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An Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2016

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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.

Research documents are produced in the official language in which they are provided to the Secretariat.

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TABLE OF CONTENTS

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GLOSSARY

CMA: Crab Management Area.

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

CPUE: Catch per unit of effort.

CW: Carapace width.

Delury Depletion: A biomass estimation technique based on declining CPUE throughout the season.

ERI: Exploitation Rate Index. Landings of the current year divided by the exploitable biomass index of the previous survey.

Exploitable biomass: Biomass of ≥95 mm carapace width male Snow Crab that are terminally molted.

Habitat index: Areal extent of cold 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 mated multiple times.

NAFO: Northwest Atlantic Fisheries Organization (Divisions)

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 migration: A migration undertaken over the course of life, generally from shallow to deep areas.

PFMI: An index of potential harm caused to pre-recruits by fishing. Numerator defined as the ratio of landings to CPUE of kept crab times the CPUE of discards and numerator defined as the pre-recruit biomass index in the previous year ((Landings/CPUE kept)*(CPUE discard)) / PBI (y-1)

Pre-recruit male: ≥75 mm carapace width male crab that is adolescent (not terminally molted) and is expected to contribute to the exploitable biomass after another molt.

Pre-recruit biomass: Biomass of >75 mm carapace width adolescent males expected to contribute to the exploitable biomass and fishery over the next 2-3 years.

Primiparous female: First-time mating mature 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 by some crab during late-winter or 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.

STRAP: Stratified random assessment process. A spatial expansion method for survey catch rate data used to estimate biomass or abundance.

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.

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 Subdivision (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 2017 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 peaked at 53,500 t in 2009 and have since gradually declined to 42,000 t in 2016. Divs. 3LNO accounted for approximately 80% of the landings in recent years. Fishery catch per unit effort (CPUE) was at or near historical lows in most divisions in 2016 and the overall exploitable biomass index has declined by 80% since 2013. All divisions were at or near their lowest observed levels of biomass, with an overall decline of 40% in 2016. Overall recruitment into the exploitable biomass was at its lowest observed level in 2016. Thermal habitat, pre-recruit biomass, and predation indices collectively suggest poor broad-scale recruitment prospects; therefore, recruitment is expected to either remain at its current low level or continue declining in the next 3-4 years. Total mortality in exploitable crab increased to be at or near time series' highs and pre-recruit fishing mortality rates have been at decadal highs in all divisions in recent years. Status quo removals would maintain exploitation rate indices above long-term average levels in most divisions. Divs. 3LNO, where the majority of remaining biomass occurs, would elevate to an exceptionally high level of exploitation with status quo removals.

Évaluation du stock de crabes des neiges (*Chionoecetes opilio*) de Terre-Neuve-et-Labrador en 2016

RÉSUMÉ

L'état de la ressource de crabe des neiges (*Chionoecetes opilio*) entourant Terre-Neuve-et-Labrador dans les divisions 2HJ3KLNOP4R de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO) est évalué à l'aide de divers paramètres. Les données provenant des relevés plurispécifiques au chalut de fond menés à l'automne dans les divisions 2HJ3KLNO et au printemps dans les divisions 3LNO et la sous-division 3Ps sont examinées pour obtenir des renseignements sur les tendances relatives à la biomasse, au recrutement, à la production et à la mortalité au cours de la série chronologique. Les indices tirés des relevés plurispécifiques au chalut sont comparés à d'autres indices pertinents dans le but de déduire les changements de l'état de la ressource en 2017 et au-delà. Ces autres indices sont établis à partir des données provenant des journaux de bord des pêcheurs, des observateurs en mer, du Programme de vérification à quai (PVQ), des relevés au casier dans les eaux côtières et en haute mer, ainsi que des relevés océanographiques. Les débarquements de crabes des neiges ont atteint un sommet de 53 500 t en 2009 et ont ensuite diminué progressivement jusqu'à 42 000 t en 2016. Environ 80 % des débarquements au cours des dernières années sont attribuables à la pêche dans les divisions 3LNO. Les captures par unité d'effort (CPUE) pour la pêche ont atteint des planchers historiques ou étaient près de ceux-ci dans la majorité des divisions en 2016, et l'indice global de la biomasse exploitable a diminué de 80 % depuis 2013. Toutes les divisions ont atteint leurs plus faibles niveaux de biomasse jamais observés ou s'en sont approchées, et ont connu une baisse globale de 40 % en 2016. En 2016, le recrutement global dans la biomasse exploitable était au niveau le plus bas jamais observé. L'habitat thermique, la biomasse des prérecrues et les indices de prédation pris dans leur ensemble semblent indiquer des perspectives de recrutement à grande échelle médiocres; par conséquent, le recrutement devrait demeurer à son faible niveau actuel ou continuer à diminuer au cours des trois ou quatre prochaines années. Au cours des dernières années, la mortalité totale des crabes exploitables a augmenté pour atteindre un sommet ou presque dans la série chronologique, et les taux de mortalité par pêche des prérecrues se sont chiffrés à des maximums décennaux dans toutes les divisions. Le maintien des prélèvements actuels permettrait de maintenir les indices du taux d'exploitation au-dessus des moyennes à long terme dans la plupart des divisions. Les divisions 3LNO, où se trouve la majorité de la biomasse restante, atteindraient un niveau d'exploitation exceptionnellement élevé si les prélèvements actuels étaient maintenus.

INTRODUCTION

This document assesses the status of the Snow Crab (*Chionoecetes opilio*) resource surrounding Newfoundland and Labrador (NL) in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2HJ3KLNOP4R (Figure 1, Figure 2). The information presented follows from a formal scientific assessment and regional peer review process conducted during late February 2017 that focused on identifying changes in the exploitable biomass of Snow Crab available to the fishery.

SPECIES BIOLOGY

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 frequently. Snow Crab are sexually dimorphic, with males normally achieving larger sizes than females. Females cease molting after sexual maturity is achieved at about 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 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 about 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) because they molt less frequently at low temperatures (Dawe et al. 2012a). Adult legal-sized males remain new-shelled with low meat yield throughout the remainder of the year of their terminal molt. They are considered to be pre-recruits until the following year when they begin to contribute to the exploitable biomass as older-shelled adults. Males may live a maximum of 6-8 years as adults after the terminal molt (Fonseca et al. 2008). Exploitable crab consist of large males that have not molted within the past 6-12 months because recently-molted animals do not yield commercially acceptable meat content.

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 life history are associated with increased fishery CPUE and survey biomass indices several years later (Marcello et al. 2012; Mullowney et al. 2017). Growth rates are affected by temperature, with older age-at-recruitment within a cold regime than within a warm regime because of a lower frequency of molting in cold conditions (Dawe et al. 2012a). However, the positive effect of cold water on early survival appears stronger than the negative effect on size-at-terminal molt.

Along the Newfoundland and Labrador Shelf, cold conditions are generally associated with shallow areas (Figure 3). These shallow, cold areas have historically been associated with the most productive fisheries. Snow Crab undertake an ontogenetic migration from shallow cold areas with hard substrates to warmer deep areas with soft substrates. Large males are most common on mud or mud/sand, while small crab are common on harder substrates. Some crab also undertake a migration in the spring for mating and/or molting. Although the dynamics of spring migrations are not fully understood, they generally move from deep to shallow areas. 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 population 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 1), with inshore and offshore portions of divisions separated where applicable and some divisions combined. The approach partially conforms with Crab Management Areas (CMAs), the spatial scale at which quotas are allocated (Figure 2), while accommodating different types and amounts of available information.

FISHERY

The NL Snow Crab fishery began in Trinity Bay (CMA 6A) (Figure 2) 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 Divs. 2HJ3KLNOP4R 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 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 2016.

In the late 1980s, quota control was initiated in all management areas of each division. Current management measures include trap limits, individual quotas, trip limits, fishing areas 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 about 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 early summer. The fishery can be delayed in northern divisions (Divs. 2HJ3K) due to ice conditions in some years. Such severe ice conditions can affect the spatial distribution of fishing effort and fishery performance. The fishery can also be delayed for other reasons such as price disputes, but this has not occurred in the past few years. Late fishing seasons are believed to contribute to 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 Div. 3LNO in 2009-10, and grids in some inshore areas have been made smaller (5 x 3.5 na. mi.) in some inshore areas in recent years.

Landings for Divs. 2HJ3KLNOP4R increased steadily from 1989 to peak at 69,100 t in 1999, largely due to expansion of the fishery to offshore areas. They decreased by 20% to 55,400 t in 2000 and changed little until they decreased to 44,000 t in 2005, primarily due to a sharp decrease in Div. 3K. In recent years, landings most recently peaked at 53,500 t in 2009 and have since gradually declined to 42,000 t in 2016. Divs. 3LNO have accounted for a steadily increasing percentage of the catch, from about half in 2009 to 80% in recent years.

METHODOLOGY

MULTI-SPECIES TRAWL SURVEY DATA

Data on total catch numbers and weights were derived from depth-stratified multi-species bottom trawl surveys (Figure 4). These surveys were conducted during fall in Divs. 2HJ3KLNO and spring in Divs. 3LNO and Subdiv. 3Ps. The fall (post-season) survey has occurred annually in all but Div. 2H where it was executed each year from 1996-99, bi-annually from 2004-08, and annually from 2010-16. Sampling of Snow Crab during spring Divs. 3LNO and Subdiv. 3Ps surveys began in 1996.

The survey trawl was changed to a Campelen 1800 shrimp trawl in 1995 and 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 (Figure 4). However, in the previous assessment, Ogive Mapping (Ogmap) (Evans 2000) was introduced as the spatial expansion platform for biomass and abundance estimation. 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.

Slight changes to the spatial footprint of survey data used in Ogmap were made for the present assessment. Specifically, data north of 56 degrees latitude in Div. 2H were 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 Divs. 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 two additional survey years, and the more robust ability of Ogmap to extrapolate across areas void of coverage, the 2014 fall survey in Divs. 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 Subdiv. 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 and have been available to the fishery for at least two years. 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 an unknown but relatively long duration (i.e. 4 years or more). Carapace and legs turning black, particularly around joints, and the shell 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 about 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 both chela height (CH) and carapace width (CW) data 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 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. Total biomass or numbers were 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 total abundance of crab, the abundance of small (<50 mm CW) crab, and exploitable and pre-recruit biomasses of 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 as the survey biomass index of adult (large-clawed) legal-sized (>94 mm CW) males, regardless of shell condition. Adult males are terminally molted, so that no members of this category would molt in spring and all adults in the fall survey (including new-shelled adults) would be fully recruited to the fishery in the following year. The exploitable biomass index generated from spring survey data includes a component of 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 biomass 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 sources of error, including subjectivity in shell age classification, we would expect annual changes in biomass to be first seen in recruits and subsequently occur in the residual biomass.

The pre-recruit biomass index was calculated based on all adolescent (small-clawed) males larger than 75 mm CW caught in the surveys. Theoretically, we would expect pre-recruits to begin contributing to the exploitable biomass in the following one to two years and to the fishery in the following two to three years. A pre-recruit captured in the present survey (i.e. 2017) that undergoes a terminal molt in the subsequent spring (i.e. 2018) would contribute to the exploitable biomass as a new-shelled recruit in the following survey (i.e. 2018) and begin contributing to the fishery two years later (i.e. 2019). However, a portion of pre-recruits would molt but not undergo their terminal molt and 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 pre-recruits would molt in the following 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. 2012a). 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 unstandardized exploitable and pre-recruit biomass indices were calculated using the 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 these raw survey biomass estimates are greatly under-estimated (Mullowney et al. 2017). For the present assessment, the unstandardized trawl survey biomass estimates were scaled up to values closer to reality using conversion factors developed through Delury depletion regression analysis on fishery catch rate data from logbooks. For details on this method, see the next section on analysis of fishery logbook data. These conversion factors (đ) represented the average difference between logbook and survey-based biomass estimates in each assessment division over the time series:

$$đ = \sum_{y=2000}^{2016} (Ty/Dy * 1/n)$$

where,

T = raw trawl survey exploitable biomass estimates from Ogmap

D = Delury depletion biomass estimates from logbooks

y = year beginning in 2000

n = number of years in the analysis

The conversion factors used in the assessment were đ=0.697, 0.385, 0.126, and 0.078 for Assessment Divs. 2HJ, 3K, 3LNO, and Subdiv. 3Ps respectively. Standardized biomass indices were calculated as (T / đ). Although closer to reality, these standardized biomass estimates are not absolute and remain treated and interpreted as relative indices.

The spatial distributions of pre-recruit, exploitable, and small crab were examined using catch rates (numbers per tow) for each survey set, as were the distributions of small crab (<50 mm CW).

Crab catchability by the Campelen trawl is known to vary with crab size (Dawe et al. 2010a), as well as the diurnal cycle (Benoît and Cadigan 2014, 2016). It is highest on largest crab and at night. Further, it differs across 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, as trends in trawl survey biomass estimates were very similar in all combination of conversions, thus no conversions were applied. However, for visual interpretation in catch magnitude diurnal and vessel conversions were applied prior to mapping. Diurnal conversions were based on mean numbers per tow from day (dawn to dusk) versus night (dusk to dawn) tows for specific groups of crab (i.e., exploitable crab, pre-recruit crab, and <50 mm CW crab) over the survey time series in each Assessment Division. In all cases, day catch rates were scaled to nighttime equivalents. Vessel conversions were taken from Benoît and Cadigan (2014, 2016) from Snow Crab surveys in the Southern Gulf of St. Lawrence where multiple surveys have allowed for a comparison of the catchability of crab between DFO research vessels and other trawlers. Catches from the CCGS Alfred Needler (AN) and Wilfred Templemen (WT) were converted to Teleost (T) units (AN›T=1.62, WT›T=1.0), based on averages from the two studies. Although substrate type is also known to affect survey catchability (Dawe et al. 2010a), no conversions for substrate type were available or applied prior to mapping.

To construct and examine size compositions of males and females, vessel and time conversions were applied. Vessel conversions were as described above, while time conversions were developed from size-specific catch rates of crab in day versus night tows for the entire survey time series. All crab sexes, maturities, and divisions were pooled due to similarities across groups and divisions. Crab were segregated into 20 mm CW intervals (10-29 mm, 30-49 mm, 50-69 mm, etc.) and linear regression was used to differentiate between catch rates of day versus night tows, with differences in intercepts used to scale day tows to nighttime equivalents. For presentation, crab of both sexes were grouped by maturity and partitioned into 3 mm CW intervals before calculating the square root of mean numbers per tow each year. A square root transformation was applied because trawl size frequency distributions tended to exhibit a 'trough' pattern in most divisions and years, 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 crab.

The ratio of the exploitable to pre-recruit biomass index for each Assessment Division was interpreted as an index of recruitment potential and compared to fishery discard levels to infer potential for soft-shell wastage in the fishery. Based on consistent negative relationships between these indices in all Assessment Divisions, it is thought that the catchability of soft-shelled crab increases when the ratio of pre-recruits to exploitable crab is high, with the generally larger and older-shelled exploitable crab out-competing their softer-shelled and typically smaller counterparts for baited traps. Essentially, maintaining a high exploitable to pre-recruit ratio creates a 'buffer' against high soft-shell crab prevalence in the fishery.

The ratio of the annual landings to the most recent standardized exploitable biomass index was calculated by Assessment Division to provide an index of exploitation rate. As exploitable biomass indices are not absolute, neither are exploitation rate indices. However, long-term trends in exploitation rates provide a useful indication of trends of relative effects from fishing. In Assessment Divs. 3L Inshore and 4R, where no trawl surveys occur, exploitation rate indices were based on landings in relation to exploitable biomass estimates from trap surveys.

To qualitatively investigate the effects of fishing on the resource over time, the relative abundance of old and very old-shelled crab in the survey population was examined. For this analysis, time was broken into four periods (1995-2000, 2001-05, 2006-10, and 2011-16). The percentage of adult crab captured that were either old or very-old was partitioned into 5 mm CW intervals. Effects of fishing were inferred from a reduction in the percentage of old-shelled crab in the population at or near legal size. 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 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 *t* (A_t) were calculated as a two period moving average of stage-specific biomass indices of exploitable crab:

$$A_t = \frac{0.5 \cdot \left(B_{new}(t-1) + B_{old}(t-1)\right)}{B_{old}\ (t)} + \frac{0.5 \cdot \left(B_{new}(t-2) + B_{old}(t-2)\right)}{B_{old}\ (t-1)}$$

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. The dataset is normally incomplete in the current year due to a time lag associated with compiling data from the most recent fishery (Figure 5), thus the most recent point estimate is considered preliminary.

Logbook catch per unit of effort (CPUE; kg/trap) was calculated by year and Assessment Division as well as by CMA. Previous assessments did not standardize CPUE (Mullowney et al. 2017). However, for the present assessment, to account for seasonal changes in the timing of the fishery over the past two decades (Figure 6), a generalized linear model (GLzM) was introduced to standardize CPUE by time. The model, based on maximum likelihood, was programmed in SAS using Proc Genmod (SAS 2011). Time was binned into two week increments, with the model regressing CPUE (calculated from individual entries of number of pots and catch of crab from logbooks) against the main effects of year and the interaction effect of year and time. Both explanatory factors were treated as class variables. The model incorporated a weighting factor of effort (number of traps). CPUE was modelled as coming from a gamma distribution with a log link function and type 3 sums of squared used to calculate likelihood ratios. Late season data occurring after August were omitted due to limited and sporadic presence in the dataset, and entries of CPUE=0 were removed as it was unclear if they represented real catch rates or other practices such as dumping traps once quotas were subscribed. Model fits were assessed by the distribution of residuals along with an evaluation of the scaled deviance statistic, with values close to 1 accepted as sufficient model fits. For presentation, model outputs were plotted along with mean and median CPUEs from raw data in the logbooks.

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. CPUE was directly compared and related to other indices of biomass and associated factors, including trawl survey based biomass estimates and thermal habitat indices.

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 Assessment Division. Further, weekly CPUEs were plotted for individual CMAs within each Assessment Division for a five-year timespan to assess the performance of the fishery over a prolonged continuous timescale. The weekly estimates were fit with least squares loess regression curves to smooth trends and visually depict changes occurring in the fishery over time.

Finally, logbook data were used to adjust for biomass underestimates in trawl-based biomass indices. Delury-type depletion models (Delury 1947) were constructed based on logbook catch rates (Figure 7, Figure 8, Figure 9, Figure 10) to calculate conversion factors (đ). This analysis used weekly CPUEs in each Assessment Division beginning in the year 2000. Prior data were omitted due to little evidence of strong seasonal depletion in the fishery, with rapid expansion and substantial increases in removals occurring throughout the 1990s until a peak in 1999 (Figure 11). To estimate biomass, weekly 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 Assessment Division 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 regressions were fit to log-seasonal catch rate versus cumulative catch data, with the forecasted catch associated with a CPUE of zero (i.e. fully depleted resource) taken to be the beginning of the season biomass. For comparison with fall trawl survey biomass estimates in Divs. 2HJ3KLNO, end of season biomass was calculated by subtracting fishery removals from the beginning of the season biomass estimates. In Subdiv. 3Ps, where a spring trawl 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. Two years were omitted from the analysis because there was lack of depletion (Divs. 2HJ in 2007 and Divs. 3LNO in 2014), whereby regression slopes were close to zero. Three other data points were omitted from calculation of conversion factors, all in Divs. 2HJ (2004, 2005, and 2012). In these three years, conversion factors greatly exceeded one, indicating the trawl survey biomass index was greater than the logbook derived biomass estimates. This is at least partially explained by unusual circumstances in the Divs. 2HJ fisheries in those years. All three years were associated with fisheries featuring atypically high levels of soft-shell crab in the catch and extremely high fishery discards and exploitation rates (Mullowney et al. 2017). This would likely be associated with logbooks underestimating biomass, in relative terms to the trawl survey. The 2004-05 period in particular was associated with an unusual event; specifically, a period of severe overfishing following the establishment of the Hawke Box trawling exclusion zone. Crab harvesters who had been given exclusive access to prime fishing grounds in the Hawke Channel (Figure 1) fished the region harder than ever before and decimated the exploitable biomass to an extent not seen prior or since (Mullowney et al. 2012). Coincidentally, logbook catch rates, which were unusually concentrated within a tight area, plummeted to historical lows during those years, negatively affecting Delury regression analyses.

ECOSYSTEM INDICES

To assess the effect of the thermal regime on future fishery success, thermal habitat indices in each Assessment Division were correlated with logbook CPUE at multiple time lags to determine the lag of best fit. The thermal habitat indices used in this analysis were calculated as a three year moving average (ending in the terminal year) of the areal extent of cold bottom water distribution. Bottom temperatures used to make the habitat indices were isolated to shallow strata in each division (<200 m in Div. 2J, <300 m in Div. 3K, and <100 m in Divs. 3LNOPs) because settlement of early benthic stages occurs primarily in shallow areas such as the inshore and tops of banks (Dawe and Colbourne 2002). The thermal habitat index was calculated as the percentage of the area surveyed that was covered by water <2°C in each Assessment Division.

In Assessment Divs. 3LNO and Subdiv. 3Ps, preferred spring bottom temperatures were used whereas only fall temperature data were available for Divs. 2HJ and 3K. No thermal habitat index was calculated for Div. 4R because there were insufficient data. Spring bottom temperatures are preferred because they are more closely associated with critical life history events in Snow Crab such as mating and molting.

A complementary analysis on the effects of temperature on resource productivity was conducted by comparing bottom temperature from Station 27, a frequently sampled oceanographic station located on the approach to St. John's Harbour, to the best-fit lag of the exploitable biomass index for each Assessment Division. The temperature index was calculated as a three year moving average (ending in the terminal year) of mean bottom temperatures during March-June (i.e. spring) each year. Station 27 lies in the inner branch of the Labrador Current and is commonly used as a broad-scale proxy for thermal ocean conditions along the NL shelf (Colbourne and Fitzpatrick 2003). It is relatively shallow (176 m) and would be expected to conform to typical habitat of young crab. The coefficients of determination for correlations of the Station 27 temperature index to future exploitable biomass levels at different lags in each division were examined qualitatively to assess the timeframe from over which temperature acts to affect crab biomass. Indices of predation on crab were introduced into the previous assessment. 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. Each one of these steps involves a set of assumptions and generalizations and the resulting index is not absolute but intended to generate a plausible envelope for the order of magnitude for that 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 predators of crab (due to gape limitation of smaller fishes), and hence used in the estimations of consumption. The total biomass of predators was approximated using DFO multi-species trawl survey biomass estimates; this approach assumes that surveys properly capture the relative composition of the fish community. However, as these estimates were not corrected for gear catchability they likely reflect minimal estimates of predator biomass.

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

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

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

Data on diet composition is only available for recent years and for a small subset of crab predators (American plaice, cod and turbot). The overall fraction of crab in their diets, as well as the relative contribution by these species to the overall biomass of the entire crab predators 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 Snow Crab consumed by all piscivore and large benthivore fishes, as well as just by American plaice, cod and turbot were presented along with confidence intervals representing the full range of estimated consumption values. As consumption rates cover a large range of options, some estimates are likely above reality while others are likely below reality. Nonetheless, trends in predation of Snow Crab are likely reliable.

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 offshore Divs. 3KLNO where the fishery is largest and observer coverage is highest (Figure 12). Sampling has been consistently low in inshore CMAs and virtually absent throughout Divs. 2H and 4R. Various catch rate indices were developed from shell condition aging conducted by observers. However, unlike the five stage assessment of shell ages used on DFO research surveys, observers use only a three-stage scale of soft, new, and old-shelled. First, the total catch rate of legal-sized crab by shell condition for each Assessment Division 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 Assessment Division 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. Bubble plots of weekly catch rates and percentages of soft-shelled crab captured in the fishery were constructed and examined for each Assessment Division. 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 be indicative of wastage.

For all Assessment Divisions except 4R, a pre-recruit fishing mortality index (PFMI) was developed based on the ratio of the observed catch rate of pre-recruits discarded in the fishery to the preceding trawl survey biomass index of pre-recruits:

$$PFMI = S\left(\frac{DPI_t}{PBI_{t-1}}\right)$$

DPI is the catch rate (kg/trap) of measured under-sized adult males and under-sized, and soft-shelled, pre-recruits discarded in the fishery, in year *t*, calculated from observer sampling data. *PBI* is an index of the biomass of pre-recruits and under-sized adult males (*t* x 1000) from the preceding survey. *S* is a scaling factor to account for incomplete and annually variable levels of observer coverage:

$$S = \frac{Total\ Landings}{Observed\ Landings}$$

Long-term trends in the PFMI provide a useful indication of trends in relative levels of pre-recruit mortality. However, although it provides an indication of the level of wastage associated with catching and releasing pre-recruits in the fishery, it is not necessarily proportional to the mortality rate on the pre-recruit population.

Along with biological sampling to inform the stock assessment, observer data also form the basis of the soft-shell protocol, which was implemented in 2004 to close specific small fishing areas (10 x 7 na. mi.) when the percentage of soft-shelled crab reached 20%. The closure threshold was reduced to 15% for Assessment Divs. 3LNO and Div. 3L Inshore in 2009-10.

INSHORE DFO TRAP SURVEYS

Data were available from inshore trap surveys in Divs. 3K, 3L, and Subdiv. 3Ps (Figure 13). In Div. 3K, surveys were carried out in White Bay (CMA 3B), Green Bay (CMA 3C), and Notre Dame Bay (CMA 3D) during 1994-2016. 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 inshore fall multi-species survey strata.

In Div. 3L, 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 four 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 Subdiv. 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 in each set, with ‘fleets’ of gear deployed with traps spaced approximately 45 m apart. Each set includes six baited traps, with two additional end traps that are not baited, with crab sampled from three large-mesh and three small-mesh traps that are alternated with one another within the fleet of gear. Squid (*Illex* spp.) hung on skivers attached to the inner entry cone of each trap is used 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 affect the surveys and soak times were 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 >75 mm CW adolescent males 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 CPS trap survey in Divs. 2J3KLOP4R (Figure 14, Figure 15). These surveys were initiated following the 2003 fishery and have since 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, these surveys are more spatially-limited than the multi-species trawl surveys in the offshore as well as 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 one 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 are included at some stations to collect information on pre-recruits and females. Biological sampling of males from small-mesh traps includes determination of chela height. 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 2016, at-sea observers measured the contents of the small-mesh traps.

As a result of 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 pre-recruit 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 2016 (Figure 15). Overall, the number of small-mesh traps deployed in the survey approximately doubled to 300. 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 will be transitioning to a partially random stratified design over the next few years to increase coverage in areas beyond prime commercial fishing grounds and encompass more representative distribution of all components of the population. This transition will occur gradually, with approximately 20% of the fixed stations randomized for 2017. Nonetheless, for the present assessment most analyses remain unchanged, with a set of core stations 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 traps. These indices are developed and examined at both the Assessment Division and CMA level. 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. A pre-recruit catch rate index (defined as kg/trap of >75 mm CW adolescent males) was also derived from small-mesh pots deployed at core stations.

In previous assessments, a depth-based stratification scheme introduced in 2010 was used to develop indices of exploitable biomass from large-mesh traps. This stratification was used in conjunction with a modified version of STRAP, with an effective area fished input parameter used as an analog to the swept area of a survey trawl. However, for the present assessment, a new stratification scheme was developed and introduced. This new stratification scheme does not consider depth and more fully covers the footprint of the fishery and by extension the assumed distribution of dense aggregations of exploitable crab within CMA boundaries. It is being introduced in conjunction with a modified version of Ogmap (‘OgTrap’) for spatial expansion of survey catch rate information into biomass estimates. OgTrap utilizes the same vertex points as

Ogmap (Figure 16) to integrate catch rates over any given spatial area. Similar to the modification in STRAP, OgTrap modifies the input parameter of trawl swept area to conform to the effective fishing area of a crab trap. This value was set at 0.01 km^2. This effective fishing area parameter is higher than the previously used estimate of .0055 km^2, which came from Dawe et al. (1993). The present estimate 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 assessed in a relative sense.

As a result of the lack of small-mesh traps in the survey and targeting of deep commercial Snow Crab grounds by the 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; all trap surveys use similar techniques and the inclusion of more data are thought to improve the reliability of the results.

RESULTS AND DISCUSSION

BROAD-SCALE TRENDS: DIVISIONS 2HJ3KLNOPS4R

Fishery

Landings in Divs. 2HJ3KLNOP4R most recently peaked at 53,500 t in 2009 and have gradually declined to 42,000 t in 2016 (Figure 11). Most of the landings are from Divs. 3KLNO. Divs. 3LNO have accounted for a steadily increasing percentage of the landings in recent years, from about 50% in 2009 to 80% in 2016. In Divs. 2HJ, landings have remained relatively low at less than 2,000 t since 2011 (Figure 17). In Div. 3K, they declined by 63% since 2008 to 5,600 t in 2016, their lowest level in two decades. In Divs. 3LNO Offshore, landings have remained at 22,000-29,000 t since 1999. In Div. 3L Inshore, landings increased gradually throughout the 2000s and have remained near 8,000 t since 2013. In Subdiv. 3Ps, landings declined from a recent peak of 6,700 t in 2011 to a time series low of 1,200 t in 2016. Finally, in Div. 4R and Subdiv. 3Pn, landings increased from a historic low of 190 t in 2010 to between 700 and 900 t since 2012.

Effort, as indicated by estimated trap hauls, approximately tripled throughout the 1990s as the fishery grew (Dawe et al. 2003). Spatially, the distribution of the fishery has remained relatively broad-based, but there have been significant changes in some divisions in recent years (Figure 18). In the north, effort in Div. 2H and the northernmost portion of Assessment Div. 2HJ has gradually dissipated since 2011, with Div. 2H virtually abandoned in the past four years. In Div. 3K, during the past decade, effort was relatively intense during 2009-11, but has dissipated since then and remained near time series lows. In Divs. 3LNO Offshore, effort has gradually increased since 2009 to a historic high in 2016. In Div. 3L Inshore effort had oscillated without trend from 2005 to 2015, but increased by 40% in 2016 to a time series high. In Subdiv. 3Ps, effort reached a historic high in 2014 and has since decreased by half, with only 40-60% of the TAC taken in the past two years. Finally, in Div. 4R and Subdiv. 3Pn, effort has been relatively unchanged since 2012.

The timing of the fishery can differ both across and within some divisions (Figure 6). However, the amount of time when the bulk of effort was expended remained relatively consistent in each Assessment Division for the past five years. Generally, the fishery begins in early April for all but Divs. 2HJ, where it usually starts in early to mid-May. The fishery normally finishes first in Div. 4R in early to mid-July (i.e., weeks 12 to 14). In 2016, the last fishery was completed in Divs. 2HJ by late August (i.e., week 21).

Throughout the past twenty-five years, standardized CPUE has shown a great deal of variability both across and within all divisions, except in Divs. 4R3Pn, where it has remained relatively constant and low relative to other divisions (Figure 19). In 2016, the fishery CPUE was at or near historical lows in all divisions and the CPUE of every Assessment Division declined compared to 2015. CPUE increased steadily in Divs. 2HJ from 2011 to 2015, but decreased throughout the Assessment Division in 2016 to a relatively low level. In Div. 3K, CPUE has been low for the past six years. Particularly dramatic declines were observed in Divs. 3LNO Offshore and 3L Inshore in 2016. In Divs. 3LNO Offshore, CPUE declined by a third from near a time series high in 2013 to a two decade low in 2016. Meanwhile, in Div. 3L Inshore, CPUE was near its highest observed level during 2014-15, but abruptly declined by approximately 40% in 2016 to its lowest level in a decade. In Subdiv. 3Ps, CPUE has steadily declined since 2009 to a record low in 2016, while in Divs. 4R3Pn, following catch rates near historical highs during 2012-14, CPUE has fallen back to relatively low levels in the past two years. Overall, the fishery performed poorly in 2016.

In recent years there have been considerable spatial changes in fishery CPUE (Figure 18). In Divs. 2HJ, the Cartwright and Hawke Channels have become near-exclusively the two areas of fishing activity. In Div. 3K, very few areas have experienced high catch rates. Although high catch rates (>15 kg/trap) remain in many portions of Divs. 3LNO, some areas had notable declines in recent years. For example, catch rates along the Div. 3N slope edge decreased markedly in the past three years and localized aggregations of effort in shallow portions of the western Grand Bank have performed relatively poorly since 2010. In Subdiv. 3Ps, the decline in fishery CPUE has been both precipitous and broad-based since 2010. In Divs. 4R3Pn, catch rates in the offshore have been perpetually low, with all inshore bays having catch rates in the order of 5-15 kg/trap. Overall, the combination of landings, spatial patterns, and catch rates suggest the fishery remains strongest in Div. 3L and virtually all other areas are presently performing poorly.

Observer data indicate that although the improvement in fishery CPUE in Div. 2J in 2015 was predominately the result of an increase in recruitment into the exploitable biomass, the proportion and magnitude of new-shelled crab decreased dramatically in 2016 (Figure 20, Figure 21). The Div. 3K fishery has not benefitted from any large increase in recruitment in recent years, with perpetually low and declining catch rates of new-shelled crab observed since 2008. In Divs. 3LNO Offshore, recruitment and the residual biomass (old-shelled crab) have been slowly eroding for the last two years. In Subdiv. 3Ps, both the recruitment and residual components of the biomass observed in the fishery have decreased by more than half since 2011 and are at historical lows. The sharp reduction in abundance of crab at legal-size in population distributions in Subdiv. 3Ps during the past three years (Figure 21) suggests the population is heavily exploited.

Biomass

The overall exploitable biomass has declined since 2013 to its lowest observed level in 2016 (Figure 22, Figure 23). Trawl surveys indicate that the exploitable biomass was highest at the start of the survey series (1995-98). It declined from 1998 to 2004 and varied without trend until 2013. The exploitable biomass has declined 80% since 2013, with an overall decline of 40% in 2016. It is presently at or near time series lows in all Assessment Divisions (Figure 24).

In Divs. 2HJ, the trawl survey exploitable biomass index (Figure 24) and CPS survey index of total abundance of legal-sized crab (Figure 25) both increased sharply in 2014 and since declined by about half to relatively low levels. In Div. 3K, the trawl and trap biomass indices both declined since 2008 to their lowest observed levels in the past two years. In Divs. 3LNO Offshore, the trawl survey exploitable biomass index, which covers the entire division, has precipitously declined since 2013 to a historic low. Both trawl and trap indices declined by about 50% in 2016. In Div. 3L Inshore, the trap survey(s) exploitable biomass index (Figure 26) changed little from 2004 to 2015, but declined by a third in 2016. In Subdiv. 3Ps, the exploitable biomass index declined by 88% since 2010 to a time series low in 2016. In Div. 4R, the CPS trap survey exploitable biomass index (Figure 27) most recently peaked in 2011 and has since gradually declined.

The restricted spatial coverage of the CPS trap survey essentially measures the exploitable biomass on primary fishing grounds and is an analog of fishery CPUE. It closely agrees with fishery CPUE in each division, reflecting the occupation of like grounds with like gear. The spatially all-encompassing trawl survey generally detects changes in the biomass prior to them being detected in the CPS trap survey (and/or fishery) (Mullowney et al. 2017). This lag effect between measuring signals of change in the biomass likely reflects the inclusion of marginal grounds in the trawl survey. The extended CPUE time series is correlated against the trawl survey biomass indices in forthcoming division-specific analyses of this document and demonstrates the lag effect between the trawl versus trap-based biomass indices.

The exploitable biomass has become highly concentrated into localized areas in all Assessment Divisions (Figure 28, Figure 29). In 2016, the majority of trawl survey tows captured no exploitable crab in Divs. 2HJ, 3K, 3LNO and Subdiv. 3Ps. Fringe areas have been virtually void of exploitable crab in recent years. In Divs. 3LNO, both the trawl (Figure 28, Figure 29) and trap (Figure 14) surveys showed considerable spatial contraction in high catch rates of exploitable crab. Large catches in the trawl surveys were near exclusive to the northern portion of the Grand Bank in 2016 (Figure 28, Figure 29). However, fringe areas in the centre of the bank and along the slope edges were virtually barren of exploitable crab in the survey, contributing to a major decline in the overall exploitable biomass index.

Consistent with the picture depicted by trawl surveys, CPS trap survey catch rates (Figure 14) and fishery CPUE (Figure 18) remain relatively strong along the northern portion of the Grand Bank, but all metrics are now showing signs of declines even in this area. Catches of exploitable crab in virtually all other areas of the stock range within Divs. 2HJ, 3K, and Subdiv. 3Ps are low by all three metrics relative to both historical and recent levels. Clearly, the exploitable biomass of Snow Crab in NL is overall currently very low. With some localized exceptions, the last remaining stronghold of exploitable-sized crab is occurring along the northern Grand Bank in Div. 3L.

Recruitment

Overall recruitment into the exploitable biomass was at its lowest observed level in 2016. This is evident by decreases in the biomass of new-shelled crab in trawl surveys (Figure 30) and reductions in the catch rates of recruits in the CPS trap surveys (Figure 25, Figure 31). In Divs. 2HJ, recruitment was relatively low throughout the 2000s. It spiked to a recent high in 2014, but subsequently decreased to more typical levels in both the trap (Figure 25, Figure 31) and trawl (Figure 30) surveys in the past two years. In Divs. 3K and 3LNO Offshore, recruitment was at or near time series' lows in 2016 (Figure 25, Figure 30, Figure 31). In Div. 3L Inshore, recruitment indices from DFO and CPS trap surveys in all management areas were at or near their lowest levels in 2016 (shown in forthcoming Div. 3L Inshore section), as reflected by the overall abundance of recruits seen in the CPS trap survey (Figure 25, Figure 31). In Subdiv. 3Ps, recruitment declined since 2009 to its lowest observed level in 2016 (Figure 30). No strong inferences can be drawn from the CPS survey in this area because it has been incomplete during the past two years. In Divs. 4R3Pn, overall recruitment most recently peaked in 2012 and has since declined to low levels in all surveyed areas (shown in forthcoming Divs. 4R3Pn section), as reflected by the overall abundance of recruits in the CPS survey (Figure 25, Figure 31). This broad-scale decline of recruitment into the exploitable biomass was anticipated and reflects a lack of productivity in the stock since the early to mid-2000s (Mullowney et al. 2014).

No improvement or further reductions in recruitment into the exploitable biomass are expected in the next 2-3 years because the pre-recruit biomass index for Divs. 2HJ3KLNOPs has been declining since 2009 (Figure 32). In 2016, it was near its lowest observed level overall and in all Assessment Divisions (

Figure 33). This decline in the pre-recruit biomass is broad-scale, with few pre-recruit crab captured anywhere in multi-species trawl surveys in the past three years (Figure 34, Figure 35). To date, the impacts of this declining recruitment have been most evident in the fisheries in Div. 3K and Subdiv. 3Ps, with obvious declines in those fisheries in recent years (i.e. Figure 18). However, impacts are beginning to (and anticipated to continue to) emerge in Divs. 3LNO (Inshore and Offshore), where the bulk of remaining crab reside.

A warming oceanographic regime during the past decade (Colbourne et al. 2016), coupled with relatively low abundance of young crab since the early 2000s (Figure 36), suggests overall weak recruitment in the long term. The relatively small pulse of small crab that emerged in the trawl surveys in 2013-14 was broad-scale throughout Divs. 2J3KL (Figure 37, Figure 38). It remained prominent in Divs. 2J and 3L in 2015 and 2016 and improved again in Divs. 3KN in the 2016 fall survey. Most indications are that the present emergent pulse of small crab is spatially broad-based. A substantial increase in the presence of snow crab in the diets of predatory finfish in most divisions in the past two years (Figure 39) supports this inference, as finfish predation predominately occurs on small Snow Crab below about 40 mm CW (Chabot et al. 2008), although it is recognized an increase in predation also reflects an increased abundance of predators (DFO 2014b; Rose and Rowe, 2015; Pedersen et al. 2017).

Reproduction

The management regime of the NL, and virtually all other commercially harvested Snow Crab stocks, inherently protects the reproductive potential of populations by restricting 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. Although this could theoretically have implications for genetic selection, the strategy of maintaining a residual biomass of largest males, coupled with the ability of sub-legal-sized adolescent and adult males to successfully copulate and breed, appears to be successful in maintaining reproductive potential in this stock.

Reproductive potential is further safeguarded by the ability of mature females to store sperm and produce multiple clutches of eggs from a single mating event (Sainte-Marie 1993). The inherent reproductive resiliency is evident in the index of egg clutches of females from the multi-species trawl surveys. Data from both the fall and spring surveys throughout Divs. 2HJ3KLNO and Subdiv. 3Ps show that in nearly all years the vast majority (i.e. >80%) of mature females are carrying full clutches of viable eggs (Figure 40). This is not to say that insemination rates and per capita fecundity cannot be impacted by fishery exploitation, rather that it has not been consistently observed to date in NL Snow Crab. Indeed, some notable exceptions have occurred in all Assessment Divisions, including low percentages of clutch fullness in successive years in Divs. 2HJ in 2006 and 2007, and recent low levels in Div. 3LNO in 2013 (note uncertainty in 2014 due to incomplete survey) and this past year in Div. 3K. Nonetheless, despite such variability in clutch fullness percentages, the general inference is that stock reproductive potential appears to have been maintained under current management and fishing practices.

The metric of egg clutch fullness may best form the cornerstone to defining ‘serious harm’ to the Snow Crab resource caused by fishing. With no prolonged periods of low clutch fullness, the evidence suggests that under current management practices the species may maintain a high level of reproductive resiliency to fishing. Current prevailing theory is that productivity and recruitment success over the past two decades have been driven more by bottom-up climatic and inter-specific competition factors than top-down fishery or predation impacts (Windle et al. 2012; Dawe et al. 2012b; Mullowney et al. 2014). The scenario of low potential for serious harm induced by fishing to date and productivity being predominately environmentally-driven suggests conventional exploitation rate-based Precautionary Approach (PA) frameworks (DFO 2014a) may not be the most appropriate basis for adopting DFO's policy mandated approach of adopting a fishery decision-making framework incorporating the Precautionary Approach into management of this resource. At present, alternative PA frameworks continue to be pursued for this resource.

