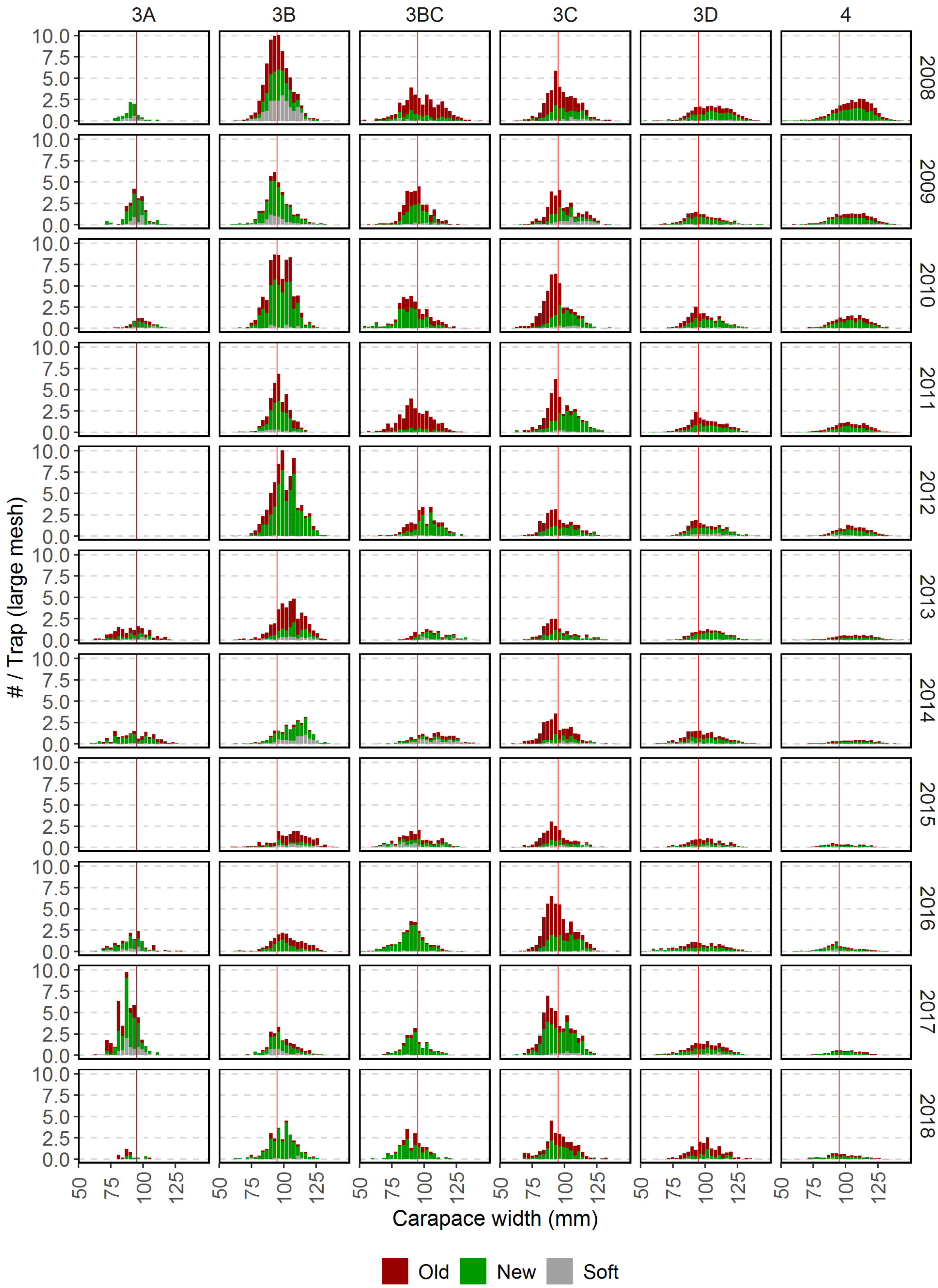

Figure A2.10. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Division 3K (2008-17). The red vertical line indicates the minimum legal size.

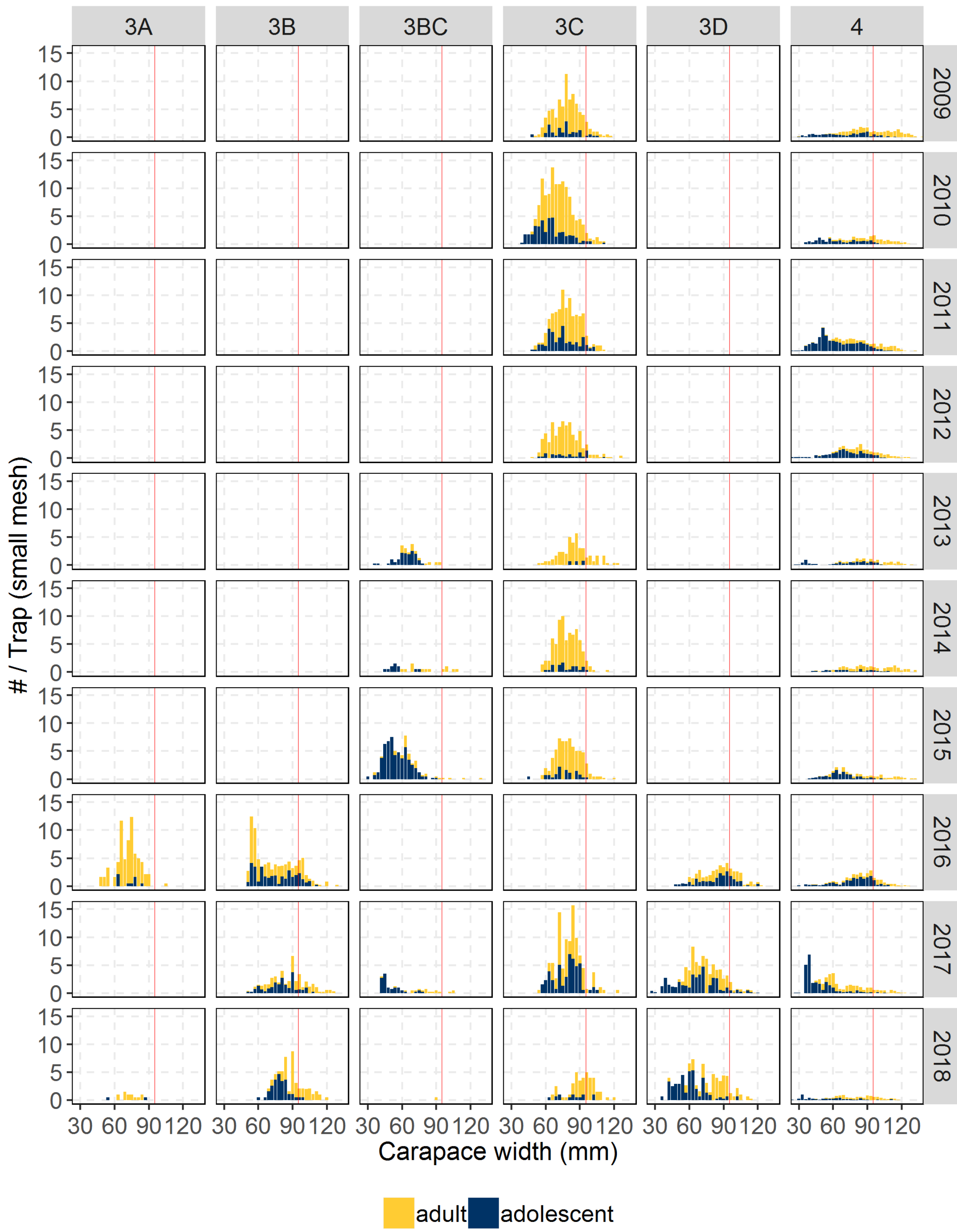

Figure A2.11. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2009-17) from CMAs in Assessment Division 3K. The red vertical line indicates the minimum legal size.

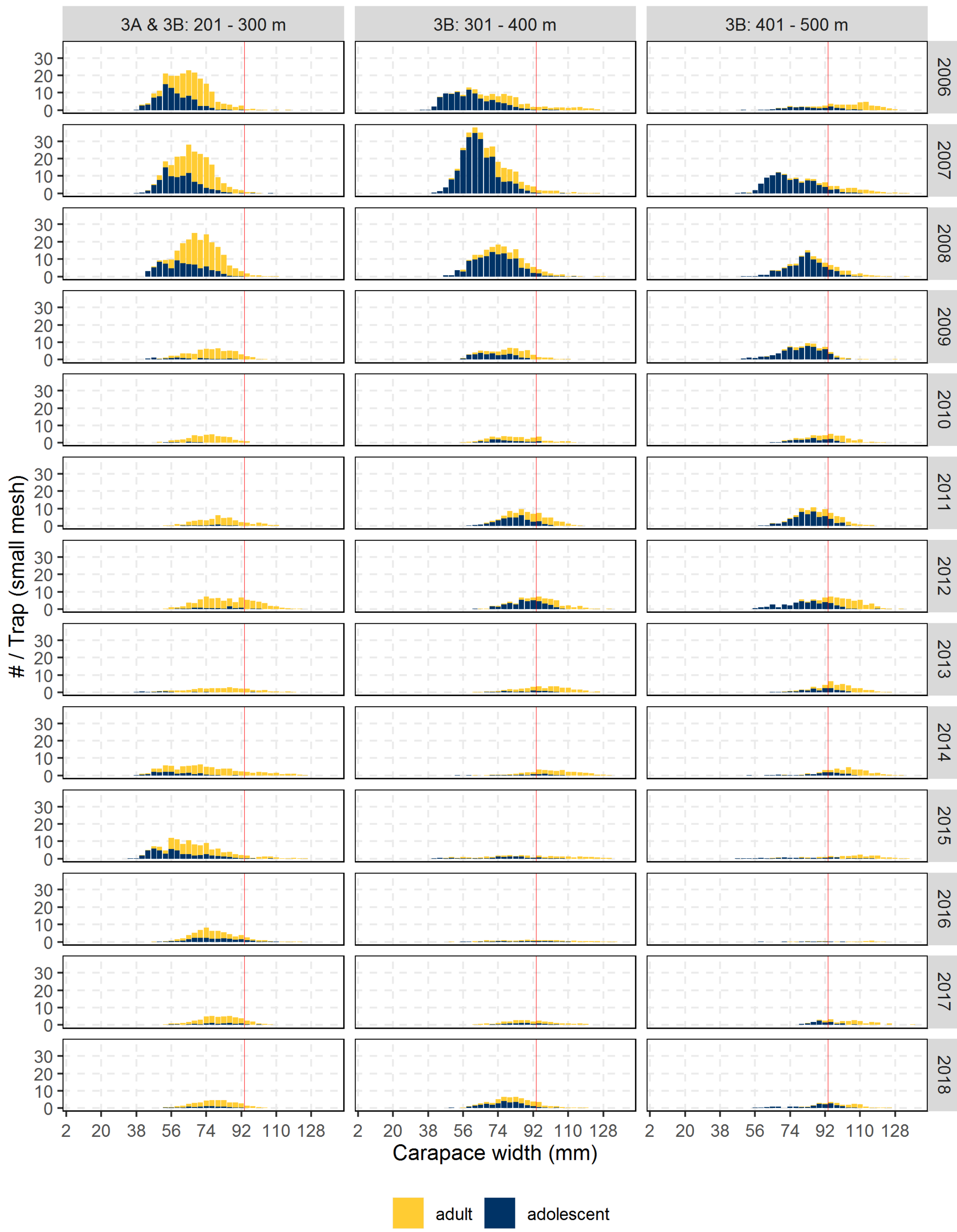

Figure A2.12. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2006-17) from White Bay (Assessment Division 3K). The red vertical line indicates the minimum legal size.

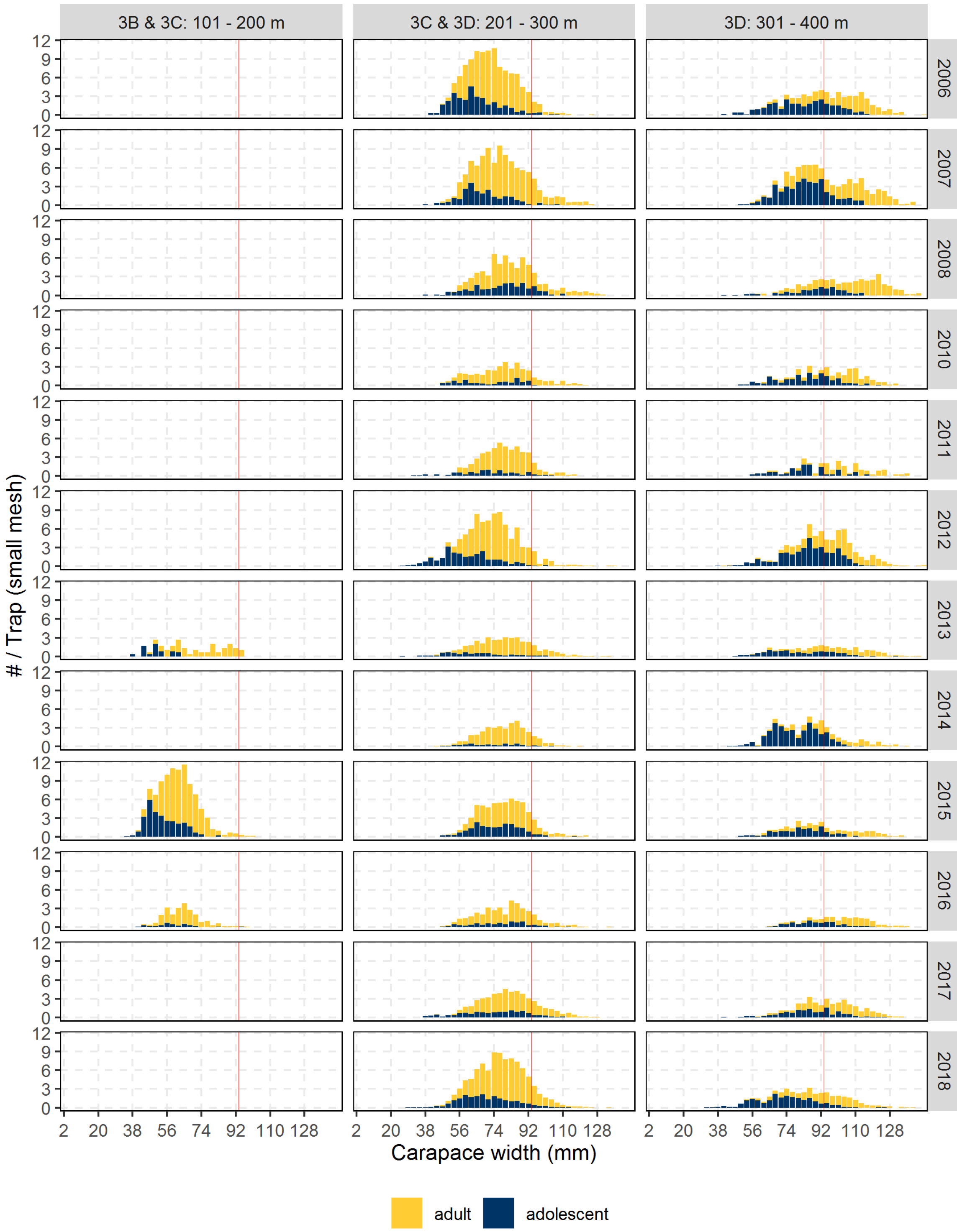

Figure A2.13. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2006-18) from Green Bay and Notre Dame Bay (Assessment Division 3K). The red vertical line indicates the minimum legal size.

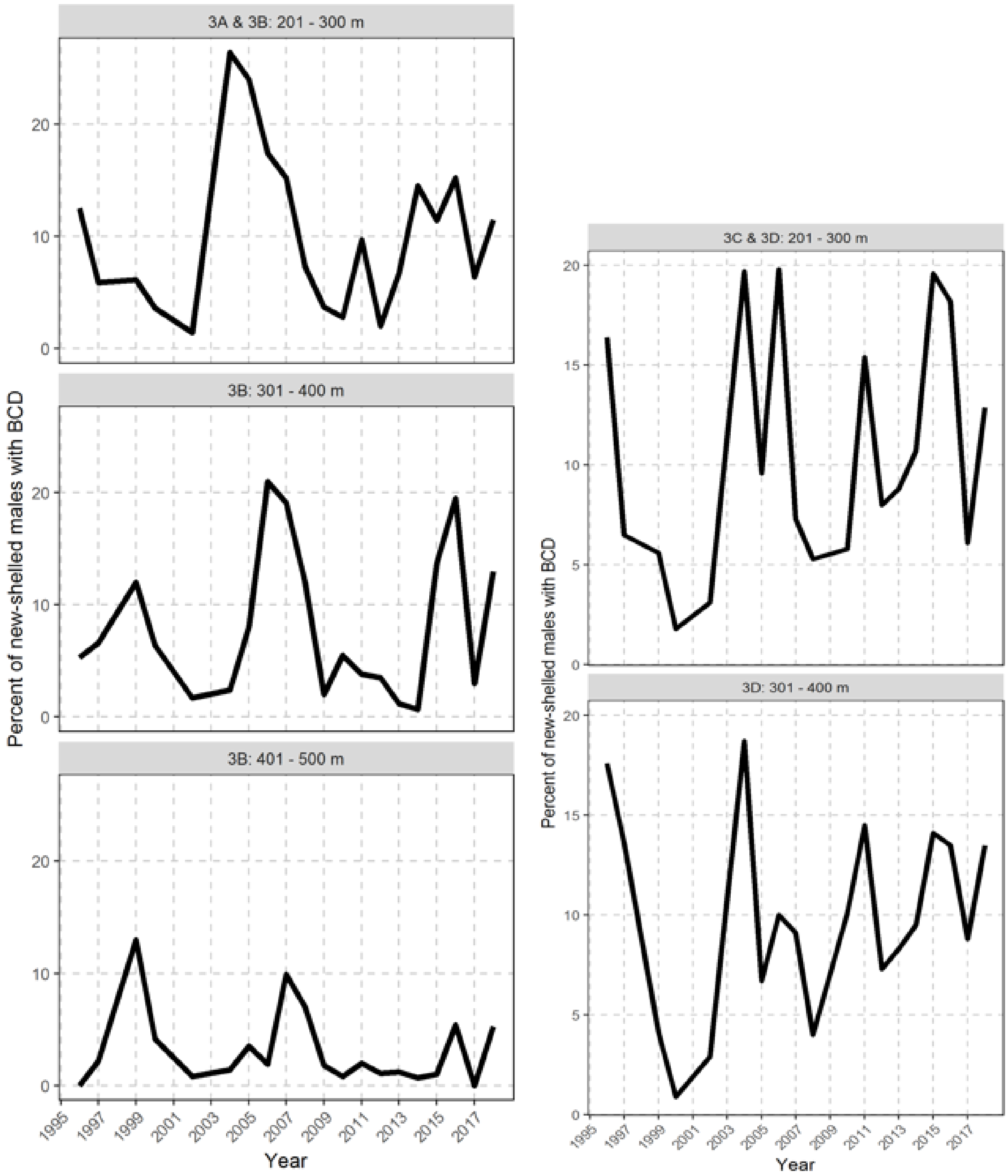

Figure A2.14. Visually observed percentage of Bitter Crab Disease in Snow Crab captured in small-mesh pots from DFO trap surveys in White Bay and Green/Notre Dame Bays.

APPENDIX 3: ASSESSMENT DIVISION 3L INSHORE DETAILS

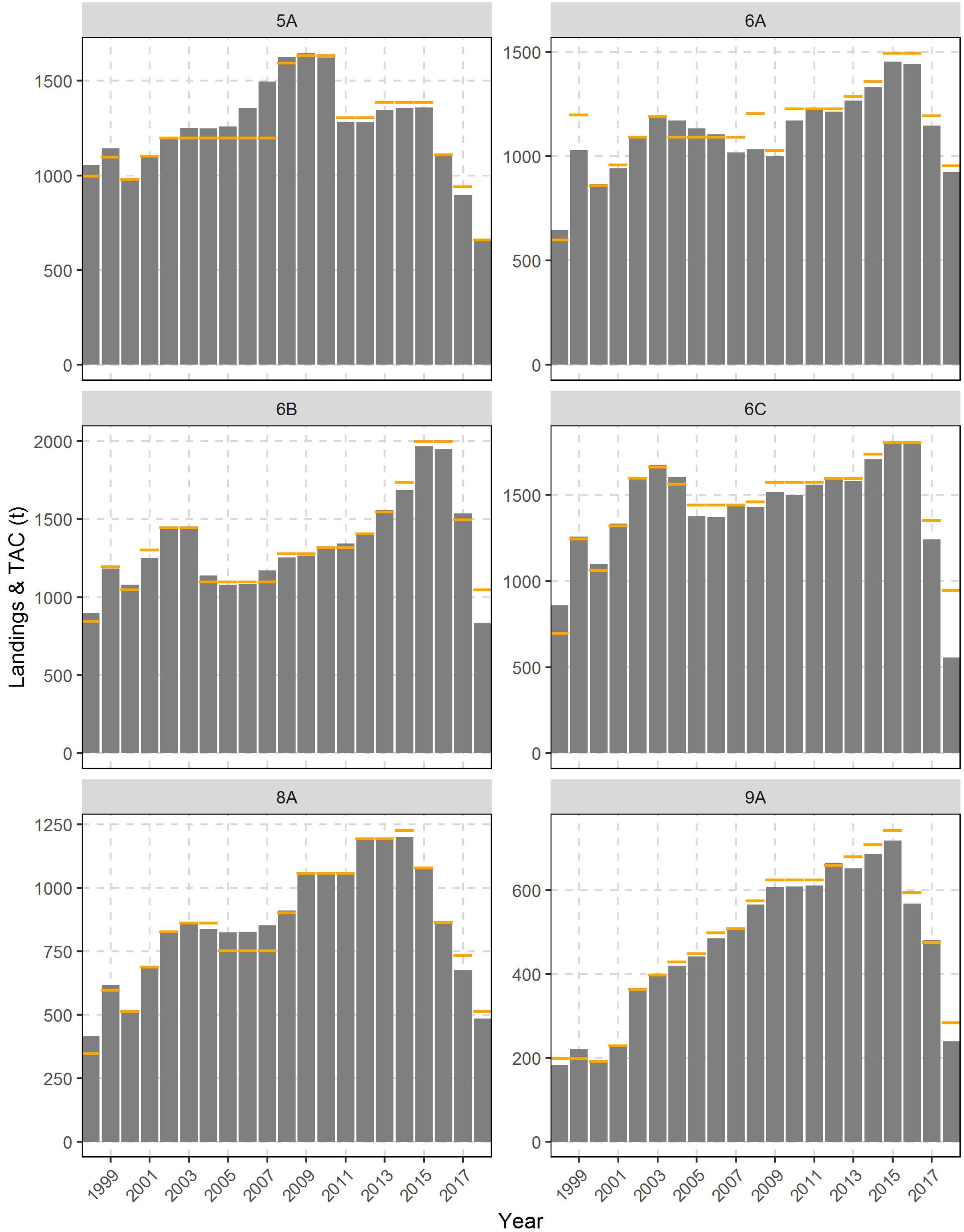

Figure A3.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Division 3L Inshore (1998-2018).

