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An Assessment of Newfoundland and Labrador Snow Crab (Chionoecetes opilio) in 2017

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Foreword

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

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GLOSSARY

AD: Assessment Division.

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

CMA: Crab Management Area.

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

CPUE: Catch per unit of effort.

CW: Carapace width (mm).

DFO: Fisheries and Oceans Canada.

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

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

Habitat index: Areal extent of cold (<2°C) bottom water in shallow areas commonly associated with early-life stages of 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 centre: North Atlantic Oscillation. A broad-scale climate forcing defined as sea level atmospheric pressure differences between two dominant east-west centers in the North Atlantic.

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

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

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

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

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

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

Primiparous female: First-time mating spawning female crab.

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

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

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

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

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

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

TAC: Total allowable catch (quota).

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

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

VMS: Vessel monitoring system.

ABSTRACT

The status of the Snow Crab (*Chionoecetes opilio*) resource surrounding Newfoundland and Labrador (NL) in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2HJ3KLNOP4R is assessed using a variety of metrics. Data from multi-species bottom trawl surveys conducted during fall in Divs. 2HJ3KLNO and spring in Divs. 3LNO and Subdiv. 3Ps are examined to provide information on trends in biomass, recruitment, production, and mortality over the time series. Multi-species trawl survey indices are compared with other relevant indices toward inferring changes in resource status for 2018 and beyond. These other indices are derived utilizing data from harvester logbooks, at-sea observers, the dockside monitoring program (DMP), and inshore and offshore trap surveys, as well as oceanographic surveys. Snow Crab landings most recently peaked at 53,500 t in 2009 and have since gradually declined to 34,000 t in 2017, their lowest level in two decades. Fishery catch per unit effort (CPUE) was at a two-decade low in 2017 with most divisions at or near historical lows. Despite a modest increase in 2017, the trawl survey exploitable biomass index has remained at its lowest observed level for the past three years. Meanwhile, the trap survey index has been at its lowest observed level in the past two years. Overall recruitment into the exploitable biomass has been very low in recent years and survey data suggest recruitment available to the 2018 fishery will remain low in most divisions. However, survey and environmental data suggest modest increases in recruitment could occur in some divisions over the next 2-4 years. Total mortality in exploitable crab has increased to be at or near time-series highs in recent years in all divisions. Status quo removals would maintain two-year average exploitation rate indices near or above long-term median levels in all divisions. New time-series highs would occur in Divisions 3L Inshore, 3LNO Offshore, and 4R3Pn. The relatively low level of residual biomass (old-shelled adult crab) at all sizes in all divisions in recent years is concerning given it is generally associated with low CPUE and high levels of discards in the fishery. Increasing recruitment potential in some divisions, coupled with a low residual biomass, suggests that wastage of soft-shelled pre-recruits could become more problematic if high levels of exploitation are maintained in the fishery in the next few years.

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 and 2). The information presented follows from a formal scientific assessment and regional peer review process conducted during late February 2018 that focused on identifying changes in the exploitable biomass of Snow Crab available to the fishery.

SPECIES BIOLOGY

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

The minimum legal size in the NL Snow Crab fishery is 95 mm CW and therefore females are excluded from the fishery and a portion of adult males remain available for reproduction. Age is not determined, but Snow Crab are believed to recruit to the fishery at 8-10 years of age in warm areas (Divs. 2J3K4R and Subdiv. 3Pn) and at slightly older ages in cold areas (Divs. 3LNO and Subdiv. 3Ps), reflecting less frequent molts at low temperatures (Dawe et al. 2012). Adult legal-sized males remain new-shelled with low meat yield throughout the remainder of the year of their terminal molt. They are not likely to contribute to the fishery until the following year when their shells are fully hardened and full of meat. Males may live a maximum of 6-8 years as adults after the terminal molt (Fonseca et al. 2008).

Snow Crab typically inhabit a narrow range of temperatures, and variation in temperature has a profound effect on production, early survival, and subsequent recruitment to fisheries (Foyle et al. 1989; Dawe et al. 2008; Marcello et al. 2012). Cold conditions during early ontogeny are associated with increased survey biomass and fishery CPUE indices several years later (Marcello et al. 2012; Mullowney et al. 2017). While growth rates are affected by temperature, with younger age-at-recruitment and typically larger sizes occurring in warm regimes, the overriding positive effect of cold water on early survival appears stronger than the negative effect on size-at-terminal molt and highest productivity occurs in cold areas.

Along the NL Shelf, cold and most productive conditions are generally found in shallow to intermediate depth areas (Colbourne et al. 2016; Mullowney et al. 2017). Historically, the most productive fisheries have been associated with shallow to intermediate-depth 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. 2018). Largest males are most commonly distributed on mud or mud/sand, while small crab are more common on harder substrates. Some crab also undertake an upslope migration in winter or spring for mating and/or molting (Mullowney et al. 2018).

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

Snow Crab in NL are part of a larger stock in Canadian Atlantic waters, ranging from southern Labrador to the Scotian Shelf (Puebla et al. 2008). However, movements of individuals within the stock are thought to be limited, so assessments are conducted at the NAFO Division level (Figure 2), with inshore and offshore portions of divisions separated where applicable and some divisions combined. Accordingly, Assessment Divisions (ADs) differ from both NAFO Divsions and the small spatial scale Crab Management Areas (CMAs) used to manage the fishery. The spatial scale of the assessment approach accommodates different types and amounts of available information among ADs and better conforms with broad-scale resource status indicators than the CMAs.

FISHERY

The NL Snow Crab fishery began in Trinity Bay (CMA 6A) in 1967. Initially, crab were taken as gillnet by-catch, but within several years a directed trap fishery developed in inshore areas along the northeast coast of Divs. 3KL. Until the early 1980s, the fishery was prosecuted by approximately 50 vessels limited to 800 traps each. In 1981, fishing was restricted to the NAFO Division adjacent to where the license holder resided. The fishery expanded throughout all areas of the Province from the 1970s to 2000s, especially following groundfish stock collapses in the early 1990s. During 1982 to 1987, there were major declines of the resource in traditional areas in Divs. 3K and 3L, while new fisheries started in Div. 2J, Subdiv. 3Ps, and offshore Div. 3K. A Snow Crab fishery began in Div. 4R in 1993. Management of the increasingly diverse fishery during the expansion years led to the development of the many quota-controlled areas, with about 3,500 active license holders participating in the fishery in the mid-2000s. Resource declines and rationalization measures have led to reduced participation in recent years. The fishery is now prosecuted by several offshore and inshore fleet sectors with about 2,600 license holders under enterprise allocation in 2017.

In the late 1980s, quota control was initiated in all CMAs of each division. Current management measures include trap limits, individual quotas, spatial and temporal closures within divisions, and differing seasons. Mandatory use of the electronic vessel monitoring system (VMS) was fully implemented in offshore fleets in 2004 to ensure compliance with regulations regarding area fished. The fishery is prosecuted using conical baited traps set in long-lines (‘fleets’), typically with a trap spacing of approximately 45 m. The minimum legal mesh size is 135 mm CW 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 in recent years and is now primarily prosecuted during spring and summer. The fishery can be delayed in northern divisions (Divs. 2HJ3K) due to ice conditions in some years. The fishery can also be delayed for other reasons such as price disputes or difficulties in capturing quotas. Late fishing seasons are often associated with a high incidence of soft-shelled immediate pre-recruits in the catch. A protocol was initiated in 2004 that results in closure of localized areas (10 x 7 na. mi.) when the percentage of soft-shelled crab within the legal-sized catch exceeds 20%. The closure threshold was reduced to 15% for Assessment Division 3LNO in 2009-10 and grids have been partitioned into quarters in some inshore areas in recent years.

Landings for Divs. 2HJ3KLNOP4R historically peaked at 69,100 t in 1999. In recent years, landings most recently peaked at 53,500 t in 2009 and have since gradually declined to 34,000 t in 2017. ADs 3L Inshore and particularly 3LNO Offshore have accounted for a steadily increasing percentage of the catch, from about half in 2009 to 80% in recent years. However, resource and fishery declines are now occurring in these most important areas.

METHODOLOGY

MULTI-SPECIES TRAWL SURVEY DATA

Data on total catch numbers and weights were derived from depth-stratified multi-species bottom trawl surveys. These surveys were conducted during fall in Northwest Atlantic Fisheries Organization (NAFO) Divisions. 2HJ3KLNO and spring in Divs. 3LNO and Subdiv. 3Ps. The fall (post-season) survey has occurred annually in all but Div. 2H where it was executed each year from 1996-99, bi-annually from 2004-08, and annually from 2010-17. 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. Based on comparative data from Divs. 3LNO, where both a spring and fall survey occurs, fall trawl surveys are deemed to have a higher catchability for Snow Crab (unpublished data). Spring surveys are considered less reliable because some population components are believed to be relatively poorly sampled during this time, when mating and molting typically occurs.

Prior to 2015, survey abundance and biomass indices were calculated using STRAP (Smith and Somerton 1981), with a set of core strata invoked from 2009-14 due to attrition of survey coverage in deepest and fringe areas of the inshore and offshore over time. However, in recent years Ogive Mapping (Ogmap) (Evans 2000) has been used as the spatial expansion platform for biomass and abundance estimation (Figure 3). Due to the greater flexibility of Ogmap to extrapolate across poorly sampled areas, it was no longer necessary to restrict trawl survey data inclusion to core strata.

Data north of 56 degrees latitude in Div. 2H are omitted because of consistently low capture of crab farther north and sporadic frequency of survey coverage in Div. 2H throughout the time series. Further, previous assessments treated the fall survey in Assessment Division (AD) 3LNO in 2014 as incomplete because of the omission of large portions of Divs. 3N and 3O (Mullowney et al. 2017). However, because of the virtual absence of crab in subsequent spring and fall trawl surveys throughout Divs. 3N and 3O since 2014, less explicit emphasis placed on the 2014 survey point estimate with three additional survey years, and the more robust ability of Ogmap to extrapolate across areas void of coverage, the 2014 fall survey in AD 3LNO was viewed as complete for this assessment. It is recognized there is still considerable uncertainty around this point estimate. The 2006 spring survey in AD 3Ps was deemed incomplete as virtually the entirety of the Assessment Division was not surveyed, including the dominant Snow Crab grounds, in that year.

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

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

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

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

Unstandardized biomass and abundance estimates from trawl surveys were computed using Ogmap (Evans 2000). A nonparametric estimate was made of the probability distribution for trawl catch (biomass or numbers) at any point in the area to be assessed (Figure 3). Total biomass or abundance was computed as the integral over the area of the mean value of the distribution. Confidence bounds were computed by bootstrap resampling from the distribution field. Biomass and abundance estimates were calculated for the abundance of smallest crab (15-25 mm CW), total abundance of small (<50 mm CW) crab, the abundances of mature females and pre-recruit males, and the biomass of pre-recruit and exploitable males. For spring surveys, the indices represent abundances or biomasses for the immediately upcoming (or on-going) fishery, whereas for fall (post-season) surveys they represent biomass for the fishery in the following calendar year.

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

We examined annual changes in abundance indices of recruits and residual crab in the exploitable biomass, in-part to evaluate the internal consistency of the data series. 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.

Pre-recruit biomass and abundance indices were calculated based on all adolescent (small-clawed) males ranging 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., 2017) that undergoes a terminal molt in the subsequent winter or spring (i.e., 2018) would be identified as a recruit into the exploitable biomass in the 2018 survey(s), and should begin contributing to the fishery in 2019. However, a portion of pre-recruits would molt but remain adolescent, which would delay their contribution to the exploitable biomass and fishery by a year. The issue is further complicated by the presence of skip-molting, whereby not all identified pre-recruits will molt in the following winter or spring and their arrival into the exploitable biomass and fishery would be delayed even further. Skip-molting is most common in large adolescent males in cold areas (Dawe et al. 2012). Along with compromising the ability to track crab from the pre-recruit to recruit and residual biomass stages, the annually variable proportion of skip-molters complicates the ability to assess shell condition in pre-recruits.

The biomass indices derived through Ogmap were calculated from raw survey data. However, it is known that catchability of crab by the survey trawl (i.e., trawl efficiency) is much lower than 1 (Dawe et al. 2010a) and that raw survey biomass estimates are greatly underestimated relative to reality (Mullowney et al. 2017). Accordingly, the raw exploitable biomass estimates were scaled up 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 forthcoming in the methods section on logbook data. These depletion conversion factors (đ) represented the average difference between logbook and survey-based biomass estimates in each AD over the time series:

$$đ = \sum_{y=2000}^{2017} (Ty/Dy * 1/n)$$

where,

T = raw trawl survey 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 present assessment found evidence to suggest the depletion method employed slightly over-estimates absolute biomass and non-linear depletion methods to standardize trawl survey biomass indices are being pursued for the next assessment.

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

Catchability of Snow Crab by the Campelen trawl 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 (Benoît and Cadigan 2014, 2016). Exploratory analyses showed conversions to account for time and vessel made negligible difference in scaling raw biomass indices to standardized estimates, with trends in unstandardized trawl survey biomass estimates similar in all combination of conversions, thus no conversions were applied prior to re-scaling exploitable biomass through fishery depletion conversions.

To examine size compositions of both sexes, crab were grouped by maturity and partitioned into 3 mm CW intervals. A square root of mean numbers per tow for each maturity-size grouping was plotted. A square root transformation was applied because trawl size frequency distributions often exhibit a ‘trough’ pattern, with crab ranging from about 30-70 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.

The ratio of the unstandardized exploitable to pre-recruit biomass index for each AD was compared to CPUE in the fishery (both indices standardized to mean of 0 and standard deviation of 1). Based on consistent positive relationships between these indices in all ADs, and negative relationships with fishery discards (Mullowney et al. 2017), the strength of this ratio is thought to reflect the ‘buffering capacity’ of the exploitable biomass to prohibit less competitive crab from trapping in the fishery. In particular, the catch rate of soft-shell crab decreases when the ratio of exploitable to pre-recruit crab is high. Long-standing management advice generated from the assessment is that maintaining a high exploitable to pre-recruit ratio in the population promotes high fishery CPUE and low wastage of soft-shell pre-recruits in the fishery.

An annual exploitation rate index for each AD was calculated as the ratio of dockside-monitored landings to the most recent depletion adjusted exploitable biomass index. As exploitable biomass indices are not absolute, neither are exploitation rate indices. Given evidence to suggest biomass is slightly over-estimated, exploitation rate indices likely slightly under-estimate absolute harvest rate. Nonetheless, long-term trends in exploitation rate indices provide a useful indication of trends of relative effects from fishing. In AD 3L Inshore and 4R3Pn, where no trawl surveys occur, exploitation rate indices were based on landings in relation to exploitable biomass estimates from trap surveys.

For the provision of advice, exploitation rate indices were smoothed to two-period averages by relating landings to an average of the biomass index from the preceding two surveys. 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. The analysis was more explicitly refined to compare the percentage of adult male crab ranging from 75-95 mm CW versus 96-115 mm CW that were either old or very-old shelled, with reduced percentages in the larger group inferred to represent relative fishing mortality.

Occurrence of advanced stages of Bitter Crab Disease (BCD), a fatal affliction and source of natural mortality, was noted in both sexes based on macroscopic examination in all trawl surveys. In cases of unclear external characteristics 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_m) were calculated as a three period moving average of stage-specific biomass indices of exploitable crab:

$$A_m = \frac{0.33 \cdot \left(B_{new}(t-1) + B_{old}(t-1)\right)}{B_{old}\ (t)} + \frac{0.33 \cdot \left(B_{new}(t-2) + B_{old}(t-2)\right)}{B_{old}\ (t-1)} + \frac{0.33 \cdot \left(B_{new}(t-3) + B_{old}(t-3)\right)}{B_{old}\ (t-2)}$$

where,

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

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

t-1 = denotes survey of previous year

FISHERY LOGBOOK DATA

Data on commercial catch (kg) and fishing effort (number of trap hauls) were obtained from vessel logbooks. These data were compiled by the Statistics Division, Policy and Economics Branch, NL Region of DFO. Return of complete and accurate fishing logbooks is a condition of license in this fishery. The dataset is normally incomplete in the current year, resulting from a time lag associated with compiling data from the most recent fishery, thus the most recent point estimates are considered preliminary (Figure 4).

Logbook catch per unit of effort (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 division. α terms indicate intercepts, β terms indicate coefficients for specific covariates, the ϵ term indicate unmodelled error around predicted CPUE, and σ^2 terms indicate variances on random effects or the error term. The model regresses the response variable of square-root transformed CPUE (catch/trap haul) from individual observations (normally on a per set basis) against fixed effects of time, binned in 5-day intervals ($\overline{\beta_{Day}}$) and gear soak time, measured in days (β_{Soak}). Random effects were used to model root CPUE at the start of the season ($\alpha_{y,D}$) and slopes for for time effects ($\beta_{Day,y,D}$) of year*CMA groupings are included in the model. The CMA parameter accounts for spatial variation across multiple management areas within any AD. The positively-skewed response variable was square-root transformed to normalize it, as stronger transformations such as logarithms were found to produced negatively-skewed distributions in some cases. Finally, the model is weighted by effort (traps). 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 occurring after November were omitted due to sporadic presence in the dataset. Entries of CPUE=0 were also removed as it was unclear if they represented real catch rates or other practices such as dumping traps once quotas were subscribed.

CPUE is used as an index of biomass, but it is recognized that it can be biased by 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 biomass is the consistent broad-spatial coverage of the fishery each year generated by the numerous CMAs. CPUE was directly compared and related to other indices of biomass and associated relevant indices, including trawl and trap survey based biomass estimates and fishery discards.

Annual logbook CPUEs were mapped for 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.

Annual fishing effort (number of traps) within any given AD was calculated based on annual dockside monitored landings (kg) divided by model-estimated CPUE (kg/trap).

Logbook data were used to adjust for survey-based exploitable biomass underestimates through catch rate depletion model conversion factors (đ) in each AD. The depletion analysis used 5-day 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 catch. Catch rate data associated with the first and last 5% of the landings 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 or dumping of excess catches near the end of the season. Ordinary least squares linear regressions were fit to log-catch rate versus cumulative catch data, with the forecasted catch associated with a log-CPUE of zero (i.e., fully depleted resource) taken to be the beginning of the season biomass.

End of season biomass estimates were examined to develop conversion factors for survey exploitable biomass estimates. End of season biomass was calculated by subtracting fishery removals from start of season biomass estimates. In Subdiv. 3Ps, where a spring survey occurs, half the annual landings were subtracted from the logbook-based biomass estimates to roughly correspond with survey timing.

A limitation associated with biomass estimation based on depletion methods is that a resource must be depleted for the method to work. Four years were omitted from analysis based on anomalous biomass estimates reflecting lack of depletion (A.D. 3LNO Offshore in 2010 and 2011, and A.D. 4R3Pn in 2002 and 2006). To account for other variability resulting from sporadic depletion patterns, a centred three-period moving average was used to smooth annual logbook-based biomass estimates prior to making comparisons for survey biomass conversion.

INSHORE DFO TRAP SURVEYS

Data were available from inshore trap surveys in ADs 3K, 3L Inshore, and 3Ps (Figure 5, 6, and 7). In AD 3K, surveys were carried out in White Bay (CMA 3B), Green Bay (CMA 3C), and Notre Dame Bay (CMA 3D) during 1994-2017. There were no surveys in either bay in 2001, and no survey was conducted in Notre Dame Bay in 2009 or 2011. The surveys have consistently occurred in late August to mid-September and occupy five of the depth strata developed for multi-species trawl surveys in the NL.

In AD 3L Inshore, long-term trap surveys (1979-2016) within two management areas, Bonavista Bay (CMA 5A) and Conception Bay (CMA 6B), have occurred. 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 in the past four years. Meanwhile, depth stratified surveys have been conducted in Trinity Bay (CMA 6A) and St. Mary's Bay (CMA 9A) during the past five years, covering virtually the entire vertical distribution of each bay. The Bonavista Bay surveys occur during late July each year, the Trinity Bay surveys have occurred during early August, the St. Mary's Bay surveys have occurred during mid-June, and the Conception Bay surveys have occurred during late September or early October.

In AD 3Ps, a trap survey has been conducted in Fortune Bay (CMA 11E) during early June since 2007. This survey occupies three depth strata encompassing the entire vertical distribution of the bay.

All surveys follow a random stratified survey design with set locations randomly distributed within each stratum, and stratum-specific set allocations weighted by area. All surveys utilize large-mesh (commercial [135 mm]) and small-mesh (27 mm) traps intermittently placed within each 'fleet' of gear, with traps spaced approximately 45 m apart. Each fleet includes six baited traps, with two additional end traps not baited. Squid (*Illex* spp.) hung on skivers is attached to the inner entry cone of each trap for bait, with approximately 2-3 pounds of squid on each skiver. Although soak times are intended to be standardized to 24-48 hours, weather and other factors can affect the surveys and soak times are ultimately variable.

For each survey series, catch rate indices of legal-sized crab by shell condition from large mesh traps (i.e., comparable to fishery index) and size frequency distributions of males by maturity status from small mesh traps were produced for assessment. A pre-recruit catch rate index, defined as kg/trap of adolescent males 65-94 mm CW was derived from small-mesh traps, and mortality was inferred from levels of BCD observed in these surveys.

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

COLLABORATIVE POST-SEASON TRAP SURVEY

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

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

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

To address concerns about the limited utility of small-mesh traps in the survey, more small-mesh traps were incorporated in the 2016 and 2017 surveys (Figure 9). Overall, the number of small-mesh traps used in the survey has more than tripled in the past two years, with about half the stations having a small-mesh trap in 2017. More small-mesh traps will be added into the survey in forthcoming years, with a goal of having a small-mesh trap included at every station by 2020. Further, the CPS survey has been transitioning to a random stratified design over the past couple years and within the next two years 50% of survey stations will be random-stratified while 50% will remain as fixed (randomly chosen from existing stations). The changes are being invoked to increase both vertical and horizontal coverage in areas beyond prime commercial fishing grounds toward encompassing a more representative depiction of all population components into the assessment.

Despite ongoing changes to the survey design most analyses remain virtually unchanged for the present assessment. A set of core stations were used to develop catch rate indices of legal-sized crab by shell condition from large-mesh pots and size frequency distributions from large and small-mesh pots. The definition of core stations changed from that used previously, to account for changing distribution in occupied sets over time. The new definition of core stations was selected as those sampled in seven of the last 10 years. This resulted in very little change to outputs at any AD or CMA scale. Consistent with products produced from DFO trap surveys and observer data, large-mesh pot size frequency distributions examined abundance by shell condition while small-mesh pot size frequency distributions examined abundance by maturity. All analyses were limited to males, with sizes partitioned into 3-mm CW bins. However, unlike the five stage assessment of shell ages used on DFO research surveys, this survey uses only a three-stage scale of soft, new, and old-shelled. A pre-recruit catch rate index (defined as kg/trap of 65-94 mm CW adolescent males) was also derived from small-mesh pots deployed at core stations.

This 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 (Figure 3) to integrate catch rates over any given spatial area. The input parameter of trawl swept area in Ogmap has been altered to conform to the effective fishing area of a crab trap, with the value set at 0.01 km^2. This effective fishing area parameter represents an intermediate value from estimates reported by Miller 1977, Brethes et al. 1985, and Dawe et al. 1993. Nonetheless, because uncertainties remain regarding the accuracy of the effective fishing area parameter, as well as the extent to which the stratification scheme represents the actual distribution of the stock, biomass estimates developed from this survey remain as indices and are assessed in a relative sense.

As a result of the historical lack of small-mesh traps in the survey and the targeting of deep commercial Snow Crab grounds by the survey design, biomass estimation was limited to exploitable-sized males from large-mesh traps. The estimation was based strictly on size because no chela measurements were taken to differentiate maturities. However, biomass estimation in some areas was not exclusive to CPS data, with data from the DFO inshore trap surveys described above also used in the analysis. The incorporation of all surveys using similar techniques was thought to improve the reliability of the results due to the inclusion of more data.

OBSERVER CATCH-EFFORT AND AT-SEA SAMPLING DATA

At-sea sampling data by observers have been collected since 1999. For each trip, observers recorded entire trap catches of males for carapace width (mm) and shell condition. Levels of sampling have been generally highest in AD 3LNO Offshore (Figure 10). Sampling has been consistently low in inshore CMAs and virtually absent throughout ADs 2HJ and 4R3Pn in recent years. Various catch rate indices were developed from shell condition aging conducted by observers. Like the three stage assessment of shell ages used in the CPS survey, observers only classify crab as soft, new, and old-shelled. First, the total catch rate of legal-sized crab by shell condition for each AD was calculated as an index of exploitable biomass from the fishery. Similarly, size frequency distributions of catch rates of male crab by shell condition and size, binned to 3 mm CW intervals, were constructed to interpret the composition of the catch. Size frequency distributions were presented and examined at both the AD and CMA level where data were sufficient.

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

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

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

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

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

Annual percentages of discards were related to fishery CPUE, with both indices standardized to mean=0 and standard deviation=1, to assess the relationship between the two variables. Bubble plots of weekly catch rates and percentages of soft-shelled 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 (10 x 7 na. mi.) when the percentage of soft-shelled crab reached 20% of the observed catch. The closure threshold was reduced to 15% for AD 3LNO Offshore and 3L Inshore in 2009-10.

ECOSYSTEM INDICES

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

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

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

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

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

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

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

Data on diet composition is only available for a few recent years and for a small subset of 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 we lack of diet composition information) is a less robust (but unavoidable) assumption. Point estimates of absolute consumption of Snow Crab by all piscivore and large benthivore fishes were presented along with a predation mortality index (predation estimate / total survey biomass).

RESULTS AND DISCUSSION

BROAD-SCALE TRENDS: DIVISIONS 2HJ3KLNOPS4R

Fishery

Landings in all ADs (2HJ3KLNOP4R) most recently peaked at 53,500 t in 2009 and have since gradually declined to 34,000 t in 2017, their lowest level in two decades (Figure 11). Most of the landings are from ADs 3K and 3LNO (3LNO Offshore and 3L Inshore combined). ADs 3LNO have accounted for a steadily increasing percentage of the landings in recent years. In AD 2HJ, landings have remained at 1,700 t for the past four years (Figure 12). In AD 3K, landings declined by 66% since 2009 to a time-series low of 5,450 t in 2017. In AD 3LNO Offshore, landings declined by 26% from 2016 to 18,050 t in 2017, the lowest level in two decades. In AD 3L Inshore, landings declined by 29% from a historical high in 2015 to 6,000 t in 2017. In AD 3Ps, landings declined from a recent peak of 6,700 t in 2011 to a time-series low of 1,200 t during the past two years. Finally, in AD 4R3Pn, landings have steadily declined since a recent peak in 2013.

Fishery timing transitioned from summer-fall to spring-summer throughout the 2000s in most ADs (Figure 13). In recent years, the fishery generally begins in early April for all but Divs. 2HJ, where it usually starts in early to mid-May. In 2017, median fishing weeks ranged from week 3 (late-April) in AD 4R3Pn to week 13 (mid-June) in AD 2HJ. The last regular fishery was completed in AD 3L Inshore by late August (i.e., week 21). Note the large end of season spike in AD 3K in 2017 reflects a fall meat yield project which 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 14). Overall effort has remained at four to five million trap hauls in each of the past six years. Spatially, the distribution of fishing has remained relatively broad-based, but there have been significant changes in some ADs in recent years (Figure 15). 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 four years. Effort in AD 2HJ has remained at its lowest level in two decades, about 200,000 trap hauls per year, in recent years. In AD 3K, effort has been maintained near a two-decade low for the past five years, with about 1.0 to 1.1 million trap hauls occurring each year. In AD 3LNO Offshore, effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level since then, at an estimated 1.5 to 2.5 million trap hauls per annum. In AD 3L Inshore, effort has nearly doubled since 2013 to a historical high of 1.0 million trap hauls in 2017. In AD 3Ps, effort has declined by 44% since 2014 to be near its lowest level in two decades, about 500,000 trap hauls, with the TAC has not been taken in eight years (Figure 12). Finally, in AD 4R3Pn, effort has remained at a low level relative to other ADs, with about 150,000 trap hauls occurring for the past seven years.

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 16). Overall, the fishery performed poorly in 2017, with CPUE in most ADs at or near historical lows. In AD 2HJ, CPUE has remained near the decadal average in recent years. In AD 3K, CPUE has been low at about 5-6 kg/trap for the past seven years. Particularly dramatic declines were observed in ADs 3LNO Offshore and 3L Inshore in 2016 and 2017. In AD 3LNO Offshore, CPUE most recently peaked near a time-series high in 2013 and has since declined by 41% to its lowest level since 1992. Meanwhile, in AD 3L Inshore, CPUE has declined by 56% since 2013 to its lowest level in 28 years. In AD 3Ps, CPUE has steadily declined since 2009 to a record low of <3 kg/trap in the past two years, while in AD 4R3Pn, CPUE has declined since 2013 to below the long-term median.

In recent years there has been considerable spatial contraction of high fishery CPUE (Figure 15). Fishery CPUE is typically highest in AD 3LNO Offshore as well as portions of AD 3L Inshore, adjacent to the southeast portion of the island of Newfoundland and extending east across the Grand Bank. Although high catch rates (>15 kg/trap) remain in northern offshore portions of AD 3LNO Offshore, several areas had notable declines in recent years. For example, catch rates along the Div. 3N slope edge decreased markedly in the past four years while localized aggregations of effort in shallow portions of the western Grand Bank have performed relatively poorly since 2010. AD 3L Inshore has shown dramatic declines in CPUE throughout most fished areas in the past two 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 have experienced high catch rates. In AD 3Ps, the decline in fishery CPUE has been both precipitous and broad-based since 2010. In AD 4R3Pn, catch rates in the offshore have been perpetually low, while all inshore bays yield catch rates in the order of 0-10 kg/trap.

Observer data indicate that although the improvement in fishery CPUE in AD 2HJ in 2015 was predominately due to an increase in recruitment into the exploitable biomass, the proportion and magnitude of new-shelled crab decreased dramatically in 2016 and 2017 (Figures 17 and 18). In 2017, the AD 3K fishery observed a modest increase in soft-shelled crab, but overall catch rates of both residual crab and recruits have remained at a similar low level since 2008. In ADs 3LNO Offshore and 3L Inshore, the compilation of recruitment and the residual biomass (old-shelled crab) have been slowly eroding for the last three years to be near times series lows. In AD 3Ps, both the recruitment and residual components of the biomass observed in the fishery have decreased by more than half since 2011 and remain near historical lows. The sharp reduction in abundance of crab at legal-size in observed population distributions in AD 3Ps during the past four years (Figure18) suggests the population is heavily exploited.

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 and most other areas are presently performing poorly.

Biomass

The fishery has strongly depleted the exploitable biomass in all ADs in recent years (Figure 19). In 2017, end of season catch rates were among the lowest observed in the past six years in all ADs, with the exception of AD 2HJ which was about average. Again, excepting AD 2HJ, increasingly negative regression slopes have occurred in catch rate depletion models in all ADs during the past three years.

A slight reduction in the degree of depletion in AD 2HJ was associated with a lower level of removals than 2016 (Figure 20), reflecting an incomplete logbook dataset, as there was no change in removals. Accordingly, the 2017 regression is preliminary. In AD 3K, the fishery began at higher catch rates than experienced since about 2010, but it quickly and precipitously depleted the biomass (Figure 21). In AD 3LNO Offshore, there had been only slight depletion of the biomass up to removals of about 25,000 t from 2010-14, but the rate of depletion has accelerated in recent years (Figure 22). The 2017 fishery began and ended at the lowest level in the time series. Temporal trends in the AD 3L Inshore fishery mirror those of the offshore, with little depletion evident from 2011-13 and deterioration since, to the extent that the 2017 fishery began and ended at its lowest levels in the time series (Figure 23). In AD 3Ps, rapid depletion under minimal removals has occurred in the past two years (Figure 24). Finally, in AD 4R3Pn, the 2017 linear regression slope was near vertical, indicative of a rapid depletion of the biomass (Figure 25).

Overall point estimates of biomass from the fishery were at or near time-series lows in all ADs in 2017 (Figure 26), with a broad-based scenario of the fishery becoming an increasingly dominant factor contributing to reduced exploitable biomass.

Multi-species trawl surveys indicate that the exploitable biomass was highest at the start of the survey series (1995-98) (Figure 27). It declined from the late 1990s to 2003 and then varied without trend until 2013. From 2013 to 2016 the exploitable biomass declined by 80%. Despite a modest increase in 2017, the trawl survey exploitable biomass index has remained at its lowest observed level for the past three years. Meanwhile, the trap survey index has been at its lowest observed level in the past two years (Figure 27) and overall fishery CPUE was at a two-decade low in 2017. The reduction in overall biomass reflects diminishing contributions of recruitment, to historical low levels in recent years, but more strongly reflects the elimination of virtually all the residual biomass in most areas.

The overall low exploitable biomass level is coupled with concentration into localized areas in all ADs (Figures 28 and 29). In 2017, the majority of trawl survey tows captured no exploitable crab, with densest concentrations found in offshore mid-latitude areas. Fringe areas of all ADs have been virtually void of exploitable crab in recent years.

Despite broad-based spatial contraction of the biomass in recent years, there were subtle signs of some localized improvements in some ADs in 2017. Particularly noteworthy are the increased survey catch rates in the central portion of AD 3K. Further, in AD 3LNO Offshore the 2017 fall trawl survey showed a higher density of moderate catches throughout the northern half of the area in NAFO Div. 3L than occurred in 2016. The spring survey in AD 3Ps also captured a broader spatial signal of exploitable crab biomass in 2017 relative to recent years.

The overall patterns of prolonged deterioration and 2017 improvements seen in trawl surveys generally reflect those seen in trap surveys. With the exceptions of AD 3Ps and localized areas in AD 3K, trap surveys showed considerable and continued spatial contraction in high catch rates of exploitable crab wherever conducted (Figure 6 and 8). Of particular note regarding improvements in 2017 is that after two years without CPS survey coverage in most areas of AD 3Ps, there are strong signs of recovery in catch rates of exploitable crab from the fall trap survey throughout most of the AD. Higher catch rates of exploitable crab from the DFO and CPS surveys were also noted in inshore areas of AD 3K (Figures 6 and 8). Nonetheless, overall, among all survey series there is a coherent depiction of an overall depleted exploitable biomass featuring some localized strong aggregations of crab.

Overall trends in trawl and trap survey exploitable biomass indices reflect variability among ADs (Figures 30 and 31). In AD 2HJ, the exploitable biomass index has changed little during the past decade with the exception of a spike in 2014 (Figure 30). The 2017 point estimate from the CPS trap survey (Figure 31) is considered preliminary due to incomplete data, with a large proportion of data from the survey not submitted prior to the assessment. In AD 3K, the post-season trawl survey exploitable biomass increased in 2017 from a historic low in 2015-16 (Figure 30). Although the post-season trap survey(s) index has remained near a historical low for the past three years (Figure 31), slight improvements were seen in some nearshore management areas in 2017 (Figure 8). In AD 3LNO Offshore, the exploitable biomass index remains at or near time-series lows in both the trawl and trap surveys (Figures 30 and 31). In AD 3L Inshore, the post season trap survey exploitable biomass index has declined by 73% since 2012, reaching a time-series low in 2017 (Figure 31). The 40% overall change from 2016 to 2017 reflects declines to time-series lows in all management areas. In AD 3Ps, the in-season trawl survey exploitable biomass index was at a time-series low in 2016 but improved slightly in 2017 (Figure 30). However, the post-season trap survey index suggests considerable improvements in the exploitable biomass throughout the major fishing grounds (Figure 31). In AD 4R3Pn, the CPS trap survey exploitable biomass index most recently peaked in 2012 and has since declined to a time-series low in 2017 (Figure 31).

Although random sampling locations are being added annually, the restricted spatial coverage of the CPS trap survey's [-s] core stations essentially measure [+s] the exploitable biomass on primary fishing grounds and constitutes an analog of fishery CPUE. Accordingly, the CPS index closely agrees with fishery CPUE in each AD, reflecting the occupation of like grounds with like gear. The concentrated distribution on strongest aggregations of biomass in the CPS survey and fishery creates the potential for hyper-stability in indices derived from both sources. The spatially all-encompassing trawl survey generally detects changes in the biomass prior to them being detected in the CPS trap survey or fishery (Figures 32 and 33). This lag effect between measuring signals of change in biomass among metrics likely reflects the inclusion of marginal grounds in the trawl survey, where signals of change would be expected to occur first. Further, the trawl survey is also not subjected to gear saturation, as occurs in crab traps (Figure 32). 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 decline.

Trap saturation is an important concept for managers and harvesters to understand in their perceptions of resource status. The asymptotic distribution of catch rate curves (Figure 32), with the slope strongly negative in the lower portions of the data, suggests that in any given AD about 80% of the biomass can be lost before the fishery or trap surveys detect a large signal of change. Hyperstable CPUE in trap-based biomass indices constitutes a mechanism to mask changes in stock size.

Collectively, the three survey and fishery metrics are consistent in showing an exploitable biomass that is at or near historic lows in all ADs, with the index with most predictive power, the trawl survey, suggesting that notwithstanding potential for localized improvements within some ADs, no major improvements are likely in the fishery of 2018.

Recruitment

Overall recruitment into the exploitable biomass has been very low in recent years and survey data suggest recruitment available to the 2018 fishery will remain low in most ADs. This is particularly evident by the low biomass of new-shelled crab in trawl surveys (Figures 27 and 30). The recent declines of recruitment into the exploitable biomass were anticipated and reflect a prolonged lack of productivity in the stock (Mullowney et al. 2014).

In AD 2HJ, recruitment into the exploitable biomass has changed little during the past decade with the exception of a 2014 spike (Figure 30). The exploitable biomass has consisted largely of incoming recruits for the past six years (i.e. about 75%), with few old-shelled crab in the population. The CPS trap survey is consistent in showing a persistent low level of recruitment into the biomass in recent years, with annual catch rates below 2 kg/trap in most years during the past decade (Figure 34). In AD 3K, recruitment increased from time-series lows in both the post-season trawl and trap survey(s) from 2016 to 2017 (Figures 30 and 34). The 2017 trawl and trap surveys suggest recruitment into the fishery should increase modestly in 2018. In AD 3LNO Offshore, recruitment into the exploitable biomass has been at or near time-series lows in both the trawl and trap surveys in the past two years (Figures 30 and 34). In AD 3L Inshore, recruitment has steadily declined for the past three years to a time-series low in 2017 (Figure 34). Recruitment indices from DFO and CPS trap surveys in all management areas were at or near their lowest levels in 2017. In AD 3Ps, overall recruitment into the exploitable biomass has been at its lowest observed level in recent years but increased in 2017, most evident in the CPS trap survey where it increased markedly (Figure 34). In AD 4R3Pn, recruitment into the exploitable biomass has been very low for the past four years (Figure 34), with catch rates of new-shelled legal-sized crab near zero.

Survey and environmental data collectively suggest modest increases in recruitment could occur in some ADs over the next 1-4 years. Although the pre-recruit biomass index for NAFO Divs. 2HJ3KLNOPs remains near a time-series low, it showed a modest increase in 2016 and 2017 (Figure 27). This overall trend is most strongly reflected in ADs 3K, 3LNO Offshore, and 3Ps (Figure 30). Trap survey data of pre-recruit abundance similarly suggest broad-scale improving prospects for recruitment into the exploitable biomass for the next few years (Figure 35). However, despite the potential for improvements, overall pre-recruit abundance levels remain near time-series lows in most ADs (Figures 27 and 30). Of particular note, the impacts of relatively low pre-recruit abundance are beginning, and are anticipated to continue, to emerge in ADs 3L Inshore and 3LNO Offshore, where the bulk of remaining crab reside.

Spatially, the recent decline in pre-recruit crab has been both precipitous and widespread since 2008 (Figures 36 and 37). Depreciating signals of catches of all magnitudes in the trawl surveys throughout all ADs have been obvious. Modest improvements seen in 2017 were most pronounced in northeastern portions of AD 3K and along the northern Grand Bank (NAFO Div. 3L) in AD 3LNO Offshore.

A warming oceanographic regime during the past decade (Colbourne et al. 2016), coupled with relatively low abundance of young crab since the early 2000s (Figures 27 and 38), 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 27) was largely localized to ADs 2HJ and 3K (Figures 38 and 39). Slight increases in the abundance of small crab in the population in the past two years have been most pronounced in ADs 3K and 3LNO Offshore (Figures 35 and 39). Although from resource limitations it appears this fishery will inevitably be reduced in scale moving forward, as recent abundances of small crab are generally not nearly as large as historic pulses, other factors being equal, they could contribute to a modest fishery in the long-run. For example, the spring trawl surveys showed a relatively high level of small crab in AD 3Ps in 2010 (Figure 35). That strong signal of small crab abundance in AD 3Ps detected in 2010 is almost certainly associated with marked improvements in new-shelled recruits captured in the CPS trap survey in 2017 (Figure 34). Whether or not the coincidental spike in small crab abundance seen in the 2010 AD 3LNO survey will make significant contributions to the exploitable biomass in that AD remains to be seen. Neither the trawl nor trap surveys have yet measured an improvement of recruitment into the exploitable biomass in AD 3LNO Offshore, but both surveys experienced an elevated catch rate of pre-recruits in 2017 (Figures 30 and 35). If the efficacy of tracking future recruitment potential through these small crab signals holds, unfortunately for AD 3Ps there has been a relatively steady-state broad distribution of low catch magnitude in the survey for the past six years (Figures 38 and 40), inferring weak prospects after the currently emerging pulse of recruitment benefits the biomass and fishery in the next few years.

Reproduction

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, it has overall been variable throughout the time series in all ADs (Figure 38). Despite this variability, like most other components of the population, the relative abundance of mature females has remained near times series lows in most ADs for about the past six years.

The spatial distribution pattern observed in the past two years is typical of a dominant shallow water presence of mature females in most years (Figures 41 and 42). 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 41). AD 3Ps is overall the shallowest of all ADs, with females typically concentrated in the central portions of the division near the fringes of the St. Pierre and Green Banks (Figure 42). These shallow areas, where the majority of reproduction occurs, are typically very cold (Figure 43). Mullowney et al. 2018 recently 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.

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 44). Data from both the fall and spring surveys throughout NAFO Divs. 2HJ3KLNOPs show that in nearly all years the vast majority (i.e., >80%) of mature females are carrying full clutches of viable eggs.

Although it is believed that insemination rates and per capita fecundity can be impacted by excessive fishery exploitation of males, it has not been persistently observed to date in NL Snow Crab. However, some notable exceptions have occurred in the clutch fullness index in all ADs. In 2017, AD 2HJ showed an appreciable decreases in the percent of females with full egg clutches, to a level below 70%. Low percentages of clutch fullness in successive years were also observed in AD 2HJ in 2006 and 2007, and recent low levels have been observed in AD 3LNO Offshore in 2013 (note uncertainty in 2014 due to incomplete survey) and in AD 3K in 2016. The annual variability in observed egg clutch fullness suggests that 2-year moving averages should be used to identify overall trends in this metric. 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.

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 45 and 46), and assumed poor catchability. However, variability in annual abundance indices could also reflect demographic changes in this component of the population. ‘Cyclic’ pulses of female abundance have been described in other areas, including the Northern Gulf of St. Lawrence (Sainte-Marie 1993; Sainte-Marie et al. 1996). For example, some chronological pulses of relatively high abundance of mature females are evident in the data, such as during 2008-09 in the trawl survey (Figure 38).

It is unknown to what extent eggs constitute a limiting factor for overall stock productivity or 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 likely been 2-3 years of age (Sainte-Marie et al.1995) and been produced from the relatively low levels of abundance of mature females that occurred in 1998-2000. 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 effects of female abundance and their contribution to stock productivity is necessary.

Environment

Overall, virtually all population components are at low levels in all ADs (Figures 45 and 46). This suggests that the stock has been in an overall unproductive state for much of the past decade. Bottom temperature has been shown to act positively on size and negatively on abundance in regulating stock productivity and ultimately biomass. Low bottom temperatures appear to promote terminal molt at small sizes in Snow Crab, resulting in relatively low recruitment and yield-per-crab from a given year class (Dawe et al. 2012). However, recruitment is more strongly affected by the positive effects of a cold regime on year class production (Dawe et al. 2008; Marcello et al. 2012) than it is by the negative effects of a cold regime on size-at-terminal molt.

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

Despite spatiotemporal differences across ADs in the time necessary for temperature to affect future biomass, an overall consistent phenomenon in the NL Snow Crab resource is that cold conditions are beneficial to future biomass (Mullowney et al. 2017). The species is uniquely adapted to thrive in some of the coldest bottom temperature conditions on earth, with high temperature regions not suitable for survival or habitation. Indeed, the recent (modest) emergent pulse of small crab observed in many areas of the NL shelf has been associated with generally cooling oceanographic conditions in recent years (Colbourne et al. 2016), with the areal coverage of cold bottom water increasing in all ADs since 2011-12 (Figure 43).

The Snow Crab thermal habitat index (defined as the areal extent of <2°C bottom water) has returned to near-average conditions in all ADs in recent years (Figure 47). Although a return to cooler conditions in the past four 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 (Colbourne et al. 2016). The ocean climate indices have varied considerably over the past decade, introducing uncertainty beyond the short-term, but the overall trend is warming. Present ‘cold’ bottom conditions are not near as spatially or temporally expansive as they were in the late-1980s and early-1990s, from which the highest exploitable biomass levels in the mid-late-1990s originated (Mullowney et al. 2014). Long-term abundance may heavily hinge on the extent to which the recent cooling conditions are sustained, although it is unclear how environmental, anthropogenic, or other factors such as predation will affect the survival and progression of recruitment pulses throughout life.

Bottom temperature may not be the only climatic factor important for Snow Crab productivity. In this assessment, extending beyond previous correlations of bottom temperature with both future biomass and CPUE, a strong association of exploitable biomass with lagged NAO (North Atlantic Oscillation [atmospheric forcing index]) was demonstrated. In its application to ocean climate phenomena, the NAO is essentially a proxy multivariate climate index. Although the association of NAO and future biomass is consistent with a linkage between cold conditions and high stock productivity (as high NAO produces cold conditions along the NL shelf), it could be that other associated climatic factors such as sea ice, bloom strength, water mixing, food availability, or predator field dynamics, affect Snow Crab survival during early ontogeny. Notwithstanding an incomplete understanding of the mechanisms associated with climatic forcing, the 3-year centered moving average annual NAO index (lagged by 7 years) was strongly correlated ($r^2 = 0.73$) with exploitable biomass indices in the stock overall (Figure 27) as well as in each AD (Figure 44). The lagged NAO analysis predicts that the exploitable biomass should enter into a recovery phase over the next few years, to levels near average for the biomass time series in each AD (Figure 44).

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 (now current) low biomass phase. This ‘test’ of stock drivers is currently occurring, with exploitation rate indices being allowed to increase to exceptionally high levels in some ADs in recent years, including the biggest areas of supply (see forthcoming section on mortality). Until the past few years, following a regime shift (Buren et al. 2014) culminating in a collapse of most of the finfish community in the late 1980s and early 1990s, the Snow Crab resource appears to have largely been under bottom-up control, in association with low exploitation rates in the largest areas of abundance (i.e. AD 3LNO Offshore).

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 48) 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 in 2017. These dramatic declines in relative predation levels are likely the result of a combination of recent declines in predatory fish abundance, as well as the most recent pulse of small crab now outgrowing sizes consumed by most predators (i.e. < 40 mm CW) (Chabot et al. 2008), as inferred by increases in pre-recruit indices in 2017. Important differences are evident in magnitude of predation mortality across ADs, with ADs 3K and 3Ps having predation levels much higher than other areas.

Although impacts of increased predation on the fishery in most areas would be expected to be minimal at present, as the ‘missing’ crab would not yet be of exploitable size, with the Snow Crab resource in decline increased top-down controls in the forms of predation and fishing are likely now (or will become) more important in regulating the resource than historically. If this is the case, and top-down forcings become dominant, the strength of linkages with bottom-up forcing (i.e., NAO) would be expected to diminish moving forward. The confluence of current events including climate-predicted improvements, exceptionally high exploitation rates, modest recovery and now decline of many finfish stocks, and low population density at all sizes (i.e. Figure 46), creates a great situation for studying the relative importance of various resource drivers on population dynamics of Snow Crab.

Mortality

The overall trajectory of most focal population components has been a prolonged decline for two decades in all ADs (Figure 49). The downward trajectory of recruitment into the exploitable biomass opposes total mortality rates gradually increasing in the exploitable component of the population throughout the time series (Figure 50). Total mortality in exploitable crab has increased to be at or near time-series highs in recent years in all ADs, reaching levels > 80% in some areas. Few residual crab remain in the exploitable biomass (Figure. 27).

Recent increases in total mortality are more closely aligned with fisheries mortality than known and quantified sources of natural mortality. Bitter Crab Disease (BCD) is one important source of consistently measured natural mortality in the population. BCD has been observed, based on macroscopic observations of crab captured in the fall trawl surveys, at generally low levels throughout NAFO Divs. 2J3LNO from 1995 to 2017 (Figure 51). 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 appears to be 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 recent study using advanced polymerase chain reaction (PCR) techniques on specimens collected since the mid-2000s to identify infections has shown trends closely reflect the visually observed patterns seen throughout the region.

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. BCD is normally most prevalent in AD 3K. In 2017, levels of BCD declined to about 6% from its level in 2016 when the highest prevalence of BCD ever recorded for this AD was observed in size classes >76 mm CW (>15%). BCD is normally uncommon in AD 3LNO Offshore, but a prolonged pulse of relatively high incidence was observed in this AD from approximately 2001 to 2006, most prominent in 40-59 mm CW crab. This sustained pulse of BCD likely reflected progression of the recruitment pulse detected in the trawl surveys as 20-30 mm CW crab in 2001-03 (Figures 38 and 45), which was subsequently tracked as pre-recruits in surveys from 2008-10 (Figures 30 and 35).

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 relatively small animals most commonly infected (Mullowney et al. 2011). Overall, the relatively low level of BCD observed in this size group in recent years is positive because it suggests this source of natural mortality is killing fewer 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 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; Urban 2015). Soft-shell crab are likely subject to more damage and mortality than hard-shelled crab. Poor handling practices, such as prolonged exposure on deck and dropping or throwing crab induces limb loss and also leads to increased mortality levels associated with catching and discarding crab (Grant 2003).

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

Discard levels in the fishery are negatively related to the relative strength of the ratio of exploitable to pre-recruit biomass indices and CPUE (Figure 52). 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. In 2017, both CPUE and the Exp:Pre ratio in the multi-species trawl survey were low in most ADs (Figure 52). Particular concern is expressed of the current situation in ADs 3K and 3Ps, where discard levels are currently very high at about 35 and 50% in the ADs respectively (Figure 53). At-sea observer sampling data suggest that the bulk of discards in AD 3K are comprised of soft-shell crab, while the bulk of discards in AD 3Ps are under-sized, old-shelled crab (Figure 54).

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, suggests that wastage of soft-shelled pre-recruits could be problematic in the fishery in the next few years and potential gains could be quickly diminished if aggressive harvest strategies persist. Mortality of both soft-shelled and under-sized males can be minimized by maintaining a relatively high level of residual biomass and, for soft-shell crab in particular, may be further reduced by fishing early in the spring before they are capable of entering traps.

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

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

Soft-shell incidence has featured relatively prominently in the observed catch in ADs 2HJ and 3K in recent years (Figure 54). 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 fishery-induced mortality on exploitable crab have varied among ADs throughout the time series (Figures 50 and 55). Status quo removals would maintain exploitation rate indices above long-term average levels in many ADs in 2018. New time-series highs would occur in ADs 3L Inshore and 4R3Pn, where the annual index would approach 100%.

In AD 2HJ, the exploitation rate index has been above the long-term average for the past two years. Status quo removals in 2018 would maintain the two-year average exploitation rate index at a relatively high level. In AD 3K, the exploitation rate index has been at a decadal high during the past two years. Status quo removals in 2018 would decrease the exploitation rate, with the two year average index being below the time-series median level. In AD 3LNO Offshore, the exploitation rate increased by a factor of five from 2014 to 2017. Status quo removals in 2018 would maintain the two year average exploitation rate index at a historic high. In AD 3L Inshore, the trap survey-based exploitation rate index has increased from 2013 to a time-series high in 2017. Maintaining status quo removals would increase the two-year average exploitation rate index to an exceptionally high level in 2018. As a result of a substantial decline in fishing in AD 3Ps, the exploitation rate index declined by more than half since it peaked in 2013. Assuming the exploitable biomass remains at the current level, status quo removals would result in an exploitation rate index near the long-term median in 2018. However, projections are hampered because the survey is conducted in the spring. In AD 4R3Pn, the exploitation rate index has increased since 2013, reflecting trends in all surveyed areas. Status quo removals would elevate the two-year average exploitation rate index to an exceptionally high level in 2018.

Current exploitation rate indices in the NL Snow Crab fishery are overall very high relative to other major fisheries for the species in Atlantic Canada and Alaska. For example, exploitation rates above 45% are not permitted under the Precautionary Approach frameworks used to manage the Snow Crab fishery in the southern Gulf of St. Lawrence, even when the biomass is extremely high (DFO 2014b). In NL, conservative (i.e. likely under-estimated) estimates of fishing exploitation rates are routinely >50% and can be as high as 80% in some ADs in some years, particularly when biomass is low. Of particular note, the lack of old-shell crab in the biomass, even at largest sizes associated with terminally molted animals (Figure 56), is concerning. The virtual absence of large old-shell males in the population is not typical of the population structure for other fished Snow Crab populations globally. The strategy of exploiting heavily and near-wholly relying on incoming recruitment each year is risky with respect to the possibility of unforeseen events to affect recruitment. Moreover, our experiences have shown that areas with low residual biomasses are generally associated with wasteful fisheries, with soft-shell prevalence and discard rates generally high in the presence of high exploitation and low residual biomass.

Beyond promoting risk and wastage in the fishery, high exploitation rates greatly increase the potential for negative biological outcomes in the population. There has been an inability for fisheries to take quotas in some ADs in recent years (Figure 12). Accordingly, in several areas it is possible for fisheries to capture almost all available exploitable males in a given year. The strategy of removing most large males from the population could have serious consequences such as sperm limitation in females or changes in growth patterns or maturation sizes if heavy exploitation is sustained. Large hard-shell males are the prime breeders and likely serve to introduce sufficient intraspecifc competition in the population to promote large size at terminal molt. As in many animal populations, large competitive males serve to maintain reproductive integrity as well as physically structure population demographics. The outcomes of the unfolding scenario of rendering the population virtually void of large males in some areas will be important to monitor from biological and managemement advice perspectives.

Overall, the scenario of a depleted exploitable biomass (Figure 57) coupled with generally high exploitation rates suggests a relatively low likelihood of any appreciable long-term gains to be gleaned from the modestly improved signals of recruitment potential (Figure 58). The trade-offs of a one versus multi-year extraction strategy, particularly in respect to a lack of residual crab in the population, should be considered. Biologically, it is advised to invoke strategies to restore the residual biomass component of the population, as there is potential for biological harm to occur if total mortality continues to near-fully deplete the exploitable biomass each year.

ASSESSMENT DIVISION 2HJ

Fishery

The AD 2HJ fishery occurs in offshore regions of central and southern Labrador in CMAs 1 and 2 (Figure 21 and 2). CMA 1 is often referred to as N5440 or 2JN, while CMA 2 is often referred to as S5440 or 2JS. The bathymetry of the region is characterized by a series of shallow water offshore banks separated by deep channels (Figure 1). The Cartwright and Hawke Channels, the two dominant fishing grounds, extend to depths of 750 m, although the fishery tends to avoid the deepest portions of the channels. In relative terms, the AD 2HJ fishery is one of the smallest fisheries for Snow Crab in NL (Figure 12). There have been exploratory fisheries in Div. 2H since the mid-1990s and a commercial TAC was first established in 2008. The fishery in Div. 2H is small relative to Div. 2J and the history of fishing in Div. 2J is longer, extending back into the early 1980s.

Landings in AD 2HJ have remained at 1,700 t for the past four years (Figure 12). Effort was substantially reduced in 2011 and has since remained at its lowest level (of about 200,000 trap hauls per year) in two decades (Figure 14). 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 59), with the southern CMA consistently fully subscribing its quota. Although poor fishing in the northern area is a contributing factor (Figure 15), it also reflects a management decision by industry stakeholders to leave 15% of the annual TAC unharvested in CMA 1 in recent years.

Logbook return rates in AD 2HJ have been relatively consistent with other ADs (Figure 4). About 85% of landings were available in the logbook dataset for this assessment. Incomplete datasets create uncertainty in calculating and interpreting logbook CPUE. Adding to uncertainty in assessing fishery performance in this AD is that observer coverage is routinely low (Figure 10).

CPUE has remained near the decadal average in recent years (Figure 16), reflecting trends throughout the AD (Figure 60), and no improvements are anticipated in 2018. In both CMAs, catch rates were approximately 6-7 kg/trap in 2017 (Figure 60), with the southern management area performing marginally better. Weekly CPUE trends are normally highest during the early portion of the season and tend to decline sharply throughout the fishery (Figures 9 and 20). This reflects depletion of the resource. The typical seasonal depletion pattern occurred in both CMAs for the past 4 years (Figure 61). Initial catch rates in the northern CMA in 2016 and 2017 (~7-8 kg/trap) and the southern CMA in 2017 (~9 kg/trap) were relatively low compared to start-of-season levels in the preceding two years, but end-of season catch rates were near average.

Spatially, there has been a reduction in the areal coverage of the fishery since 2011 (Figure 15). It has contracted into the Cartwright and Hawke Channels, with the northernmost fishing grounds of Div. 2H virtually abandoned. Along with contraction from the north, effort no longer extends into the farthest offshore areas and the slope edge. The abandonment of northernmost fishing grounds also reflects both resource shortages and a regulation change after the 2012 fishery whereby vessels previously restricted to Div. 2H were allowed access to the northern portion of the Cartwright Channel, inside Div. 2J, at the southernmost portion of CMA 1.

Size distributions from at-sea sampling by observers during the fishery suggest that two recent recruitment pulses benefitted the fishery during 2007-09 and 2012-15 (Figures 18 and 62). This can be seen by an increase in abundance of soft- and new-shelled legal-sized crab during those periods. The overall strength of the signal from the most recent pulse in size frequency distributions has diminished, thus it has now likely near-fully contributed to the fishery. Observed catch rates across all sizes were relatively low in 2017.

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 63). Weekly levels of soft-shell in the catch typically exceeded 20% after about week 12 (i.e., late June) during those years. However, minimal soft-shell catches have been observed in the past three years.

Total mortality in exploitable crab has been at or near its highest level in recent years (Figure 50). The trend in total mortality has reflected that of fishing mortality in recent years. The exploitation rate index has been above the long-term average for the past two years (Figure 50). Status quo removals in 2018 would maintain the two-year average exploitation rate index at a relatively high level.

All inferences from fishery data are that caution is warranted in the 2018 fishery.

Surveys

Both the trawl and trap-based exploitable biomass indices have changed little during the past decade with the exception of a 2014 spike (Figure and 31) in the trawl index. Note that the 2017 trap survey index is preliminary due to omission of a relatively large proportion of survey data from the dataset associated with late return of the information. Notably, the spatially-broad trawl survey has captured very few exploitable crab outside the Cartwright and Hawke Channels during the past decade (Figure 28).

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 decade with the exception of a 2014 spike (Figure 30 and 34). The trap-survey trend (Figure 34) only incorporates data from CMA 2. Interestingly, however, a high level of recruitment into the biomass in the northern area during 2013 (Figure 64) preceded the high level of recruitment seen in the trap survey in the southern area in 2014 (Figure 65).

The 2017 trawl and trap surveys suggest recruitment will remain unchanged in 2018. The year over year population demographics look very similar both in terms of size and shell composition structure (Figures 45 and 66), and notwithstanding a preliminary likely inflated biomass estimate from the southern area in the CPS trap survey (Figure 67), the biomass appears to be relatively unchanged.

Looking at prospects beyond 2018, with the exception of 2014, the pre-recruit biomass index has been relatively low in recent years and was at or near its lowest level for the last 3 years (Figure 30). The 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 68). However, like the trawl survey, there is no strong indication of an imminent influx of pre-recruits seen in the Torngat survey small mesh trap data in the most recent two years.

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 2017 the abundance of small crab was near average levels (Figure 38). 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 39). 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 the past two years (Figure 48) as well as a spike in BCD prevalence in 60-75mm CW crab (Figure 51), is consistent with tracking these crab through ontogeny, although neither survey has yet to capture them in high abundance as pre-recruits (Figures 30 and 58). Other factors being equal, this promising signal of small crab abundance should start contributing to pre-recruit indices in the near future.

Overall, key resource indicators suggest there has been a prolonged decline in the resource, with both the pre-recruit and exploitable biomass near their lowest observed levels for the past three years. The exploitable biomass has been strongly correlated with fishery CPUE at a one year lag for two decades (Figure 32). If this pattern holds, the fishery performance would be expected to remain similar in 2018. If all factors remain equal, short-term prospects appear overall poor, but modest improvements in the exploitable biomass could occur in 2019-20.

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). Within the Assessment Division there are six CMAs (Figure 2). The effort distribution in Green Bay (CMA 3C), Notre Dame Bay (CMA 3D), and the offshore (CMA 4) forms a continuum stretching from the shallow nearshore waters of Green Bay (i.e., 200-300 m) into the deeper trenches of Notre Dame Bay (i.e., 300-400 m) and the Funk Island Deep in the offshore (i.e., 400-500 m) (Figure 1). White Bay (CMA 3B) is a deep (i.e., 400-500 m) fjord protected at the mouth by a shallow sill (i.e., 200-300 m) that forms the basis of a relatively discrete pocket of fishing effort (Figure 15). 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.

Overall landings in the AD declined by 66% since 2009 to a time-series low of 5,450 t in 2017 (Figure 12). This overall trend reflects patterns in the offshore (CMA 4) and CMA 3D, the two largest CMAs in terms of fishery scale (Figure 69). In these two dominant areas, TACs, and landings levels are at or near their lowest levels in a decade. In 2017, the TACs remained unchanged in most CMAs, with the exception of White Bay (CMA 3B) where the TAC was reduced. The TAC has not been reached for the last two years in CMAs 3A and 3BC. At just over a million traps hauls a year, overall effort has been maintained near a two-decade low for the past five years (Figure 14).

Overall CPUE declined by 55% from 2008 to 2011 and has been low for the past seven years (Figure 16), reflecting trends in most management areas (Figure 70). An exception to the recent overall trend occurs in Green Bay (CMA 3C) where CPUE has oscillated with a gradual declining trend throughout the time series. Interestingly, most CMAs have shown a quasi-cyclical pattern in CPUE. In CMAs 3A, 3BC, and 4 (i.e., the offshore areas) the most recent peak occurred in 2013 and catch rates have since been on a steep three-year decline and are now at or near historical lows in 2017. The oscillating pattern in CMAs 3C and 3D is slightly out of phase with the offshore, with modest increases now occurring. Nonetheless, in general, the fishery has performed relatively poorly throughout most of the AD in recent years.

It should be noted that evidence has been presented that the CPUE calculated in AD 3K has 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 are reporting the full amount to effort (pot hauls) in their logbooks in association with half the catch. The extent of the issue is unclear; 25-30% of the fleet has been fishing under such arrangements in the past four years, with the fraction of those mistakenly over-reporting effort in their catch logs unknown. However, it is noteworthy that there is very little difference in trap survey (forthcoming) versus logbook catch rates.

Notwithstanding a potential downward bias in recent years, in 2017, the fishery CPUE declined throughout the season in every CMA (Figure 71), reflecting resource depletion. This depletion was most pronounced in CMAs 3A, 3B, and 4 where late season catch rates were below 2 kg/trap. Particularly concerning is CMAs 3A, 3BC, and 3B where the initial catch rates in 2017 were near or lower than the late season catch rates in 2016, suggesting a lack of recruitment to replenish the exploitable biomass and support the fishery in those areas.

Observer sampling during the fishery shows increasing catch rates of new-shelled and/or soft-shelled crab in all CMAs in 2017, with the exception of CMA 4 (Figure 72). The emergence of a recruitment pulse into the White Bay (CMA 3B) fishery, likely beginning in 2012, followed an anomalous event in 2010 whereby the fishery was closed prematurely due to a high level of soft-shell in the catch (the early closure was initiated by harvesters). Only half the TAC was subscribed in that year and catch rates were atypically low. Such proactive action appears to have benefitted the White Bay fishery, with catch rates in this area higher than most other portions of the AD for the subsequent five years (Figure 70). However, as seen in an eroding size frequency distribution (Figure 72) and steep decline in fishery CPUE in the past two years (Figure 70), benefits gleaned from that recruitment event now appear over.

In Green Bay (CMA 3C), size frequency distributions from observer sampling suggest a persistent high exploitation rate, evident by a sharp ‘knife-edge’ effect at legal-size for nine consecutive years (Figure 72). Fishery catch rates here have consistently been among the lowest in the AD, rarely exceeding 5 kg/ trap during the past five years and only exceeding 10 kg/trap once in the past two decades (Figure 70). However, despite the inferences of heavy exploitation, an increase in sub- and legal-sized new-shell crab was seen in the fishery in 2017 (Figure 72), coincident with an increase in catch rates.

An increase in recruitment appears to be entering into the fishable portion of the biomass in Green Bay. Similarly, in neighbouring Notre Dame Bay (CMA 3D), slight increases in catch rates occurred in most sizes of new-shelled crab in 2016 and 2017 and an increased level of recently molted soft-shell crab was observed in the population (Figure 72). This improving situation in the exploitable biomass began three years ago. 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. However, beginning in approximately 2014, a notable change in shape of the observed population occurred as the primary size mode became centred near legal-size and the distribution became right-skewed. The mode has now progressed to a relatively large size of about 111 mm CW suggesting recruitment has entered into the fishery, which contributed to a modest improvement in CPUE in the past two years (Figure 70).

In the offshore (CMA 4 plus small contributions from CMAs 3A and 3BC), observer sampling shows a gradually dissipating exploitable biomass since 2009, with progressive depreciation in catch rates of legal-sized crab and no evidence of any strong recruitment pulses entering the population (Figure 72). The overall picture is one of gradual erosion of the exploitable biomass since 2008 largely due to gradually depreciating recruitment into the biomass and fishery. This is consistent with persistently declining fishery catch rates in this dominant offshore management area (Figure 70).

Soft-shell crab incidence in the catch is a perpetual issue in AD 3K (Figures 54 and 73). The bulk of discards in this AD are typically attributable to soft-shell crab (Figure 54). 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 (i.e., week 8) in most years since 2005. This persistently high incidence of soft-shelled crab in the catch is thought to reflect, at least in-part, a depleted residual biomass (Figure 30). 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 has been at or near its highest level in recent years (Figure 50). At about 50%, the exploitation rate index has been at a decadal high during the past two years (Figure 50). Status quo removals in 2018 would decrease the exploitation rate, with the two year average index being below the time-series median level (Figure 50). Offshore CMAs (3A, 3BC, and 4) and CMA 3D would have trap survey-based exploitation rate indices near or below 30% in 2018 (Figure 74).

Surveys

The post-season trawl survey exploitable biomass index increased in 2017 from a historic low in 2015-16 (Figure 30). Although the post-season trap survey(s) index has remained near a historical low for the past three years (Figure 31), slight improvements were seen in some nearshore management areas in 2017 (Figure 74). 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 28).The exploitable biomass has consisted largely of incoming recruits throughout the time series (50-75%), with few old-shelled crab (Figure 30). This suggests high mortality of large adult male crab.

Recruitment increased from time-series lows in both the post-season trawl and trap survey(s) from 2016-17 (Figures 30 and 34). The increase of catch rates of recruits in the CPS survey was particularly strong in CMA 3C (Figure 75). Although modest increases in recruitment were observed in all other CMAs, the overall CPS survey catch rates remain relatively low

(< 5 kg/ trap) (Figure 34), with recruitment comprising the majority of biomass in any given CMA and year. The DFO trap survey results are generally consistent with the CPS survey results. In White Bay, an unusually high abundance of recruitment was seen throughout the bay in 2012 (Figure 76), but catch rates have since declined to about 5 kg/trap. It is noteworthy that the best comparison with the CPS survey is made with the 201-300 m and 301-400 m strata, which constitute the majority of the area, with the deepest stratum very small and generally beyond depths where the fishery occurs. Nonetheless, the DFO survey typically finds large soft-shelled pre-recruits in this deep hole, thus the improved signal in 2017 could reflect increased recruitment potential for 2018.

Interestingly, unlike the CPS survey which has shown and abrupt increase in CMA 3C in the past two years, the DFO survey has measured the improvement in CMA 3D, specifically in the deepest confines of it (Figure 77). 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. We interpret the improved signal from the CPS survey in CMA 3C and the DFO survey in CMA 3D as reflecting a general improvement in recruitment throughout the area.

Overall, the collective information from trawl and trap surveys suggest recruitment should increase in 2018, with increases most likely in near to shore regions. Size frequency distributions from large-mesh pots in the CPS survey show increased levels of new- and soft-shelled crab across a broad size range in all CMAs, except CMA 4 and 3D (Figure 78).

Looking beyond 2018, both the trawl and trap pre-recruit abundance indices increased from historical lows during 2016 (Figures 30 and 35). Although they both decreased in 2017, pre-recruit potential appears improved over the lowest observed levels during 2012-15.

Small-mesh trap usage by the CPS survey has been sporadic or non-existent in most CMAs throughout the times series (Figure 79). Only Green Bay (CMA 3C) and the offshore (CMA 4) have been consistently covered. Overall catch rates have been consistently high in Green Bay, but the overwhelming majority of crab have terminally molted below legal-size in all but the most recent year (Figure 79). The high proportion of sub-legal size crab that did not terminally molt in 2017 has contributed to a currently increased exploitable biomass in the area (Figure 78) and a positive outlook for recruitment into the biomass in 2018 that could sustain the fishery beyond 2018.

Small-mesh traps in the DFO surveys show a depleted biomass in all areas of White Bay (CMA 3B) (Figure 80). The surveys tracked a mode of adolescents across years and depths, beginning at about 47 mm CW in the shallowest stratum in CMA 3A/White Bay in 2005 to pre-recruit-sized animals with modes of about 75-85 mm CW in the two deeper strata in 2011 and 2012. The deep progression over time reflects the ontogenetic migration of Snow Crab in this area (Mullowney et al. 2011). This recruitment pulse led to the high exploitable biomass experienced from 2012-14. Although another small pulse of adolescents was detected at about 47 mm CW in the shallowest stratum in 2015, there has been no strong signal of pre-recruit crab in the population since 2012 and expectations are that the exploitable biomass and fishery in 3A/White Bay will decline further in the next couple of years.

An emerging pulse of small crab in Green Bay seen in the CPS survey (Figure 79) is not as clear in small-mesh pot data from the DFO trap survey (Figure 81), which show no clear trends in modal progression or abundance levels in recent years. A relatively high abundance of small crab (<50 mm) was captured in the 2014 trawl survey relative to preceding years, and in 2016 and 2017, another smaller spike in small crab abundance occurred (Figure 38). Coincidentally, the DFO trap survey in White Bay captured a pulse of crab centred at about 47 mm CW in the shallow stratum at the mouth of the bay in 2015 (Figure 80), as did shallow water traps deployed in a shallow water area along the CMA 3B and 3C line (Figure 81). Other factors being equal, collectively, these surveys provide evidence to suggest some increased long-term recruitment prospects for the exploitable biomass and fishery. The NAO climate prediction suggests the biomass should start entering into a growth phase in the next few years (Figure 44), with the increased pre-recruit signal seen in the past two years (Figure 30) consistent with this scenario.

