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An Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2019

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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GLOSSARY

AD: Assessment Division.

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

CMA: Crab Management Area.

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

CPUE: Catch per unit of effort.

CW: Carapace width (mm).

DFO: Fisheries and Oceans Canada.

EBI: Exploitable biomass index.

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

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

Habitat index: Areal extent of cold (<2°C) bottom water in shallow areas commonly associated with early-life stages of crab.

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

Legal-size: ≥95 mm carapace width male 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.

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

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

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

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

TAC: Total allowable catch (quota)

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

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 multispecies bottom trawl surveys, inshore and offshore trap surveys, harvester logbooks, at-sea observers, the Dockside Monitoring Program (DMP), as well as oceanographic surveys are used to inform trends in biomass, recruitment, production, and mortality over the time series. Snow Crab landings declined to a 25-year low of 26,400 t in 2019, while effort decreased to under 3 million trap hauls, the lowest level in two decades. Overall fishery catch per unit of effort (CPUE) was at a time-series low in 2018, but increased back to near the previous historical low in 2019. Despite modest increases in recent years, the trawl survey exploitable biomass index (EBI) has remained at a low level and the trap survey EBI remains near the time-series low. Overall recruitment into the exploitable biomass has been very low in recent years and is expected to remain low in 2020. Total mortality in exploitable crab had been very high in recent years, but is now estimated to be near time-series' averages in most Assessment Divisions (AD). In 2019, fishery exploitation rates remained high in ADs 2HJ and 3K, declined in ADs 3LNO and 3L Inshore, and remained at low levels in ADs 3Ps and 4R3Pn. Elements of the proposed Precautionary Approach (PA) Framework presented in this assessment are tentative. Limit Reference Points (LRPs) have been established by a peer-reviewed Science process, but Upper Stock Reference (USR) lines remain under development. In 2020, with status quo landings, most ADs are projected to fall within the cautious zone of the proposed PA Framework; however, AD 3LNO is projected to fall within the healthy zone. Broad-scale climate indices appear favourable for improved recruitment to occur in most major areas of the stock range over the next few years. A sharp decline in male size-at-maturity (i.e., terminal molt size) in most ADs in recent years that persisted in some ADs in 2019 could dampen short-term prospects for recruitment into the Snow Crab exploitable biomass.

INTRODUCTION

This document assesses the status of the Snow Crab (*Chionoecetes opilio*) resource surrounding Newfoundland and Labrador (NL) in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2HJ3KLNOP4R (Figure 1, Figure 2). The information presented follows from a formal scientific assessment and regional peer-review process conducted during late February 2020 that focused on identifying changes in the exploitable biomass of Snow Crab available to the fishery.

SPECIES BIOLOGY

Snow Crab are sexually dimorphic, with males normally achieving larger sizes than females. The Snow Crab life cycle features a spring hatching followed by a planktonic larval period that involves several stages before settlement. Small benthic stages of both sexes molt multiple times each year, but molt frequency slows as crab grow. Females cease molting during their ninth or tenth molt at the same time sexual maturity is achieved at approximately 40–75 mm carapace width (CW). Males enter puberty at their eighth or ninth molt and during this sexually mature adolescent stage will generally continue to molt near-annually until their terminal molt, when they develop enlarged claws (becoming adults) that likely enhance their competitive ability in mating dynamics. Males can molt to adulthood at any size greater than approximately 40 mm CW, but terminal molt typically occurs after ten to thirteen molts over a size range spanning about 55–135 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 (i.e., Divs. 2J3K4R) and at slightly older ages in cold areas (i.e., Divs. 3LNO and Subdivision [Subdiv.] 3Ps), reflecting less frequent molts (skip-molting) at low temperatures (Dawe et al. 2012). However, population density also affects molt frequency with more frequent molting (lower incidence of terminal molt at small size) under high density conditions, at least in males (Mullowney and Baker 2021). Adult legal-sized males remain soft- or new-shelled with less than full meat yield for almost a year following their terminal molt. They are not likely to efficiently contribute to the fishery (i.e., render maximum meat yield) until the following year when their shells are fully hardened and full of meat. Males may live a maximum of 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-mid ontogeny are associated with increased survey biomass and fishery CPUE indices several years later (Marcello et al. 2012; Baker et al. 2021). While growth rates are positively affected by temperature, with overall higher molt frequency and molt increments occurring in warm conditions, the overriding positive effect of cold water on early-to-mid-life stages appears stronger than the dampening effects on growth rates, with highest productivity occurring in cold areas. Mullowney and Baker (2021) showed that along the NL shelf overall size-at-maturity has been highest in cold AD 3LNO during the past 25 years, suggesting high population density in cold conditions was the dominant determinant of terminal size.

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

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

Snow Crab in NL are part of a larger genetic stock unit in Canadian Atlantic waters, ranging from southern Labrador to the Scotian Shelf (Puebla et al. 2008). However, large movements of individuals within the stock are thought to be limited, so assessments are conducted at the AD level whereby some NAFO Divisions (Figure 2) are separated into inshore and offshore portions were applicable and some divisions combined. Accordingly, ADs differ from both NAFO Divisions and the small spatial scale Crab Management Areas (CMAs) used to manage the fishery. The spatial scale of the assessment approach accommodates different types and amounts of available information among ADs and better conforms with broad-scale resource status indicators than the CMAs, which have no biological basis. Le Corre et al. (2020) recently modelled downstream flow of Northern Shrimp larvae from northern source areas (including Divs. 2HJ) to southern sink areas (Divs. 3KL) in conjunction with the Labrador Current and the Baffin Island Current along the NL shelf. This study highlights how this information could be useful in determining the appropriate spatial scale for resource management and may be useful for other species with pelagic larvae, such as Snow Crab.

FISHERY

The NL Snow Crab fishery began in Trinity Bay (CMA 6A) in 1967. Initially, Snow Crab were taken as gillnet by-catch, but within several years a directed trap fishery developed in inshore areas along the northeast coast of Divs. 3KL. Until the early 1980s, the fishery was prosecuted by approximately 50 vessels limited to 800 traps each. In 1981, fishing became restricted to the NAFO Division adjacent to where the license holder resided. The fishery expanded throughout all areas of the province from the 1970s–2000s, especially following groundfish stock and fishery collapses in the early 1990s. During 1982–87, there were major declines of the Snow Crab resource in traditional areas in Divs. 3K and 3L, while new fisheries started in Div. 2J, Subdiv. 3Ps, and offshore Div. 3K. A Snow Crab fishery began in Div. 4R in 1993. Management of the increasingly diverse and complex fishery during the expansion years led to progressive development and refinement of the many quota-controlled areas (CMAs), with approximately 3,500 active license holders representing various vessel-size fleet sectors participating in the fishery in the mid-2000s. Resource declines and rationalization measures have led to reduced participation during the past decade. The fishery is now prosecuted by about 2,400 license holders representing three dominant fleet sectors in 2019.

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

The fishery was traditionally prosecuted during summer and fall, but has become earlier during the past decade and is now primarily prosecuted during spring and summer. The fishery can be delayed in northern NAFO Divisions (Divs. 2HJ3K) due to ice conditions in some years. The fishery can also be delayed (or extended) for other reasons such as price disputes or difficulties in capturing quotas. Late fishing seasons are often associated with a high incidence of soft-shelled immediate pre-recruits in the catch, particularly under high fisheries exploitation rates (Mullowney et al. 2021). A soft-shell protocol was initiated in 2004 to protect soft-shelled immediate pre-recruits from handling mortality by closing localized areas (70 nM^2 grids in the offshore and 18 nM^2 in inshore areas of ADs 3L Inshore, 3K, 3Ps, and 4R3Pn) for the remainder of the season when a threshold level of 20% of the legal-sized catch is reached. That threshold has since been reduced to 15% in ADs 3LNO Offshore and 3L Inshore and grids have been partitioned into quarters in some inshore areas in recent years. It became evident during 2010–12 that this protocol, as implemented, is inappropriate and ineffectual in controlling handling mortality. This is largely due to very low observer coverage, together with the decision to treat unobserved grids as if they had no problem. Approximately <1–5% of fishery landings have been observed in any given AD in recent years. This corresponds with about <0.1–0.2% of the catch being sampled. 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. In addition, failure to draw all the inferences possible from moderate-sized samples frequently resulted in failure to invoke the protocol even when it was clear that the level of soft-shelled crabs had exceeded the threshold. A recent analysis (DFO 2020) showed that a high proportion of cells had no ability to invoke closure due to complete absence of observer coverage in a given year. This was further compounded by low sample sizes prohibiting adherence to closure thresholds when observer coverage was present. Moreover, grid cells need to be monitored repeatedly during the season to gauge true levels of soft-shell crab within them (Mullowney et al. 2021).

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 steadily declined to 26,400 t in 2019. 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 2016. However, resource and fishery declines have recently occurred in these most important areas.

METHODOLOGY

MULTISPECIES TRAWL SURVEY DATA

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

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

The catchability of the survey trawl for Snow Crab differs by season and area. Based on comparative data from Divs. 3LNO, where both a spring and fall survey occurs, fall trawl surveys are deemed to have a higher catchability for Snow Crab. Spring surveys are considered less reliable because some population components are believed to be relatively poorly sampled during this time, when mating and molting typically occurs. The catchability of Snow Crab by the Campelen trawl also varies with crab size. It is highest on largest 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, which was in use until 2008 (Benoît and Cadigan 2014; 2016). Previous exploratory analyses have shown that conversions to account for time and vessel make negligible difference in scaling raw exploitable biomass indices to standardized estimates. This is because time-series trends within any given AD hold in all combinations of catchability conversions, and the effect size of any given vessel or area-specific conversion is small relative to a subsequent re-scaling adjustment applied to survey exploitable biomass estimates through a comparison with biomass estimates derived through fishery depletion estimations. Accordingly, no vessel or area-specific conversions were applied prior to re-scaling survey exploitable biomasses in this assessment, however for some qualitative analyses a vessel conversion factor was applied to the raw data collected from the Wilfred Templeman to aid in interpretation of trends.

Data north of 56 degrees latitude in Div. 2H are omitted because of consistently low capture of 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 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. To standardize data capture, only the right chelae of males were measured. A model which separated males into two data '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 and trap survey data combined, with trap survey data refined to those from the Fisheries and Oceans Canada (DFO) inshore trap series described below. For this analysis, proportions of 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 crab that had either just molted (were new-soft or new-shelled) or skip-molted (were adolescent male in intermediate or older-shelled condition or immature female in intermediate or older-shelled condition) to focus on the most recent molting outcomes with size-specific proportions of molt-type outcomes (terminal molt versus other[=adolescent/immature molt or skip-molt]) estimated in a binomial generalized additive mixed model (GAMM) defined as:

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

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

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

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

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

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

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

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

The pre-recruit abundance index was calculated based on all adolescent (small-clawed) males with 65–94 mm CW captured in the surveys. Theoretically, 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 of transition rate of crab into the fishery is further complicated by the presence of skip-molting, whereby not all identified pre-recruits will molt in the following winter or spring and their arrival into the exploitable biomass and fishery would be delayed even further. Skip-molting is most common in mid-large adolescent males in cold areas (Dawe et al. 2012) and under high population density conditions, whereby skip-molting is more common than terminally-molting for crab not undergoing a regular molt in any given year (Mullowney and Baker 2021).

The exploitable biomass indices derived through Ogmap were calculated from unstandardized raw survey data. However, it is known that catchability of crab by the survey trawl (i.e., trawl efficiency) is lower than 1, even for the most efficiently captured large males (Dawe et al. 2010a), and that raw survey biomass estimates are underestimated to variable extents across ADs relative to reality (Mullowney et al. 2017). Accordingly, the raw exploitable biomass estimates were scaled to values closer to 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:

$$đ = \sum_{y=2000}^{2019} (Ty/Dy * 1/n)$$

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 crab (<50 mm CW), were mapped and examined using catch rates for each survey set.

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

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

Relative size-specific proportions of adult male crab in the survey population were examined to qualitatively investigate fishing effects. For this analysis, crab were partitioned into 3-mm CW and two-year survey bins, with shell condition proportions plotted. A low level of intermediate to very old-shell crab in the population was inferred as representing the relative effects of fishing. Occurrence of advanced stages of Bitter Crab Disease (BCD), a fatal affliction and source of natural mortality, was noted in both sexes based on macroscopic examination in all trawl surveys. In cases of unclear external characteristics, crab were dissected and classified based on observation of the hemolymph (i.e., ‘blood’). Observation of cloudy or milky hemolymph supported the classification of such specimens as infected.

Finally, total annual mortality rates in any given year (A_t) were calculated based on stage-specific biomass indices of exploitable crab:

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

where,

B_{new} = recruitment (shell conditions soft, new)

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

t = denotes survey year

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

The 2019 multispecies trawl survey fall season experienced a significant number of un-fishable weather and sea conditions resulting in the most significantly impacted survey coverage of ADs 2HJ and 3K since the survey began in 1995. In 2019, 69% of allocated stations were completed in Div. 2H, 67% were completed in Div. 2J, and 49% were completed in Div. 3K (Figure 4). However, 100% planned coverage is rarely achieved in any given year. To investigate the effects of the reduced coverage on exploitable biomass indices, three approaches were considered:

1. Generation of 25 test datasets per AD with data from 1996 to 2018 reduced to mimic the 2019 survey coverage levels. Sets were randomly selected from strata according to the number of stations occupied per strata in the 2019 fall survey. Ogmap was executed on each test data set to calculate the EBI. The 25 test biomass indices were plotted against the 1995–2018 exploitable biomass indices generated for the previous stock assessment (baseline). The test and baseline EBIs were not adjusted using catch rate depletion model conversion factors as is presented in the assessment and associated documents; rather, raw exploitable biomass indices were used.
2. Calculation of percent (%) change between the baseline EBI and each of the 25 test dataset EBIs:

   $$\%\ change = \frac{EBI_{Test} - EBI_{Baseline}}{EBI_{Baseline}} \times 100$$

   The 25 test dataset % change points were plotted in a scatterplot against the average % change over the time series to determine whether the average deviated from a zero % change (no change between the test EBI and the baseline EBI).
3. Determined the minimum, median, and maximum catches in each strata from 2016–18 and replaced the missing sets from the 2019 survey with these values to generate a minimum catches, median catches, and maximum catches dataset. Ogmap was executed on these three datasets to calculate exploitable biomass indices. The 2019 EBI from the three datasets was plotted and compared to the 2019 EBI presented in the current assessment.

FISHERY LOGBOOK DATA

Data on commercial catch (kg) and fishing effort (number of trap hauls) were obtained from vessel logbooks. These data were compiled by the Statistics Division, Policy and Economics Branch, NL Region of DFO. Return of complete and accurate fishing logbooks is a condition of license in this fishery. Logbook return rates are calculated as the percentage of the fishery landings accounted for in the logbook data in comparison to landings recorded by the DMP. The dataset is normally most incomplete in the current assessment year (Figure 5), resulting from a time lag associated with compiling data from the most recent fishery, thus the terminal points are considered preliminary.

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

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

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

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

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

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

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

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

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

Standardized annual logbook CPUEs were mapped in 10’ x 10’ (nautical minutes) cells, encompassing the entire fishery distribution each year, and used to qualitatively assess spatial fishery performance within each AD. Further, time-binned (5-day increment) CPUEs were plotted for individual ADs and CMAs within each AD for a six-year timespan to assess fishery performance over a prolonged continuous timescale. The 5-day estimates were fit with least squares loess regression curves to visually depict changes occurring in the fishery over time.

Logbook data were used to adjust for survey-based exploitable biomass underestimates through catch rate depletion model conversion factors (đ) in each AD. The depletion analysis used 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 July in any given AD and year were omitted to control for small sample size effects potentially associated with atypical fishing practices such as high levels of searching at the beginning of the season, dumping of excess catches near the end of the season, or recruitment of exploitable males at the end of season. A linear mixed model was fit to log-catch rate versus cumulative effort (i.e., number of pots) data by AD and year, with the forecasted intercept used to calculate the beginning of the season biomass:

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

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

where,

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

pot_cum = cumulative number of pots

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

INSHORE DFO TRAP SURVEYS

Data were available from inshore trap surveys in ADs 3K, 3L Inshore, and 3Ps (Figure 6, Figure 7, Figure 8). In AD 3K, surveys were carried out in White Bay (CMA 3B), Green Bay (CMA 3C), and Notre Dame Bay (CMA 3D) during 1994–2019. There were no surveys in these bays in 2001, no survey was conducted in Notre Dame Bay in 2009 and 2011, and no survey was conducted in White Bay in 2019. The surveys have consistently occurred in late August to mid-September and occupy five of the depth strata developed for multispecies trawl surveys.

In AD 3L Inshore, long-term trap surveys within Bonavista Bay (CMA 5A) and Conception Bay (CMA 6B) have occurred from 1979 to 2019. 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 depth-stratified survey design with set locations randomly distributed within each stratum, and stratum-specific set allocations weighted by area. All surveys utilize large-mesh (commercial [135 mm]) and small-mesh (27 mm) traps intermittently placed within each ‘fleet’ of gear, with traps spaced approximately 45 m (i.e., 25 fathoms) apart. Each fleet includes six baited traps, with two additional end traps not baited. Squid (*Illex* spp.) hung on skivers is attached to the inner entry cone of each trap for bait, with approximately 2–3 pounds of squid on each skiver. Although soak times are intended to be standardized to 24–48 hours, weather and other factors can affect the surveys and soak times are ultimately variable. Biological sampling is conducted at-sea from all traps at each station. Sampling of males includes determination of CW, shell condition (same categories as trawl survey), determination of chela height, and presence of BCD. As per the trawl surveys, females are sampled from small-mesh traps for the same morphometrics as males, with examination of the abdomen rather than chela height used to determine maturity, and the relative fullness and stage of egg clutches estimated.

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

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

TORNGAT JOINT FISHERIES BOARD (TJFB) POST-SEASON TRAP SURVEY

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

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

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

COLLABORATIVE POST-SEASON TRAP SURVEY

Data were examined from an industry-DFO CPS trap survey in all ADs (Figure 9, Figure 10). These surveys were initiated in 2003 and have occurred each year following the fishery, typically beginning in early September and ending in November. They are conducted by Snow Crab harvesters accompanied by at-sea observers and historically focused on commercial (i.e., deep) fishing grounds within individual CMAs. Thus, at localized spatial scales these surveys are more vertically-limited than the multispecies trawl surveys in the offshore or the Inshore DFO trap surveys in select inshore CMAs. The CPS survey began transitioning to a partly random stratified design in 2017. In 2019, approximately 50% of survey stations were randomly allocated 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.

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

Stemming from the temporal and spatial inconsistencies and limitations in the distribution of small-mesh traps, indices are not available for all areas in all years. Furthermore, small-mesh traps have not adequately sampled small crab in some areas because the survey design focused near-exclusively on capturing exploitable crab and had limited sampling in shallow-water, which tends to be associated with small-crab distribution in many areas.

To address concerns about the limited utility of small-mesh traps in the survey, more small-mesh traps were incorporated in the 2016–19 surveys (Figure 10). Overall, more than half of the stations had a small-mesh trap in 2019. 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 2022.

Despite ongoing changes to the survey design most analyses remain virtually unchanged for the present assessment. Only core stations were used to develop catch rate indices of legal-sized crab by shell condition from large-mesh traps and size frequency distributions from large and small-mesh traps. The definition of core stations was established in 2018 to account for changing distribution in occupied stations over time. The definition of core stations was selected as those sampled in seven of the last 10 years, as of 2019. Catch rate indices of legal-sized crab by shell condition from large mesh-traps, large-mesh trap size frequency distributions by shell condition, and small-mesh trap size frequency distributions by maturity were produced for assessment. All analyses were limited to males, with sizes partitioned into 3-mm CW bins. However, unlike the five stage assessment of shell ages used on DFO 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 65–94 mm CW adolescent males) was also derived from small-mesh traps deployed at core stations.

The stratification scheme used for biomass estimation for this survey (Figure 3) closely conforms to the footprint of the fishery and by extension the assumed distribution of dense aggregations of exploitable crab within CMA boundaries. Spatial expansion of survey catch rates into biomass within polygons is conducted using a modified version of Ogmap (‘OgTrap’). OgTrap utilizes the same vertex points as Ogmap to integrate catch rates over any given spatial area. The input parameter of trawl swept area in Ogmap has been altered to conform to the effective fishing area of a crab trap, with the value set at 0.01 km^2. This effective fishing area parameter represents an intermediate value from estimates reported by Miller (1977), Brêthes et al. (1985), and Dawe et al. (1993). Nonetheless, because uncertainties remain regarding the accuracy of the effective fishing area parameter, as well as the extent to which the spatially biased stratification scheme represents the actual distribution of the resource, biomass estimates developed from this survey remain as indices and are assessed in a relative sense.

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

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

OBSERVER CATCH-EFFORT AND AT-SEA SAMPLING DATA

At-sea sampling data by observers have been collected since 1999. For each trip, observers sampled entire catches of males for CW (mm) and shell condition for as many traps as time allowed. Overall levels of sampling have been generally highest in AD 3LNO Offshore (Figure 11, Figure 12). Sampling has been consistently low in inshore CMAs and virtually absent throughout ADs 2HJ and 4R3Pn in recent years. Various catch rate indices were developed from shell condition staging conducted by observers. Like the three stage assessment of shell ages used in the post-season surveys, observers classify crab as soft, new, and old-shelled. The total catch rate of legal-sized crab by shell condition for each AD was calculated as an index of in-season exploitable biomass from the fishery. Similarly, size frequency distributions of catch rates of male crab by shell condition and size, binned to 3-mm CW intervals, were constructed to interpret the composition of the catch. Size frequency distributions were presented and examined at both the AD and CMA level where data were sufficient. Relative proportions of legal-sized crab by shell condition throughout the fishing season were also examined. For this analysis, crab were partitioned into 5-day increments with shell condition proportions plotted. This analysis provides a depiction of the timing of sampling throughout the fishing season and whether comparisons between years are representative.

Observer sampling data 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 crab measured during commercial fishing activities deemed to be discarded. A generalized linear mixed model (gLMM) was used to standardize discard percentages. The binomial model with a logit link function regressed raw data from observations of discarded weights from individual fishing sets:

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

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

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

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

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

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

Along with biological sampling to inform the stock assessment, observer data also form the basis of the soft-shell protocol. This management tool was implemented in 2004 to close specific small fishing areas offshore (10 x 7 na. mi.) and inshore (5 x 3.5 na. mi.) when the percentage of soft-shelled crab reaches 20% of the observed catch. The closure threshold was reduced to 15% for ADs 3LNO Offshore and 3L Inshore in 2009–2010.

ECOSYSTEM INDICES

Spring and fall bottom temperature climatological maps and 2019 observations and anomalies were determined using the methodology described and presented in Cyr et al. (2021). The changes in thermal habitat indices in each AD were examined to qualitatively assess Snow Crab productivity potential. The rationale being that increases in thermal habitat index indicate increases in potential Snow Crab habitat, and it is assumed that this improved habitat availability would accordingly increase Snow Crab productivity potential. The thermal habitat indices were calculated as the percentage of the surveyed area covered by water with a bottom temperature of <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 conducted by DFO Quebec region. Spring temperature indices are preferred because they are more closely associated with critical life history events in Snow Crab such as mating and molting.

A lagged index of the North Atlantic Oscillation (NAO) was compared with the trawl-derived EBI from ADs 2HJ, 3K, 3LNO Offshore, and 3Ps 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 throughout the ecosystem 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-year centred moving average of the annual NAO, which is calculated by averaging monthly values each year. For the ADs compared, a 7-year lag was applied to the NAO index prior to conducting cross correlations and comparisons with exploitable biomass index.

The centred 7-year lagged NAO index was used as an explanatory variable (standardized over the time series) along with ERI 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.

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

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

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

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

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

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

PRECAUTIONARY APPROACH

In June 2018, DFO Science held a CSAS Regional Peer Review process to develop a PA Framework for Snow Crab in the NL Region. The key objective of the meeting was to define LRPs consistent with the PA for Newfoundland and Labrador Snow Crab, based on the best scientific information available. DFO Science proposed a PA Framework for the NL Snow Crab resource and fishery (Mullowney et al. 2018b). The adopted parts of the framework include the LRPs, differentiating the Critical from Cautious Zones, and the Upper Removal Reference (URR). Harvest Control Rules (HCRs) and Upper Stock References (USRs) have been proposed but not adopted into the framework. The PA and decision-making framework is based on three key metrics of stock health:

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

LRPs, as set by the peer-review process, were identified as CPUE = 5 kg/trap, discards = 20%, and proportion of females with full egg clutches = 0.6. As USR points have not been established by fisheries management, 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:

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

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

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

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

where,

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

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

$NAO7$ = centered, lagged by 6–8 years index of annual NAO, calculated as annual mean NAO based on monthly data values before centering the 3-year average.

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

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

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

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

where,

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

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

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

AD = Assessment Division

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 HCR have been developed for the fishery. However, the proposed 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 estimate.

RESULTS AND DISCUSSION

BROAD-SCALE TRENDS: DIVISIONS 2HJ3KLNOP4R

Fishery

Landings for Divs. 2HJ3KLNOP4R increased steadily from 1989 to peak at 69,100 t in 1999, largely due to expansion of the fishery to offshore areas. Landings decreased by 20% to 55,400 t in 2000 and changed little until they decreased to 44,000 t in 2005, primarily due to a sharp decrease in AD 3K. In recent years, landings remained near 50,000 t from 2007 to 2015, but have since steadily declined to a 25-year low of 26,400 t in 2019 (Figure 13). Most of the landings are from ADs 3K and 3LNO (3LNO Offshore and 3L Inshore combined), but during the past 3 years AD 3LNO has accounted for a steadily decreasing percentage of the landings in response to quota cuts throughout the AD.

In AD 2HJ, landings have remained near 1,700 t for the past six years (Figure 14). In AD 3K, landings have remained relatively low for the past four years (6,000 t in 2019). In AD 3L Inshore, landings declined by 67% from a time-series high in 2015 to 2,750 t in 2019 and were 7% below the total allowable catch (TAC). In AD 3LNO Offshore, landings declined by 48% from 2016 to less than 13,000 t in 2019 because of reductions in the TAC, to the lowest level in two decades. In AD 3Ps, landings increased from decadal lows to almost 2,800 t in 2019, exceeding the TAC, which was set at 2,649 t. Finally, in AD 4R3Pn, landings have steadily declined since a recent peak in 2013 and were 186 t in 2019, 39% below the TAC.

Fishery timing transitioned from summer-fall to spring-summer throughout the 2000s in most ADs (Figure 15). In recent years, the fishery generally begins in early April for all but AD 2HJ, where it usually starts in early- to mid-May and reflects longer ice cover in the spring in this AD in many years. In 2019, median fishing weeks ranged from late-April in AD 3Ps to mid-June in AD 2HJ. There were earlier incidences in the timing of median fishing days in all ADs except 4R3Pn in 2019, mainly due to an earlier end of season. The large end-of-season spike in AD 3K in 2017 reflects a fall meat yield project that occurred during November.

Fishing effort, as indicated by estimated trap hauls, increased by a factor of five throughout the 1990s as the fishery grew (Figure 16). Overall effort remained at approximately 3.5–4.5 million trap hauls per year over that time, but decreased to under 3 million trap hauls in 2019, the lowest level in two decades. Spatially, the distribution of fishing has remained relatively broad-based, but there have been significant changes in some ADs in recent years (Figure 17). In the north, effort in the northernmost portion of AD 2HJ has gradually dissipated since 2011, with NAFO Div. 2H virtually abandoned in the past eight years. In recent years, effort in AD 2HJ has remained at a consistent low level of about 200,000 trap hauls per year. In AD 3K, effort decreased to a 25-year low in 2019, with about 600,000 trap hauls and has contracted primarily into the Funk Island Deep and areas west. The furthest offshore portions of this AD appear to have been abandoned. In AD 3L Inshore, effort nearly doubled from 2013 to 2017, when it reached a historical high of 1 million trap hauls. In 2019, effort decreased again to about 500,000 trap hauls. In AD 3LNO Offshore, effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level since then, at an estimated 1.5 to 2.5 million trap hauls per year. However, effort decreased in 2019 to about 1.1 million trap hauls. Effort along the NAFO Div. 3N edge has been decreasing in recent years, with very low fishing activity in 2019. In AD 3Ps, effort has declined by about 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 and was at a 25-year low in 2019, with about 35,000 trap hauls.

Fishery CPUE tends to lag behind survey biomass trends by 1–2 years in all ADs, thus the fishery is typically delayed in reflecting stock status, indicative of hyperstability in the CPUE index. Throughout the past 25 years, CPUE (kg/trap) has shown a great deal of variability both across and within ADs, except in AD 4R3Pn where it has remained relatively constant and low relative to other ADs (Figure 18).

Overall, the fishery performed poorly in 2017 and 2018, with CPUE at a historical low. In 2019, the overall CPUE increased back to previous historical lows. In AD 2HJ, standardized CPUE has remained near the decadal average in recent years (Figure 18). In AD 3K, standardized CPUE increased in 2019 from a time-series low in 2017 to near the time-series average. In AD 3L Inshore, standardized CPUE had declined by 68% from 2013 to 2018 to below 5 kg/trap, its lowest level in the time series, but increased slightly to around 5 kg/trap in 2019. With the exception of 2018, this is a time-series low. In AD 3LNO Offshore, standardized CPUE most recently peaked near a time-series high in 2013 and declined to its lowest level since 1992 in 2018. AD 3LNO CPUE increased in 2019, but remains near a historic low level. In AD 3Ps, standardized CPUE increased from time-series lows in 2016 and 2017 to well over 5 kg/trap in 2019. Finally, in AD 4R3Pn, standardized CPUE has increased from a low in 2018 to near time-series average in 2019.

In recent years there has been considerable spatial contraction of high levels of fishery CPUE (Figure 17). 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 some high catch rates (>15 kg/trap) remain in northern offshore portions of AD 3LNO Offshore, there have been notable declines in recent years. For example, catch rates along the Div. 3N slope edge decreased markedly in the past six years while localized aggregations of effort in shallow portions of the western Grand Bank have performed relatively poorly since 2010. Some areas of AD 3L Inshore (CMAs 6B, 6C and 9A) have shown dramatic declines in CPUE in the past four 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 and even more so in 2019. In AD 3Ps, the decline in fishery CPUE had been both precipitous and broad-based from 2010 to 2017, however, all major fishing areas had improved catch rates in 2018 and 2019. In AD 4R3Pn, catch rates in the offshore have been perpetually low and effort in 2019 was particularly sparse. All inshore bays have yielded catch rates in the order of 0–10 kg/trap over the past three years.

Overall, the combination of landings, spatial patterns, and spatial distribution of catch rates from the various sources of fishery data suggest the fishery remains strongest in an aggregated area along the northern Grand Bank in AD 3LNO Offshore, with improvements in 2019 in ADs 3K, 3Ps, and some localized areas in 3L Inshore.

Observer data on shell composition are used to infer dynamics of recruitment into the biomass. These data indicate that although the improvement in fishery CPUE in AD 2HJ in 2015 was predominately due to an increase in recruitment into the exploitable biomass, the proportion and magnitude of new-shelled crab decreased dramatically in 2016 and 2017. In 2018, the presence of both soft-shelled crab and residual crab in the fishery increased, but there was a large decrease in residual crab in 2019 (Figure 19, Figure 20, Figure 21). However, the level of observer sampling was very low in AD 2HJ in 2018 and it is likely the increase in 2018 is not a true representation of catch rates and composition that year. The AD 3K fishery has observed overall catch rates of both residual crab and recruits at a consistent low level since 2008, however, increases were observed in 2019. In ADs 3LNO Offshore and 3L Inshore, the compilation of recruitment and the residual biomass (old-shelled crab) were at a time-series low in 2018, however, slight increases in recruits were observed in both ADs in 2019. In AD 3Ps, both the recruitment and residual components of the biomass observed in the fishery decreased by more than half from 2011 to 2017. In 2018, a sharp increase in the observed catch rates of recruits occurred, indicating a strong recruitment pulse entering the system, followed by an increase in residuals in 2019. Observer coverage was extremely low in AD 4R3Pn in 2019 and the catch rates and composition are very likely not representative of the resource in that AD.

Biomass

The fishery has strongly depleted the exploitable biomass in all ADs in recent years (Figure 22, Figure 23). With the exception of ADs 3Ps and 4R3Pn, end of season catch rates remained among the lowest observed levels in 2019.

In AD 2HJ, depletion rates were relatively consistent from 2014 to 2018, however, there was much quicker depletion in 2019, with an end of season catch rate the lowest in six years (Figure 24). This is particularly disconcerting given the contraction of the fishery back into the two dominant centres of the Hawke and Cartwright Channels. In AD 3K, the 2019 fishery began at the highest catch rates since 2010, but it quickly and precipitously depleted the biomass (Figure 25). In AD 3L Inshore, there was little depletion evident from 2011 to 2013, but deterioration has occurred since, to the extent that the 2019 fishery began near its lowest level and ended at its lowest level in the time series, with precipitous depletion throughout the season (Figure 26). 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. In 2019, the depletion was not as drastic as the previous year, with an end of season catch rate higher than in 2018 (Figure 27). In AD 3Ps, rapid depletion under minimal removals occurred in 2016 and 2017, but minimal depletion was noted in 2018 and none occurred in 2019, with both start and end of season catch rates near the highest recorded in several years (Figure 28). Finally, in AD 4R3Pn, the 2017–19 linear regression slopes were extremely steep, indicative of a rapid depletion of the biomass. However, the start of season catch rate in 2019 was higher than in 2018 (Figure 29).

Overall point estimates of biomass calculated from fishery depletion regressions were at or near time-series lows in all ADs in 2019 (Figure 30), with the exception of AD 3Ps where a point estimate was not calculated due to no seasonal depletion. Nonetheless, overall, the broad-based scenario is one of the fishery becoming an increasingly dominant factor contributing to reduced exploitable biomass.

Investigation into the effect of the reduced fall multispecies coverage in ADs 2HJ and 3K (Figure 4) on EBI estimation found it very likely that the 2019 estimates were inflated, particularly in AD 2HJ, compared to estimates from previous assessments. Comparison of the 25 test dataset estimates to the 2018 assessment (baseline) estimates in AD 2HJ found most of the test dataset exploitable biomass estimates to be higher than the baseline estimates, but within the baseline 95% confidence intervals (CIs) (Figure 31). In AD 3K, the test dataset estimates were more variable throughout the time series and in some years outside the baseline CIs (Figure 32). Calculation of the percent change between the EBI from the test datasets and the baseline show the test dataset EBI to be about 12% greater than the baseline EBI in AD 2HJ and 3.6% greater in AD 3K (Figure 33). Comparing the baseline EBI to the minimum, median, and maximum catch dataset exploitable biomass estimates found the baseline estimate to lie between the maximum catch and the median catch estimates in both ADs 2HJ and 3K, with the median catch estimate being very close to the minimum catch estimate (Figure 34). Due to lack of certainty in the extent of potential biomass estimation in ADs 2HJ and 3K, no adjustments were made to the 2019 exploitable biomass indices, but corroborating evidence is highlighted throughout this document.

Multispecies trawl surveys indicate that the overall exploitable biomass was highest at the start of the survey series (1995–98) (Figure 35). The index declined from the late 1990s to 2003 and then varied without trend until 2013. From 2013 to 2016, the exploitable biomass declined by 80%. Modest increases have been observed in the trawl survey EBI from 2017 to 2019. Meanwhile, the trap survey index has declined by nearly 60% to a time-series low in 2018, with a slight increase in 2019, and overall fishery CPUE also increased slightly in 2019 from a two-decade low in 2018 (Figure 35). The low in exploitable biomass in recent years reflects diminishing contributions of recruitment into it, to time-series low levels, but concomitantly and more strongly reflects the elimination of virtually all the residual biomass in some areas. In 2019, there were increases in the residual biomass, however the exploitable biomass is still dominated by recruits.

The overall low exploitable biomass level in recent years was coupled with concentration of it into localized areas in all ADs (Figure 36, Figure 37). However, despite this contraction, there were signs of some localized improvements in 2019. Particularly noteworthy are the increased survey catch rates throughout the northern and eastern portions of Div. 3L in the fall survey and the eastern portion of Div. 3L in the spring survey. As well, the fall and spring surveys showed notable catches of exploitable crab along the eastern edge of Div. 3N, where there have not been signs of exploitable crab since 2015. The overall patterns of prolonged deterioration and modest improvements seen in trawl surveys from 2017 to 2019 are generally reflected by patterns seen in trap surveys (Figure 35). It is expected that with the CPS survey undergoing a transition in survey design in recent years, more holistic trends in spatial distribution of population components including the exploitable biomass will be more apparent as the time series builds.

Overall trends in trawl and trap survey exploitable biomass indices mask spatiotemporal variability among ADs (Figure 38, Figure 39), as well as potential confounding factors occurring within any given area. In AD 2HJ, the EBI has changed little during the past 15 years and persistently consists of very low residual biomass. Despite consistency across the two surveys, stock status interpretation is compromised by incomplete trap surveys during the past three years and reduced coverage of the fall multispecies trawl survey in 2019. The 2017–19 point estimates from the CPS trap survey in AD 2HJ are considered incomplete due to incomplete and improperly collected data; large proportions of data were not collected properly and therefore unavailable for analyses and many core stations were not surveyed. In AD 3K, an increase in the EBI was seen in the trawl survey, however there was reduced coverage of the fall multispecies trawl survey in AD 3K in 2019 primarily affecting the areas of traditionally low crab biomass, which may have resulted in an overestimation of the exploitable biomass. This increase is not reflected in the trap survey, which may be due to exclusion of a key Snow Crab area in the trap survey in 2019 (just south of the 2J/3K boundary). In AD 3L Inshore, the exploitable biomass is severely depleted in some areas. The trap survey EBI remained near a time-series low in 2019, with some areas of the AD particularly low. There were some signs of improvements in this AD in the Inshore DFO trap surveys in 2019, with spatial expansion of high catch rates specifically in Bonavista Bay, Trinity Bay, and St. Mary's Bay (Figure 7). In AD 3LNO Offshore, the trawl-derived EBI showed a further increase in 2019, however the trap-derived EBI showed a larger, albeit modest, increase and remains near the time-series low. In AD 3Ps, the trawl and trap survey exploitable biomass indices showed conflicting signals in 2019, with a similar level as 2018 in the in-season trawl survey and an increase in the post-season trap survey index. However, the increases in exploitable biomass in the trap survey appear localized to the major fishing grounds. Finally, in AD 4R3Pn, the EBI is low in 2019, with few residual crab seen in the survey population. The trap survey EBI in AD 4R3Pn most recently peaked in 2012 and declined to a time-series low in 2017. The index increased in the past 2 years, reflecting localized improvements.

Although almost 50% of the sampling locations were randomly determined in 2018 and 2019, 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 EBI closely agrees with fishery CPUE, reflecting the occupation of like grounds with like gear (Figure 40). The concentrated distribution on strongest aggregations of exploitable biomass in the CPS survey and fishery creates the potential for hyperstability in indices derived from both sources. The spatially all-encompassing trawl survey generally detects changes in the biomass prior to them being detected in the CPS trap survey or fishery (Figure 40, Figure 41). This lag between measuring signals of change in biomass among metrics likely reflects the inclusion of marginal grounds in the trawl survey, where, operating under an assumption of some degree of density dependent regulation, signals of change in stock size would be expected to occur first. Further, the trawl survey is also not subjected to gear saturation, as occurs in crab traps. Differences in spatial representativeness and gear catchabilities across surveys and the fishery lead to trap CPUE signals temporally lagging behind trawl survey indices and exhibiting overall little dynamic range in catch rates when biomass is high. This can be particularly problematic when a resource is declining and underscores the importance of establishing and maintaining well-designed surveys for this resource assessment.

Trap saturation is an important concept for managers and harvesters to understand in their perceptions of resource status (Mullowney et al. 2018b). Hyperstable CPUE in trap-based biomass indices constitutes a mechanism to mask changes in stock size and should be more fully examined in future research initiatives.

Collectively, the three survey and fishery metrics are consistent in showing an exploitable biomass that has shown some improvements, but virtually all information consistently indicates that the biomass remains near historic lows. The index with most predictive power (the trawl survey) suggests potential for improvements within some ADs and consequently the fishery of 2020.

Recruitment

Overall recruitment into the exploitable biomass has been very low in recent years and survey data suggest recruitment available to the 2020 fishery will remain low in most ADs. This is particularly evident by the low biomass of new-shelled crab in trawl surveys in some ADs relative to earlier in the time series, even though the exploitable biomass is presently dominated by incoming recruits (Figure 35, Figure 38).

In AD 2HJ, recruitment into the exploitable biomass has changed little during the past 15 years (Figure 38). The 2019 trawl survey suggests recruitment will remain unchanged in 2020. This suggests little change in fishery prospects for 2020. In AD 3K, the post-season trawl and trap survey indices of recruitment into the exploitable biomass have shown some slight increases in 2019 (Figure 38, Figure 42), suggesting potential for improvement in the fishery in 2020. 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 recent years, but increased slightly in 2018 and 2019. This suggests better prospects for the 2020 fishery. In AD 3Ps, there were conflicting signals in the trawl and trap surveys, with the trap survey showing a larger increase. Recruitment into the exploitable biomass was near a decadal high in 2018 and 2019, with the exception of Fortune Bay. Due to the conflicting signals between surveys, there is uncertainty surrounding the degree of improved prospects for the 2020 fishery in AD 3Ps.

For ADs where no trawl surveys occur, trap-derived indices are used. In AD 3L Inshore, recruitment into the exploitable biomass steadily declined to a time-series low in 2017 and recruitment indices from DFO and CPS trap surveys showed some increases in 2019 (Figure 42). The increase in recruitment within AD 3L Inshore is localized, and not seen across the entire AD. This suggests any improvements in the fishery in 2020 may not be widespread. In AD 4R3Pn, recruitment into the exploitable biomass was low from 2014 to 2017; however, survey data from 2018 and 2019 suggest localized improvements may occur in 2020.

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 35, Figure 38, Figure 43). In reality however, the proportion and rate of the 65–94 mm CW adolescents measured by these surveys that reach exploitable biomass depends on several factors including mortality, skip-molting incidence, and the size at which crab terminally molt. The overall abundance of pre-recruits in the stock increased to near or above the time-series average in 2019. This largely reflects trends in the largest AD (3LNO Offshore). The distribution of pre-recruit crab follows that of exploitable crab closely and changes seen in exploitable crab distribution are reflected in the pre-recruits as well (Figure 44, Figure 45). Both surveys are suggesting the potential for localized improvements of recruitment into the exploitable biomass in forthcoming years, with the notable exception of AD 2HJ. Although there was a decrease in AD 3Ps, the pre-recruit abundance index remains at a high level for the time series. Potential for localized improvements of recruitment are suggested by increased abundance of pre-recruits in the trap surveys in ADs 3K, 3L Inshore, 3LNO Offshore, and 4R3Pn. The scenario of low exploitable biomass levels in these ADs coupled with increased potential of recruitment into the biomass suggests soft-shell crab incidence may be high in the fishery in some areas over the next couple of years if protective measures to ensure efficient transition of these crab into the exploitable biomass are not taken.

The relatively low abundance of young crab (<50 mm CW) since the early 2000s (Figure 35, Figure 46), suggest overall weak recruitment potential in the long term relative to levels experienced in the mid-to late-1990s. The pulse of small crab that emerged in the trawl surveys in 2013–14 (Figure 35) was largely localized to ADs 2HJ and 3K (Figure 46). Slight increases in the abundance of small crab in the population in 2017, and more so in 2019, were most pronounced in ADs 3K and 3LNO Offshore. Recent abundance levels of small crab are generally not nearly as large as historic pulses. For example, the spring trawl surveys showed a relatively high level of small crab in AD 3Ps in 2010 that is almost certainly associated with marked improvements in new-shelled recruits in 2017–19 in that AD (Figure 38). Unfortunately, there has been a relatively steady-state broad distribution of low catch magnitude of these small crab in AD 3Ps for the past seven years (Figure 46), inferring weak prospects after the currently emerging pulse of recruitment benefits the exploitable biomass and fishery over the next few years. The spike in small crab abundance seen in the 2010 survey in AD 3LNO Offshore is likely beginning to contribute to the exploitable biomass in that AD in the last couple years (Figure 46, Figure 38). Both the trawl and trap surveys have shown modest improvement of recruitment into the exploitable biomass in AD 3LNO Offshore (Figure 38, Figure 42). The distribution of small crab has not contracted in recent years to the same extent seen in exploitable crab (Figure 47, Figure 48) with small crab still caught in most of the same areas despite generally lower catch magnitudes relative to the early part of the time series.

Females

The management regime of the NL (and most other commercially harvested Snow Crab 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 35), it has overall been variable throughout the time series in all ADs (Figure 46). Despite this variability, like most other components of the population, the relative abundance of mature females has remained near time-series lows in most ADs in recent years, with slight increases in 2019 in ADs 3K, 3LNO Offshore, and 3Ps. The time series of mature female abundance has been particularly variable in AD 2HJ.

The spatial distribution pattern observed in recent years is typical of a dominant shallow water presence of mature females (Figure 49, Figure 50). 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 49). AD 3Ps is overall the shallowest of all ADs, with females typically concentrated in the central portions of the AD near the fringes of the St. Pierre and Green Banks (Figure 50). These shallow areas, where the majority of reproduction occurs, are typically very cold. Mullowney et al. (2018a) described winter and spring breeding migrations of female and male crab into shallow water along offshore parts of the NL shelf, a behavior known to occur in some inshore bays for decades.

The sporadic capture of females by the 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 51, Figure 52), 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 46).

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

Environment

Overall, virtually all population components remain at low levels in all ADs in 2019 (Figure 51, Figure 52), however some ADs are showing improvements. This suggests that the stock had been in an overall unproductive state for much of the past decade, but productivity may have been improving in recent years. Bottom temperature has been shown to relate positively on size and negatively on abundance in regulating stock productivity and ultimately biomass. Cold bottom temperatures appear to promote terminal molt at small sizes in Snow Crab, resulting in relatively low recruitment and yield-per-crab from a given year class (Dawe et al. 2012). This outcome appears particularly applicable under low population densities of large males (Mullowney and Baker 2021). However, recruitment is more strongly affected by the positive effects of cold environmental conditions on year class production (Dawe et al. 2008, Marcello et al. 2012) than it is by the negative effects of cold conditions on size-at-terminal molt. This is consistent with positive benefits of cold conditions in promoting early-mid-life survival and subsequently increased densities of crab in the population.

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. Cold bottom temperature conditions have been experienced between the mid-1980s and the mid-1990s, and from about 2012–17. The recent (modest) emergent pulse of small crab observed in many areas of the NL shelf has been associated with generally cooling oceanographic conditions in those recent years (Cyr et al. 2021).

Spring and fall bottom temperatures were generally warmer in 2019 than the 1980–2010 reference period (Figure 53). The Snow Crab thermal habitat index (defined as the areal extent of <2°C bottom water) has returned to near-average conditions in most ADs in recent years, with the exception of ADs 2HJ and 3K (Figure 54). 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 crab, expectations for the future should be tempered as climatic conditions are still relatively warm (Cyr et al. 2021). The ocean climate indices have varied considerably over the past decade, introducing uncertainty beyond the short term, but the overall trend is warming. 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 warming conditions are sustained, although it is unclear how environmental, anthropogenic, or other factors such as predation will affect the survival and progression of recruitment pulses throughout life.

Bottom temperature may not be the only climatic factor important for Snow Crab productivity. A strong association of exploitable biomass with lagged NAO (atmospheric forcing index) was demonstrated (Figure 55). 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), other climatic factors such as sea ice, bloom strength, water mixing, food availability, or predator field dynamics may affect Snow Crab survival during early ontogeny. 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 for which there was data (Figure 56). The lagged NAO analysis predicts that the exploitable biomass should enter into a recovery phase over the next few years, to levels near or above average for the biomass time series (Figure 55). However, the recent positive NAO phase did not translate into bottom conditions as cold as observed in the early-1990s which appeared to create favourable conditions for young stages of crab.

It is unclear if or by how much potential forthcoming climate-predicted improvements will be affected by the fishery. In a review of stock drivers, Mullowney et al. (2014) warned that the fishery had the potential to take stronger control of stock productivity dynamics if exploitation rates were allowed to elevate during the predicted low biomass phase. This ‘test’ of stock drivers is currently occurring, with exploitation rate indices being allowed to increase to exceptionally high levels in some ADs in recent years. Until the past few years, following a regime shift culminating in a collapse of most of the finfish community in the late-1980s and early-1990s (Buren et al. 2014), the Snow Crab resource appears to have largely been under bottom-up control, in association with low exploitation rates in the largest areas of abundance (i.e., AD 3LNO Offshore). However, recent assessments have highlighted that other factors such as top-down forcings from heavy exploitation and increased predation have increased in importance. Notwithstanding incomplete resolution on the extent to which high exploitation rates will affect forthcoming recovery, the recently increased reductions in size-at-maturity in males (see size-at-maturity section below for details) can only serve to reduce the proportion of animals progressing through size and dampen forthcoming recruitment. If quota decisions follow CPUE more closely than survey biomass, in a relative sense the lagged signal of CPUE in reflecting stock size promotes over-exploitation when the biomass is in decline and under-exploitation when the biomass increases. Recent high exploitation rates across all ADs are a direct result of quota reductions not matching the scale of biomass declines, and unintended consequences such as reductions in size-at-maturity in males can undoubtedly interfere with environmental regulation of the resource.

Besides exerting a direct impact on early-life survival, climate shifts could affect Snow Crab productivity via other routes such as predation. A general prolonged shift toward warmer conditions throughout the 2000s appears to have affected the Snow Crab resource in the form of increased predation in recent years (Figure 57) 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 were observed in all ADs by 2019. These dramatic declines in relative predation levels are likely the result of a combination of recent declines in predatory fish abundance, as well as the most recent pulse of small crab now outgrowing sizes consumed by most predators (i.e., <40 mm CW)

(Chabot et al. 2008), as inferred by increases in some pre-recruit indices in recent years. Important differences are evident in overall magnitude of predation mortality across ADs, with ADs 3K and 3Ps having predation levels much higher than other areas.

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

Mortality

The overall trajectory of most focal population components has been a prolonged decline of abundance indices for two decades in all ADs (Figure 58). 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 crab was very high in all ADs during 2015–17 (Figure 59). There are no indices of total mortality for ADs 3L Inshore and 4R3Pn as this calculation relies on trawl survey data.

In AD 2HJ, total mortality declined slightly in 2018, with a further decline in 2019 (Figure 59). In AD 3K, total mortality was at its highest level for the past three years, however, it declined in 2019. The trends in total mortality indices in ADs 2HJ and 3K are likely influenced by crab movements across the divisional boundary. In the previous assessment (Baker et al. 2021), evidence was presented suggesting the possibility that recruits from AD 3K may have moved into southern portions of AD 2HJ as residual crab in 2018. In 2019, there are no indications that this has persisted and therefore the calculation of total mortality based on present residual crab and previous recruits and residuals indicates a very low total mortality in AD 3K. Such issues have the potential to affect stock status interpretations and indicates the stock may be assessed at inappropriate spatial scales. In AD 3LNO Offshore, total mortality declined from its highest observed level in 2016 to a time-series low in 2019. Finally, in AD 3Ps, total mortality in exploitable crab has varied considerably throughout the time series, but the three-year moving average remained low in 2019. The high variability in the total mortality index in AD 3Ps likely reflects the shell condition-based methodology, with a spring survey potentially affecting the subjective shell condition classifications.

Recent trends in total mortality are more closely aligned with fisheries mortality than known and quantified sources of natural mortality. BCD is one important source of consistently measured natural mortality in the population. BCD has been observed, based on macroscopic observations of crab captured in the fall trawl surveys, at generally low levels throughout NAFO Divs. 2J3KLNOPs from 1995 to 2019 (Figure 60). The prevalence and distribution of this parasitic affliction throughout the NL Shelf has been described in detail by Dawe (2002) and appears related to circulation features (Dawe et al. 2010b) and the density of small crab (Mullowney et al. 2011).

BCD, which is fatal to crab, occurs primarily in new-shelled crab of both sexes and is most commonly acquired during molting (Dawe 2002). Although the macroscopic analyses used to classify crab as infected are known to underestimate true prevalence, and trawl survey sample populations show lower levels of BCD than trap survey sample populations, a study using advanced polymerase chain reaction (PCR) techniques on specimens collected since the mid-2000s to identify infections has shown trends closely reflect the visually observed patterns seen throughout the region (D. Mullowney, 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 60). BCD is normally most prevalent in AD 3K, however, in 2019, BCD was not detected in the fall trawl survey in the two large size classes of crab, and only at low levels in the two smallest size classes. Recent years had seen levels of BCD of more than 10% in sizes >94 mm CW in AD 3K. BCD is normally uncommon in AD 3LNO Offshore, but a prolonged pulse of relatively high incidence was observed in this AD from approximately 2001–06, most prominent in 40–59 mm CW crab. This sustained pulse of BCD likely reflected progression of the recruitment pulse detected in the trawl surveys as 20–30 mm CW crab in 2001–03 (Figure 51, Figure 52), which was subsequently tracked as pre-recruits in surveys from 2008 to 2010 (Figure 58).

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

Beyond direct removals of crab from the system, the fishery also imposes mortality on Snow Crab through discarding. Crab that are caught and released as under-sized or legal-sized soft-shelled males are subject to multiple stresses and have unknown survival rates. Time out of water, air temperature, water temperature, wind speed, sunlight, shell hardness, and crab size may all influence the mortality level on discarded Snow Crab (Miller 1977, Dufour et al. 1997, Grant 2003, van Tamelen 2005, Urban 2015). Soft-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 study in the Bering Sea, Urban (2015) predicted only about 5% mortality on discarded Snow Crab. This estimate is virtually identical to the estimate of Grant (2003) in NL for Snow Crab subjected to best handling practices, specifically in the form of minimal dropping distances and exposure time on deck. However, Grant (2003) showed that mortality rates increased substantially under poor handling practices. It must be noted that both studies featured predominately hard-shelled crab and both authors cautioned that unobserved latent mortality was unaccounted for in their studies. Despite not explicitly knowing discard mortality rates, minimizing fisheries induced mortality and wastage of crab not retained in the fishery (particularly most vulnerable soft-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 recent low biomass.

Particular concern is expressed on the current situation in ADs 2HJ and 3L Inshore, where discard levels are currently very high at approximately 40% of the catch (Figure 61). In AD 2HJ, this represents a substantial increase in discards compared to 2018, when discards represented less than 20% of the observed catch, while in AD 3L Inshore discard levels were at the similar level in 2018. At-sea observer sampling data suggest that the discards in AD 2HJ are comprised of mostly legal-sized soft-shell crab, while the bulk of discards in AD 3L Inshore are under-sized, old-shelled crab (Figure 62). Accordingly, relative levels of resource wastage in the form of discard mortality are likely highest in the AD 2HJ fishery, assuming survival is lowest in soft-shell crab.

Discard levels in the fishery are negatively related to CPUE (Figure 63) (Mullowney et al. 2018b). This likely reflects competition for baited pots, with the catchability of less competitive crab (both under-sized and soft-shelled) increasing when the exploitable biomass is relatively low. The relatively low level of residual biomass (old-shelled adult crab) 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, suggest that wastage of soft-shelled pre-recruits could be problematic in the fishery in the next few years in some ADs, and potential gains could be quickly diminished if aggressive harvest strategies in the form of high exploitation rates persist.

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

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

Soft-shell incidence has featured relatively prominently in the observed catch in ADs 2HJ and 3K in recent years (Figure 62). 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 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 (3K, 3LNO Offshore) are associated with reduced total mortality rates and associated reductions in exploitation rates, while ADs remaining at low levels with little signs of recovery (2HJ) are associated with persistent high total mortality and exploitation rates (Figure 59). Evidence suggests that reducing exploitation rates constitutes an effective strategy toward promoting recovery of the exploitable biomass. This is further bolstered by the presence of stronger residual components to the exploitable biomass in less heavily exploited areas. Generally, maintaining high catch rates is a good management strategy to avoid high discarding (Figure 64).

In AD 2HJ, the exploitation rate index has been at or above the long-term average for the past four years (Figure 59) and the long-term average here is higher than in any other AD. The ERI averaged 67% during 2016–19. Status quo removals in 2020 would maintain the ERI at this high level. In AD 3K, the ERI declined from a decadal high in 2017 to near time-series average levels in 2019. Under status quo removals in 2020 the ERI would decrease to a time-series low. In AD 3LNO Offshore, the exploitation rate index increased by a factor of five from 2014–17, but decreased in 2019 to near time-series average levels. The ERI would decline slightly with status quo removals in 2020. In AD 3Ps, the exploitation rate index was near its lowest observed levels in the time series in 2018 and 2019. Projections are hampered because the survey is conducted in the spring, but status quo removals would result in the exploitation rate index being at the same low level in 2020. Since these projections have limited applicability, the ERI from trap surveys was also reviewed. This trend also projects low exploitation rates under status quo landings in 2020 (Figure 65).

There are no trawl-based biomass indices available in ADs 3L Inshore and 4R3Pn from which to calculate exploitation rate indices. Accordingly, the shorter time series of trap surveys are used as the basis (Figure 65). In AD 3L Inshore, the overall trap survey-derived ERI increased to its highest observed level in 2018, but decreased in 2019 closer to the time-series average. The decline in ERI does not reflect quota control but resource limitation. Quotas have been non-prohibitive in many areas and if recent quotas were fully taken the ERI would be higher. Status quo removals would decrease the ERI to a time-series low in 2020. In AD 4R3Pn, the overall ERI declined to near the time-series low in 2019. Status quo removals in 2020 would further decrease the exploitation rate index.

Recent exploitation rate indices in the NL Snow Crab fishery are overall very high relative to other major fisheries for the species in Atlantic Canada and Alaska. For example, exploitation rates above 45% are not permitted under the PA frameworks used to manage the Snow Crab fishery in the southern Gulf of St. Lawrence, even when the biomass is extremely high (DFO 2014b). In NL, conservative (i.e., likely under-estimated) estimates of fishing exploitation rates are routinely >50% and can be as high as 80% in some ADs in some years. Of particular note, the lack of old-shelled 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-wholly relying on incoming recruitment each year is risky with respect to the possibility of unforeseen events to affect recruitment. Moreover, experience has shown that areas with low residual biomasses are generally associated with wasteful practices and recruitment over-fishing, with soft-shell prevalence and discard rates generally high in the presence of high exploitation and low residual biomass.

Beyond promoting risk and wastage in the fishery, high exploitation rates greatly increase the potential for negative biological outcomes in the population. There has been an inability for fisheries to take quotas in some ADs in recent years. Accordingly, in several areas it is possible for fisheries to capture almost all available exploitable males in a given year. The strategy of removing most large males from the population could have serious consequences such as sperm limitation in females or changes in growth patterns or maturation sizes if this heavy exploitation is sustained. Large hard-shelled males are the prime breeders and likely serve to introduce sufficient intraspecifc competition in the population to promote large size-at-terminal molt. As in many animal populations, large competitive males serve to maintain reproductive integrity as well as physically structure population demographics. The outcomes of the unfolding scenario of rendering the population virtually void of large males in some areas will be important to continue to monitor from biological and managemement advice perspectives. Overall, the scenario of a low exploitable biomass coupled with high exploitation rates suggests a relatively low likelihood of any appreciable long-term gains in some ADs. This scenario is most apparent in AD 2HJ where exploitable biomass is low and exploitation rates remain high. However, improved signals of recruitment potential (Figure 66, Figure 67, Figure 68) as well as decreasing exploitation rates (Figure 59, Figure 65) in most other ADs should result in forthcoming gains if fisheries-induced mortality is not excessive in the next few years. Biologically, recent works have verified that it is safest to maintain a high residual biomass component of the exploitable male population if biological harm through fishing is to be avoided (Mullowney and Baker 2021) and recruitment overfishing minimized (Mullowney et al. 2021).

Size-at-maturity

A sharp decline in male size-at-maturity (i.e., size-at-terminal molt) occurred in all major ADs in recent years. However, all ADs showed increases in male size-at-maturity in 2019, albeit it is still at a low level in ADs 2HJ, 3K, and 3L Inshore (Figure 69). These results suggest 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 most ADs in recent years. However, it should be noted that concerns have been raised that the data presented herein could be confounded due to originating from mixed sources (trawl and trap surveys) and that future work is aiming to investigate if gear catchability biases could affect outcomes.

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

Precautionary Approach

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 70). Data from both the fall and spring surveys throughout Divs. 2HJ3KLNOPs show that in nearly all years the vast majority (i.e., >80%) of mature females are carrying full clutches of viable eggs. In 2019, all ADs were in the healthy zone for egg clutches.

Although it is believed that per capita fecundity can be impacted by excessive fishery exploitation of males, it has not been persistently observed to date in NL Snow Crab.

However, some notable exceptions have occurred in the clutch fullness index in all ADs. Low percentages of clutch fullness were observed in AD 2HJ in 2006 and 2007, in AD 3K in 2015, in AD 3LNO Offshore in 2013 (note uncertainty in 2014 due to incomplete survey) and in AD 3Ps in 2014–16. With no broad-scale prolonged periods of low clutch fullness presently, the overall evidence suggests that the species may maintain a high level of reproductive resiliency to historic levels of fishery exploitation. To benefit management by assessing the extent to which high exploitation rates can be sustained before unwanted changes or harm is caused to the resource, investigations into possible top-down fishery effects in light of current high exploitation rates on males in most ADs are warranted. This includes more in-depth monitoring of female insemination levels.

Discards levels, assuming status quo removals, were predicted to be within the proposed cautious zone for all ADs in 2020, with the exception of AD 3LNO Offshore, where they were predicted to be in the healthy zone (Figure 70).

In 2020, assuming status quo removals, CPUE is predicted to be in the healthy zone in AD 3LNO and cautious zone in all other ADs (Figure 70).

Together, following a guiding rule of assessing stock status as being in the lowest of three zones across the three metrics, the assessment indicates that all ADs, except AD 3LNO Offshore are predicted to be in the proposed cautious zone, while AD 3LNO Offshore is predicted to be in the proposed healthy zone in 2020 (Figure 70). However, the PA and harvest control rules, including those pertinent to addressing the relative importance of each metric in overall stock status assessment, remain in development and therefore cannot be implemented in the 2020 fishery.

In early-2020, members of the harvesting sector submitted an alternative PA Framework for Snow Crab to be reviewed by DFO Science. It was noted during the 2020 Snow Crab assessment that several participants from the harvesting sector do not support DFO Science’s current proposed PA Framework for use in decision-making.

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 17). 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. The bottom water temperature in these two deep channels is warmer than the surrounding shallow banks.

In relative terms, the AD 2HJ fishery is one of the smallest fisheries for Snow Crab in NL, with the exception of AD 4R3Pn (Figure 13). 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 six years (Figure 14). Effort declined to its lowest level in decades (about 140,000 trap hauls per year) in 2013 and has since remained around 200,000 trap hauls per year (Figure 16). The shortfalls in achieving the TAC in 2011–13 and again in 2016 reflect events in the northernmost fishing grounds of CMA 1 (i.e., 2JN) (Figure A1.1), with the southern CMA consistently fully subscribing its quota. Although poor fishing in the northern area is a contributing factor (Figure 17), it also reflects a management decision by industry stakeholders to leave 15% of the annual TAC unharvested in CMA 1 from 2014 to 2018 to promote conservation measures (Figure A1.1). This measure was not continued in 2019, however the TAC was still not fully taken in this CMA.

Logbook return rates in AD 2HJ have been relatively consistent with other ADs, but only approximately 70% of landings were available in the logbook dataset for this assessment (Figure 5). 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 12).

Standardized CPUE has remained near the decadal average in recent years (Figure 18), reflecting trends in CMA 2; however, CPUE continued to decline in CMA 1 (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 23). 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 three years and there was little replenishment of the resource between 2018 and 2019. This indicates declining recruitment into the fishery; however, end-of-season catch rates in 2018 and 2019 were higher than the previous two years.

Spatially, there has been a reduction in the areal coverage of the fishery since 2011 (Figure 17). It has contracted into the Cartwright and Hawke Channels, with the northernmost fishing grounds of Div. 2H virtually abandoned. Along with contraction from the north, effort no longer extends into the farthest offshore areas and the slope edge. The abandonment of northernmost fishing grounds also reflects both resource shortages and a regulation change after the 2012 fishery whereby vessels previously restricted to Div. 2H were allowed access to the northern portion of the Cartwright Channel, inside Div. 2J, at the southernmost portion of CMA 1.

The coupling of reduced or stable fishery catch rates with contraction of the fishery back into the core areas of known concentrations of exploitable biomass is indicative of hyperstability occurring in the CPUE index in this AD, and in particular the southern portion of it, with the northernmost CMA 1 more clearly showing signals of resource depletion in the fisheries data, even in the historically best performing fishing grounds of the Cartwright Channel.

Size distributions from at-sea sampling by observers during the fishery suggest that two recent recruitment pulses benefitted the fishery during 2007–09 and 2012–15 (Figure 21). This can be seen by an increase in abundance of soft and new-shelled legal-sized crab during those periods. In 2019, there was virtually no old-shelled legal-sized crab in the observed catch (Figure 21), indicating a decline in the residual biomass and reflecting trends in CMA 2 where observer sampling occurred (Figure A1.4).

Discards in the fishery were very high in 2019, with around 40% of the catch discarded (Figure 61) with the majority of these discards soft-shelled (Figure 62).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 and this occurred again in 2019.

Total mortality in exploitable crab had been at its highest level in recent years, but declined in 2018 and 2019 (Figure 59). The trend in total mortality has reflected that of fishing mortality in recent years (Figure 59), however, in 2018 and 2019 the ERI remained high while total mortality declined. The drop in total mortality could be a partial artefact of immigration of large crab from AD 3K into southern areas of AD 2HJ in 2018 (see Mortality section above for more details).

The ERI has been above the long-term average for the past three years. Status quo removals in 2020 would maintain the ERI at this high level (67% of the exploitable biomass). 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 2020 fishery.

Surveys

Both the trawl and trap-based exploitable biomass indices have changed little during the past 15 years (Figure 38, Figure 39), with the exception of a 2014 spike in the trawl index. However, the trap-based exploitable biomass estimates in 2017, 2018, and 2019 are considered highly uncertain and should be viewed with caution, particularly in CMA 2 (S5440) (Figure A1.6). The 2017–19 trap surveys omitted a large proportion of core stations (Figure 9) and in the 2018 trap survey shell conditions were identified inaccurately in CMA 2 (S5440). The 2019 trawl EBI is likely an overestimation due to the reduced coverage of the survey in AD 2HJ (see Biomass section above). However, the spatially-broad trawl survey has captured very few exploitable crab outside the Cartwright and Hawke Channels during the past decade (Figure 36).

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 38), and the 2019 surveys suggest recruitment will remain unchanged in 2020. Interestingly, a high level of recruitment into the biomass in the northern area during 2013 (Figure A1.7) preceded the high level of recruitment seen in the trap survey in the southern area in 2014 (Figure A1.8, Figure A1.9). The shell conditions were identified incorrectly in the majority of stations in 2018 and 2019 and therefore the levels of recruits versus residual crab from large-mesh pots could not be accurately estimated this year (Figure A1.8).

In 2018, a modest increase in residual crab (Figure 38), no prior increase in recruits in 2017 (Figure 38), the general location of the new residual crab within the deep channel extending from AD 3K to southern AD 2HJ (St. Anthony Basin) (Figure 36), and the lack of increase in residual crab in 2018 following in increase in recruits in 2017 in AD 3K (Figure 38) indicated a possibility that recruits from AD 3K had moved into southern portions of AD 2HJ as residual crab. This does not appear to be the case in 2019 as the residual crab were found in the northern portion of AD 3K where they are usually recorded in the surveys (Figure 36). This situation highlights the difficulties is assessing a stock based on delineations (ADs and CMAs) that are not set based on biological criteria as much as resource management considerations.

Looking at prospects beyond 2020, the pre-recruit biomass index has been relatively low in recent years and was at or near its lowest level for the last five years (Figure 38). The modest 2014 spike in pre-recruits in the trawl survey appeared to be associated with the progression of a mode of crab into legal-size in small-mesh traps from the Torngat survey in CMA 1 (2JN) during 2015 (Figure A1.10). There has been an increase in small adolescent crab in the small-mesh traps from the Torngat survey in the last two years, suggesting the potential for some small improvements in 2–4 years if they survive and do not terminally molt smaller than commercial size.

Long-term recruitment prospects appeared to improve from 2013 to 2016. The abundance of small crab (15–25 mm CW) in the population was higher than it had been for roughly a decade, but in the last three years the abundance of small crab was near average levels (Figure 46). These smallest crab in the trawl survey have consistently been captured in shallow areas, on top of the Hamilton Bank and adjacent nearshore plateaus (Figure 47). However, the trawl survey was not able to complete stations on the Hamilton Bank in 2019, therefore those small crab may have been missed. The persistently low signal of small crab in the survey trawl prior to 2013 suggests no improvements are likely before the most recent emergent mode of small crab contributes to the fishery. The high consumption level of Snow Crab by large predators in 2016 and 2017 (Figure 57), as well as a spike in BCD prevalence in 60–75 mm CW crab (Figure 60), is consistent with tracking these crab through ontogeny, although neither survey has yet to capture them in high abundance as pre-recruits (Figure 38). Other factors being equal, this promising signal of small crab abundance should start contributing to pre-recruit or exploitable indices in the near future if any remnant portions of the pulse remain as adolescent males in the population.

Size-at-terminal molt in males has precipitously declined in recent years, indicating dampened short-term recruitment prospects into the exploitable biomass (Figure 69). An increase was seen in male size-at-terminal molt in 2019, however, the maturation of 50% of males remains well below exploitable size (i.e., 75–80 mm CW). It is unknown if this trend will continue, but it should be monitored closely moving forward.

The proposed PA indicates that stock status would be in the provisional cautious zone in 2020 with status quo removals (Figure 70). Predicted discards, and predicted CPUE were within the proposed cautious zones, while the proportion of females with full egg clutches was considered healthy.

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 five years. If this pattern holds, the fishery performance would be expected to remain similar in 2020.

A lower exploitation rate is required to promote recovery of the exploitable biomass in AD 2HJ.

ASSESSMENT DIVISION 3K

Fishery

The AD 3K fishery occurs off the northeast coast of Newfoundland predominately within a network of deep trenches located between nearshore shallow water plateaus and the Funk Island Bank in the offshore (i.e., St. Anthony Basin and Funk Island Deep) (Figure 1). Bottom temperatures are cooler in the shallow nearshore areas and the Funk Island Bank and warmer in the Funk Island Deep area (Figure 53).

Within the AD 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 17). White Bay (CMA 3B) is a deep (i.e., 400–500 m) fjord protected at the mouth by a shallow sill (i.e., 200–300 m) that forms the basis of a relatively discrete pocket of fishing effort. There are two distinct pockets of effort in CMA 3A, one concentrated near the mouth of White Bay in the south and another in an easterly extension of the management area that stretches into the offshore at depths of approximately 200–300 m. Finally, CMA 3BC is relatively shallow (i.e., 200–300 m) and bathymetric features are similar to the offshore and southern portions of CMA 3A. Effort within CMA 3BC essentially forms a western extension of the offshore fishery.

Landings have remained relatively low for the past four years (Figure 14). 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 are at or near their lowest levels in a decade. In 2019, the TACs within the CMAs remained unchanged, with the exception of CMA 3B which had a TAC reduction. The TAC has not been reached for the last six years in CMA 3A. At below a million traps hauls a year, overall effort reached a two-decade low in 2019 (Figure 16).

Standardized CPUE increased in 2018 and 2019 from a time-series low in 2017, to around the time-series average (Figure 18). This reflects trends in most management areas (Figure A2.2). Interestingly, most CMAs have shown a quasi-cyclical pattern in CPUE, with most CMAs experiencing the most recent peak in 2013–14. In general, the fishery has performed relatively poorly throughout most of the AD in recent years, but showed signs of improvement in 2018 and 2019.

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

Spatially, the fishery data are reflecting a constricting of fishing activity primarily into the Funk Island Deep area and inshore bays, with much of the offshore fringe areas not fished in the last two years (Figure 17).

In 2019, the fishery CPUE declined throughout the season in all CMAs (Figure A2.3), reflecting resource depletion. This depletion was pronounced in all CMAs, with the lowest late season catch rates in CMA 3A. Compared to the other CMAs in this AD, there has been little replenishment of the resource between seasons in CMA 3A. In 2019, the end-of-season catch rates in CMAs 3B and 4 were much higher than in previous years, near the level where the previous season started.

Discards in the fishery decreased in 2019 to around 20% discarded (Figure 61). Observer sampling during the fishery showed catch rates of new-shelled and/or soft-shelled crab starting to increase in all CMAs in 2017, with the exception of CMA 4 (Figure A2.4). With the exception of CMA 3D in 2018, these trends have continued over the last two years resulting in increased catch rates of new-shelled crab in all CMAs in 2019. As well, there was an increase in soft-shelled crab in CMA 3BC.

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

Improvements in recruitment in Green Bay (CMA 3C) and neighbouring Notre Dame Bay (CMA 3D) started to emerge in 2016 (Figure A2.4). From about 2009–13 the overall magnitude of catch rates of most sizes of crab showed a steady decline as the size frequency distribution became platykurtic, particularly in CMA 3D. Beginning in approximately 2014, a notable change in shape of the observed population occurred in this CMA as the primary size mode became centered near legal-size and the distribution became right-skewed. In Green Bay (CMA 3C), size frequency distributions from observer sampling suggested a persistent high exploitation rate, evident by a sharp 'knife-edge' effect at legal-size from 2009 to 2017. However, in 2018 and 2019, the knife-edge effect was not evident in Green Bay, with high frequencies of crab larger than legal size evident.

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

Soft-shell crab incidence in the catch is a perpetual issue in AD 3K (Figure A2.5). In general, a large portion of discards in this AD are attributable to soft-shell crab (Figure 62). However, the majority of discarded crab were represented by undersized crab in 2018 and 2019. Soft-shell incidence tends to increase as the season progresses, with the fishery consistently experiencing soft-shell percentages exceeding 20% by about the end of May in most years since 2005 (Figure A2.5). This persistently high incidence of soft-shelled crab in the catch is thought to reflect, at least in-part, a depleted residual biomass. A high incidence of soft-shell crab in the catch ultimately reflects inefficiency in resource extraction. It is wastage that occurs on pre-recruits and constitutes an opportunity cost to the future fishery as well as a biological loss to future reproductive potential.

Total mortality in exploitable crab was at its highest levels (>75%) during the past four years (Figure 59), however, it dropped dramatically in 2019. This is thought to partially be a result of the movement of crab back into AD 3K in 2019 from AD 2HJ in 2018 (see Mortality section above for more details). This would result in more residuals than recruits from the previous year which affects the calculation of the total mortality index. The ERI declined from a decadal high in 2017 (Figure 59). Under status quo removals in 2020 the ERI would decrease to a time-series low. CMAs 3B, 3D, and 4 would have decreased trap survey-based exploitation rate indices, while there would be a slight increase in CMA 3C. (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 38, Figure 39); however, the trawl survey EBI increased in 2019. Two factors that may have contributed to the discrepancy between the trawl and trap survey exploitable biomass indices are:

1. the CPS survey missed stations in the St. Anthony Basin where trawl and fishery catches tend to be high (Figure 9), and
2. the fall multispecies trawl survey missed offshore areas of the AD where catches tend to be low (Figure 36).

Similar to AD 2HJ, exploitable males in AD 3K are generally found deep, predominately at fringe areas of the Funk Island Deep and St. Anthony Basin, with few exploitable crab captured in the farthest offshore areas (Figure 36). In 2018, a portion of the pocket of crab that is generally found within AD 3K in the St. Anthony Basin, appeared to have moved north and was centered in AD 2HJ; however catches in 2019 showed a return to the more typical distribution of crab in AD 3K. The exploitable biomass has consisted largely of incoming recruits throughout the time series (50–75%), however there was an increase in residual crab in 2019 from previous low levels (Figure 38). Trap survey catch rates of residual crab remained unchanged in most CMAs in 2019, except White Bay (CMA 3B) where residual crab catch rates were near average and CMA 3BC where residual crab catch rates reached time-series highs (Figure A2.7).

The overall CPS survey catch rates in AD 3K remain relatively low (~5 kg/trap), particularly for recruits (Figure 42). Recruitment catch rates from the post-season trap survey remained low in 2019, except in White Bay (CMA 3B), where recruitment was unchanged from the modest increase seen in 2018, and Green Bay (CMA 3C), which saw an increase to near time-series highs (Figure A2.7). The Inshore DFO trap survey did not occur in White Bay in 2019. In 2018, catch rates were low (below or at 5 kg/trap) in the 201–300 m and 301–400 m strata (Figure A2.8), which constitute the majority of the area, as the deepest stratum is very small and generally beyond depths where the fishery occurs. 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. This was again seen in 2019 with an increase in recruits in CMA 3C in the CPS trap survey and CMA 3D in the Inshore DFO trap survey (Figure A2.7, Figure A2.9). 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.

Size frequency distributions from large-mesh pots in the CPS survey show increased levels of new-shelled crab across a broad size range in CMAs 3B and 3C, and in the small sizes in CMA 3A (Figure A2.10). There were almost exclusively old-shelled crab caught in CMA 3BC in 2019. Overall numbers per trap were very low in CMAs 3A, 3D, and 4, however this has been the case over much of the time series. Looking beyond 2020, both the trawl and trap pre-recruit abundance indices were near historical lows in 2018 (Figure 38, Figure 43), but both increased in 2019 to time-series average (trawl survey) or high (trap survey) levels. This suggest there may be improvements in the short-term (2–4 years).

Small-mesh trap usage by the CPS survey has been sporadic or non-existent in most CMAs throughout the times series (Figure A2.11). Only Green Bay (CMA 3C) and the offshore (CMA 4) have been consistently covered. There was an increase in adolescent crab in most CMAs, but the overwhelming majority of crab caught in all CMAs (including those terminally molted) were below legal-size. While small-mesh trap use has been very patchy in CMA 3BC, in 2019 there was large catches of very small adolescent crab, which was also seen in CMA 4.

Small-mesh traps in the DFO surveys showed a depleted biomass in all areas of White Bay (CMA 3B), with a very small hint of potential increased recruitment in the middle

(301–400 m) stratum in 2018 (Figure A2.12). There is no new data for 2019. The surveys tracked a mode of adolescent males across years and depths, beginning at about 47 mm CW in the shallowest stratum in CMA 3A/White Bay in 2005 to pre-recruit-sized crab with modes of about 75–85 mm CW in the two deeper strata in 2011 and 2012. The deep progression over time reflects the ontogenetic migration of Snow Crab in this area (Mullowney et al. 2011). This recruitment pulse led to the high exploitable biomass experienced from 2012 to 2014. Another very small pulse of adolescents was detected at about 47 mm CW in the shallowest stratum in 2015, which may have started to appear as pre-recruits in the 301–400 m depth stratum in 2018.