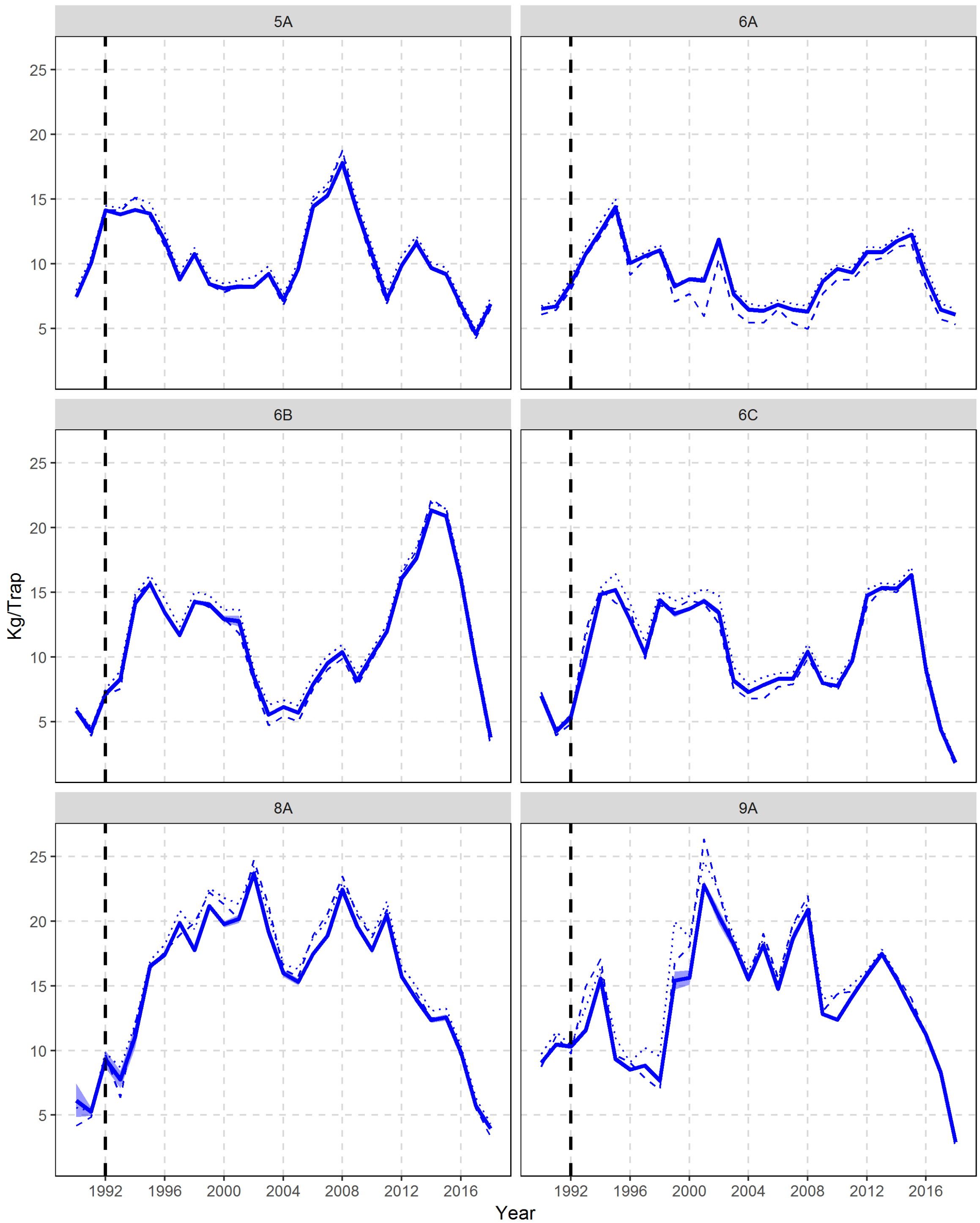

Figure A3.2. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Division 3L Inshore. Solid line is average predicted CPUE and band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed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

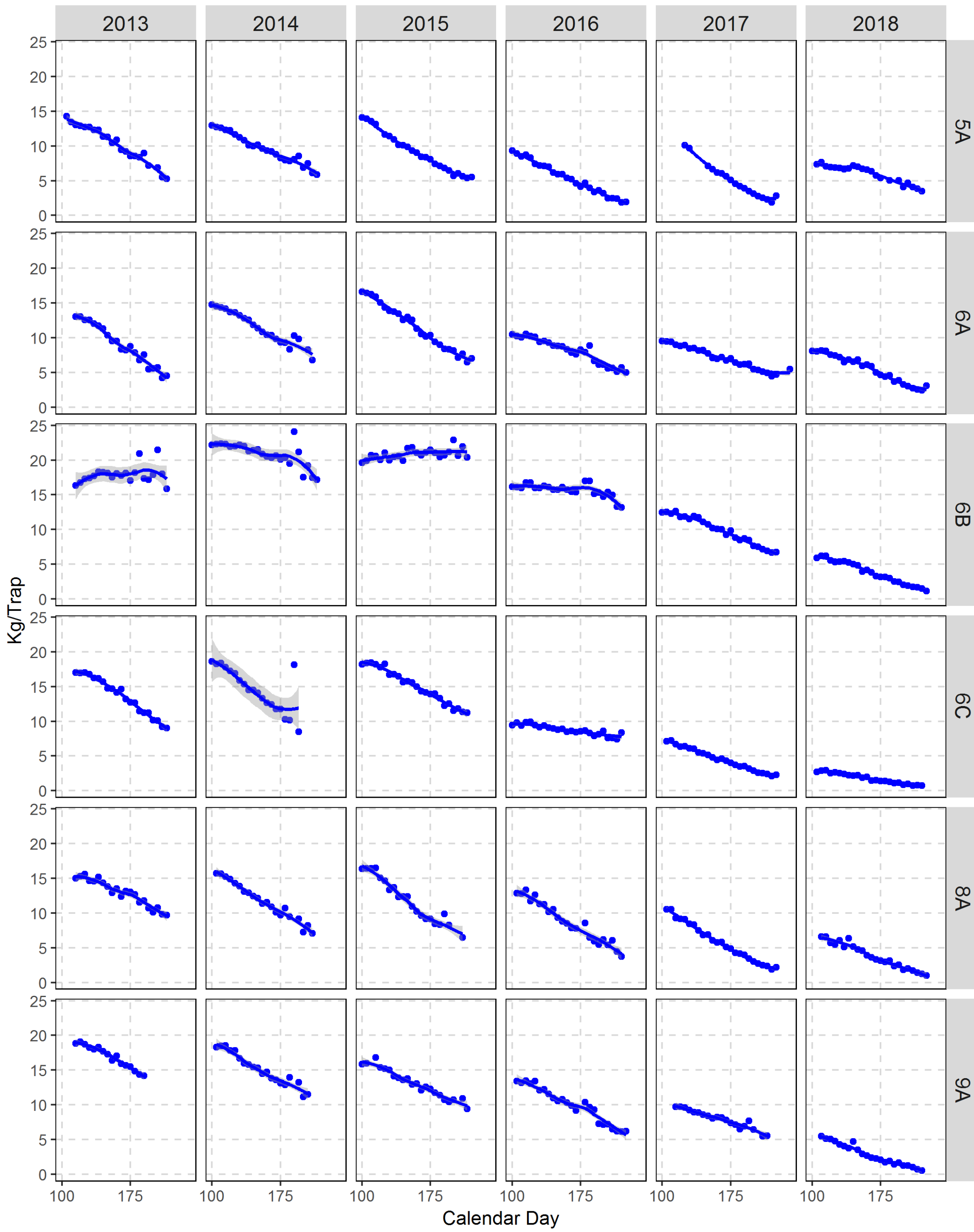

Figure A3.3. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2013-18), by Crab Management Area (CMA) in Assessment Division 3L Inshore.

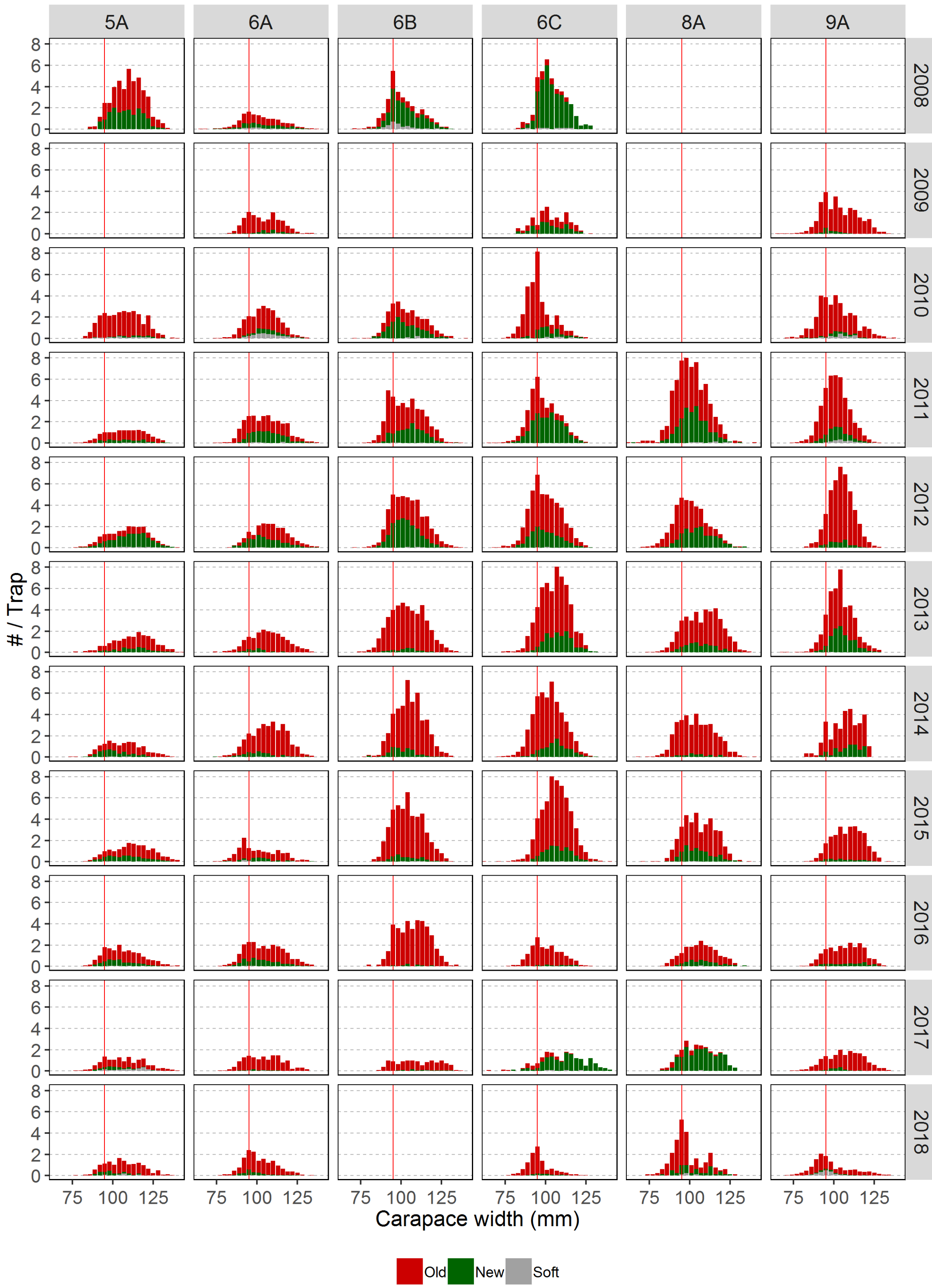

Figure A3.4. Trends in male carapace width distributions by shell condition from observer sampling in Assessment Division 3L Inshore (2008-18). The red vertical line indicates the minimum legal size.

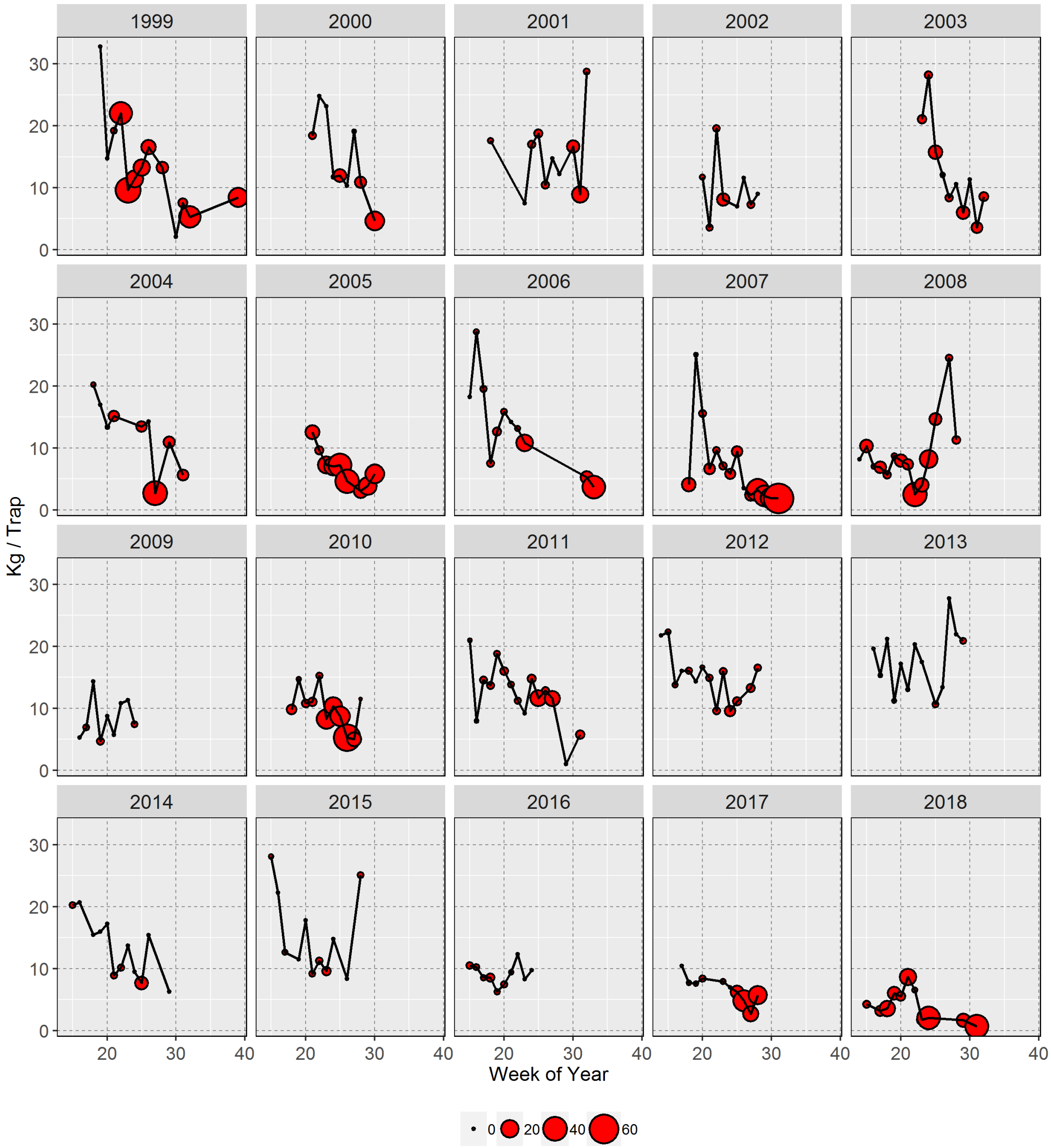

Figure A3.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shelled Snow Crab in the catch in CMAs within the Assessment Division 3L Inshore (1999-2018). Bubble size depicts percentage of soft-shelled Snow Crab and solid line depicts unstandardized observed catch rates.

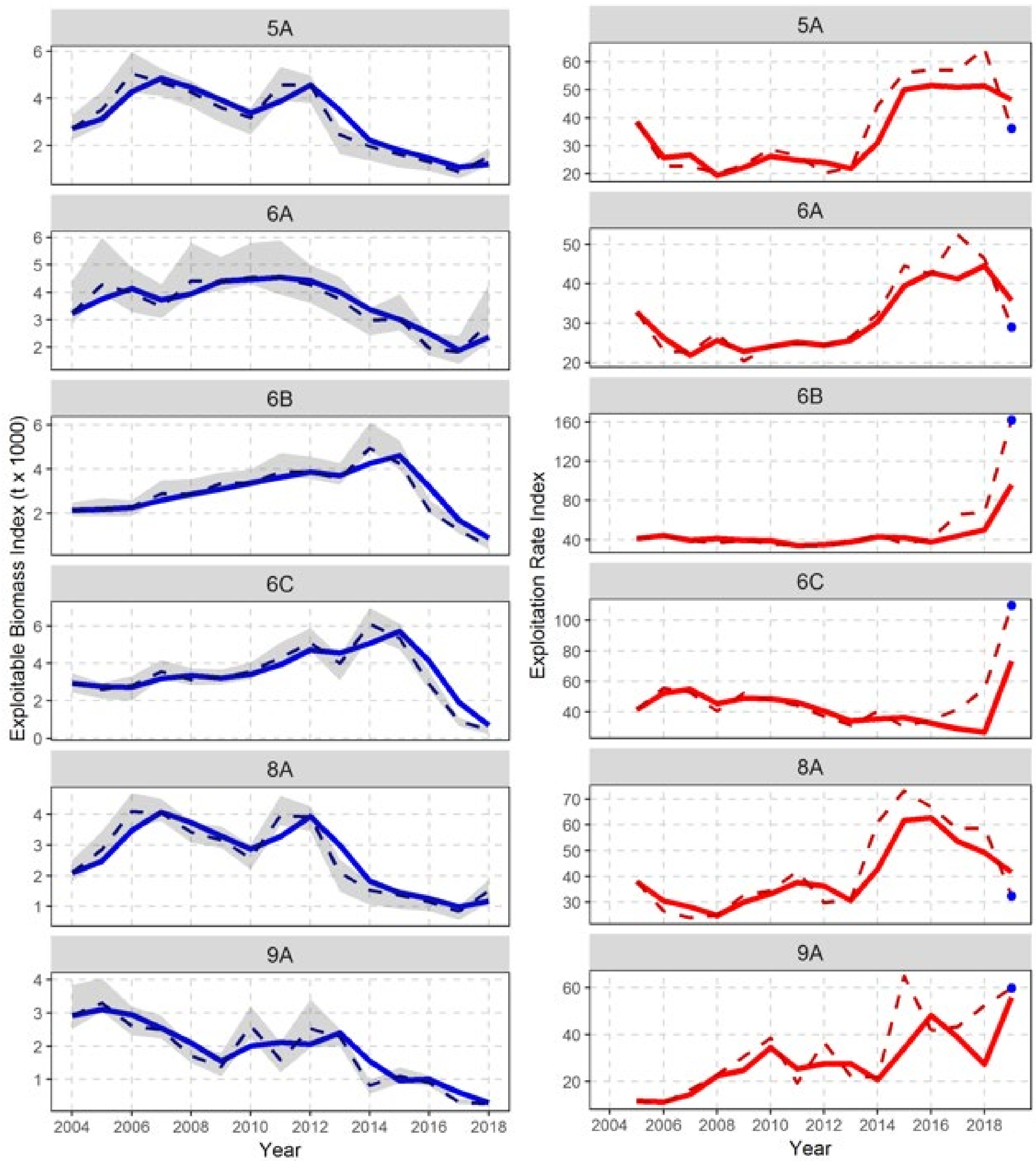

Figure A3.6. ***Left:*** *Annual trap-based exploitable biomass index (t * 1000). Solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the confidence interval of the annual estimates.* ***Right:*** *Trends in the exploitation rate index (ERI) in CMAs within Assessment Division 3L Inshore. Solid line represents ERI based on a 2-year moving average of trap-based exploitable biomass and the dashed line represents the trend in annual estimates. The blue point is the annual estimate of ERI in 2019 based on status quo landings.*

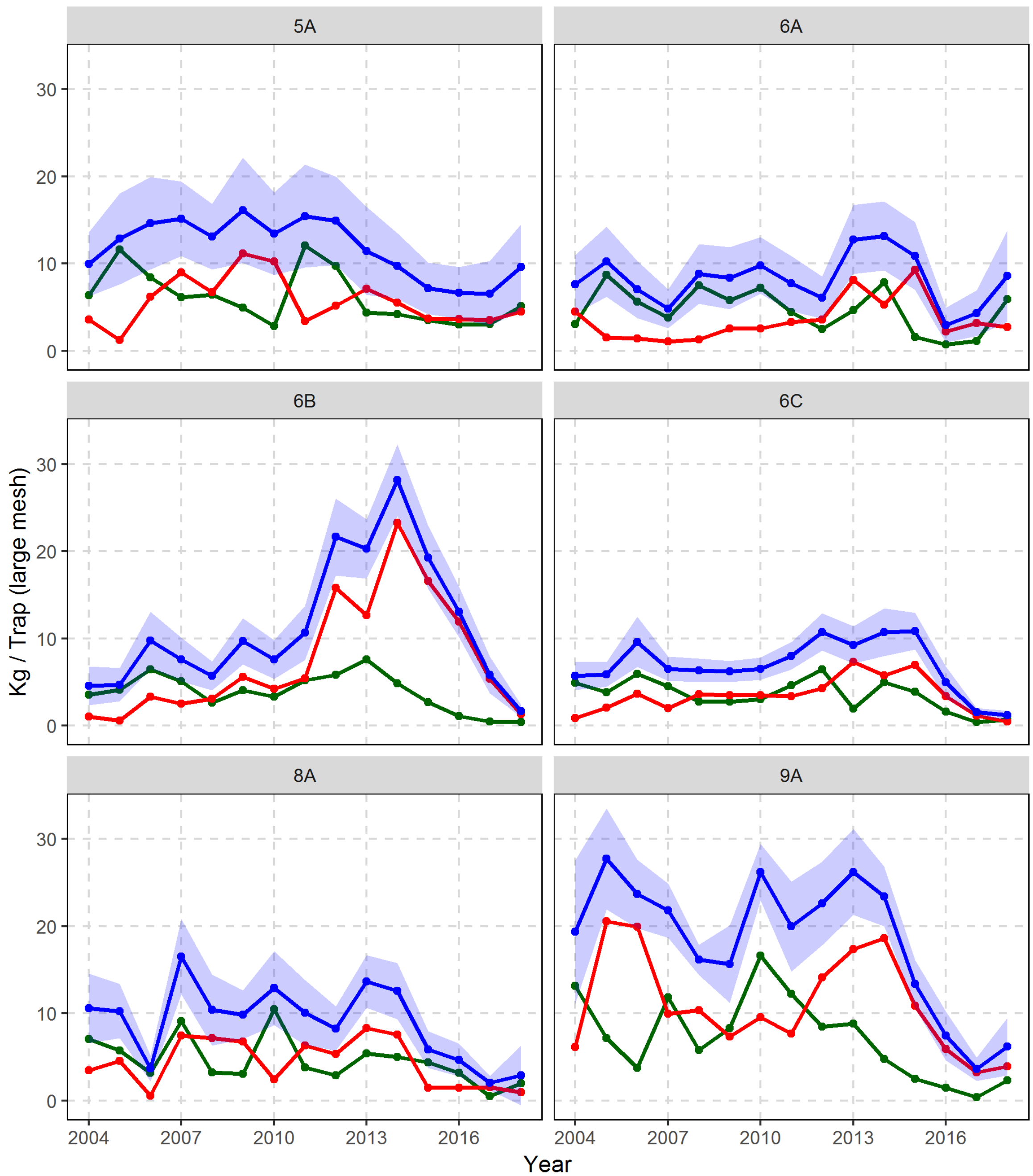

Figure A3.7. Trends in CPUE (kg/trap) by shell condition for legal-sized Snow Crab (recruits = green, residuals = red, all = blue) from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Division 3L Inshore.

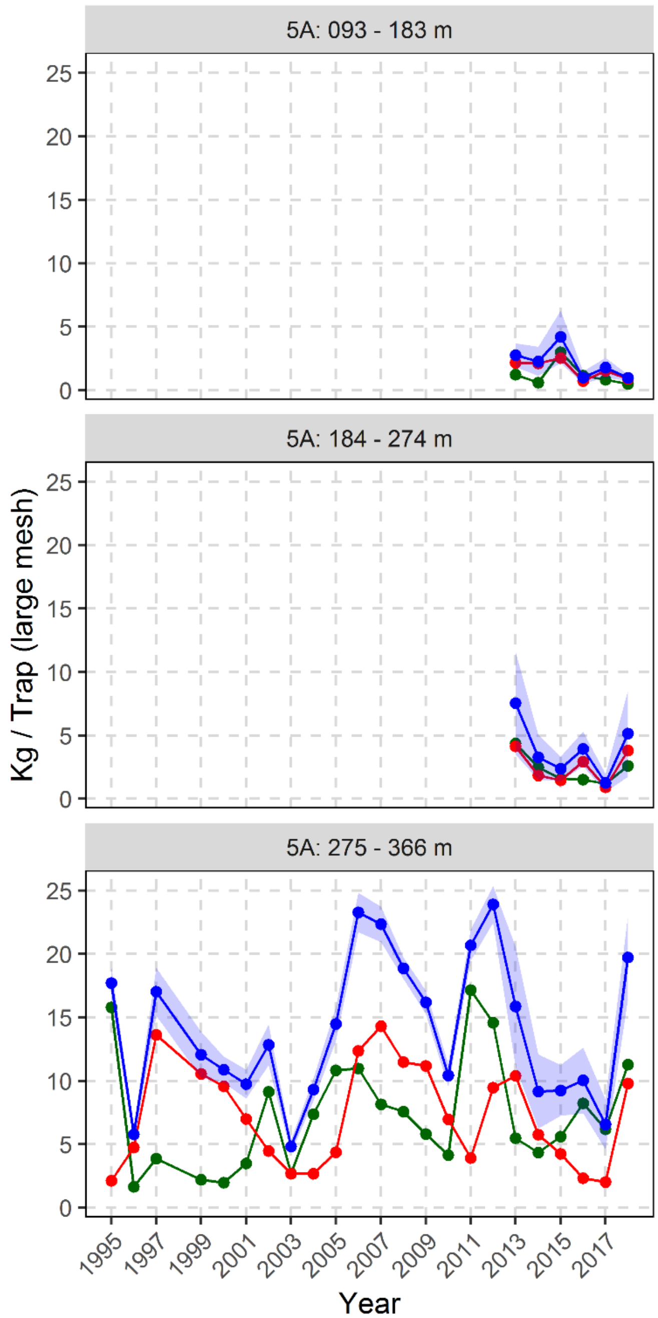

Figure A3.8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized Snow Crab from DFO trap surveys in Bonavista Bay (Assessment Division 3L Inshore).