BCD incidence levels 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 82) 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. The present ‘cycle’ of BCD in White Bay is another piece of evidence consistent with improved forthcoming recruitment prospects for the fishery. In Green and Notre Dame Bays the ‘cycles’ of BCD and crab biomass have historically been out of phase by approximately 2-4 years. Levels of BCD peaked in 2015 and in 2017 increases in recruitment into the exploitable biomass were observed.

Despite several inferences of improving long-term recruitment prospects, it has to be cautioned that the level of biomass to be gleaned from the next recruitment pulse is unknown. Expectations must be tempered. Most data suggest this emergent pulse of small crab is weaker than those seen historically and high levels of discards (Figure 53) or predation (Figure 48) may dampen potential prospects.

Caution is encouraged in making decisions on the resource at the CMA level in this AD as they could affect biological functioning. Most information presented herein shows that broad-scale resource trends are consistent throughout the AD. Although specific aspects of spatial connectivity (such as migration routes) are not well understood, of potential concern is that excessive fishing in one CMA could directly affect adjacent areas. Similarly, cautious actions in a given CMA have the potential to benefit adjacent areas. Broad-scale spatial stratification by size is evident in Snow Crab populations in the northern portions of the NL shelf, including Division 3K (Dawe and Colbourne, 2002). Among other connectivity processes, large-scale ontogenetic migrations extending beyond CMA boundary lines knowingly occur in this AD (Mullowney et al. 2018), 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 (Figure 2). 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). All but CMAs 6C and 8A are further sub-divided into inner and outer management areas, but those finer-scale areas are not considered in the assessment.

All the bays in this AD feature deep holes in their central interior portions. Bonavista and Trinity Bays are open at their mouths, thus the deep water inner portions are continuous with the offshore bathymetry (Figure 1). 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 here is cold (Figure 43) and most of the area is characterized by productive Snow Crab grounds.

Overall, landings in AD 3L Inshore increased throughout the 2000s, but declined by 29% from a historical high in 2015 to 6,000 t in 2017 (Figure 12). In 2017, the TACs decreased in all CMAs, resulting in subsequent declines in landings (Figure 3). The reduced TAC was not reached in CMAs 5A, 6A, 6C, and 8A. Effort had oscillated without trend from 2005 to 2015 but has nearly doubled since 2013 to a historical high of one million trap hauls in 2017 (Figure 14).

Overall CPUE has declined by 56% since 2013 to its lowest level in 28 years (Figure 16). There have been strong recent declines in every CMA, with many now at or near time-series lows (Figure 4). Although recent catch rate declines have been substantial in all CMAs, particularly precipitous declines in CPUE have occurred in Conception Bay (CMA 6B) and the Northeast Avalon (CMA 6C) during the past two years.

Strong depletion of the resource during the 2017 fishery was evident in all areas except Trinity Bay (CMA 6A) (Figure 5). Fishery CPUEs ended at or near historical lows (<5 kg/ trap) in Bonavista Bay (CMA 5A), NE Avalon (CMA 6C), Southern Avalon (CMA 8A), and St. Mary's Bay (CMA 9A). In Trinity Bay, CPUE consistently ranged from 5-7 kg/trap throughout the season. This represents a fairly low CPUE for this CMA compared to historic levels. For example, start of season CPUE of about 7 kg/trap in 2017 was similar to end of season CPUE in 2015 and below the end of season CPUE of about 9 kg/trap in 2014. In Conception Bay (CMA 6B) and NE Avalon (CMA 6A), the start-of-season fishery CPUEs in 2017 were equivalent to or below the end-of-season CPUEs of 2016. This indicates the resource in each CMA has experienced little to no recruitment between fisheries, consistent with emerging patterns of strong resource depletion through fishing. Particularly alarming signals are the near-zero CPUEs observed in CMAs 6C and 8A at the end of the fishery in 2017, suggesting a near-fully depleted biomass.

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 of legal size, with extremely low incidence of new-shelled crab in the AD as a whole and within most CMAs (Figures 17 and 86). New-shelled crab were virtually absent in Conception Bay (CMA 6B), Trinity Bay (CMA 6A), and St. Mary's Bay (CMA 9A) (Figure 86). Large increases in new-shelled crab were observed in NE Avalon (CMA 6C) and Southern Avalon (CMA 8A) across all size ranges. However, the discrepancies of these trends with other data sources (e.g., CPS data) indicate these data could be misidentified shell categories and should be viewed with caution. In general, with the absence of a large recruitment event in 2018, these data suggest further dissipation of the already depleted exploitable biomass.

Observed weekly soft-shell encounters remained relatively low in AD 3L Inshore from 2012-16. 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 (Figure 87). These soft-shell observations were near-exclusive to Bonavista Bay (CMA 5A). This indicates potential wastage in the fishery but could also suggest some localized potential for recruitment improvements in that bay for 2018. Nonetheless, the sustained period of about seven years with little to no soft-shell crab observed in the fishery is indicative of recently declining recruitment and with little exception suggests no major improvements in recruitment into the exploitable biomass are expected for 2018.

Biomass declines have been greatly outpacing adjustments to removals. The overall trap survey-based exploitation rate index increased from 2013 to a time-series high in 2017 (Figure 55). Maintaining status quo removals would increase the two-year average exploitation rate index to an exceptionally high level of about 70% in 2018, with an annual point estimate of about 90%. Under status quo removals, all CMAs would reach or remain near time-series highs levels of exploitation (Figure 88). CMAs NE Avalon (CMA 6C) and St. Mary's Bay (CMA 9A) would reach exploitation rates in excess of 100% under status quo removals. The consequences of such high exploitation are unknown, but the potential for biological harm to the resource through fishing elevates as exploitation elevates to such high levels. The entire AD is currently heavily exploited.

Surveys

The trap survey exploitable biomass index has declined by 73% since 2012, reaching a time-series low in 2017 (Figure). The 40% overall change from 2016-17 reflects declines to time-series lows in all CMAs (Figure 88). In all CMAs, the exploitable biomass index has been at its lowest observed level in the past two years.

The declining biomass is largely a result of declining recruitment renewal since 2010, sequentially followed by a decline in residual crab since 2014 (Figure 34). Overall recruitment into the exploitable biomass has steadily declined for the past three years to a time-series low in 2017, with the catch rate index at 1 kg/trap. Recruitment indices from DFO and CPS trap surveys in all CMAs were at or near their lowest levels in 2017 (Figures 89, 90, 91, 92, and 93). Resource renewal has been low and is expected to remain low in 2018.

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 (Figure 89). The index has remained near this low level since, although it was <5 kg/trap in 2017. 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 (Figure 90). Nonetheless, overall, both surveys are consistent in showing the relative abundance of exploitable crab to be near a historical low in 2017.

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 has remained at that level during the last two years (Figure 89). This drop in recruitment in 2015 was reflected in the DFO trap surveys within the shallow (93-183 m) and deep (367-549 m) strata (Figure 91). Again, both surveys are consistent in showing the overall relative abundance of exploitable crab to be near a historical low in 2017.

In Conception Bay (CMA 6B), catch rates of legal-sized new-shelled crab were at a time-series low (<1 kg/trap) in 2017 (Figures 89 and 92). Dramatic declines in residual crab were also observed in CMA 6B in both the CPS and DFO trap surveys (Figures 89 and 92). Both surveys showed an alarming rate of decline in overall relative abundance of exploitable crab in recent years, from about 30 kg/trap in 2014 to about 5 kg/trap in 2017. This constitutes an 88% decline in biomass in three years. With the recruitment index near zero, all indications are of an exploitable biomass in a near-fully depleted state in this area.

In the Northeast Avalon (CMA 6C) and Southern Shore (CMA 8A), the recruitment index of new-shelled legal-sized crab fluctuated at 3-6 kg/trap between 2011 and 2015 (Figure 89), but catch rates of recruits in both CMAs declined to a time-series lows in 2017, near 0 kg/trap. Like Conception Bay, given that trends in residual crab catch rates have generally lagged behind those in recruitment, the prognosis for the exploitable biomass available to the 2018 fishery is very poor.

St. Mary's Bay (CMA 9A) has been experiencing a prolonged and steady decline in catch rates of recruits since 2010 and both surveys showed the index of new-shelled legal-sized crab and residual crab were at time-series lows in 2017 (Figures 89 and 93). Of particular note, the recruitment index is near zero in all surveyed areas. Like virtually all other areas, the exploitable biomass in St. Mary's Bay appears severely depleted and prospects for the 2018 fishery are poor.

Overall, the prolonged decline in recruitment throughout the AD is now becoming manifest in dissipating catch rates of old-shelled residual crab, which have begun to decline in all surveys in all management areas. 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 94). The overall prognosis for the 2018 fishery is very poor and no major improvements in biomass available to the fishery are expected in the short term, although there was a suggestion of a modest increase in pre-recruit potential in small-mesh traps from the CPS survey in most CMAs in 2017 (Figure 95).

The overall AD pre-recruit abundance index was at its lowest level in a decade in 2015, but has since returned to near the decadal average (Figure 35). However, it must be cautioned that this decadal average level of pre-recruits has been associated with the recent prolonged decline in exploitable biomass throughout the AD.

Small-mesh trap size frequency distributions from the DFO surveys in Bonavsita Bay (Figure 96) suggest there are some pre-recruit adolescents remaining in the population in the deepest stratum of the bay, but the overall level is below that seen in most years since 2011. Meanwhile, the signal of pre-recruits from Trinity Bay (Figure 97) is better, with the relative abundance of pre-recruits of most sizes the highest in the five year survey time series. The DFO survey in Conception Bay has captured virtually no pre-recruit adolescents in any strata in the past seven years (Figure 97), while the St. Mary's Bay survey captured an emergent signal of small pre-recruits (<75mm CW) in the deepest stratum in 2017 (Figure 99). Given that such signals of small pre-recruits are often associated with large increases in survey catch rates of pre-recruits in the following year, the St. Mary's Bay survey signal of pre-recruits will be of particular interest in 2018.

The incidence of BCD, which provides a signal of the relative strength of the density of small and intermediate-sized crab and associated recruitment prospects, has been nil in Conception Bay for four consecutive years (Figure100).

Overall, virtually all data are coherent and consistent in showing a broad-scale decline of recruitment into the exploitable biomass in AD 3L Inshore. For 2018, only Bonavista Bay appears to have appreciable prospects for recruitment into the fishery. However, given that recent levels of recruitment potential higher than that of 2017 have not resulted in improvements to the fishery one of two possibilities are likely occurring; the recruitment is too low to appreciably renew the biomass or the fishery is imposing a high mortality on soft-shell crab before they can recruit. More broadly, in the AD as a whole, in the short-term beyond 2018 there are modest inferences of emerging pulses of small crab in the population that could marginally improve the fishery within a few years in some CMAs. However, overall, the scenario of a severely depleted exploitable biomass coupled with low recruitment prospects and high exploitation rates suggests expectations of potential for improvements in the short term must be tempered, particularly if exploitation rates are not better controlled than at present.

There are interesting contrasts between fast and slow changing populations within this AD. Recruitment pulses oscillate relatively quickly in Bonavista Bay, similar to ADs 2HJ and 3K. However, in Conception Bay, the process of recruitment entering into the exploitable biomass is prolonged over many years, similar to the Grand Bank (AD 3LNO Offshore). Among other possibilities, this reflects a higher incidence of skip-molting in crab inhabiting colder water areas (Dawe et al. 2012) and manifests itself in temporal differences between thermal changes in the environment and impacts on the fishery, with relatively short lags in warm areas and long lags in cold areas (i.e. AD 3LNO Offshore). Moreover, it explains, at least in part, why recent and present impacts of a broad-scale decline in recruitment stemming from prolonged warming are last to be felt by the ADs 3LNO Offshore and 3L Inshore fisheries. In these ADs, the most recent increase and subsequent decline of the pre-recruit biomass index (2007-11) has been delayed relative to AD 3K (2006-10) as were/are changes in the exploitable biomass and fishery performance indices. The Snow Crab resource is impacted by bottom-up (i.e., thermal) processes in all areas, but the rate of changes induced by temperature shifts differs substantially across thermal regimes.

Careful consideration of short-term removal strategies in AD 3L Inshore are advised. The exploitable biomass in most areas is both severely depleted and dominated by old-shell crab. Accordingly, along with high fisheries-induced mortality it is also likely that natural mortality could be a coincident important determinant of population abundance. Natural mortality cannot be controlled, but harvest rate can be adjusted to ensure that the population does not become virtually void of large males. Under the current scenario, it is theoretically possible for the fishery to take virtually every large male in the population in some areas. The consequences of near-fully depleting the population of large males are unknown, but biological risks include impacts to stock reproductive capacity.

ASSESSMENT DIVISION 3LNO OFFSHORE

Fishery

The AD 3LNO Offshore fishery occurs on and surrounding the Grand Bank off Newfoundland's southeast coast (Figure 21). It is a massive, shallow, cold, and productive environment for Snow Crab that encompasses CMAs Nearshore (NS), Midshore (MS), Midshore Extended (MSex), 3L Extended (3Lex), 3L Extended in 3N (3Lex3N), 3L Extended in 3O (3Lex3O), 8B, 3L Outside 200 Miles (3L200), 3N Outside 200 Miles (3N200), and 3O Outside 200 Miles (3O200) (Figure 2). Like other ADs, the numerous management areas have no biological basis and serve to differentiate fishing grounds among a large number of vessels in several fleet sectors.

The fishing pattern normally forms a continuum extending from inshore bays of eastern Newfoundland into dense masses of effort in CMAs NS and MS, then extends farther east in a thin band along the northern Grand Bank from the MSex to 3L200 (Figure 15). 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.

This Assessment Division alone has accounted for a steadily increasing proportion of the landings from the NL Region. Overall, landings increased gradually since 2009 to a historic high of 28,750 t in 2015 (Figure 12). Landings declined by 26% from 2016 to 18,050 t in 2017, the lowest level in two decades. TACs were reduced in all CMAs in AD 3LNO Offshore in 2017, resulting in subsequent declines in landings (Figure 101). CMA 8B has not reached the TAC since 2009, while it has not been taken in CMA 3N200 in four years. The decline in landings to historic lows in these two CMAs in the past two years is particularly noteworthy.

Effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level since that time (Figure 14), with 1.5 to 2 million trap hauls occurring each year. Overall CPUE most recently peaked near a time-series high in 2013 and has since declined by 41%, to its lowest level since 1992 (Figure 16). Substantial declines have occurred in all management areas in recent years (Figure 102), although catch rates remain relatively high in the central portions of the AD in CMAs MS and MSex (Figure 102). Catch rates have sharply declined to be near historical lows (~5 kg/trap) in CMAs 3L200 and 3N200 (Figure 102).

Spatially, the fishery data are reflecting a situation where fishing remains relatively strong along the central northern Grand Bank, but has 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 15). Reductions in fishery strength are also evident in CMA NS, MS, and MSex. More generally, the fishery along the northern portion of the Grand Bank in NAFO Div. 3L is one of the few areas yet to be strongly impacted by a broad scale decline in productivity and recruitment in the NL Snow Crab stock (Mullowney et al. 2016). However, reductions in catch rates in this area are also beginning to emerge.

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. Relative to other ADs, there is little evidence of declining CPUE in some CMAs throughout each season (Figure 103). However, the fisheries have performed successively poorer throughout each of the past two (MSex, NS, 3Lex), three (MS) or four (3L200, 3N200) years in most CMAs (Figure 103).

The shape, magnitude, and shell composition of size distributions from at-sea sampling by observers changed considerably from 2008 to 2017 (Figure 18). The mode of the size distributions abruptly shifted left to approximately 92-98 mm CW in 2008-09, followed by a marked increase in the magnitude of new-shelled crab in the population during 2010-12, while the primary mode gradually returned to larger sizes. Since then, the overall magnitude of the distributions has been gradually decreasing due in large part to diminishing contributions from new-shelled crab, and the primary mode returned to 115 mm CW in 2017. These observer data clearly depict a prolonged period of strong recruitment contributing to the exploitable biomass from about 2008 to 2012, and subsequently a resource not being renewed at a high rate and gradually being eroded. Accordingly, in the absence of strong recruitment, the magnitude of the exploitable biomass is expected to decline further in the forthcoming years as gains from the strong recruitment period continue to dissipate. Coincident with an aging demographic, these size frequencies show an overall declining population throughout the entire AD in recent years (Figure 104).

The percentage of the catch discarded has been inversely related to fishery CPUE throughout the time series (Figure 52). Despite this relationship, overall discards have remained low (10-20%) relative to all other ADs throughout the times series, reflecting relatively strong CPUE. Discards have been near wholly comprised of under-size adult male crab for five consecutive years (Figure 54). This indicates poor recruitment prospects as inferred from few soft- and under-sized new-shelled crab in the catch. The fishery in AD 3LNO Offshore has generally been very efficient at extracting the resource (relative to other ADs), with soft-shelled crab incidence rarely a major concern (Figure 105). However, the phenomenon reflects opposing reasons in historic versus recent years. 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. It is essentially the converse of how AD 2HJ and 3K fisheries have historically operated under low residual biomasses and high exploitation. However, in AD 3LNO, in the presence of a progressively depleting residual biomass, the virtual lack of soft-shell crab in the catch such as has occurred in the past five years, reflects a low level of soft-shell crab in the population reflecting the broad-scale dissipation of recruitment.

Total mortality in exploitable crab has been steadily increasing since 2009 to be at or near its highest level in most recent years (Figure 50). The 2018 total mortality estimate is deemed anomalous. The exploitation rate index increased by a factor of five from 2014 to 2017 (Figure 50). The annual point estimate was nearly 90% in 2017 and the two-year average was about 70%. Status quo removals in 2018 would maintain the two year average exploitation rate index at a historic high of about 70%. Based on localized trap survey biomass indices, particularly high exploitation rate indices (> 55%) are predicted for CMAs MS and NS, if status quo removals are maintained (Figure 106).

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

Surveys

The trawl survey exploitable biomass index, which covers the entire AD, has precipitously declined by about 75% from 2013 to 2016 (Figure 30) and exploitable biomass indices remain at or near time-series lows in both the trawl and localized trap surveys (Figures 30 and 31). All surveyed management areas, with the exception of MSex, were at or near historical lows for exploitable biomass in 2016 and 2017 (Figure 106). Most surveyed CMAs were at or near historical low catch rates of residual crab (old-shelled, legal-sized crab) in 2017, and the two that were not (MS and MSex) declined in 2017 (Figure 107). Particularly dramatic declines in survey catch rates have occurred in the past two years in CMAs 3Lex and MS.

Both the trawl and trap surveys show considerable spatial contraction in high catch rates of exploitable crab in recent years (Figure 8 and 28). The trawl survey index of exploitable biomass shows the resource has become increasingly localized into portions of NAFO Div. 3L (Figure 28); the majority of survey trawls in NAFO Divs. 3N and 3O caught no exploitable crab for the last four years and catches that were noted in these divisions recorded low numbers of individuals. Similarly, 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 8). The CPS trap survey, which does 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) show declines in exploitable biomass that were noted in the trawl survey 2-3 years ago. The spatial differences in coverage of the two surveys largely account for the delayed signal in the trend of exploitable biomass indices derived from the two surveys and highlight deficiencies in the CPS survey design with respect to its ability to detect changes in the resource in a hyper-stable catch rate scenario. Nevertheless, the recorded spatial contraction and reduced biomass index reflected in the CPS trap survey indicates that prime fishing grounds in AD 3LNO are now experiencing declines in exploitable biomass previously signaled from the trawl survey.

Overall recruitment into the exploitable biomass has been at or near time-series lows in both the trawl and trap surveys in the past two years (Figures 30 and 34). In 2017, all CMAs covered by the CPS survey recorded recruit catch rates at or near historical lows (Figure107), with catch rates near or below 5 kg/trap. Despite such low catch rates of new-shelled recruits, the proportion of the catch represented by recruitment modestly increased in CMAs MSex and MS (Figure107), highlighting the emerging reductions in residual biomass. Chronologically, the survey data in these two dominant centres of biomass, as well as CMA NS, show strong internal consistency in that the pulses of high residual biomass from which present declines are emerging were preceded by pulses of recruitment from 2010-13.

CPS survey size frequency distributions indicate that the pulse of recruitment that has recently benefitted CMAs MS, MSex, and NS, which first emerged as small 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 108). This is particularly evident by the advancement of the primary mode from sub-legal size in each CMA in 2009-10 to about 115 mm CW in CMAs MS and MSex in 2015 and 2016. The size frequencies also show an aging demographic in all areas of the AD, with a general increasing proportion of old-shelled crab in the population over time. Collectively, low catch rates of both recruit and residual crab in most CMAs indicate an overall depleted resource and a population of crab on the Grand Bank suffering from a lack of renewal and now a depletion of all crab in the exploitable biomass.

Recruitment prospects remain poor. No major increases in the exploitable biomass are expected in 2018. The trawl survey pre-recruit biomass index has steadily declined since 2009 and has been at its lowest level for the past four years (Figure 30). The general decline in pre-recruit crab is widespread, with a steadily depreciating signal of catches of all magnitudes in the trawl survey throughout the AD since 2009 to a nearly barren state in 2015 and 2016 (Figure 36 and 37). In 2017, there was a modest increase in the number of trawl stations catching pre-recruits throughout NAFO Div. 3L and the northern portion of Div. 3O. Somewhat contradictory, the CPS pre-recruit index has increased in the most recent 2 years (Figure 35). However, this apparent contradiction reflects a localized improvement in CMA 8B (Figure 109). The disagreement between the trawl and CPS trap survey largely reflects the limited number of consistently sampled core stations containing small-mesh traps in the CPS data series (Figure 9). The improved signal of pre-recruits in the CPS survey reflects high catch rates in the westernmost fringes of the Grand Bank. Nonetheless, this is consistent with greatly improving pre-recruit prospects further west in AD 3Ps (Figure 35). In continuation, despite their limited spatial distribution, small-mesh traps in the CPS trap survey tracked the most recent recruitment pulse into the exploitable biomass in the MS and MSex CMAs from 2008-13 (Figure109).

In the short-term, despite an inference of broad-scale poor recruitment prospects, the small-mesh traps indicate potential for localized improvements in CMA 8B in the next few years. The pulse of approaching recruits centered at about 80 mm CW in 2017 (Figure109) could benefit CMA 8B fishery in the near future. However, the leading tail of this pulse should already be benefiting the fishery, but it has not been detected in CPUE (Figure 101). Given that the exploitable biomass in this area is very low (Figure 106) and that the quota has been nowhere near achievable in recent years (Figure 101), there is a strong potential that this approaching mode of pre-recruits is or could be subjected to high soft-shell capture mortality before it can contribute to the fishery if adequate controls to protect it are not employed.

The generally poor broad-scale pre-recruit prospects seem inconsistent with improving prospects for the exploitable biomass over the next few years from the climate (NAO)-predicted correlations (Figure 44). In extension, relative to the 1995-2005 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 2008-10 (Figure 30) most likely emerged from the relatively strong pulse of small crab captured during 2001-03 (Figure 38). The small spike in small crab abundance seen in the survey in 2010 (Figure 38) was also seen in AD 3Ps (Figure 38). This is consistent with the aforementioned trends from small-mesh traps in the CPS survey that have tracked a mode of small crab on the western Grand Bank that should currently or very shortly make contributions to the exploitable biomass. Nonetheless, the apparently localized nature of this recruitment pulse and the lack of any sustained strong pulses of small crab in the survey since the early 2000s is a major point of concern and strongly suggests that, overall, the AD 3LNO Offshore exploitable biomass will either not improve markedly or decline further in the forthcoming years. Other factors beyond climate such as a high level of predation in the past four years (Figure 48) and the recent development of exceptionally high fishery exploitation rates (Figure 50) suggest a strong potential for top-down interferences to override the climate signal in the forthcoming years.

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. 2018) and key resource trends are clearly broad-scale. It is obvious that the resource decline is progressively and aggressively approaching the concentrations of high biomass in the central portion of the population range. Despite fishery performance currently remaining relatively high in a hyper-stability scenario on an extant dense group(s) of crab, further reductions in these most productive areas appear imminent. Virtually all information suggests low recruitment into the exploitable biomass has been prolonged and that short-term renewal prospects are poor. Assuming the two decade relationship between lagged exploitable biomass index and fishery CPUE holds (Figure 32), 2018 is likely to be the poorest performing fishery in this AD in the past two decades. The fishery is being enabled to exploit this biologically key AD at exceptionally high levels. Biological outcomes of this practice are unknown but could potentially extend beyond AD 3LNO boundaries.

ASSESSMENT DIVISION 3PS

Fishery

The AD 3Ps fishery occurs off the south coast of Newfoundland (Figure 2 and 15). 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 (Figure 1) in CMA 10B. In terms of scale, the fisheries in all other management areas of the AD are small compared to CMAs 10A and 10B. Like other ADs, there is little scientific basis for the numerous CMAs and fishery and resource trends among CMAs are often synchronous.

Relative to other ADs along the NL continental shelves, AD 3Ps is shallow. The tops of the two major offshore banks, the St. Pierre Bank in the west and the Green Bank in the east (Figure 1), are both shallower than 100 m depth and the intersecting Halibut Channel is less than 200 m depth throughout. These shallow areas of the AD, where the bulk of the fishery occurs (Figure 15), are cold, but temperatures increase abruptly at the slope edges (Figure 43). In spring of 2017, the distribution of bottom water was typical, with virtually the entire shallow water plateau of the continental shelf comprised of water <1°C, little areal extent of 1-3°C bottom water, and temperatures exceeding 3°C along the slope edges to the west and south and within Fortune Bay (Figure 43). By the fall of 2017, warm bottom water had encroached over much of the St. Pierre Bank and covered additional area in Fortune Bay.

Landings declined from a recent peak of 6,700 t in 2011 to a time-series low of 1,200 t during the past two years (Figure 12). Effort has declined by 44% since 2014 to be near its lowest level (about 500,000 trap hauls) in two decades (Figure 14). The TAC has not been taken in eight years (Figure 12). These overall trends in removals and effort reflect a relatively consistent pattern in every CMA (Figure 110). However, the larger fisheries in CMAs 10A and 10B play a particularly strong role in influencing the overall trends observed in the AD.

Fishery CPUE has steadily declined since 2009 to a record low of <3 kg/trap in the past two years (Figure 16), reflecting precipitous declines throughout the major fishing areas of the AD (Figure 111). With the exception of CMA 11W, all management areas were at or below 5 kg/trap in 2017. The declines in CMAs 10A and 10B, from about 15-16 kg/trap in 2009-10 to ≤3 kg/trap in 2016 and 2017, have been particularly large and precipitous (Figure 111). In 2016 and 2017, the fishery in all CMAs (with the exception of CMA 11W) began below or near 5 kg/trap (Figure 112). These exceptionally low CPUEs suggest a severely depleted resource. The limited information from CMA 11W compromises interpretation of the performance of the fishery in that area. Nonetheless, the broad-scale and rapid decline in CPUE throughout AD 3Ps is striking.

In-season data from observer sampling are consistent with the logbook data in depicting a poorly performing fishery. In Placentia Bay (CMA 10A), the magnitude of legal-sized crab of all sizes has dropped considerably since 2012 (Figure 113). This drop coincided with the virtual disappearance of new-shelled crab in the population. In 2017, there was a modest increase in new-shelled and soft-shelled crab in Placentia Bay. The decline in overall abundance of crab since 2012 also occurred in the offshore (CMAs 10B and 11S). The sharp ‘knife-edge’ appearance at legal-size in the size frequency distributions of CMAs 10A and 11s suggest high exploitation pressure from the fishery (Figure 113).

Discards comprised half the catch in the past two years (Figure 53). In the past decade, the majority of discards have been under-sized old-shelled crab, a high proportion of which are likely terminally molted adults (Figure 54). After an extended period of time with few soft-shell reported in the catch, soft-shell occurrences became more prominent from 2014 to 2017 (Figure 114). In 2017, levels of soft-shell crab in the catch increased throughout the duration of the fishery. This coincided with a notable increase in the observed abundance of under-size new-shelled crab in the population (Figure 113), suggesting some improvements in the exploitable biomass could be forthcoming.

With large quota cuts and reductions in removals, the overall exploitation rate index has declined by more than half since 2013 and is at a relatively low level (Figure 50), with the 2017 point estimate <25%. In 2017, the exploitation rate was reduced in all CMAs (Figure 115). Assuming the exploitable biomass remains at the current level, status quo removals would result in an exploitation rate index near the long-term median in 2018. However, if the biomass increases in the 2017 survey, the exploitation rate index will continue to remain relatively low. Despite reductions in fishing pressure, it is concerning that discards comprised half the catch for the last two years. Continuing to fish under elevated mortality levels on small and pre-recruit crab could potentially impair reproductive capacity of the resource or minimize potential gains from forthcoming recruitment. Nonetheless, relative to most other ADs, the AD 3Ps fishery data are suggesting more potential for positive developments in forthcoming years.

Surveys

The in-season trawl survey exploitable biomass index was at a time-series low in 2016, but improved slightly in 2017 (Figure 30). However, the post-season trap survey index suggests considerable improvements in the exploitable biomass throughout the major fishing grounds (Figure 34). The CPS trap survey was not or only partially conducted in most areas in 2015 and 2016 because of poor resource status (Figure 116). 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 an increase in recruits observed in all CMAs surveyed, except Fortune Bay (CMA 11E) (Figure 116). In the DFO trap survey in Fortune Bay (CMA 11E), total catch rates of exploitable crab in the two deepest depth strata have been at time-series lows in the past two years, while the catch rates in the shallowest strata improved in 2017 (Figure 117).

On the broad-scale, the residual biomass in AD 3Ps, represented by intermediate- to old-shelled legal-sized crab, began to decline after 2010 (Figure 30). The trawl survey has not captured any large catches of exploitable crab anywhere in the Subdivision since 2011 (Figure 29). Although there was a modest increase in positive stations in 2017, during the prior four years there were an increasingly high percentage of survey tows that captured very few or no exploitable crab.

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 118). However, with the exception of Fortune Bay, the CPS trap survey observed substantial catch rates of new-shelled and soft-shelled crab across a wide size range in 2017 (Figure 118). The somewhat conflicting information between the trawl survey exploitable biomass and the CPS-derived exploitable biomass is most likely a result of a new recruitment pulse entering after the spring trawl survey was complete. For example, there was no indication in most fishery data of imminent biomass improvements.

The decline in the exploitable biomass and the subsequent increase in 2017 reflect trends in recruitment. Overall recruitment into the exploitable biomass has been at its lowest observed level in recent years, but increased slightly in 2017 (Figures 30 and 34).

Recruitment into the exploitable biomass in 2018 will improve from the lowest levels experienced in recent years (Figures 30 and 34). Further, survey data of pre-recruit abundance suggest improving prospects for the next few years (Figures 30, 35, and 119). However, prospects for Fortune Bay remain poor with little signs of recruitment prospects in the next 2-4 years (Figure 119). Small-mesh traps from the DFO survey in Fortune Bay have captured virtually no adolescent crab of any size for the past five years (Figure 120); the few crab captured were small terminally molted adults.

The potential recruitment identified in the large-mesh pots during the CPS survey likely corresponds with the presence of a relatively large mode of 15-25 mm CW crab in the trawl survey from 2009-11 (Figure 38). The prior major prolonged pulse of crab of this size occurred from 2003-05. Subsequently, the pre-recruit biomass index increased to a very high level in 2009 (Figure 30), a lag period of 4-6 years from detection of small crab in the survey. In extension, the exploitable biomass index was high from 2009-11. All factors remaining equal recruitment prospects appear favourable in the short-term. This includes coherence with the NAO-predicted trend in exploitable biomass (Figure 44).

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

Overall, prospects in AD 3Ps are presently more favourable than in most other ADs. The resource has not yet recovered, but there are strong signals that it is improving markedly. The low exploitation rate in 2017 is not thought to be inconsequential to this improvement, and it is anticipated that if harvest rates remain relatively low that an improved fishery can be sustained beyond 2018.

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 (Figures 1 and 2). The area encompasses nine CMAs. The offshore CMA OS8 is separated from the numerous inshore CMAs by a line at eight nautical miles from headlands of the shoreline. There is little fishing activity in the southwestern CMAs 12A and 12B and the largest scale fishery occurs in Bay St. George (CMA 12C). The bathymetry off the west coast is characterized by a shallow water nearshore plateau that borders the deep Esquiman Channel (Figure 1). The bathymetry off the south coast is characterized by the presence of the Burgeo Bank extending through CMA 12A into NAFO Subdiv. 3Pn. Bottom temperatures in this Assessment Division are the warmest along the NL shelf (Figure 43), and it is comparatively unproductive for Snow Crab. Fishery CPUE is consistently low compared to other ADs (Figure 16) and the fishery has historically tended to be opportunistic in nature, with harvesters choosing to prosecute it when commercial quantities of Snow Crab are believed to be present.

Overall landings increased from a historic low of 190 t in 2010 to 750-900 t in 2013, but have steadily declined since that peak (Figure 12), reflecting patterns in most CMAs (Figure 121). Landings in 2017 remained relatively unchanged in CMA 12A and Bonne Bay (CMA 12G), but landings declined off Port aux Port (CMA 12D), Port au Choix (CMA 12H), CMA 12B, and in the offshore (CMA OS8). Declines in landings in the Inner and Outer Bay of Islands (CMAs 12E and 12F) and Bay St. George (CMA 12C) coincided with declines in TAC in 2017. Effort has been relatively unchanged (at a low level of about 150,000 trap hauls) since 2012 (Figure 14). The offshore fishery has been patchily distributed for the past nine years, with pockets of effort occurring along adjacent inshore management area lines (Figure 15).

CPUE has been low throughout the time series relative to most other Assessment Divisions and has declined since 2013 to below the long-term median (Figure 16), reflecting trends throughout all major fishing areas (Figure 122). Most CMAs experienced catch rates near time-series highs during 2012-13, but CPUE has declined to low levels during the past three years in most areas (Figure 122). CPUE remains relatively strong (i.e. >7 kg/trap) in CMA 12G.

There appears to be high levels of resource depletion by the fishery in most CMAs (Figure 123). Strong declines or extremely low CPUEs throughout the season in 2017 are particularly evident in Bay St. George (CMA 12C), Port au Choix (CMA 12H), Port-aux-Port (CMA 12D), and the offshore (CMA OS8). The depletion plots give an overall suggestion of a broad-scale fishery that has recently declined. Fishery observer coverage in AD 4R3Pn remains poor (Figure 124), but overall more common incidences of soft-shelled catches were evident in 2016 and 2017 (Figure 125).

The overall exploitation rate index index has increased since 2013 (Figure 55), reflecting trends in all surveyed areas (Figure 126). Status quo removals would elevate the two-year average exploitation rate index to an exceptionally high level in 2018, with all surveyed management areas reaching new time-series highs. Annual point estimates of exploitation rate would reach 100% in Bonne Bay and Bay St. George in 2018, and be above 80% in the Bay of Islands, under status quo removals.

Surveys

Trends in the fishery data reflect trends in the CPS trap survey data. The post-season trap survey exploitable biomass index most recently peaked in 2012 and has since declined to a time-series low in 2017 (Figure 31), reflecting trends in all surveyed areas (Figure 126). The residual biomass (old-shelled legal-sized crab) declined in all CMAs during the last two years (Figure 127), and overall total catch rates were about 1 kg/trap in the 2017 survey (Figure 34).

The abrupt 2011 increase in the exploitable biomass index (Figure 31) 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 127). Overall recruitment has been very low for the past four years (Figure 34). This reflects declines to low levels of 1 kg/trap or less in all CMAs (Figure 127).

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 128). Small-mesh trap size frequency distributions tracked approaching modes of adolescent males quite well from 2008-10 (Figure 129), immediately preceding the improvements in recruitment into the biomass. Although the signal of strong short-term recruitment prospects (i.e.,>75 mm CW adolescents) from these traps is now weak, a pulse of small 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 (Figure129). A very modest increase in small crab centered near 70 mm was also observed in CMA 12C during the 2017 trap survey. These trends indicate the possibility of modest localized improvements in 2-3 years.

The scenario of a low exploitable biomass and CPUE, coupled with an approaching pulse of pre-recruit crab in CMA 12EF suggests that excessive fishing in 2018 could be detrimental to yield in subsequent years due to associated high soft-shell mortality.

Overall, the exploitable biomass is currently severely depleted and the rapidly elevating levels of fishery exploitation are a concern.

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FIGURES

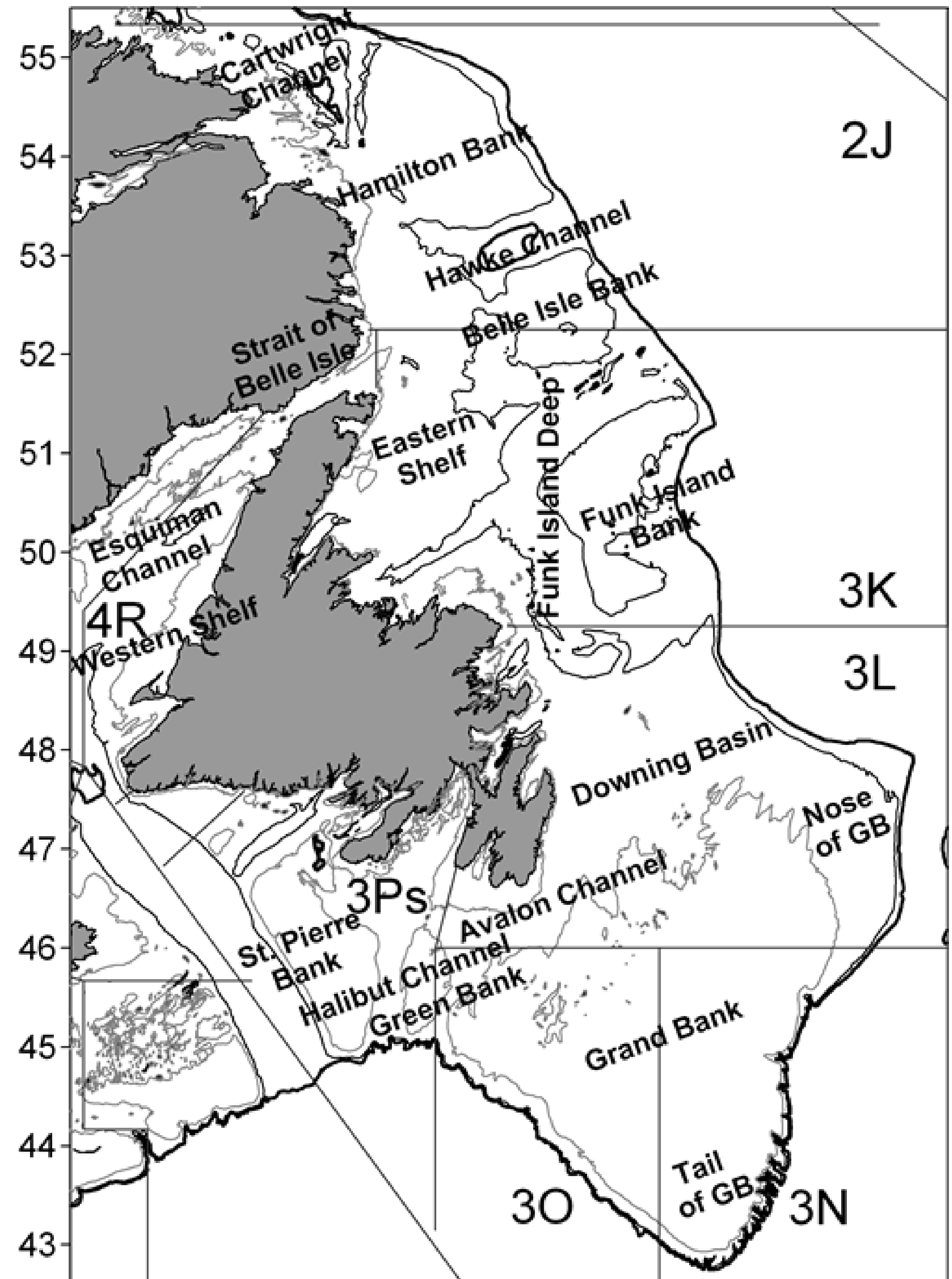

Figure 1. Map of Newfoundland and Labrador Continental Shelf showing place names, bathymetrical features, and Northwest Atlantic Fisheries Organization (NAFO) Divisions.

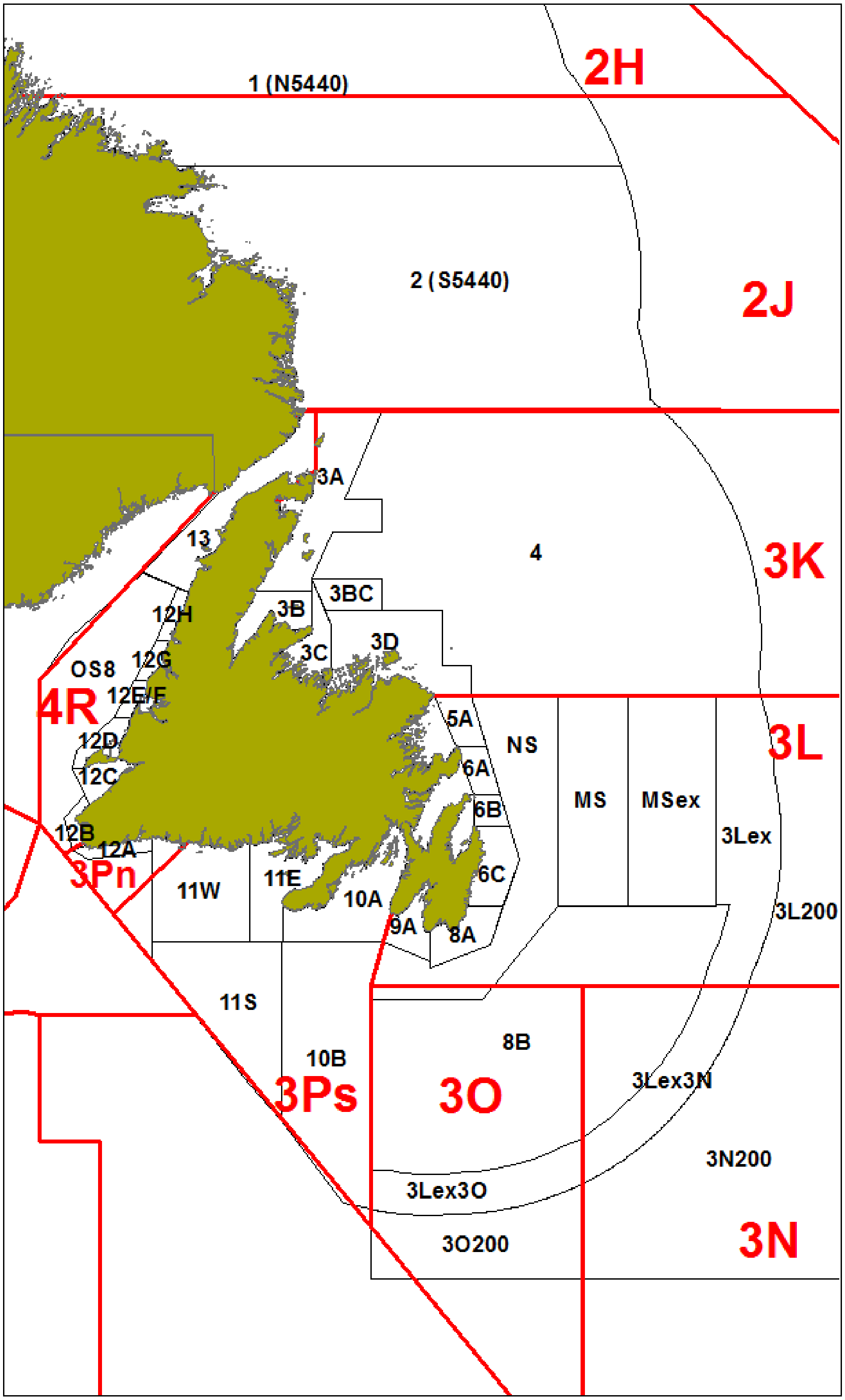

Figure 2. NAFO Divisions (red lines) and Newfoundland and Labrador Snow Crab Management Areas (black lines).

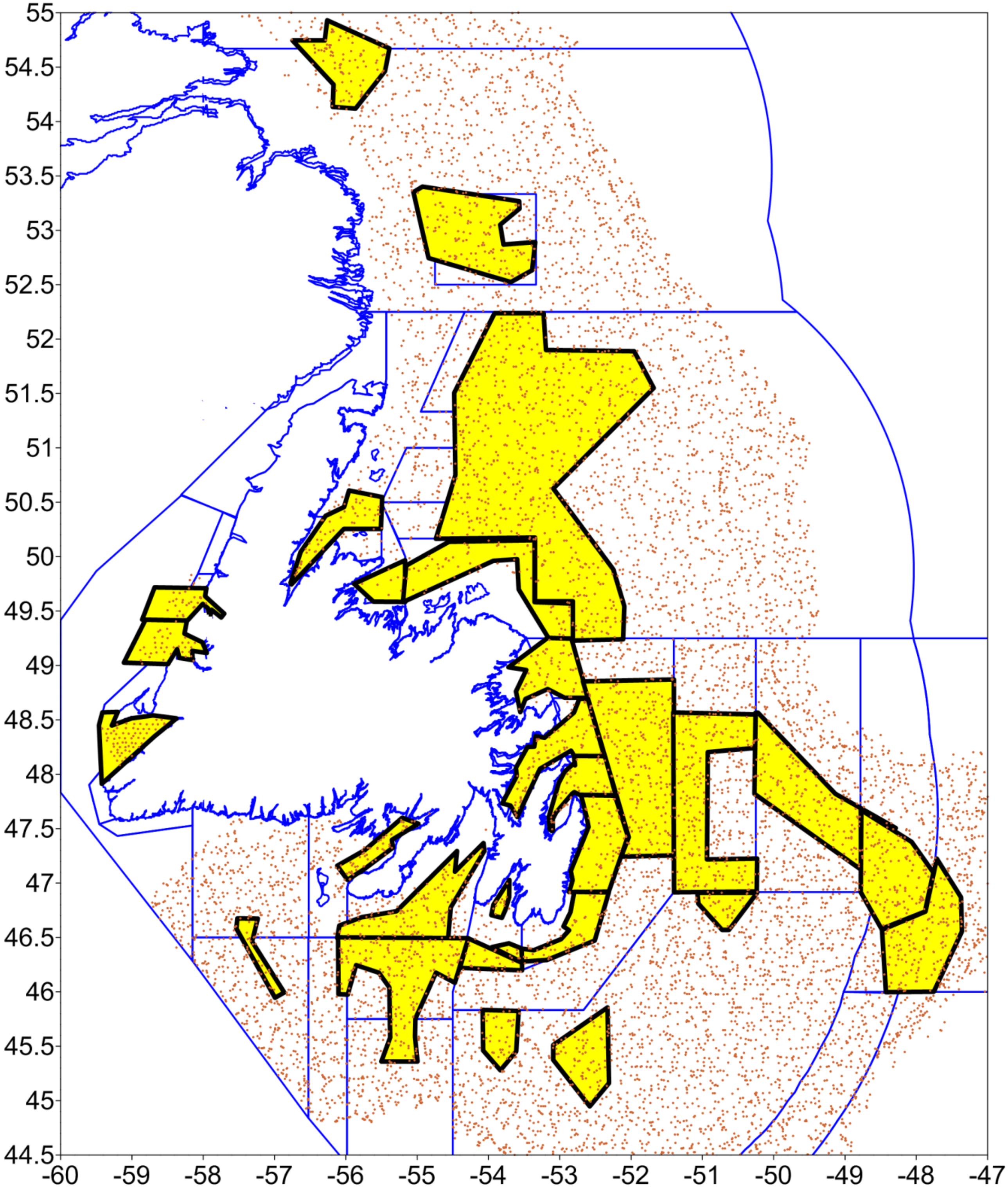

Figure 3. Map of ogmap vertices (red dots) and strata developed for biomass estimation from DFO and CPS trap surveys (yellow polygons).

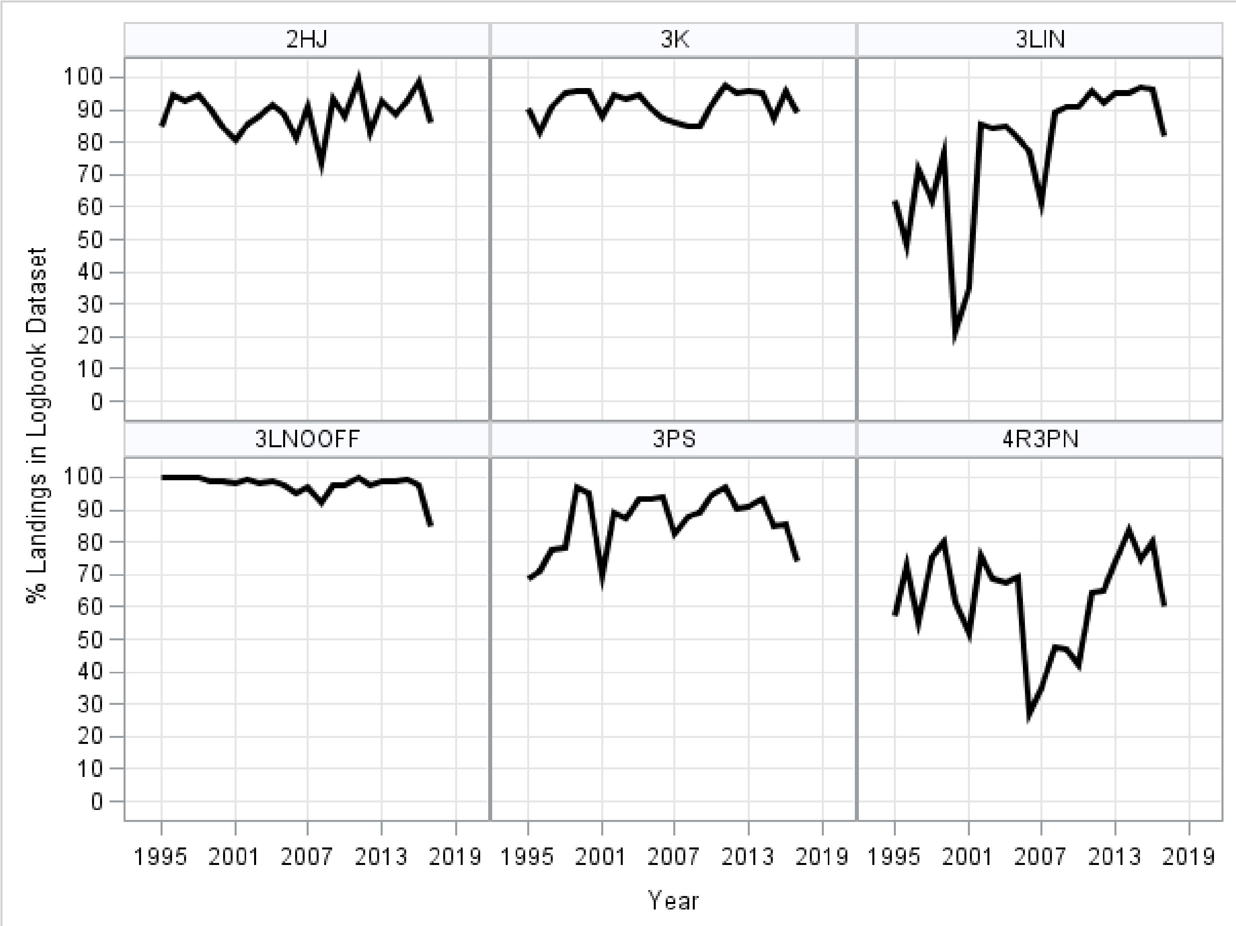

Figure 4. Logbook returns rates by Assessment Division and year (1995-2017).

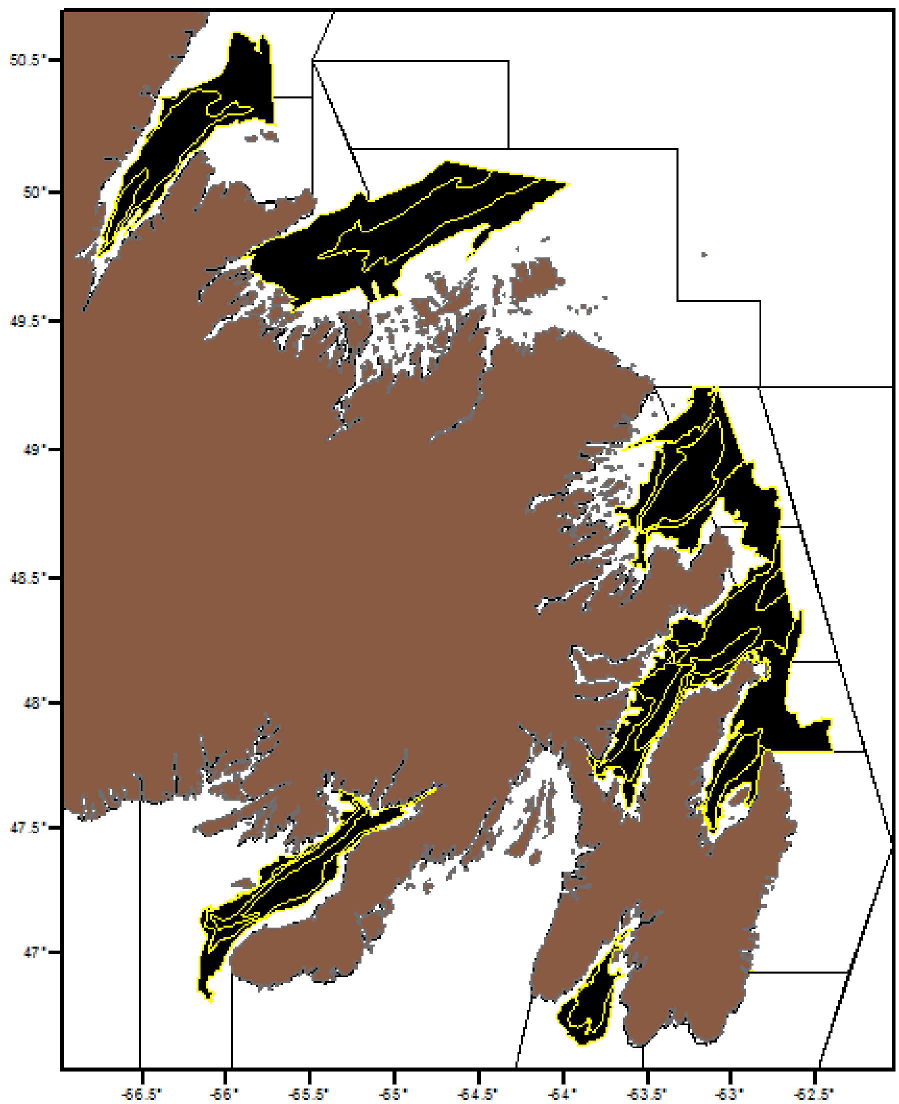

Figure 5. Strata occupied during DFO inshore trap surveys.

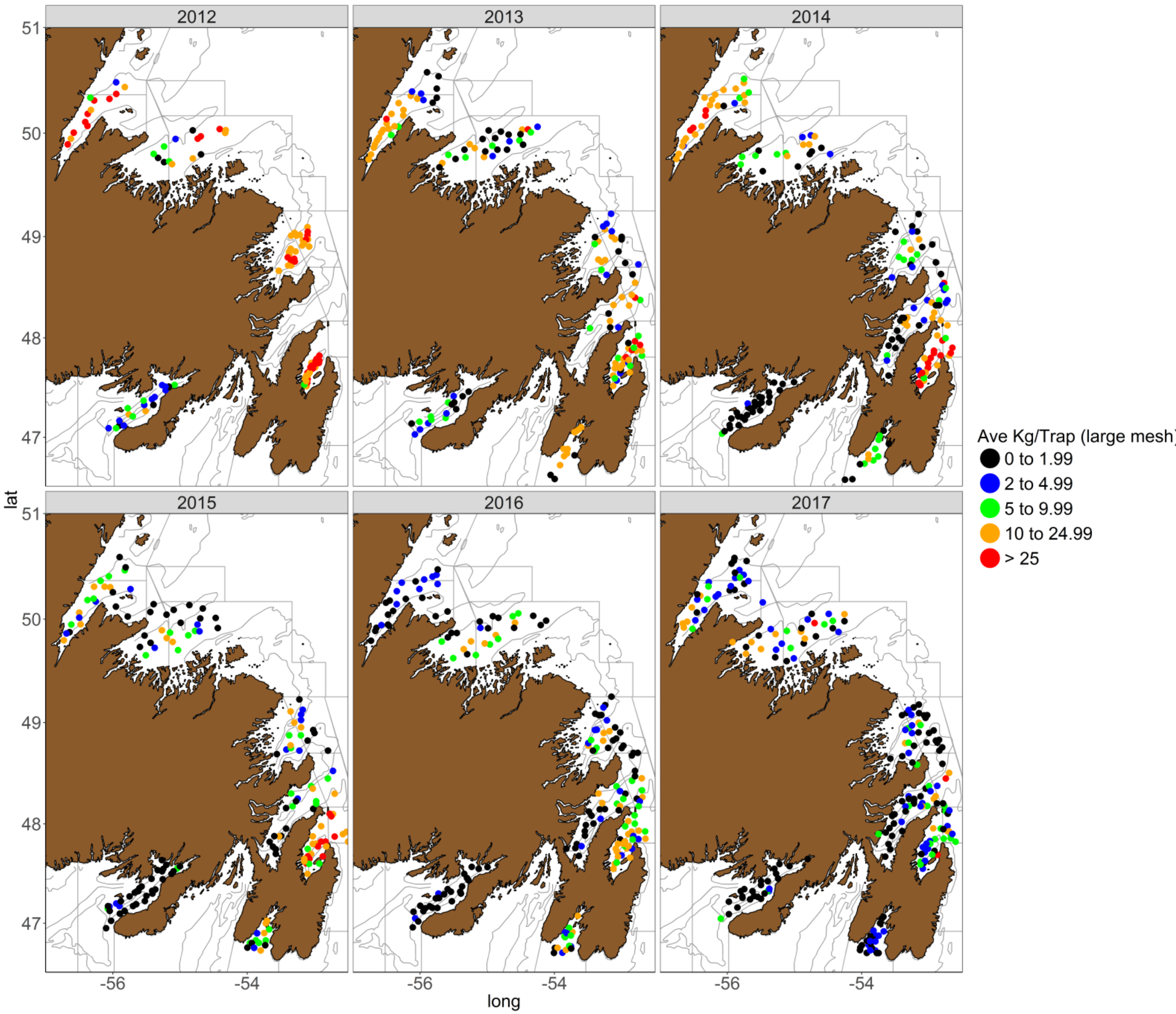

Figure 6. Location of set positions and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the DFO inshore trap surveys (2012-17).

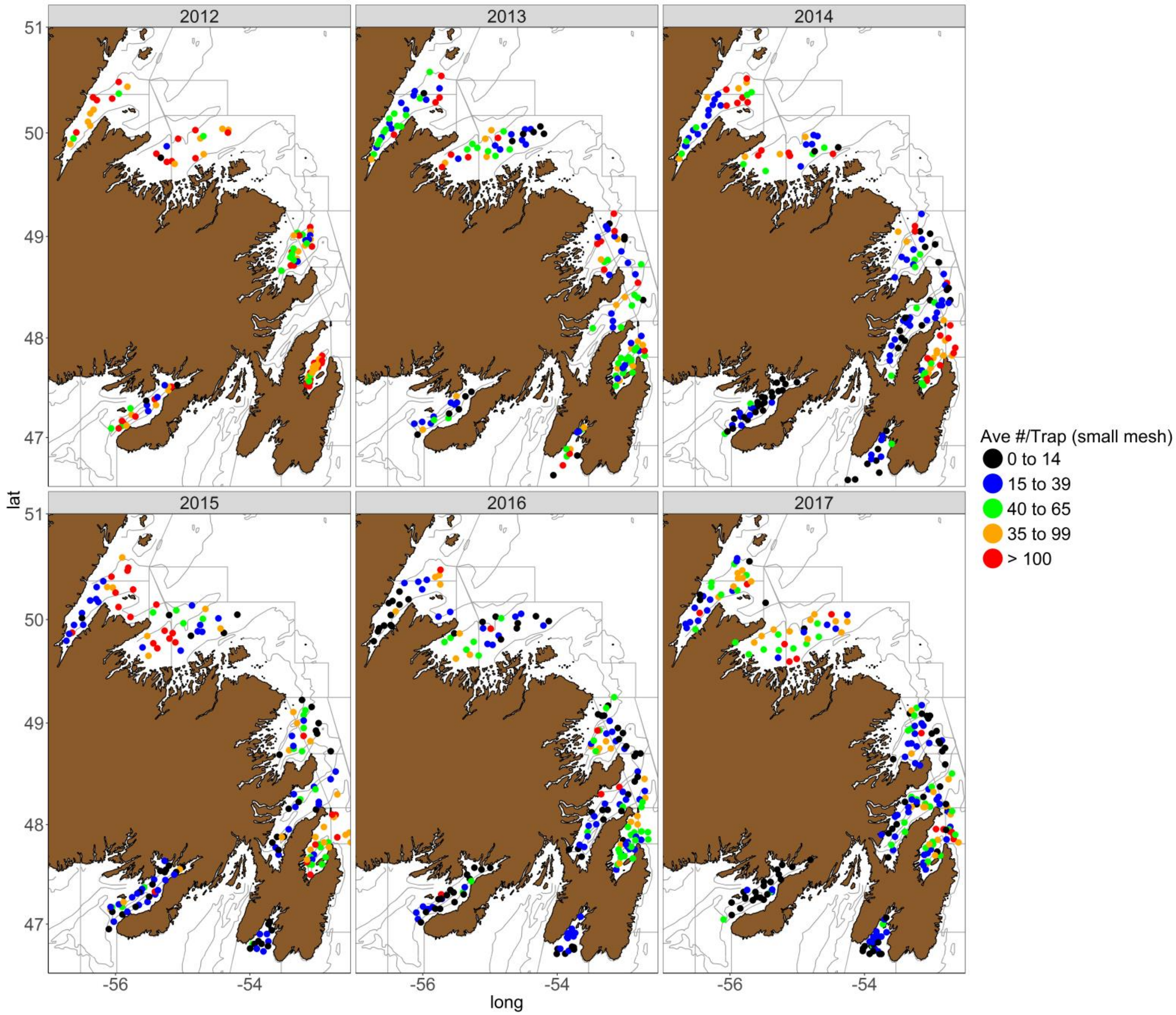

Figure 7. Location of set positions and CPUE (#/trap) of all Snow Crab in small-mesh traps from the DFO inshore trap surveys (2012-17).

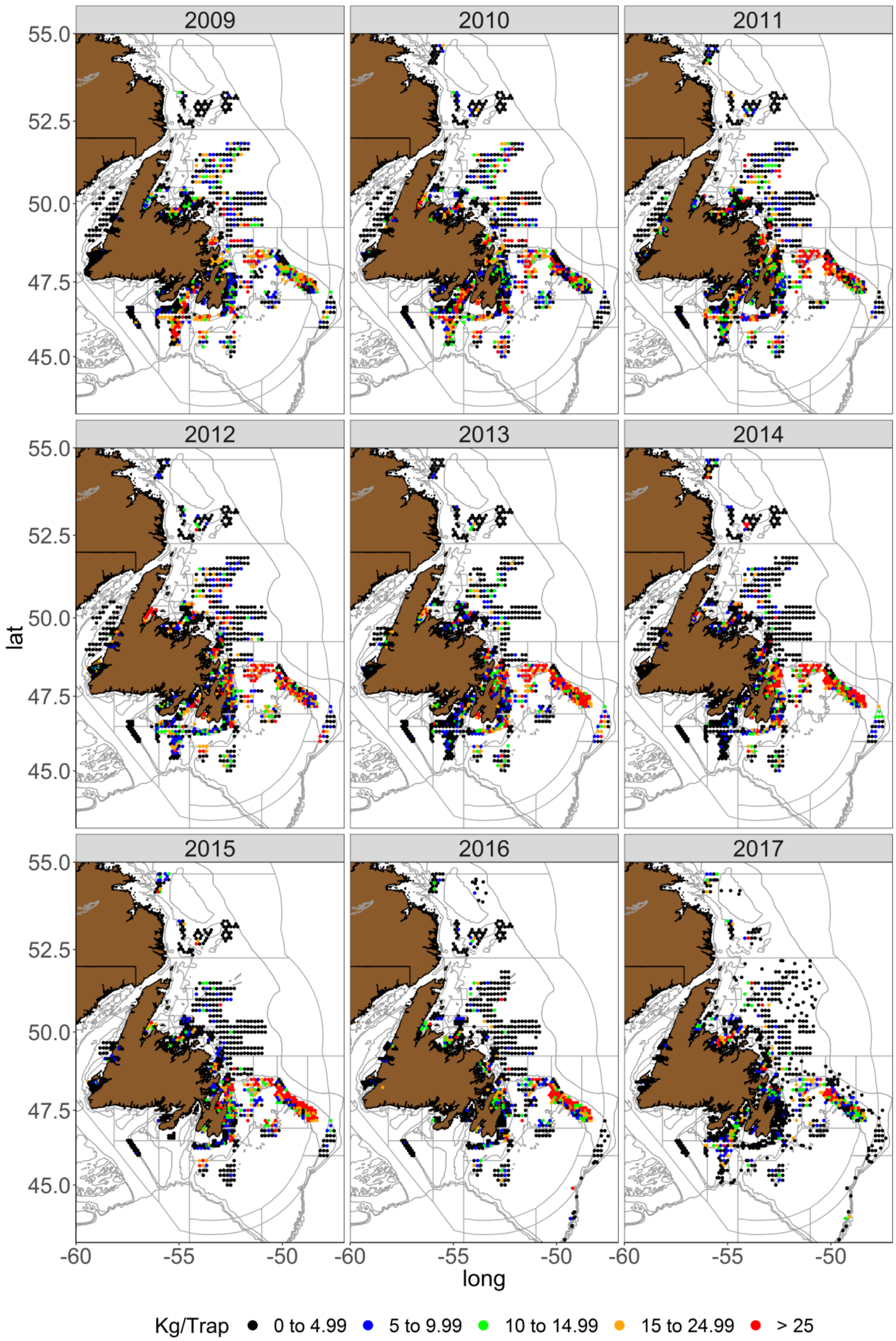

Figure 8. Location of set locations and CPUE (kg/trap) of exploitable Snow Crab in large-mesh traps from the CPS trap survey (2009-17).

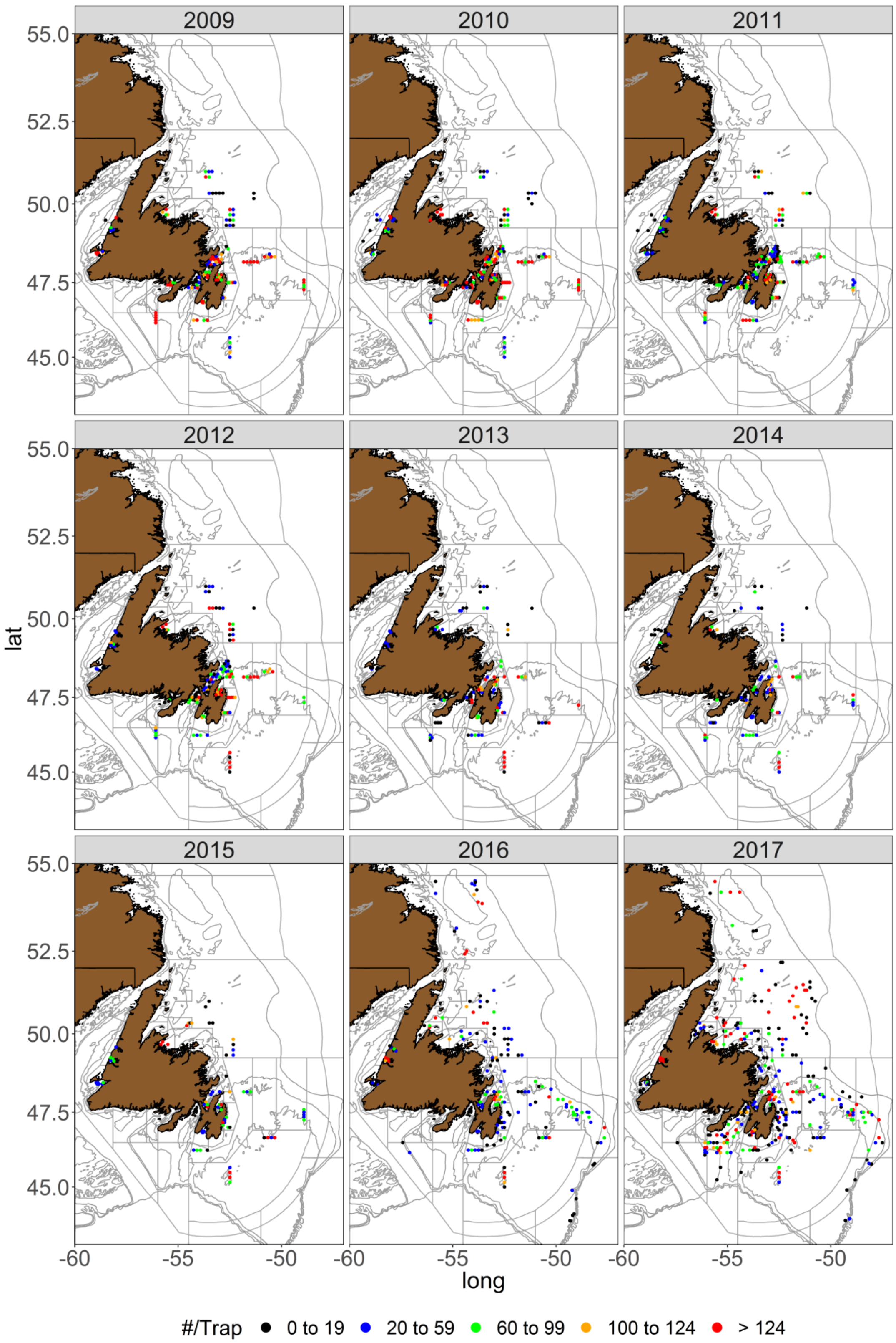

Figure 9. Location of set locations and CPUE (#/trap) of Snow Crab in small-mesh traps from the CPS trap survey (2009-17).