The pulse of adolescent crab in Green Bay seen in the CPS survey in 2019 (Figure A2.11) was also evident in the small-mesh traps of the Inshore DFO trap survey, with only a slight decrease from the high in 2018 (Figure A2.13). Collectively, these surveys provide evidence to suggest the potential for modest increased long-term recruitment prospects for the exploitable biomass and fishery. However, a large proportion of crab appear to be terminally molting smaller than exploitable size, so the extent to which this potential recruitment is realized in the fishery is likely diminished and remains unclear.

BCD incidence levels generally represent another metric of recruitment potential via the density dependence attributes of the disease in reflecting the relative abundance of small to mid-sized crab (Mullowney et al. 2011). For example, the progression of a spike in BCD in the shallow stratum of White Bay in 2005 through to the mid-depth stratum in 2006 and finally into the deepest stratum in 2007 (Figure A2.14) reflected the high abundance of crab in the pseudo-cohort of adolescents ranging from about 45–75 mm CW. This led to the record high exploitable biomass in 2012 that persisted until about 2014. The previous ‘cycle’ of BCD in White Bay from 1996–99 preceded the relatively high exploitable biomass experienced from about 2002–07. While the percent of new-shelled males with BCD most recently peaked in 2016 and was relatively high again in 2018, the increase was evident in the largest size categories (CW >76 mm) (Figure 60). 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 previous three years. Observed BCD incidence levels have been highly variable in Green Bay (CMA 3C) and Notre Dame Bay (CMA 3D) over the time series and were near average in 2019, with between 10–15% of new-shelled males having BCD (Figure A2.14).

There were signals inferring improvement in long-term recruitment prospects in 2019. However, expectations must be tempered and also examined in-light of recent declines in size-at-maturity. Although not to the extent seen in some other ADs, size-at-terminal molt in males has precipitously declined in recent years, suggesting potentially dampened short-term recruitment prospects into the exploitable biomass (Figure 69). A slight increase was seen in male size-at-terminal molt in 2019, however, the maturation of 50% of males remains well below exploitable size (i.e., 60–70 mm CW). Some of this may be an artefact of gear bias, but Mullowney and Baker (2021) confirmed that AD 3K has seen dampened size-at-maturity in males in the trawl survey.

The proposed PA indicates that stock status is projected to be in the provisional cautious zone in 2020 with status quo removals (Figure 70). Predicted discards and predicted 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 AD 3K (Dawe and Colbourne 2002). Among other connectivity processes, large-scale ontogenetic migrations extending beyond CMA boundary lines knowingly occur in this AD (Mullowney et al. 2018a), following a dominant west-east downslope trajectory from the shallow nearshore plateaus toward the warm waters of the Funk Island Deep and St. Anthony Basin as crab grow.

ASSESSMENT DIVISION 3L INSHORE

Fishery

The AD 3L Inshore fishery occurs in coastal bays and near to shore regions within 25 nm of headlands off the east coast of Newfoundland. It incorporates Bonavista Bay (CMA 5A), Trinity Bay (CMA 6A), Conception Bay (CMA 6B), Northeast 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. 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 1). Overall, the bottom water in these areas is cold (Figure 53).

Overall, landings declined by 67% from a time-series high in 2015 to 2,750 t in 2019 (Figure 14). In 2019, the landings were 7% below the TAC. As in 2017 and 2018, the TACs decreased in all CMAs in 2019, resulting in subsequent declines in landings (Figure A3.1). The reduced TAC was not fully taken in CMAs 6B, 6C, and 9A. Effort oscillated without trend in this AD from 2005 to 2015 (Figure 16). There was a time-series high in 2017 of close to 1 million trap hauls per year, however declined to a two decade low of less than 500,000 trap hauls per year in 2019.

Overall standardized CPUE increased very slightly in 2019 from the lowest level in the time series (<5 kg/trap) in 2018 (Figure 18). There were strong declines starting around 2015 leading to near time-series lows in all CMAs in 2018 (Figure A3.2). However, improvements were seen in CMAs 5A, 6A, and 8A in 2019, particularly in CMA 5A where the standardized CPUE returned to over 10 kg/trap. Time-series lows remained in 2019 in Conception Bay (CMA 6B), Northeast Avalon (CMA 6C), and St. Mary's Bay (CMA 9A).

Strong depletion of the resource during the 2019 fishery was evident in CMAs 5A, 6A, and 8A, however the start-of-season catch rates were higher than the previous end-of-season catch rates indicating replenishment of the resource between seasons (Figure A3.3). Fishery CPUEs ended at or near historical lows (<5 kg/trap) in all CMAs except Bonavista Bay (CMA 5A), with alarming end-of-season fishery CPUEs (~1 kg/trap) in Conception Bay (CMA 6B), Northeast Avalon (CMA 6C), and St. Mary's Bay (CMA 9A). These extremely low CPUEs suggest a near-fully depleted biomass. Start-of-season CPUEs were extremely low and remained low over the duration of the season in CMAs 6B, 6C, and 9A indicating the resource experienced little to no recruitment between seasons, 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 crab (Figure 19), with low incidence of new-shelled crab in the AD as a whole and within most CMAs (Figure A3.4). Very low numbers of new-shelled crab were observed in all CMAs, with the exception of Southern Avalon (CMA 8A), where almost all of the observed crab were new-shelled. In 2017, large increases in new-shelled crab were observed in Northeast Avalon (CMA 6C) and Southern Avalon (CMA 8A) across all size ranges. However, the discrepancies of these trends with other data sources (e.g., CPS data) and the lack of pulses in 2018, indicate these data were likely misidentified shell categories. Another year of data will be necessary to determine if this is the case for CMA 8A in 2019.

Discards in the fishery have been very high in the last two years, with over 40% discarded (Figure 61). The majority of these discards were old-shelled undersized males (Figure 62). Observed weekly soft-shell encounters remained relatively low in AD 3L Inshore from 2012 to 2016 (Figure A3.5). However, in 2017, for the first time in seven years, a relatively large pulse of soft-shelled crab was observed near the end of season. In 2018 and 2019, soft-shelled crab were observed throughout the season. This is likely indicative of a low residual biomass.

Biomass declines have been greatly outpacing adjustments to removals with quotas non-prohibitive in several CMAs in recent years. The overall trap survey-derived ERI increased in 2013 and remained at its highest observed level until 2018 (Figure 65). It declined in 2019, but remains high relative to pre-2013. Status quo removals would decrease the exploitation rate to time-series low levels in 2020. Under status quo removals, most CMAs would see decreased levels of exploitation in 2020 (Figure A3.6). The consequences of such high exploitation in recent years are unknown, but the potential for biological harm to the resource through fishing elevates as exploitation reaches and becomes sustained at such high levels.

Surveys

The exploitable biomass is very low in this AD. The post-season trap survey EBI remained near a time-series low in 2019 (Figure 39). In all CMAs, the EBI has been at its lowest observed level in recent years, however slight increases were seen in 2019, particularly in Bonavista Bay (CMA 5A), Trinity Bay (CMA 6A), and Southern Avalon (CMA 8A) (Figure A3.6).

The low biomass is largely a result of declining recruitment renewal since 2010, sequentially followed by a decline in residual crab in 2014 (Figure 42). 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 and 2019, recruitment indices from DFO and CPS trap surveys remained near their lowest levels in most CMAs (Figure A3.7, Figure A3.8, Figure A3.9, Figure A3.10, Figure A3.11). In general, resource renewal has been low and is expected to remain low in 2020.

In the CPS survey in Bonavista Bay (CMA 5A), there was a sharp reduction of new-shelled legal-sized crab in the catch from about 12 kg/trap in 2012 to 6 kg/trap in 2013 and 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 and 2019 (Figure A3.8). In 2018, the DFO survey also observed a significant increase in residual crab in the two deepest strata of Bonavista Bay, however this was not sustained in the deepest of the strata in 2019. Both surveys are consistent in showing the modest improvements in exploitable crab in this CMA, which may result in modest improvements for the 2020 fishery.

In Trinity Bay (CMA 6A), recruitment has been variable throughout the time series, but the CPS survey showed the abundance of new-shelled legal-sized crab plummeted in 2015 to approximately 1 kg/trap and remained at that level for two years (Figure A3.7). In 2018, the CPS survey noted an increase in recruitment to near long-term averages, however, recruitment dropped very low again in 2019. The drop in recruitment in 2015 was reflected in the Inshore DFO trap surveys within the shallow (93–183 m) and deep (367–549 m) strata (Figure A3.9). Meanwhile, the increase in recruitment in the 2018 CPS surveys was observed in the middle strata (184–366 m) in the DFO surveys. An increase in recruitment was seen in the Inshore DFO trap survey in the shallowest strata in 2019 that was not reflected in the CPS survey. Catch rates of residual crab increased in 2019 in the CPS survey, which was also seen in the Inshore DFO trap survey in the middle strata (184-366 m). Again, both surveys are consistent in showing the overall relative abundance of exploitable crab was near a historical low in 2017, but started increasing in 2018. No major improvements in exploitable biomass available to the 2020 fishery is expected in this CMA.

In Conception Bay (CMA 6B), catch rates of legal-sized new-shelled crab were at time-series lows (<1 kg/trap) in 2017 and 2018 (Figure A3.7, Figure A3.10). The CPS survey in this CMA was considered incomplete in 2019 because the inner portion of the bay was not surveyed (Figure 9), however there were very slight increases in recruits in both depth strata in the Inshore DFO trap survey in 2019 (Figure A3.10). Dramatic declines in residual crab were also observed in CMA 6B in both the CPS and Inshore DFO trap surveys (Figure A3.7, Figure A3.10). Both surveys showed an alarming rate of decline in overall relative abundance of exploitable crab from 2014 to 2018. With the recruitment index near zero, all indications are of an exploitable biomass in a near-fully depleted state in this area. The prospects for the fishery in 2020 are likely poor.

In the Northeast Avalon (CMA 6C) and Southern Avalon (CMA 8A), the recruitment index of new-shelled legal-sized crab fluctuated at 3–6 kg/trap between 2011 and 2015, but catch rates of recruits in both CMAs declined to time-series lows in 2017, near 0 kg/trap (Figure A3.7). In 2018 and 2019, catch rates of recruits remained at time-series lows in the Northeast Avalon, however, a very modest increase in recruitment was observed in the Southern Avalon. Very slight increases in residuals were seen in both CMAs in 2019, but they remain near time-series lows. No major improvements in exploitable biomass available to the 2020 fishery is expected in these two CMAs.

St. Mary’s Bay (CMA 9A) experienced a prolonged and steady decline in catch rates of recruits from 2010–17, with both surveys showing the index of new-shelled legal-sized crab and residual crab at time-series lows in 2017 (Figure A3.7, Figure A3.11). In 2019, catch rates of recruits in both the DFO survey and CPS survey increased to at or near time-series high levels of recruitment, however the catch rates of residuals declined to a time-series low. With the increase in recruits in 2019, there may be small improvements in the 2020 fishery.

Overall, the prolonged decline in recruitment throughout the AD has now manifested into low catch rates of old-shelled residual crab. This is evident in size frequency distributions from large-mesh traps in the CPS surveys, with the abundance of legal-sized crab eroding to very low levels in all areas in recent years (Figure A3.12). However, there have been some small improvements in recruitment in all CMAs except 6B and 6C in the last 1–2 years. Overall, no major improvements in biomass available to the fishery are expected in 2020 in this AD.

The overall pre-recruit abundance index for the AD was at its lowest level in a decade in 2015, but has increased to a time-series high in 2019 (Figure 43). Small-mesh traps from the CPS survey showed modest increases in adolescent crab in all CMAs starting in 2017 and progressively increasing (Figure A3.13). In St. Mary's Bay (CMA 9A), a particularly large pulse of adolescent crab with a mode ~63 mm was observed in 2018 and 2019.

Small-mesh trap size frequency distributions from the Inshore DFO trap survey in Bonavista Bay show increases in pre-recruit adolescents in all depth strata in 2019, not just the deepest stratum as has been the case for most of the time series (Figure A3.14). The signal of pre-recruits from Trinity Bay improved in the deeper strata in 2018 and in all strata in 2019, with the relative abundance of pre-recruits the highest in the survey time series (Figure A3.15). The Inshore DFO trap survey in Conception Bay captured virtually no pre-recruit adolescents in any strata from 2011 to 2017, however modest levels of adolescent males were observed over a broad range of size categories less than exploitable size in 2018 and 2019 (Figure A3.16). The St. Mary's Bay survey captured a relatively large pulse of adolescent crab (<95 mm CW) in the deepest stratum in 2018, which was maintained in 2019. As well, there were adolescent crab captured in the shallow stratum in 2019, the most in that stratum for the time series (Figure A3.17).

The incidence of BCD provides a signal of the relative strength of the density of small and intermediate-sized crab and associated recruitment prospects. In Bonavista Bay there was some incidence of BCD in 2017/18, but almost nil BCD in 2019 (Figure A3.18). BCD incidence has been nil in Trinity Bay for most of the time series, however there was a spike in BCD in the deepest stratum (367–549 m) in 2019. There was a very slight increase in BCD incidence in Conception Bay in 2019, after five years of almost no incidence.

Overall, virtually all data are coherent and consistent in showing a broad-scale depleted exploitable biomass, with some small localized improvements in 2019 in AD 3L Inshore. In the short-term beyond 2020 there are modest inferences of emerging pulses of pre-recruits in the population that could lead to improvements in the fishery within a few years in some CMAs, and therefore localized improvements in overall biomass available to the fishery could occur within the next two years. However, expectations of potential for improvements in the short term should be tempered, particularly if discard levels remain high and exploitation rates return to the high levels of recent 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 69). A slight increase was seen in male size-at-terminal molt in 2019, however, the maturation of 50% of males remains well below exploitable size (i.e., ~55 mm CW).

The proposed PA indicates that stock status is projected to be in the cautious zone in 2020 with status quo removals (Figure 70). Predicted discards and predicted CPUE were within the proposed cautious zones, while the proportion of females with full egg clutches was considered healthy.

There is considerable spatiotemporal variability in stock status among the CMAs and careful consideration of short-term removal strategies in AD 3L Inshore are advised as some CMAs have shown a very low exploitable biomass dominated by old-shelled crab. It is unknown how broad-scale forthcoming improvements beyond 2020, if they become manifest, may be, as movement and density-dependent regulation dynamics are relatively poorly understood both among the CMAs within the AD as well as in association with neighbouring ADs.

ASSESSMENT DIVISION 3LNO OFFSHORE

Fishery

The AD 3LNO Offshore fishery occurs on and surrounding the Grand Bank off Newfoundland’s southeast coast (Figure 17). It is a massive, shallow, cold, and productive environment for Snow Crab that encompasses CMAs Nearshore (NS), Midshore (MS), Midshore Extended (MSex or MSX), 3L Extended (3Lex or 3LX), 3L Extended in 3N (3Lex3N), 3L Extended in 3O (3Lex3O), 8B, 3L Outside 200 Miles (3L200), 3N Outside 200 Miles (3N200), and 3O Outside 200 Miles (3O200) (Figure 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. Virtually the entire AD consists of cold bottom temperatures, with the exception of the Southeast Shoal and the deep edges of the Grand Bank (Figure 53).

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 17). 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 landings from the NL Region (Figure 13). Overall, landings increased gradually since 2009 to a historic high of 28,750 t in 2015 (Figure 14). Landings declined by 48% from 2016 to 12,800 t in 2019 because of reductions in the TAC, to the lowest level in two decades. TACs were reduced in all CMAs in this AD in 2017 and 2018, resulting in subsequent declines in landings; however, TACs were unchanged in CMAs 3Lex, MS, and MSex in 2019 (Figure A4.1). The TAC has not been fully taken in CMA 8B since 2009 or in CMA 3N200 since 2011. Effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level since that time, with 1.5 to 2 million trap hauls occurring each year (Figure 16). However, in 2019 there was a decline in effort to just over 1 million trap hauls per year, the lowest level in over 20 years.

Overall, standardized CPUE most recently peaked near a time-series high in 2013 and declined by 49% in 2018 to its lowest level since 1992 (Figure 18). There was a slight increase in 2019, but it remains near historic time-series lows. Substantial declines have occurred in all CMAs in recent years, with recent and particularly precipitous declines in CMAs NS, MSex, 3N200, 3L200, 3Lex, and 3L200 (Figure A4.2). However, there were slight increases in 2019 in CMAs NS, 3L200, MS, and 8B. Catch rates remained at or below ~5 kg/trap in CMAs 3L200 and 3N200 in 2019.

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 17). A substantial reduction in fishing effort was seen in CMA 3N200 in 2019.

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. However, in 2019, start of season catch rates were somewhat improved in CMAs 3Lex and NS indicating some replenishment between fishing seasons. In 2019, CMAs 3L200, 3N200, 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 19, Figure 20, Figure 21). 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 crab in the population during 2010–2012, while the primary mode gradually moved to larger sizes. Since then, the overall magnitude of the distributions has been gradually decreasing due in large part to diminishing contributions from new-shelled crab, and the primary mode returned to 115 mm CW in 2017. These observer data clearly depict a prolonged period of strong recruitment contributing to the exploitable biomass from about 2008–12, and subsequently a resource not being renewed at a high rate and gradually being eroded. The shape and shell composition of size distributions changed in 2019 to reflect a similar trend to that seen in 2010–11, with a mode of 101–104 mm CW and an increase in new-shelled crab. In 2019, the improvements in recruitment were observed during the fishery in all CMAs except 3N200 (Figure A4.4).

Discards in the fishery remained low in 2019, with 20% or less throughout the time series (Figure 61). The majority of these discards were undersized males (both old and new-shelled) (Figure 62). Historically, there had to be high levels of soft-shell crab in the population, as the resource was consistently productive and strong recruitment occurred each year. The historic situation likely reflects imposition of an efficient harvest that maintained a strong residual biomass that prohibited persistent high levels of soft-shell crab from emerging as a major concern in the fishery through trap competition. However, the presence of a progressively depleting residual biomass and the virtual lack of soft-shell crab in the catch from 2013 to 2017, reflected a low level of soft-shell crab in the population and the broad-scale dissipation of recruitment (Figure A4.5). However, in 2018 and 2019, small increases in soft-shell crab were observed in the last half of the fishery.

Total mortality declined from its highest observed level in 2016 to its lowest level in 2019 (Figure 59). The ERI increased by a factor of five from 2014 to 2017, but decreased back to time-series average levels in 2019. The ERI would further decline with status quo removals in 2020. This is also reflected in the exploitation rates derived from the CPS trap survey, with status quo removals in 2020 resulting in decreasing exploitation rates in all CMAs (Figure A4.6).

Surveys

The trawl survey exploitable biomass index, which covers the entire AD, precipitously declined by about 75% from 2013 to 2016, but has increased in the past three years (Figure 38). The trap-derived EBI has not shown the same level of recovery yet and remains near the time-series low (Figure 39). All surveyed CMAs were at historical lows for trap-derived exploitable biomass in 2018, but started to increase very slightly in 2019 (Figure A4.6). Many surveyed CMAs remained at or near historical low catch rates of residual crab (old-shelled, legal-sized crab) in 2019, with only CMA 3Lex showing an increase (Figure A4.7). Particularly dramatic declines in survey catch rates have occurred in recent years in CMAs 3Lex, MS, MSex, and NS, with no improvement seen in CMA MSex in 2019.

Both the trawl and trap surveys show considerable spatial contraction in high catch rates of exploitable crab in recent years (Figure 9, Figure 36, Figure 37). The trawl survey index of exploitable biomass shows the resource has become increasingly localized into portions of Div. 3L; the majority of survey trawls in Divs. 3N and 3O caught no exploitable crab for the last five years, with catches particularly absent from the slope edges. However, both the fall and spring trawl surveys saw catches of exploitable crab along the slope edge of Div. 3N in 2019 (Figure 36, Figure 37). The CPS trap survey is also showing that the distribution of exploitable crab is becoming contracted in the northern portion of the Grand Bank (Figure 9). However, in 2018 and 2019, the Whale Deep (in the northern portion of Div. 3O) exhibited very modest signs of improvement and in 2019 there was some improvement seen in the northern portion (particularly the Nose) of the Grand Bank. The CPS trap survey, where core stations do not cover fringe and marginal areas and intensively targets the MS and particularly the MSex CMAs (where fishery catch rates are the highest in the province), continues to show low levels of exploitable biomass that were noted in the trawl survey two years ago. The spatial differences in coverage of the two surveys largely account for the delayed signal in the trend of exploitable biomass indices derived from the two surveys and highlight deficiencies in the CPS survey design with respect to its ability to detect changes in the resource in a hyper-stable catch rate scenario. Once random stations are incorporated into the assessment of CPS data, some of these deficiencies may be resolved. Nevertheless, the recorded spatial contraction and lower biomass index reflected in the CPS trap survey indicates that prime fishing grounds in AD 3LNO Offshore have been experiencing declines in exploitable biomass previously signaled in the trawl survey.

Overall recruitment into the exploitable biomass has been at or near time-series lows in both the trawl and trap surveys in recent years, but increased slightly in the last two years (Figure 38, Figure 42). This represents trends in most CMAs (Figure A4.7). Since 2013, the catch in the large-mesh traps has been dominated by old-shelled crab, however, in 2019 the catch was dominated by new-shelled crab in all CMAs except 3Lex, where the catch was evenly composed of crab with all three shell conditions (Figure A4.8). Both CMAs 3Lex and 8B had higher proportions of soft-shelled crab in the large-mesh traps than in previous years.

CPS trap survey size frequency distributions indicate that the pulse of recruitment that has recently benefitted CMAs MS, MSex, and NS, which first emerged as small crab in the traps in 2008 and was captured as soft-shell 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 modest increase in recruitment observed in 2018 increased in 2019 to match catch rates seen in 2008, particularly in CMAs MS and MSex. Catch rates have improved in most CMAs, with a particularly large increase in CMA 3Lex, which had very low catch rates in 2018. Recruitment prospects are more positive based on the increases seen in 2019, indicating potential increases in the exploitable biomass in 2020.

The trawl survey pre-recruit abundance index steadily declined since 2009 to its lowest level from 2014–16. There have been slight increases in the index in the last two years, with a larger increase in 2019 (Figure 38). The largest aggregations of pre-recruit catches were found throughout Div. 3L, and the southeast edge of the Grand Bank in Div. 3N (Figure 44, Figure 45). The CPS pre-recruit index has increased in the last three years, increasing to the highest level of the time series in 2019 (Figure 43), with increases primarily in CMAs 3L200, 3Lex, MS, and MSex (Figure A4.9).

The small-mesh traps indicate potential for localized improvements in CMAs 3Lex, MS, and MSex in the next few years, with large catches of adolescent crab centered around 75 mm CW in those CMAs (Figure A4.9). The pulse of adolescent crab in CMA 8B, which first appeared in the small mesh traps in 2012 and can be seen centered around progressively larger sizes, appears to have dissipated in 2019. However, the leading tail of this pulse could have led to the increase in CPUE in the fishery in this CMA in 2019 (Figure A4.2).

Relative to the 1995–2003 period, few small crab have been captured by the trawl survey during the past decade (Figure 46). The strong pulse of pre-recruits observed in the survey from 2008 to 2010 most likely emerged from the relatively strong pulse of small crab captured during 2001–03. The small spike in small crab abundance seen in the survey in 2010 was also seen in AD 3Ps. There has been a lack of sustained strong pulses of small crab in the survey since the early 2000s, however there were small signals of small crabs in 2017 and again in 2019 that may indicate future improvements if sustained.

Size-at-terminal molt in males has oscillated throughout the time series and the maturation of 50% of males was around exploitable size in 2019 (Figure 69). It is unknown if this trend will continue, but trends should be monitored closely moving forward.

The proposed PA indicates that stock status is projected to be in the provisional healthy zone in 2020 with status quo removals (Figure 70). The proportion of females with full egg clutches, the predicted discards, and the predicted CPUE were all within the proposed healthy zones.

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

ASSESSMENT DIVISION 3PS

Fishery

The AD 3Ps fishery occurs off the south coast of Newfoundland (Figure 2, Figure 17). In the inshore, it predominately occurs within the confines of two major bays: Fortune Bay (CMA 11E) and Placentia Bay (CMA 10A). While the land and bathymetrical features partition Fortune Bay as relatively discrete from the remainder of the AD, Placentia Bay forms a continuum with the expansive offshore. Historically, most major aggregations of Snow Crab have been found in a deep-water trough (i.e., maximum 275 m depth) extending out of Placentia Bay and into the Halibut Channel in CMA 10B (Figure 1). 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 17), are cold, but temperatures increase abruptly at the slope edges (Figure 53).

Landings declined from a recent peak of 6,700 t in 2011 to a time-series low of 1,200 t in 2017 (Figure 14). In 2018 and 2019, the landings increased and exceeded the TAC, with landings at a five year high of about 2,800 t in 2019. The previous eight years the TAC had not been taken, and varied by CMAs (Figure A5.1). Effort has declined by 60% since 2014 to be near its lowest level in two decades in 2018 and 2019 (Figure 16). These overall trends in removals and effort reflect a relatively consistent pattern in every CMA, with the exception of CMA 11E (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 around 8 kg/trap in 2019 (Figure 18). CPUE in CMAs 10A and 10B improved from particularly large and precipitous declines in previous years, and CMA 11S also showed signs of improvement and CPUE was maintained at a time-series high in CMA 11W (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, the start-of-season and end-of-season CPUE levels were higher than observed in the previous three years in 2018 and 2019. CPUE in CMA 11E showed no depletion throughout the season and instead, increased as the season progressed.

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

Discards comprised half the catch in 2016 and 2017, but declined sharply in 2018 and 2019 to near time-series lows (Figure 61). In the past decade, the majority of discards were under-sized old-shelled crab, a high proportion of which were likely terminally molted adults (Figure 62). After an extended period of time with few soft-shell crab reported in the catch, soft-shell occurrences became more prominent from 2014 to 2017, but have decreased in the last two years (Figure A5.5). In 2017, levels of soft-shell crab in the catch increased throughout the duration of the fishery. This was followed by a recruitment pulse of exploitable crab in 2018 (Figure 38). The greatly reduced proportion of discards in the catch in the last two years is attributed to the increase in available exploitable crab that outcompete small or soft-shelled crab at a trap. A continuation of current measures is recommended to re-establish a strong residual biomass to continue to help minimize discards.

Previous large quota reductions, followed by an increase in exploitable biomass resulted in the ERI being at a low level in 2019 and status quo removals would result in a further reduction of the ERI in 2020 (Figure 65). This reflects trends in all CMAs, except 11S (Figure A5.6).

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

Surveys

The in-season trawl survey EBI was at a time-series low in 2016, but has improved during the past three years (Figure 38). The post-season trap survey index shows an increase in the EBI throughout the major fishing grounds (Figure 39, Figure A5.6), whereas the trawl EBI remained near the 2018 level in 2019 (Figure 38). The CPS trap survey was not or only partially conducted in most areas in 2015 and 2016 because of poor resource status (Figure 9). 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 of both residual and recruit crab observed in CMAs 10A and 10B (Figure A5. 7). In the Inshore DFO trap survey in Fortune Bay (CMA 11E), total catch rates of exploitable crab were very low in all strata, reflecting the same trends as the CPS survey in that CMA (Figure A5.8).

On the broad-scale, the residual biomass in AD 3Ps, represented by intermediate- to old-shelled legal-sized crab, began to decline after 2010, but significantly increased in 2018 and remained near that level in 2019 (Figure 38). 2018 was the first year since 2011 that the trawl survey captured any relatively large catches of exploitable crab anywhere in the AD (Figure 37). The large catches of exploitable crab were found in CMAs 10A and 10B in 2019, with virtually no crab caught in the other CMAs in the spring trawl survey.

Size frequency distributions from the CPS survey showed substantial declines in catch rates of legal-sized old-shelled crab in all occupied CMAs from about 2010–16 (Figure A5.9). However, with the exception of CMAs 11E and 11S, the CPS trap survey observed substantial catch rates of new-shelled and old-shelled crab in 2018 and 2019.

The decline in the exploitable biomass and the subsequent increase in 2017 reflect trends in recruitment. Overall recruitment into the exploitable biomass had been at its lowest observed level in recent years, but started increasing in 2017 (Figure 42). Recruitment into the exploitable biomass was at a time-series high in 2019, however this was driven by CMAs 10A and 10B (Figure A5.7). There was a significant improvement in the pre-recruit abundance index in 2018 (with high variability based on a couple very large catches), but a decrease in 2019 (Figure 38, Figure 45). However, the 2019 pre-recruit abundance index level was still a decadal high suggesting short-term prospects have improved significantly from the recent 2013-2016 low period. The same trends of increasing trawl pre-recruit abundance index have also been seen in the CPS survey (Figure 43).

The small-mesh traps from the CPS survey indicate potential for localized improvements in CMAs 10A and 10B in the next few years (particularly CMA 10B), with large catches of adolescent crab along a wide range of sizes (Figure A5.10). Prospects for Fortune Bay remain relatively low, with very little sign of significant recruitment prospects in the next 2–4 years (Figure 45, Figure A5.10, Figure A5.11). Small-mesh traps from the Inshore DFO trap survey in Fortune Bay have captured virtually no adolescent crab of any size for the past six years, however there was a very small signal seen in 2019 (Figure A5.11).

The 2018 recruitment pulse likely corresponds with the presence of a relatively large mode of small crab in the trawl survey from 2009 to 2011 (Figure 46, Figure 58). The prior major prolonged pulse of crab of this size occurred from 2003 to 2005. Subsequently, the pre-recruit abundance index increased to a very high level in 2009, a lag period of 4–6 years from detection of small crab in the survey. In extension, the EBI was high from 2009–11. The delayed arrival of the 2009–11 pulse of small crab to recruitment was likely partially a result of a significant skip-molting event that occurred in AD 3Ps in 2012 and 2013. The recruitment spike in 2018 was not sustained in 2019, however remained above the low levels seen around 2013–16 (Figure 58).

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 originally 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.

Size-at-terminal molt in males has oscillated dramatically throughout the time series and the maturation of 50% of males was slightly below exploitable size in 2019 (Figure 69). It is unknown if this trend will continue, but trends should be monitored closely moving forward.

The proposed PA indicates that stock status would be projected to be in the provisional cautious zone in 2020 with status quo removals (Figure 70). Predicted discards and predicted CPUE were within the proposed cautious zones, while the point estimate for the proportion of females with full egg clutches was considered cautious.

Overall, prospects in AD 3Ps are favourable. The resource has not yet fully recovered, but most major stock status signals have improved markedly. The low exploitation rates in 2017 and 2018 are not thought to be inconsequential to this improvement. It is anticipated that if harvest rates remain relatively controlled in the coming years that an improved fishery can be sustained beyond 2020.

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 AD are the warmest along the NL shelf (Figure 53), and it is comparatively unproductive for Snow Crab. Fishery CPUE is consistently low compared to other ADs (Figure 18) 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 900 t in 2013, but have steadily declined since that peak and were 186 t in 2019 (Figure 14), reflecting patterns in most CMAs (Figure A6.1). Landings and TAC declined in every CMA in 2019, with the exception of CMA 12E where the TAC declined, but the landings increased. Effort has remained at a fairly low level (~150,000 trap hauls per year) since 2012, and 2019 was the second lowest year in the time series (Figure 16). The offshore fishery has been patchily distributed, with pockets of effort occurring along adjacent inshore management area lines (Figure 17).

Standardized CPUE has been low throughout the time series relative to most other ADs and declined from a peak in 2013 to near time-series low in 2018 (Figure 18). There was an increase in standardized CPUE in 2019 to above the time-series average, reflecting trends throughout all CMAs except 12A, 12B, and 12G (Figure A6.2).

A pattern of annual stepwise decreases in CPUE has occurred in most CMAs in recent years, with start-of-season catch rates similar to end-of-season catch rates from the preceding years (Figure A6.3). This indicates relatively poor recruitment after the fishery is complete. However, in 2019, start-of-season catch rates were somewhat improved in CMAs 12C, 12D, 12E, 12F, and OS8 indicating some replenishment between fishing seasons.

Fishery observer coverage in AD 4R3Pn remains extremely poor (Figure A6.4), with data only collected in CMAs 12E and 12F. The limited data showed an exploitable biomass dominated by recruits with very few crab under legal size. Discards levels have been low in this AD in recent years (Figure 61) and mostly consist of undersized crab (Figure 62). Overall, more common incidences of soft-shelled catches were evident in 2016 and 2017, but absent in the limited observed catch in 2018 and 2019 (Figure A6.5).

The overall ERI declined to one of the lowest levels in the time series in 2019 (Figure 64), reflecting trends in the major fishing areas (Figure A6.6). Status quo removals in 2020 would result in further reduction to the exploitation rate index.

Surveys

In recent years the exploitable biomass in AD 4R3Pn has been severely depleted, with few residual crab in the population. The trap survey EBI most recently peaked in 2012 and declined to a time-series low in 2017 (Figure 39). However, there have been slight increases in the exploitable biomass in the last two years, which have been greatest in CMAs 12C and 12EF (Figure A6.6). Overall, total catch rates in 2019 were much improved from the levels of around 1 kg/trap observed during the 2017 survey (Figure 42, Figure A6.7), however, residual catch rates remain very low.

The abrupt 2011 increase in the EBI (Figure 42) was associated with sharp increases in recruitment (new-shelled legal-sized crab) in Bay St. George (CMA 12C), and the Inner and Outer Bay of Islands (CMAs 12F and 12E), and an increasing trend in Bonne Bay (CMA 12G) (Figure A6.7). Recruitment into the exploitable biomass was low from 2014 to 2017, but survey data from 2018 and 2019 suggest localized improvements may occur in 2020, particularly in CMAs 12C and 12EF.

Size frequency distributions from large-mesh traps showed an influx of recruitment into the exploitable biomass in most CMAs during 2010–12 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 and continued into larger sizes in 2019. After five years with virtually no signs of recruitment, there was a small signal of recruitment into the exploitable biomass in Bay St. George (CMA 12C) in 2018 and 2019. Small-mesh trap size frequency distributions tracked approaching modes of adolescent males quite well from 2008 to 2010, immediately preceding the improvements in recruitment into the biomass (Figure A6.9). 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 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 crab centered near 70–80 mm was also observed in CMA 12C during 2018 and 2019 and in CMA 12G in 2019. These trends indicate the possibility of modest localized improvements in 1–2 years.

Overall, the exploitable biomass has shown slight improvements in the last two years, however there are few residual crab. Poor monitoring coverage throughout this AD, particularly outside the main fishing areas of CMAs 12C, 12EF, and 12G, results in large uncertainty in the biomass estimates provided in 2019 and predictions for 2020. Caution is warranted when developing conclusions from these estimates. This AD is not included in the proposed PA due to ongoing data deficiencies.

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FIGURES

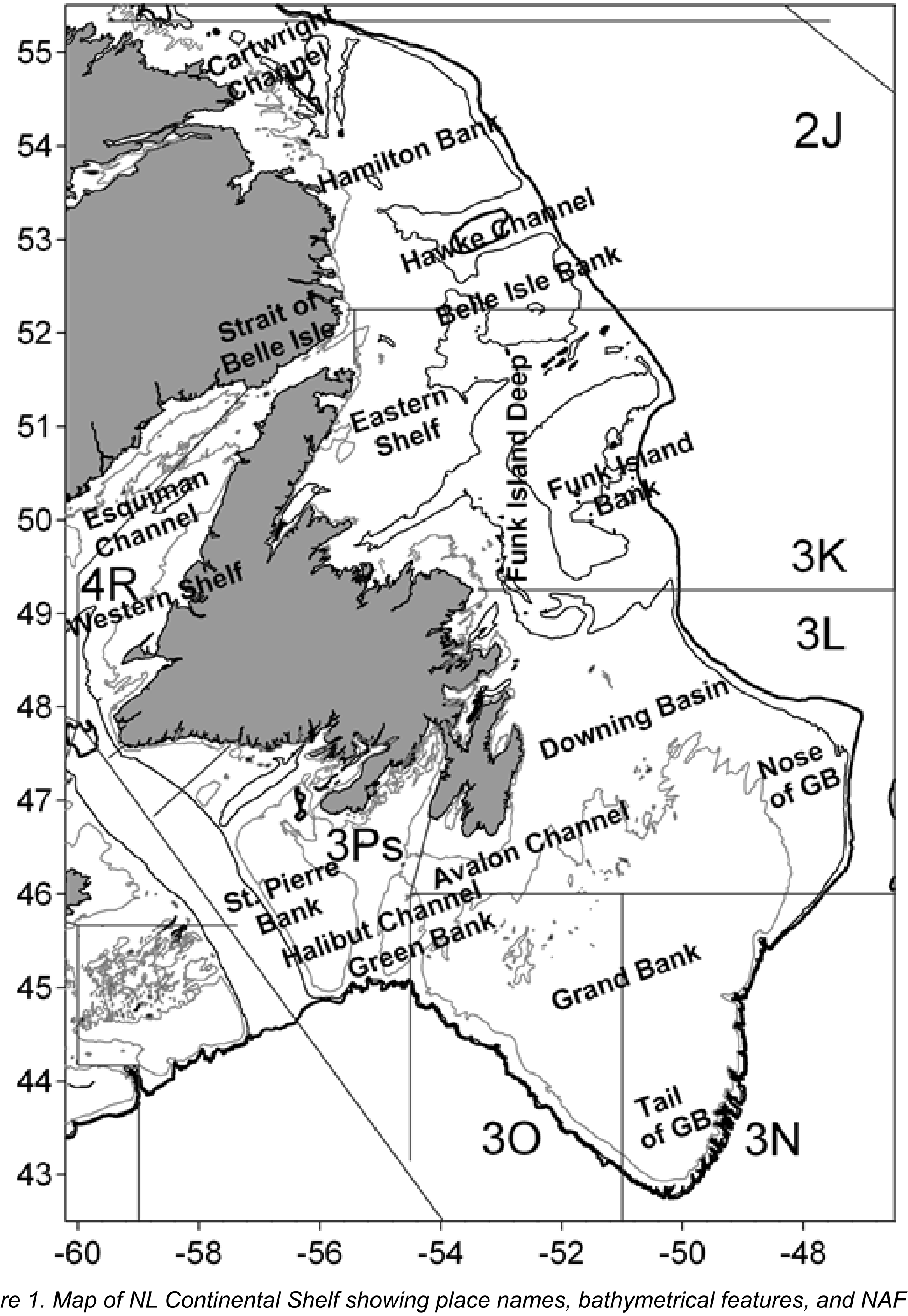

Figure 1. Map of NL Continental Shelf showing place names, bathymetrical features, and NAFO Divisions.

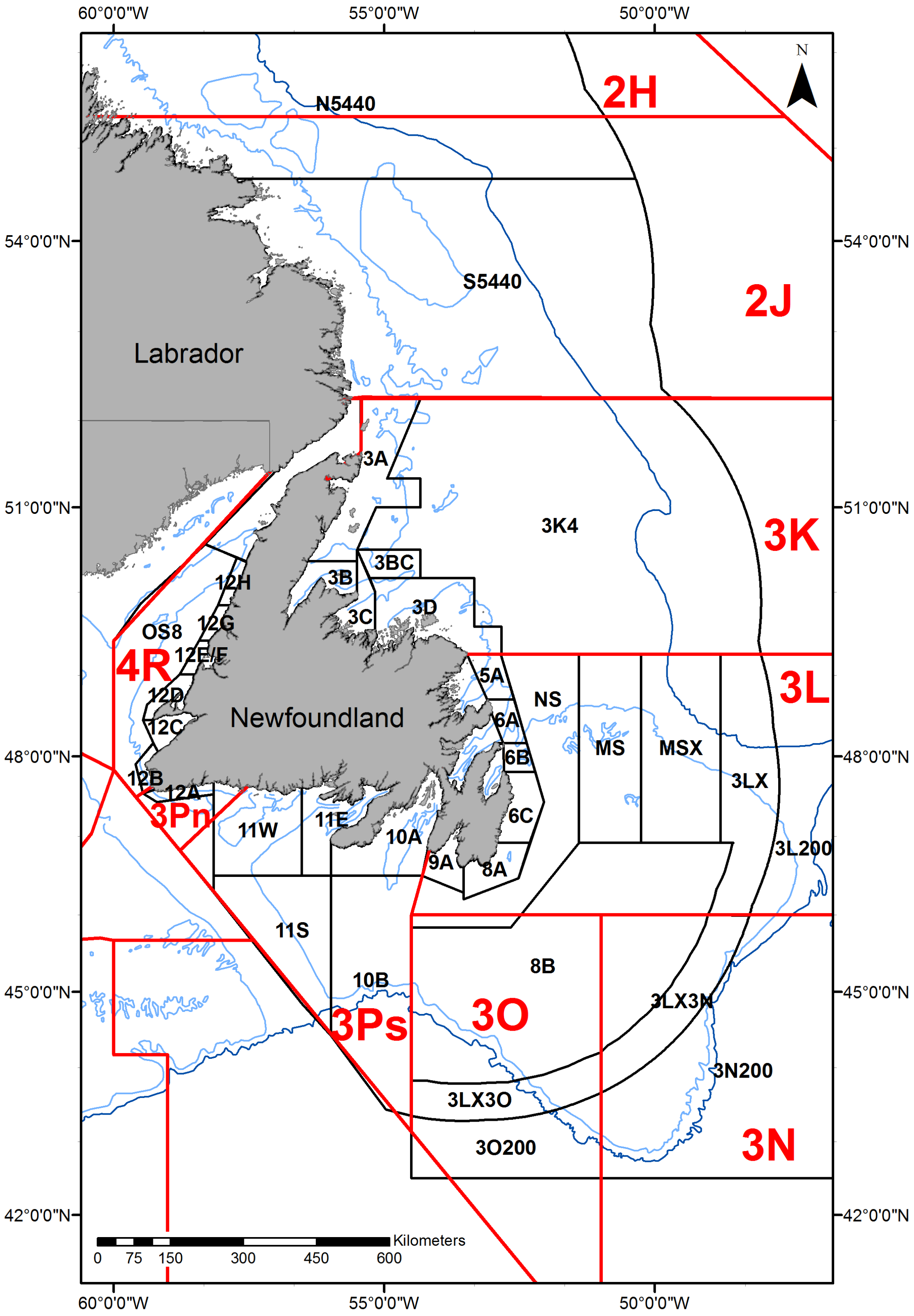

Figure 2. NAFO Divisions (red lines) and NL Snow Crab Management Areas (CMAs) (black lines).

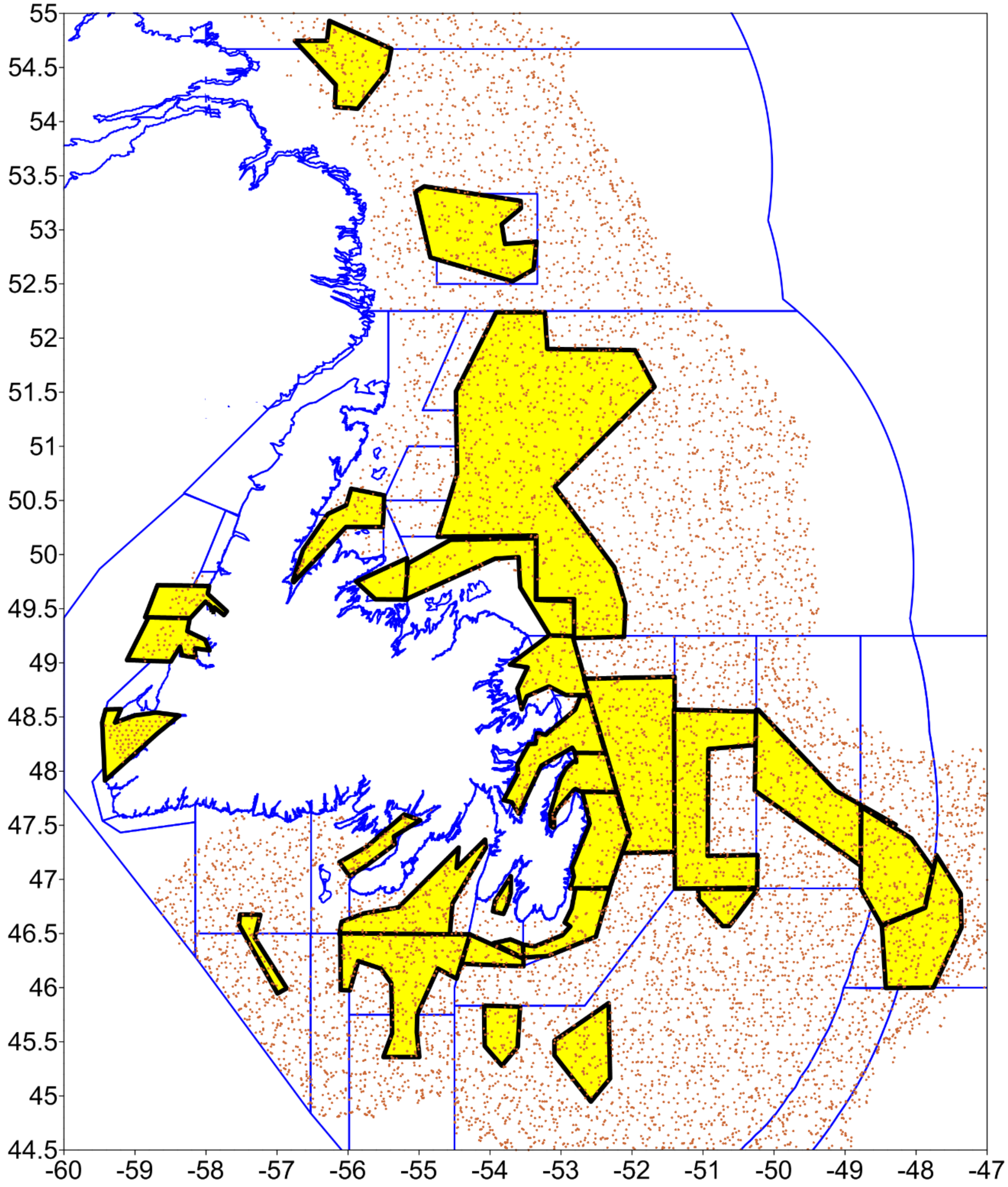

Figure 3. Map of Ogmap vertices for biomass estimation from multispecies trawl surveys (red dots) and strata developed for biomass estimation from DFO, Torngat, and CPS trap surveys (yellow polygons).

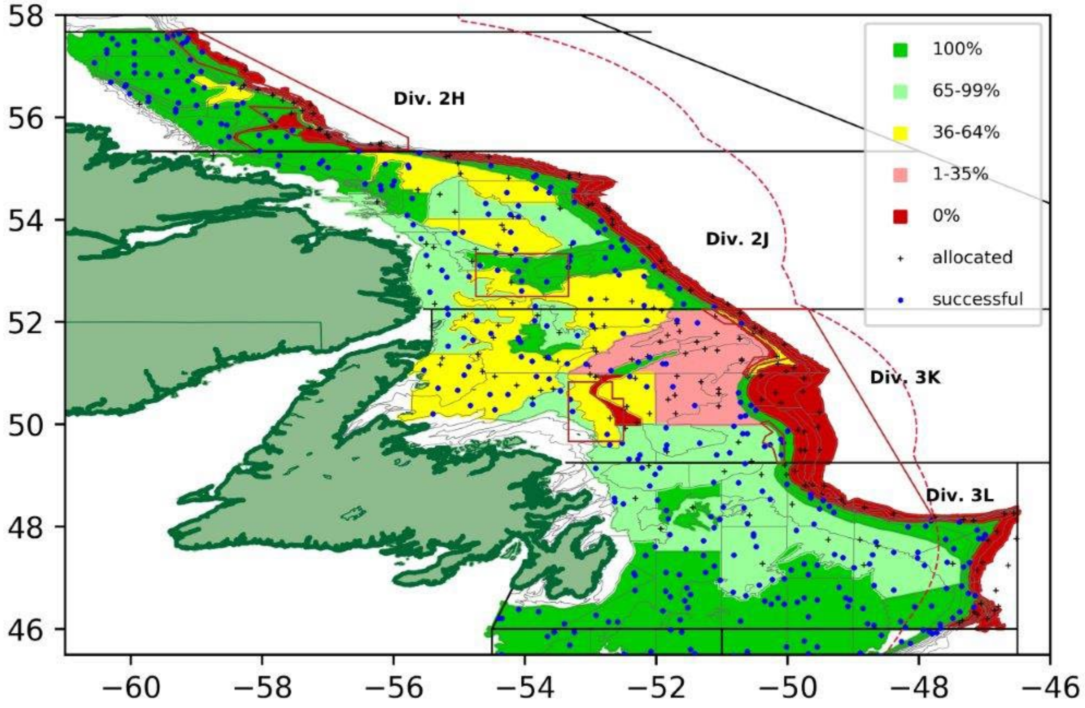

Figure 4. Percent of allocated sets completed during 2019 Fall DFO multispecies trawl survey in Divisions 2HJ3KL.

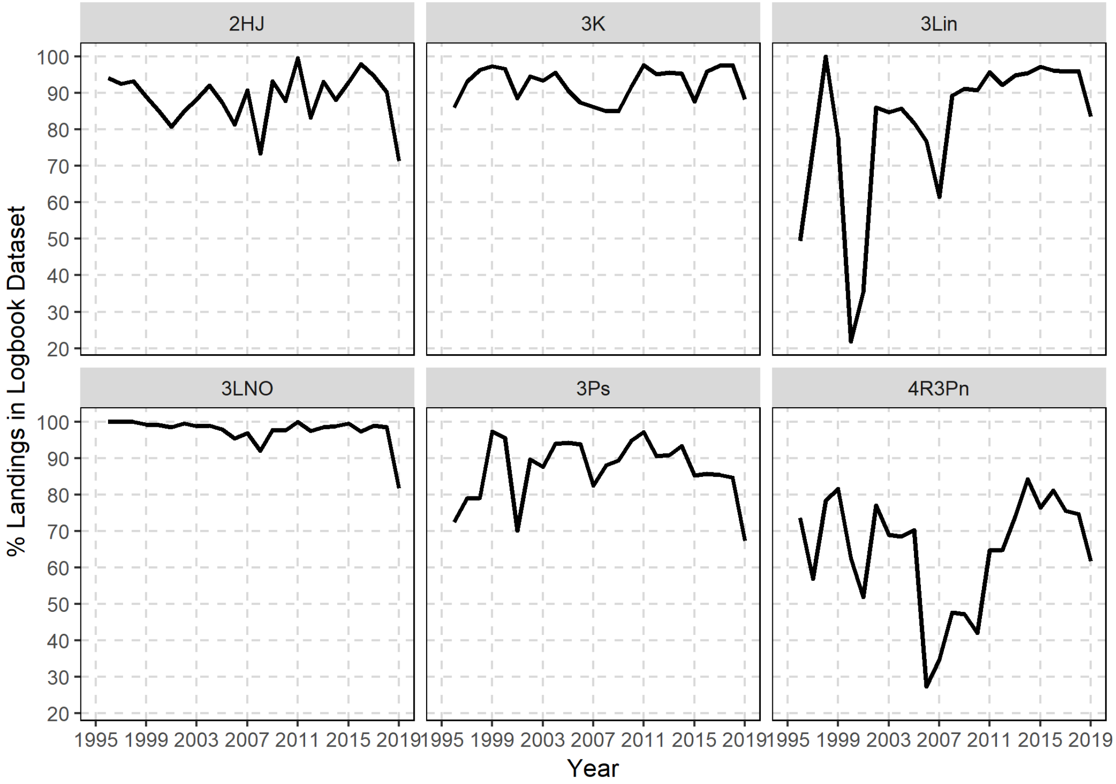

Figure 5. Logbook returns rates by AD and year (1995–2019).

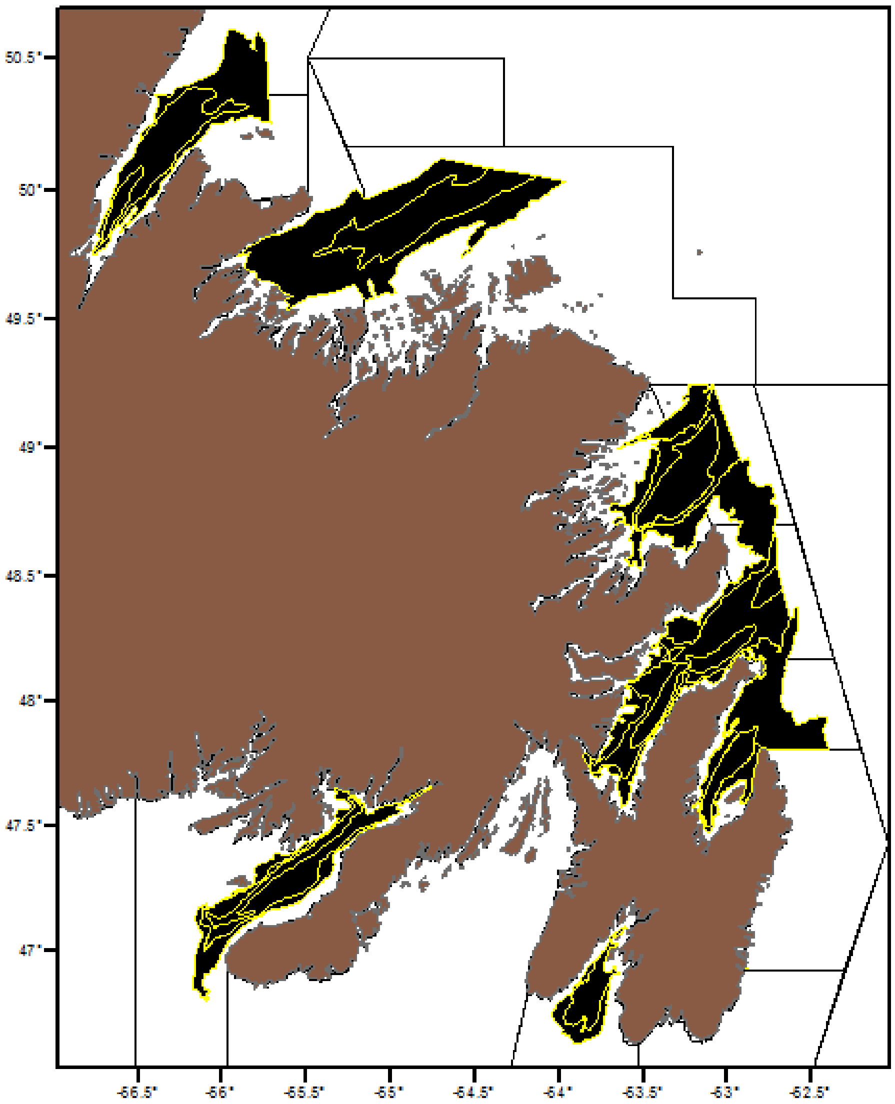

Figure 6. Strata occupied during Inshore DFO trap surveys.

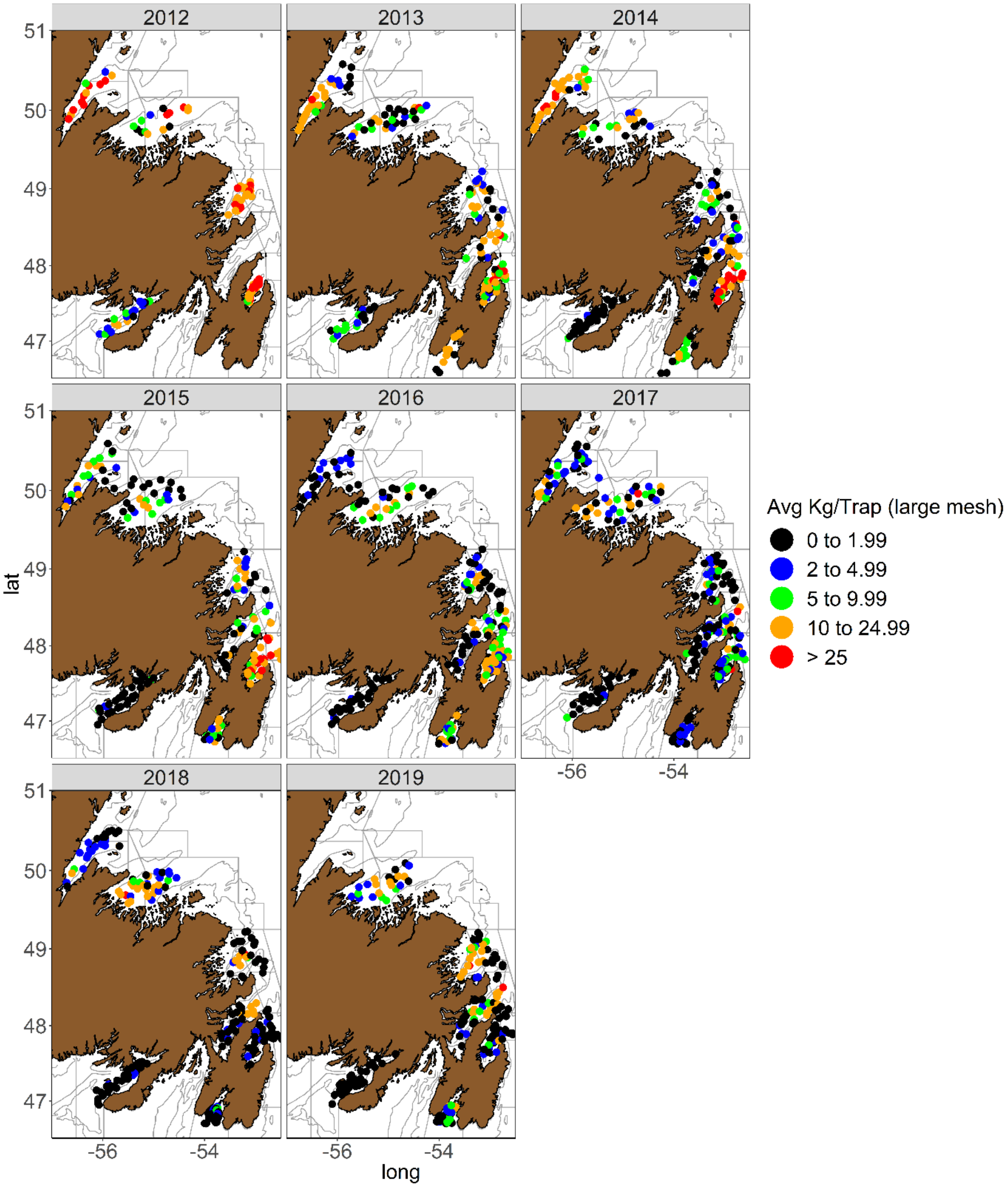

Figure 7. Set positions and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the DFO inshore trap surveys (2012–19).

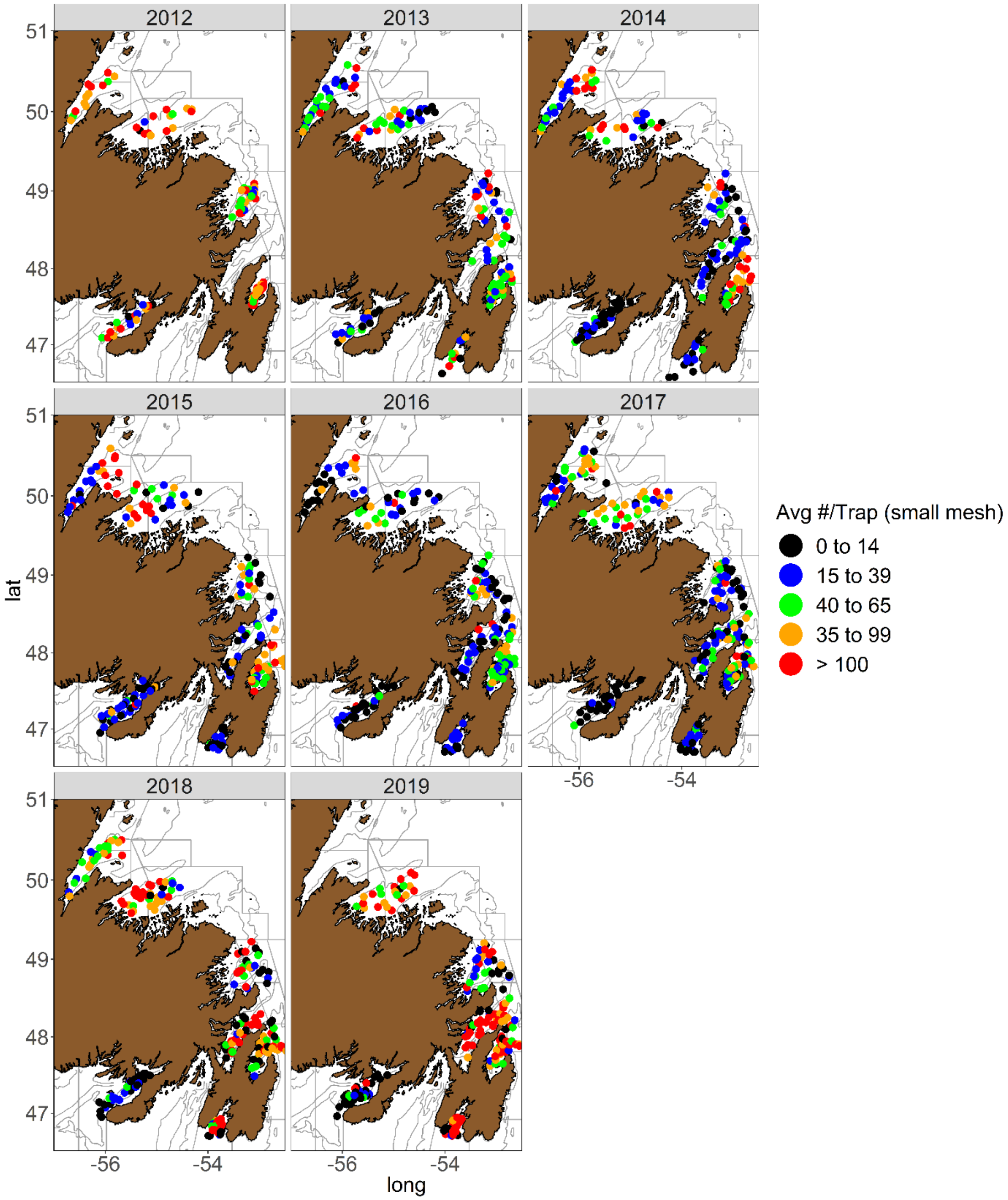

Figure 8. Set positions and CPUE (#/trap) of Snow Crab in small-mesh traps from the DFO inshore trap surveys (2012–19).

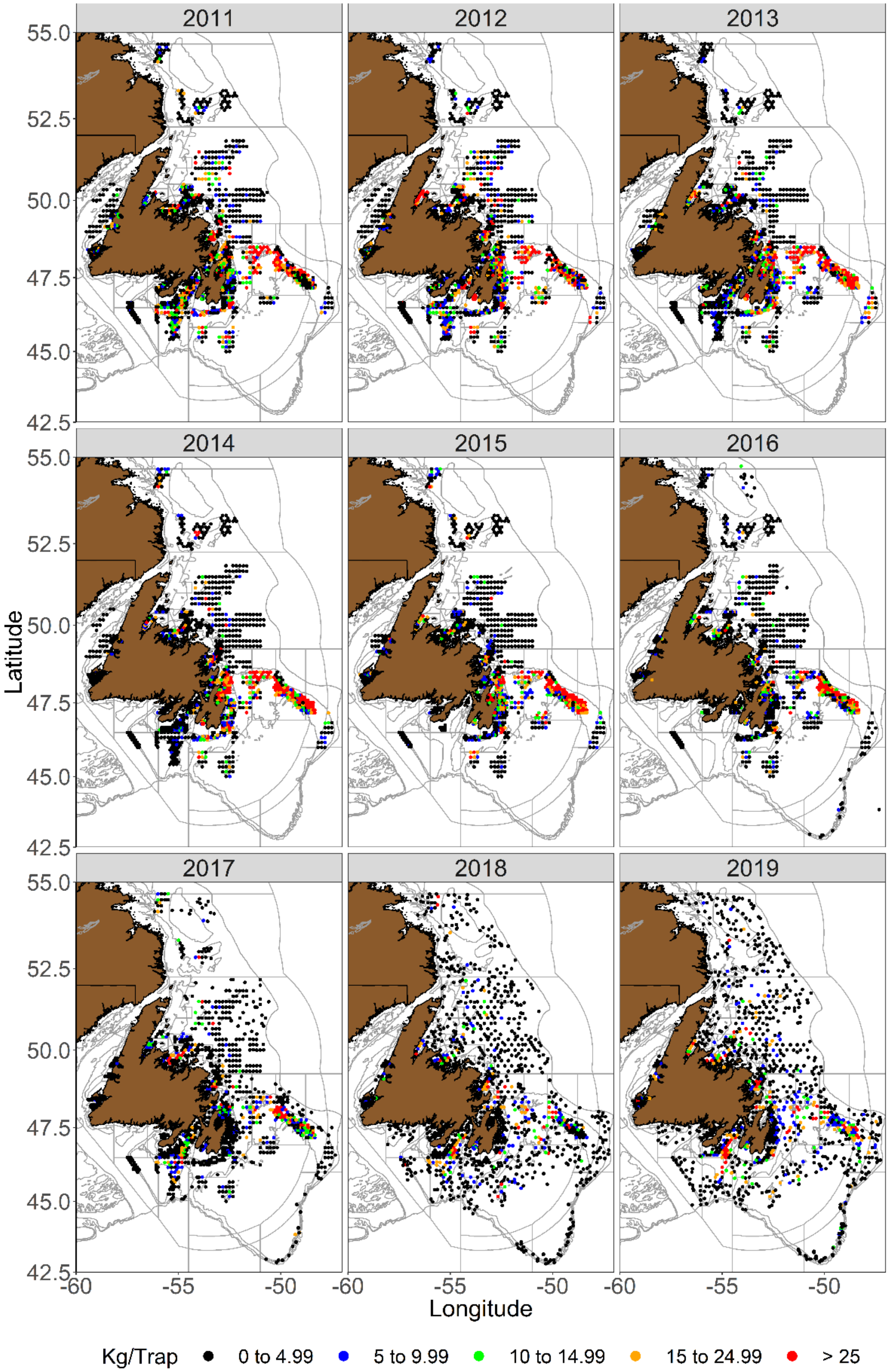

Figure 9. Set positions and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the CPS trap survey (2011–19).

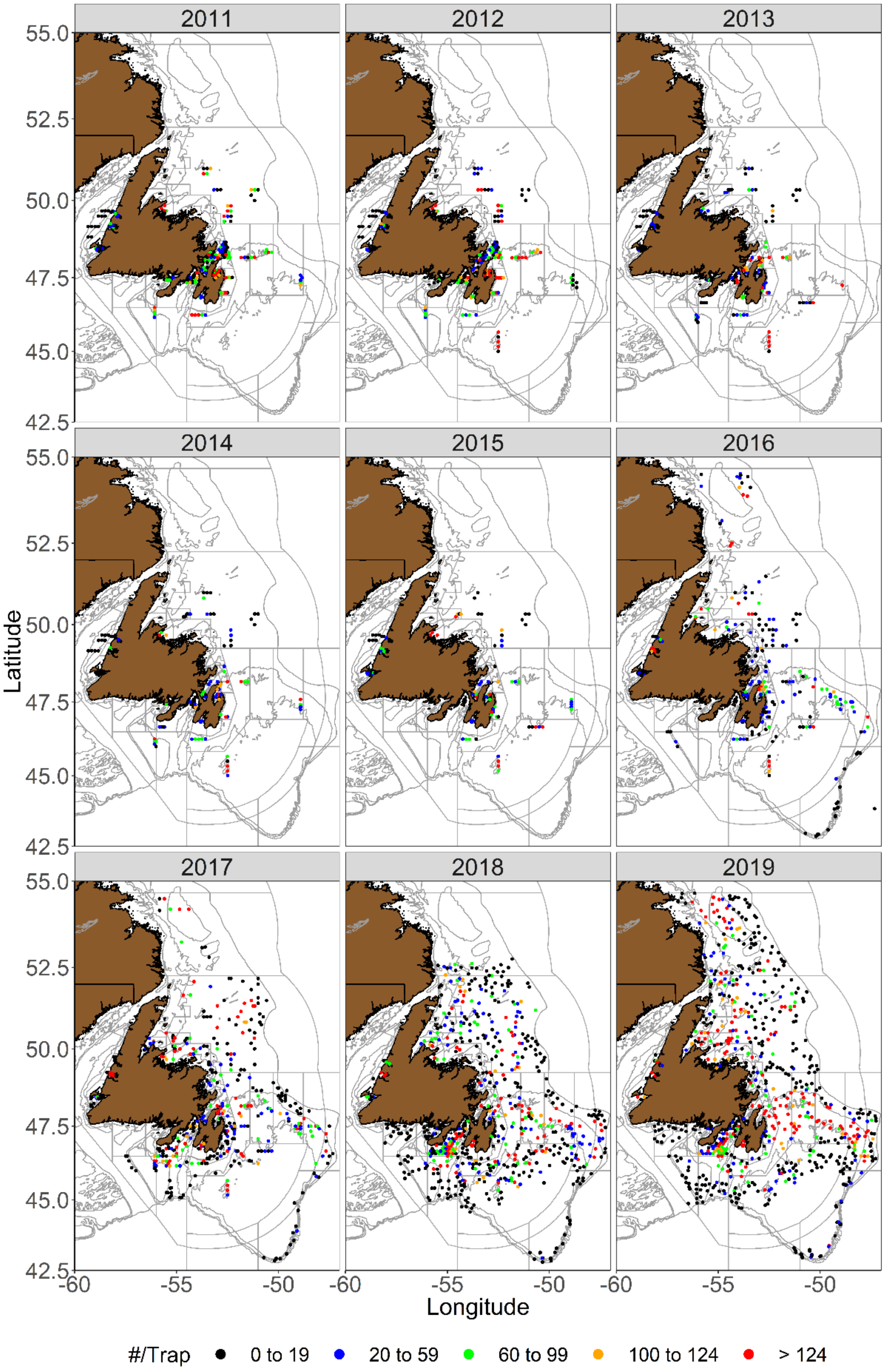

Figure 10. Set positions and CPUE (#/trap) of Snow Crab in small-mesh traps from the CPS trap survey (2011–19).

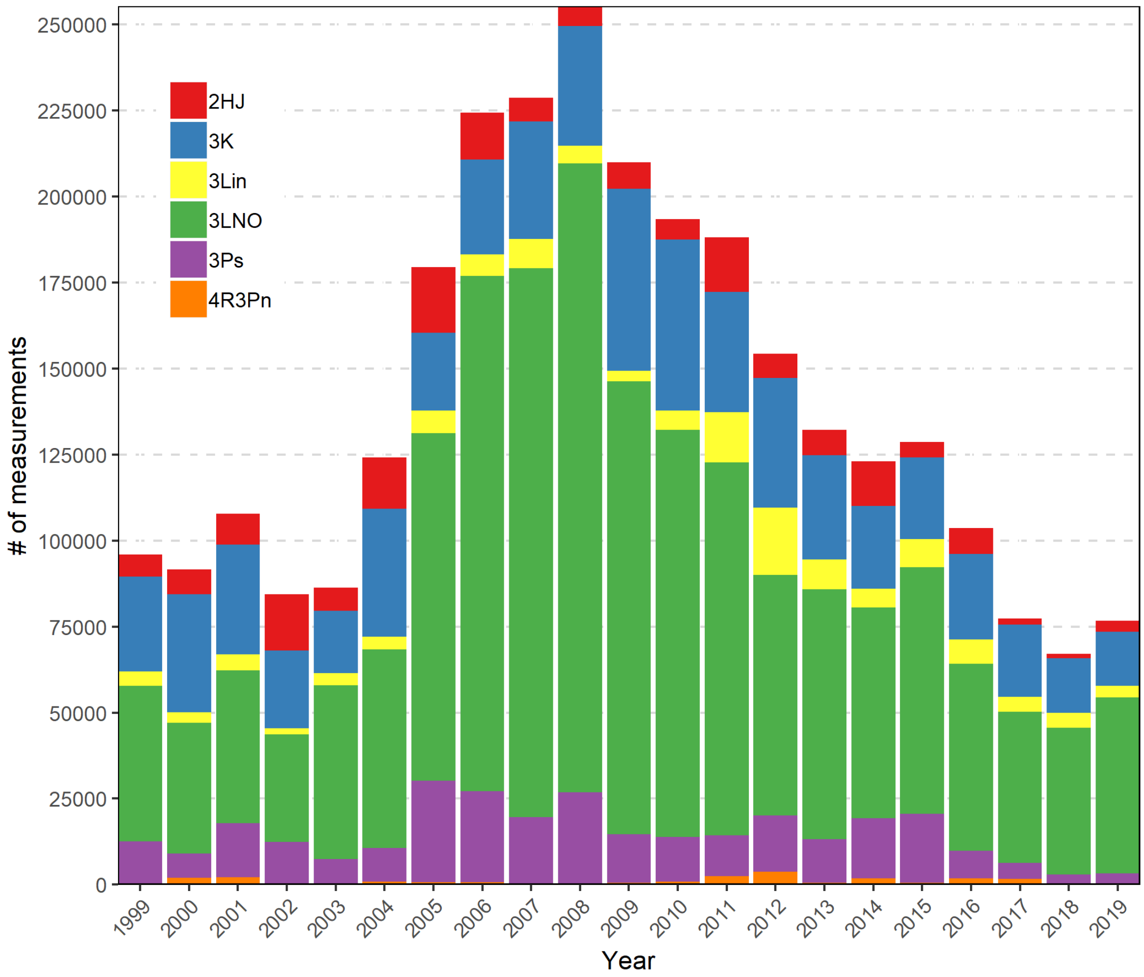

Figure 11. Annual at-sea observer sampling by AD (1999–2019).

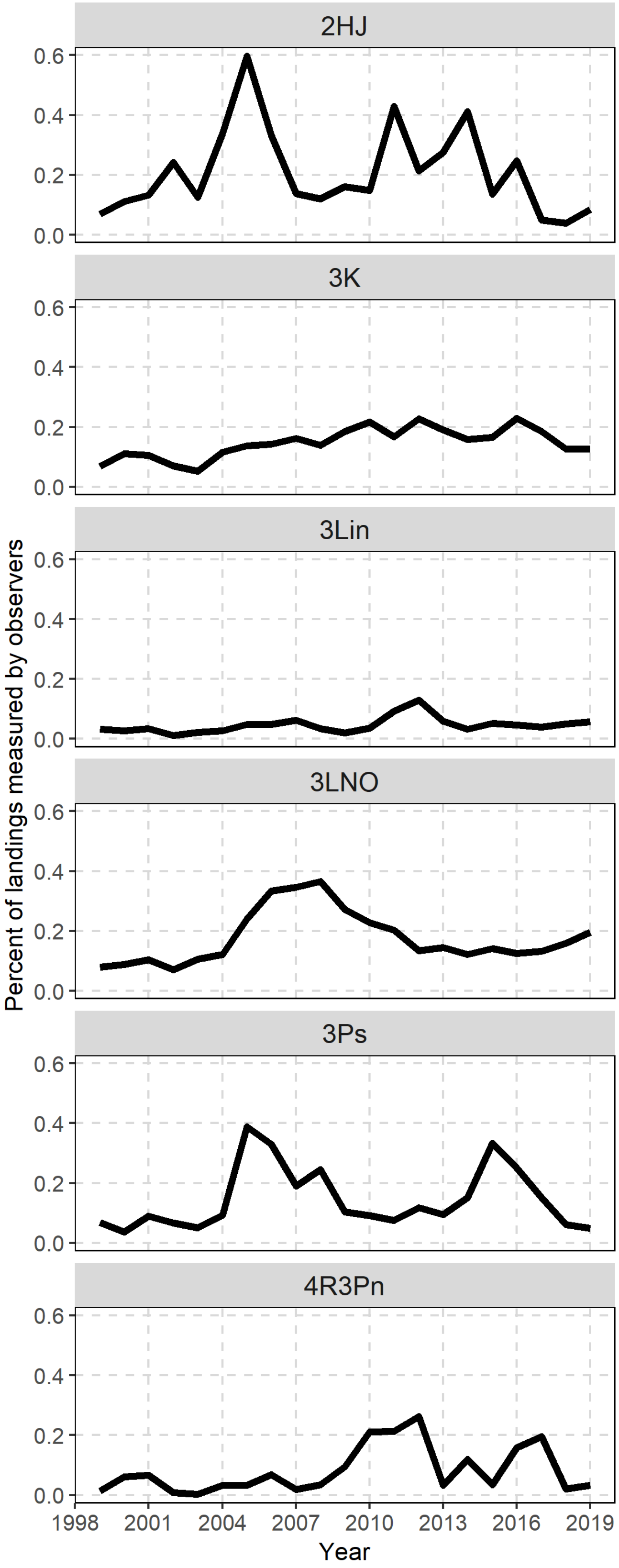

Figure 12. Percent of landings with annual observer sampling by AD (1999–2019).

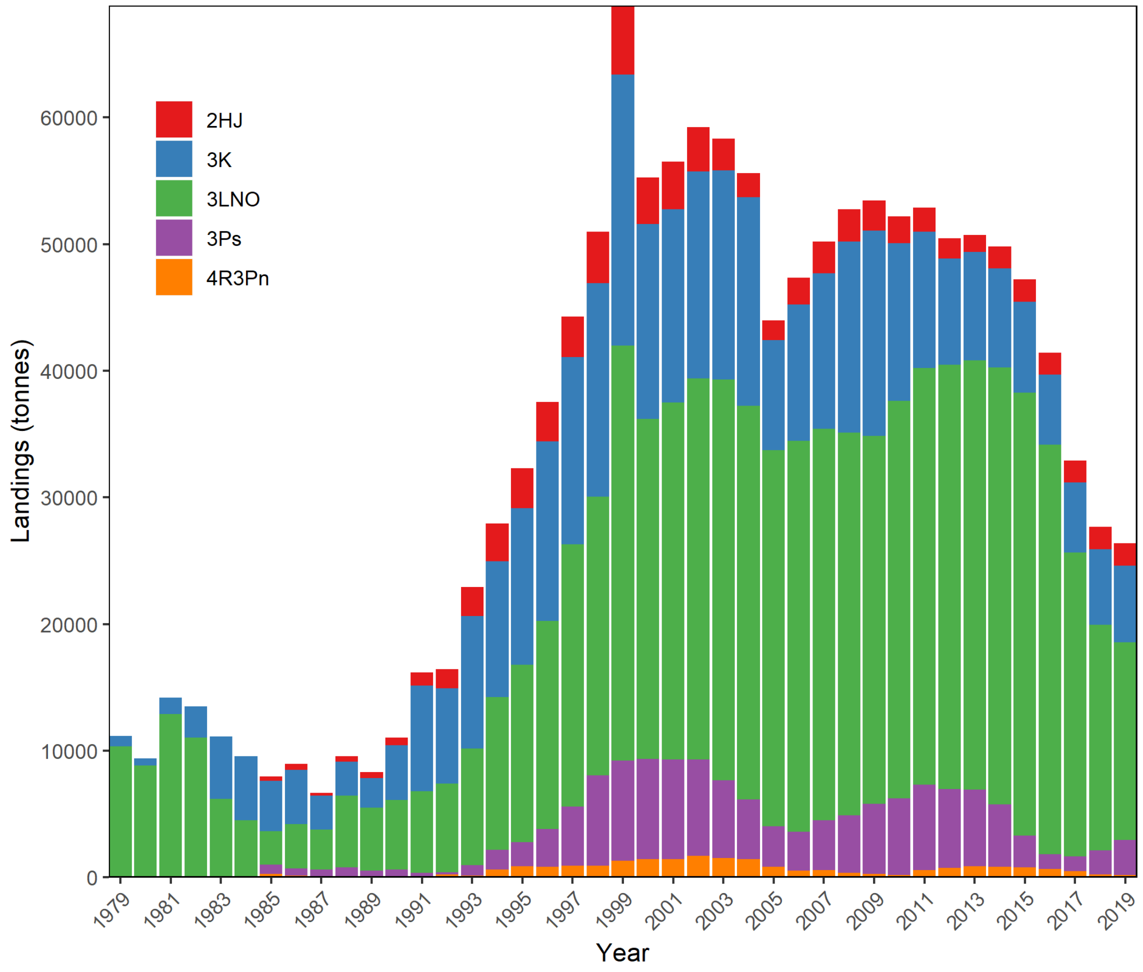

Figure 13. Annual landings (tonnes) of Snow Crab by AD (3LNO = 3LNO Offshore + 3L Inshore) (1979–2019).