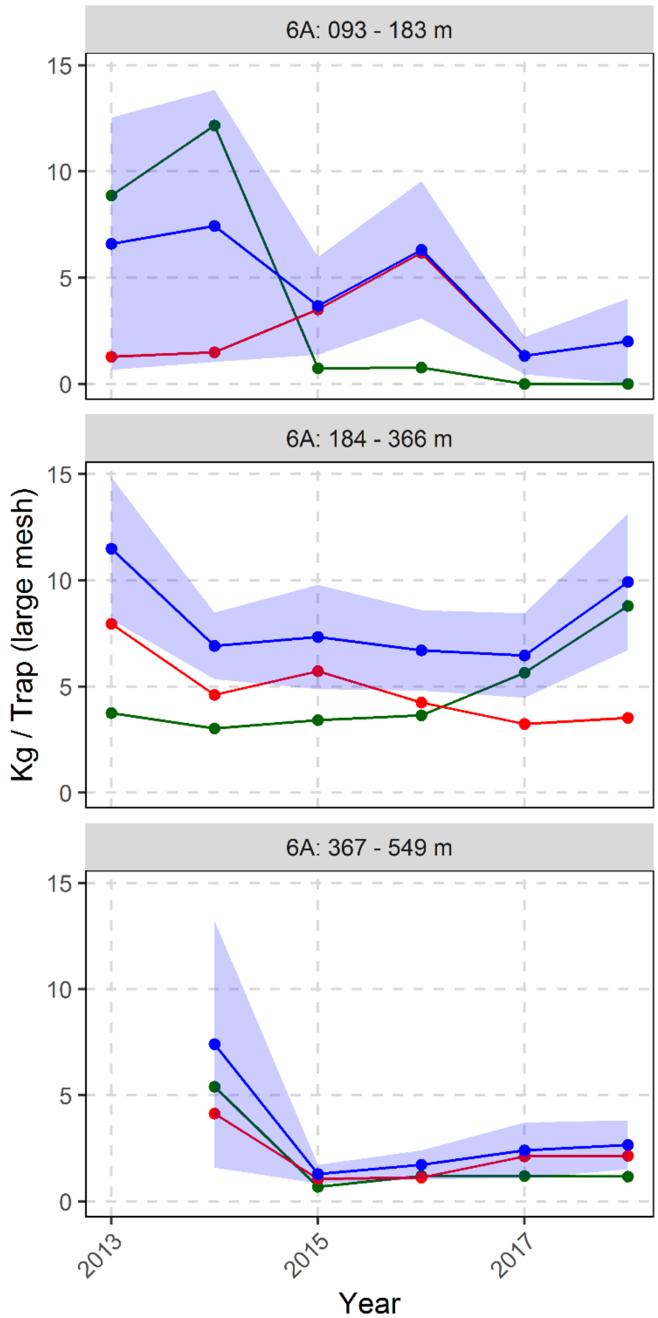

Figure A3.9. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized Snow Crab from DFO trap surveys in Trinity Bay (Assessment Division 3L Inshore).

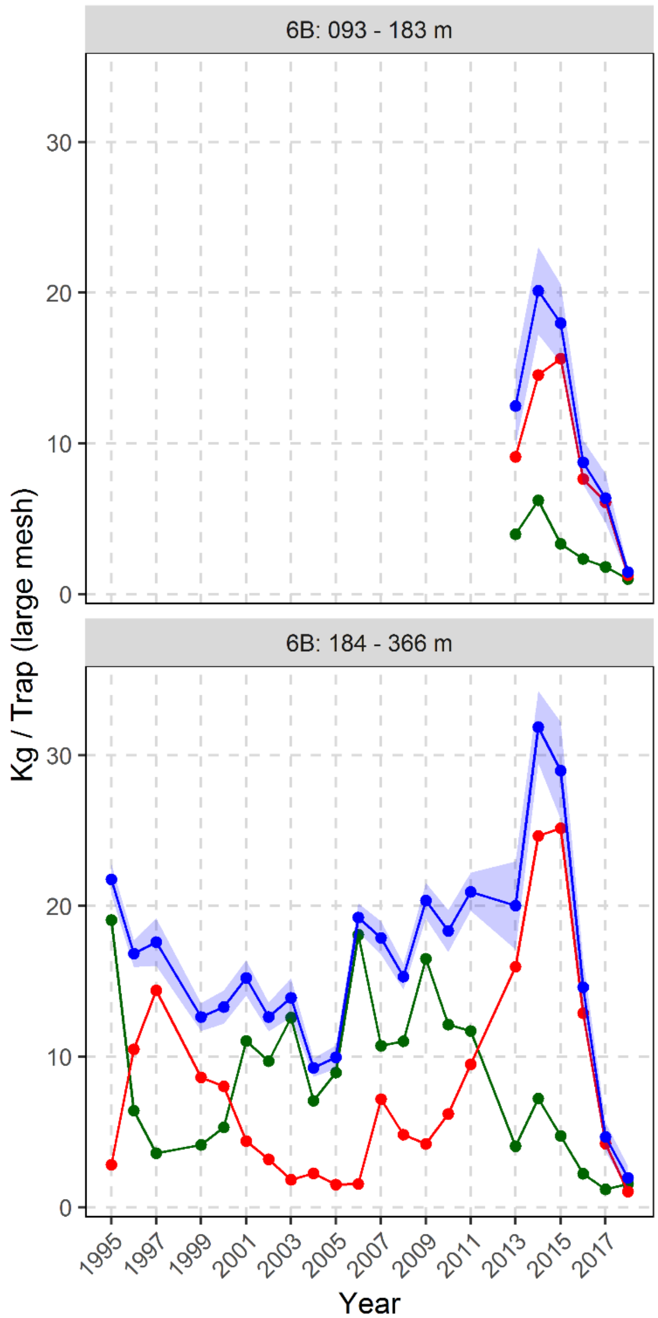

Figure A3.10. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized Snow Crab from DFO trap surveys in Conception Bay (Assessment Division 3L Inshore).

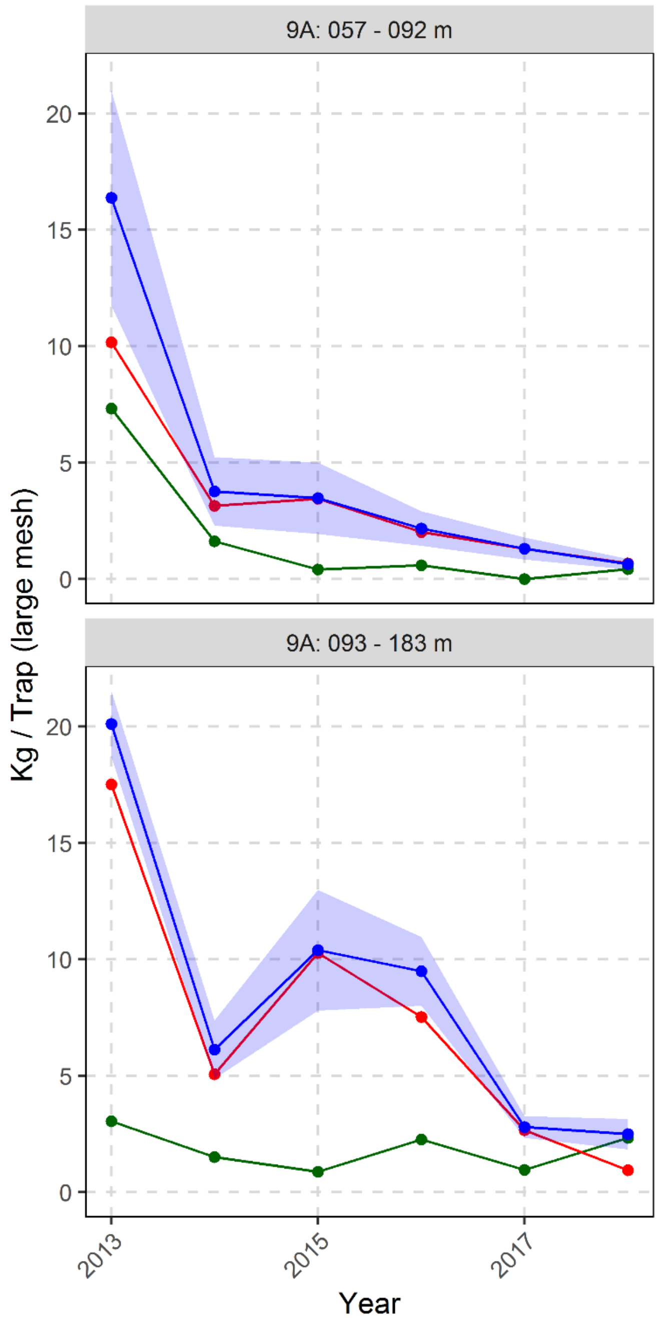

Figure A3.11. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized Snow Crab from DFO trap surveys in St. Mary's Bay (Assessment Division 3L Inshore).

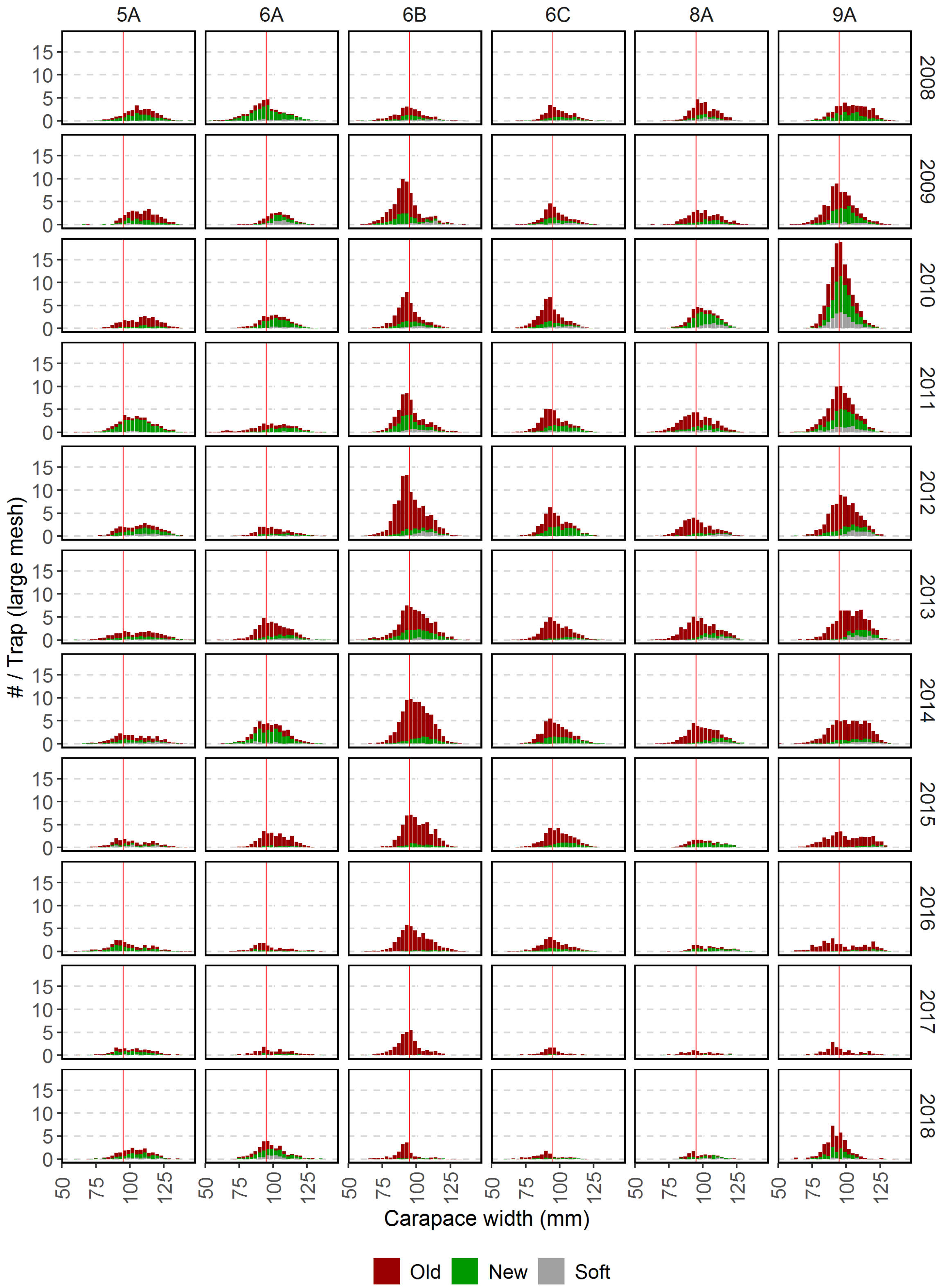

Figure A3.12. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Division 3L Inshore (2008-18). The vertical line indicates the minimum legal size.

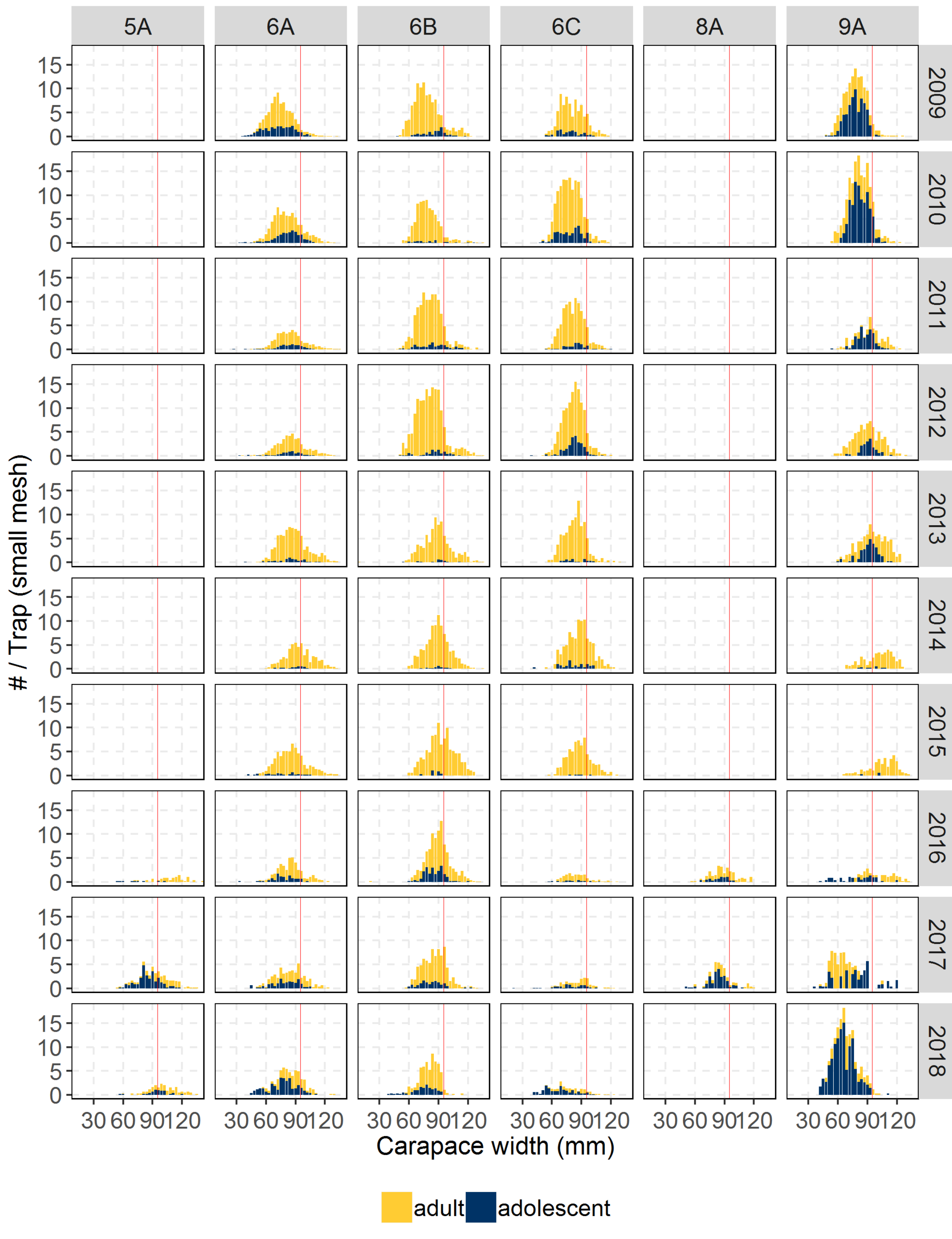

Figure A3.13. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2009-18) from CMAs in Assessment Division 3L Inshore. The red vertical line indicates the minimum legal size.

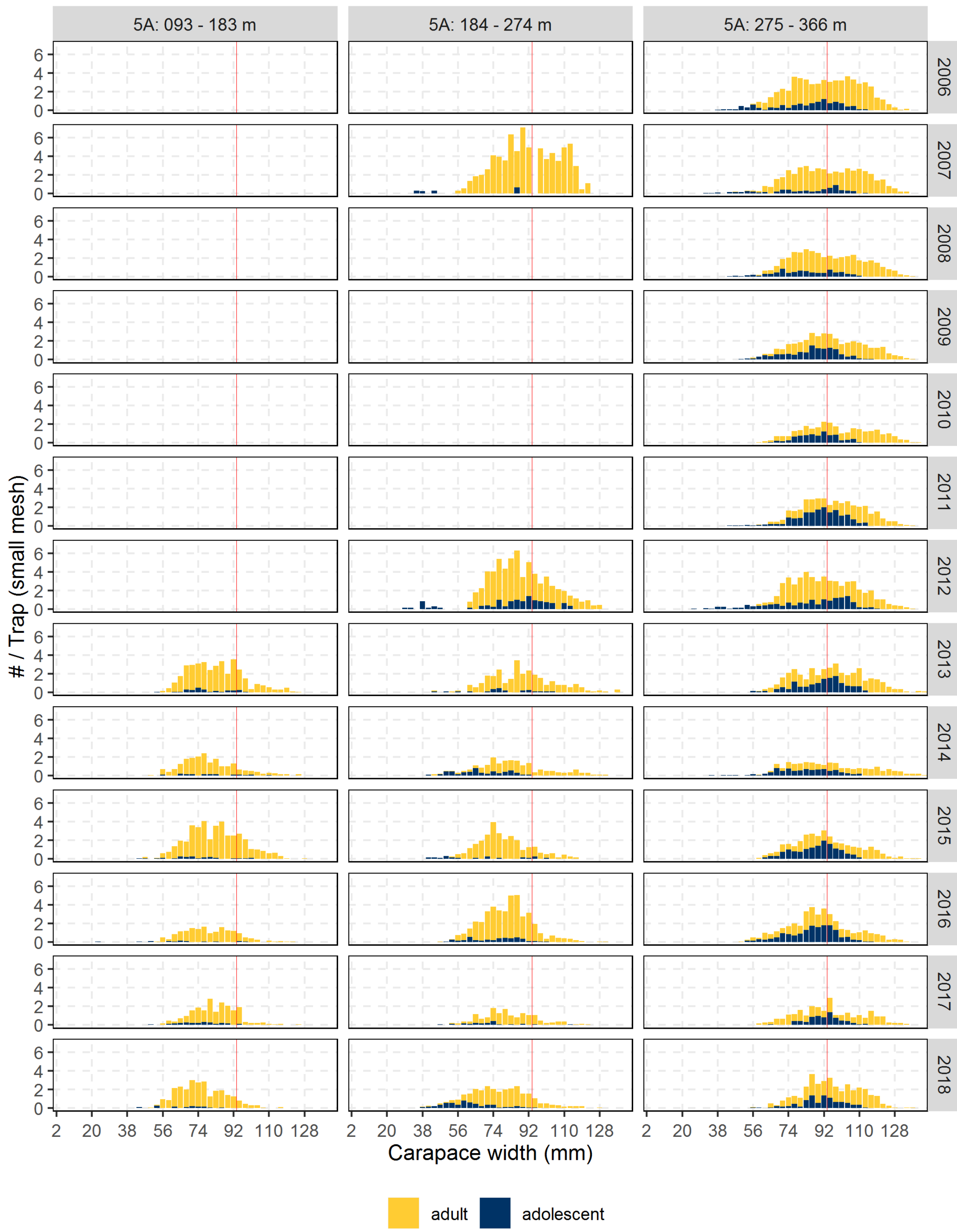

Figure A3.14. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2006-17) from Bonavista Bay (Assessment Division 3L Inshore). The red vertical line indicates the minimum legal size.

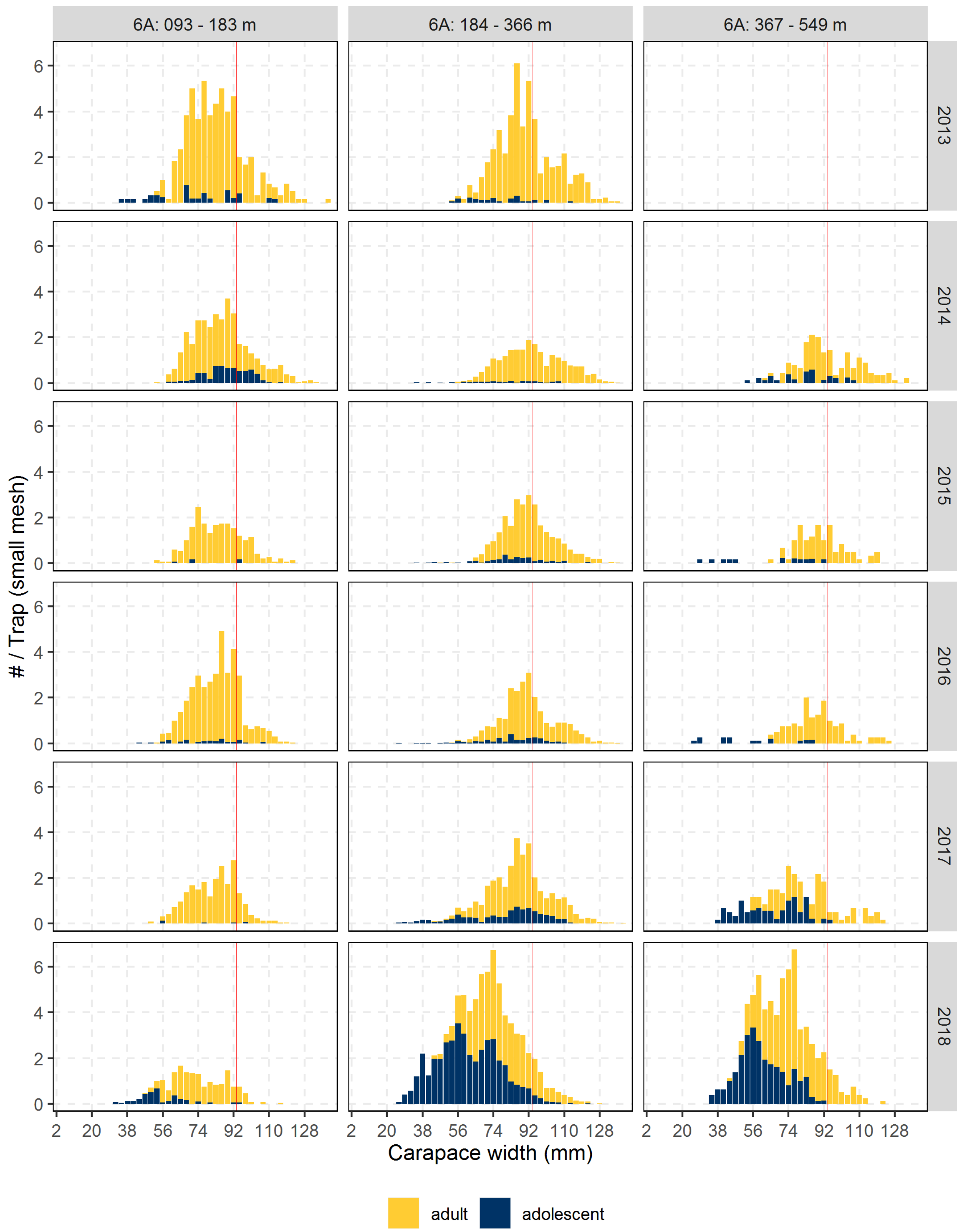

Figure A3.15. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2013-18) from Trinity Bay (Assessment Division 3L Inshore). The red vertical line indicates the minimum legal size.