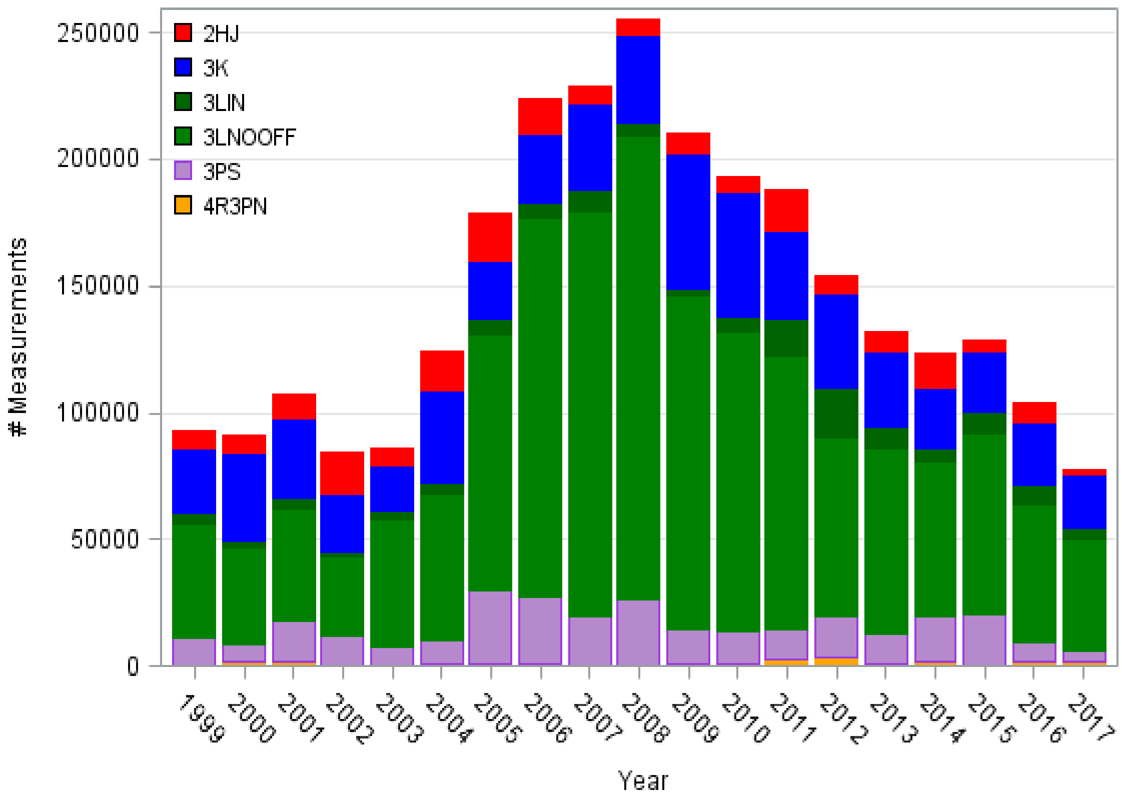

Figure 10. Annual observer sampling by Assessment Division (1999-2017).

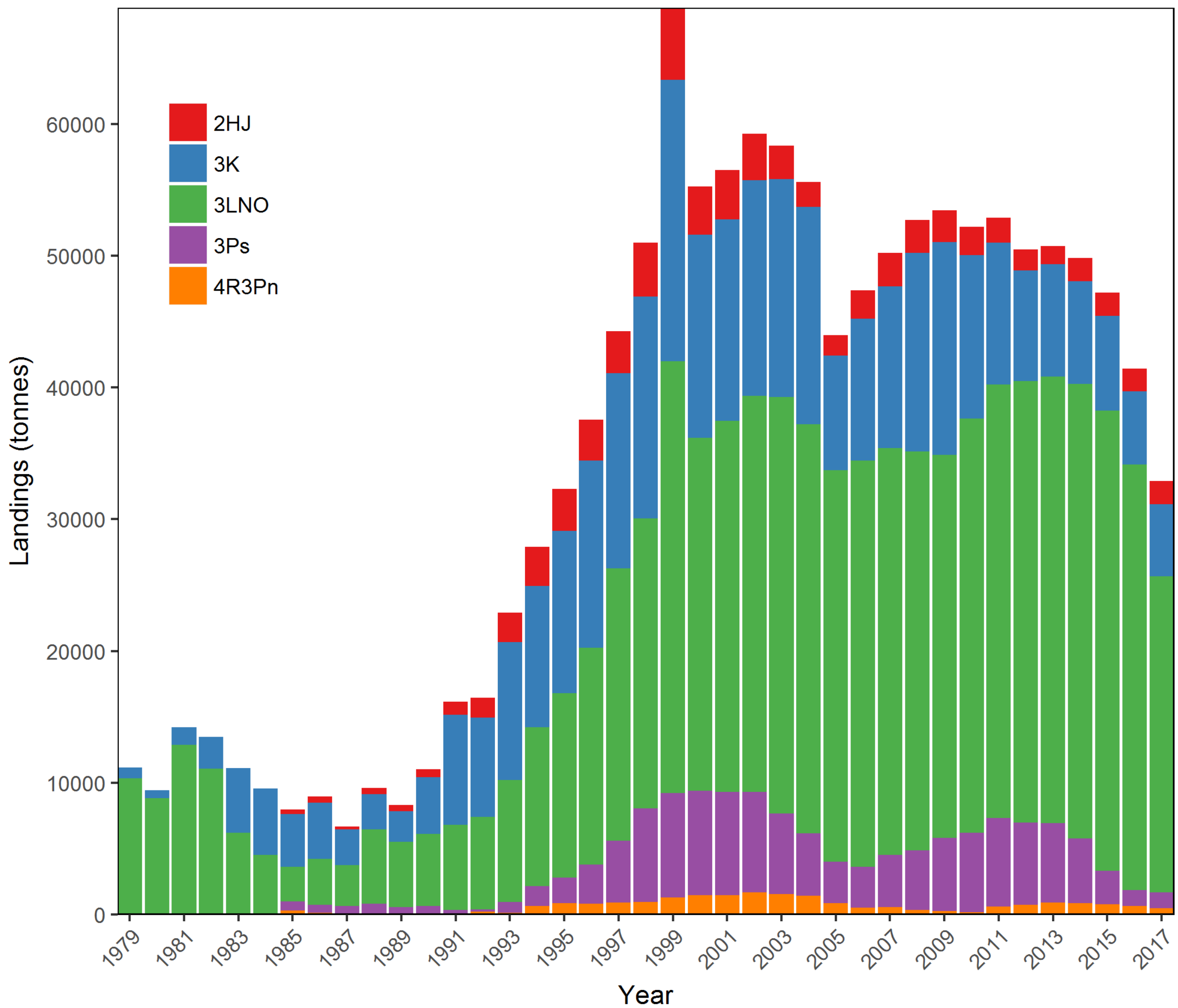

Figure 11. Annual landings (tonnes) of Snow Crab by Assessment Division (1979-2017).

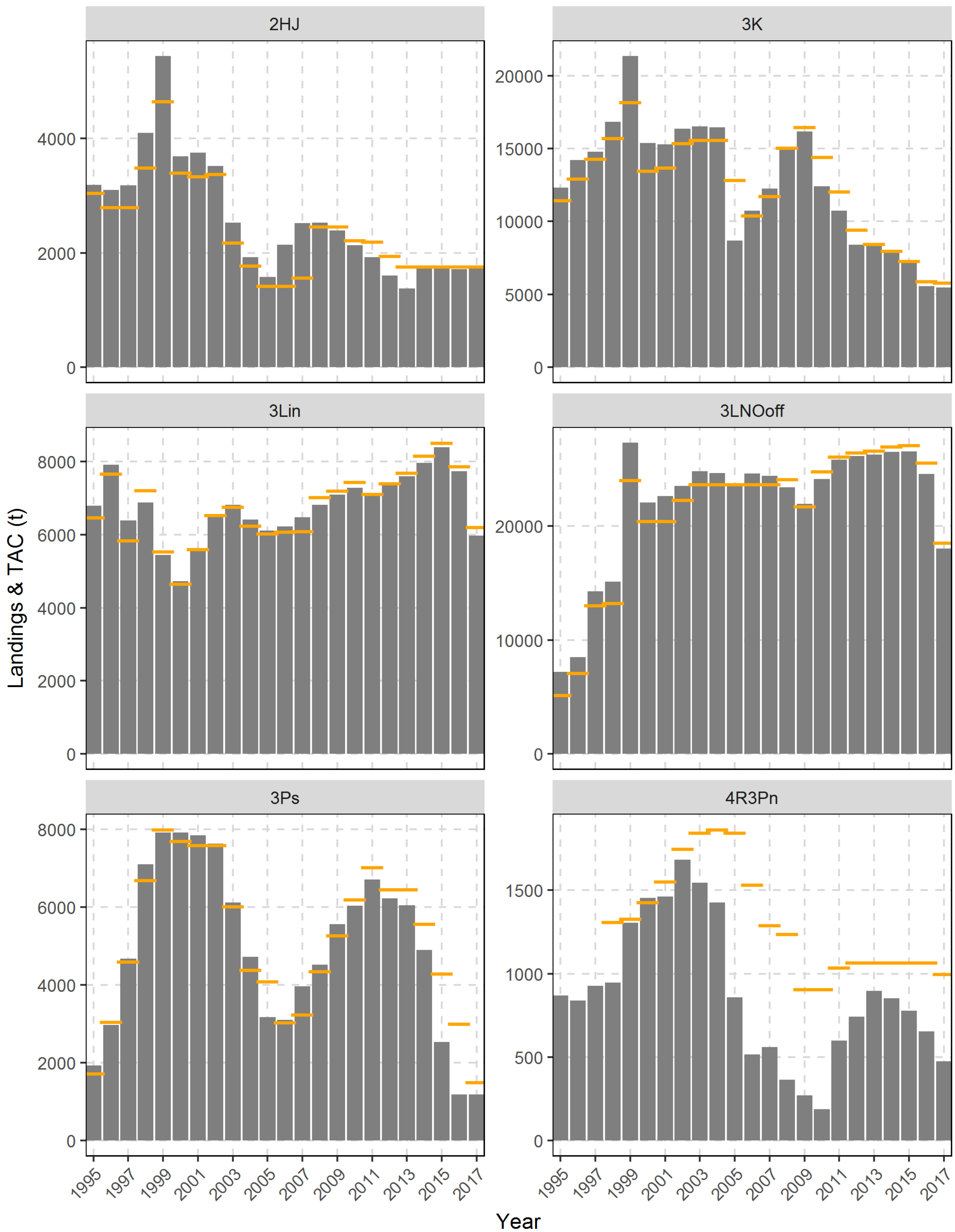

Figure 12. Annual landings (t) of Snow Crab and total allowable catch (TAC) by Assessment Division from 1995 to 2017.

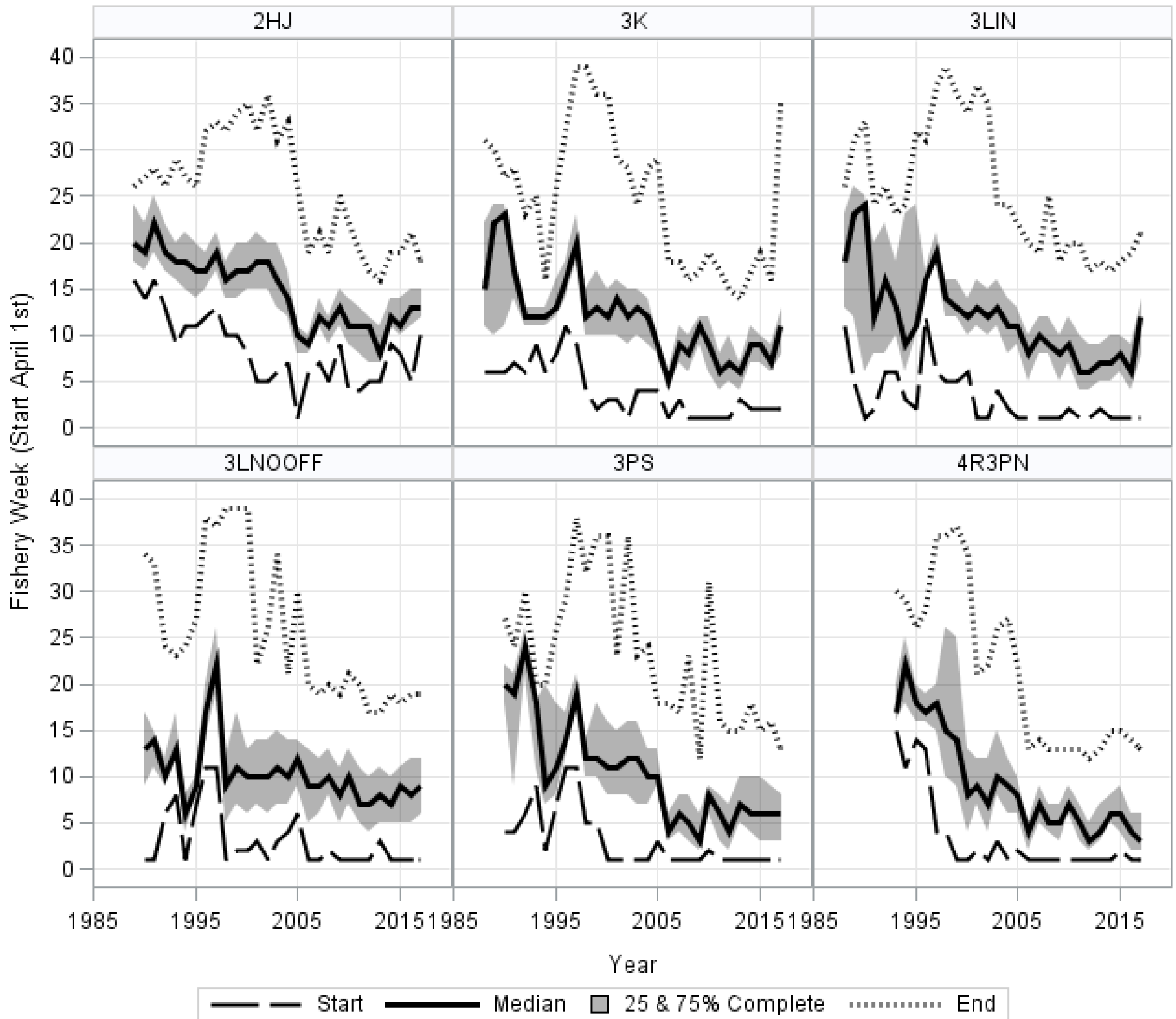

Figure 13. Trends in timing of the fishery by Assessment Division.

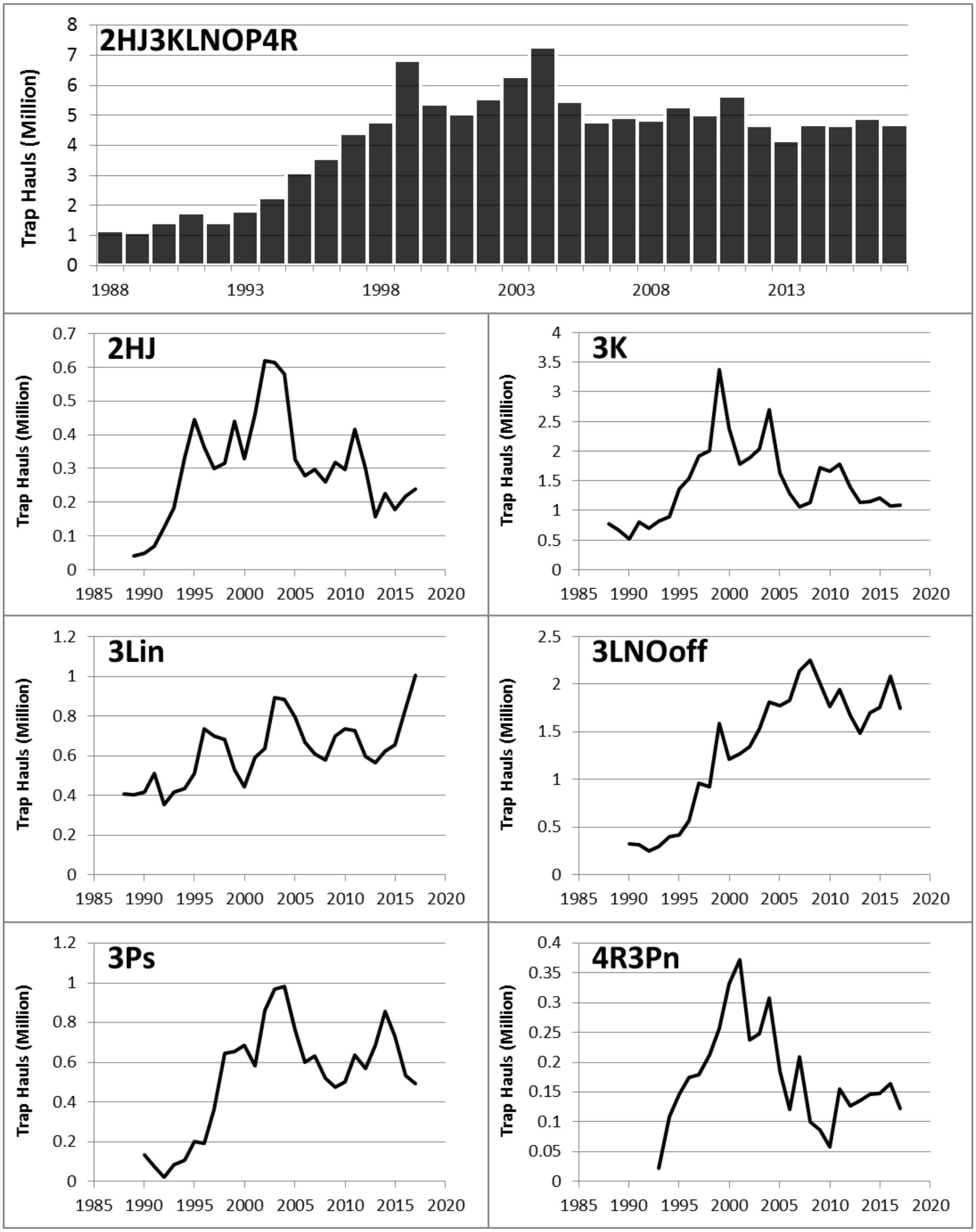

Figure 14. Estimated effort (number of trap hauls) by Assessment Division and in total, by year (1988-2017).

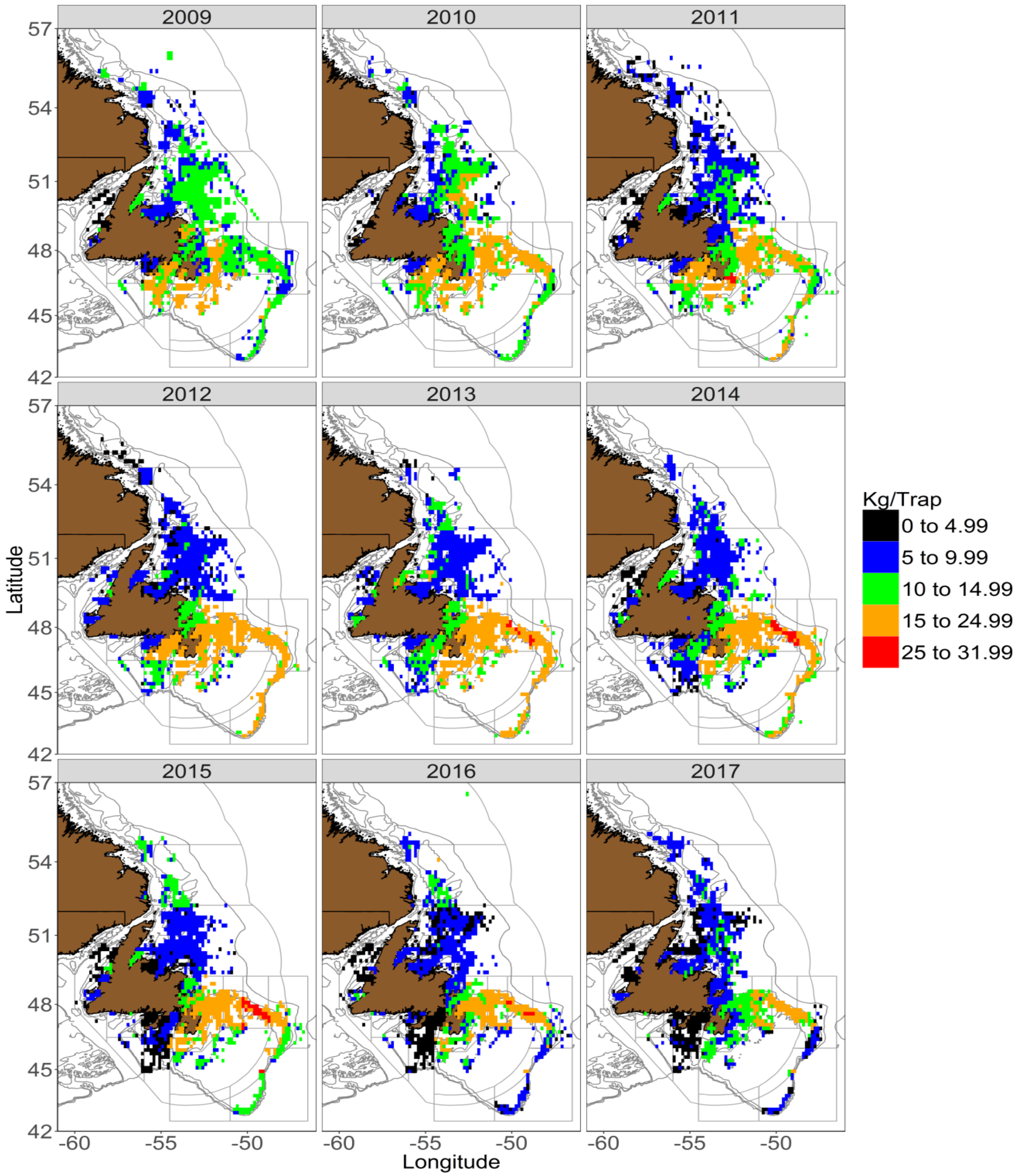

Figure 15. Locations of fishery sets and catch rates (kg/trap) from logbooks (2009-17).

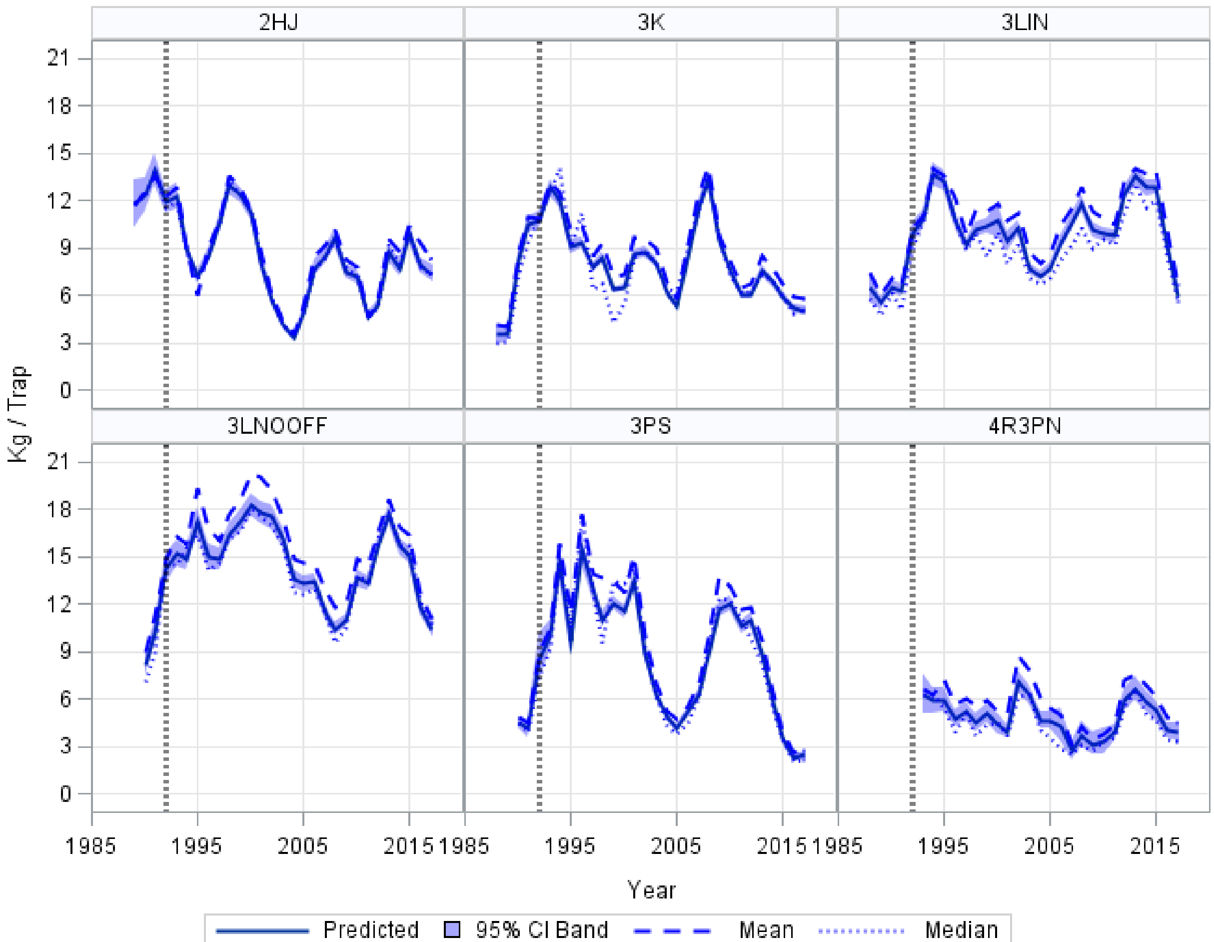

Figure 16. Standardized CPUE (kg/trap) by Assessment Division. Solid line is predicted CPUE and band is 95% confidence intervals. Vertical dashed line represents the beginning of the cod moratorium.

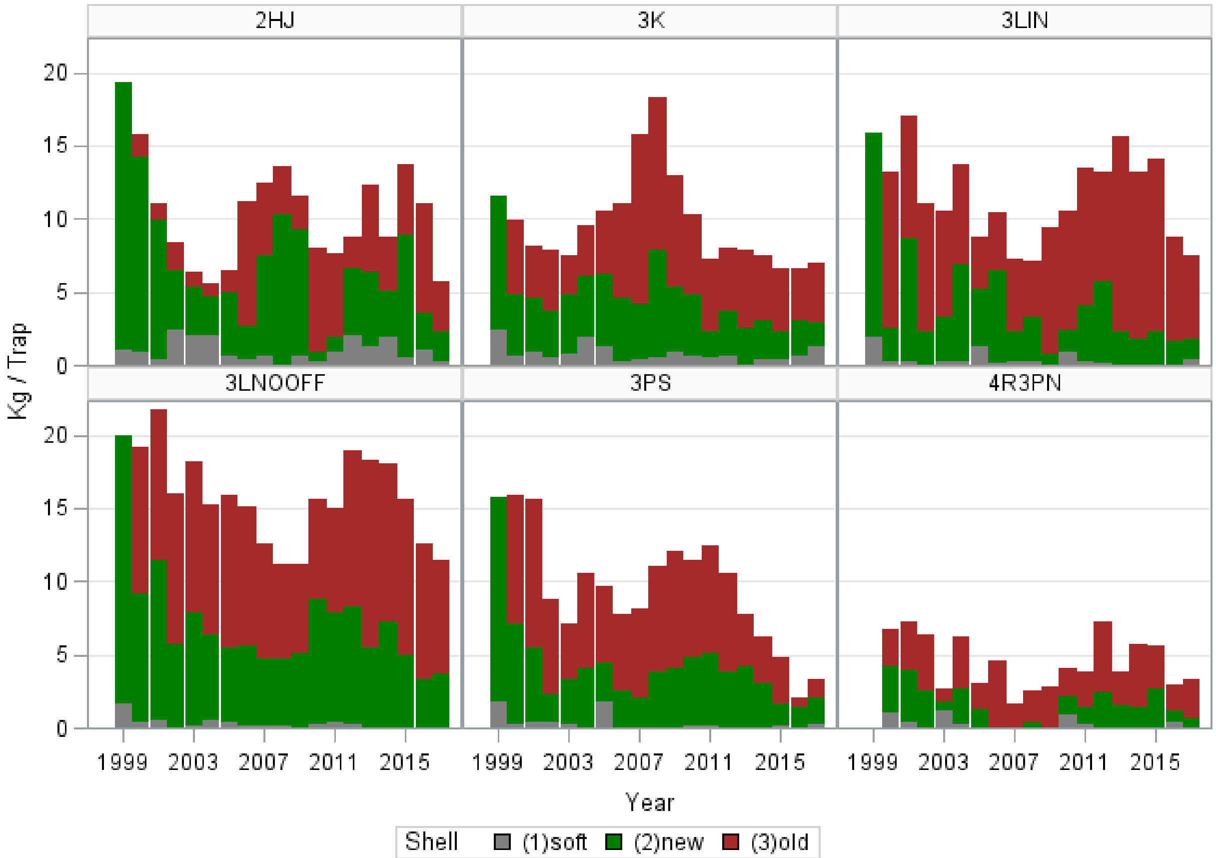

Figure 17. Trends in catch rates (kg/trap) of legal-sized crab by shell condition from observer at-sea sampling by Assessment Division.

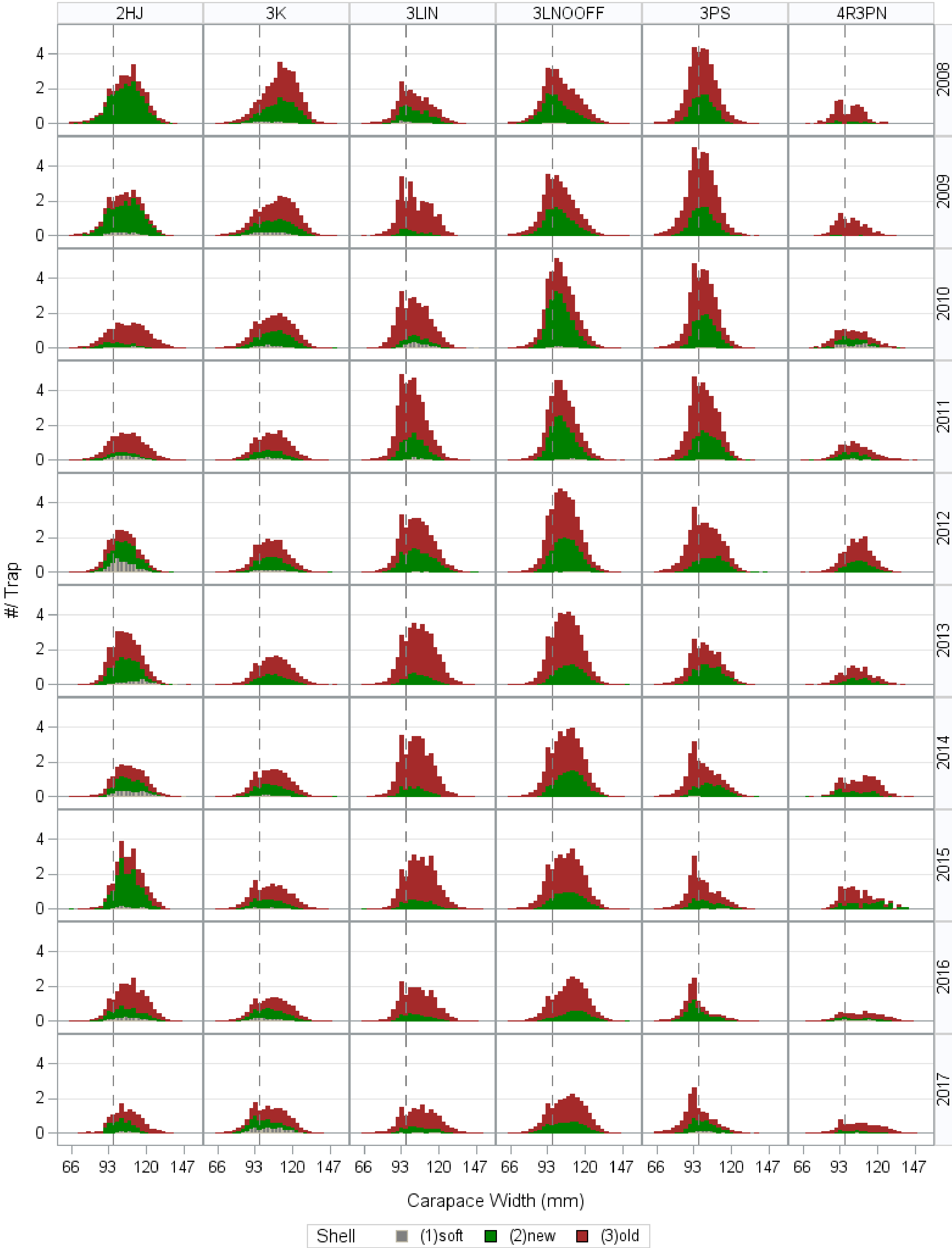

Figure 18. Catch rates (#/trap) based on male carapace width distributions by shell condition from observer sampling in each Assessment Division. The vertical line indicates the minimum legal size.

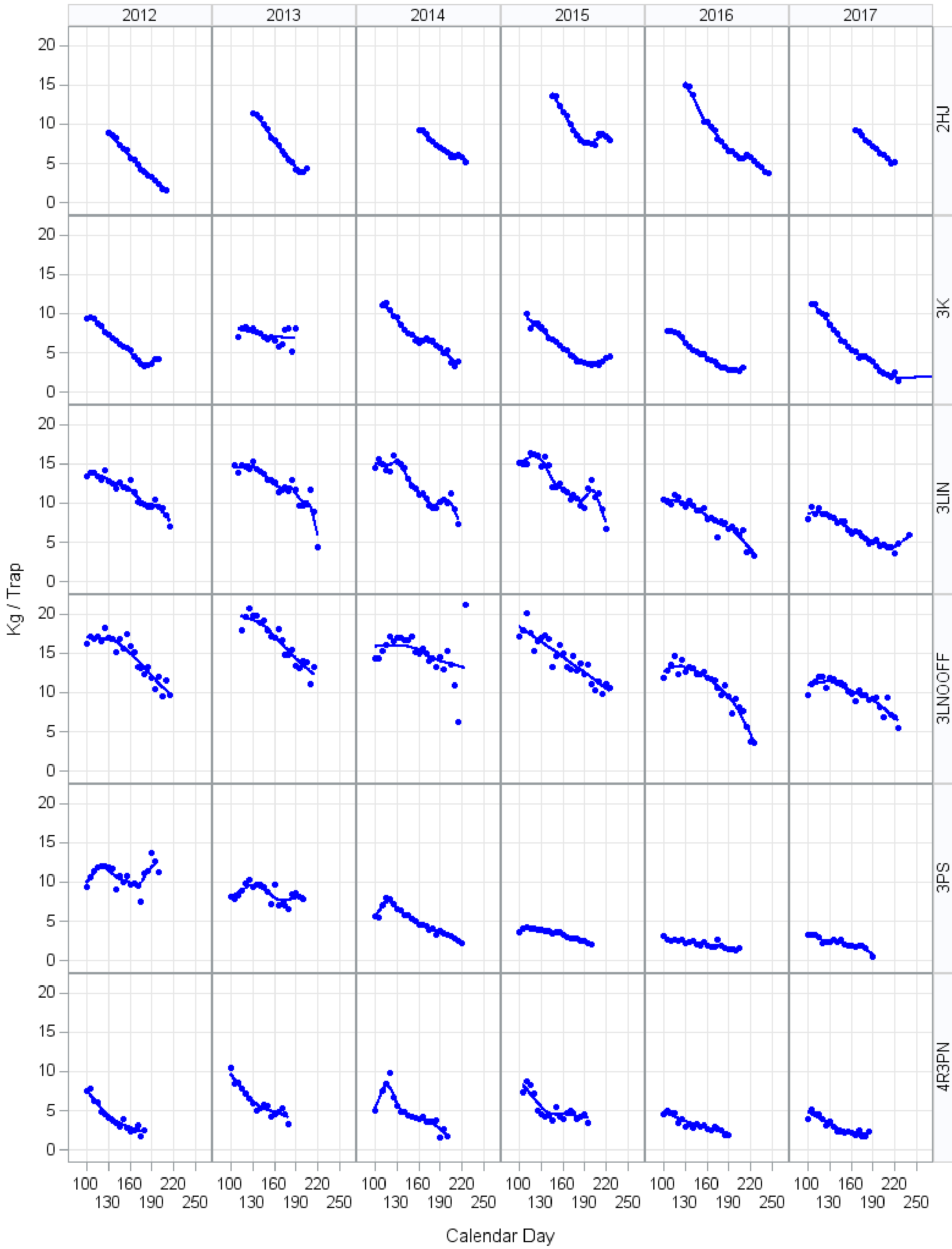

Figure 19. CPUE (kg / trap) of Snow Crab throughout the season (calendar day) in each Assessment Division (2012-17). Derived from logbooks. Points denote means of 5-day time increments and trend lines are loess regression curves.

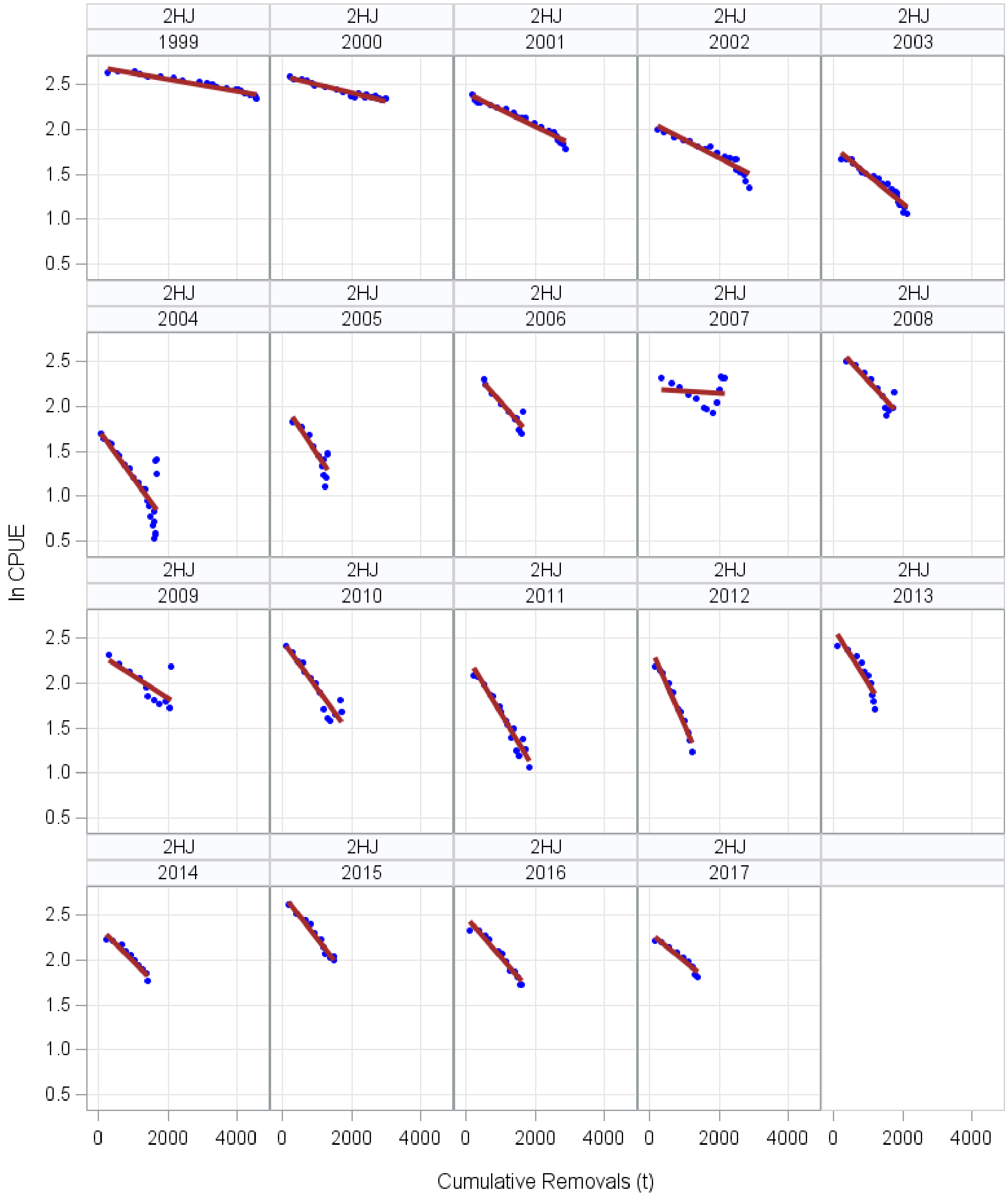

Figure 20. Fishery catch rate depletion regression models on 5-day time increment catch rates from logbooks in Assessment Divisions 2HJ (1999-2017).

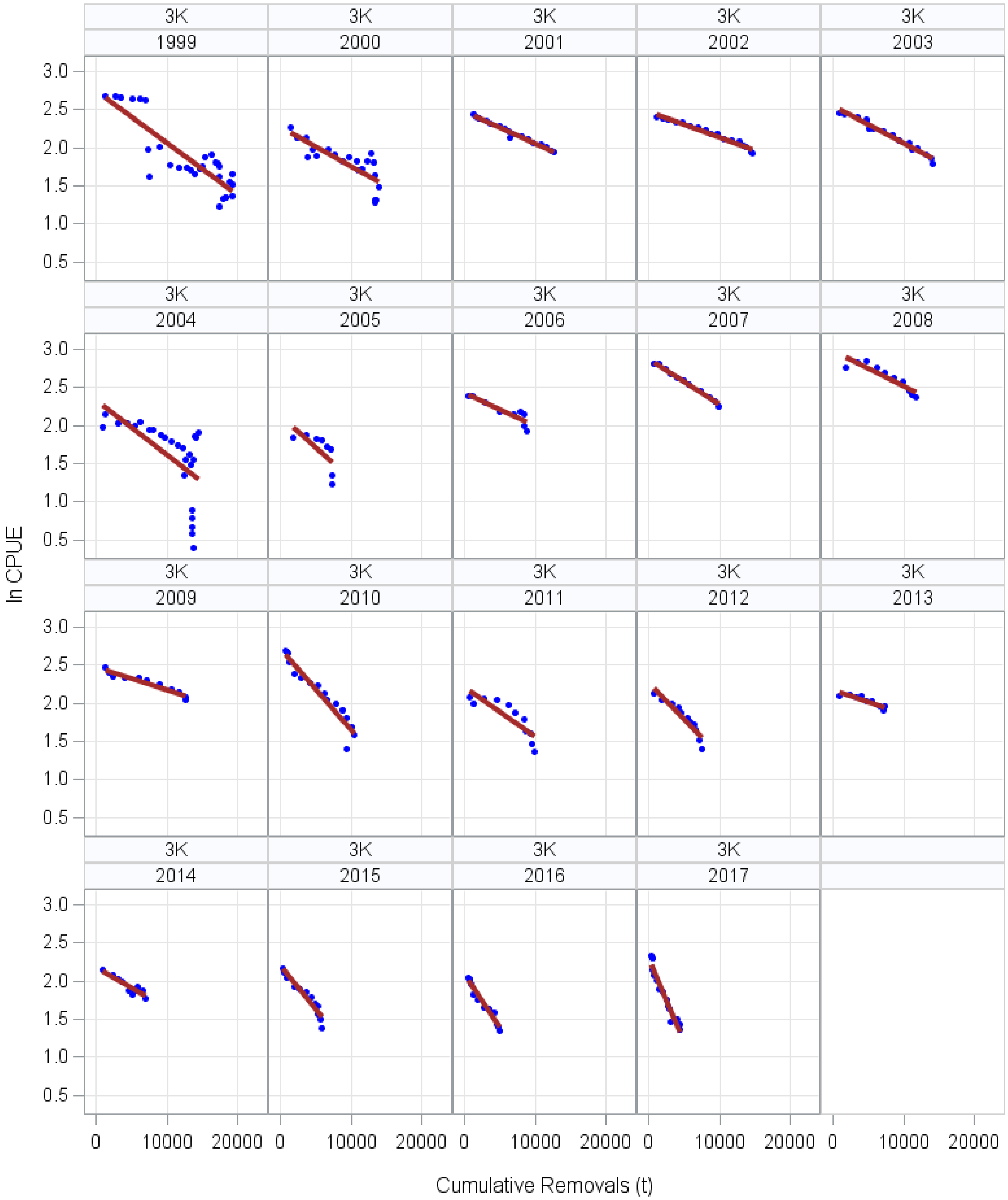

Figure 21. Fishery catch rate depletion regression models on 5-day time increment catch rates from logbooks in Assessment Division 3K (1999-2017).

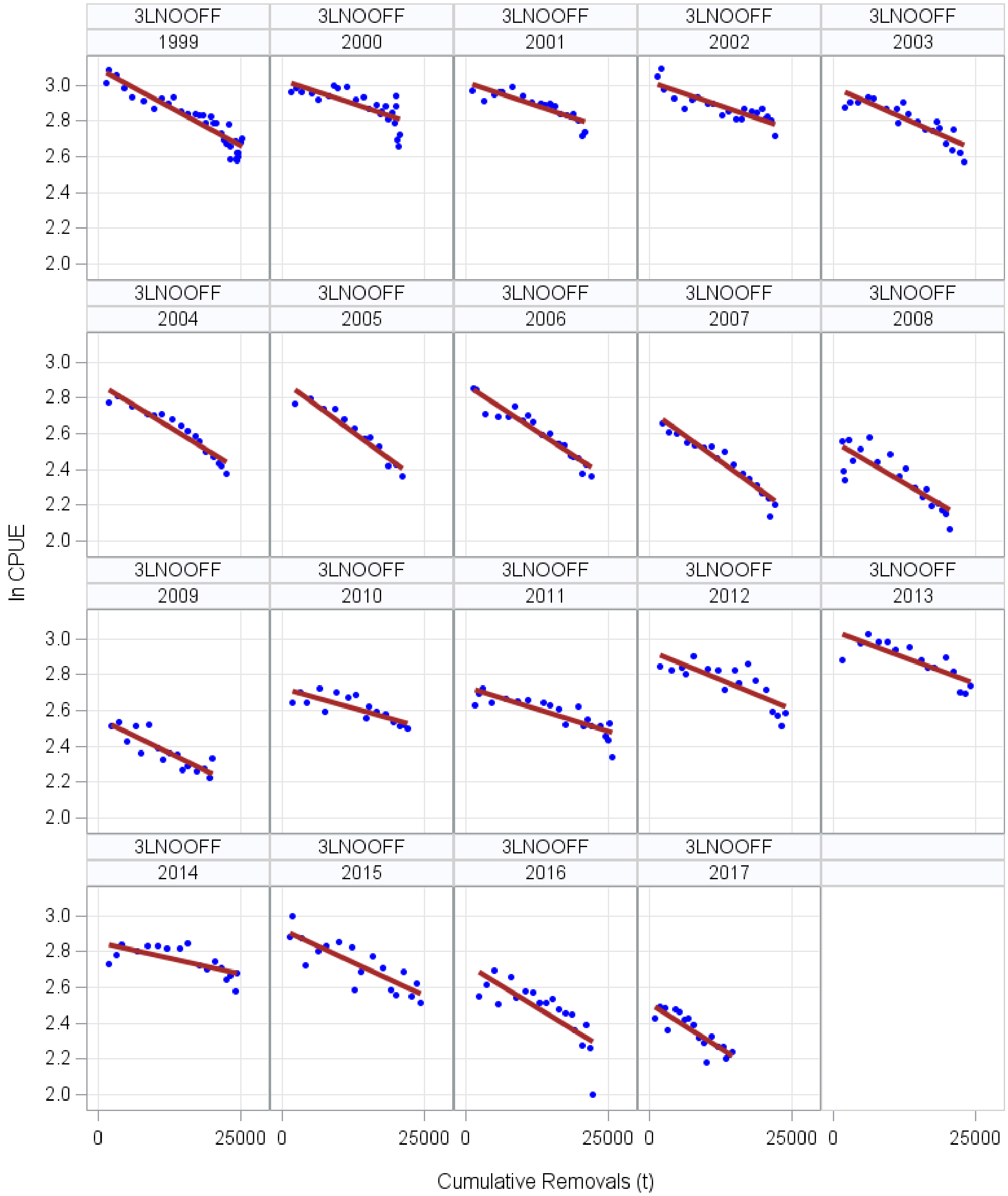

Figure 22. Fishery catch rate depletion regression models on 5-day time increment catch rates from logbooks in Assessment Divisions 3LNO offshore (1999-2017).

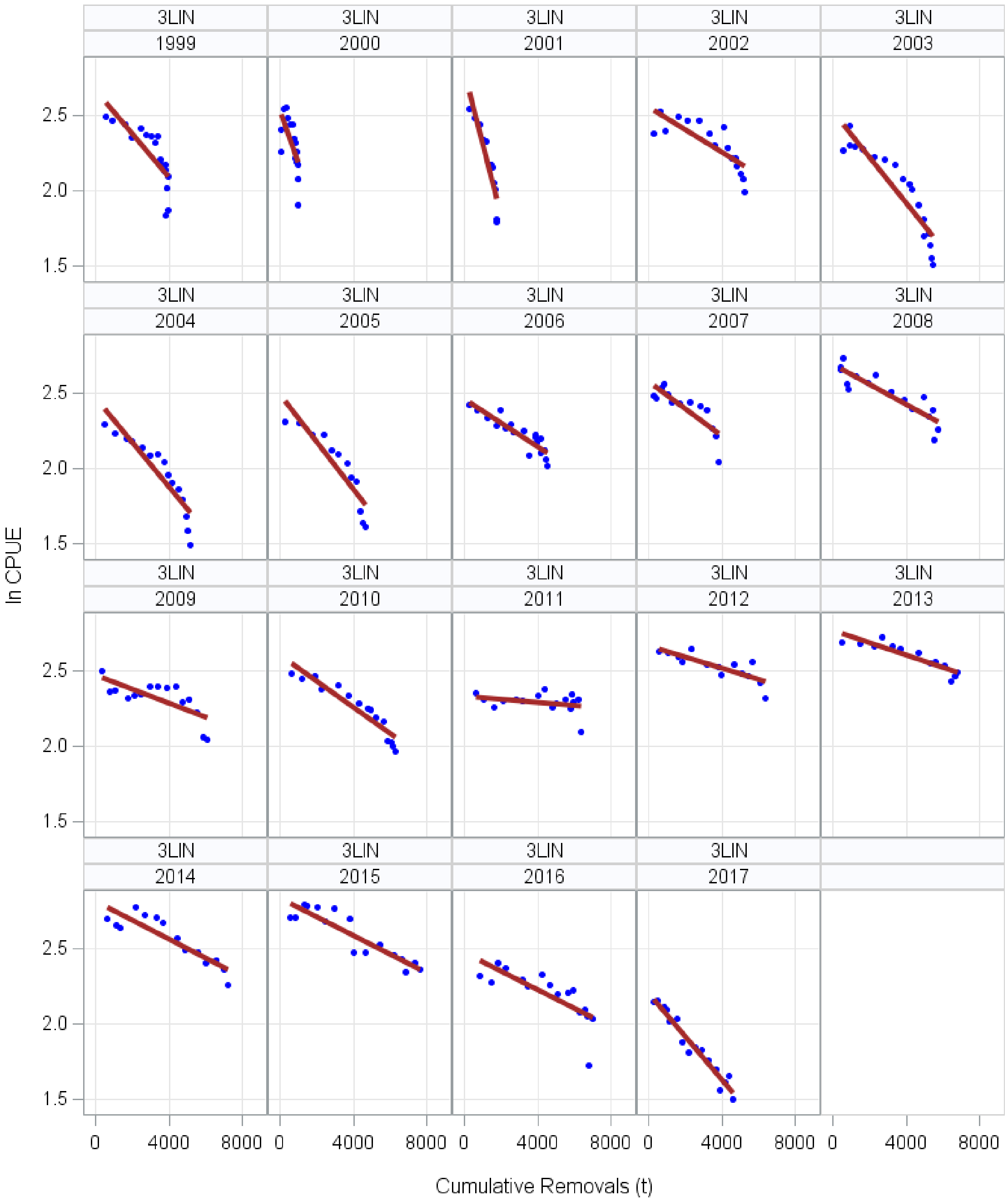

Figure 23. Fishery catch rate depletion regression models on 5-day time increment catch rates from logbooks in Assessment Division 3L inshore (1999-2017).

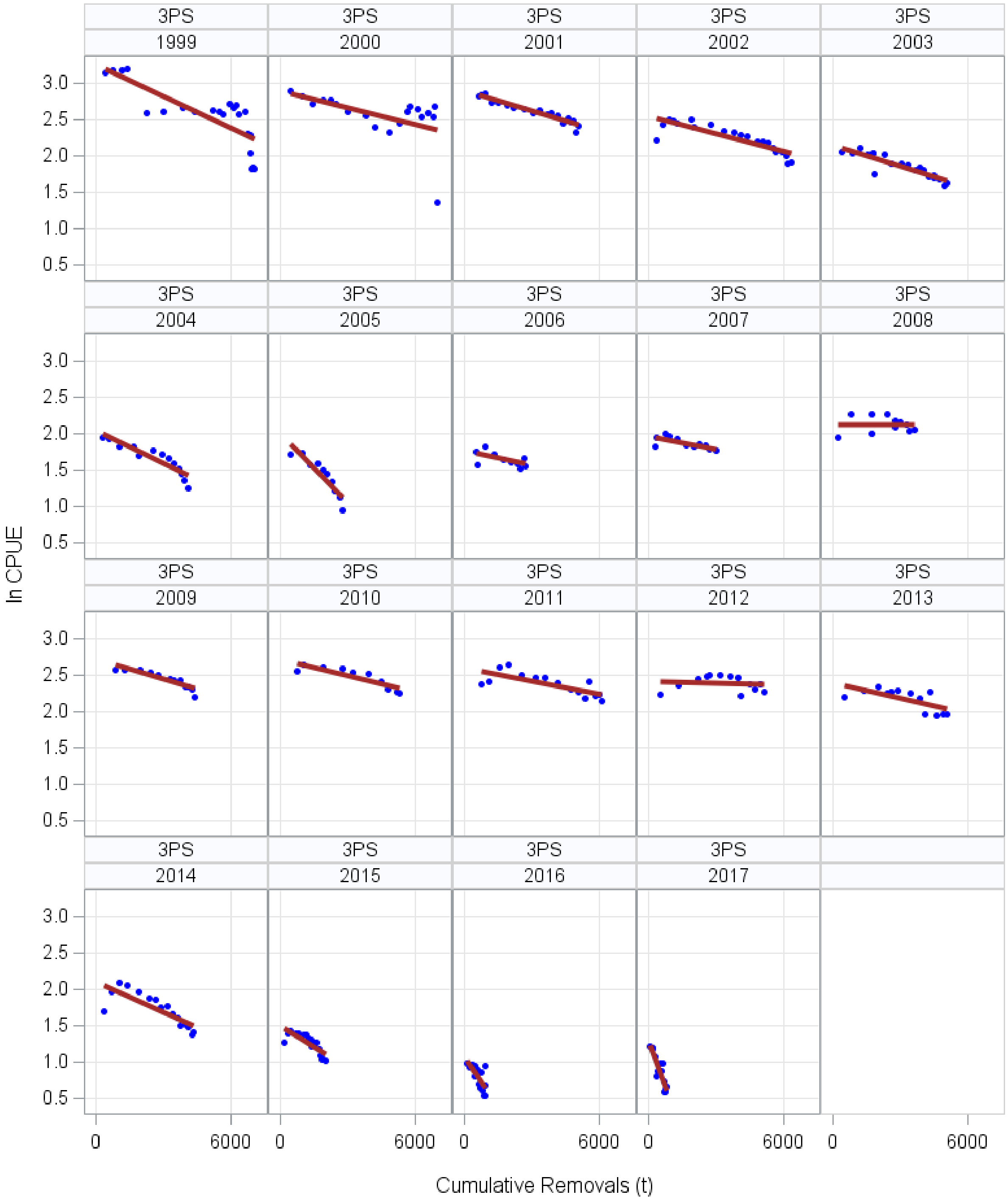

Figure 24. Fishery catch rate depletion regression models on 5-day time increment catch rates from logbooks in Assessment Subdivision 3Ps (1999-2017).

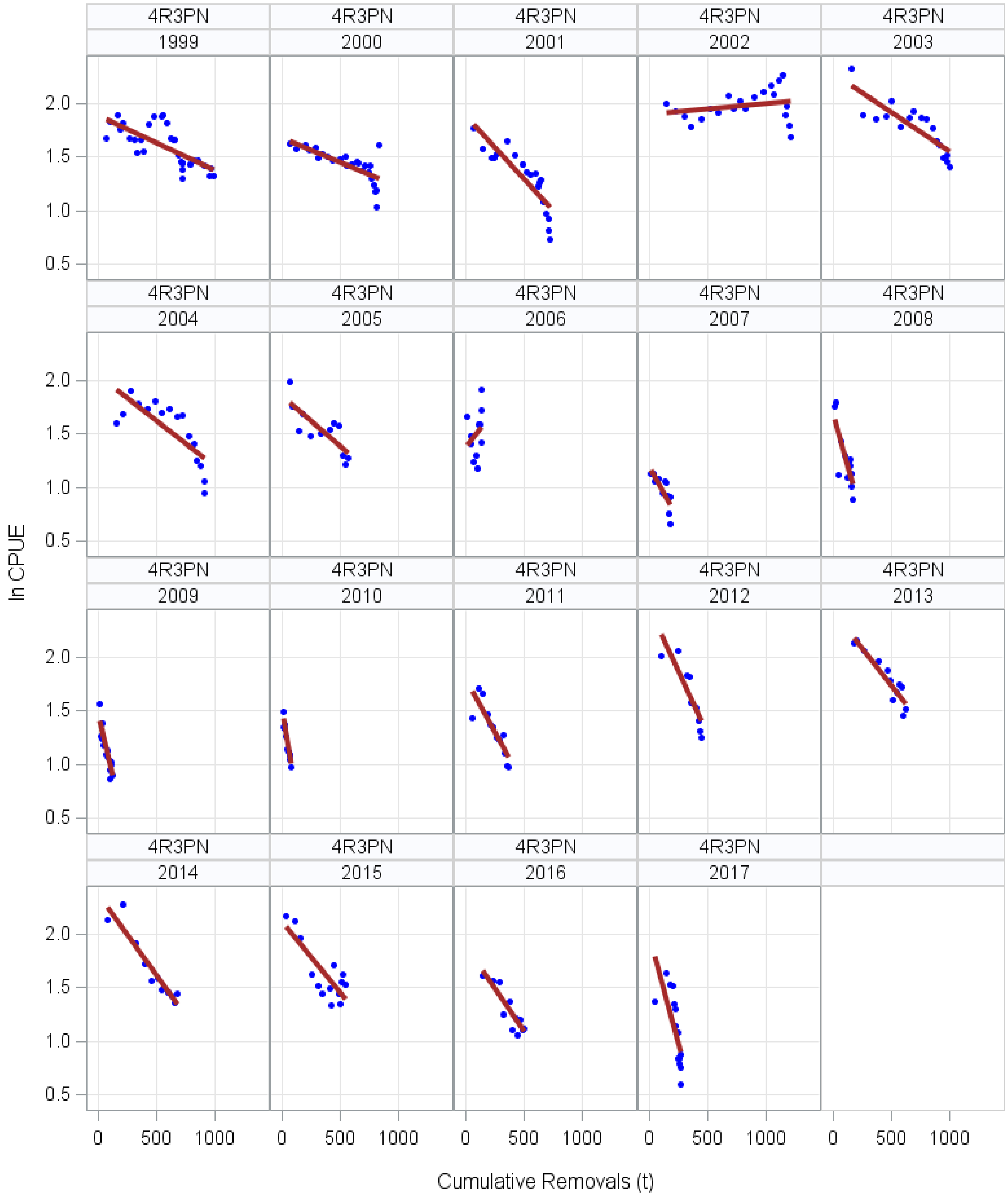

Figure 25. Fishery catch rate depletion regression models on 5-day time increment catch rates from logbooks in Assessment Divisions 4R3Pn (1999-2017).

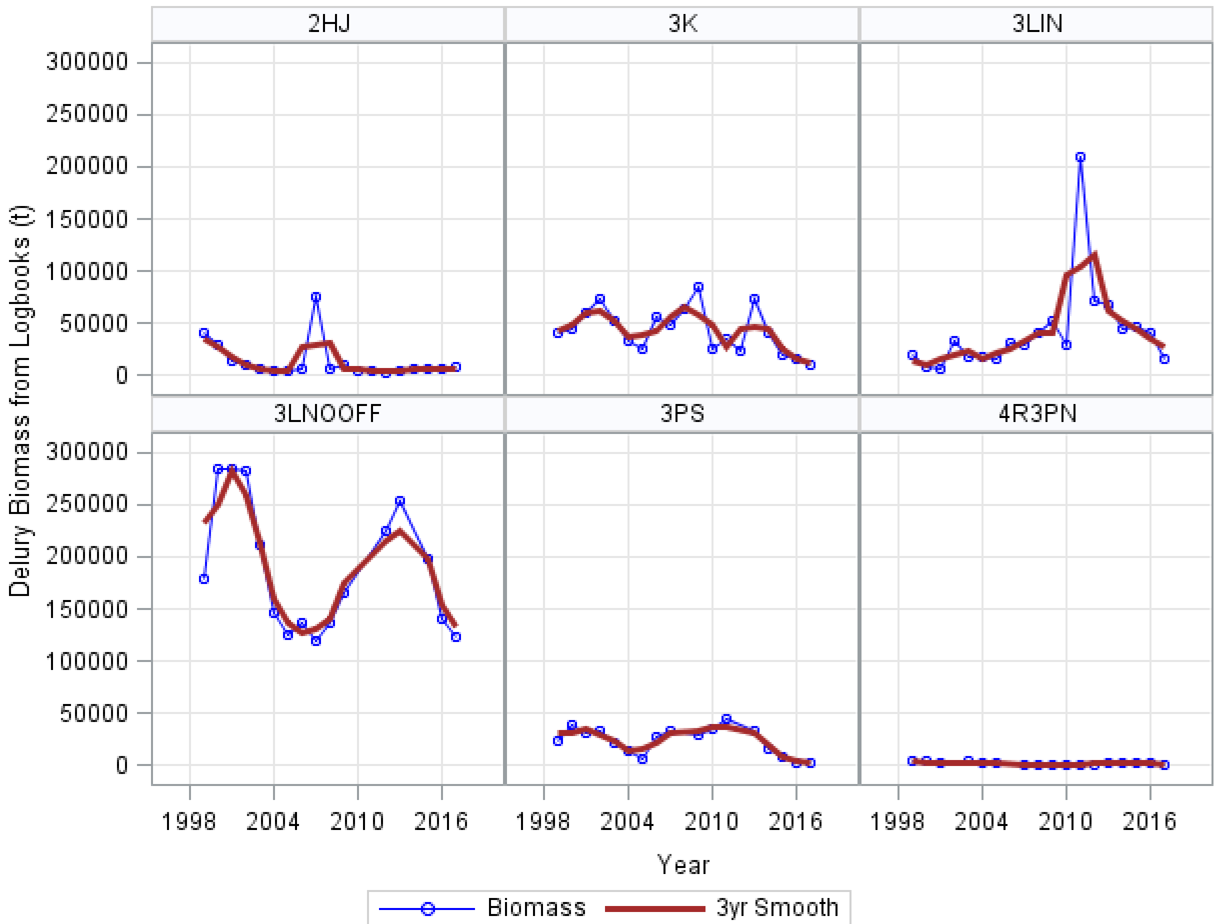

Figure 26. Fishery depletion model biomass estimates of crab (t) from logbooks and 3-year centered moving averages used to smooth estimates for trawl catchability (q) conversion factors in each Assessment Division.

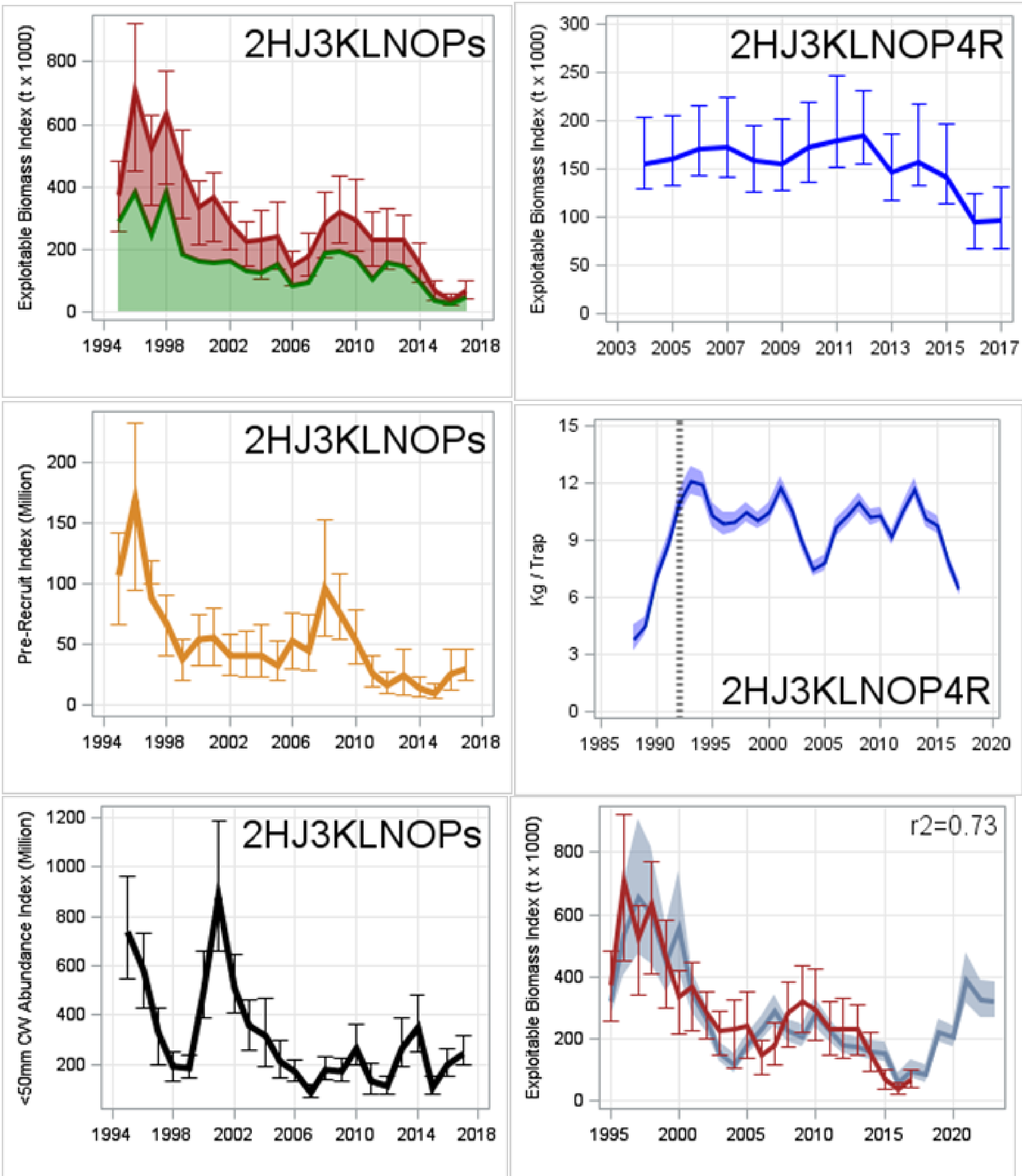

*Figure 27. Summary of Snow Crab stock status in Assessment Divisions 2HJ3KLNOP4R: Top-left: Annual exploitable biomass index (t *1,000) by shell condition (1995-2017) based on trawl surveys. Top-right: Trap survey-based exploitable biomass index for Divisions 2HJ3KLNOP4R (t*1,000) (2004-17). Middle-left: Pre-recruit index (# million) from trawl surveys (1995-2017). Middle-right: Fishery CPUE for Divisions 2HJ3KLNOP4R (1988-2017). Bottom-left: Annual abundance index (# million) of small crab (<50 mm carapace width) from trawl surveys (1995-2017). Bottom-right: Exploitable biomass index (t *1,000) from trawl survey (red) and 3-year centered moving average of annual North Atlantic Oscillation (NAO) index lagged by 7 years (1995-2025).*

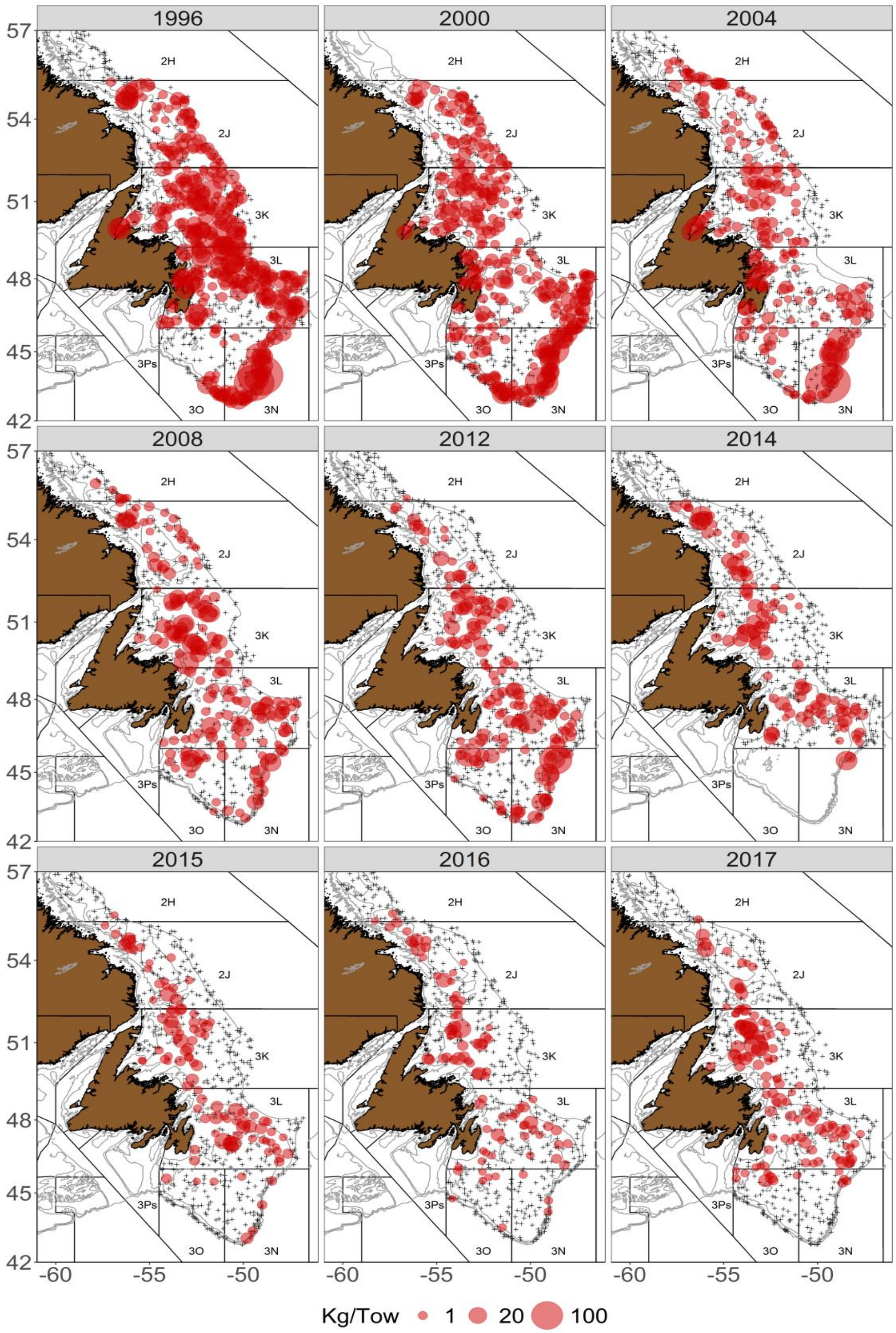

Figure 28. Distribution of exploitable males (kg/tow) from Assessment Divisions 2HJ3KLNO fall bottom trawl surveys from 1996, 2000, 2004, 2008, 2012, and 2014-17. Data standardized by vessel.