Females have tended to be sporadically captured by the survey trawl throughout the time series, which is thought to reflect their small size. This corresponds with a 'trough' in size frequency distributions from the Campelen trawl (Figure 41, Figure 42), and assumed poor catchability. Nonetheless, it is apparent that following an initial high period in the late-1990s, the abundance of mature females has since remained comparatively low in all divisions since (Figure 41, Figure 42). 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 43, Figure 44). However, variability in trawl survey performance is also evident. For example, while the spring trawl survey captured a relatively high abundance of mature females in Div. 3L in 2014, the fall survey did not. 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).

It is unknown to what extent eggs are a limiting factor for overall stock productivity and what effect(s) female abundance has on subsequent recruitment. Interestingly, historically, some of the largest recruitment pulses observed in the stock to date have been born from periods of low mature female abundance. For example, the 20-30 mm CW crab observed in the 2001-2002 surveys would have been approximately 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 (Mullowney et al. 2017). Similarly, the present pulse of small crab of about the same size would have been produced from apparently low mature female abundance levels seen during recent years (i.e. 2011-12). Further research into the effects of female abundance on stock productivity, specifically in relation to environmental impacts such as thermal conditions and spring bloom dynamics, is necessary.

Environment

It is becoming increasingly apparent that bottom temperature acts positively on size and negatively on abundance in regulating stock productivity and ultimately biomass. Low bottom temperatures 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. 2012a). 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 are associated with the production of strong year classes and subsequent strong recruitment (Boudreau et al. 2011; Marcello et al. 2012; Mullowney et al. 2014; Émond et al. 2015).

A lagged thermal habitat index defined as a three-year moving average of bottom temperature from the Station 27 oceanographic monitoring station related negatively to exploitable biomass indices in all major Assessment Divisions (Figure 45). In other regions, such as the Southern Gulf of St. Lawrence, 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 (Figure 46), which is used as a proxy in lieu of small crab abundance from trawl surveys due to poor capture of small crab by the Campelen trawl (Marcello et al. 2012). Differences in time lags across divisions in both the exploitable biomass and CPUE correlations with thermal indices are thought to reflect a longer time necessary for a crab to progress from a small to large animal in cold conditions, with processes such as skip-molting more common in cold conditions. Shorter lags associated with the biomass indices compared to fishery CPUE indices are consistent with lags that normally occur between these indices, as described earlier, with peaks and troughs in the exploitable biomass indices preceding those in fishery based indices.

Ultimately, temperature impacts on snow crab abundance are auto-correlated over time, and temperature affects Snow Crab throughout its various life stages (Figure 47). For example, the strongest correlations between habitat indices and subsequent exploitable biomass are found at lags of about 3-5 years in warmest Divs. 2HJ and 3K. Although this is also the case for Divs. 3LNO, the effect persists longer, with a correlation greater than r^2=0.40 occurring at a time lag of up to 6-8 years later. In Subdiv. 3Ps, where virtually all crab are captured in conditions <0ºC (i.e. Figure 3), the lag of strongest correlation is longest at 5-7 years.

Despite spatiotemporal differences across divisions in the time necessary for temperature to affect future biomass, an overall consistent phenomenon is that cold conditions are beneficial to future biomass. 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 present emergent pulse of small crab observed in many areas of the NL shelf has been associated with generally cooling oceanographic conditions in the past four years (Colbourne et al. 2016), with the areal coverage of cold bottom water increasing in all divisions since 2011-12 (Figure 45, Figure 46).

Although a return to cooler conditions in the past four years is positive because it appears to have promoted the emergence of a pulse of small crab, expectations for the future should be tempered as climatic conditions are still relatively warm (i.e. 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, despite the change in direction in the most recent years. 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 likely originated (Mullowney et al. 2014).

For the immediate future, the thermal habitat index from the Station 27 oceanographic monitoring station suggests further reductions or no improvements are likely to occur in the exploitable biomass in all major Assessment Divisions in the next 2 to 3 years (Figure 45). 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.

Until the past few years, following a regime shift in the late 1980s and early 1990s (Buren et al. 2014) that culminated with the collapse of most of the finfish community, the Snow Crab resource appears to have largely been under bottom-up temperature control. The Snow Crab resource was most productive throughout the 1990s, but productivity diminished with warming over the past decade (Mullowney et al. 2014). However, top-down controls now appear to be becoming more important. Besides exerting a direct impact on early-life survival, a shift toward warmer conditions now appears to be indirectly affecting the Snow Crab resource in the form of increased predation (Figure 39) as temperate finfish populations respond positively to warming. Some recent improvements are now being realized in several important finfish stocks such as the formerly dominant Northern Cod (Rose and Rowe 2015; Pedersen et al. 2017). Indeed, trends in predation mortality suggest that this factor may already be an important driver for Snow Crab in

Southern Newfoundland (Subdiv. 3Ps), and it may become one in other areas in the short to medium term. Predation mortality on Snow Crab has increased since the late-2000s and early-2010s in most divisions (Figure 39), and shows important differences in magnitude across ecosystem units. Southern Newfoundland (Subdiv. 3Ps) has predation levels an order of magnitude higher than other areas. Still, predation mortality in the Grand Bank (Divs. 3LNO) and Newfoundland Shelf (Divs. 2J3K) has coarsely increased five-fold over the last 4-5 years.

Although impacts of increased predation on the fishery in most areas would be expected to be minimal at present, with the Snow Crab resource in decline, increased top-down controls in the forms of predation appear likely to become more important in regulating the resource and consequently impact the fishery in the coming years. If this is the case, the strength of linkages with bottom-up forcing (i.e. temperature) could diminish.

Mortality

Bitter Crab Disease (BCD) has been observed, based on macroscopic observations of crab captured in the fall trawl surveys, at generally low levels throughout Divs. 2J3LNO from 1995 to 2016 (Figure 48). The prevalence and distribution of this parasitic disease 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).

The disease, which is fatal to crab, occurs primarily in new-shelled crab of both sexes and appears to be acquired during molting (Dawe 2002). Although the macroscopic analyses used to classify crab as infected are known to underestimate true prevalence, 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 patterns seen throughout the offshore (personal communication, Earl Dawe).

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 further offshore. BCD has been consistently low in fall trawl surveys in Div. 2J, although two consecutive years of prevalence exceeding 10% have now occurred for 60-75 mm CW crab (Figure 48). BCD is normally most prevalent in Div. 3K. In 2016, the highest prevalence of BCD ever recorded for this division was seen in size classes >76 mm CW. However, it is unknown if this point is anomalous and subsequent years of data are necessary to assess if this is a concern. BCD is normally uncommon in Divs. 3LNO, but a prolonged pulse of relatively high incidence was observed in Div. 3L from approximately 2001 to 2006, most prominent in 40-59 mm CW crab. This likely reflected progression of the recruitment pulse detected in the trawl surveys as 20-30 mm CW crab in 2000-03.

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 particular is positive because it suggests this source of natural mortality is killing fewer crab in most areas of Divs. 2HJ3KLNO than historically. However, it is also negative because it suggests a decreased density or abundance of these crab, representing future fishery prospects. At present, overall, BCD is not thought to be exerting much of a regulatory effect on the NL Snow Crab stock, but its importance could once again increase as the newly emergent recruitment pulses grow into sizes more commonly associated with disease prevalence over the next few years.

Beyond natural sources of mortality such as disease, 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 in the fishery 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 handing practices, specifically in the form of minimal dropping distances and exposure time on deck. However, Grant (2003) showed 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 is unaccounted for. 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 an advised best practice for the NL Snow Crab fishery, particularly in light of a declining biomass.

Discard levels in the fishery are negatively related to the relative strength of the ratio of exploitable to pre-recruit biomass indices (Figure 49). This likely reflects competition for baited traps, with the catchability of less competitive crab (both under-sized and soft-shelled) increasing when the exploitable biomass is relatively low. In 2016, the ratio of the exploitable biomass to pre-recruit crab in the multi-species trawl surveys declined in all Assessment Divisions compared to 2015 ratios. Particular concern is expressed of the current situation in Assessment Divs. 3K and 3Ps, where discard levels are currently quite high at about 25 and 50% in the two divisions respectively. At-sea observer sampling data suggest that the bulk of discards in 3K are comprised of soft-shell crab while the bulk of discards in 3Ps are under-sized old-shelled crab (Figure 50).

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. It became evident during 2010-12 that this protocol, as implemented, is inappropriate and ineffectual in controlling handling mortality. This is largely because of very low observer coverage and the decision to treat unobserved grids as if they were below the threshold. In addition, failure to draw all the inferences possible from moderate-sized samples frequently resulted in failure to invoke the protocol even when it was clear that the level of soft-shelled crab had exceeded the threshold. These shortcomings undermine the intent of the protocol.

Soft-shell incidence has featured relatively prominently in the catch in Divs. 2HJ and 3K in recent years, during a period of generally low and declining recruitment prospects 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 recruitment if and when the situation improves. Further, with expected further declines in the exploitable and pre-recruit biomass, the capture and release of under-sized crab could become more problematic in the forthcoming years, such as appears to be occurring in Subdiv. 3Ps. Measures should be taken to reduce the level of capture and handling on these crab toward safeguarding against declining female insemination rates and promoting serious harm to the resource through fishing.

Pre-recruit fishing mortality rates have been at decadal highs in all divisions within the past few years (Figure 51), suggesting increased wastage of pre-recruits in the fishery. In Div. 2HJ, a high incidence of discarding and a low exploitable: pre-recruit biomass ratio in 2002-04 (Figure 49) was associated with high catch rates of legal-sized soft-shell crab (i.e. immediate pre-recruits) in the fishery (Figure 50) and extremely high levels of pre-recruit mortality (Figure 51). This pattern has somewhat repeated itself in recent years. Catch rates of legal-sized soft-shell crab were relatively high from 2012 to 2014 and 2016 when the exploitable: pre-recruit biomass ratio was low (or undertook a sharp decline in 2016) and the pre-recruit fishing mortality index was relatively high. Similarly, in Div. 3K high levels of soft-shell crab were captured in the fishery in 2004-05, with high levels of discards and pre-recruit mortality during that period, and all indices have been trending in that direction again during the past three years. In Divs. 3LNO and Subdiv. 3Ps, there has been a virtual absence of soft-shell crab and a low level of under-size new-shelled crab in the catch during recent years. Most discards have been under-sized old-shelled crab (Figure 50). Despite this, the pre-recruit fishing mortality index has been moderate to high in both Assessment Divisions, which we interpret to reflect a relatively high level of mortality on the few pre-recruit crab in the population. Further, concern is expressed at the potential to impact reproductive capacity of the stock through high levels of discards on under-sized old-shelled males, assumed to be terminally molted, with few exploitable males in the population in Subdiv. 3Ps.

Trends in fishery-induced mortality on exploitable crab have varied among divisions throughout the time series (Figure 52) and status quo removals would maintain exploitation rate indices above long-term average levels in most Assessment Divisions in 2016. In Divs. 2HJ, the exploitation rate index doubled to 60% in 2016, but remains below historical peaks (Figure 52). Status quo removals in 2017 would increase the exploitation rate index to 67%. Historically, exploitation rates above 50% in the index in Divs. 2HJ have been associated with high levels of soft-shell discards. In Div. 3K, the exploitation rate index was at its second highest level in the time series in 2016. Maintaining current removals would leave the exploitation rate index unchanged in 2017, reflecting slight changes throughout most of the division. In Divs. 3LNO Offshore, the exploitation rate index doubled to 60%, a historic high, in 2016. Status quo removals would double the index to exceptionally high levels. In Div. 3L Inshore, the trap survey-based exploitation rate index increased gradually from 2006 to 2016 to a time series high. Maintaining status quo removals would increase the exploitation rate by 52% in 2017. As a result of a substantial decline in fishing in Subdiv. 3Ps, the exploitation rate index declined by more than half since it peaked in 2013. The impact of maintaining current removals is unknown, as projections are not possible because the survey is conducted in the spring. In Divs. 4R3Pn, the overall exploitation rate index has increased since 2013 in all surveyed areas and status quo removals in 2017 would elevate the exploitation rate index to a new high.

Trends in total mortality in exploitable crab have generally reflected trends in exploitation rates in recent years (Figure 53) and throughout the time series in most divisions. Although total annual mortality rates on exploitable crab have been variable both within and across Assessment Divisions, in 2016 they increased to be at or near time series' highs in all Assessment Divisions except Subdiv. 3Ps where total mortality has decreased to near average levels in the past two years (Figure 53, Figure 54) as fishing has been drastically reduced (Figure 17).

DIVISIONS 2HJ

Fishery

The Divs. 2HJ fishery occurs in offshore regions of central and southern Labrador in CMAs 1 and 2 (Figure 1, Figure 55). 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. The Cartwright and Hawke Channels, the two dominant fishing grounds, extend to depths of up to 750 m, although the fishery tends to avoid the deepest portions of the channels. In relative terms, the Divs. 2HJ fishery is one of the smallest fisheries for Snow Crab in NL (Figure 17). 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 Divs. 2HJ have remained at less than 2,000 t since 2011 (Figure 17, Figure 56). Effort was substantially reduced in 2011 and was at its lowest level during 2013-2015 (Figure 17), reflecting trends in both CMAs (Figure 56). Although there was a modest increase in effort in 2016, it remained below historical norms. 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 56). Although poor fishing in the area is a contributing factor (Figure 18), 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 Divs. 2HJ have historically been low relative to other divisions (Mullowney et al. 2017). In 2014, less than half the logbooks from fishing trips were accounted for in the logbook dataset, but the situation improved in 2015 with 65% of the logbook data available for the assessment. In 2016, a total of 58% of the logbooks were accounted for in the dataset, with the offshore fleet having 77% of the logbooks available and the inshore fleet just 39% (Figure 5). Incomplete datasets create uncertainty in calculating and interpreting logbook CPUE. Adding to uncertainty in assessing fishery performance in this Assessment Division is that the catch rate index derived from the typically incomplete logbook dataset is deemed the most reliable because observer coverage is routinely low (Figure 12).

CPUE increased steadily from 2011 to 2015, but decreased throughout the division in 2016 to a relatively low level (Figure 19), and no improvements are anticipated in 2017. In both CMAs, catch rates were approximately 6-7 kg/trap in 2016 (Figure 57), 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 (Figure 58). This reflects depletion of the resource. The typical seasonal depletion pattern occurred in both CMAs in 2016. Initial catch rates in the northern CMA in 2016 were relatively low (~9 kg/trap) compared to start-of-season levels in the preceding two years, but end-of season catch rates were near average. The near identical level of the late season catch rates in 2015 compared to the beginning of season catch rates in 2016 suggests minimal recruitment into the fishery here. In contrast, the biomass available to the fishery seemed to benefit from recruitment in the southern management area, with the fishery following the usual pattern of early season catch rates being substantially higher than late season catch rates from the preceding season.

Spatially, there has been a marked reduction in the areal coverage of the fishery since 2011 (Figure 18). 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. Along with reflecting resource shortages, the abandonment of northernmost fishing grounds also partially reflects 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 (Figure 59). This can be seen by an increase in abundance of soft- and new-shelled legal-sized crab during those periods coupled with subsequent advancement to old-shell ages for most crab in the population such as seen in 2016. 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.

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. Weekly levels of soft-shell in the catch typically exceeded 20% after about week 12 (i.e. late June) during those years (Figure 60). However, minimal interference has occurred in the past two years.

Despite abrupt annual fluctuations, the pre-recruit fishing mortality index in Divs. 2HJ has been increasing since 2005 (Figure 51). The abrupt fluctuations ultimately reflect variability in the pre-recruit biomass index (Figure 33), while the long-term increasing trend reflects a relatively low and overall declining level of pre-recruits in the population (Figure 33). For exploitable crab, total mortality was at its highest observed level in 2016 (Figure 53, Figure 54). The trend in total mortality has reflected that of fishing mortality in recent years. While below historic peaks, the exploitation rate index doubled to 60% in 2016 (Figure 52). Historically, exploitation rates above 50% are associated with high levels of soft-shell discards in this region. Status quo removals in 2017 would increase the exploitation rate index to 67%.

All inferences from fishery data are that caution is warranted in the 2017 fishery.

Surveys

The trawl and CPS trap survey-based exploitable biomass indices both increased sharply in 2014 and since declined by about half to relatively low levels (Figure 61). The trawl index returned to a low level in 2015 while the CPS trap survey biomass index declined significantly in 2016. This delayed signal in the CPS trap survey relative to the trawl index is expected given the spatial characteristics of the two surveys, as described above. It also suggests the biomass is declining on the primary fishing grounds of the Cartwright and Hawke Channels where the CPS survey targets. Notably, the trawl survey has captured very few exploitable crab outside the Cartwright and Hawke Channels during the past decade (Figure 28).

Recruitment was low throughout the 2000s relative to the high levels of the late-1990s. It spiked to a recent high in 2014, but subsequently decreased to more typical levels in both the trap and trawl surveys in 2015 and 2016 (Figure 25, Figure 30). The CPS survey trend only incorporates data from CMA 2JS (Figure 62, Figure 63). Interestingly however, the high level of recruitment seen in the CPS survey in the southern area in 2014 was preceded by a high level of recruitment into the biomass in the northern area during 2013, as seen in the Torngat survey of CMA 1 (2JN) (Figure 63).

Short-term recruitment prospects appear poor. 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 in 2015 and 2016 (Figure 33). 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 64). 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.

Beyond short-term prospects, long-term recruitment prospects appear to have improved during the past four years. The abundance of small crab (<50 mm CW) in the population is higher than it has been for roughly a decade (Figure 36). 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 37). During the 2016 fall trawl survey, notable catches of small crab were widely distributed compared to previous years. With a mode of 16-21 mm CW in 2016 (Figure 65), these crab would be expected to be 2-3 years old (i.e. Sainte-Marie et al. 1995). However, the 2013-14 distributions infer there could be a year-class or two in front of these not visible in the 2015-16 size distribution, with the Campelen trawl poorly capturing sizes of about 30-75 mm CW. If these small crab survive and progress through sizes at rates similar to historically seen, they would be expected to begin to contribute the fishery in about 2019-20. The persistently low signal of small crab in the survey trawl prior to 2012 suggests no improvements are likely before the most recent emergent mode of small crab contributes to the fishery.

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 in 2015 and 2016. The exploitable biomass has been strongly correlated with fishery CPUE at a one year lag for two decades (r^2=0.76) (Figure 66). If this pattern holds, the fishery performance would be expected to remain similar or decline in 2017. Consistent with this, lagged correlations of the thermal habitat index with the exploitable biomass (r^2=0.70) and fishery CPUE (r^2=0.49) suggest no improvement or further deterioration in the biomass and fishery in the coming year or two (Figure 45, Figure 46). If all factors remain equal, short-term prospects appear poor but modest improvements in the exploitable biomass might be expected to occur in 2019-20.

DIVISION 3K

Fishery

The Div. 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, Figure 67). Within the Assessment Division there are six CMAs. 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). White Bay (CMA 3B) is a deep (i.e. 400-500 m) fjord protected at the mouth by a shallow sill (i.e. 200-300 m) that forms the basis of a relatively discrete pocket of fishing effort. There are two distinct pockets of effort in CMA 3A, one concentrated near the mouth of White Bay in the south and another in an easterly extension of the management area that stretches into the offshore at depths of approximately 200-300 m. Finally, CMA 3BC is relatively shallow (i.e. 200-300 m) and bathymetric features are similar to the offshore and southern portions of CMA 3A. Effort within CMA 3BC essentially forms a western extension of the offshore fishery.

Overall landings in the division declined by 63% since 2008 to 5,600 t in 2016, their lowest level in two decades (Figure 17, Figure 68). Meanwhile, effort has been near its lowest level for the past four years (Figure 17, Figure 68). These overall trends reflect patterns in the offshore (CMA 4) and CMA 3D, the two largest CMAs in terms of fishery scale. In these two dominant areas, TACs, landings, and effort levels are all at or near their lowest levels in a decade (Figure 68). In 2016, the fisheries in CMAs 3A, 3C, and 3BC also had reductions in TACs and landings, but there was little change in effort in 3A and 3BC. In CMA 3B, the fishery data of TAC, landings, and effort have changed little during the past decade, with the exception of a low percentage of the TAC being harvested in 2010 (Figure 68).

Overall CPUE declined by 55% from 2008 to 2011 and has since changed little (Figure 19), remaining near a historic low and reflecting trends throughout most of the division. An exception to the recent overall trend occurs in CMA 3B where CPUE has remained relatively high in most recent years (Figure 17, Figure 68). 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 to be at or near historical lows in 2016. The quasi-cyclical 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 division in recent years. In 2016, the fishery CPUE declined throughout the season in CMAs (Figure 70), reflecting resource depletion. This depletion was most pronounced in CMAs 3A, 3BC, and 4 where late season catch rates were below 2 kg/trap. However, no depletion was evident in CMA 3C in 2016 and late season catch rates in CMA 3D were the highest if the five year time series. Particularly concerning is CMAs 3A and 3BC where the initial catch rates in 2016 were the same or lower than the late season catch rates in 2015, suggesting a lack of recruitment to replenish the exploitable biomass and support the fishery in those areas in 2016.

Observer sampling during the fishery shows the population of crab in White Bay (CMA 3B) to be consistently dominated by old-shelled animals, inferring a relatively strong residual biomass and a relatively low exploitation rate (Figure 71). However, these observer data are not deemed fully reliable due to subjectivity in shell condition assessment. Observers in this area were re-trained on shell condition classification following the 2012 fishery. Subsequently, a high proportion of new-shelled animals was recorded in the catch in 2013. Since that point, the high contribution of new-shelled animals in the size frequency distribution has given way to a population dominated by old-shell animals, consistent with the arrival and progression of a recruitment pulse into the fishery that now persists as residual crab in the exploitable biomass. This scenario is supported by trends in CPUE, which peaked in 2013 and has since declined (Figure 69). Chronologically, the emergence of this recruitment pulse into the 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. Only half the TAC was subscribed in that year (Figure 68), catch rates were atypically low (Figure 69), and the early closure was initiated by harvesters. Such proactive action appears to have benefitted the White Bay fishery in recent years, with catch rates in this area higher than most other portions of the division for the past five years (Figure 69). However, as seen in an eroding size frequency distribution, benefits gleaned from that recruitment event now appear to be fading.

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 eight consecutive years (Figure 71). Fishery catch rates here are consistently among the lowest in the division, 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 2016, coincident with an increase in catch rates (Figure 69, Figure 70). A modest 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 an increased level of recently molted soft-shell crab was observed in the population (Figure 71). This improving situation in the exploitable biomass began a couple years ago. From about 2008-13 the overall magnitude of catch rates of most sizes of crab showed a steady decline as the size frequency distribution became platykurtic (Figure 71). However, beginning in about 2014 a notable change in shape of the observed population occurred, as the primary size mode became centered 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 2016 (Figure 69) and will likely support a strong fishery in 2017 relative to most recent years.

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. 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 (Figure 69). This is consistent with persistently declining fishery catch rates, particularly in the dominant offshore management area (Figure 69).

Soft-shell crab incidence in the catch has been an on-going issue for the past decade in Div. 3K (Figure 72). The bulk of discards in this division are attributable to soft-shell crab (Figure 50). 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. By extension, the depleted residual biomass is thought to reflect a relatively high level of fishery exploitation. Trap survey-based exploitation rate indices have been unchanged or increasing since 2013 in all CMAs (Figure 73). Under a scenario of increasing exploitation rates, soft-shell crab incidence in the fishery would not be expected to become reduced. An exception to increasing exploitation rates from 2013-16 is CMA 3C, where exploitation rates have been near-constant and about the lowest in the time series. However, this level of exploitation appears to be high, as inferred from the strong ‘knife-edge’ effect that characterizes size frequency distributions (Figure 71) and perpetually low CPUE (Figure 70).

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. The pre-recruit fishing mortality index increased since 2007 to a decadal high in 2016 (Figure 51), closely reflecting the exploitation rate index (Figure 52) in pattern. The exploitation rate index was at its second highest level in the time series in 2016 and maintaining current removals would leave the overall exploitation rate index unchanged in 2017, reflecting slight changes throughout most of the division (Figure 73). However, the exploitation rate index in White Bay (CMA 3B) would double to a historical high (Figure 73).

Most inferences from fishery data are that despite seven consecutive years of TAC reductions, overall, the resource in Div. 3K continues to deteriorate and top-down fishery effects are contributing to a lack of recovery. Although a prolonged period of climate-induced low productivity is considered an underlying reason for the lack of recovery in the Div. 3K Snow Crab resource (Mullowney et al. 2014), there is little management or industry can do to control it, with the fishery being the only controllable variable. An aim of maximizing fishing efficiency is advised. This entails reducing wastage by minimizing discards to promote some recovery of the exploitable biomass. At present, nearly all fishery data are suggesting wastage will likely remain high and potential improvements such as in CMAs 3C and 3D are likely to be modest under current levels of fishery exploitation.

Surveys

The post-season trawl and trap survey exploitable biomass indices have both declined since 2008 to their lowest observed levels during the past two years (Figure 24, Figure 74). Similar to Div. 2J, exploitable males in Div. 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 CPS trap survey shows that the exploitable biomass decreased substantially in all management areas in 2009 and has declined gradually, to its overall lowest observed level in 2016 (Figure 74). The catch rate of exploitable crab from the CPS trap survey was also near a time series low in 2016 (Figure 25), reflecting catch rates at or near time series lows in CMAs 3B, 3BC, 3D, and 4 (Figure 75). The improvement in catch rate in CMA 3C (Green Bay) in 2016, which contributes little to the overall biomass, is the only increasing point in any CMA in the past three years.

Recruitment is at or near time series' lows throughout the division (Figure 25, Figure 30). Catch rates of recruits in the CPS trap survey in 2016 were at or near their lowest observed levels (<5 kg/trap) in all but CMA 3C (Figure 75). Like the overall biomass, this 2016 point estimate in CMA 3C is the only increasing point in any CMA during the past three years.

Trends in the CPS trap survey are generally consistent with those seen in the depth-stratified DFO trap surveys (Figure 76). In White Bay (CMA 3B), the biomass was exceptionally high and at a historical peak in 2012, but has since declined to be at or near its lowest level in all depth strata (Figure 76). Meanwhile, an improvement was seen in the deep stratum in Notre Dame Bay (CMA 3D) in 2016. This improvement was similarly seen in the CPS survey, but detected in CMA 3C (Green Bay). Such inconsistencies highlight deficiencies of the Crab Management Area boundaries in this area. The DFO survey treats the entirety of Notre Dame and Green Bays as a single unit that more closely conforms with the bathymetry, recognizing that both the shallow and deep strata extend across the CMA line (Figure 13). Fishery data further demonstrate the tight connectivity of these two CMAs, both with each other and adjacent CMAs, with CPUE trends closely mirroring one another for over two decades (Figure 69).

Size frequency distributions from both the CPS trap (Figure 77) and multi-species trawl (Figure 78) surveys show low levels of adolescent pre-recruit-sized males and a consistently depleting exploitable biomass since approximately 2008. However, slight improvements were noted in these pre-recruit-sized crab in the trap surveys in CMAs 3BC and 3C in 2016 (Figure 77), as well as in the more spatially all-encompassing trawl survey (Figure 78). Notwithstanding minor improvements in 2016, the prolonged diminishing signal of pre-recruit-sized crab in the population reflects low resource productivity. The trawl survey has captured very few small crab in most years since 2001, especially from about 2009-15. It is most likely that the high level of small crab abundance (i.e. <30 mm CW) from 2000-02 burgeoned into the most recent level of high exploitable biomass in 2007-08 (Figure 24, Figure 25). Accordingly, there has now been a relatively low level of stock productivity for over a decade.

With some exceptions, small-mesh trap data from the CPS and DFO trap surveys throughout the division highlight the relatively low level of productivity experienced over the past decade. For example, highest abundances of sub-legal-sized adolescent crab in the CPS survey were seen in 2006, and very few crab in that area have since progressed through sizes into large adolescent crab, with the majority terminally molting as small adults (Figure 79). Similarly, highest levels of pre-recruits in offshore areas (CMAs 3A, 3BC, 4) in the CPS survey occurred in 2005. There are concerns about both the limited number of small-mesh traps as well as their spatial distribution in the CPS survey, which compromises their capacity to form representative indices of the population. Nonetheless, the suggestion of a small emergent mode of adolescent males ranging from about 40-65 mm CW in 2015 and 75-95 mm in 2016 is consistent with a small increase in pre-recruits in the trawl survey in 2016. From the DFO trap surveys, small-mesh traps 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 (Figure 80). 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 2012-2014 (Figure 76). 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 this area will decline further in the next couple of years. In Green and Notre Dame Bays, the surveys suggest few crab in the shallow stratum have grown to large sizes in recent years, with the vast majority terminally molting at small sizes. Nonetheless, consistent with the trawl and CPS small-mesh trap data, a small signal of adolescent crab has progressed from about 65-80 mm CW in 2014 to approach or be at legal-size in 2016 (Figure 81).

Overall, recruitment is expected to remain low in the short term because trawl (Figure 33) and trap (Figure 82) pre-recruit indices are near historical lows throughout the division. The decline in survey catch rates of pre-recruits has been widespread throughout the division since about 2009 (Figure 82). However, in 2016, modest improvements in pre-recruit catch rates were observed in CMA 4 (Figure 82). In extension of the survey data, the thermal habitat indices suggests further deterioration of recruitment potential over the next year or two (Figure 45, Figure 46) before some recovery of the biomass might occur, other factors remaining equal.

Toward potential improvements in the biomass beginning in about 2019 or 2020, a relatively high abundance of small crab (<50 mm) was captured in the 2014 trawl survey relative to preceding years (Figure 36, Figure 78), and in 2016, another smaller spike in small crab abundance occurred. Coincidentally, the DFO trap survey in White Bay captured a pulse of crab centered at about 47 mm CW in the shallow stratum at the mouth of the bay in 2015 (Figure 80). Collectively, these surveys provide evidence to suggest some increased long-term recruitment prospects for the exploitable biomass and fishery.

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 615 of White Bay in 2005 through stratum 614 in 2006 and finally into deepest stratum 613 in 2007 (Figure 83) reflected the high abundance of crab in the pseudo-cohort of adolescents ranging from about 45-75 mm CW (Figure 80). This led to the record high exploitable biomass in 2012 that persisted until about 2014 (Figure 76). The previous ‘cycle’ of BCD in White Bay from 1996 to 1999 preceded the relatively high exploitable biomass experienced from about 2002-07 (Figure 76). The present ‘cycle’ of BCD in White Bay is consistent with improved forthcoming recruitment prospects for the fishery. Similarly, in Green and Notre Dame Bays the ‘cycles’ of BCD (Figure 83) and crab biomass (Figure 76) have historically been out of phase by about 2-4 years, with presently increasing levels of BCD in the population inferring improved recruitment forthcoming into the fishery.

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 is being subjected to much higher levels of top-down predation pressure (Figure 39).

Like Div. 2J, small crab in Div. 3K (i.e. <50 mm CW) tend to aggregate in shallow waters near shore, as well as on top or along the perimeter of offshore banks (Figure 37). The present pulse of small crab appears relatively broad-based throughout Divs. 2J, 3K, and 3L (Figure 37, Figure 38), with the near absence of small crab in the Div. 3K survey in 2015 deemed anomalous (Figure 37).

Caution is encouraged in making decisions on the resource at the CMA level in this division. Most information presented herein shows that broad-scale resource trends are consistent throughout most of the division. 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. For example, the shallow waters of Green Bay could serve to source recruitment into the deeper adjacent channels of Notre Dame Bay and the offshore, and the impacts of excessive fishing in that area (i.e. Figure 71, Figure 77) could reach well beyond CMA 3C borders. Spatial segregation by size is evident in Snow Crab populations in the northern portions of the NL shelf, including Div. 3K (Dawe and Colbourne 2002). Large-scale ontogenetic migrations are known to occur in the Eastern Bering Sea (McBride 1982; Orensanz et al. 2004; Ernst et al. 2005), where crab undertake down-slope movements over the course of life such as seen in White Bay (Figure 80). In the case of the Eastern Bering Sea, these movements follow warm temperature fields (Orensanz et al. 2004; Ernst et al. 2005; Parada et al. 2010), which is also consistent with the physical attributes of Div. 3K whereby deeper waters are warmer (Figure 3). Basic tenets of species biology including larval drift and post-settlement movement dynamics do not seem to conform to the small scale CMAs in this Assessment Division, and indeed all divisions along the NL Shelf. Although further efforts to understand the connectivity of resource components both within Div. 3K and across all divisions are necessary, at-present, management and industry are encouraged to consider broad-scale trends in decision making processes.

Finally, regarding immediate prospects for the fishery of 2017; assuming the strong correlation (r^2=0.67) of fishery CPUE with the trawl survey exploitable biomass index established over the past twenty years holds (Figure 84), little change is expected in the 2017 fishery in Div. 3K as a whole.

DIVISIONS 3LNO OFFSHORE

Fishery

The Divs. 3LNO Offshore fishery occurs on and surrounding the Grand Bank off Newfoundland’s southeast coast (Figure 1, Figure 85). 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). Like other Assessment Divisions, 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 further extends east in a thin band along the northern Grand Bank from the MSex to 3L200 (Figure 18). 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, from 30% of the total in 1998 to 60% in 2016. Overall, landings increased gradually since 2009 to a historic high of 28,750 t in 2015 (Figure 17). In 2016, landings decreased slightly to 24,500 t. Landings in CMAs NS, MS, MSex, and 3Lex have remained relatively stable at or near historic highs since 2009 (Figure 86). There were small declines in the landings in CMA 3L200 and 8B in 2016 (Figure 86), but the most substantial decline in landings was observed in CMA 3N200 where they decreased by more than a third in 2016. This decline coincided with a time series high in effort.

Since the late 1990s there have been an estimated 1.2-2.4 million trap hauls per annum on the Grand Bank (Figure 17). Effort in this Assessment Division has steadily increased since 2013 to reach a historic high in 2016 (Figure 17). The recent increases in effort are reflected in all CMAs, except MSex and 8B (Figure 86). The effort in CMA MSex has remained steady at approximately 175,000 traps for the last five years. Effort in CMA 8B dropped substantially in 2015 and remained near average in 2016. The TAC has not been taken in CMA 8B in six of the past seven years.

CPUE declined by a third from near a time series' high in 2013 to a two decade low in 2016 (Figure 19). With the exception of CMA MSex, substantial declines have occurred in all CMAs in recent years (Figure 87). Catch rates have sharply declined to near historical lows (~5 kg/trap) in CMAs 3L200 and 3N200. Meanwhile, CPUE in MSex has remained near or at historical highs of >20 kg/trap (Figure 87). Spatially, the fishery data are reflecting a situation where fishing remains relatively strong along the 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 18). Reductions in fishery strength are also evident in CMA NS. More generally, the fishery along the northern portion of the Grand Bank in Div. 3L is one of the few areas yet to be impacted by a broad scale decline in productivity and recruitment in the NL Snow Crab stock (Mullowney et al. 2016).

There has been no evidence of resource depletion from the fishery near the middle of the northern Grand Bank (CMA 3Lex) in the past five years (Figure 88). Catch rates in the order of 18-25 kg/trap have been maintained throughout the fishing seasons. Meanwhile, a pattern of annual stepwise decreases in CPUE has occurred in CMAs 3L200, 3N200, and 8B in recent years, with little evidence of declining CPUE throughout each season but fisheries have performed successively poorer throughout each of the past four (3L200, 3N200) or five (8B) years (Figure 88). In 2016, CPUE in CMAs 3Lex, MS, and NS also declined compared to previous years, but no substantial intra-year decline in CPUE was observed.

Size distributions from at-sea sampling by observers reflected a primary mode at a large size of 110 mm CW in 2006-07 (Figure 21). The population was predominately comprised of old-shelled crab. However, the shape, magnitude, and shell composition of the population distribution changed considerably from 2008-14. 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 for new-shelled crab, and the primary mode returned to 115 mm CW in 2016. These observer data clearly depict a prolonged period of strong recruitment contributing to the exploitable biomass from about 2008-12 and subsequently a resource not being renewed at a high rate and gradually being eroded. Accordingly, the renewal rate and magnitude of the exploitable biomass is expected to decline further in the forthcoming years as gains from the strong recruitment period dissipate. These size frequency distributions highlight a population dominated by old-shelled crab in virtually all areas of the Grand Bank (Figure 89, Figure 90). While the overall magnitude of the population remains relatively high in most CMAs, extremely low catch rates of both old- and new-shelled crab in CMAs 3L200 and 3N200 have occurred in the past two years.

The percentage of the catch discarded in the past four years has been low (≤10%) (Figure 49). This depicts declining recruitment prospects and reflects a near absence of soft-shelled and under-sized new-shelled crab in the catch (Figure 50); the two components of the population that contribute to immediate recruitment into the fishery. The fishery in Divs. 3LNO Offshore is generally very efficient at extracting the resource, with soft-shelled crab incidence rarely a major concern (Figure 50, Figure 91). This has been especially clear in the past four years, with virtually no soft-shell in the observed catch (Figure 91). Comparatively, any reductions of recruitment into the exploitable biomass here are less prone to top-down fishery effects than in most other divisions and more clearly reflect bottom-up productivity factors. It is noteworthy that even in the latest stages of the fisheries of the past four years, soft-shell crab incidence did not approach 15% as it did from 2010-12. This further implies that the recent prolonged recruitment pulse has now near-fully contributed to the exploitable biomass and that recruitment prospects have substantially diminished.

The pre-recruit fishing mortality index has been at or near the time series' high in the past two years (Figure51) and the exploitation rate index doubled to 60%, a historic high, in 2016 (Figure 52). Status quo removals would double the index again in 2017, with increases occurring in all management areas (Figure 92). CMAs 3L200, MS, and NS would have particularly high exploitation rates that would more than double under status quo removals (Figure 92).

Surveys

The trawl survey exploitable biomass index, which covers the entire Assessment Division, has precipitously declined since 2013 to a historic low (Figure 24). Both trawl and trap indices declined by about 50% in 2016 (Figure 93), with the CPS trap survey index declining between 27-74% in the various management areas (Figure 93). All surveyed management areas, with the exception of MSex, were at or near historical lows for exploitable biomass in 2016. All CMAs, again with the exception of MSex, exhibited declines and/or near historical catch rates of residual crab (old-shelled, legal-sized crab) in 2016 (Figure 94). Particularly dramatic declines in catch rates were observed 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 14, Figure 28, Figure 29). The trawl survey index of exploitable biomass shows the resource has become increasingly localized into portions of Div. 3L (Figure 28); the majority of survey trawls in 3N and 3O caught no exploitable crab for the last three 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 14). The CPS trap survey, which does not cover fringe and marginal areas and intensively targets the MS and particularly the MSex management areas (Figure 14), where fishery catch rates are the highest in the Province (Figure 18), is now beginning to show the declines in exploitable biomass that were noted in the trawl survey two years ago. The spatial differences in coverage of the two surveys largely account for the delayed signal in the trend of exploitable biomass indices derived from the two surveys and highlight deficiencies in the CPS survey design with respect to its ability to detect changes in the resource. Nevertheless, the recorded spatial contraction and reduced biomass index reflected in the CPS trap survey indicate that prime fishing grounds in Divs. 3LNO are now experiencing declines in exploitable biomass.

Overall recruitment was at a historic low in 2016, reflecting low levels throughout most of the Assessment Division (Figure 94). The multi-species trawl survey in 2016 recorded a historic low in biomass of new-shelled exploitable crab (Figure 30). CMA 3Lex was the only management area with recruit catch rates from the CPS trap survey not near or at historical lows (Figure 94). All other CMAs recorded catch rates <5 kg/trap. Extremely low catch rates of new-shelled crab are evident throughout almost every CMA in the large-mesh traps of the CPS survey, however the proportion of the catch represented by new-shelled crab is increasing in CMAs NS, 3Lex, and 8B (Figure 95). Moreover, the size frequency distributions indicate that the pulse of recruitment that has recently benefitted CMA MSex has now fully made its contribution to the exploitable biomass. This is evident by the advancement of the primary mode from 95 mm CW in 2012 to 115 mm CW in 2016 and an increasing proportion of old-shelled crab in the population (Figure 95). Collectively, low catch rates of both recruits and residuals in most CMAs indicate an overall depleted resource and a population of crab on the Grand Bank suffering from a lack of renewal.

Recruitment prospects are very poor. The trawl survey pre-recruit biomass index has steadily declined since 2009 and has been at its lowest level for the past three years (Figure 33). The decline in pre-recruit crab is widespread, with a steadily depreciating signal of catches of all magnitudes in the trawl survey throughout the division since 2009 to a nearly barren state in

2015 and 2016 (Figure 34, Figure 35). Relative to the 1995-2005 period, few small crab have been captured by the trawl survey during the past decade (Figure 96). The strong pulse of pre-recruits observed in the survey from 2008-10 (Figure 33) most likely emerged from the relatively strong pulse of small crab captured during 2001-03 (Figure 36). 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 the Divs. 3LNO Offshore exploitable biomass will decline further in the forthcoming years.

Small-mesh traps in the CPS trap survey tracked the most recent recruitment pulse into the exploitable biomass in the MSex CMA from 2006-13 (Figure 97, Figure 98). These traps indicate that despite a strong inference of a widespread decline in recruitment in the next few years, a pulse of approaching recruits centered at about 70 mm CW in 2016 (Figure 97) should benefit CMA 8B in the near future. The leading tail of this pulse was expected to begin contributing to the pre-recruit biomass index (i.e. >75 mm CW adolescents) in 2016 and an increase in the pre-recruit biomass was observed in 8B during 2016 (Figure 98). Small-mesh traps deployed in CMA NS and MSex are consistent with the broader-scale trawl survey pre-recruit index that shows poor recruitment prospects during the next few years and few adolescent males in the population.