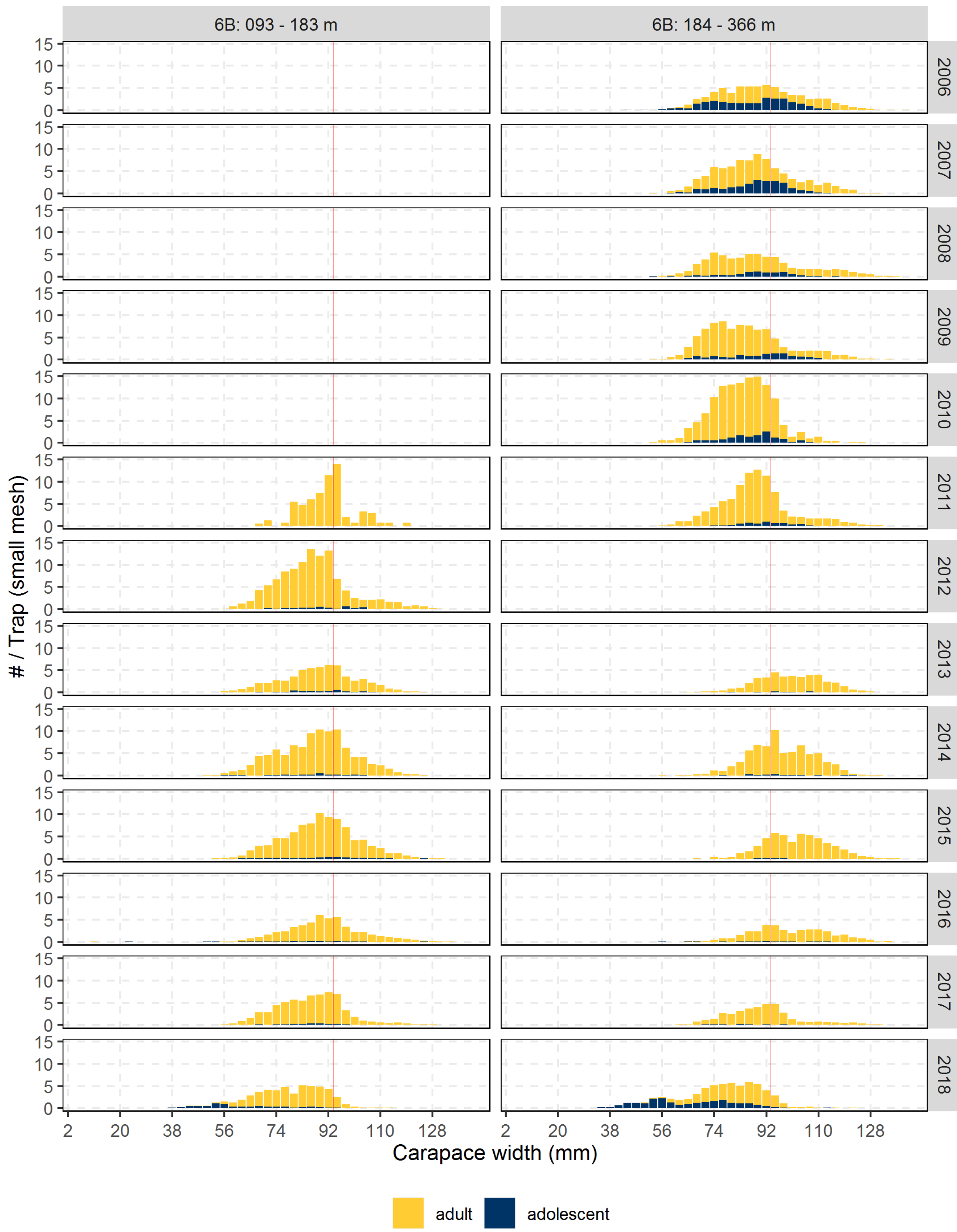

Figure A3.16. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2006-18) from Conception Bay (Assessment Division 3L Inshore). The red vertical line indicates the minimum legal size.

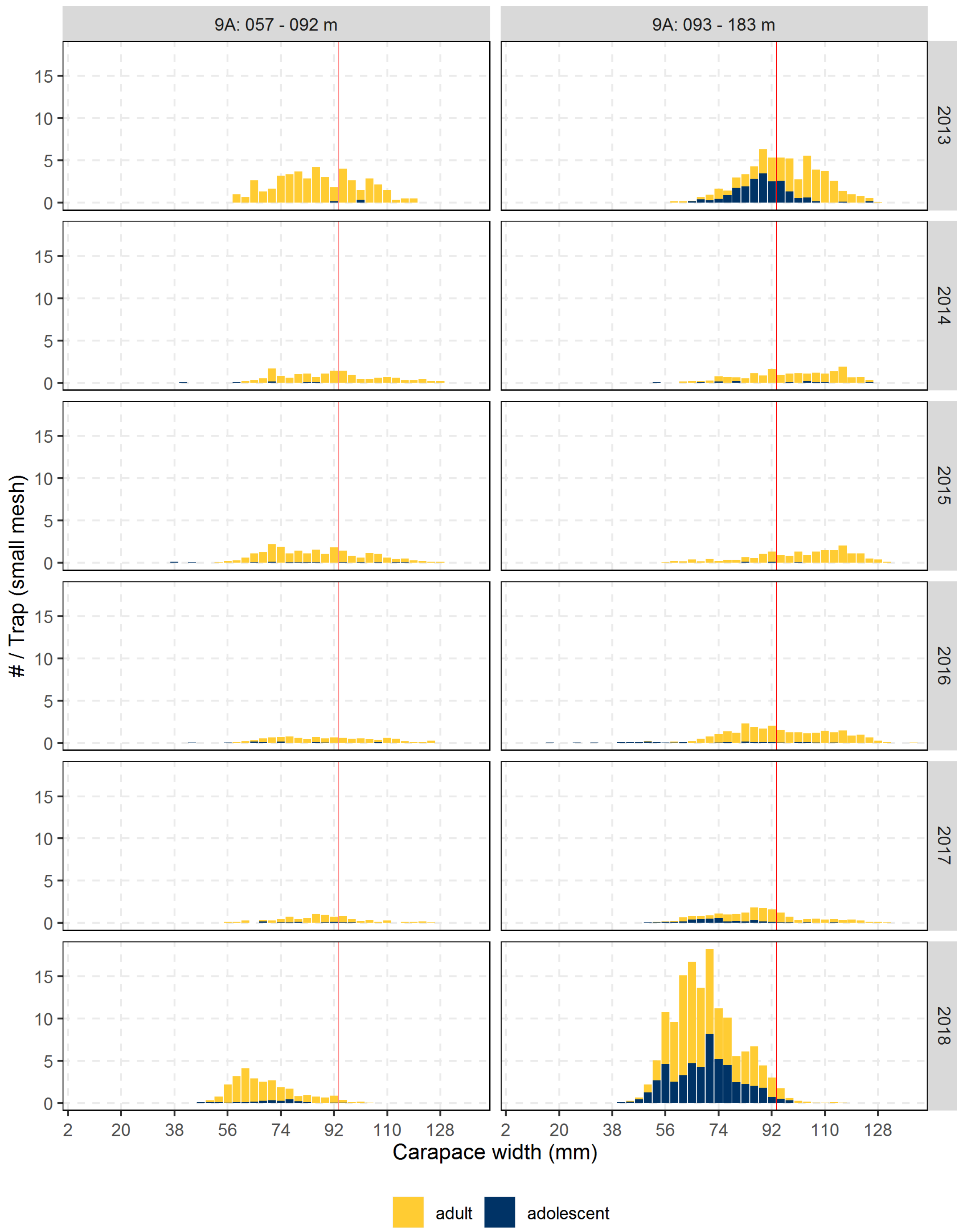

Figure A3.17. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2013-18) from St. Mary's Bay (Assessment Division 3L Inshore). The red vertical line indicates the minimum legal size.

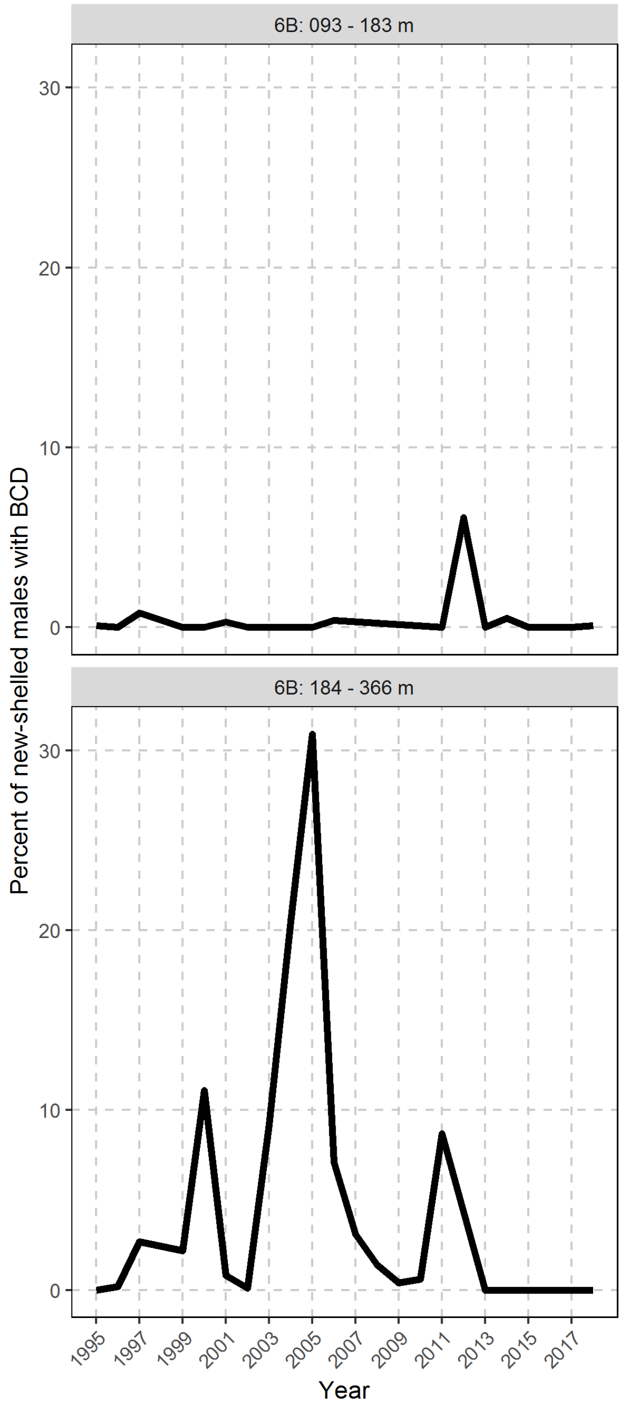

Figure A3.18. Visually observed percentage of Bitter Crab Disease in Snow Crab captured in small-mesh pots from DFO trap surveys in Conception Bay.

APPENDIX 4: ASSESSMENT DIVISION 3LNO OFFSHORE DETAILS

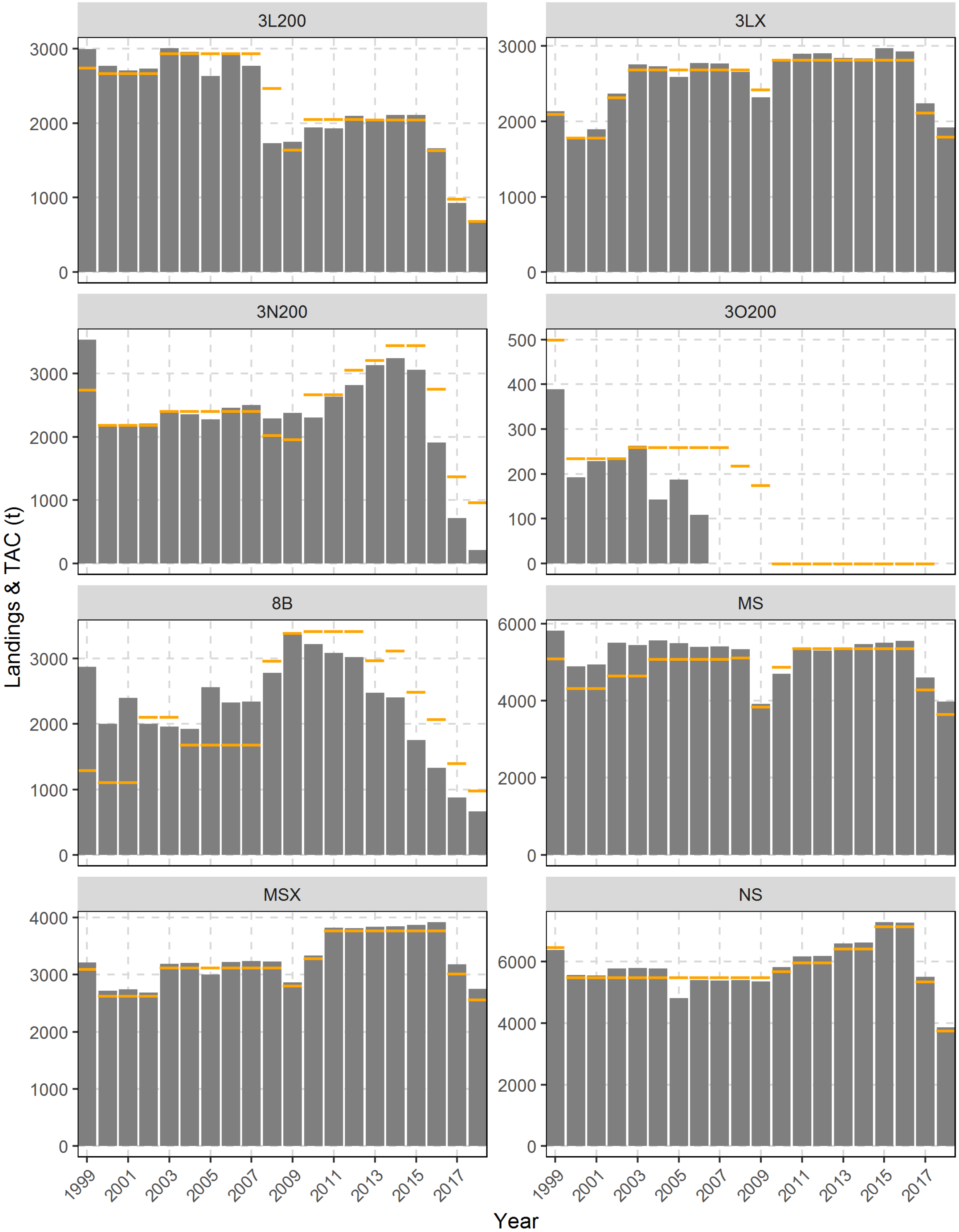

Figure A4.1.Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Divisions 3LNO Offshore (1999-2018).

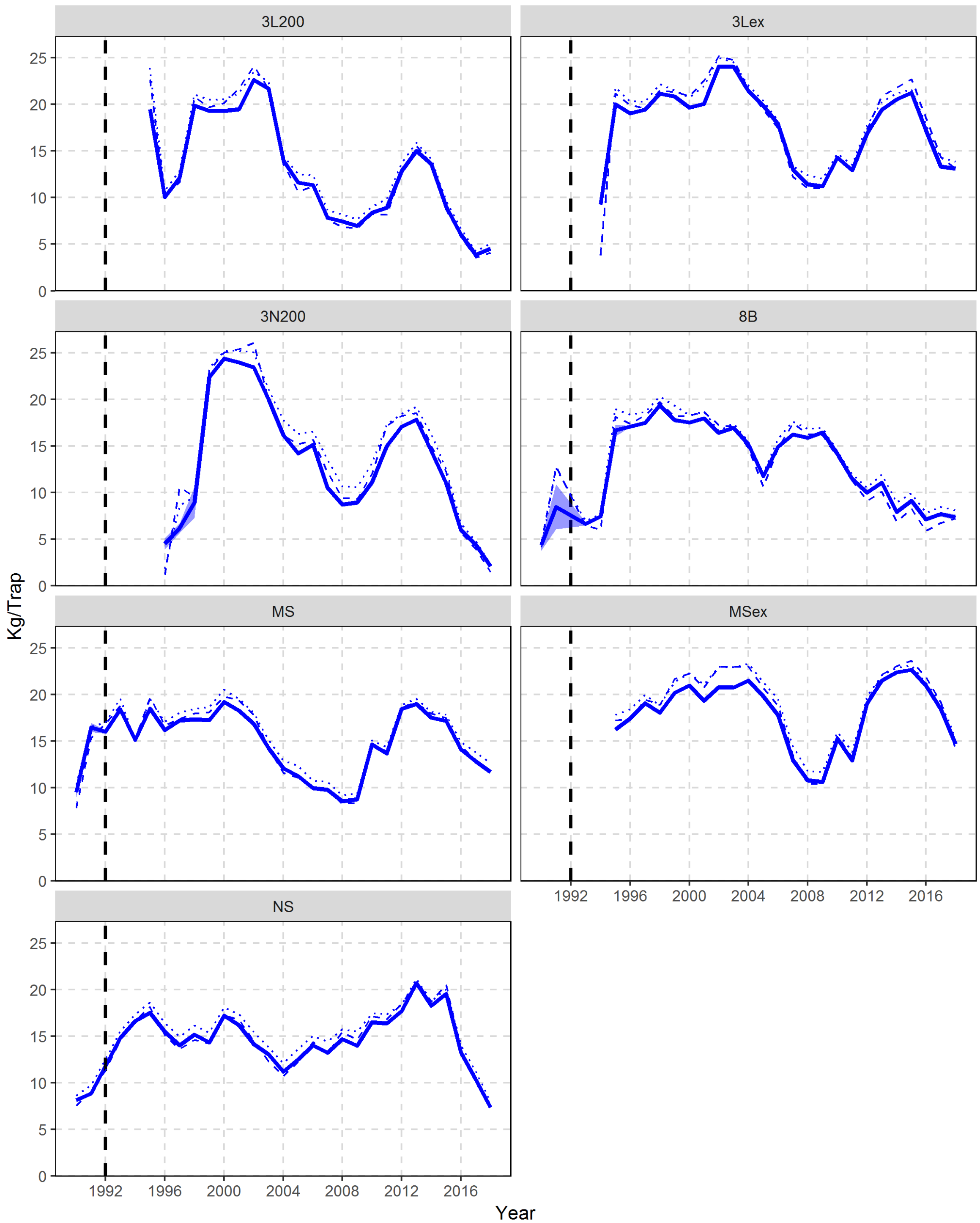

Figure A4.2. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Division 3LNO Offshore. Solid line is average predicted CPUE and band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical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

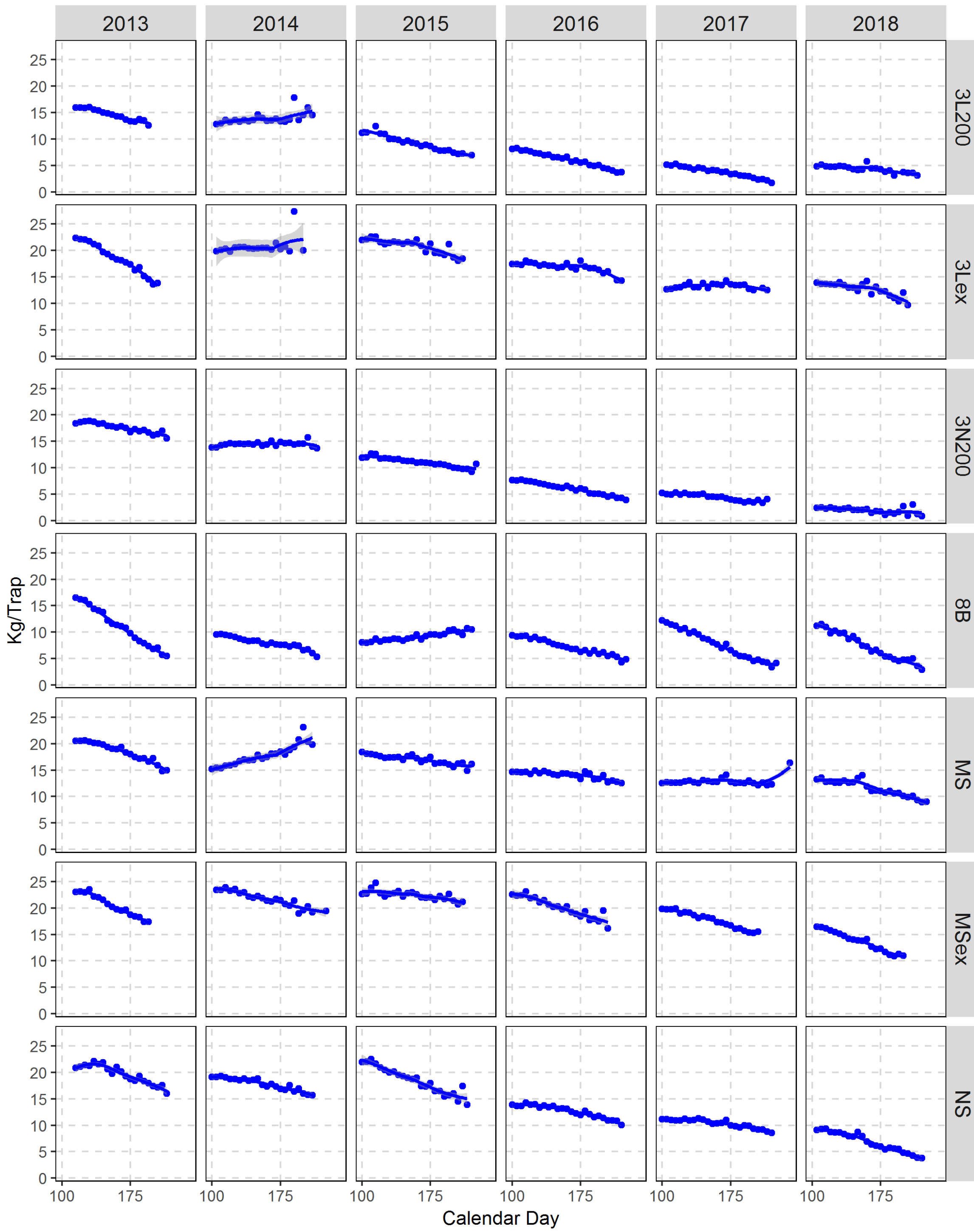

Figure A4.3. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2012-18), by Crab Management Area (CMA) in Assessment Divisions 3LNO Offshore.

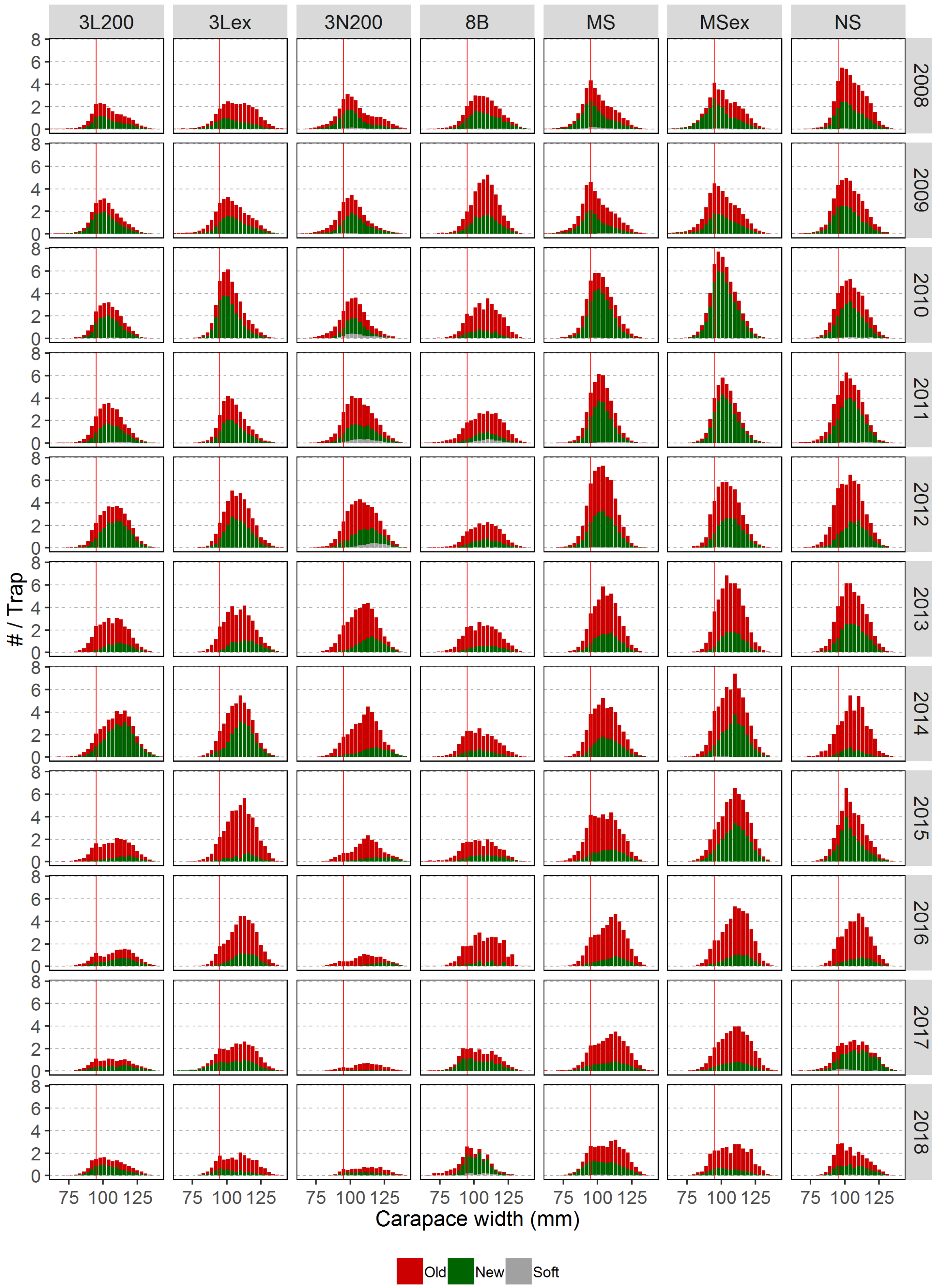

Figure A4.4. Trends in male carapace width distributions by shell condition from observer sampling in CMAs (Crab Management Areas) within Assessment Divisions 3LNO Offshore (2008-18). The red vertical line indicates the minimum legal size.