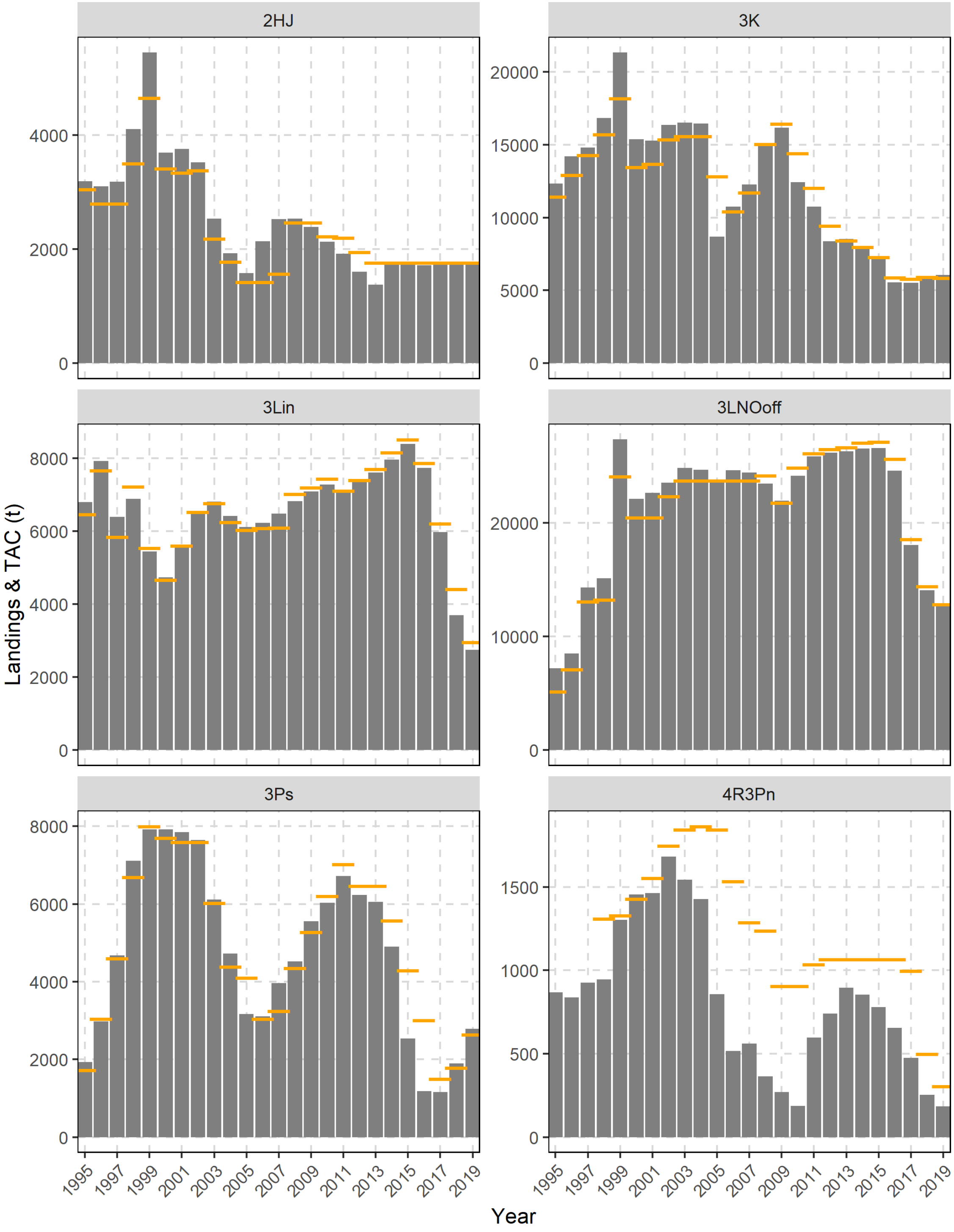

Figure 14. Annual landings (grey bars) of Snow Crab and TAC (yellow dashes) by AD from 1995 to 2019.

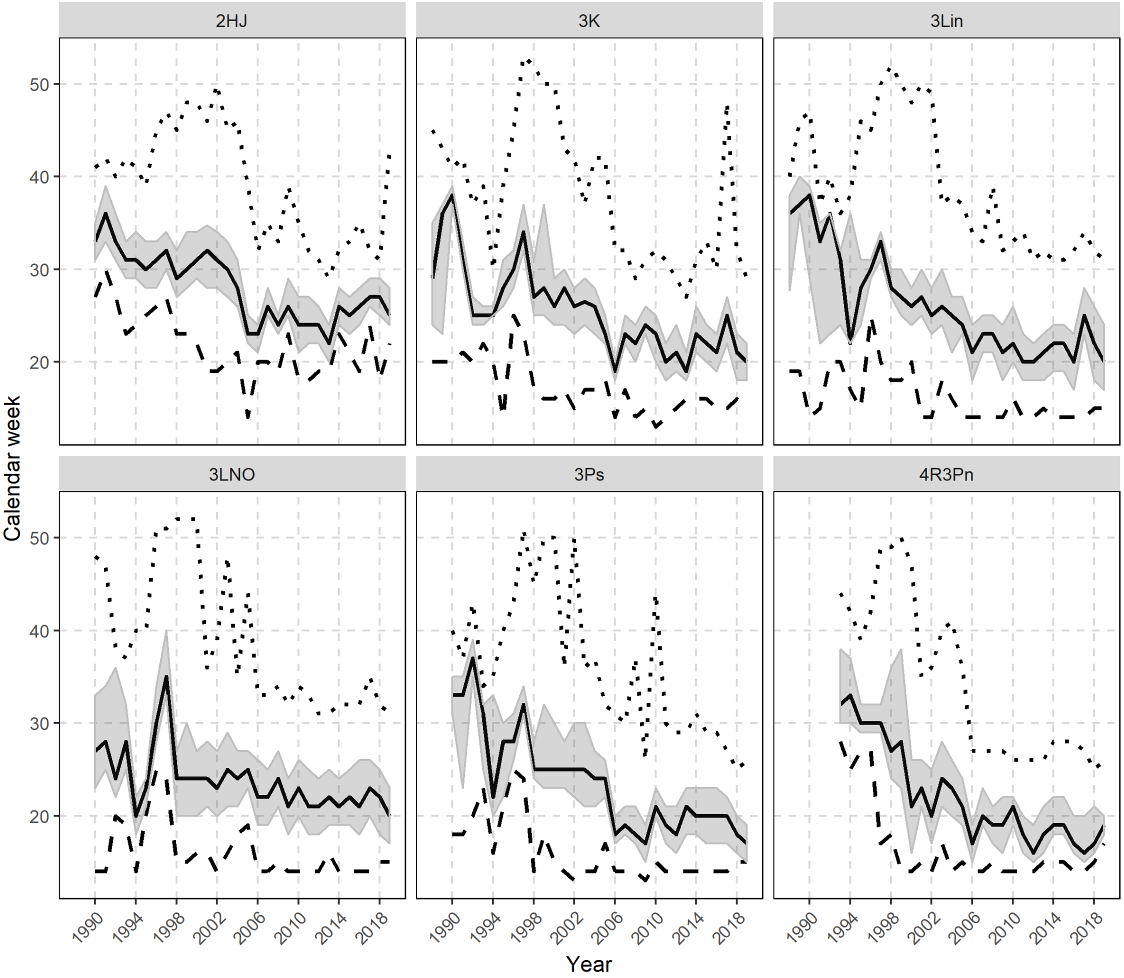

Figure 15. Trends in timing of the fishery by AD. Solid line = median timing of fishery, Dashed line = start of fishery, Dotted line = end of fishery, Shaded area = fishery 25–75% complete.

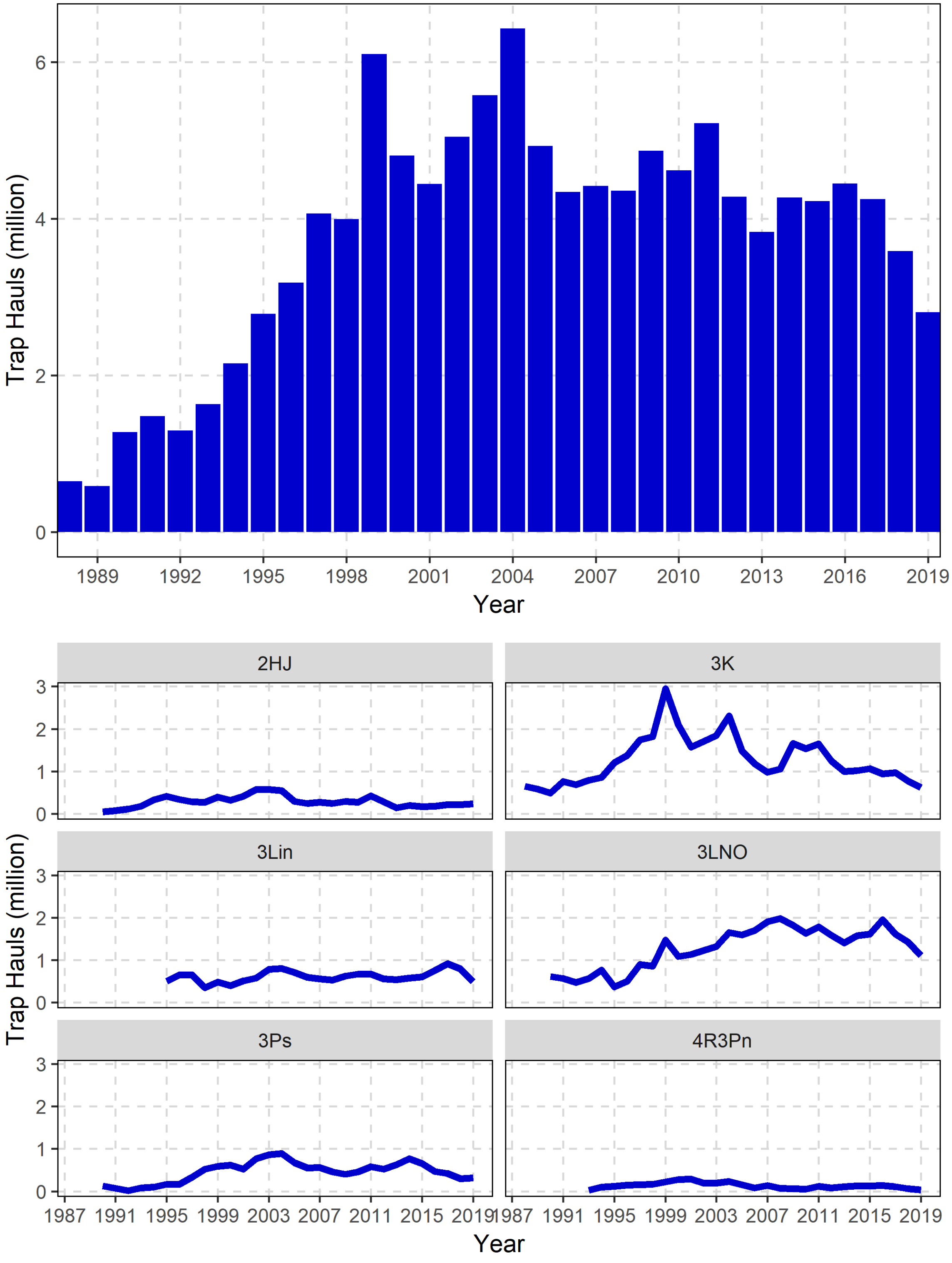

Figure 16. Estimated effort (number of trap hauls) by AD and in total, by year (1988–2019).

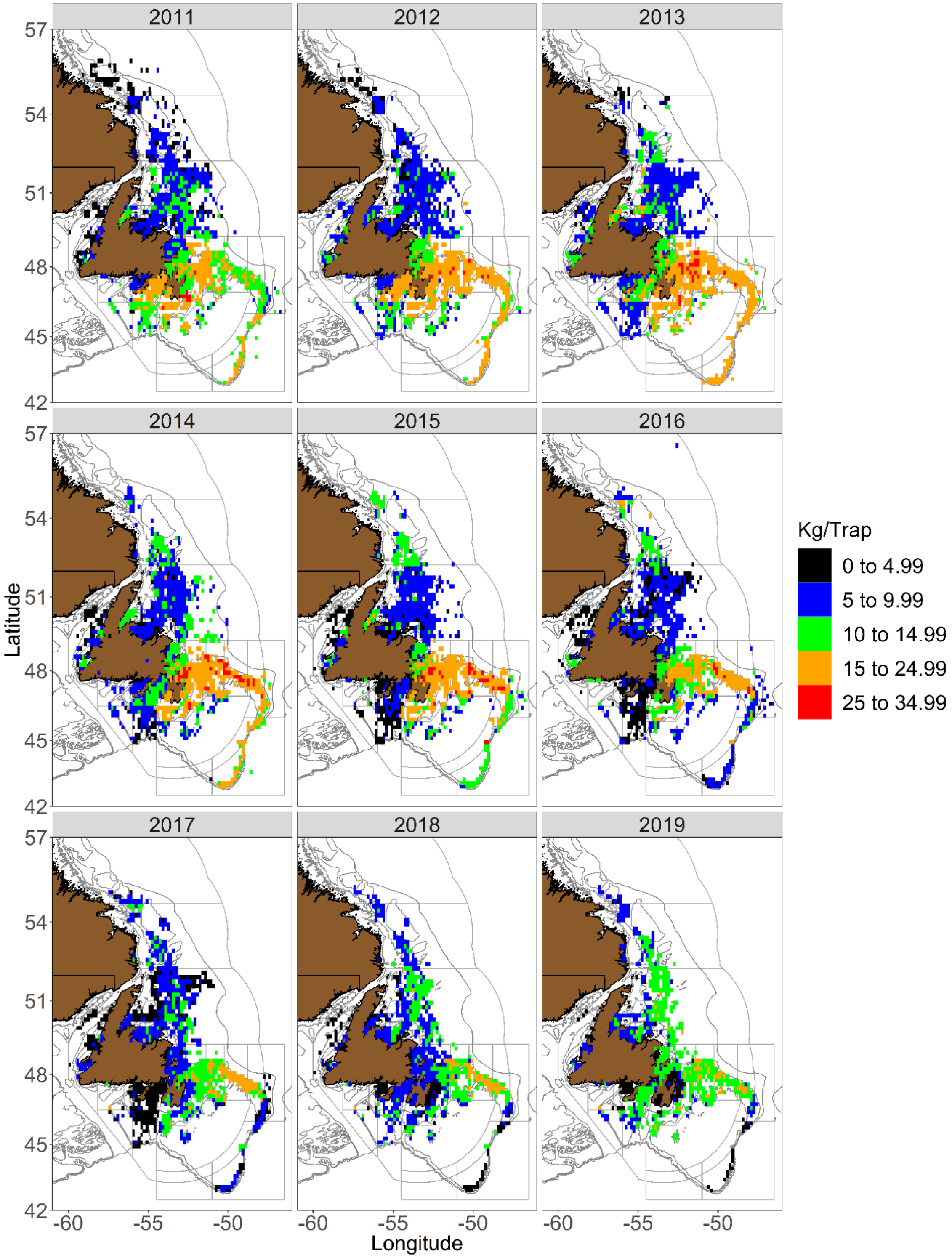

Figure 17. Locations of fishery sets and catch rates (kg/trap) from commercial logbooks (2011–19).

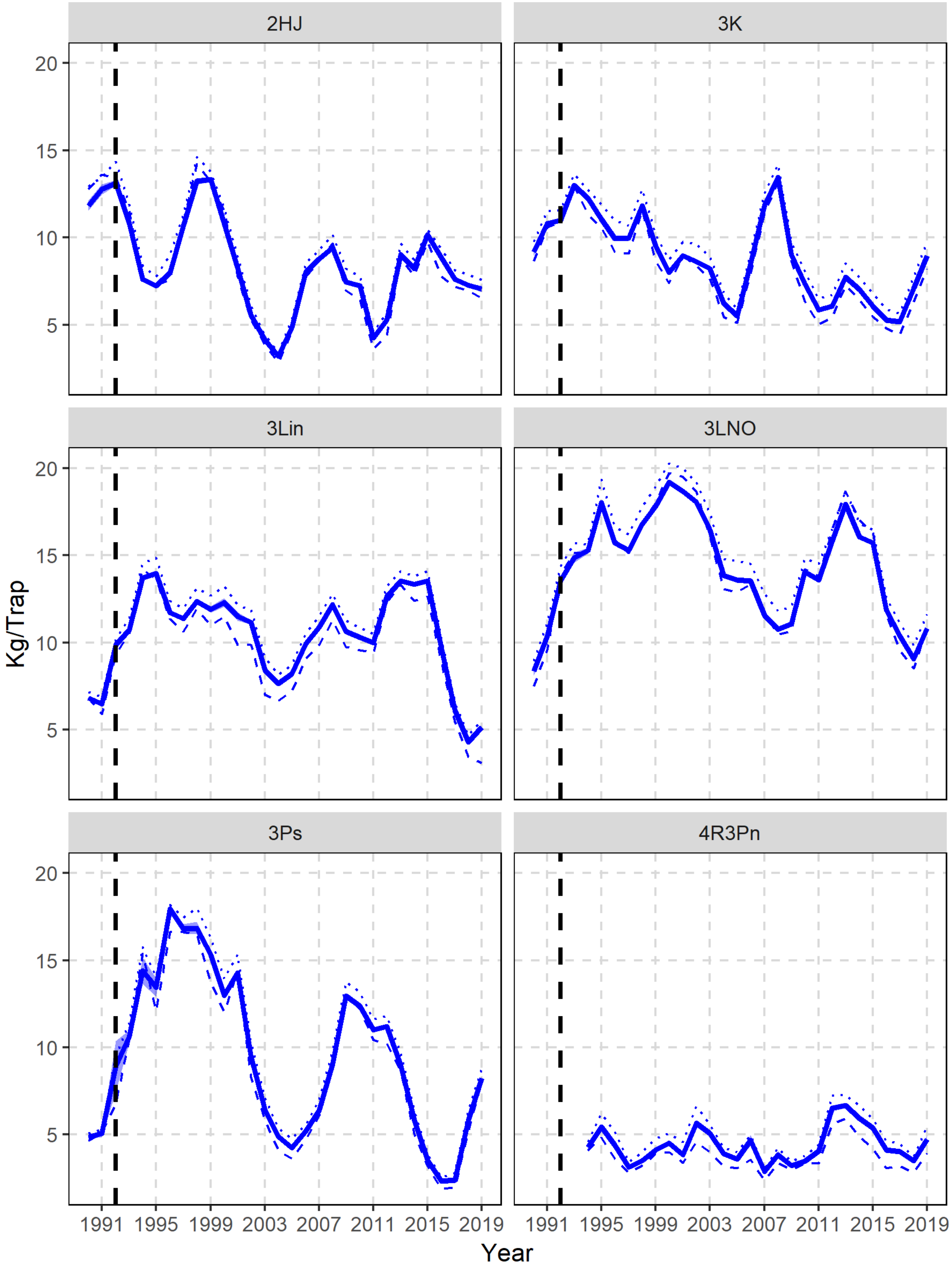

Figure 18. Standardized CPUE (kg/trap) by AD. Solid line is average predicted CPUE and shaded band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

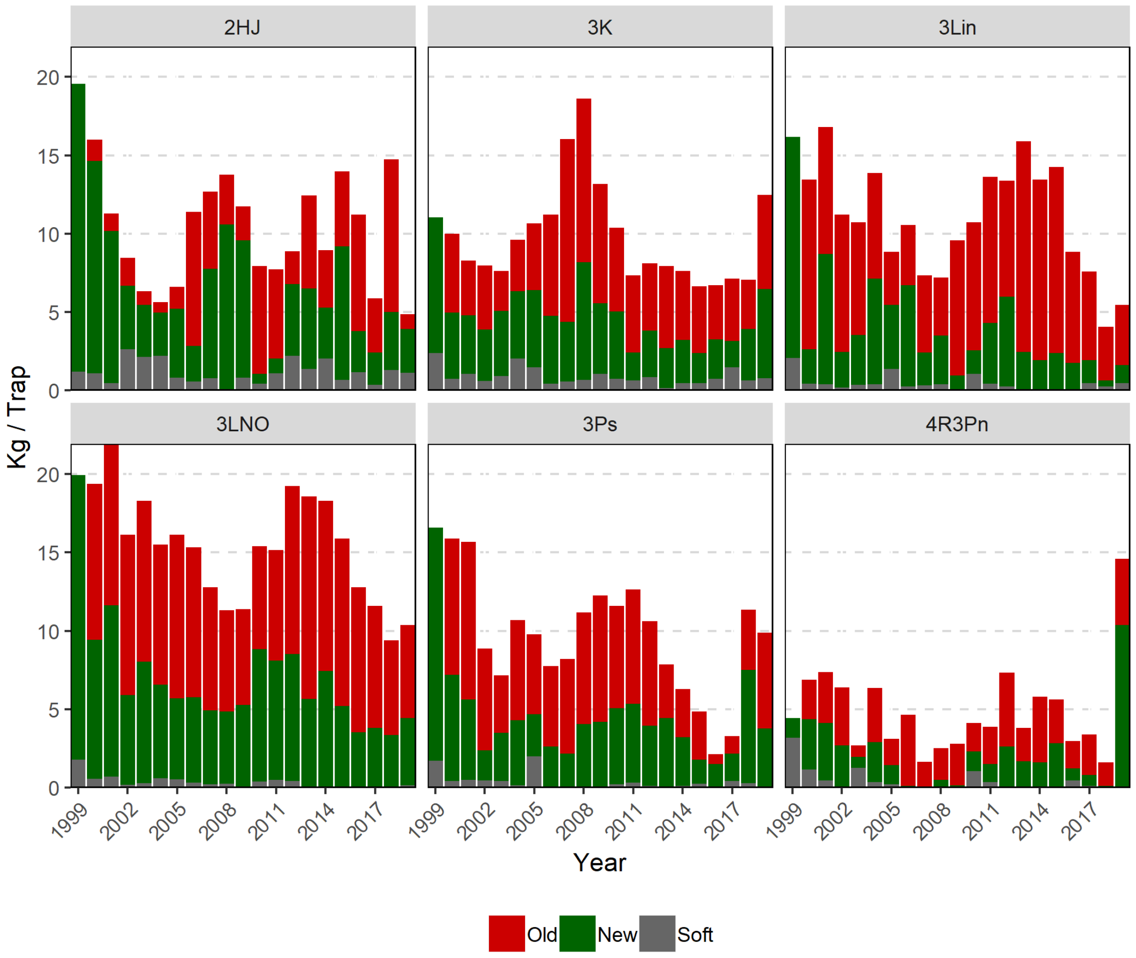

Figure 19. Trends in catch rates (kg/trap) of legal-sized Snow Crab by shell condition from observer at-sea sampling by AD (1999–2019).

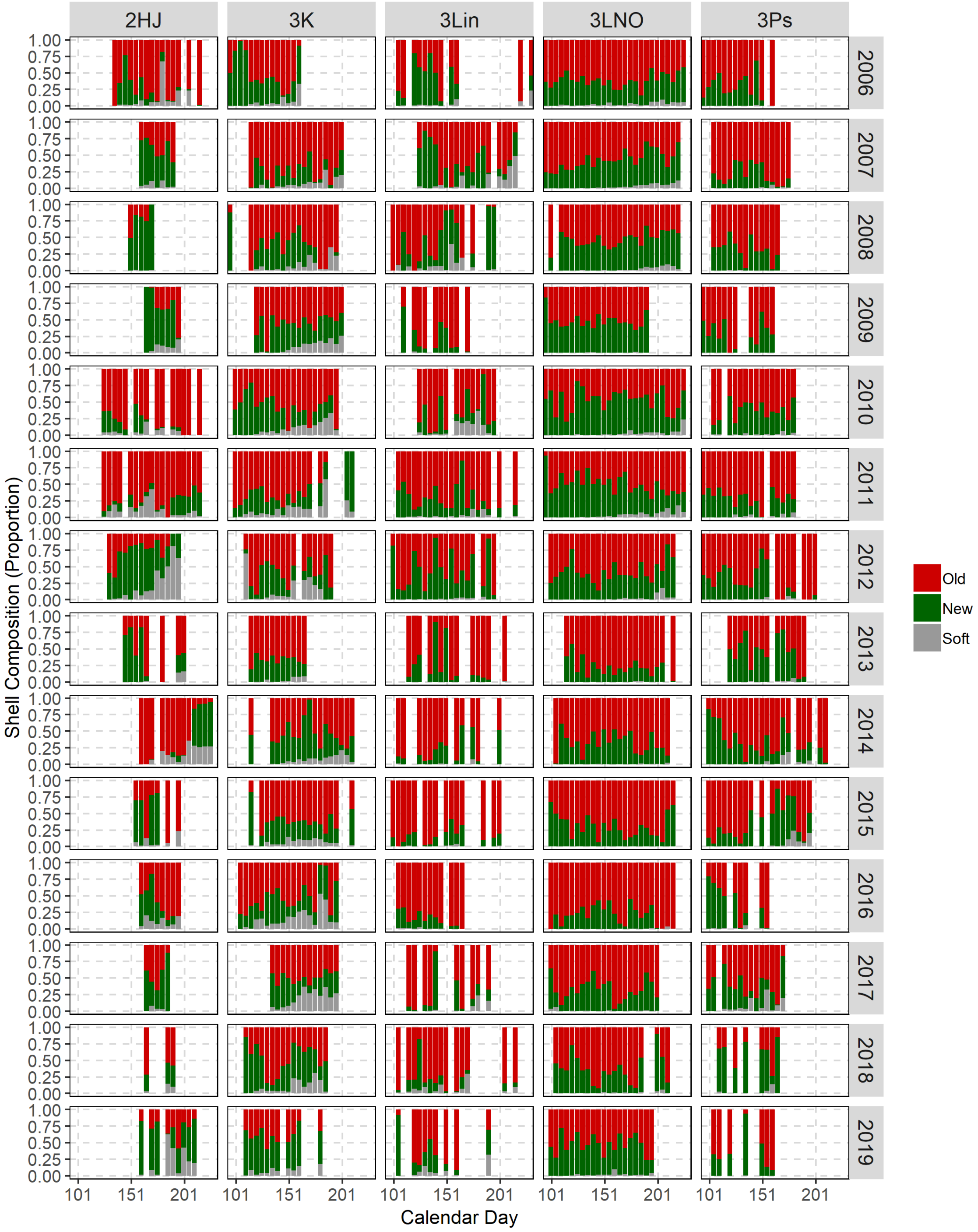

Figure 20. Proportion of legal-sized Snow Crab by shell condition from observer at-sea sampling throughout fishing season (binned in 5-day increments) by AD (2006–19).

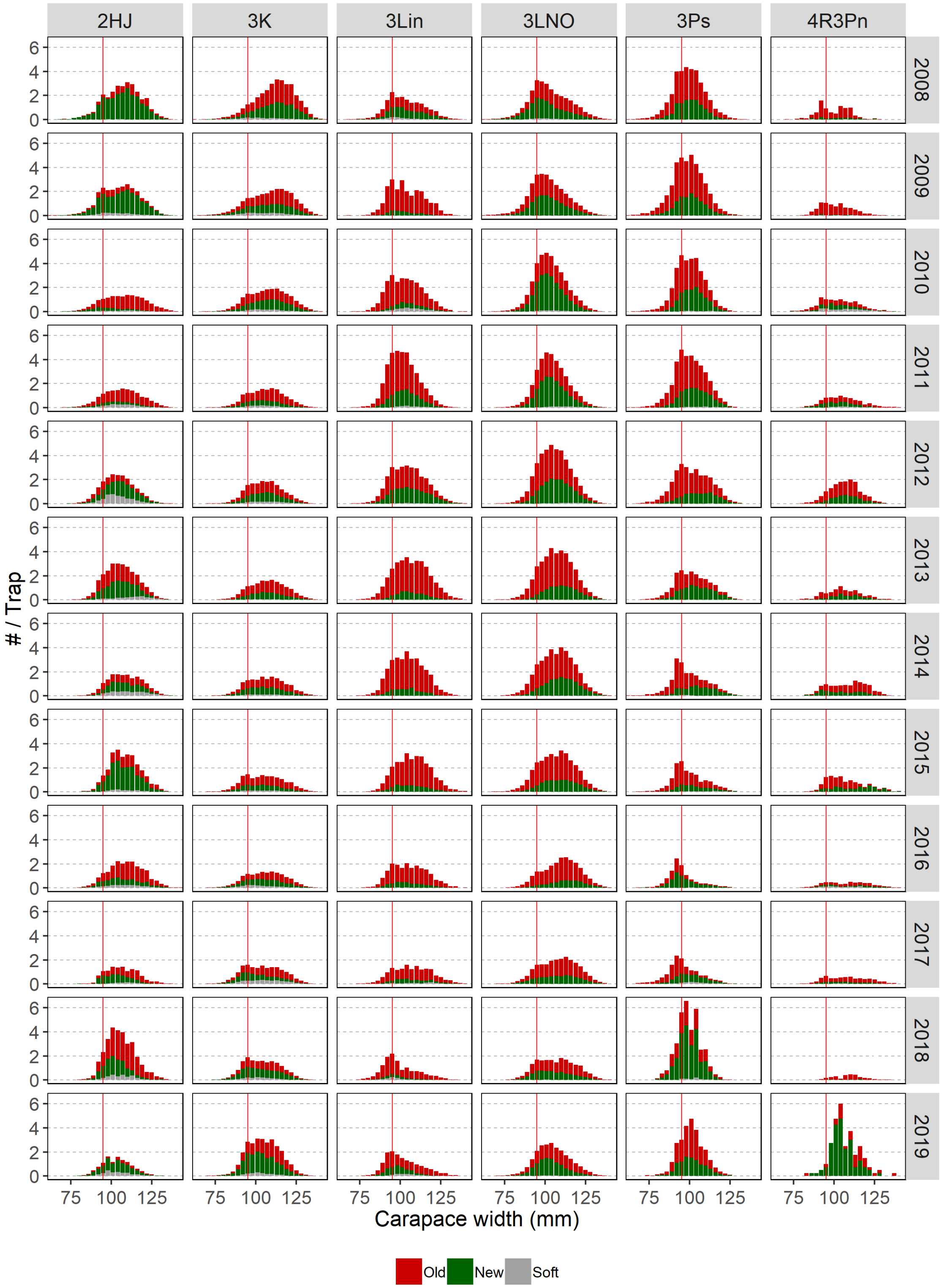

Figure 21. Catch rates (#/trap) of male Snow Crab based on carapace width distributions by shell condition from observer at-sea sampling in each AD (2008–19). The red vertical line indicates the minimum legal size.

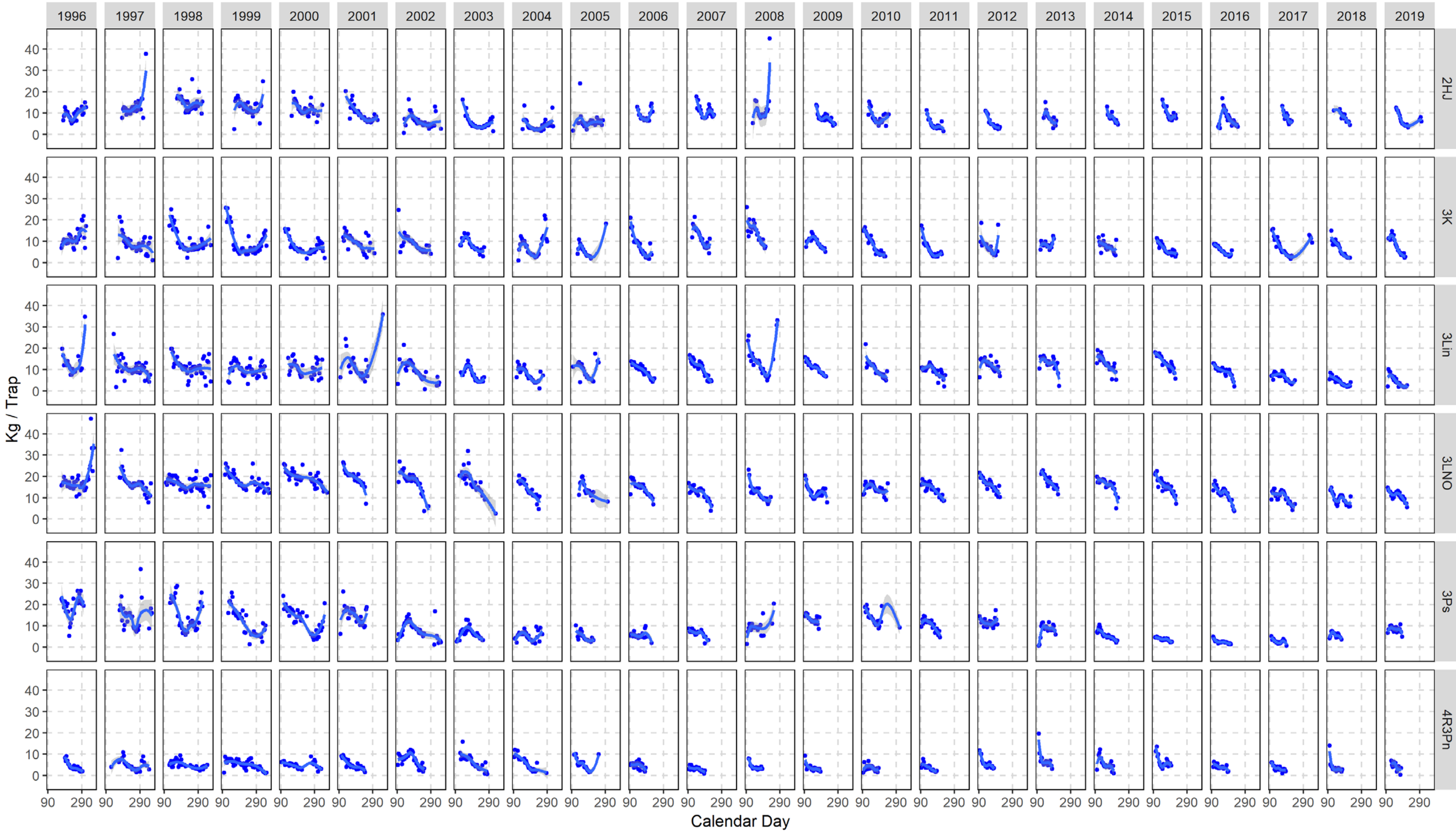

Figure 22. Unstandardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each AD (1996–2019). Derived from logbooks. Points denote mean CPUE in 5-day increments and trend lines are loess regression curves.

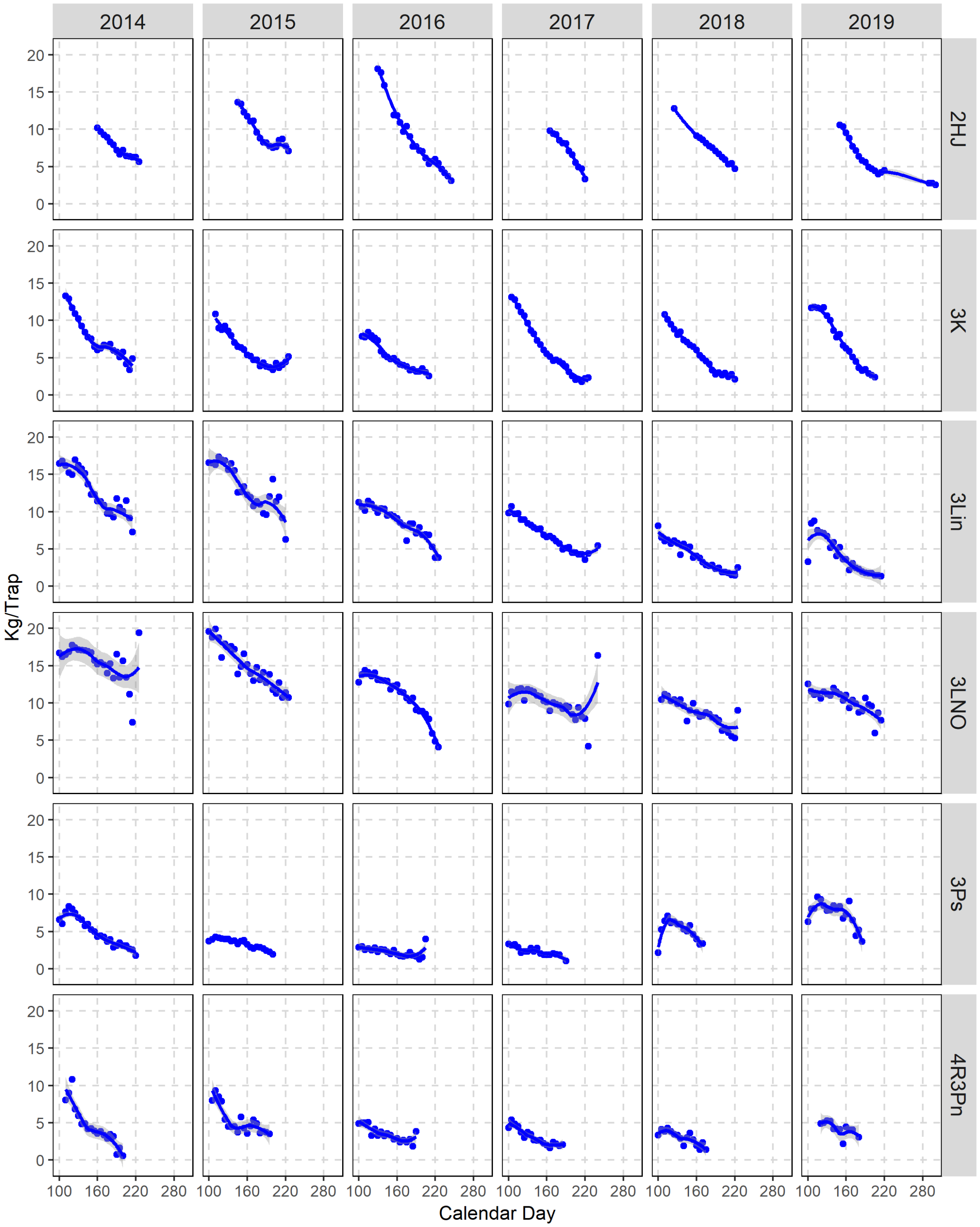

Figure 23. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each AD (2014–19). Derived from logbooks. Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

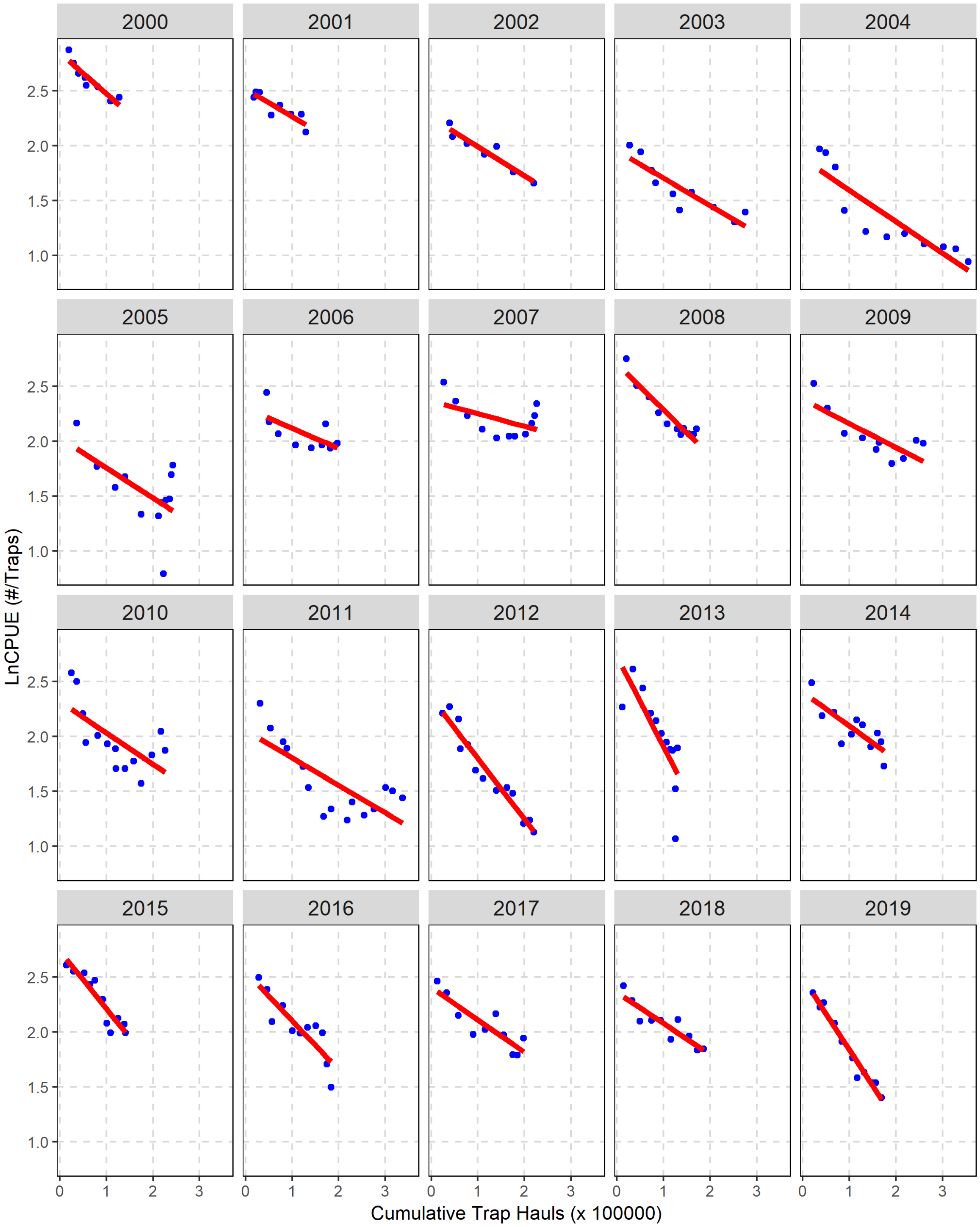

Figure 24. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in AD 2HJ (2000–19). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

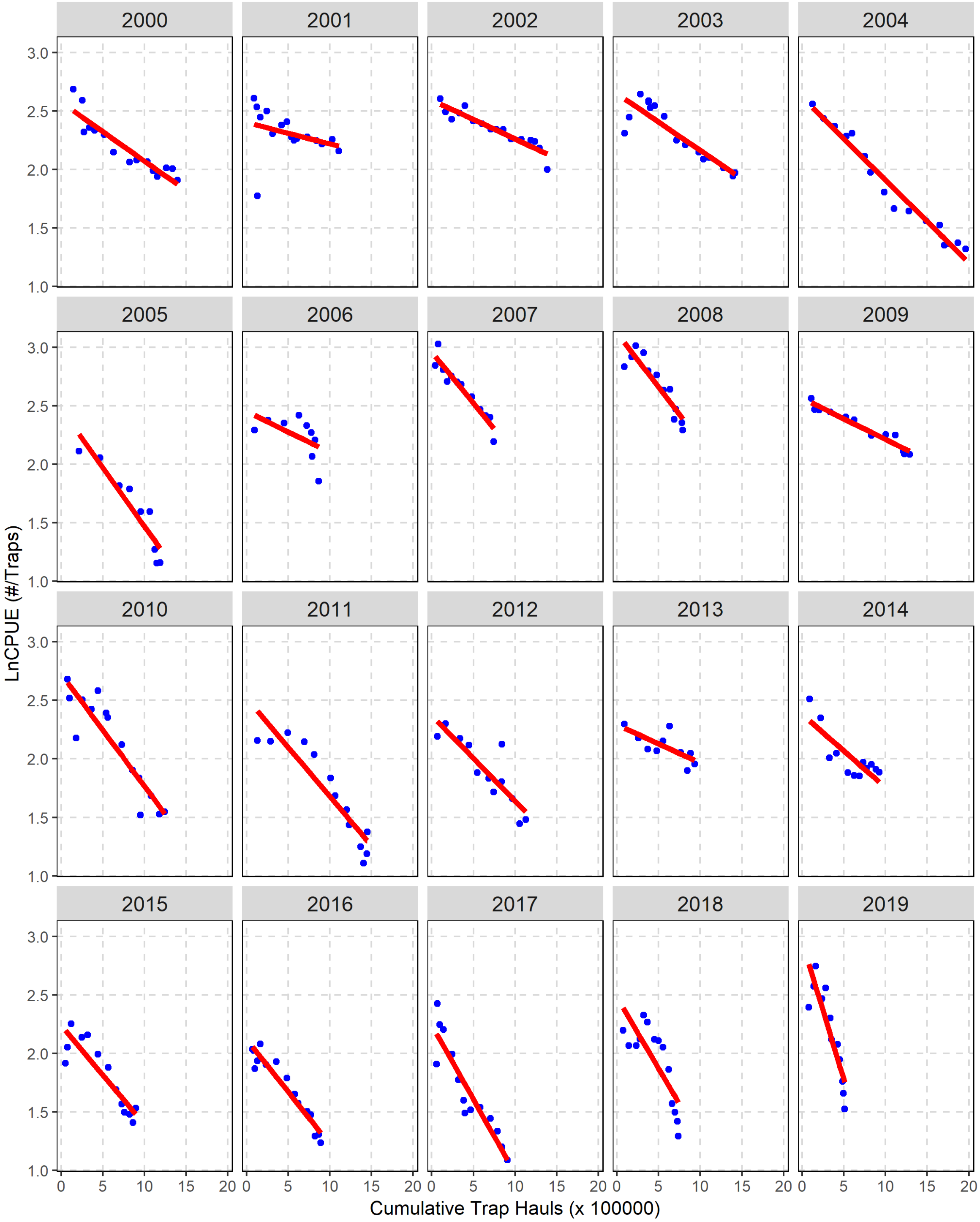

Figure 25. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in AD 3K (2000–19). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

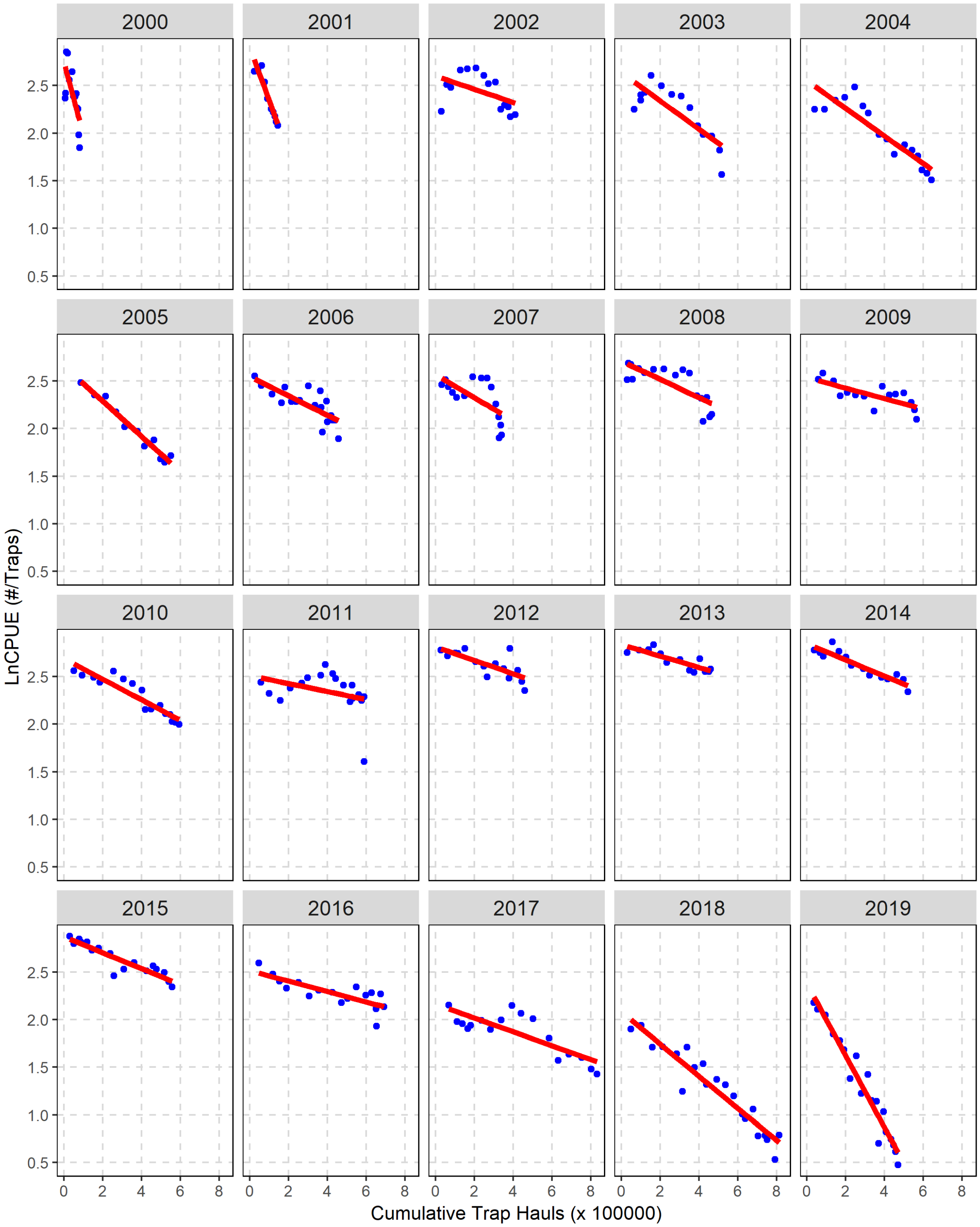

Figure 26. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in AD 3L inshore (2000–19). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

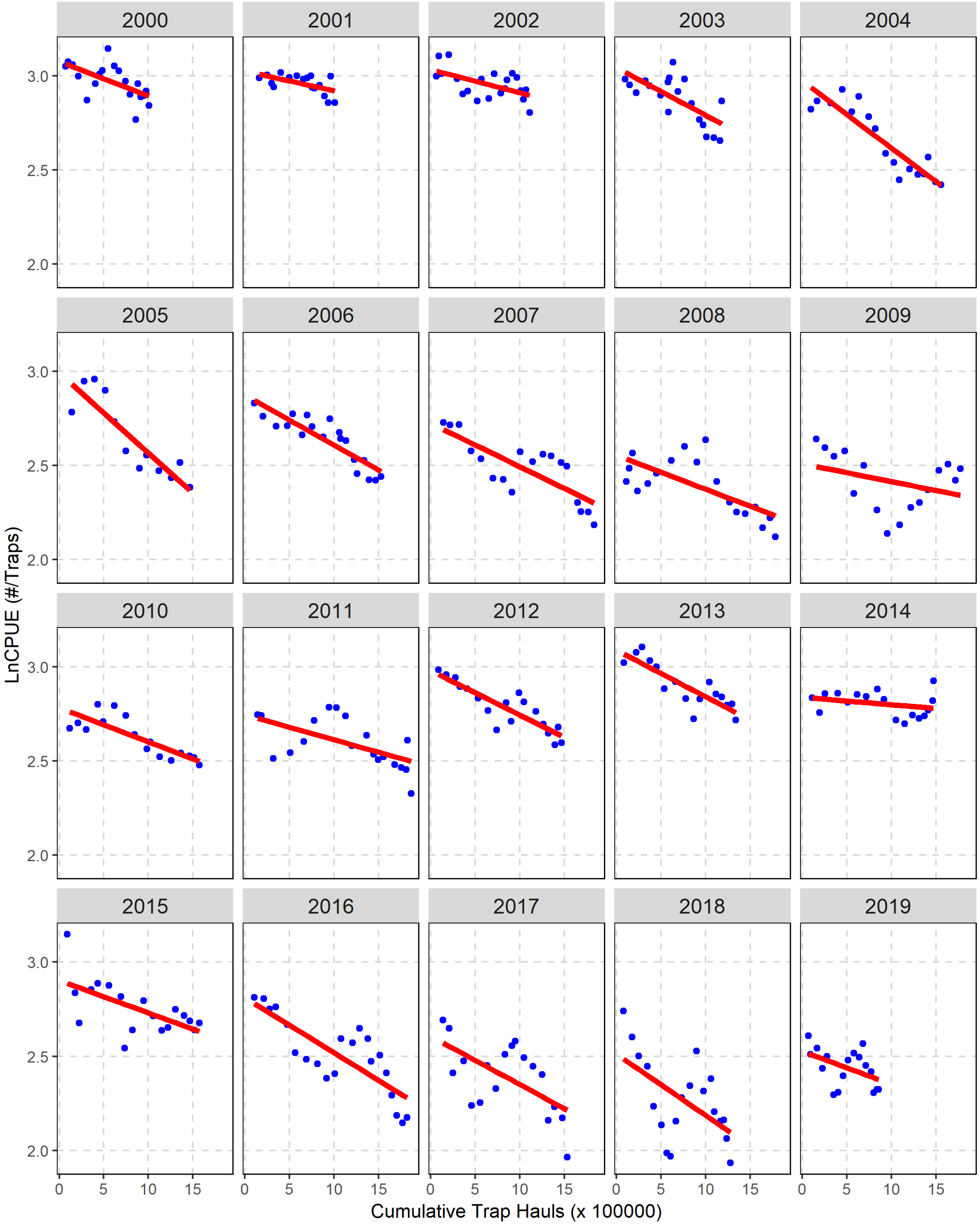

Figure 27. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in AD 3LNO Offshore (2000–19). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

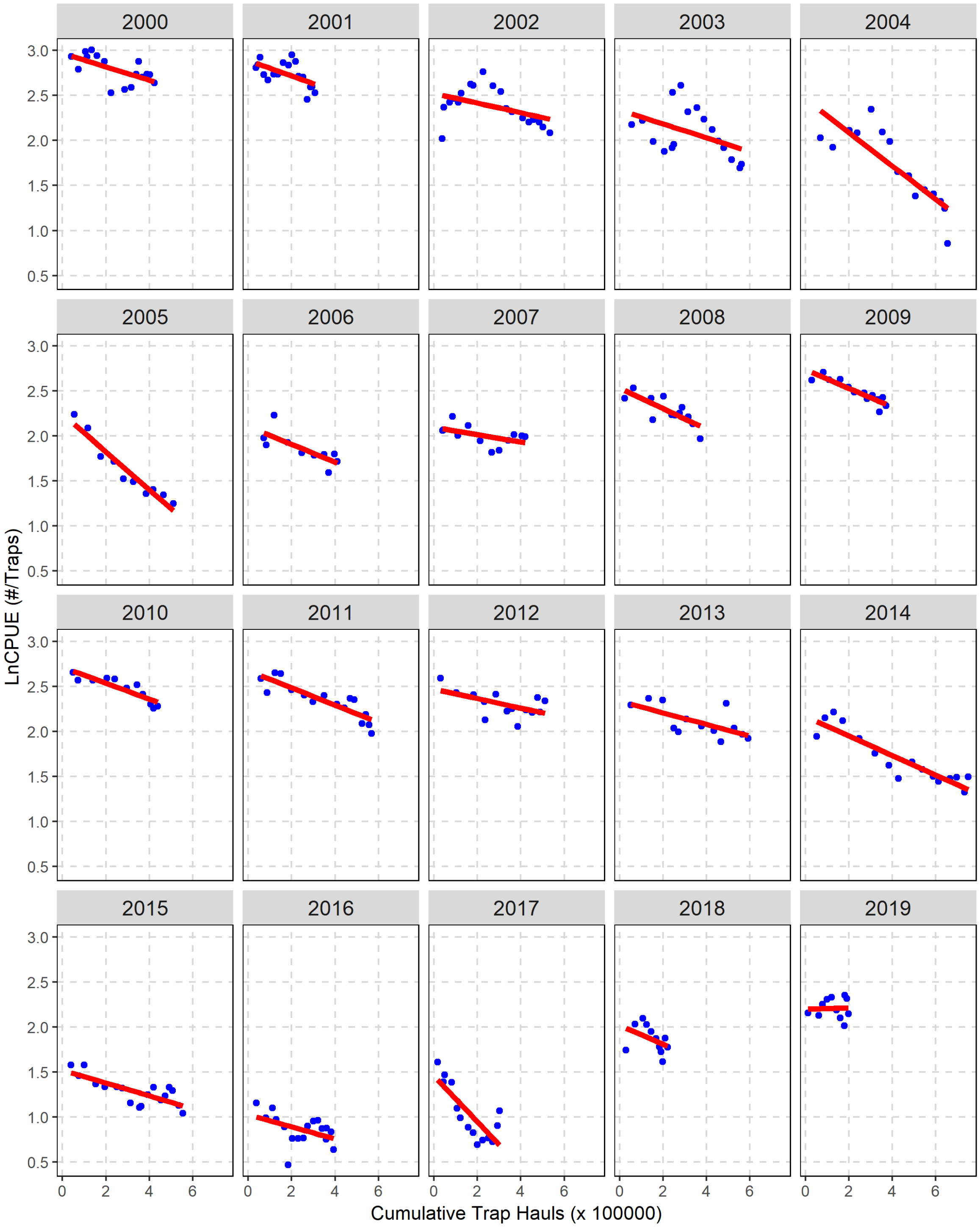

Figure 28. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in AD 3Ps (2000–19). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

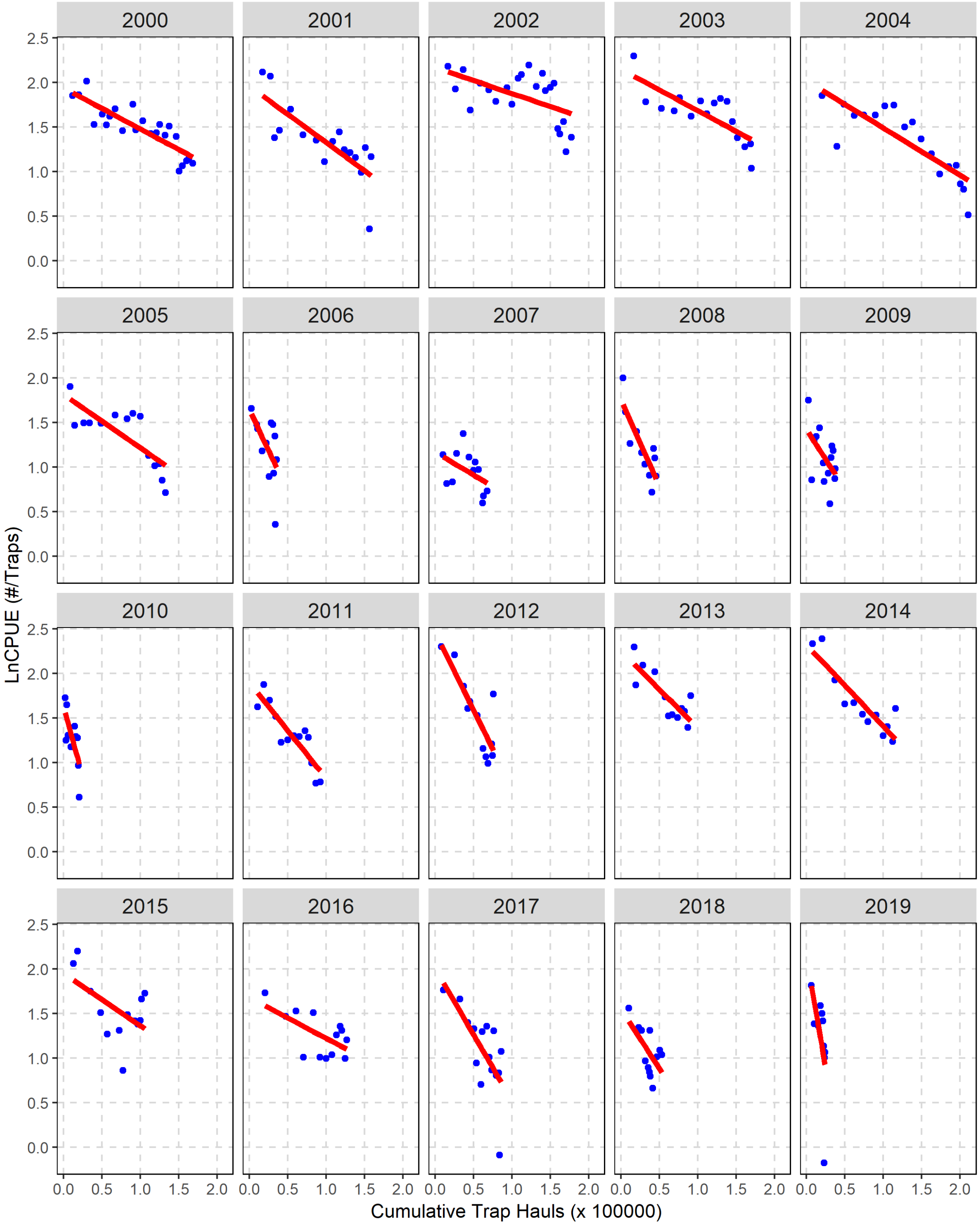

Figure 29. Fishery catch rate depletion regression models on 5-day increment catch rates from logbooks in AD 4R3Pn (2000–19). Blue points represent unstandardized catch rates and red line is fitted Delury depletion estimates.

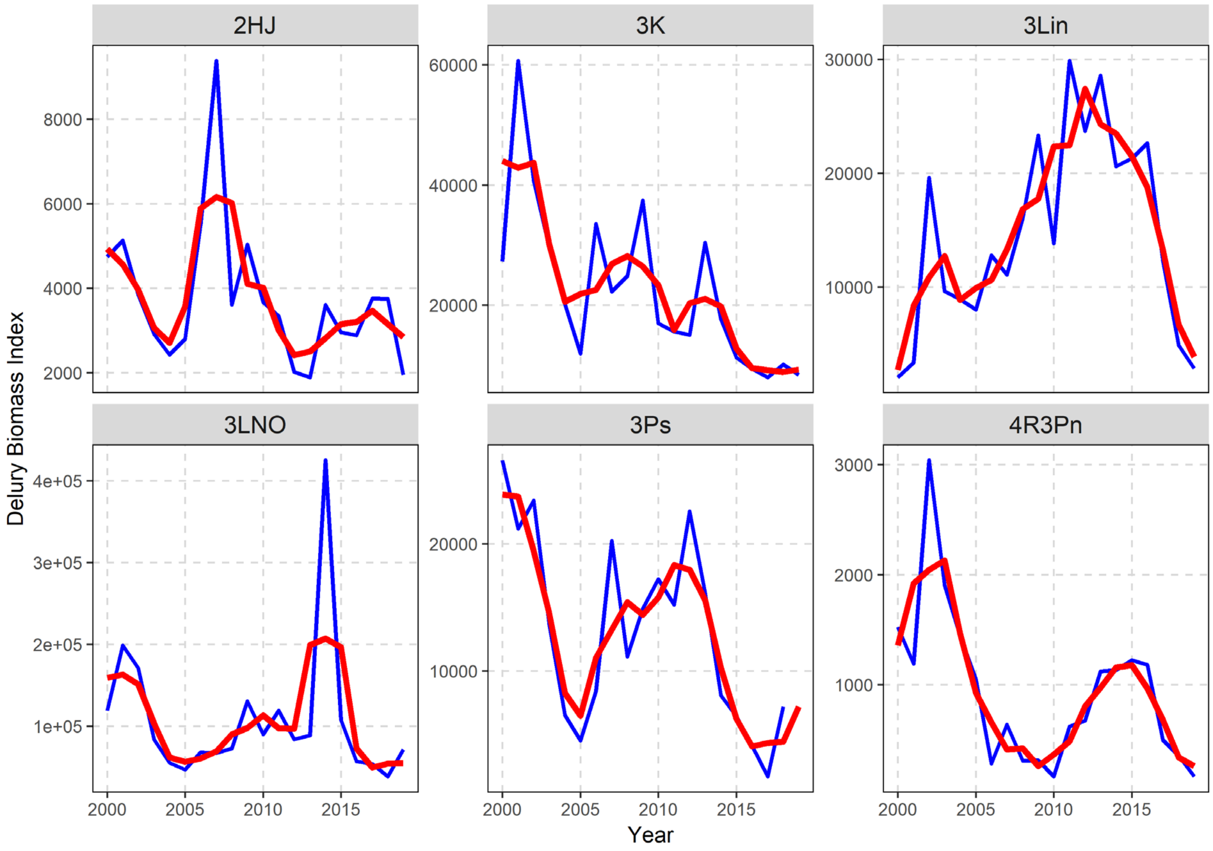

Figure 30. Fishery depletion model biomass estimates (t) of exploitable Snow Crab from logbooks (blue) and 3-year centered moving averages (red) in each AD (2000–19).

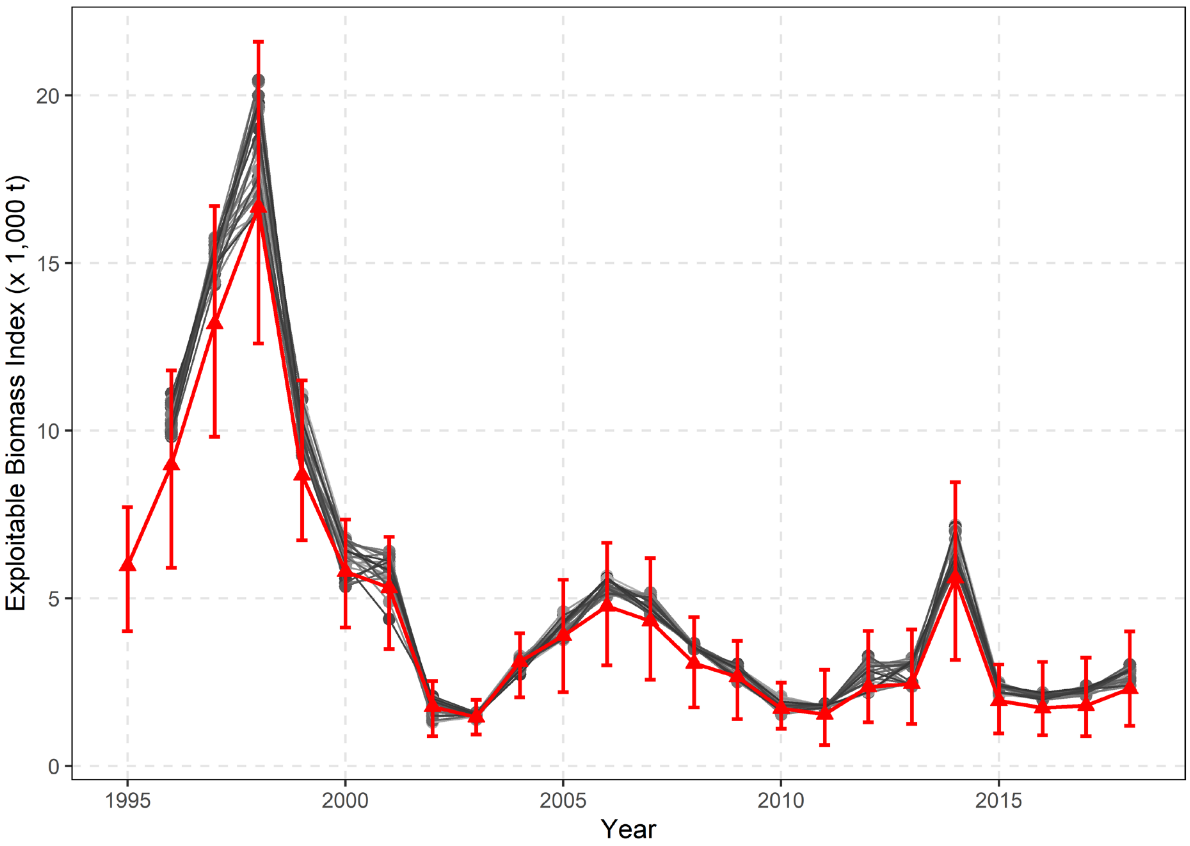

Figure 31. EBI for 25 test datasets with 2019 fall multispecies survey coverage (gray lines) and the EBI presented in the 2018 stock assessment (red lines) in AD 2HJ.

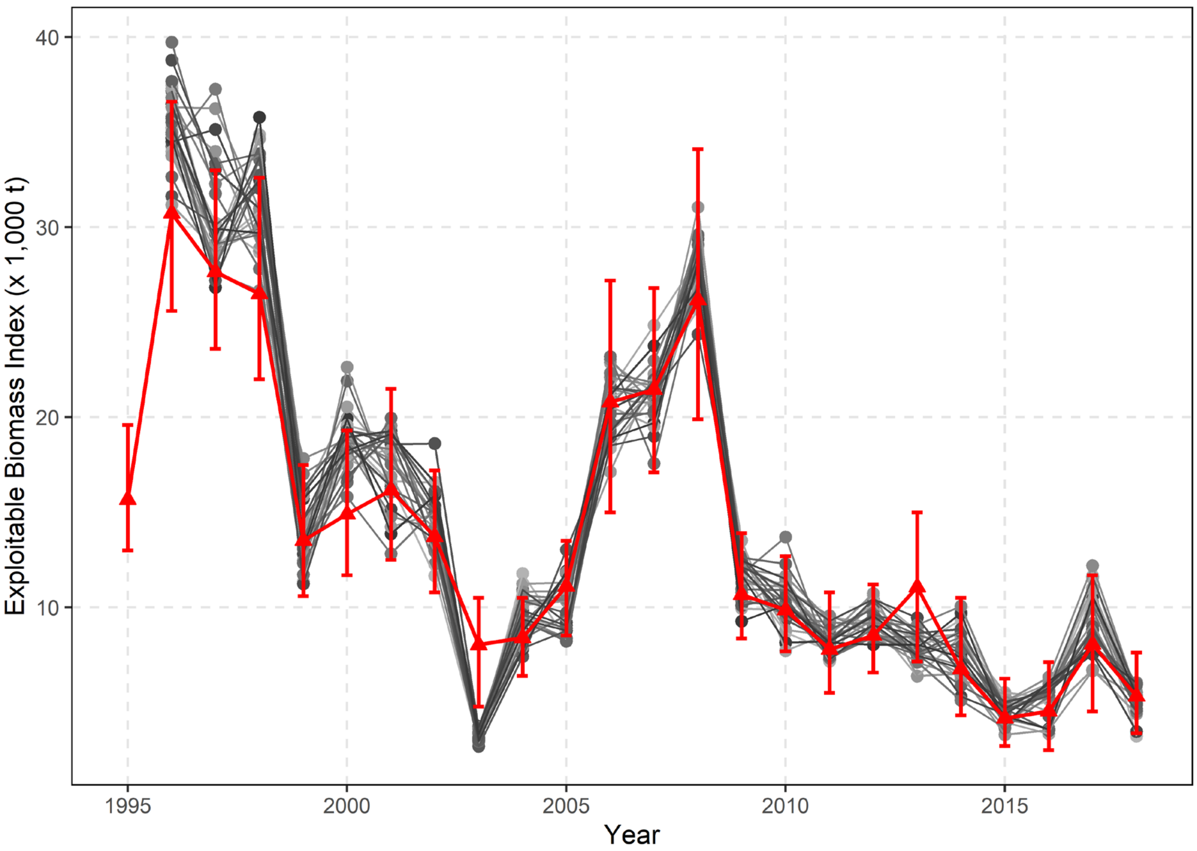

Figure 32. EBI for 25 test datasets with 2019 fall multispecies survey coverage (gray lines) and the EBI presented in the 2018 stock assessment (red lines) in AD 3K.

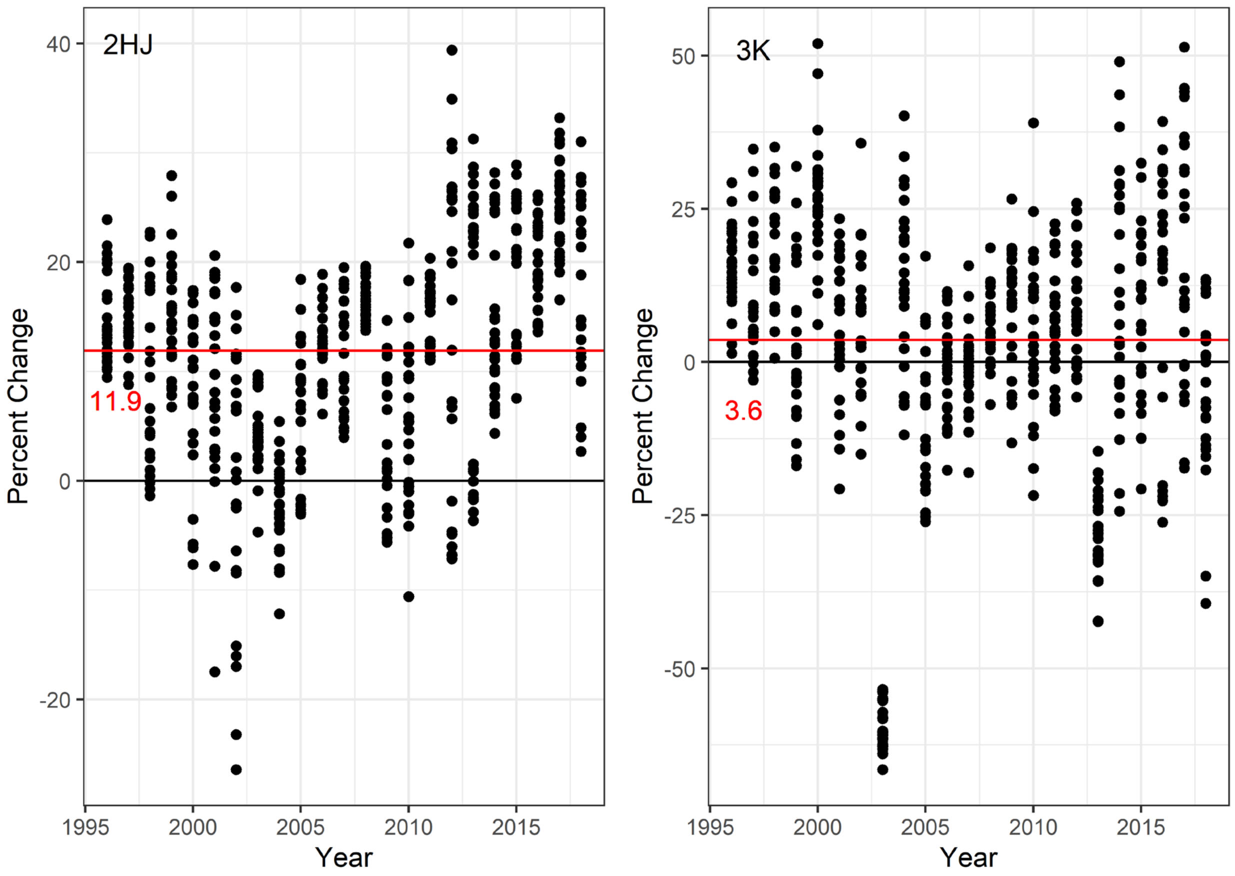

Figure 33. Percent change in EBI for 25 test datasets with 2019 fall multispecies survey coverage from the EBI presented in the 2018 stock assessment (1995–2018) in AD 2HJ (left) and 3K (right). Red line denotes mean % change over the time series.

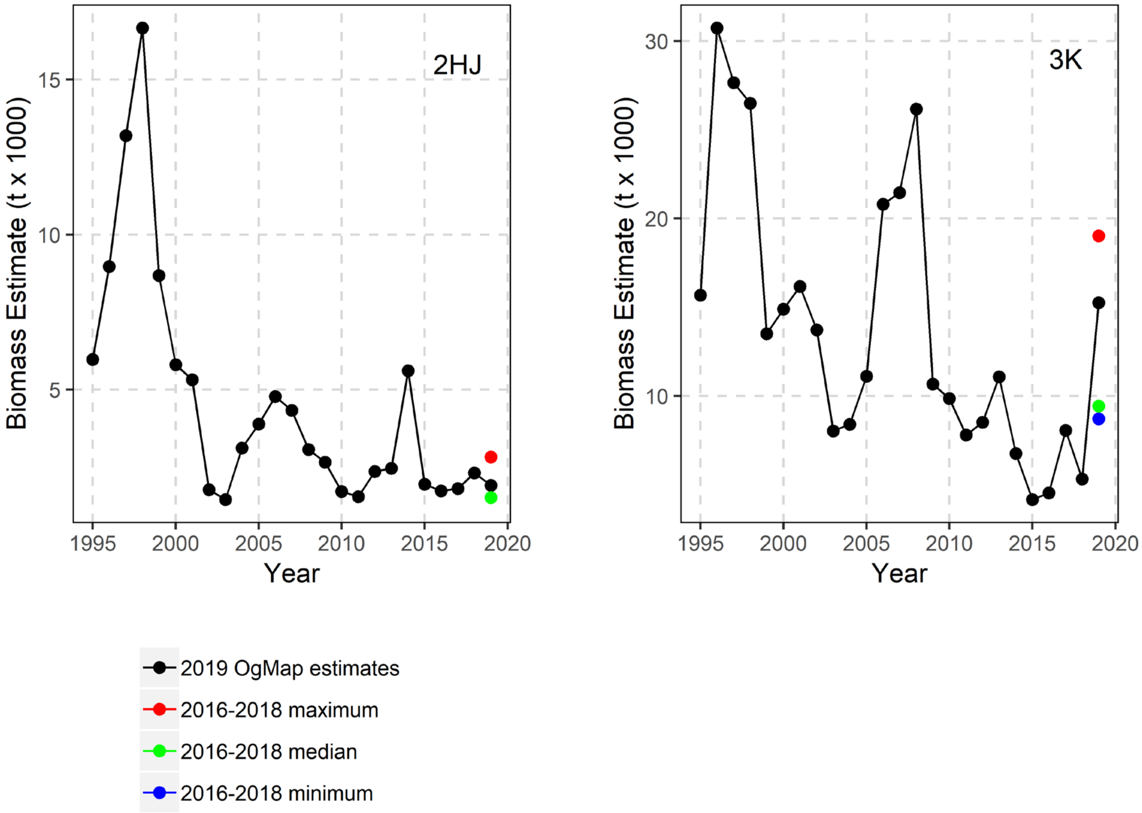

Figure 34. Comparison of exploitable biomass estimates presented in the current stock assessment with test datasets using 2016–18 minimum, median, and maximum biomass estimates to fill in missing 2019 survey sets in AD 2HJ (left) and 3K (right).