Management and industry are advised to carefully consider the rate at which crab are extracted from this Assessment Division throughout the next few years. Despite the fishery currently performing at a high level in some northern portions of the Grand Bank, all available information suggests recruitment into the exploitable biomass has been low in recent years, short-term recruitment prospects are poor, and the exploitable biomass and fishery CPUE are declining with further declines expected in the forthcoming years. An anticipated decline of the Snow Crab resource on the Grand Bank will have a large impact on the overall biomass available to the NL Snow Crab fishery. Assuming the long-term relationship between the lagged exploitable biomass index and fishery CPUE holds (Figure 99), 2017 is likely to be the poorest performing fishery in this area in the past two decades.

DIVISION 3L INSHORE

Fishery

The Div. 3L Inshore fishery occurs in coastal bays and near-shore regions within 25 nm of headlands off the east coast of Newfoundland (Figure 1, Figure 100). 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 feature deep holes in their central interior portions. Bonavista and Trinity Bays are open at their mouths, thus the deep water inner portions are continuous with the offshore bathymetry. In contrast, Conception and particularly St. Mary's Bays feature shallow sills at their mouths. The bathymetry in the areas east of the Avalon Peninsula encompassing CMAs 6C and 8A is dominated by the Avalon Channel, a deep-water trough through which the southerly flowing cold inner branch of the Labrador Current passes. Overall, the bottom water here is cold (Figure 3) and most of the area is characterized by productive Snow Crab grounds.

Overall, landings in Div. 3L Inshore increased throughout the 2000s and have remained at approximately 8,000 t since 2013 (Figure 17). In 2016, landings in CMAs 6A, 6B, and 6C remained relatively consistent in comparison to recent years (Figure 101). However, landings declined in CMAs 5A, 8A, and 9A. Effort had oscillated without trend from 2005-2015 but increased by 40% in 2016 to a time series' high (Figure 17). The 2016 spike in effort was observed in all CMAs, except 9A, where a gradual increase in effort has been occurring since 2001 (Figure 101).

Overall CPUE was near its highest observed level during 2014-15 but abruptly declined by about 40% in 2016 to its lowest level in a decade (Figure 19). This reflected declines in every management area ranging from 20-48% (Figure 102). Particularly large declines in fishery CPUE were observed in Conception Bay (CMA 6B) and the Northeast Avalon (CMA 6C). In Bonavista Bay (CMA 5A), fishery CPUE was at historical lows.

Depletion of the resource during the 2016 fishery was evident in all areas except Trinity (CMA 6A) and Conception (CMA 6B) Bays (Figure 103). In Bonavista Bay (CMA 5A), fishery CPUE declined throughout the season to end at an all-time low (<5 kg/trap). In Trinity Bay, CPUE was consistently near 10 kg/trap throughout much of the season. Although there was not a dramatic decline in CPUE throughout the season, this represents a fairly low CPUE for this CMA when compared to historical levels. Similarly, fishery CPUE in Conception Bay remained consistent throughout the season, but at a lower level than most previous years. In CMA 6C, the fishery CPUE generally declined throughout the season to a time-series low (≤10 kg/trap). In CMA 8A, there was strong indications of depletion of the resource by the fishery with a notable drop in CPUE early in the fishery. In St. Mary's Bay (CMA 9A) there was a relatively short fishing season, but a small decline in CPUE was noted and in general CPUE was at recent lows.

In-season data from observer sampling indicate that catches consisted almost exclusively of old-shelled crab of legal size, with extremely low incidence of new-shelled crab. New-shelled crab were virtually absent in Conception Bay (CMA 6B) and CMA 6C (Figure 104). In the absence of a large recruitment event in 2017, these data suggest dissipating abundance in the exploitable biomass in the near future.

The overall trap survey-based exploitation rate index increased gradually from 2006-16 to a time series' high (Figure 52). Maintaining status quo removals would increase the exploitation rate by 52% in 2017. This reflects projected increases in all management areas, which would each remain near or achieve new time series' highs (Figure 105). Bonavista Bay (CMA 5A) and Trinity Bay (CMA 6A) would reach the highest exploitation rates in the division with values of almost 80% (Figure 105).

Surveys

The CPS trap survey exploitable biomass index changed little from 2004 to 2015, but declined by a third in 2016. This reflected decreases ranging from 12 to 46% in the various CMAs (Figure 26). Each CMA was at its lowest level of exploitable biomass recorded in the time series.

The declining biomass is largely a result of declining recruitment. Overall recruitment into the exploitable biomass has steadily declined since 2010 to a time-series low (Figure 25). Recruitment indices from DFO and CPS trap surveys in all management areas were at or near their lowest levels in 2016 (Figure 106, Figure 107, Figure 108). 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 106). The index has remained at that lower level since and was <5 kg/trap in 2016. The DFO survey similarly tracked this decline in recruitment in Bonavista Bay and showed minor signs of improvement in recruitment in the deep strata (184-366 m) in 2016 (Figure 107). In Trinity Bay (CMA 6A), recruitment has been variable throughout the time series, but the CPS survey showed the abundance of new-shelled legal-sized crab plummeted in 2015 to approximately 1 kg/trap and remained at that level in 2016 (Figure 106). This drop in recruitment in 2015 was reflected in the DFO trap surveys within the shallow (93-183 m) and deep strata (367-549 m) (Figure 107). In Conception Bay (CMA 6B), catch rates of legal-sized new-shelled crab were at a time series low (1 kg/trap) in 2016

(Figure 106, Figure 108), but both surveys showed the overall biomass remains at or above the long-term average level. 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 106). Although this steady state remained in CMA 8A in 2016, catch rates of recruits declined to a time series low in CMA 6C. St. Mary's Bay (CMA 9A) has been experiencing a prolonged and steady decline in catch rates of recruits since 2010 and both surveys showed the index of new-shelled legal-sized crab was at a time series low in 2016 (Figure 106, Figure 108). Meanwhile, the consistent low level of recruits is beginning to be reflected in the catch of old-shelled crab, which exhibited declining trends within the last year or two in all surveys in all management areas. This can be seen in size frequency distributions from large-mesh traps in the CPS surveys, with the abundance of legal-sized crab eroding in all areas in recent years (Figure 109).

Small-mesh trap size frequency distributions from CPS and DFO surveys throughout the division suggest very poor short-term recruitment prospects in most management areas, except Bonavista Bay (CMA 5A) (Figures 110-114). With the exception of Bonavista Bay, virtually no adolescent crab larger than 75 mm CW were captured anywhere in either 2015 or 2016. In Bonavista Bay, a pulse of adolescent males has been detected in the deep strata (275-366 m) for the last two years (Figure 111). These trends are consistent with the large-mesh CPS survey results in 2016 that showed extremely low catch rates of new-shelled individuals in every management area, except Bonavista Bay (Figure 106, Figure 107). However, the sharp 'knife-edge' appearance at legal-size in the size frequency distributions in Bonavista Bay is suggestive of a high exploitation rate by the fishery (Figure 109). If high exploitation persists in 2017, there is concern that a high level of soft-shell incidence could be an issue in the fishery.

Recruitment is expected to remain low in most management areas in the short-term as inferred from pre-recruit indices from DFO and CPS trap surveys (Figure 115, Figure 116). Pre-recruit abundance indices have been at or near their lowest levels in a decade during the past three years in most management areas, with the exception of Bonavista Bay (CM 5A) (Figure 116). In the absence of a high level of wastage imposed by the fishery via soft-shell capture and mortality, improvements there appear likely to occur because relatively high pre-recruit abundances have been recorded for the last four years.

The incidence of BCD, which provides a signal of the relative strength of the density of small and intermediate-sized crab and subsequent recruitment prospects, has been nil in Conception Bay for four consecutive years (Figure 117). Overall, excepting Bonavista Bay, virtually all data are suggesting a broad-scale decline of recruitment into the exploitable biomass in Div. 3L Inshore in the short-term, and there are currently no inferences of any emerging pulses of the smallest crab in the population.

Contrasting temporal trends across management areas depict differences in Snow Crab life-history in warm versus cold areas. Recruitment pulses oscillate relatively quickly in Bonavista Bay (i.e. Figure 107), similar to Divs. 2J and 3K. However, in Conception Bay (i.e. Figure 108), the process of recruitment into the exploitable biomass is prolonged over many years, similar to the Grand Bank (Divs. 3LNO Offshore). This reflects a higher incidence of skip-molting in crab inhabiting colder water areas (Dawe et al. 2012a) 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. Divs. 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 Divs. 3LNO Offshore and Div. 3L Inshore fisheries. In these divisions, the most recent increase and subsequent decline of the pre-recruit biomass index (2007-11) has been delayed relative to Div. 3K (2006-10) as were/are changes in the exploitable biomass (Figure 70, Figure 72) and fishery performance (Figure 19) indices. The

Snow Crab resource is strongly driven by bottom-up (thermal) processes in all areas, but the rate of changes induced by temperature shifts differs substantially.

Like Divs. 3LNO Offshore, harvesters and managers are advised to give careful consideration to short-term removal levels in Div. 3L Inshore. The exploitable biomass in most areas is dominated by old crab and it is likely that natural mortality will become a more important determinant of population abundance in the forthcoming years. However, recruitment prospects also appear very poor in most areas. A strategy of aggressive resource extraction in the short-term to minimize loss to natural causes could be employed, and conversely, an approach of lightly extracting the resource in the short-term could be deemed the best approach in prolonging the yield from the current biomass which is not expected to renew itself to any appreciable level in the foreseeable future. Finally, in contrast to all other CMAs within the division, concern is expressed about the potential for a high incidence of soft-shell crab in the Bonavista Bay fishery in 2017 if the exploitation rate is not decreased. Such wastage could impair the potential yield from the present recruitment pulse.

SUBDIVISION 3PS

Fishery

The Subdiv. 3Ps fishery occurs off the south coast of Newfoundland (Figure 1, Figure 118). 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 Subdivision, Placentia Bay forms a continuum with the expansive offshore. Historically, most major aggregations of Snow Crab have been found in a deep-water trough (i.e. maximum 275 m depth) extending out of Placentia Bay and into the Halibut Channel in CMA 10BCD. In terms of scale, the fisheries in all other management areas of the Subdivision are small compared to CMAs 10A and 10BCD. Like other Assessment Divisions, there is little scientific basis for the numerous CMAs in Subdiv. 3Ps and fishery and resource trends among CMAs are often synchronous.

Relative to other Assessment Divisions along the Newfoundland and Labrador continental shelves, Subdiv. 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, Figure 118), are both shallower than 100 m depth and the intersecting Halibut Channel is less than 200 m depth throughout. These shallow areas of the Subdivision, where the bulk of the fishery occurs (Figure 18), are cold, but temperatures increase abruptly at the slope edges (Figure 3). In spring of 2016, 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 5°C along the slope edges to the west and south (Figure 3). By the fall of 2016, warm bottom water had encroached over much of the St. Pierre Bank and into Fortune Bay, with temperatures above 5°C seen in these areas.

Landings declined from a recent peak of 6,700 t in 2011 to 1,200 t in 2016 (Figure 17). Effort reached a historical high in 2014 and has since decreased by half and only 40-60% of the TAC taken in the past two years (Figure 17). These overall trends in removals and effort reflect a relatively consistent pattern in every CMA (Figure 119). However, the larger fisheries in CMAs 10A and 10BCD play a particularly strong role in influencing the overall trends observed in the Subdivision.

CPUE has steadily declined since 2009 to a record low in 2016, reflecting precipitous declines throughout most of the Subdivision in recent years (Figure 19, Figure 120). With the exception of CMA 11W, all management areas were at or below 5 kg/trap in 2016 (Figure 120). The declines in CMAs 10A and 10BCD, from about 15-16 kg/trap in 2009-10 to 3 kg/trap in 2016, have been particularly large and precipitous. In 2016, the fishery in all management areas (with the exception of CMA 11W) began below or near 5 kg/trap. These exceptionally low CPUEs suggest a severely depleted resource. The limited information from CMA 11W (only one week of data present in the logbook series [Figure 121]), compromises interpretation of the performance of the fishery in that area. Nonetheless, the broad-scale and rapid decline in CPUE throughout Subdiv. 3Ps is striking; no other Assessment Division has undergone such a large change in CPUE since 2011 (Figure 19).

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 122). This drop coincided with the virtual disappearance of new-shelled crab in the population. The decline in overall abundance of crab since 2012 has also occurred in the offshore (CMAs 10BCD, 10X, 11S), but a substantial reduction in the abundance of new-shelled crab did not occur until 2015. In 2016, both areas exhibited minor increases in the abundance of new-shelled crab (Figure 122). Nonetheless, observer data suggests dissipating recruitment in the exploitable biomass and a population dominated by small crab throughout the Subdivision in recent years. The sharp ‘knife-edge’ appearance at legal-size in the size frequency distributions is suggestive of a high exploitation rate by the fishery (Figure 122).

Discard data from observers further exemplify the decline in recruitment that has been occurring in Subdiv. 3Ps, with continually low/dwindling catch rates of under-sized soft- or new-shelled crab since 2005 (Figure 50). 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. The coupling of low fishery catch rates and low percentages of soft-shelled crab in the catch (Figure 50, Figure 123) in most recent years is consistent with a depleted exploitable biomass. However, in 2014 and especially in 2015 levels of soft-shell crab in the catch increased throughout the duration of the fishery (Figure 123). This coincided with a notable increase in the observed abundance of under-size new-shelled crab in the population (Figure 50), suggesting some modest improvements in the exploitable biomass could be forthcoming. Despite these inferences, overall, the fishery data show that the exploitable biomass is currently very low throughout Subdiv. 3Ps and that the recent decline in fishery performance is largely a result of a decline in recruitment into the exploitable biomass.

With large quota cuts and reductions in removals (Figure 17, Figure 119), the overall exploitation rate index has declined by more than half since 2013 (Figure 52), counter to trends in all other Assessment Divisions. In 2016, the exploitation rate was reduced in all but Fortune Bay (Figure 124). The impact of maintaining the current level of fishery removals on the exploitation rate is unknown. However, it is concerning that discards comprised half the catch in 2016 (Figure 49). The four highest levels in the pre-recruit fishing mortality index have occurred during the past four years (Figure 51). Continuing to fish under elevated mortality levels on sub-legal-sized crab could potentially impair reproductive capacity of the resource or minimize potential gains from any presently occurring recruitment.

Surveys

The trawl survey exploitable biomass index declined by 88% since 2009 to a time series low in 2016 (Figure 24, Figure 125). The CPS trap survey was not or only partially conducted in most areas in 2015 and 2016 (Figure 14) because of poor resource status. Therefore, no biomass indices are available from that survey for Placentia Bay or Halibut Channel. However, the exploitable biomass index for Fortune Bay (CMA 11E) shows a relatively steady decline since 2010 (Figure 125). Raw catch rates from the limited areas surveyed within each CMA showed little change in resource status in most areas, although improvements occurred in Placentia Bay due to an increase in new-shelled legal-sized crab abundance (Figure 126). Although incomplete surveys compromise the ability to characterize this increase as representative, it is consistent with inferences drawn from observer data in suggesting potential for a modest increase in fishery prospects for 2017. However, such potential improvements do not appear to be broad-based. In the DFO trap survey in Fortune Bay (CMA 11E), total catch rates of exploitable crab in all three depth strata have been at time series lows in the past three years (Figure 127).

On the broad-scale, the residual biomass in Subdiv. 3Ps, represented by intermediate- to old-shelled legal-sized crab, began to decline after 2010 (Figure 25, Figure 30). The trawl survey has not captured any large catches of exploitable crab anywhere in the Subdivision since 2011 (Figure 29). In the past four years an increasingly high percentage of survey tows have captured very few or no exploitable crab. The CPS survey catch rates are consistent with this broad-scale decline in the resource. Size frequency distributions showed substantial declines in catch rates of legal-sized old-shelled crab in all CMAs from about 2010-13 (Figure 128), with no or little sign of improvement in any area since. Despite some subtle signals of localized improvements, such as in the limited area occupied by the CPS survey in CMA 10A, the overall breadth of survey data is consistent with the fishery data in showing a residual biomass that is severely depleted.

The decline in the exploitable biomass reflects poor recruitment. Overall recruitment has declined since 2009 to its lowest observed level, with few new-shelled legal-sized crab captured in the spring trawl survey (Figure 1230, Figure 129) or fall CPS trap survey (Figure 25, Figure 128) in the past four years.

Recruitment is expected to remain low in the short-term (2-3 years) because the trawl survey pre-recruit biomass index has been at its lowest level for four consecutive years (Figure 33). Moreover, long-term recruitment prospects appear poor with few small crab (i.e. <50 mm CW) captured in the spring trawl survey in the past four years (Figure 136, Figure 129). 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 130); the few crab captured were small terminally molted adults. Catch rates of adolescent males in the small-mesh CPS survey traps in CMA 11S were relatively high in 2014 but very low in 2016 (Figure 131). Spatially, in 2016, the capture of small adolescent crab by the trawl survey was reduced to a relatively small area north of Halibut Channel and St. Pierre Bank (Figure 38). Indeed, all population components have shown a marked reduction in the abundance in the trawl survey in the past four years (Figure 129) and pre-recruit biomass indices from the DFO and CPS trap surveys continue to decline or remain low (Figure 132).

The recent low recruitment with overall poor prospects for the foreseeable does not correspond with the presence of a relatively large mode of 15-30 mm CW crab in the trawl survey from 2009-11 that would be expected to have already or presently be contributing to the pre-recruit and/or exploitable biomass. The last 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 33), 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 (Figure 24). However, there are only subtle suggestions in the fishery or survey data of any potential improvements. Further compromising the ability to be definitive on short-term prospects is the abandonment of the CPS survey in most areas in recent years. The relatively high catch rate of 40-50 mm CW males in the offshore (CMA 11S) area in 2014 occurred subsequent to the smaller crab pulse in the trawl survey from 2009-11 and supports the possibility that modest improvements in the exploitable biomass are possible in the near future. However, the suite of data presented herein suggests that the overall exploitable biomass and recruitment potential is low.

Several factors may have contributed to dampening the lack of yield from the emergent 2009-11 recruitment pulse. Firstly, spring bottom temperatures in Subdiv. 3Ps in recent years have been relatively cold (Figure 46). Such cold conditions promote terminal molt at small sizes (Dawe et al. 2012a). Accordingly, it is possible that high proportions of crab have terminally molted as under-sized adults here in recent years. Secondly, natural mortality on mid-sized crab in the population may have increased in recent years, specifically in the form of increased predation. The index of predation of Snow Crab by large benthivores and piscivores in 3Ps increased sharply in 2010 and has since varied at an atypical temporal pattern of consistently high consumption rates (Figure 39). Finally, the pre-recruit fishing mortality index was high during the past four years and fisheries-induced mortality could have contributed to a low yield from any crab from that recruitment pulse that approached or entered pre-recruit size (Figure 51).

Key summary indices from Subdiv. 3Ps yield conflicting information. Both the pre-recruit and exploitable biomass indices are presently very low, yet their within-year correspondence suggests year effects in the catchability of the survey trawl are common and compromises the reliability of predictions for the pre-recruit index. However, the exploitable biomass index serves as a good predictor of fishery CPUE in the following year (r^2=0.72) and suggests fishery performance is likely to remain low in 2017 (Figure 133). In opposition to this, the lagged habitat index would suggest that both the exploitable biomass and fishery CPUE should now be improving (Figure 45, Figure 46). This would be consistent with the emergence of the pulse of small crab detected in the trawl survey in 2009-11, but there are only subtle signs of increasing recruitment potential in recent survey or fishery data. The scenario suggests that the reliability of the thermal habitat index as a predictor of long-term productivity and recruitment potential may be diminishing. This is thought to reflect a current shift in trophic control in the ecosystem and on this resource. In the absence of high abundances of finfish for the past two and a half decades, this resource has been predominately under bottom-up control. However, survey data from Subdiv. 3Ps (DFO 2015) and the broader-scale Newfoundland and Labrador Shelf (DFO 2014b) are suggesting finfish abundances have recently been increasing in association with prolonged warming and top-down predation controls are becoming more important regulators of not only the Snow Crab resource, but also of northern shrimp (*Pandalus borealis*). Northern shrimp is another cold-water crustacean that benefitted from cold water and release of predation controls (DFO 2014b) following the collapse of finfish stocks in the early 1990s, but is presently in decline in the transitioning ecosystem.

Despite conflicting signals and uncertainties and the possibility of some localized short-term improvements, the overall scenario suggests poor short-, mid-, and long-term recruitment prospects for Subdiv. 3Ps Snow Crab.

DIVISIONS 4R3PN

Fishery

The Divs. 4R3Pn fishery occurs along the west and southwest coasts of Newfoundland (Figure 1, Figure 134). 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 Subdiv. 3Pn. Bottom temperatures in this Assessment Division are the warmest along the NL shelf, and it is comparatively unproductive for Snow Crab. Fishery CPUE is consistently low compared to other Assessment Divisions (Figure 19) 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 since 2012 (Figure 17). Effort has been relatively unchanged since 2012 (Figure 17). These overall trends in landings and effort reflect patterns in most CMAs (Figure 135). In all areas, removals increased from 2011 13. They remained relatively unchanged in CMAs 12A, 12B, Bay St. George (CMA 12C), the Inner and Outer Bay of Islands (CMAs 12E and 12F), and Bonne Bay (CMA 12G), but have declined once again off Port aux Port (CMA 12D) and Port au Choix (CMA 12H), as well as in the offshore (CMA OS8) (Figure 135). The offshore fishery has been patchily distributed for the past six years, with pockets of effort occurring along adjacent management area lines (Figure 18). It has performed consistently poor relative to the inner areas (Figure 136).

CPUE has been low throughout the time series relative to most other Assessment Divisions (Figure 19). Most management areas within Divs. 4R3Pn experienced catch rates near time series' highs during 2012-14, but CPUE declined back to low levels in most management areas during the past two years (Figure 136). CPUE remains relatively strong (i.e. >5 kg/trap) in CMAs 12C and 12G.

There appears to be high levels of resource depletion by the fishery in most CMAs (Figure 137). Strong declines in CPUE or extremely low CPUEs throughout the season are particularly evident in Bay St. George (CMA 12C), Port au Choix (CMA 12H), and the offshore (CMA OS8) (Figure 37). The depletion plots give an overall suggestion of a broad-scale fishery now in decline.

The overall exploitation rate index has increased since 2013 (Figure 52) in all surveyed areas (Figure 138). Status quo removals would elevate the exploitation rate index to a new high (Figure 52), predominately reflecting a large increase in the Bay of Islands (CMAs 12E and 12F) (Figure 138).

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 2011 and has since gradually declined (Figure 27). This pattern is reflected in most surveyed areas. The residual biomass (old-shelled legal-sized crab) declined in most CMAs in 2016, except in the offshore (CMA OS8), where survey catch rates have remained relatively poor throughout the time series (Figure 139).

The abrupt 2011 increase in the exploitable biomass index (Figure 27) 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 139). Overall recruitment has been low for the past three years (Figure 25). This reflects declines to low levels in all CMAs (Figure 139).

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 140). Small-mesh trap size frequency distributions tracked approaching modes of adolescent males quite well from 2008-2010 (Figure 141), 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 about 55 mm CW emerged in the Outer Bay of Islands (CMA 12F) in 2016 (Figure 141).

Despite the possibility of some localized future improvements, recruitment prospects appear relatively weak for the next 2-3 years, as pre-recruit indices have been low in most surveyed areas following relatively high levels during the 2008-13 period (Figure 142). The pre-recruit index from the small-mesh traps shows a large increase in pre-recruits in Bay St. George (CMA 12C); however, this is affected by the presence of a few large adolescent males

(Figure 141) and does not reflect any approaching mode, thus marked improvements in the exploitable biomass are not expected to develop from it.

Like virtually all areas of distribution for NL Snow Crab, the short-term outlook for the resource in Divs. 4R3Pn is poor.

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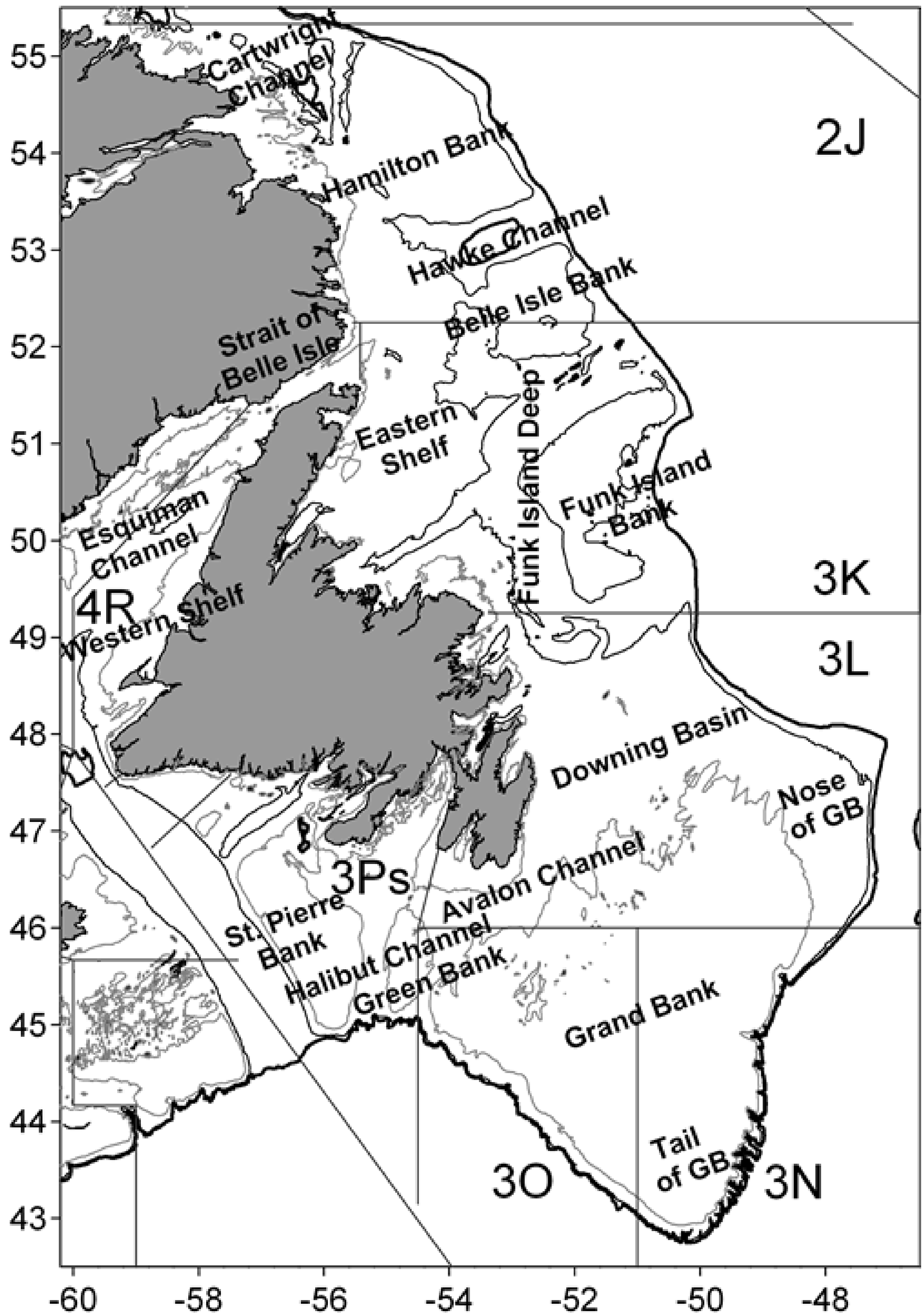

Figure 1. Map of Newfoundland and Labrador Continental Shelf showing place names, bathymetrical features, and Northwest Atlantic Fisheries Organization (NAFO) Divisions.

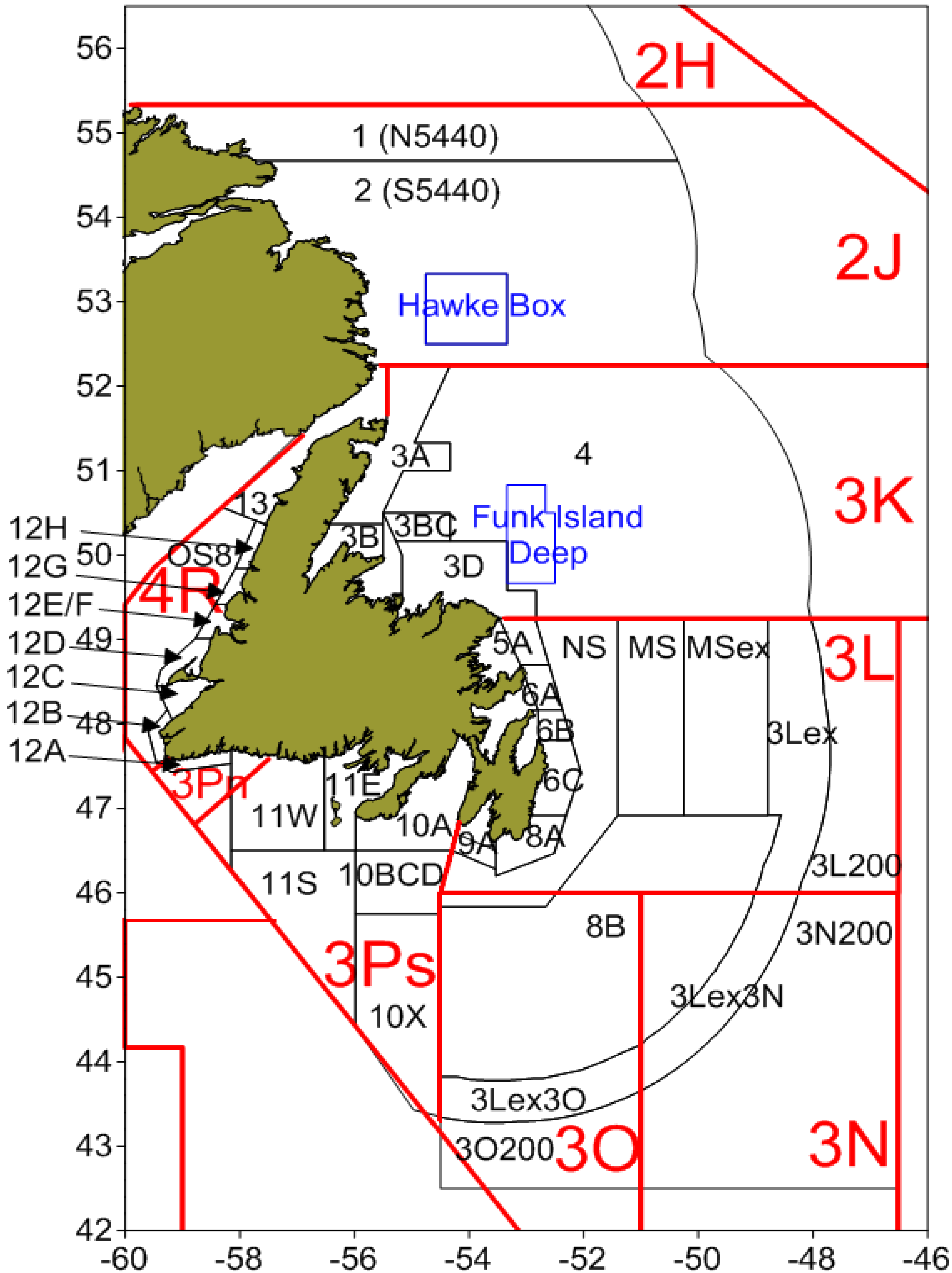

Figure 2. Map of NAFO Divisions (red lines), NL Snow Crab Management Areas (black lines), and trawling and gillnetting closures (blue boxes).

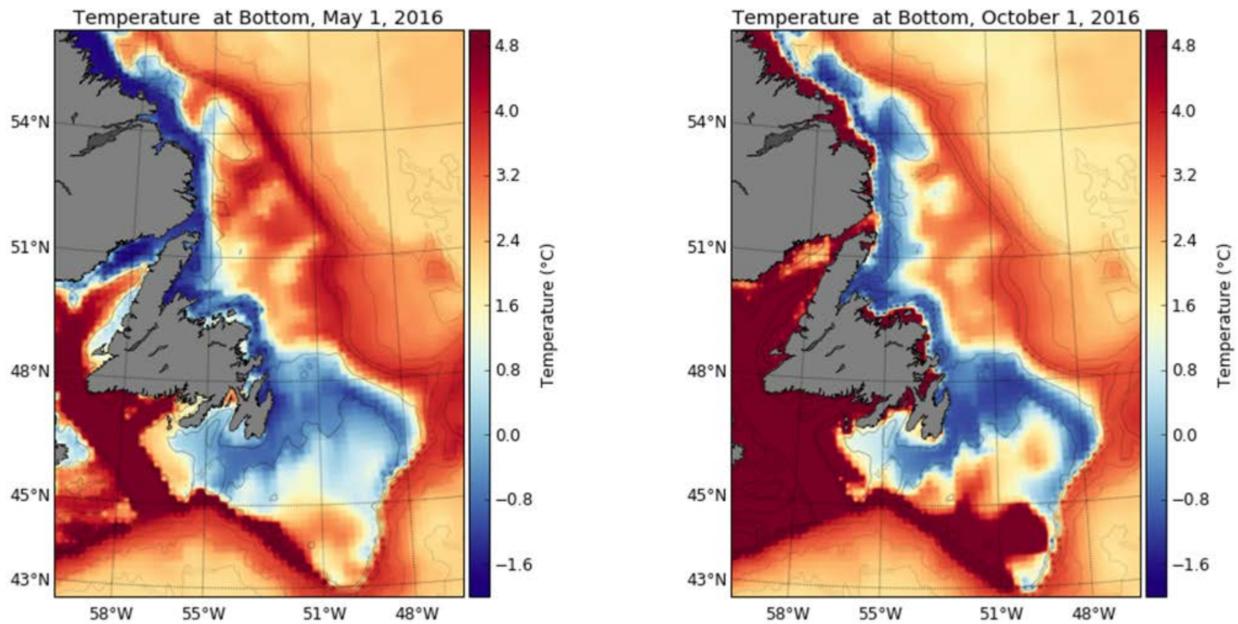

Figure 3. Maps of bottom temperatures along the NL shelf during spring (May 1st - left panel) and fall (October 1 – right panel) in 2016.

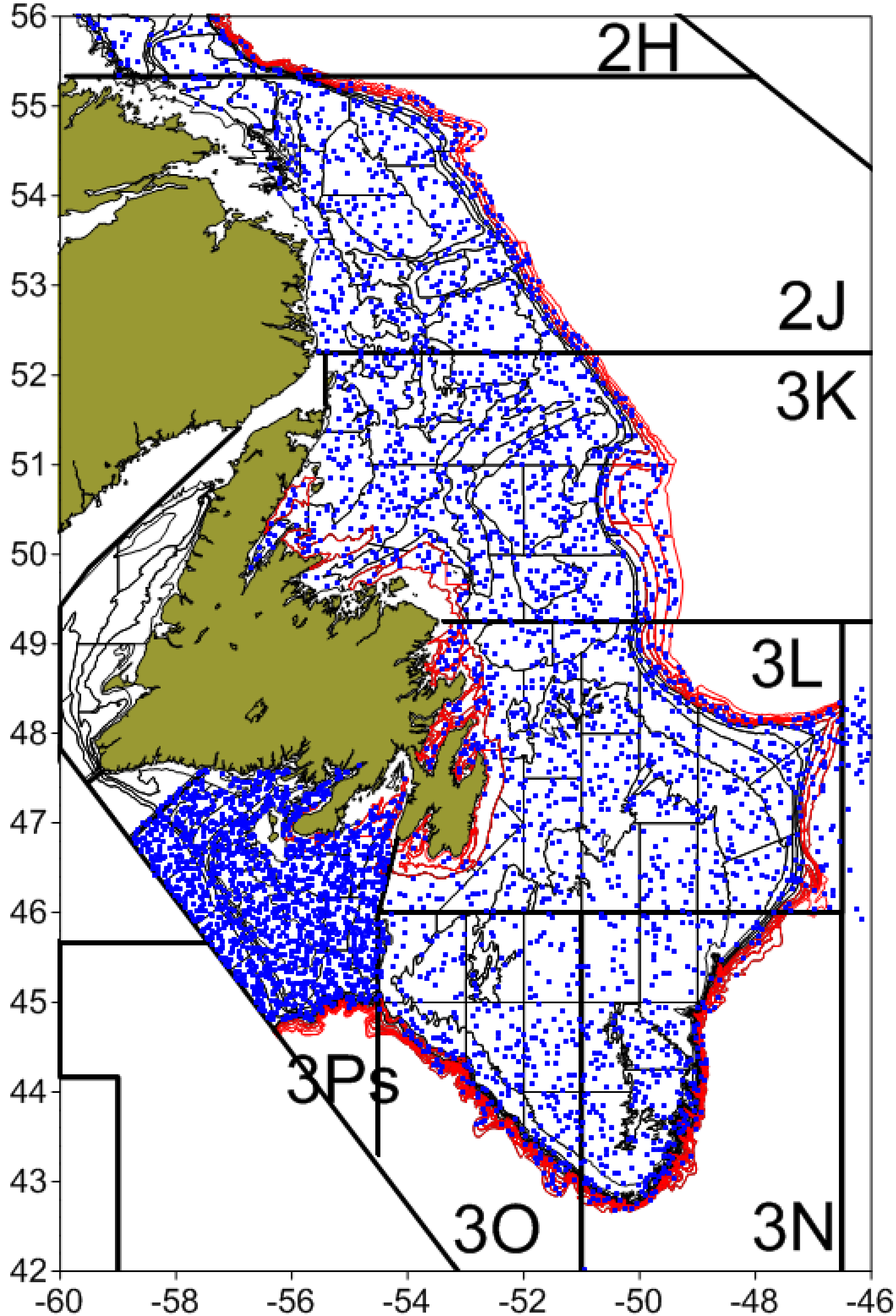

Figure 4. DFO multi-species trawl survey strata used in previous assessments with core strata shown in black. Ogmap vertex positions shown as blue dots.

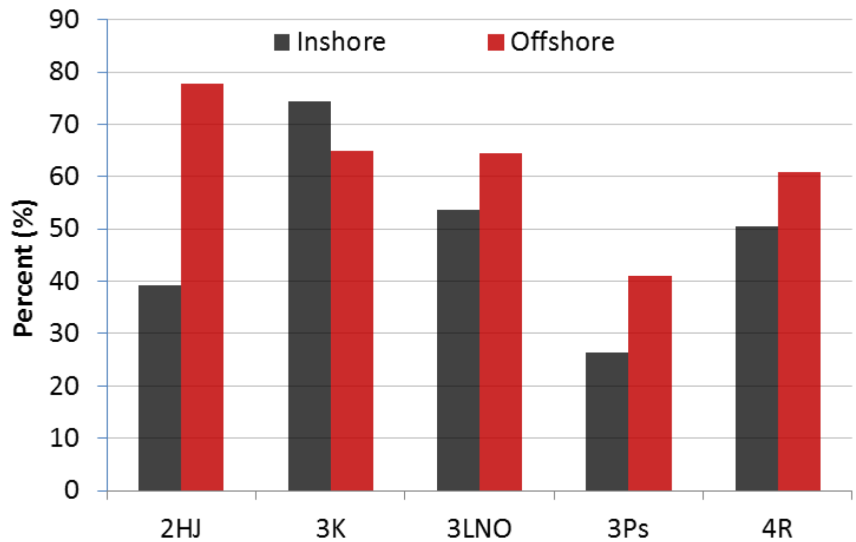

Figure 5. Percentage of logbooks contained in the database for the 2016 assessment by Assessment Division.

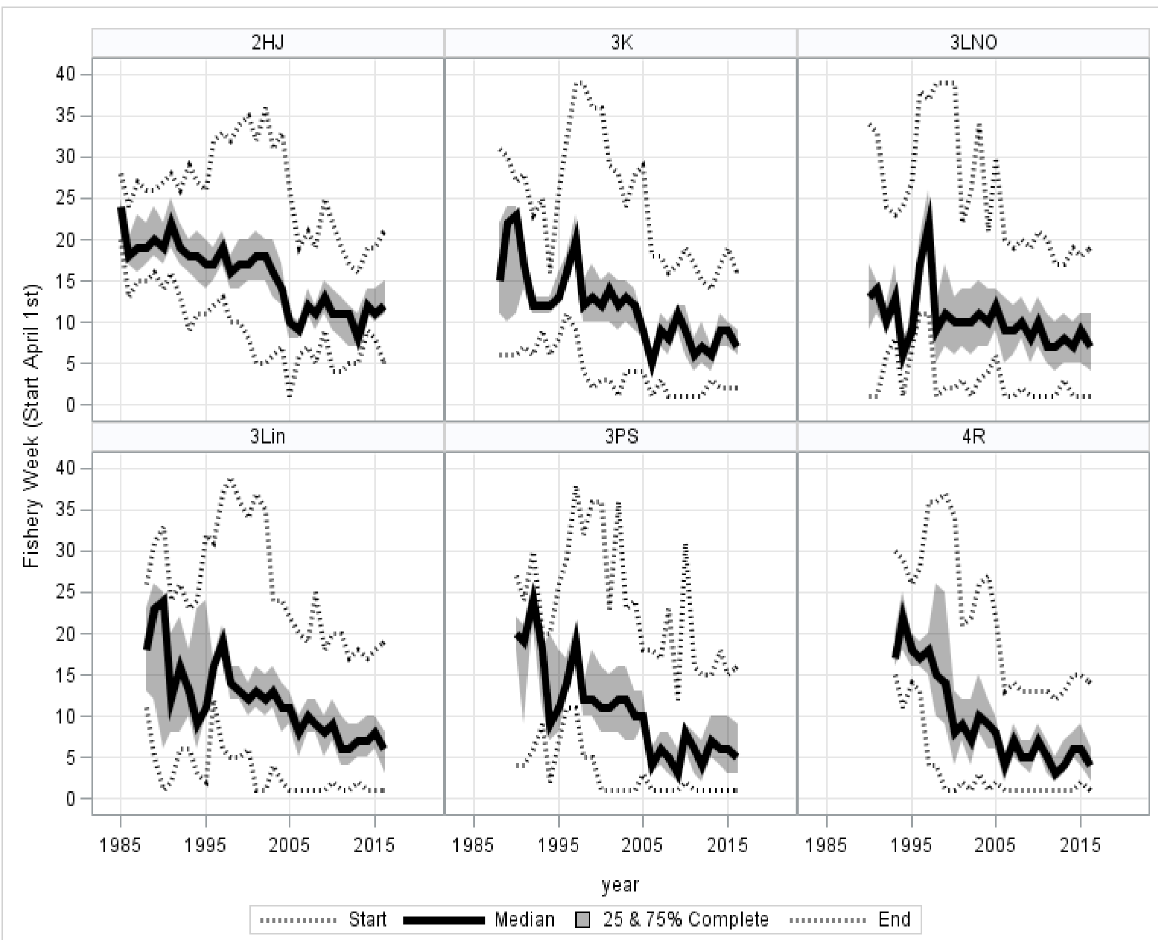

Figure 6. Trends in timing of the fishery by Assessment Division.