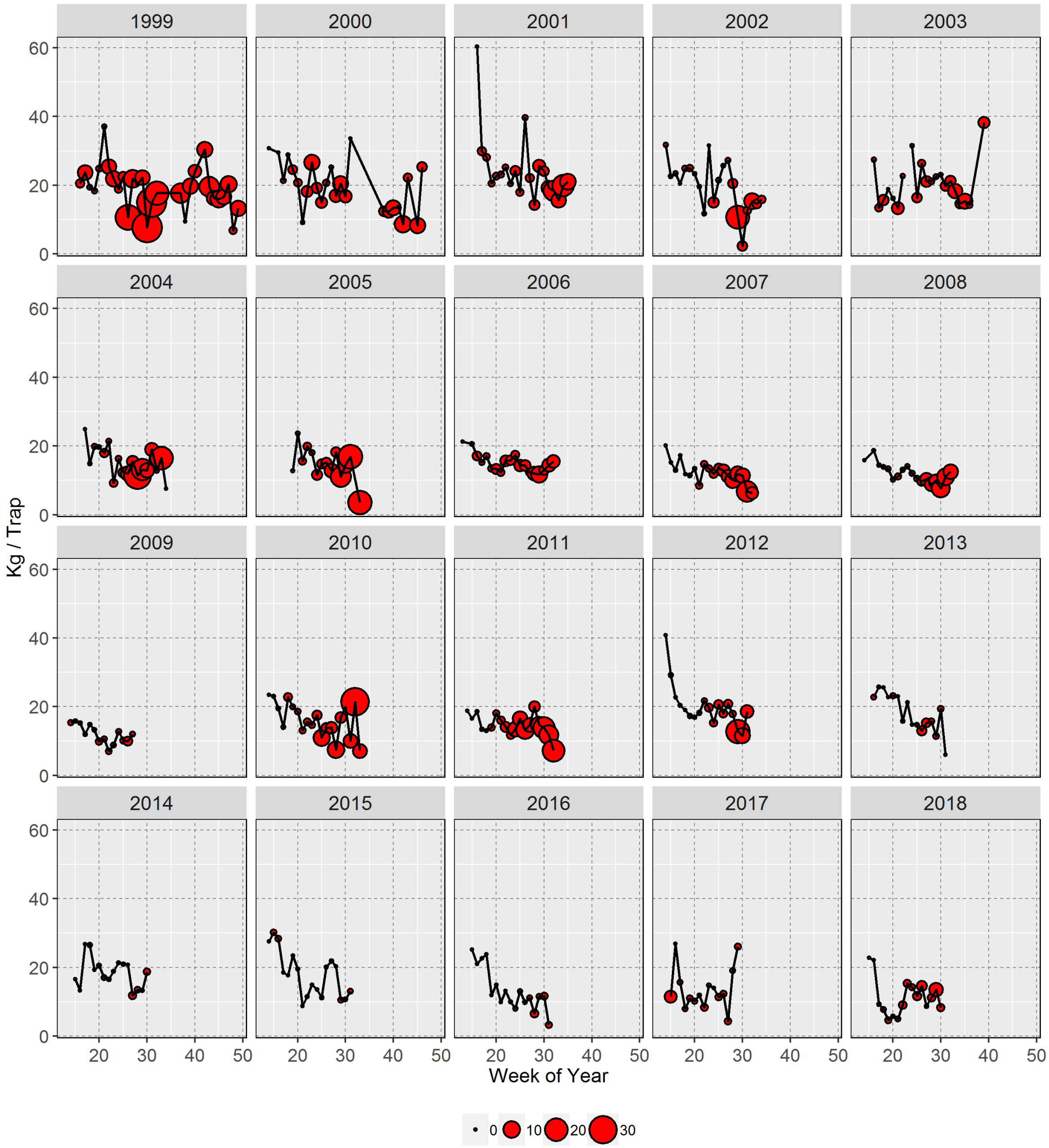

Figure A4.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shelled Snow crab in the catch in CMAs within the Assessment Divisions 3LNO Offshore (1999-2018). Bubble size depicts percentage of soft-shelled Snow Crab and solid line depicts unstandardized observed catch rates.

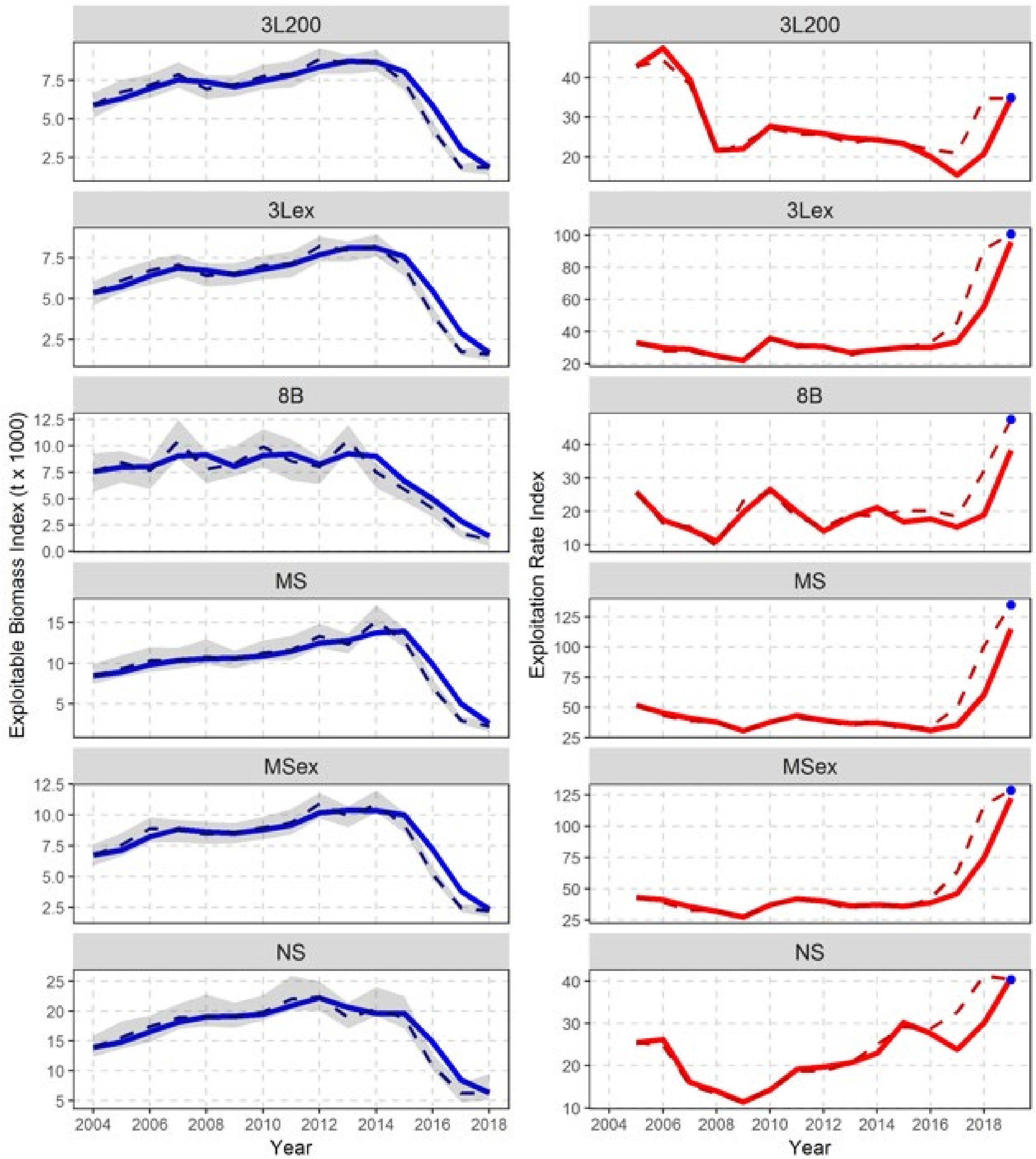

*Figure A4.6. **Left:** Annual trap-based exploitable biomass index (t * 1000). Solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the confidence interval of the annual estimates. **Right:** Trends in the exploitation rate index (ERI) in CMAs within Assessment Division 3LNO Offshore. Solid line represents ERI based on a 2-year moving average of trap-based exploitable biomass and the dashed line represents the trend in annual estimates. The blue point is the annual estimate of ERI in 2019 based on status quo landings.*

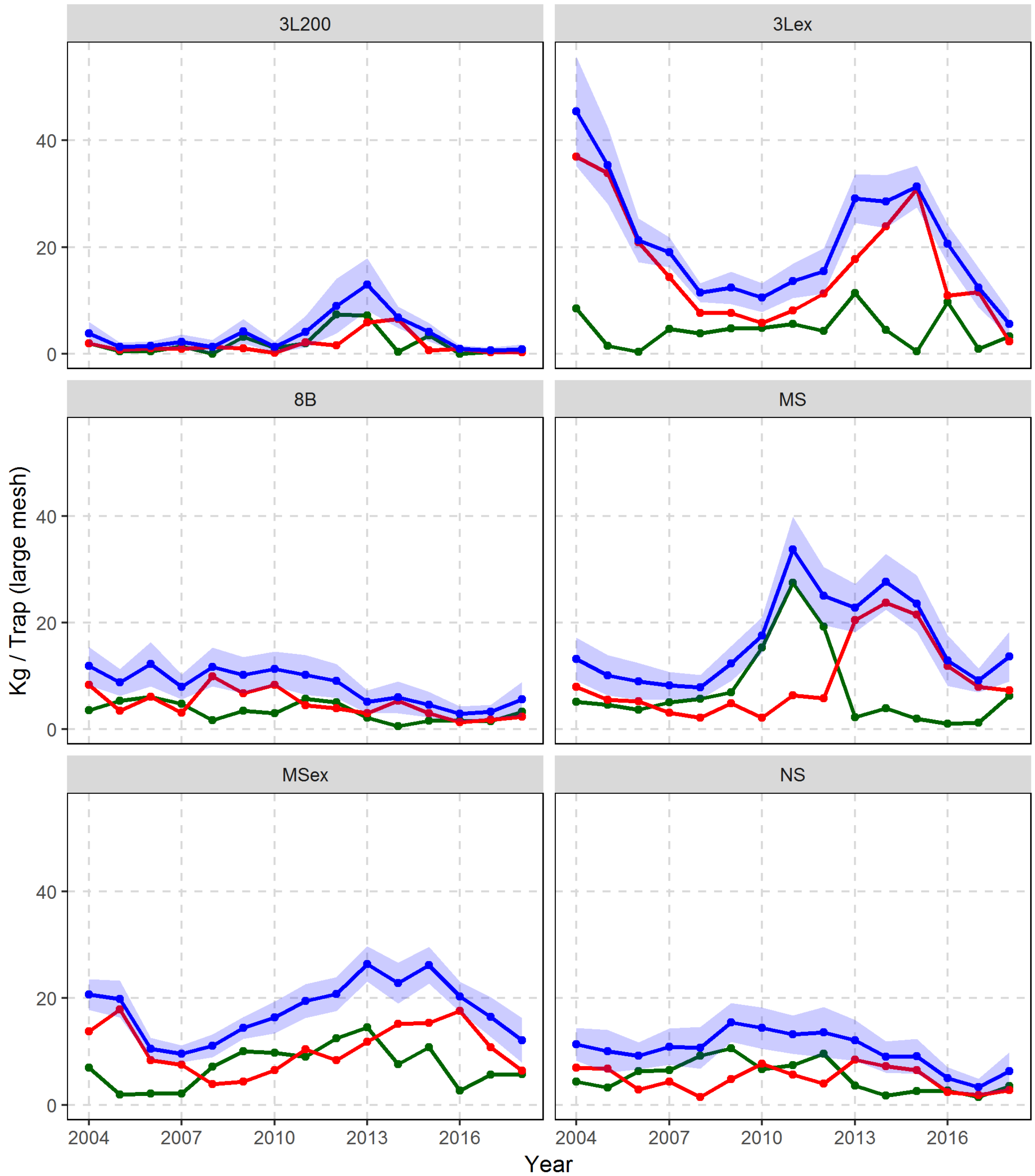

Figure A4.7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized Snow Crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Divisions 3LNO Offshore.

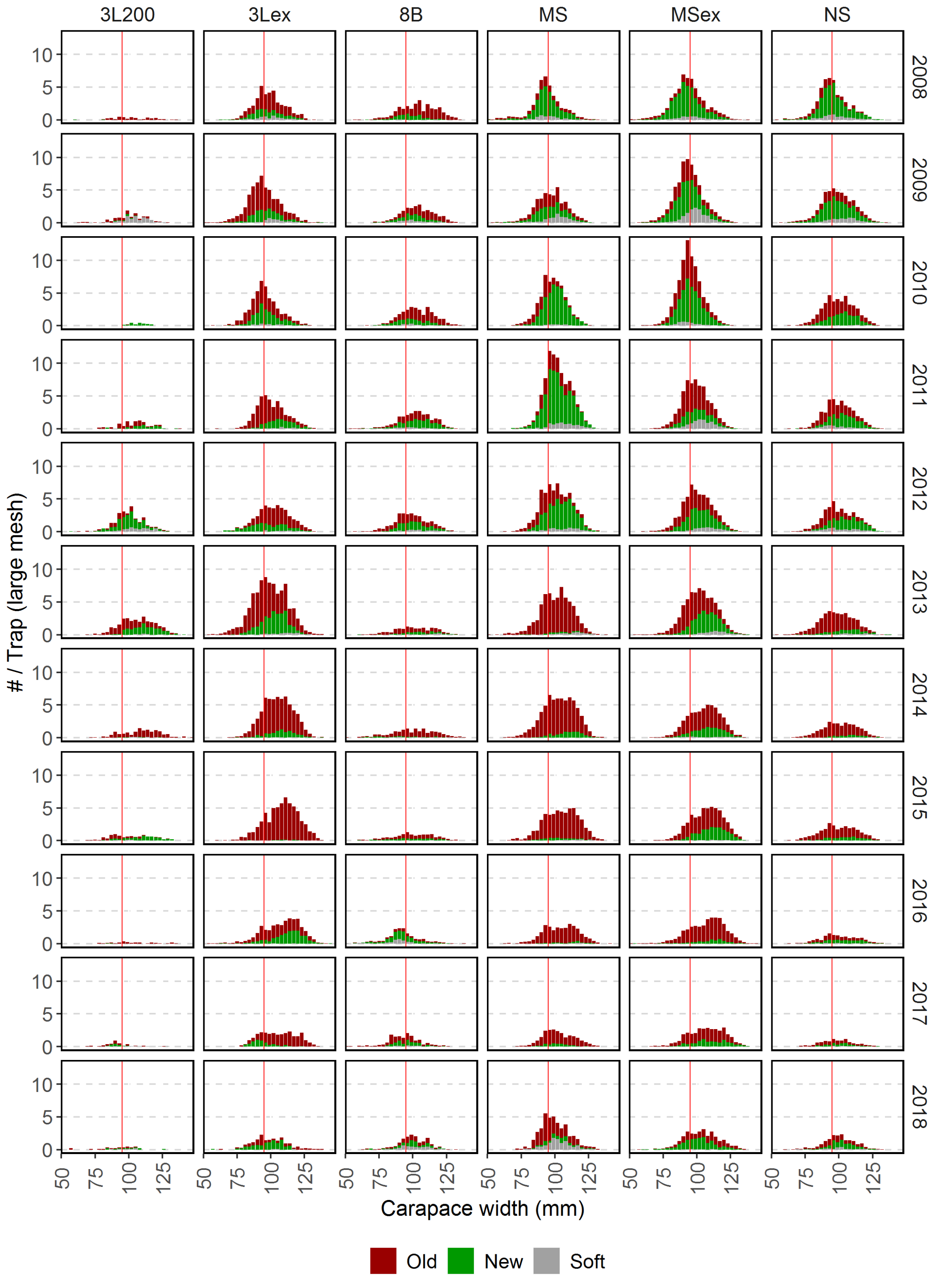

Figure A4.8. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Divisions 3LNO Offshore (2008-18). The red vertical line indicates the minimum legal size.

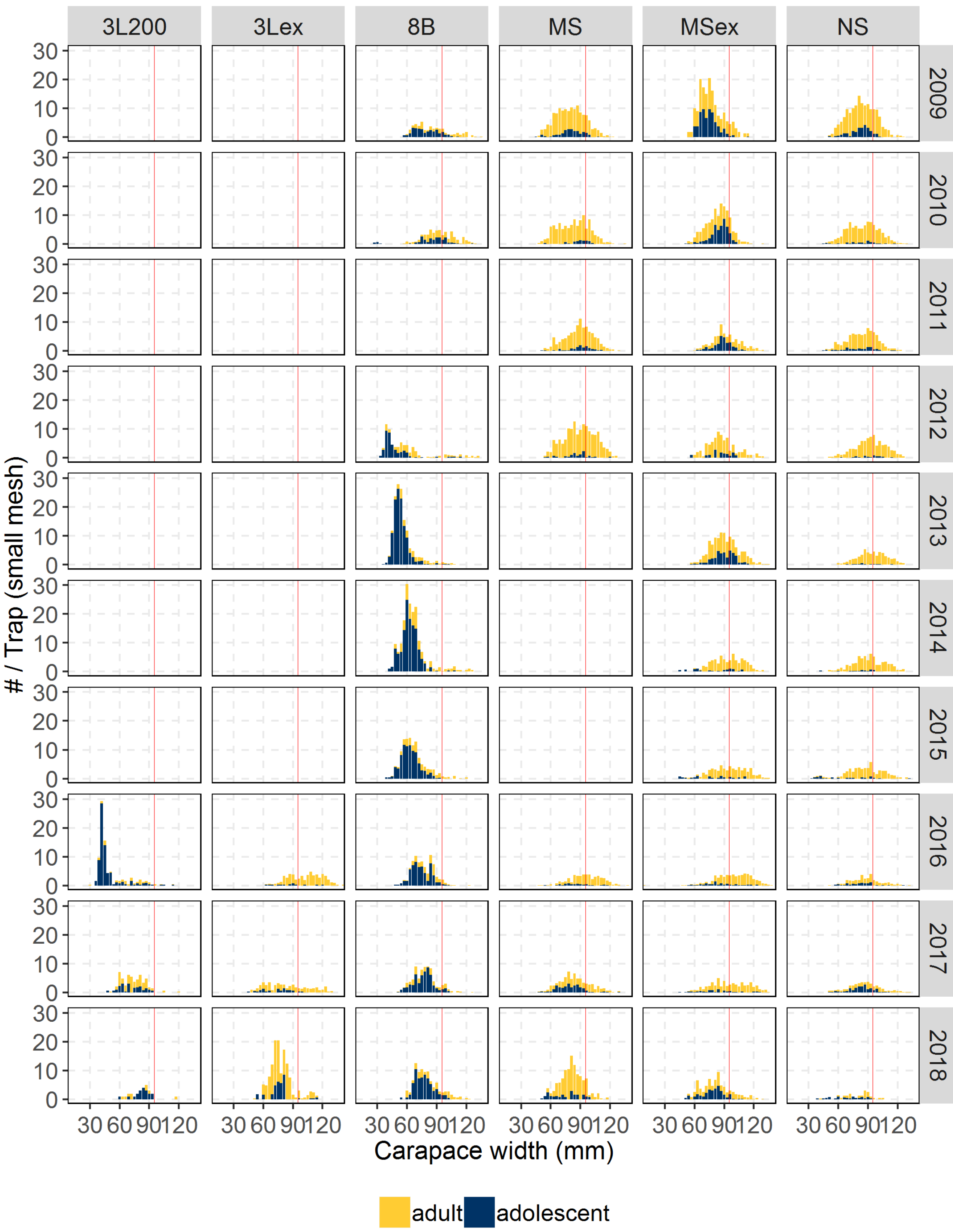

Figure A4.9. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2009-18) from CMAs in Assessment Divisions 3LNO Offshore. The vertical line indicates the minimum legal size.

APPENDIX 5: ASSESSMENT DIVISION 3PS DETAILS

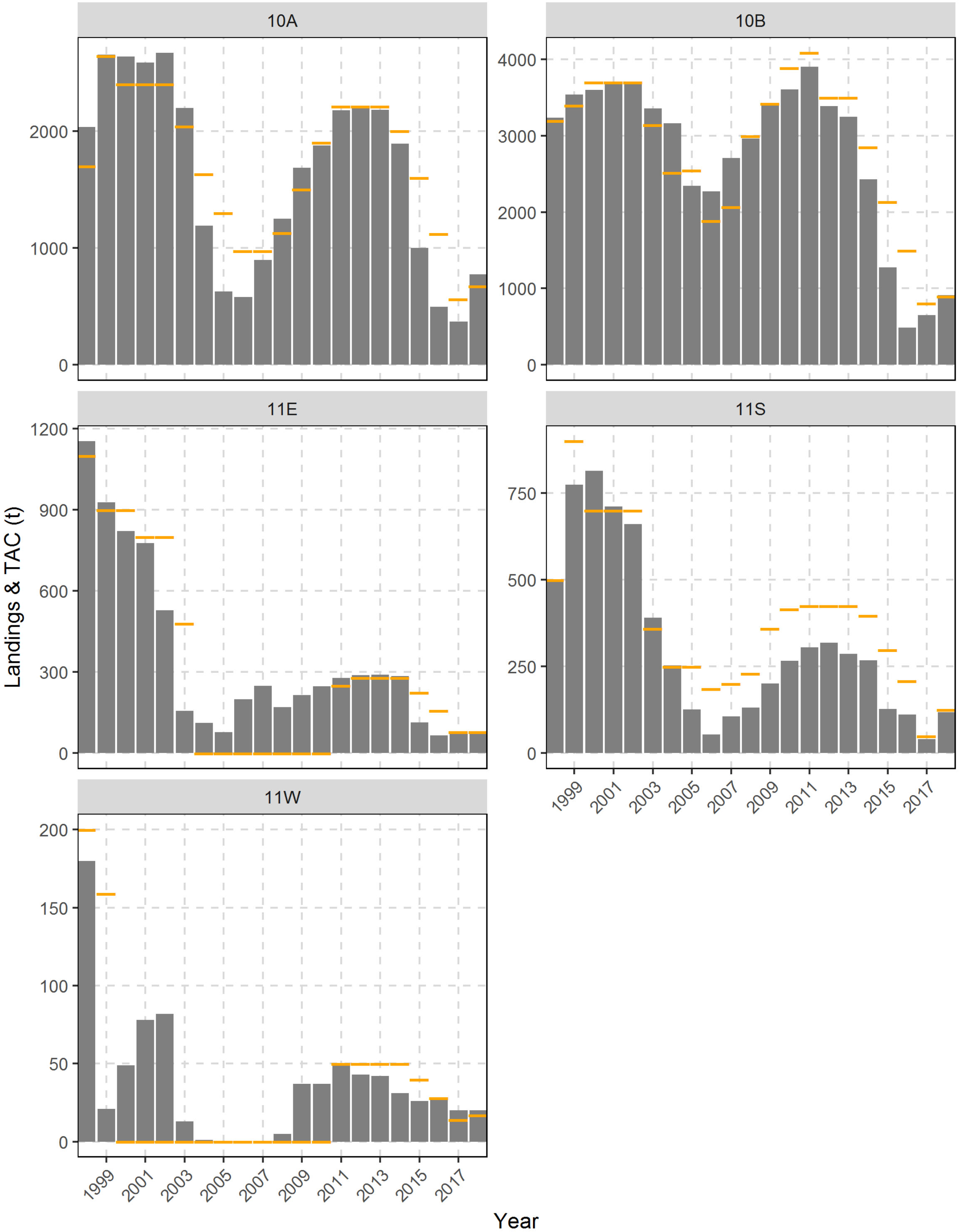

Figure A5.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Subdivision 3Ps (1998-2018).