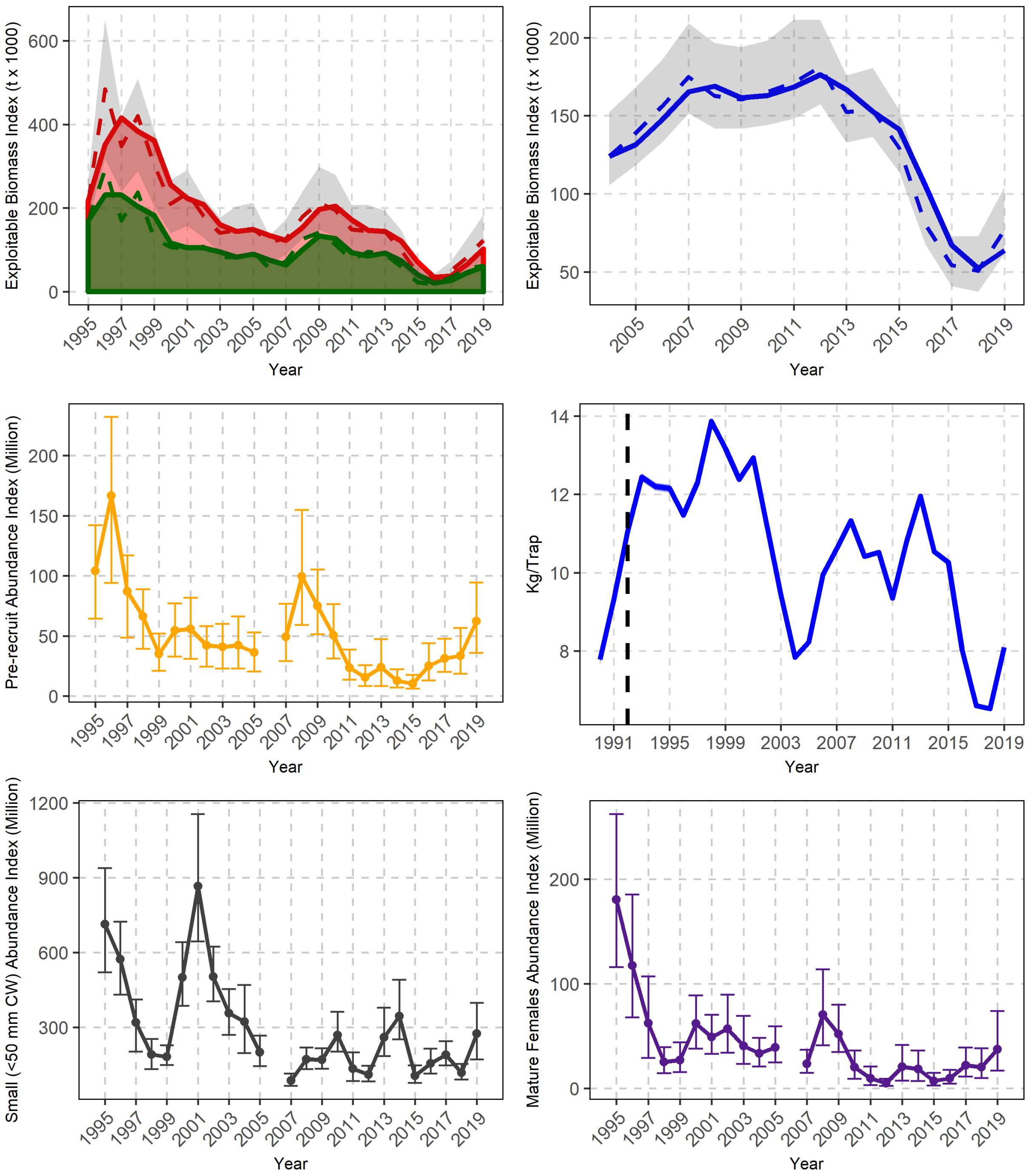

*Figure 35. Summary of Snow Crab stock status in AD 2HJ3KLNOP4R: **Top-left**: Annual EBI (t*1,000) by shell condition (1995–2019) based on trawl surveys. Shaded coloured area is 2-year moving average of biomass and dashed line is annual estimate (red = residuals, green = recruits). Shaded grey 95% CIs apply to annual estimates. **Top-right**: Trap survey-based EBI (2004–2019). Solid line is 2-year moving average, dashed line is annual estimate, and shaded area is the 95% confidence intervals. **Middle-left**: Pre-recruit index (# million) from trawl surveys (1995–2019). **Middle-right**: Fishery CPUE (kg/trap) from commercial logbooks (1990–2019). **Bottom-left**: Annual abundance index (# million) of small crab (<50 mm carapace width) from trawl surveys (1995–2019). **Bottom-right**: Annual abundance index (# million) of mature female crab from trawl surveys (1995–2019).*

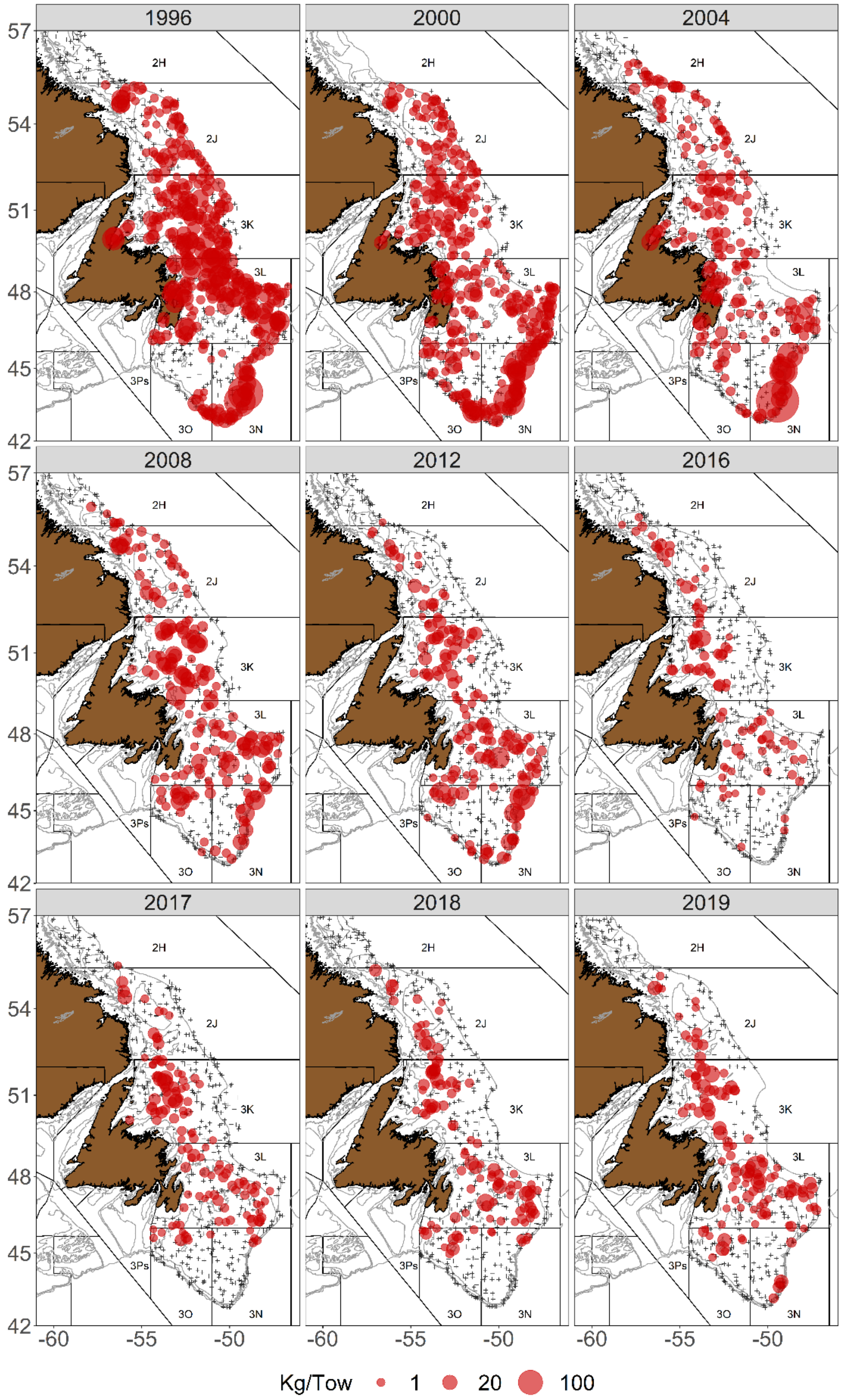

Figure 36. Distribution of exploitable males (kg/tow) from Divs. 2HJ3KLNO fall bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2016–19. Data standardized by vessel.

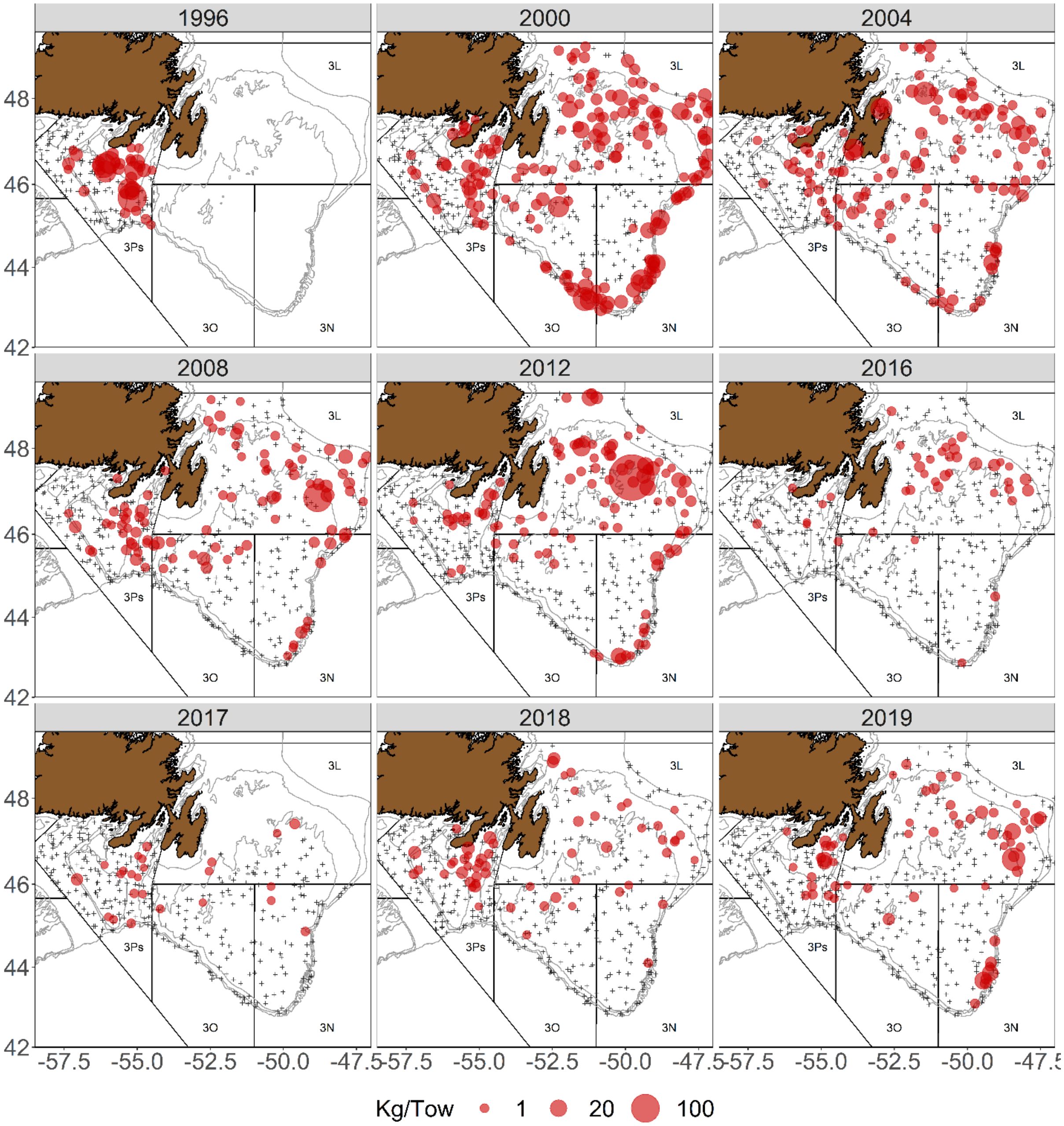

Figure 37. Distribution of exploitable males (kg/tow) from Divs. 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2016–19. Data standardized by vessel.

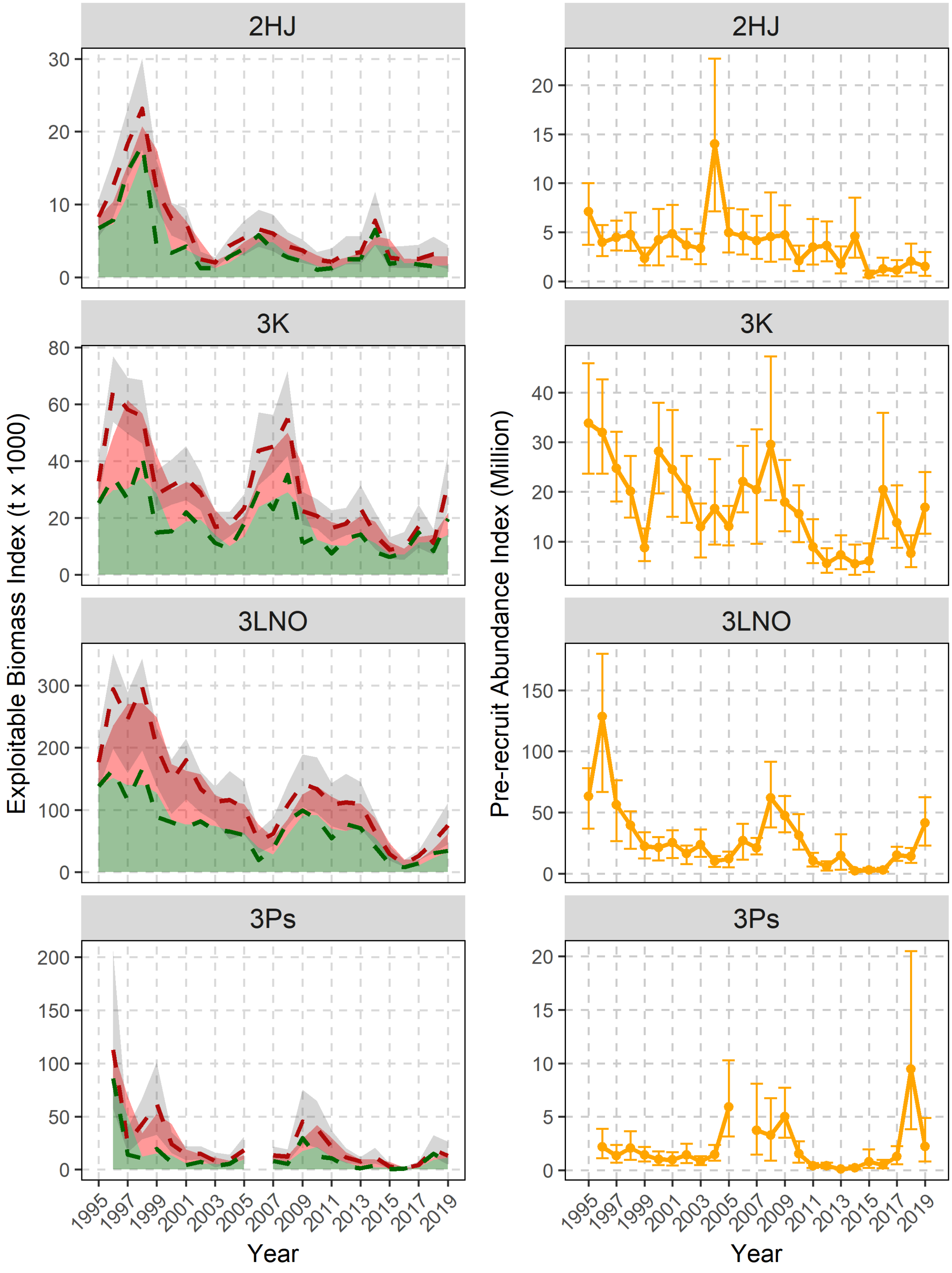

Figure 38. ***Left***: *Trawl survey exploitable biomass indices (t*1,000) by shell condition and AD. Shaded coloured area is 2-year moving average of biomass and dashed line is annual estimate (red = residuals, green = recruits). Shaded grey 95% CIs apply to annual estimates.* ***Right***: *Trawl survey pre-recruit abundance index (# million) by AD.*

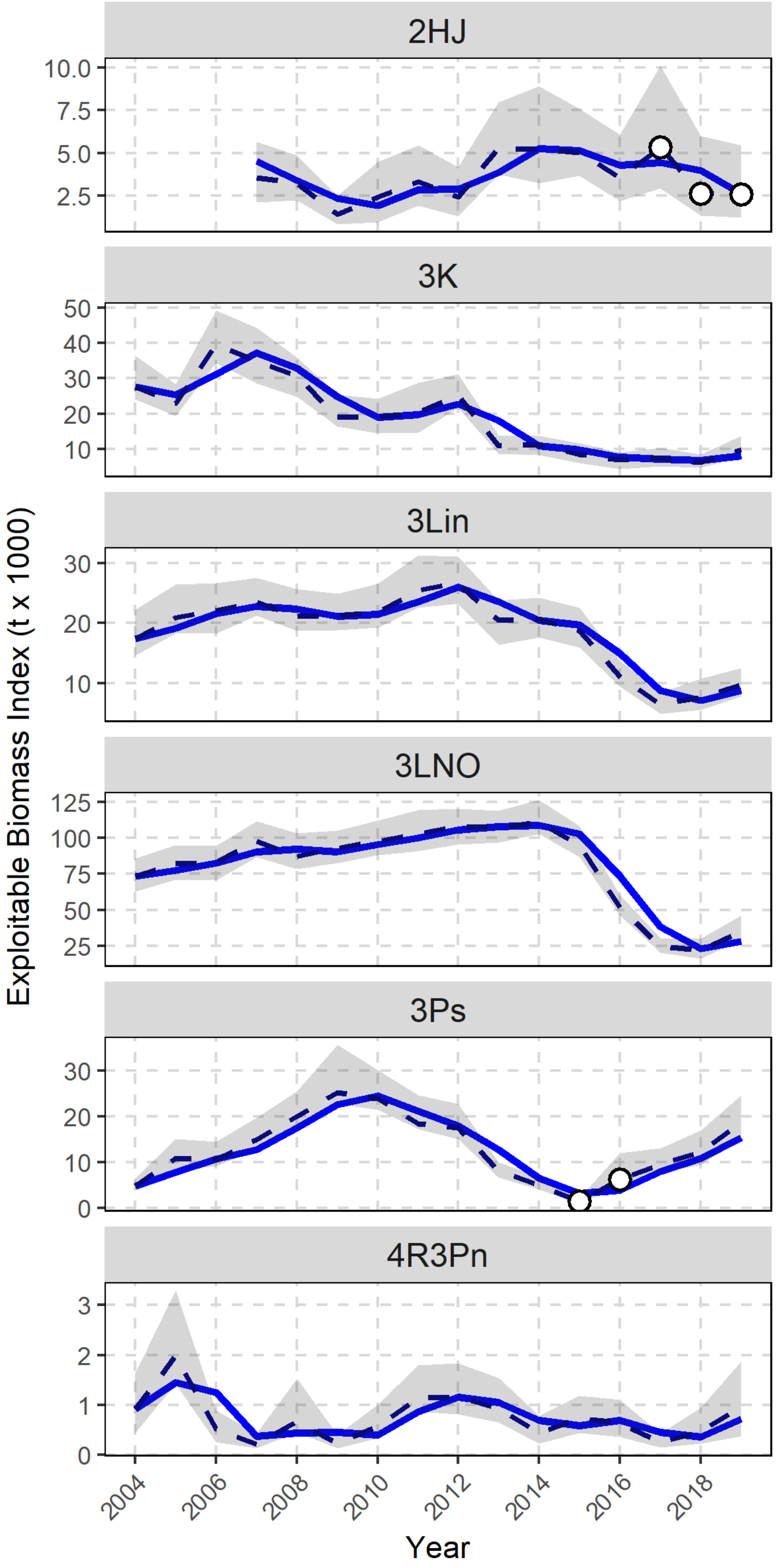

*Figure 39. Trap survey exploitable biomass indices (t*1,000) by AD (2004–19). Dashed line shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate. White dots depict incomplete surveys.*

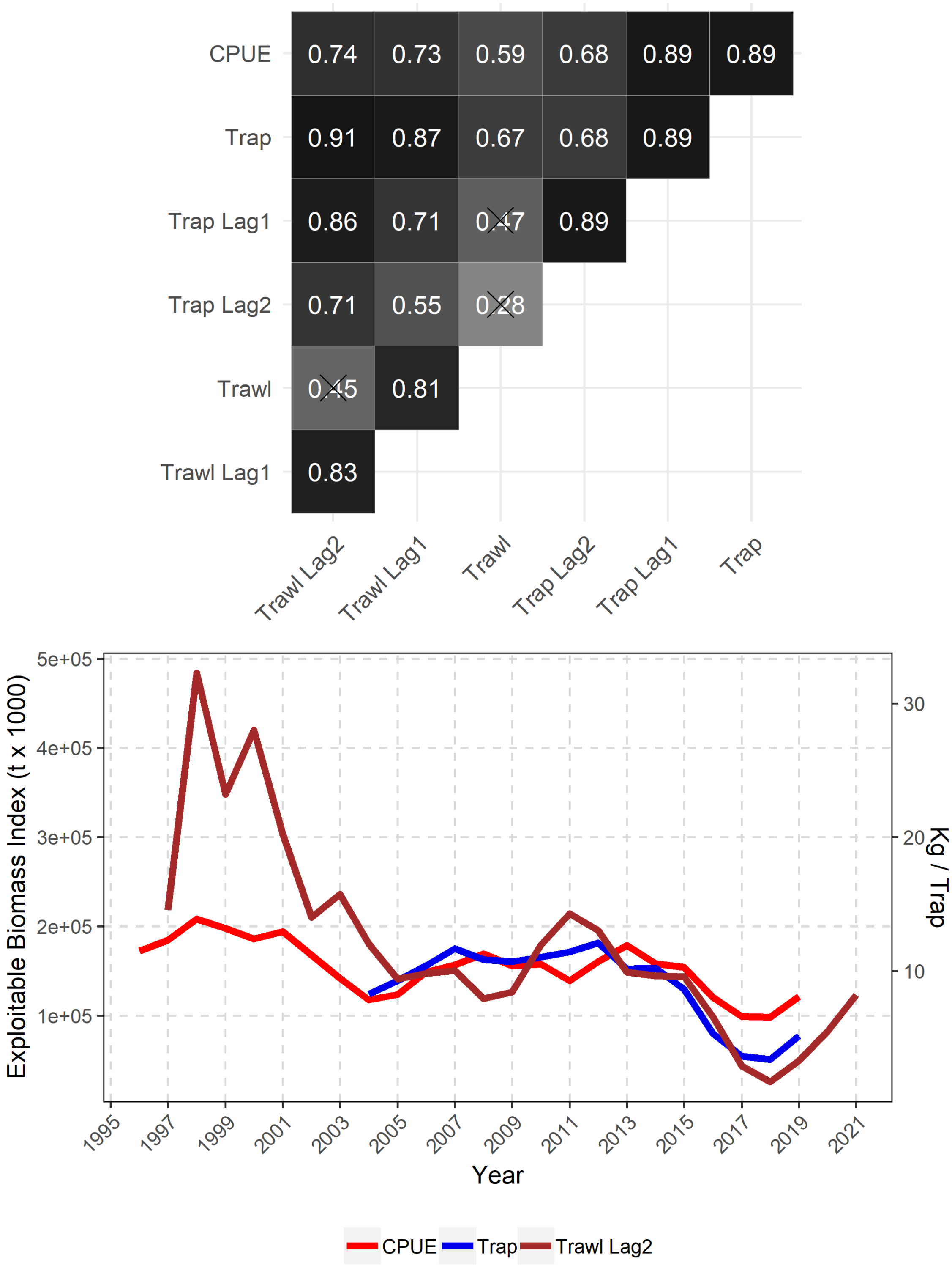

*Figure 40. **Top**: Pearson correlation coefficients of exploitable biomass indices from multispecies trawl surveys, CPS trap surveys, and fishery CPUE with lags of 0, 1, and 2 years. **Bottom**: Trends in exploitable biomass indices based on the trawl survey (brown), trap surveys (blue), and fishery CPUE (red).*

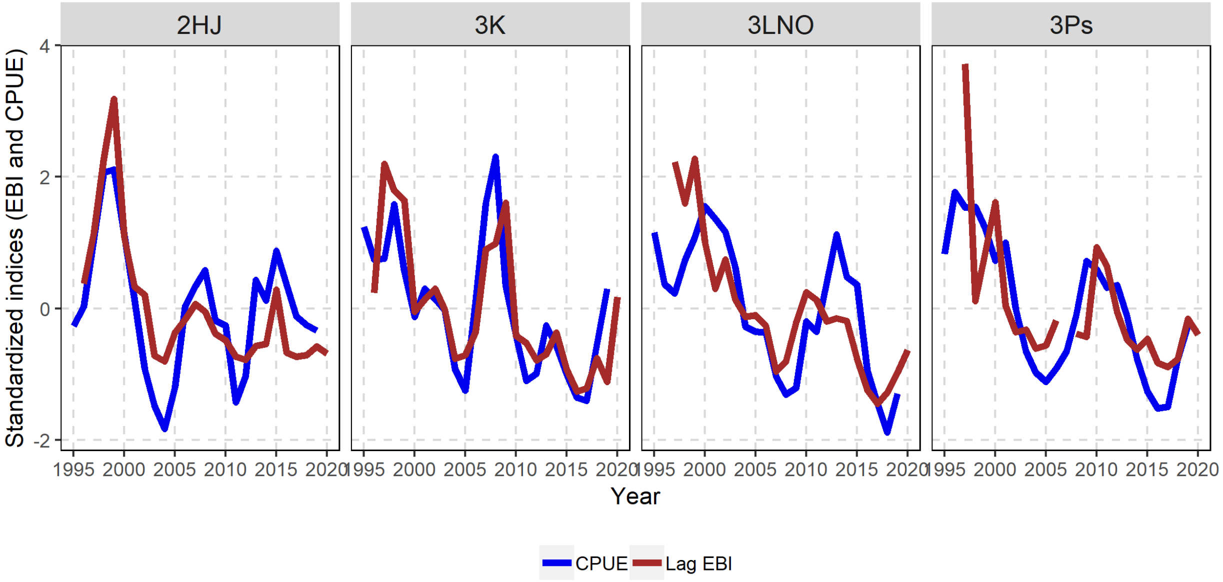

Figure 41. One-year lagged trawl survey exploitable biomass indices versus fishery CPUE by AD (1995–2019).

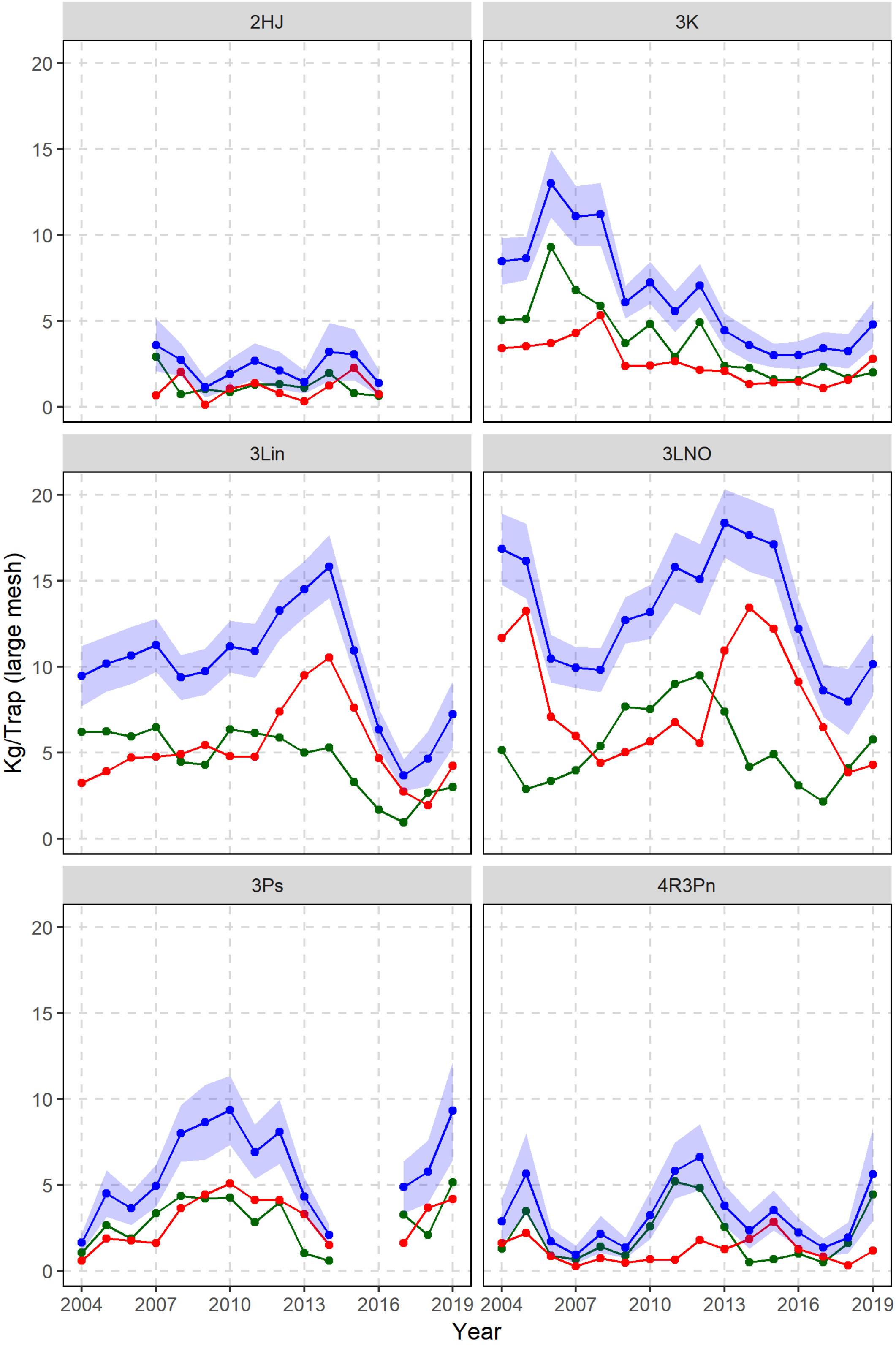

Figure 42. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from core stations in the CPS trap survey by AD (2004–19). Shaded area represents the 95% confidence interval.

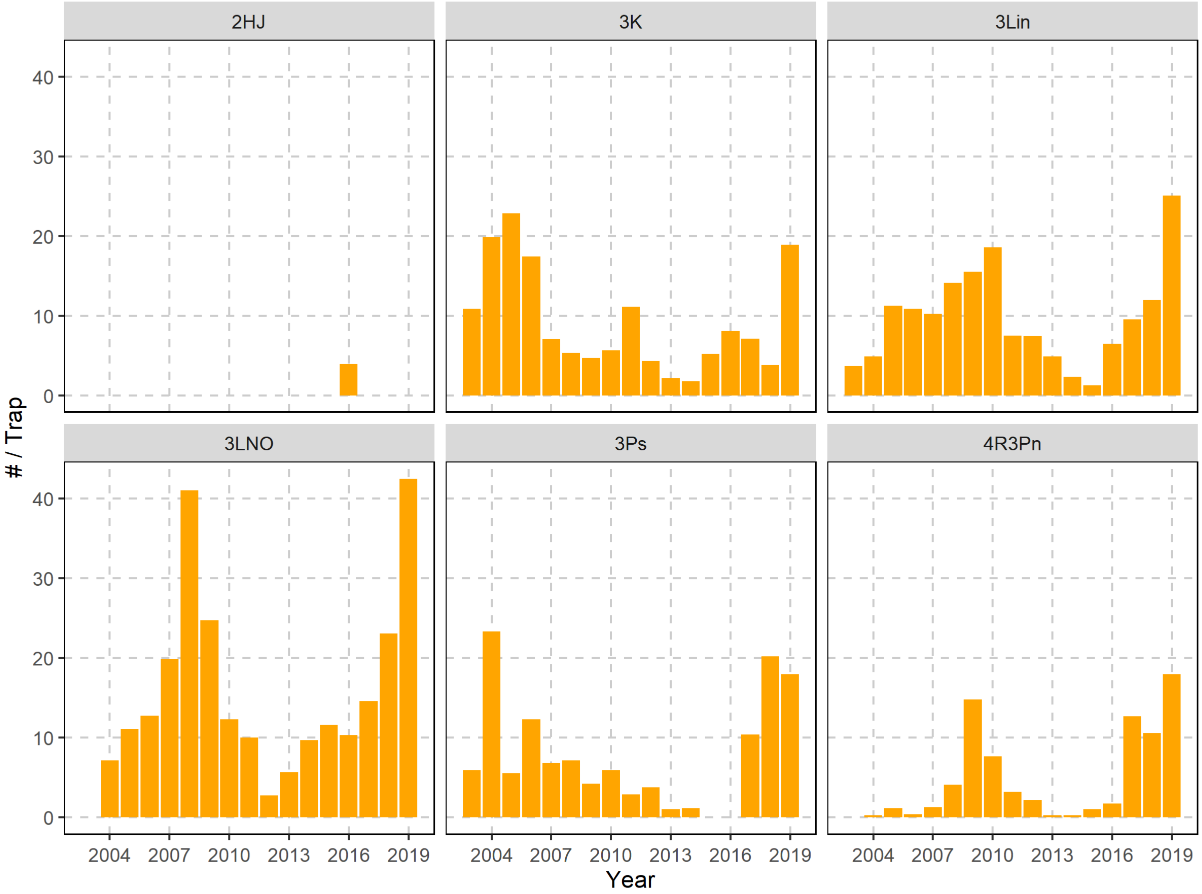

Figure 43. Annual CPUE (#/trap) of pre-recruits from small-mesh traps at core stations in the CPS trap survey by AD (2004–19).

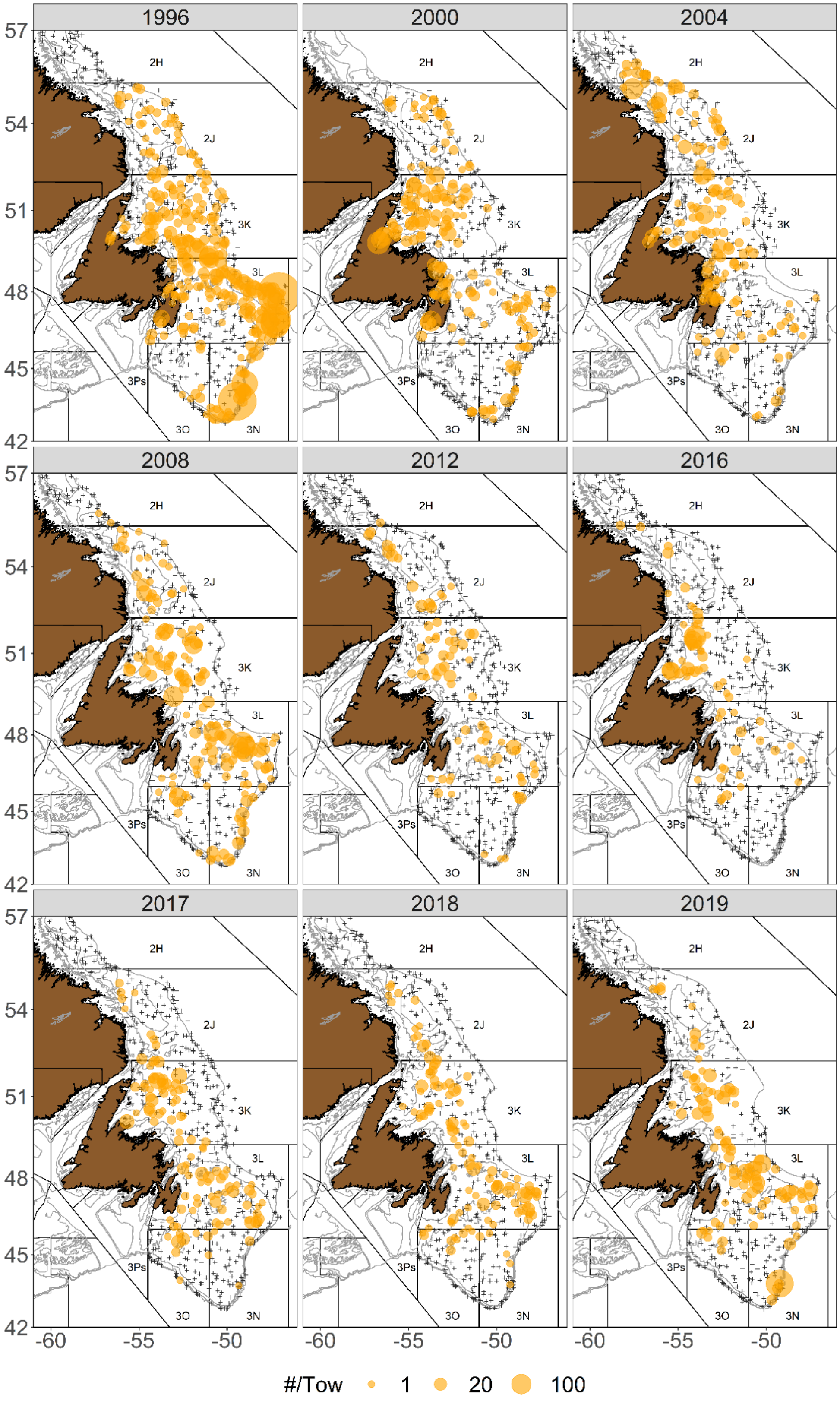

Figure 44. Distribution of pre-recruit males (#/tow) from Divs. 2HJ3KLNO fall bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2016–19.

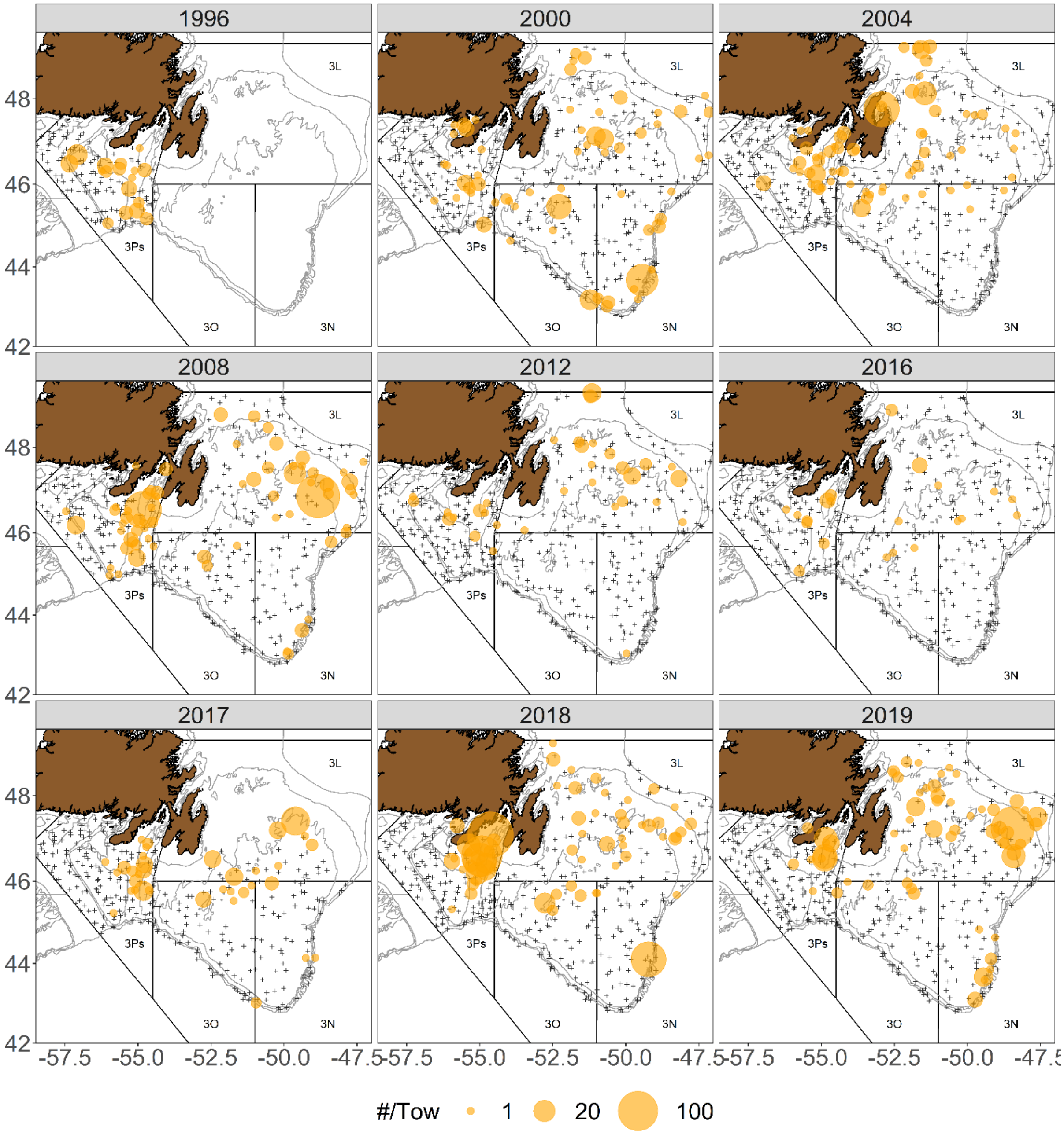

Figure 45. Distribution of pre-recruit males (#/tow) from Divs. 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2016–19.

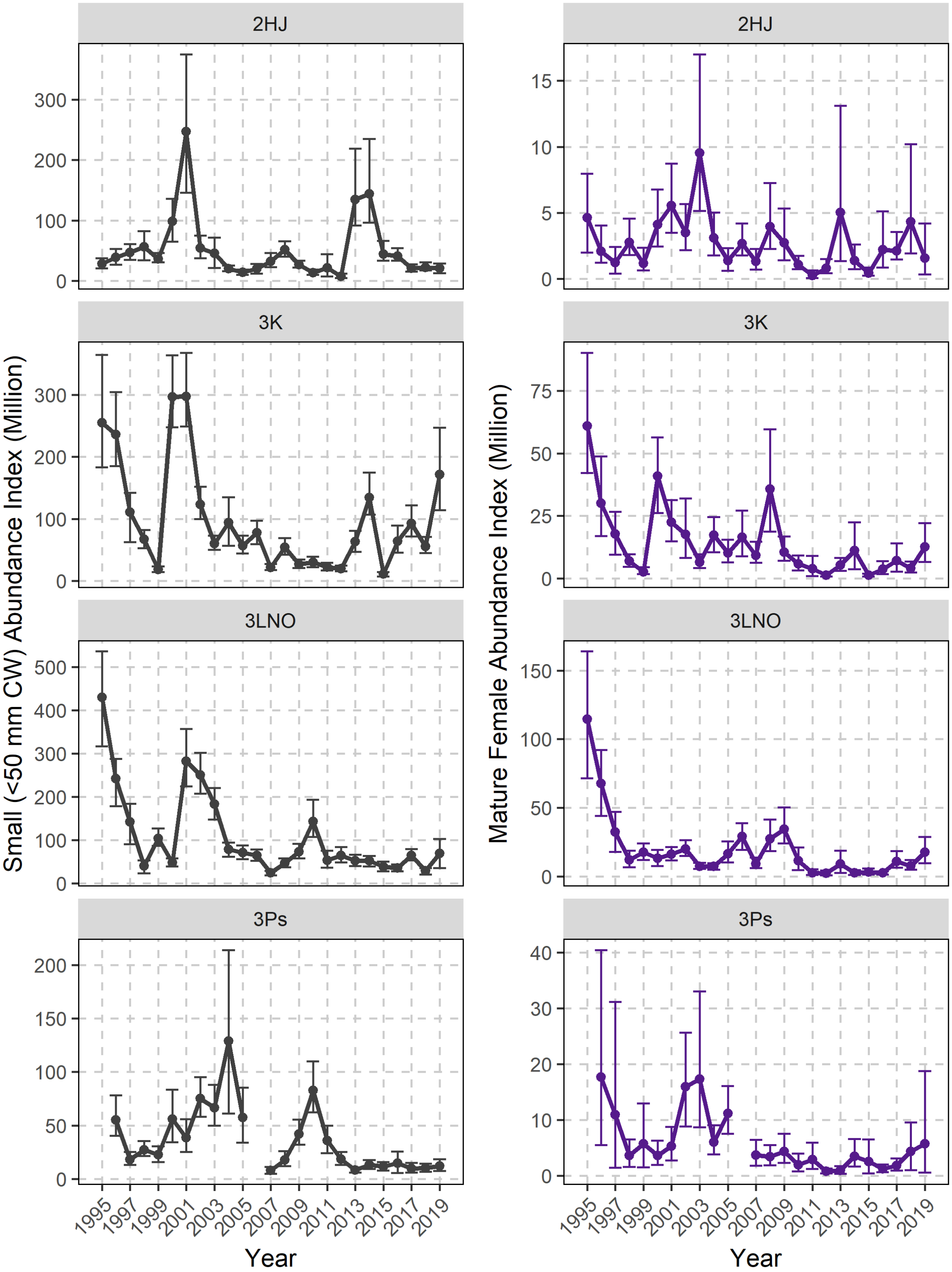

*Figure 46. **Left**: Abundance indices (# million) of small crab (<50 mm carapace width) from fall and spring trawl surveys by AD (1995–2019). **Right**: Abundance indices (# million) of mature female crab from fall and spring trawl surveys by AD (1995–2019).*

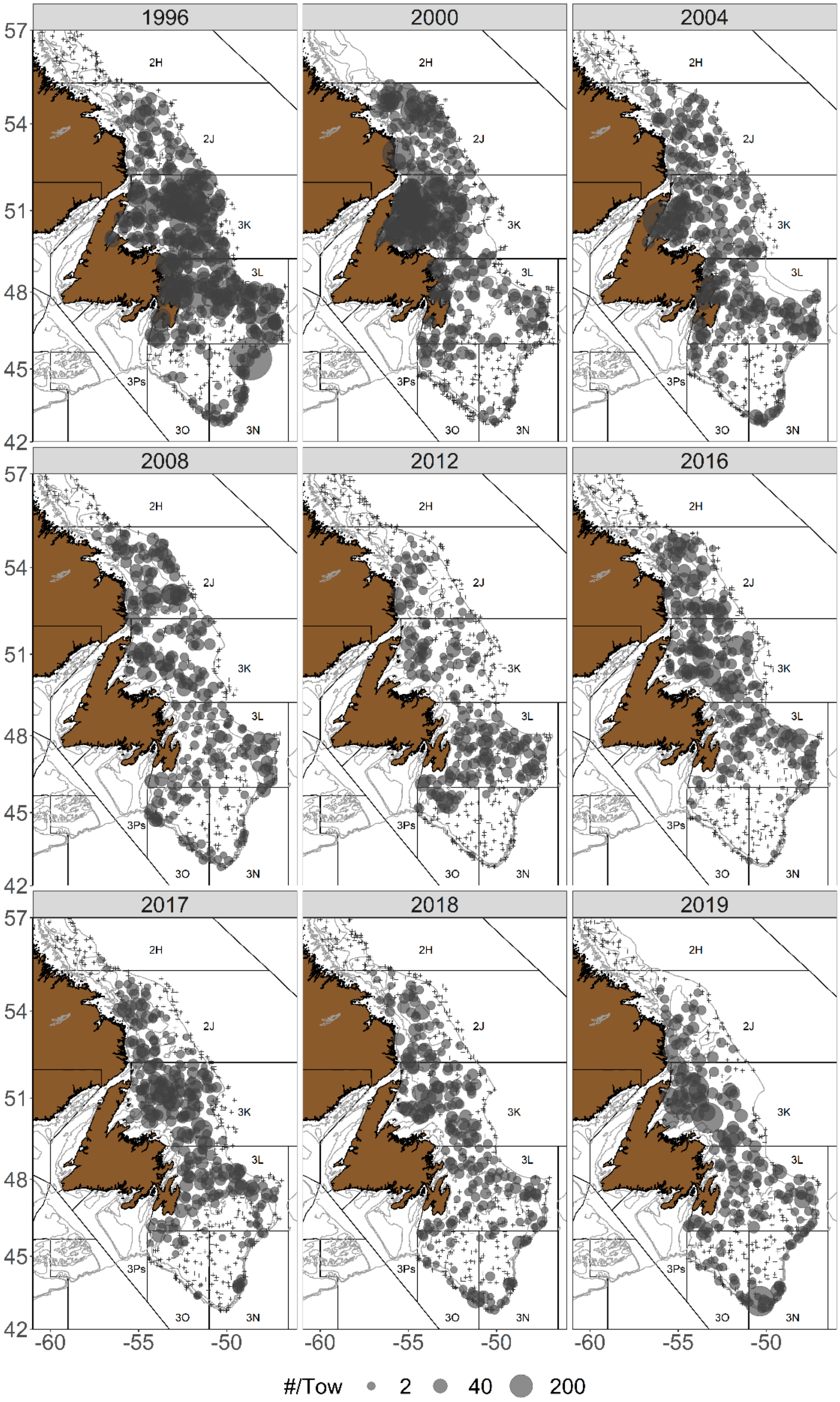

Figure 47. Distribution of small (<50 mm CW) crab (#/tow) from Divs. 2HJ3KLNO fall bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2016–19.

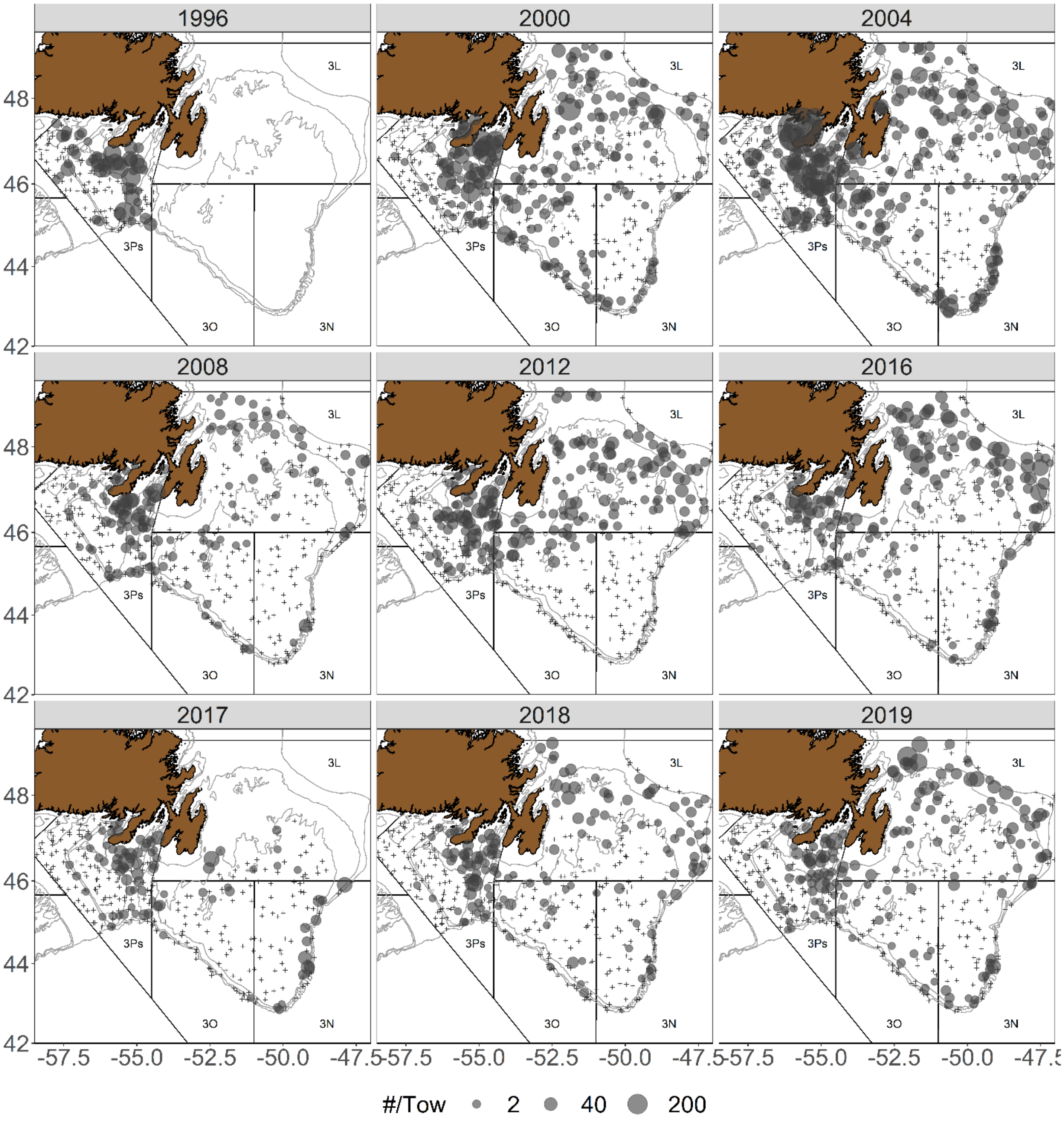

Figure 48. Distribution of small (<50 mm CW) crab (#/tow) from Divs. 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2016–19.

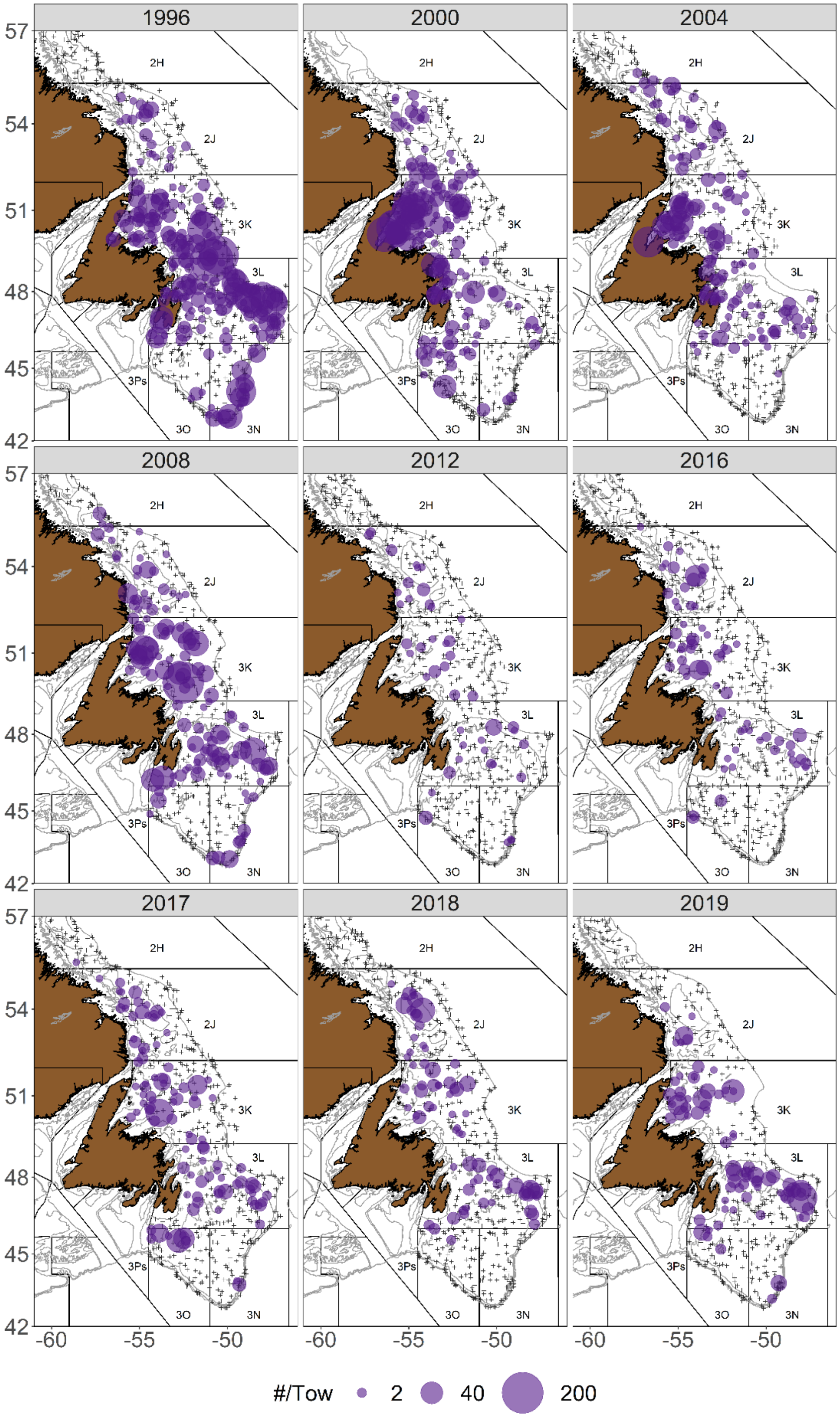

Figure 49. Distribution of mature females (#/tow) from Divs. 2HJ3KLNO fall bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2016–19.

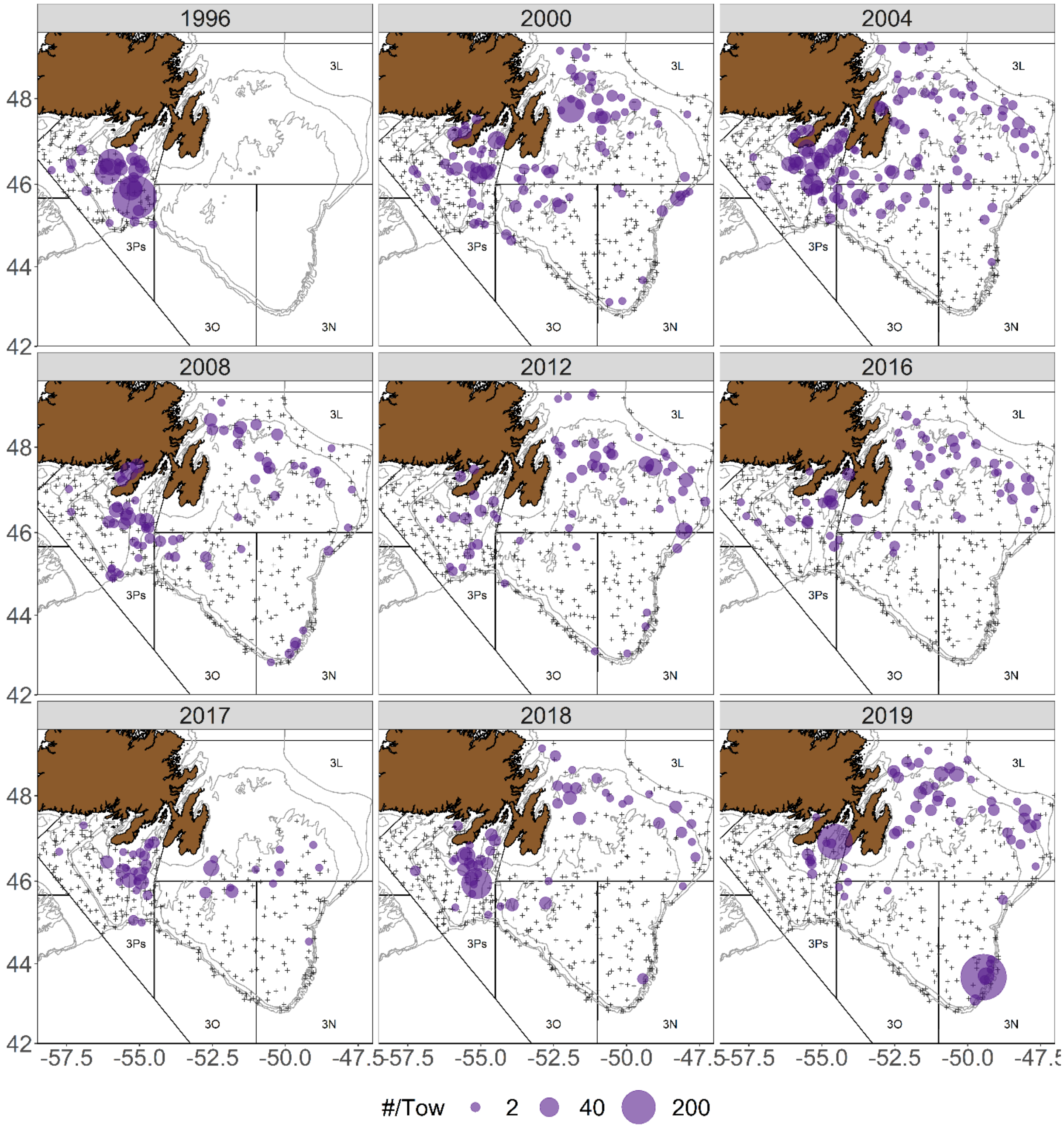

Figure 50. Distribution of mature females (#/tow) from Divs. 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2016–19.

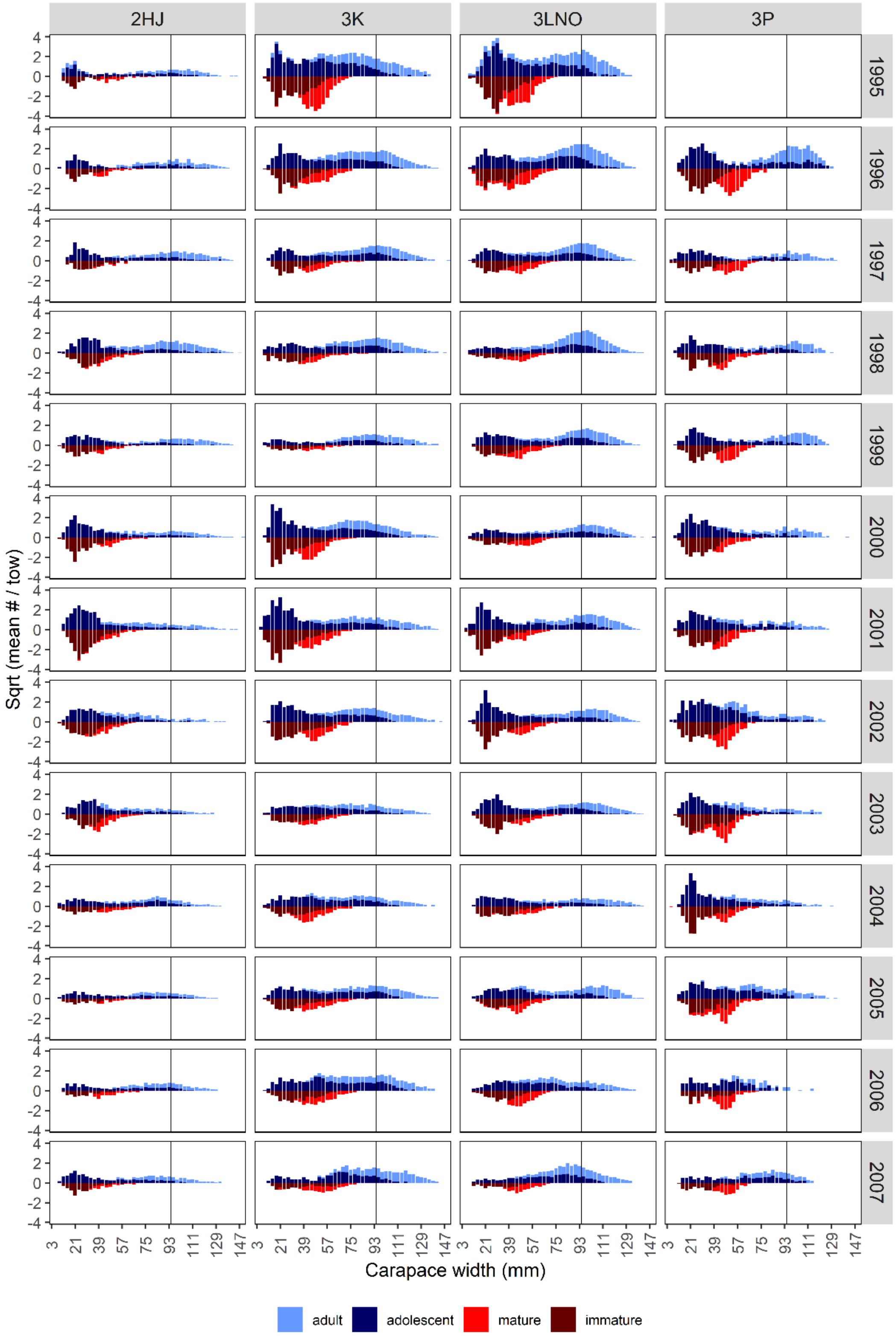

Figure 51. Abundance indices (#/tow) by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (AD 3Ps) and fall (ADs 2HJ, 3K, and 3LNO Offshore) trawl surveys from 1995 to 2007. Vertical line is legal-size. Data standardized by vessel.

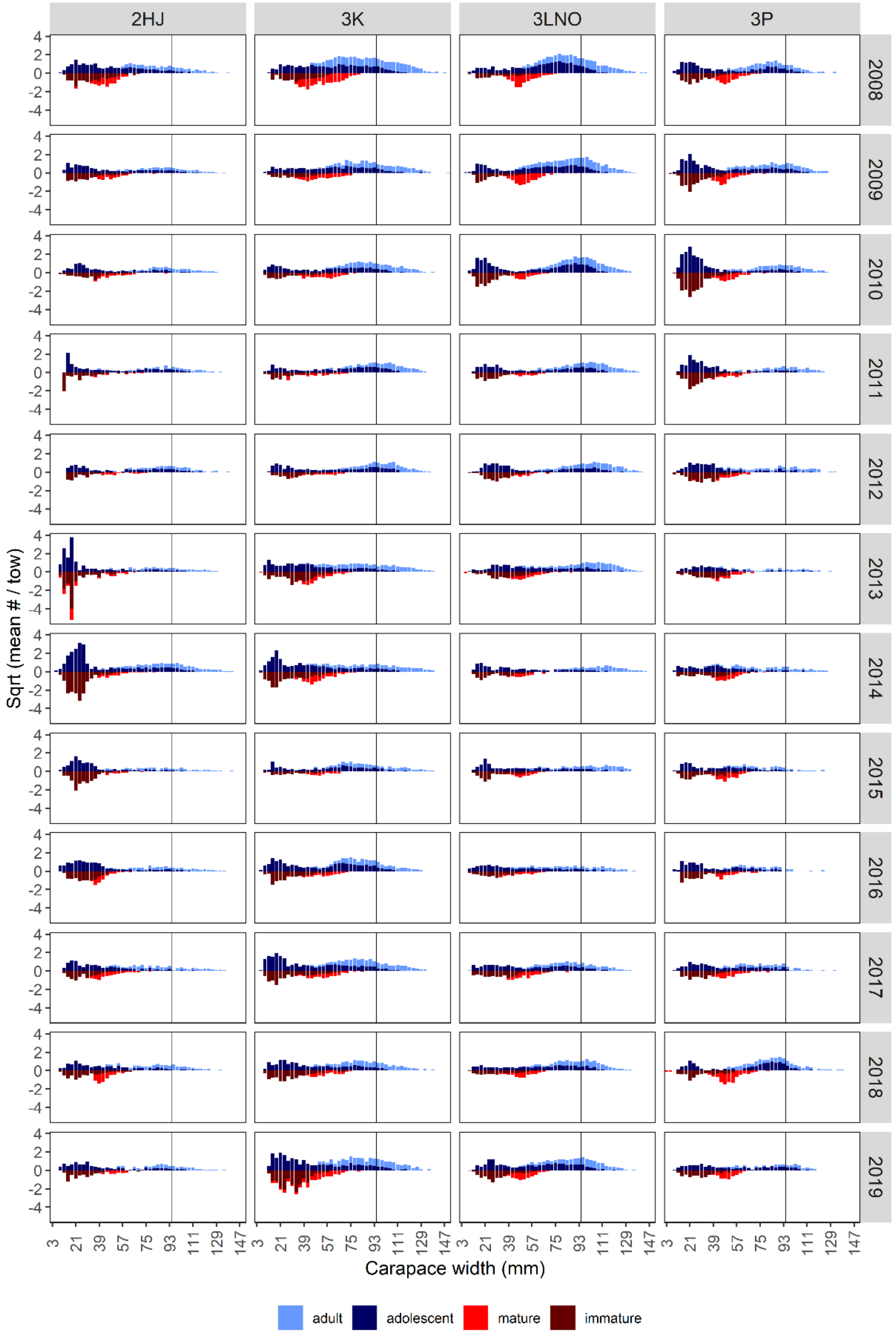

Figure 52. Abundance indices (#/tow) by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (AD 3Ps) and fall (ADs 2HJ, 3K, and 3LNO Offshore) trawl surveys from 2008 to 2019. Vertical line is legal-size. Data standardized by vessel.

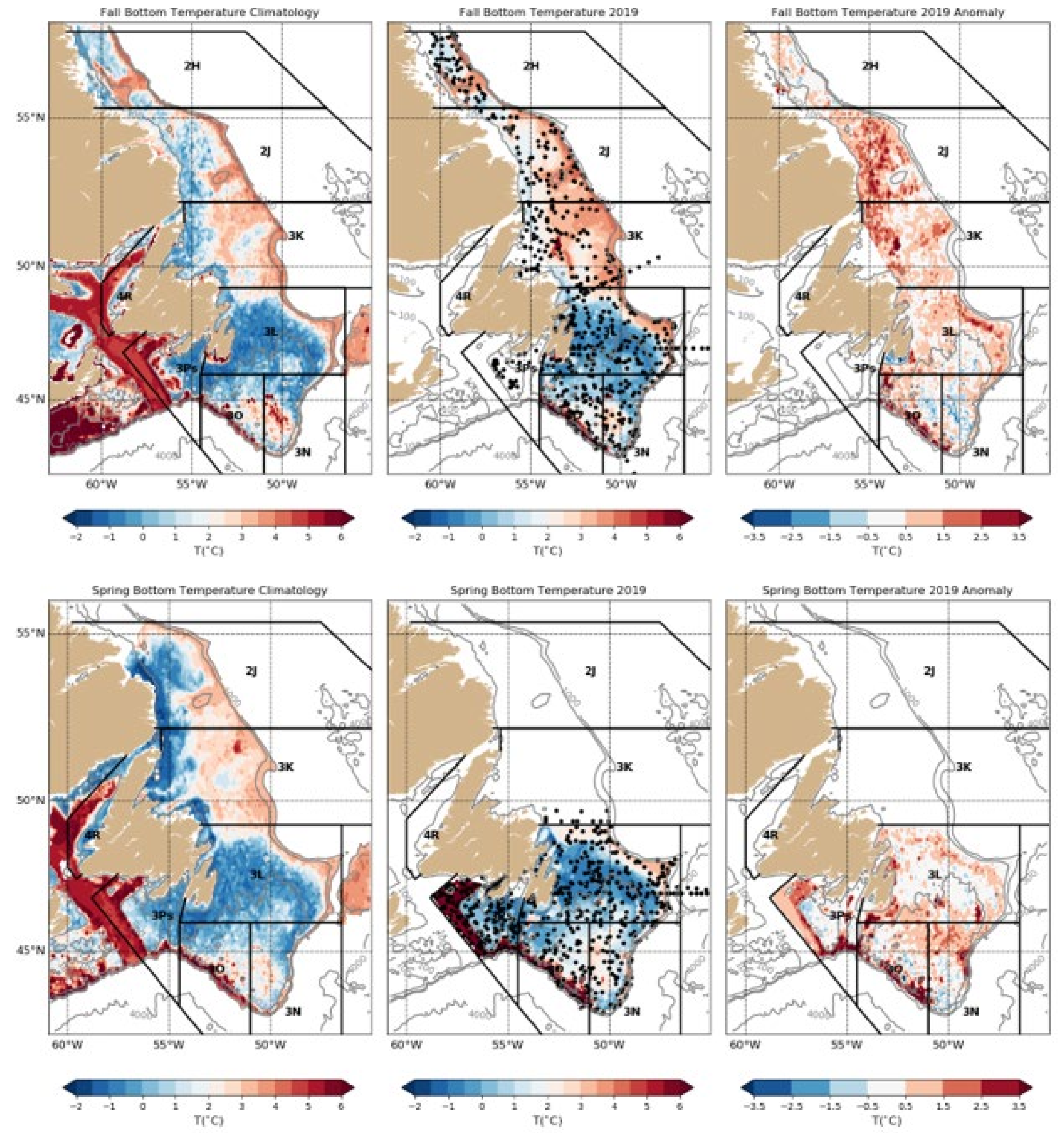

Figure 53. Mean 1981–2010 bottom temperatures (left), 2019 bottom temperatures (center), and 2019 anomalies (right) in fall (top) and spring (bottom) along the NL shelf. The location of observations used to derive the temperature field is shown as black points in the center panel.

Figure 54. Snow Crab thermal habitat indices by AD and Year (1980–2019). Note: f = fall and s = spring.