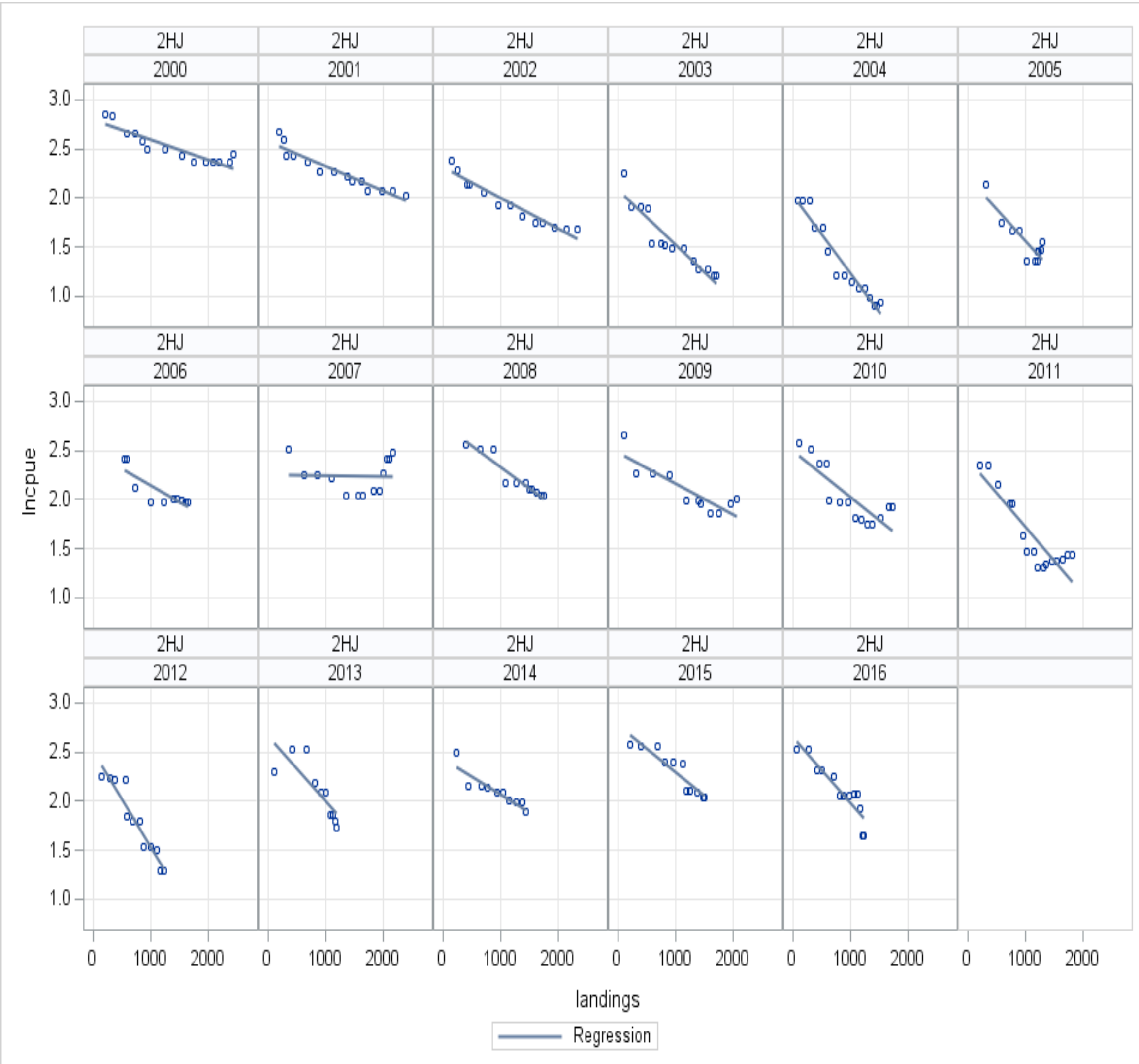

Figure 7. Delury depletion regression models on weekly catch rates from logbooks in Divs. 2HJ.

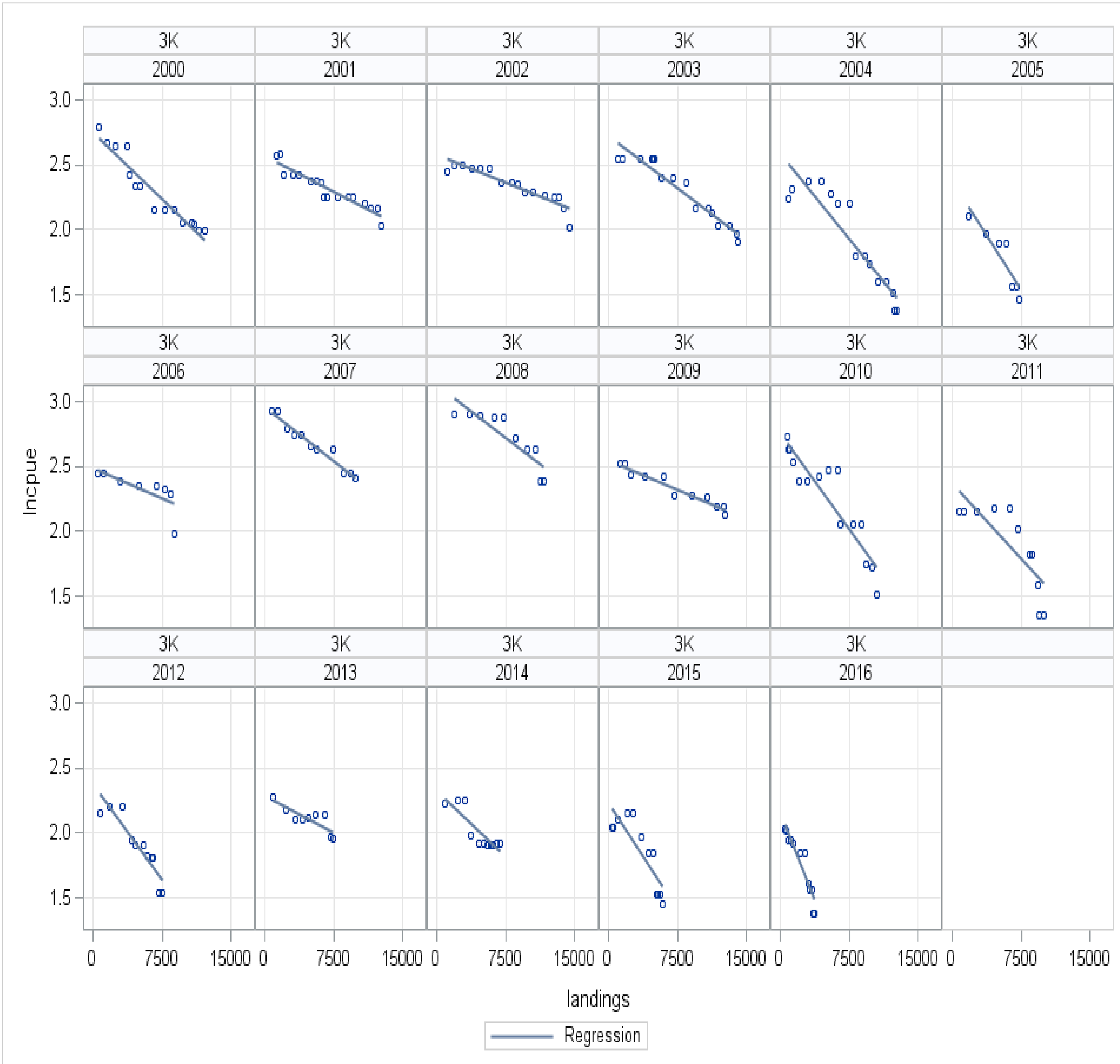

Figure 8. Delury depletion regression models on weekly catch rates from logbooks in Div. 3K.

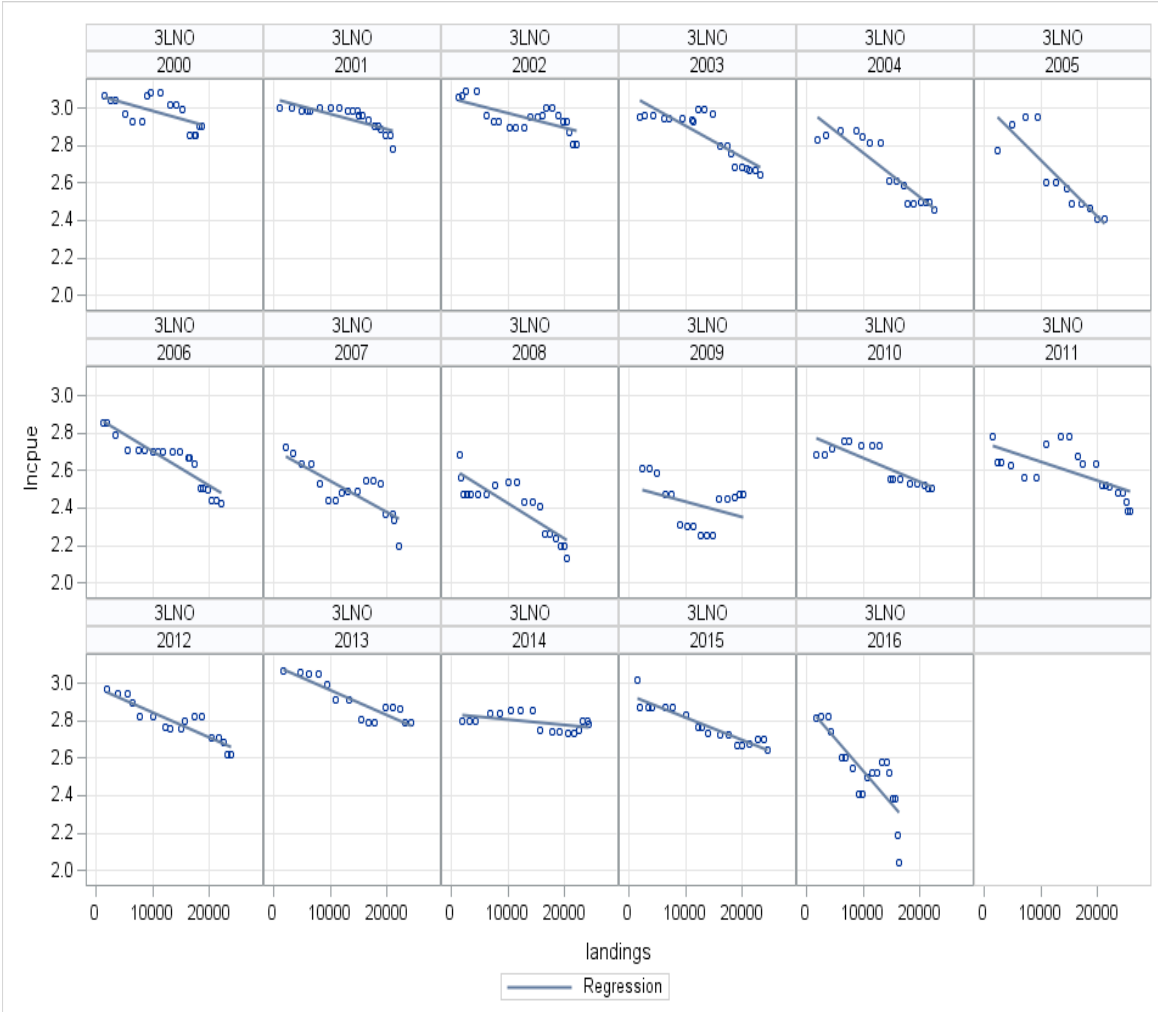

Figure 9. Delury depletion regression models on weekly catch rates from logbooks in Divs. 3LNO.

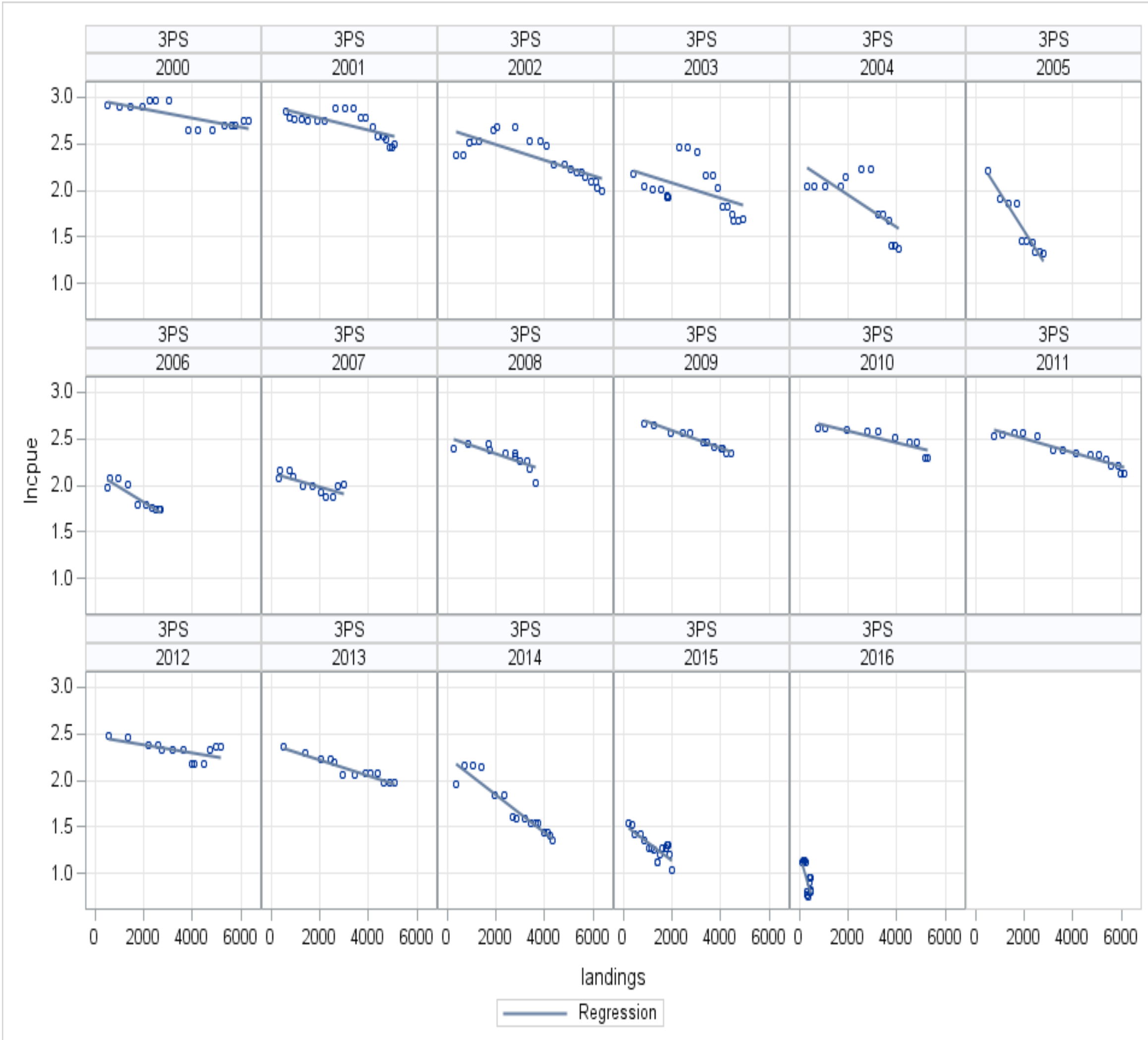

Figure 10. Delury depletion regression models on weekly catch rates from logbooks in Subdiv. 3Ps.

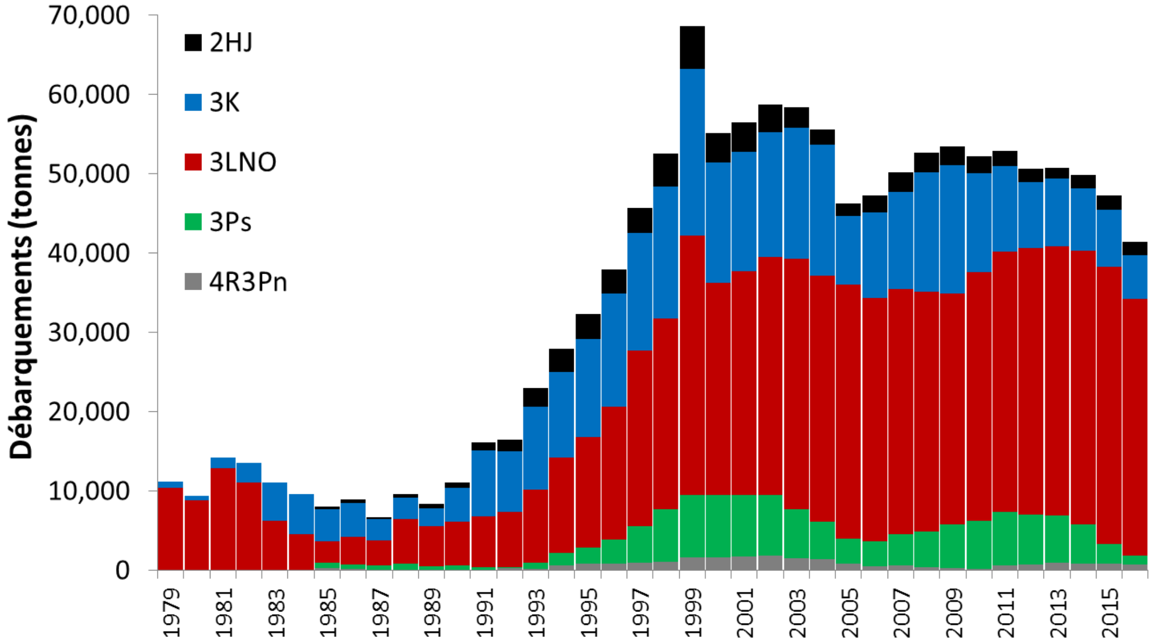

Figure 11. Annual landings of Snow Crab (1979-2016) by Assessment Division.

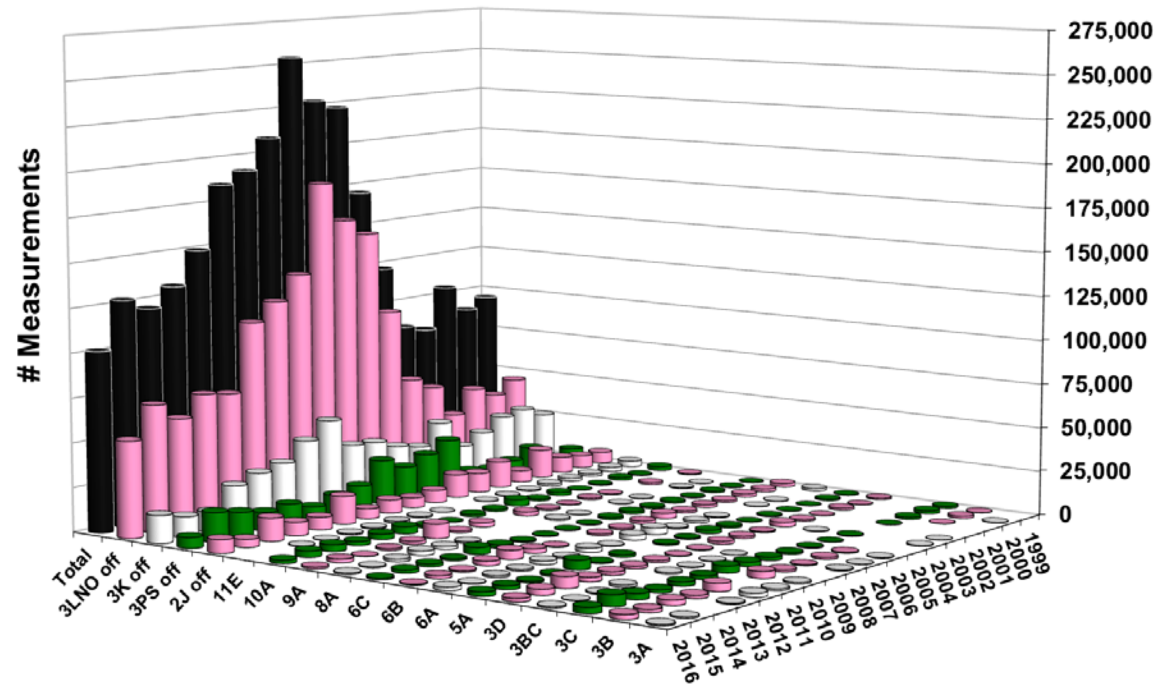

Figure 12. Observer sampling by Crab Management Area (CMA) and year (1999-2006). Data are pooled for offshore CMAs in each Assessment Division.

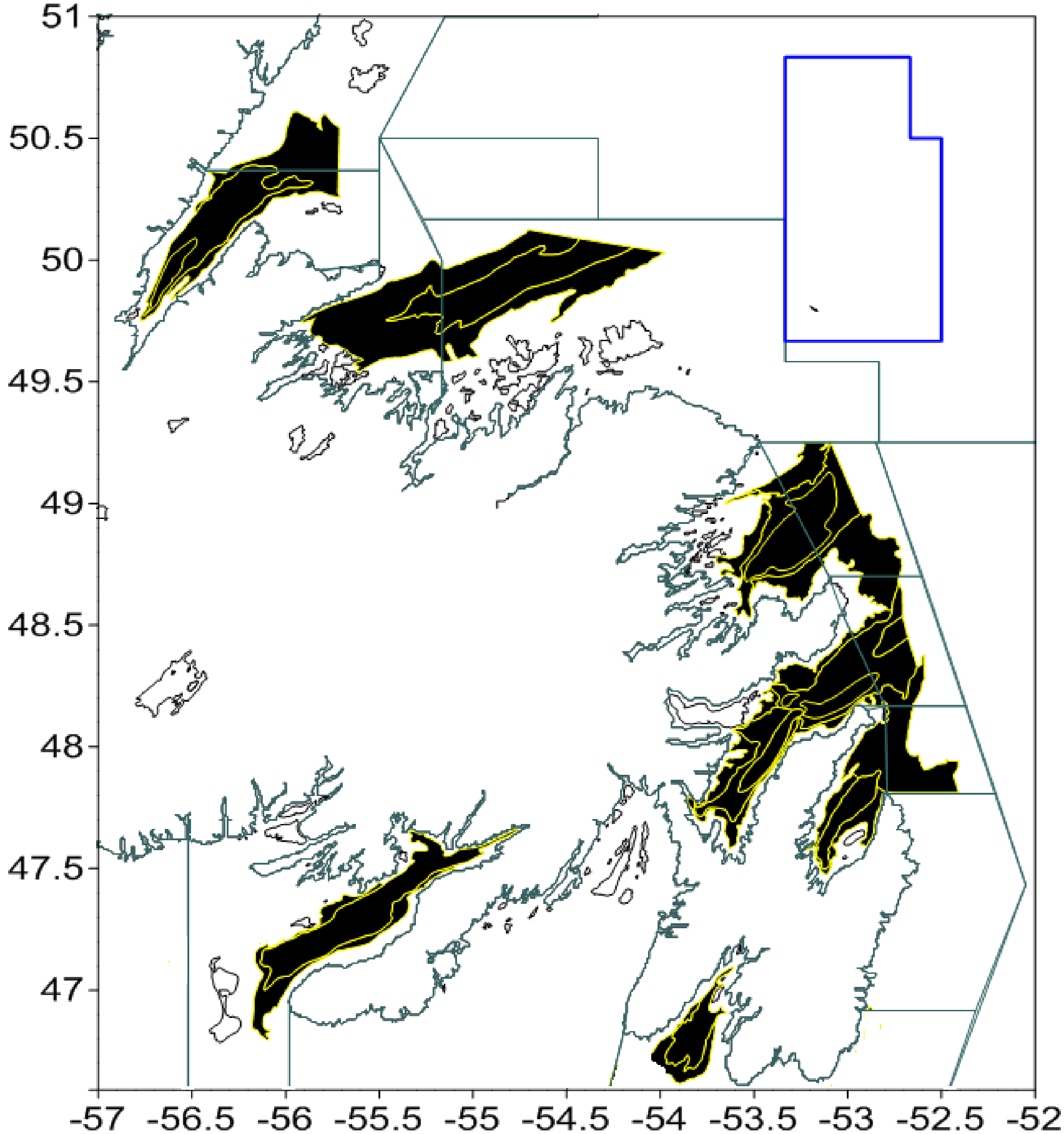

Figure 13. Strata occupied during DFO inshore trap surveys.

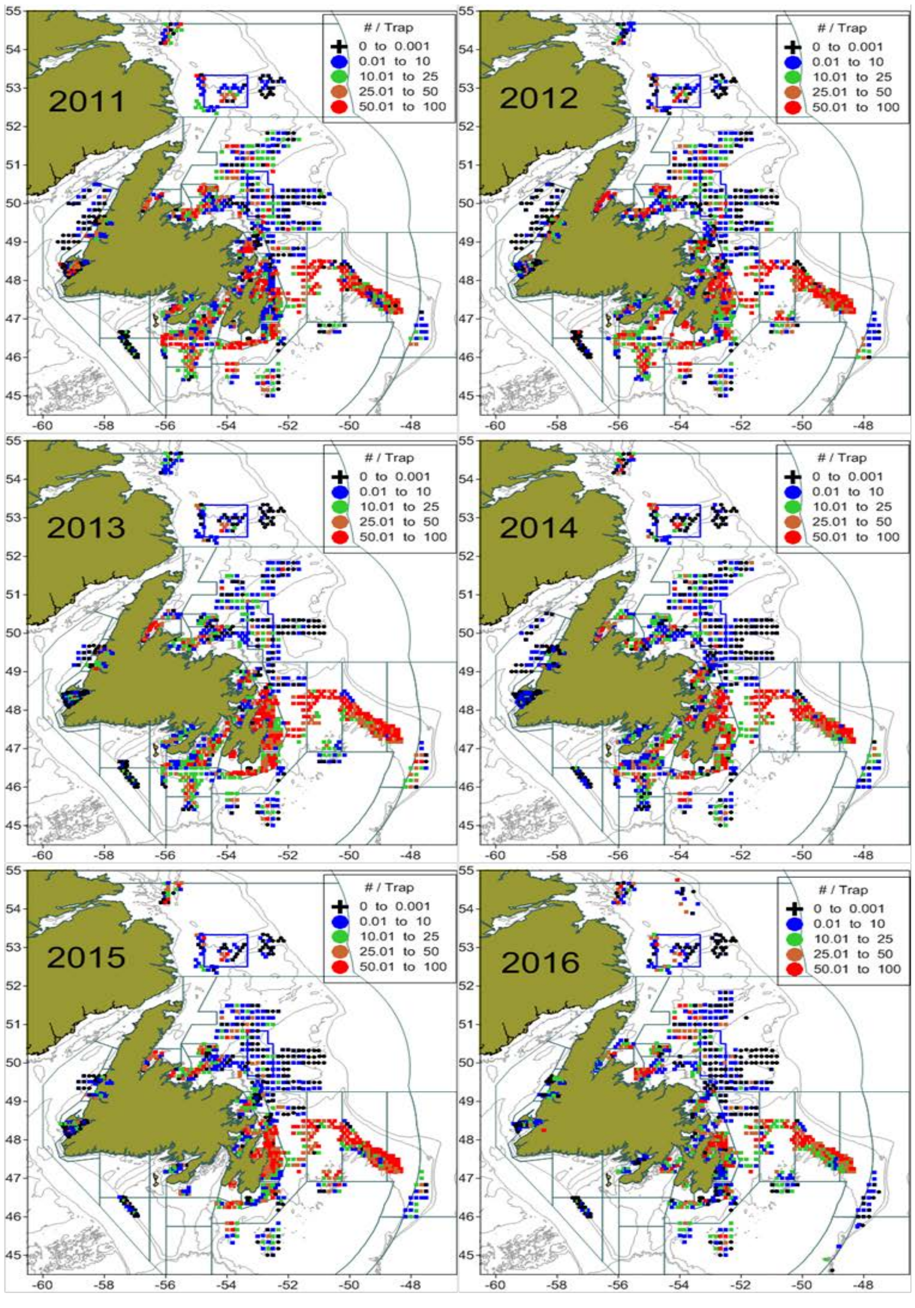

Figure 14. Collaborative Post-season Trap survey large-mesh trap locations and catch rates of all crab (2011-16).

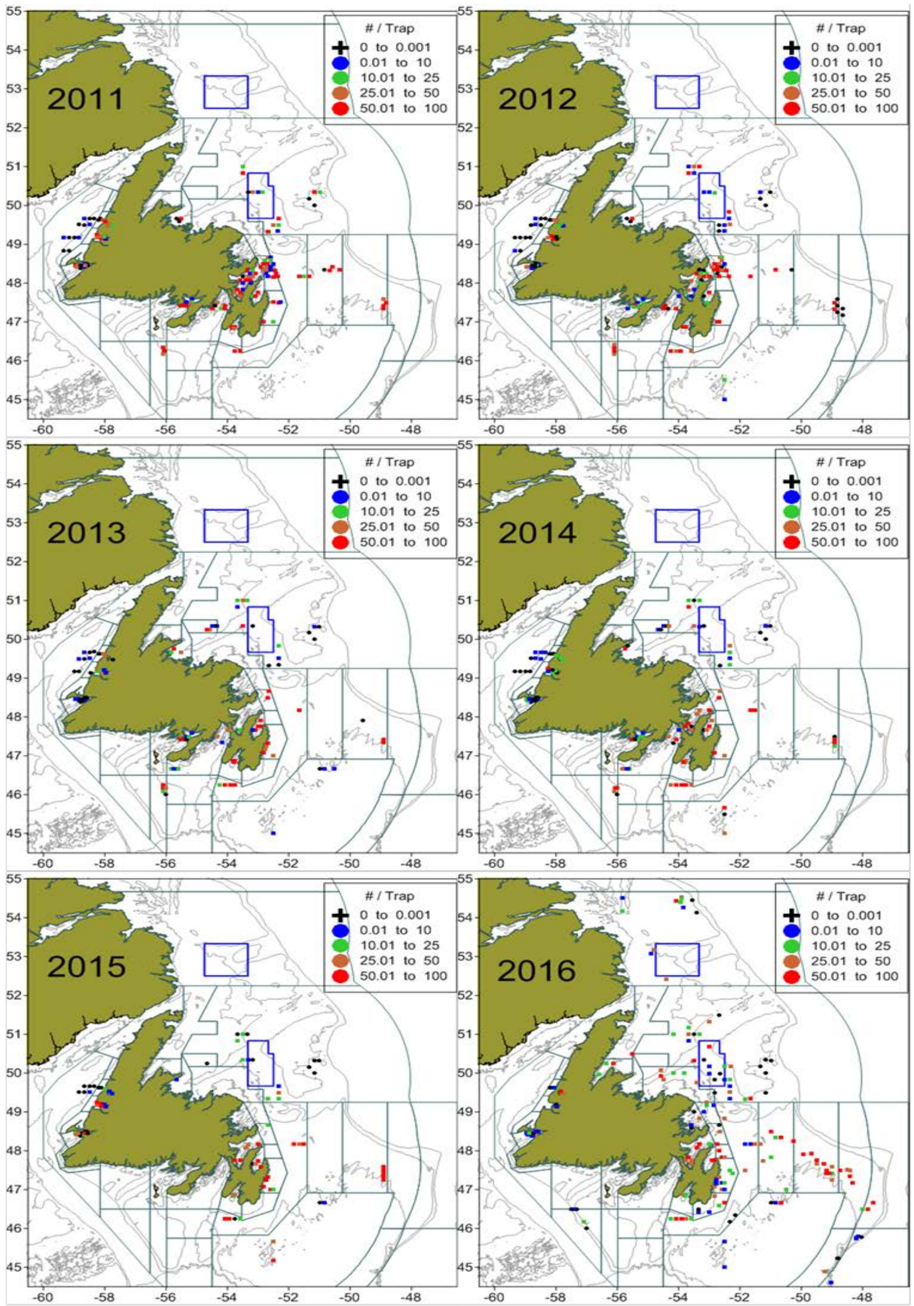

Figure 15. Collaborative Post-season Trap survey small-mesh trap locations and catch rates of all crab (2011-16).

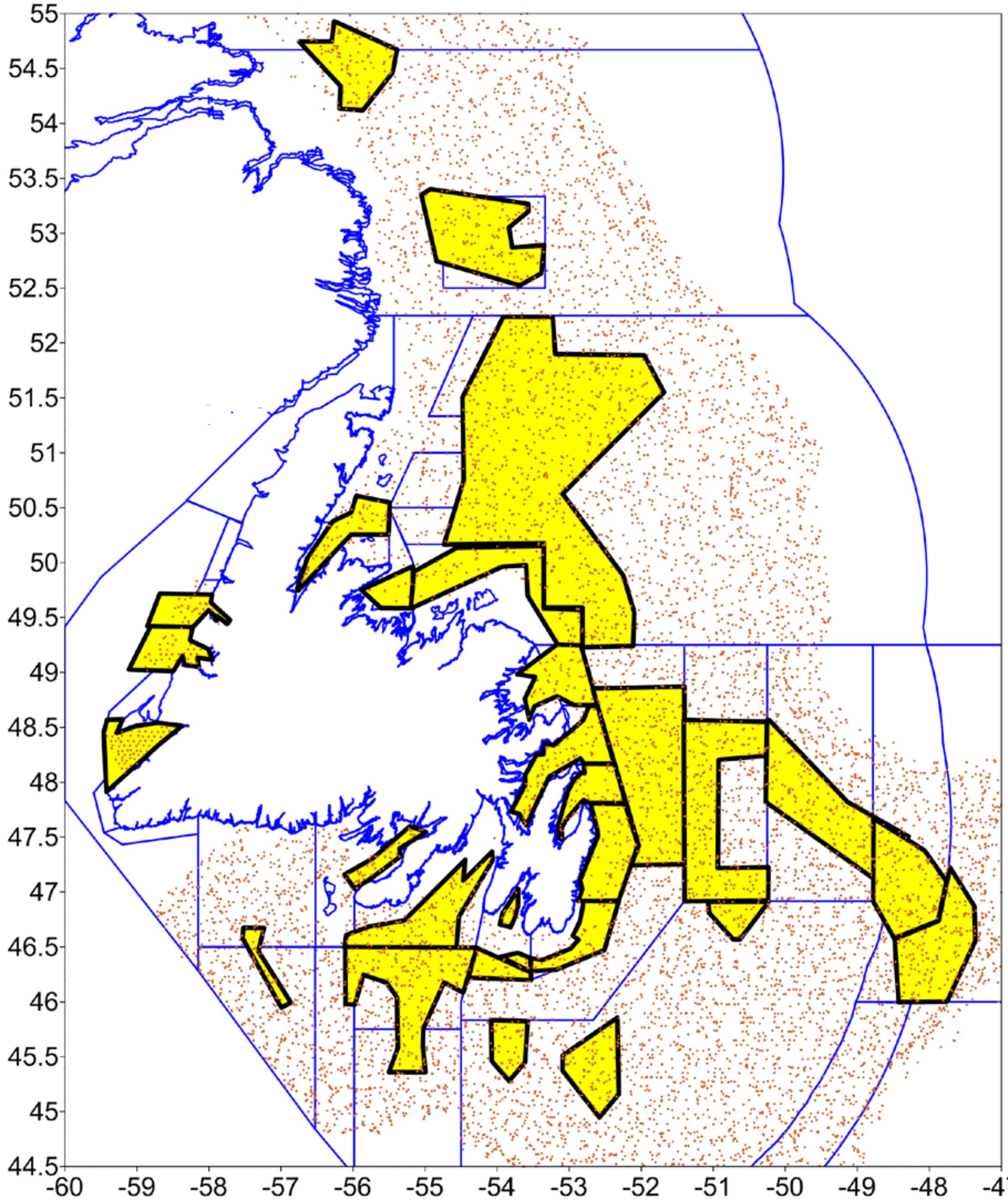

Figure 16. Map of ogmap vertices (red dots) and strata developed for biomass estimation from trap surveys (yellow polygons).

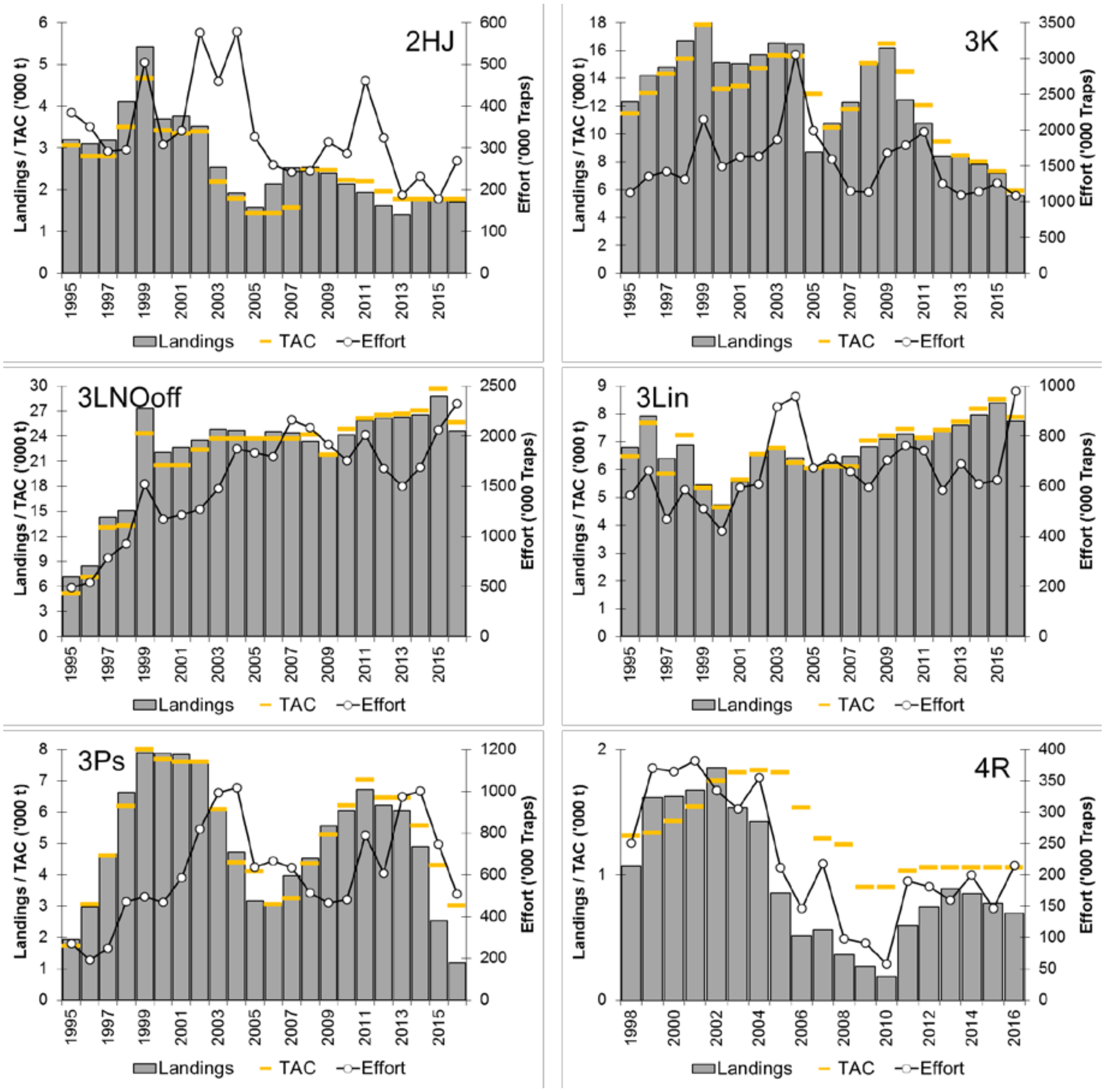

Figure 17. Annual Snow Crab landings, total allowable catch (TAC), and estimated effort by Assessment Division.