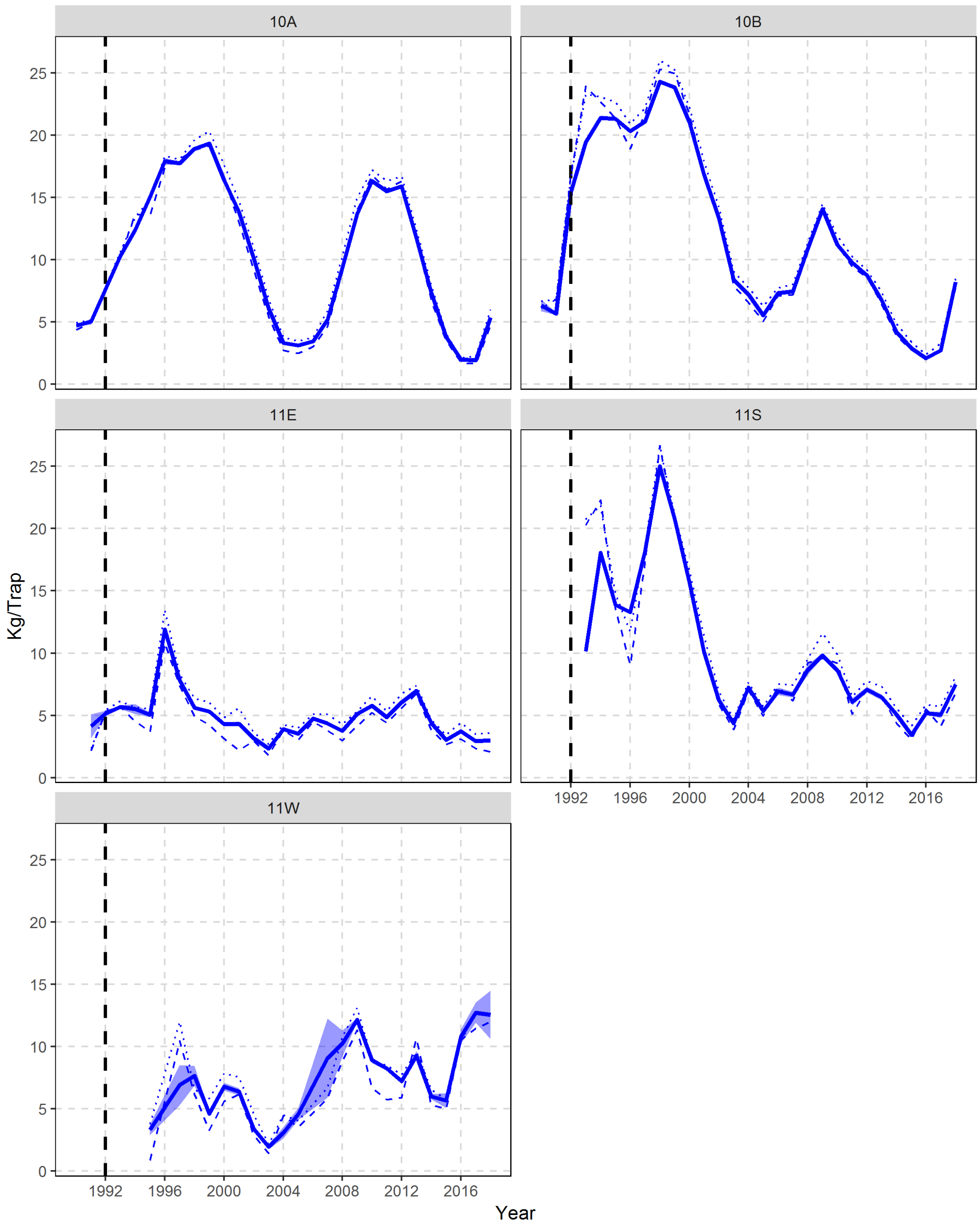

Figure A5.2. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Subdivision 3Ps. Solid line is average predicted CPUE and band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed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

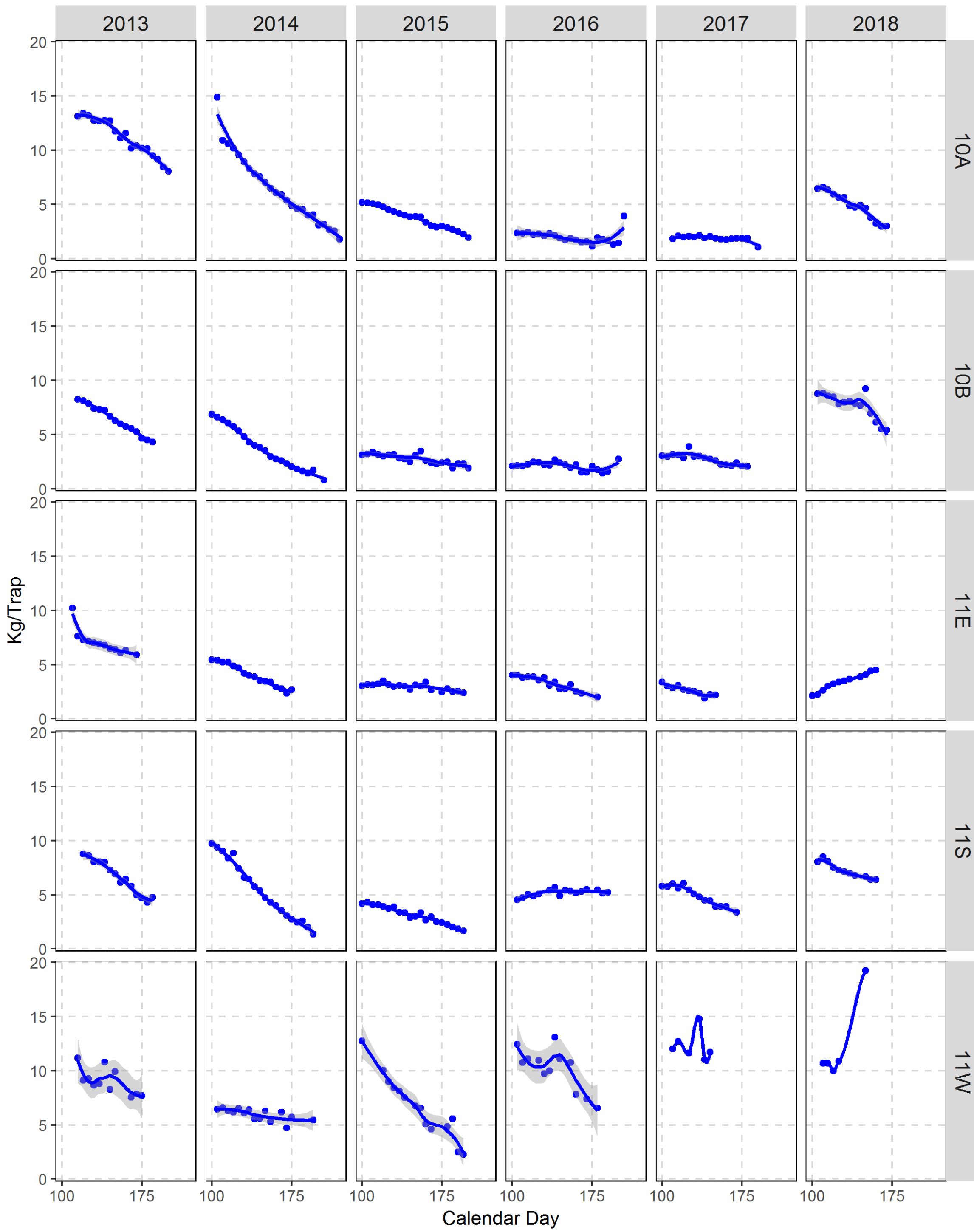

Figure A5.3. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2013-18), by Crab Management Area (CMA) in Assessment Subdivision 3Ps.

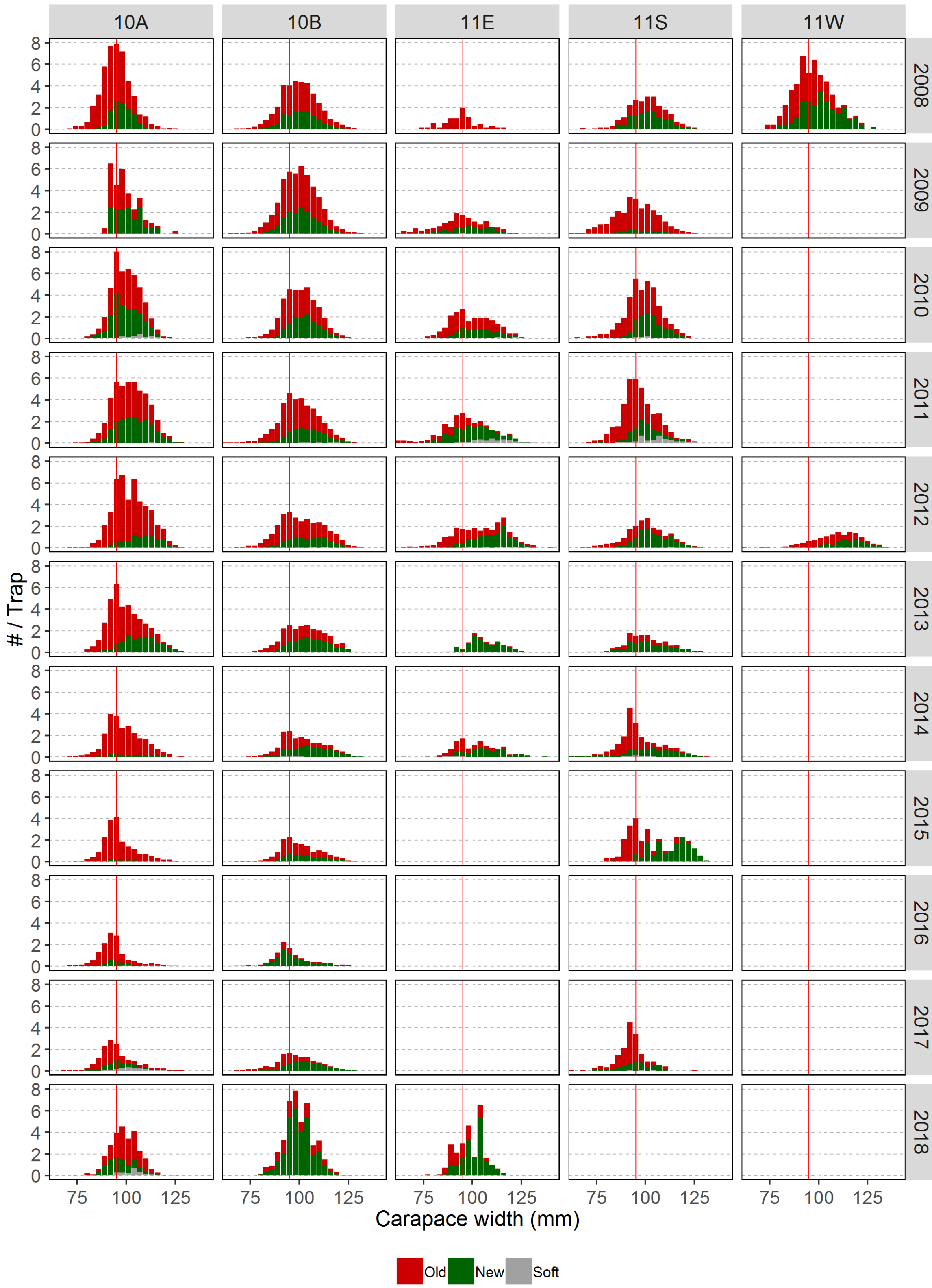

Figure A5.4. Trends in male carapace width distributions by shell condition from observer sampling in CMAs (Crab Management Areas) within Assessment Subdivision 3Ps (2008-18). The red vertical line indicates the minimum legal size.

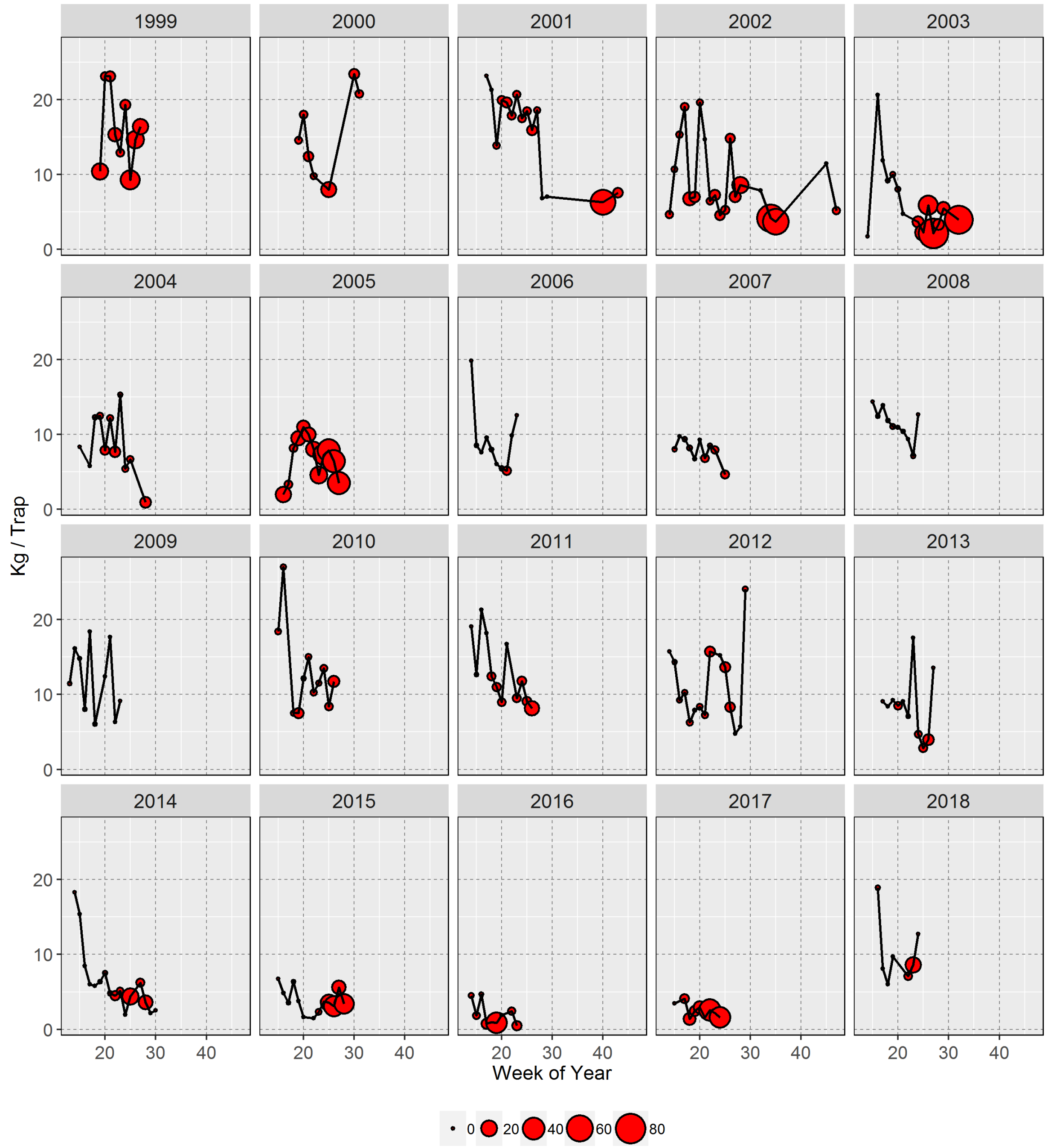

Figure A5.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shelled Snow Crab in the catch in CMAs within the Assessment Subdivision 3Ps (1999-2018). Bubble size depicts percentage of soft-shelled Snow Crab and solid line depicts unstandardized observed catch rates.

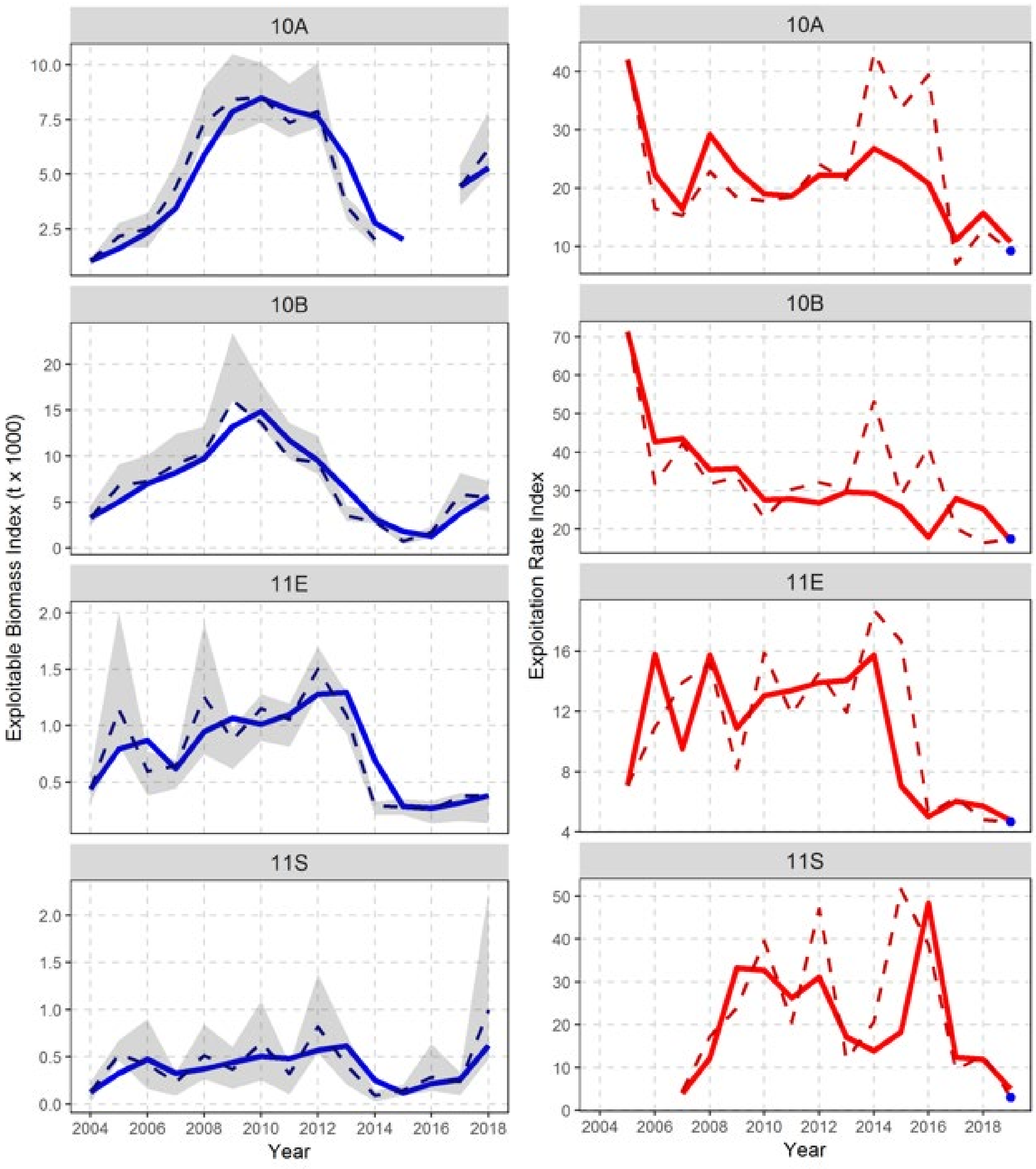

*Figure A5.6. **Left:** Annual trap-based exploitable biomass index (t * 1000). Solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the confidence interval of the annual estimates. **Right:** Trends in the exploitation rate index (ERI) in CMAs within Assessment Division 3Ps. Solid line represents ERI based on a 2-year moving average of trap-based exploitable biomass and the dashed line represents the trend in annual estimates. The blue point is the annual estimate of ERI in 2019 based on status quo landings.*

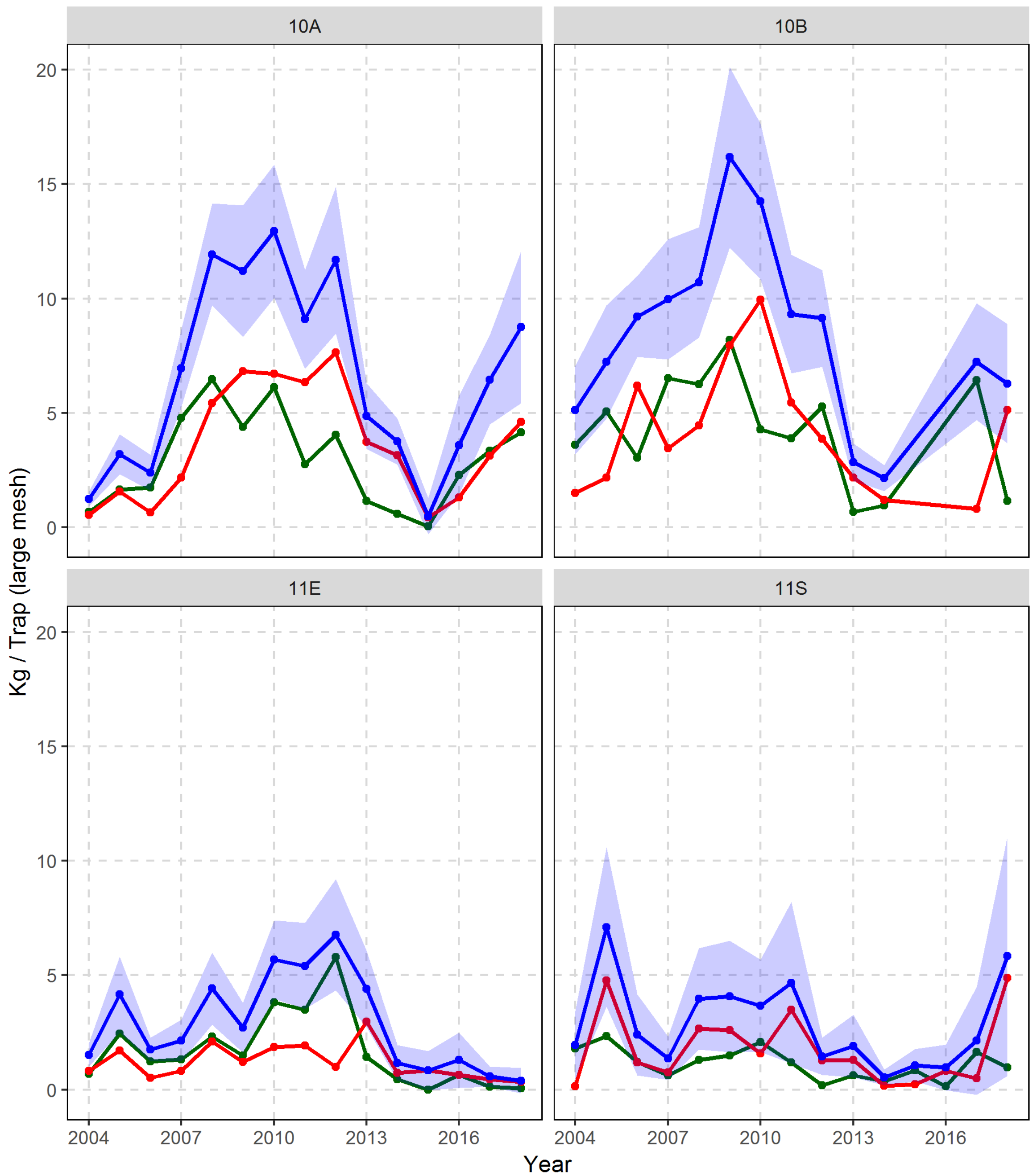

Figure A5.7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized Snow Crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Subdivision 3Ps.