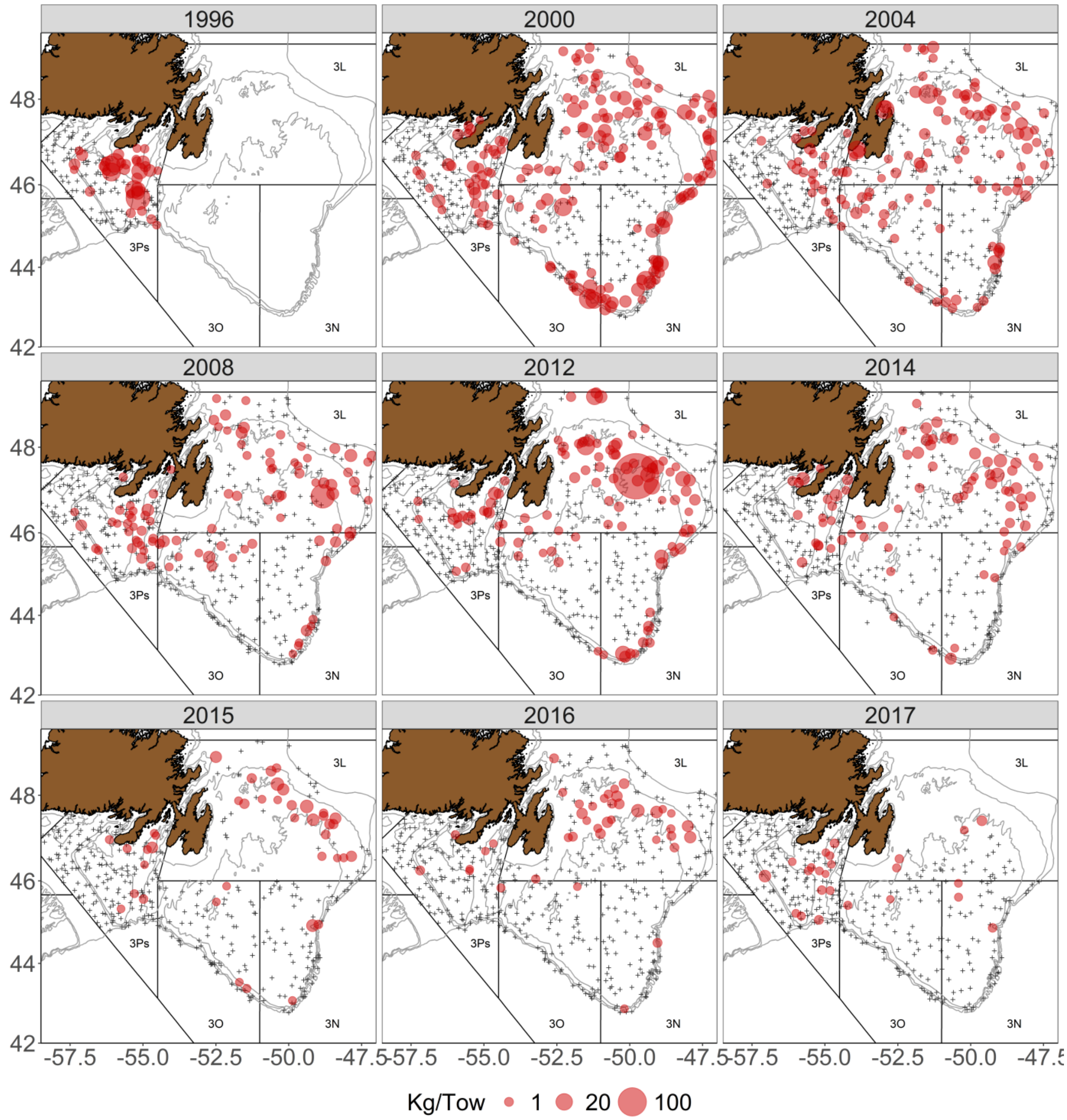

Figure 29. Distribution of exploitable males (kg/tow) from Assessment Divisions 3LNOPs spring bottom trawl surveys from 1996, 2000, 2004, 2008, 2012, and 2014-17. Data standardized by vessel.

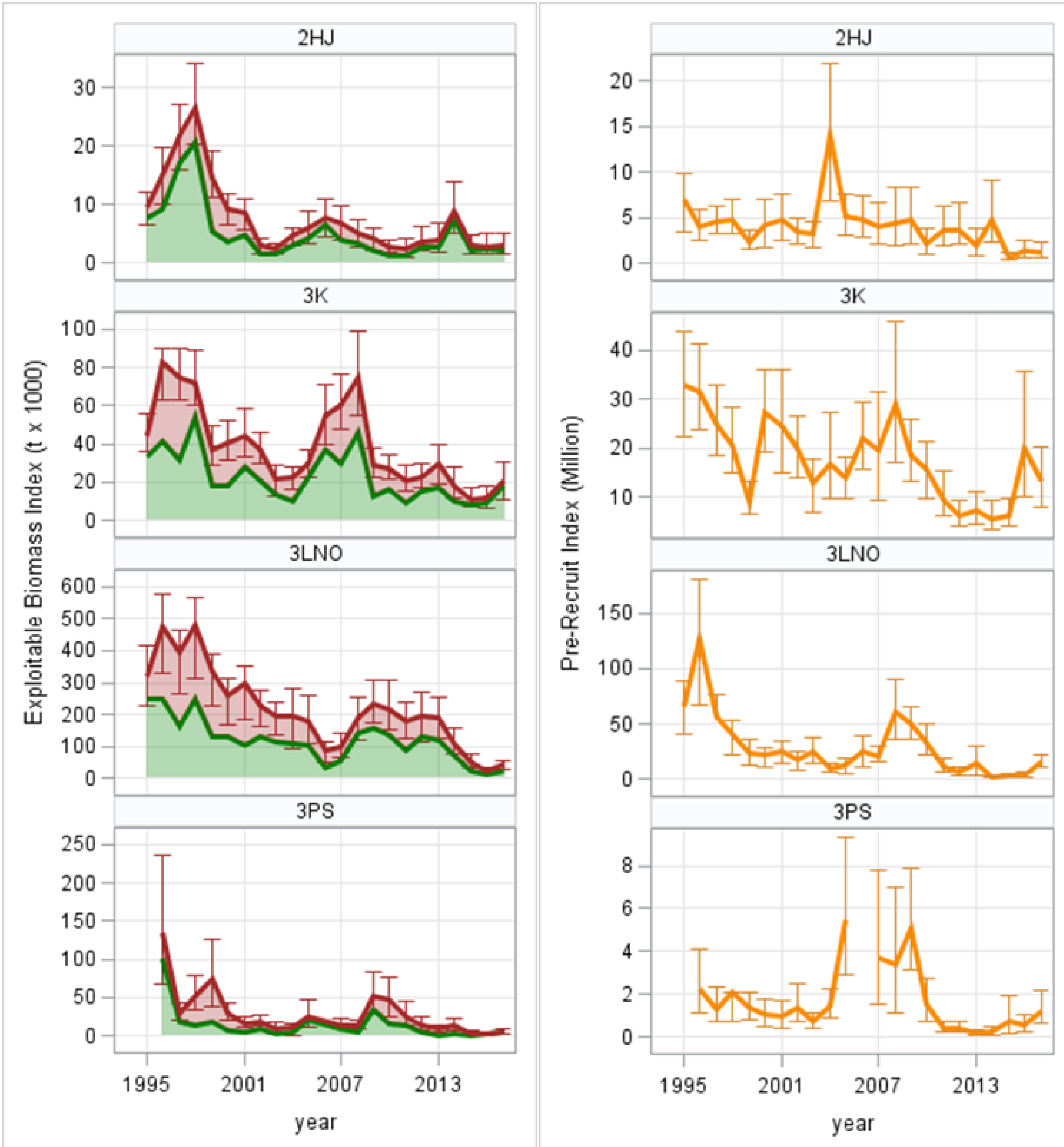

*Figure 30. Left: Trawl survey exploitable biomass indices (t * 1,000) by shell condition and Assessment Division. Soft and new-shell crab represent recruitment (green) and intermediate and old-shell crab represent residual biomass (red). Right: Overall trawl survey pre-recruit biomass index (t * million) by Assessment Division.*

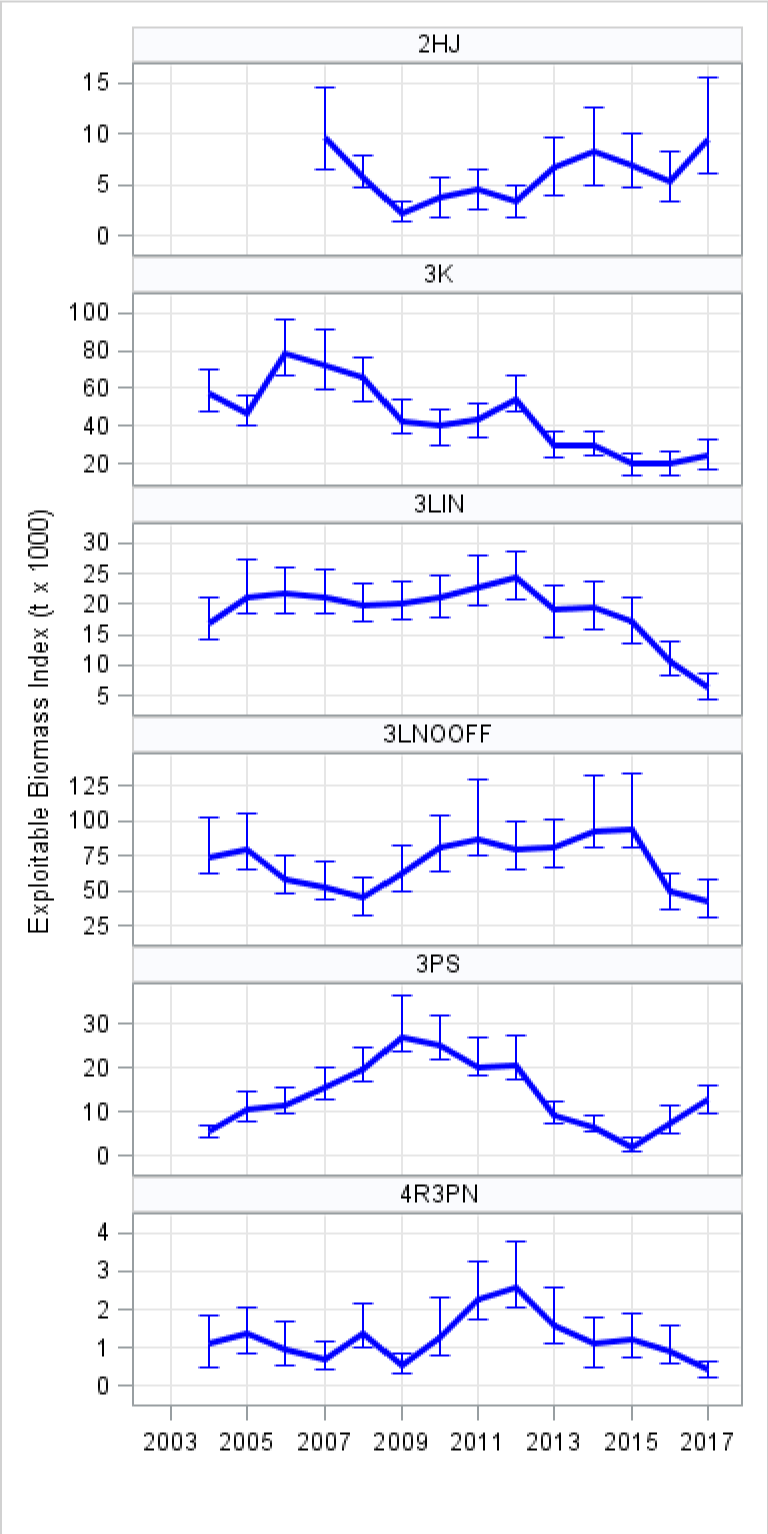

Figure 31. Trap survey-based exploitable biomass index by Assessment Division 2HJ3KLNOP4R (2004-17).

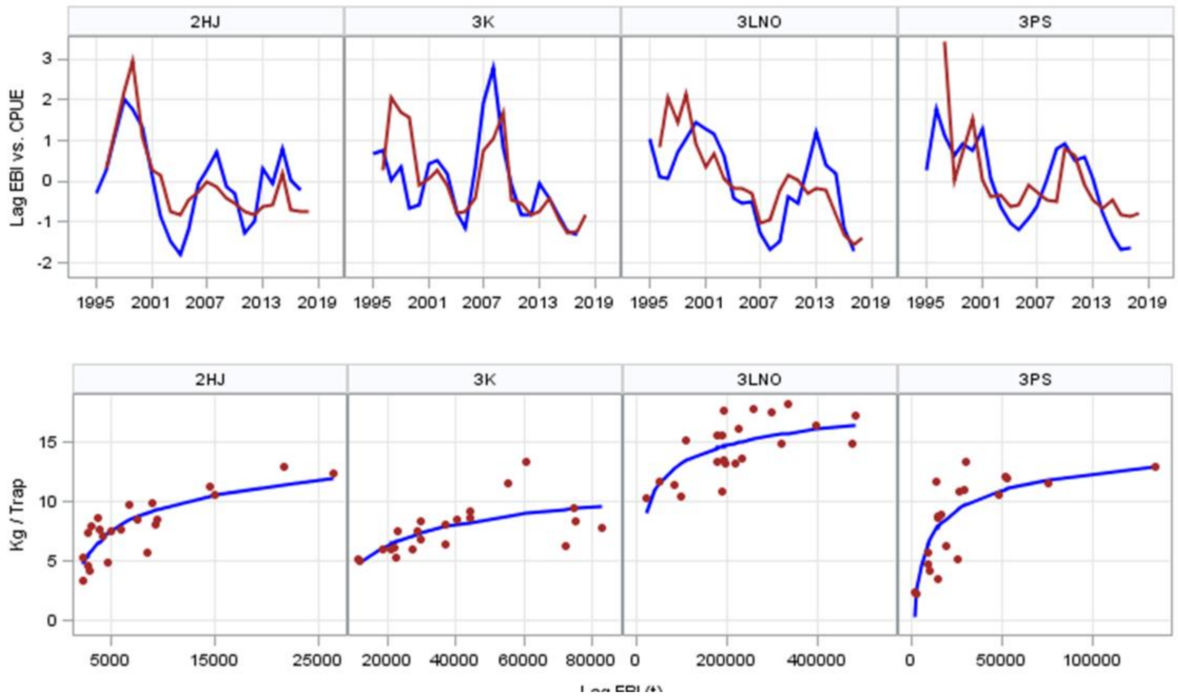

Figure 32. (Top) One-year lagged trawl survey exploitable biomass indices versus fishery CPUE by Assessment Division (1995-2017). (Below) Scatter plots of the relationships between CPUE and lagged biomass fit against non-linear Holling Type II functional response curves.

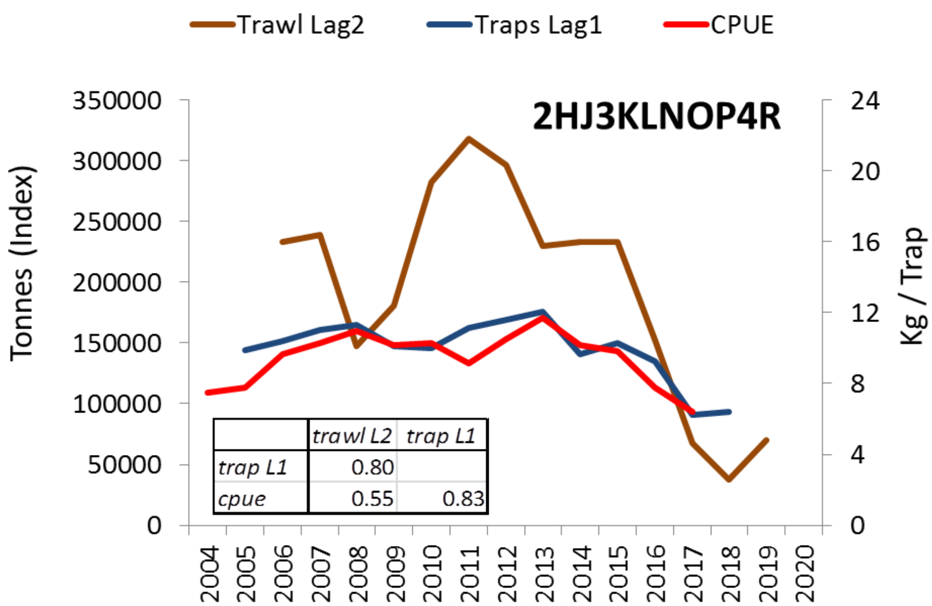

Figure 33. Trends in exploitable crab abundance indices based on the trawl survey (brown), trap surveys (blue), and fishery CPUE (red).

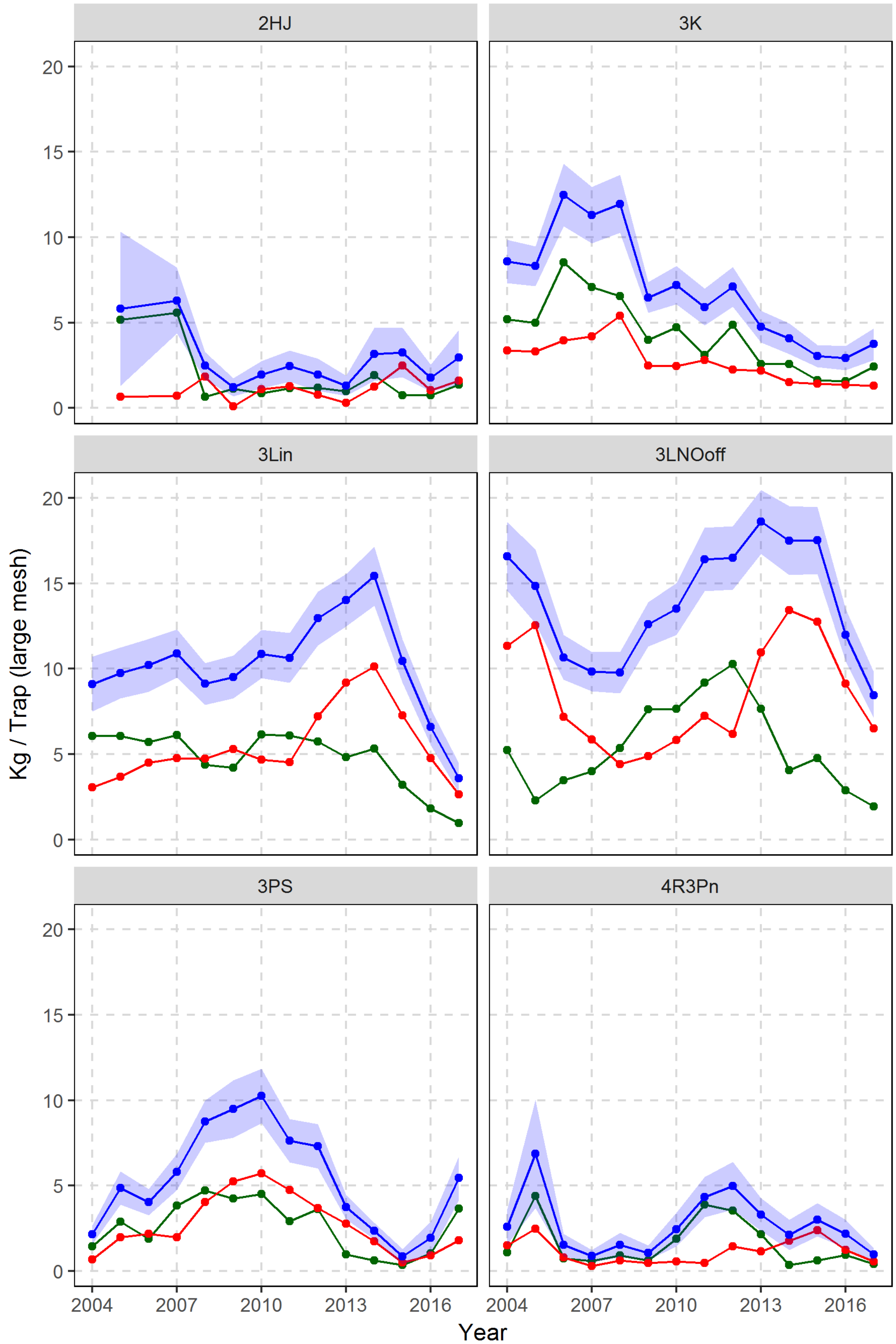

Figure 34. Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for legal-sized crab from cores stations in the CPS survey in Assessment Divisions (2004-17).

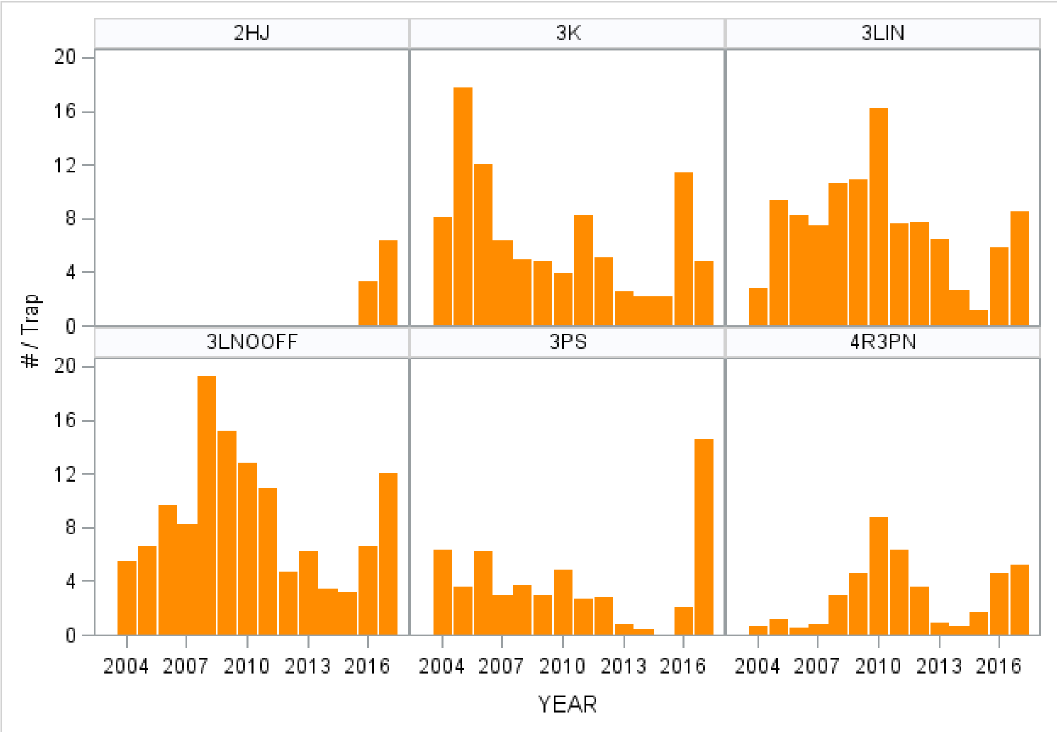

Figure 35. Annual CPUE (#/trap) of pre-recruits from small-mesh traps at core stations in the CPS trap survey by Assessment Division (2004-17).

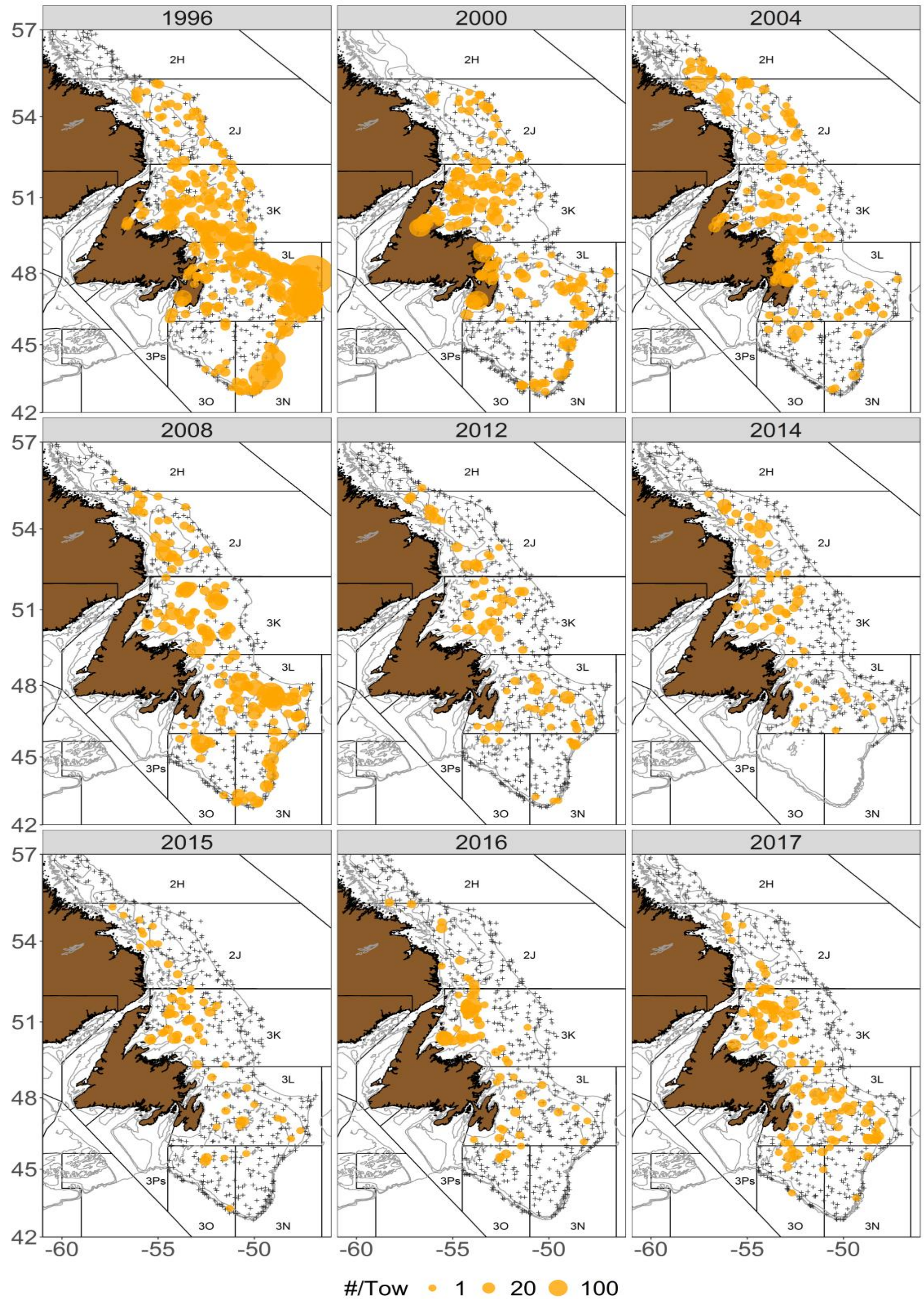

Figure 36. Distribution of pre-recruit males (#/tow) from Assessment Divisions 2HJ3KLNO fall bottom trawl surveys from 1996, 2000, 2004, 2008, 2012, and 2014-17. Data standardized by vessel.

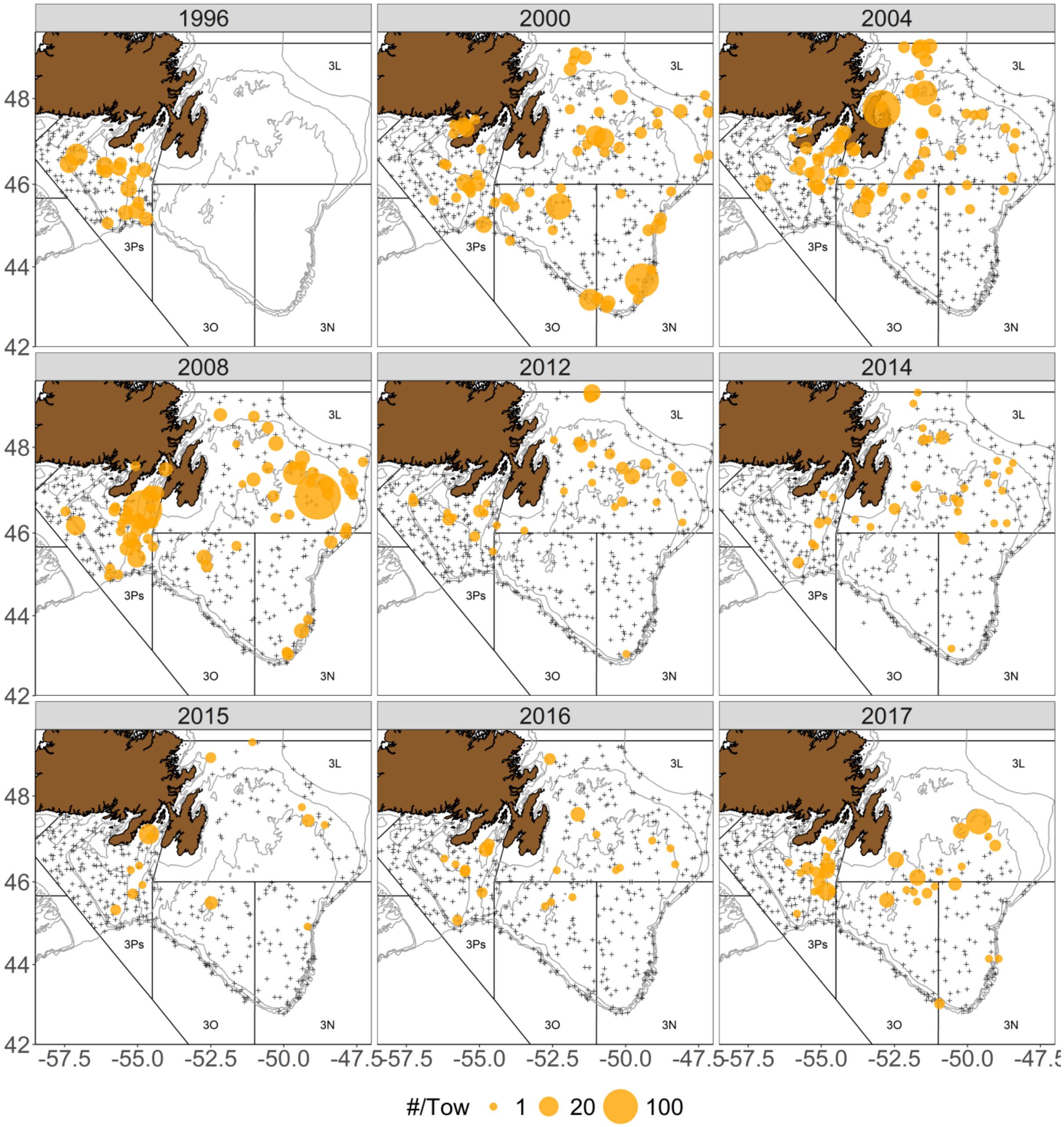

Figure 37. Distribution of pre-recruit males (#/tow) from Assessment Divisions 3LNOPs spring bottom trawl surveys from 1996, 2000, 2004, 2008, 2012, and 2014-17. Data standardized by vessel.

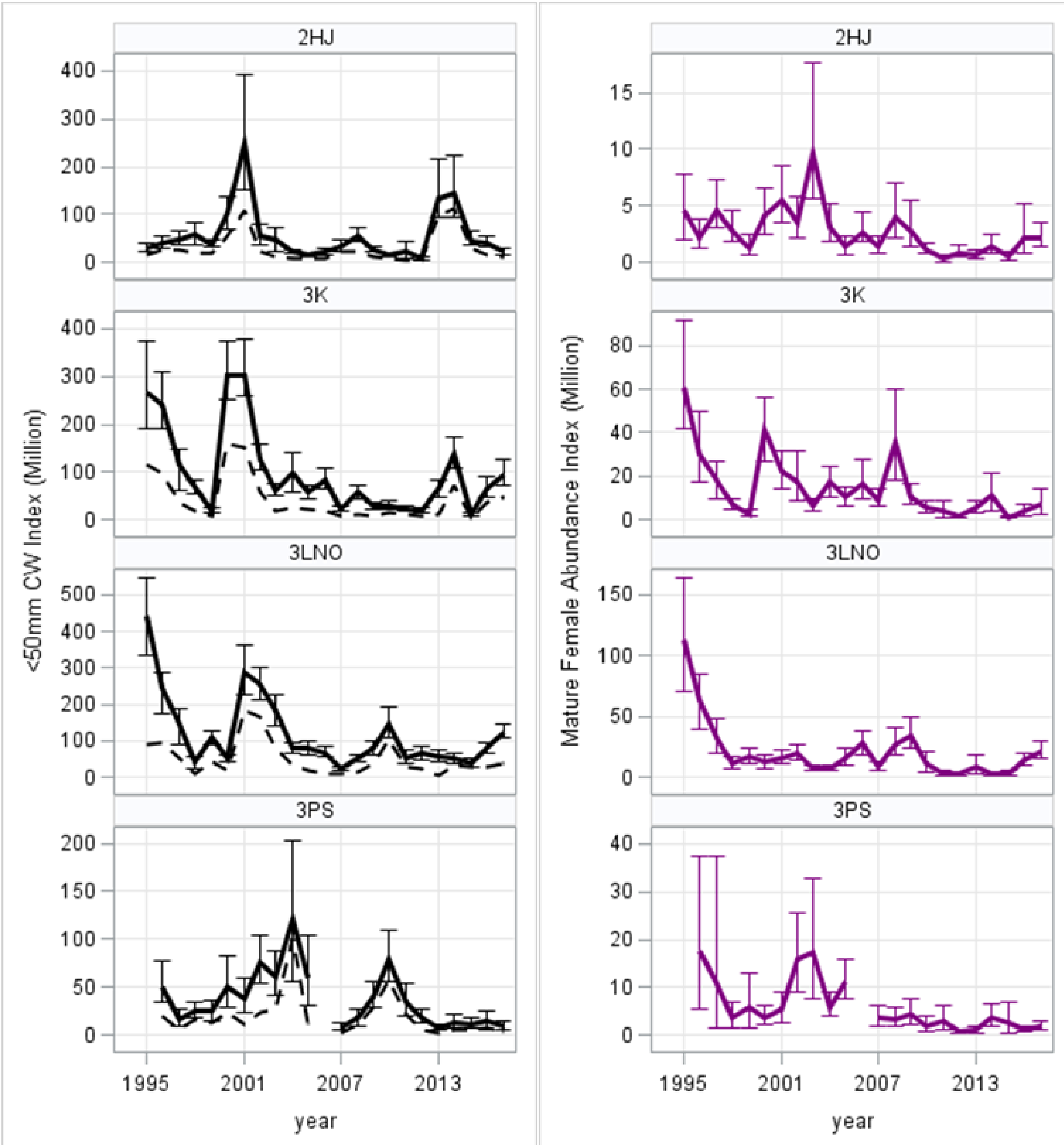

Figure 38. Left: Biomass indices (# million) of small crab (< 50 mm carapace width) from fall and spring trawl surveys by Assessment Division. Right: Annual biomass indices (# million) of female crab from fall and spring trawl surveys by Assessment Division.

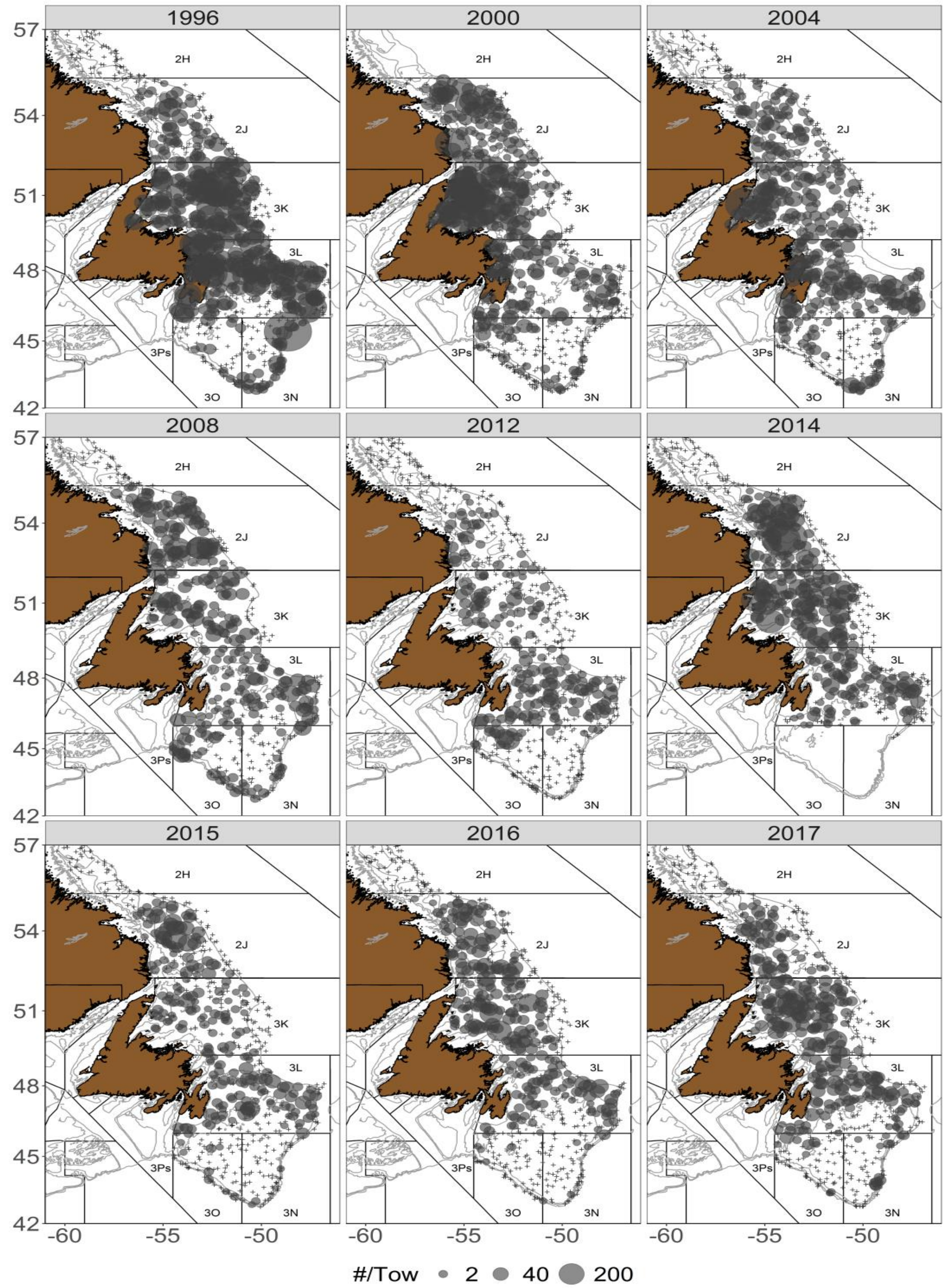

Figure 39. Distribution of small (<50 mm) crab (#/tow) from Assessment Divisions 2HJ3KLNO fall bottom trawl surveys from 1996, 2000, 2004, 2008, 2012, and 2014-17. Data standardized by vessel.

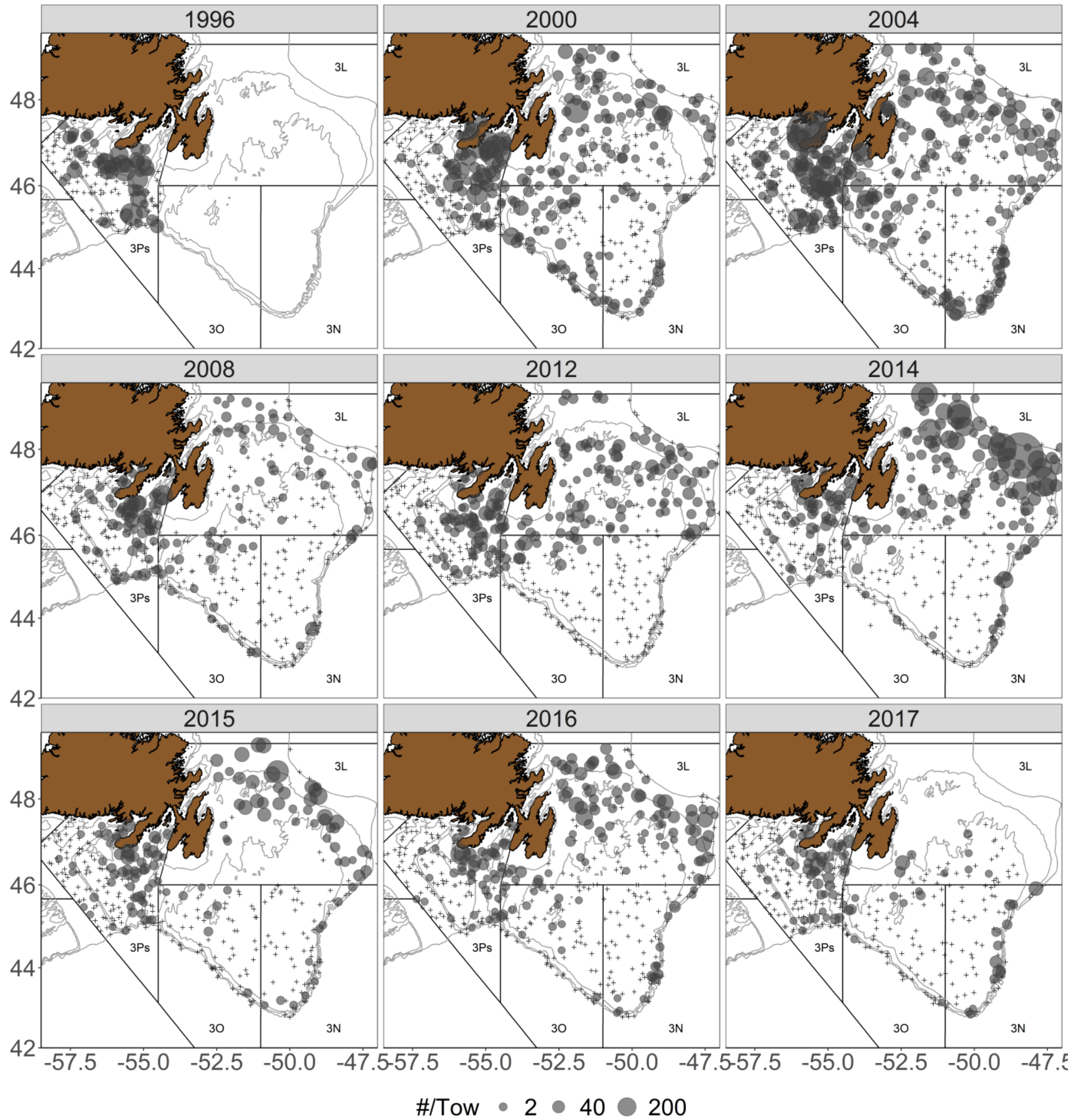

Figure 40. Distribution of small (<50 mm) crab (#/tow) from Assessment Divisions 3LNOPs spring bottom trawl surveys from 1996, 2000, 2004, 2008, 2012, and 2014-17. Data standardized by vessel.

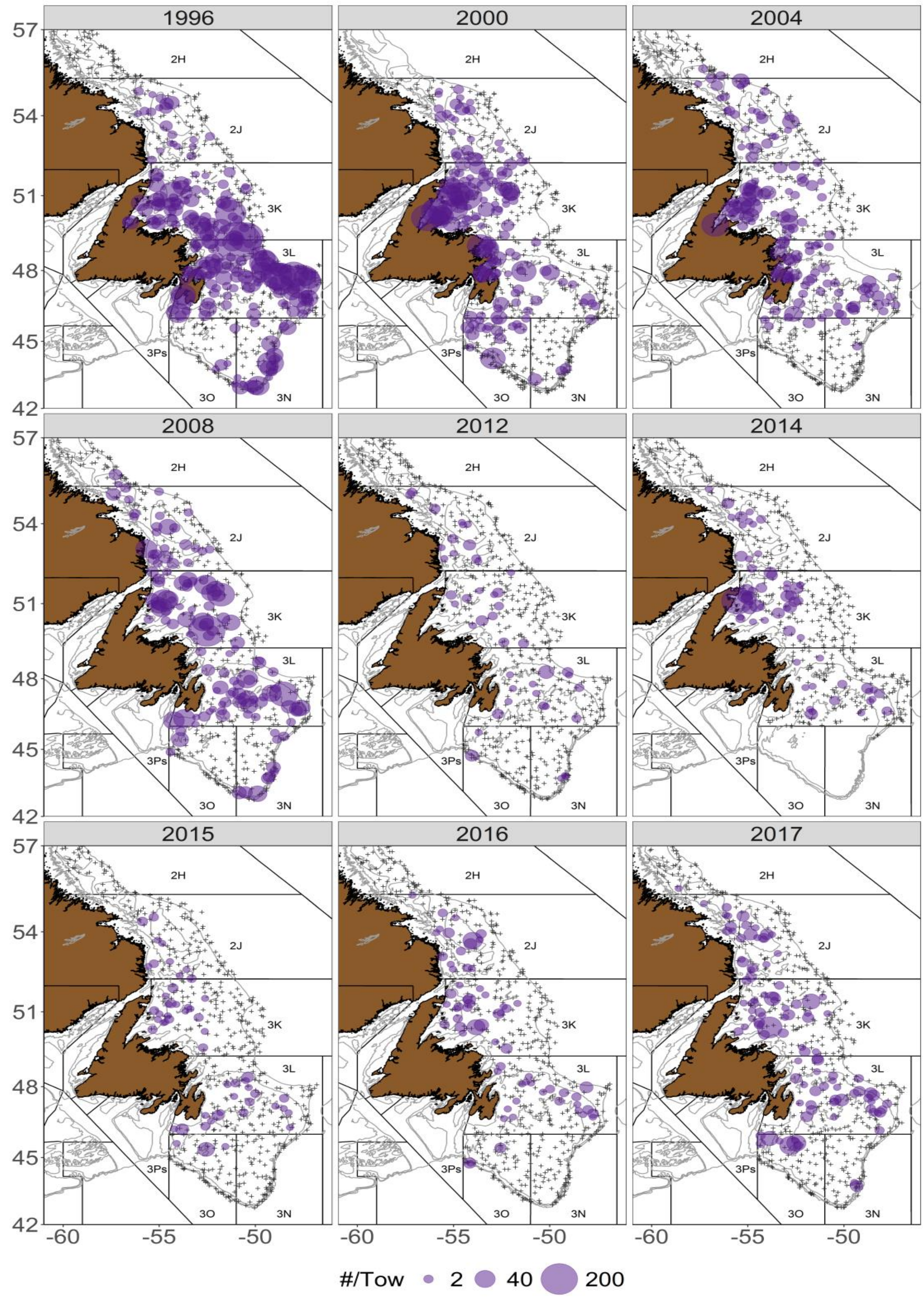

Figure 41. Distribution of mature females (#/tow) from Assessment Divisions 2HJ3KLNO fall bottom trawl surveys from 1996, 2000, 2004, 2008, 2012, and 2014-17. Data standardized by vessel.

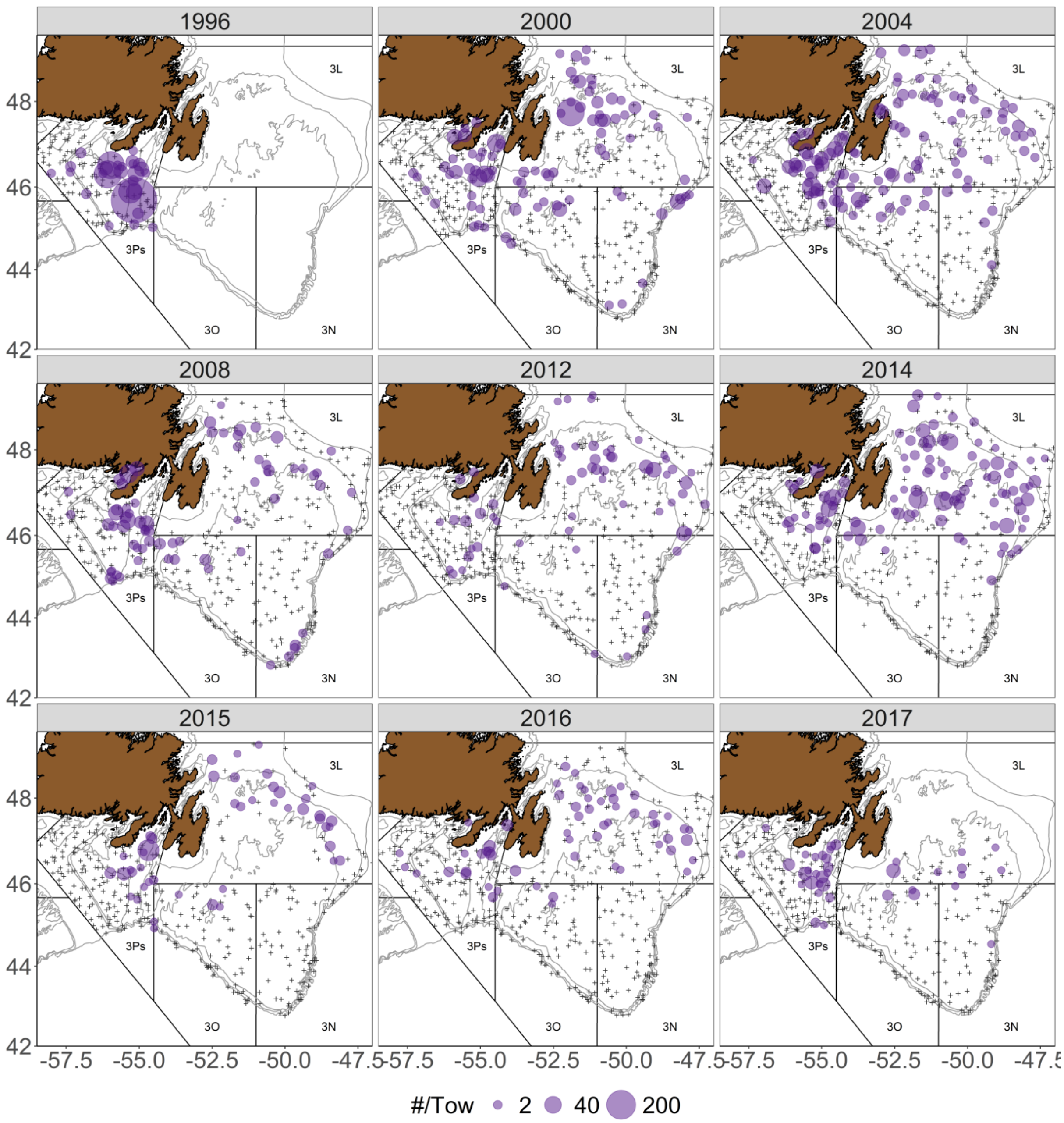

Figure 42. Distribution of mature females (#/tow) from Assessment Divisions 3LNOPs spring bottom trawl surveys in 1996, 2000, 2004, 2008, 2012, and 2014-17. Data standardized by vessel.

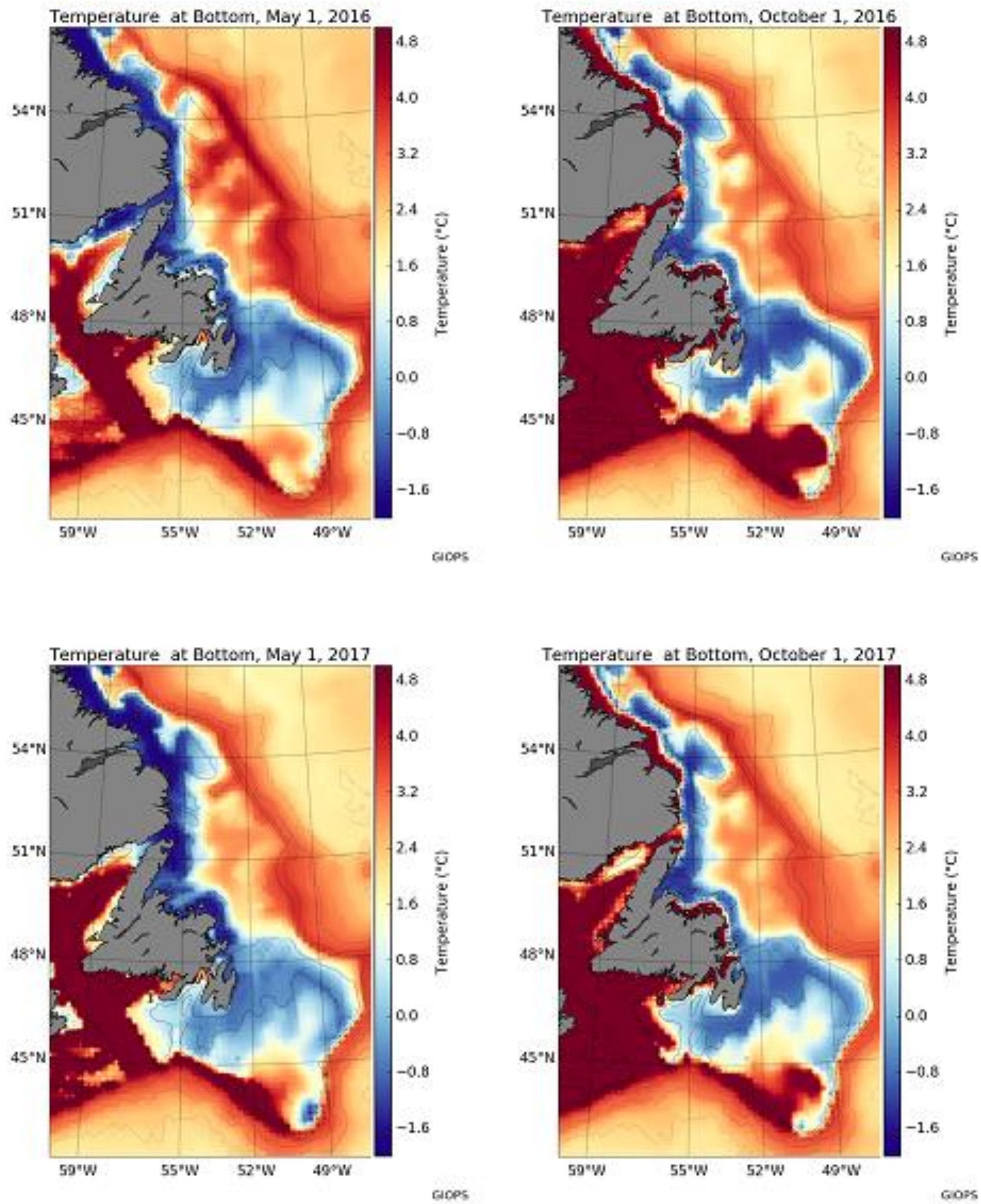

Figure 43. Maps of bottom temperature (°C) off Newfoundland and Labrador in spring (left) and fell (right) during 2016 and 2017. Data taken from DFO Ocean Navigator site using GIOPS database.

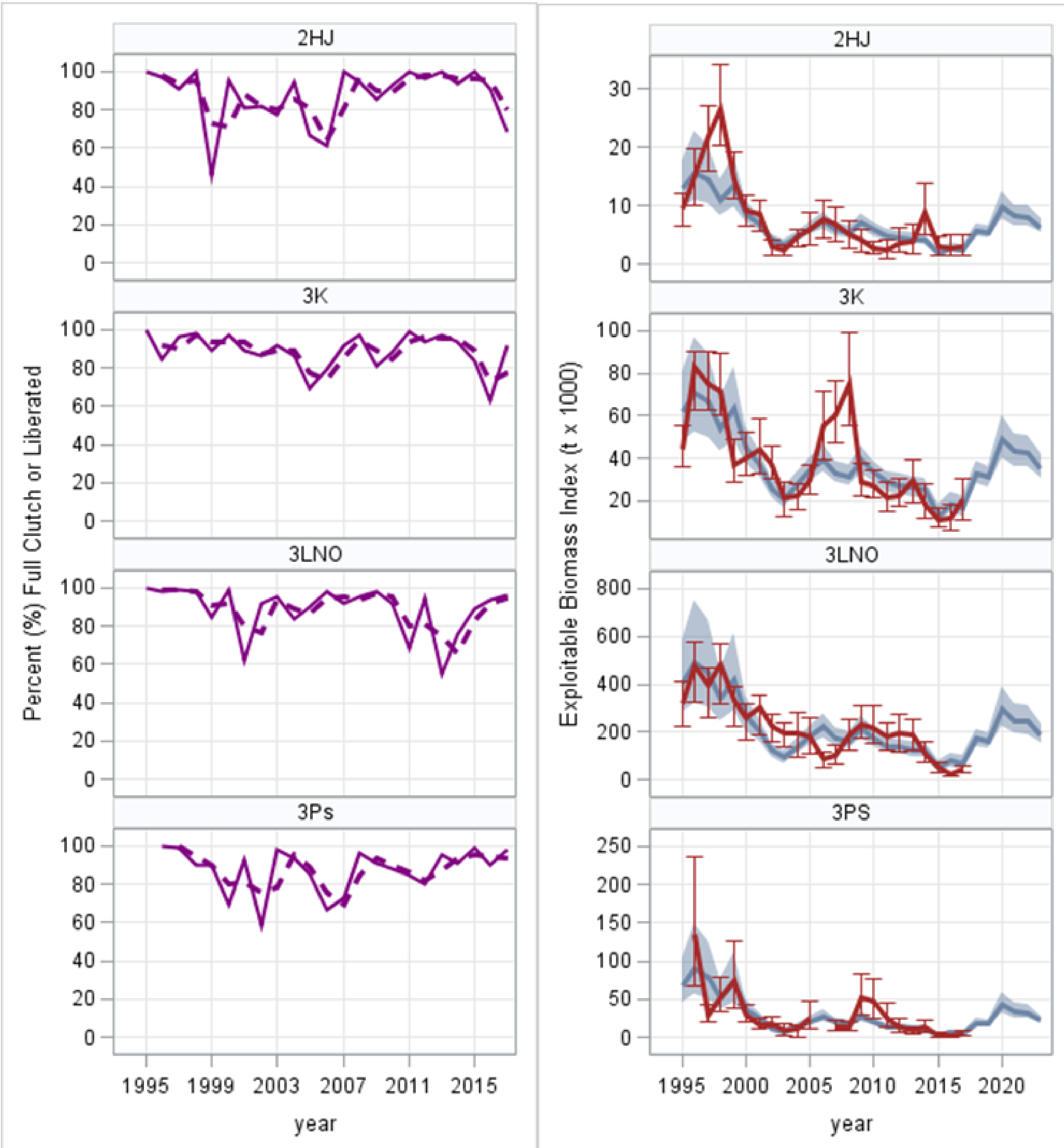

*Figure 44. Right: Percentage of mature females liberated or bearing full clutches of viable eggs in fall and spring trawl surveys by Assessment Division. Both annual (solid line) and 2-year moving averages (dashed line) are presented. Left: Trends in the exploitable biomass indices (t * 1,000) and 3-year centered moving average lagged North Atlantic Oscillation (NAO) index (blue).*

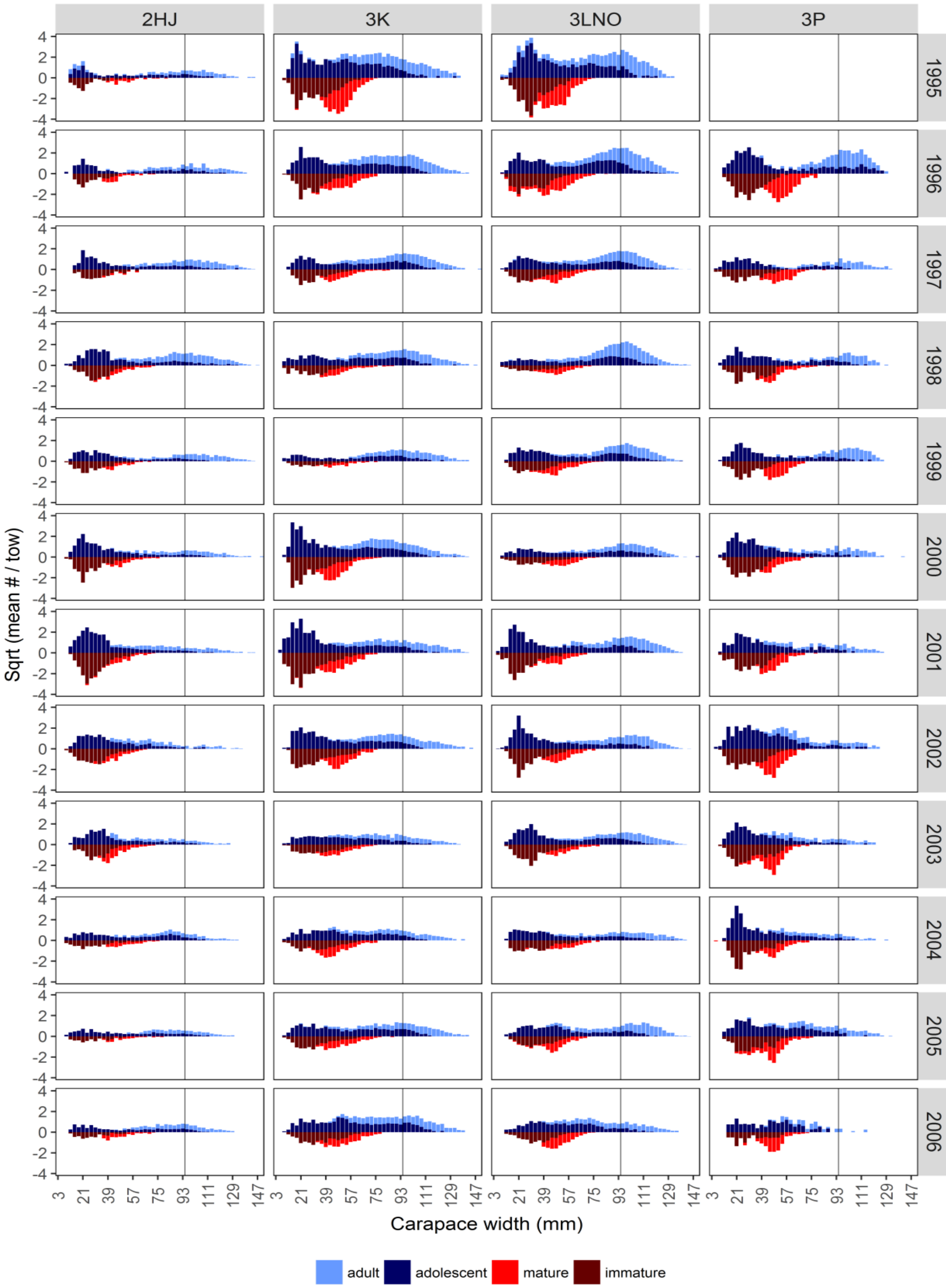

Figure 45. Abundance indices (#/tow) by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (Subdivision 3Ps) and fall (Divisions 2HJ3KLNO) trawl surveys from 1995 to 2006. Dashed vertical line is legal-size. Data standardized by vessel.

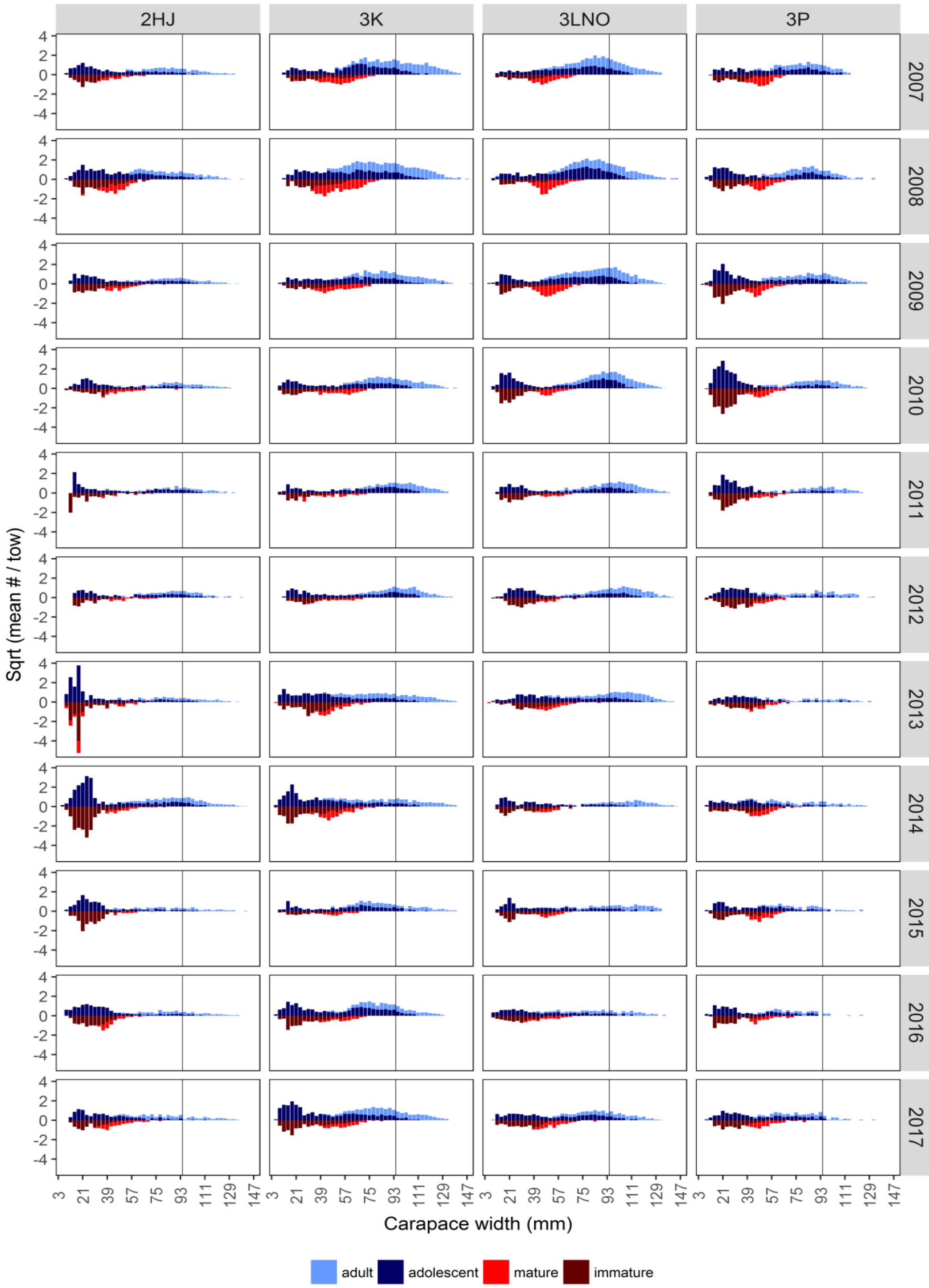

Figure 46. Abundance indices (# / tow) by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (Subdivision 3Ps) and fall (Divisions 2HJ3KLNO) trawl surveys from 2007-17. Dashed vertical line is legal-size. Data standardized by vessel.

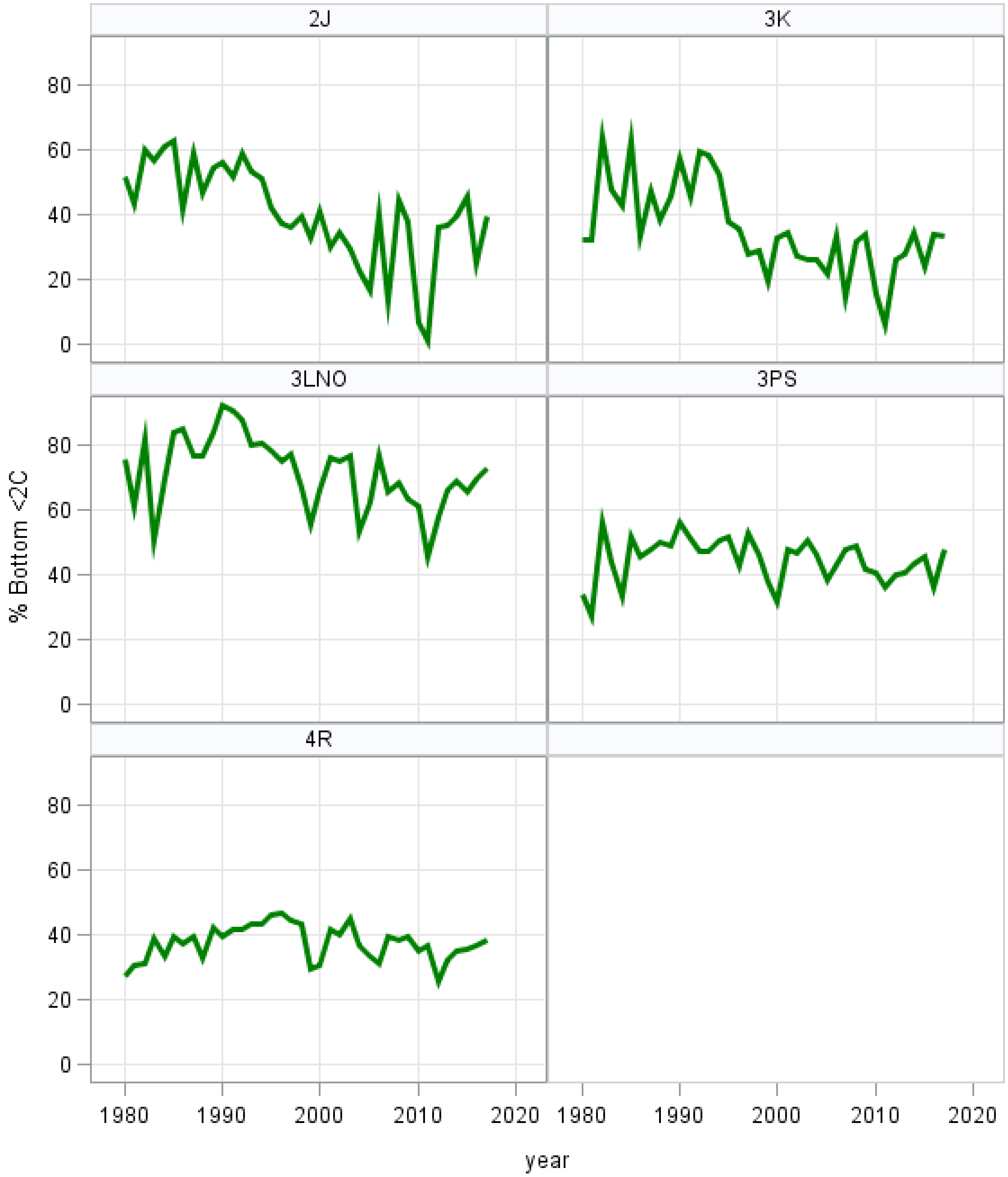

Figure 47. Snow Crab thermal habitat indices by Assessment Division and Year (1990-2017).