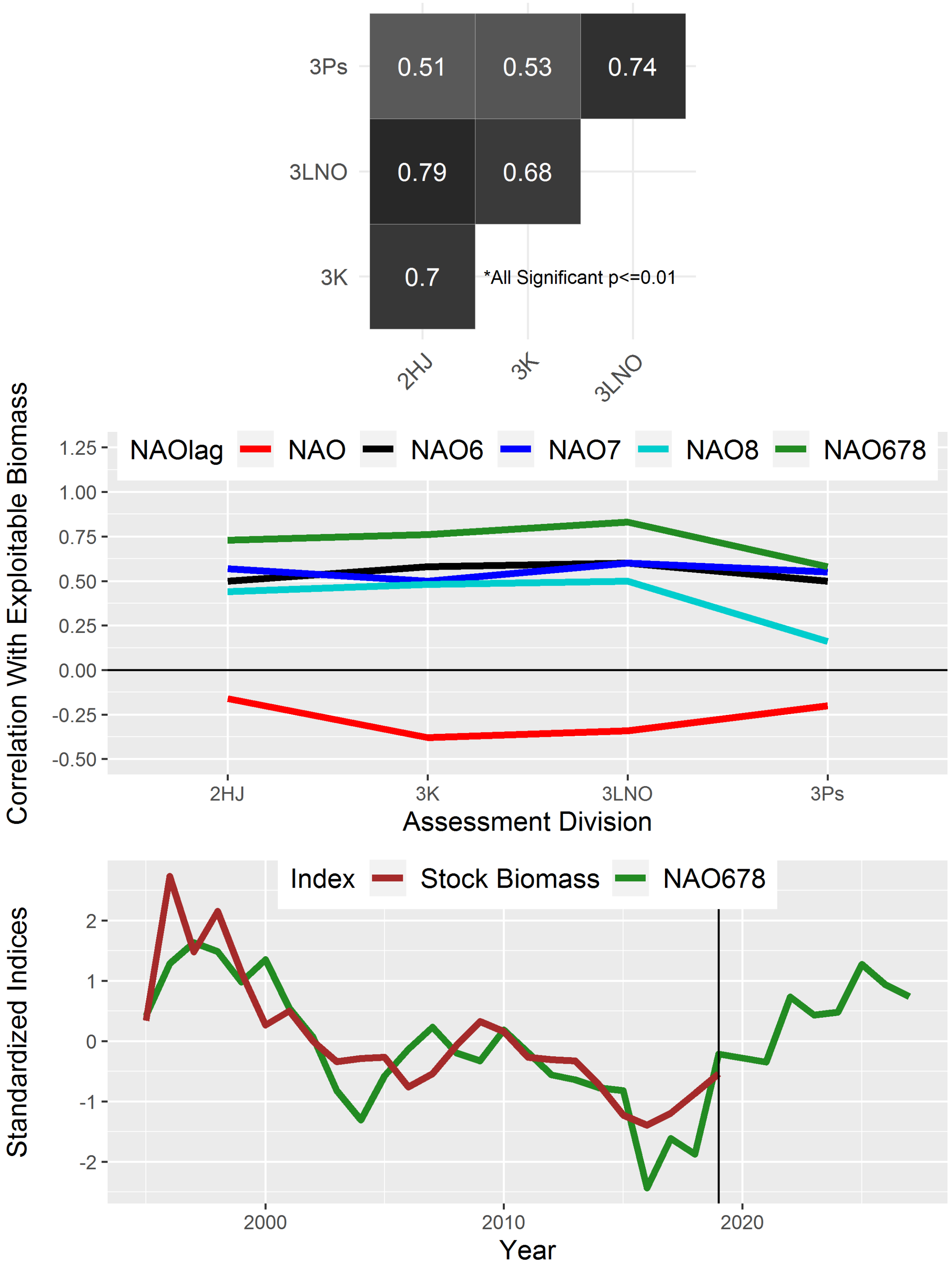

Figure 55. ***Top****: Pearson correlation coefficients of exploitable biomass indices by AD from multispecies trawl surveys.* ***Middle****: Pearson correlation coefficients of exploitable biomass indices against lagged indices of the NAO (0,6,7,8 year lags) by AD.* ***Bottom****: Stock-level EBI in relation to a lagged index of the NAO defined as an average of monthly values from 6 to 8 years ago.*

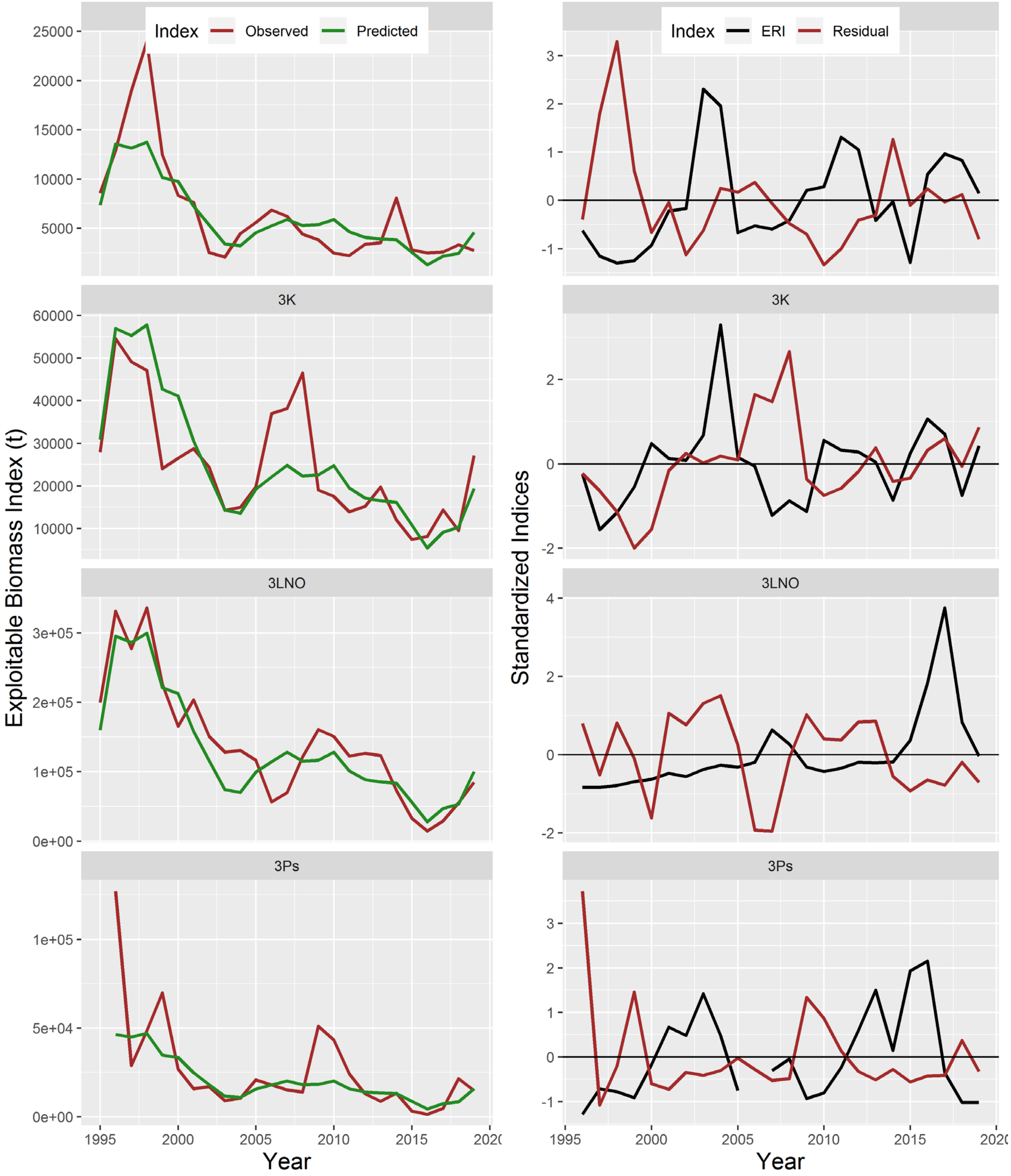

*Figure 56. **Left**: AD exploitable biomass indices from trawl surveys (red) versus a lagged index of the NAO defined as an average of monthly values from 6 to 8 years ago (green). **Right**: Residuals from a linear model regressing exploitable biomass indices against lagged NAO index versus fishery exploitation rate indices.*

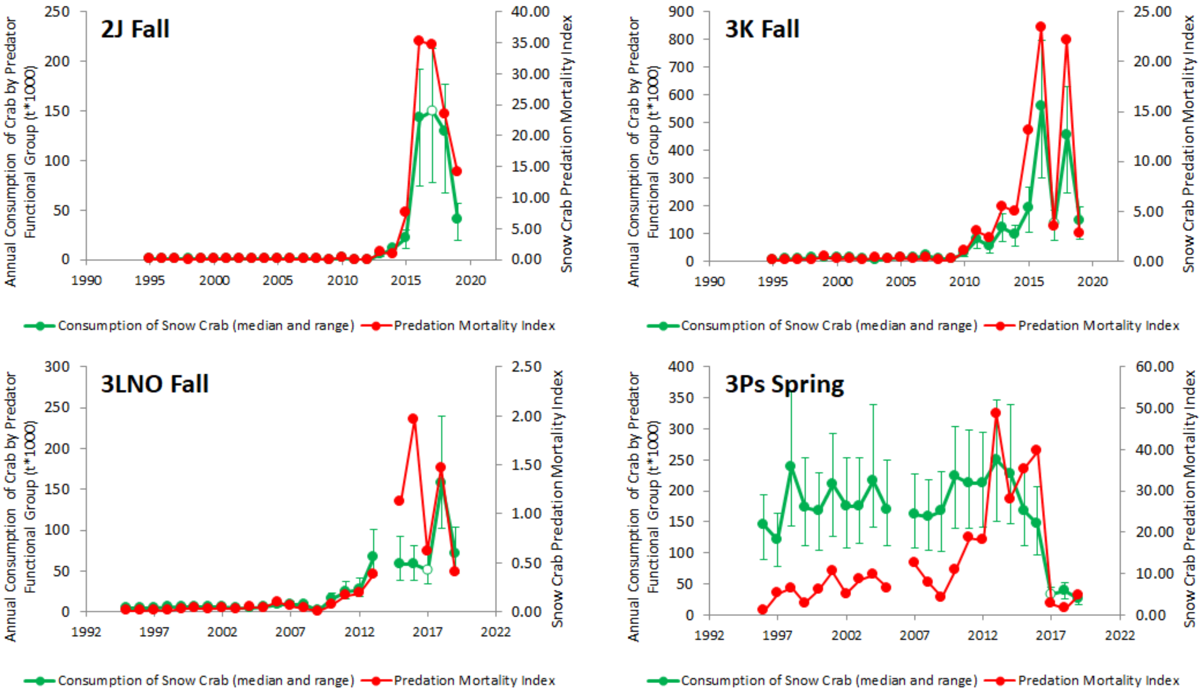

Figure 57. Consumption of Snow Crab by predators and Snow crab predation mortality index by Ecosystem Production Units (1995–2019).

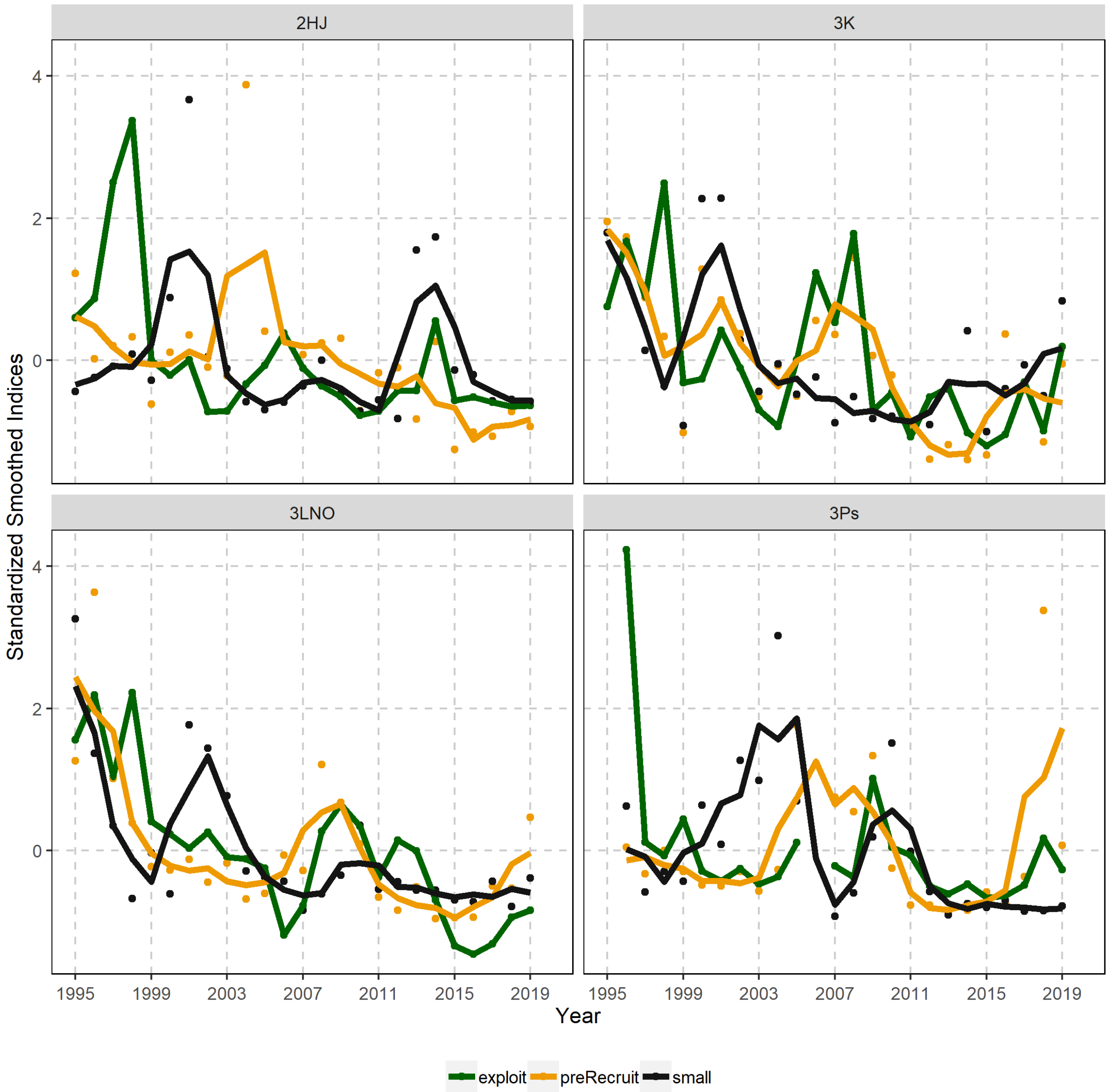

Figure 58. Standardized annual (points) and 3-year centered moving average (solid line) abundance indices of small crab (black) and pre-recruits (orange) and biomass indices of new shelled (>94 mm) crab (green) by AD (1995–2019).

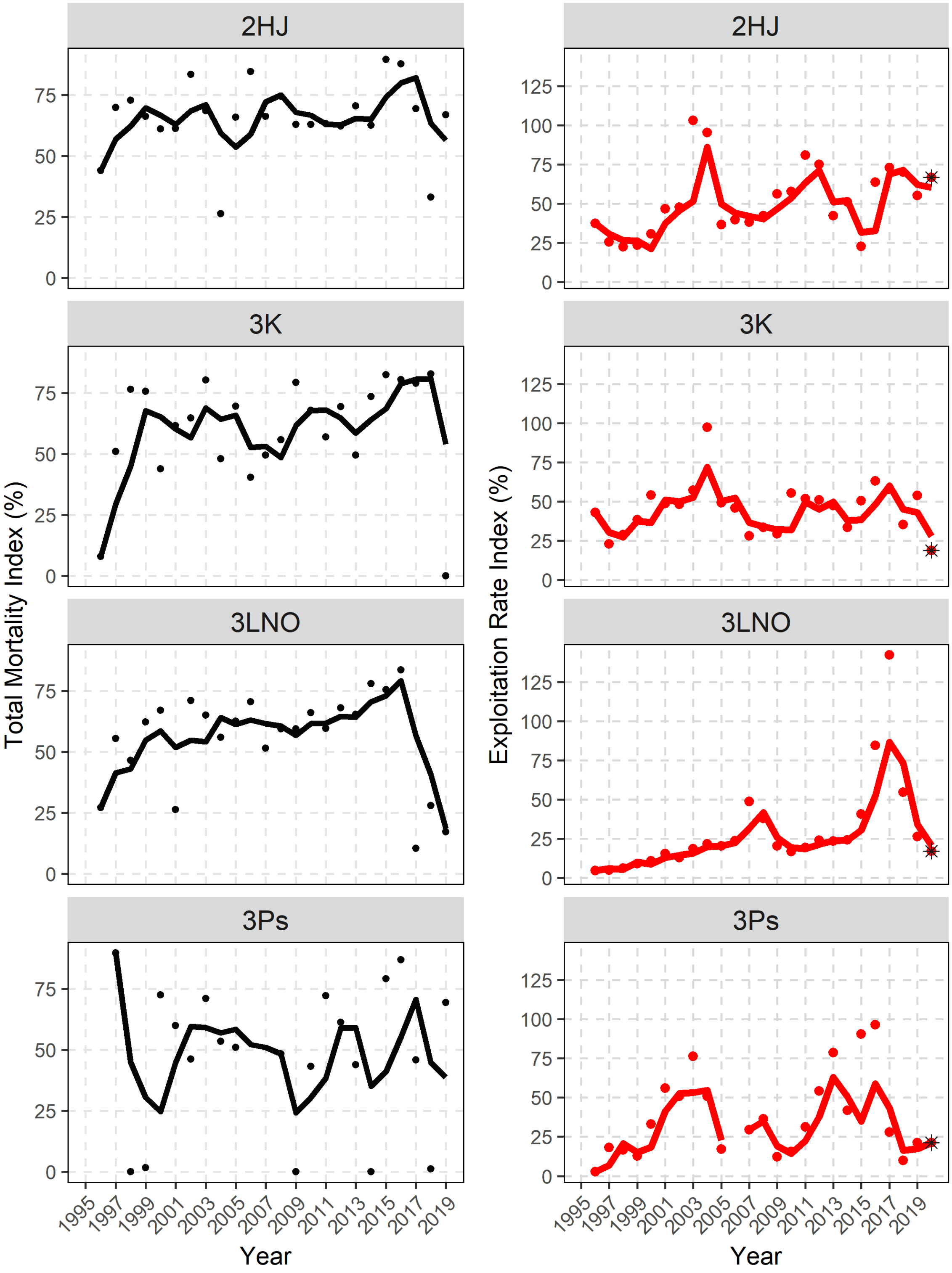

*Figure 59. **Left**: Trends in the annual (points) and 3-year moving average (solid line) total annual mortality index (%) of exploitable Snow Crab by AD. Note: if annual mortality index was <0 it was plotted as 0 for presentation. **Right**: Trends in the annual (points) and 2-year moving average (solid line) trawl-based ERI (%) by AD; 2020 stars depict projected exploitation rate indices under status quo removals in the 2020 fishery.*

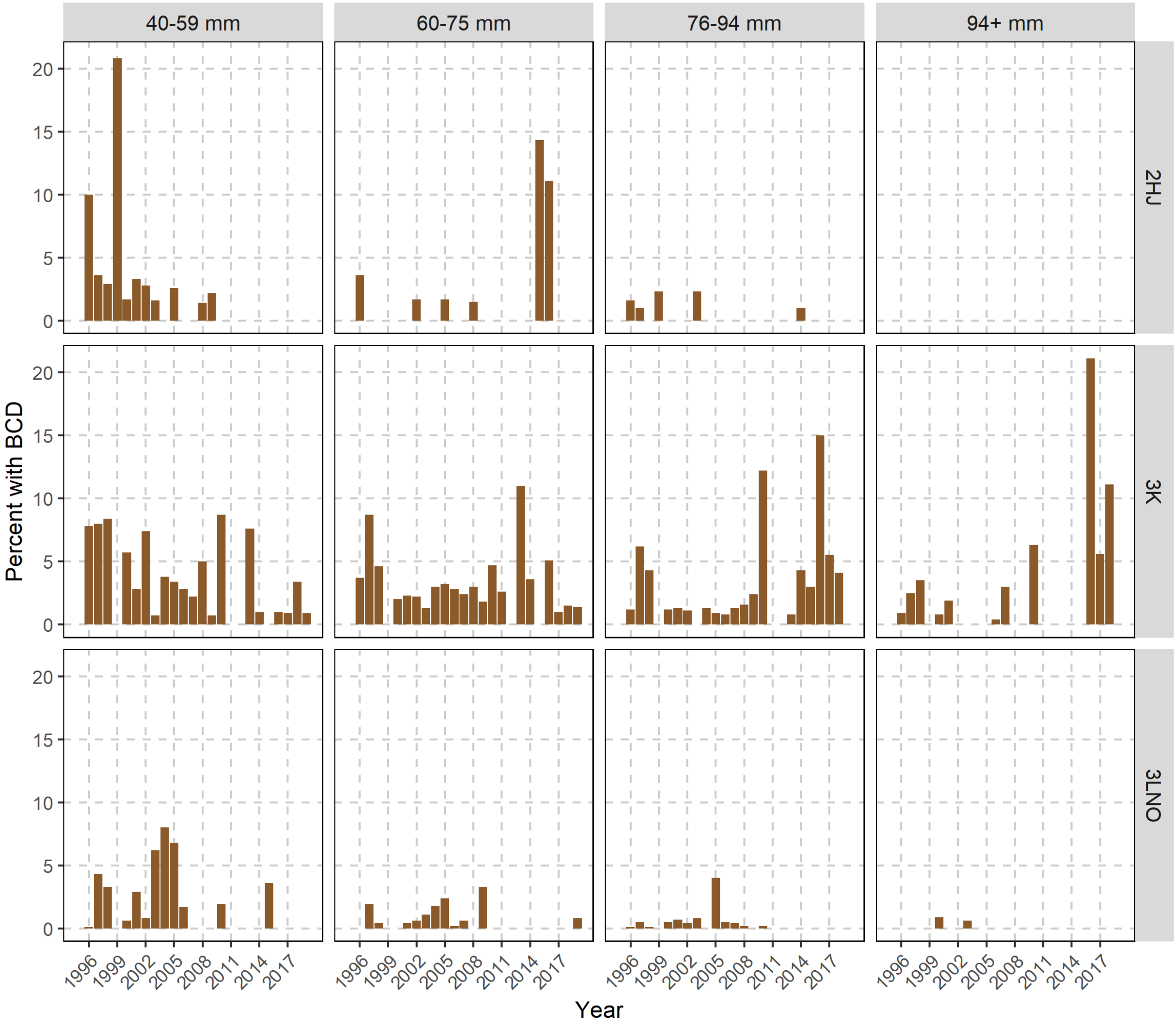

Figure 60. Annual prevalence of Bitter Crab Disease (BCD) from macroscopic observations in Snow Crab in fall multispecies trawl surveys by AD and carapace width (1996–2019).

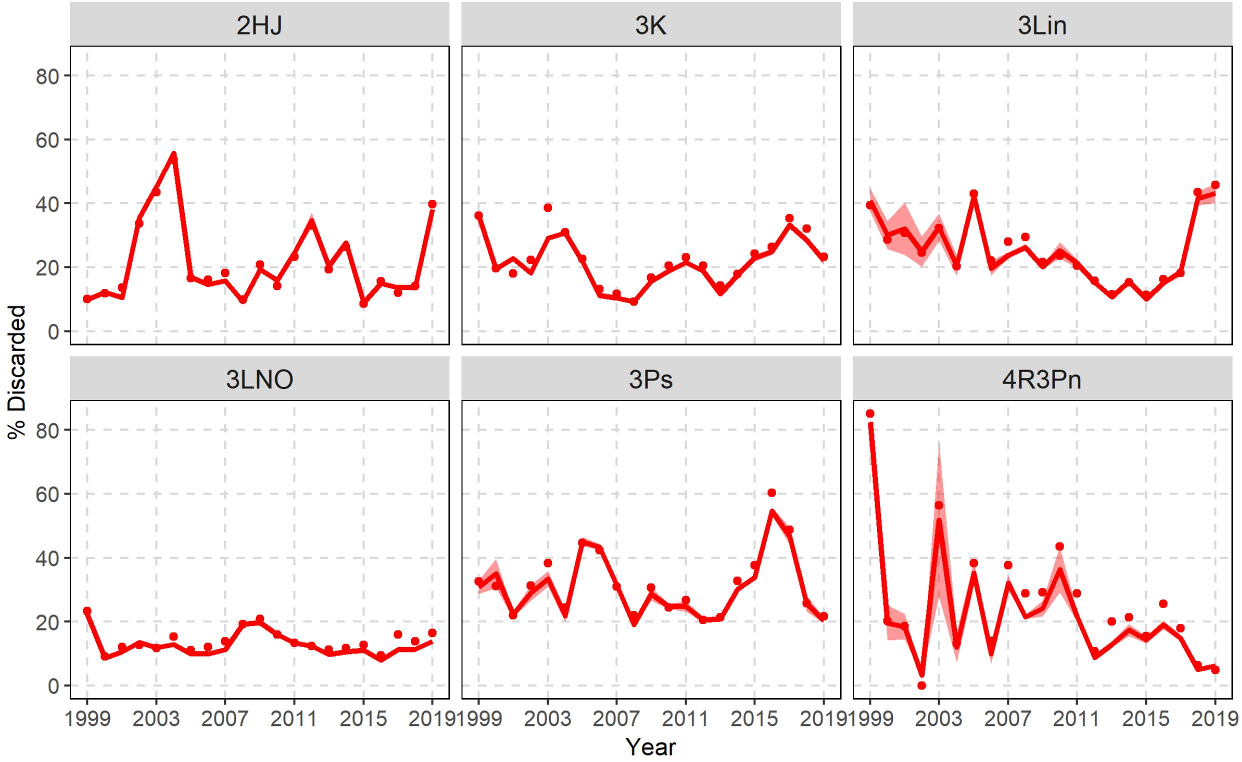

Figure 61. Trends in discards (%) based on raw estimates (points) and standardized values (solid lines) by AD. The shaded area represents the 95% confidence interval.

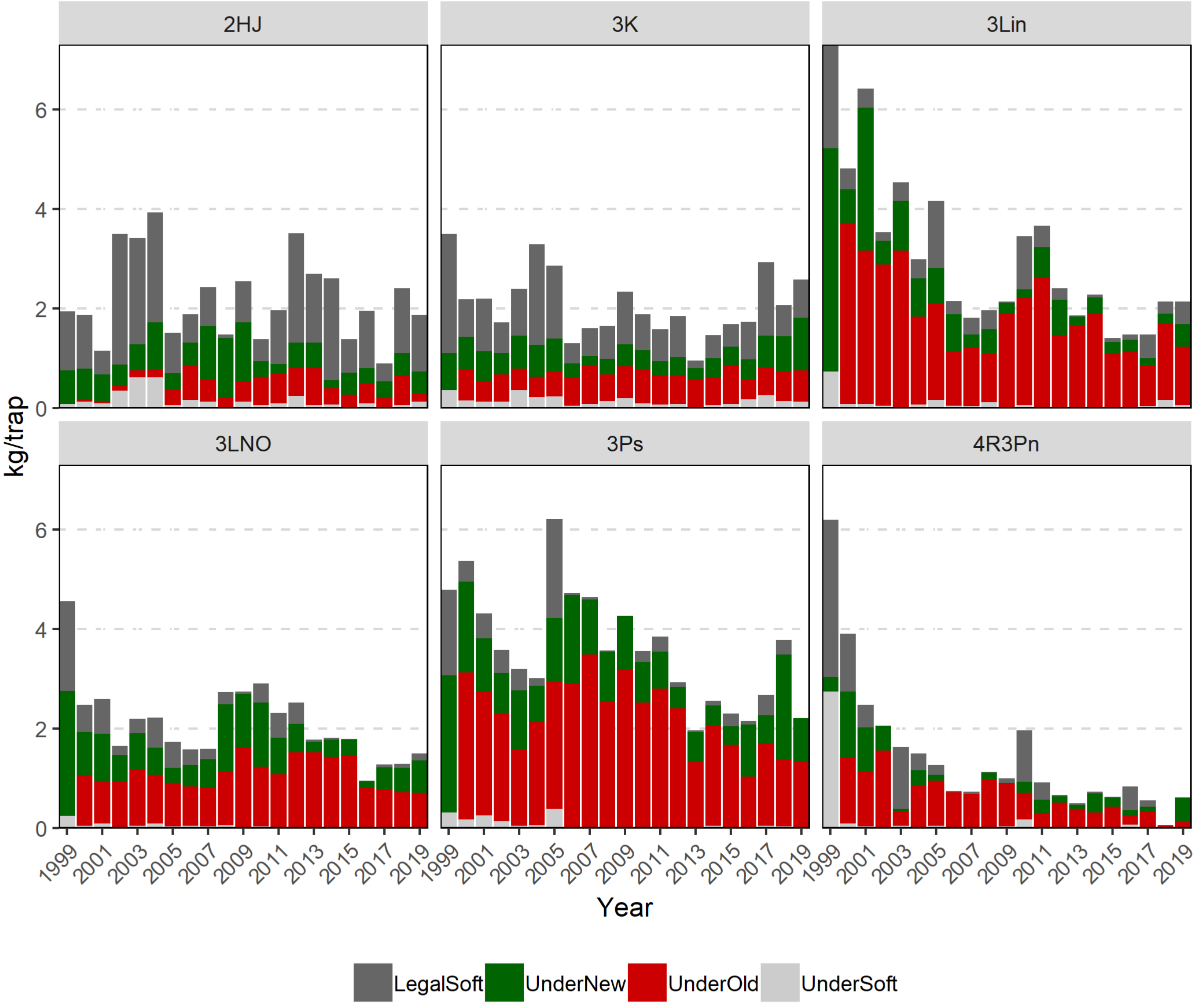

Figure 62. Trends in observed catch rates of discards (kg/trap) based on size and shell condition groups (legal-sized soft-shelled, undersized new-shelled, undersized old-shelled, and undersized soft-shelled) by AD (1999–2019).

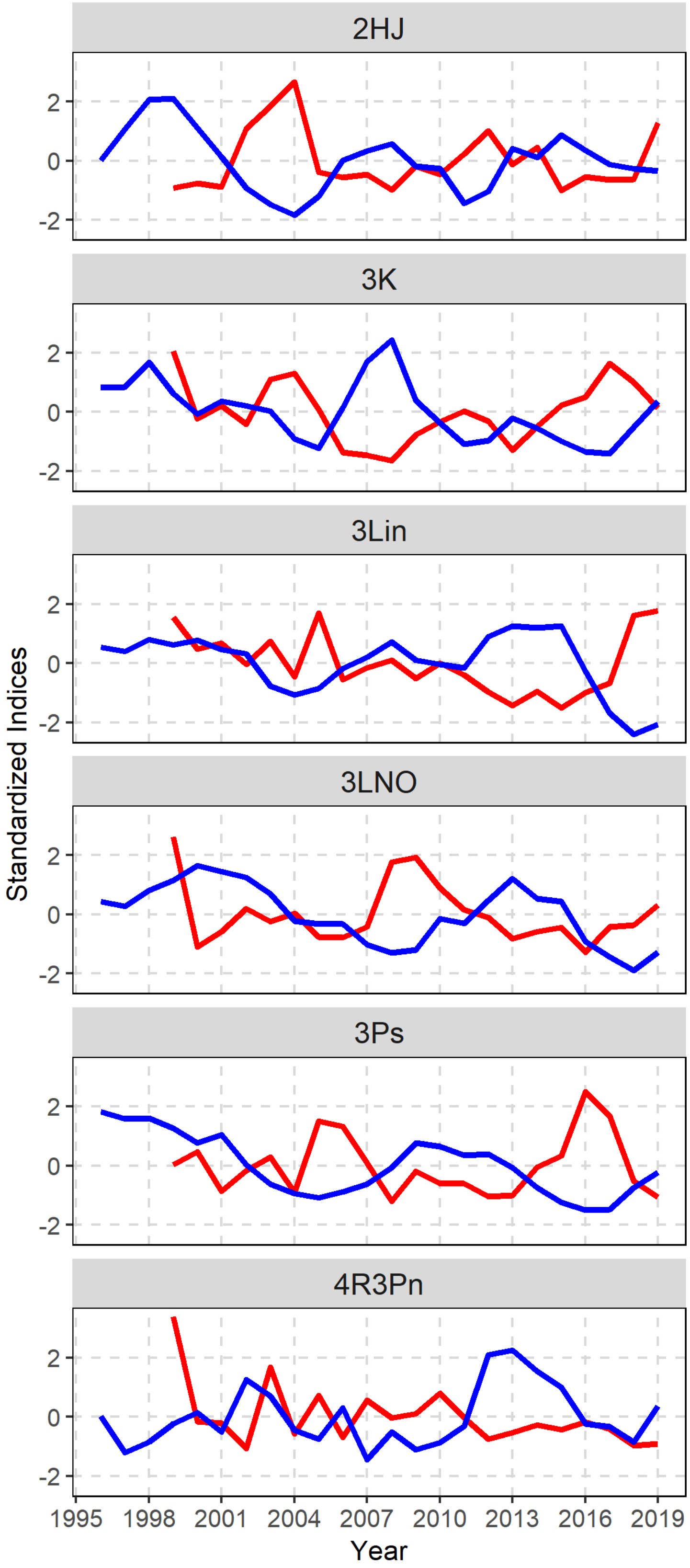

Figure 63. Trends in standardized fishery CPUE (blue) and discard rates (red) by AD (1996–2019).

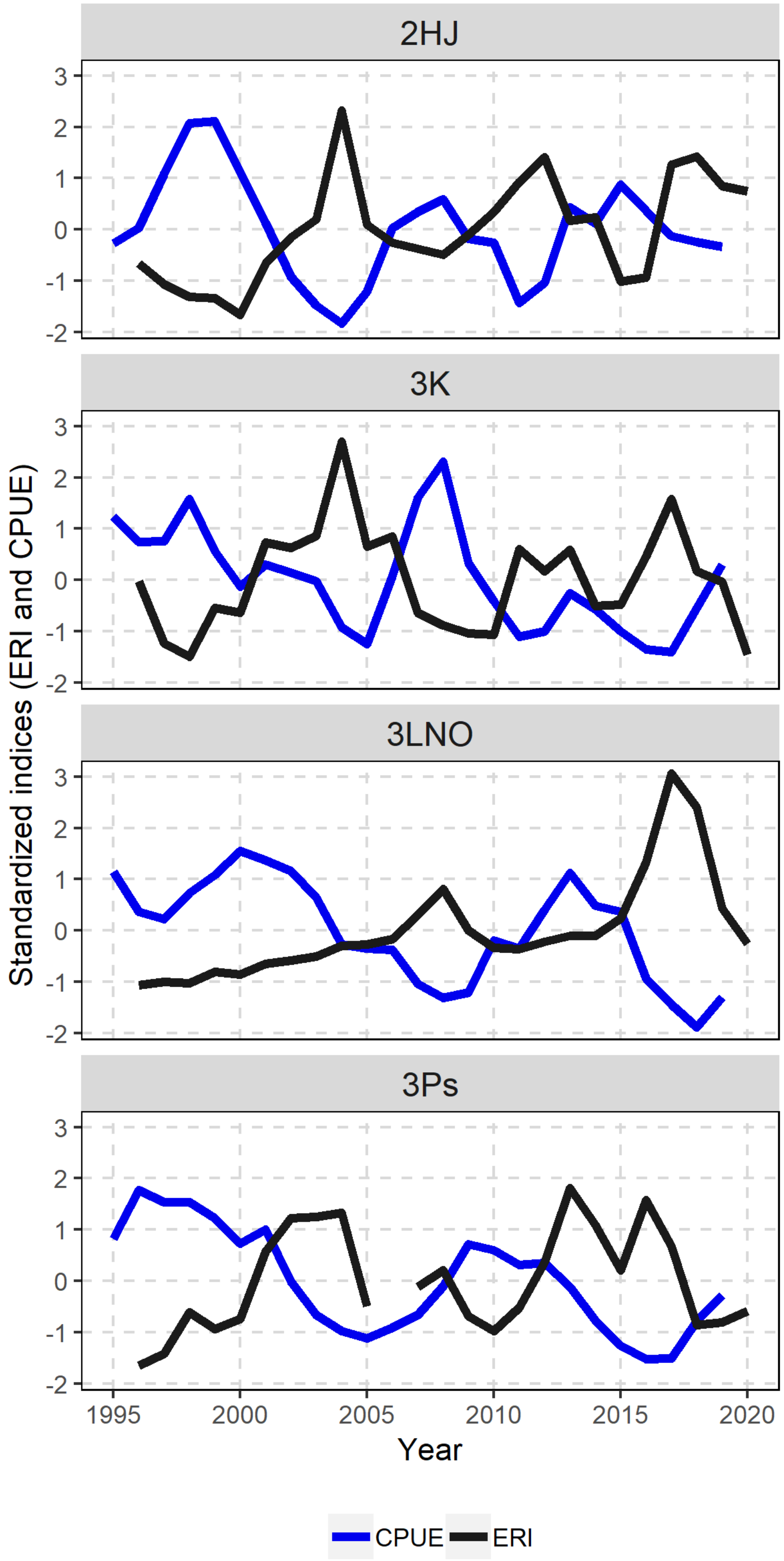

Figure 64. Trends in standardized fishery CPUE (blue) and exploitation rate indices (black) by AD (1995–2019).

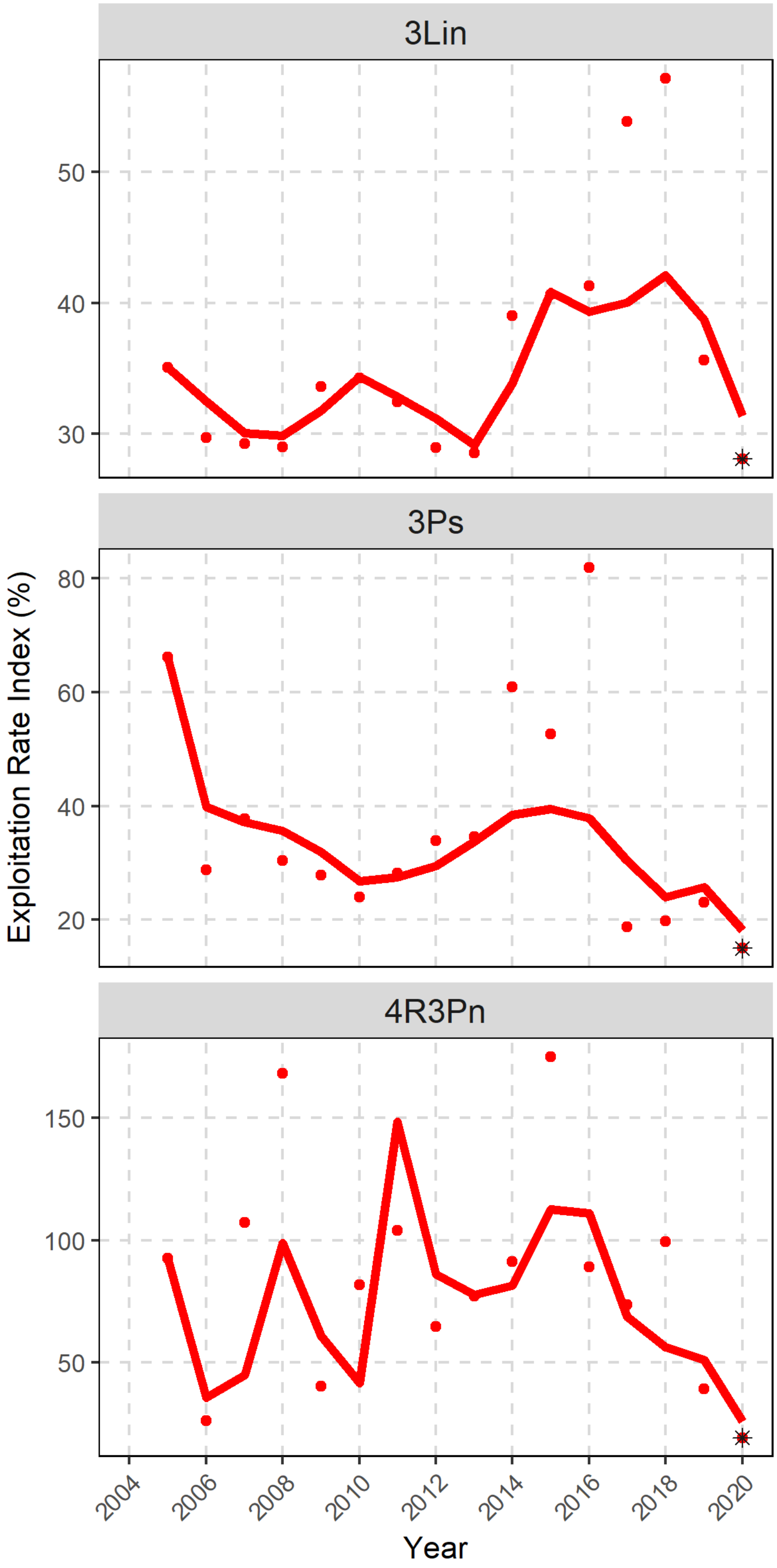

Figure 65. Trends in the annual (points) and 2-year moving average (solid line) trap-based ERI (%) by AD; 2020 stars depict projected exploitation rate indices under status quo removals in the 2020 fishery.

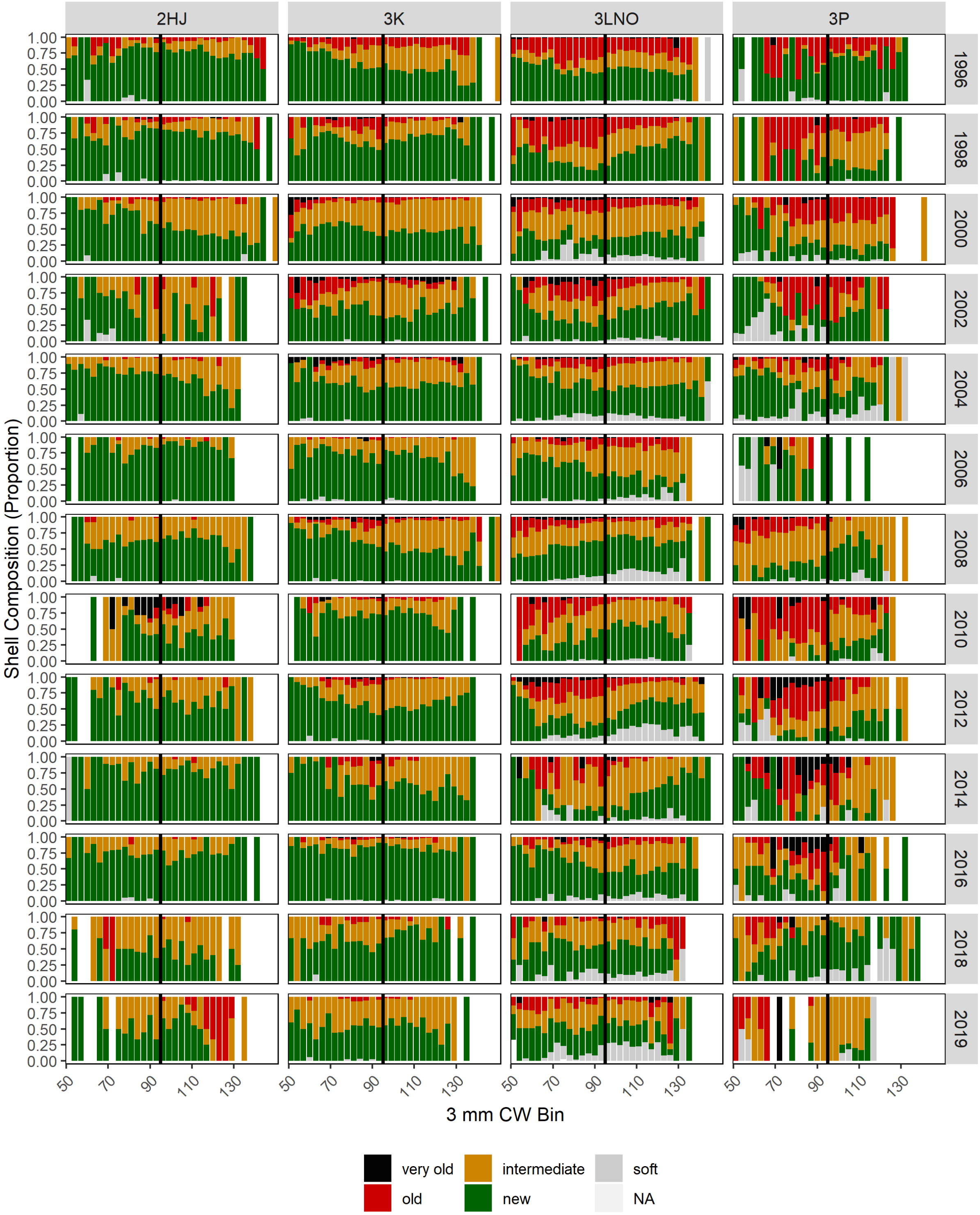

Figure 66. Shell composition of adult male Snow Crab by 3 mm carapace width intervals from multispecies trawl surveys by AD (1995–2019). Years binned to two year increments (1995+1996=1996, 2019 is single year). Vertical black lines depict legal-size. (Grey = soft shelled, green = new shelled, orange = intermediate shelled, red = old shelled, black = very old shelled).

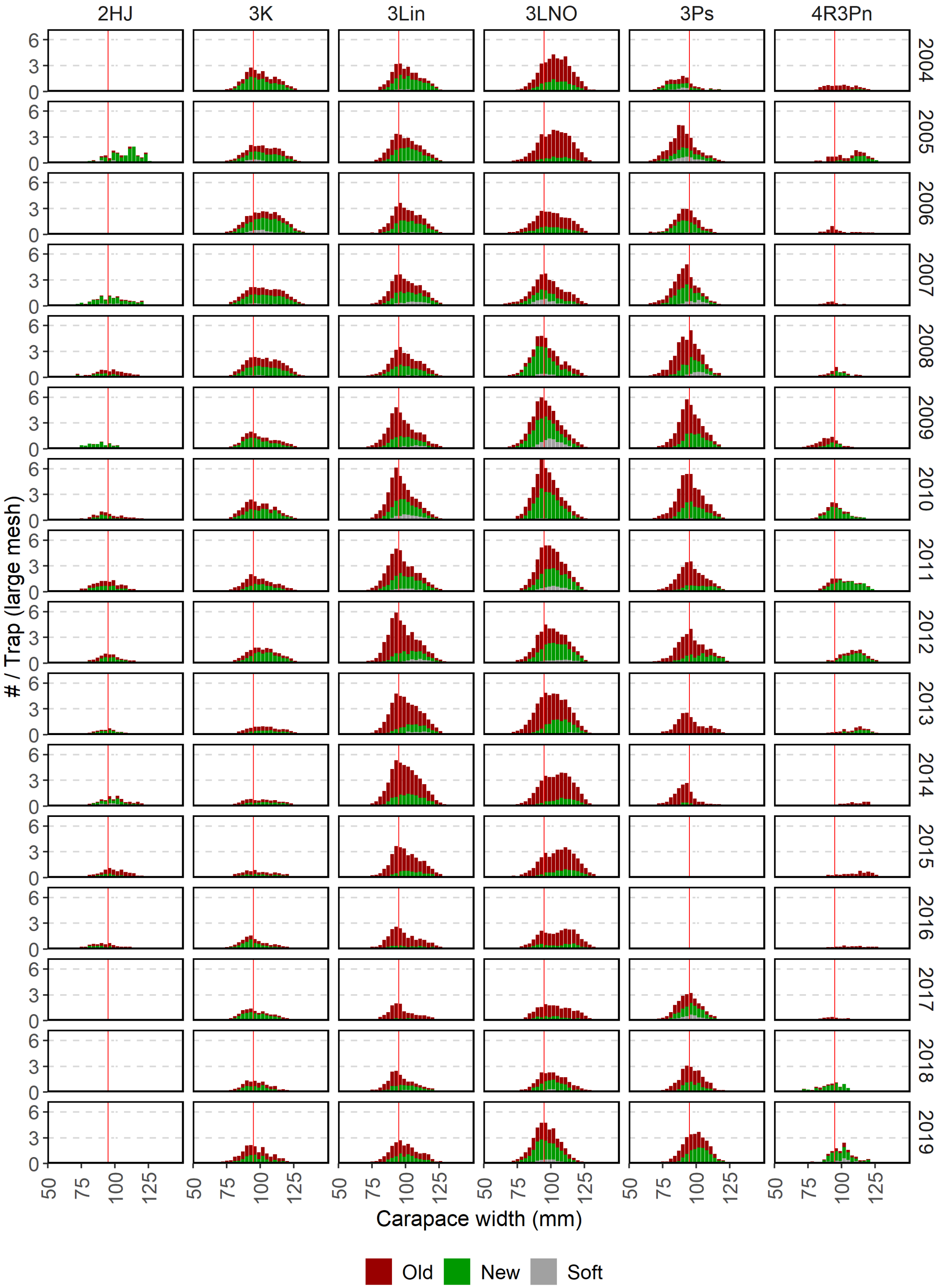

Figure 67. Trends in CPUE (#/trap) by carapace width and shell condition from male Snow Crab in large-mesh traps at core stations in the CPS trap survey by AD (2004–19). The red vertical line indicates the minimum legal size.

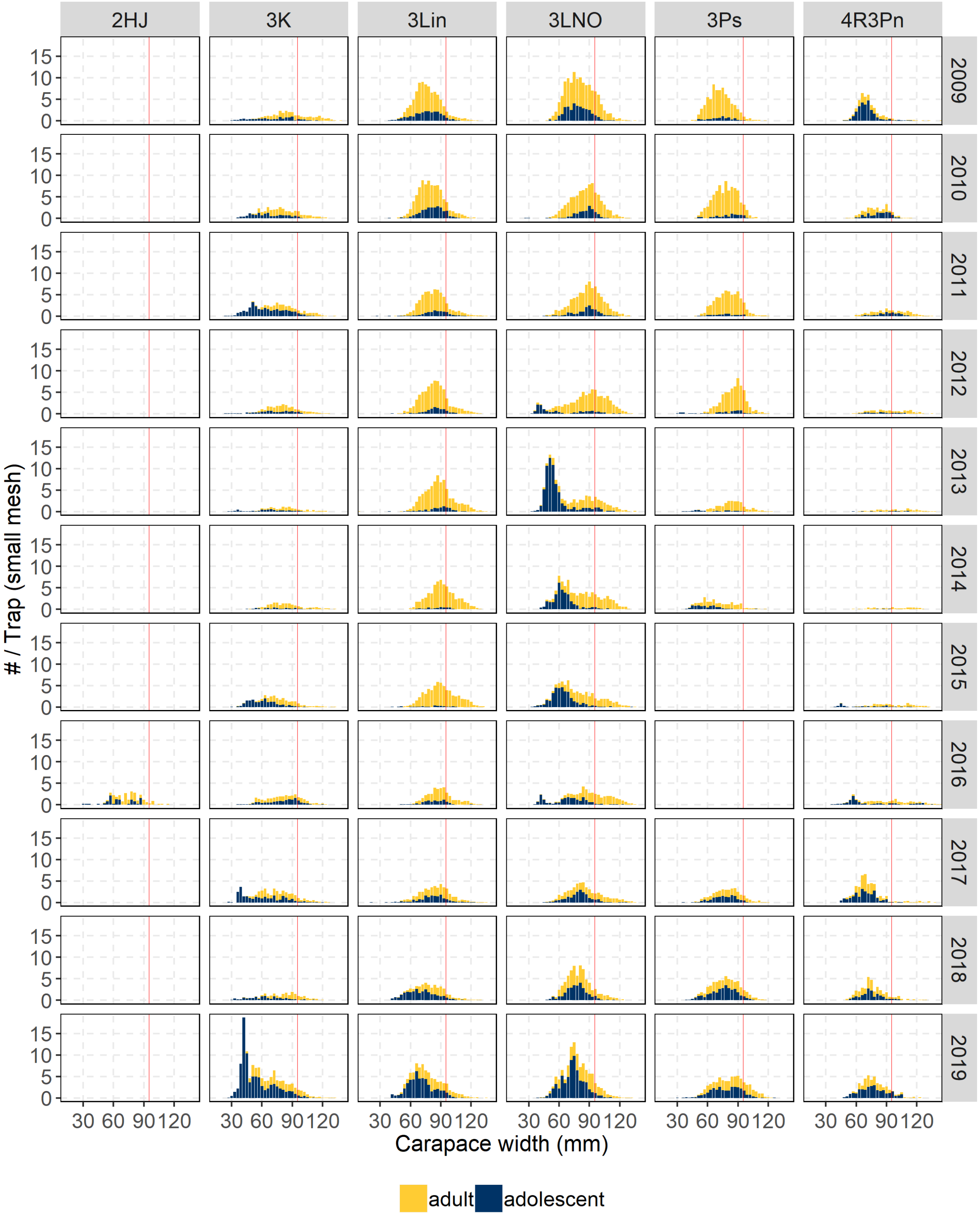

Figure 68. Trends in CPUE (#/trap) by carapace width and maturity (blue – juveniles and adolescent males, yellow – adult males) from small-mesh traps at core stations from the CPS trap survey by AD (2009–19). The red vertical line indicates the minimum legal size.

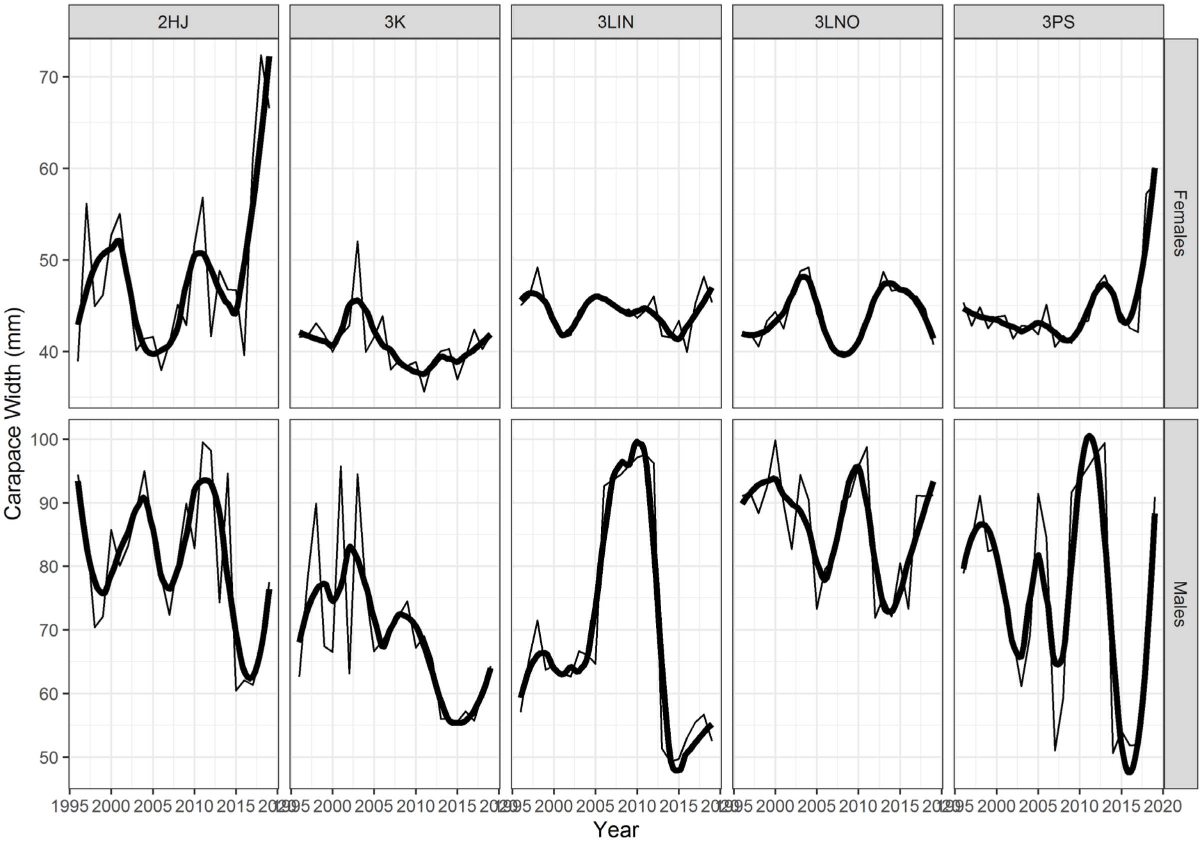

Figure 69. Size of female (top) and male (bottom) 50% size-at-maturity by AD (1995–2019). Thin lines represent annual estimates from GAMM. Thick lines represent a smoothed line through annual estimates.

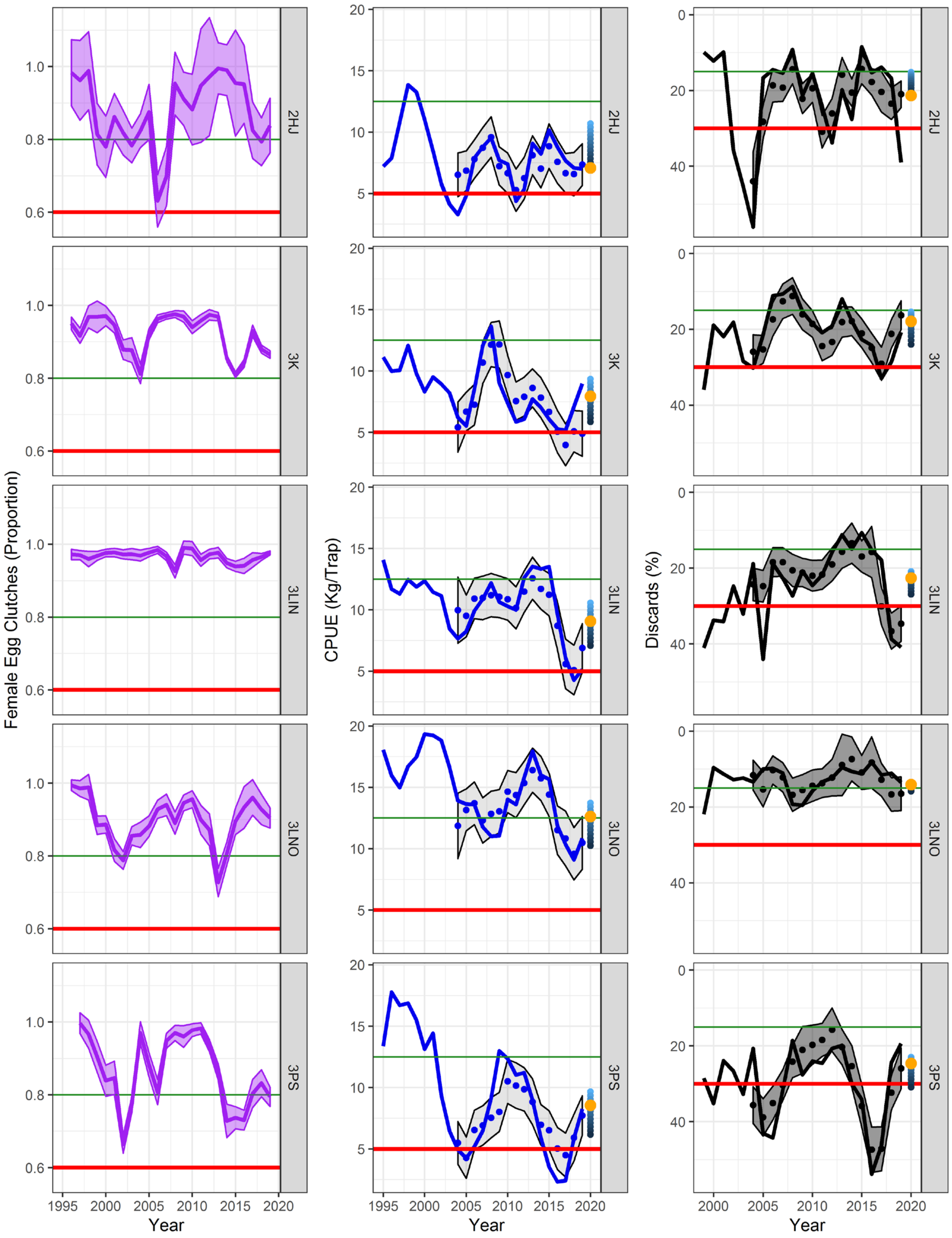

Figure 70. Observed trends in proportion of females with full egg clutch (left), CPUE (middle), and % discards (right) (solid lines) as well as predicted values for CPUE and discards (points) in relation to LRPs (red horizontal lines) and provisional USRs (green horizontal lines) for each metric in the proposed PA Framework, by AD. Shaded areas represent 95% confidence (egg clutches) or prediction intervals (CPUE and discards). Orange points represent predicted values under status quo landings in forthcoming fishery. Vertical blue shades in 2020 are the predicted values under varying levels of ERI (light to dark blue: ERI = 0–60%)

APPENDIX 1: ASSESSMENT DIVISION 2HJ DETAILS

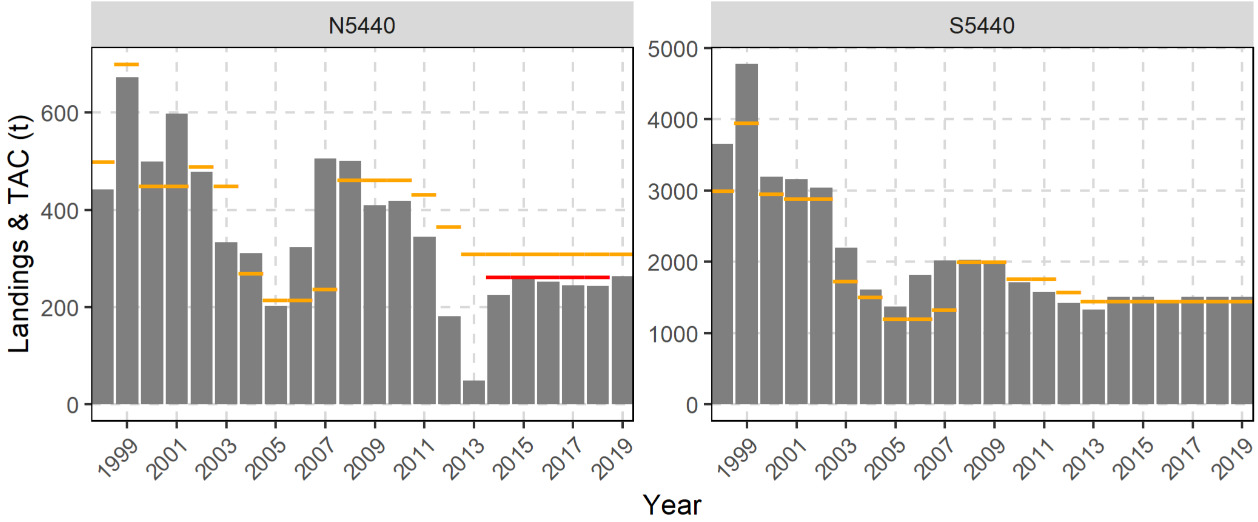

Figure A1.1. Annual landings (grey bars) and total allowable catch (TAC) (yellow dashes) in CMAs within AD 2HJ (1998–2019). Red dashes are the voluntary TAC (15% reduction of TAC) set by harvesters in N5440 from 2014 to 2018.

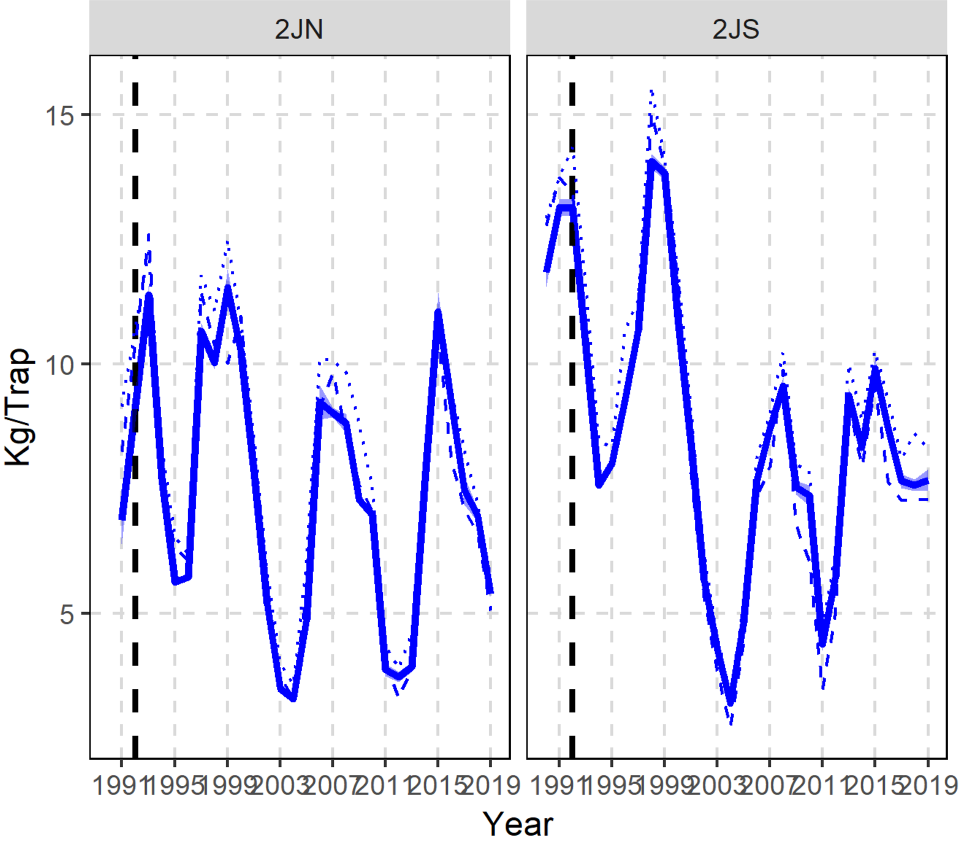

Figure A1.2. Standardized CPUE (kg/trap) in CMAs within AD 2HJ. Solid line is average predicted CPUE and shaded band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

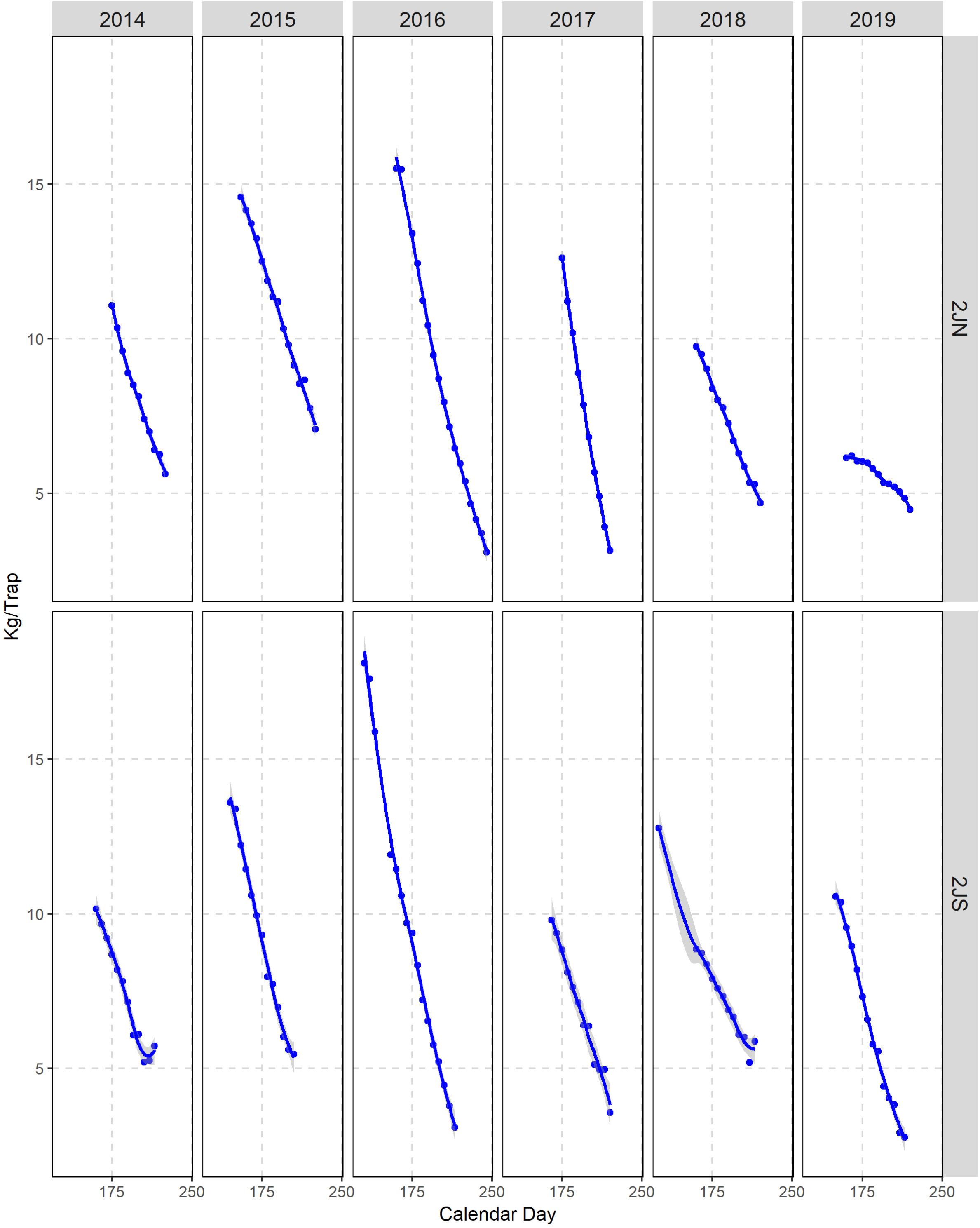

Figure A1.3. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each CMA in AD 2HJ (2014–19). Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

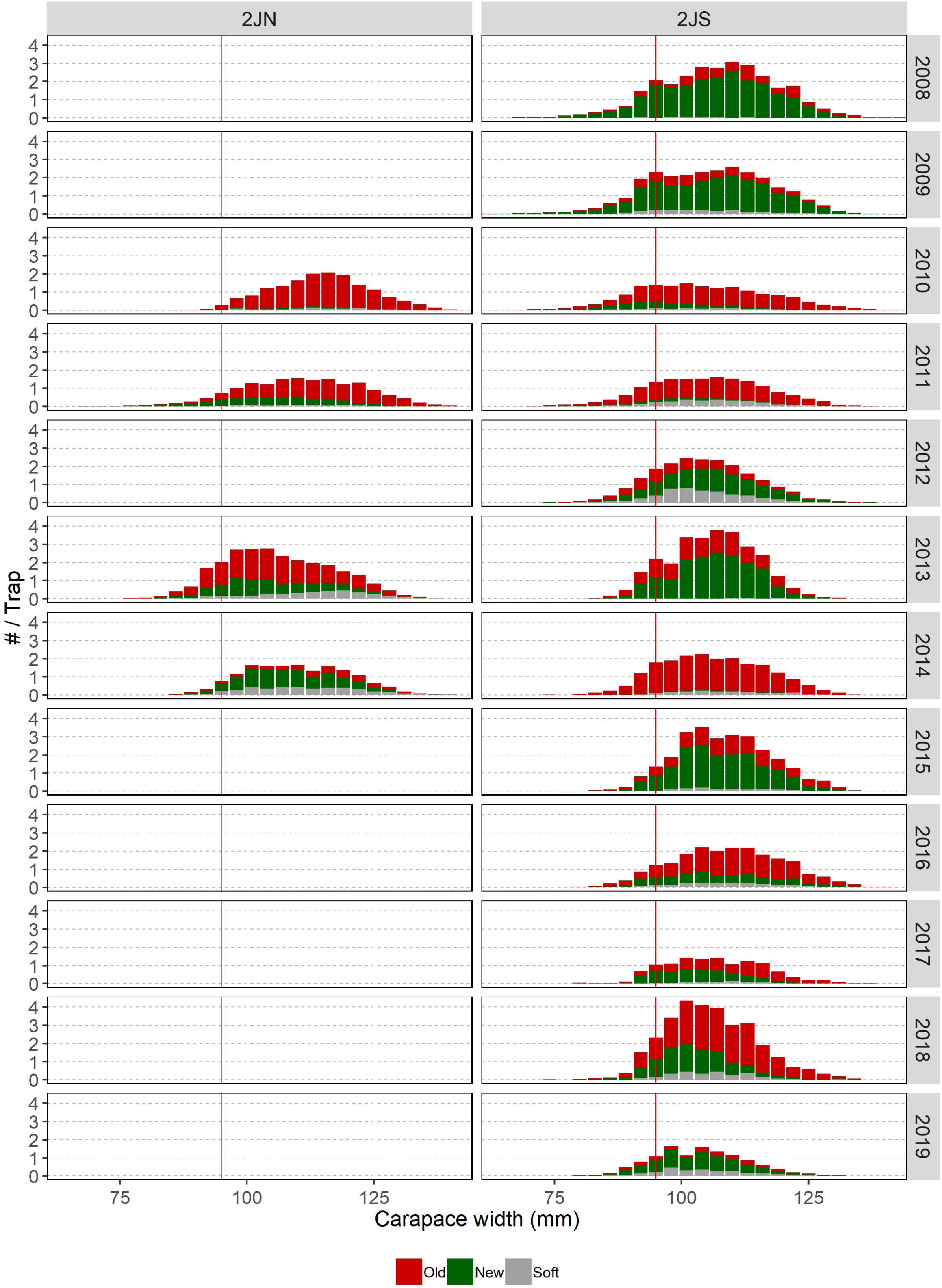

Figure A1.4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each CMA in AD 2HJ (2008–19). The red vertical line indicates the minimum legal size.

Figure A1.5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within AD 2HJ (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

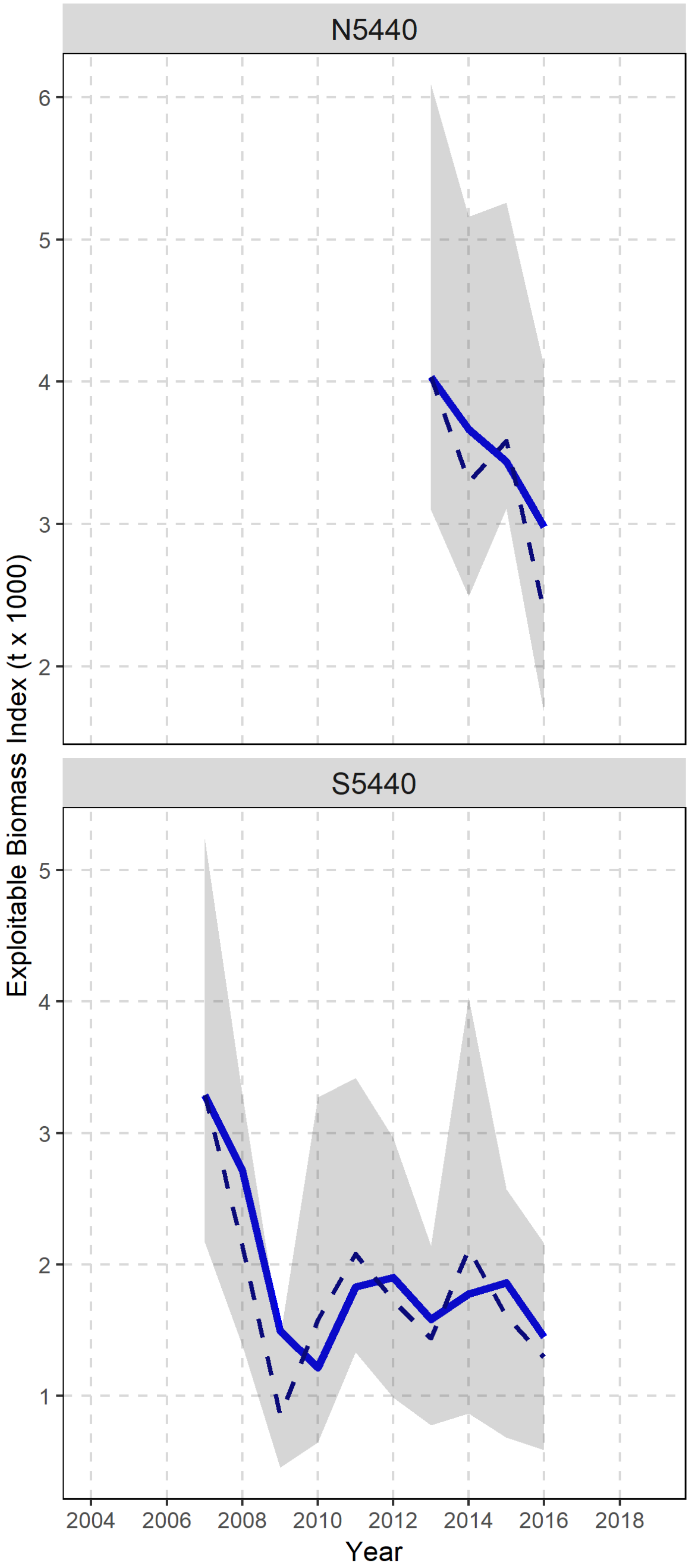

*Figure A1.6. Trap survey exploitable biomass indices (t*1,000) by CMAs in AD 2HJ (2007–16). Dashed lines shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate.*

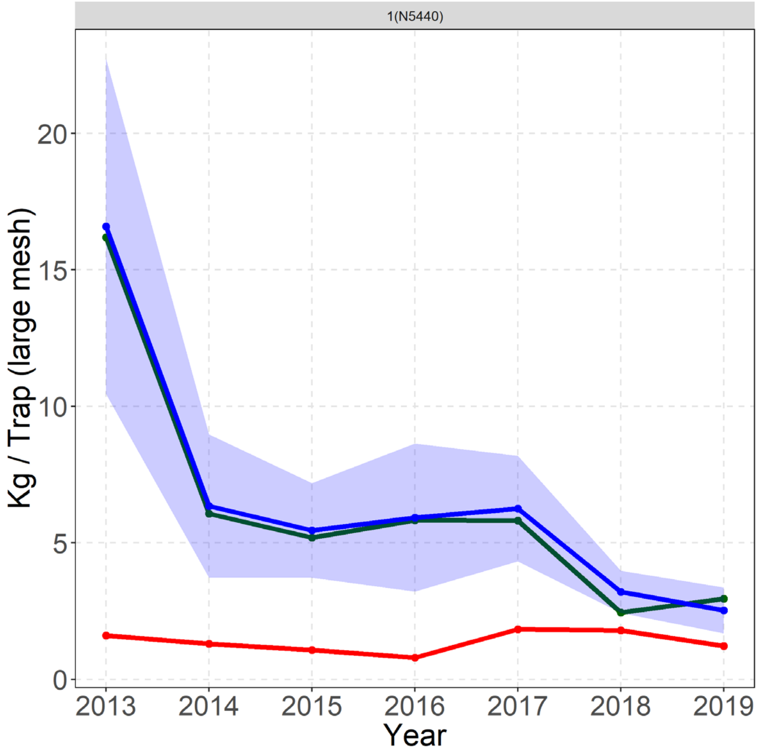

Figure A1.7. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab in the TJFB survey in CMA 1 (N5440) (2013–19). Shaded area represents the 95% confidence interval.

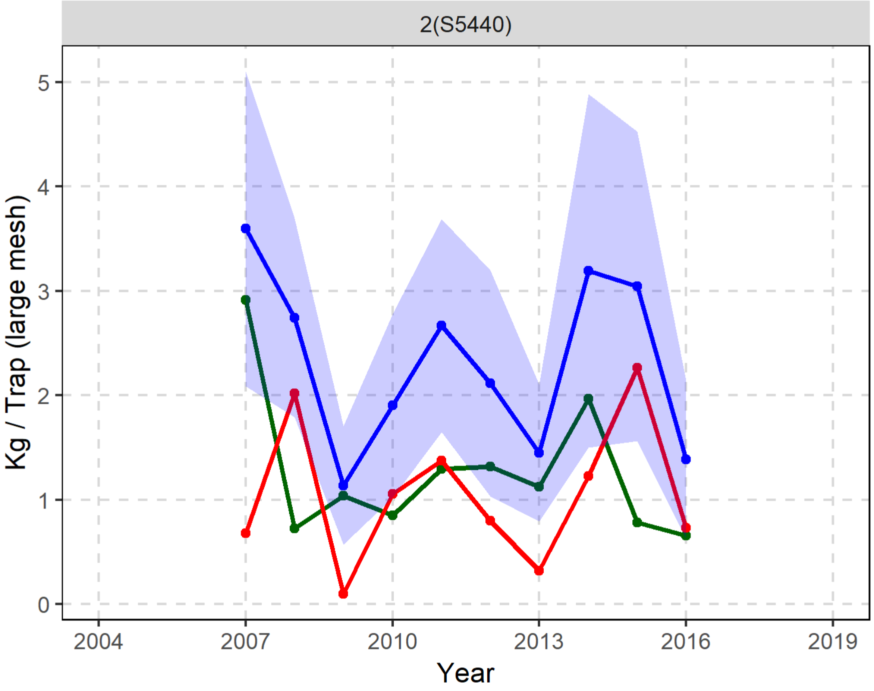

Figure A1.8. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from core stations in the CPS trap survey in CMA 2 (S5440) (2007–16). Shaded area represents the 95% confidence interval.

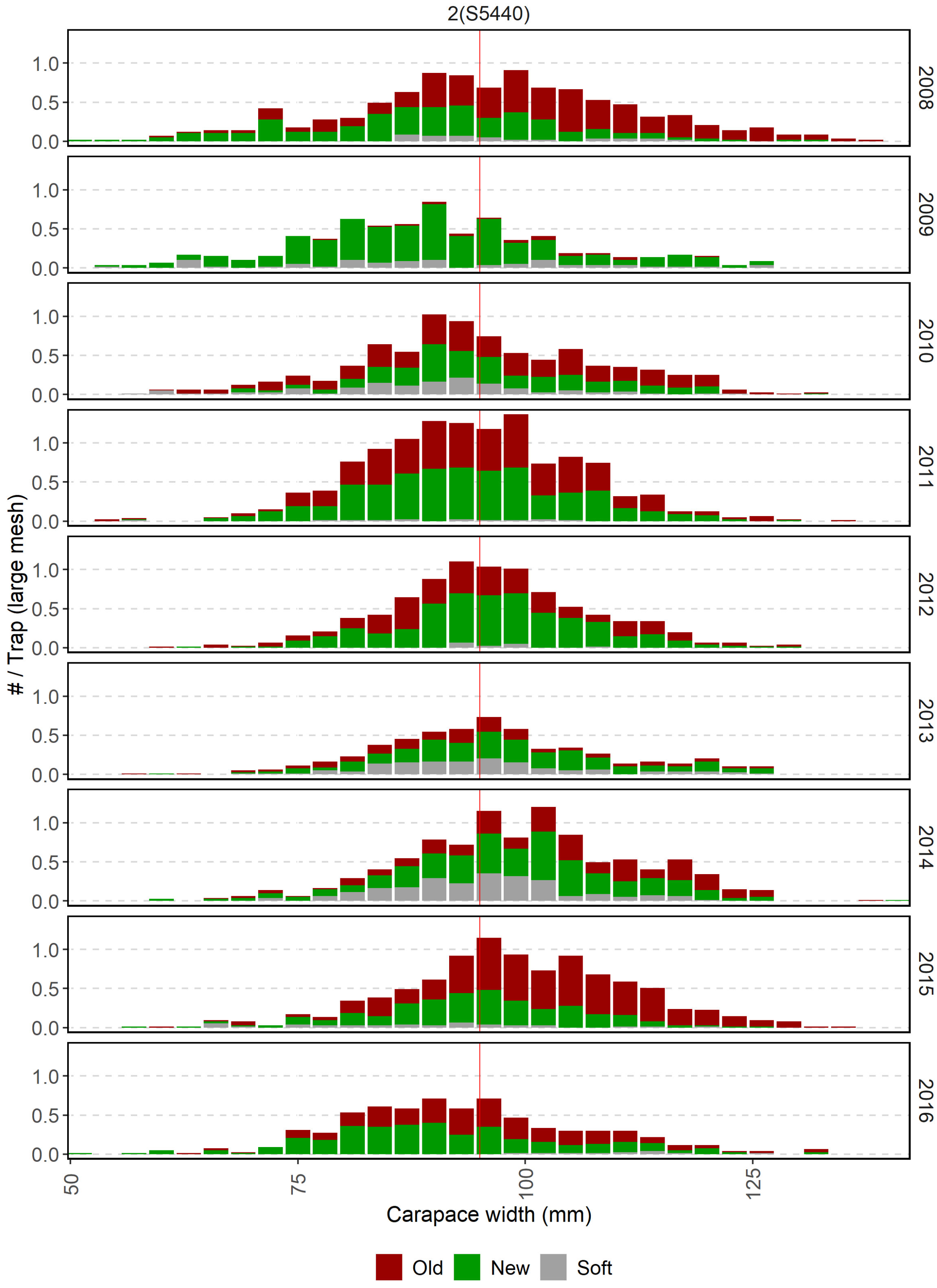

Figure A1.9. CPUE (#/trap) by carapace width and shell condition from male Snow Crab in large-mesh traps at core stations in the CPS trap survey in CMA 2JS in AD 2HJ (2008–16). The red vertical line indicates the minimum legal size.