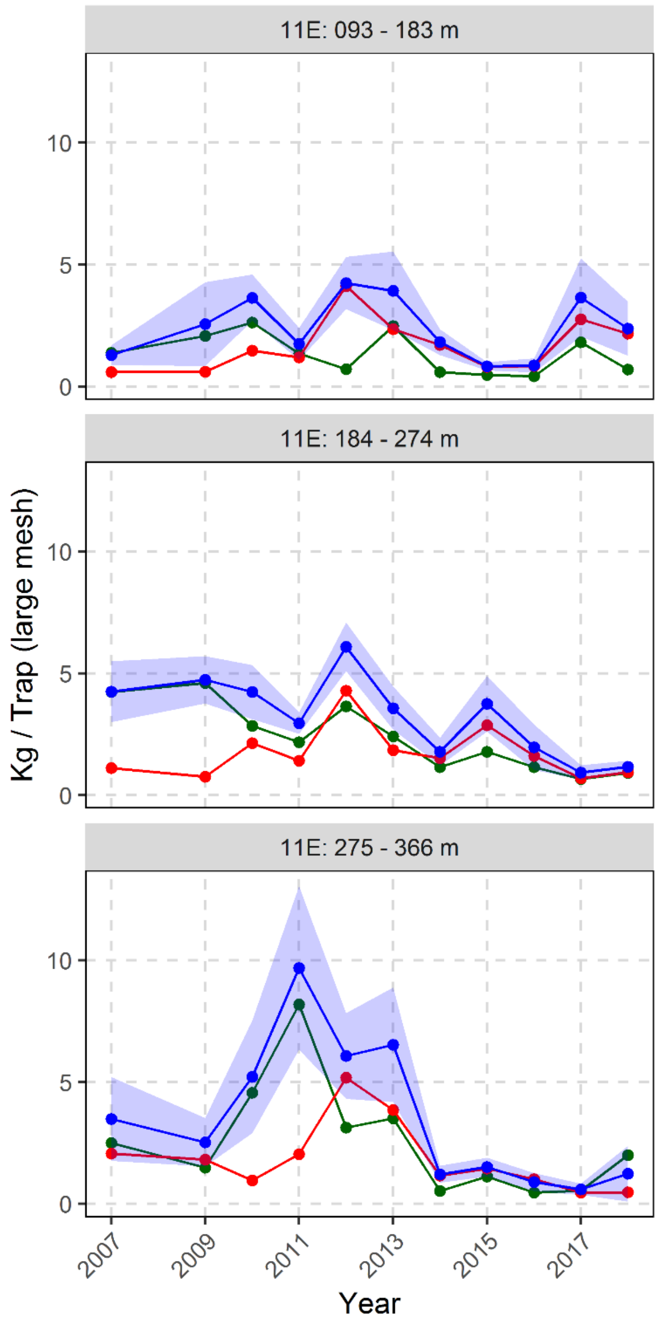

Figure A5.8. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized Snow Crab from DFO trap surveys in Fortune Bay (Assessment Subdivision 3Ps).

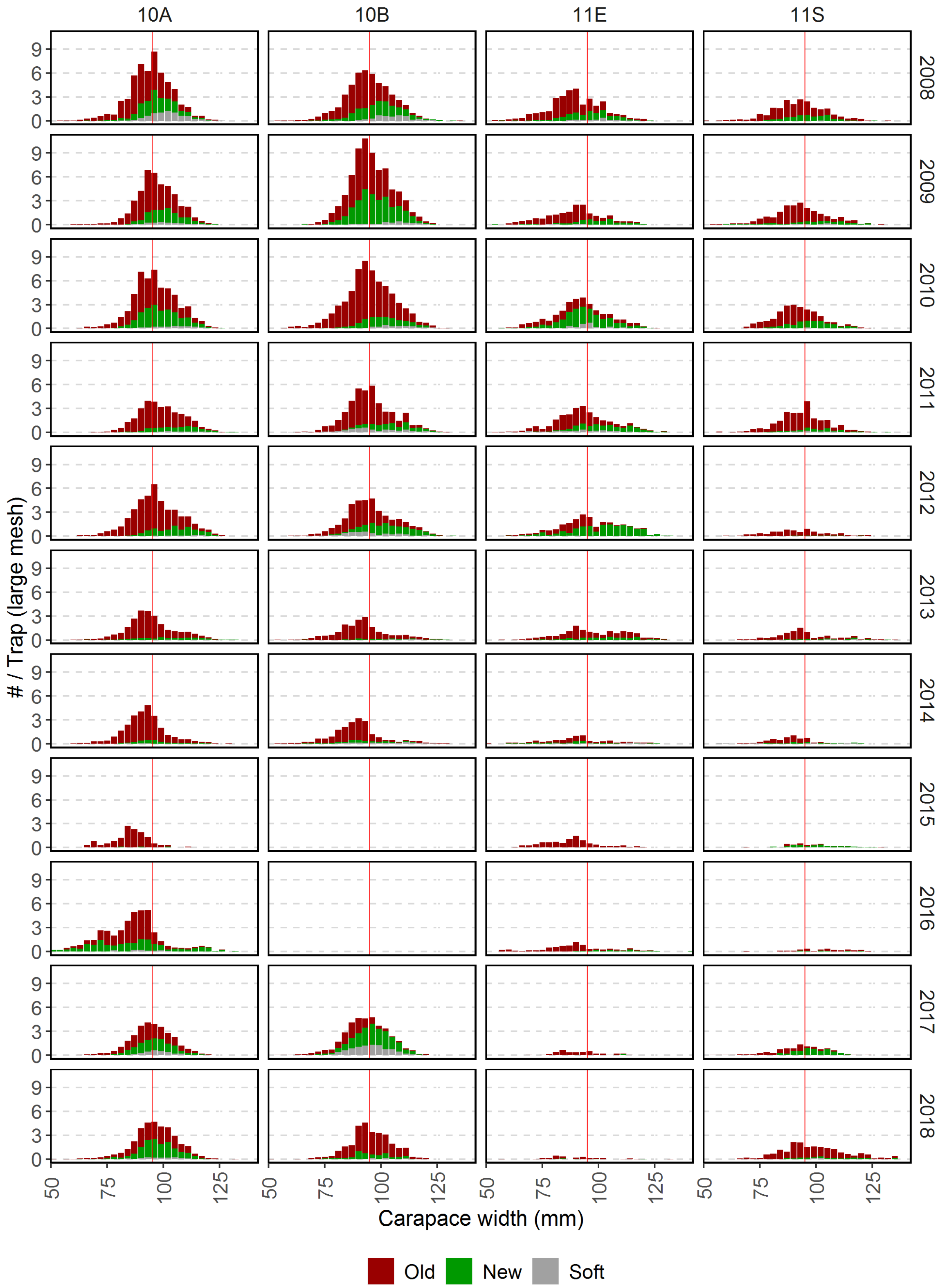

Figure A5.9. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Subdivision 3Ps (2008-18). The red vertical line indicates the minimum legal size.

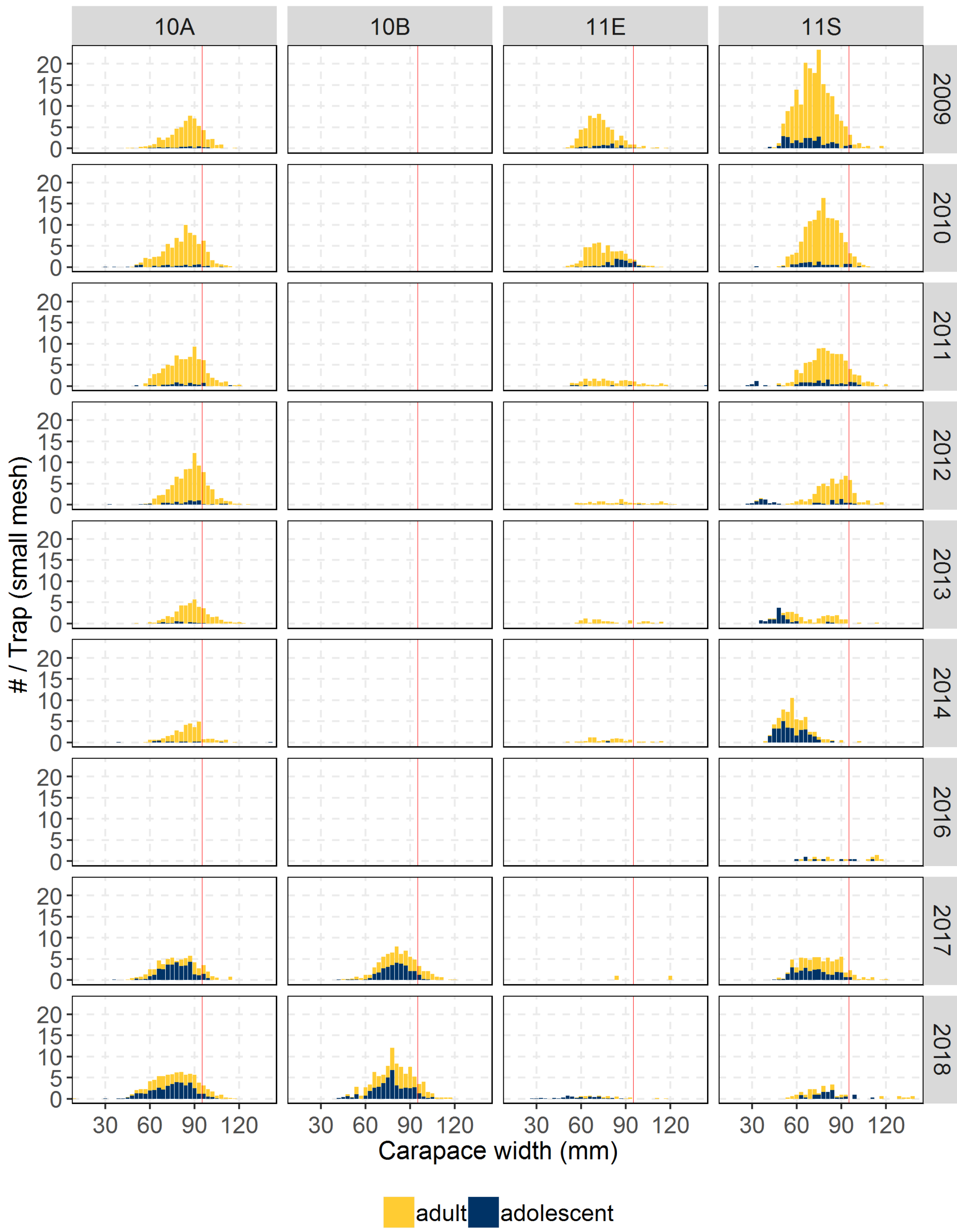

Figure A5.10. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2009-18) from CMAs in Assessment Subdivision 3Ps. The red vertical line indicates the minimum legal size.

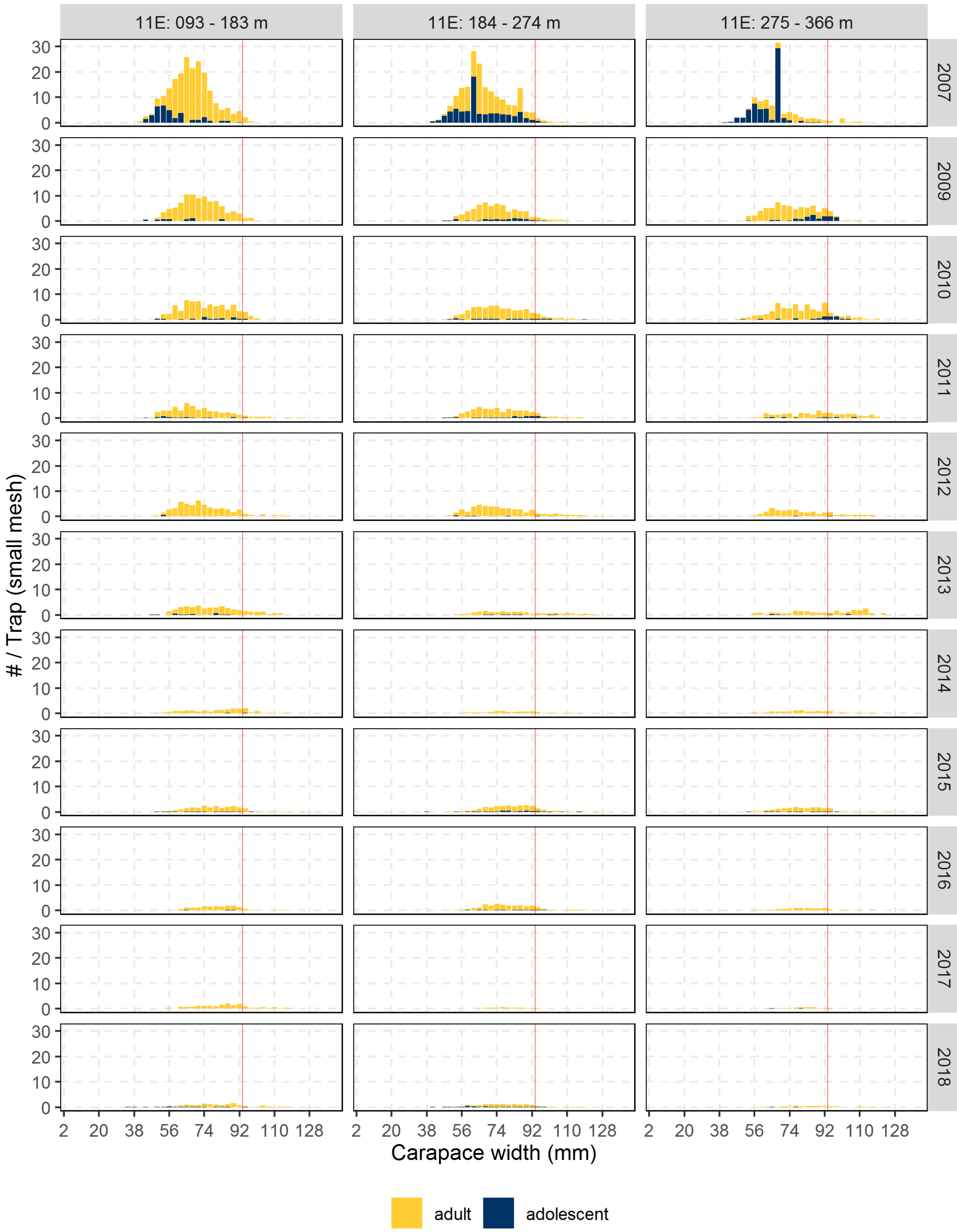

Figure A5.11. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2007-18) from Fortune Bay (Assessment Subdivision 3Ps). The red vertical line indicates the minimum legal size.

APPENDIX 6: ASSESSMENT DIVISION 4R3PN DETAILS

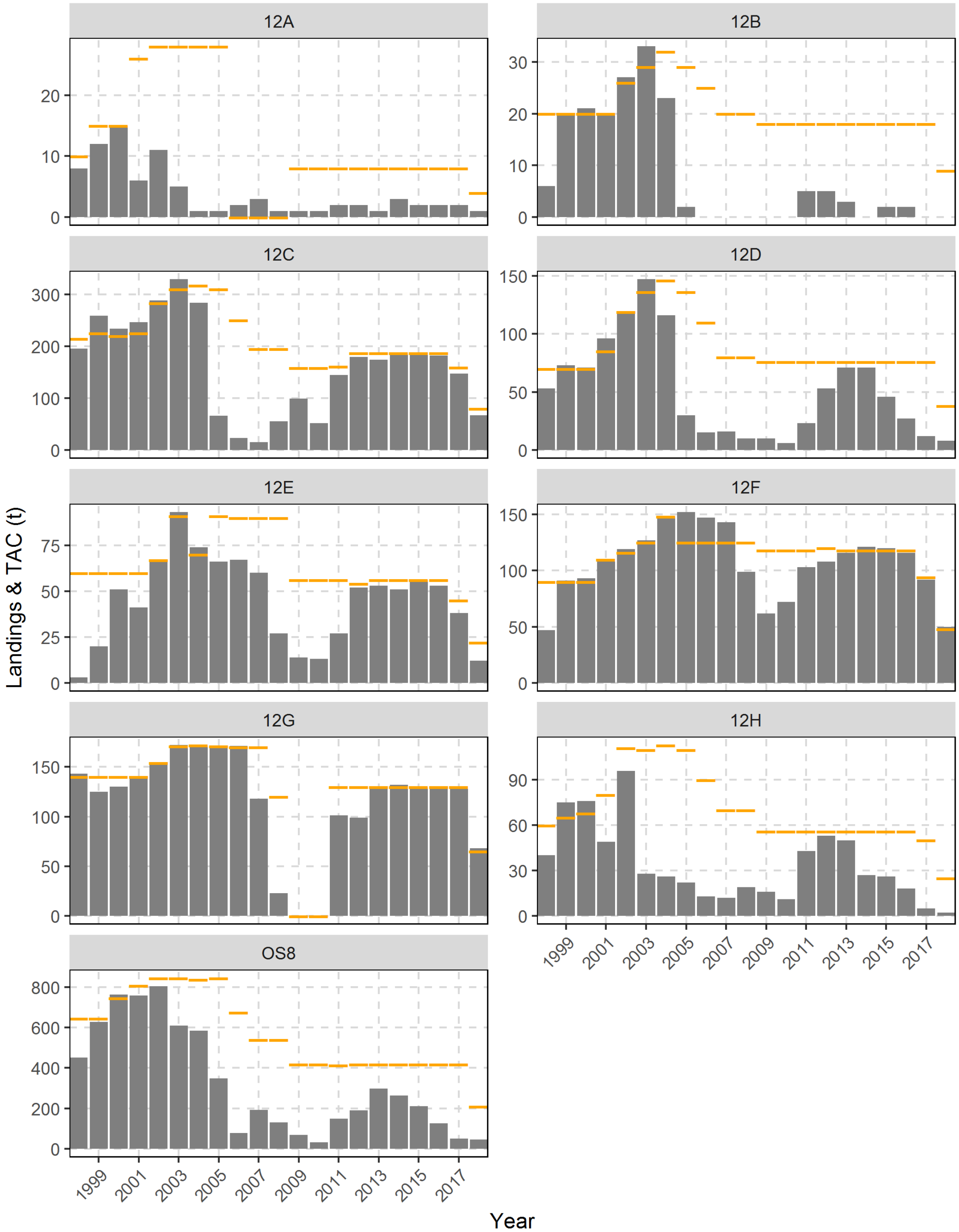

Figure A6.1. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Divisions 4R3Pn (1998-2018).

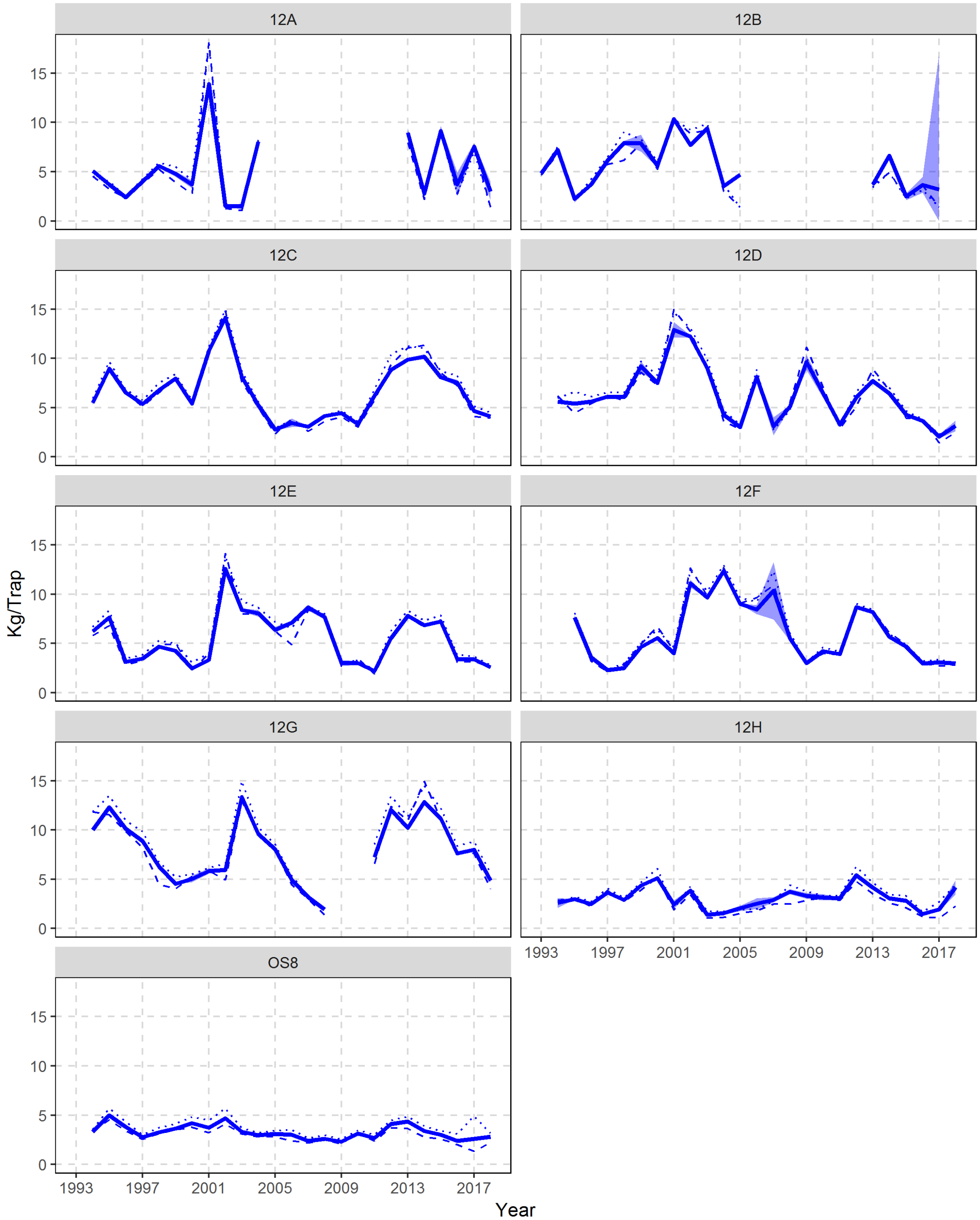

Figure A6.2. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Divisions 4R3Pn. Solid line is average predicted CPUE and band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed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

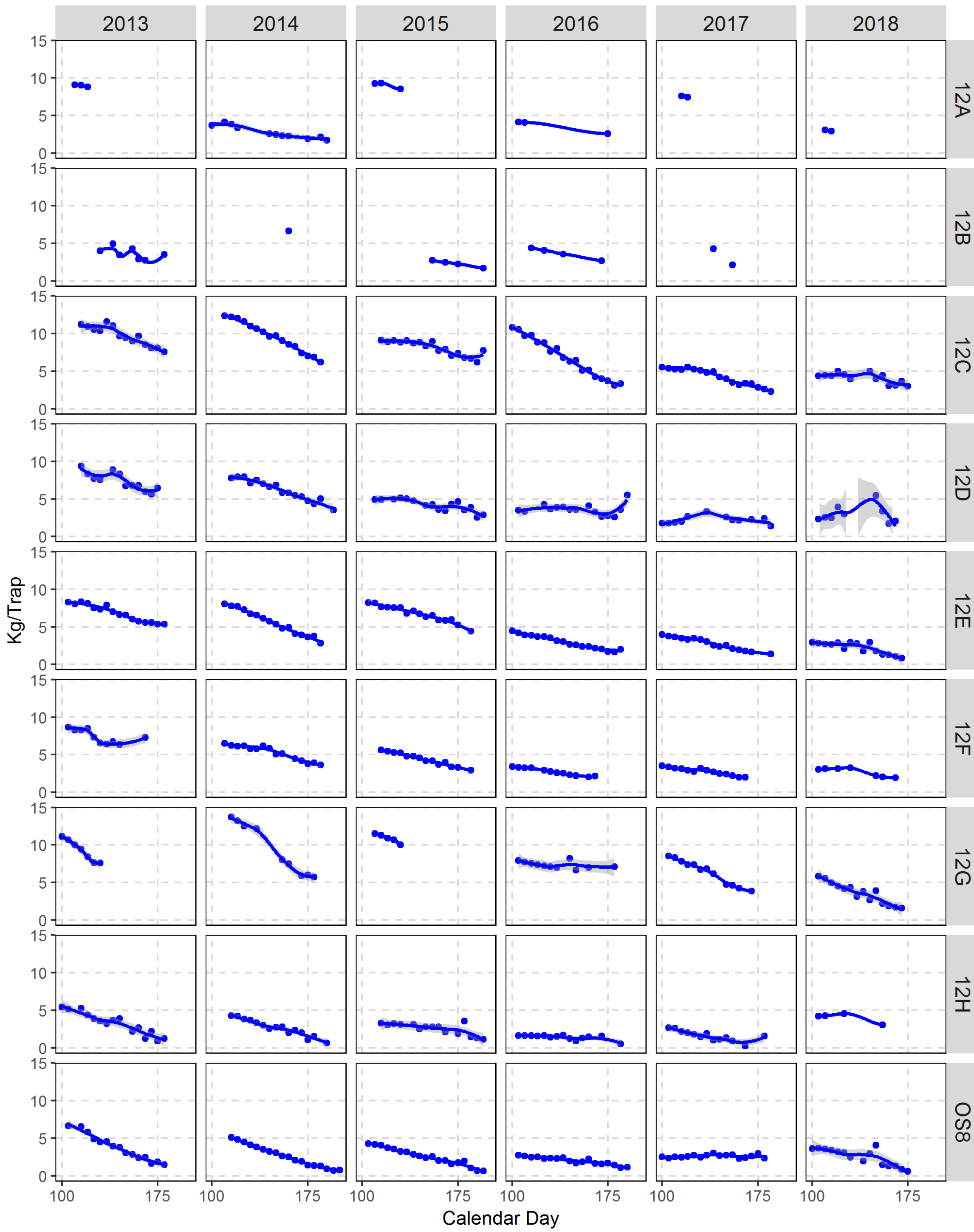

Figure A6.3. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2013-18), by Crab Management Area (CMA) in Assessment Divisions 4R3Pn.