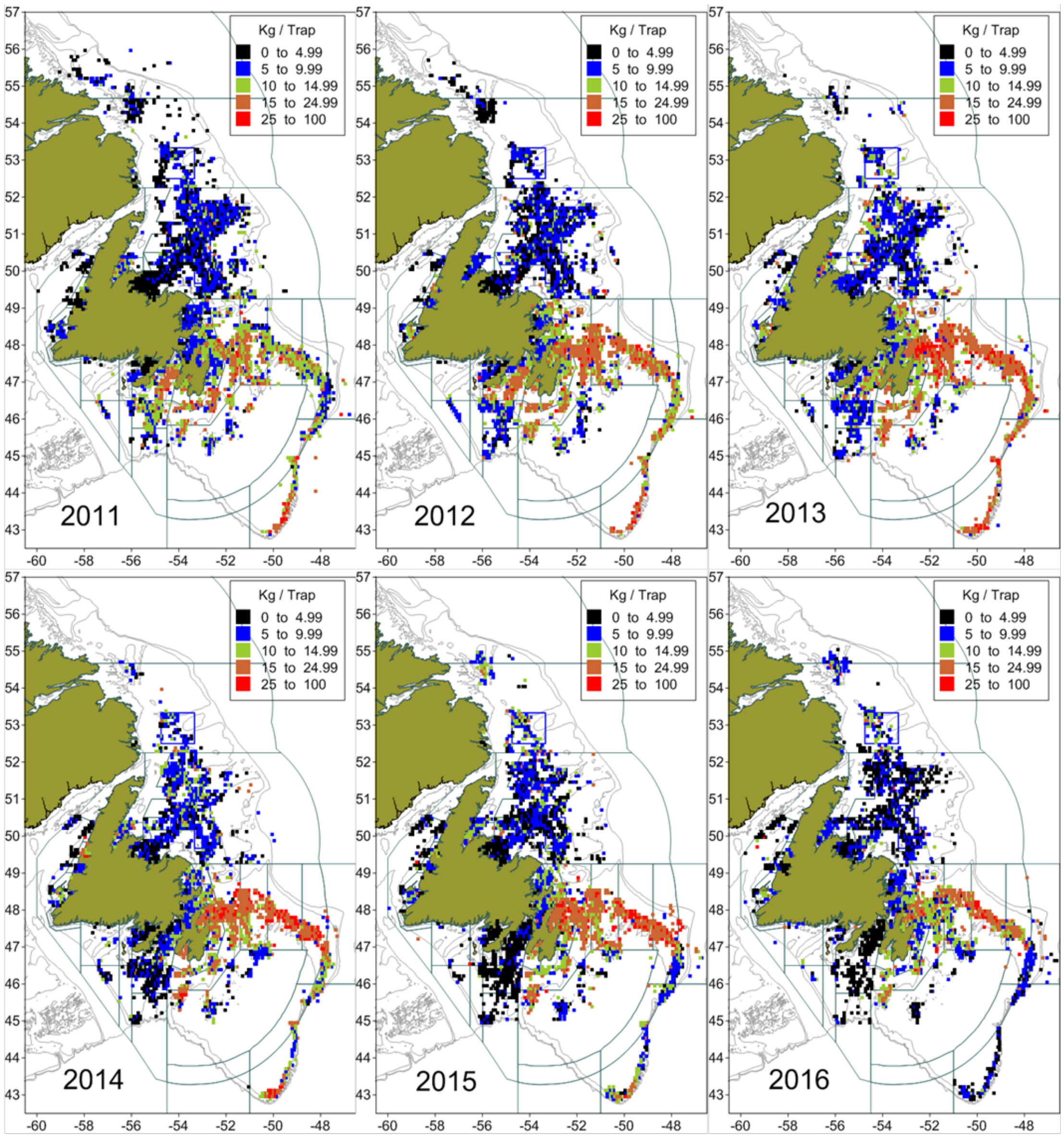

Figure 18. Spatial distribution of catch rates from Snow Crab fishery logbooks (2011-16).

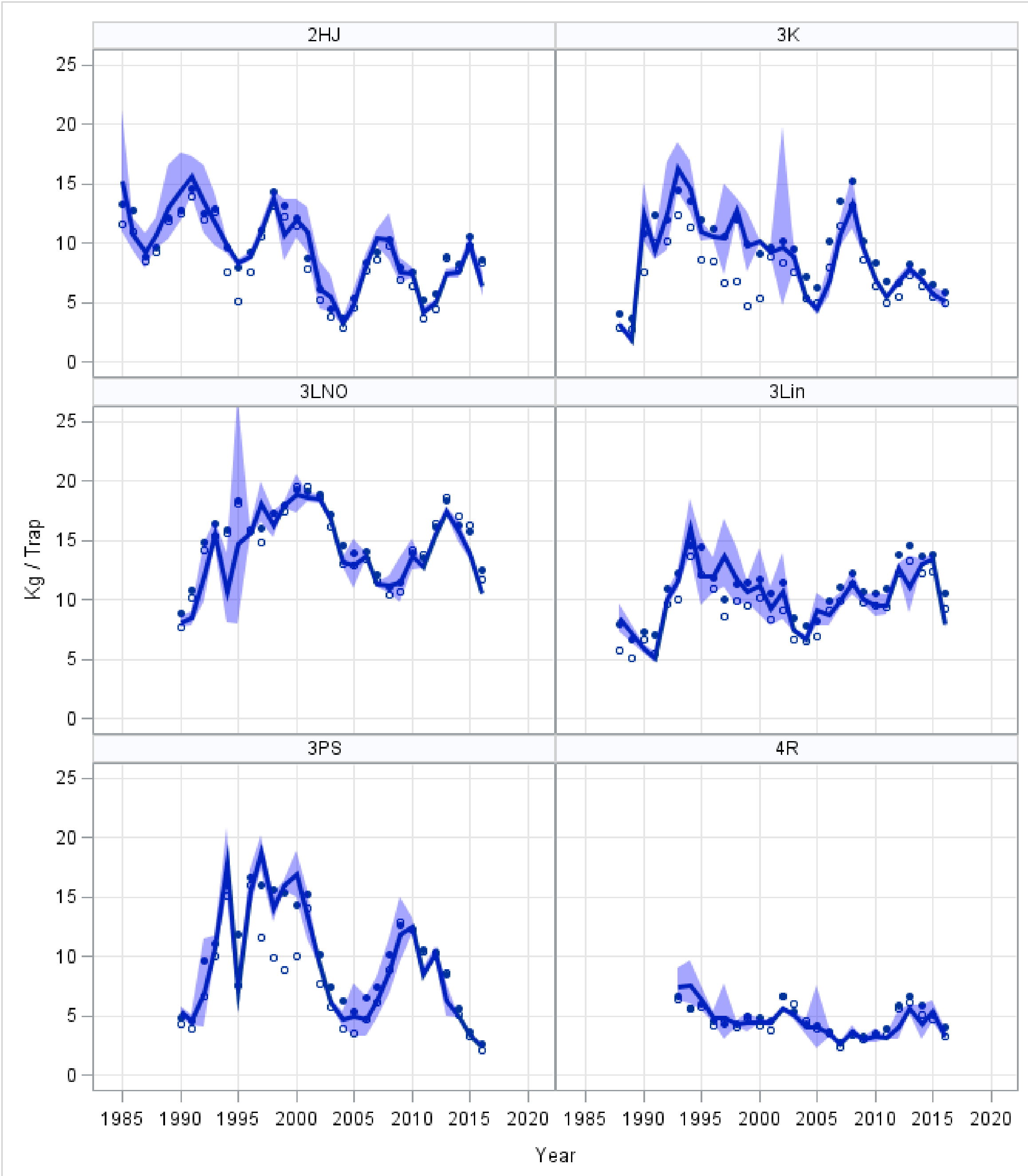

Figure 19. Standardized CPUE (kg/Trap) by Assessment Division. Open circles depict median catch rates and closed circles depict mean catch rates. Solid line is predicted CPUE and band is 95% confidence intervals.

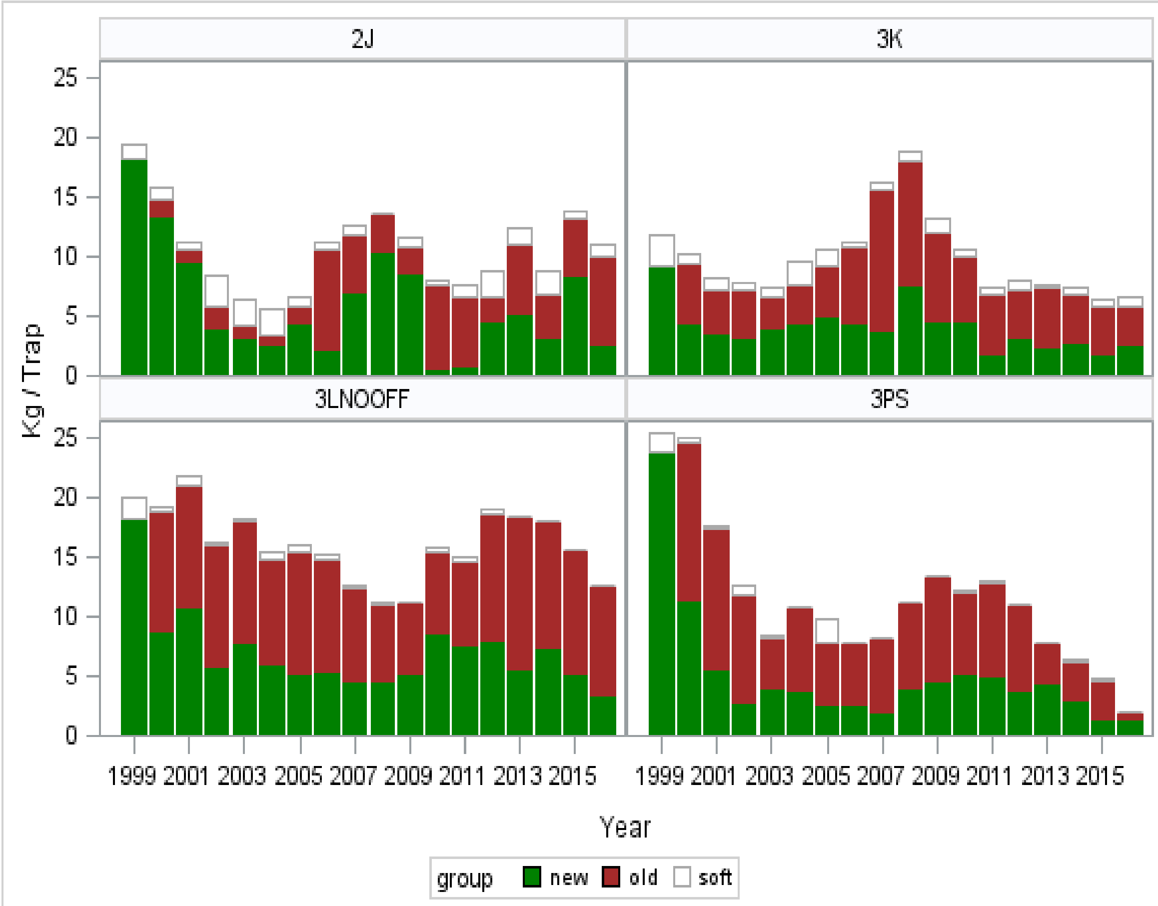

Figure 20. Trends in catch rates of legal-sized Snow Crab by shell condition from observer at-sea sampling by Assessment Division.

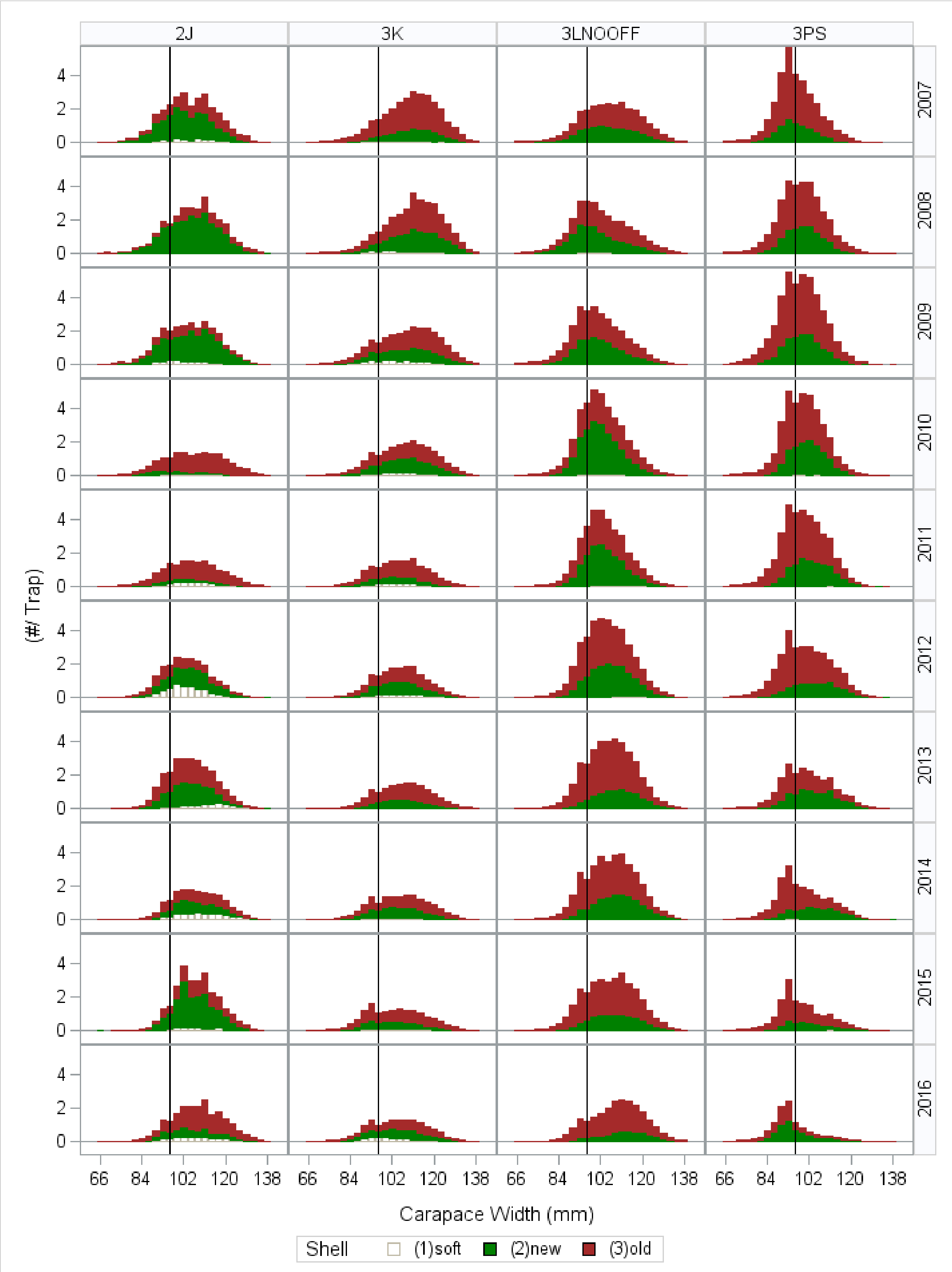

Figure 21. Trends in male carapace width distributions by shell condition from observer sampling by Assessment Division (2007-16). The vertical line indicates the minimum legal size.

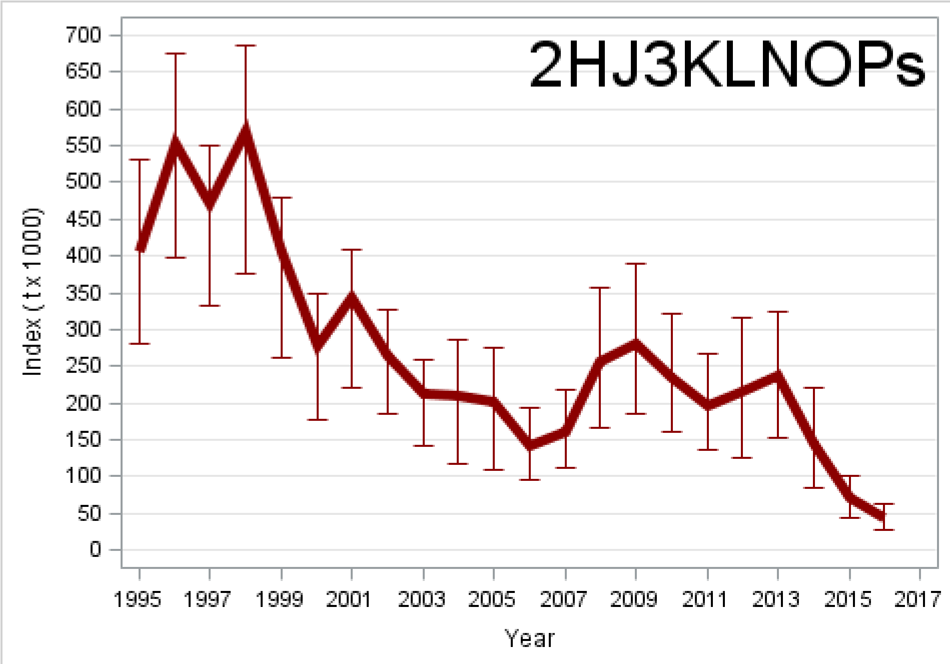

Figure 22. Overall trawl survey exploitable biomass index for Divs. 2HJ3KLNO and Subdiv. 3Ps (1995-2016). Index is the sum of annual point estimates and confidence intervals for individual Assessment Divisions.

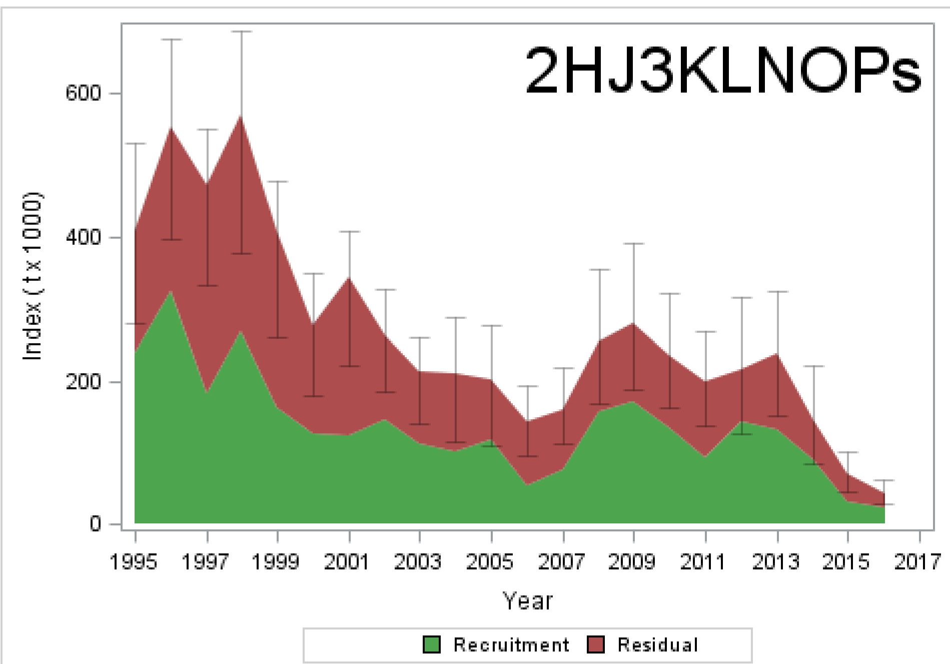

Figure 23. Overall trawl survey exploitable biomass index by shell condition for Divs. 2HJ3KLNO and Subdiv. 3Ps (1995-2016). Index is the sum of annual point estimates and confidence intervals for individual Assessment Divisions. Soft and new-shell crab represent recruitment and intermediate and old-shell crab represent residual biomass.

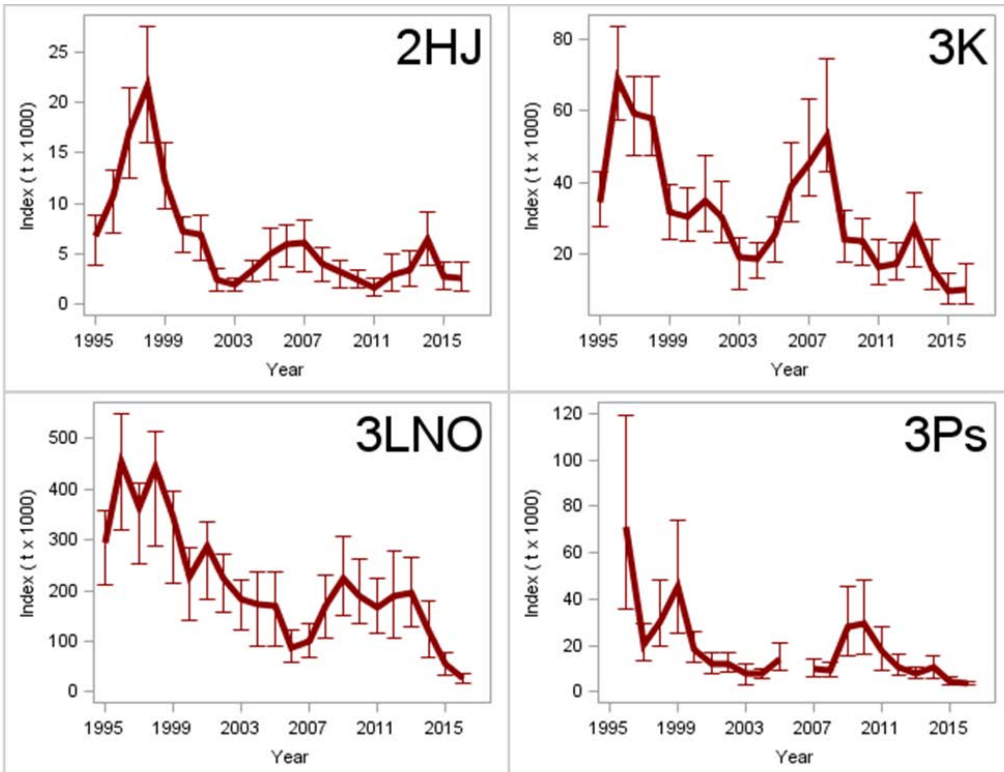

Figure 24. Trawl survey exploitable biomass indices by Assessment Division.

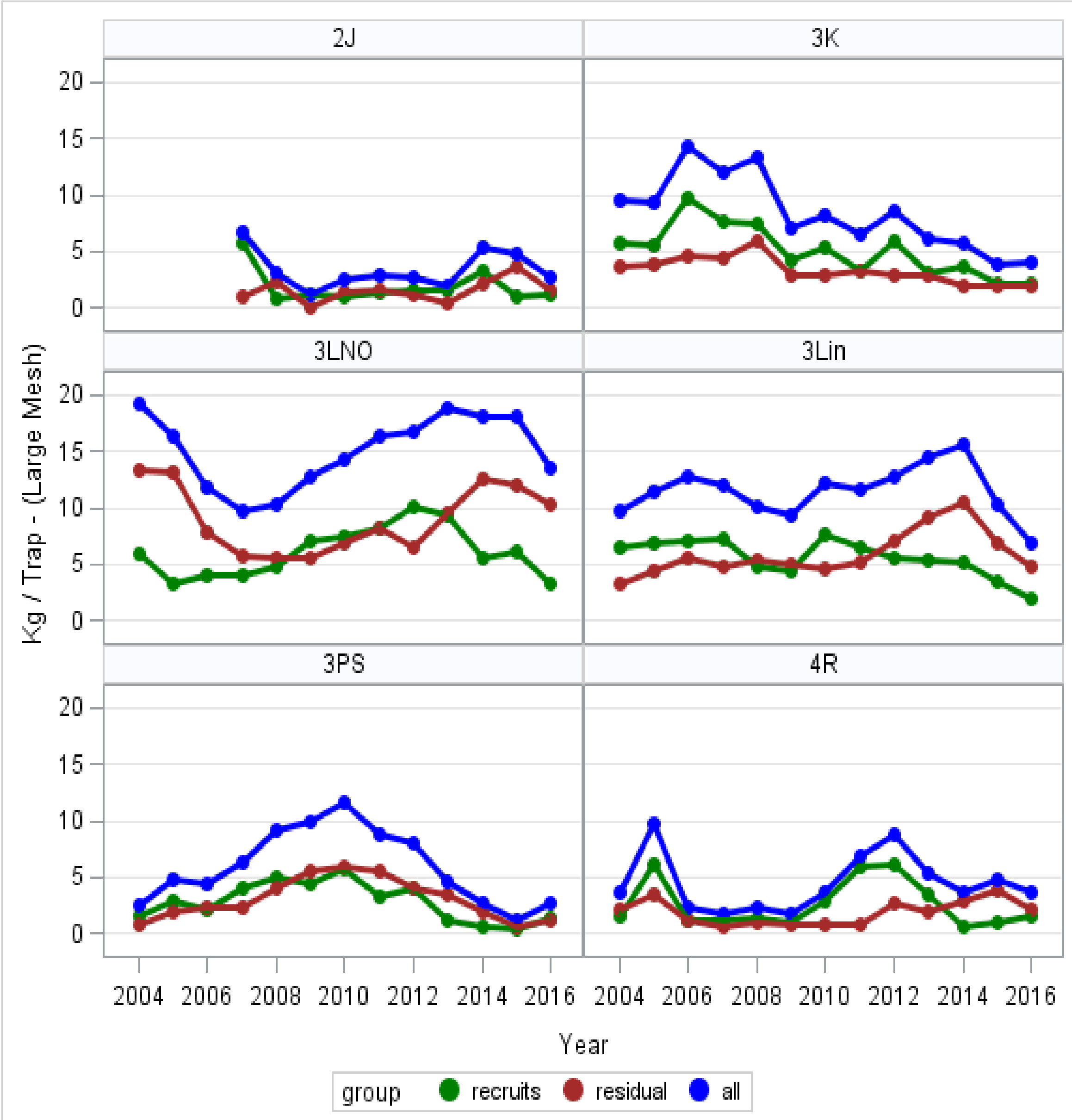

Figure 25. Trends in CPUE by shell condition for legal-sized crab from core stations in the CPS trap survey by Assessment Division.

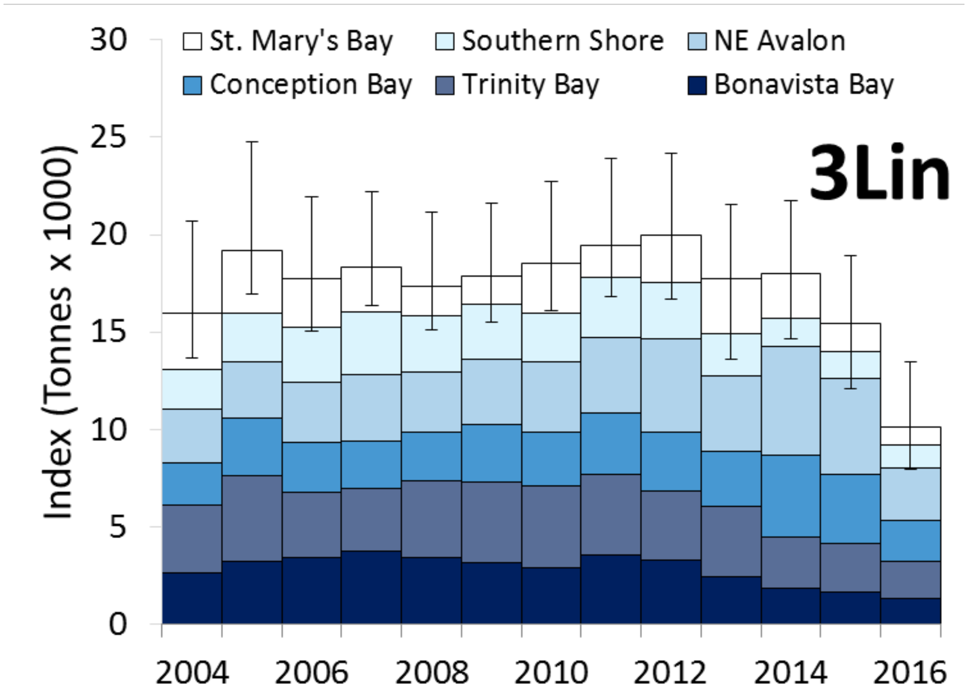

Figure 26. Trends in the trap survey-based exploitable biomass index for Assessment Div. 3L inshore.

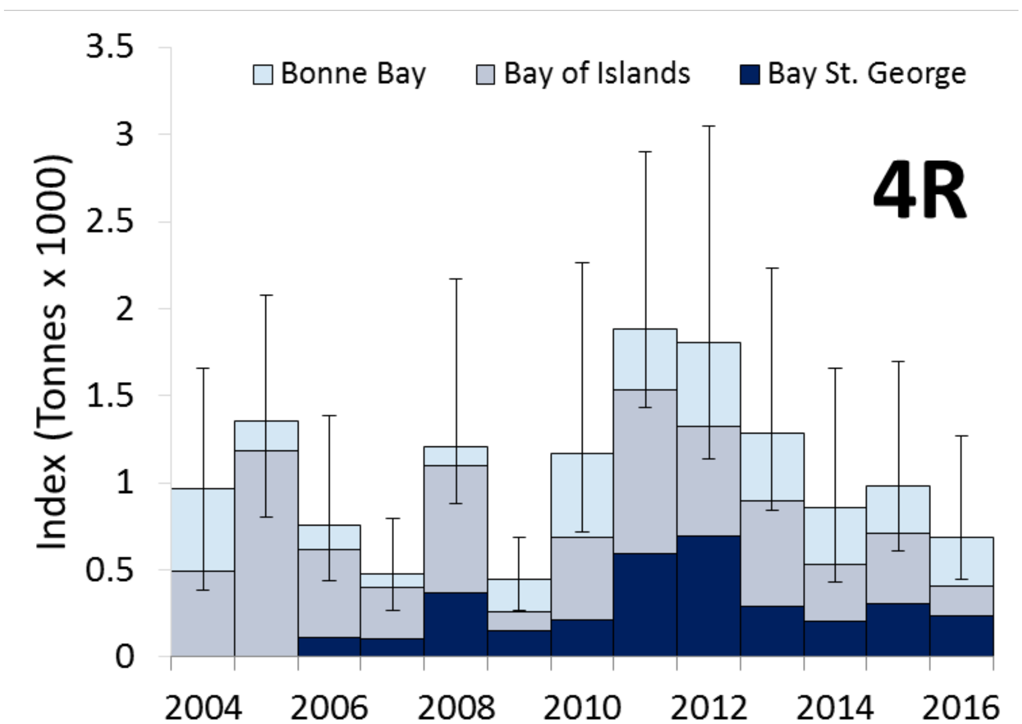

Figure 27. Trends in the trap survey-based exploitable biomass index for Assessment Div. 4R.

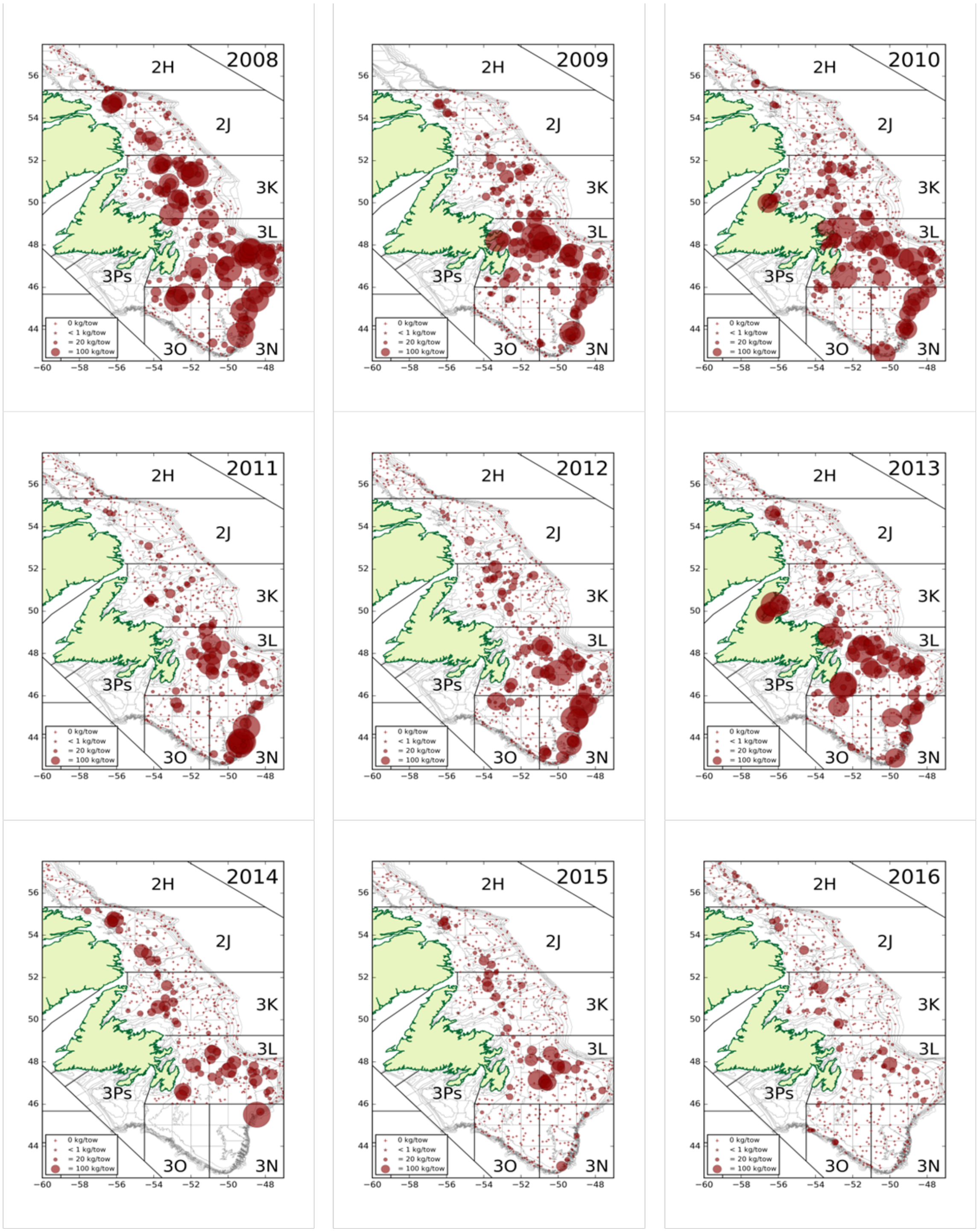

Figure 28. Distribution of exploitable males (#/tow) from Divs. 2HJ3KLNO fall bottom trawl surveys from 2008-16. Data standardized by vessel and diel cycle.

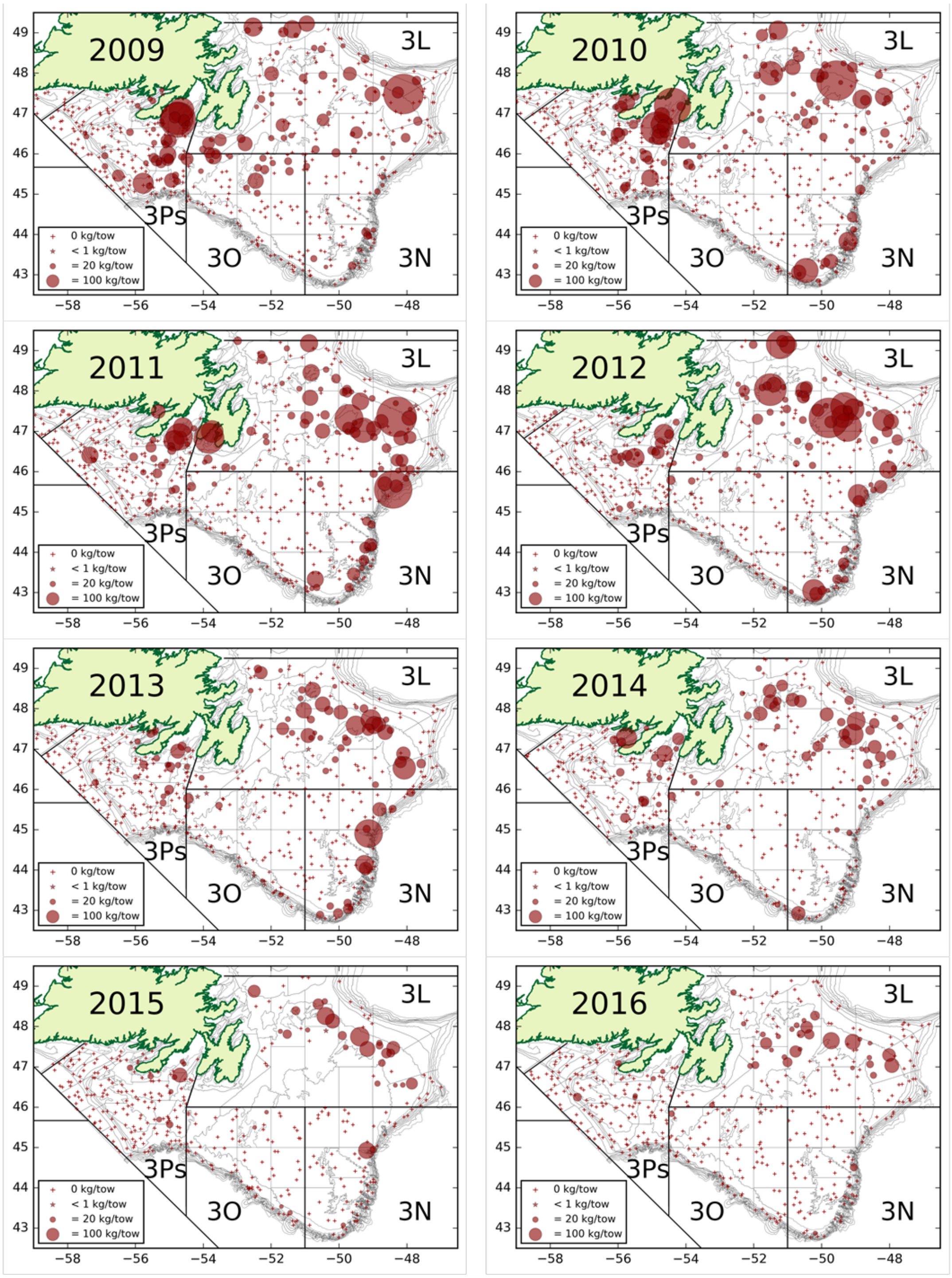

Figure 29. Distribution of exploitable males (#/tow) from Divs. 3LNO and Subdiv. 3Ps spring bottom trawl surveys from 2008-16. Data standardized by vessel and diel cycle.

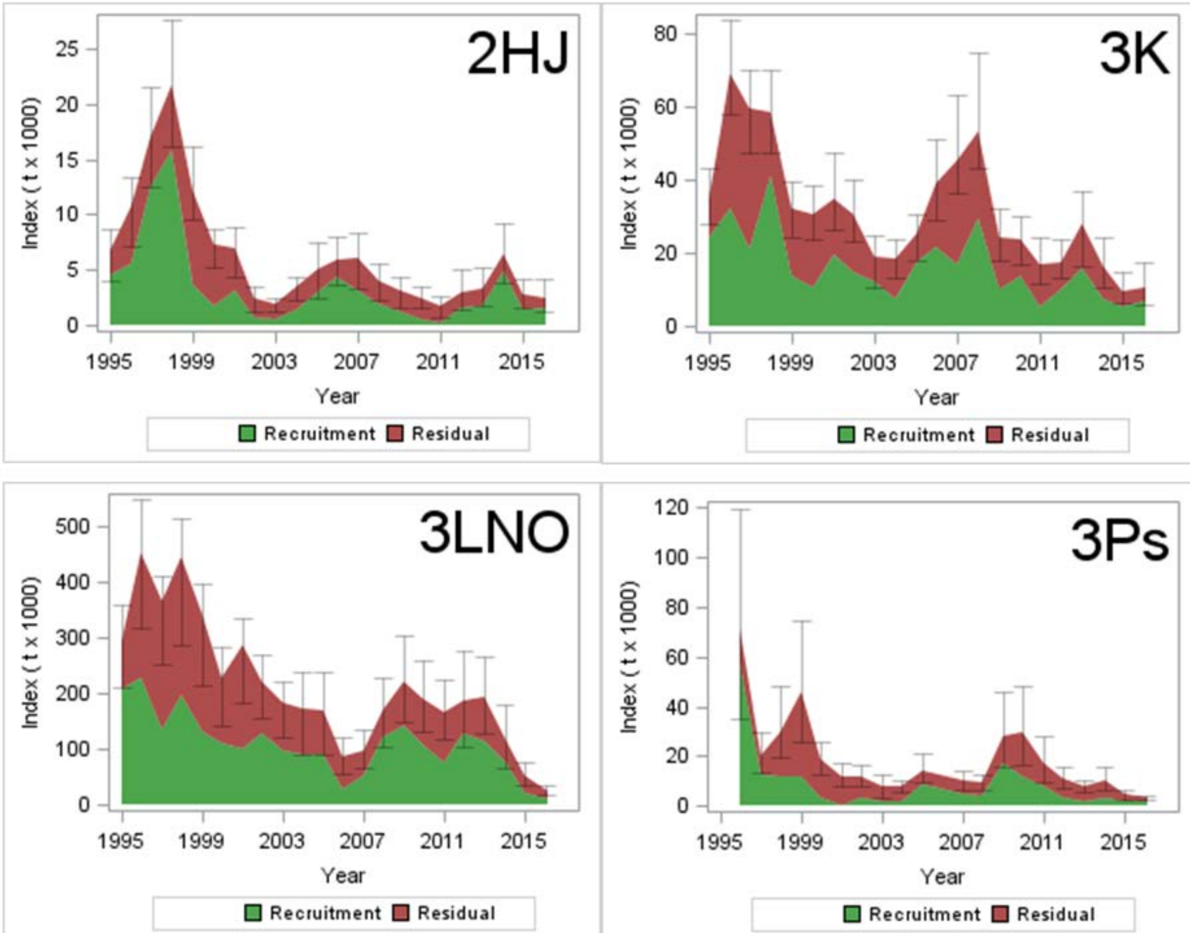

Figure 30.Trawl survey exploitable biomass indices by shell condition and Assessment Division. Soft and new-shell crab represent recruitment and intermediate and old-shell crab represent residual biomass.