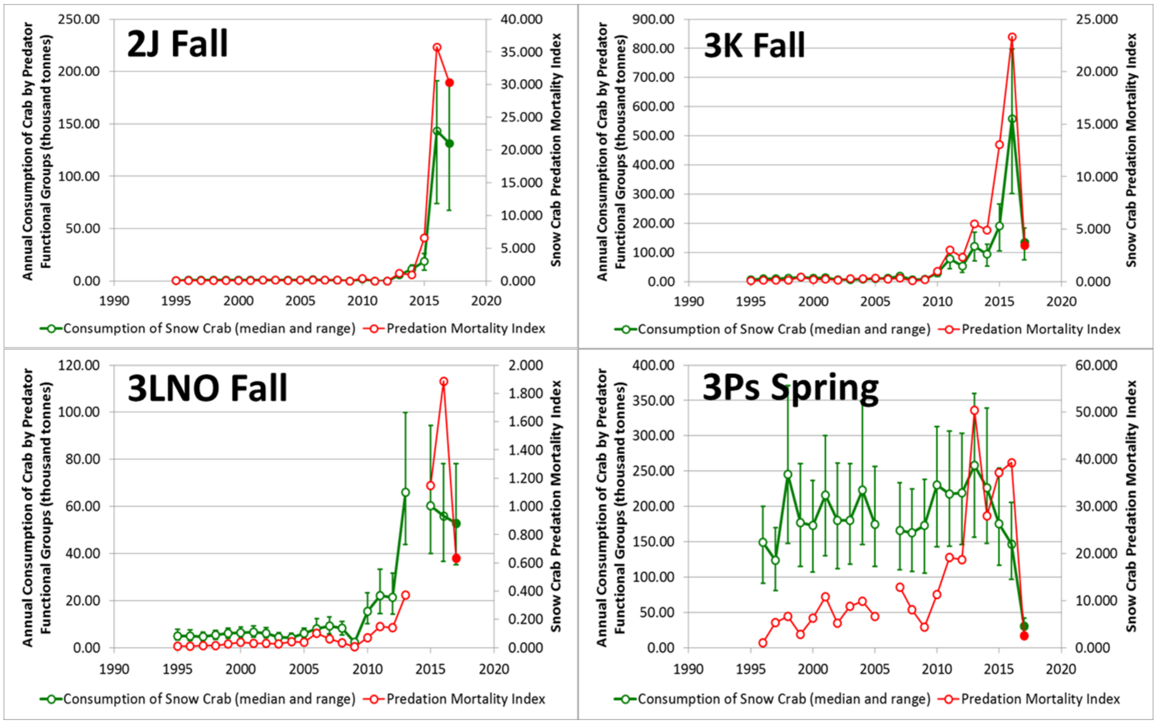

Figure 48. Snow Crab predation mortality indices by Assessment Division and Year (1990-2017).

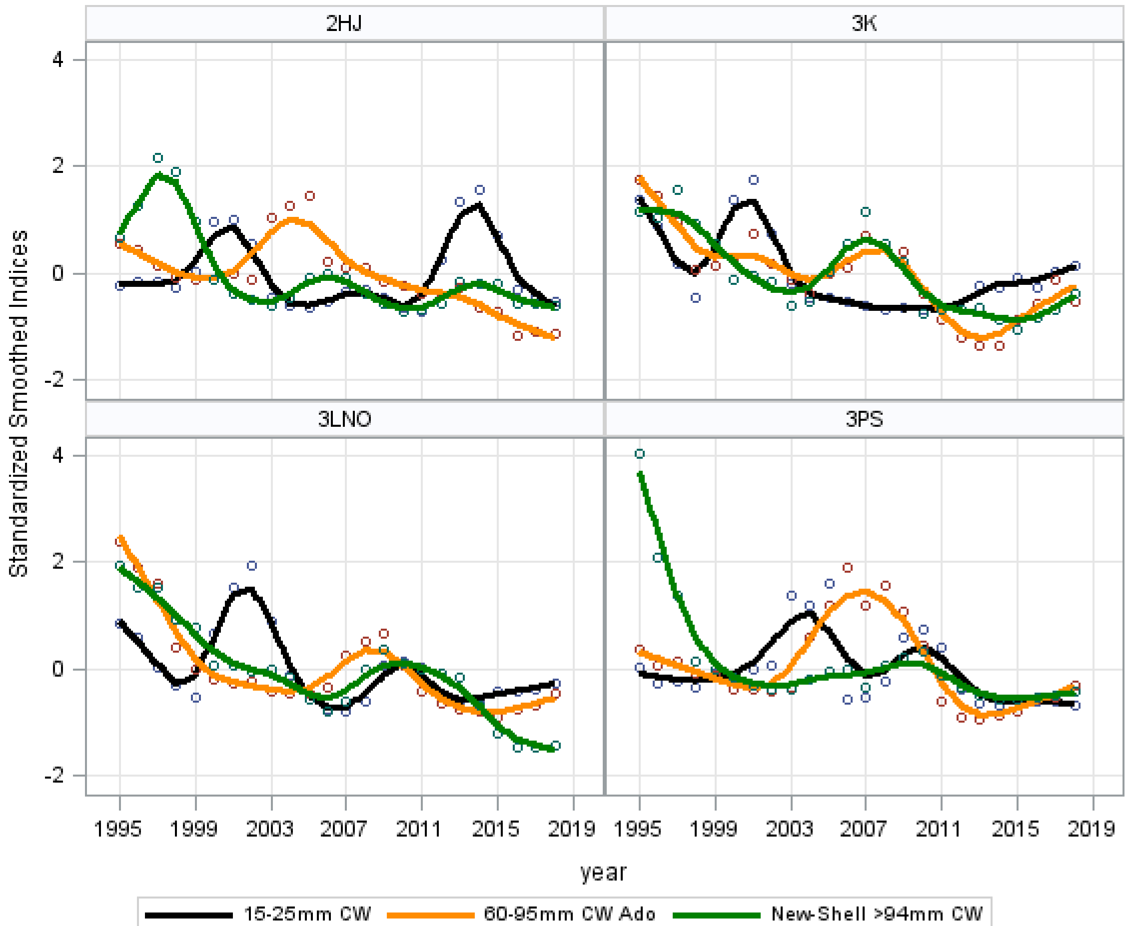

Figure 49. Standardized annual (circles) and 3-year centre moving average (solid line) indices of Snow Crab abundance by Assessment Division: Small crab (black), pre-recruits (orange), and new shelled (>94 mm) crab (green).

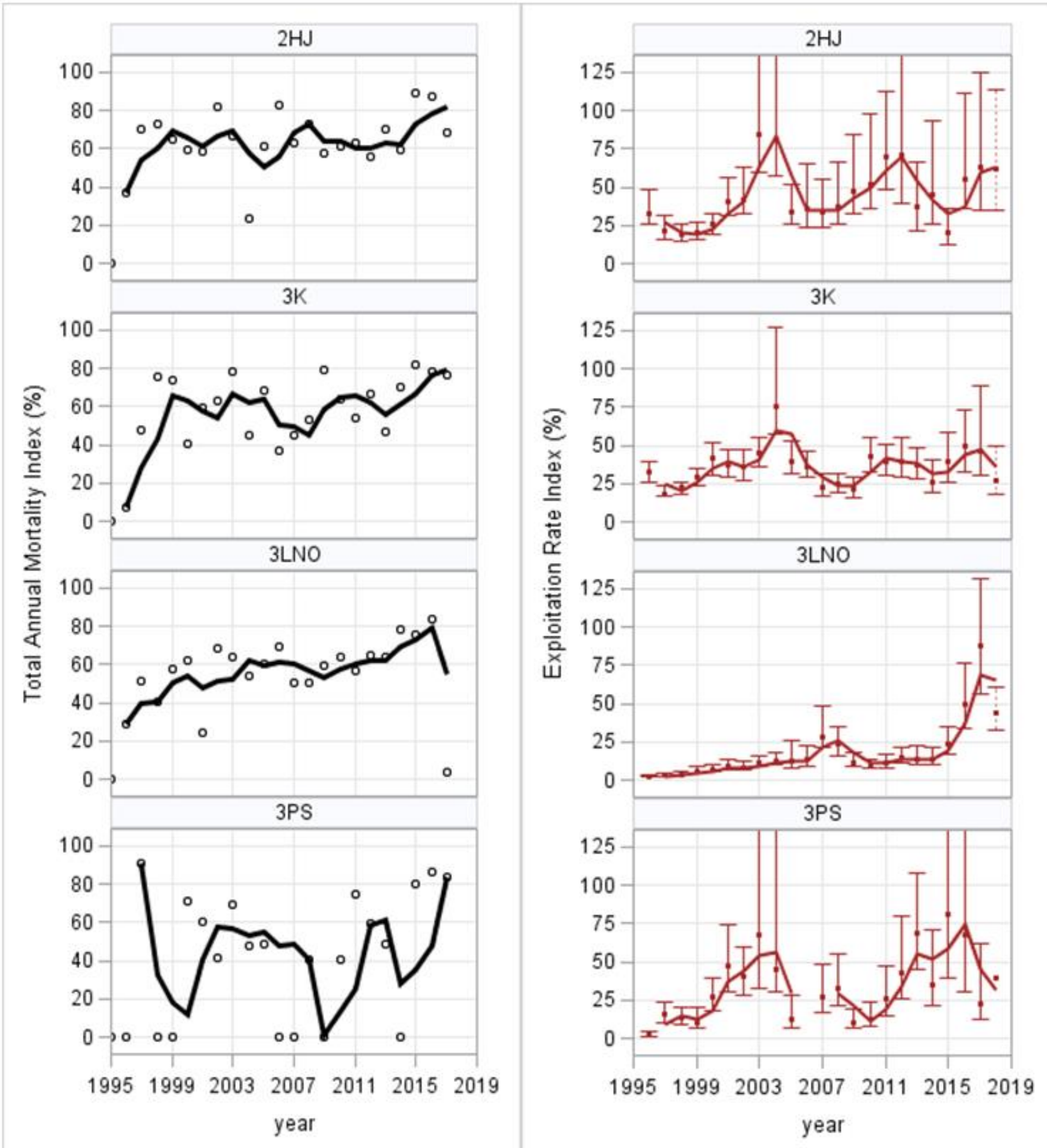

Figure 50. Left: Trends in the annual (circles) and 3-year moving average (solid line) total annual mortality index (%) of exploitable crab by Assessment Division. Note if annual mortality index was <0 it was plotted as 0 for presentation. Right: Trends in the annual (circles) and 2-year moving average exploitation rate index (solid line) (%) by Assessment Division; 2018 points depict projected exploitation rate indices under status quo removals in the 2018 fishery.

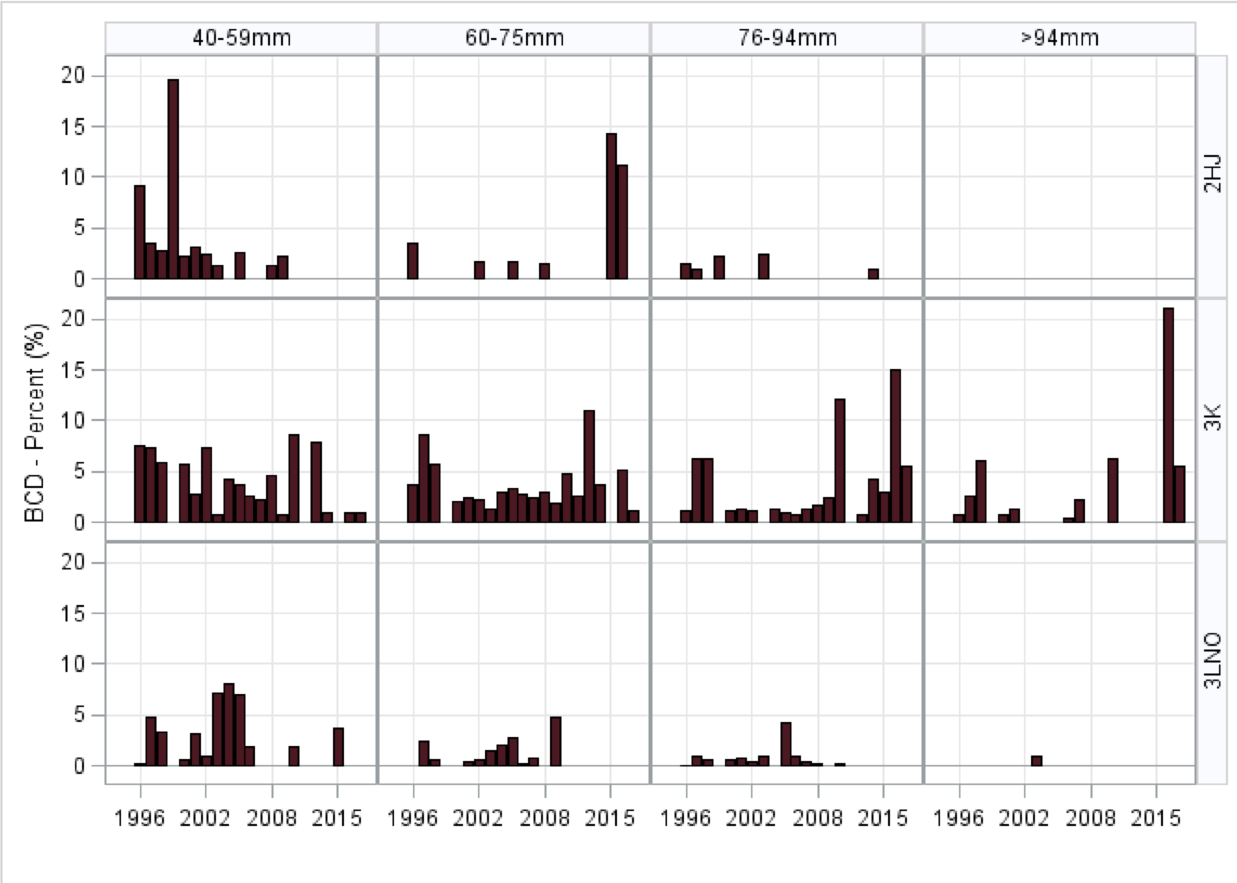

Figure 51. Annual prevalence of Bitter Crab Disease (BCD) from macroscopic observations in new-shelled adolescent male crab in fall multi-species trawl surveys by Assessment Division and carapace width (1996-2017).

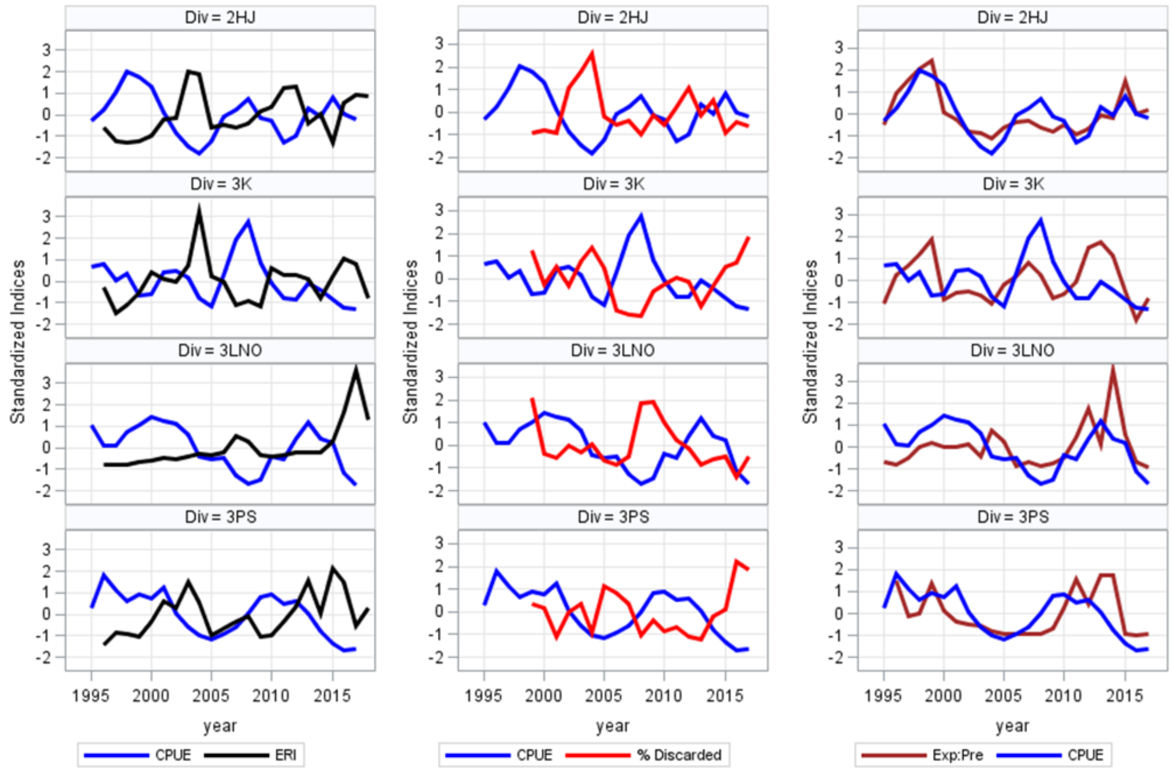

Figure 52. Trends in exploitation rates, discards, and the ratio of exploitable to pre-recruit crab versus fishery CPUE, by Division.

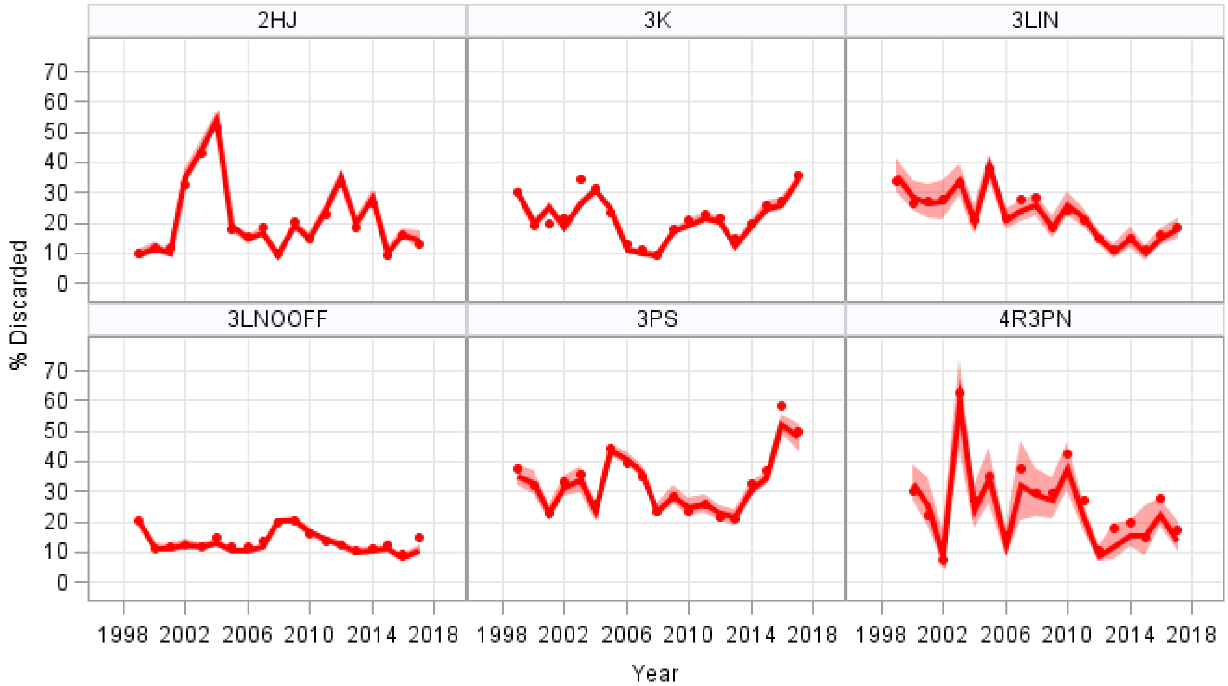

Figure 53. Trends in discards (%) based on raw estimates (points) and modelled fits (solid lines). The shaded area represents the 95% confidence interval.

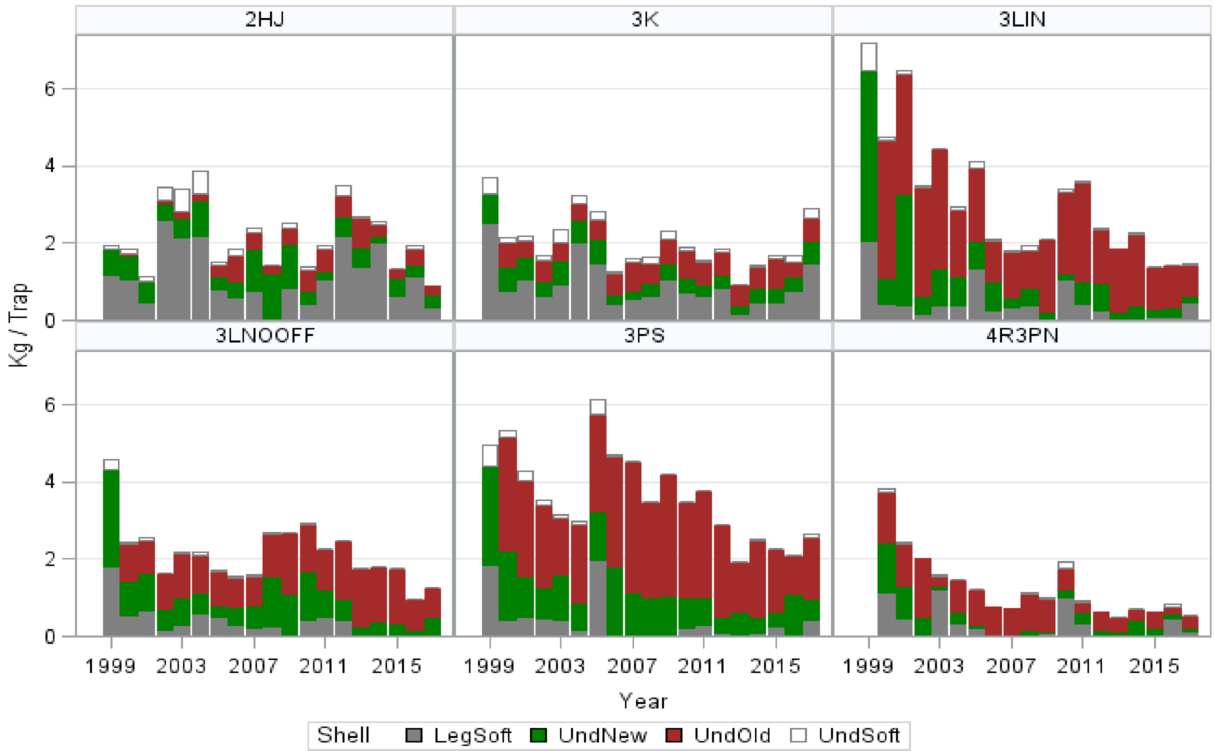

Figure 54. Trends in observed catch rates of discards (kg/trap) based on size and shell condition groups (legal-sized soft-shelled, undersized new-shelled, undersized old-shelled, and undersized soft-shelled discards) by Assessment Division.

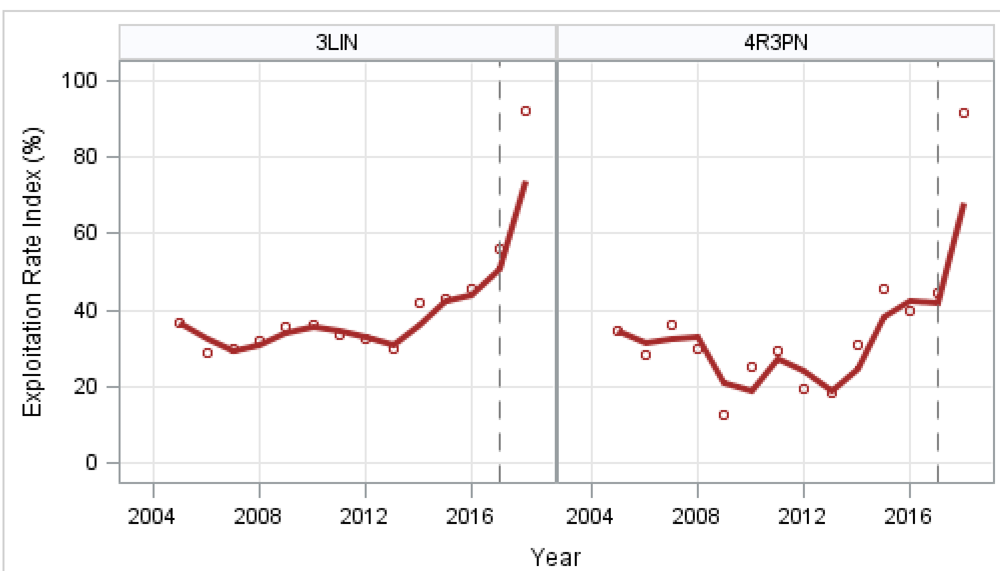

Figure 55. Trends in trap survey-based exploitation rate indices (brown) and 2-year moving average exploitations rates by in Assessment Divisions 3L Inshore and 4R3Pn. Dashed lines depict projected 2018 exploitation rate indices based on status quo landings in the 2018 fishery.

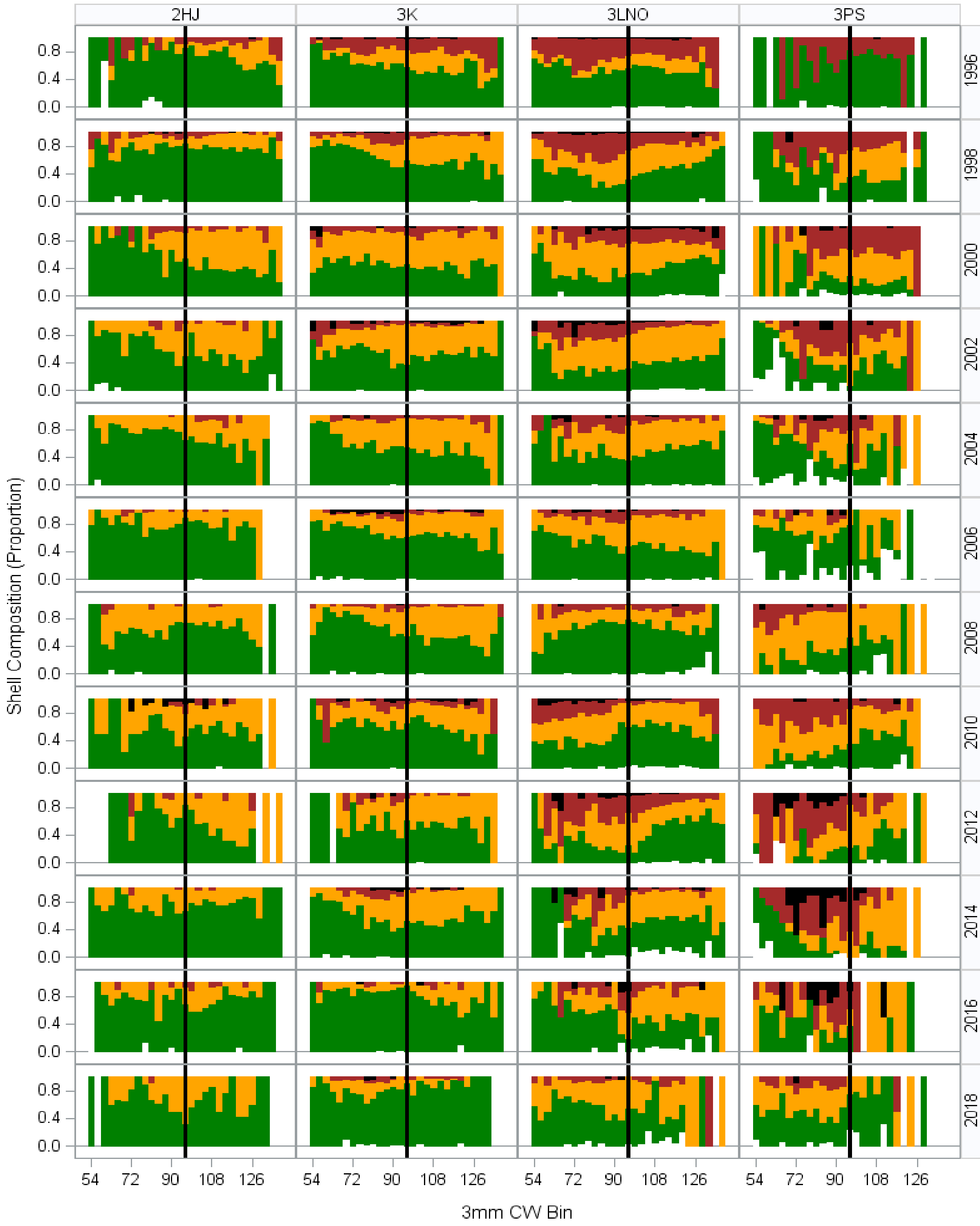

Figure 56. Shell composition of adult male crab by 3-mm carapace width intervals from multi-species trawl surveys since 1995 in each Assessment Division. Years binned to two year increments (1995+1996=1996). Vertical black lines depict legal-size. (White = soft shelled, green = new shelled, orange = intermediate shelled, red = old shelled, black = very old shelled)

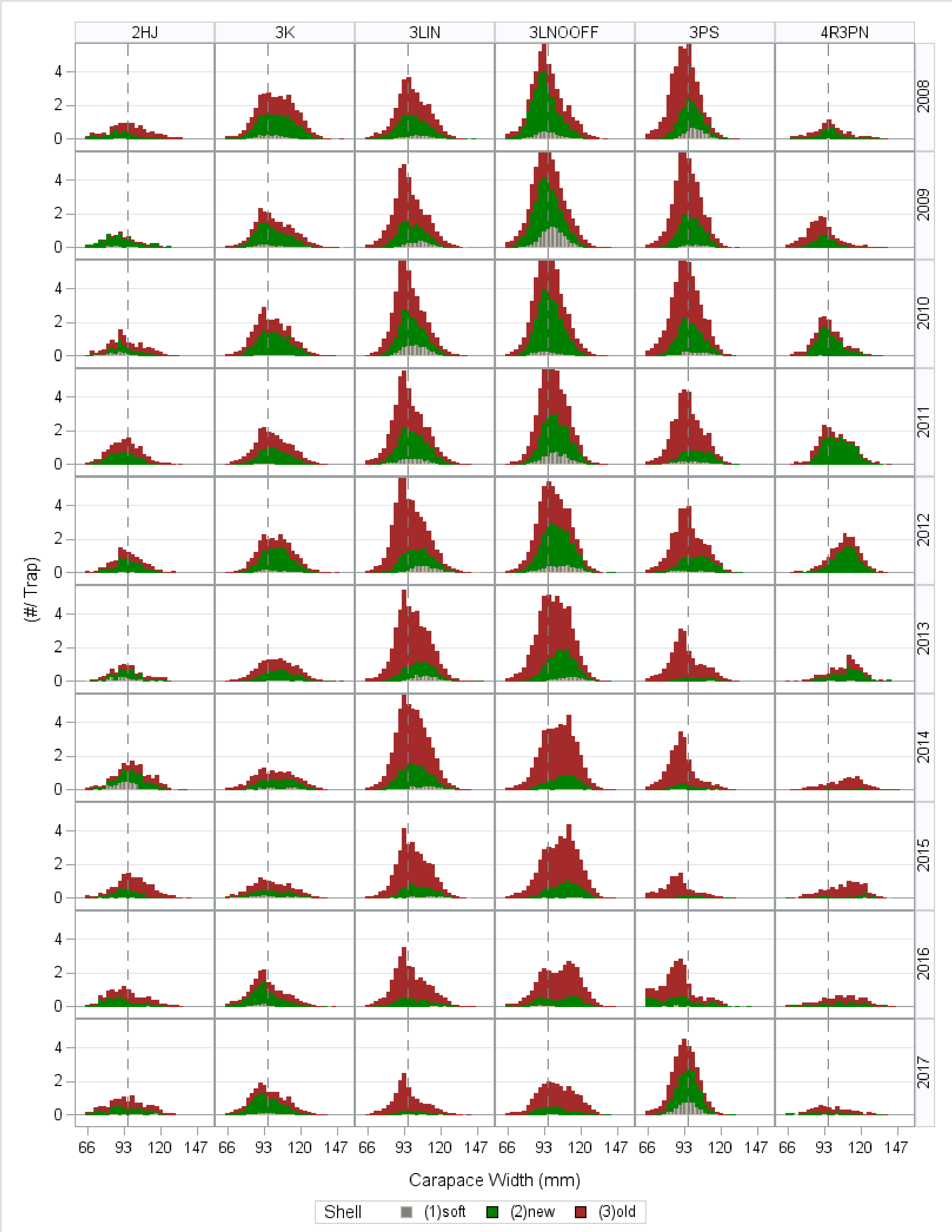

Figure 57. Trends in CPUE (#/trap) by male carapace width distributions and shell condition from large-mesh traps in the CPS survey by Assessment Division (2008-17). The vertical line indicates the minimum legal size.

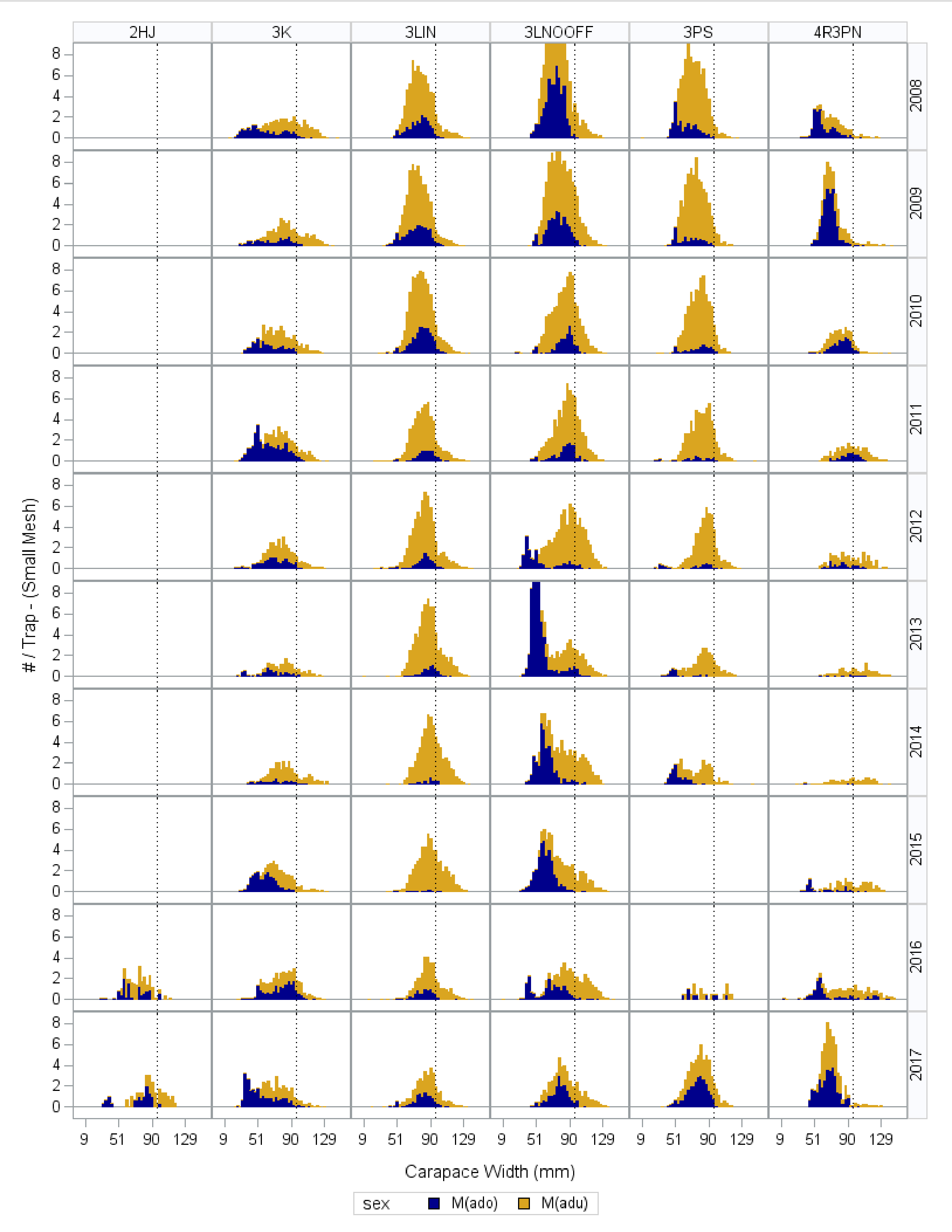

Figure 58. Trends in CPUE (#/trap) by male carapace width distributions and maturity (blue – juveniles and adolescent males, yellow – adult males) from small-mesh traps in core stations from the CPS survey, presented by Assessment Division (2008-17). The vertical line indicates the minimum legal size.

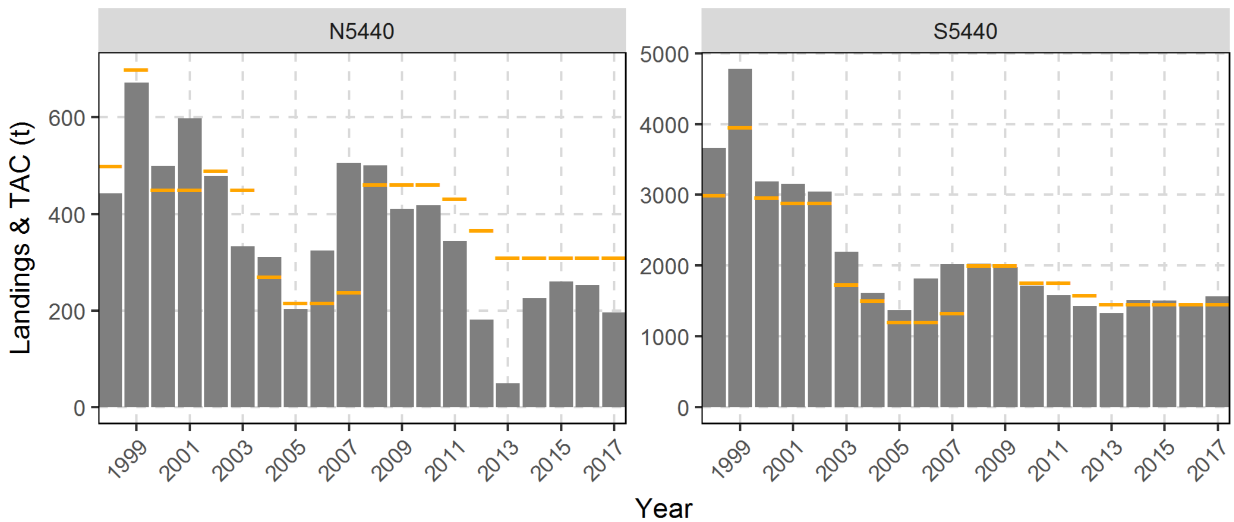

Figure 59. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Divisions 2HJ (1998-2017).

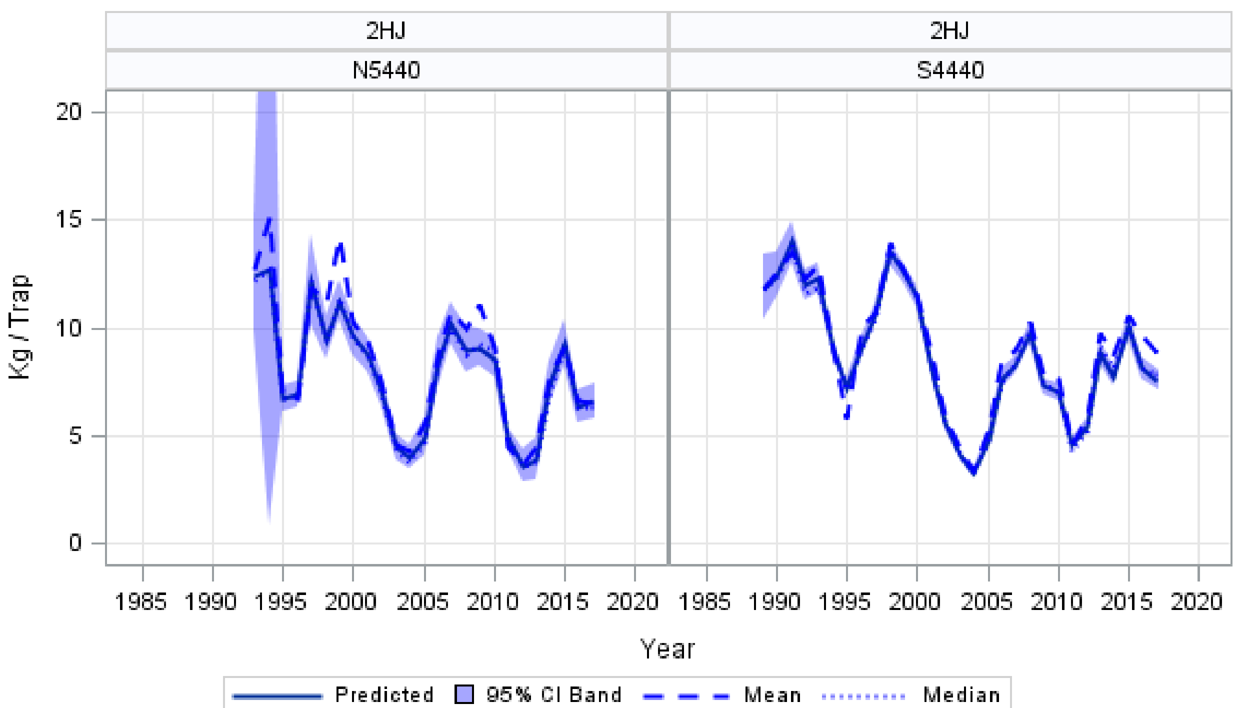

Figure 60. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Divisions 2HJ.

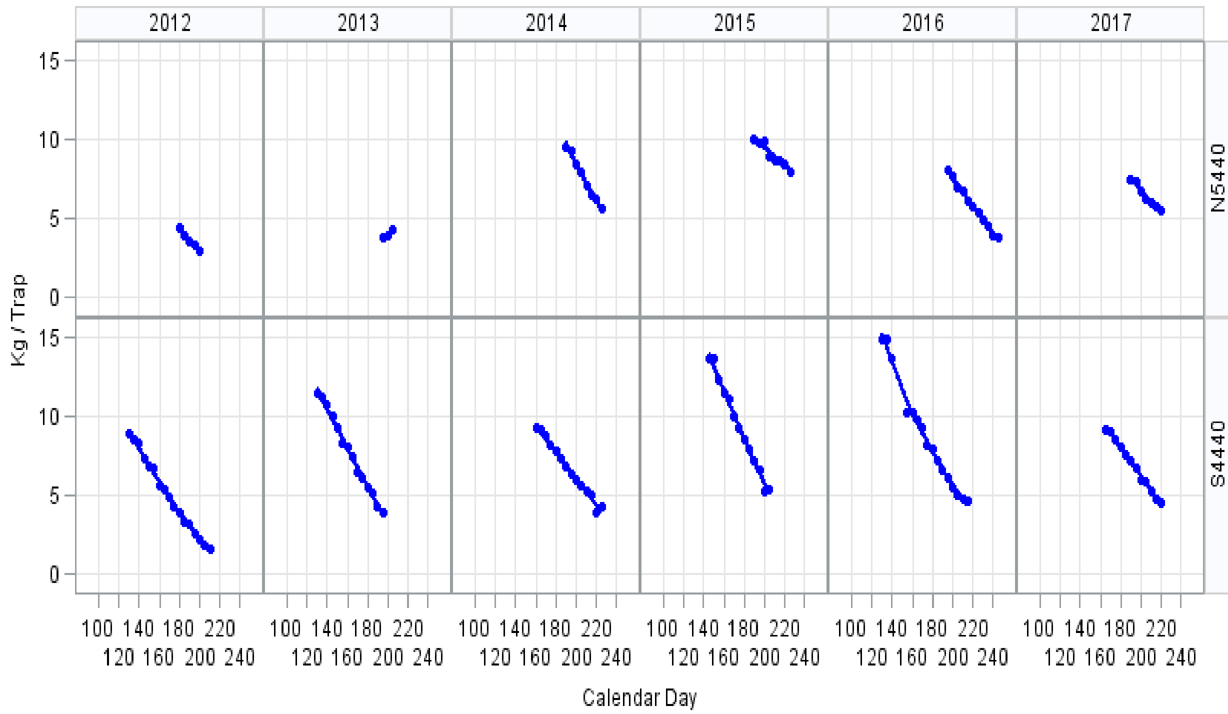

Figure 61. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2012-17), by Crab Management Area (CMA) in Assessment Divisions 2HJ.

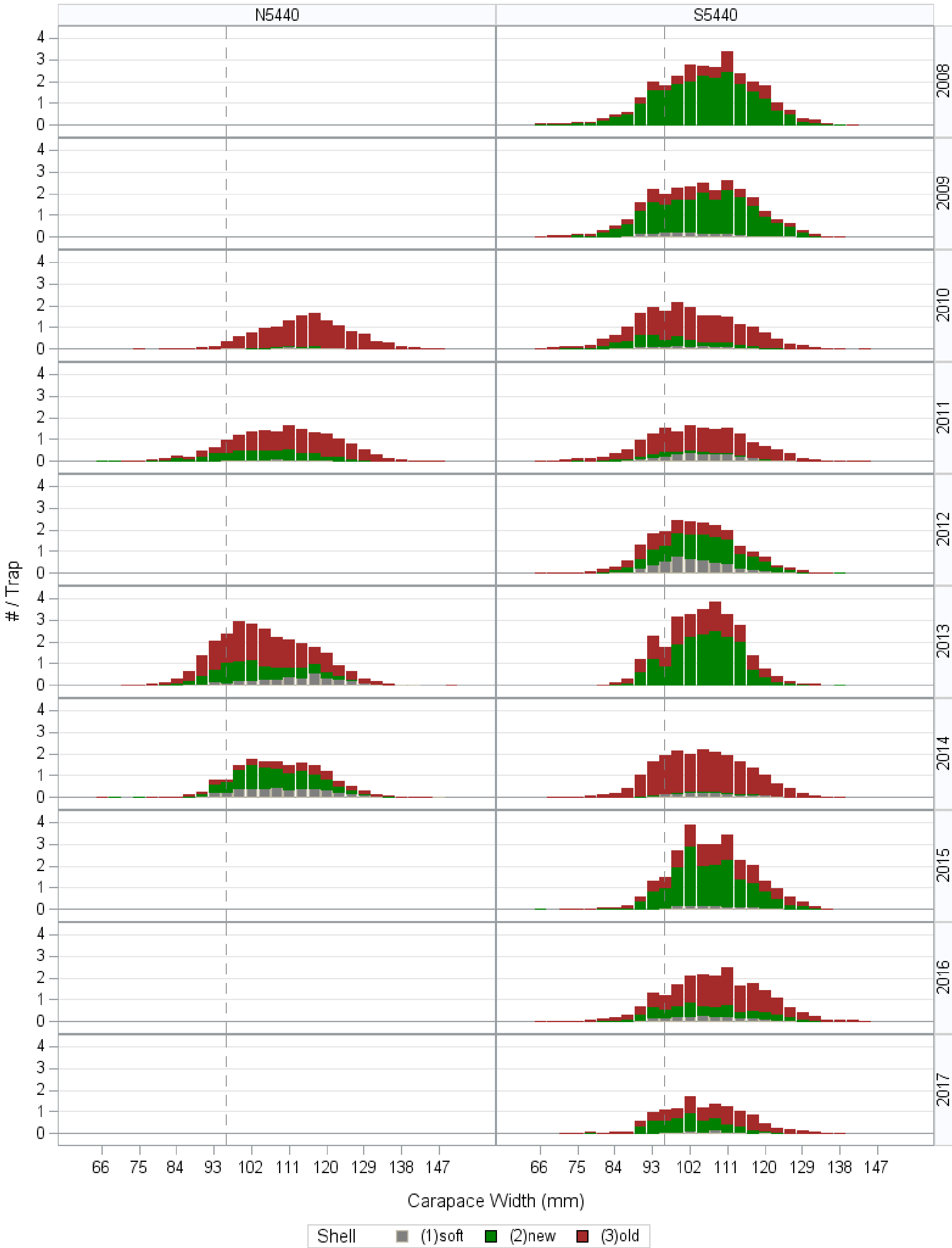

Figure 62. Trends in male carapace width distributions by shell condition from observer sampling in Divisions 2HJ (2008-17). The vertical line indicates the minimum legal size.

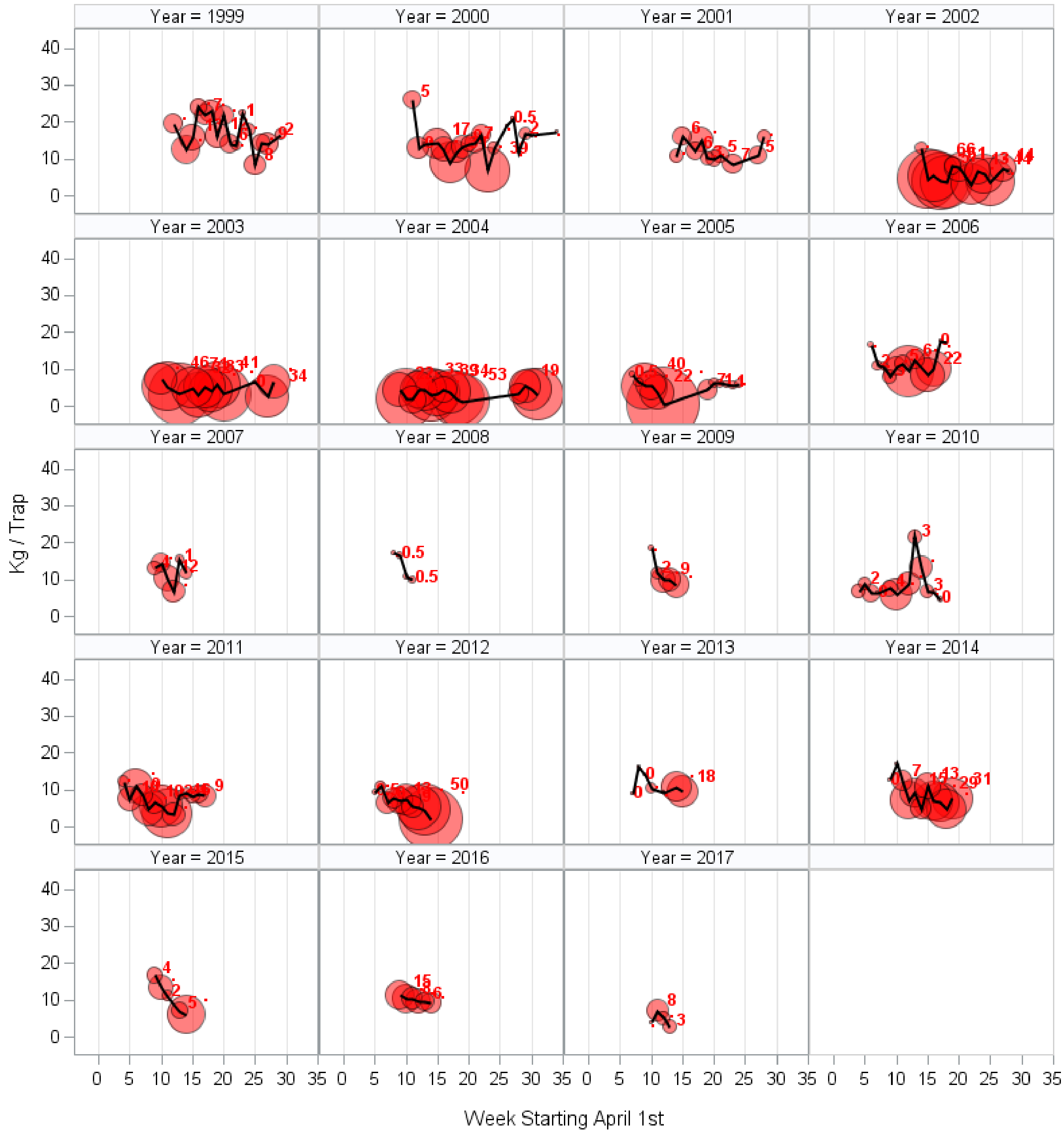

Figure 63. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within the Assessment Divisions 2HJ (1999-2017). Bubble size and labels depict percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

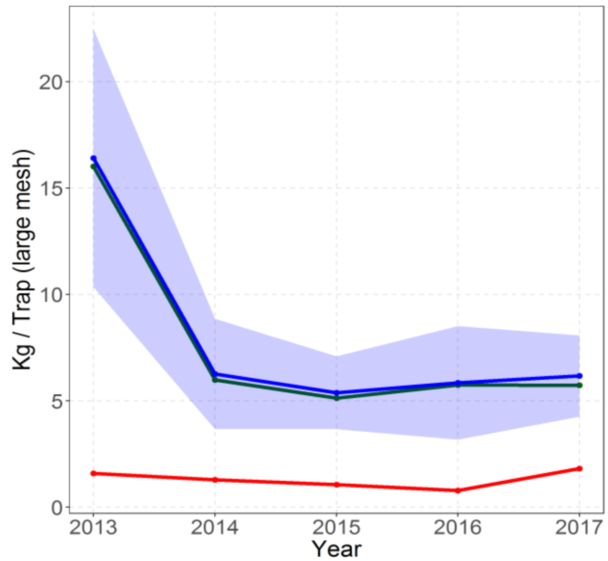

Figure 64. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from the Torngat Joint Fisheries Secretariat survey (CMA 2JN).

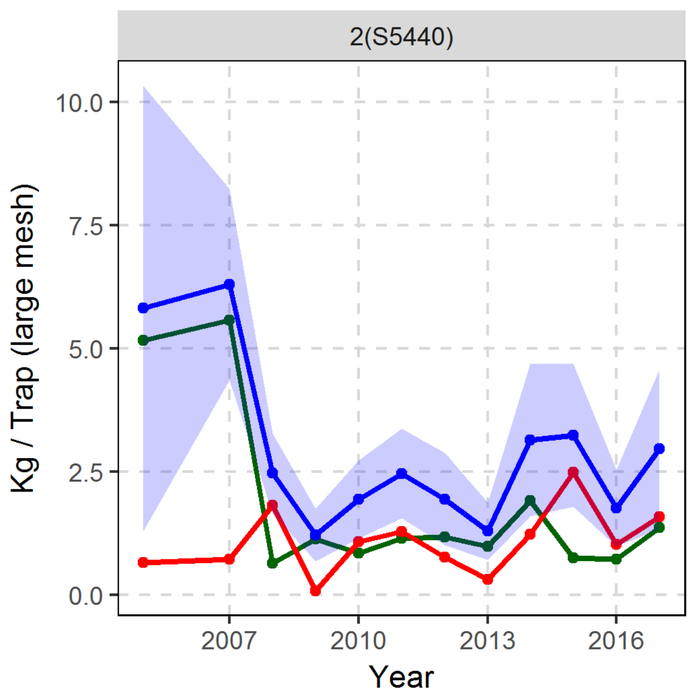

Figure 65. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from core stations in the CPS trap survey (CMA 2JS).

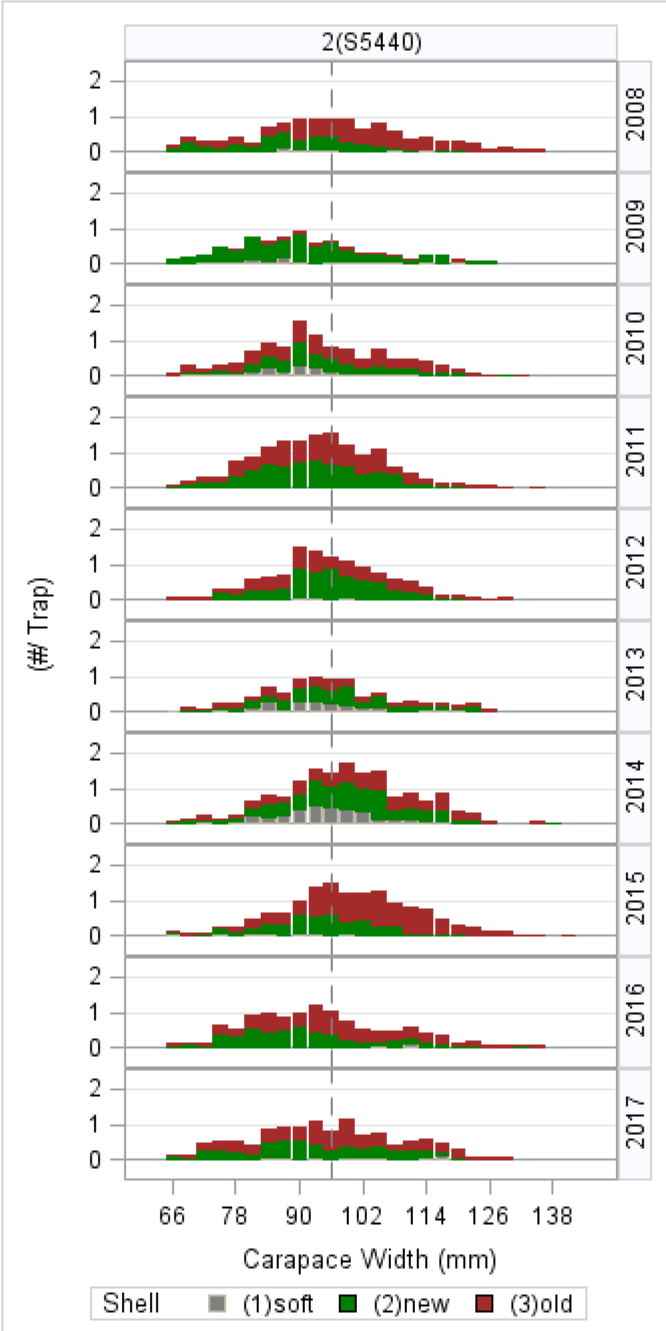

Figure 66. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMA 2JS in Assessment Divisions 2HJ (2008-17). The vertical line indicates the minimum legal size.

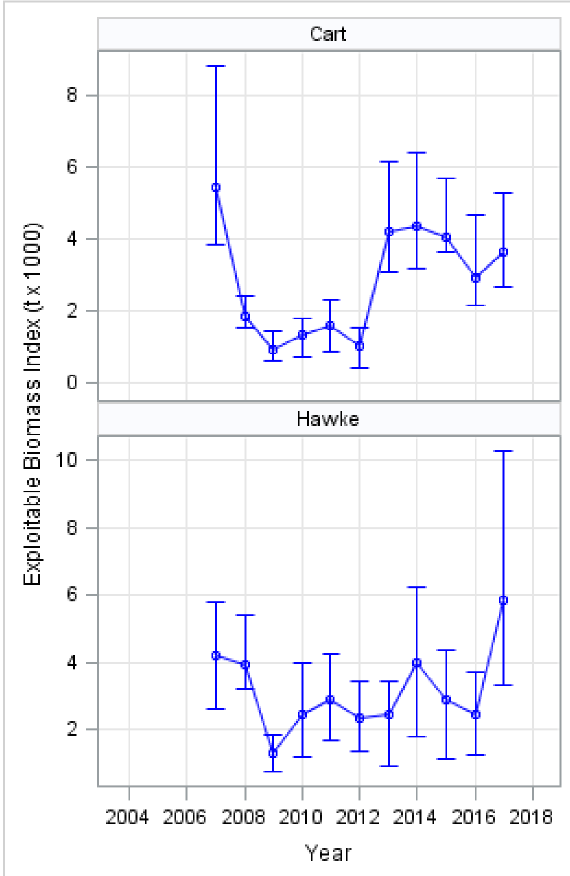

Figure 67. Annual trap-based exploitable biomass index estimates from Cartwright and Hawke Channel areas in Assessment Division 2HJ.

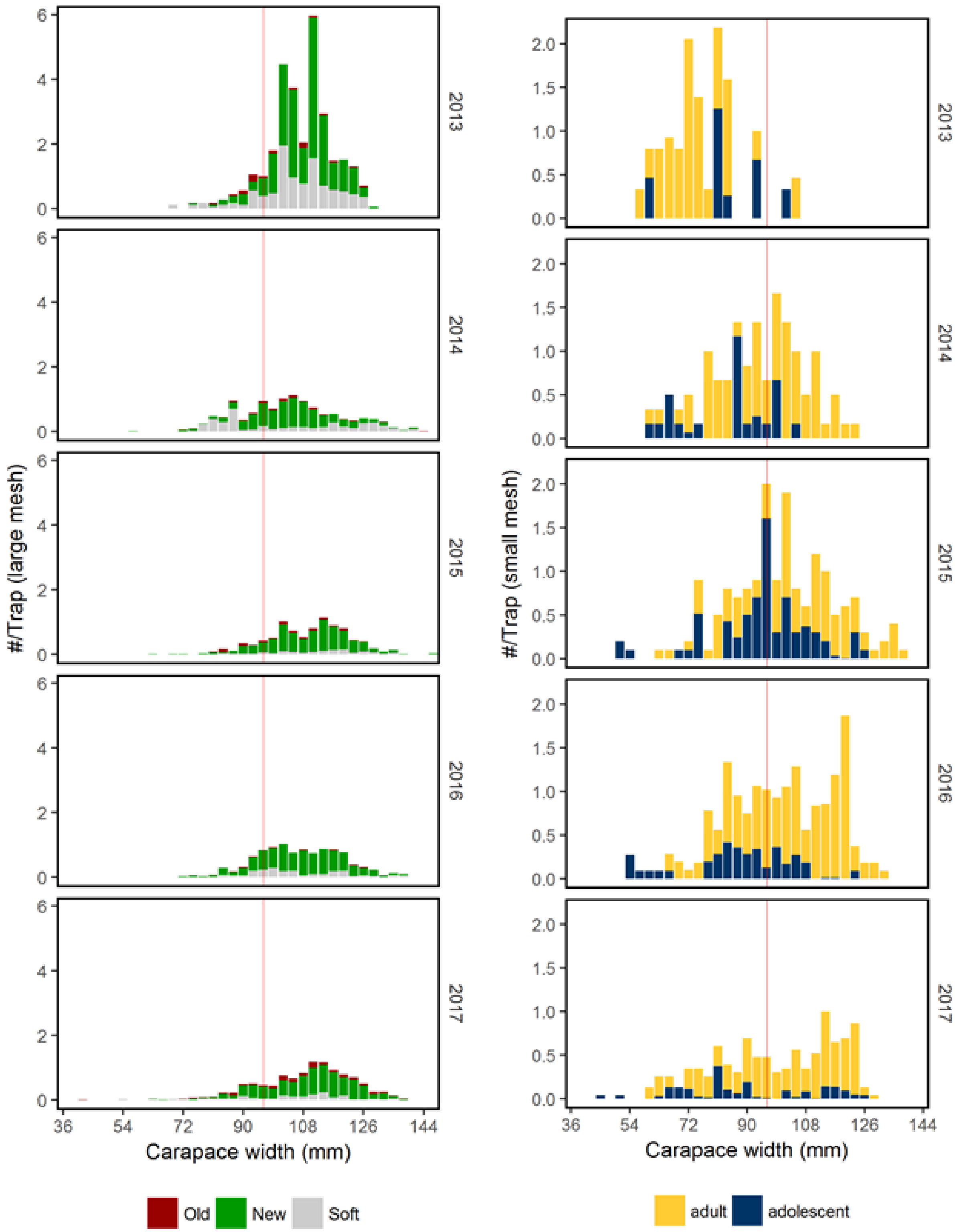

Figure 68. Left: CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps in theTorngat Joint Fisheries Secretariat survey (CMA 2JN) (2013-17). Right: CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the Torngat Joint Fisheries Secretariat survey (2013-17). The vertical line indicates the minimum legal size.

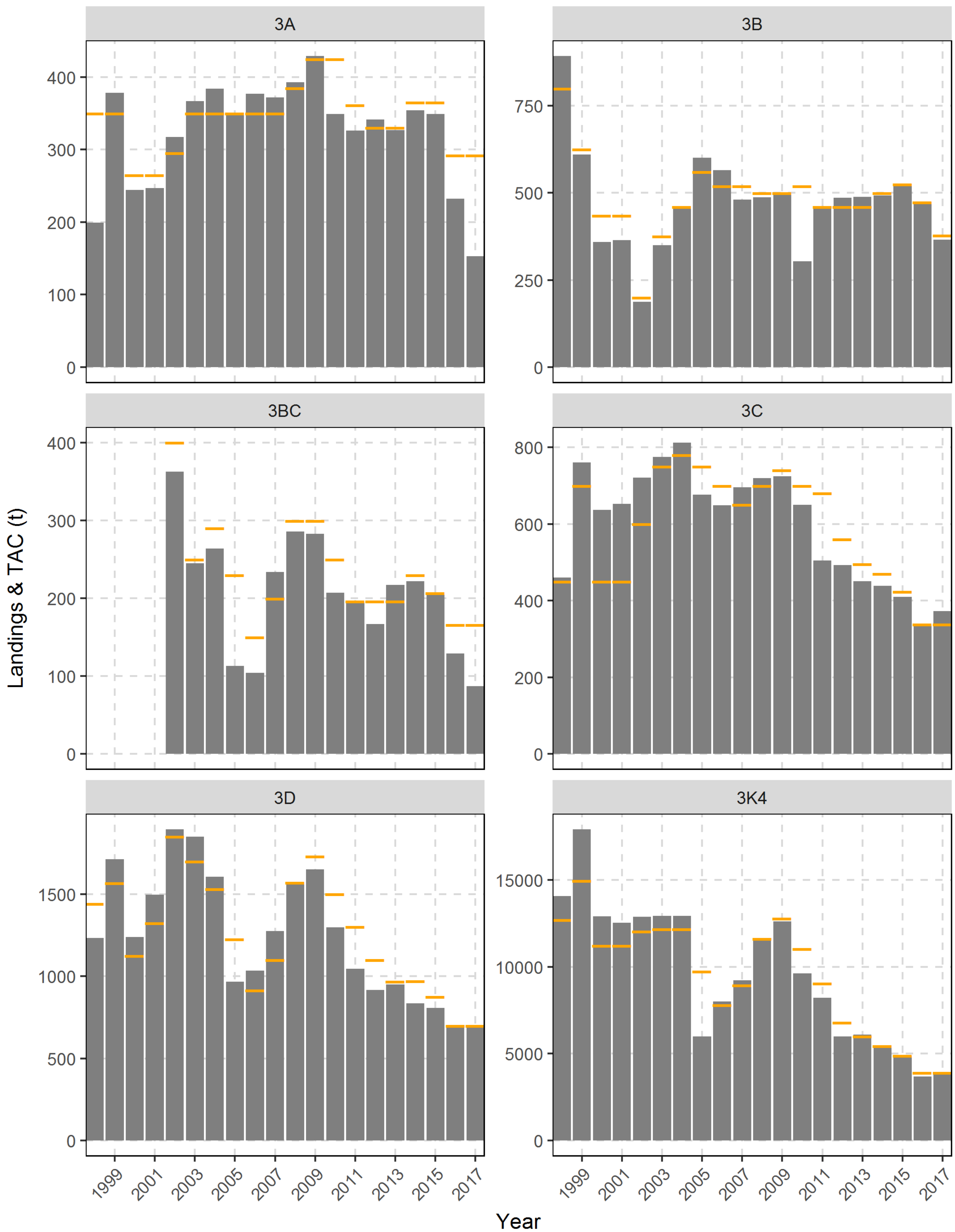

Figure 69. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Division 3K (1998-2007).

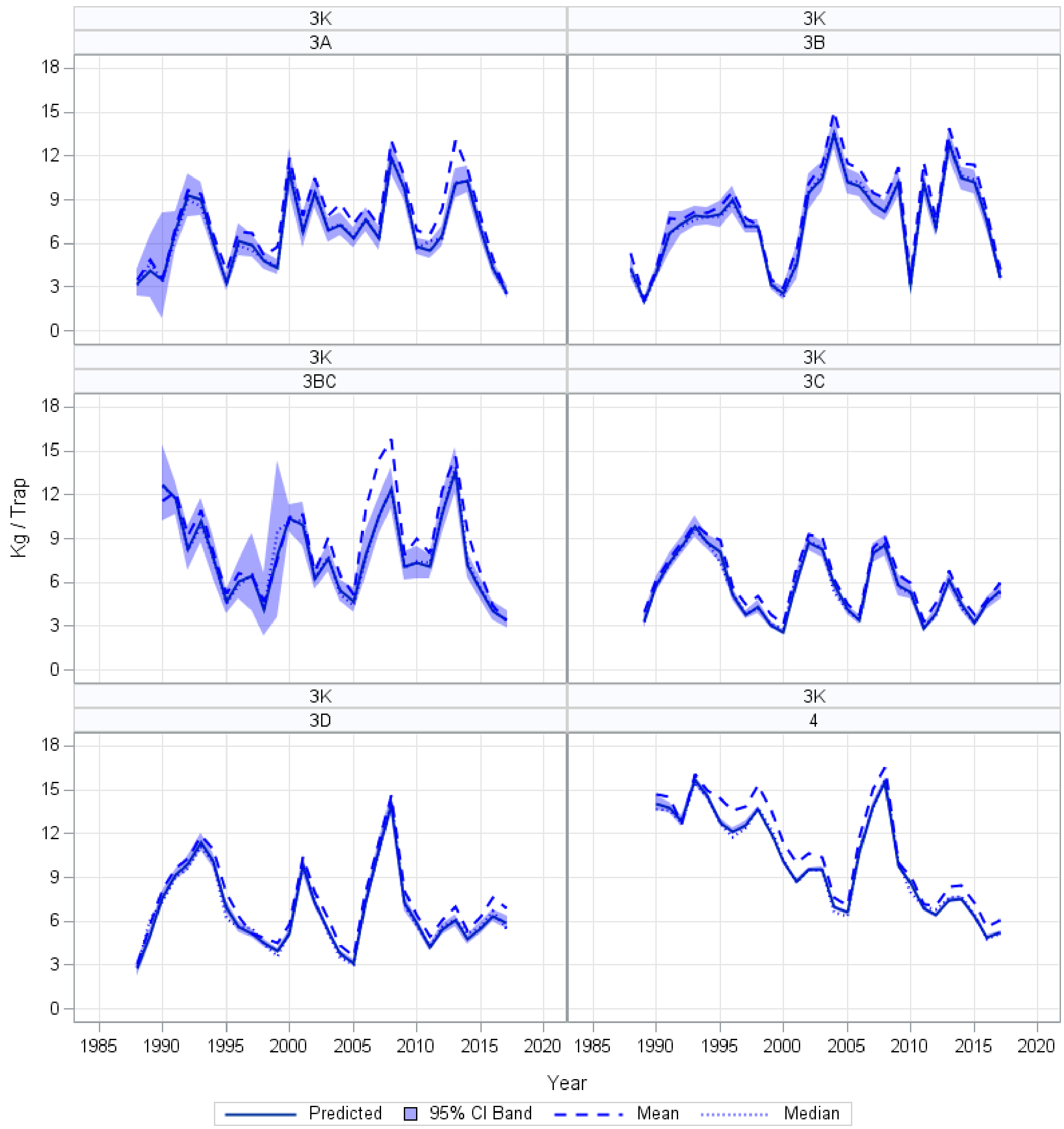

Figure 70. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Division 3K.