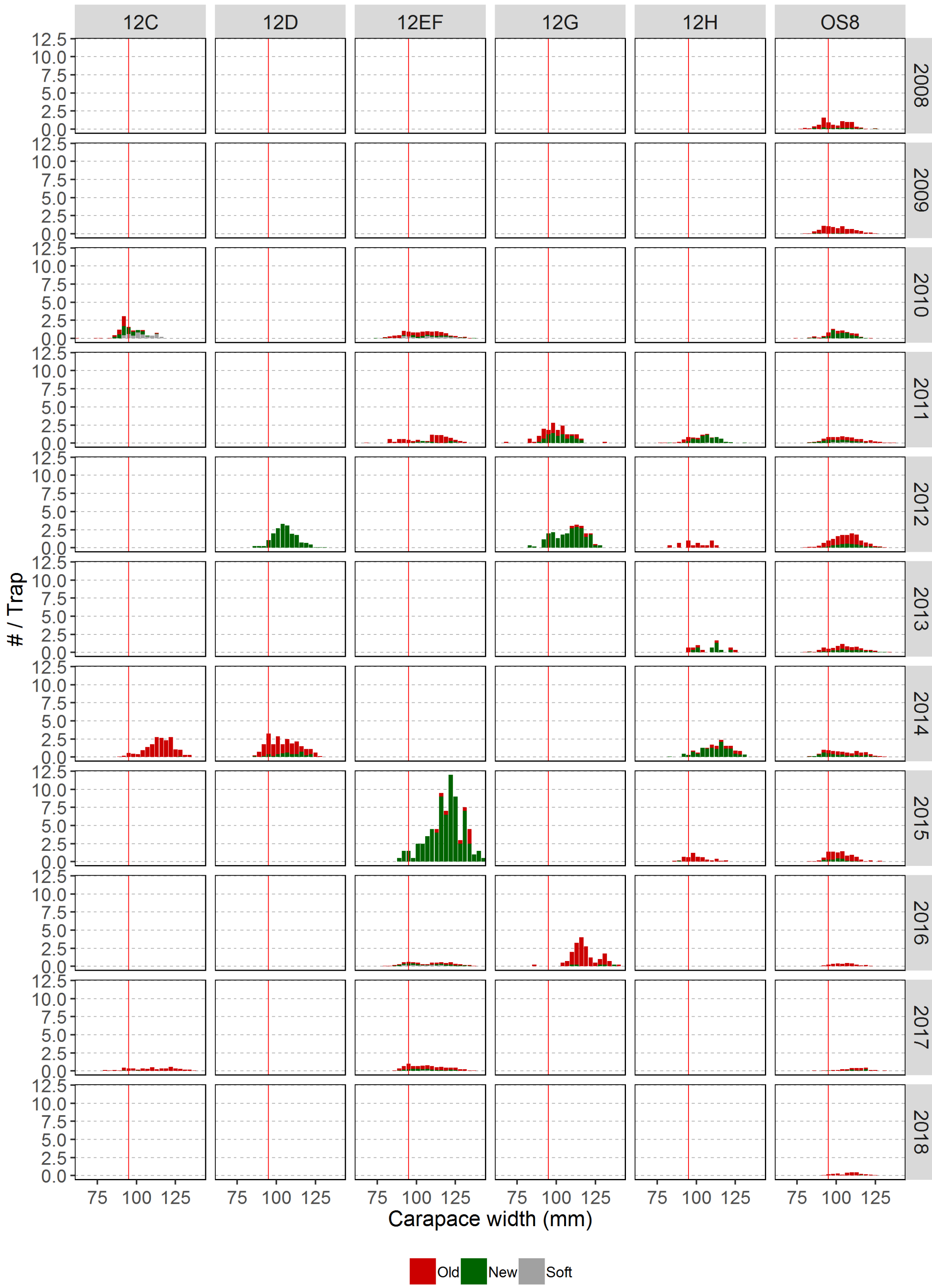

Figure A6.4. Trends in male carapace width distributions by shell condition from observer sampling in Divisions 4R3Pn (2008-18). The red vertical line indicates the minimum legal size.

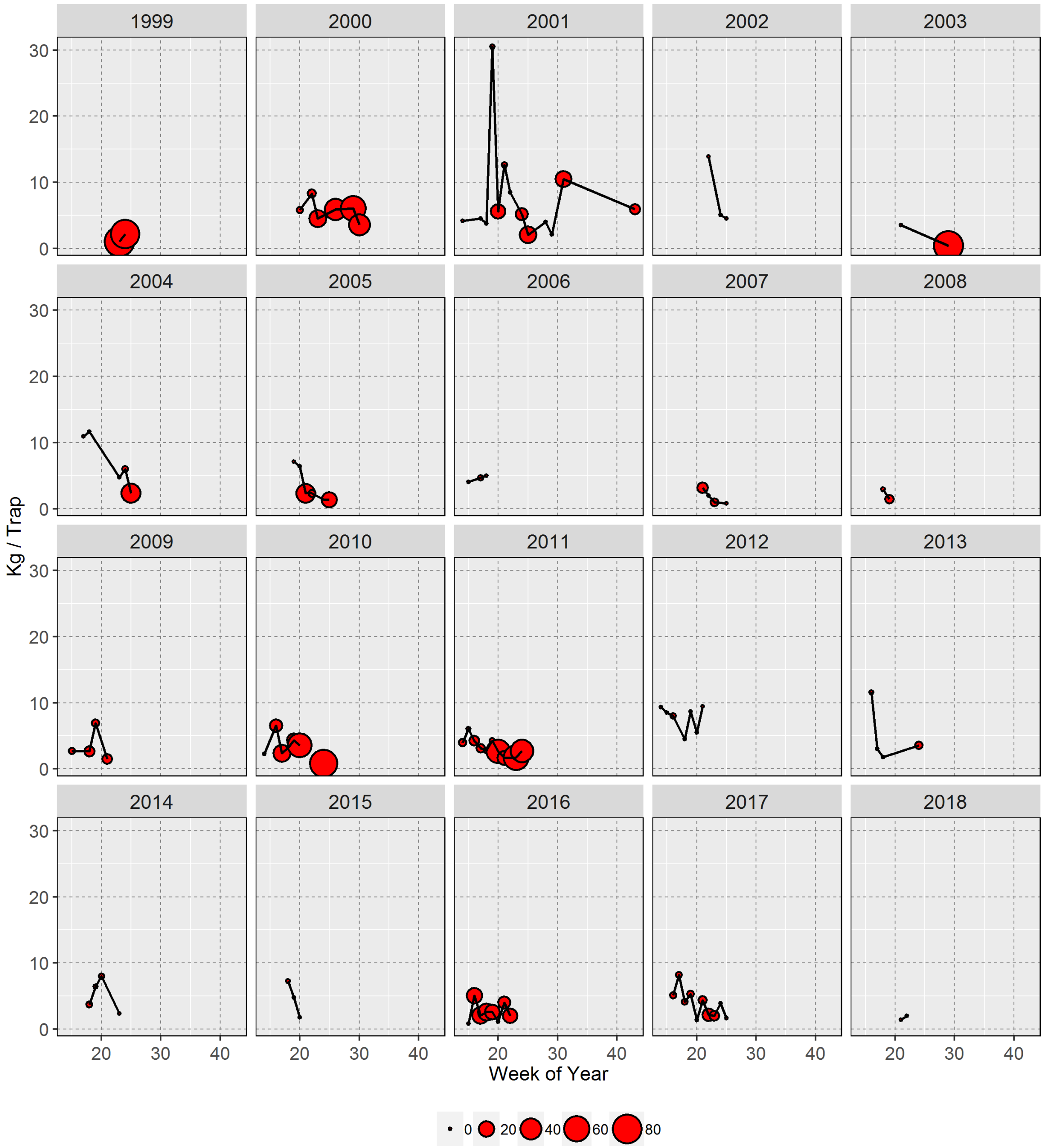

Figure A6.5. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shelled Snow Crab in the catch in CMAs within the Assessment Divisions 4R3Pn (1999-2018). Bubble size depicts percentage of soft-shelled Snow Crab and solid line depicts unstandardized observed catch rates.

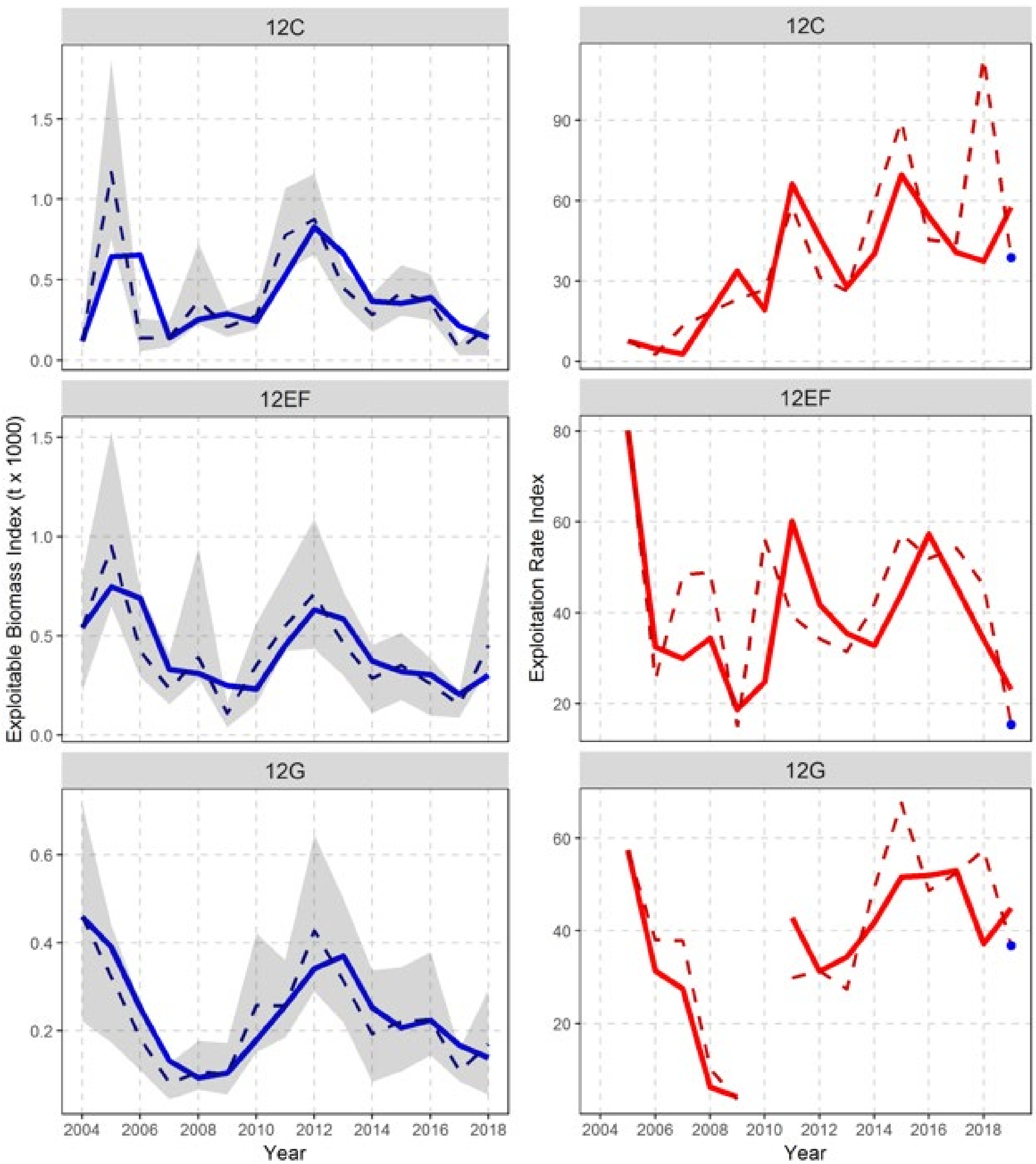

Figure A6.6. ***Left:*** *Annual trap-based exploitable biomass index (t * 1000). Solid line represents 2-year moving average, dashed line represents the trend in annual estimates, and shaded area represents the confidence interval of the annual estimates.* ***Right:*** *Trends in the exploitation rate index (ERI) in CMAs within Assessment Division 4R3Pn. Solid line represents ERI based on a 2-year moving average of trap-based exploitable biomass and the dashed line represents the trend in annual estimates. The blue point is the annual estimate of ERI in 2019 based on status quo landings.*

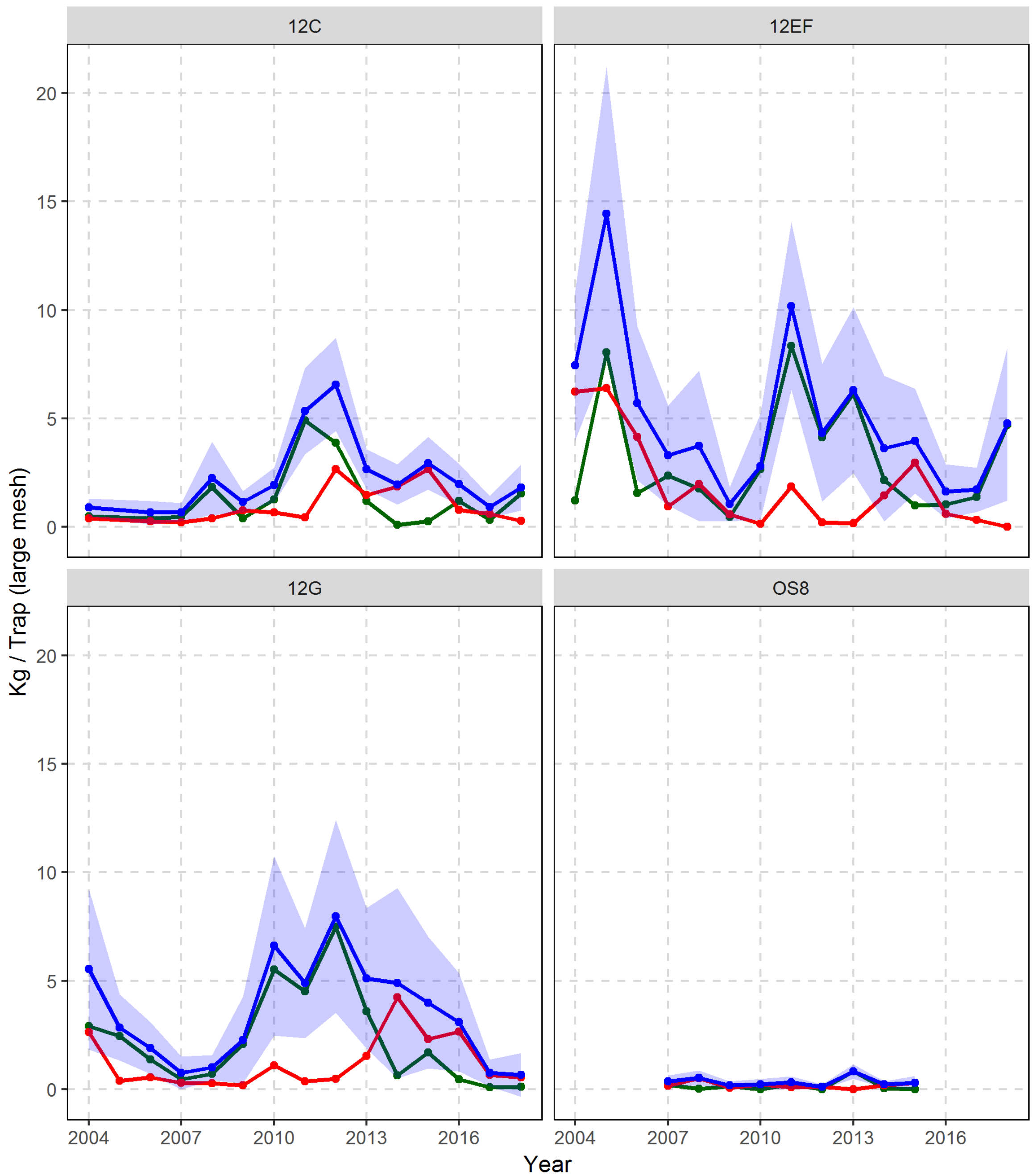

Figure A6.7. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized Snow Crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Division 4R3Pn.

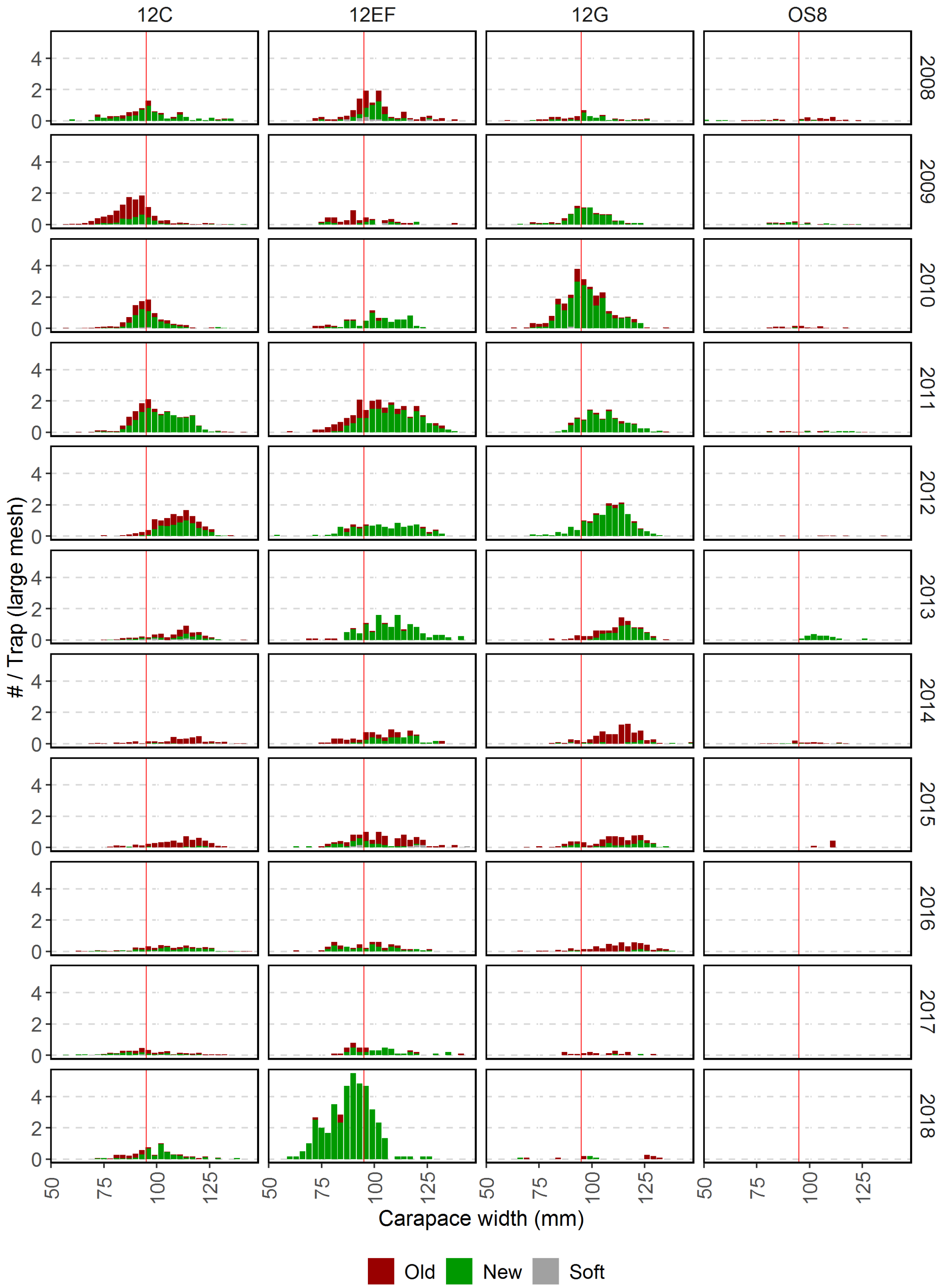

Figure A6.8. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Division 4R3Pn (2008-18). The red vertical line indicates the minimum legal size.

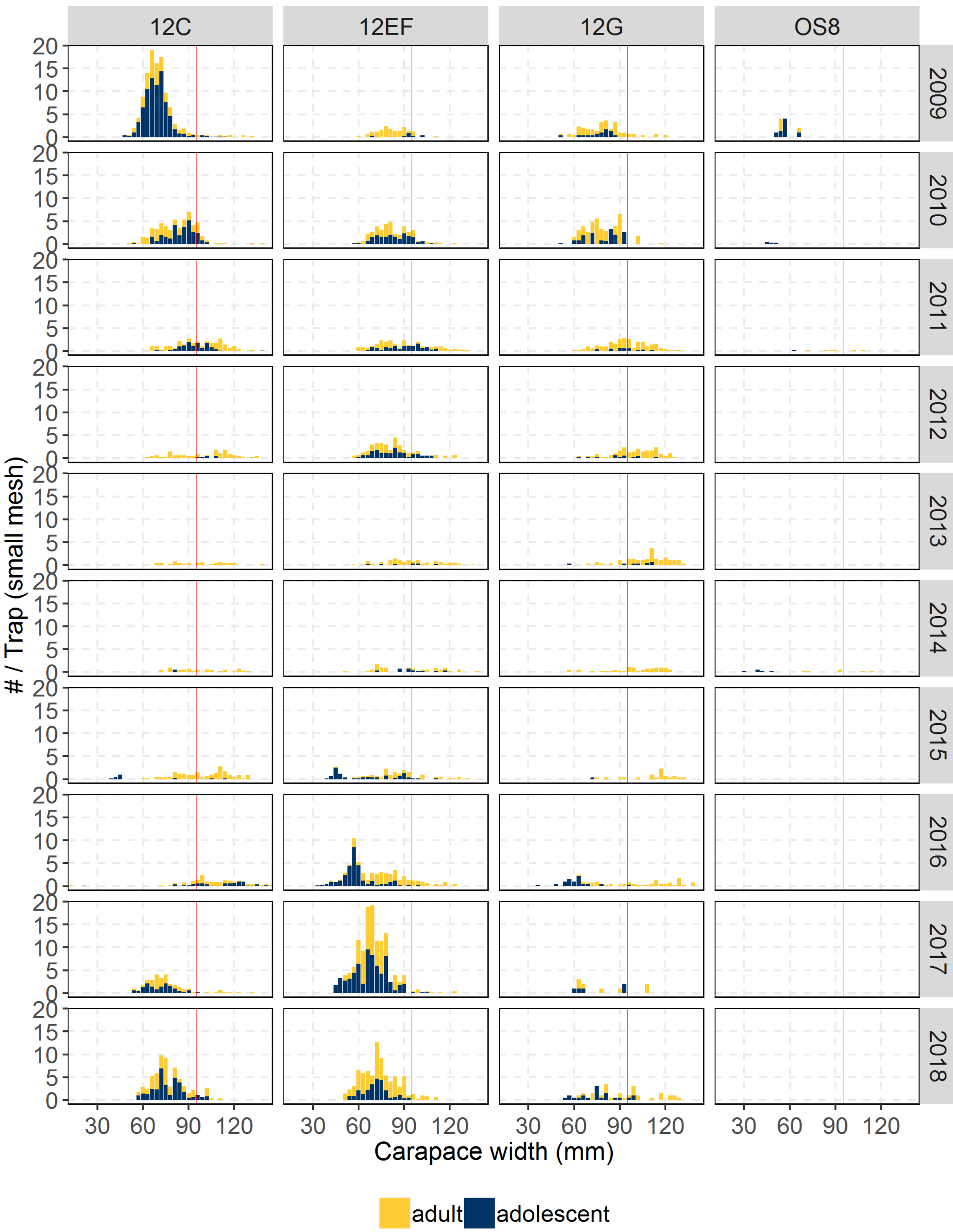

Figure A6.9. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2009-18) from CMAs in Assessment Division 4R3Pn. The vertical line indicates the minimum exploitable size.