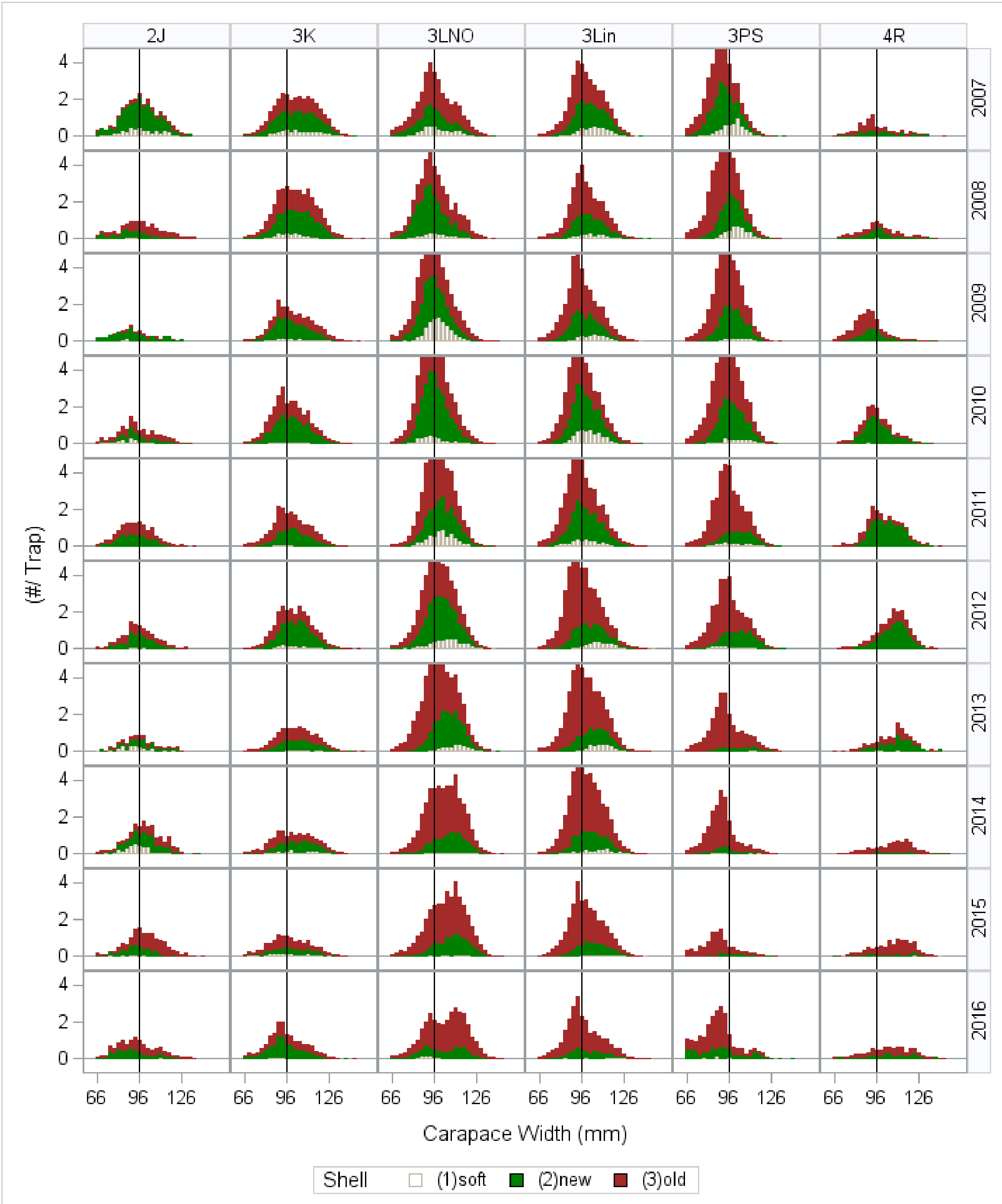

Figure 31. Trends in male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey by Assessment Division. The vertical line indicates the minimum legal size.

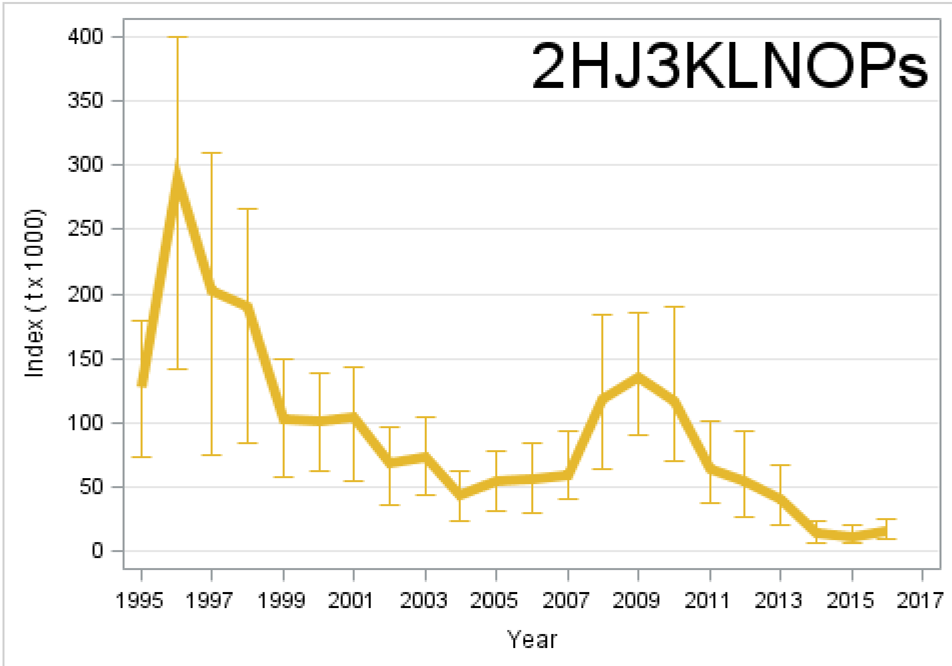

Figure 32. Overall trawl survey pre-recruit biomass index for Divs. 2HJ3KLNO and Subdiv. 3Ps (1995-2016). Index is the sum of annual point estimates and confidence intervals for individual Assessment Divisions.

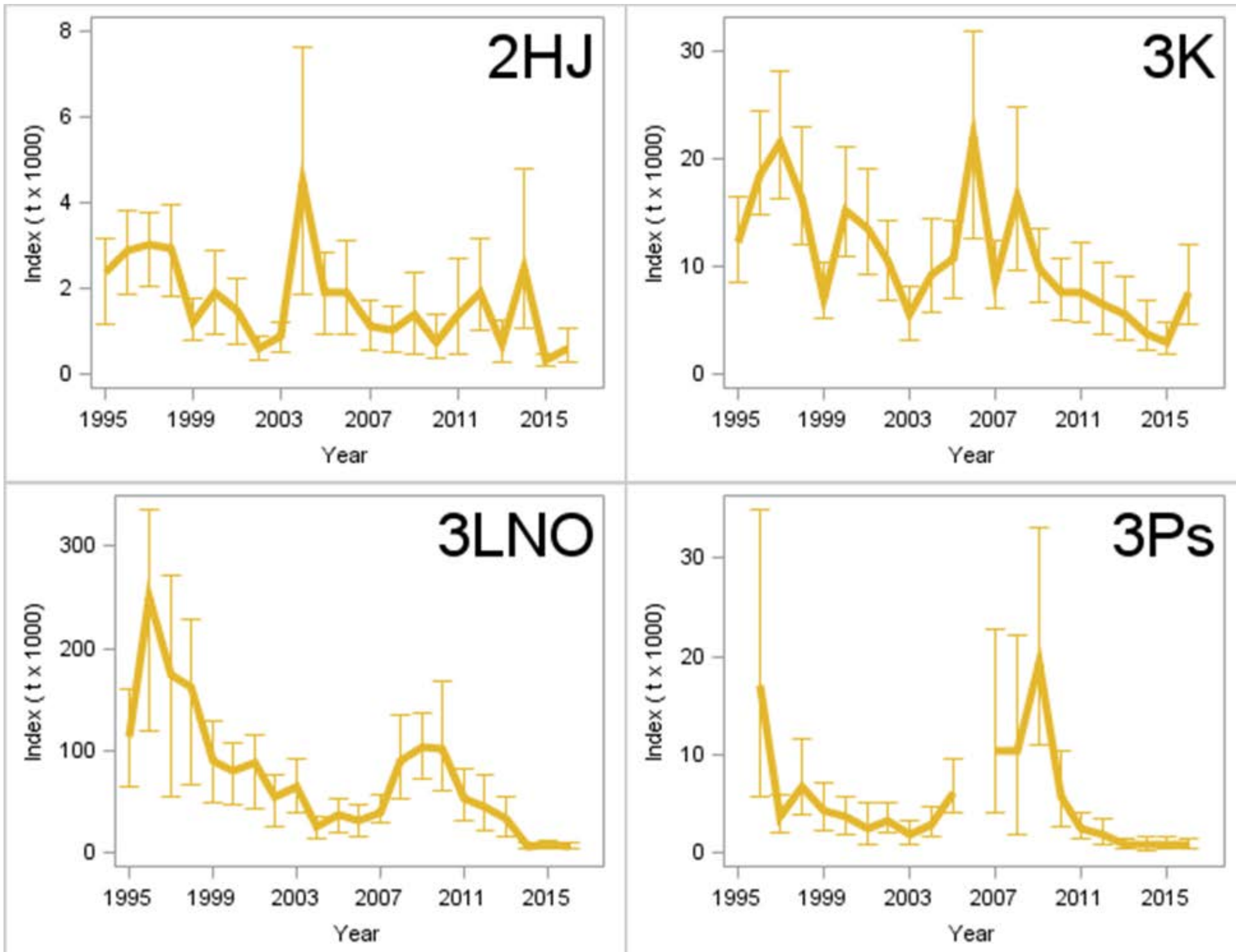

Figure 33.Trawl survey pre-recruit biomass indices by Assessment Division.

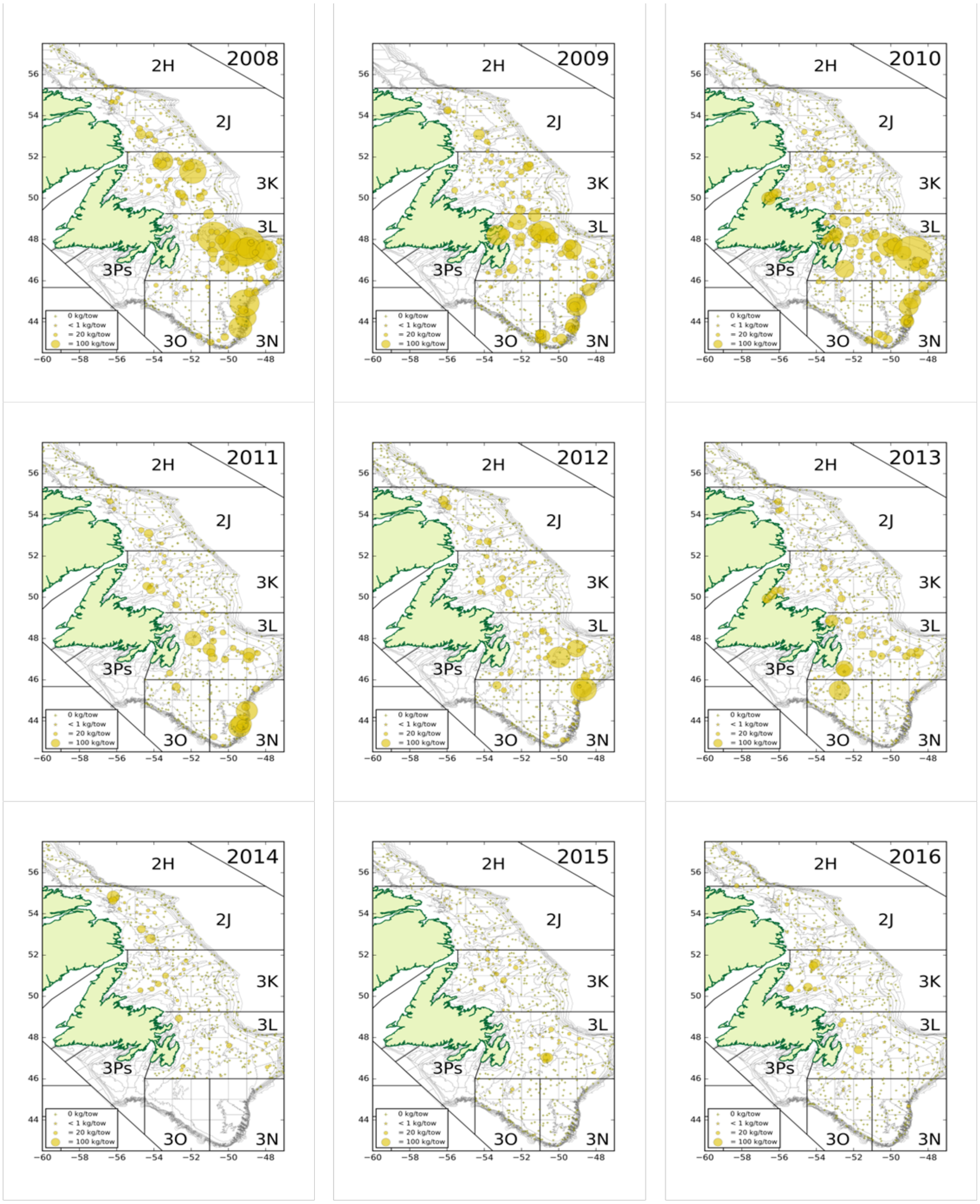

Figure 34. Distribution of pre-recruit males (#/tow) from Divs. 2HJ3KLNO fall bottom trawl surveys (2008-16). Data standardized by vessel and diel cycle.

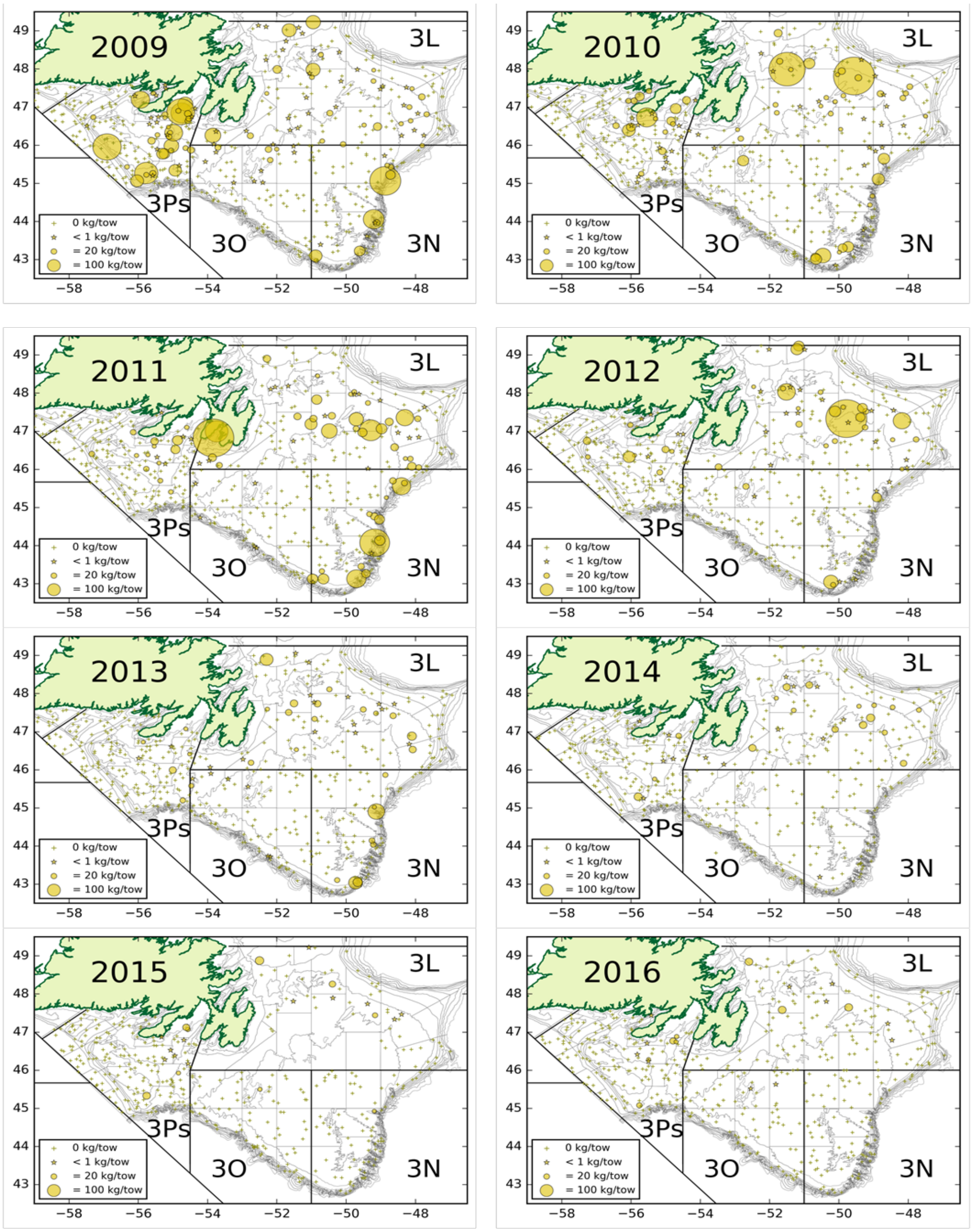

Figure 35. Distribution of pre-recruit males (#/tow) from Divs. 3LNO and Subdiv. 3Ps spring bottom trawl surveys (2008-16). Data standardized by vessel and diel cycle.

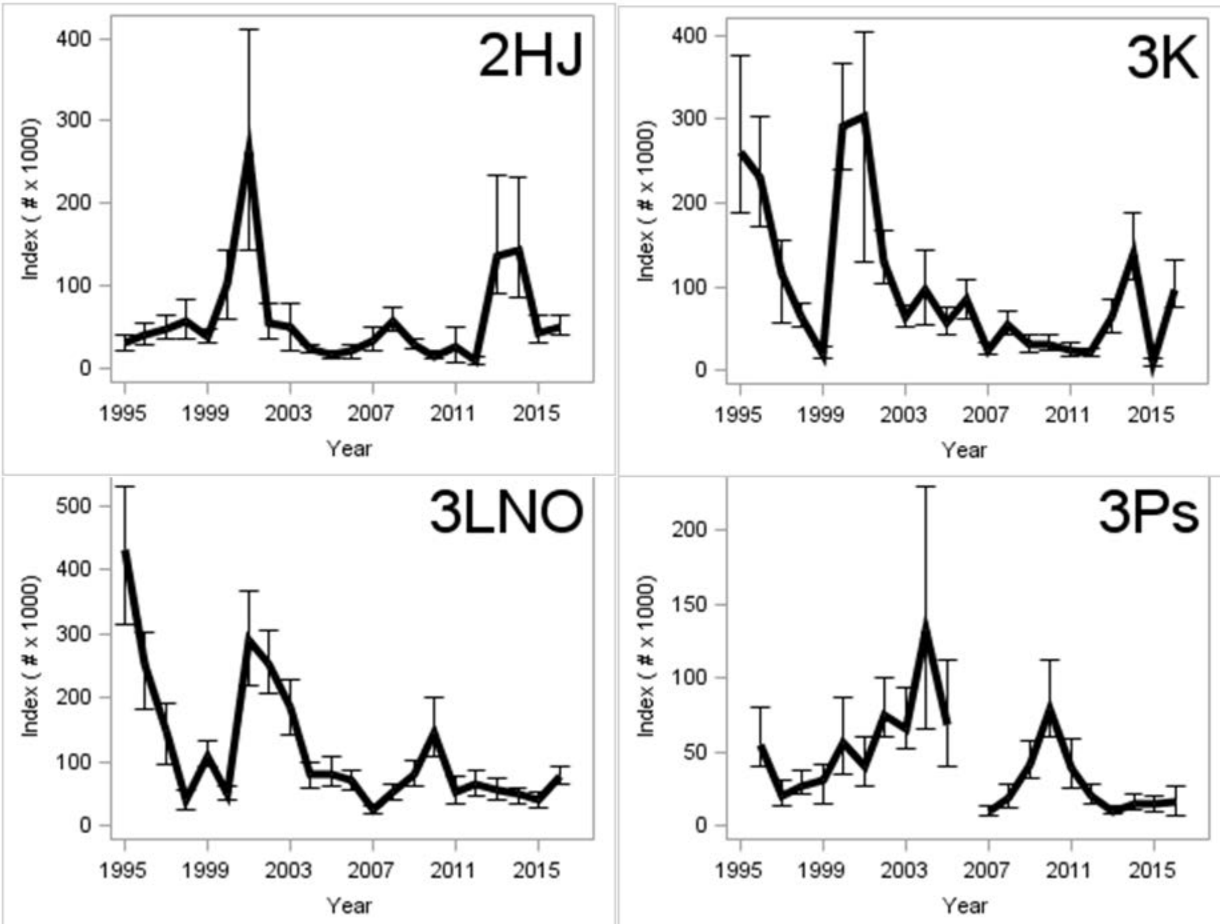

Figure 36. Trawl survey indices of small crab (<50 mm CW) abundance by Assessment Division. Data standardized by diel cycle.

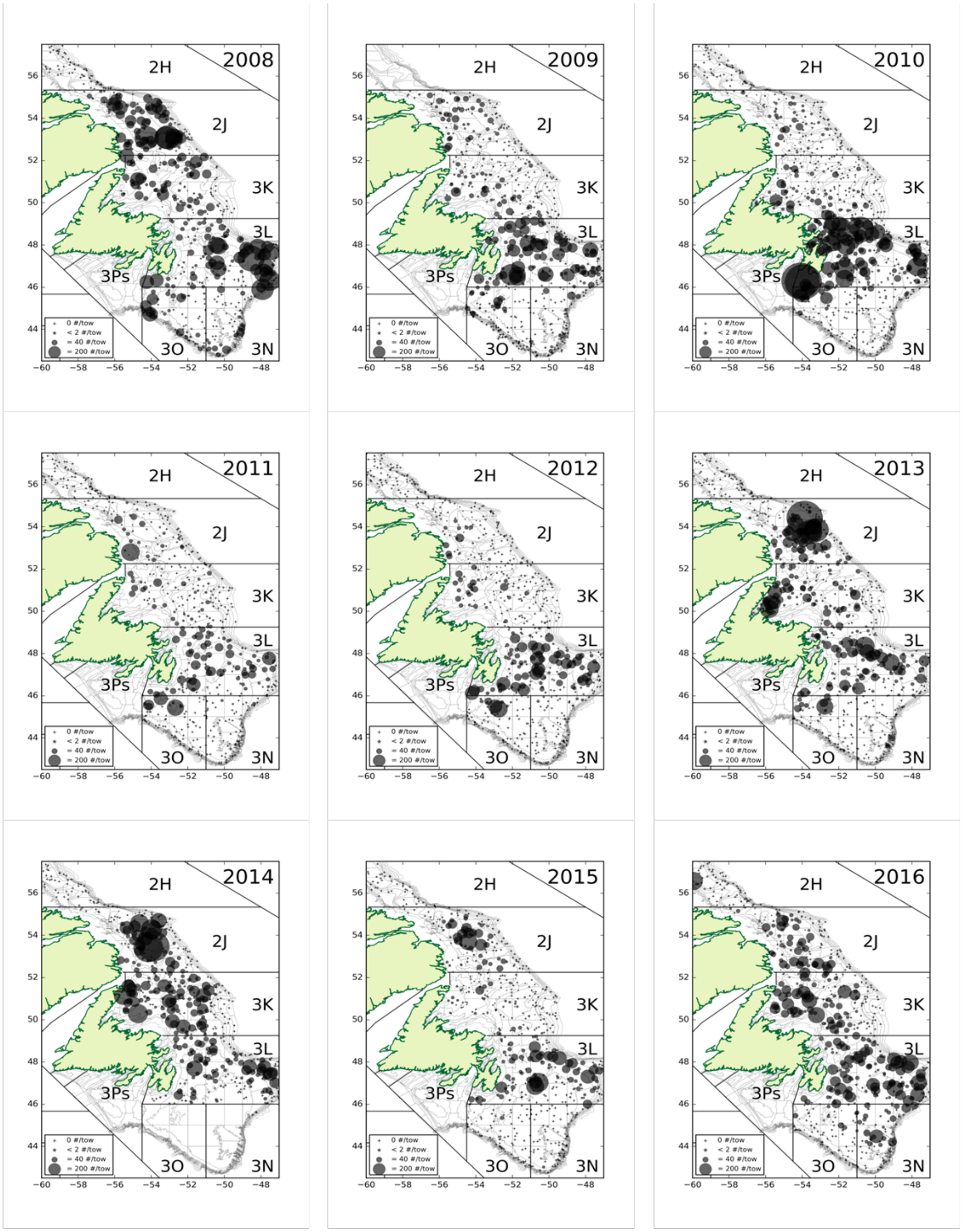

Figure 37. Distribution of small (<50 mm CW) crab (#/tow) from Divs. 2HJ3KLNO fall bottom trawl surveys (2008-16). Data standardized by diel cycle.

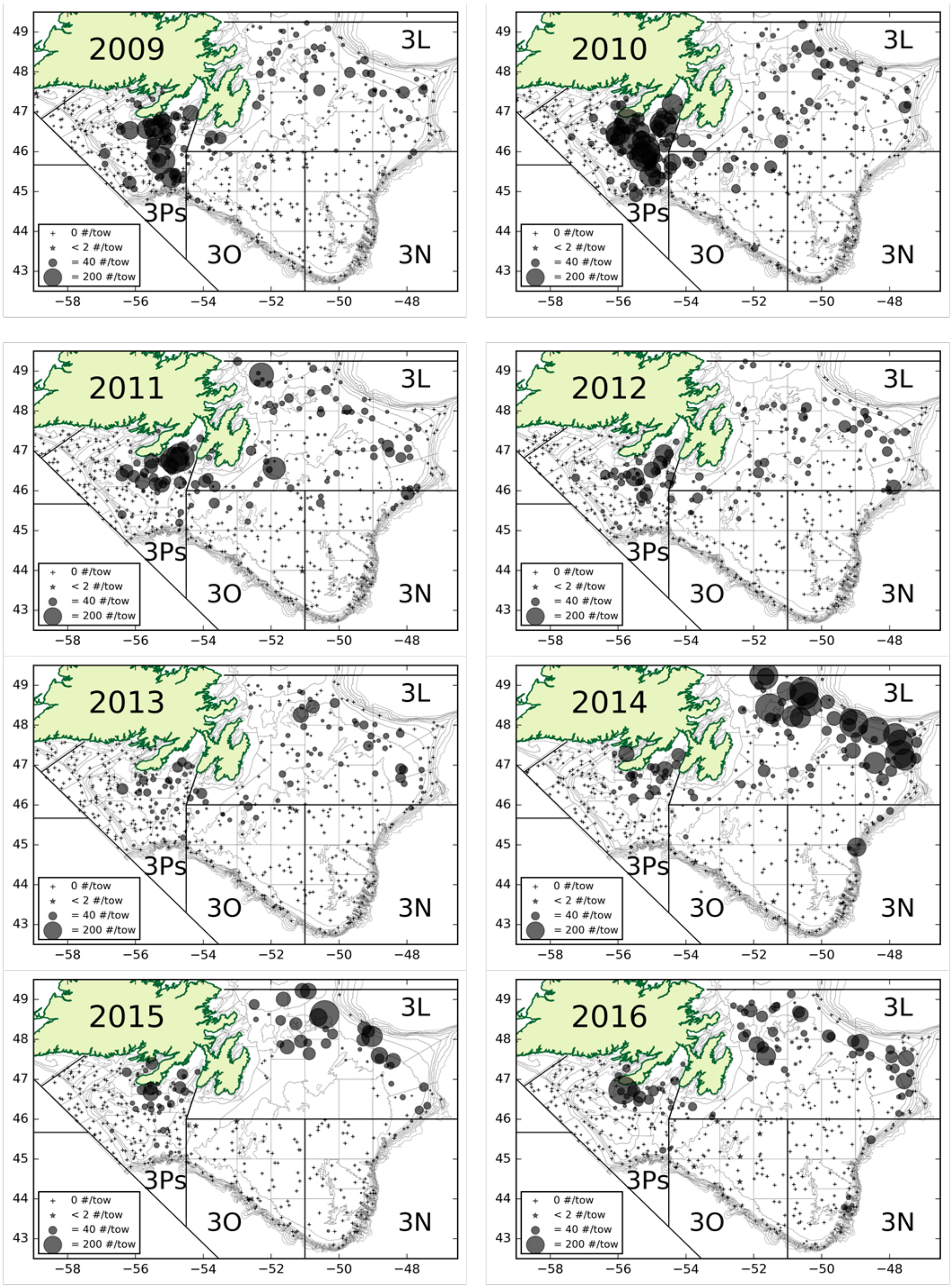

Figure 38. Distribution of small (<50 mm CW) crab (#/tow) from Divs. 3LNO and Subdiv. 3Ps spring trawl surveys (2008-16). Data standardized by diel cycle.

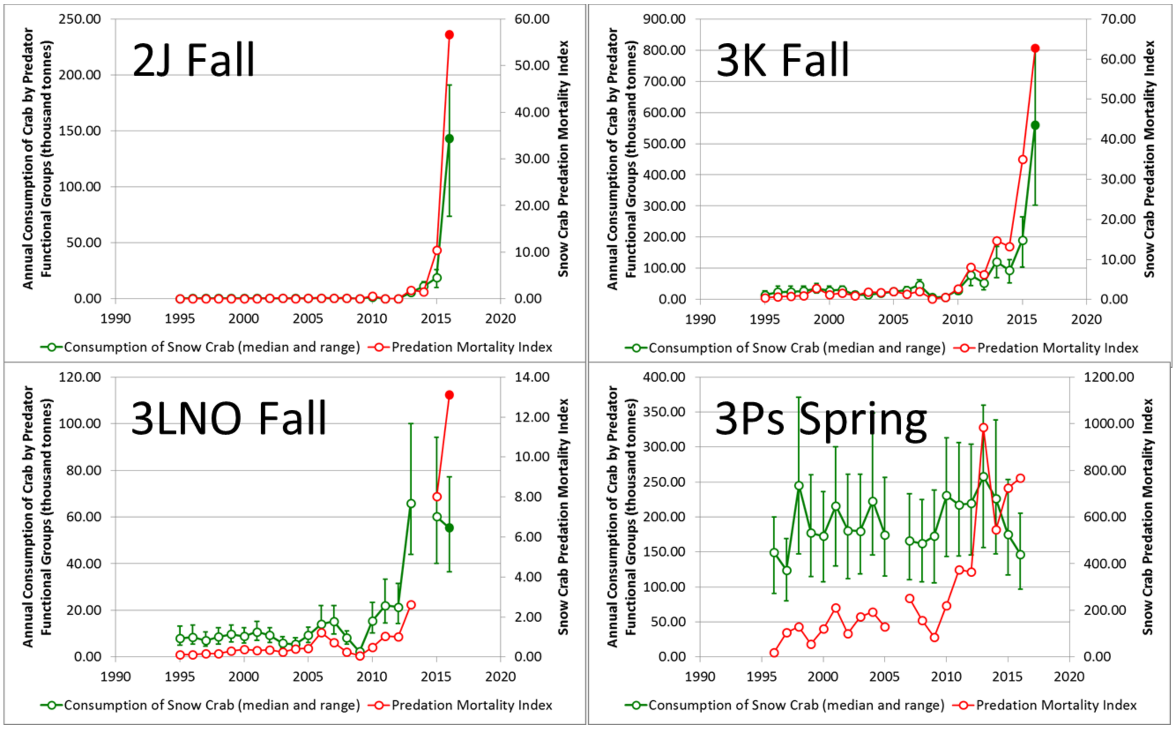

Figure 39. Consumption of snow crab by predators by Assessment Division. Green represents estimated consumption and red is an index of predation mortality. Solid symbols in 2016 denote preliminary data, with only cod and turbot stomachs processed to date.

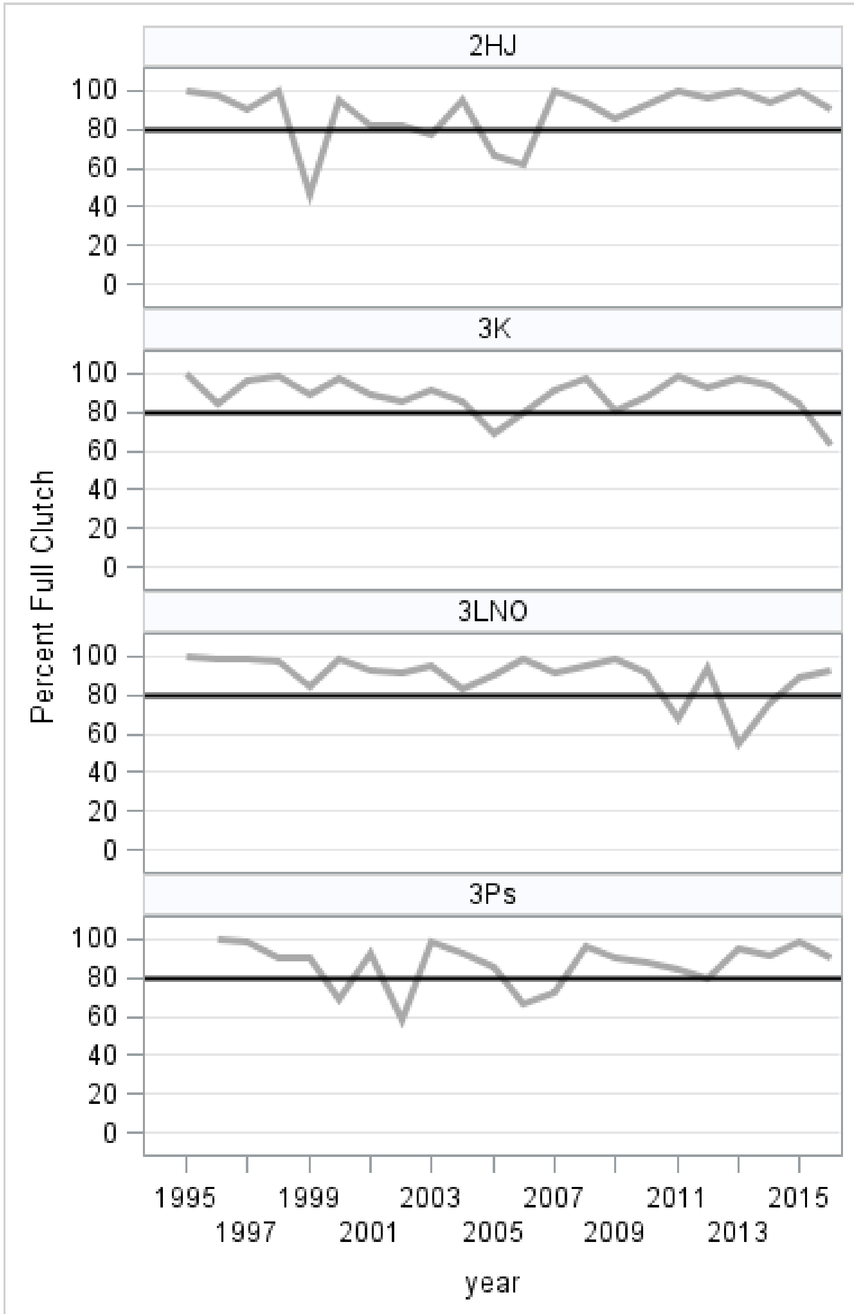

Figure 40. Trends in the percentage of mature females bearing full clutches of viable eggs in fall and spring trawl surveys by Assessment Division.

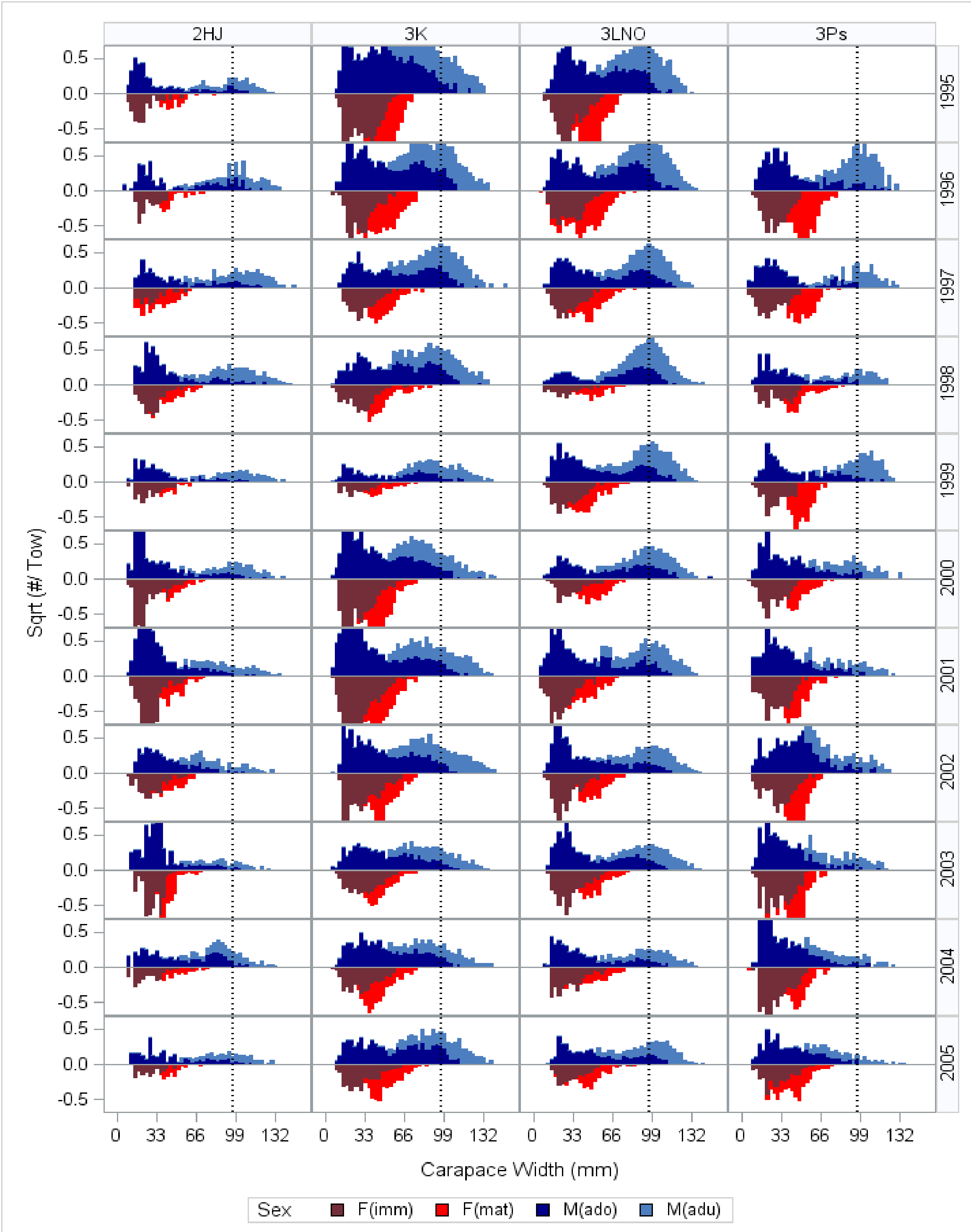

Figure 41. Abundance indices by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (Subdiv. 3Ps) and fall (Divs. 2HJ3KLNO) trawl surveys (1995-2005). Dashed vertical line is legal-size. Data standardized by vessel and diel cycle.