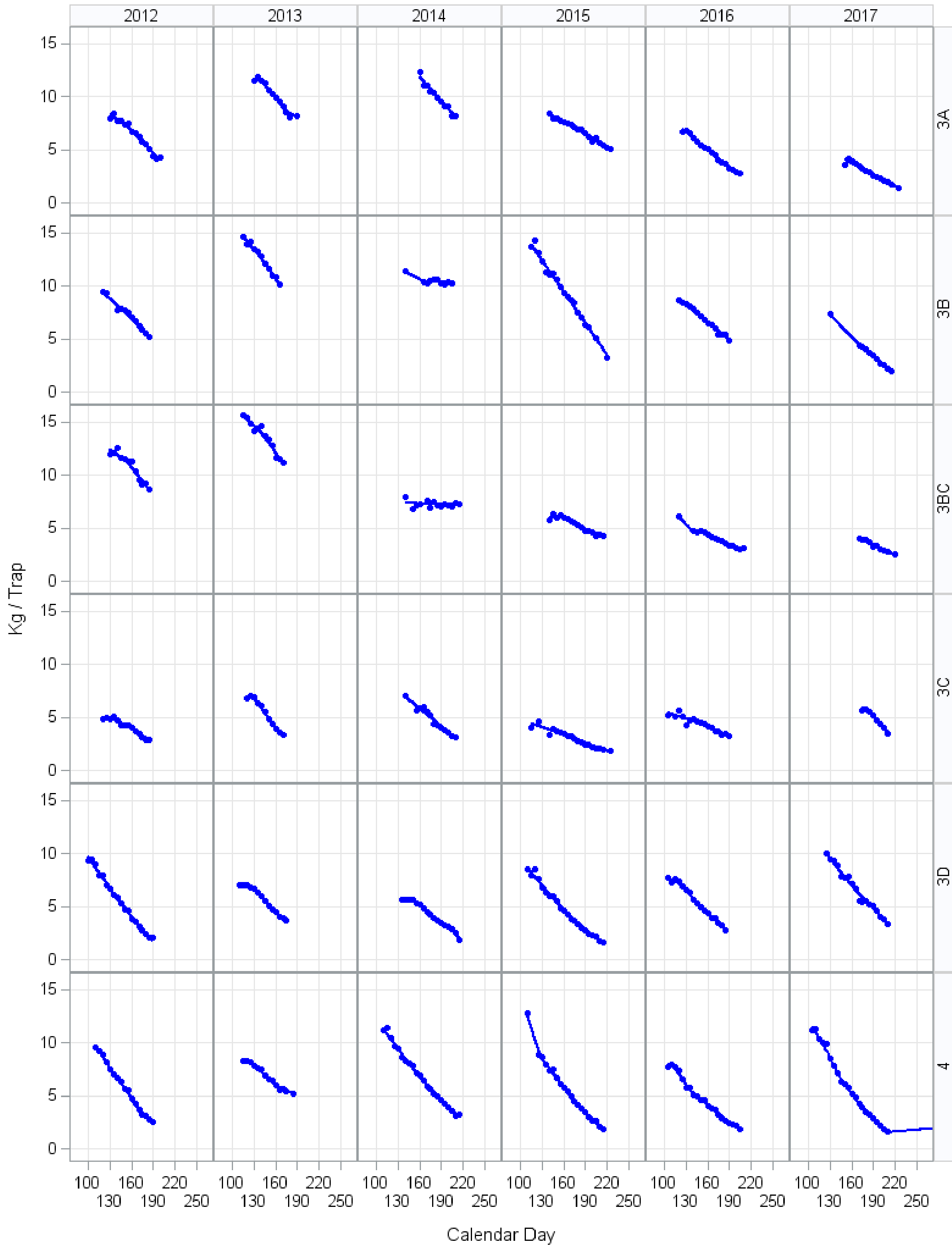

Figure 71. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2012-17), by Crab Management Area (CMA) in Assessment Division 3K.

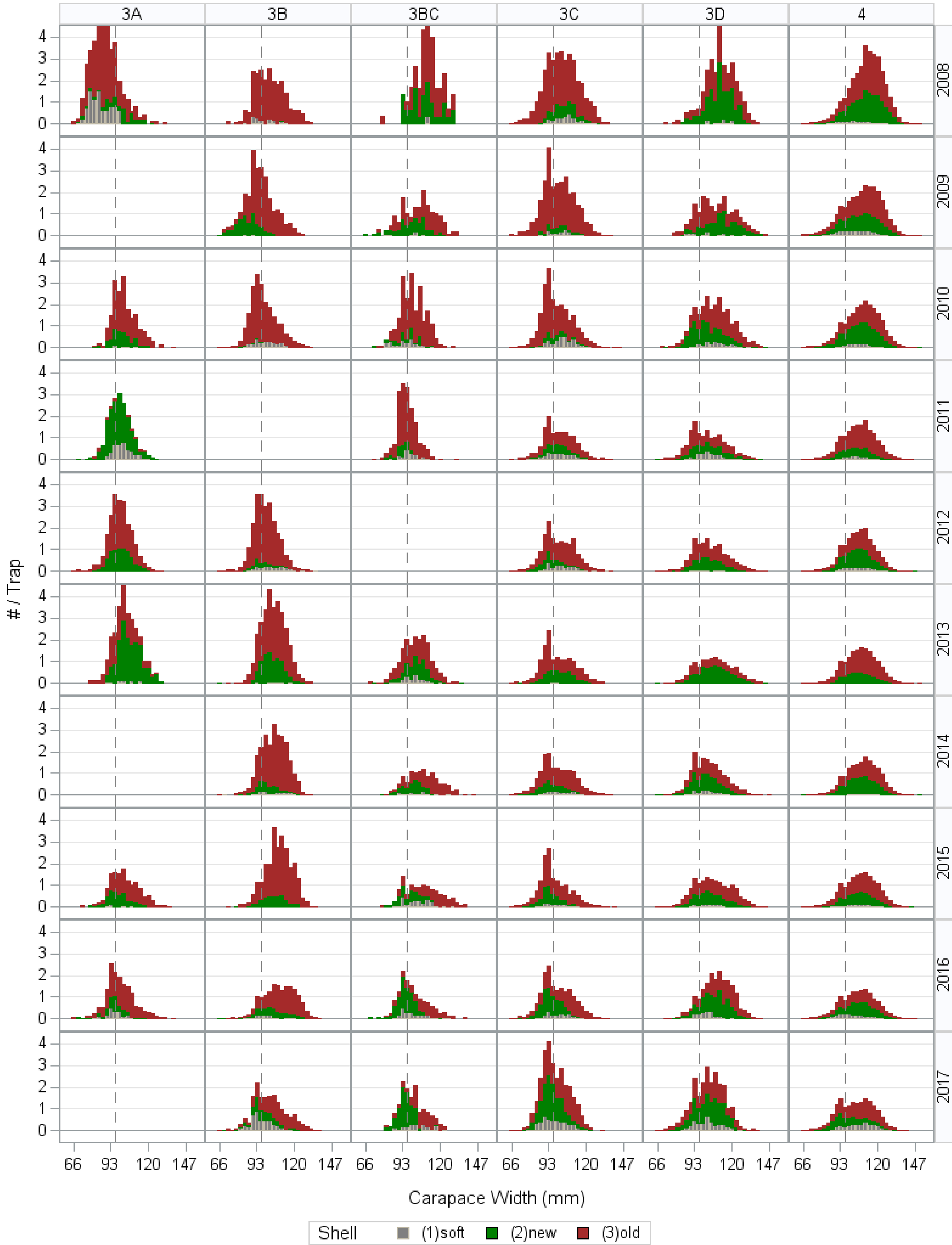

Figure 72. Trends in male carapace width distributions by shell condition from observer sampling in Divisions 3K (2008-17). The vertical line indicates the minimum legal size.

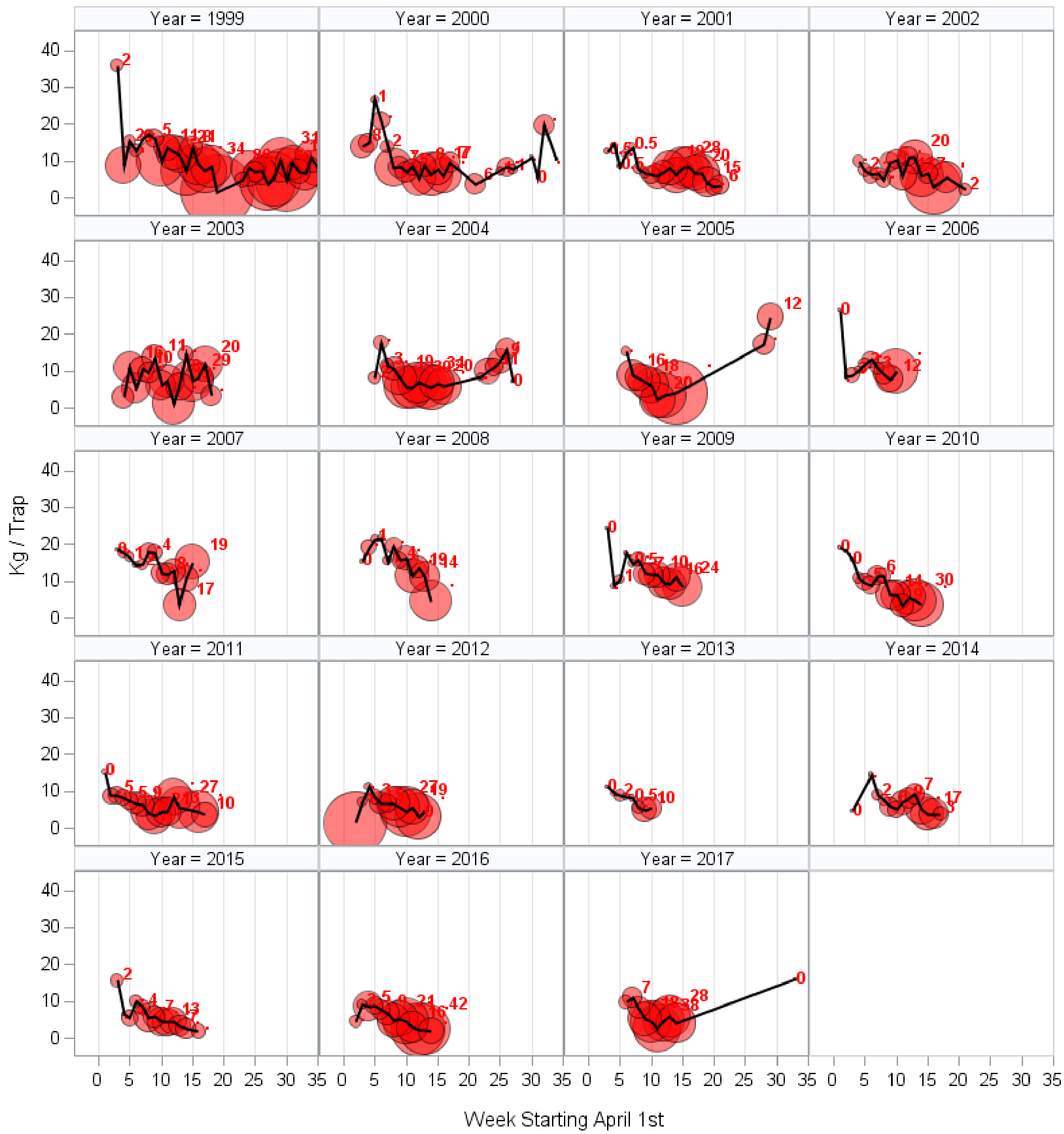

Figure 73. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within the Assessment Division 3K (1999-2017). Bubble size and labels depict percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

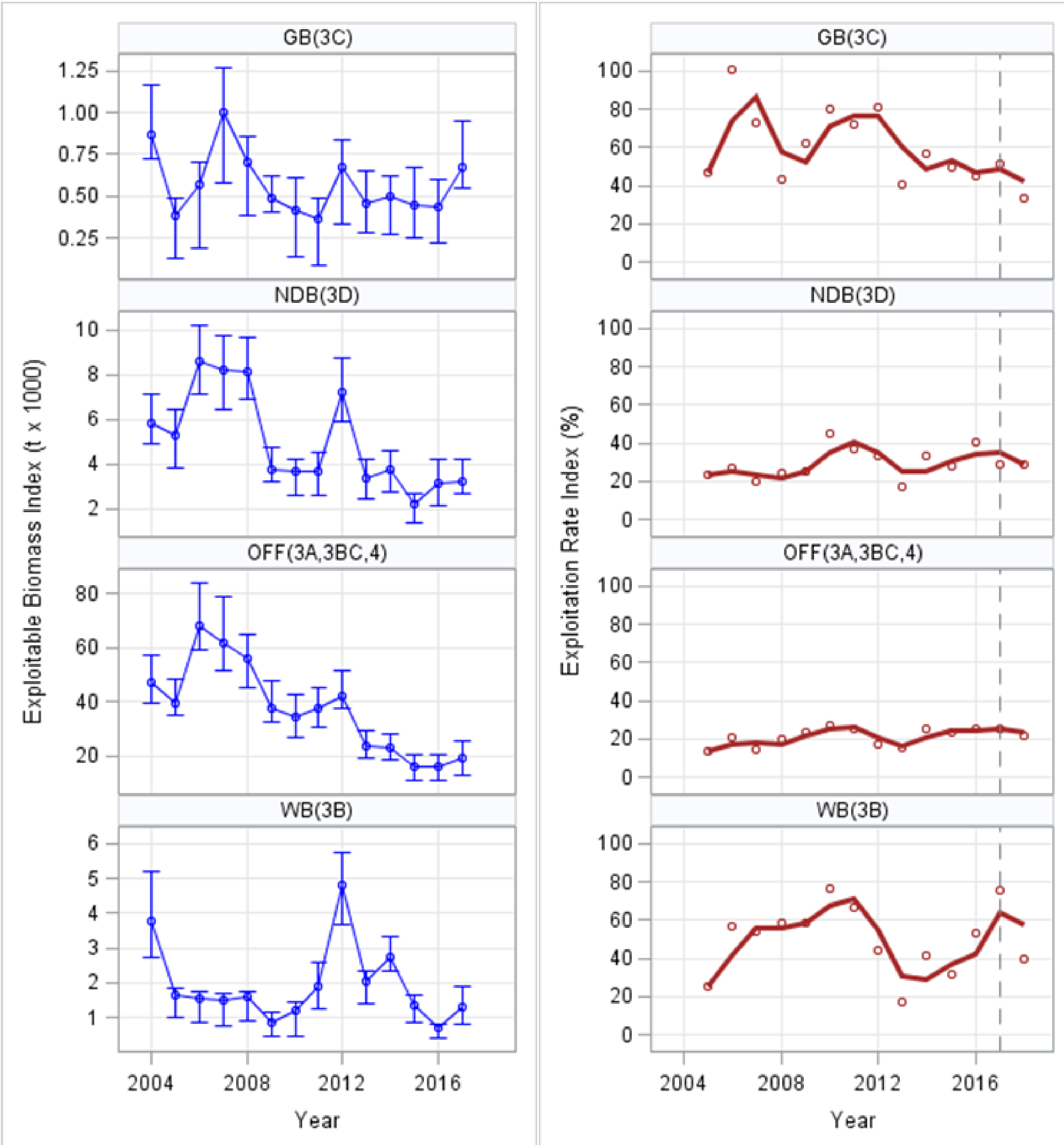

*Figure 74. Left: Annual trap-based exploitable biomass index estimates (t * 1000). Right: Trends in the exploitation rate index in CMAs within Assessment Division 3K. Line represents 2-year moving average and points represent annual estimates.*

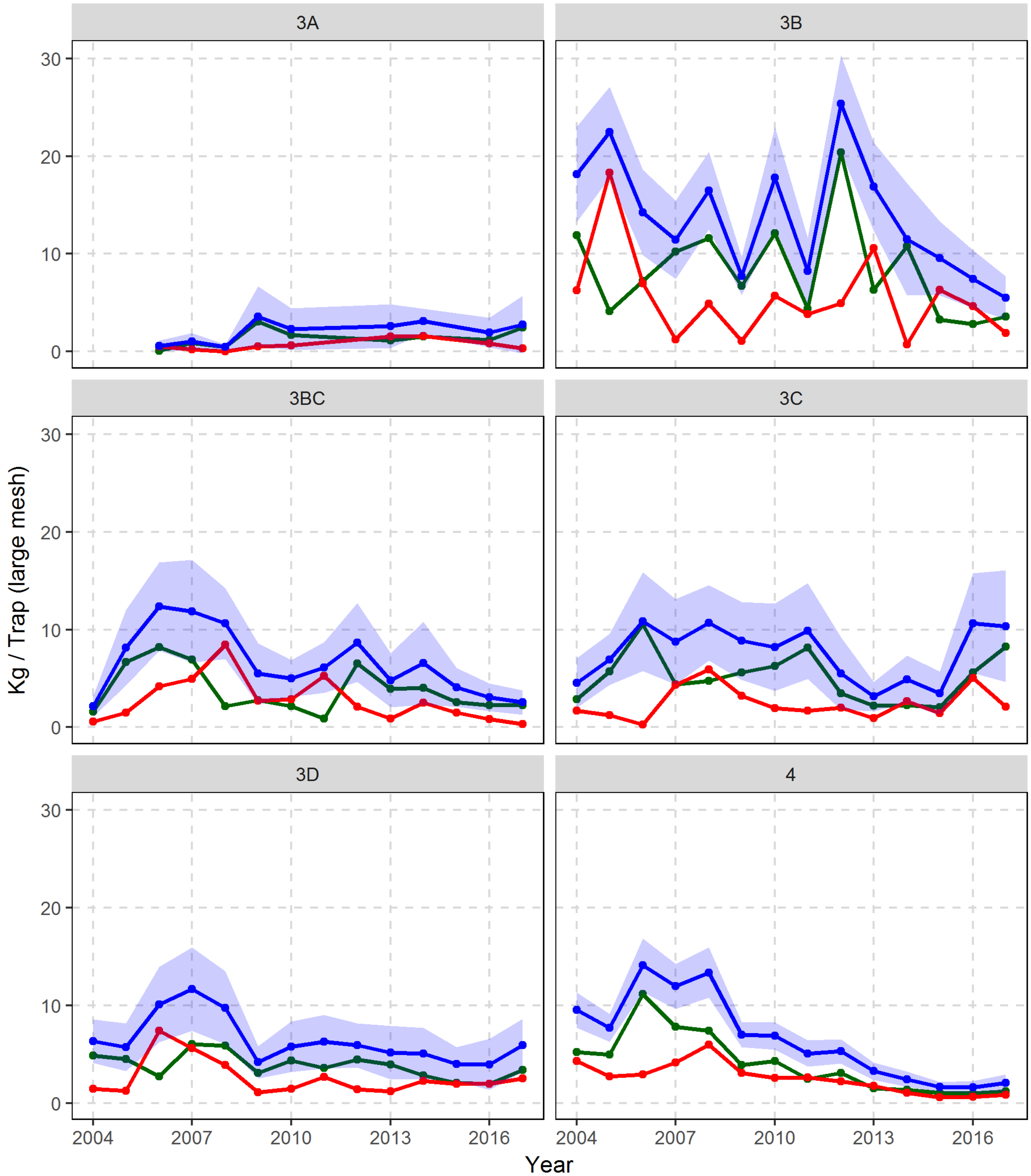

Figure 75. Trends in CPUE (kg/trap) by shell condition for legal-sized crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Division 3K.

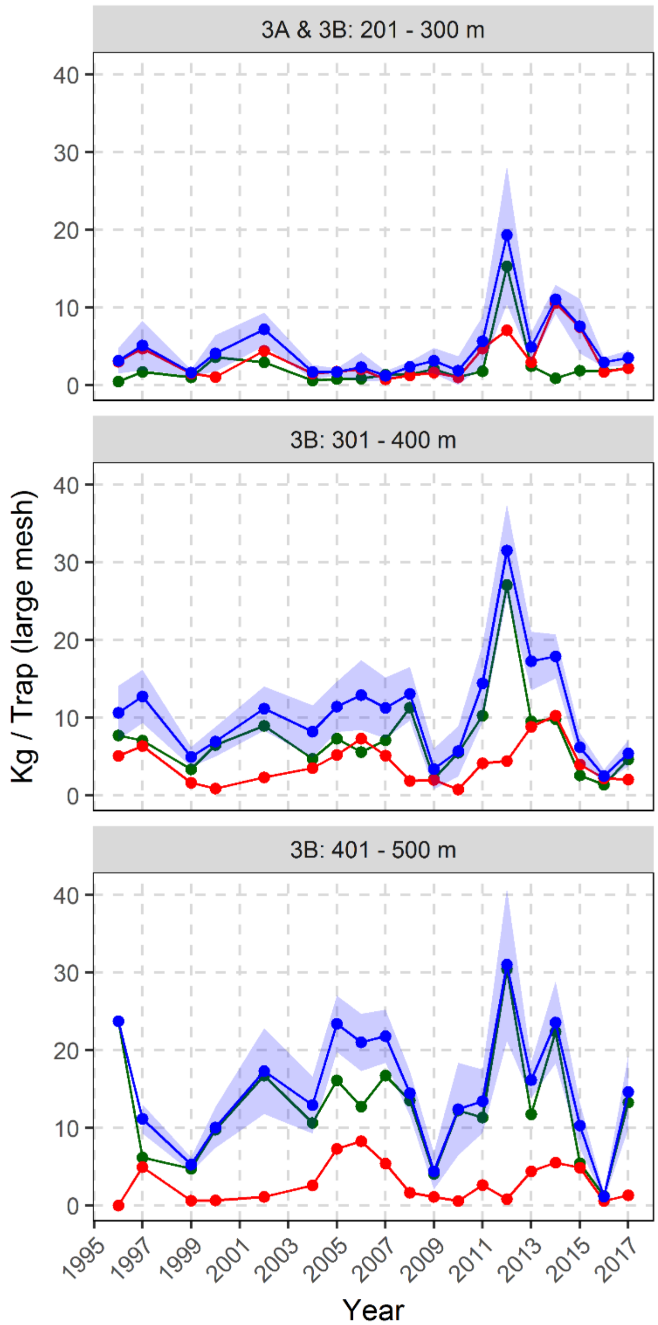

Figure 76. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from DFO trap surveys in White Bay (Assessment Division 3K).

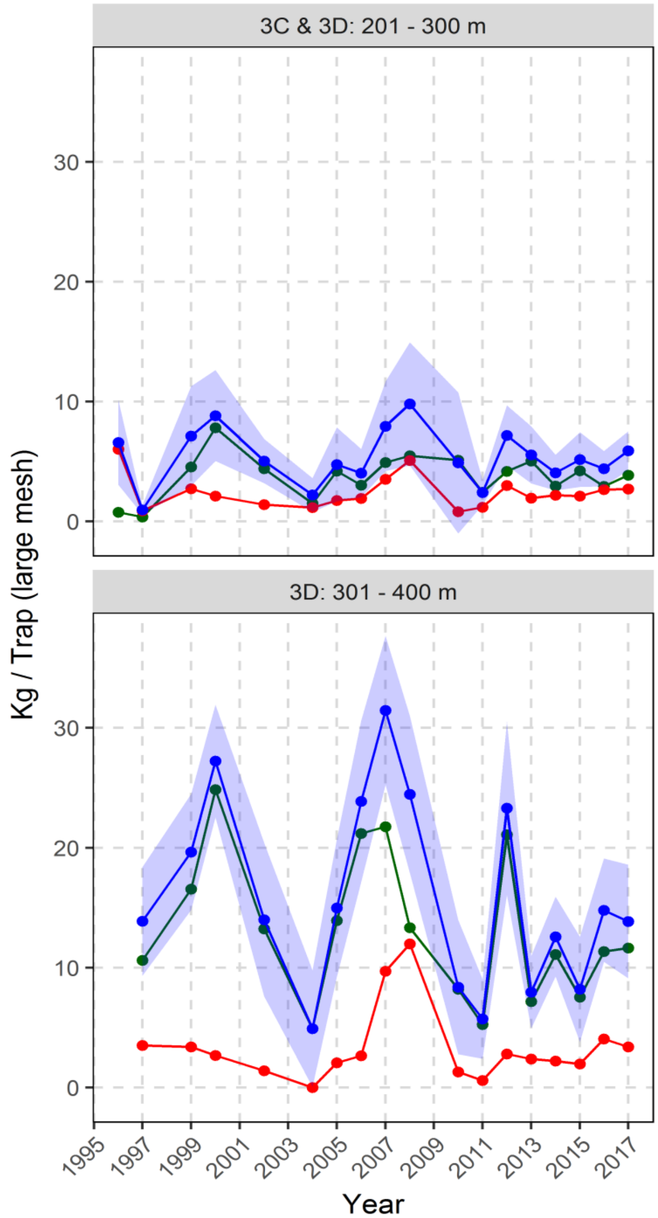

Figure 77. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from DFO trap surveys in Green Bay and Notre Dame Bay (Assessment Division 3K).

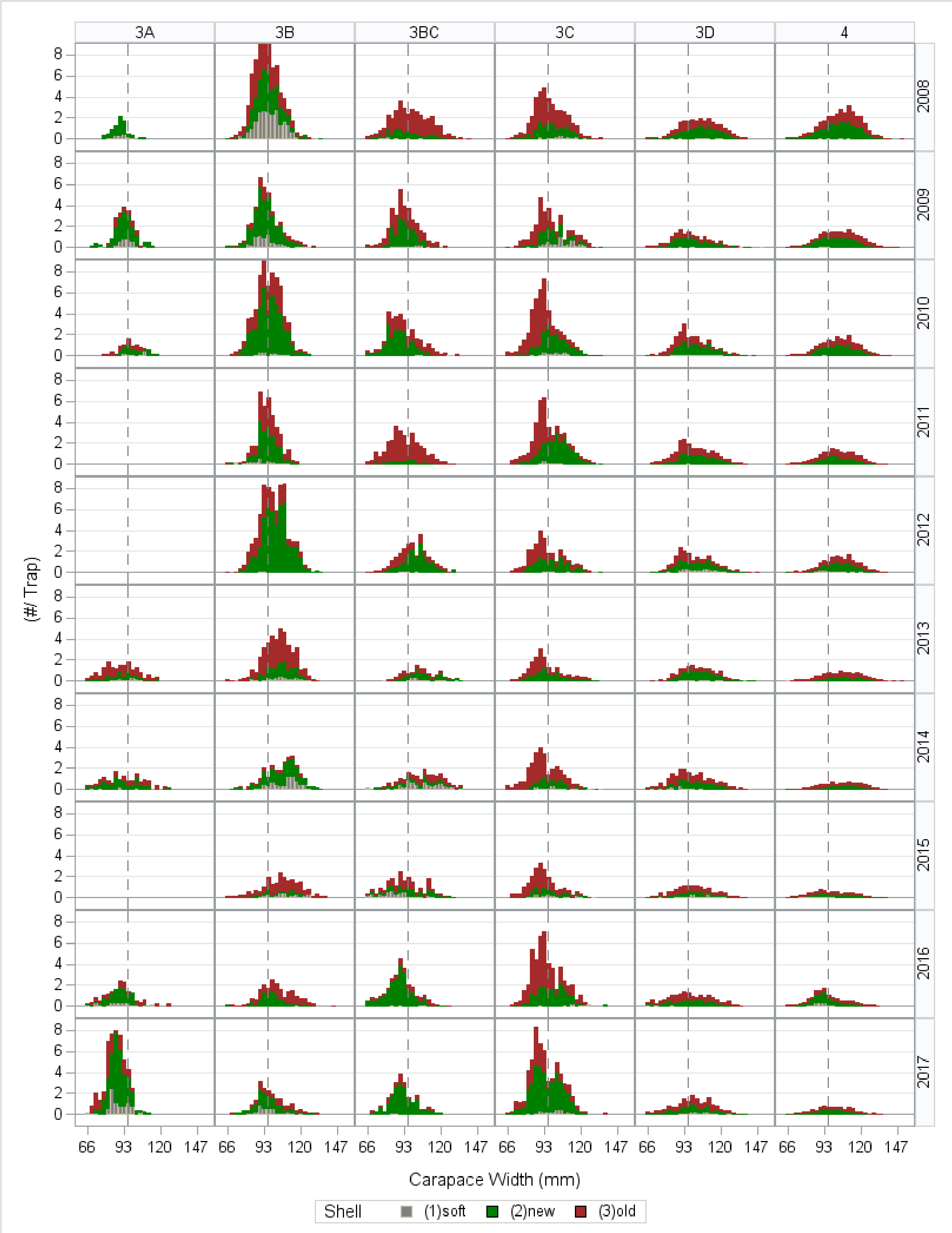

Figure 78. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Division 3K (2008-17). The vertical line indicates the minimum legal size.

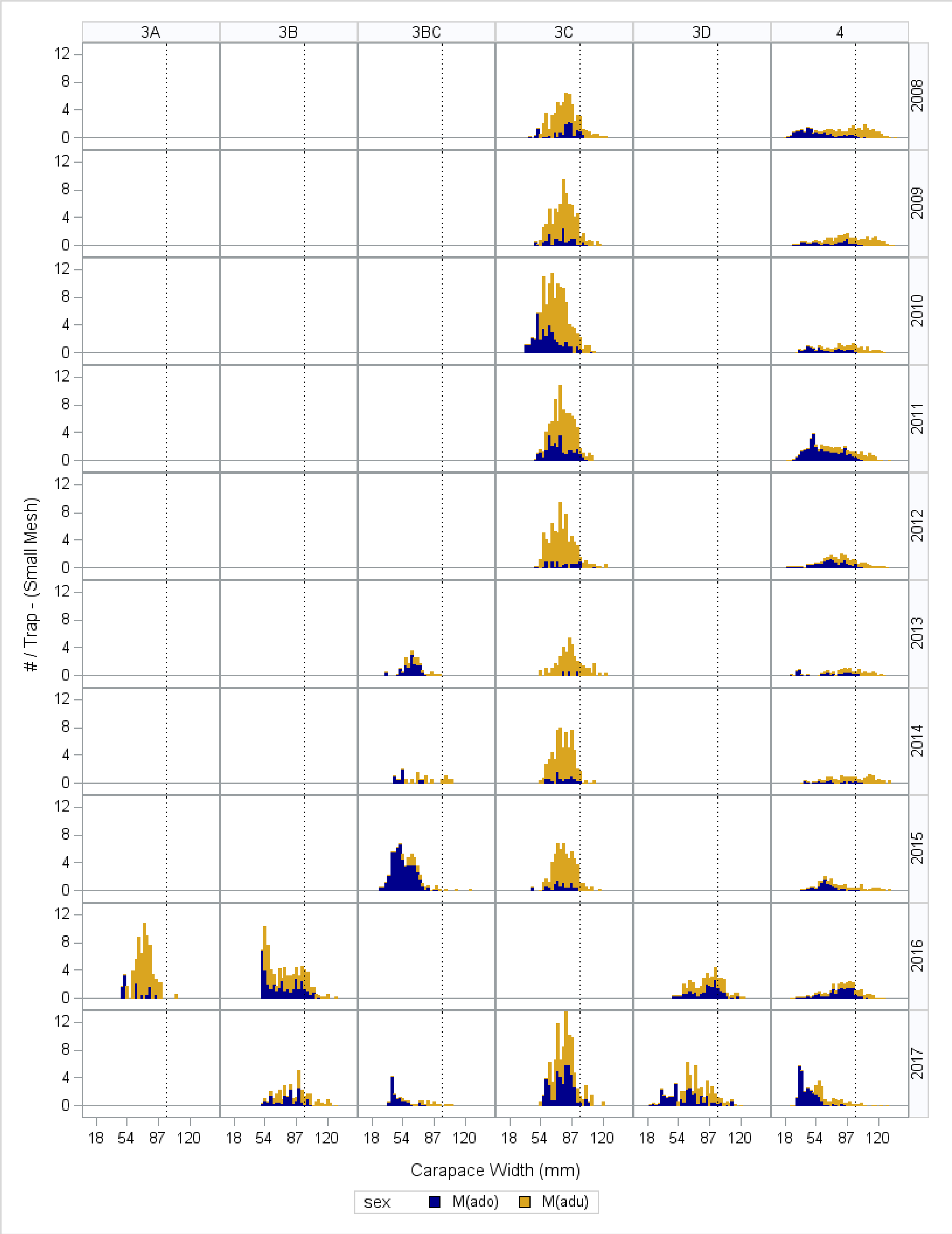

Figure 79. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2008-17) from CMAs in Assessment Division 3K. The vertical line indicates the minimum legal size.

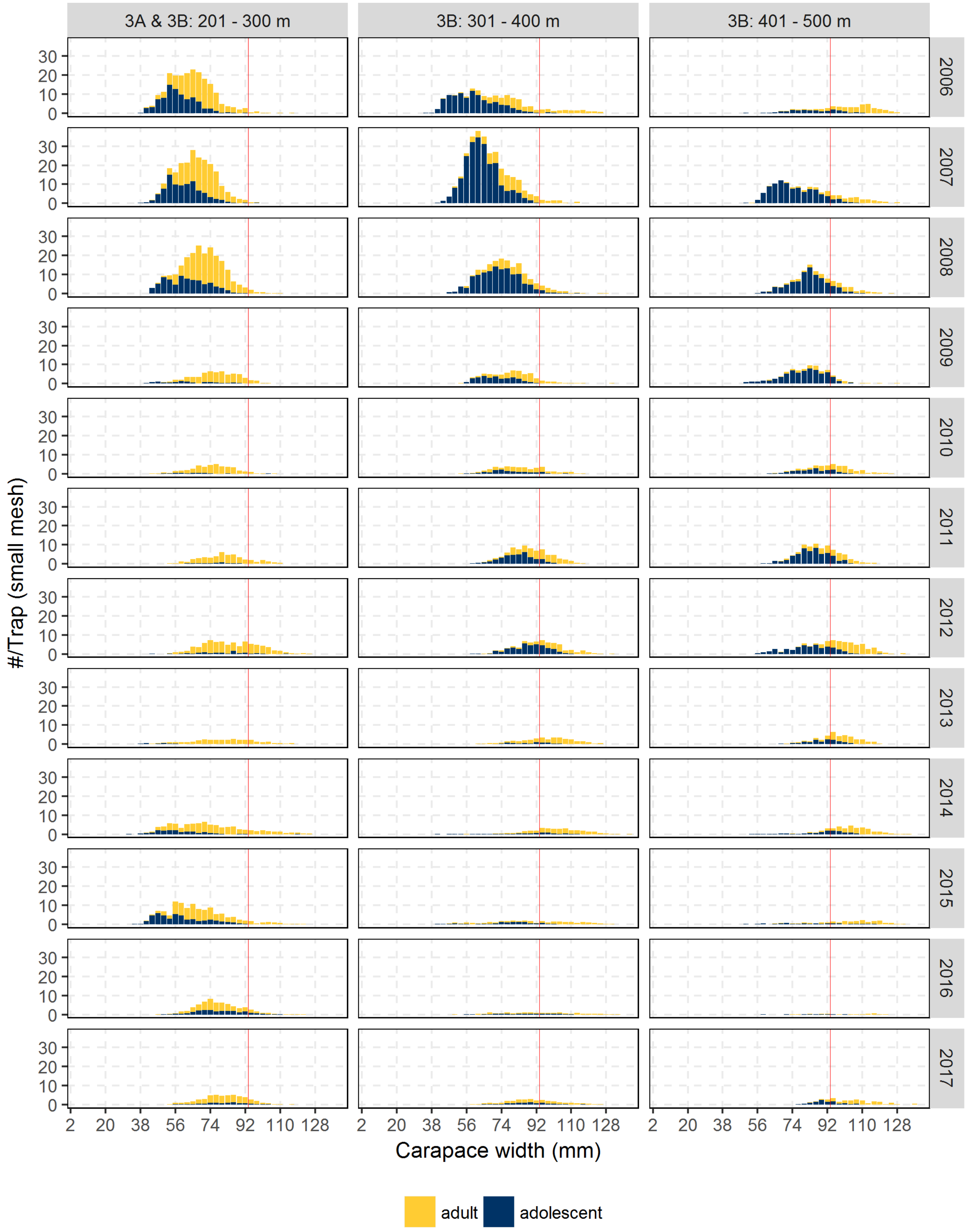

Figure 80. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2006-17) from White Bay (Assessment Division 3K). The vertical line indicates the minimum legal size.

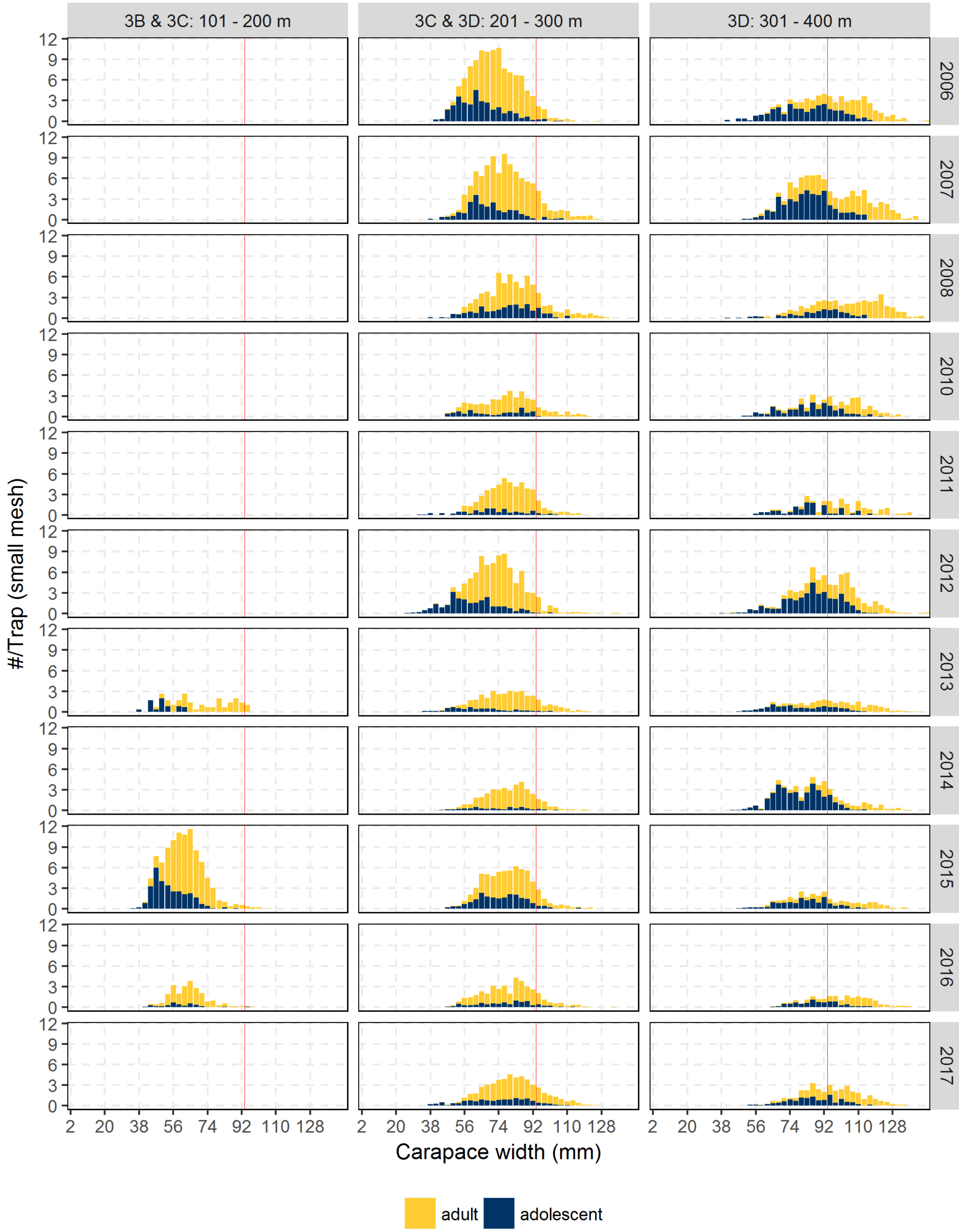

Figure 81. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2006-2017) from Green Bay and Notre Dame Bay (Assessment Division 3K). The vertical line indicates the minimum legal size.

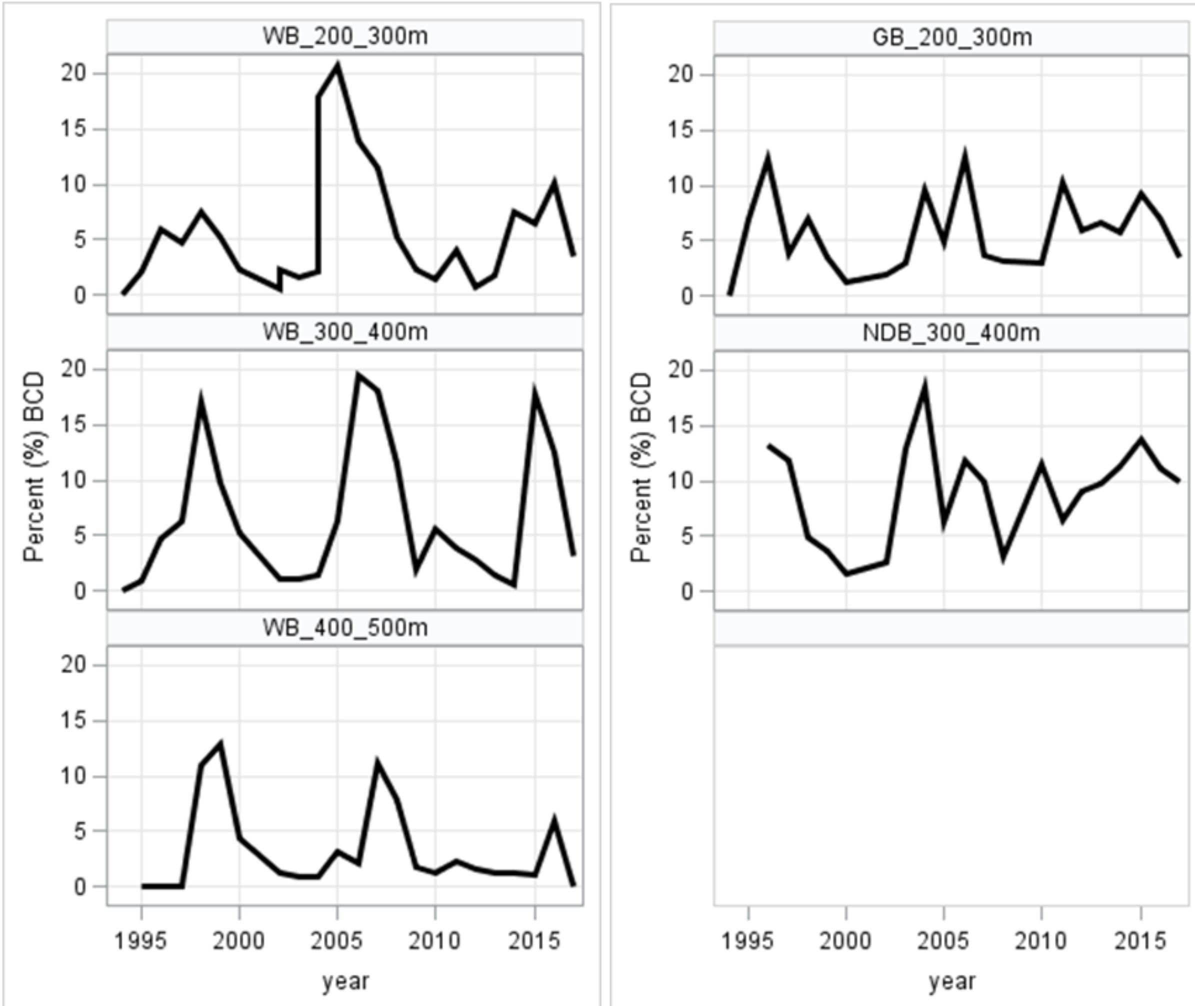

Figure 82. Visually observed percentage of Bitter Crab Disease in crab captured in small-mesh pots from DFO trap surveys in White and Green/Notre Dame Bays.

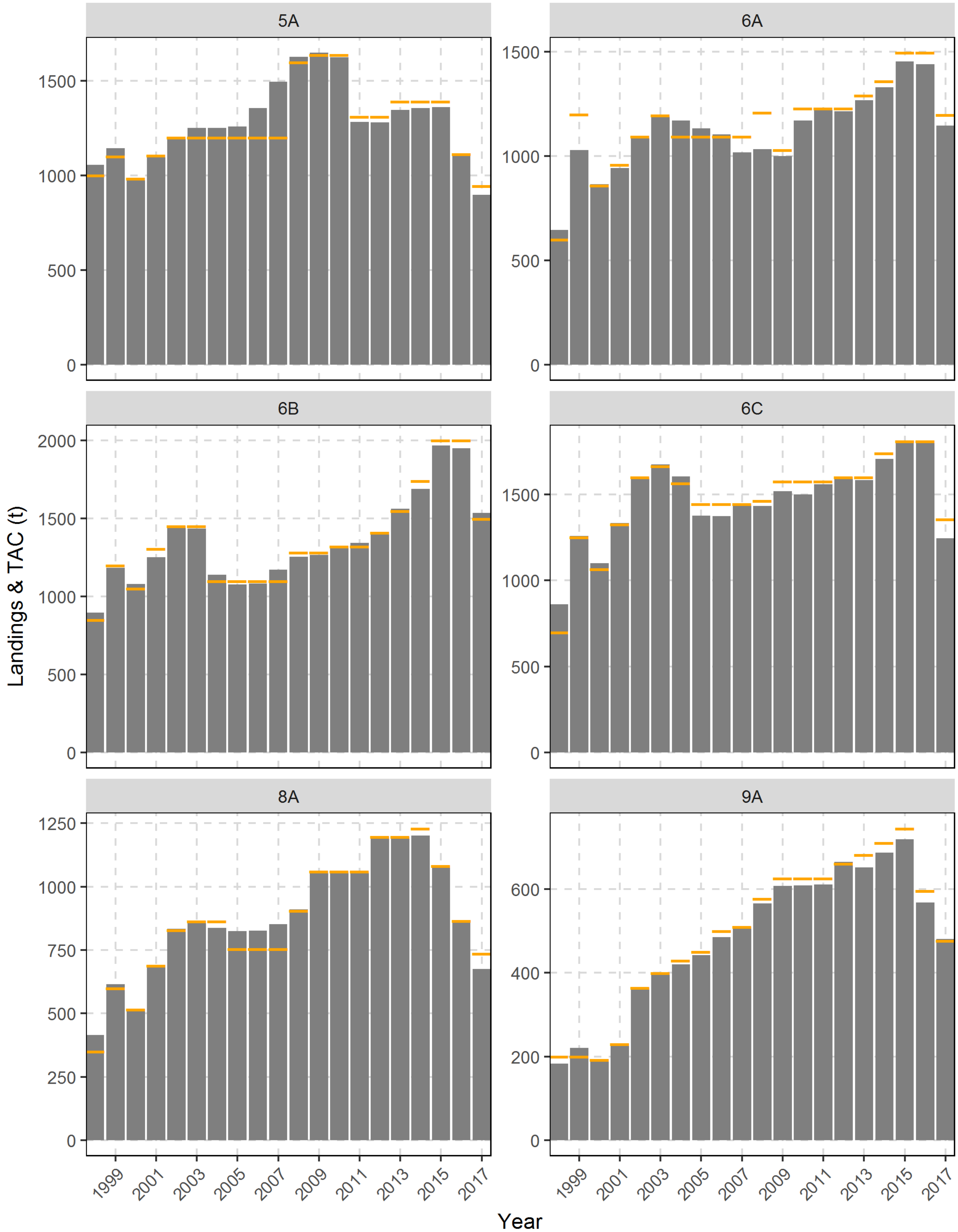

Figure 83. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Division 3L inshore (1998-2007).

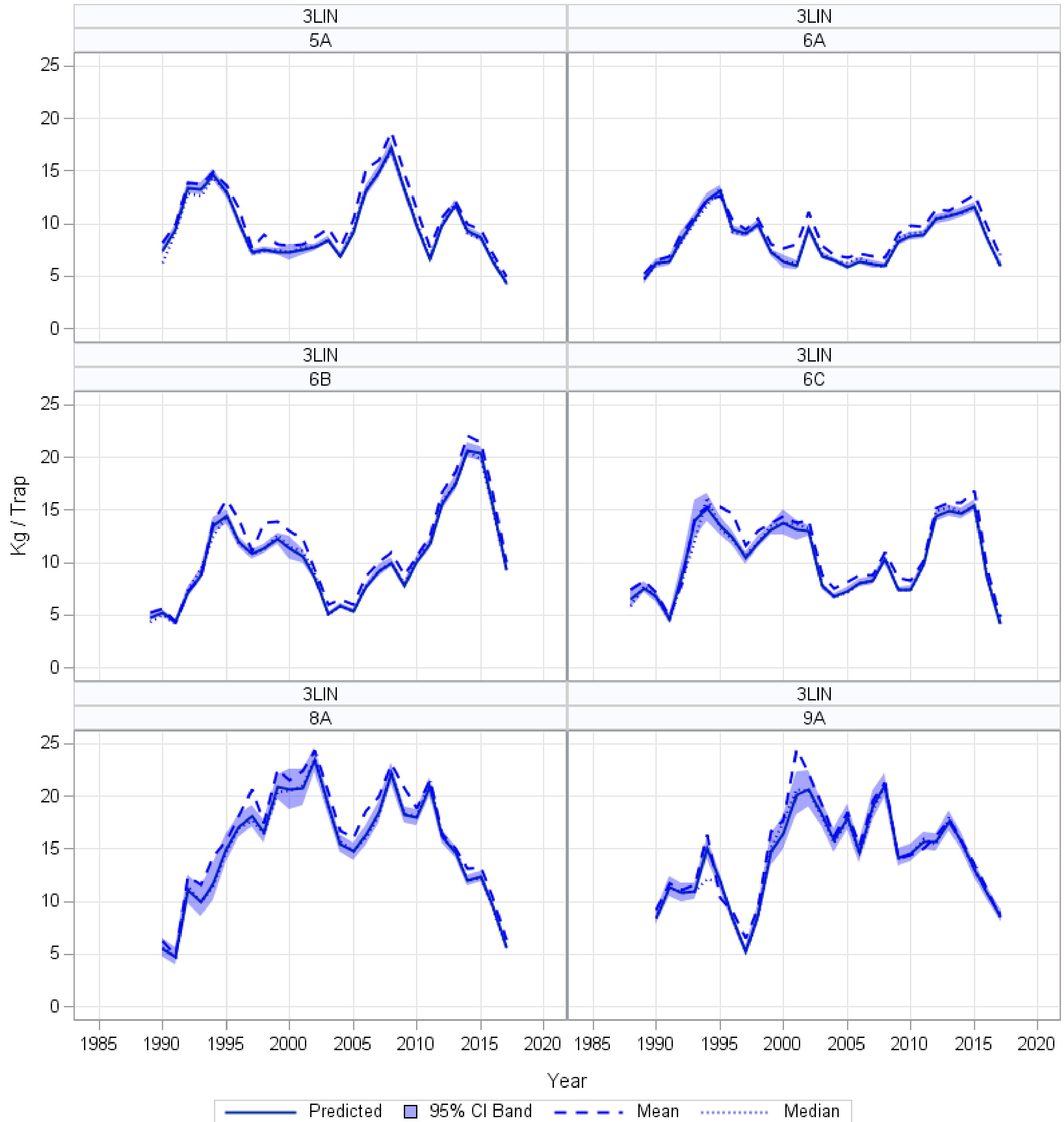

Figure 84. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Division 3L inshore.

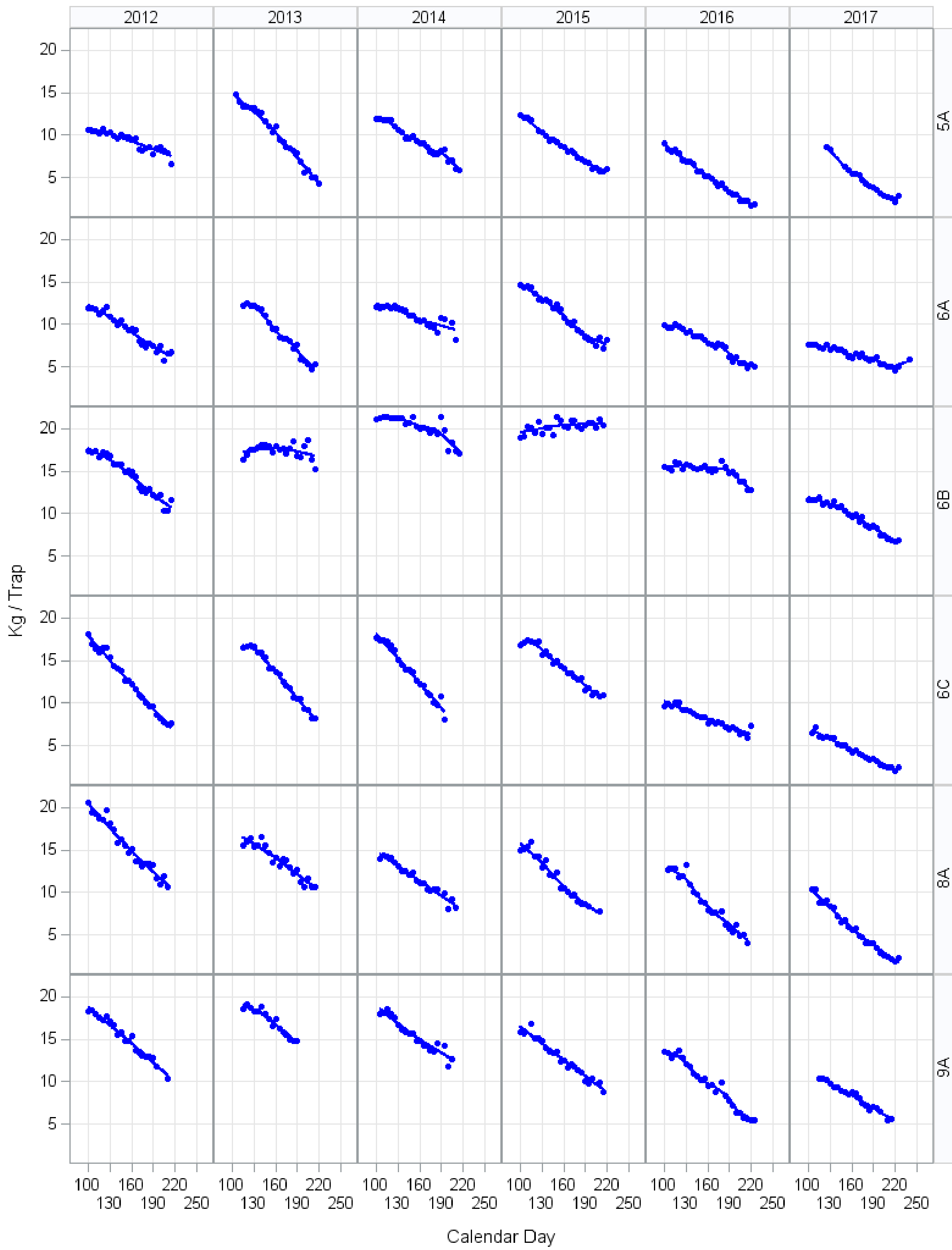

Figure 85. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2012-17), by Crab Management Area (CMA) in Assessment Division 3L inshore.

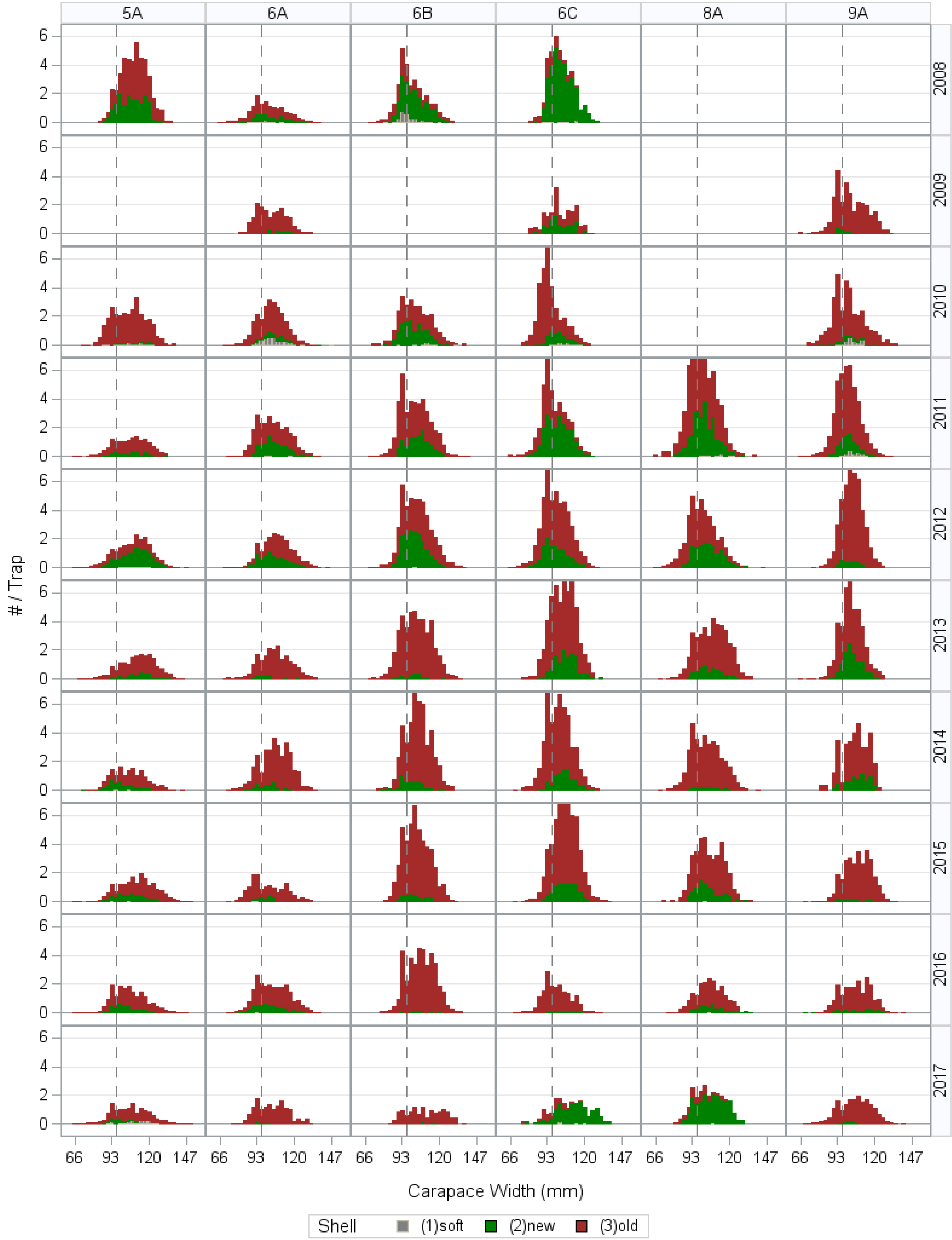

Figure 86. Trends in male carapace width distributions by shell condition from observer sampling in Assessment Division 3L inshore (2008-17). The vertical line indicates the minimum legal size.

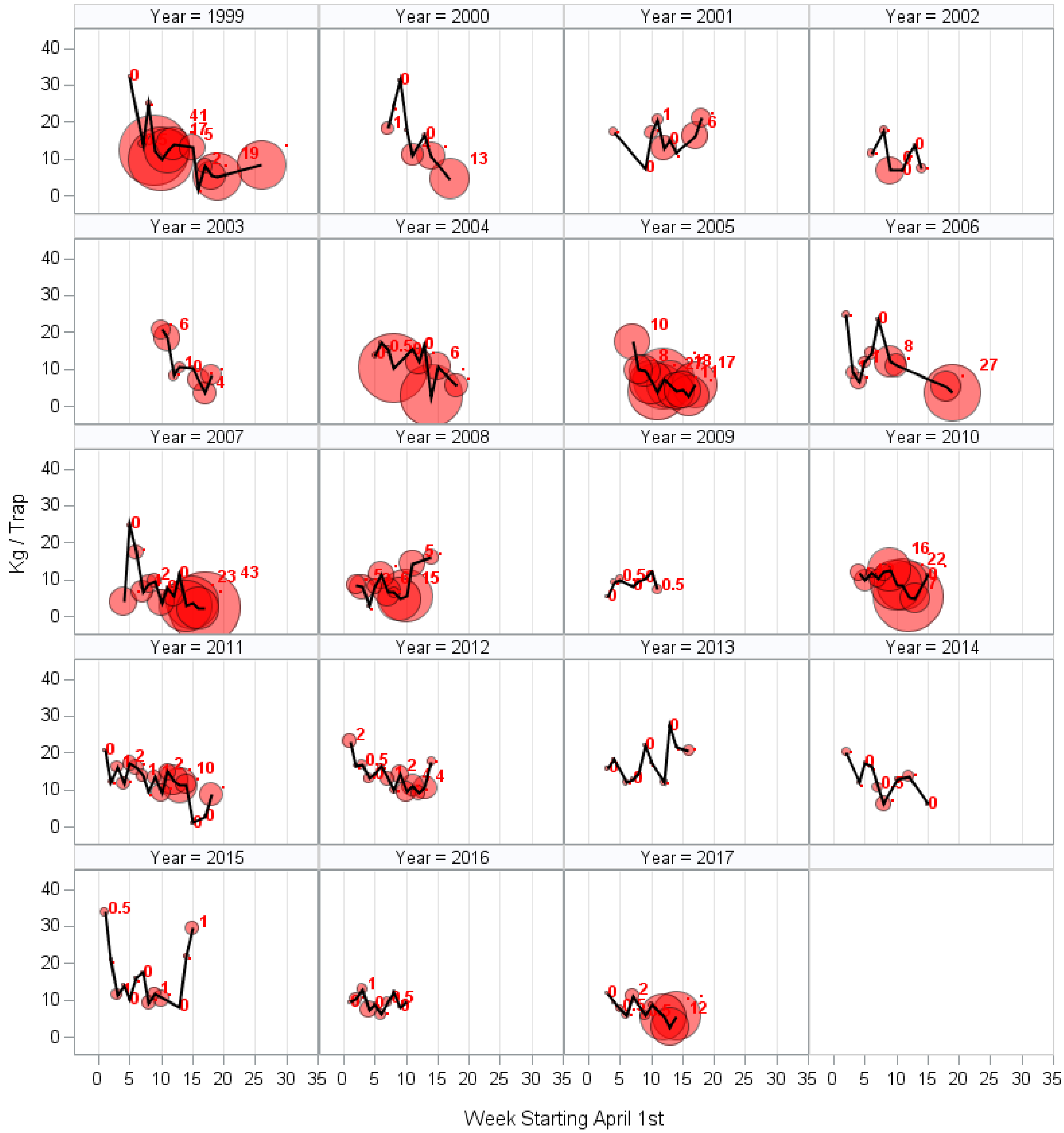

Figure 87. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within the Assessment Division 3L inshore (1999-2017). Bubble size and labels depict percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

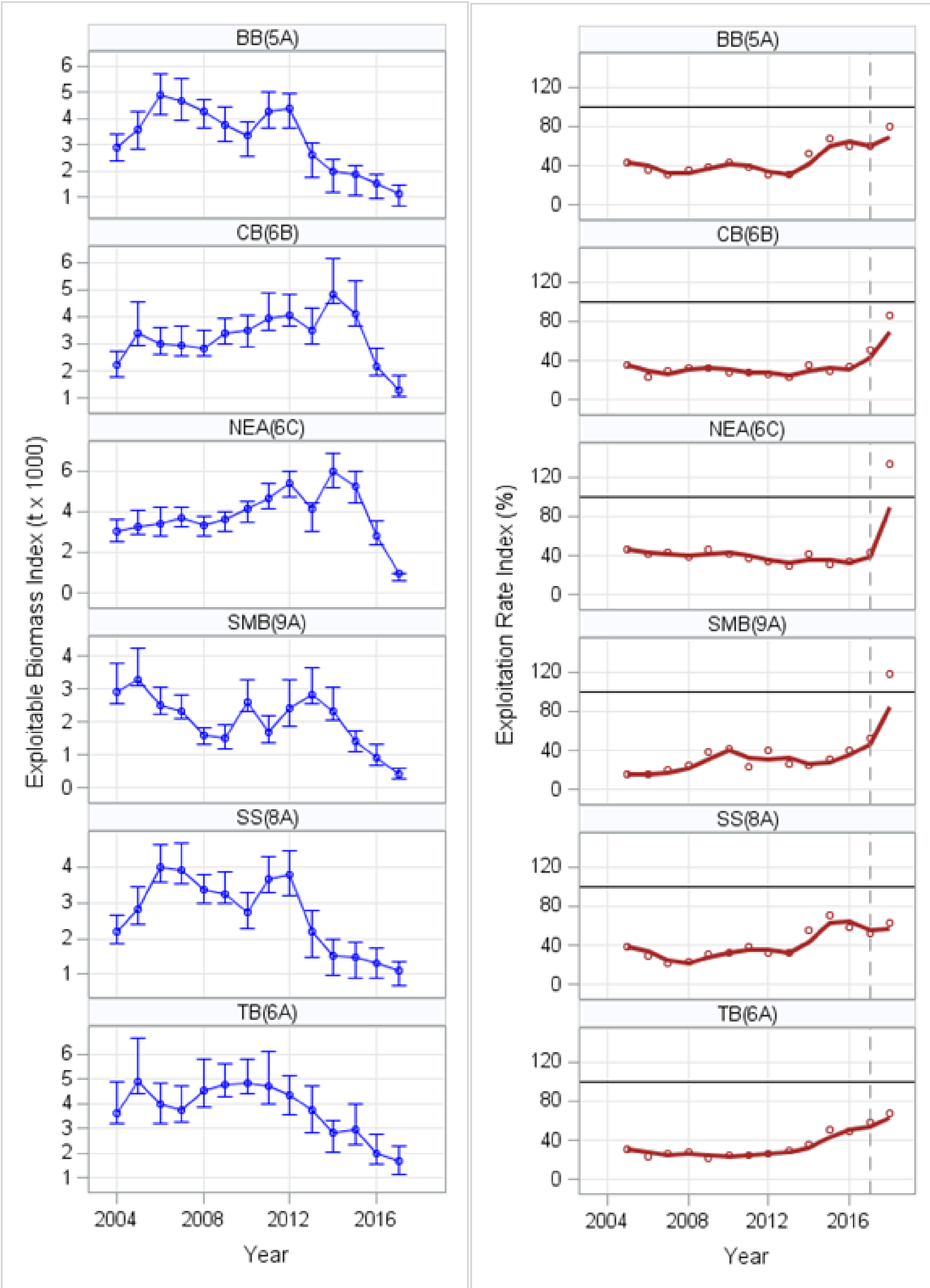

*Figure 88. Left: Annual trap-based exploitable biomass index estimates (t * 1000). Right: Trends in the exploitation rate index in CMAs within Assessment Division 3K. Line represents 2-year moving average and points represent annual estimates.*

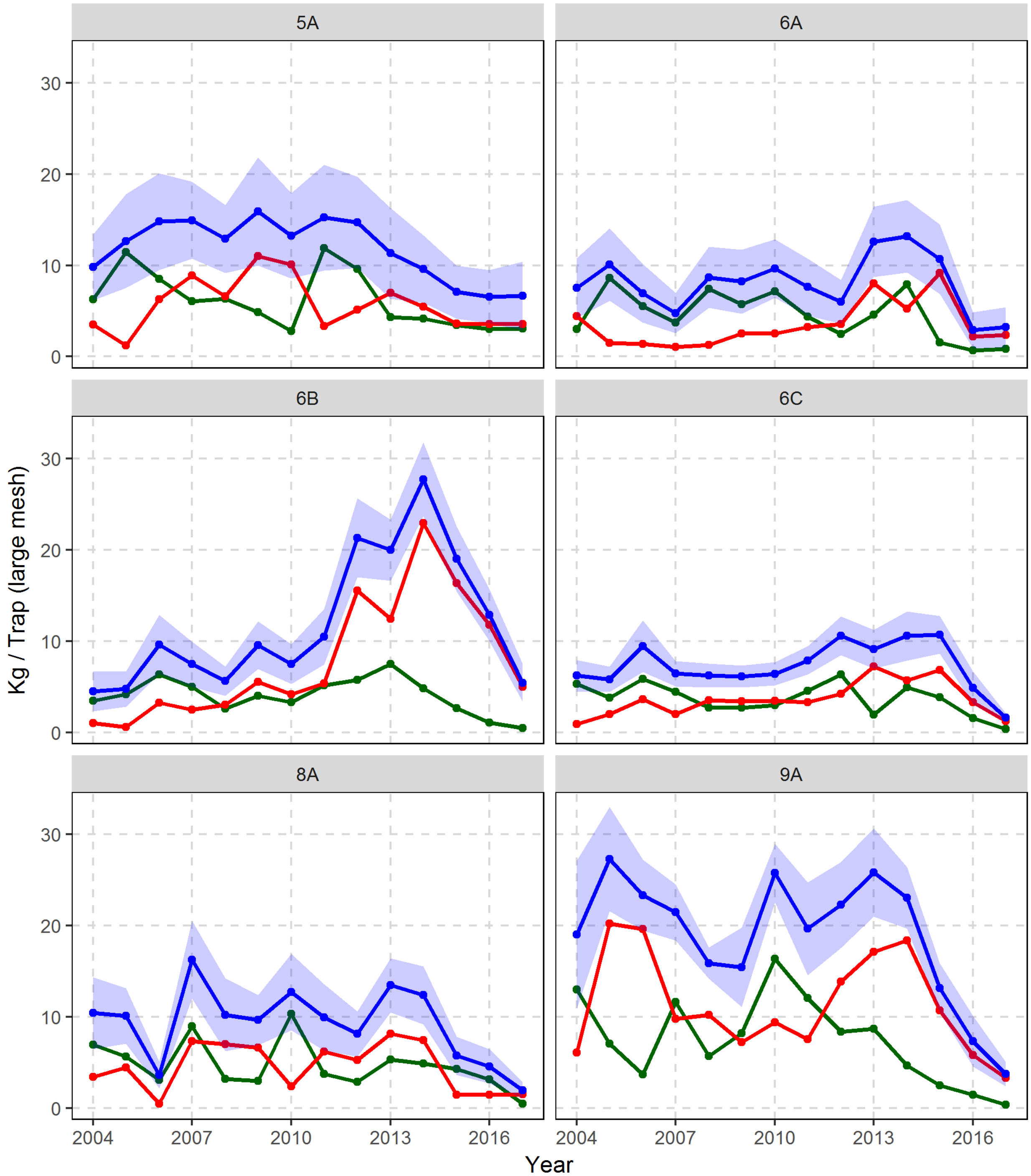

Figure 89. Trends in CPUE (kg/trap) by shell condition for legal-sized crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Division 3L inshore.