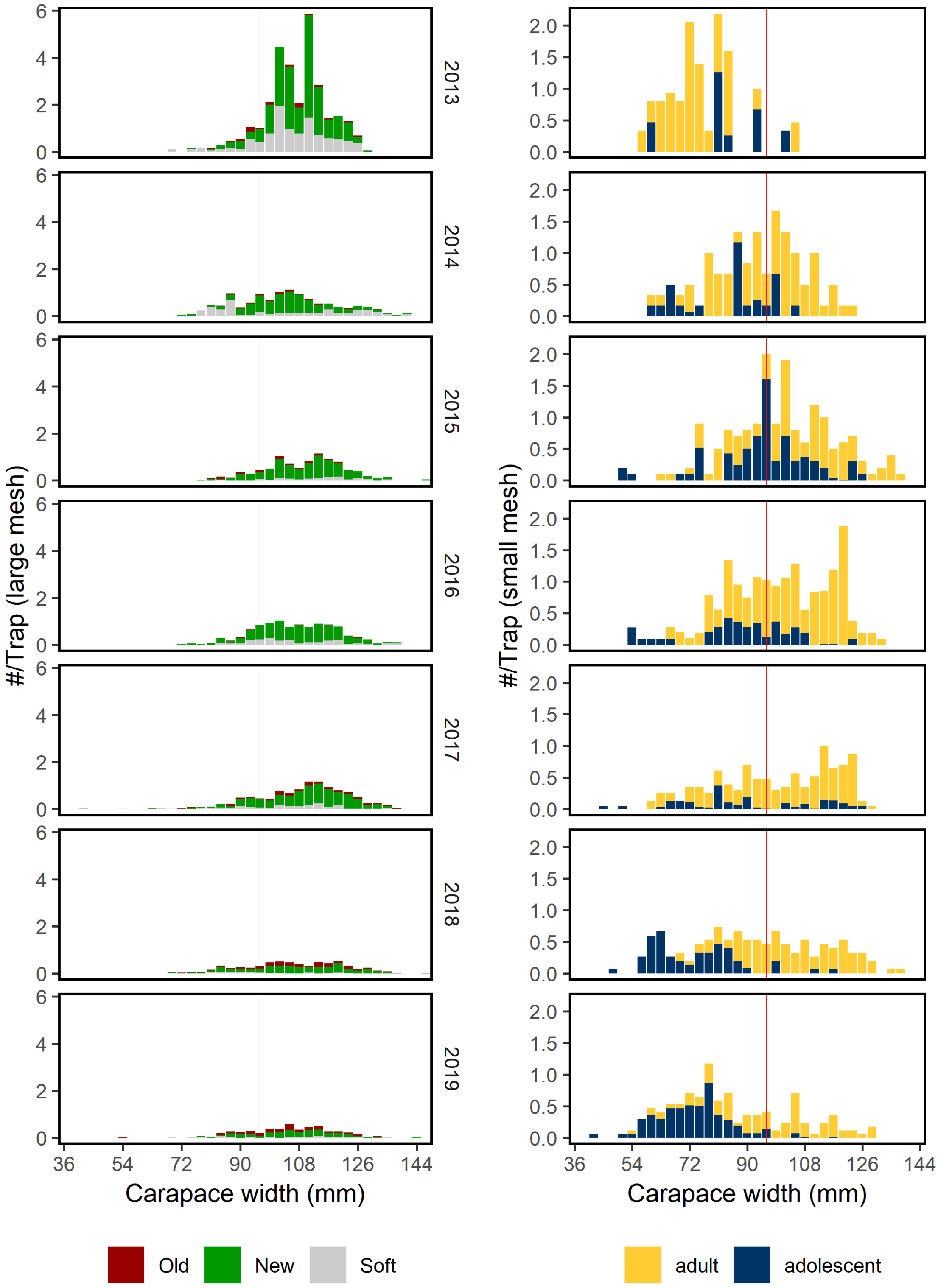

Figure A1.6. ***Left***: *CPUE (#/trap) by carapace width and shell condition from male Snow Crab in large-mesh traps in the TJFB survey in CMA 1(N5440) in AD 2HJ (2013–19). The red vertical line indicates the minimum legal size.* ***Right***: *CPUE (#/trap) by carapace width and maturity from small-mesh traps in the TJFB survey in CMA 1(N5440) in AD 2HJ (2013–19). The red vertical line indicates the minimum legal size.*

APPENDIX 2: ASSESSMENT DIVISION 3K DETAILS

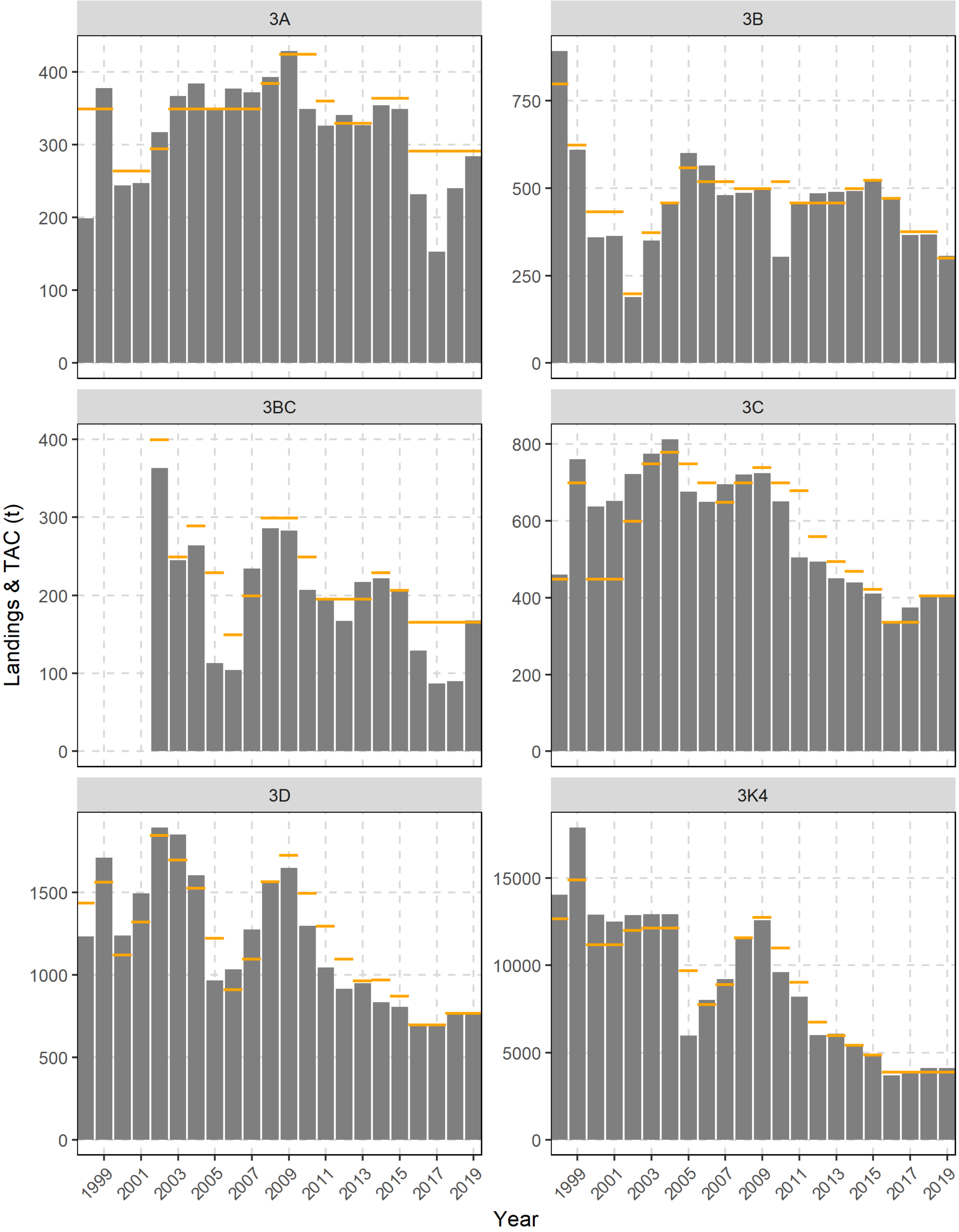

Figure A2.1. Annual landings (grey bars) and TAC (yellow dashes) in CMAs within AD 3K (1998–2019).

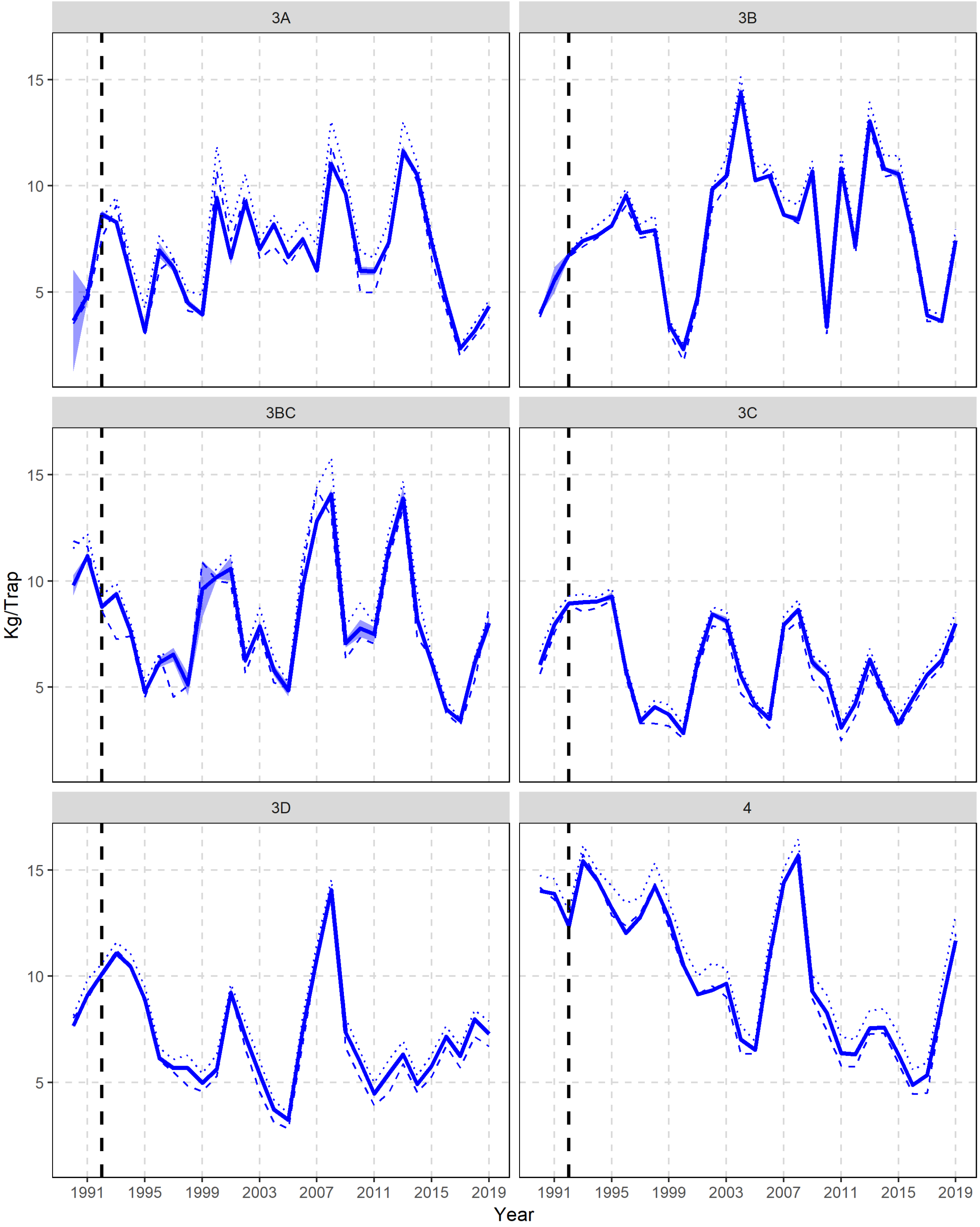

Figure A2.2. Standardized CPUE (kg/trap) in CMAs within AD 3K. Solid line is average predicted CPUE and shaded band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

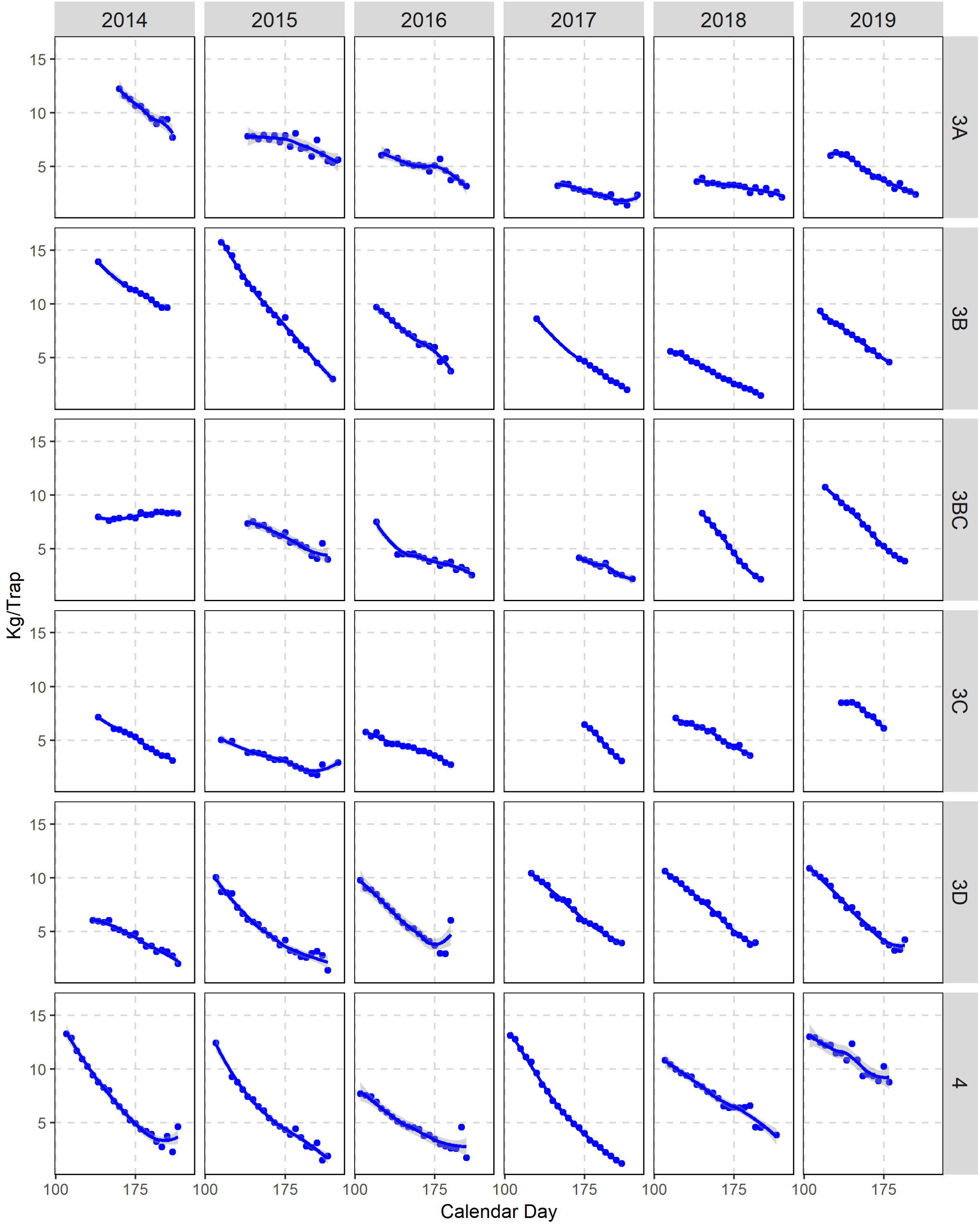

Figure A2.3. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each CMA in AD 3K (2014–19). Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

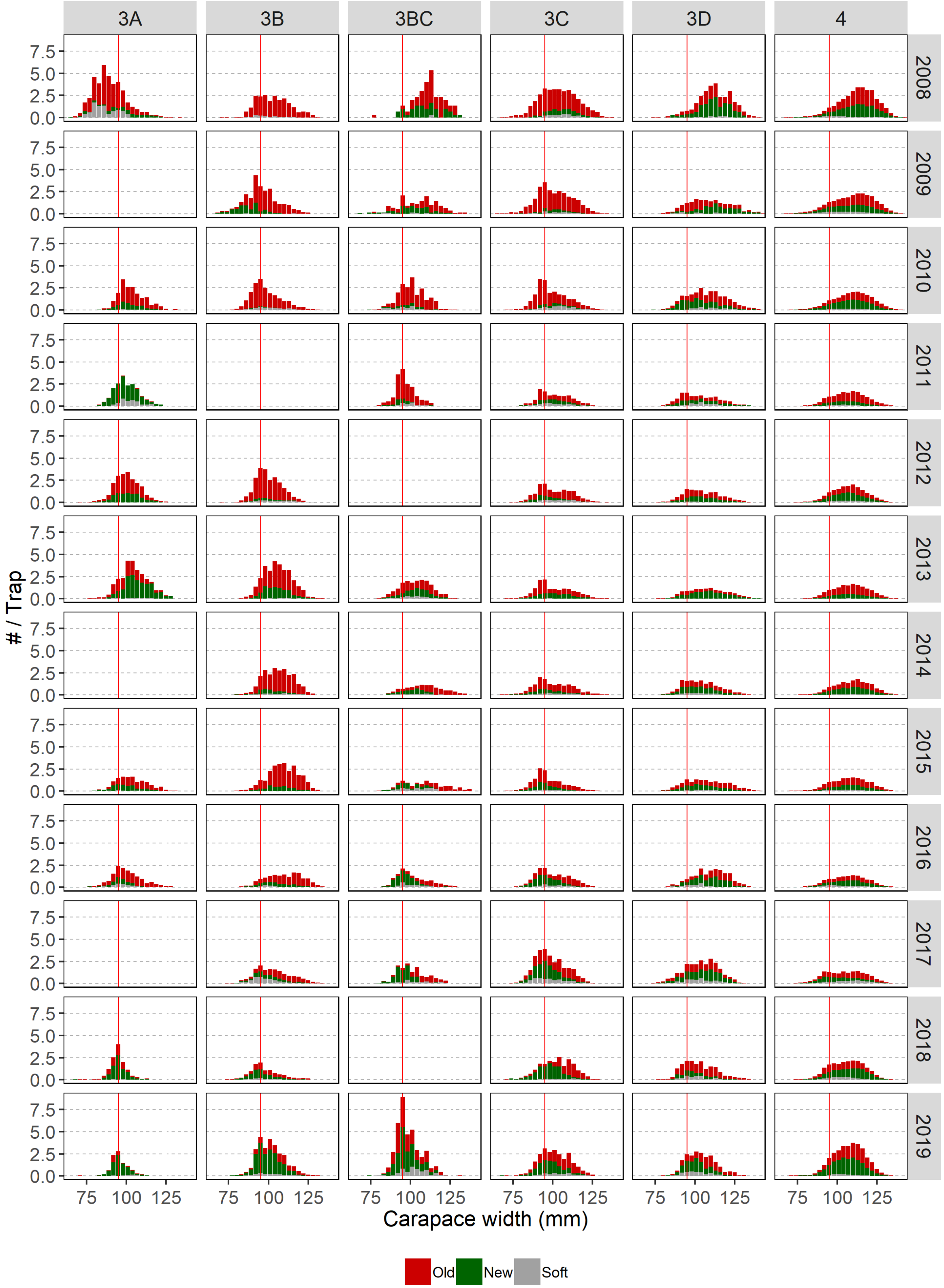

Figure A2.4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each CMA in AD 3K (2008–19). The red vertical line indicates the minimum legal size.

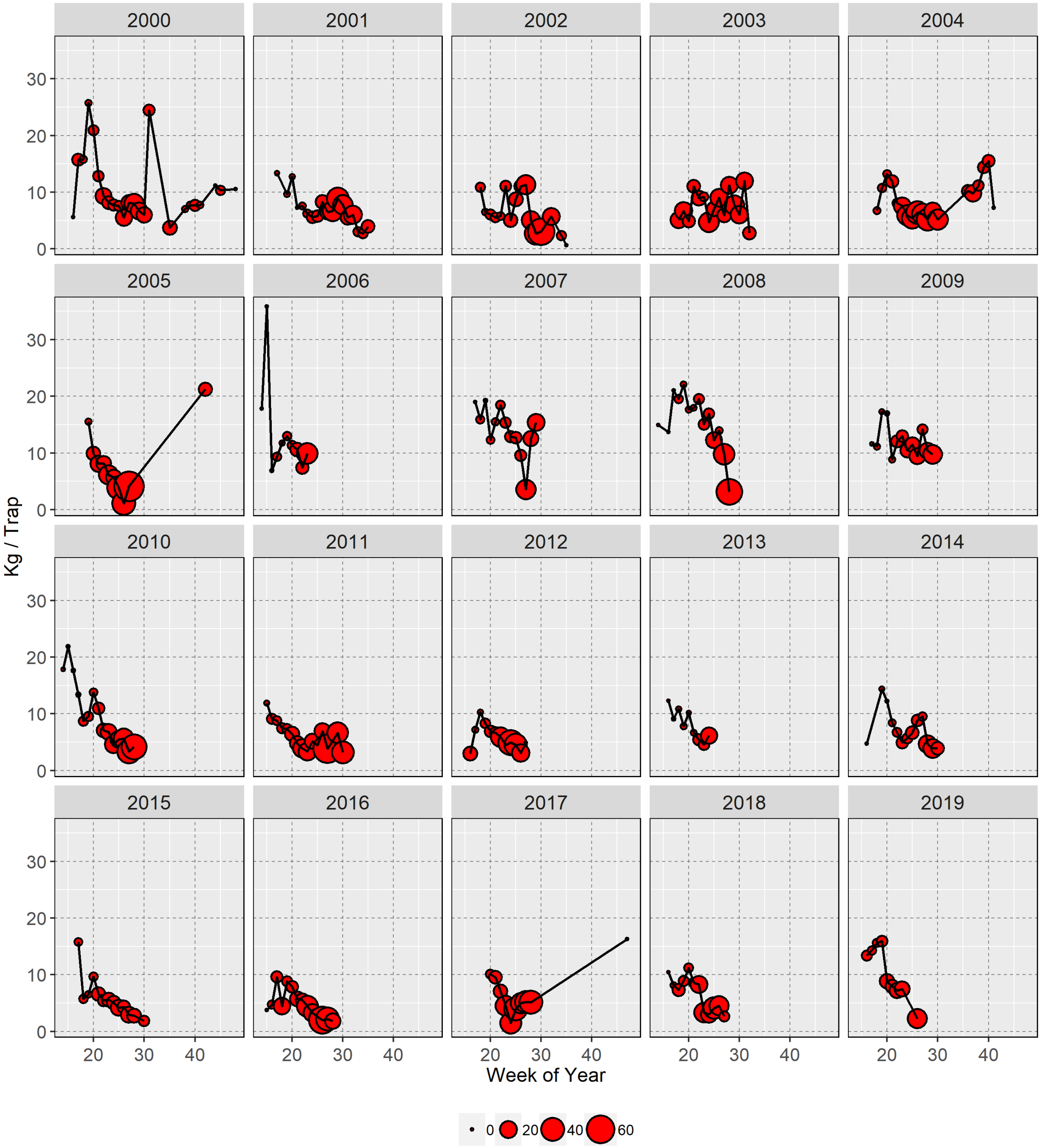

Figure A2.5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within AD 3K (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

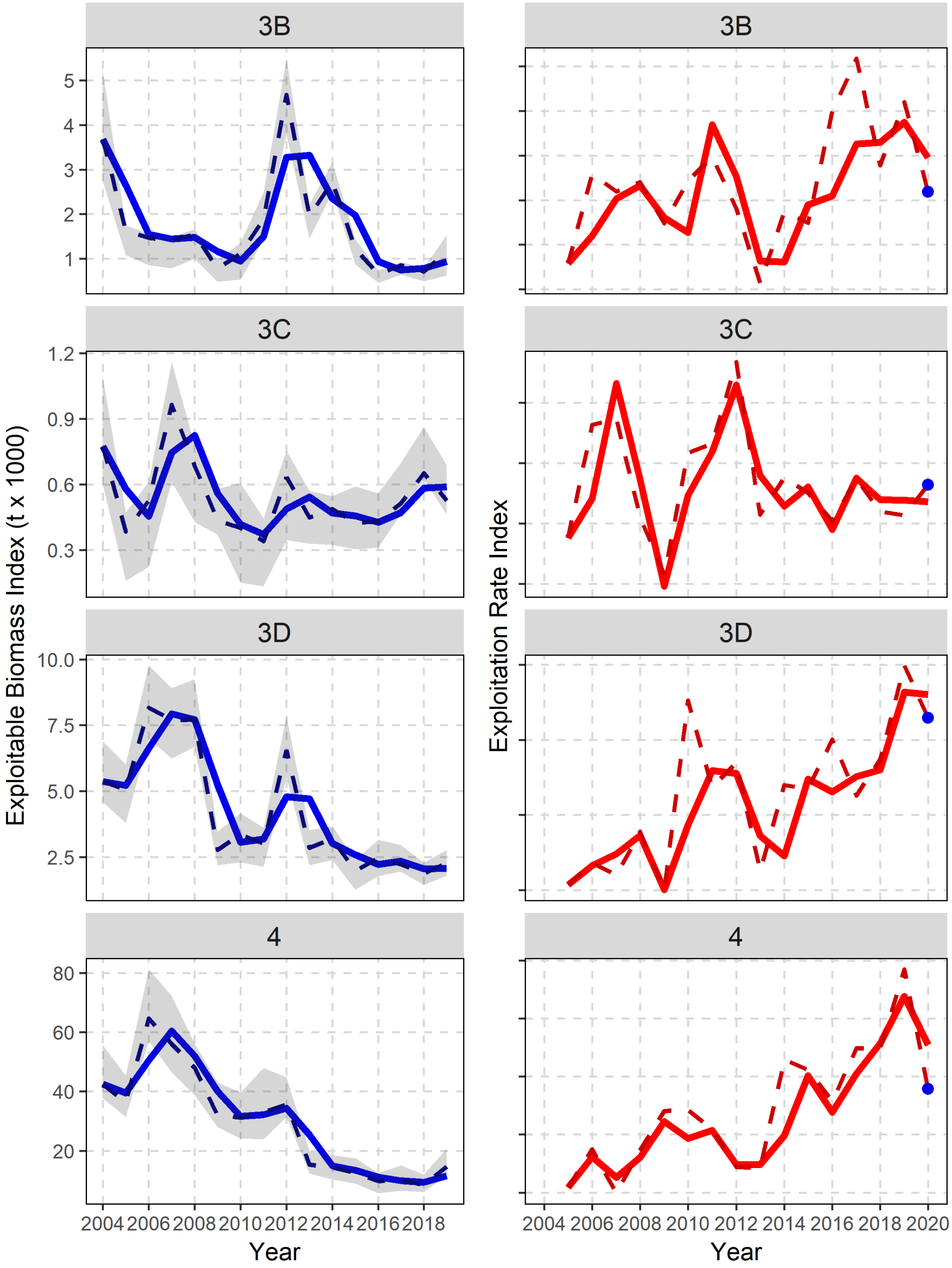

Figure A2.6. ***Left****: Trap survey exploitable biomass indices (t*1,000) by CMA in AD 3K (2004–19). Dashed lines shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate.* ***Right****: Trends in the annual (points) and 2-year moving average (solid line) trap-based ERI (%) by CMA in AD 3K; 2020 stars depict projected exploitation rate indices under status quo removals in the 2020 fishery.*

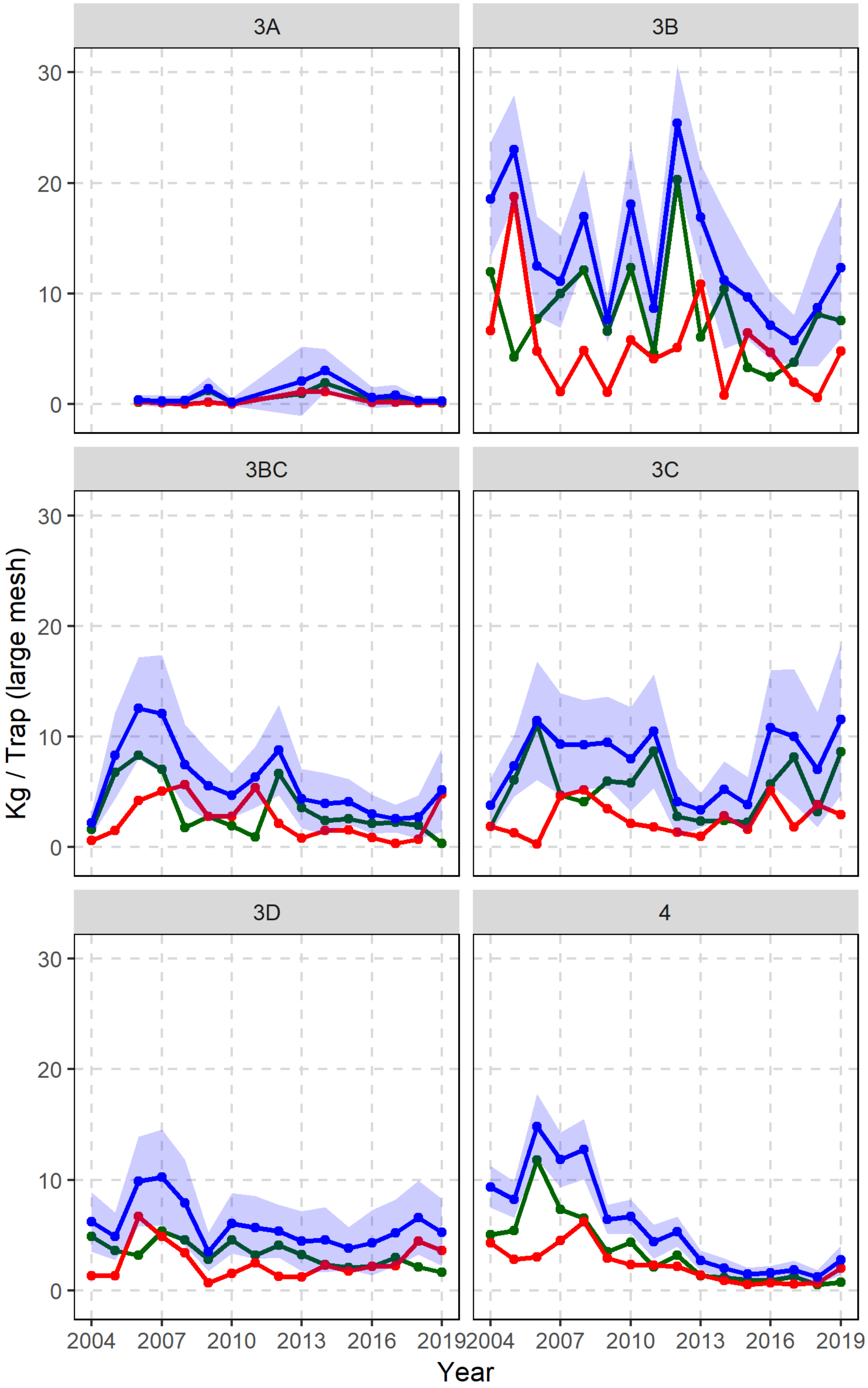

Figure A2.7. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from core stations in the CPS trap survey by CMA in AD 3K (2004–19). Shaded area represents the 95% confidence interval.

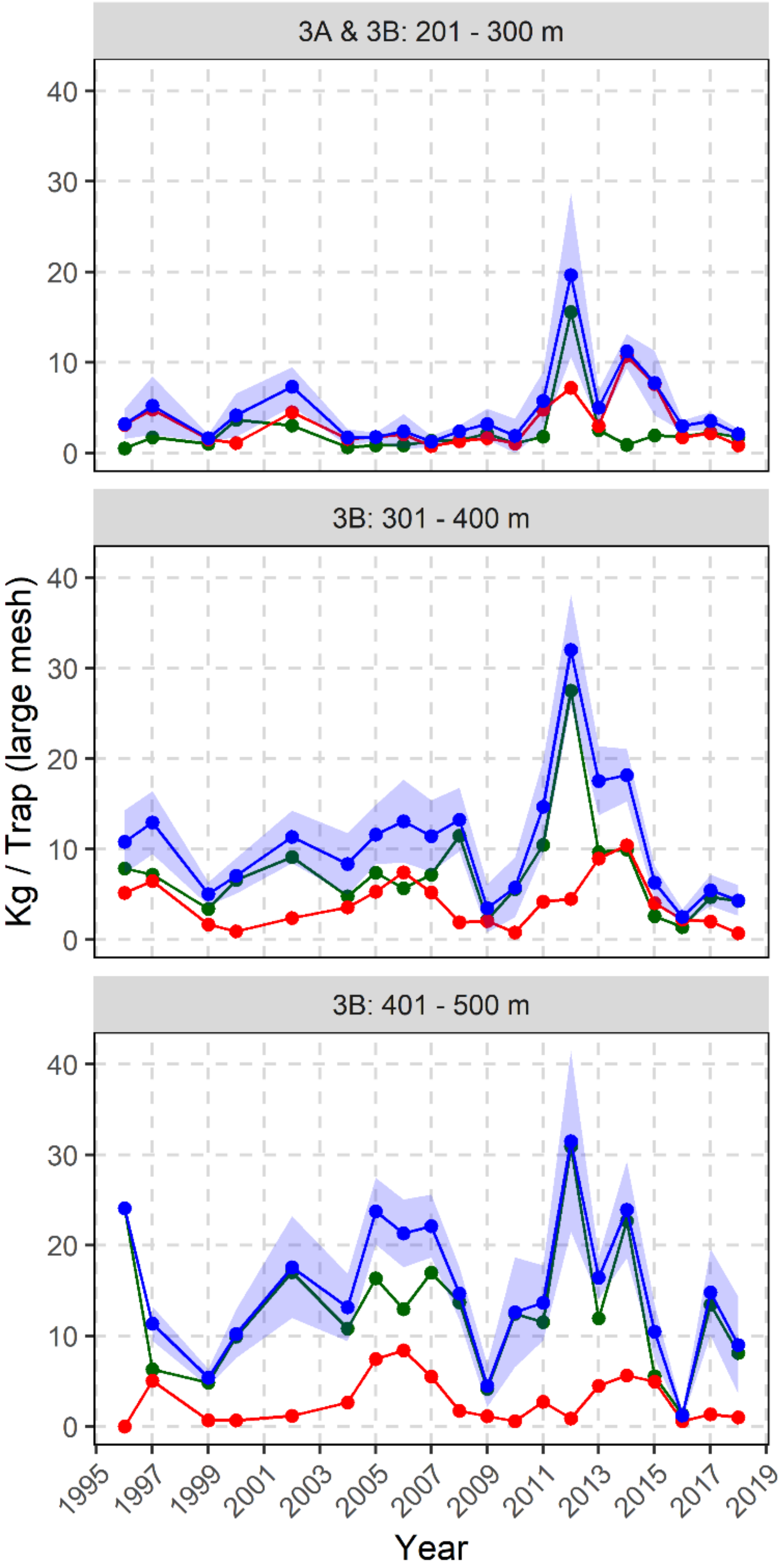

Figure A2.8. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from Inshore DFO trap surveys in White Bay in AD 3K (1996–2018). Shaded area represents the 95% confidence interval.

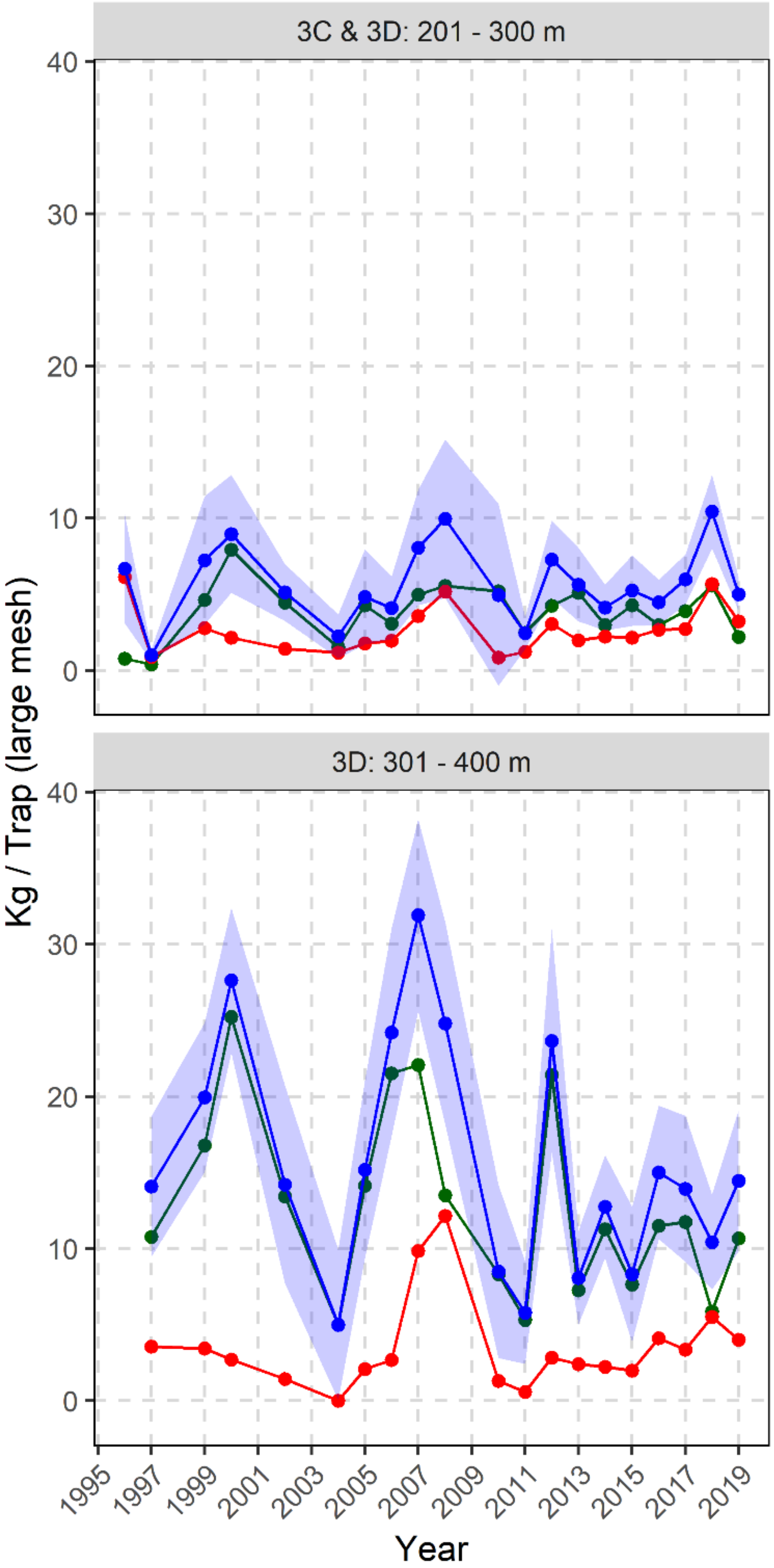

Figure A2.9. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from Inshore DFO trap surveys in Green Bay and Notre Dame Bay in AD 3K (1996–2019). Shaded area represents the 95% confidence interval.

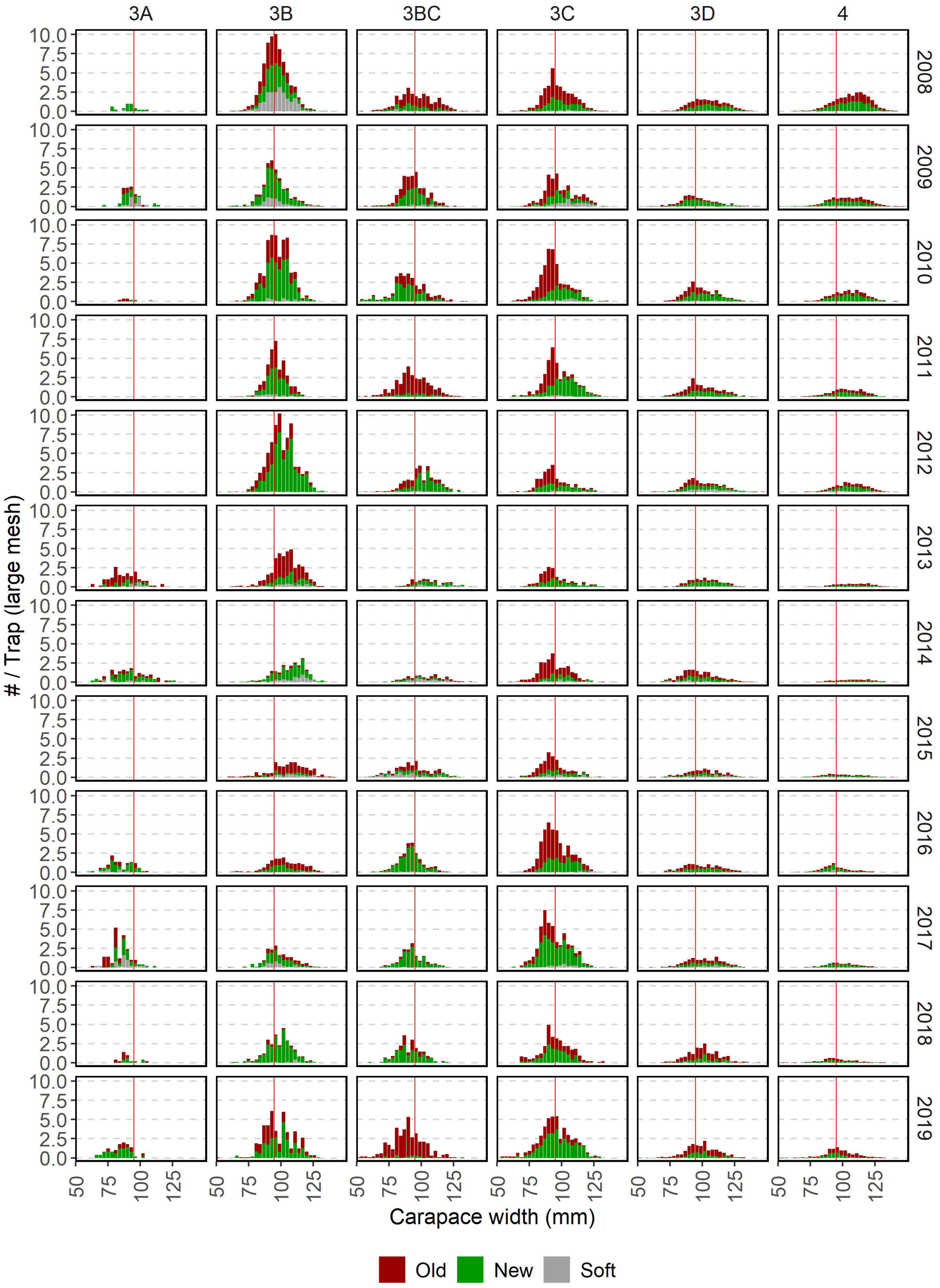

Figure A2.10. CPUE (#/trap) by carapace width and shell condition from male Snow Crab in large-mesh traps at core stations in the CPS trap survey by CMA in AD 3K (2008–19). The red vertical line indicates the minimum legal size.

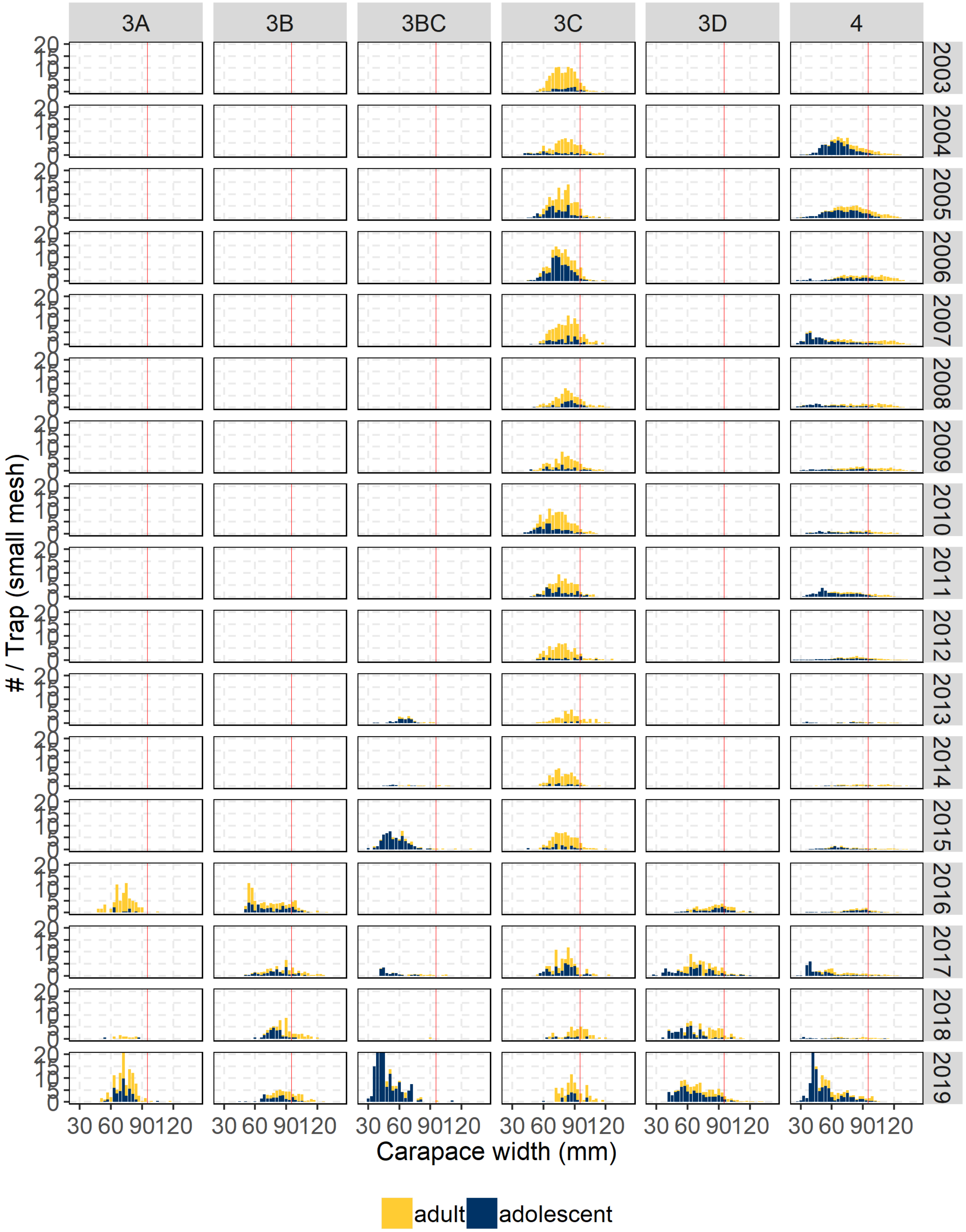

Figure A2.11. CPUE (#/trap) by carapace width and maturity from small-mesh traps at core stations in the CPS trap survey by CMA in AD 3K (2003–19). The red vertical line indicates the minimum legal size.

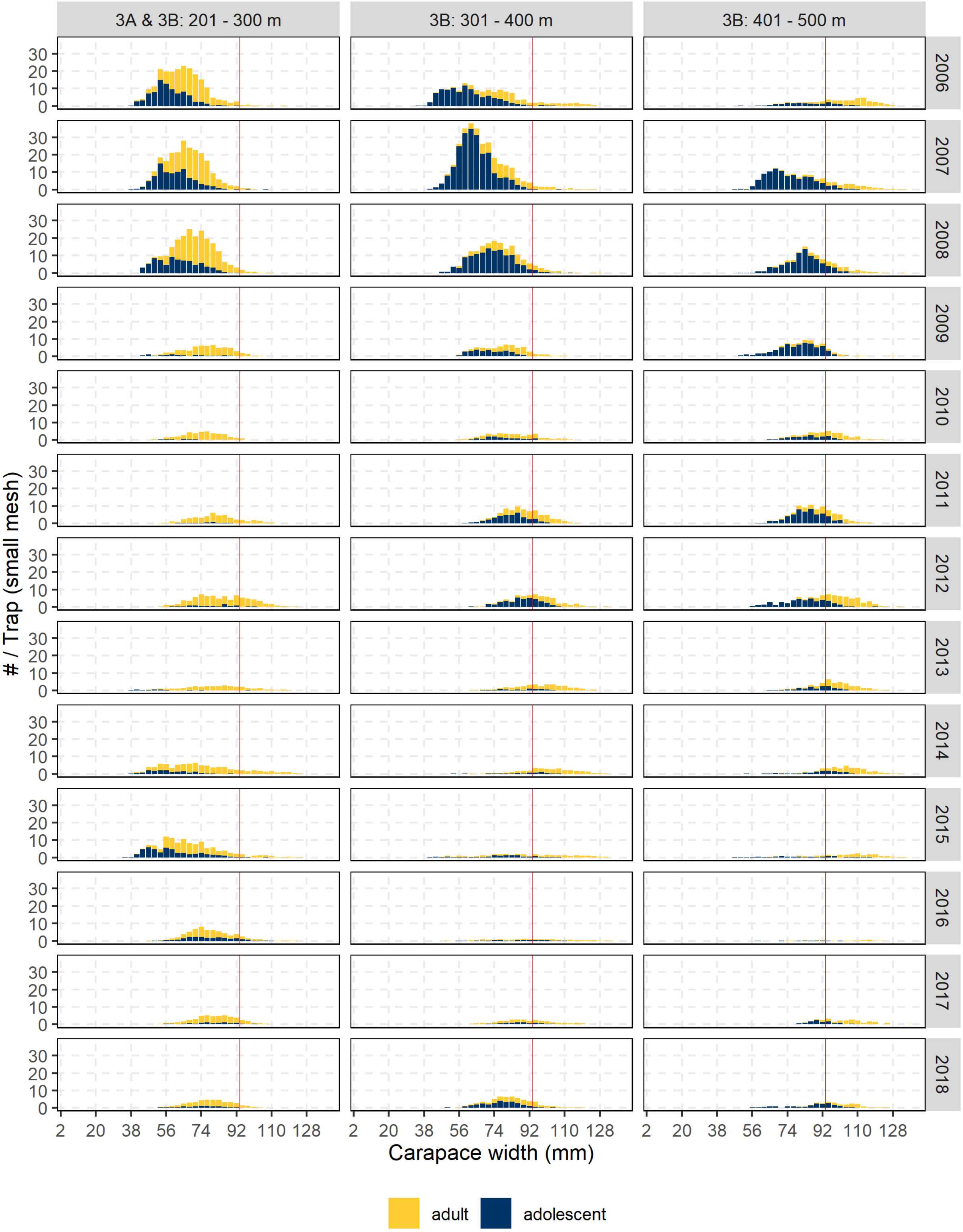

Figure A2.12. CPUE (#/trap) by carapace width and maturity from small-mesh traps in the Inshore DFO trap survey in White Bay in AD 3K (2006–18). The red vertical line indicates the minimum legal size.

Figure A2.13. CPUE (#/trap) by carapace width and maturity from small-mesh traps in the Inshore DFO trap survey in Green Bay and Notre Dame Bay in AD 3K (2006–19). The red vertical line indicates the minimum legal size.

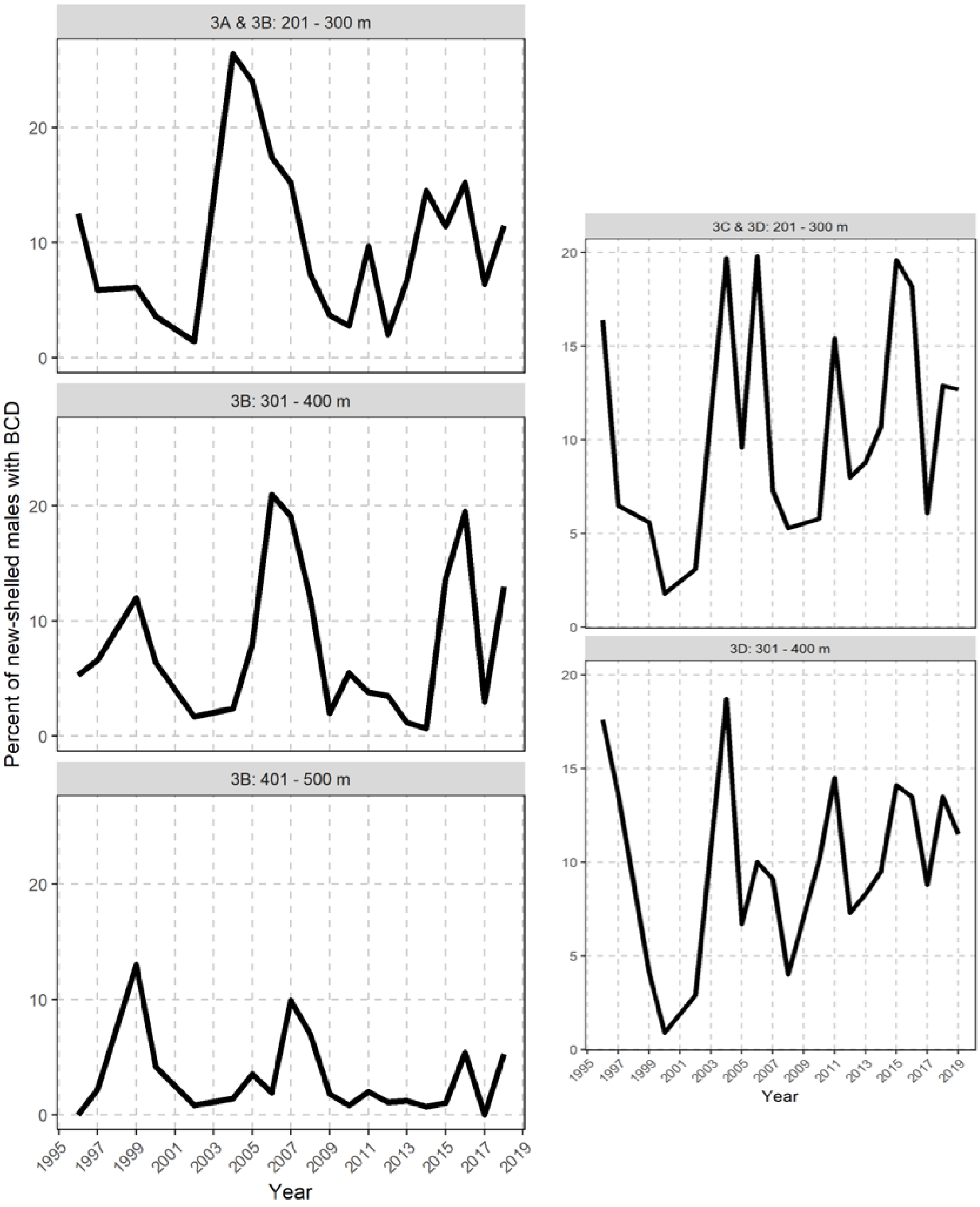

Figure A2.14. Visually observed percentage of BCD in new-shelled males from Inshore DFO trap surveys in White Bay and Green/Notre Dame Bays in AD 3K (1996–2019). Note: no survey in White Bay in 2019.

APPENDIX 3: ASSESSMENT DIVISION 3L INSHORE DETAILS

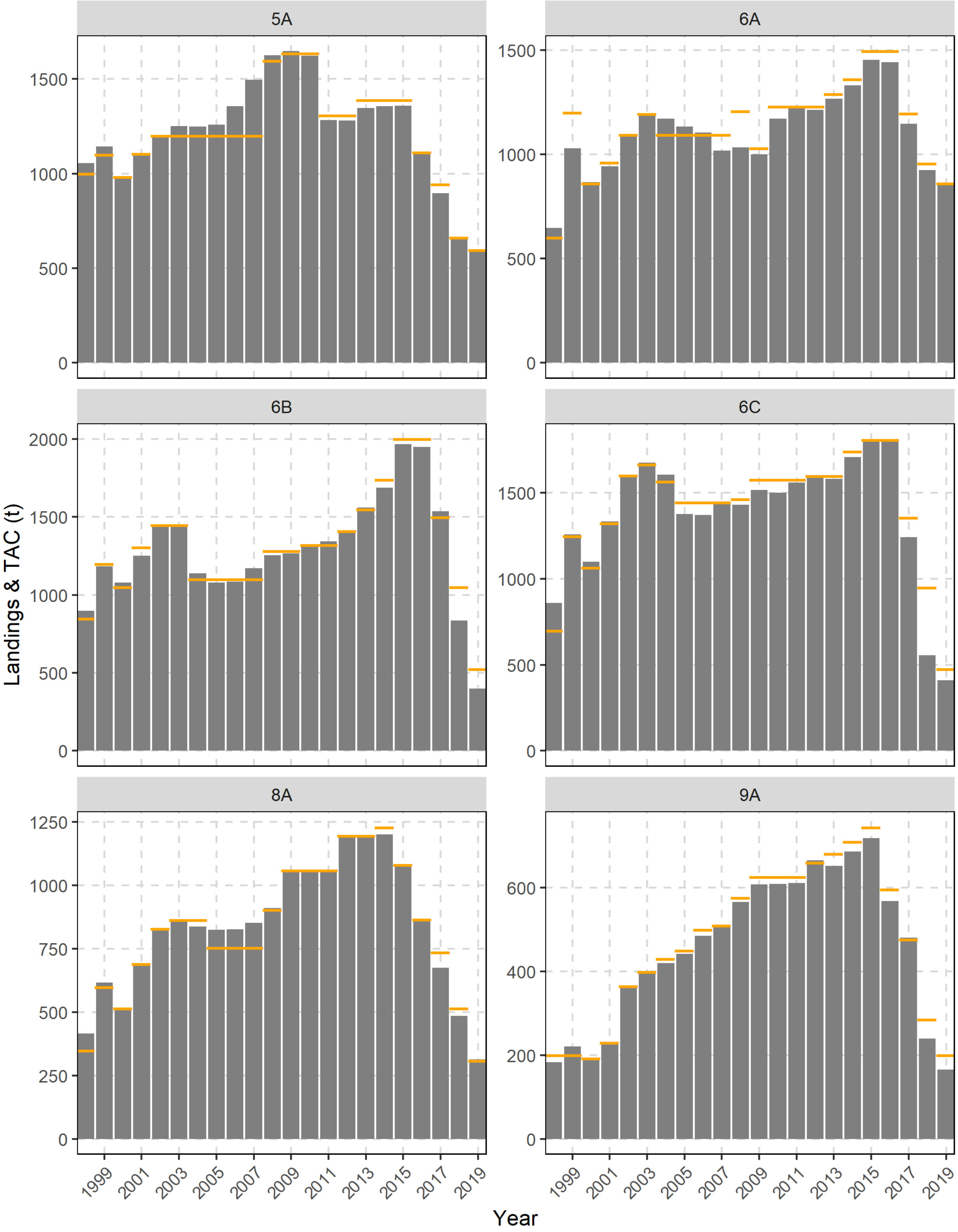

Figure A3.1. Annual landings (grey bars) and TAC (yellow dashes) in CMAs within AD 3L Inshore (1998–2019).

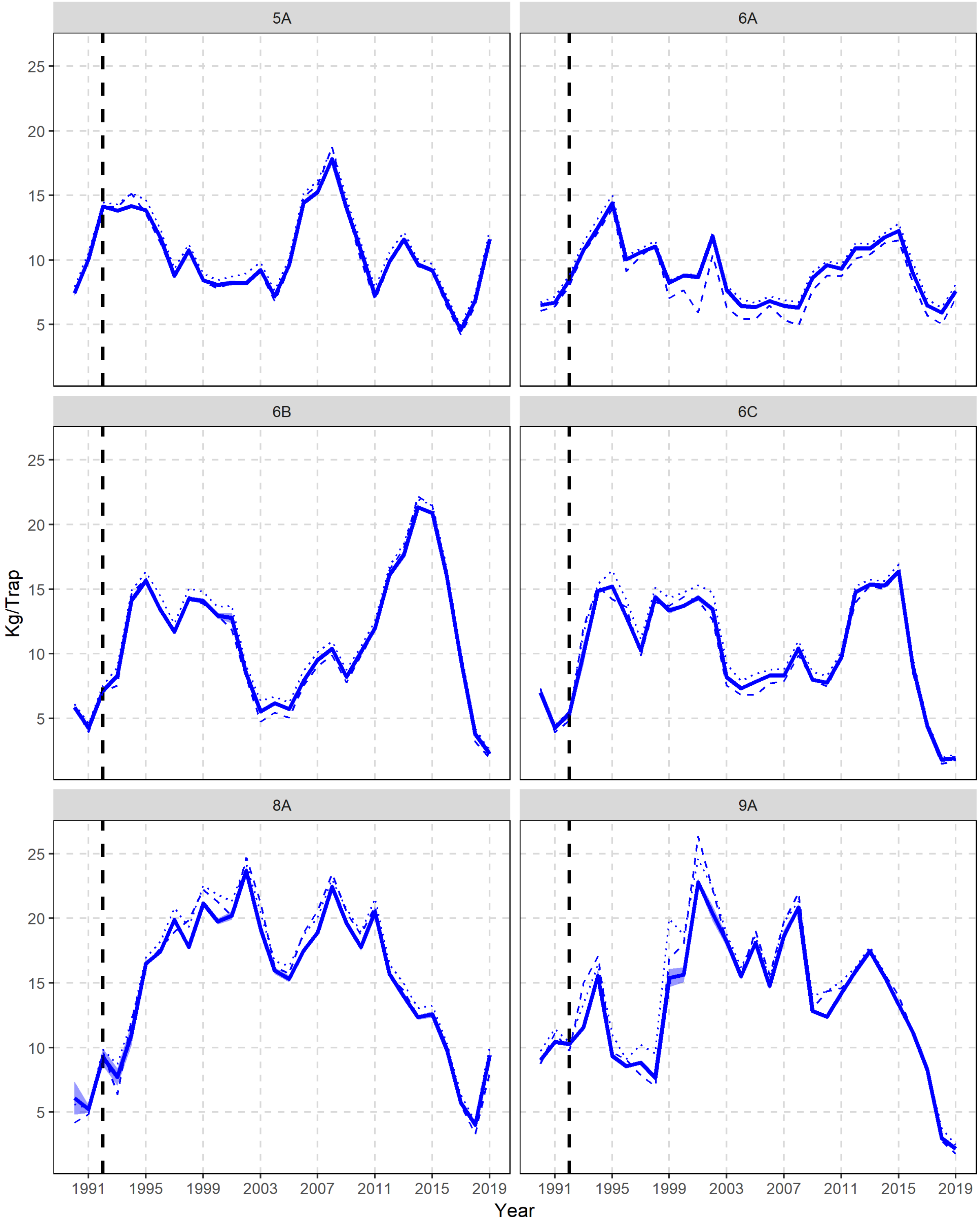

Figure A3.2. Standardized CPUE (kg/trap) in CMAs within AD 3L Inshore. Solid line is average predicted CPUE and shaded band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

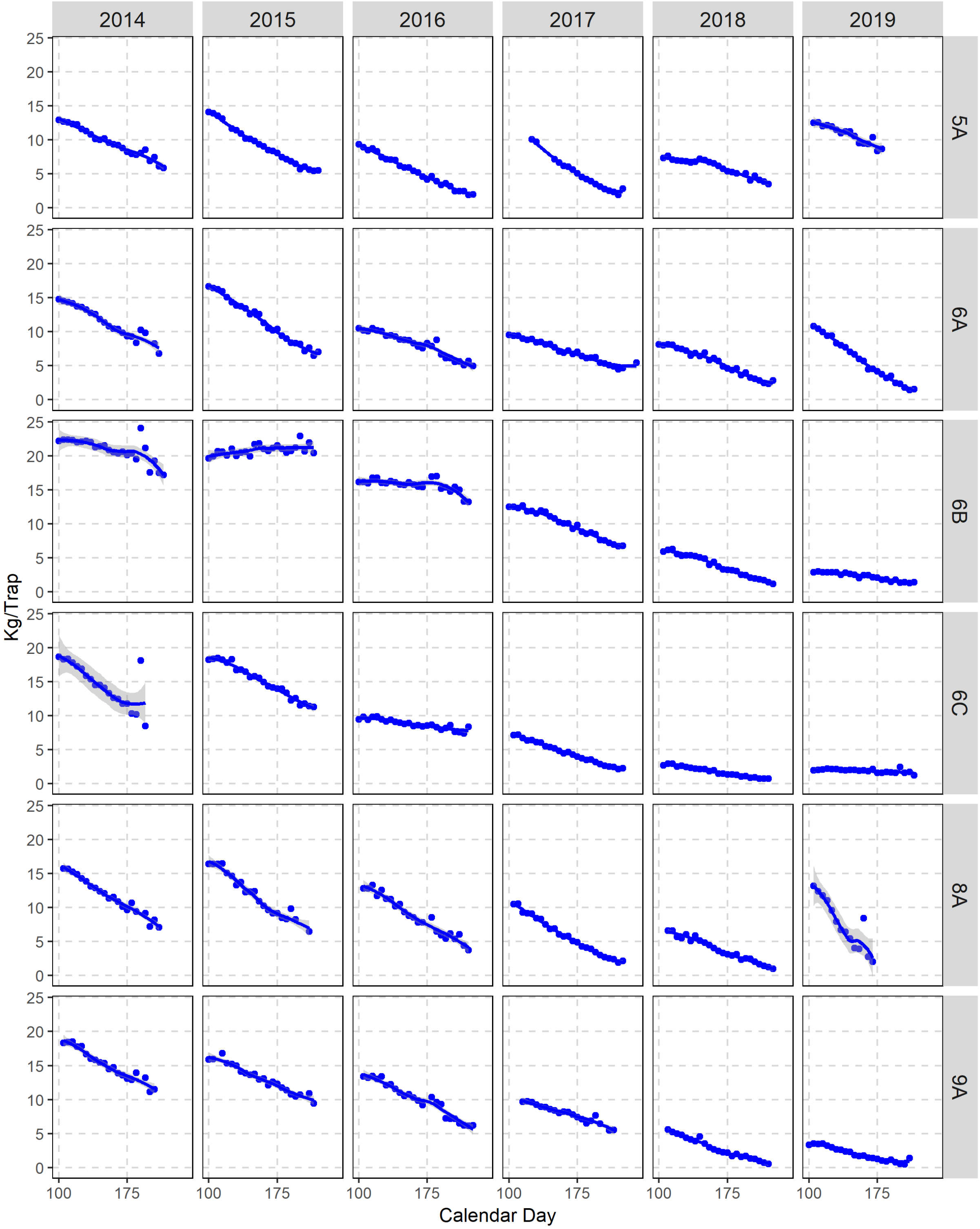

Figure A3.3. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each CMA in AD 3L Inshore (2014–19). Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

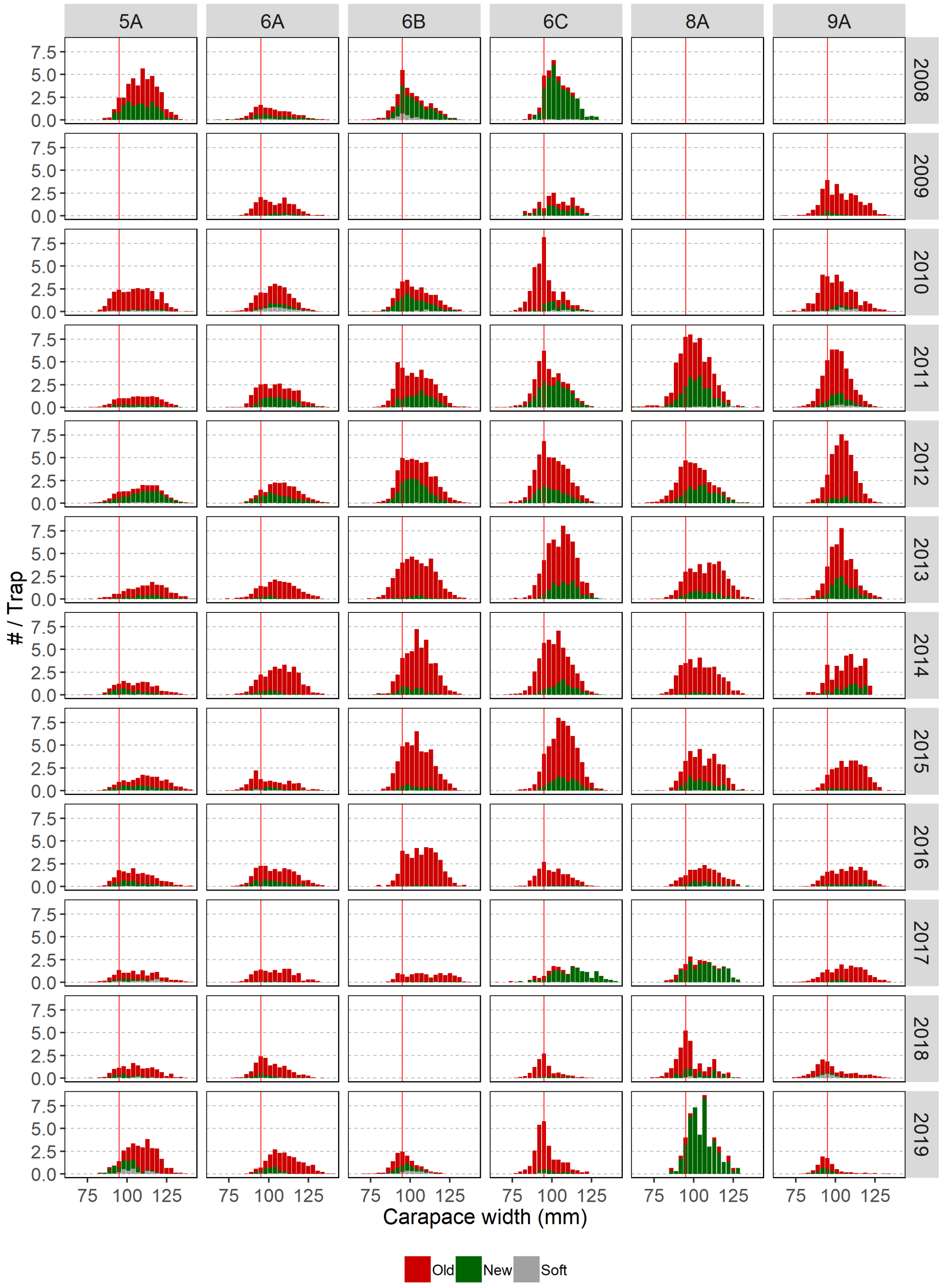

Figure A3.4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each CMA in AD 3L Inshore (2008–19). The red vertical line indicates the minimum legal size.

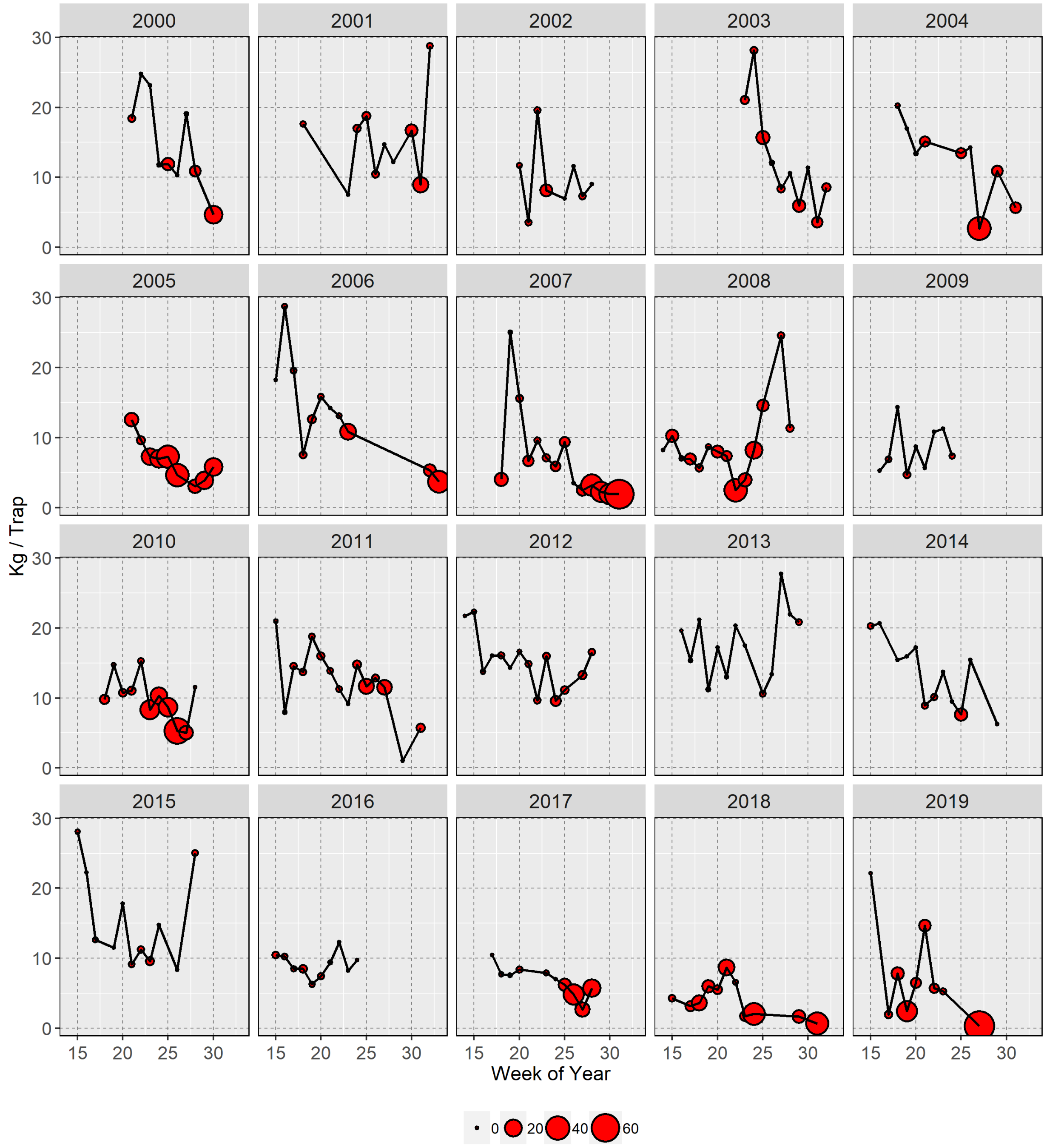

Figure A3.5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within AD 3L Inshore (1999–2019). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

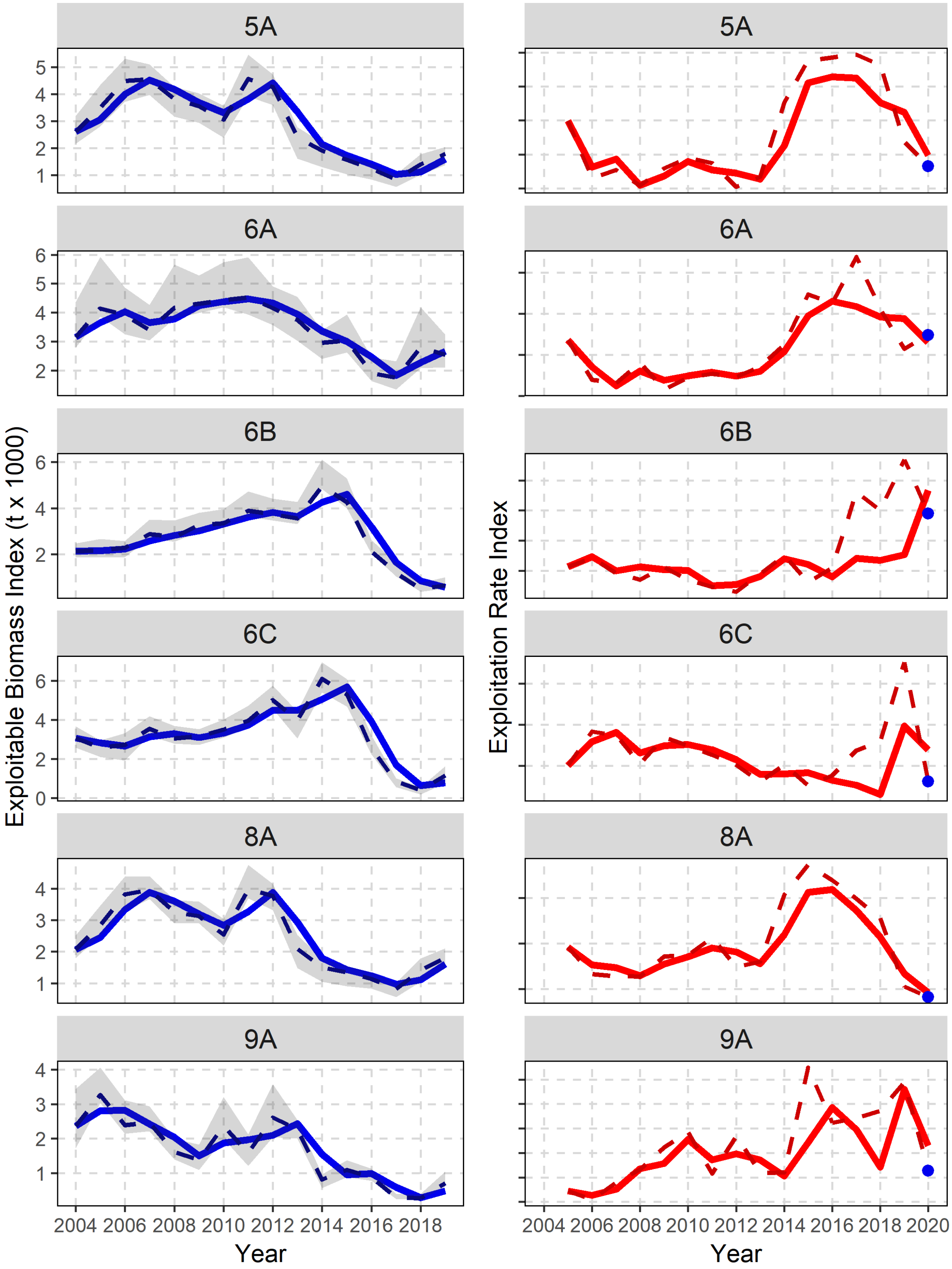

Figure A3.6. ***Left****: Trap survey exploitable biomass indices (t*1,000) by CMA in AD 3L Inshore (2004–19). Dashed lines shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate.* ***Right****: Trends in the annual (points) and 2-year moving average (solid line) trap-based ERI (%) by CMA in AD 3L Inshore; 2020 stars depict projected exploitation rate indices under status quo removals in the 2020 fishery.*

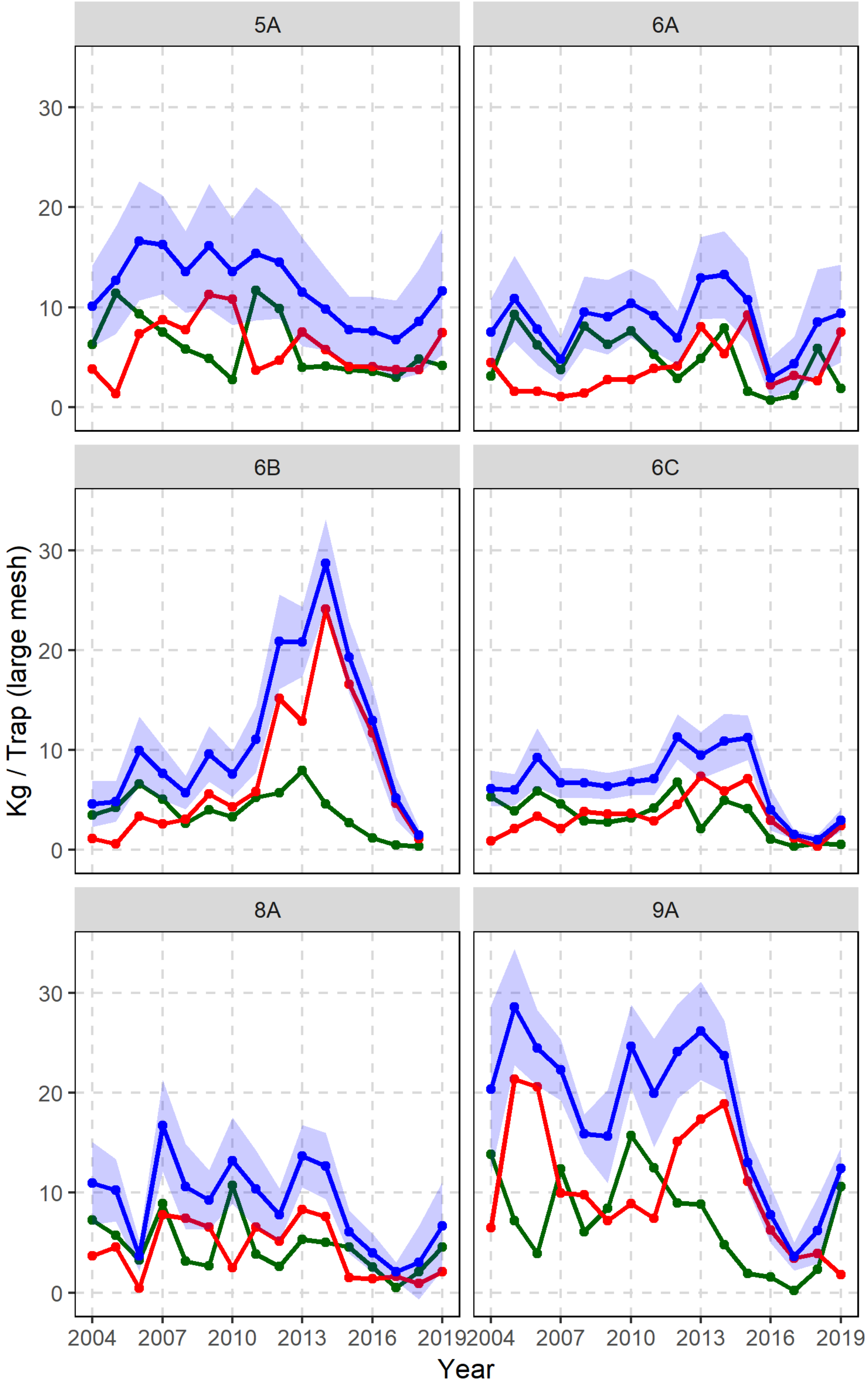

Figure A3.7. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from core stations in the CPS trap survey by CMA in AD 3L Inshore (2004–19). Shaded area represents the 95% confidence interval.