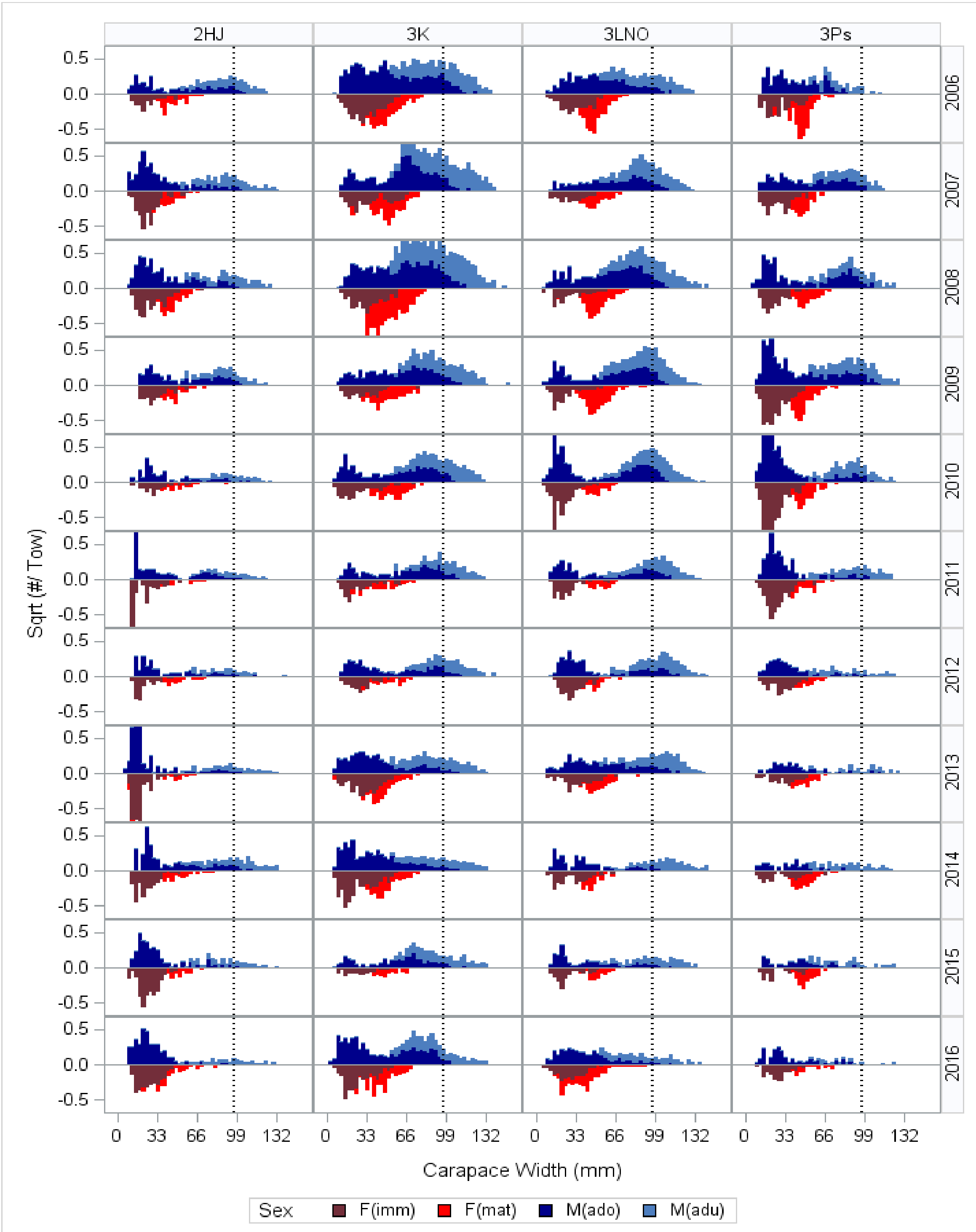

Figure 42. Abundance indices by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (Subdiv. 3Ps) and fall (Divs. 2HJ3KLNO) trawl surveys (2006-16). Dashed vertical line is legal-size. Data standardized by vessel and diel cycle.

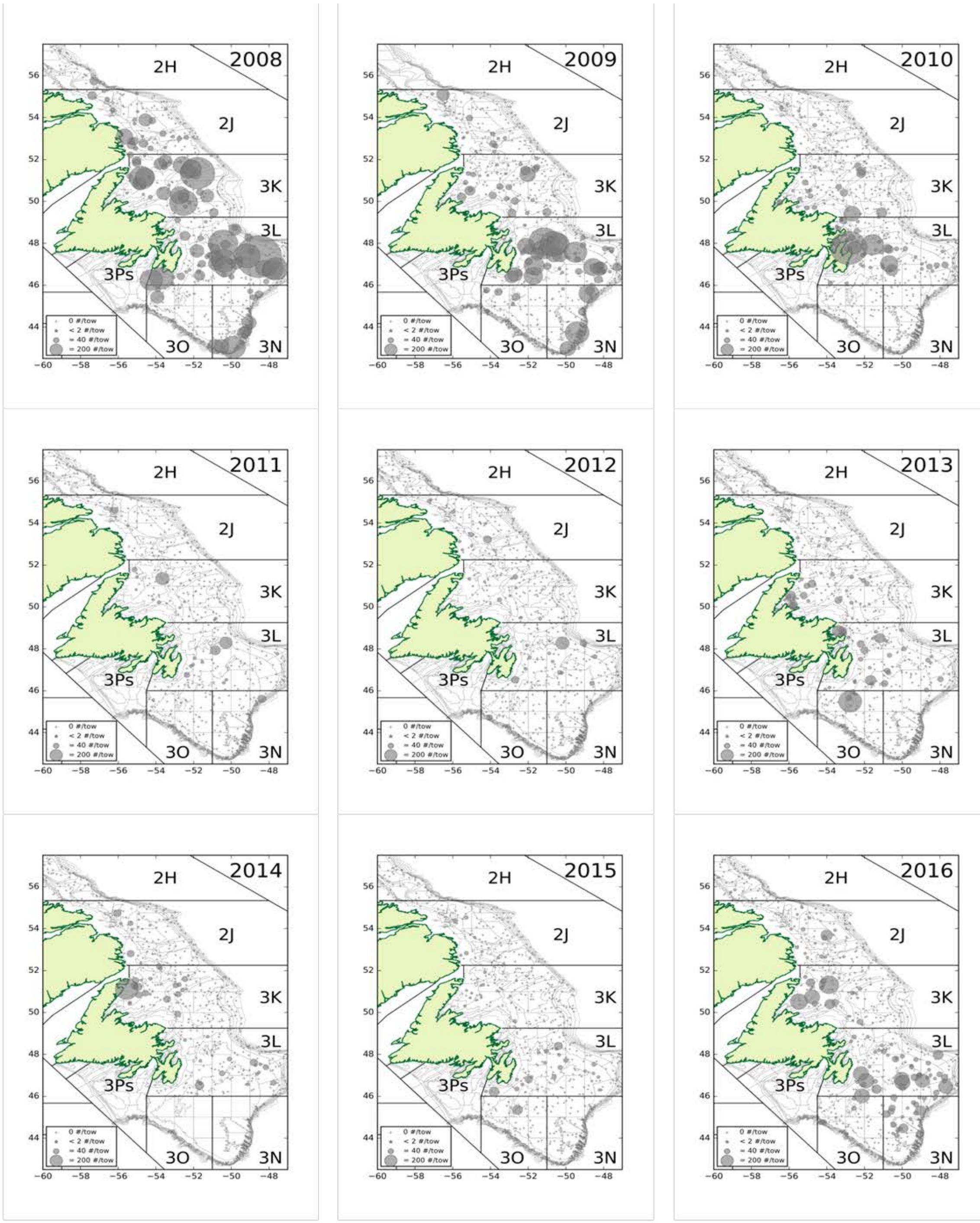

Figure 43. Distribution of mature females (#/tow) from Divs. 2HJ3KLNO fall bottom trawl surveys (2008-16). Data standardized by diel cycle.

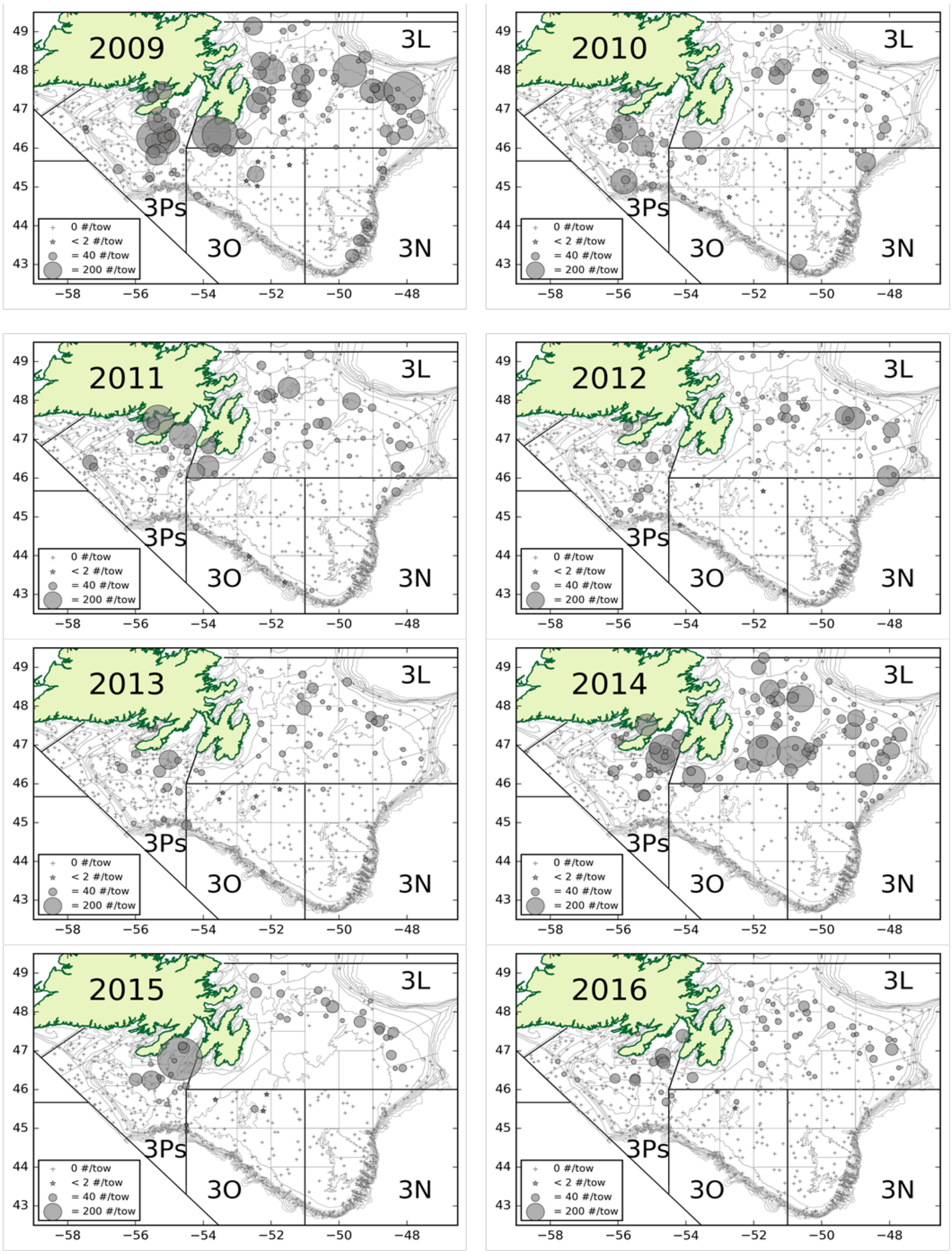

Figure 44. Distribution of mature females (#/tow) from Divs. 3LNOPs spring bottom trawl surveys (2008-16). Data standardized by diel cycle.

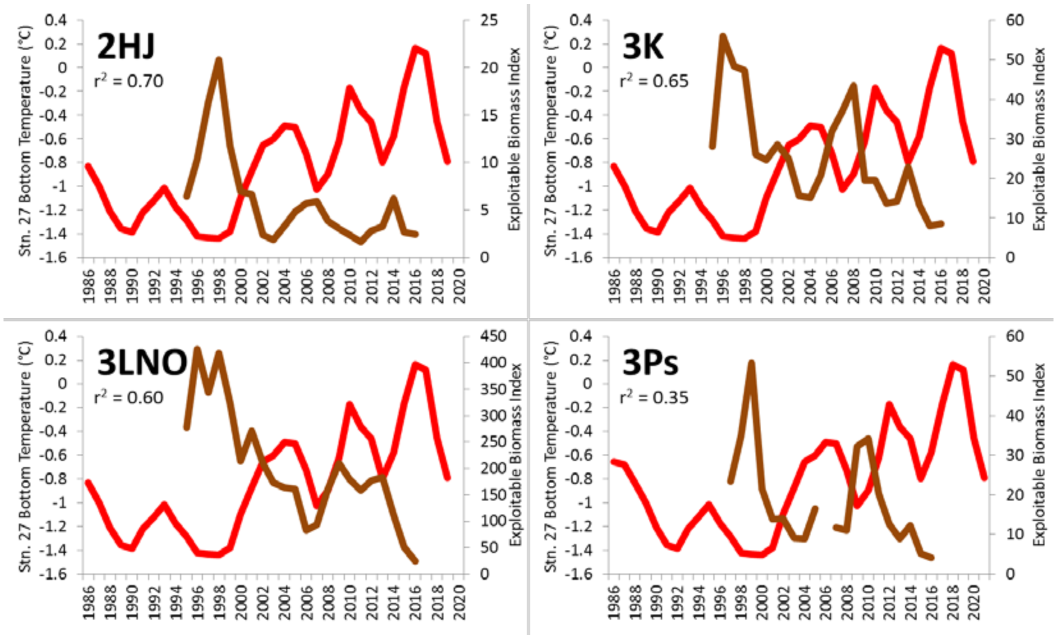

Figure 45. 3-year moving average, ending in the terminal years, of spring (March-June) bottom temperatures at Station 27 (red line) versus exploitable biomass indices (brown line) by Assessment Division. Temperature index lagged by three years in Divs. 2HJ, 3K, and 3LNO, and five years in Subdiv. 3Ps.

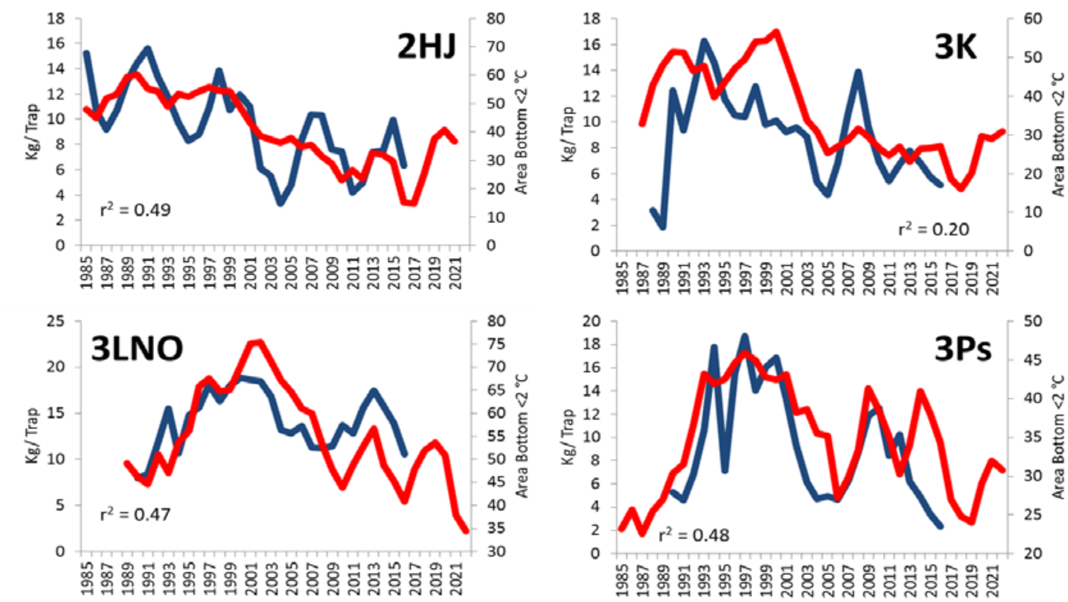

Figure 46. Lagged snow crab thermal habitat indices versus fishery CPUE by Assessment Division. Index defined as a three year moving average, ending in the terminal year, of fall bottom temperatures below 2°C in Divs. 2HJ and 3K, and as a three-year moving average of spring bottom temperatures below 1°C in Divs. 3LNO and Subdiv. 3Ps. Thermal habitat indices lagged by 5 years in Divs. 2HJ, 6 years in Div. 3K and Subdiv. 3Ps, and 10 years in Divs. 3LNO.

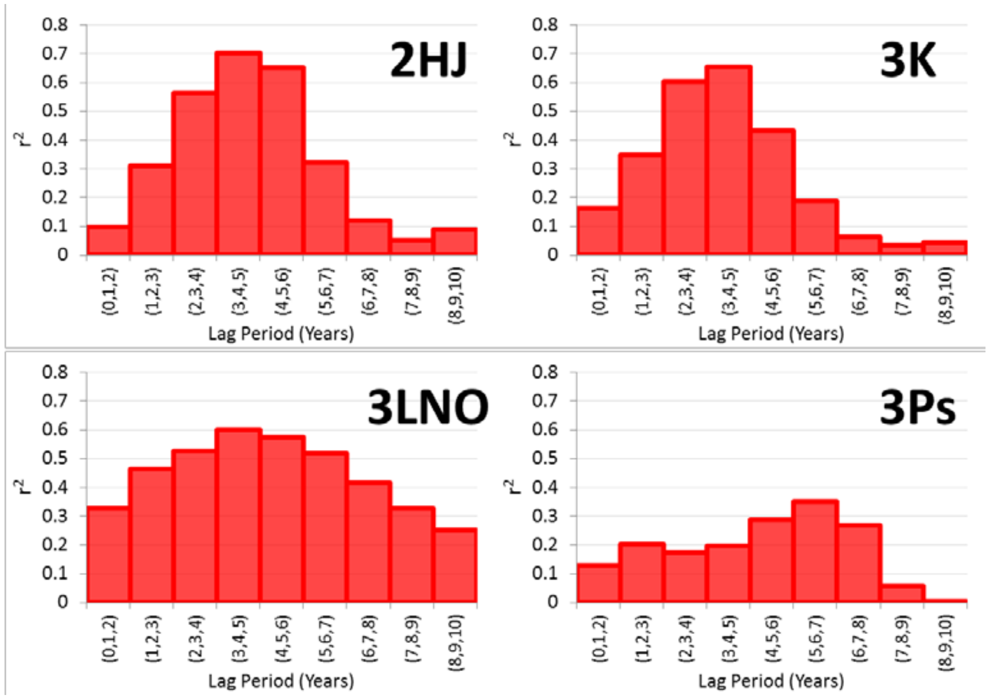

Figure 47. Coefficients of determination for relationships of lagged spring bottom temperature from Station 27 with Snow Crab exploitable biomass indices by Assessment Division. Temperature index calculated as a three year moving average ending in the terminal year.

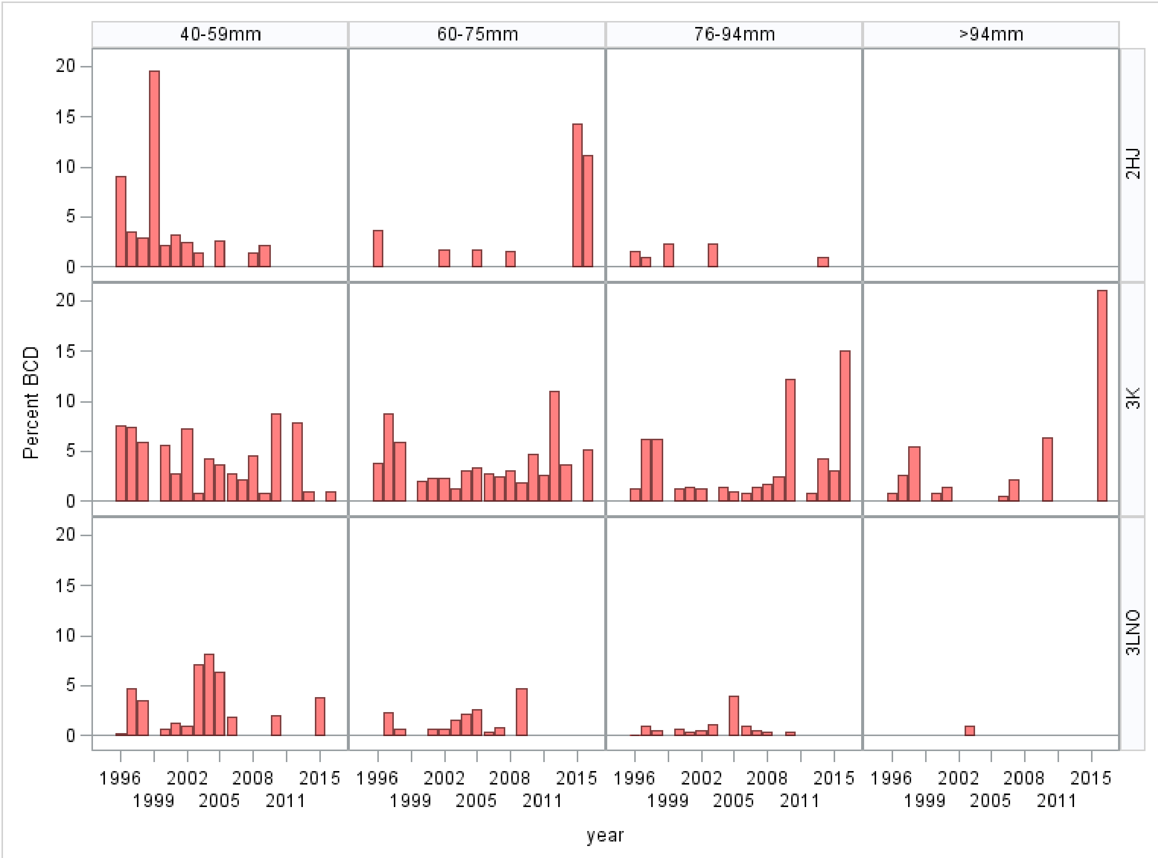

Figure 48. Annual trends in prevalence of Bitter Crab Disease from macroscopic observations in adolescent male crab in fall multi-species trawl surveys, by Assessment Division, year, and carapace width.

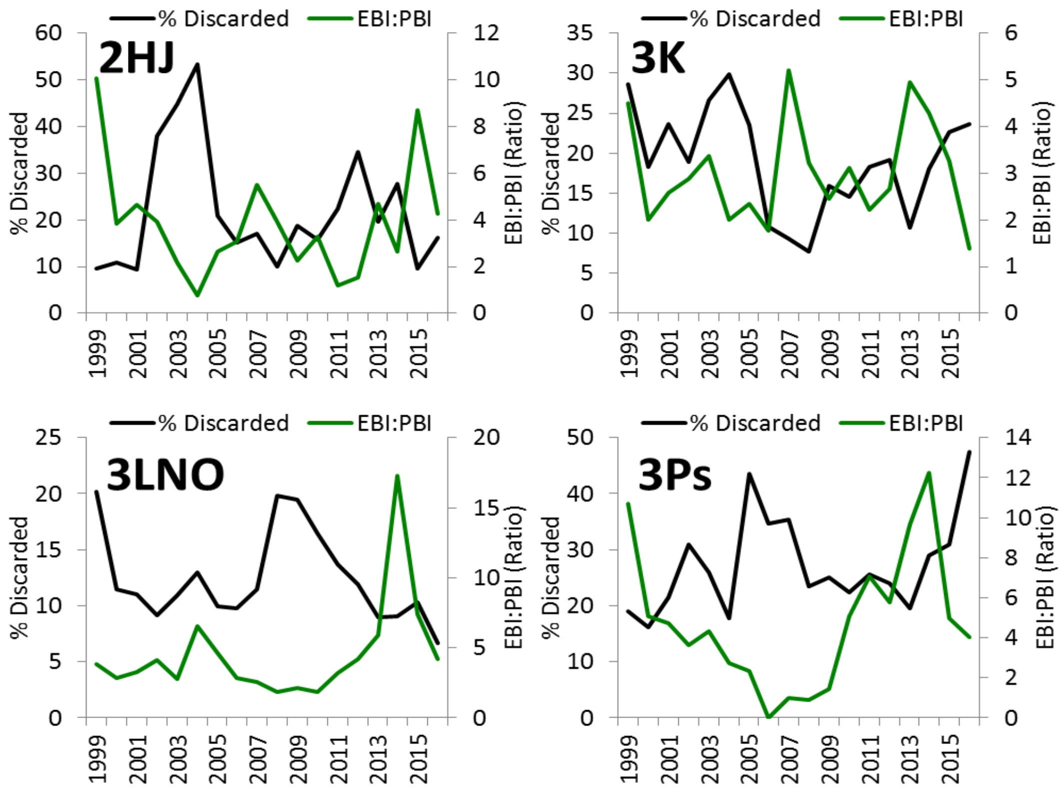

Figure 49. Trends in the ratio of exploitable to pre-recruit biomass indices from trawl surveys in relation to the observed percentage of the catch discarded in the fishery by Assessment Division.

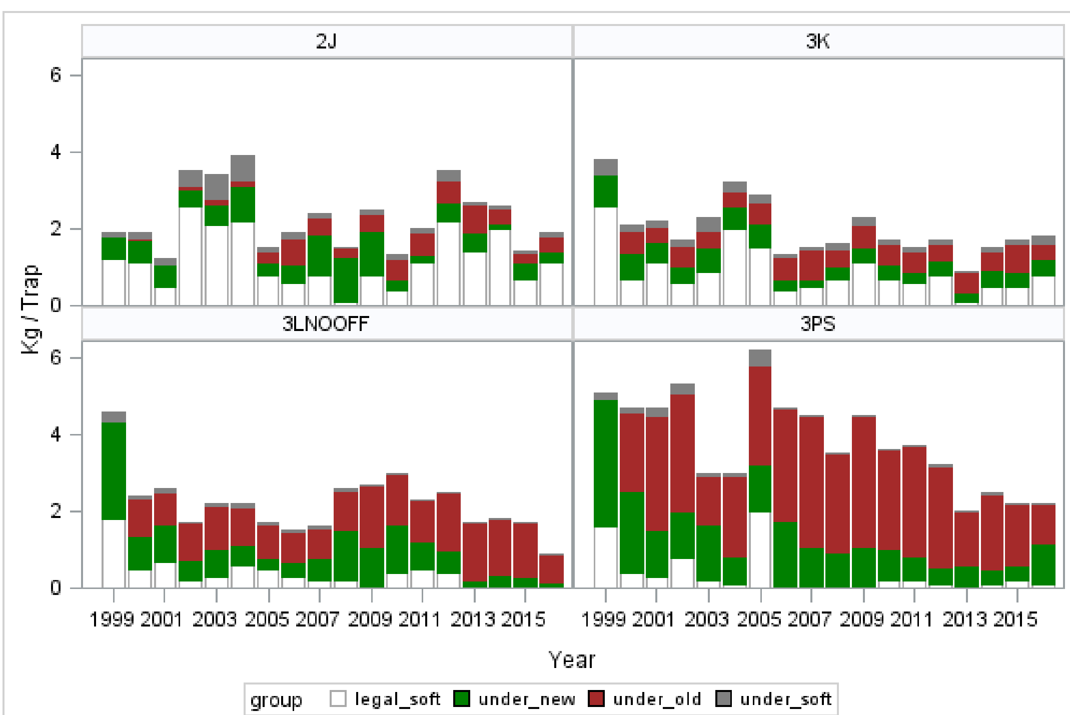

Figure 50. Trends in observed catch rates of total discards, undersized discards, and legal-sized soft-shelled discards by Assessment Division.

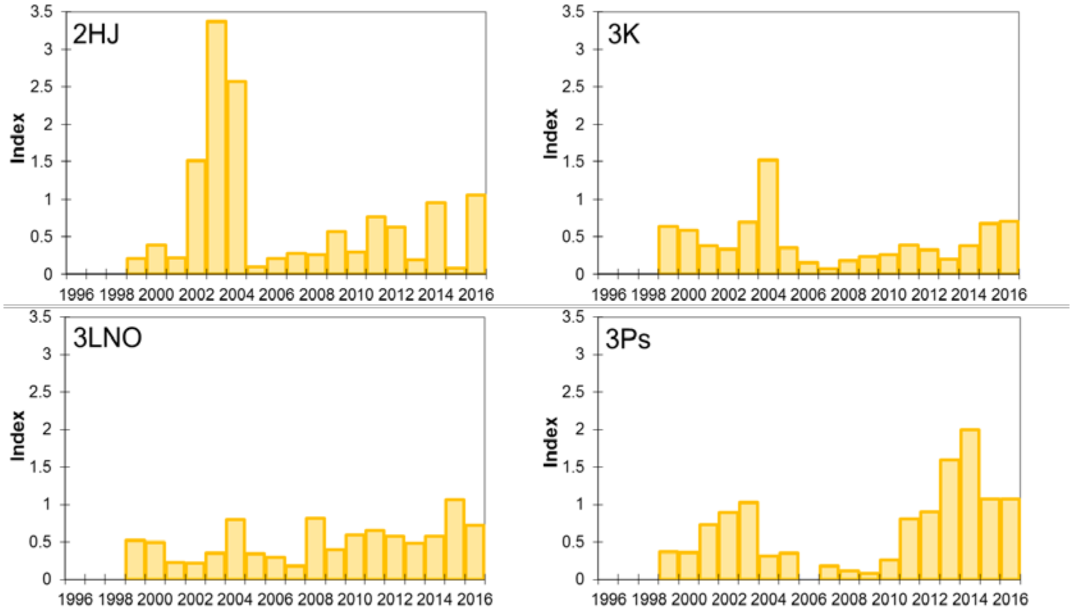

Figure 51. Trends in the pre-recruit fishing mortality rate index by Assessment Division.

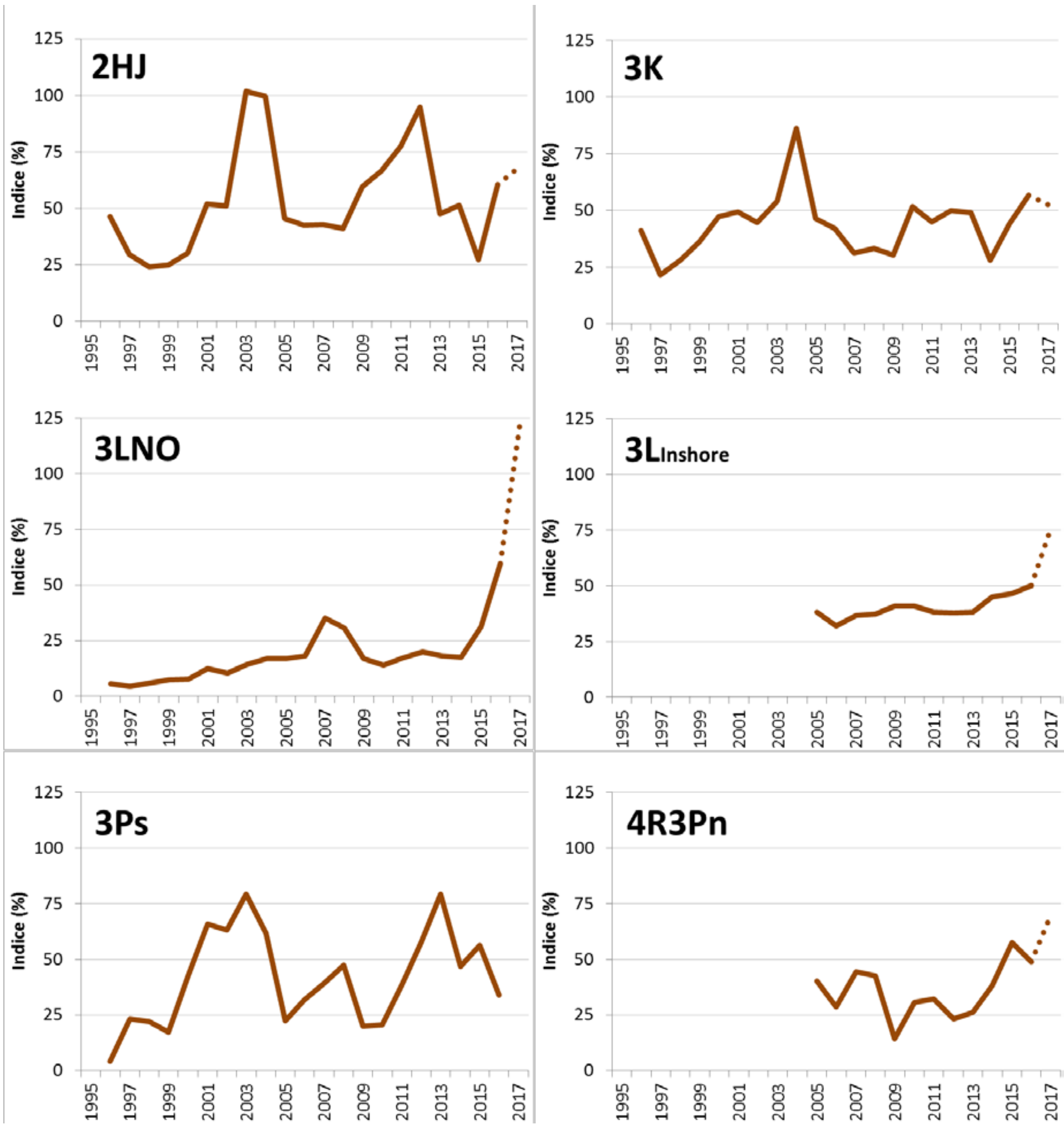

Figure 52. Trends in the exploitation rate indices by Assessment Division. Dashed lines depict projected 2017 exploitation rate indices based on status quo landings. Divs. 2HJ, 3K, 3LNO, and Subdiv. 3Ps based on trawl surveys. Divs. 3L Inshore and 4R based on trap surveys.

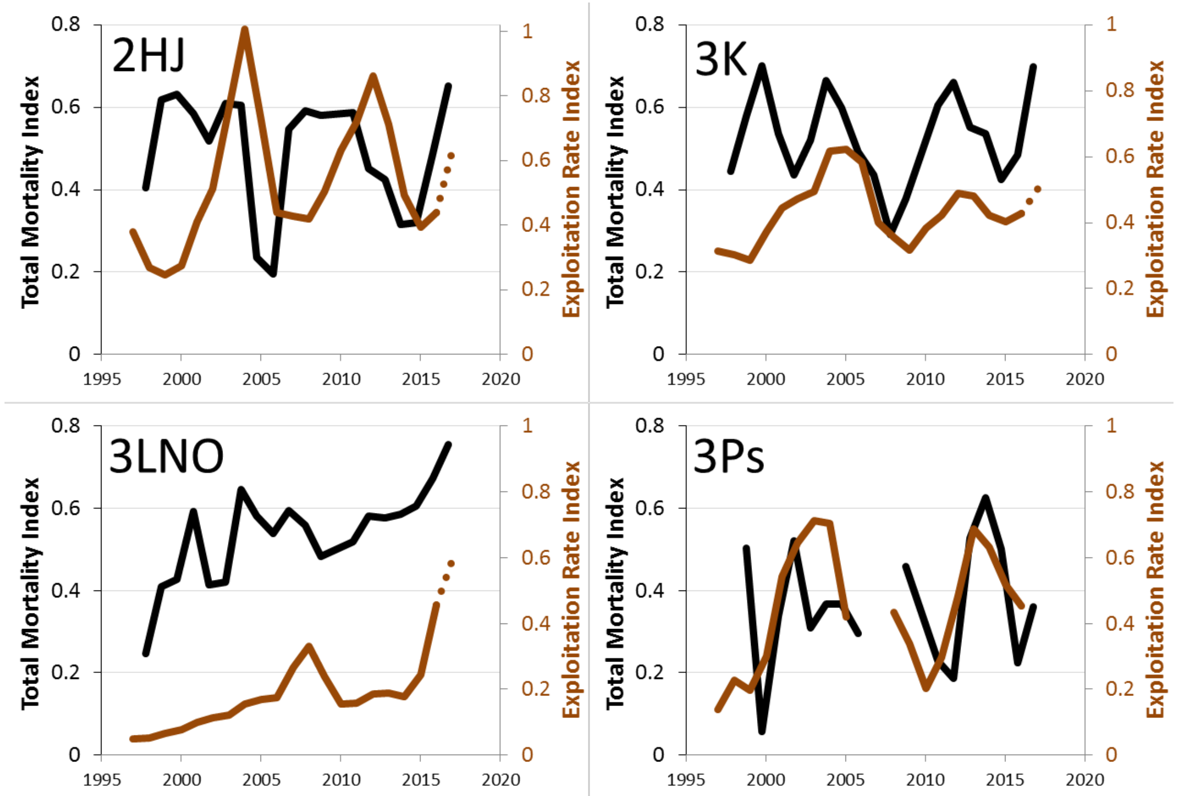

Figure 53. Comparison of trends in total mortality and exploitation rate indices by Assessment Division. Both indices calculated and shown as a two-year moving average. Dotted lines show projected exploitation rate indices in 2017 assuming status quo exploitation rates from 2016.

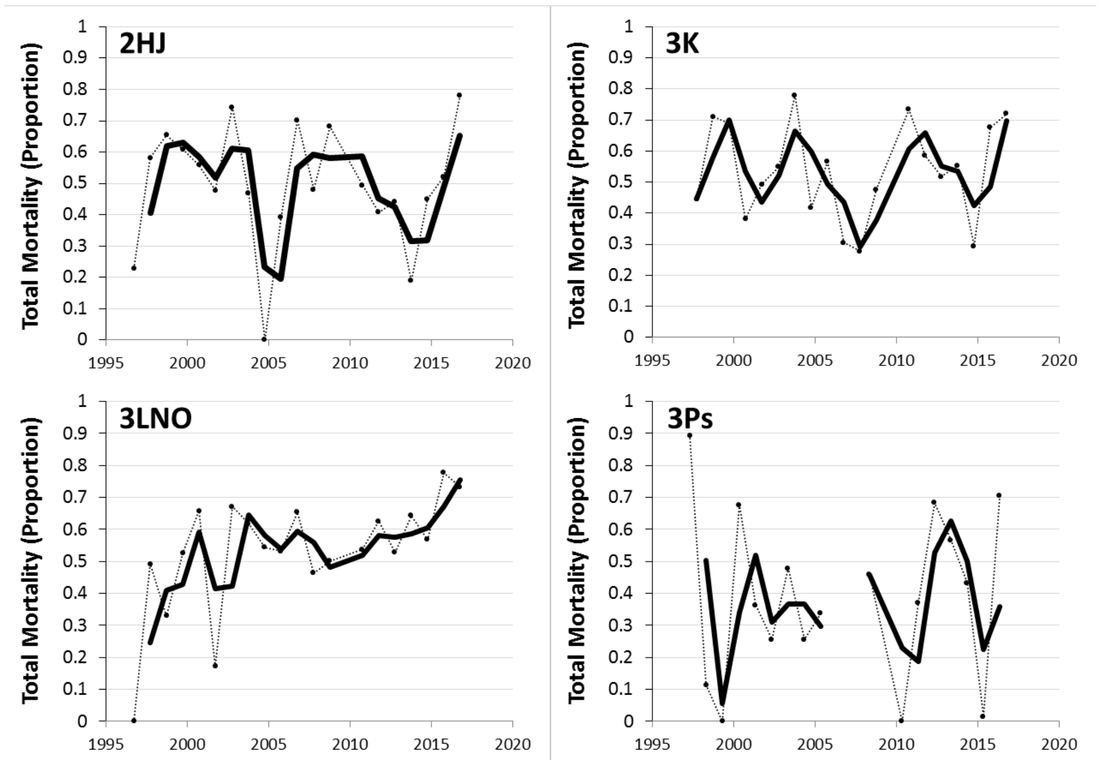

Figure 54. Trawl survey shell condition-based index of annual mortality of exploitable crab, by Assessment Division. Annual point estimates (thin lines) versus two period moving averages (thick lines).

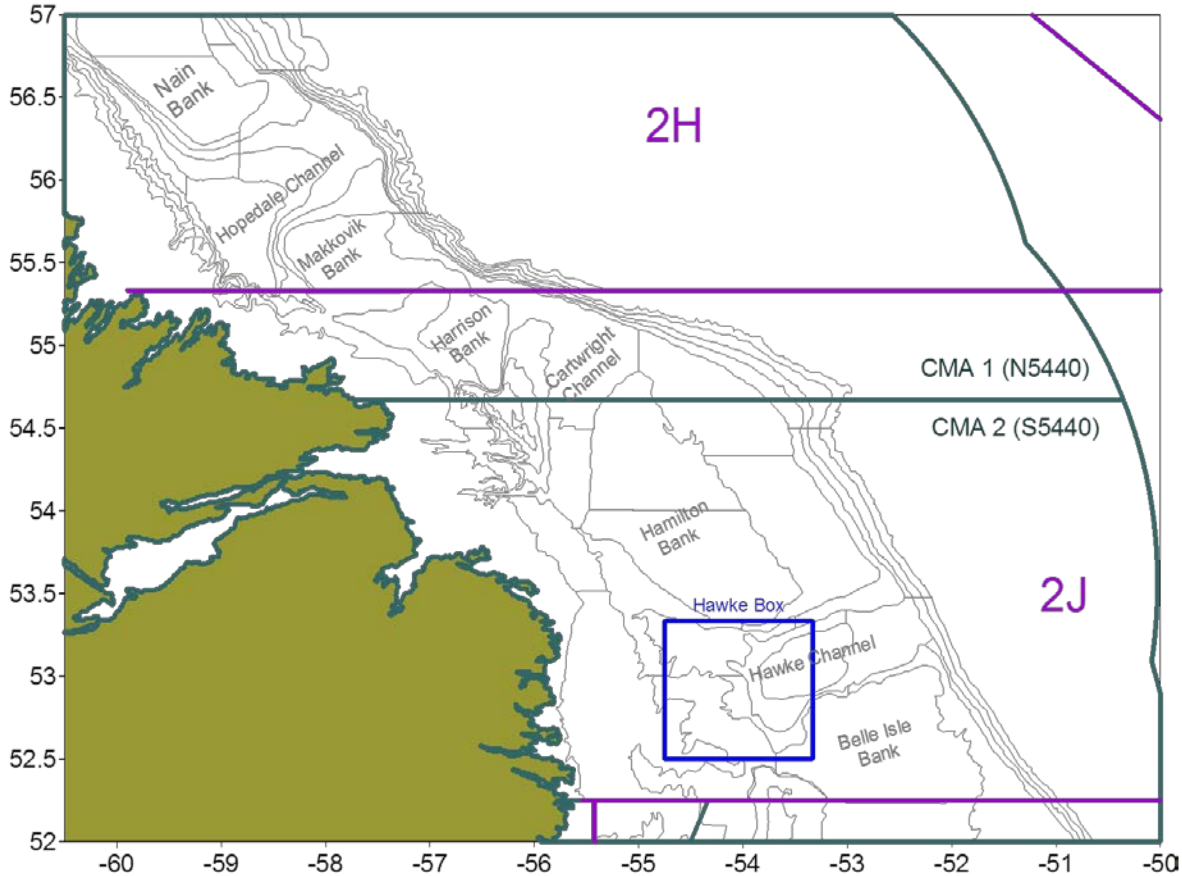

Figure 55. Map of Divs. 2HJ showing important bathymetric features, CMAs, and the Hawke Channel closure area.