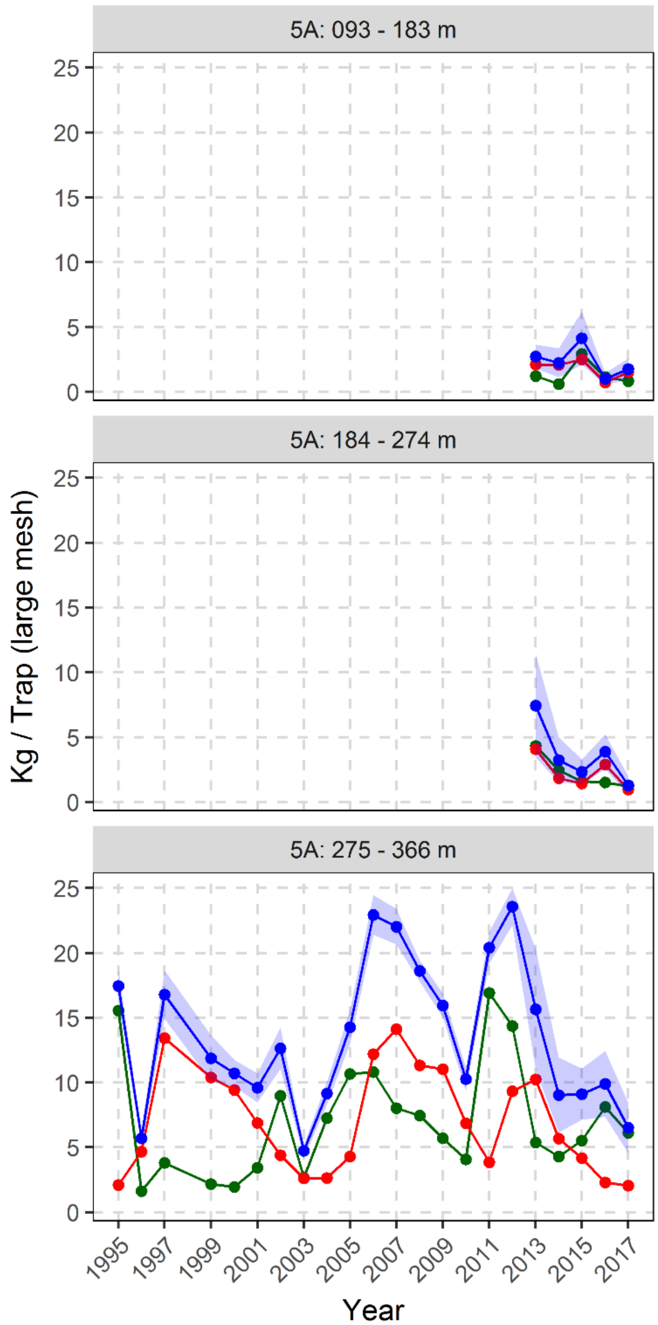

Figure 90. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from DFO trap surveys in Bonavista Bay (Assessment Division 3L inshore).

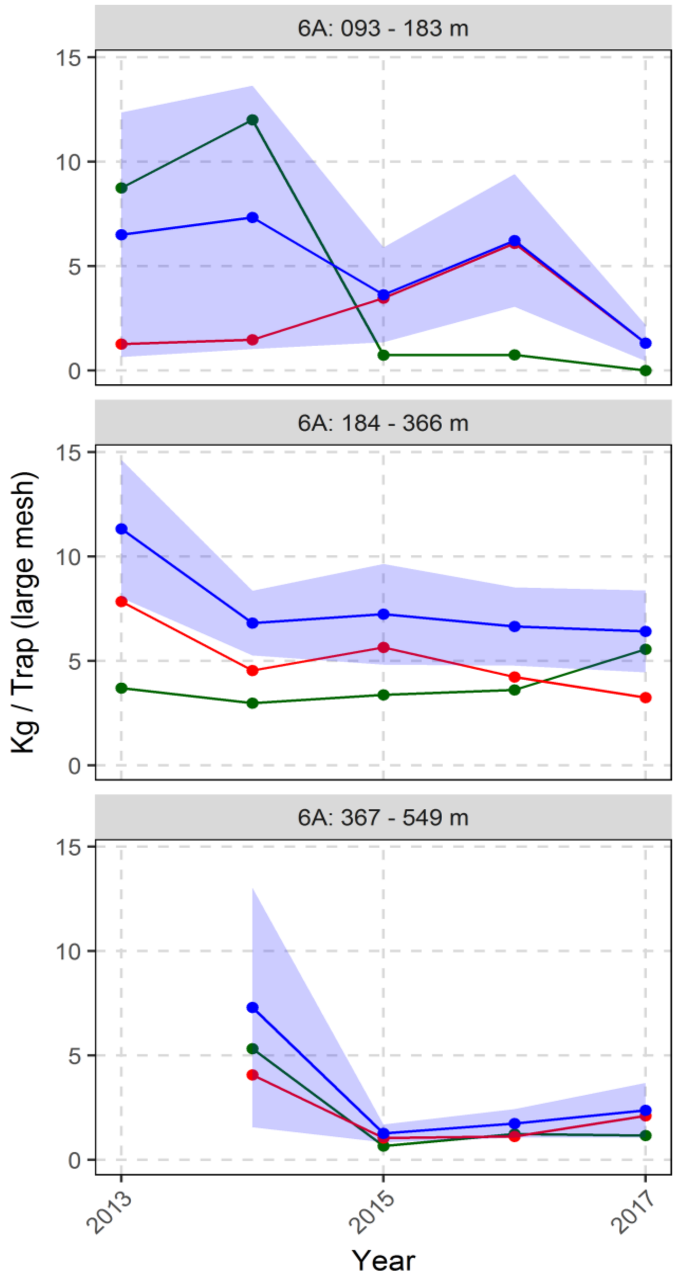

Figure 91. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from DFO trap surveys in Trinity Bay (Assessment Division 3L inshore).

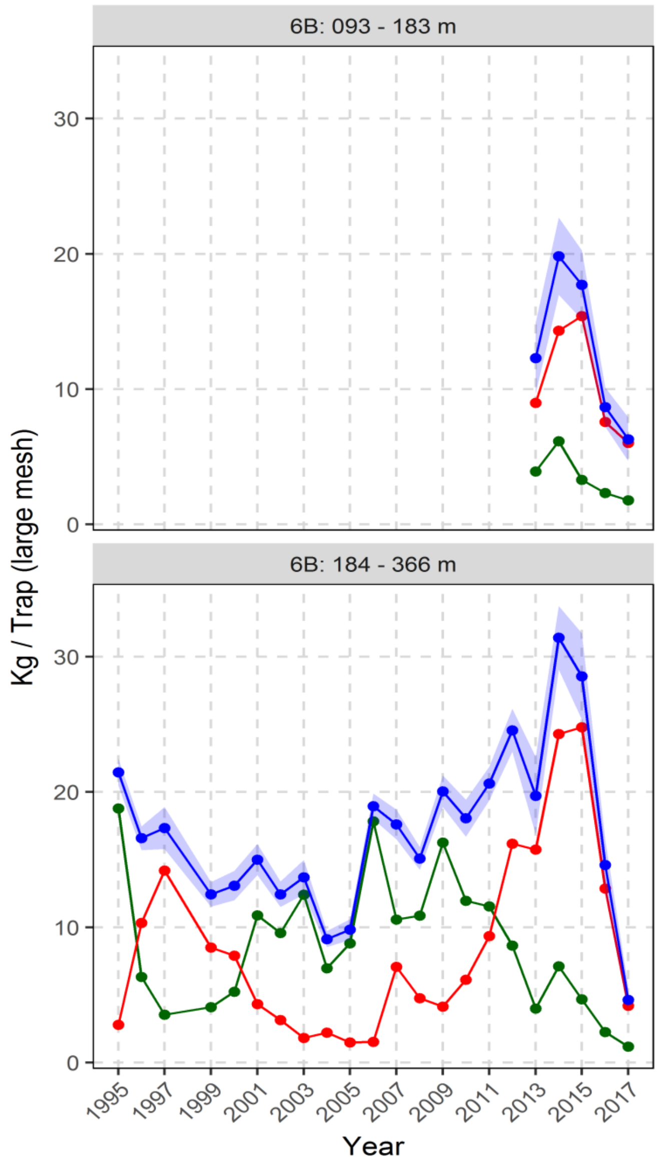

Figure 92. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from DFO trap surveys in Conception Bay (Assessment Division 3L inshore).

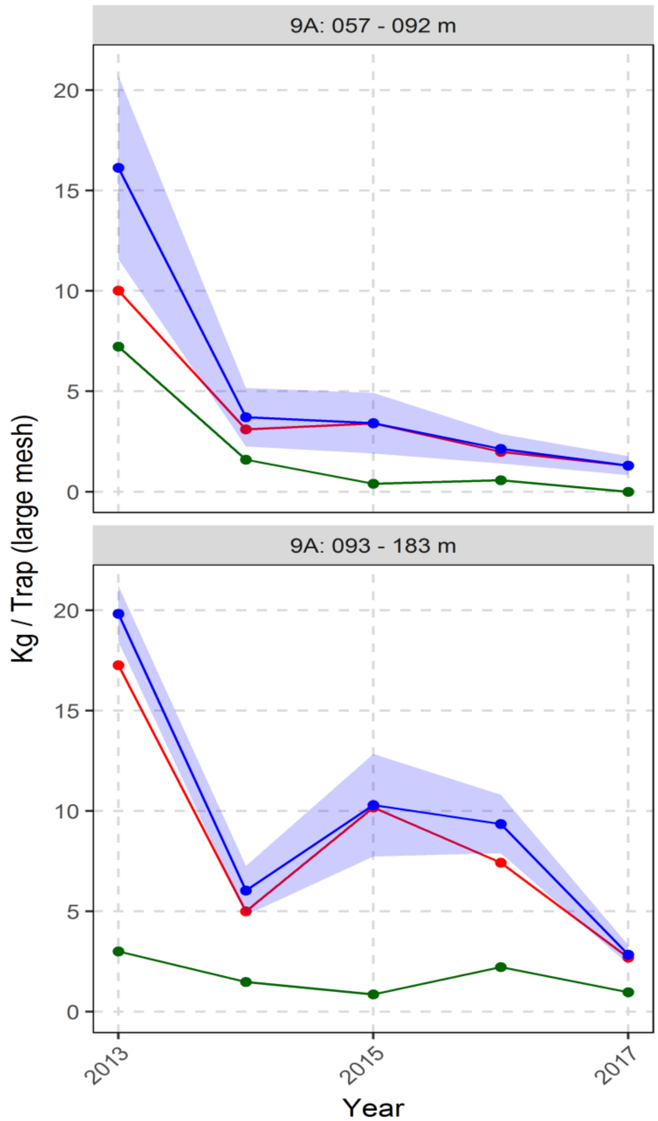

Figure 93. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from DFO trap surveys in St. Mary's Bay (Assessment Division 3L inshore).

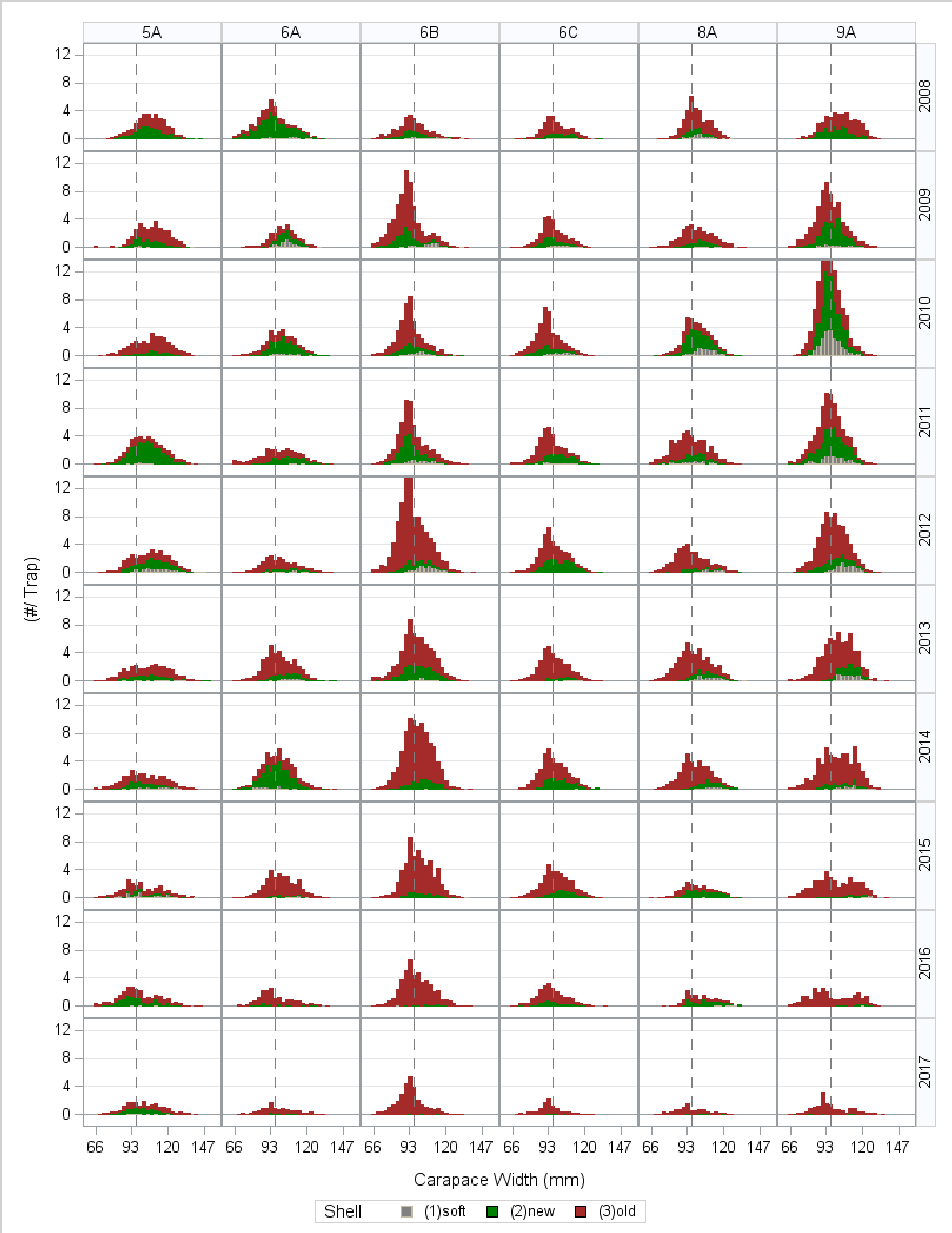

Figure 94. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Division 3L inshore (2008-17). The vertical line indicates the minimum legal size.

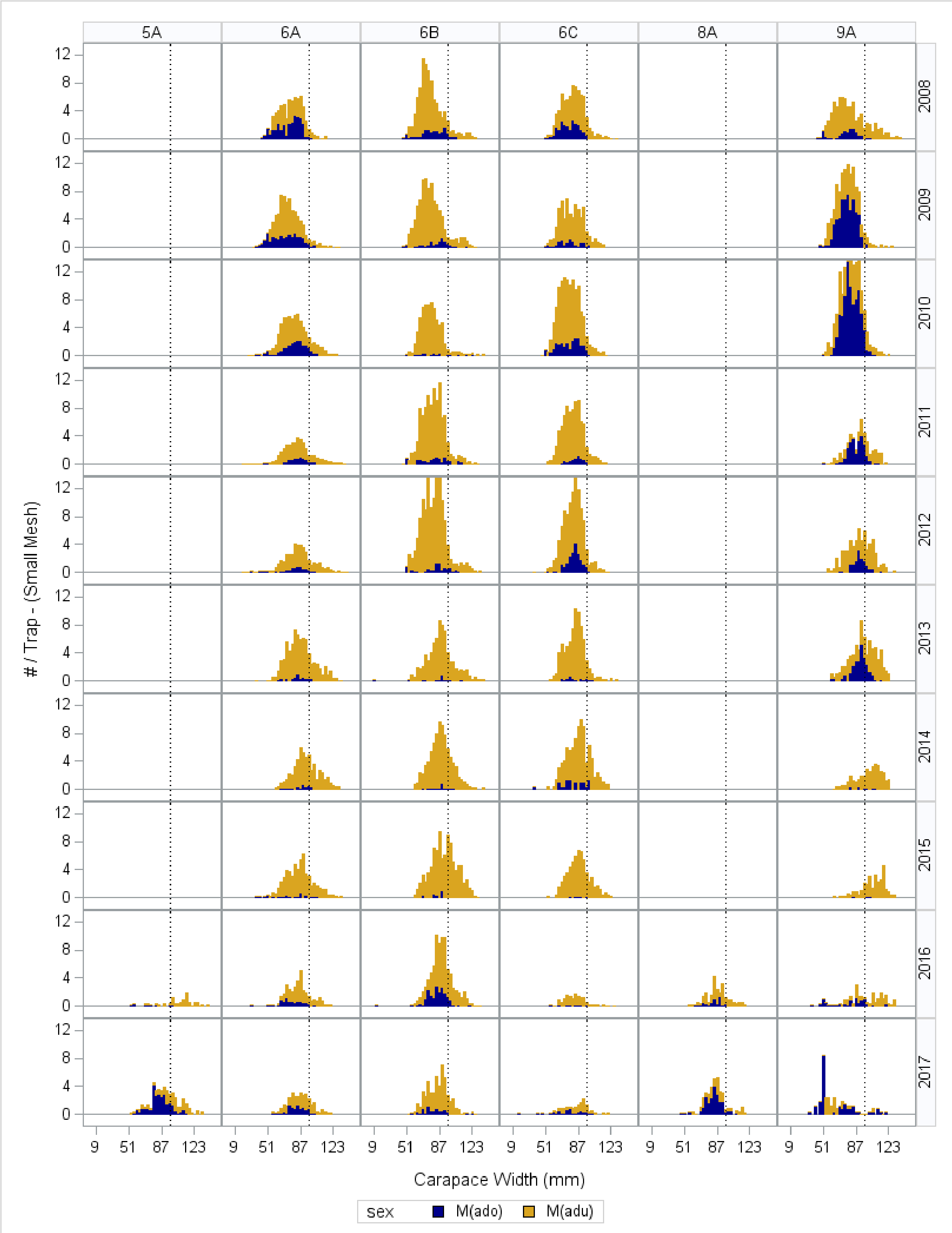

Figure 95. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2008-17) from CMAs in Assessment Division 3L inshore. The vertical line indicates the minimum legal size.

Figure 96. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2006-17) from Bonavista Bay (Assessment Division 3L inshore). The vertical line indicates the minimum legal size.

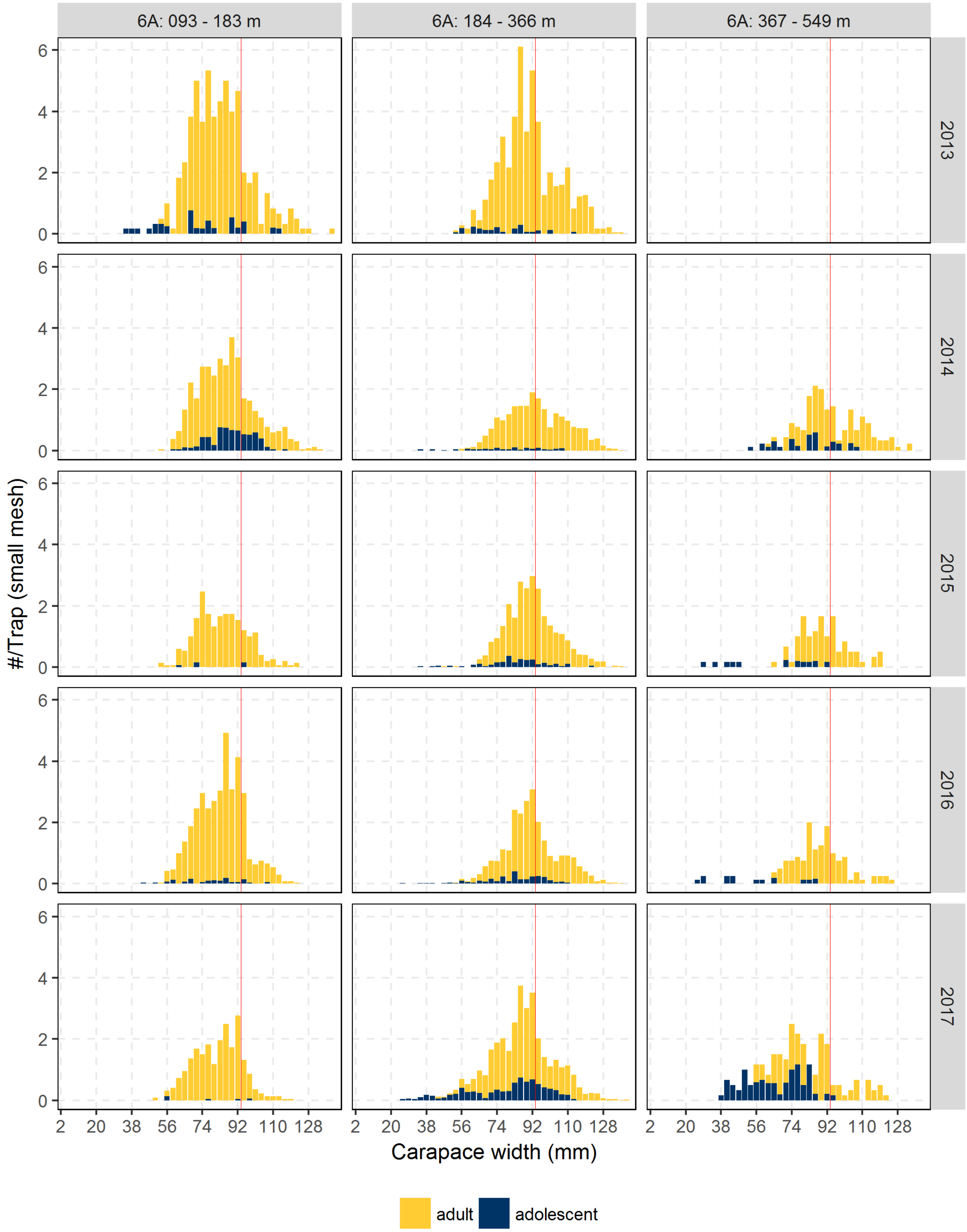

Figure 97. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2013-17) from Trinity Bay (Assessment Division 3L inshore). The vertical line indicates the minimum legal size.

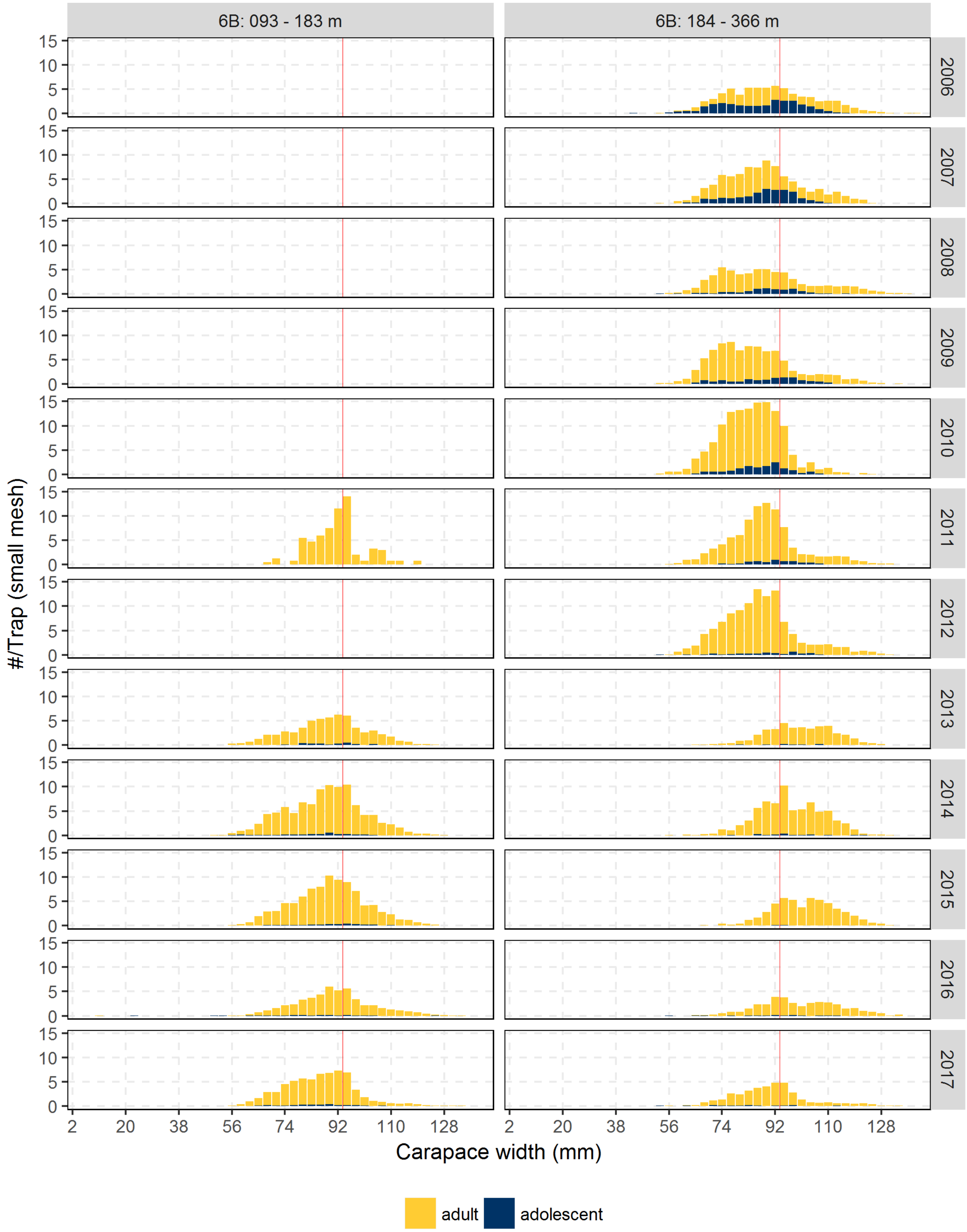

Figure 98. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2006-17) from Conception Bay (Assessment Division 3L inshore). The vertical line indicates the minimum legal size.

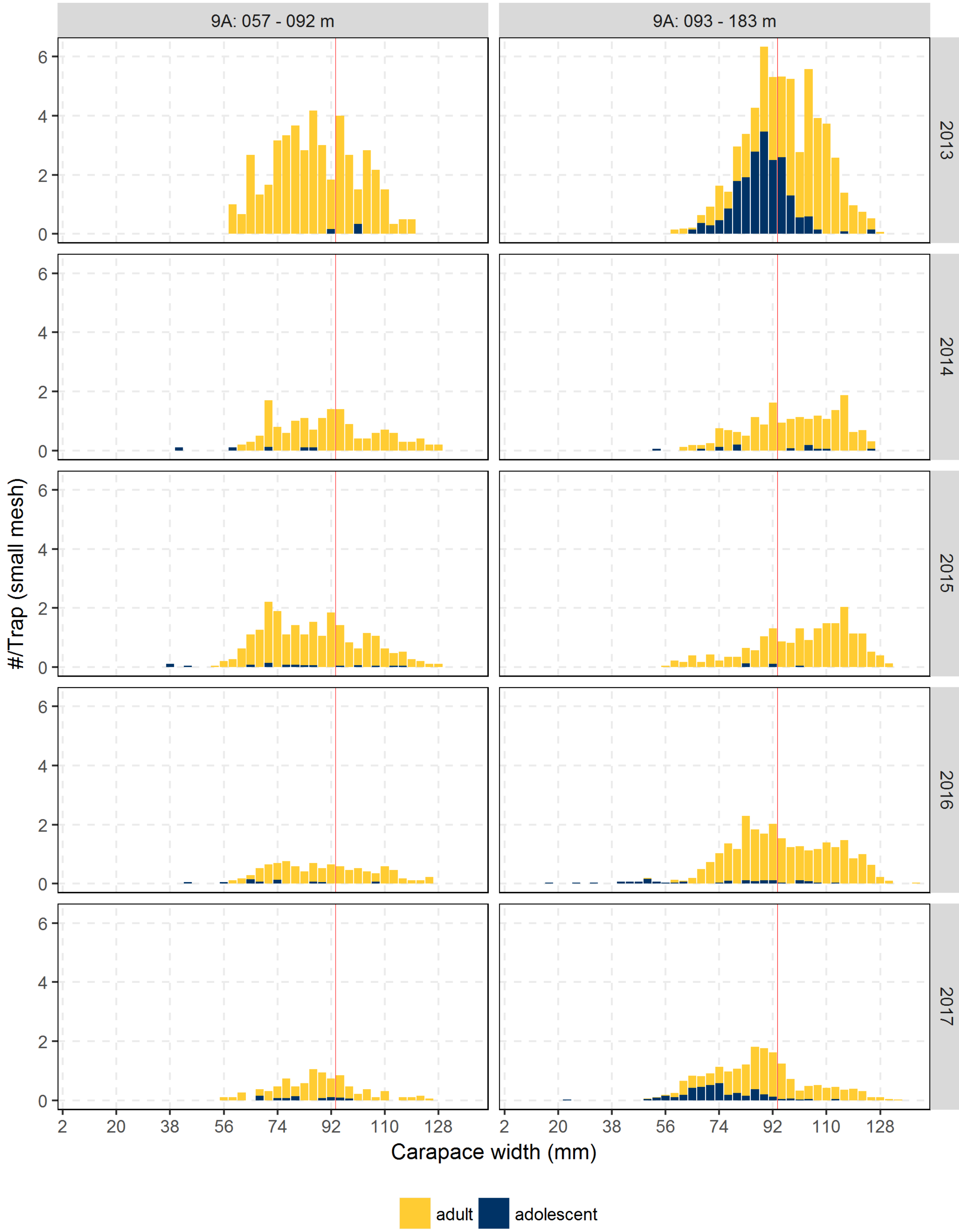

Figure 99. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2013-17) from St. Mary's Bay (Assessment Division 3L inshore). The vertical line indicates the minimum legal size.

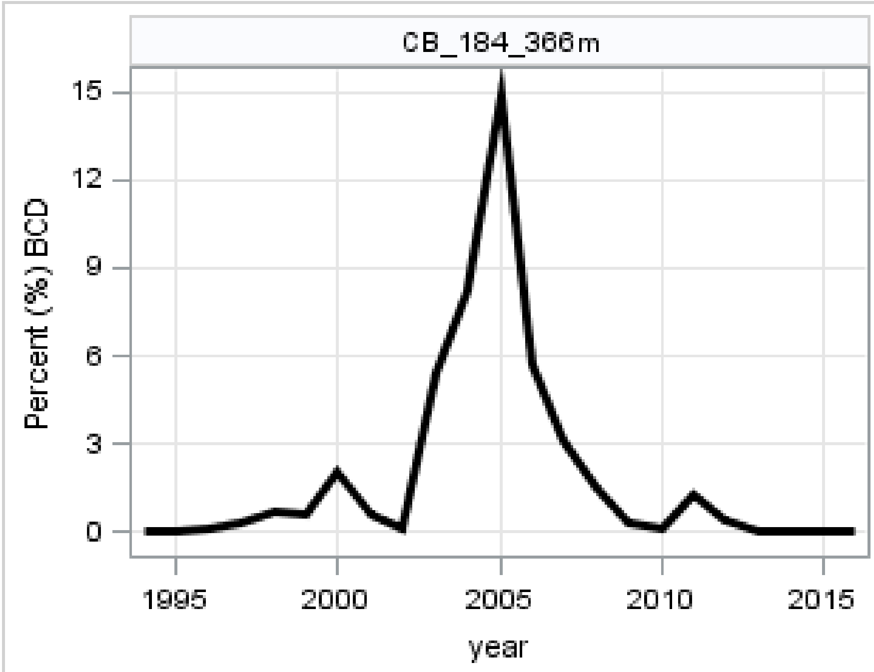

Figure 100. Visually observed percentage of Bitter Crab Disease in crab captured in small-mesh pots from DFO trap surveys in Conception Bay.

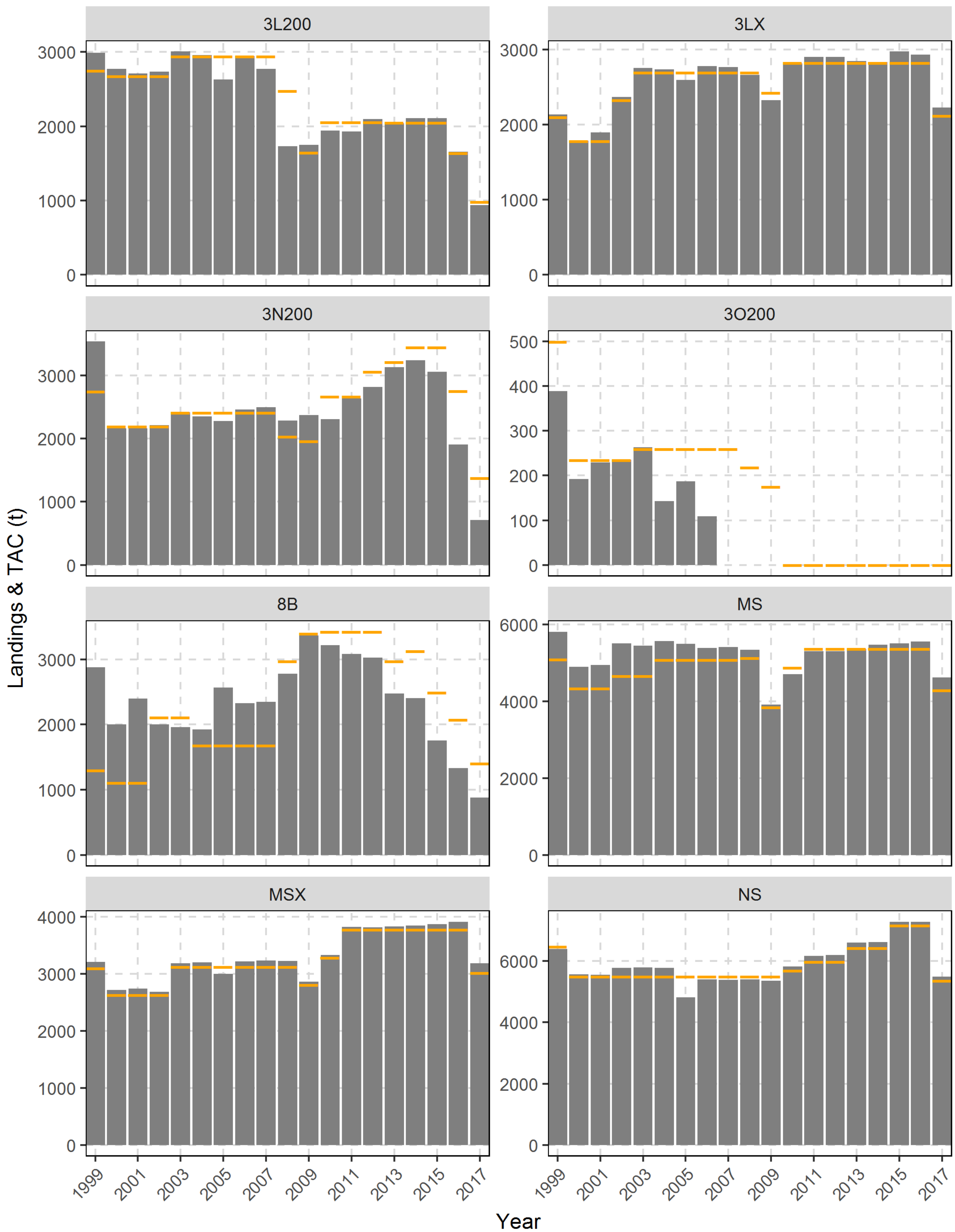

Figure 101.Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Divisions 3LNO offshore (1999-2017).

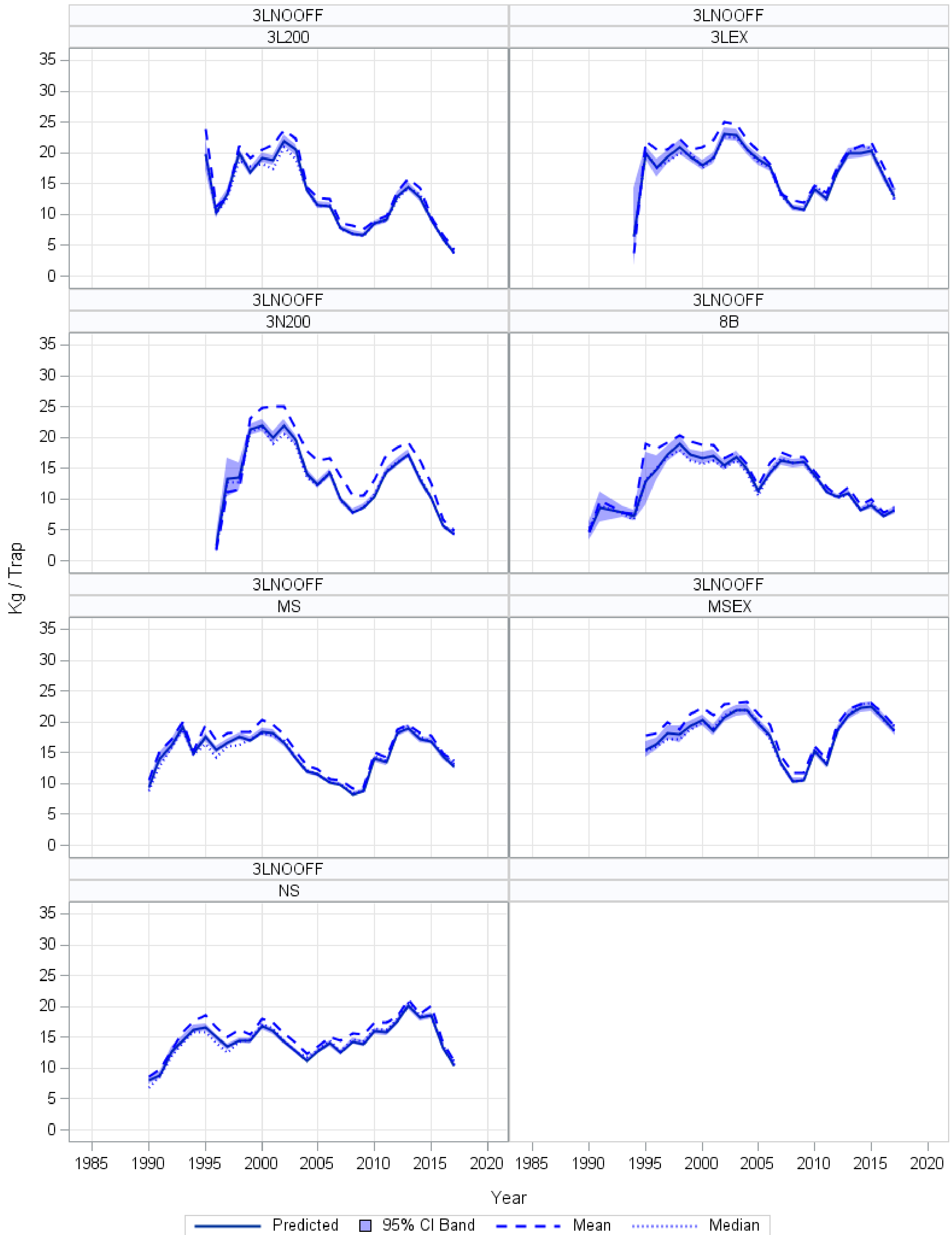

Figure102. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Division 3LNO offshore.

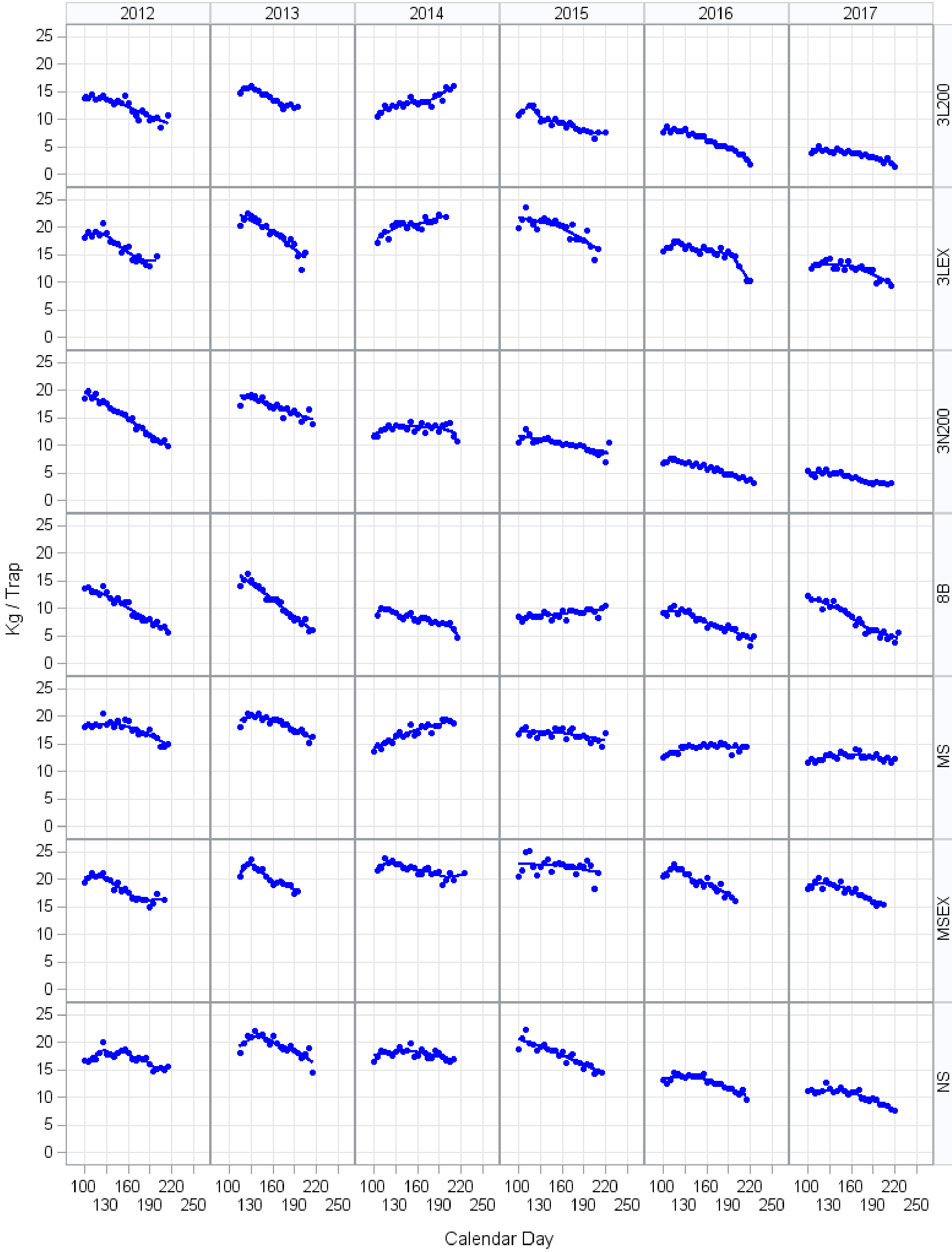

Figure 103. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2012-17), by Crab Management Area (CMA) in Assessment Divisions 3LNO offshore.

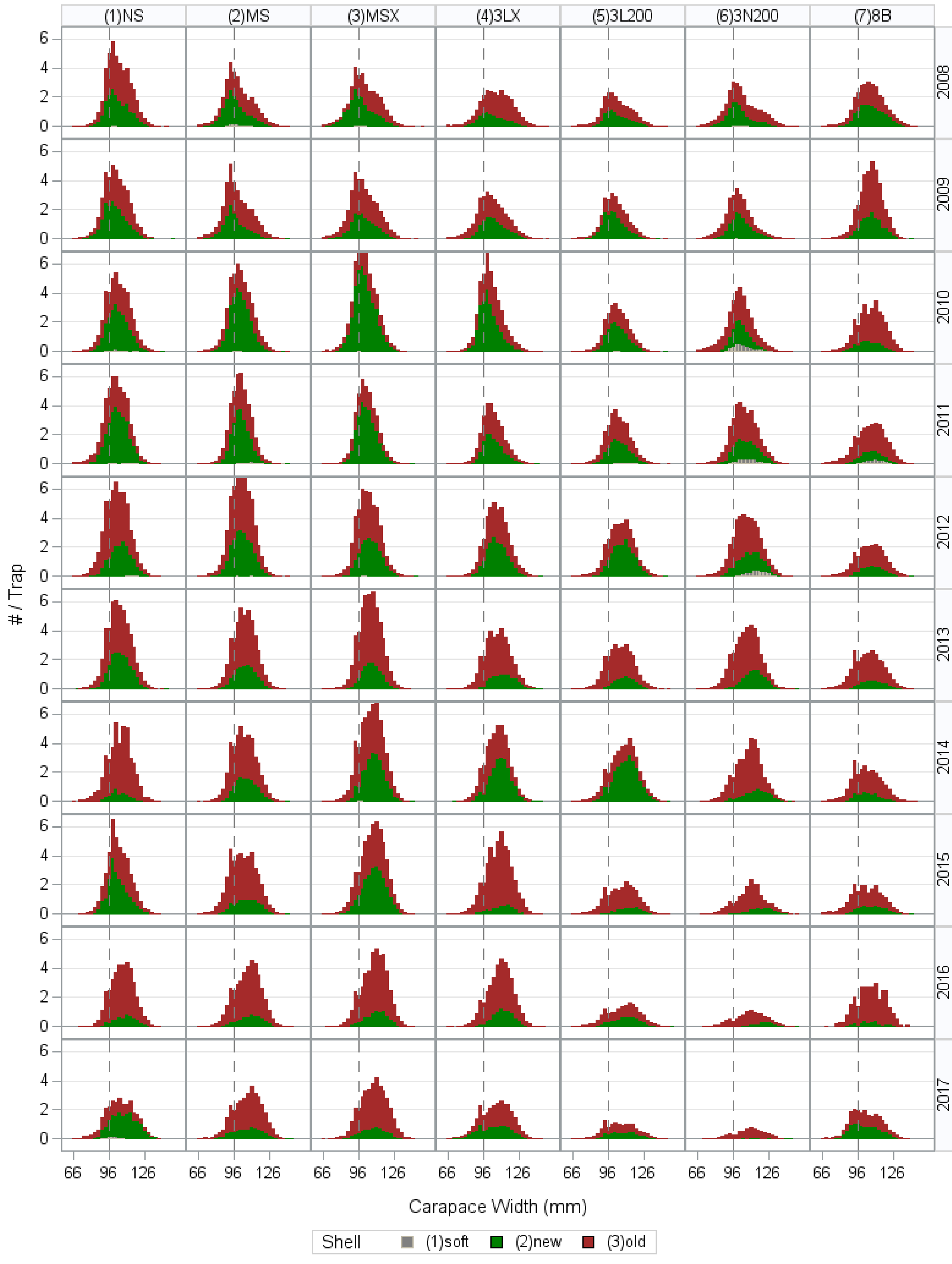

Figure 104. Trends in male carapace width distributions by shell condition from observer sampling in CMAs (Crab Management Areas) within Assessment Divisions 3LNO offshore (2008-17). The vertical line indicates the minimum legal size.

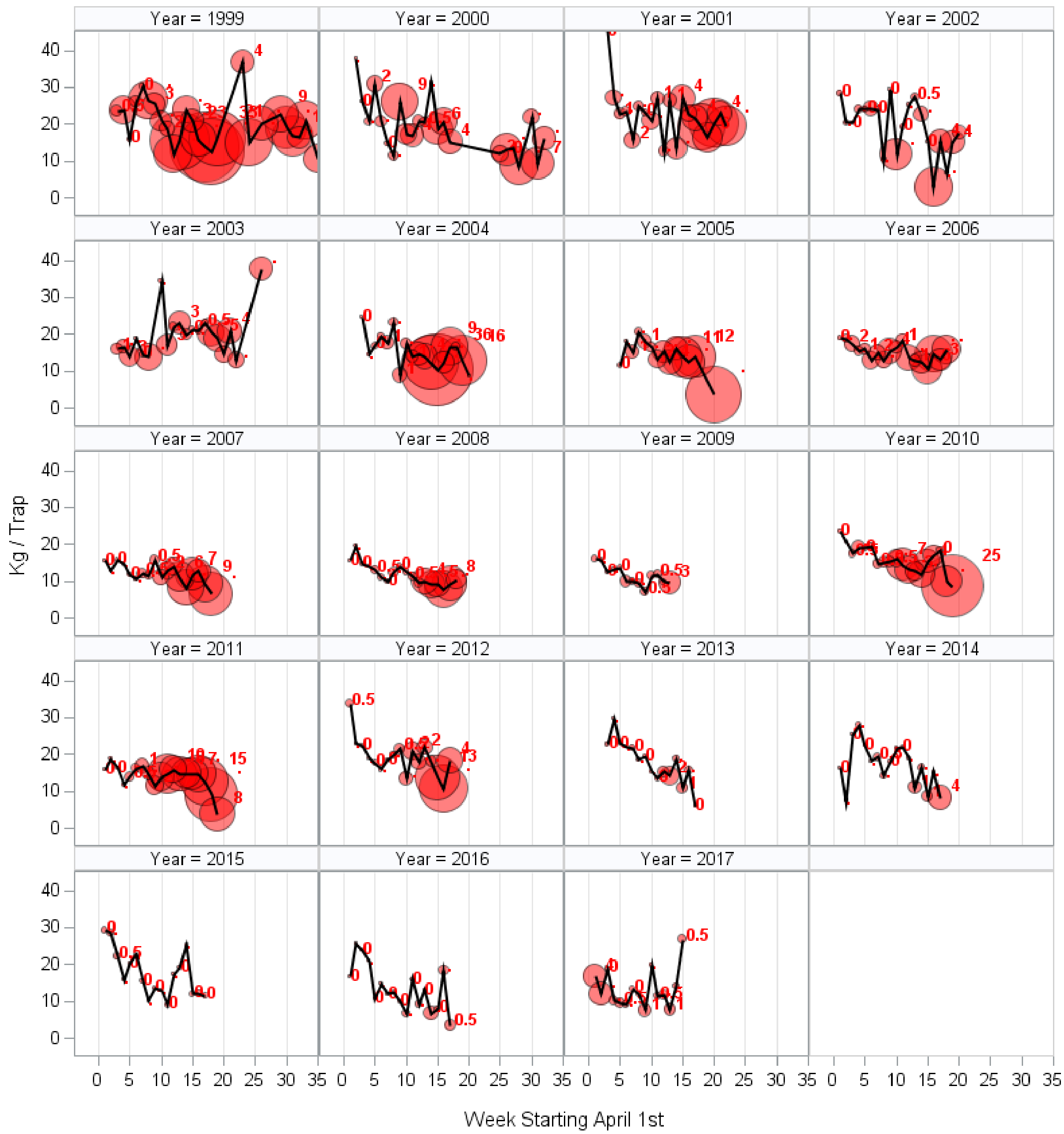

Figure 105. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within the Assessment Divisions 3LNO offshore (1999-2017). Bubble size and labels depict percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

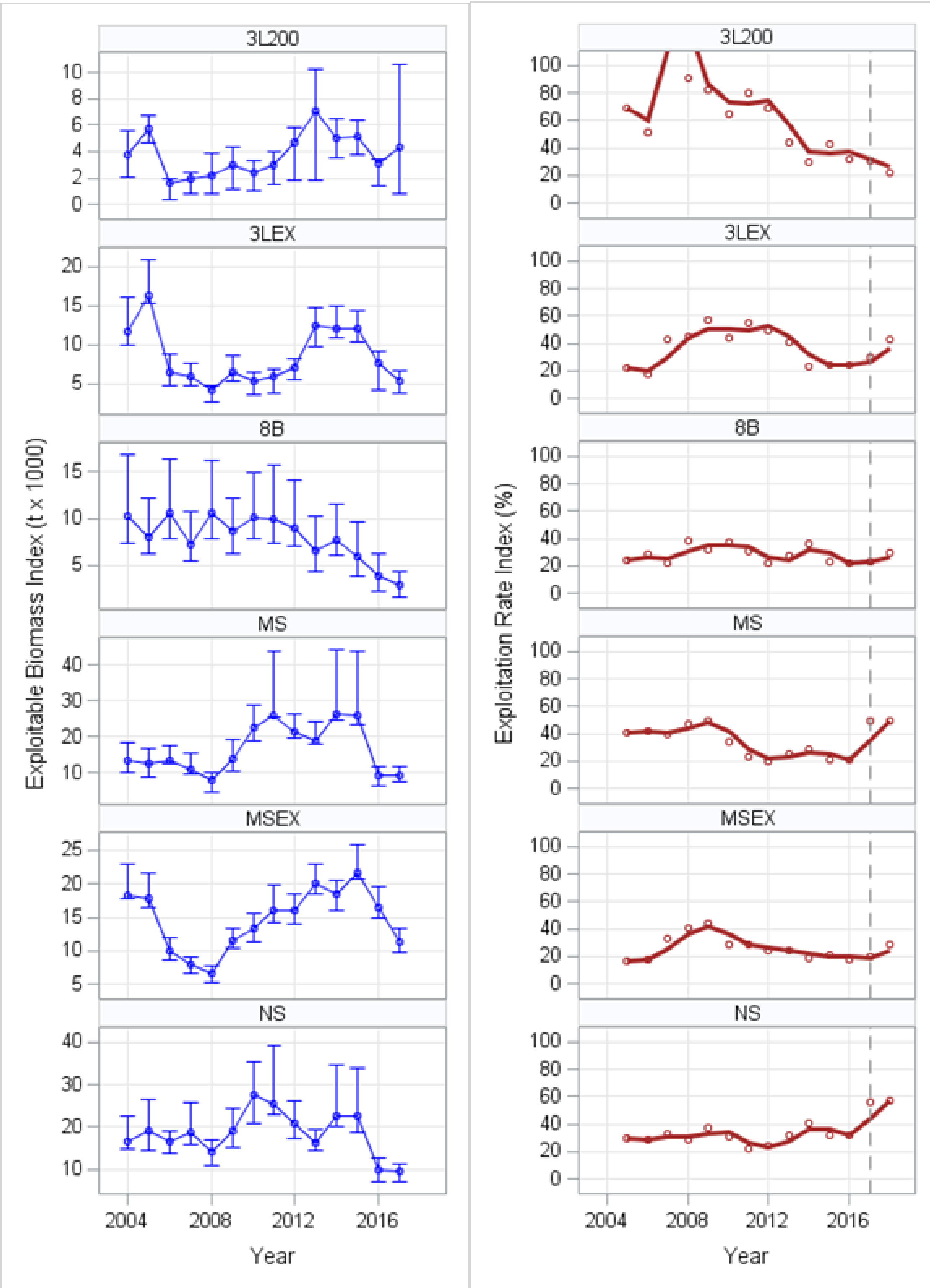

*Figure106. Left: Annual trap-based exploitable biomass index estimates (t * 1,000). Right: Trends in the exploitation rate index in CMAs within Assessment Divisions 3LNO offshore. Line represents 2-year moving average and points represent annual estimates.*

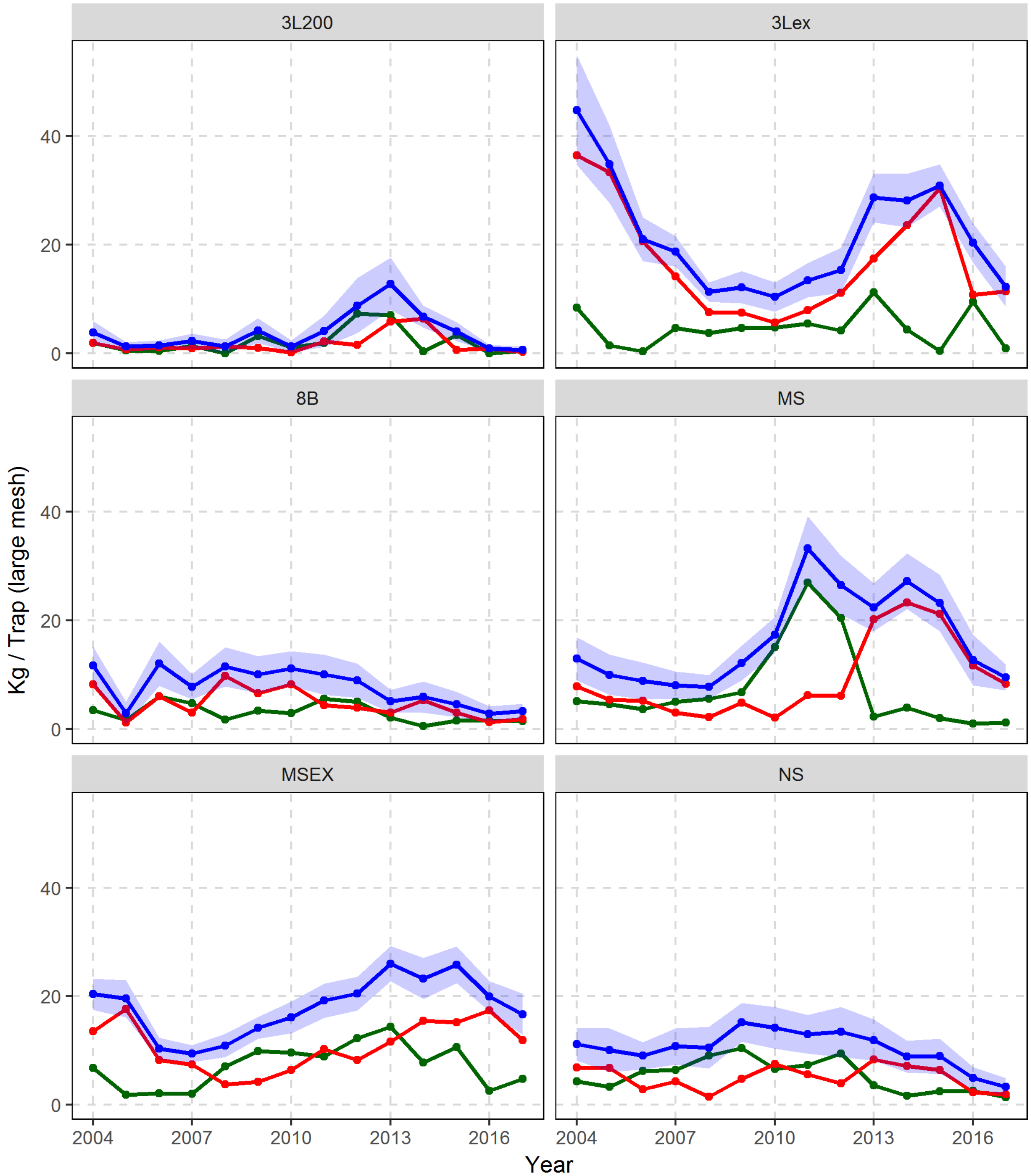

Figure 107. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Divisions 3LNO offshore.

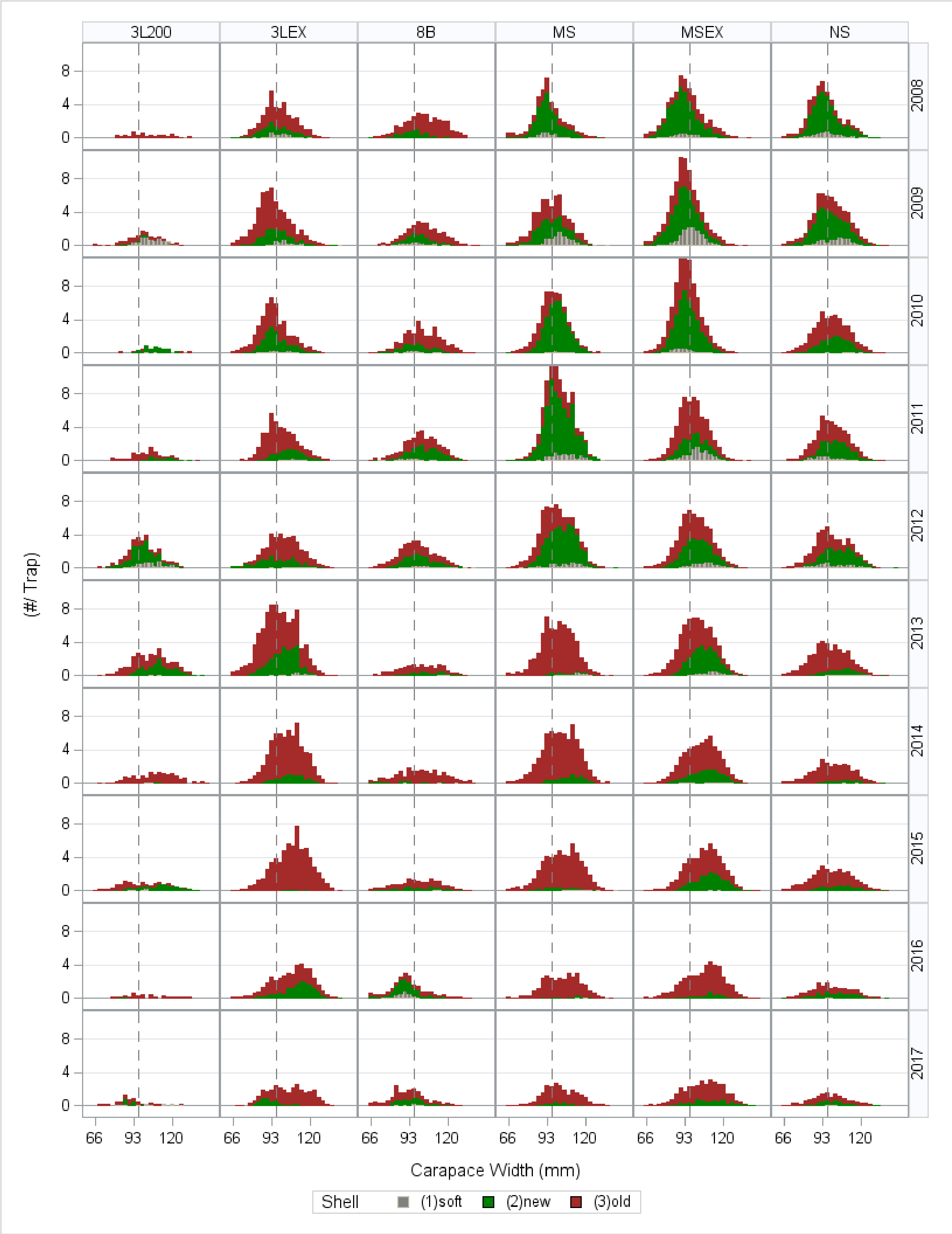

Figure 108. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Divisions 3LNO offshore (2008-17). The vertical line indicates the minimum legal size.

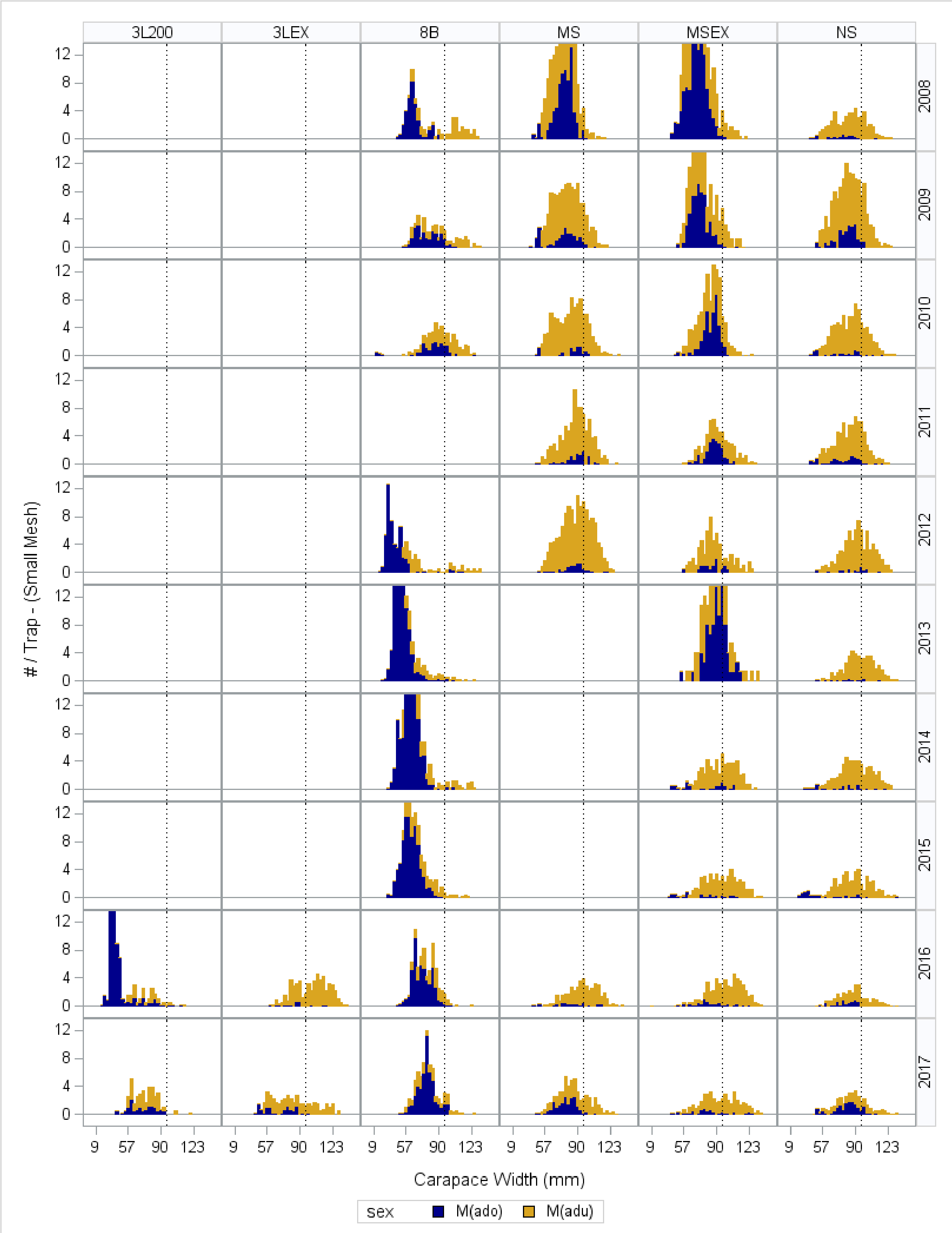

Figure 109. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2008-17) from CMAs in Assessment Divisions 3LNO inshore. The vertical line indicates the minimum legal size.

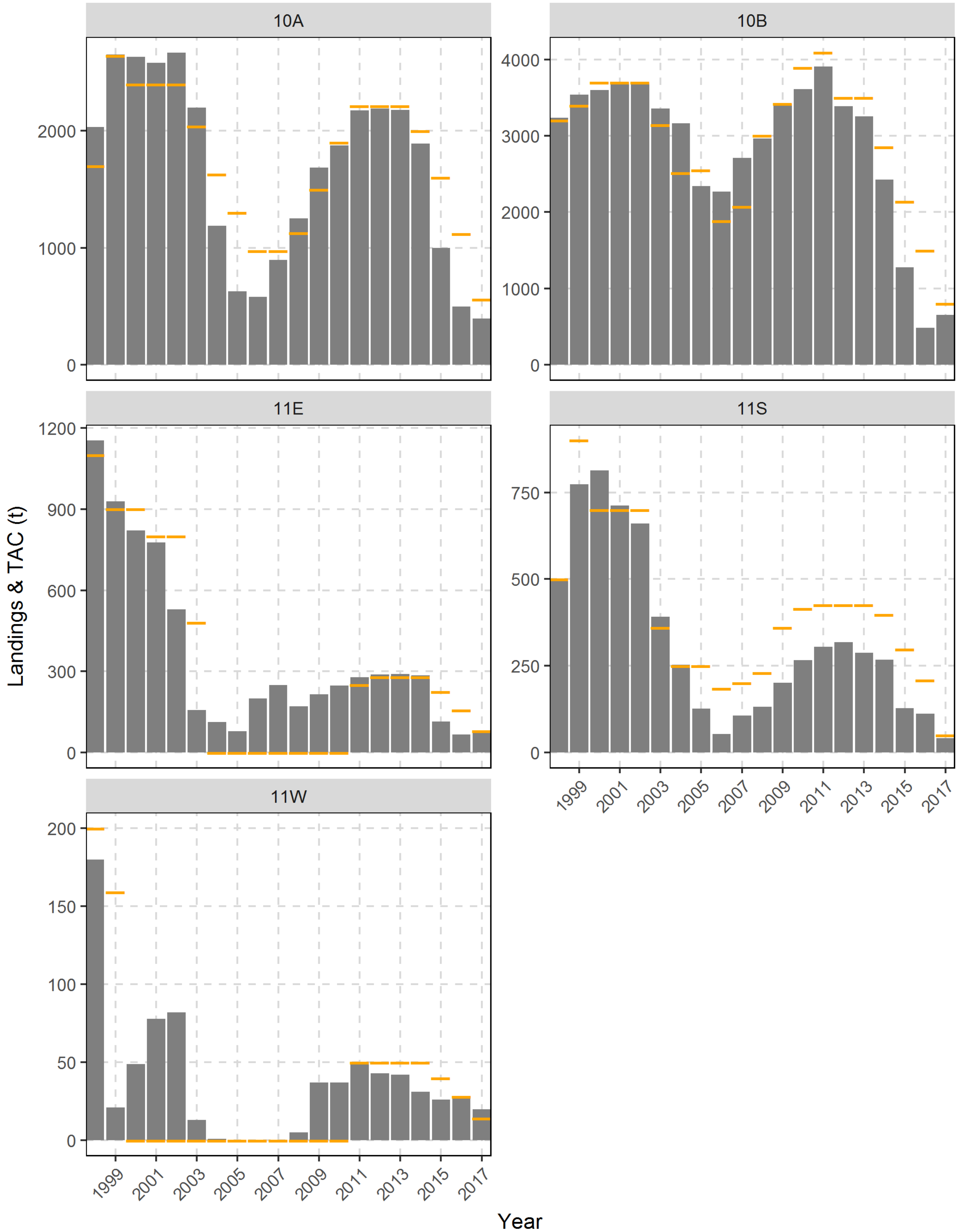

Figure 110. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Subdivision 3Ps (1998-2017).