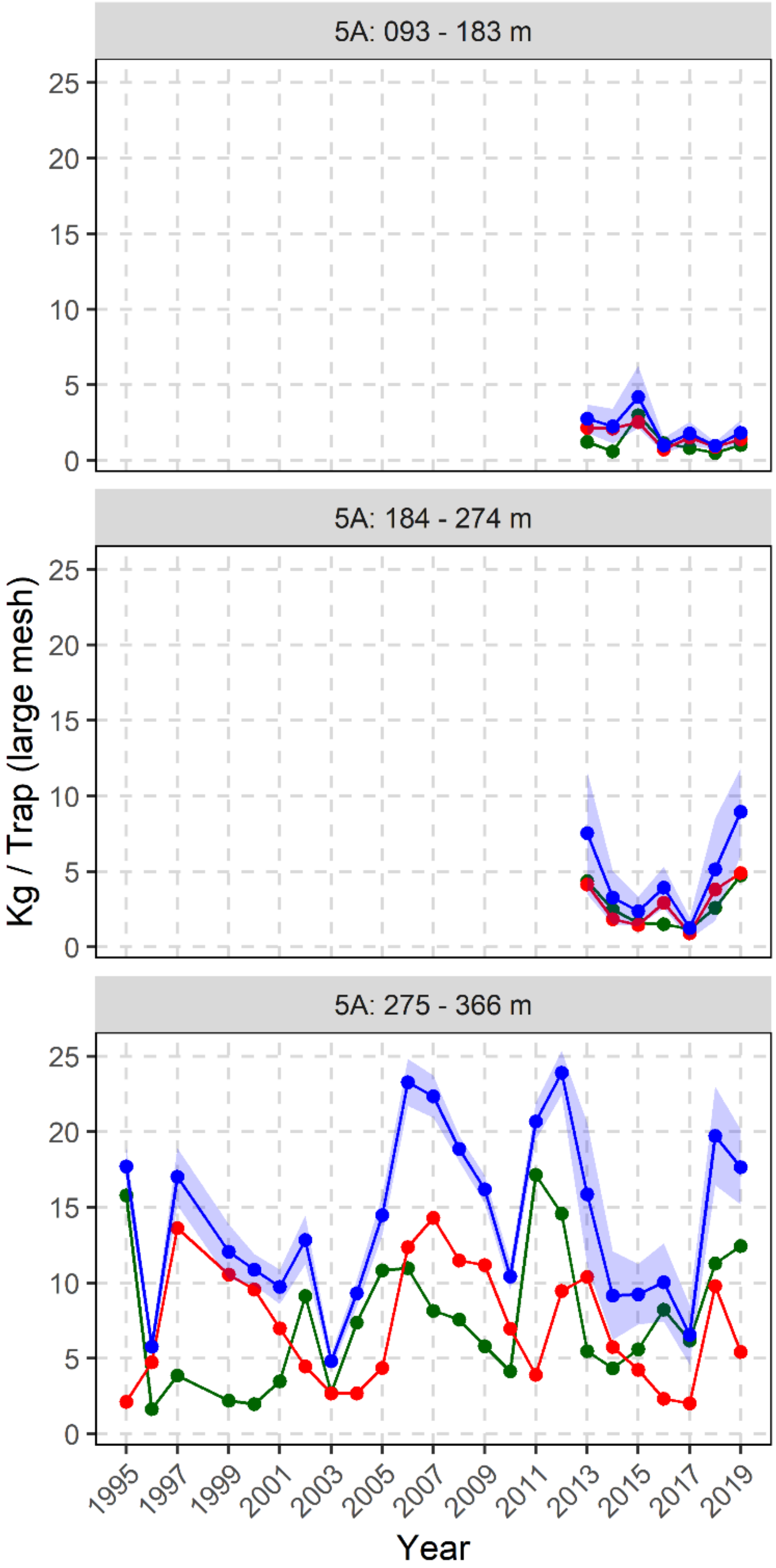

Figure A3.8. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from Inshore DFO trap surveys in Bonavista Bay in AD 3L Inshore (1995–2019). Shaded area represents the 95% confidence interval.

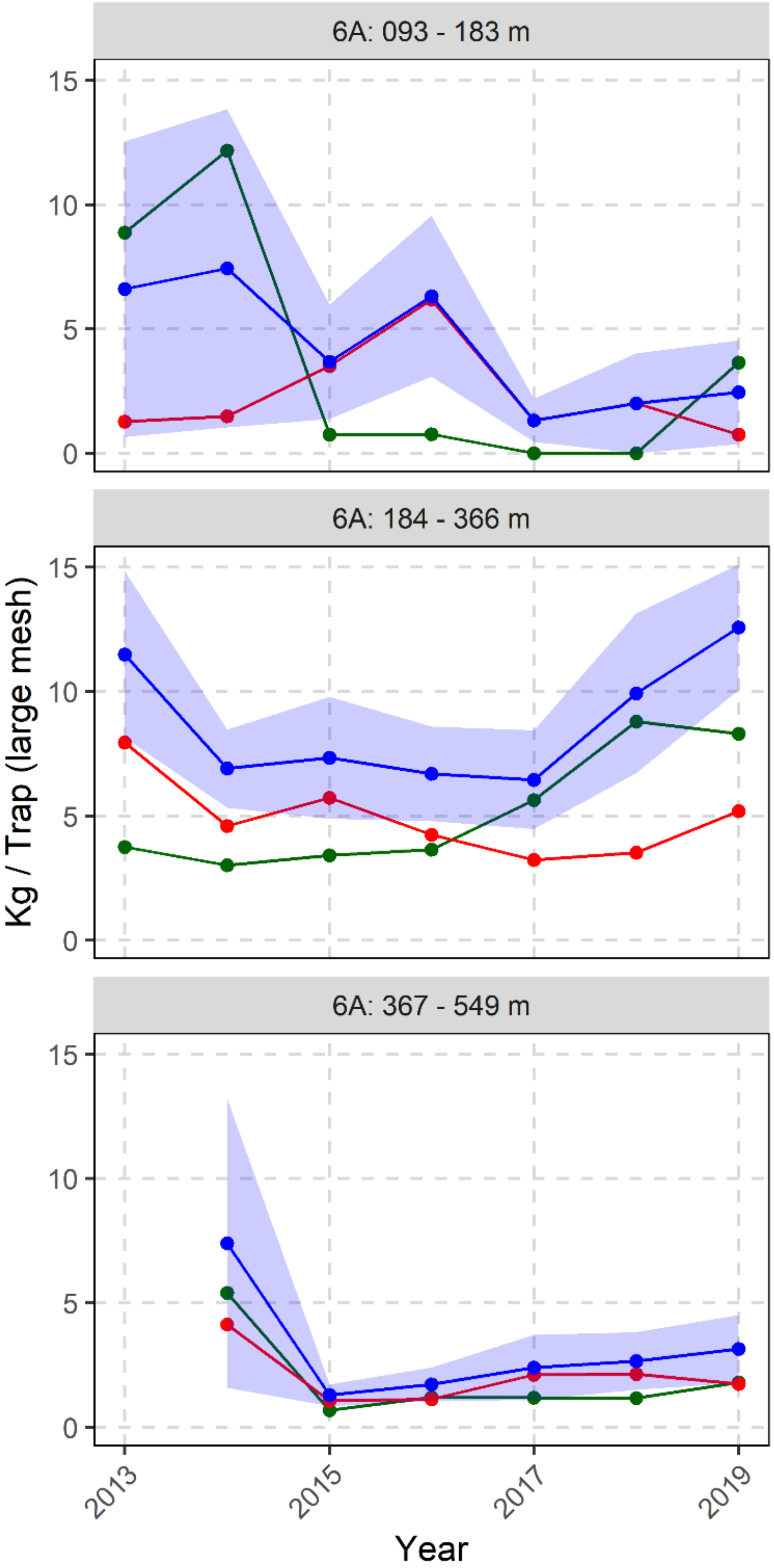

Figure A3.9. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from Inshore DFO trap surveys in Trinity Bay in AD 3L Inshore (2013–19). Shaded area represents the 95% confidence interval.

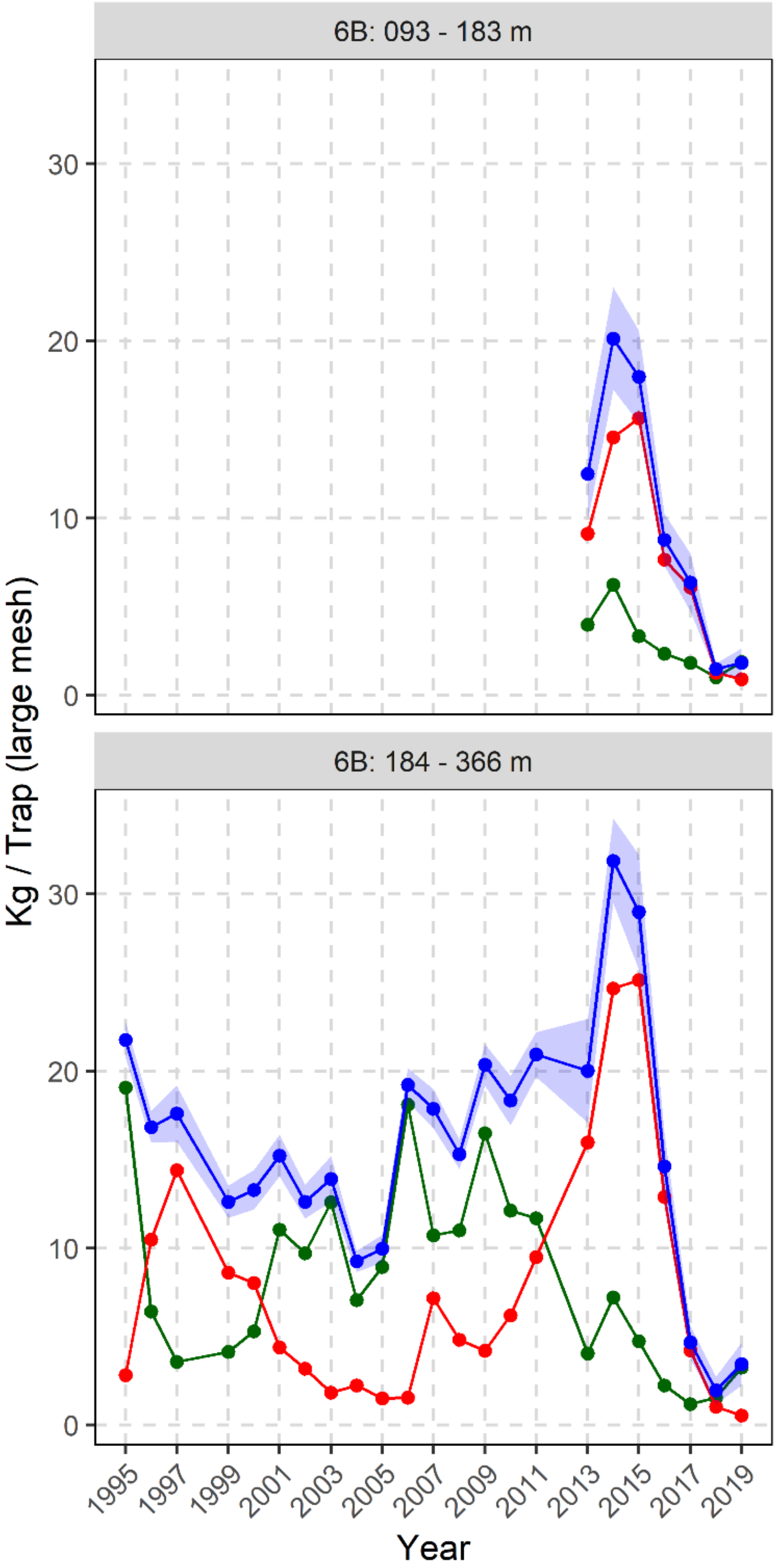

Figure A3.10. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from Inshore DFO trap surveys in Conception Bay in AD 3L Inshore (1995–2019). Shaded area represents the 95% confidence interval.

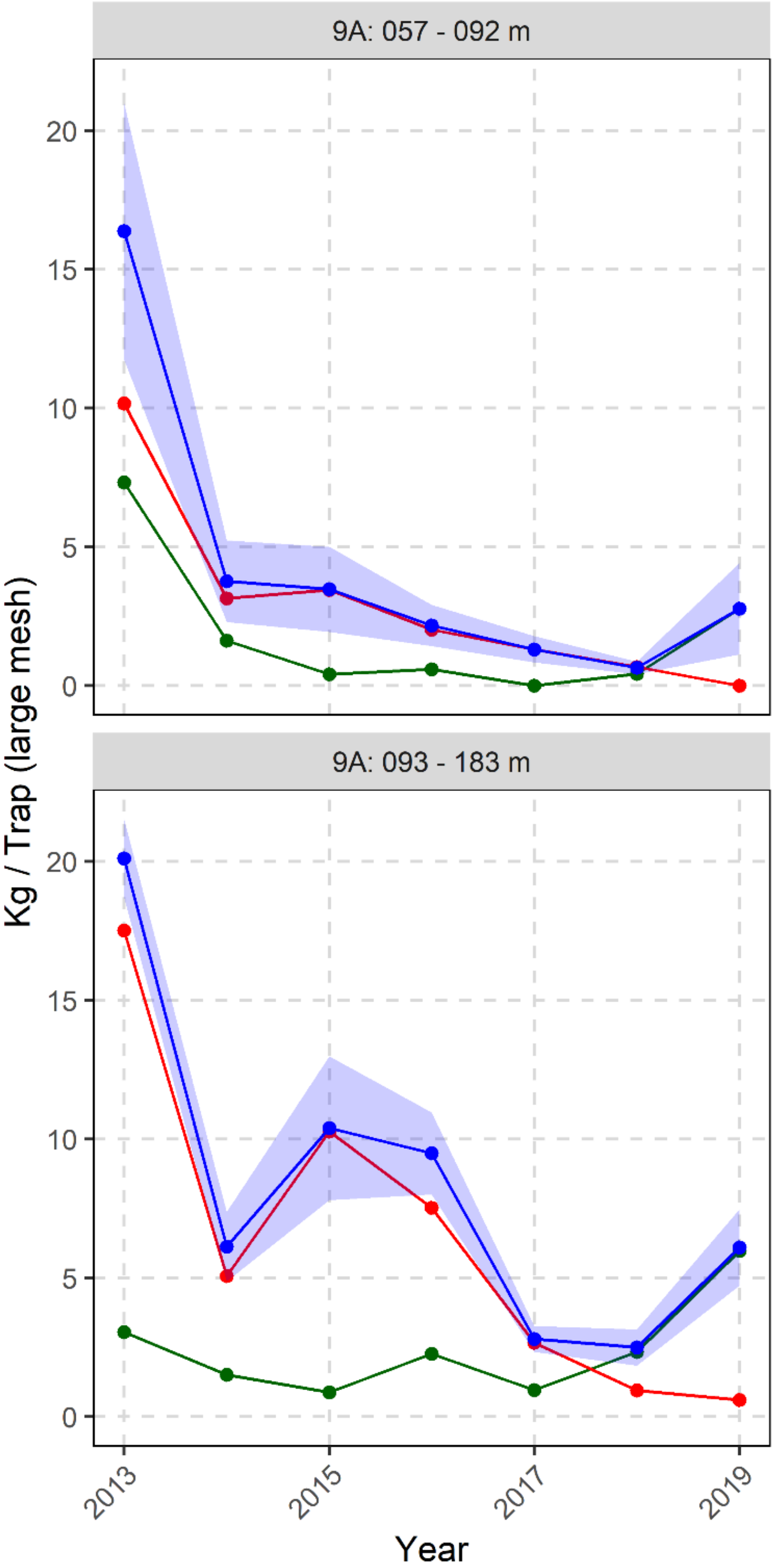

Figure A3.11. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from Inshore DFO trap surveys in St. Mary's Bay in AD 3L Inshore (2013–19). Shaded area represents the 95% confidence interval.

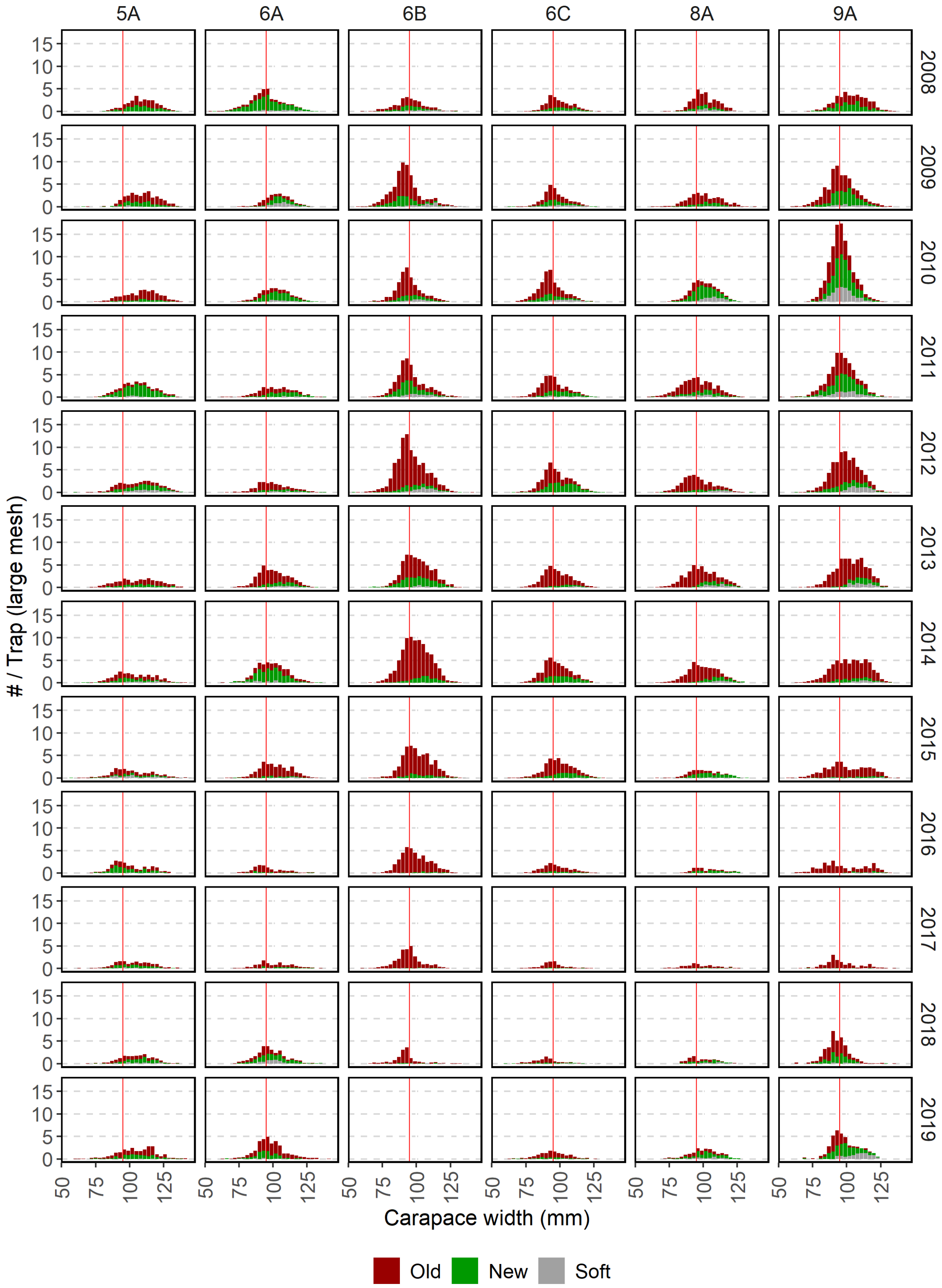

Figure A3.12. CPUE (#/trap) by carapace width and shell condition from male Snow Crab in large-mesh traps at core stations in the CPS trap survey by CMA in AD 3L Inshore (2008–19). The red vertical line indicates the minimum legal size.

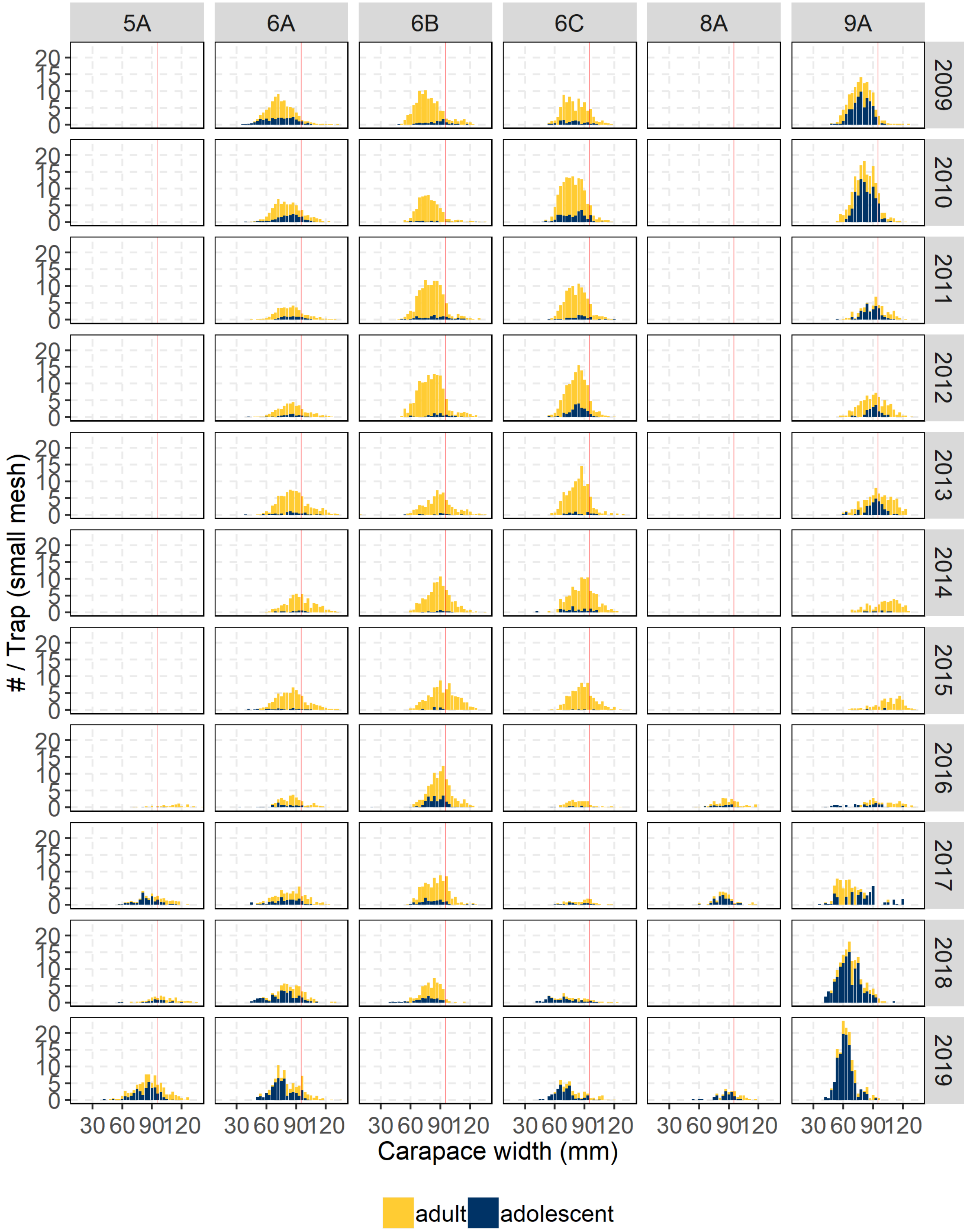

Figure A3.13. CPUE (#/trap) by carapace width and maturity from small-mesh traps at core stations in the CPS trap survey by CMA in AD 3L Inshore (2009–19). The red vertical line indicates the minimum legal size.

Figure A3.14. CPUE (#/trap) by carapace width and maturity from small-mesh traps in the Inshore DFO trap survey in Bonavista Bay in AD 3L Inshore (2006–19). The red vertical line indicates the minimum legal size.

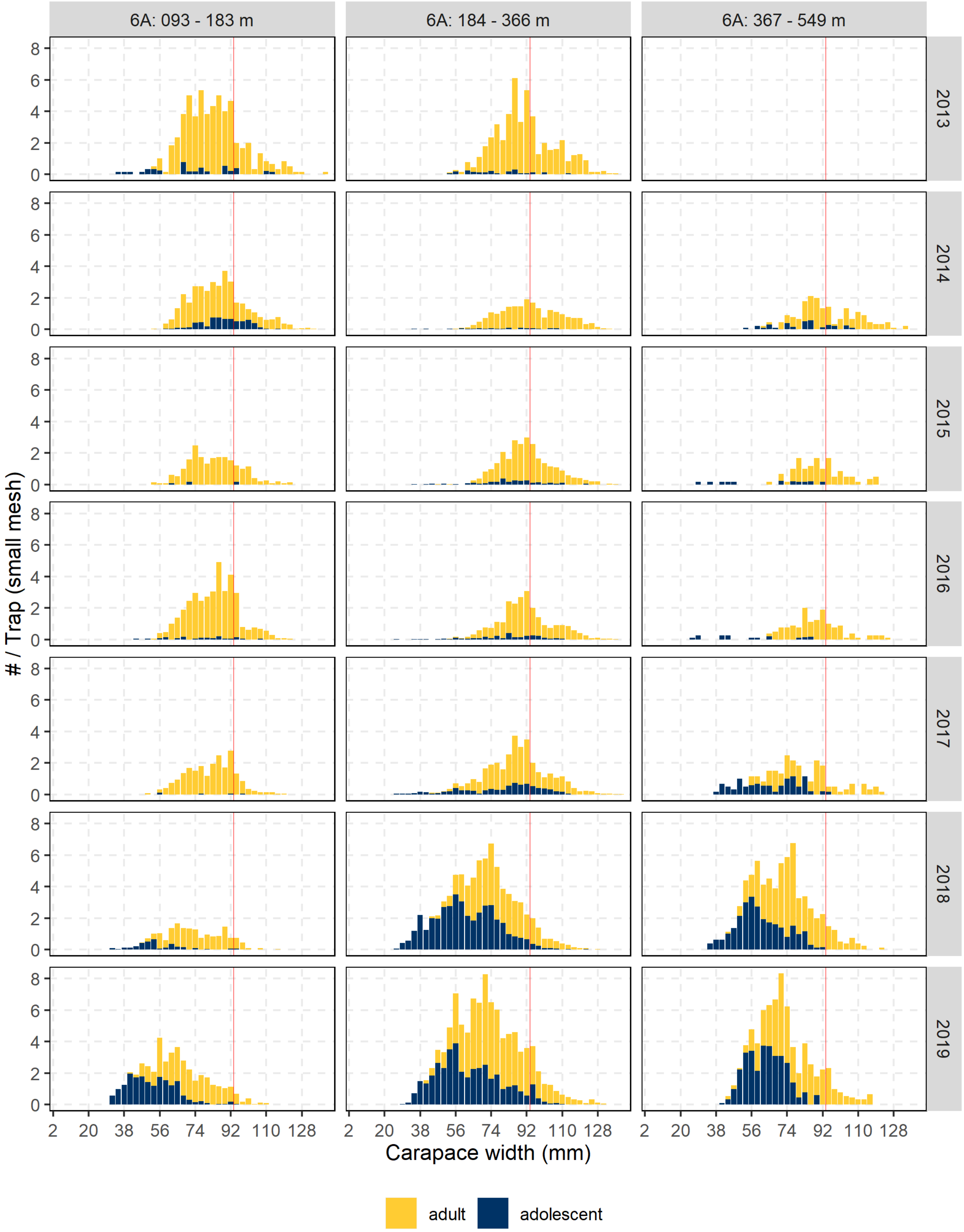

Figure A3.15. CPUE (#/trap) by carapace width and maturity from small-mesh traps in the Inshore DFO trap survey in Trinity Bay in AD 3L Inshore (2013–19). The red vertical line indicates the minimum legal size.

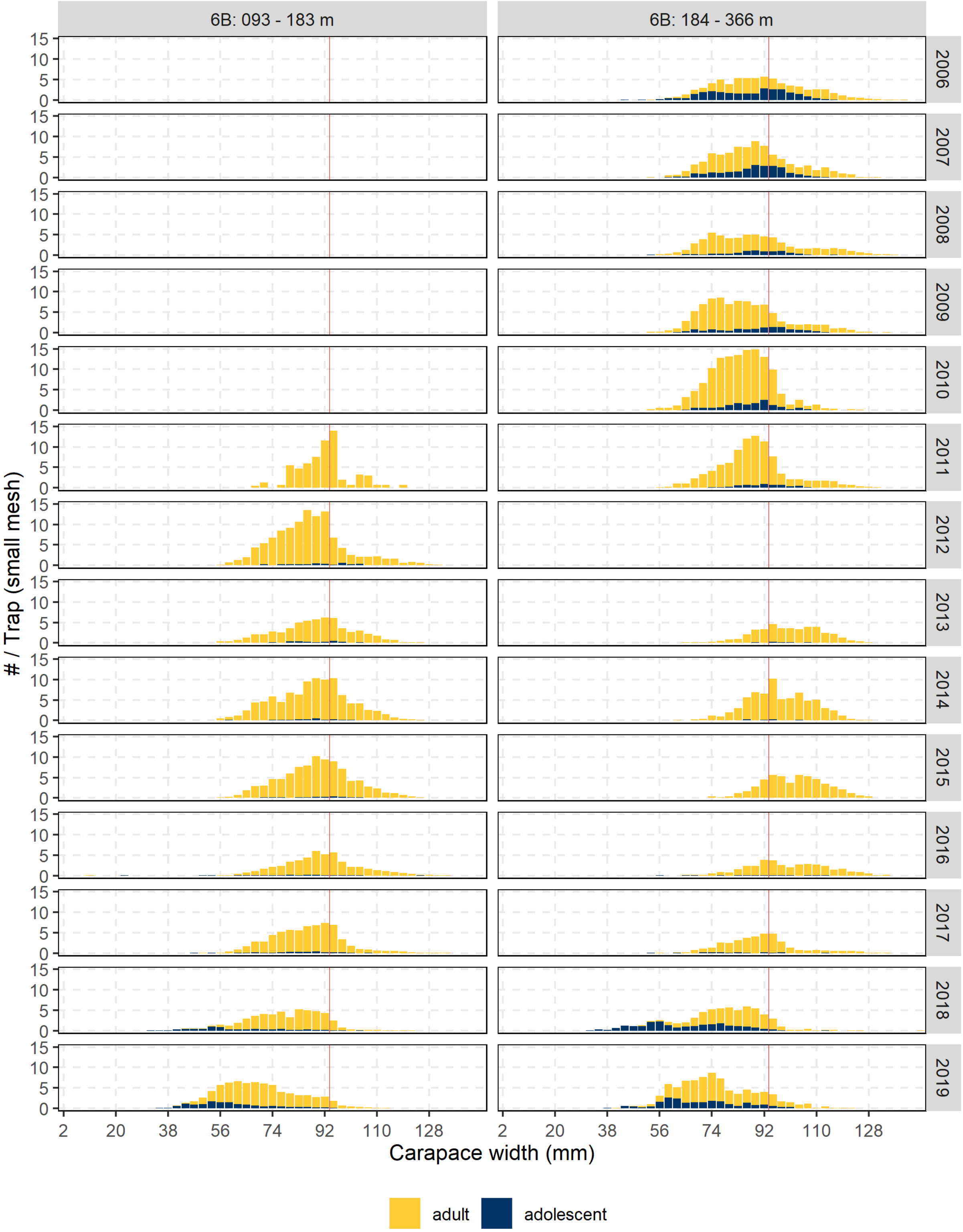

Figure A3.16. CPUE (#/trap) by carapace width and maturity from small-mesh traps in the Inshore DFO trap survey in Conception Bay in AD 3L Inshore (2006–19). The red vertical line indicates the minimum legal size.

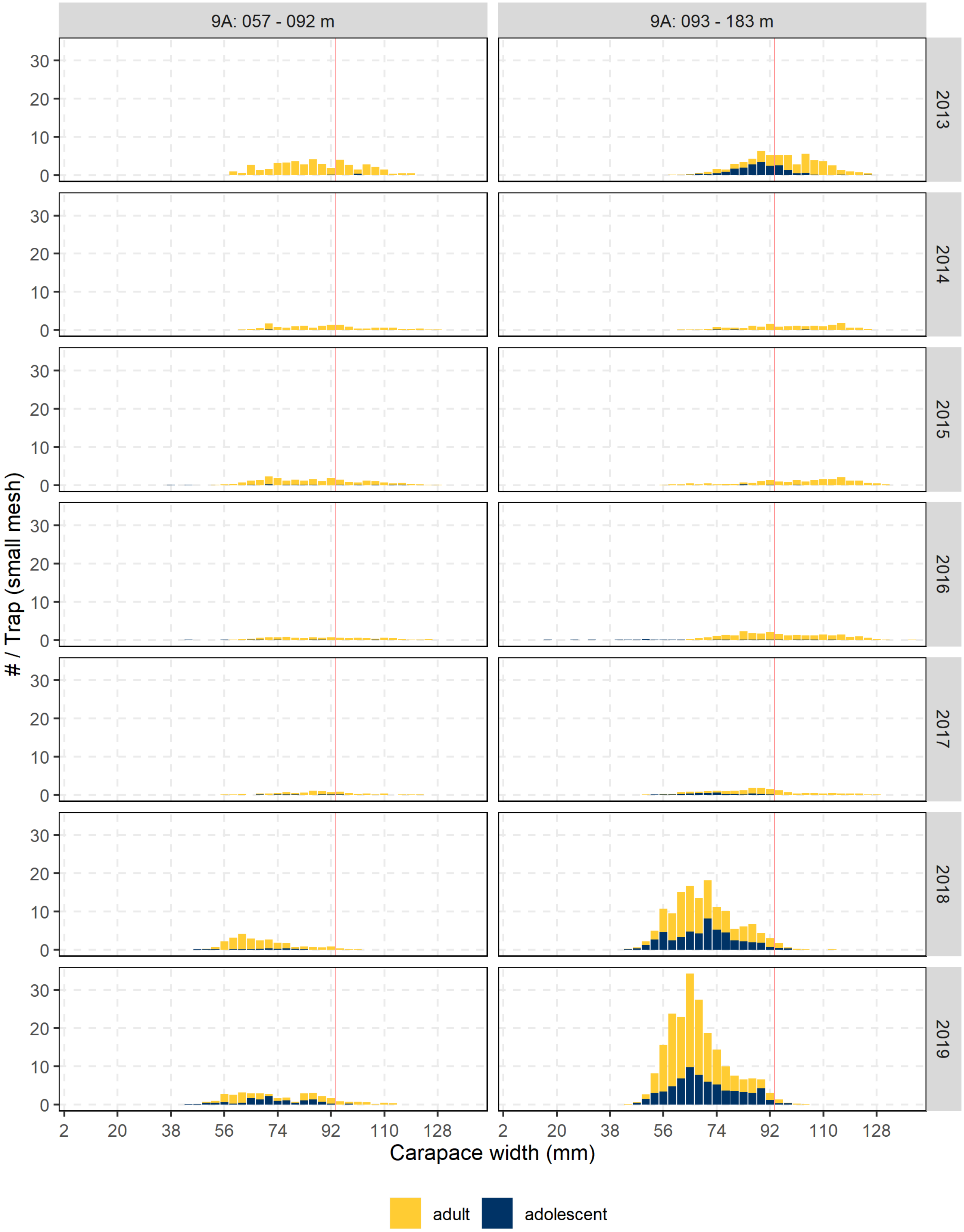

Figure A3.17. CPUE (#/trap) by carapace width and maturity from small-mesh traps in the Inshore DFO trap survey in St. Mary's Bay in AD 3L Inshore (2013–19). The red vertical line indicates the minimum legal size.

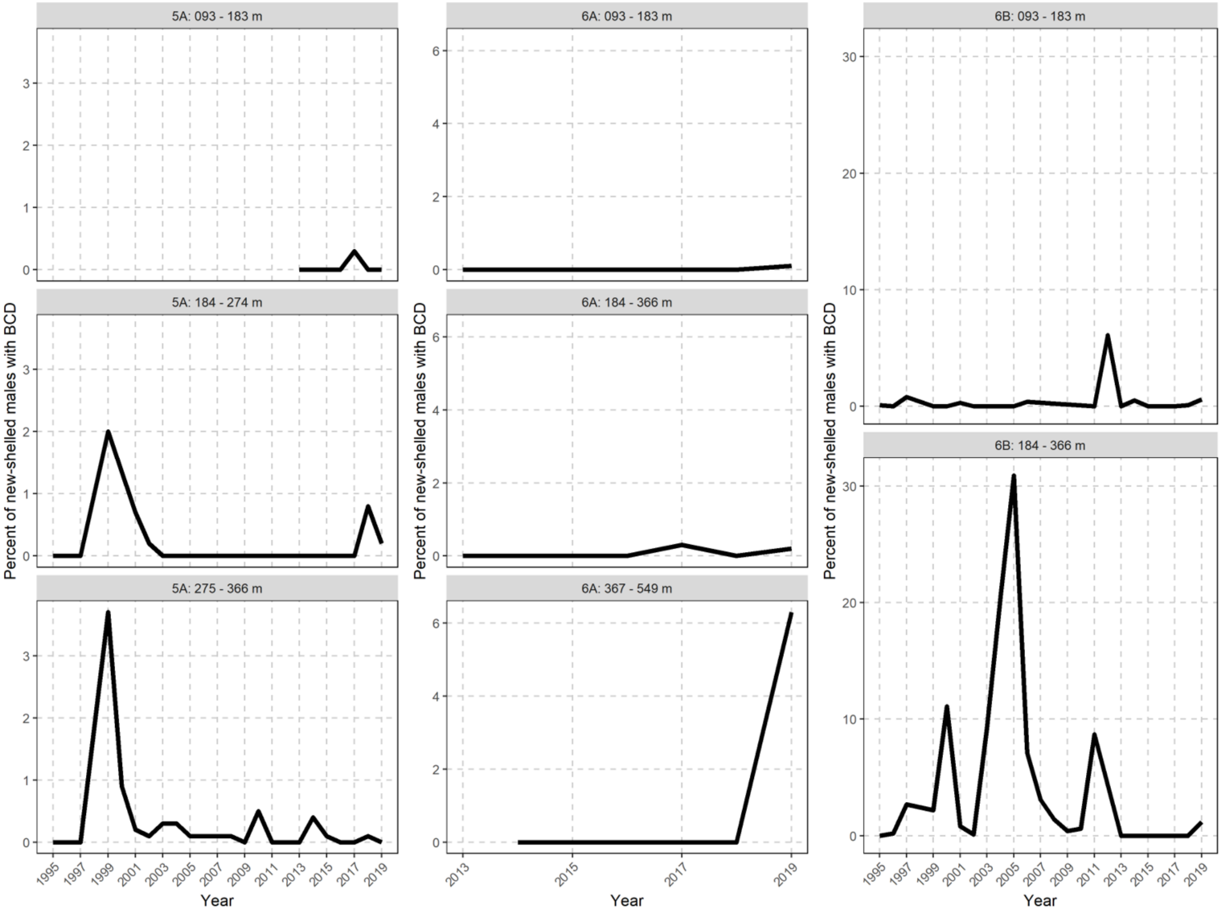

Figure A3.18. Visually observed percentage of BCD in new-shelled males from Inshore DFO trap surveys in Bonavista Bay, Trinity Bay, and Conception Bay in AD 3L Inshore (1995–2019).

APPENDIX 4: ASSESSMENT DIVISION 3LNO OFFSHORE DETAILS

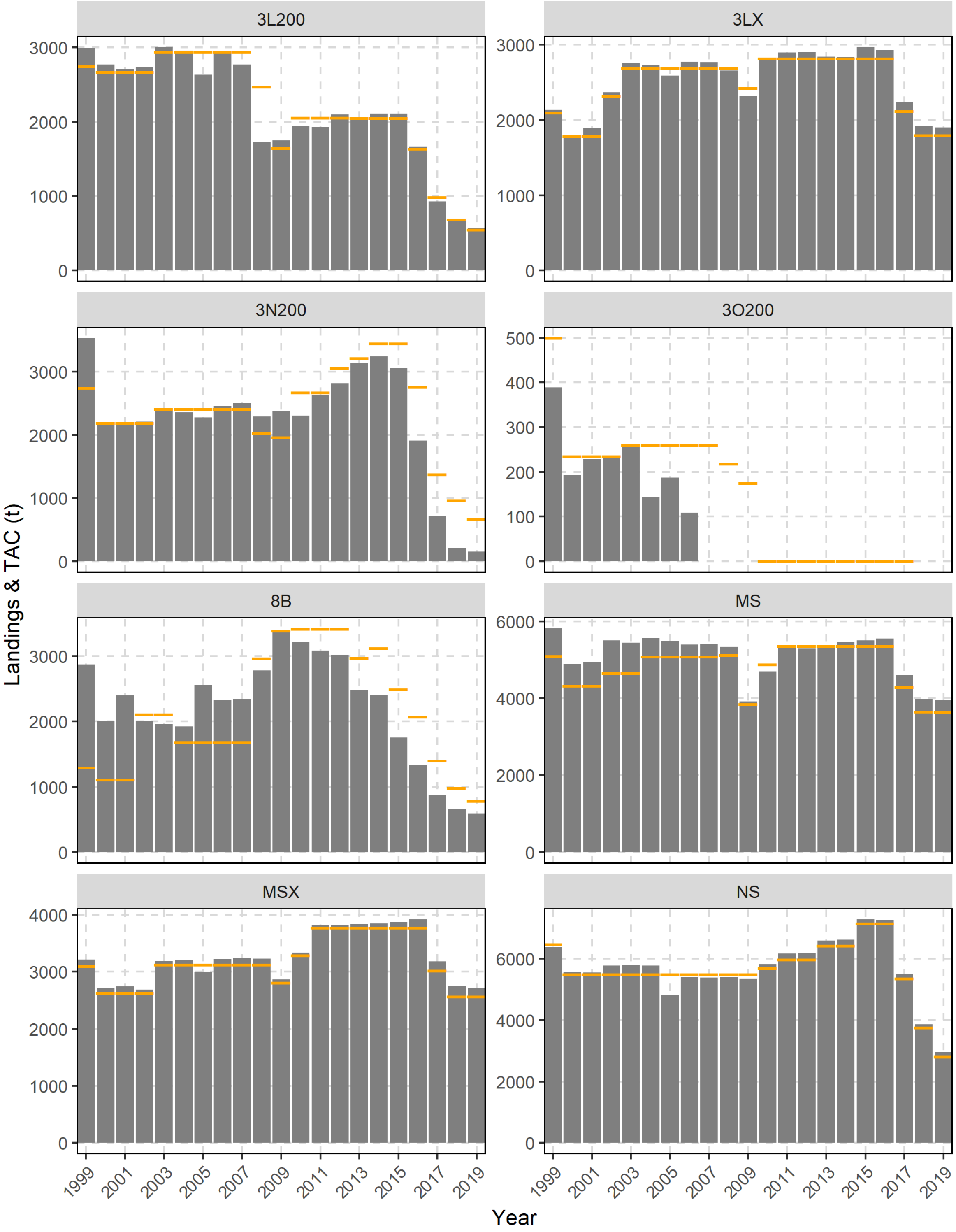

Figure A4.1. Annual landings (grey bars) and TAC (yellow dashes) in CMAs within AD 3LNO Offshore (1999–2019).

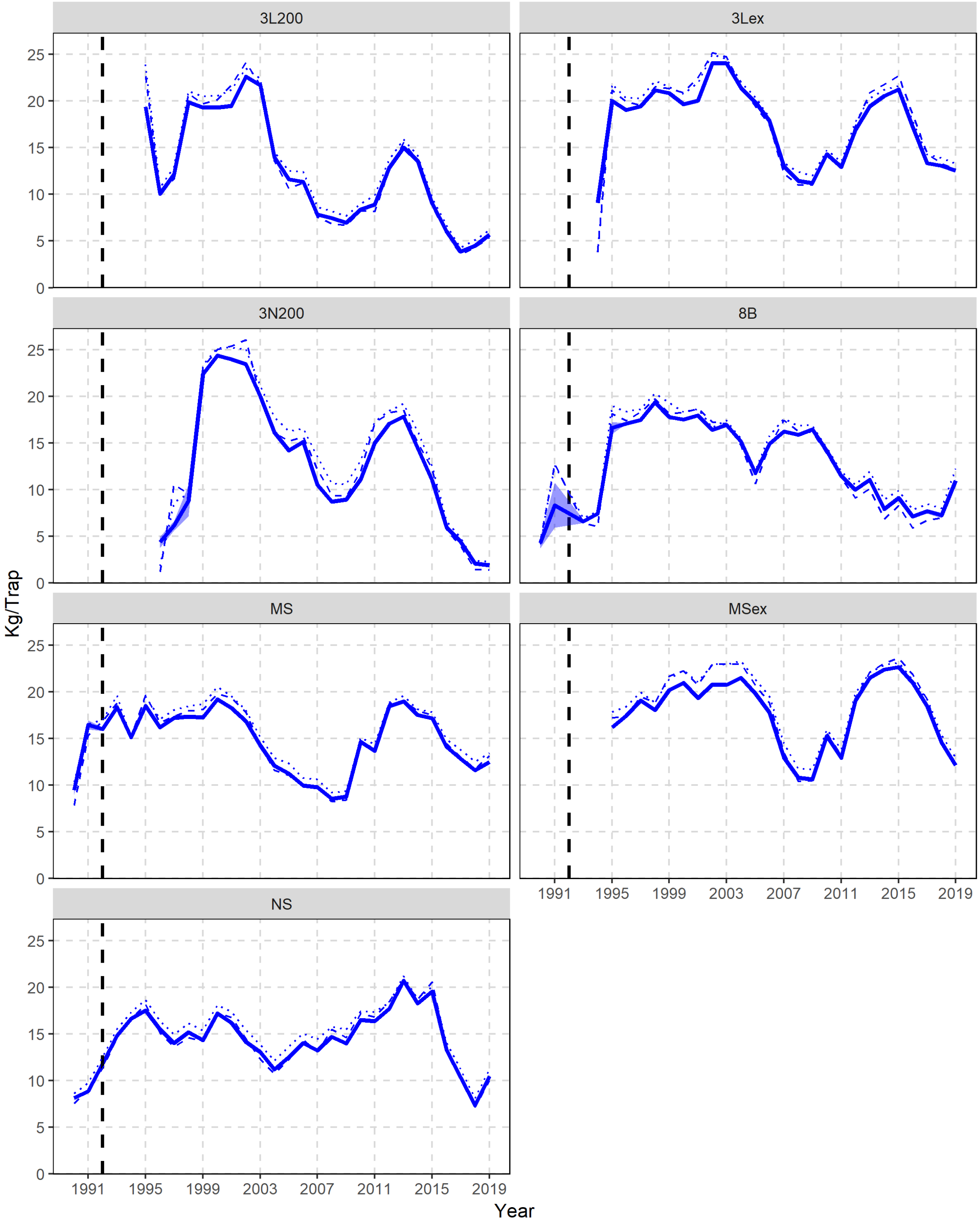

Figure A4.2. Standardized CPUE (kg/trap) in CMAs within AD 3LNO Offshore. Solid line is average predicted CPUE and shaded band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

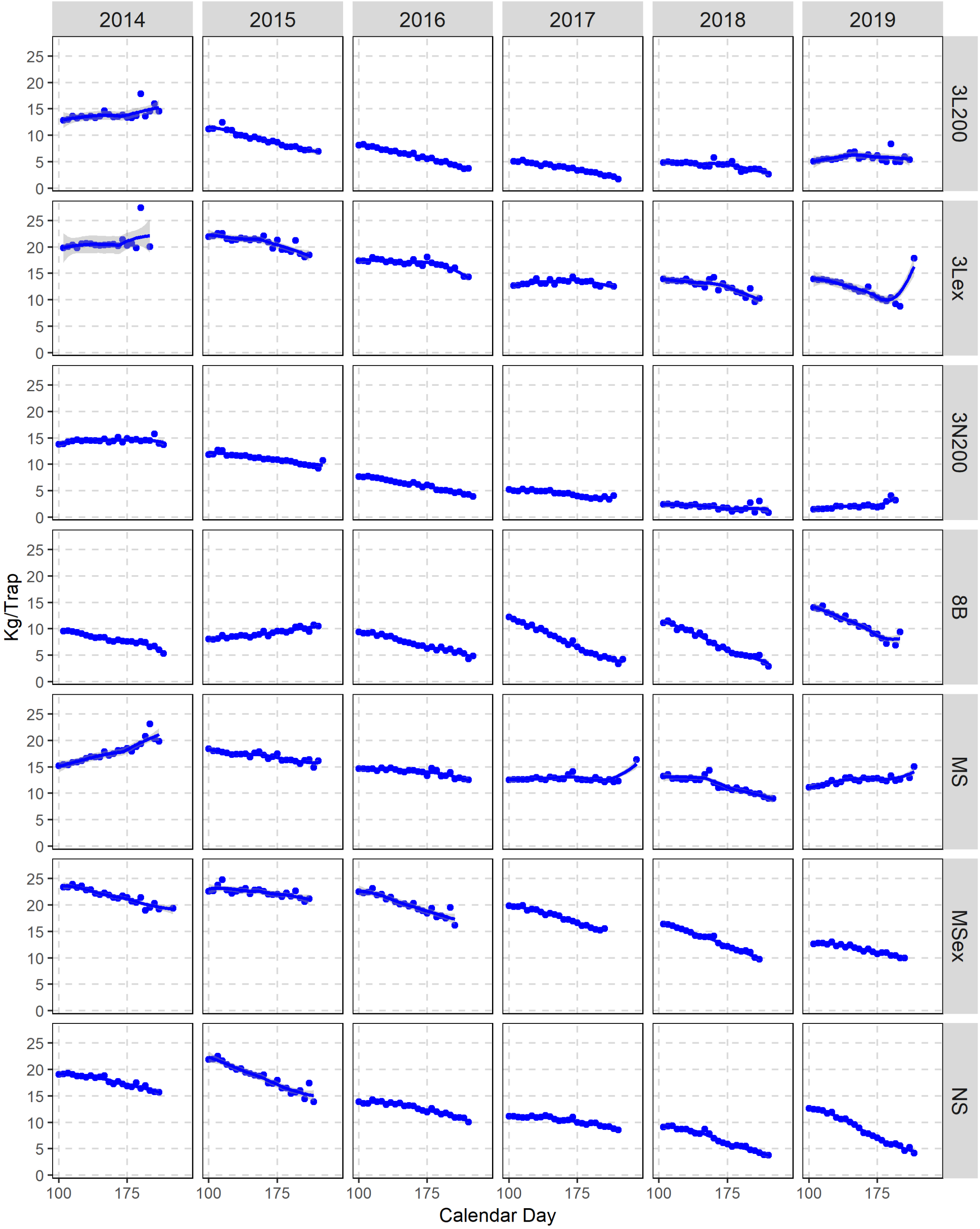

Figure A4.3. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each CMA in AD 3LNO Offshore (2014–19). Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

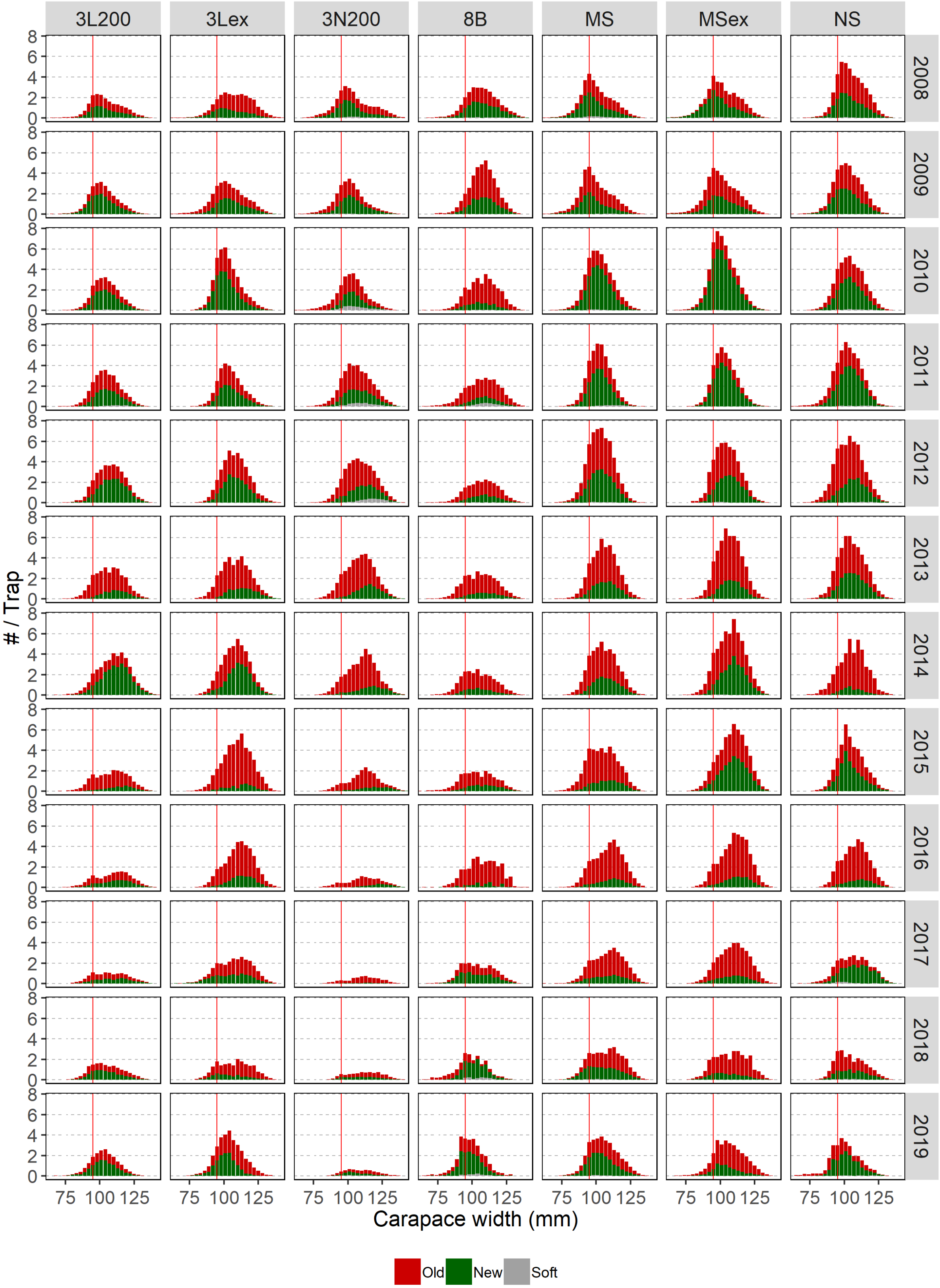

Figure A4.4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each CMA in AD 3LNO Offshore (2008–19). The red vertical line indicates the minimum legal size.

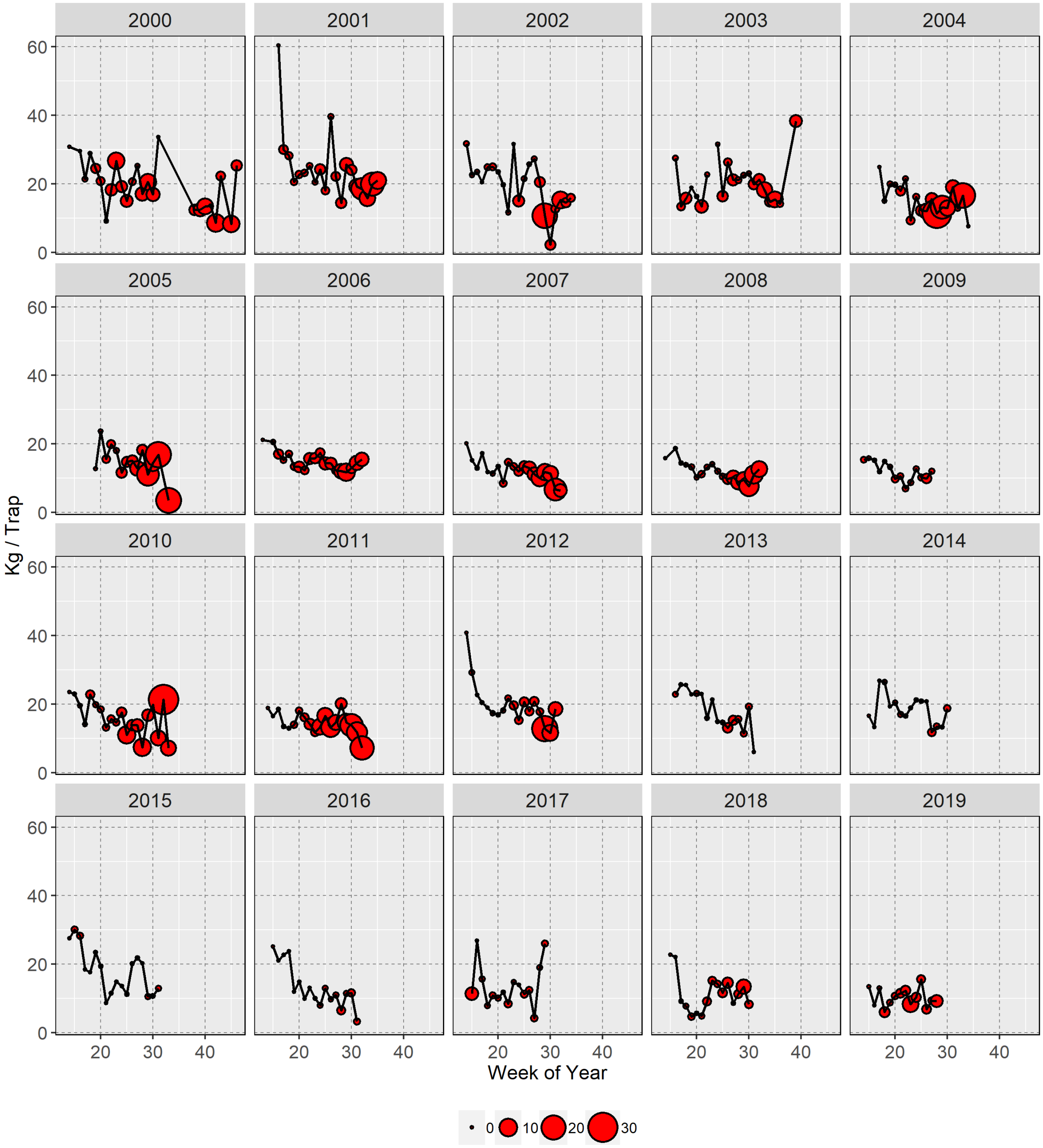

Figure A4.5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within AD 3LNO Offshore (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

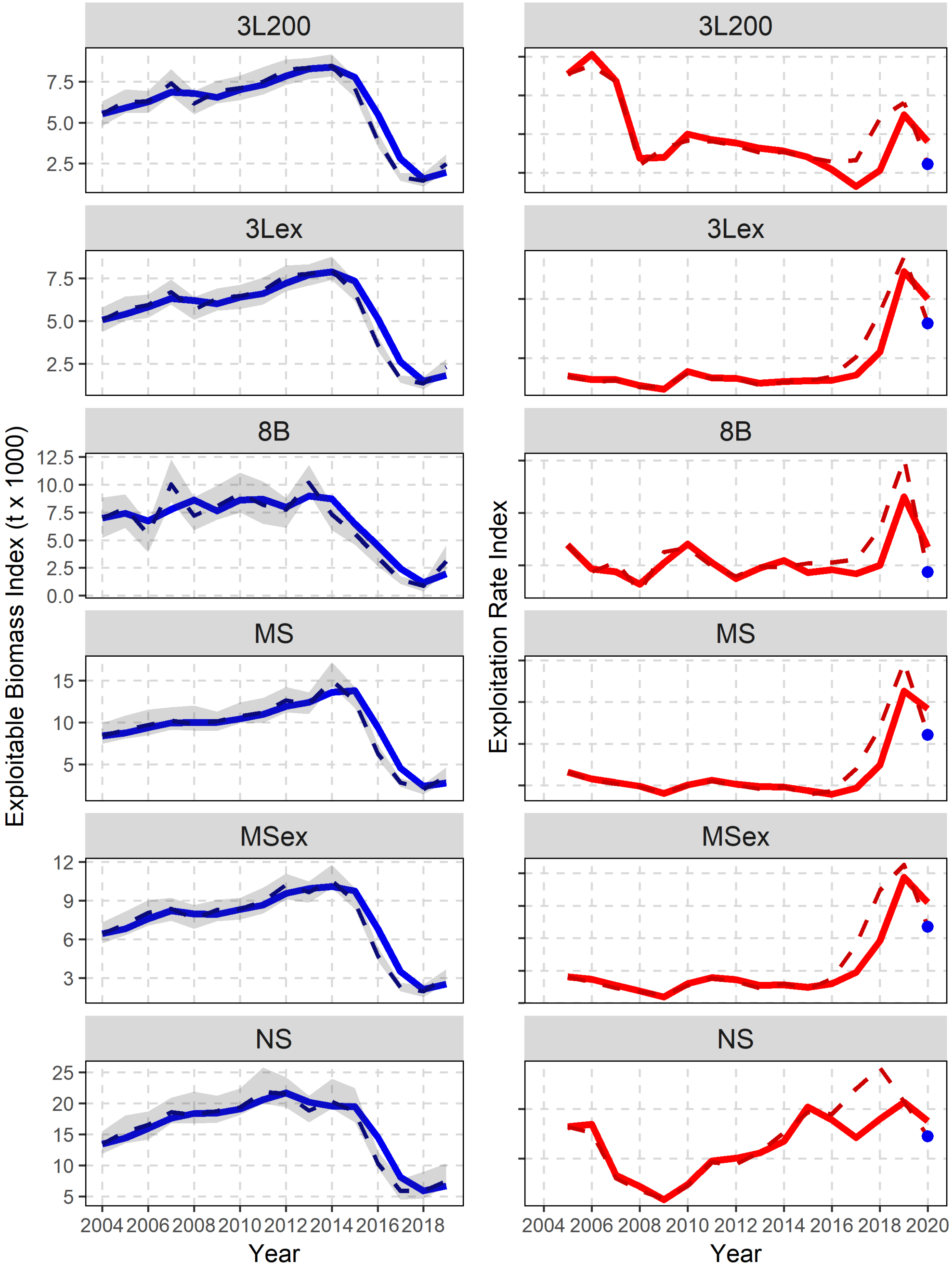

Figure A4.6. ***Left****: Trap survey exploitable biomass indices (t*1,000) by CMA in AD 3LNO Offshore (2004–19). Dashed lines shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate.* ***Right****: Trends in the annual (points) and 2-year moving average (solid line) trap-based ERI (%) by CMA in AD 3LNO Offshore; 2020 stars depict projected exploitation rate indices under status quo removals in the 2020 fishery.*

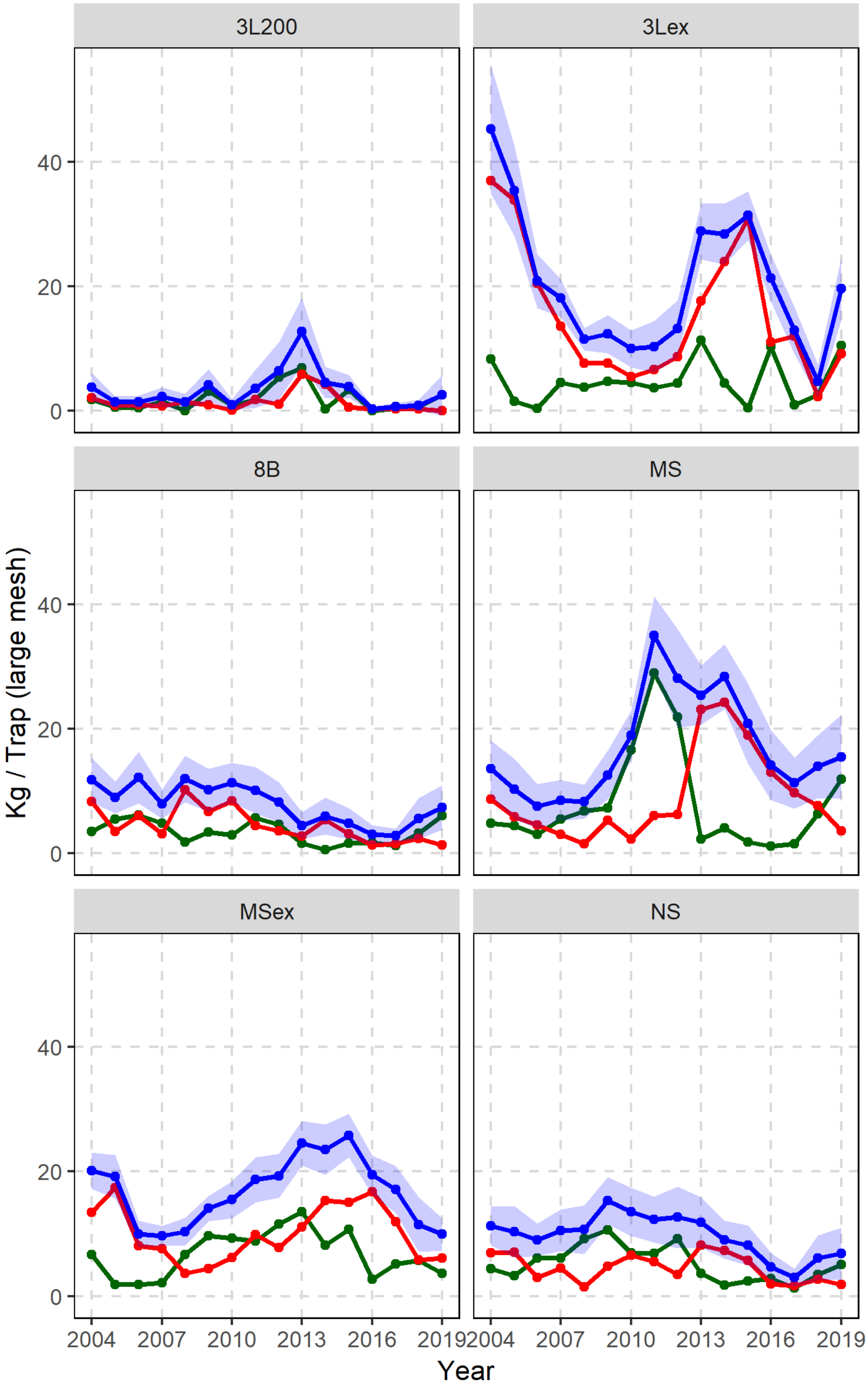

Figure A4.7. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from core stations in the CPS trap survey by CMA in AD 3LNO Offshore (2004–19). Shaded area represents the 95% confidence interval.

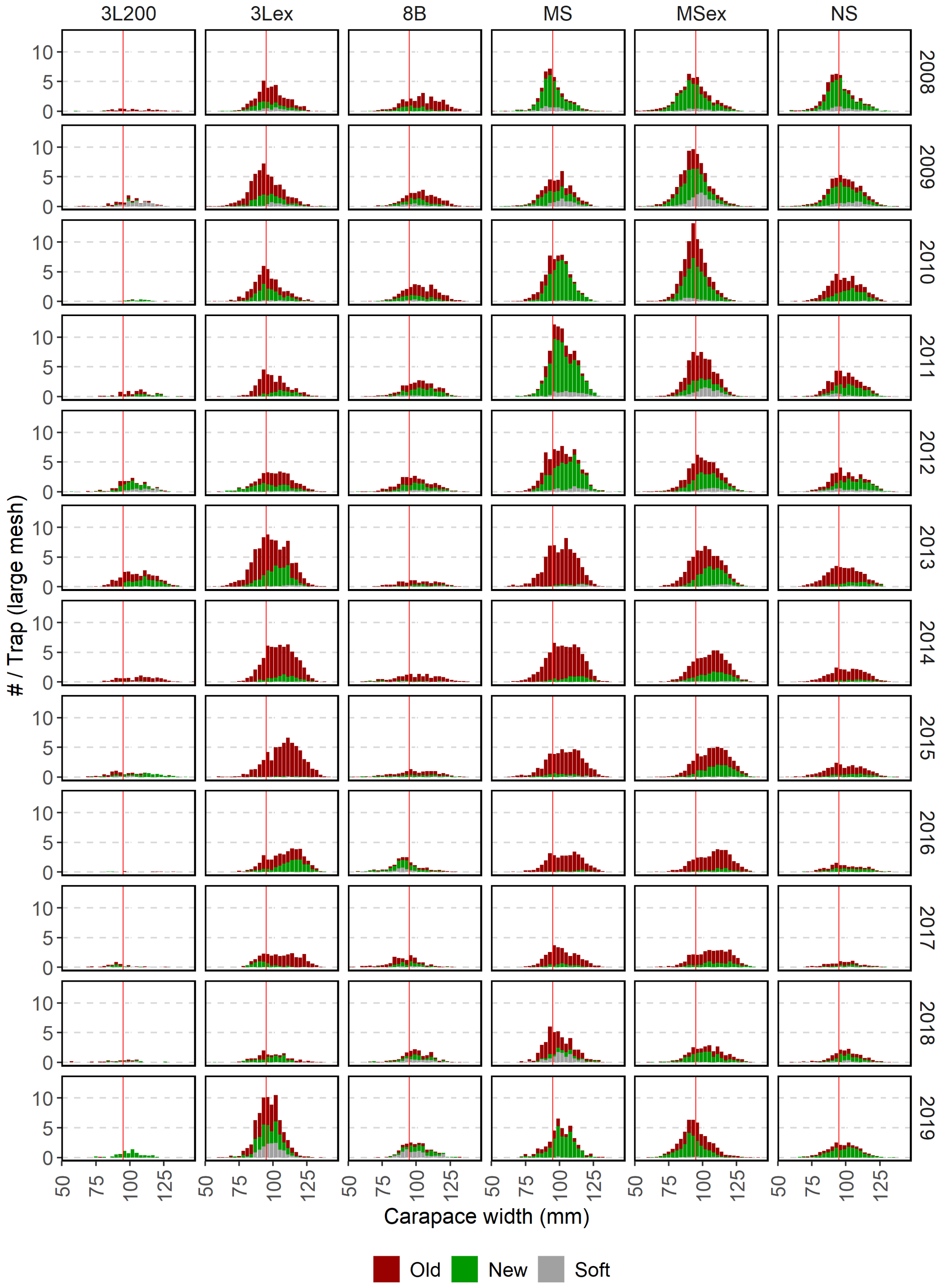

Figure A4.8. CPUE (#/trap) by carapace width and shell condition from male Snow Crab in large-mesh traps at core stations in the CPS trap survey by CMA in AD 3LNO Offshore (2008–19). The red vertical line indicates the minimum legal size.

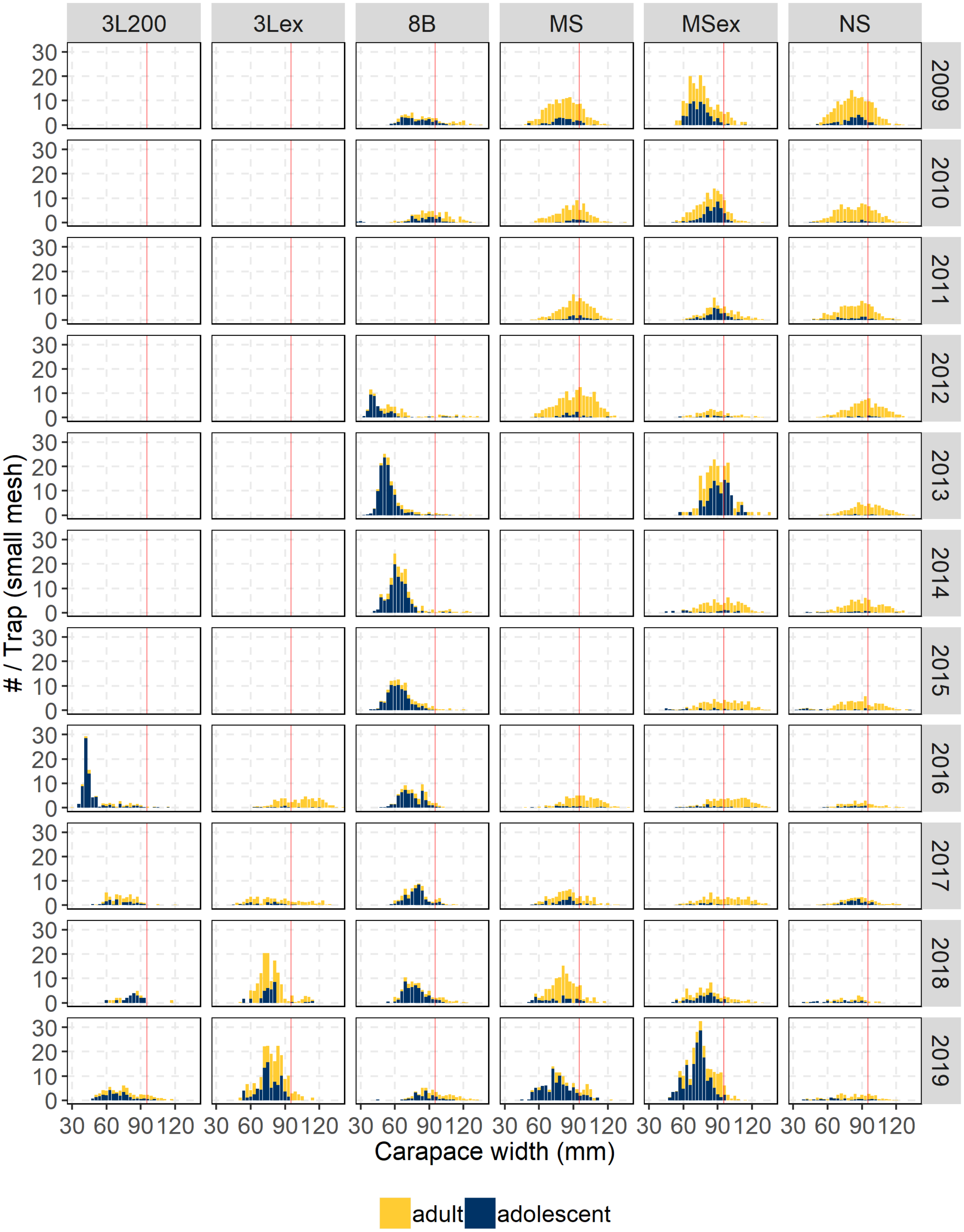

Figure A4.9. CPUE (#/trap) by carapace width and maturity from small-mesh traps at core stations in the CPS trap survey by CMA in AD 3LNO Offshore (2009–19). The red vertical line indicates the minimum legal size.

APPENDIX 5: ASSESSMENT DIVISION 3PS DETAILS

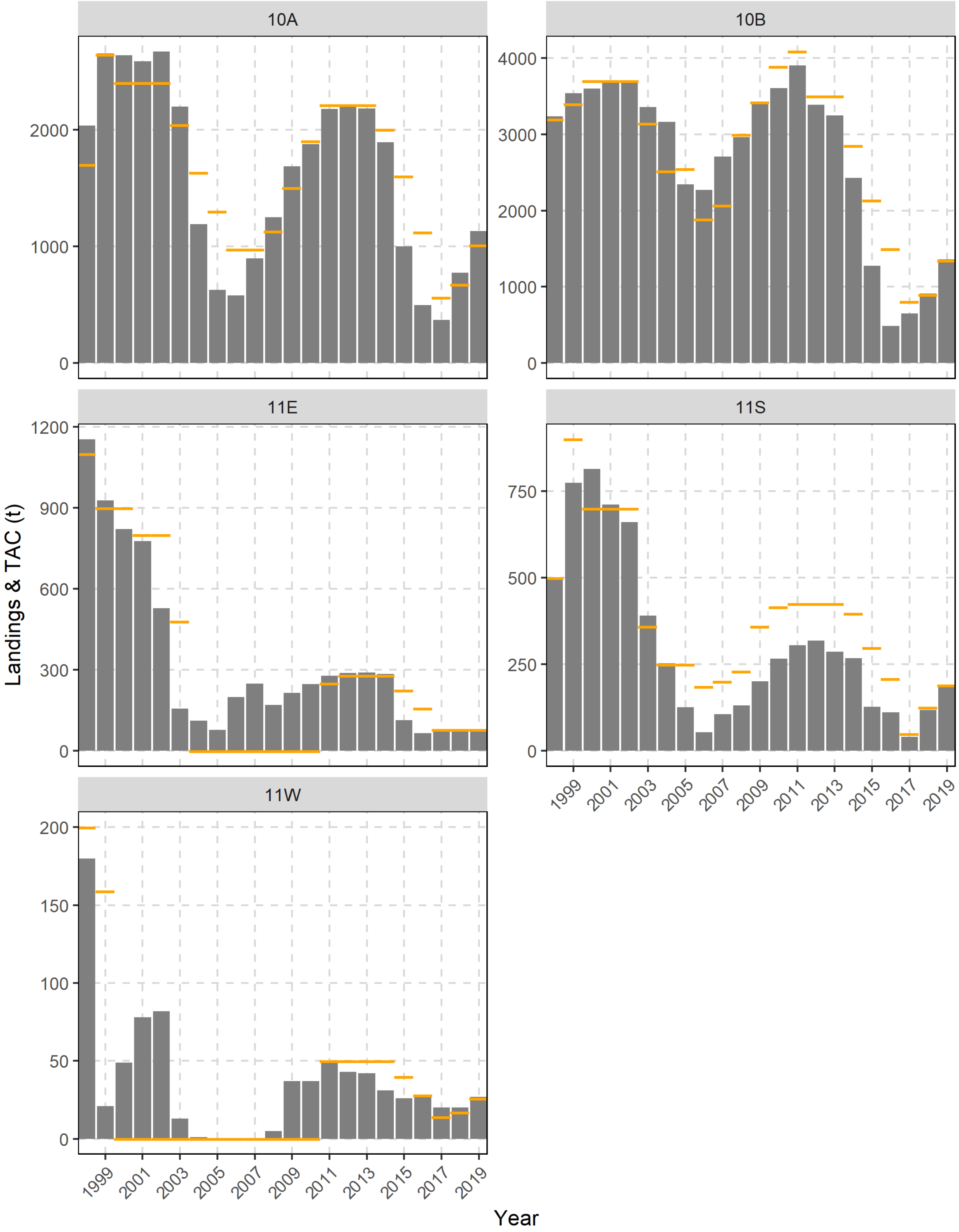

Figure A5.1. Annual landings (grey bars) and TAC (yellow dashes) in CMAs within AD 3Ps (1998–2019).

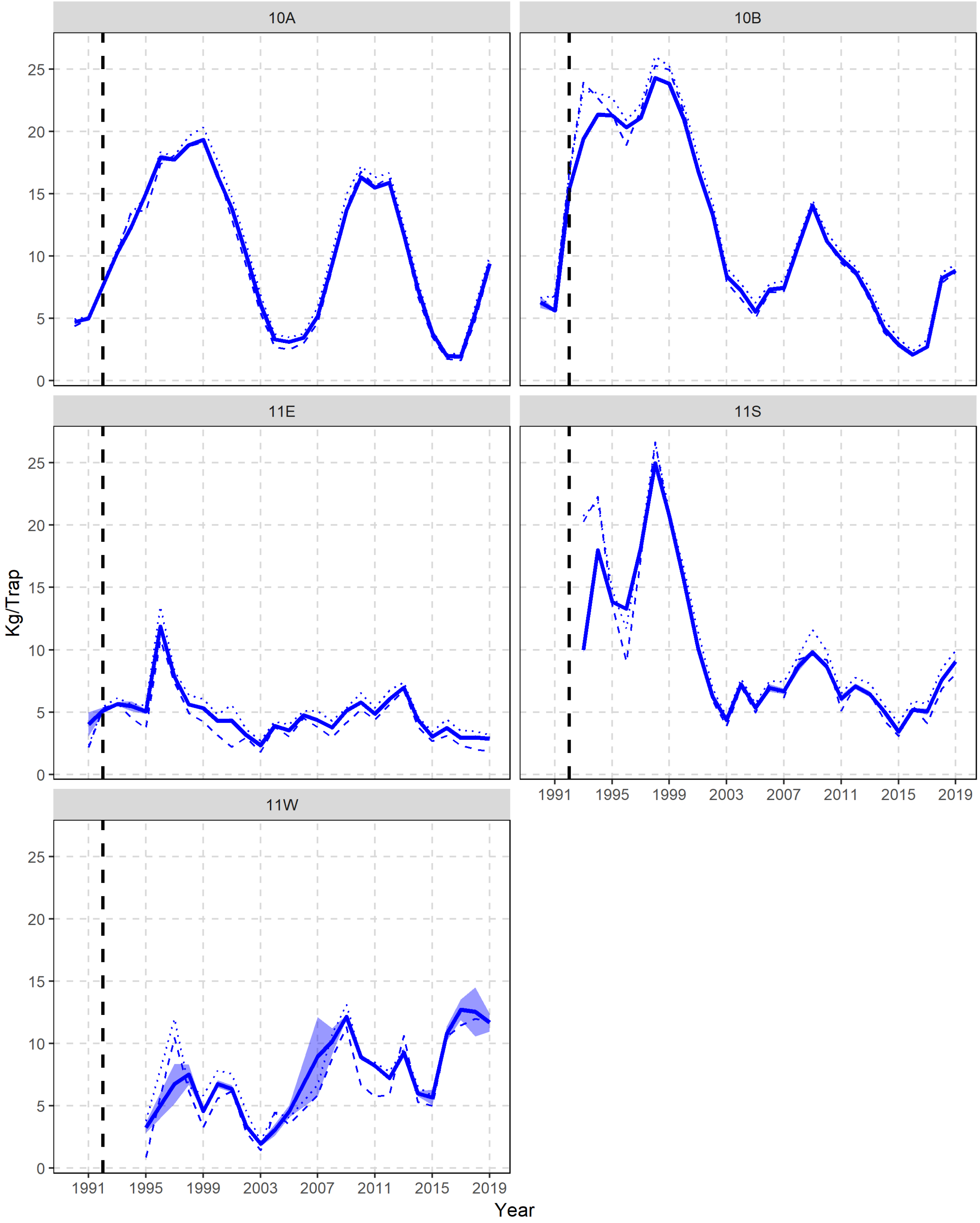

Figure A5.2. Standardized CPUE (kg/trap) in CMAs within AD 3Ps. Solid line is average predicted CPUE and shaded band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

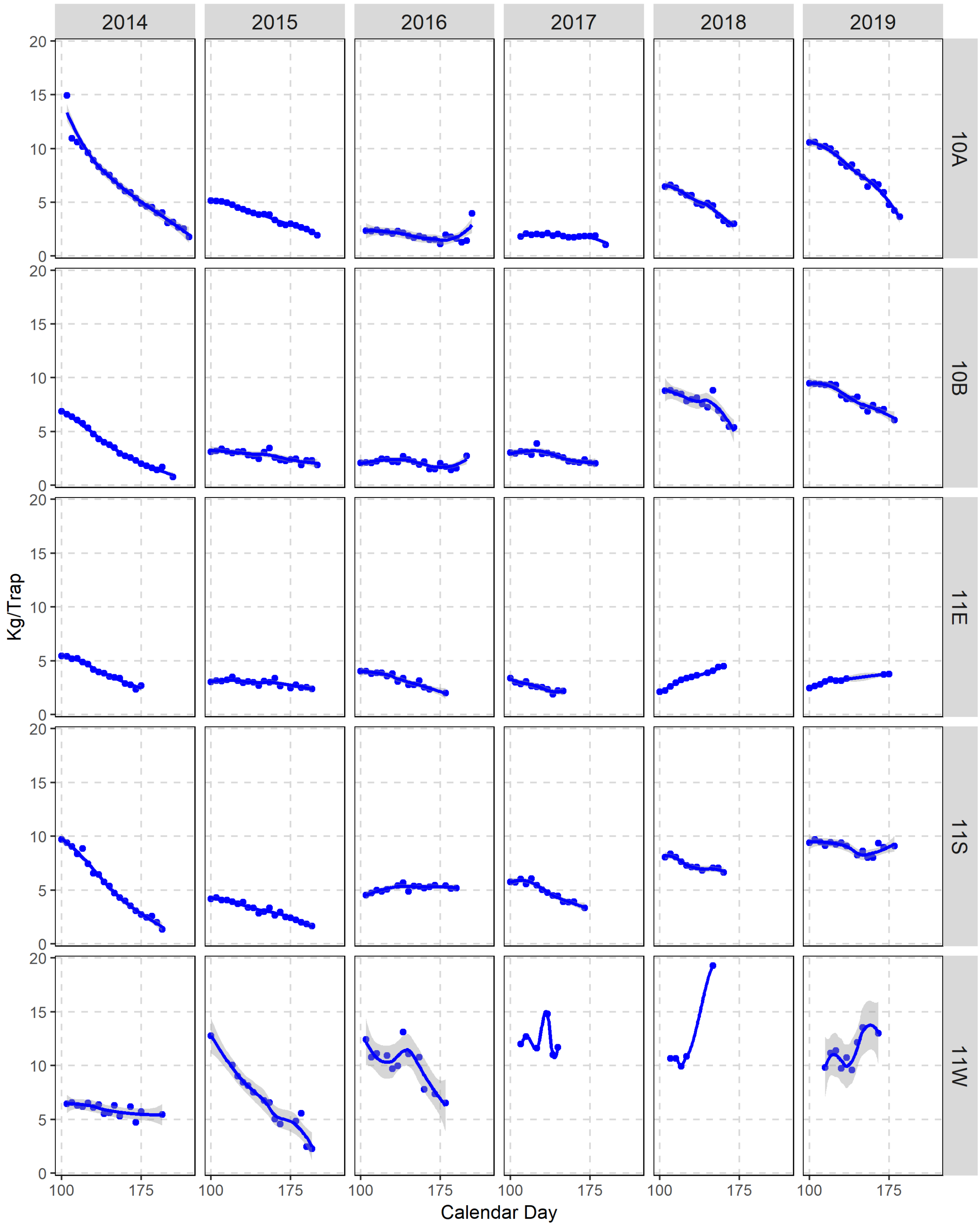

Figure A5.3. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each CMA in AD 3Ps (2014–19). Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

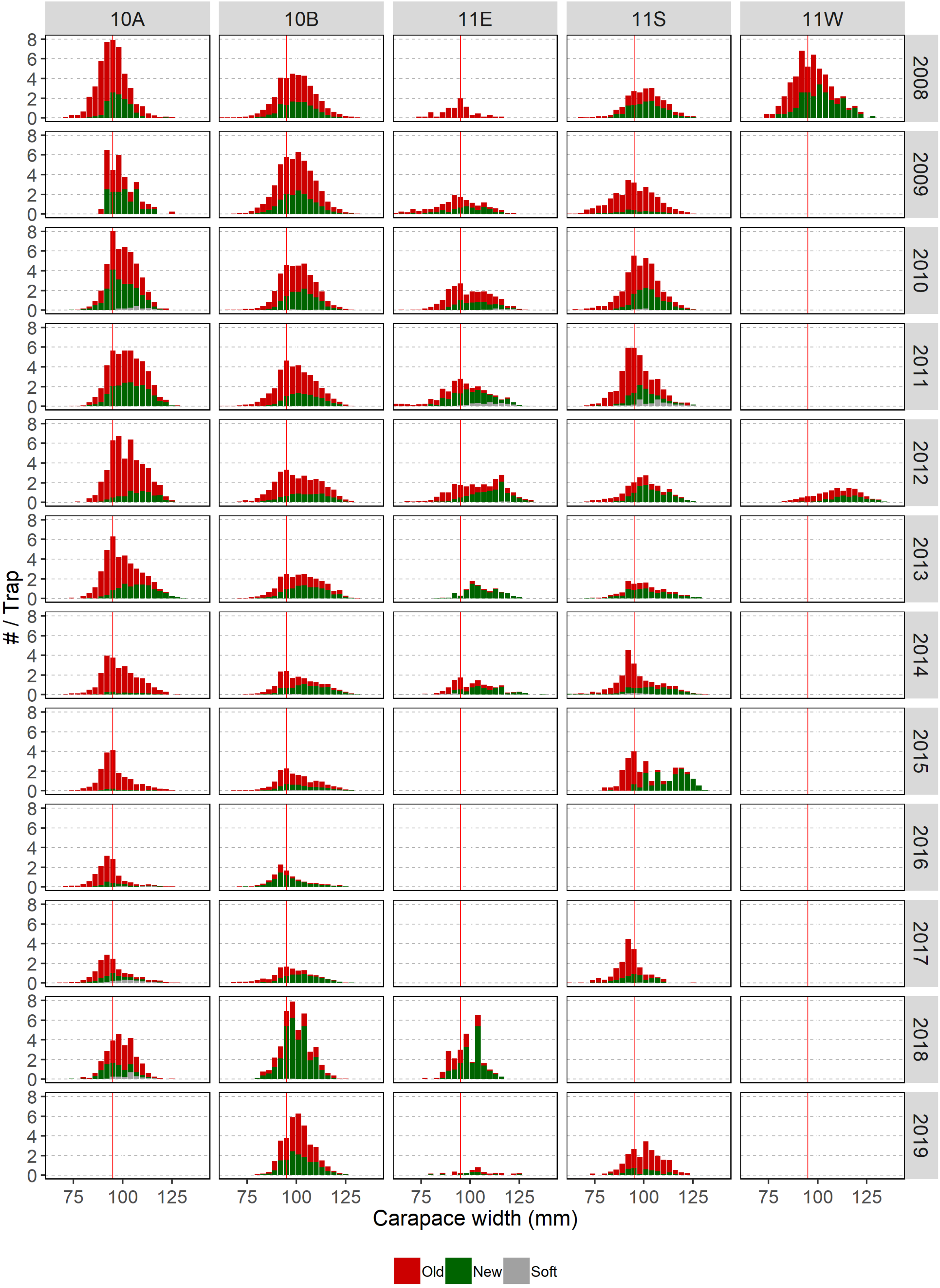

Figure A5.4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each CMA in AD 3Ps (2008–19). The red vertical line indicates the minimum legal size.

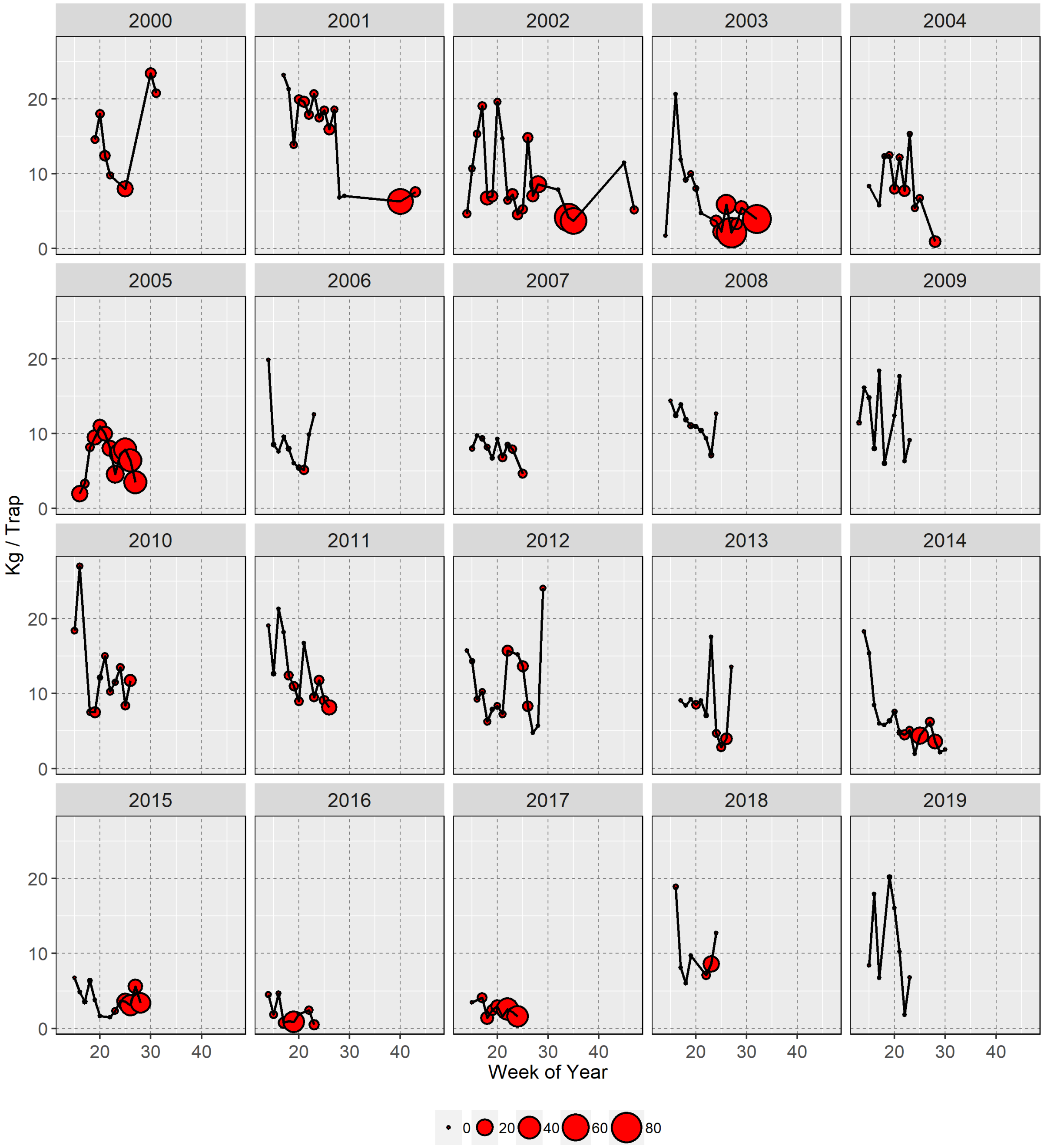

Figure A5.5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within AD 3Ps (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

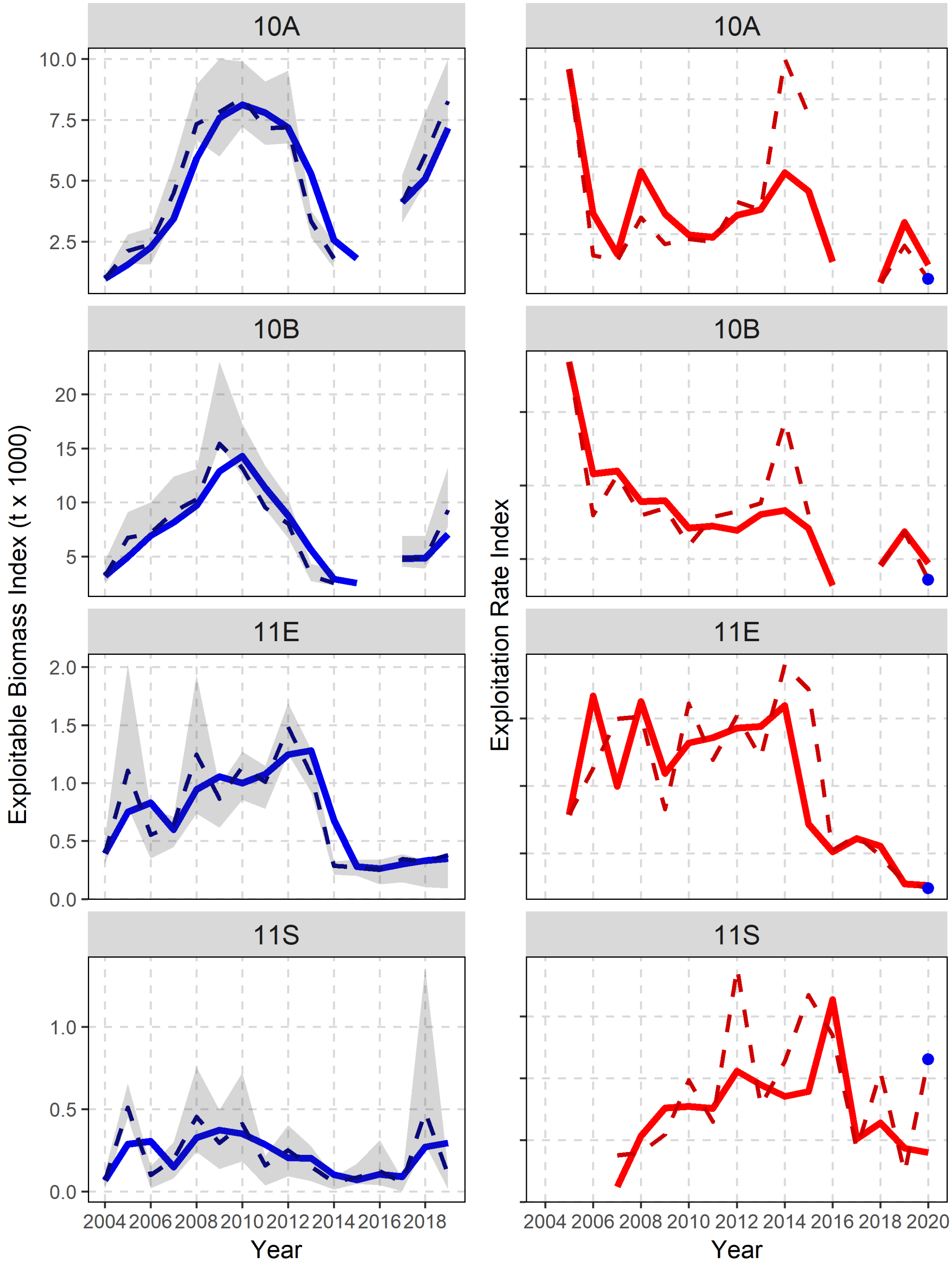

Figure A5.6. ***Left****: Trap survey exploitable biomass indices (t*1,000) by CMA in AD 3Ps (2004–19). Dashed lines shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate.* ***Right****: Trends in the annual (points) and 2-year moving average (solid line) trap-based ERI (%) by CMA in AD 3Ps; 2020 stars depict projected exploitation rate indices under status quo removals in the 2020 fishery.*

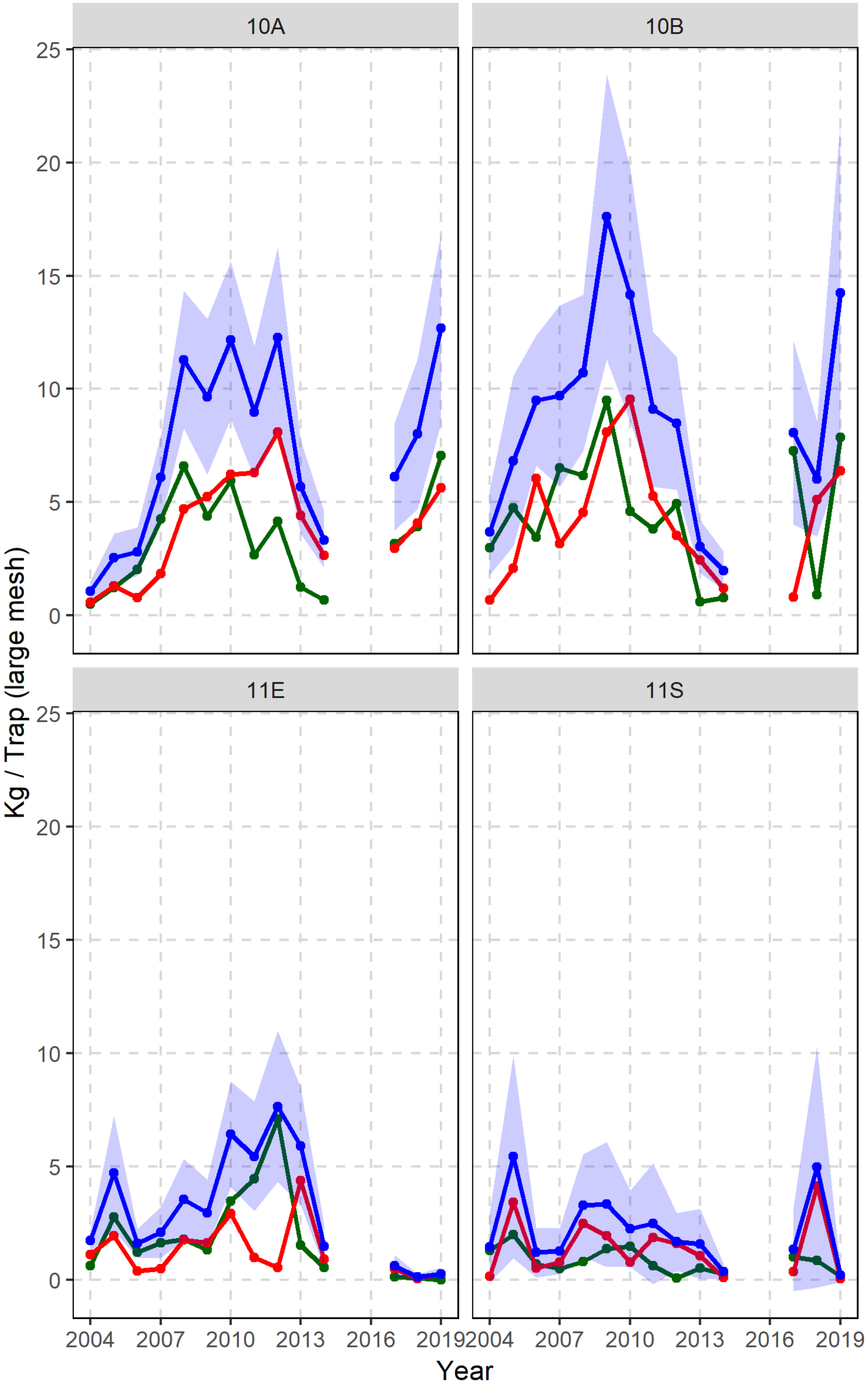

Figure A5.7. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from core stations in the CPS trap survey by CMA in AD 3Ps (2004–19). Shaded area represents the 95% confidence interval.

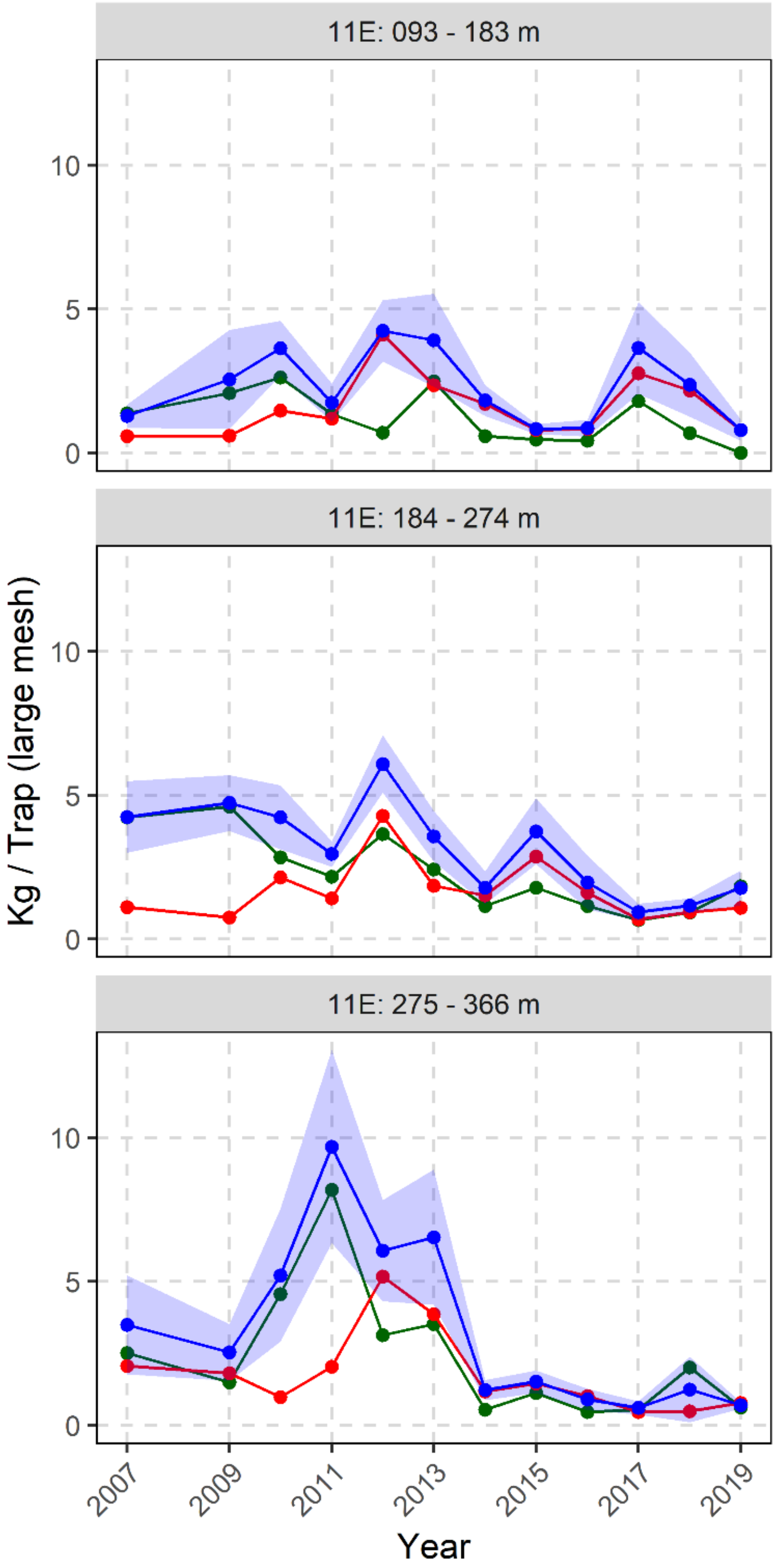

Figure A5.8. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from Inshore DFO trap surveys in Fortune Bay in AD 3Ps (2007–19). Shaded area represents the 95% confidence interval.

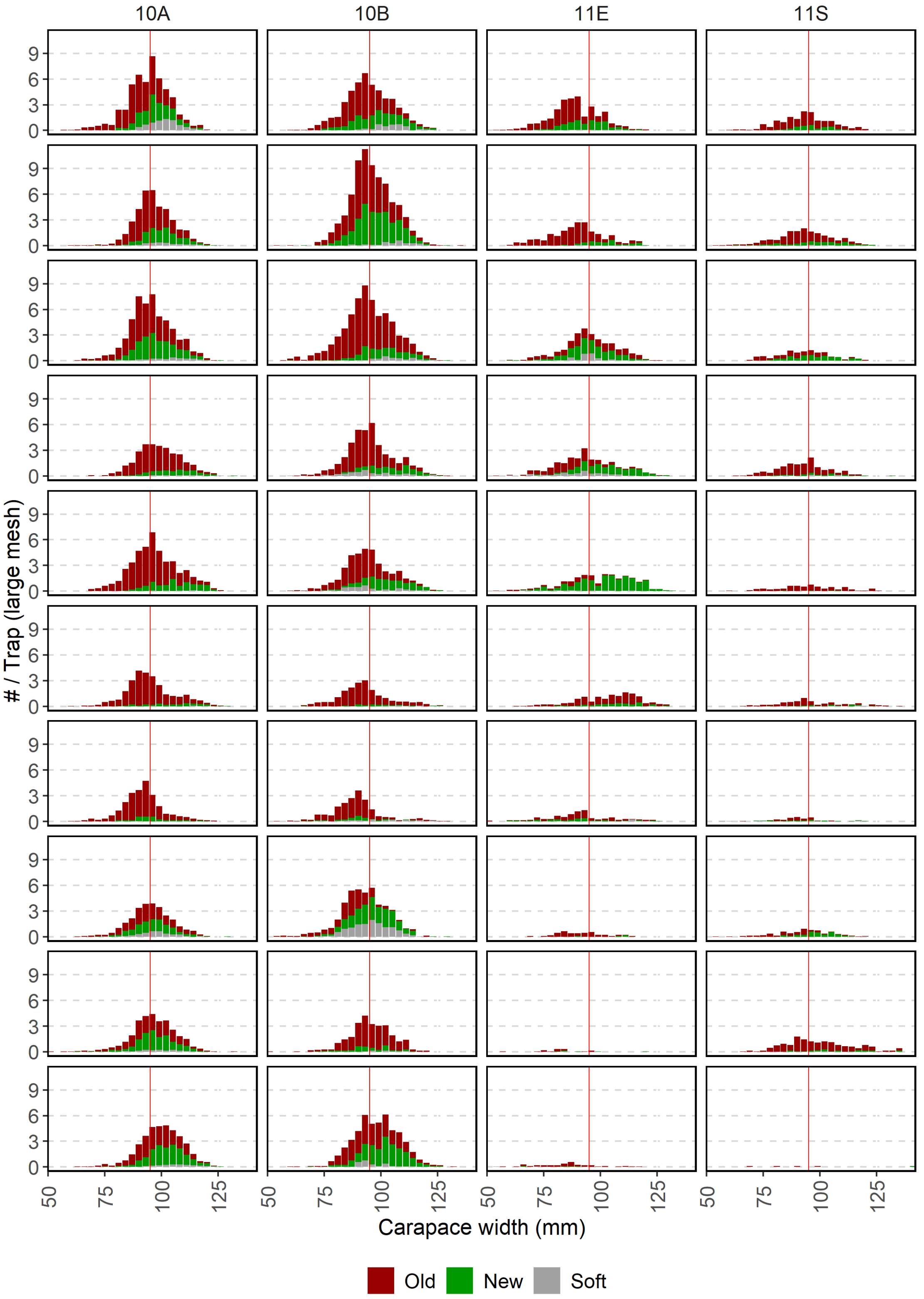

Figure A5.9. CPUE (#/trap) by carapace width and shell condition from male Snow Crab in large-mesh traps at core stations in the CPS trap survey by CMA in AD 3Ps (2008–19). The red vertical line indicates the minimum legal size.

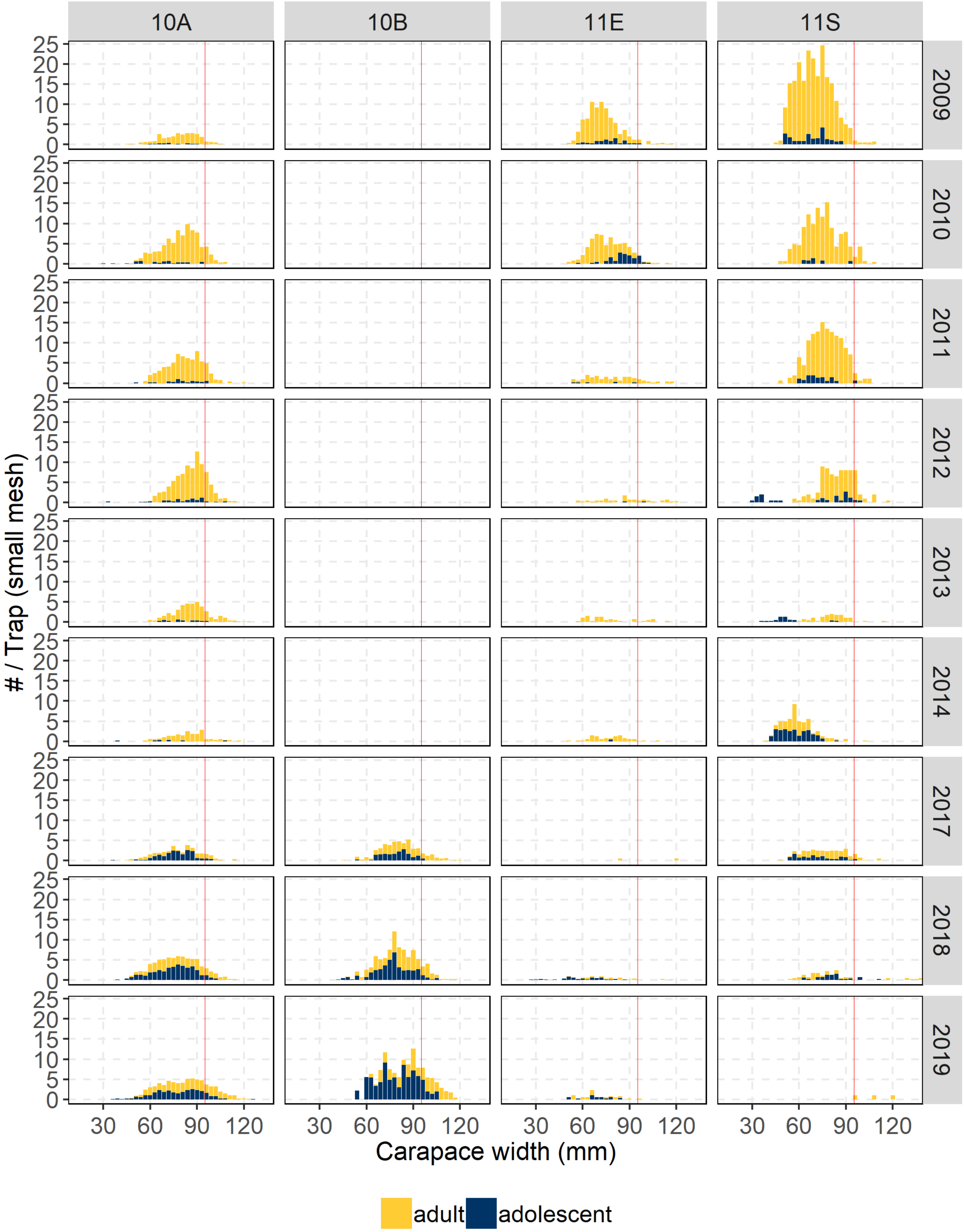

Figure A5.10. CPUE (#/trap) by carapace width and maturity from small-mesh traps at core stations in the CPS trap survey by CMA in AD 3Ps (2009–19). The red vertical line indicates the minimum legal size.

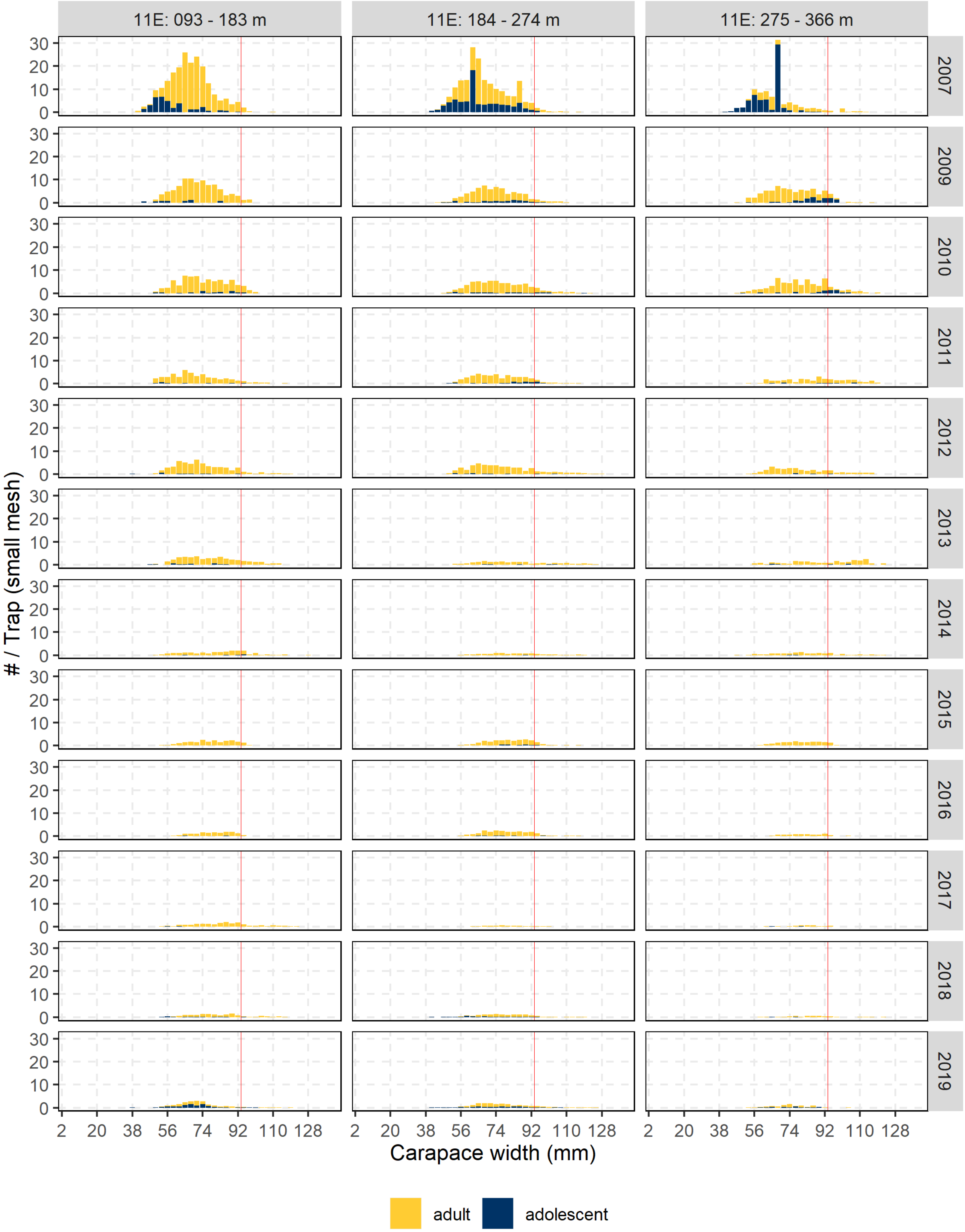

Figure A5.11. CPUE (#/trap) by carapace width and maturity from small-mesh traps in the Inshore DFO trap survey in Fortune Bay in AD 3Ps (2007–18). The red vertical line indicates the minimum legal size.

APPENDIX 6: ASSESSMENT DIVISION 4R3PN DETAILS

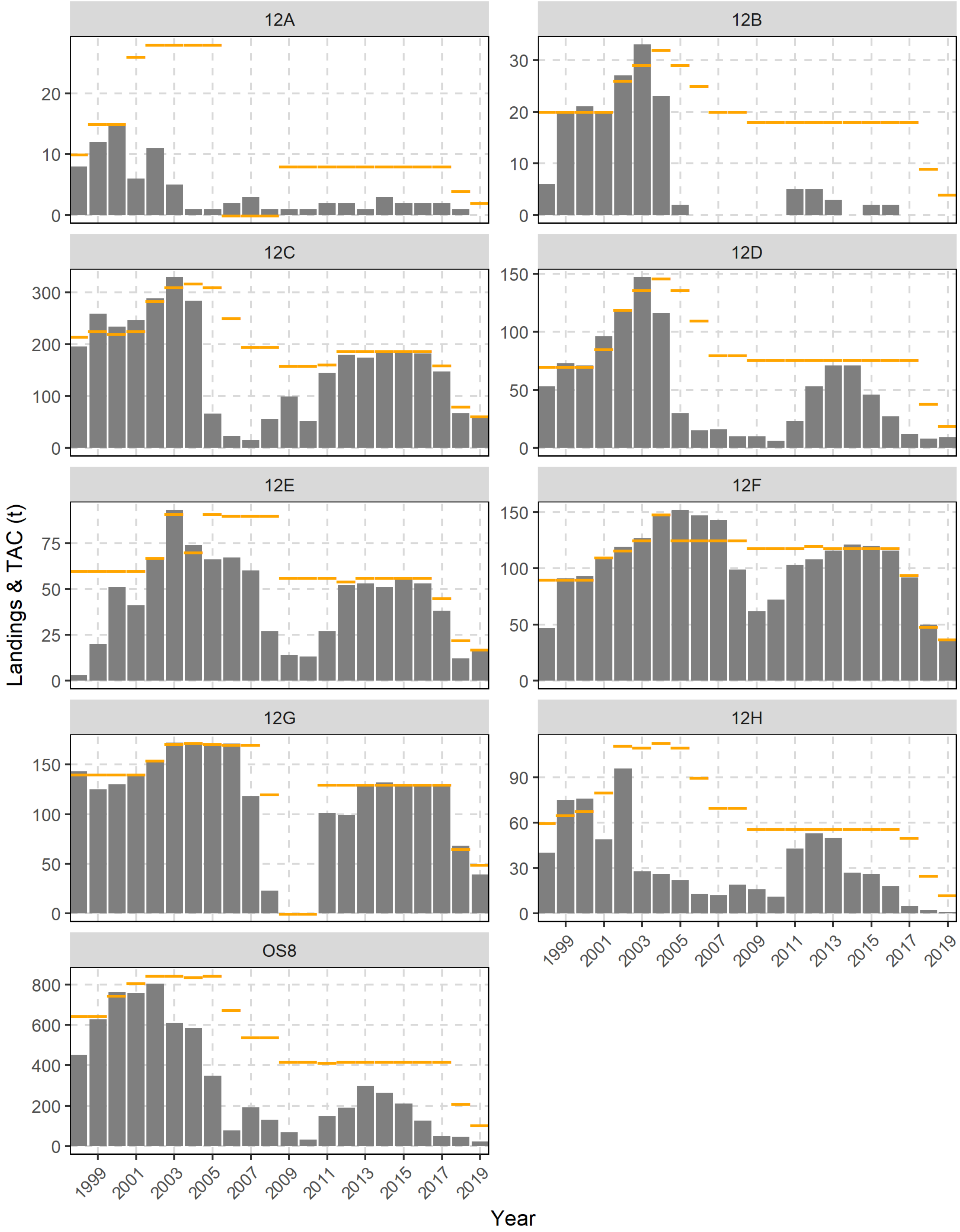

Figure A6.1. Annual landings (grey bars) and total allowable catch (yellow dashes) in CMAs within AD 4R3Pn (1998–2019).

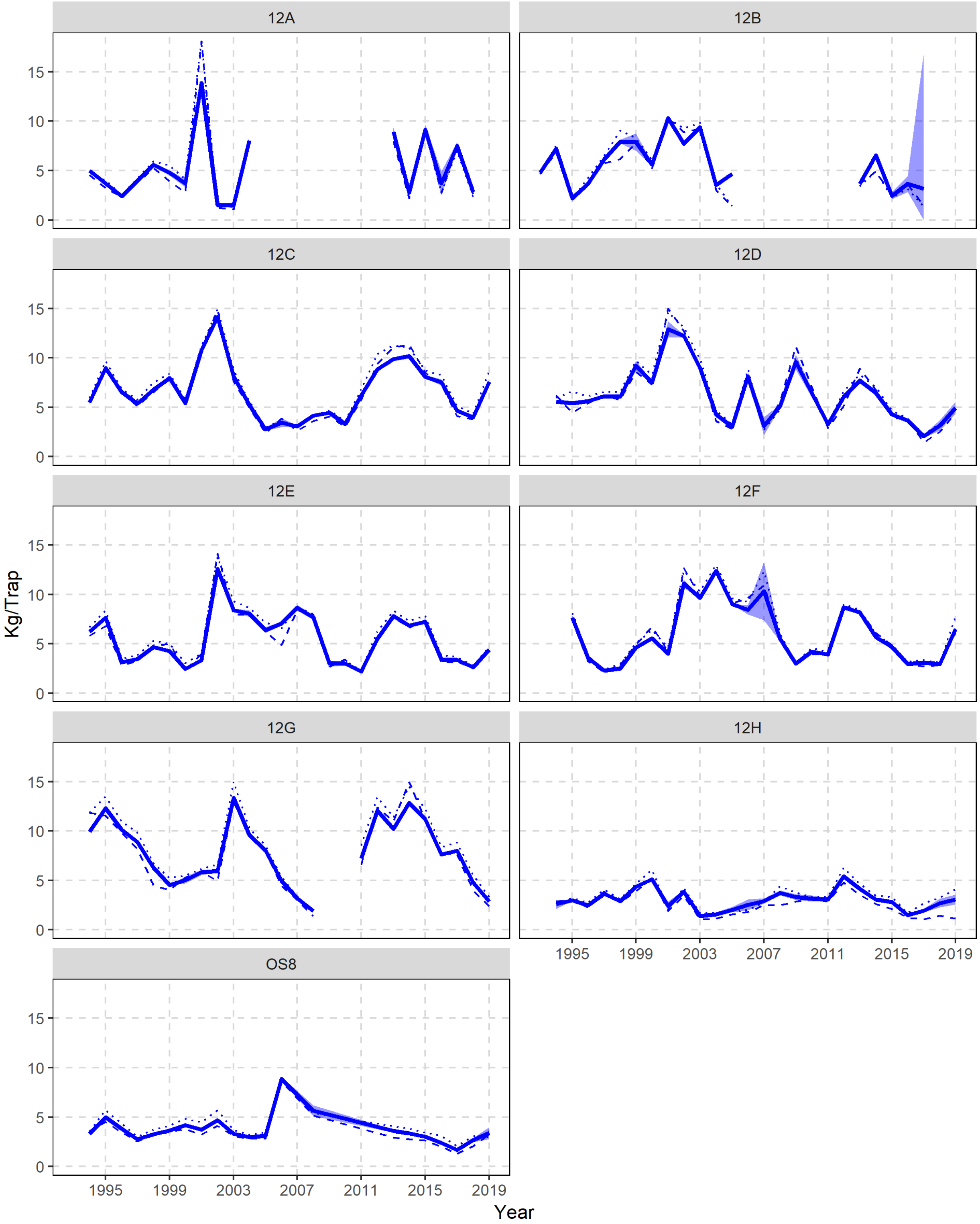

Figure A6.2. Standardized CPUE (kg/trap) in CMAs within AD 4R3Pn. Solid line is average predicted CPUE and shaded band is 95% confidence interval. Dotted line represents average raw CPUE and dashed line represents median raw CPUE. Vertical dashed line represents the beginning of the cod moratorium.

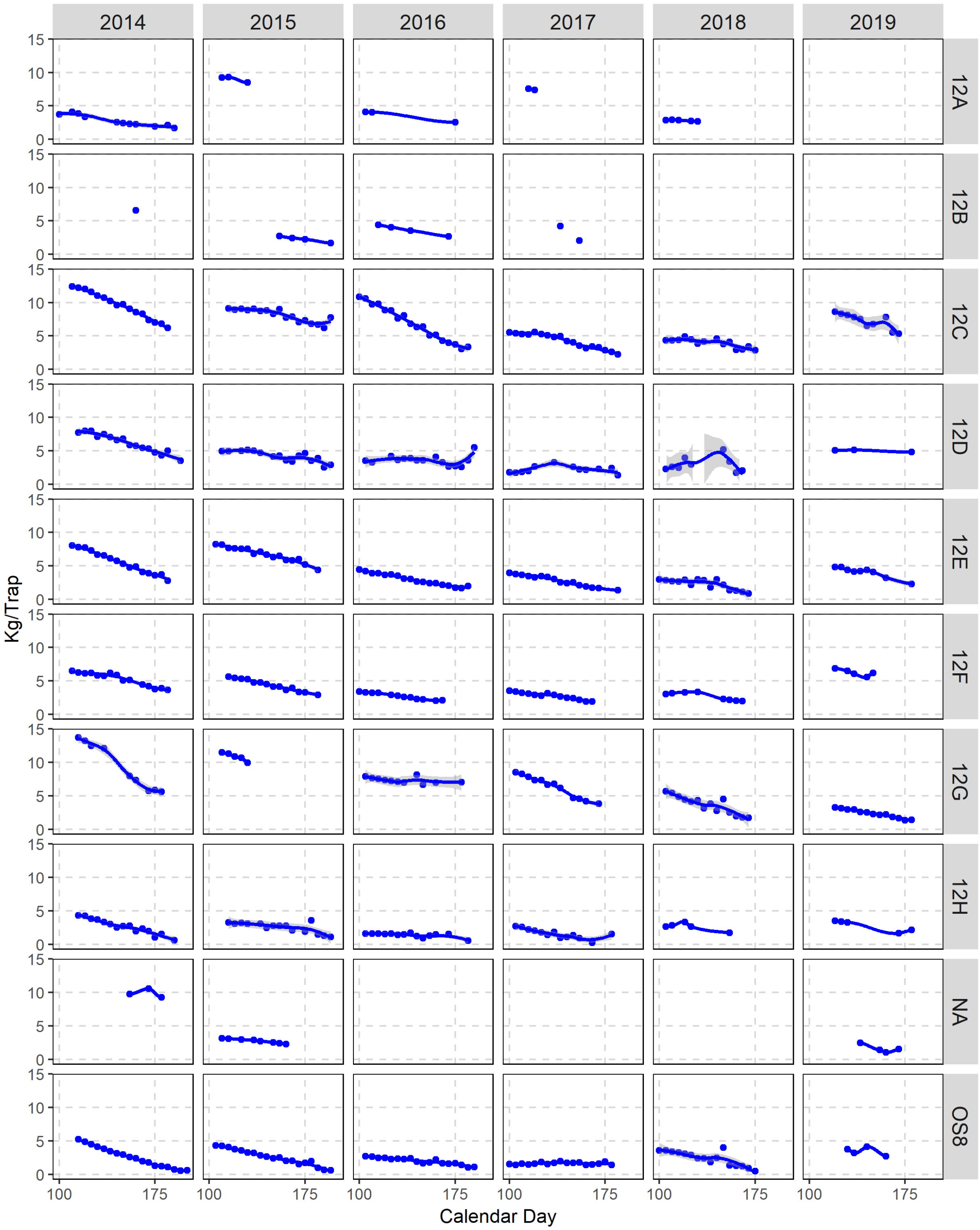

Figure A6.3. Standardized CPUE (kg/trap) of Snow Crab throughout the season (calendar day) in each CMA in AD 4R3Pn (2014–19). Points denote mean CPUE of 5-day increments and trend lines are loess regression curves.

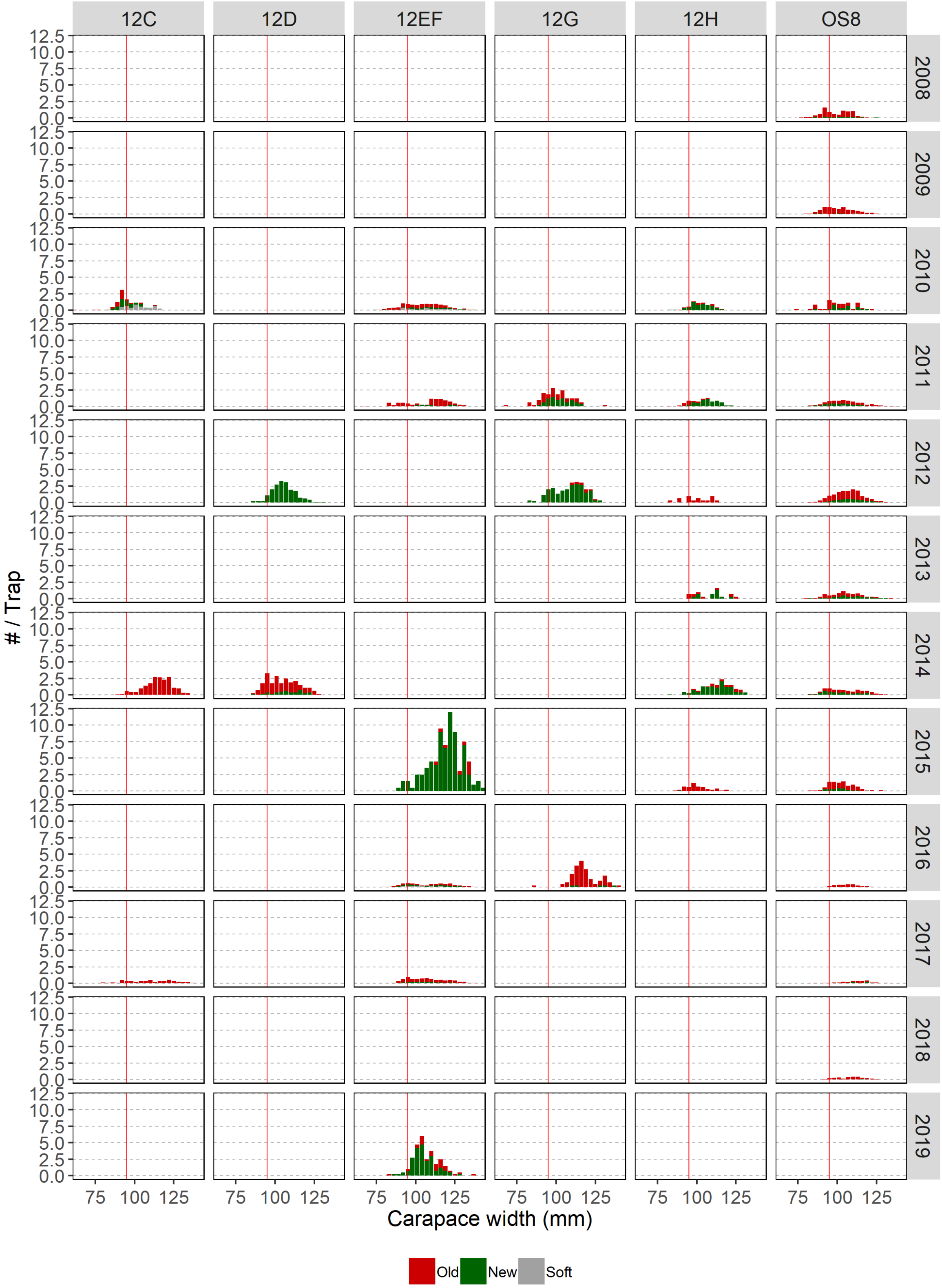

Figure A6.4. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer at-sea sampling in each CMA in AD 4R3Pn (2008–19). The red vertical line indicates the minimum legal size.

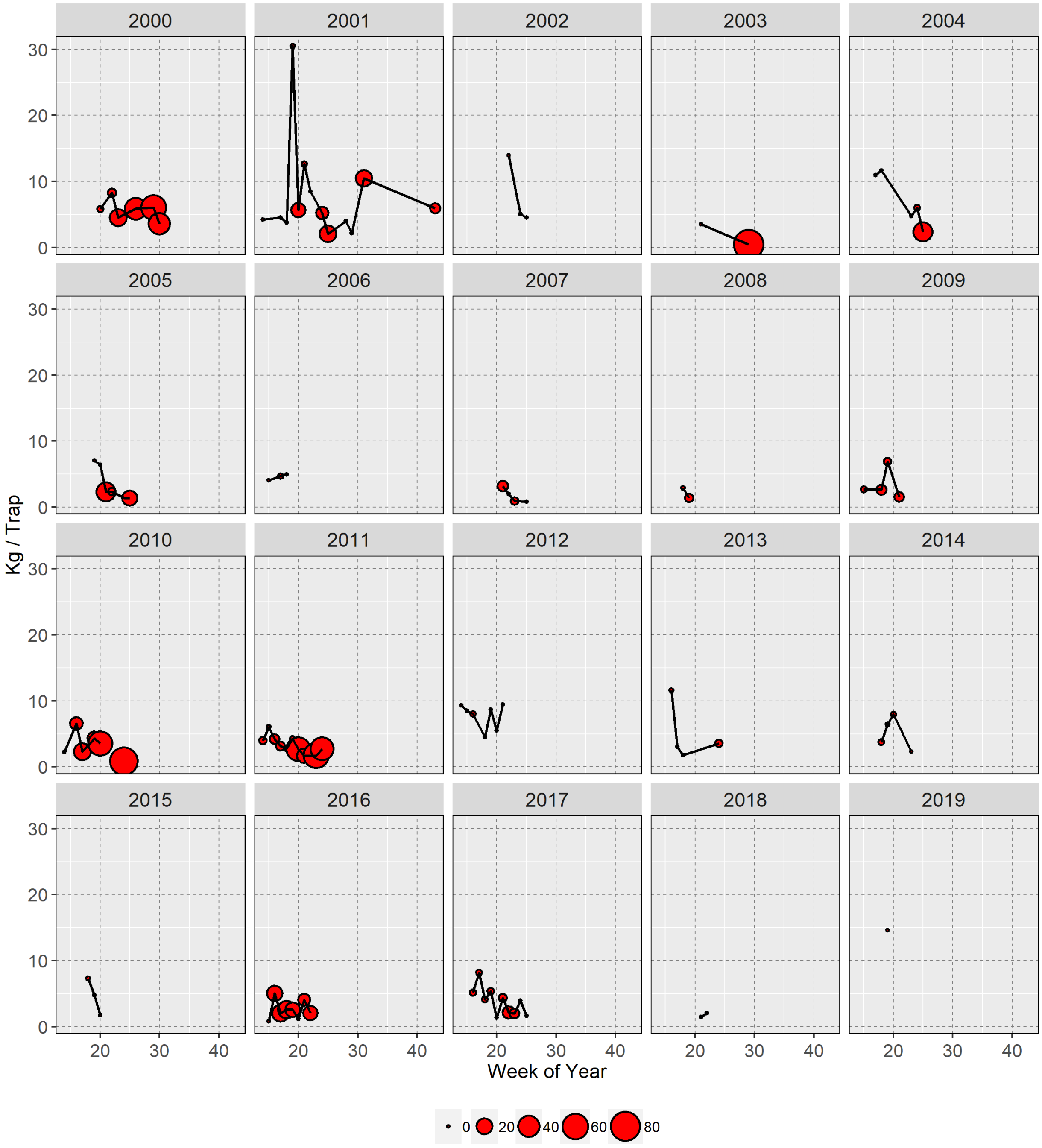

Figure A6.5. Observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within AD 4R3Pn (2000–19). Bubble size depicts percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

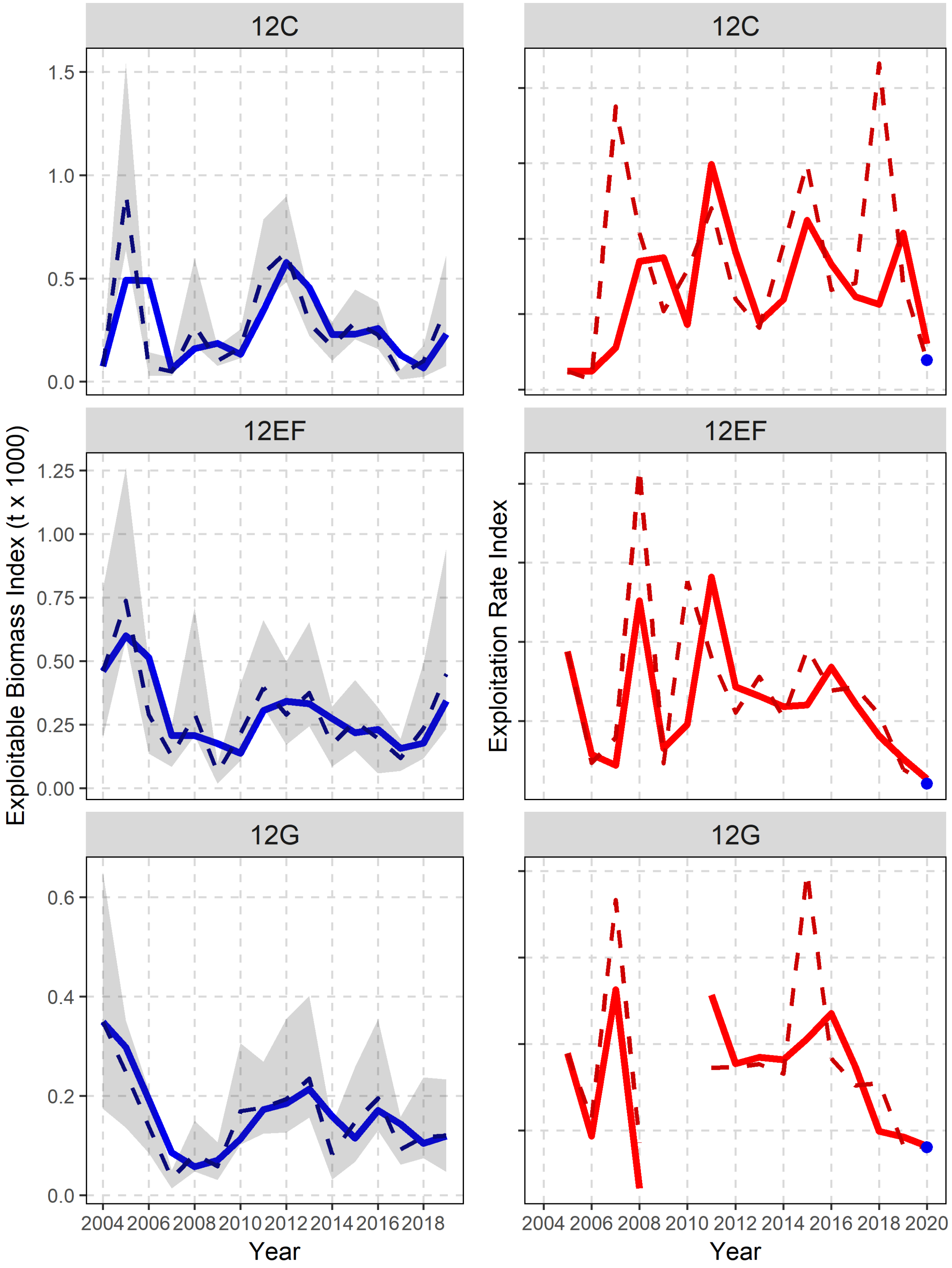

*Figure A6.6. **Left**: Trap survey exploitable biomass indices (t*1,000) by CMA in AD 4R3Pn (2004–19). Dashed lines shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate. **Right**: Trends in the annual (points) and 2-year moving average (solid line) trap-based ERI (%) by CMA in AD 4R3Pn; 2020 stars depict projected exploitation rate indices under status quo removals in the 2020 fishery.*

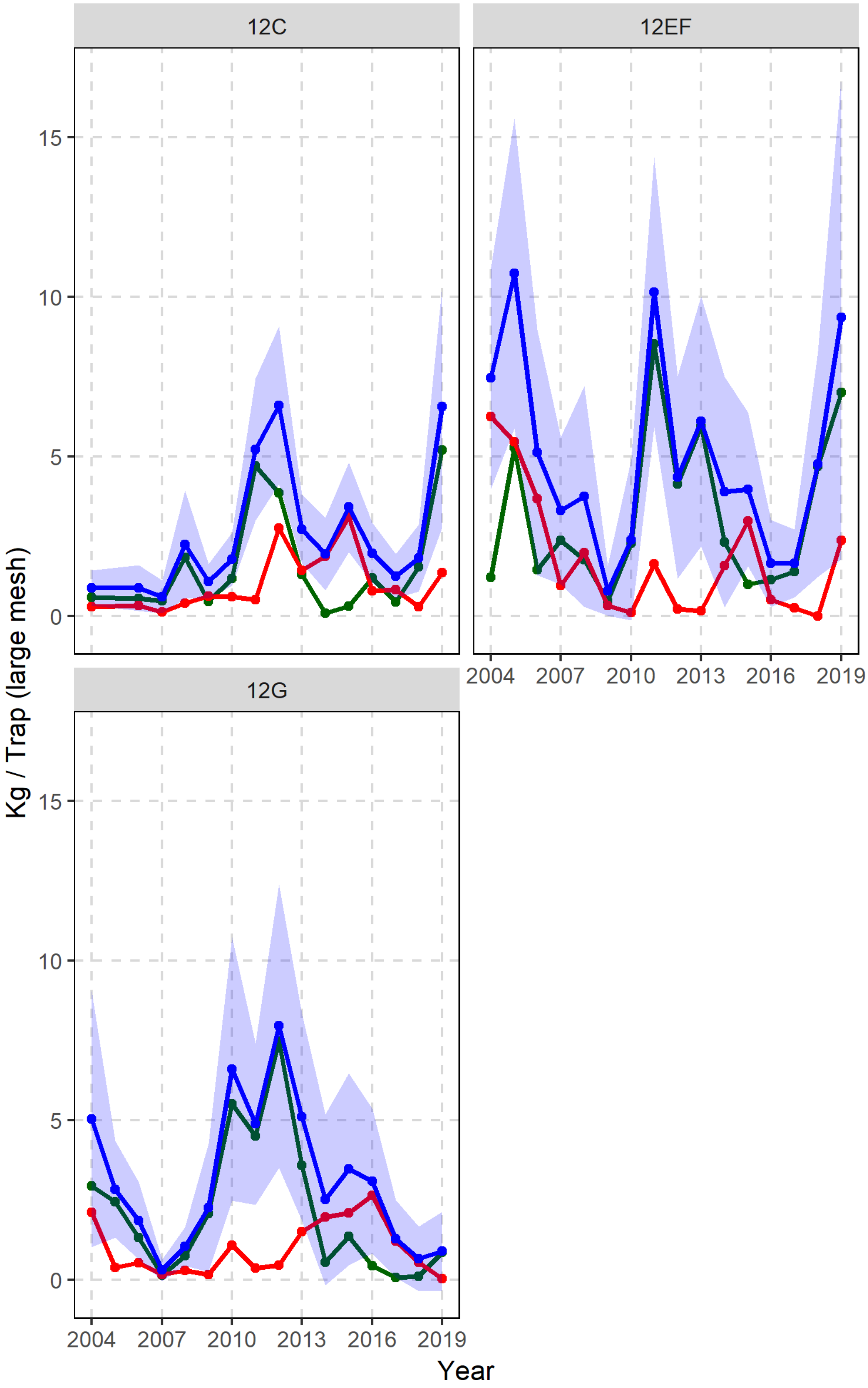

Figure A6.7. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable Snow Crab from core stations in the CPS trap survey by CMA in AD 4R3Pn (2004–19). Shaded area represents the 95% confidence interval.

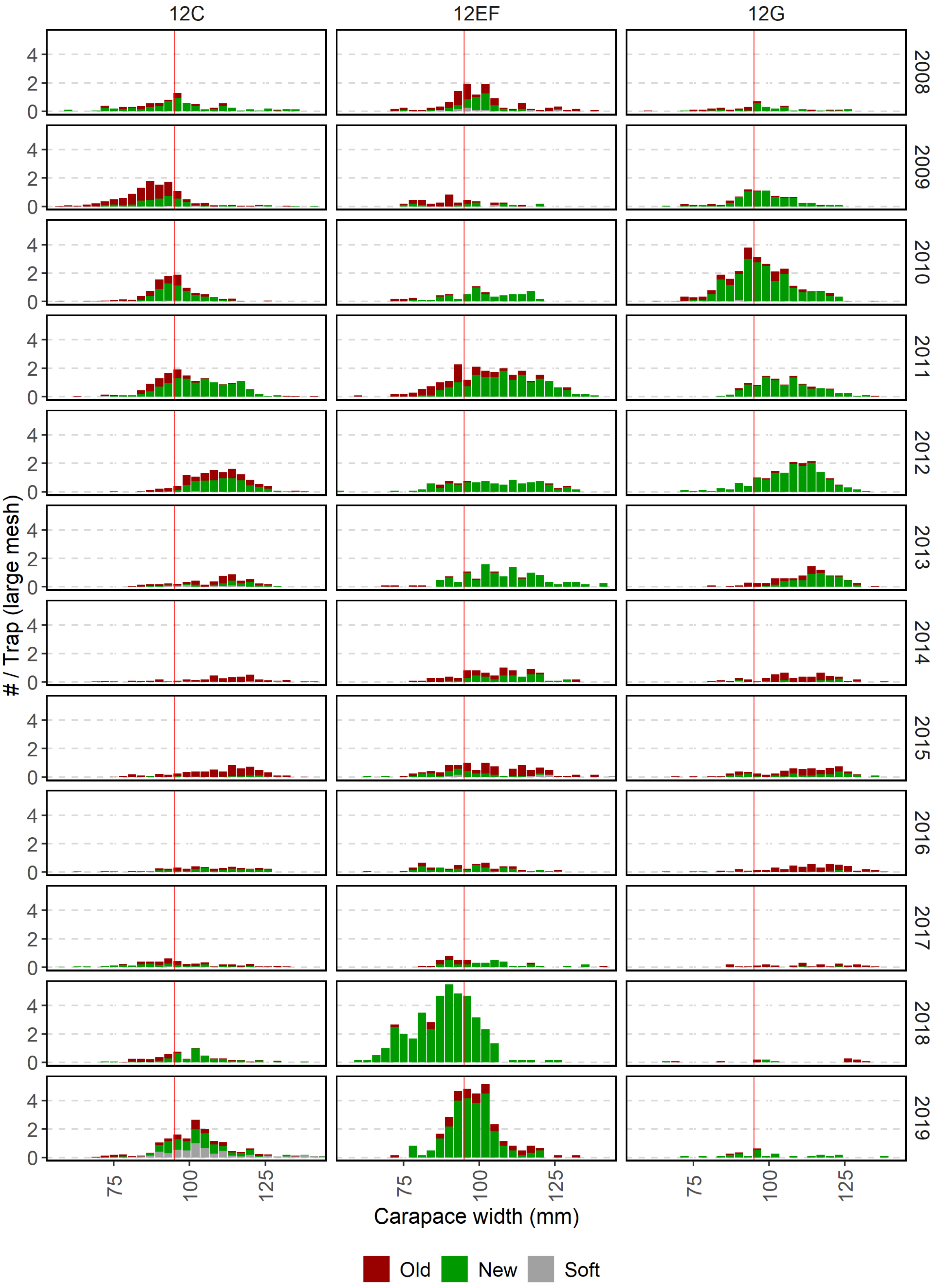

Figure A6.8. CPUE (#/trap) by carapace width and shell condition from male Snow Crab in large-mesh traps at core stations in the CPS trap survey by CMA in AD 4R3Pn (2008–19). The red vertical line indicates the minimum legal size.

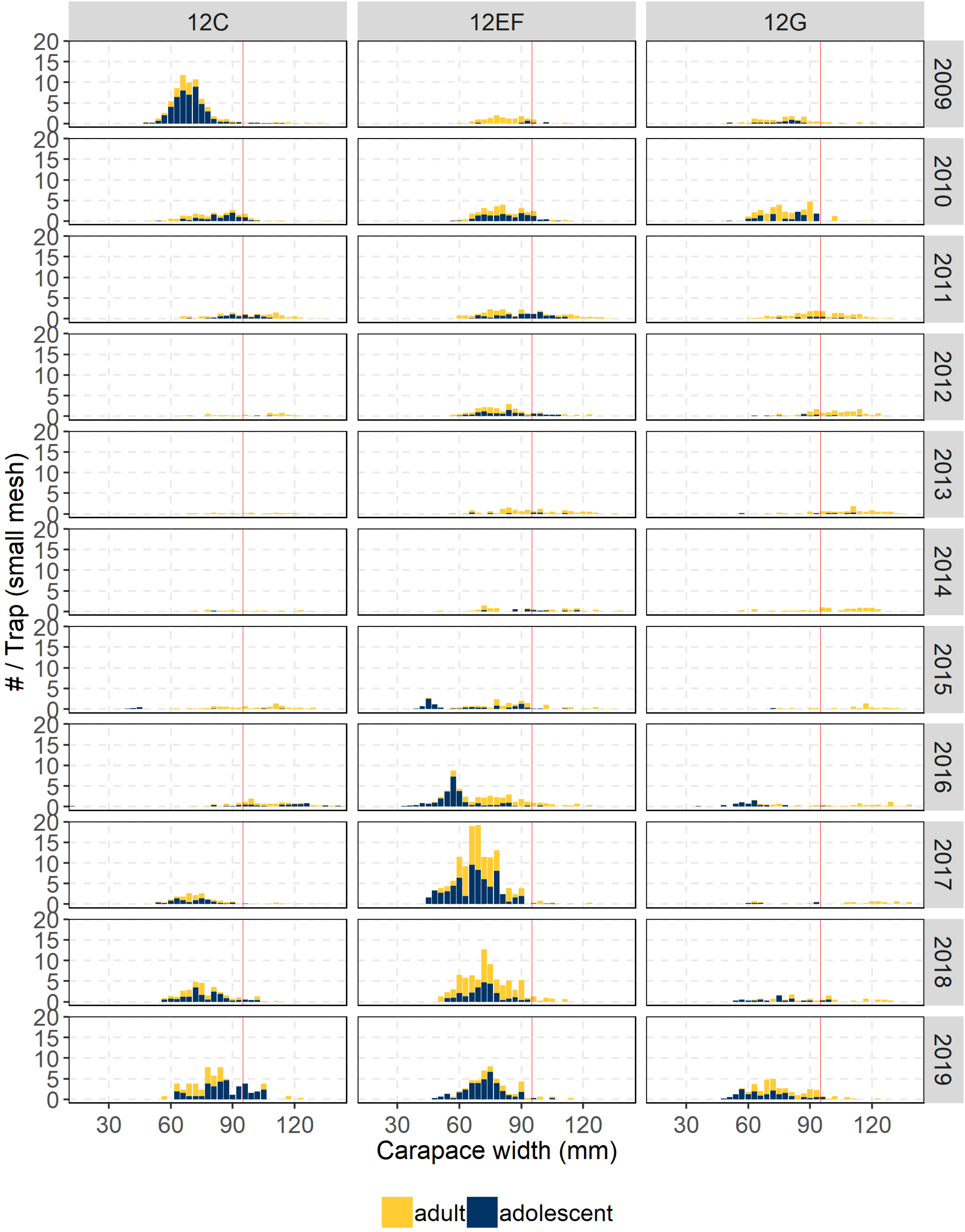

Figure A6.9. CPUE (#/trap) by carapace width and maturity from small-mesh traps at core stations in the CPS trap survey by CMA in AD 4R3Pn (2009–19). The red vertical line indicates the minimum legal size.