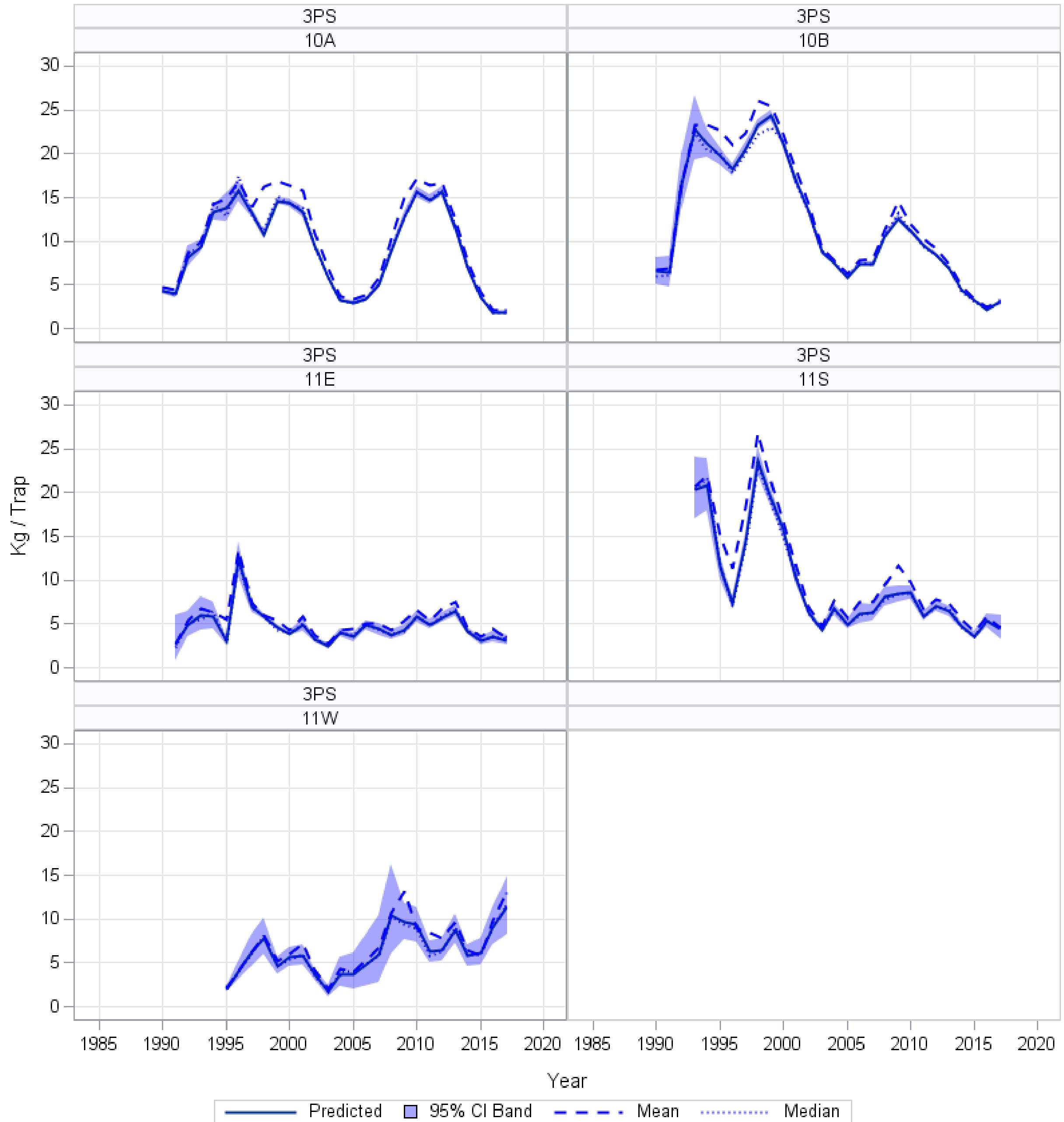

Figure 111. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Subdivision 3Ps.

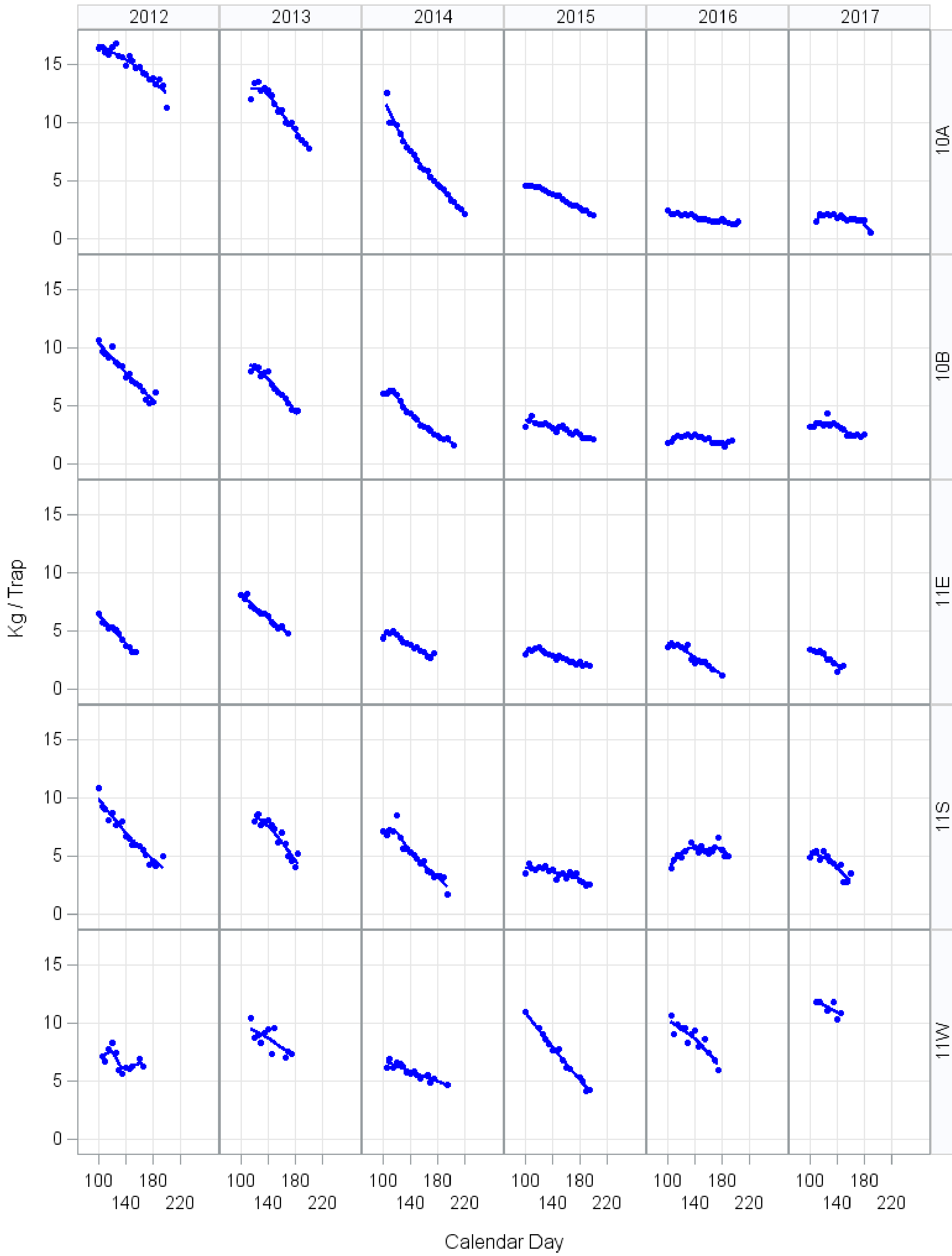

Figure 112. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2012-17), by Crab Management Area (CMA) in Assessment Subdivision 3Ps.

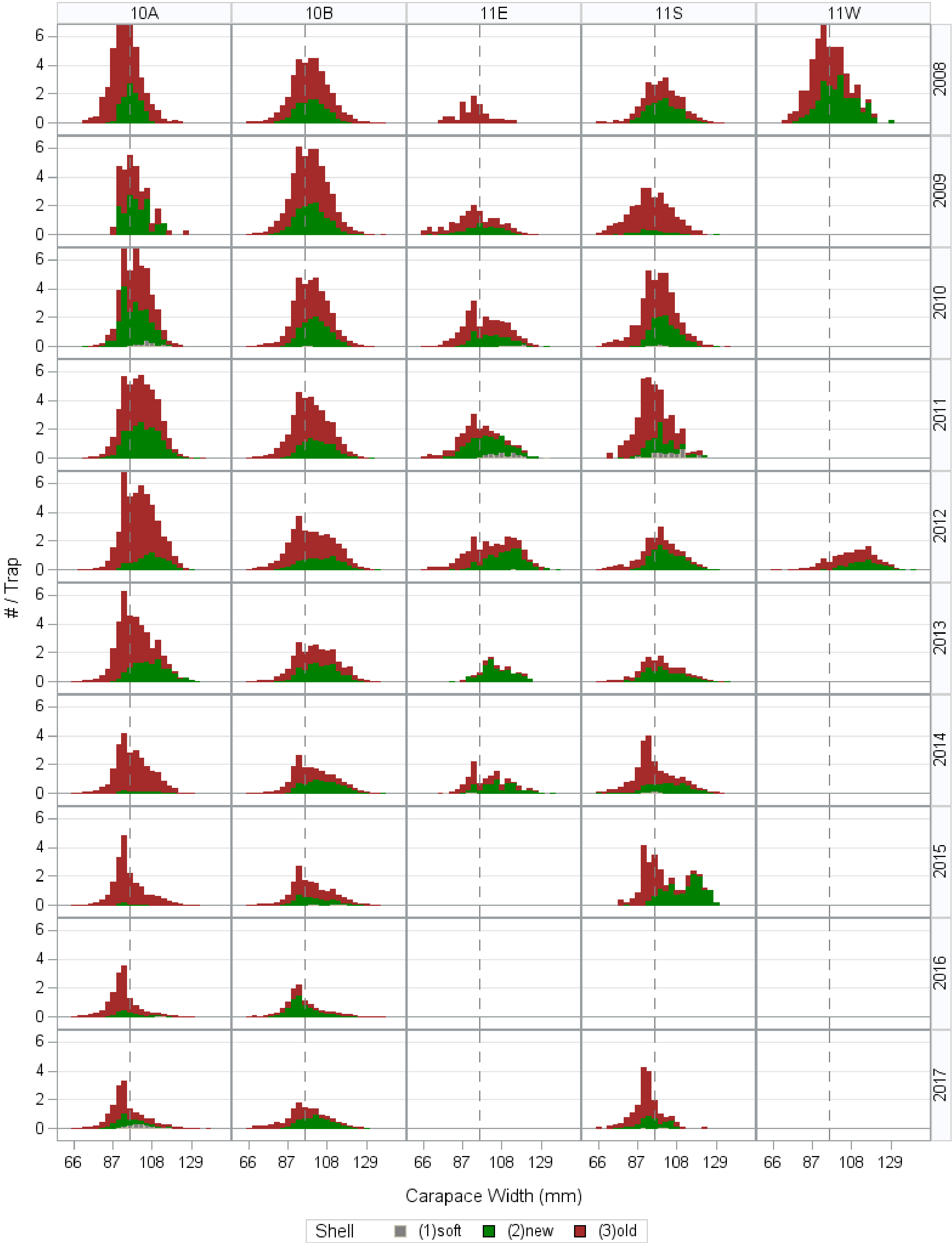

Figure 113. Trends in male carapace width distributions by shell condition from observer sampling in CMAs (Crab Management Areas) within Assessment Subdivision 3Ps (2008-17). The vertical line indicates the minimum legal size.

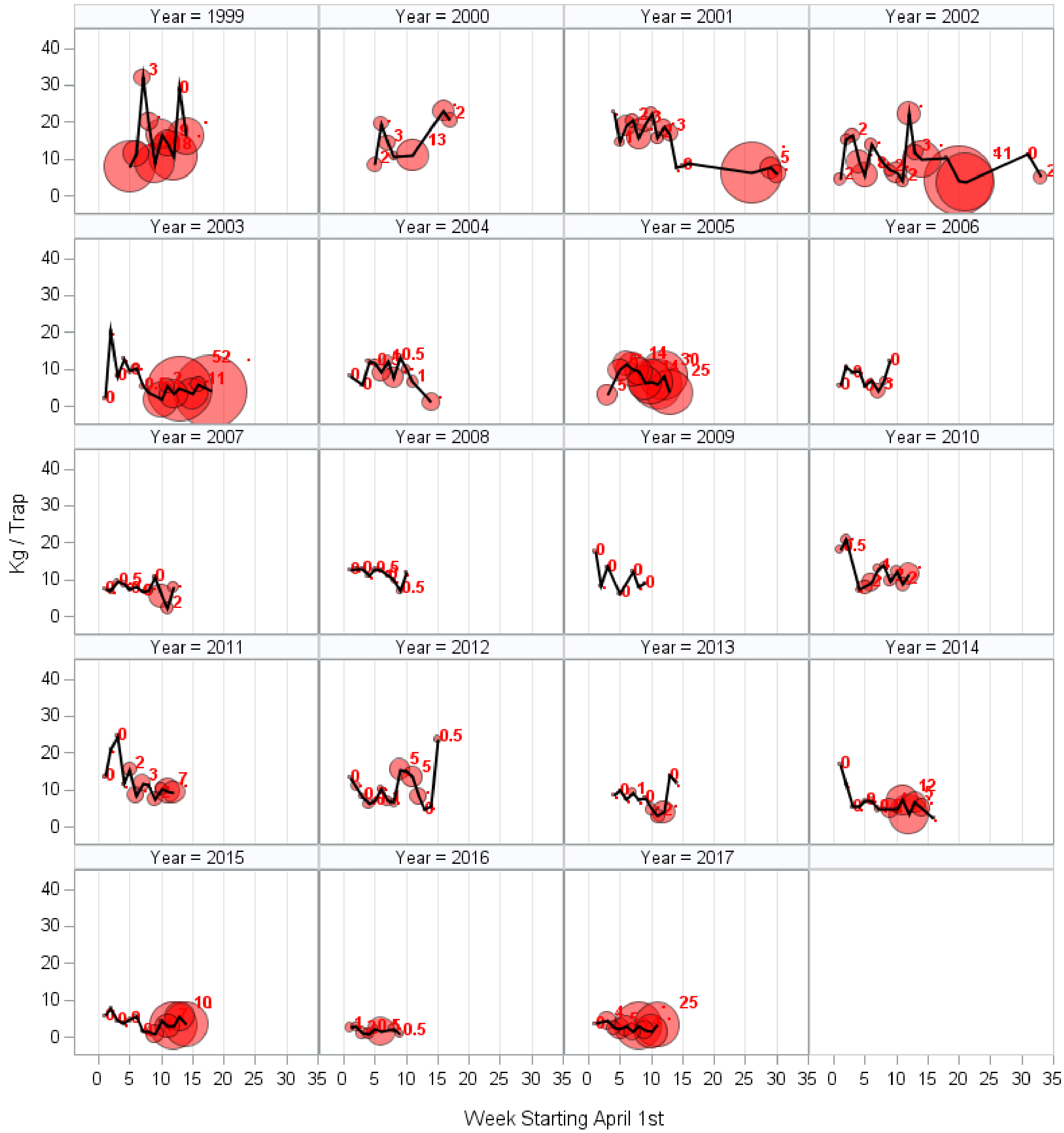

Figure 114. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within the Assessment Subdivision 3Ps (1999-2017). Bubble size and labels depict percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

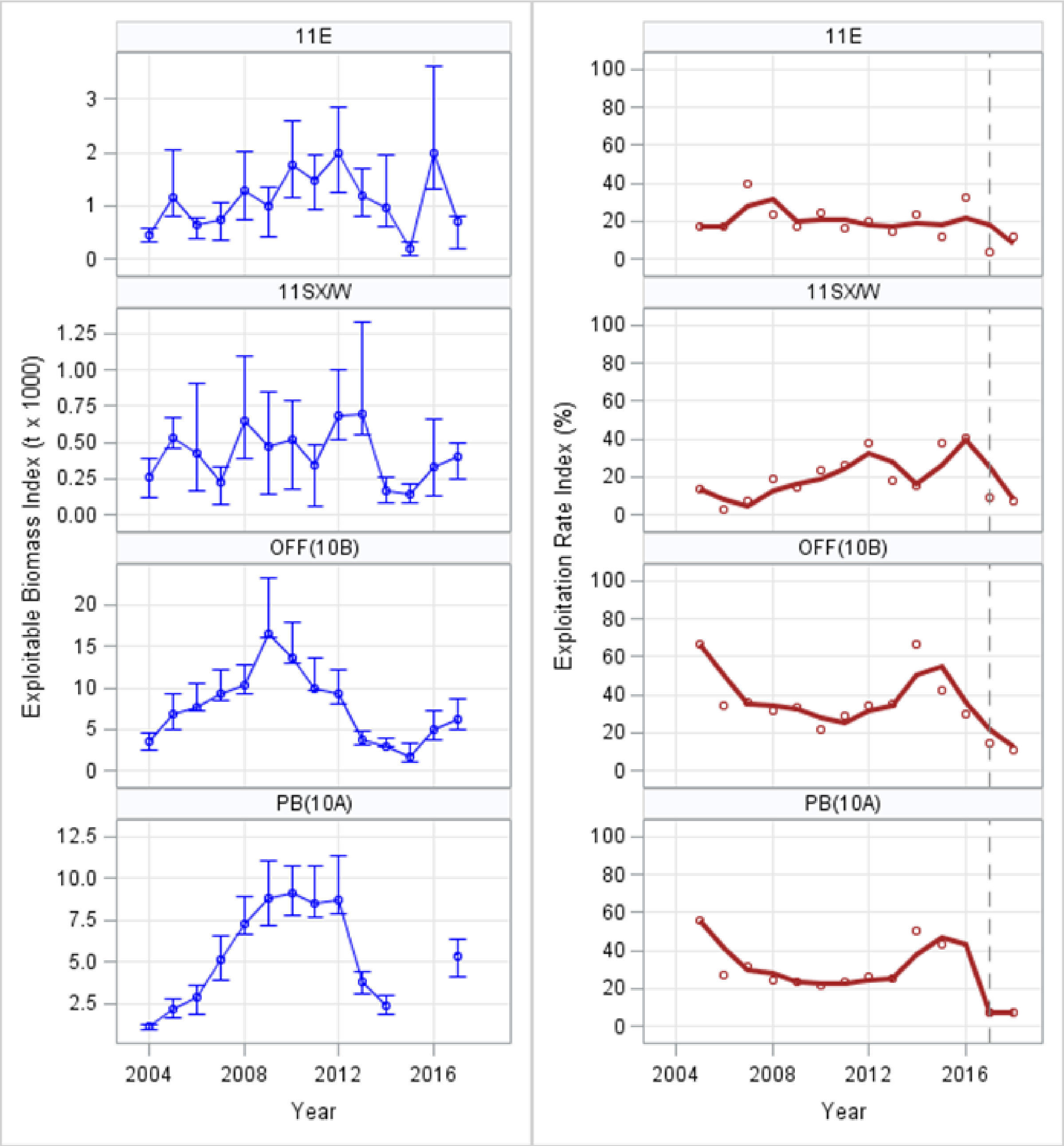

*Figure 115. Left: Annual trap-based exploitable biomass index estimates (t * 1,000). Right: Trends in the exploitation rate index in CMAs within Assessment Subdivision 3Ps. Solid line represents 2-year moving average and points represent annual estimates.*

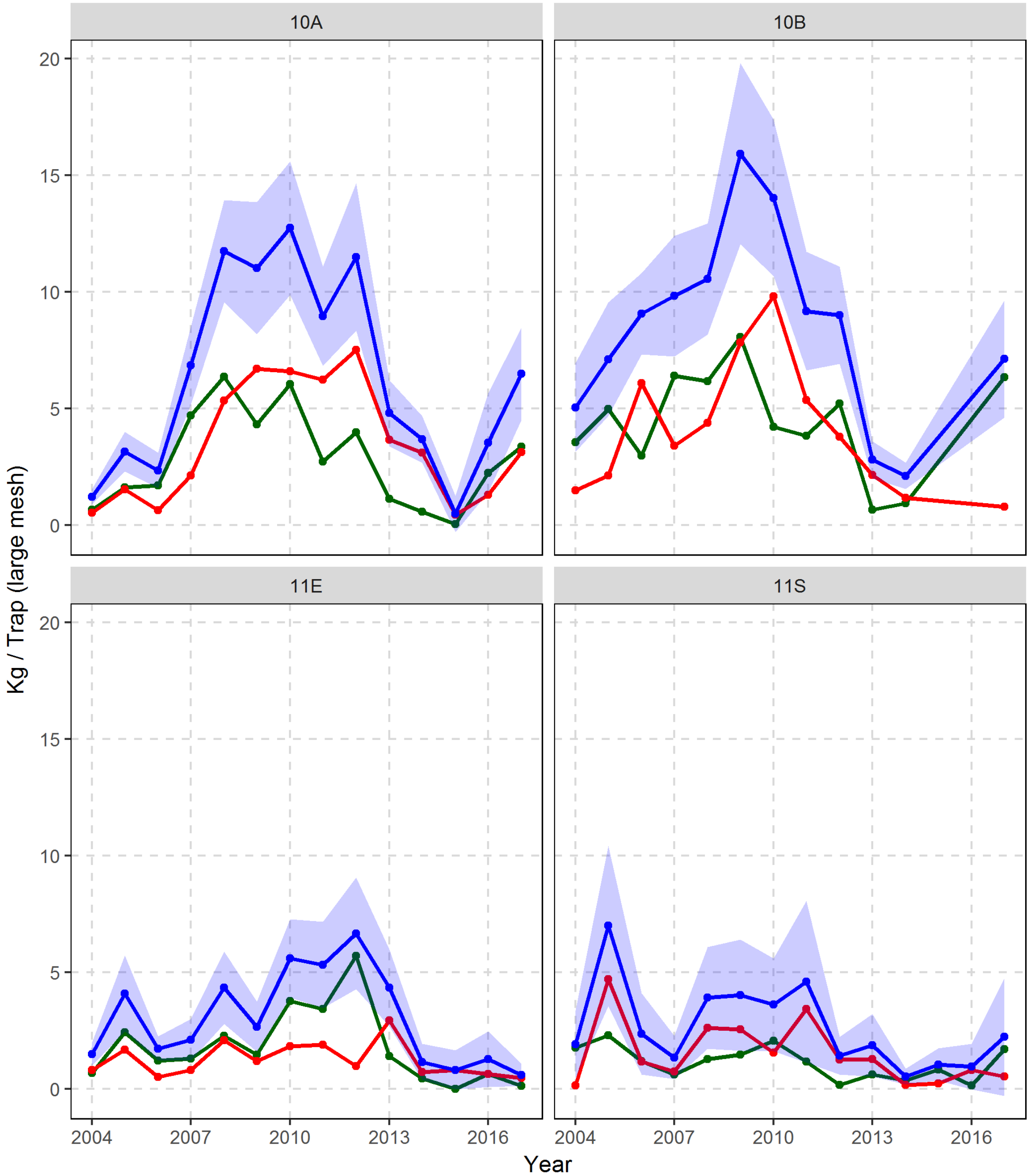

Figure 116. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Subdivision 3Ps.

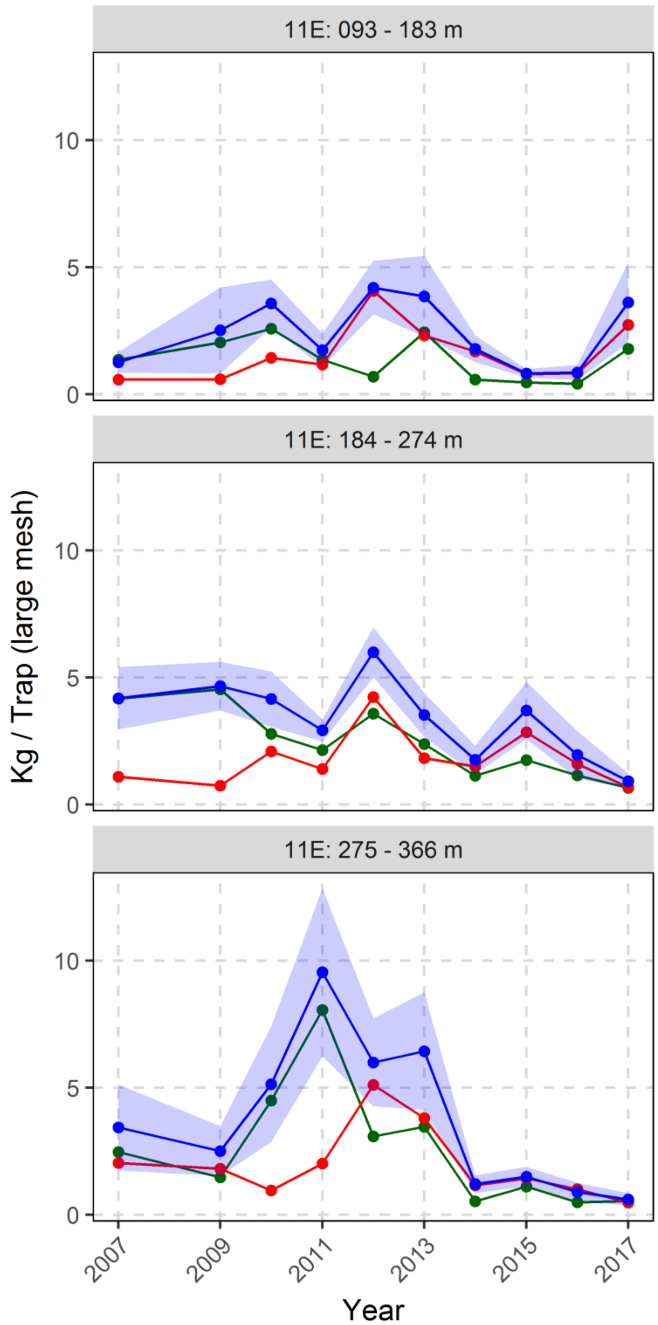

Figure 117. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, all = blue) of legal-sized crab from DFO trap surveys in Fortune Bay (Assessment Subdivision 3Ps).

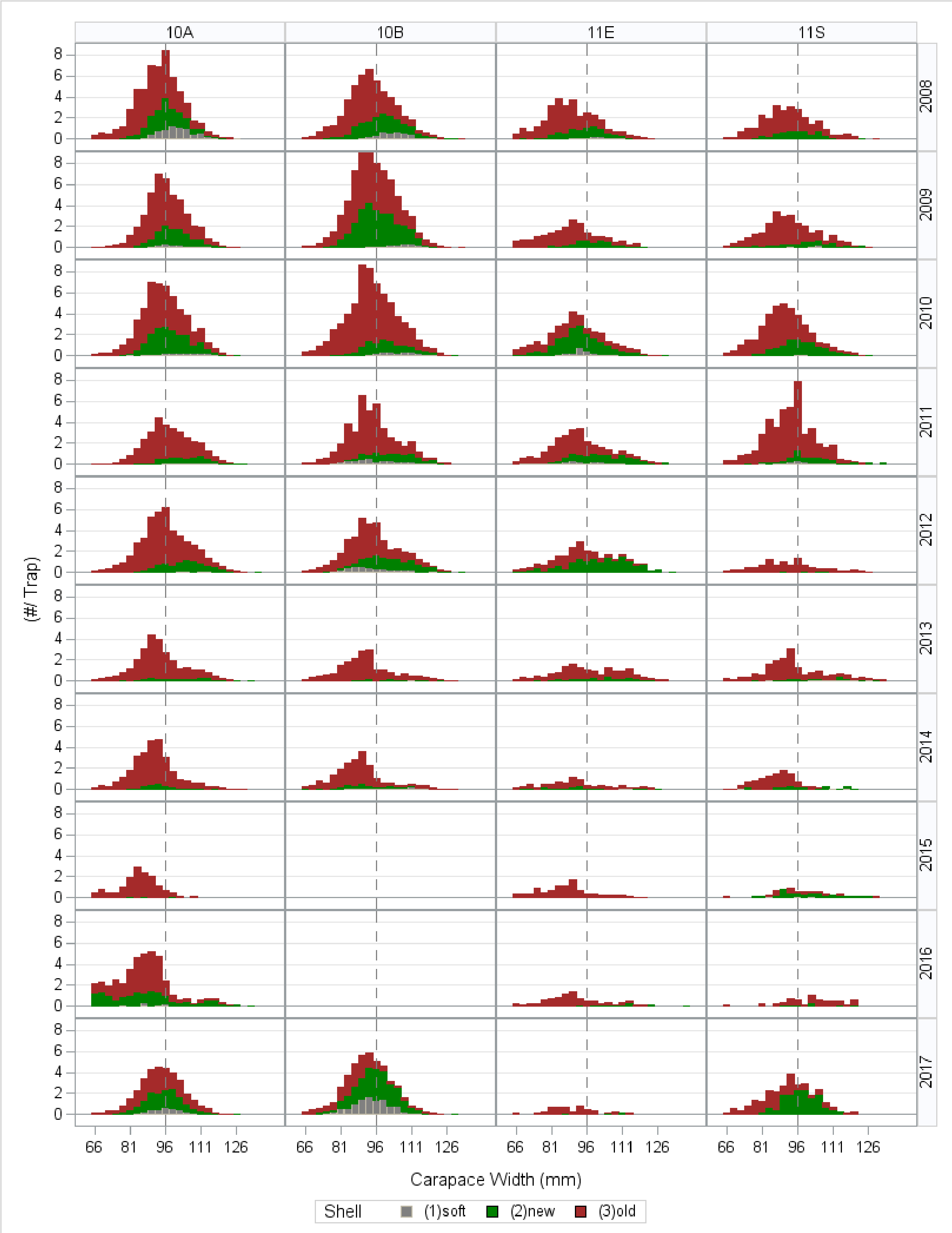

Figure 118. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Subdivision 3Ps (2008-17). The vertical line indicates the minimum legal size.

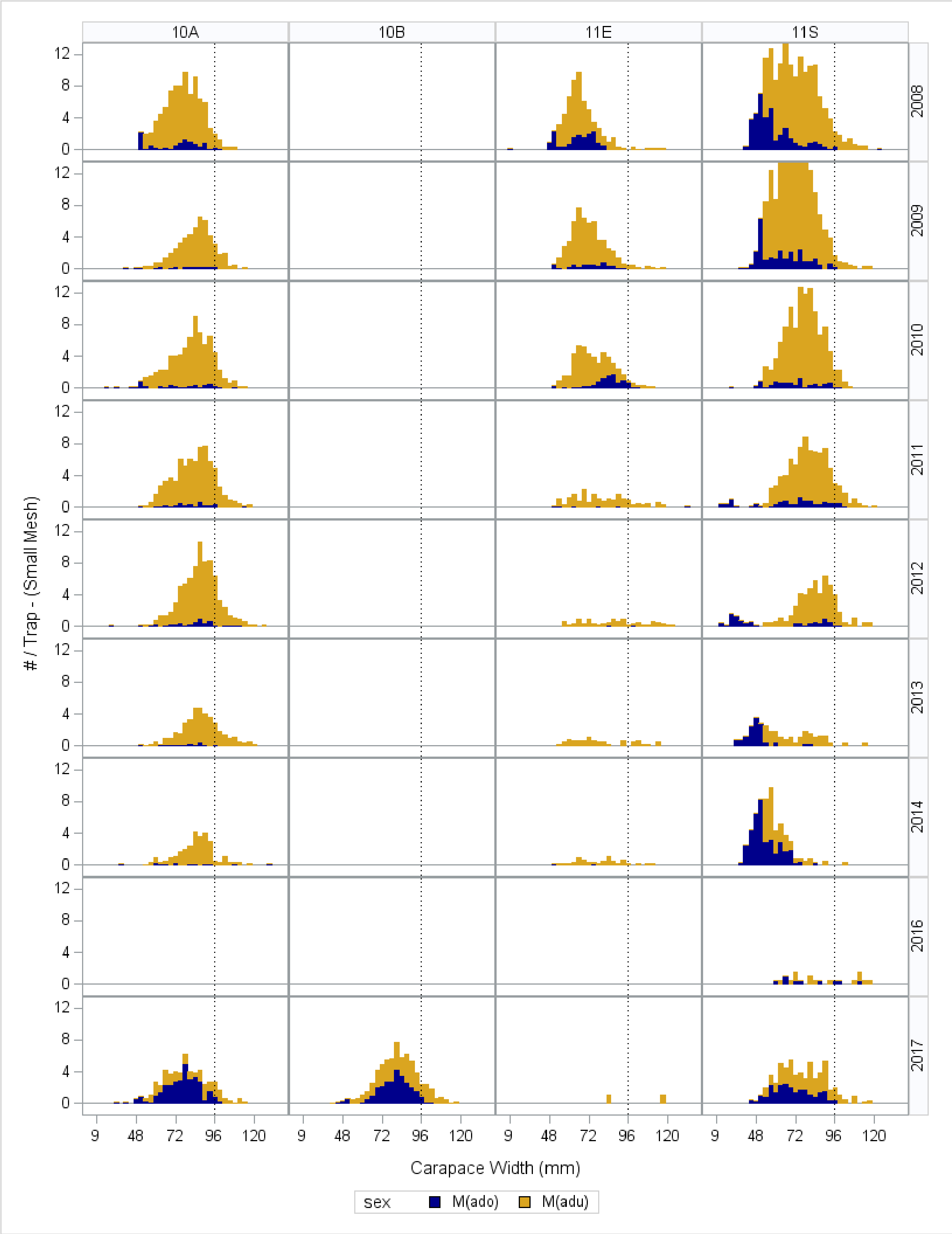

Figure 119. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2008-17) from CMAs in Assessment Subdivision 3Ps. The vertical line indicates the minimum legal size.

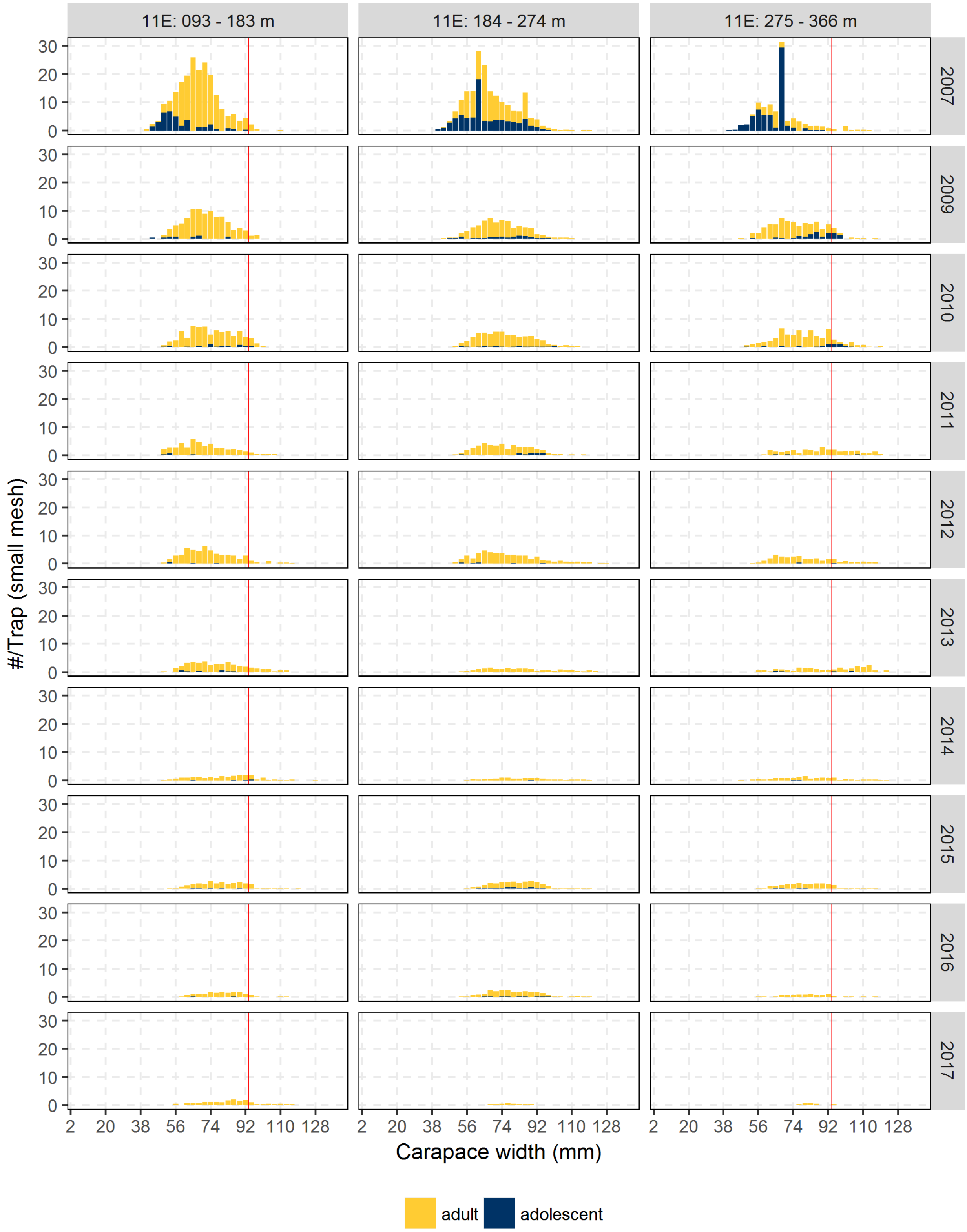

Figure 120. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the DFO trap survey (2007-17) from Fortune Bay (Assessment Subdivision 3Ps). The vertical line indicates the minimum legal size.

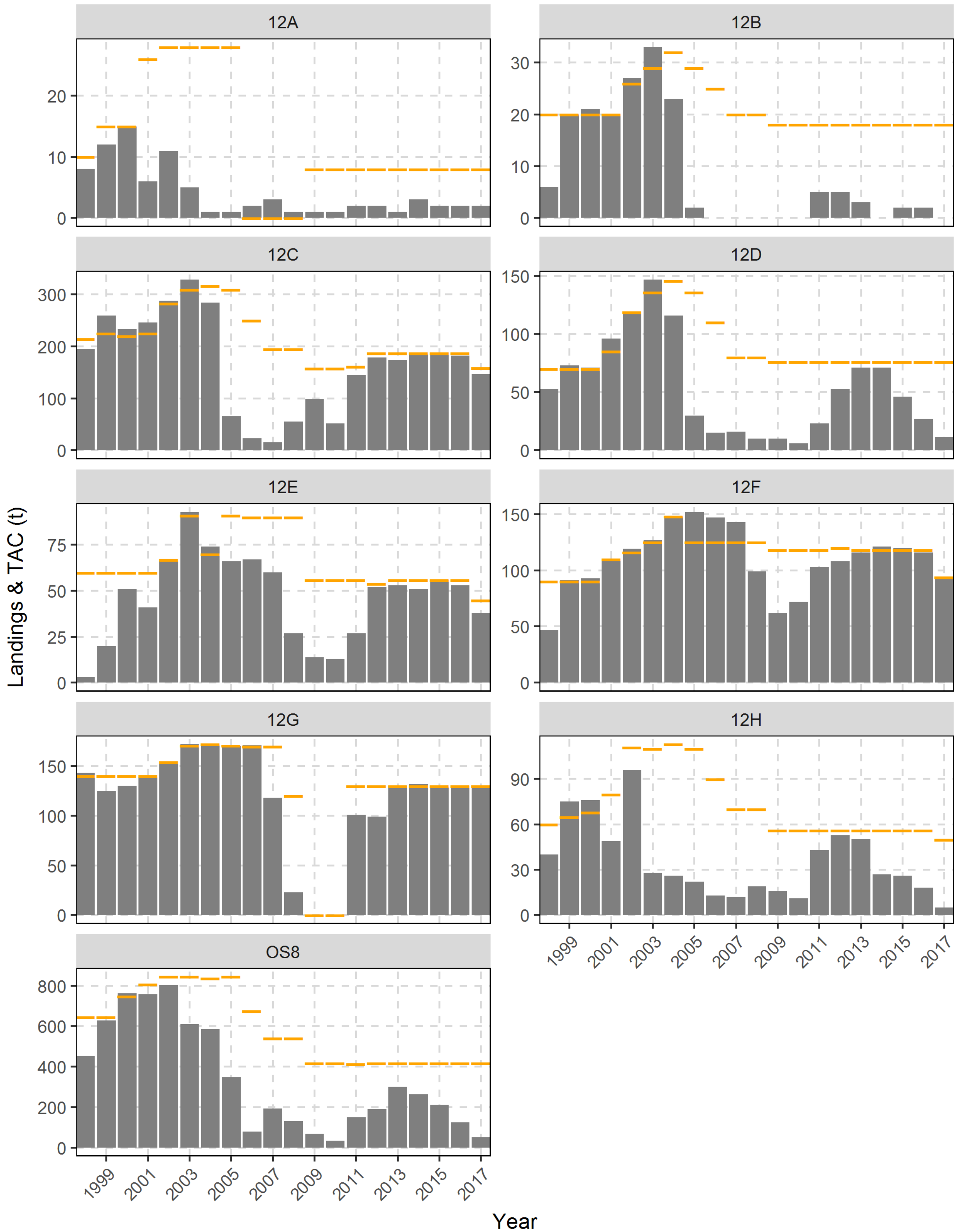

Figure 121. Total allowable catch (TAC) (yellow dashes) and landings (grey bars) in Crab Management Areas (CMAs) within Assessment Divisions 4R3Pn (1998-2017).

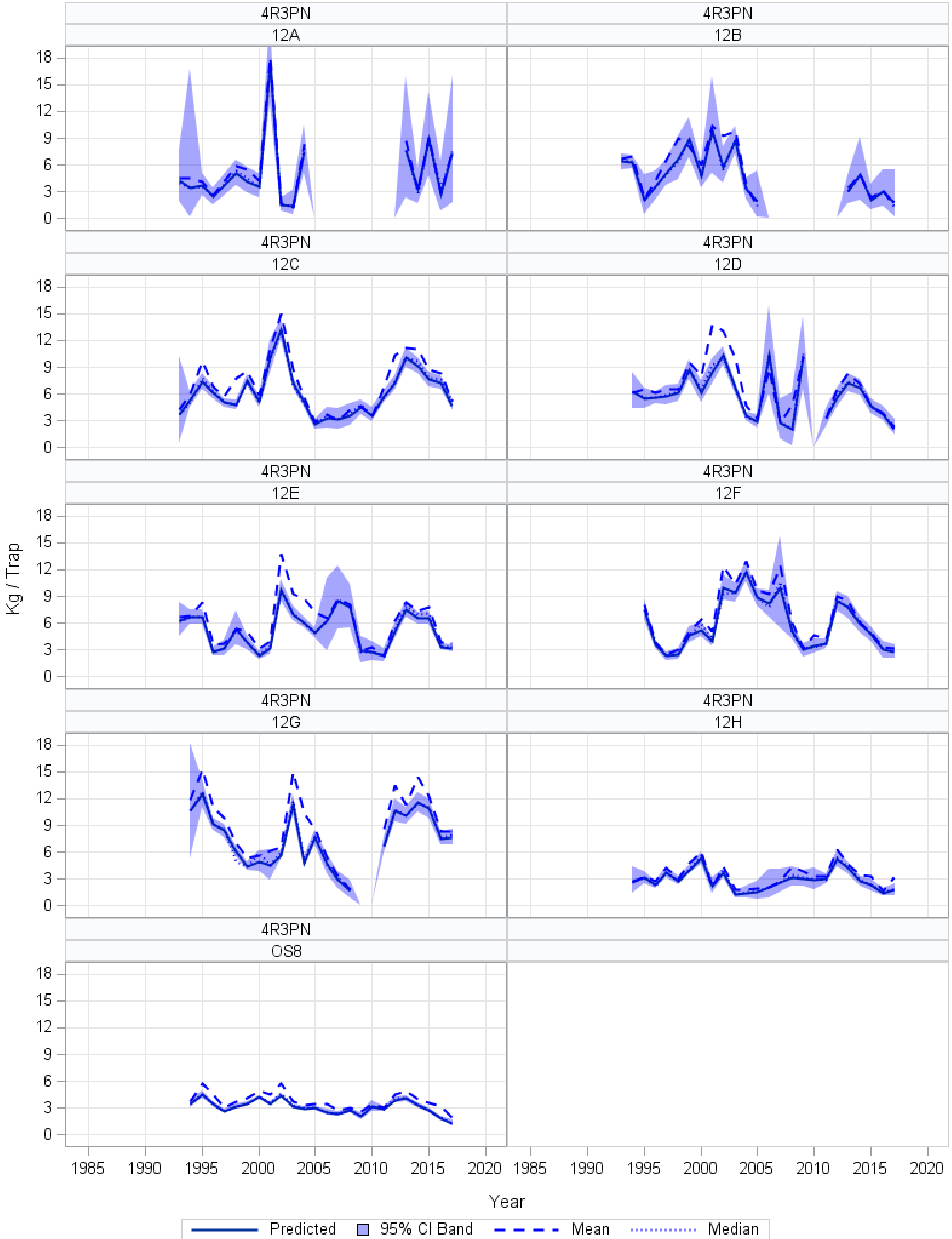

Figure 122. Trends in predicted, standardized CPUE (kg/trap) in Crab Management Areas (CMAs) within Assessment Divisions 4R3Pn.

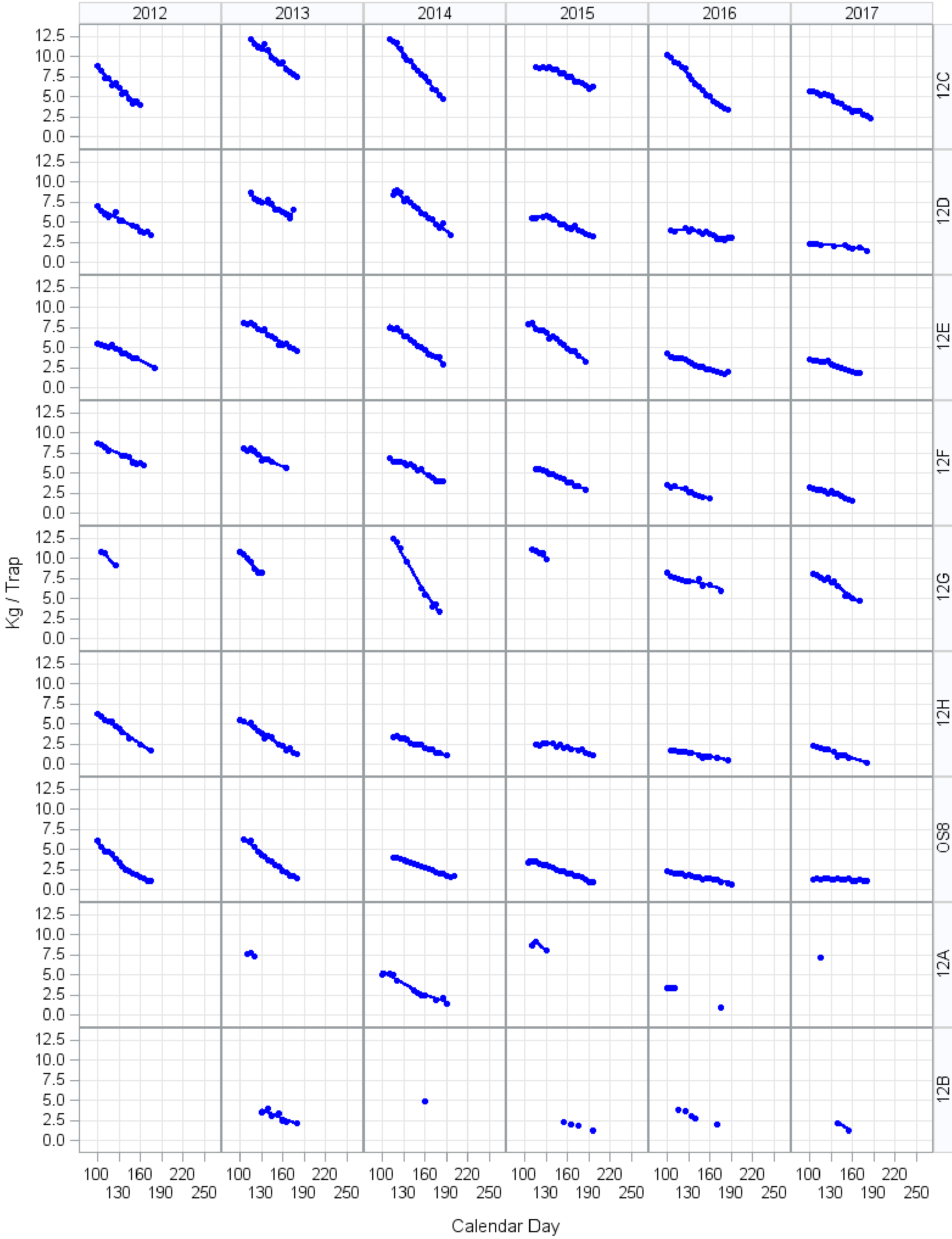

Figure 123. Trends in standardized CPUE (kg/trap) throughout the season fit with loess regression curves (2012-17), by Crab Management Area (CMA) in Assessment Divisions 4R3Pn.

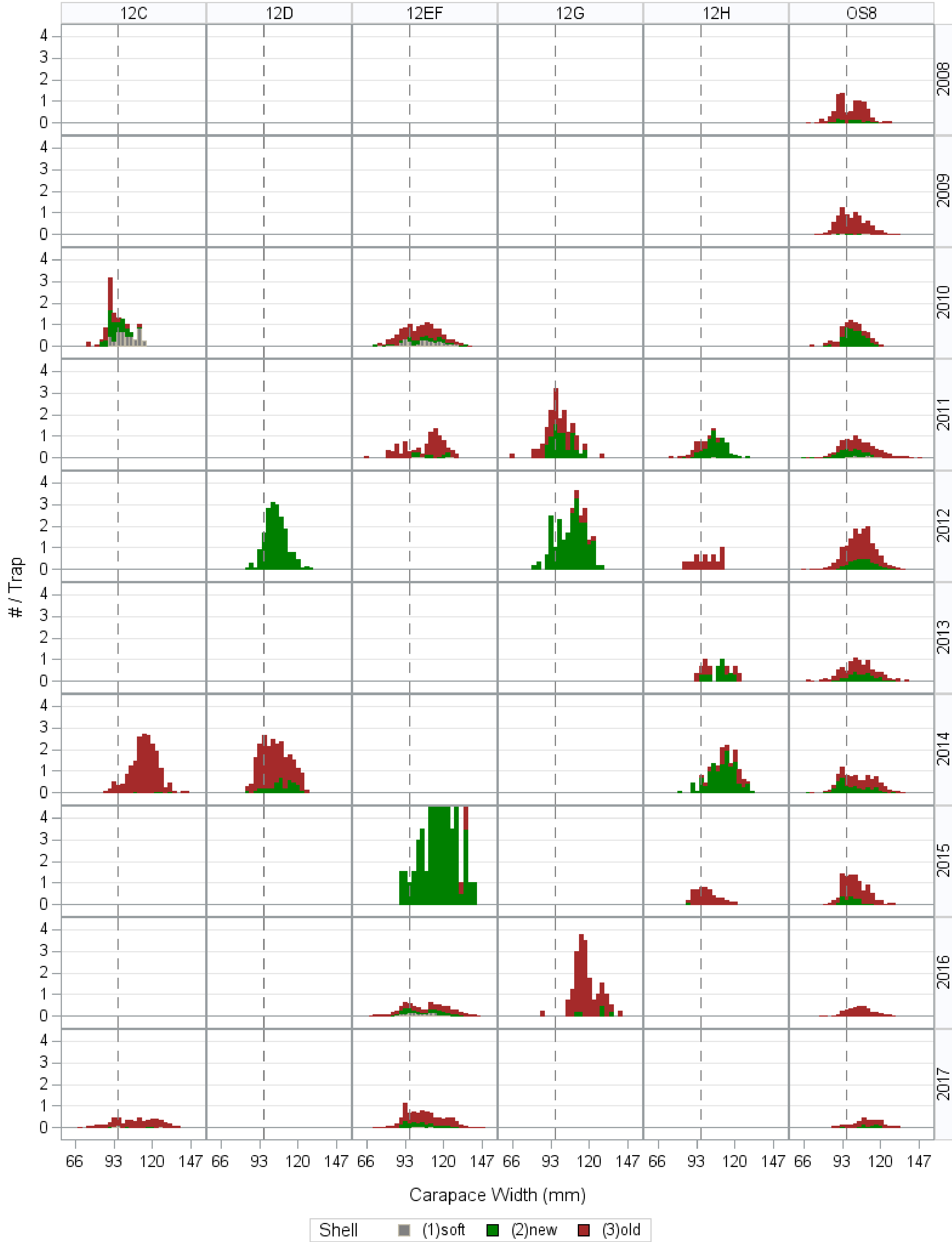

Figure 124. Trends in male carapace width distributions by shell condition from observer sampling in Divisions 4R3Pn (2008-17). The vertical line indicates the minimum legal size.

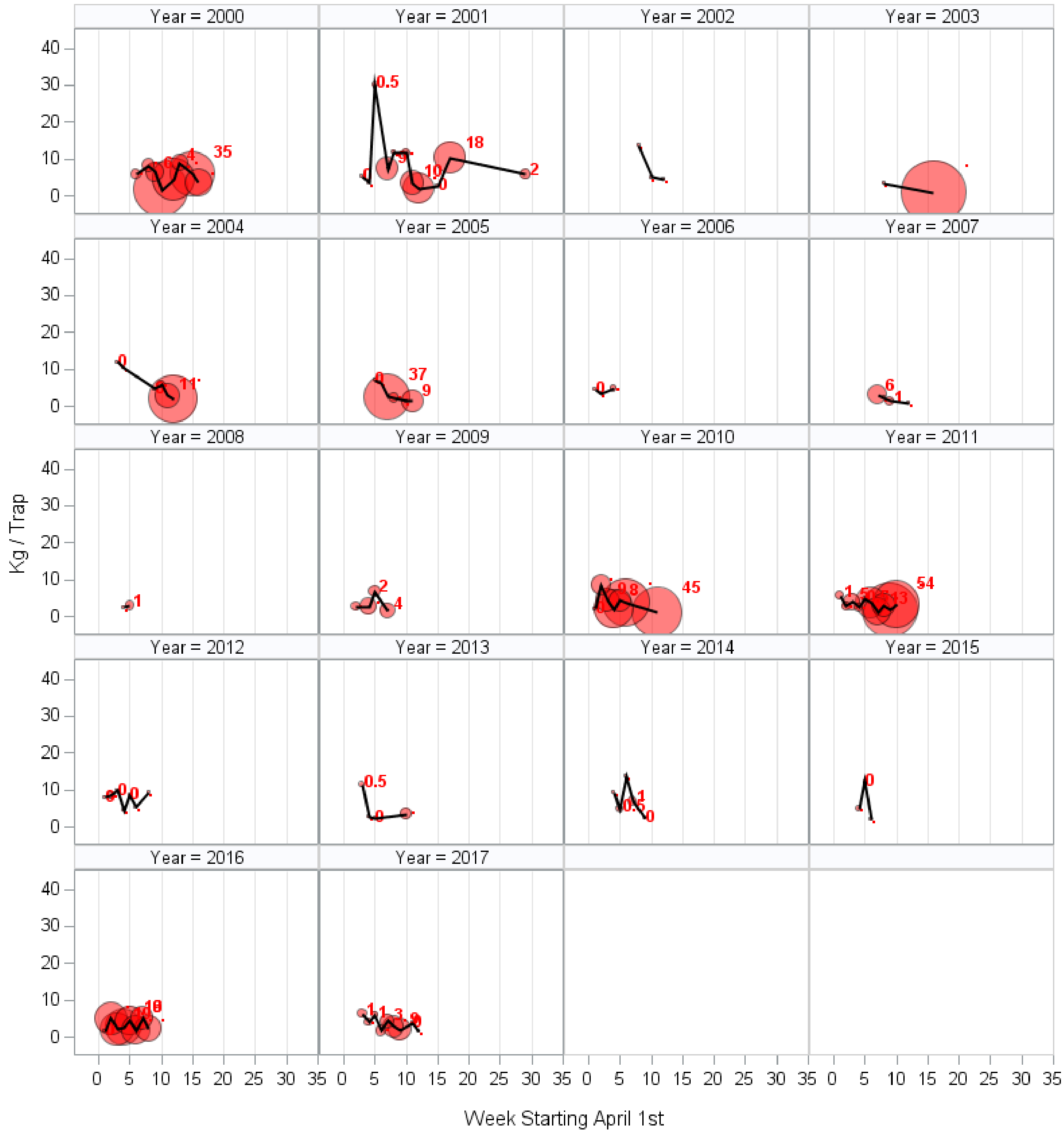

Figure 125. Trends in observed weekly catch rates (kg/trap) and the percentage of soft-shell crab in the catch in CMAs within the Assessment Divisions 4R3Pn (2000-17). Bubble size and labels depict percentage of soft-shell crab and solid line depicts unstandardized observed catch rates.

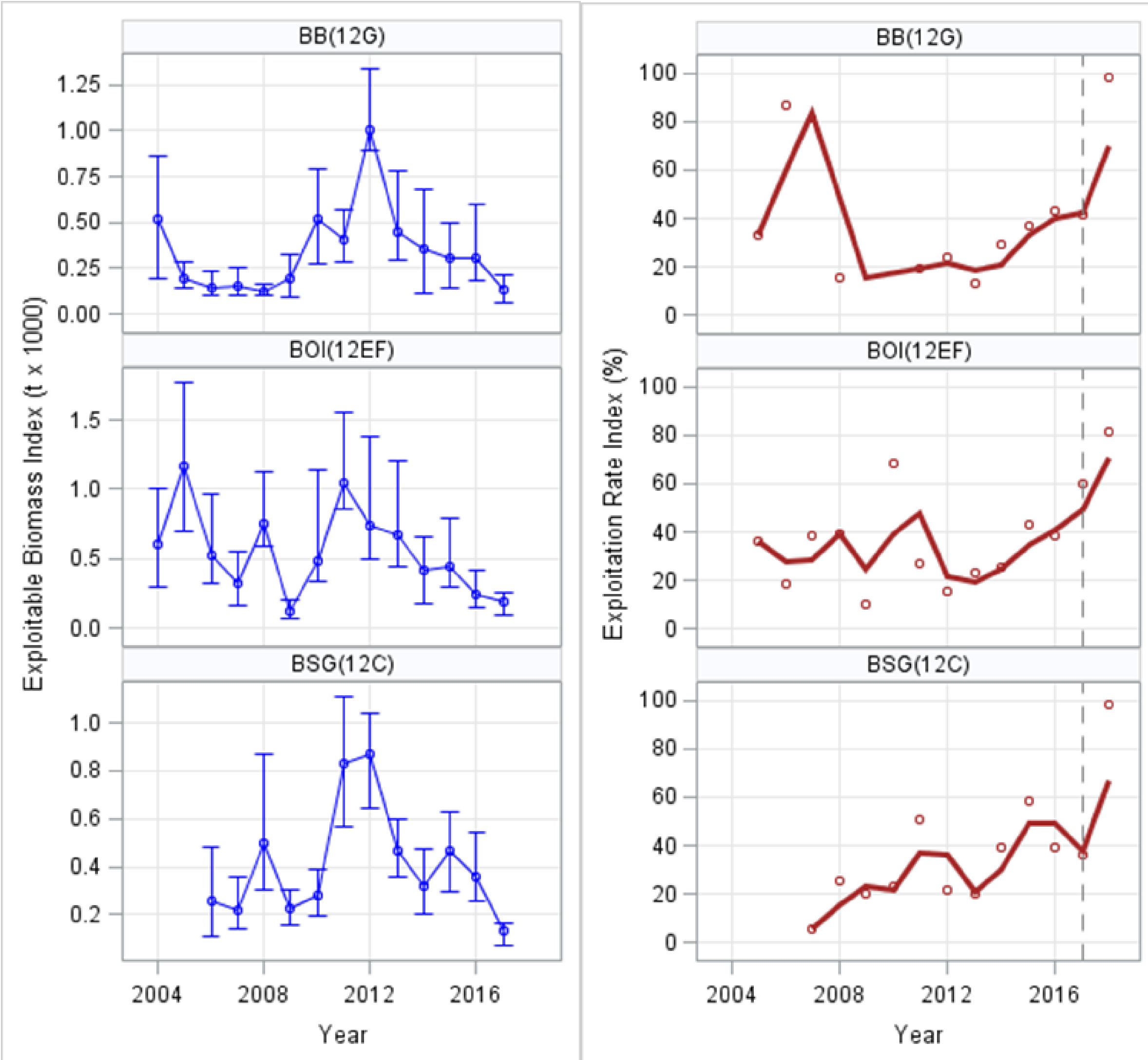

*Figure 126. Left: Annual trap-based exploitable biomass index (t * 1,000). Right: Trends in the exploitation rate index in CMAs within Assessment Divisions 4R3Pn. Line represents 2-year moving average and points represent annual estimates.*

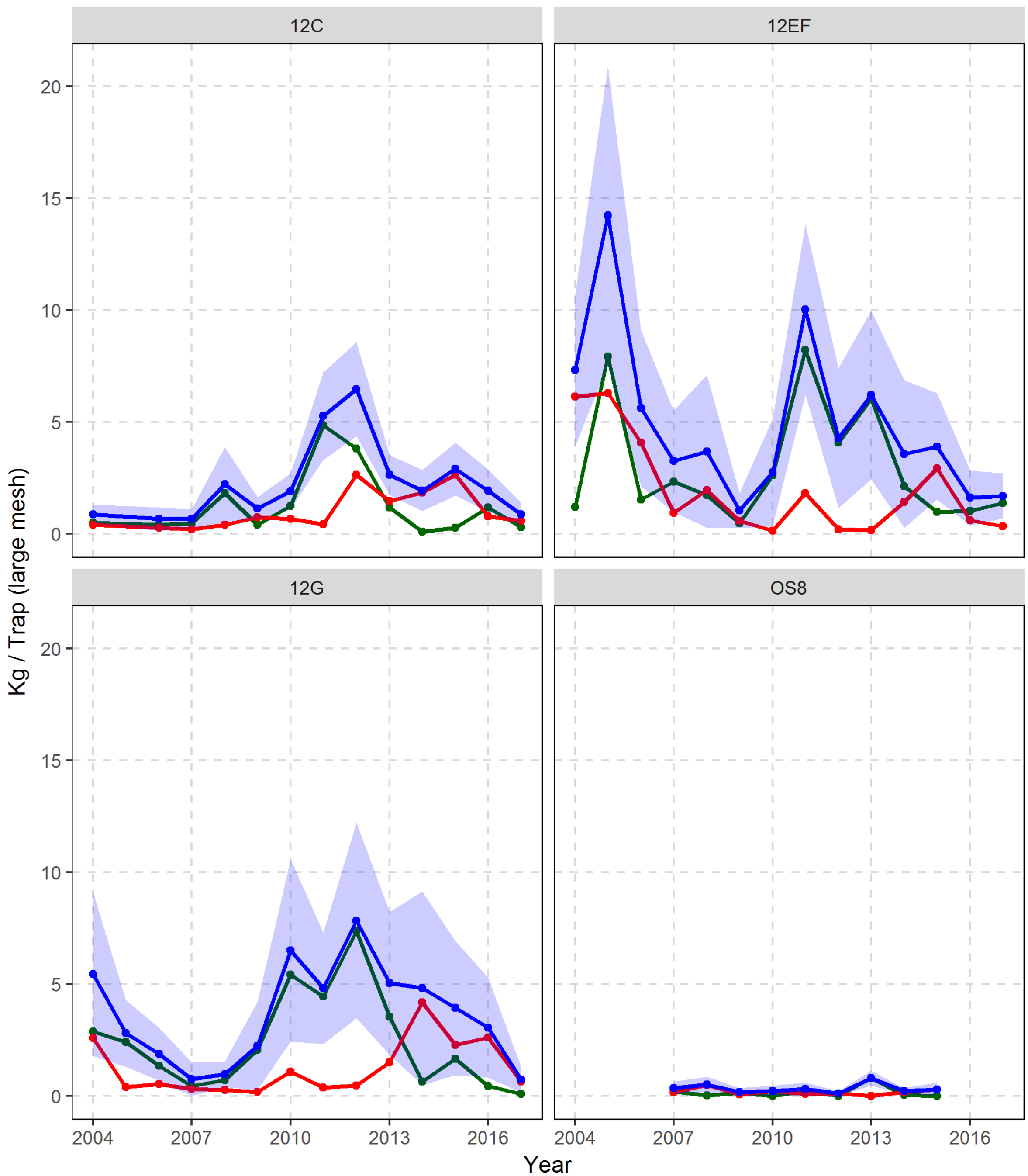

Figure 127. Trends in CPUE (kg/trap) by shell condition (recruits = green, residuals = red, total = blue) for legal-sized crab from core stations in the Collaborative Post-season (CPS) trap survey in CMAs (Crab Management Areas) within Assessment Divisions 4R3Pn.

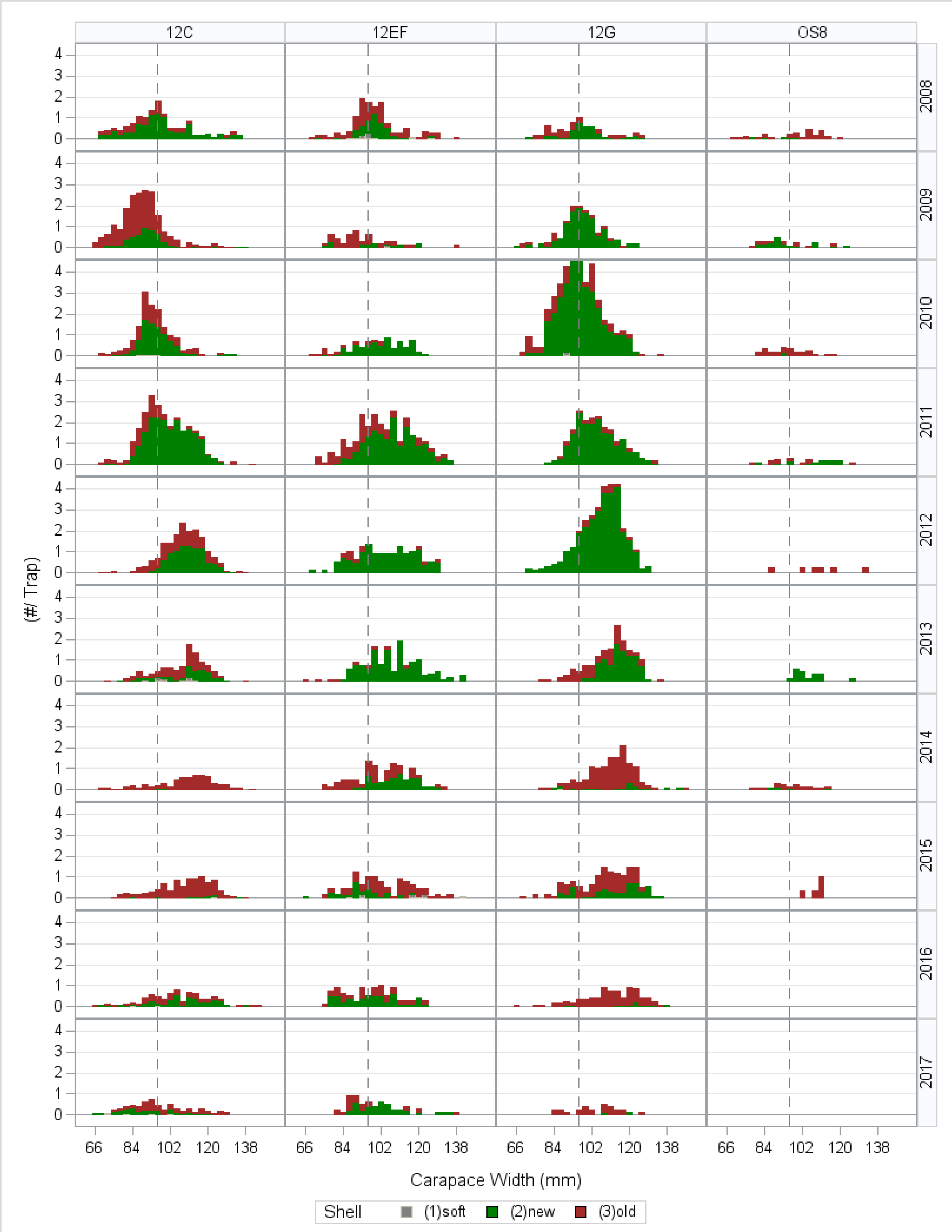

Figure 128. CPUE (#/trap) based on male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in CMAs (Crab Management Areas) within Assessment Divisions 4R3Pn (2008-17). The vertical line indicates the minimum legal size.

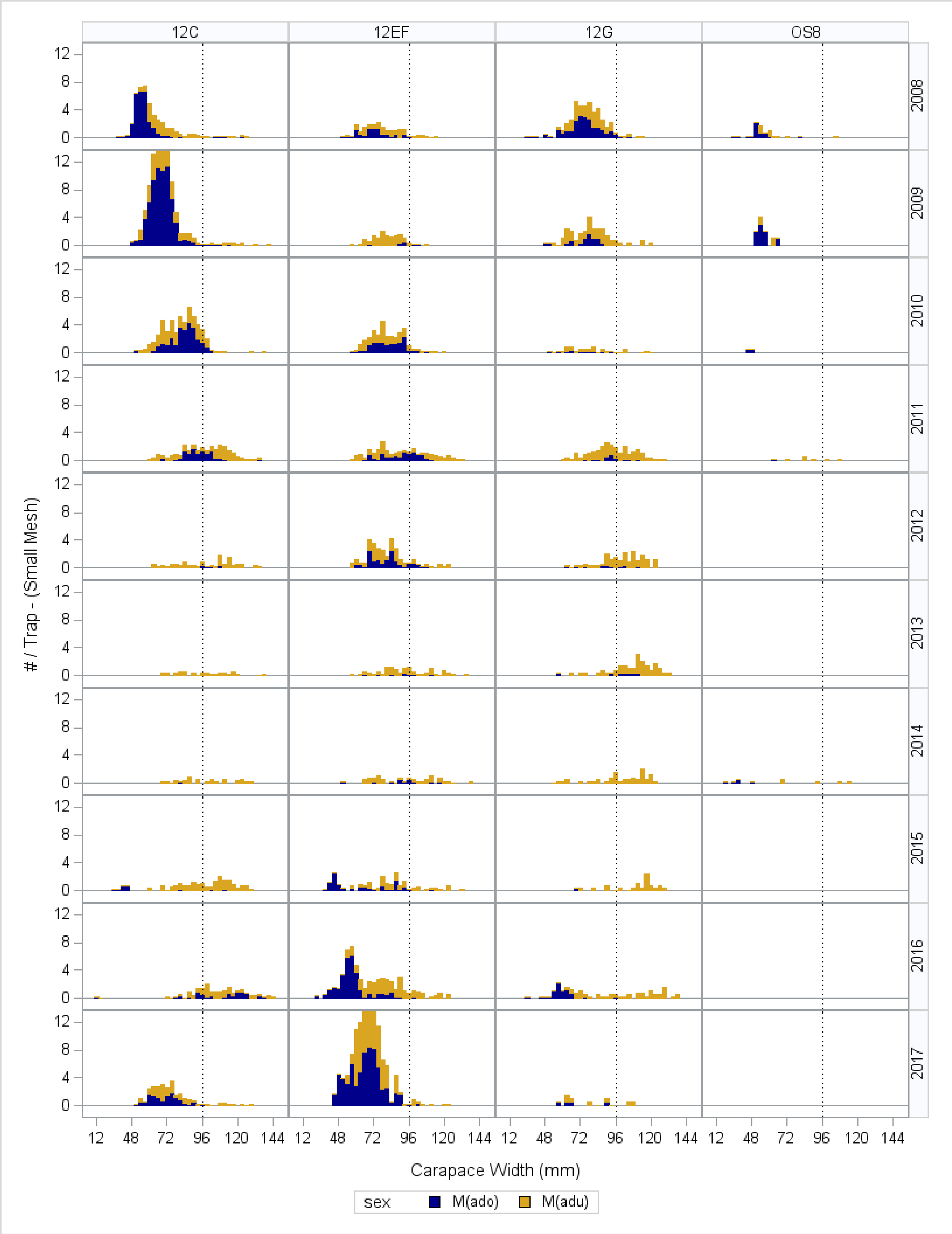

Figure 129. CPUE (#/trap) based on male carapace width distributions by maturity from small-mesh traps in the CPS trap survey (2008-17) from CMAs in Assessment Divisions 4R3Pn. The vertical line indicates the minimum legal size.