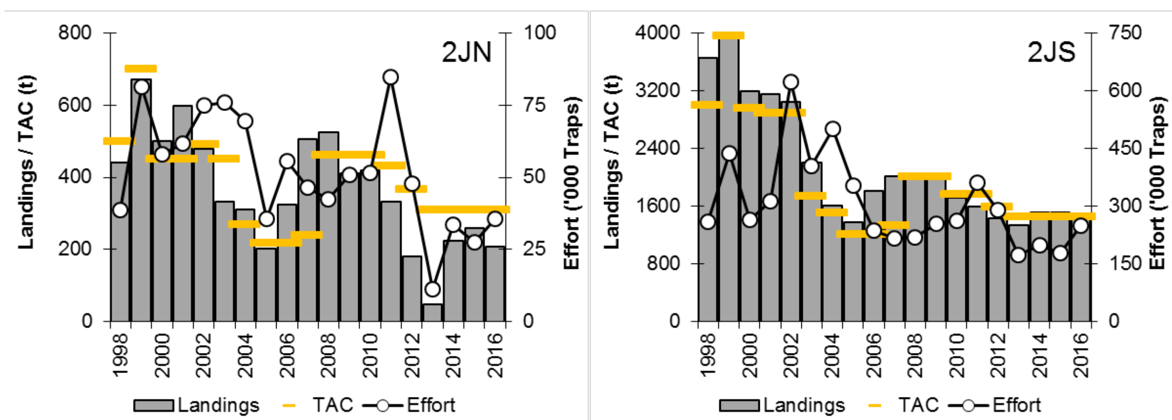

Figure 56. TAC, landings, and estimated effort for CMAs in Divs. 2HJ. 2016 effort is preliminary.

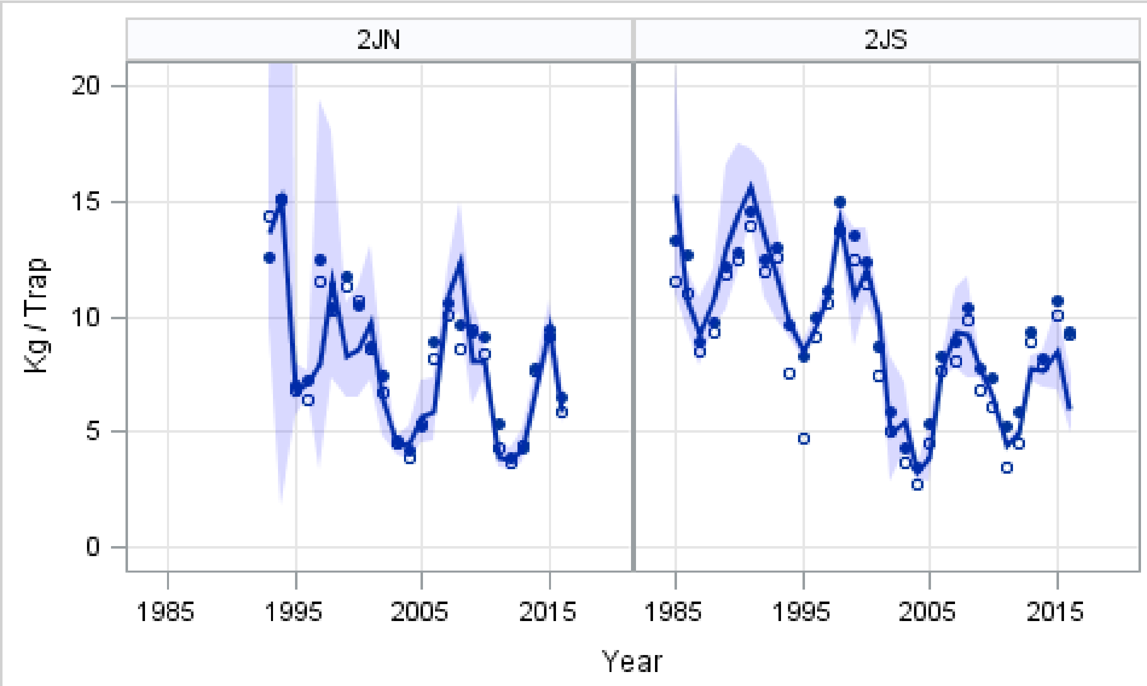

Figure 57. Trends in standardized CPUE (kg/trap) for CMAs in Divs. 2HJ. Open circles are medians and closed circles are means.

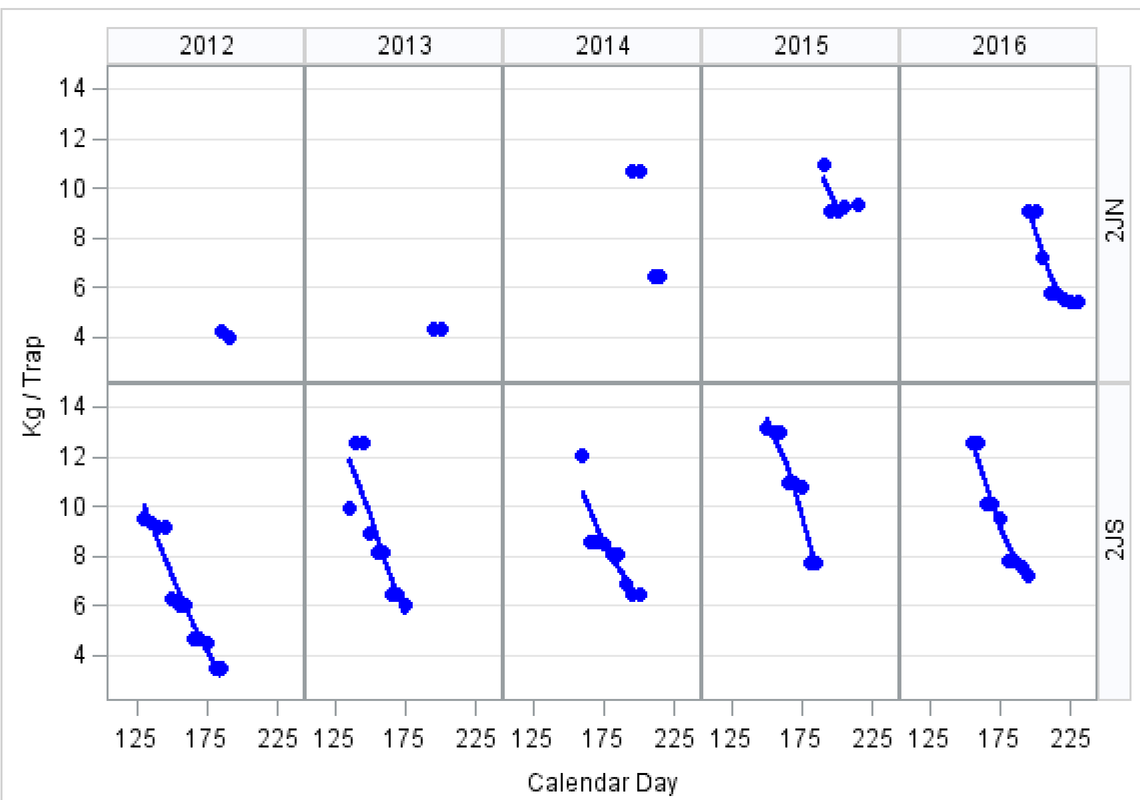

Figure 58. Trends in standardized CPUE (Kg/Trap) throughout the season fit with loess regression curves (2012-16), by CMA.

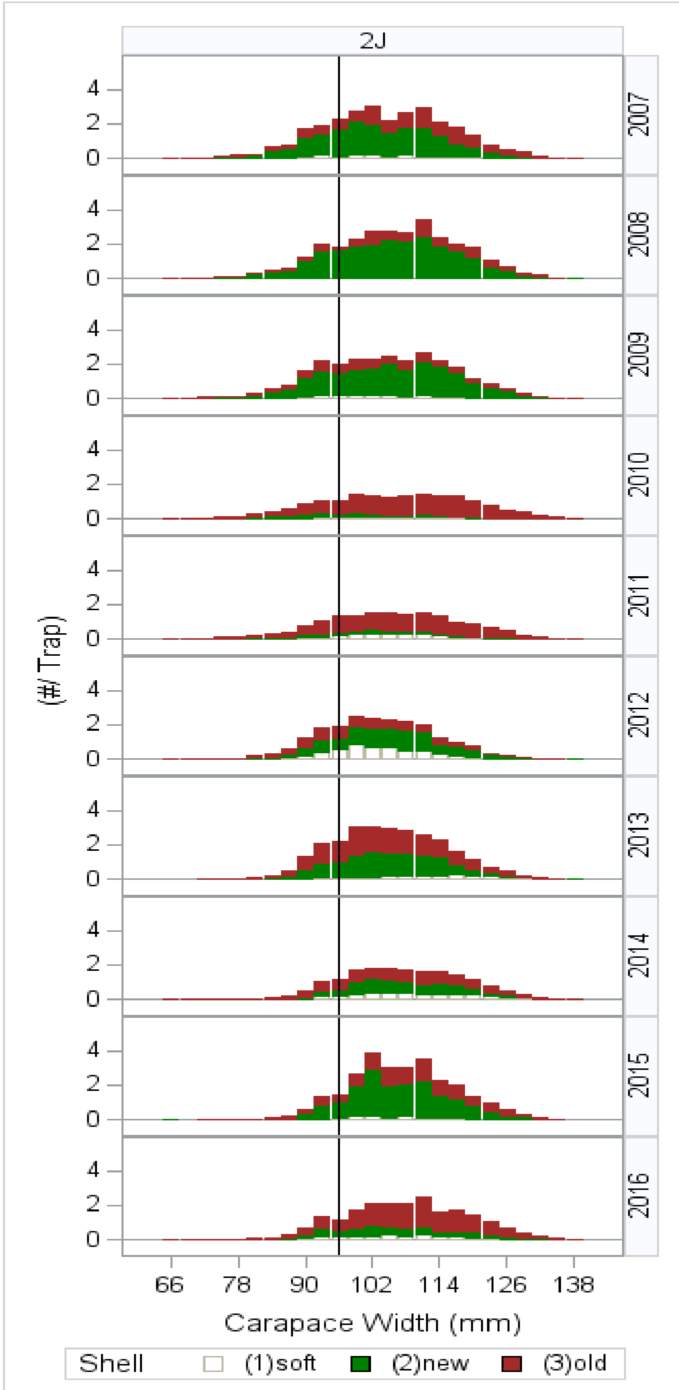

Figure 59. Trends in male carapace width distributions by shell condition from observer sampling in Divs. 2HJ (2007-16). The vertical line indicates the minimum legal size.

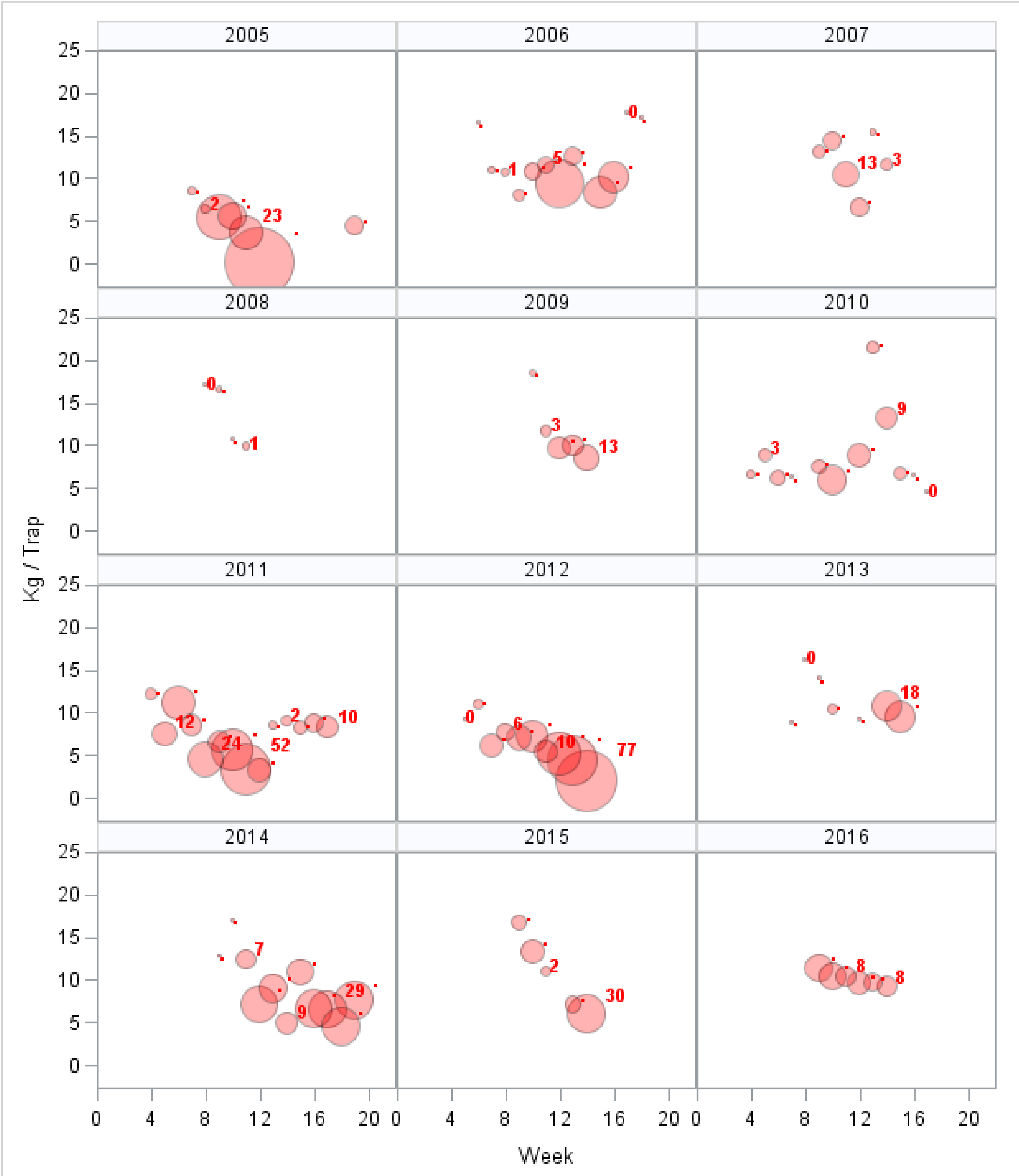

Figure 60. Trends in observed weekly catch rates versus the percentage of soft-shell crab in the catch in Divs. 2HJ (2005-16). Bubble labels depicts percentage of soft-shell.

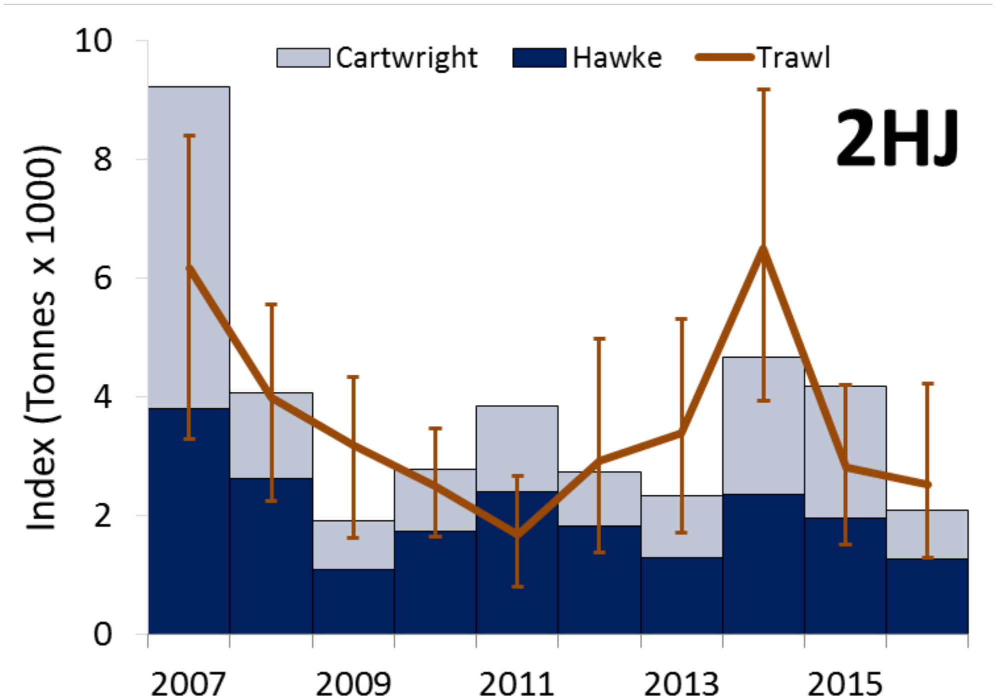

Figure 61. Trends in trap survey-based exploitable biomass index versus the multi-species trawl survey exploitable biomass index in Divs. 2HJ (2007-16).

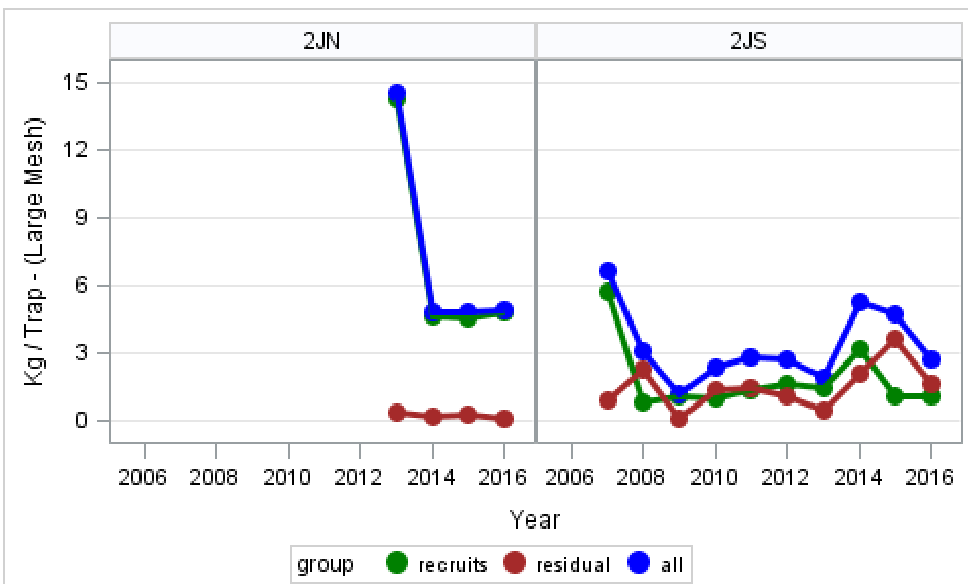

Figure 62. Trends in CPUE (Kg/Trap) by shell condition for legal-sized crab from core stations in the CPS trap survey (CMA 2JS) and the Torngat Joint Fisheries Secretariat survey (CMA 2JN).

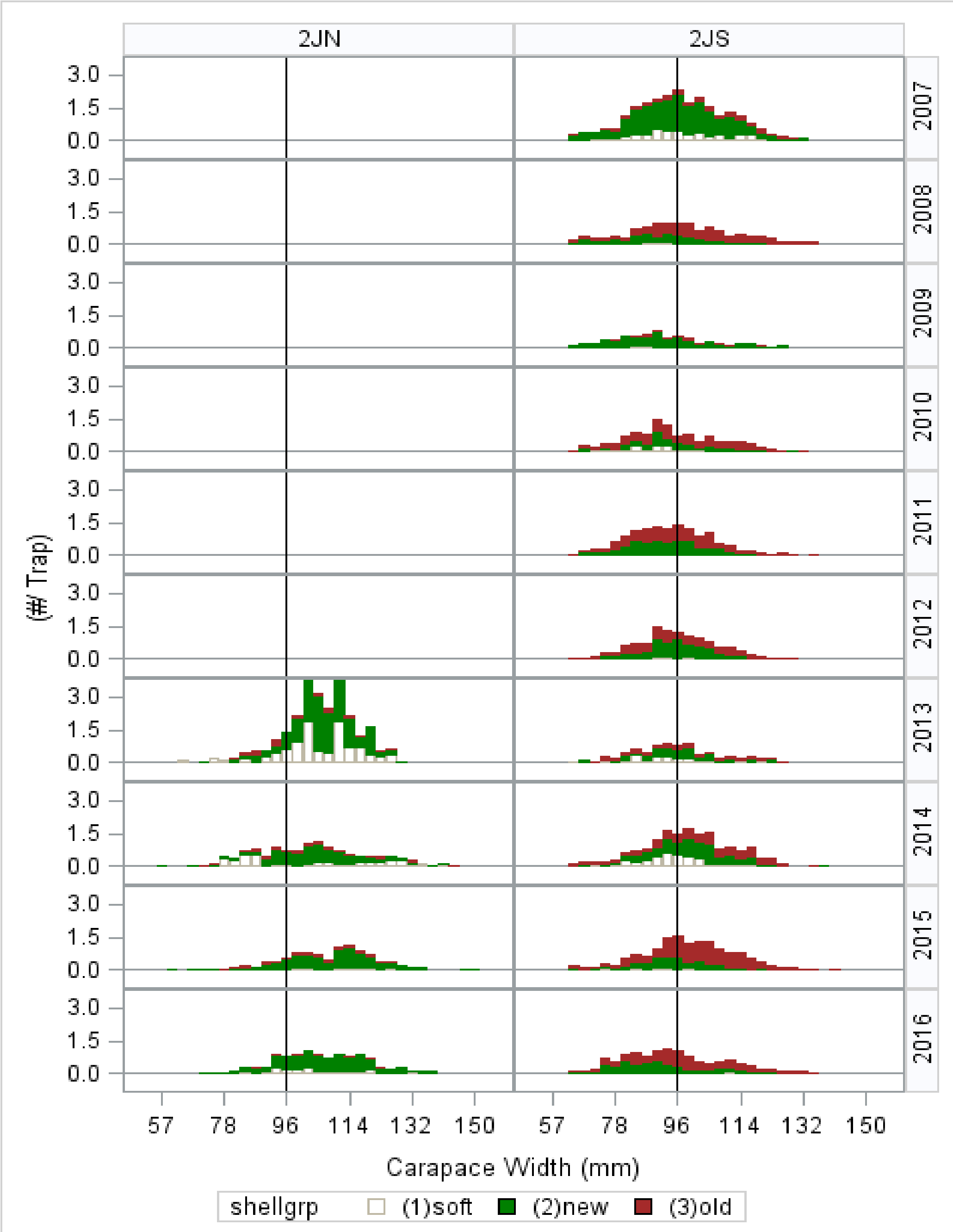

Figure 63. Trends in male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey (CMA 2JS) and the Torngat Joint Fisheries Secretariat survey (CMA 2JN) (2007-16). The vertical line indicates the minimum legal size.

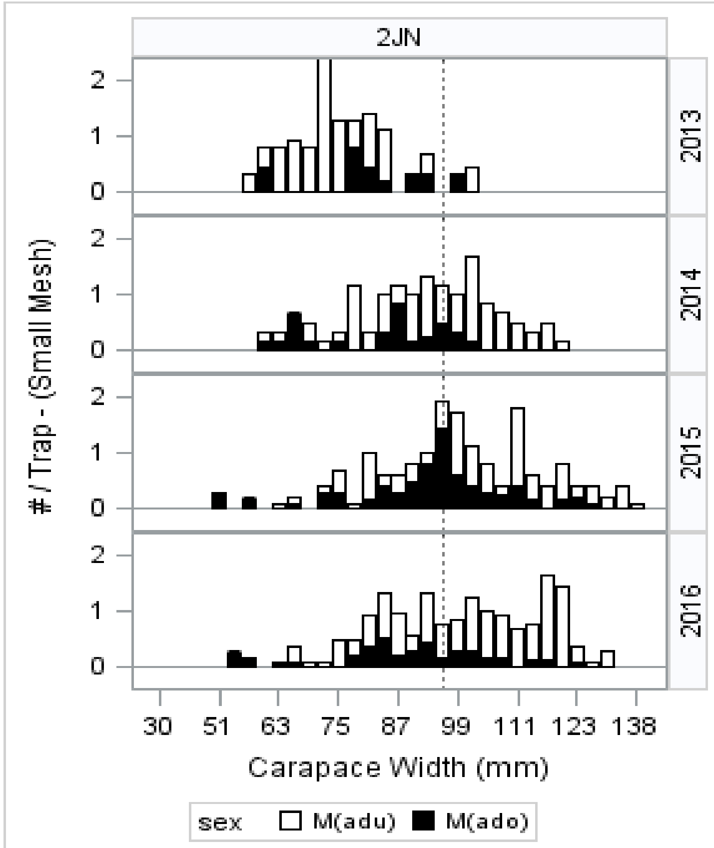

Figure 64. Trends in male carapace width distributions by maturity from small-mesh traps in the Torngat Joint Fisheries Secretariat survey (2013-16). The vertical dotted line indicates the minimum legal size.

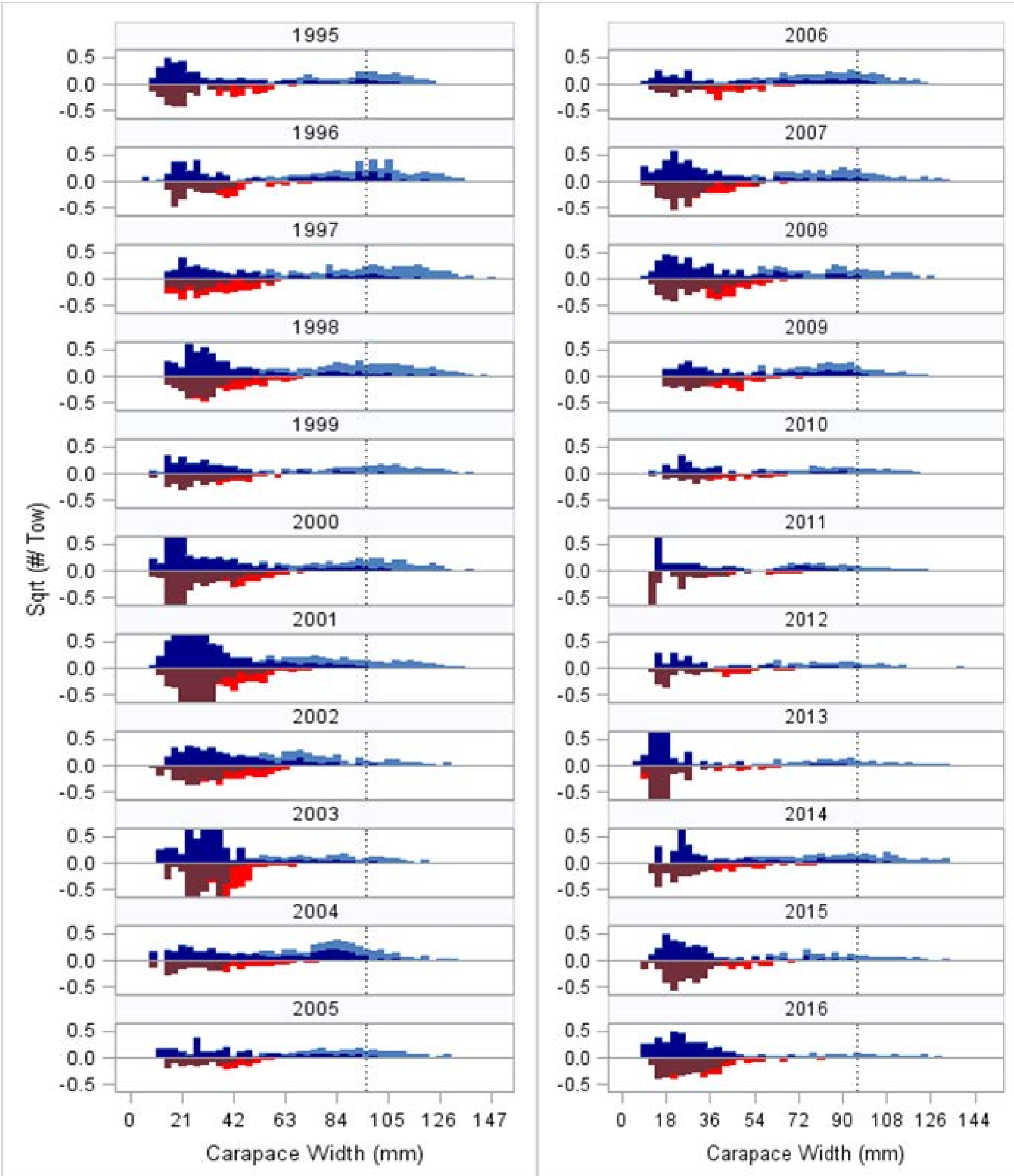

Figure 65. Abundance indices by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from the Divs. 2HJ fall trawl survey. Dashed vertical line is legal-size.

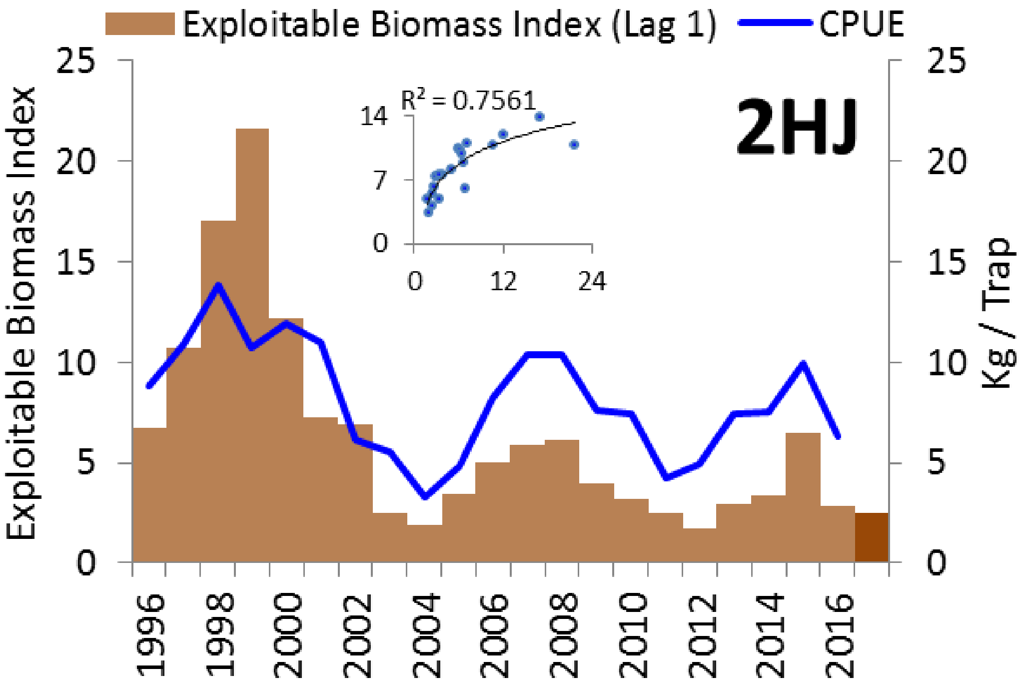

Figure 66. Standardized CPUE (Kg/Trap) versus trawl survey exploitable biomass index lagged one year for Divs. 2HJ. Dark bar in 2017 depicts most recent biomass estimate from the 2016 fall survey.

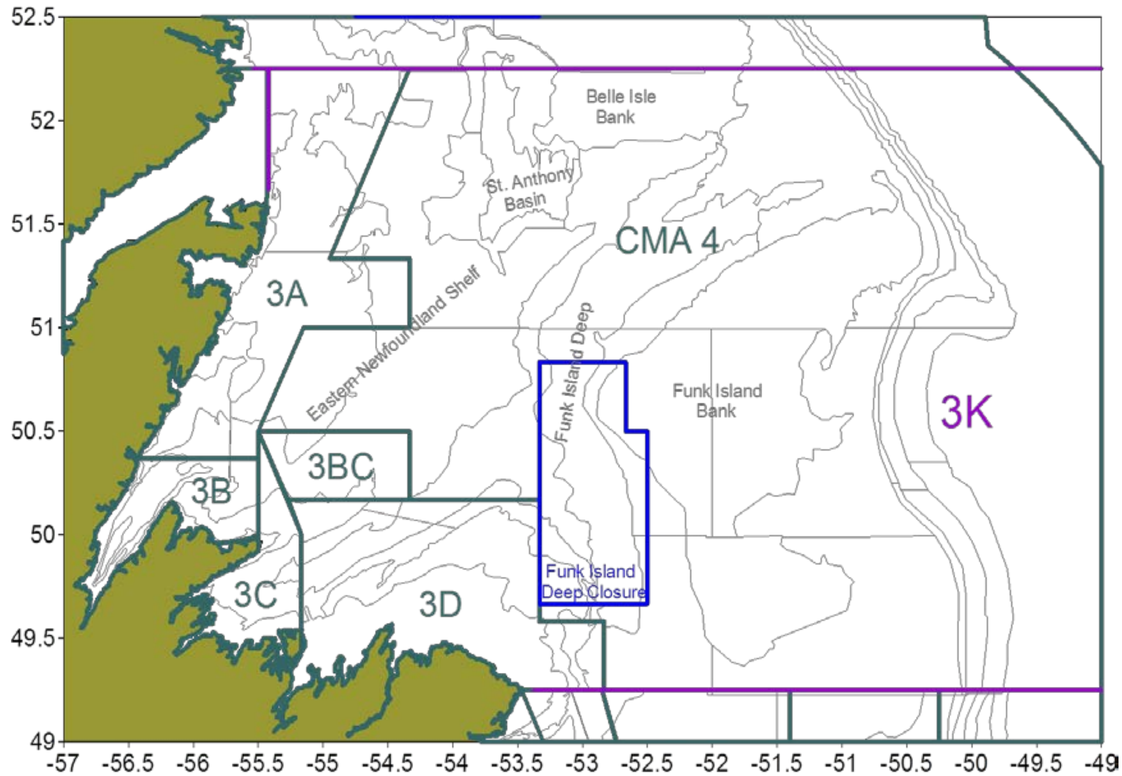

Figure 67. Map of Div. 3K showing important bathymetric features, CMAs, and the Funk Island Deep closure area.

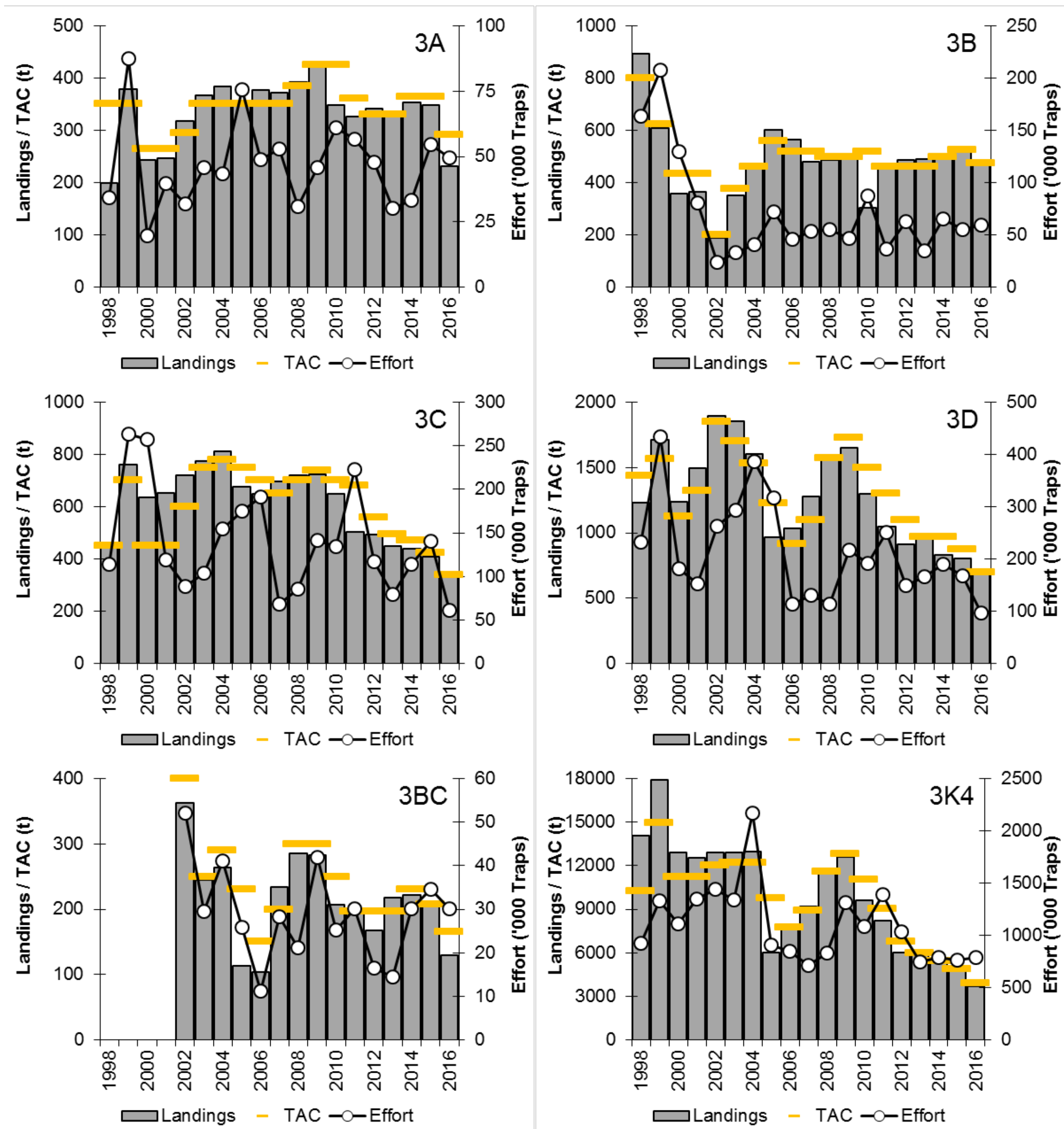

Figure 68. TAC, landings, and estimated effort by CMA in Assessment Div. 3K. 2016 effort is considered preliminary.

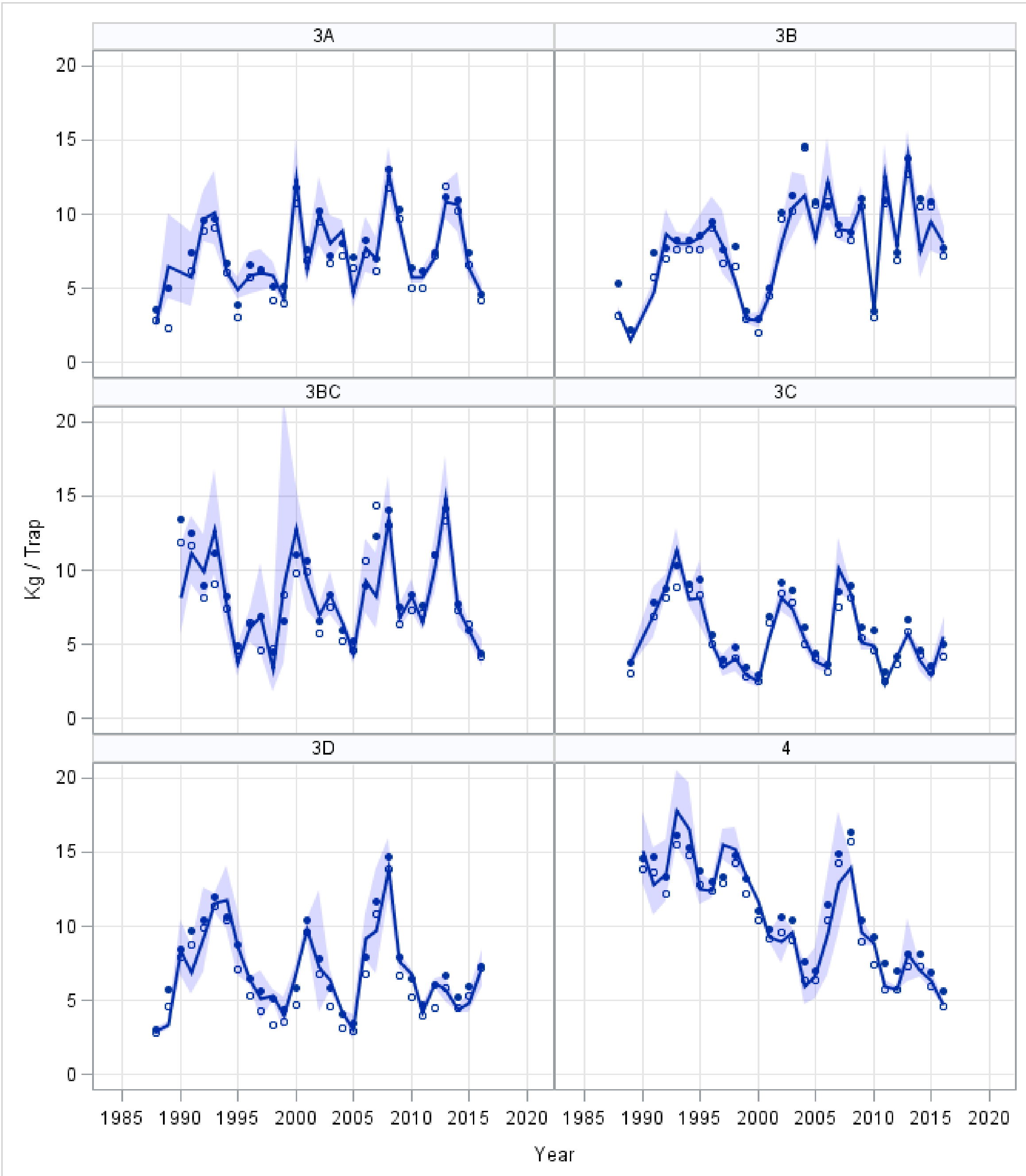

Figure 69. Trends in standardized catch per unit effort (CPUE, Kg/Trap) for CMAs in Div. 3K. Open circles are medians and closed circles are means.

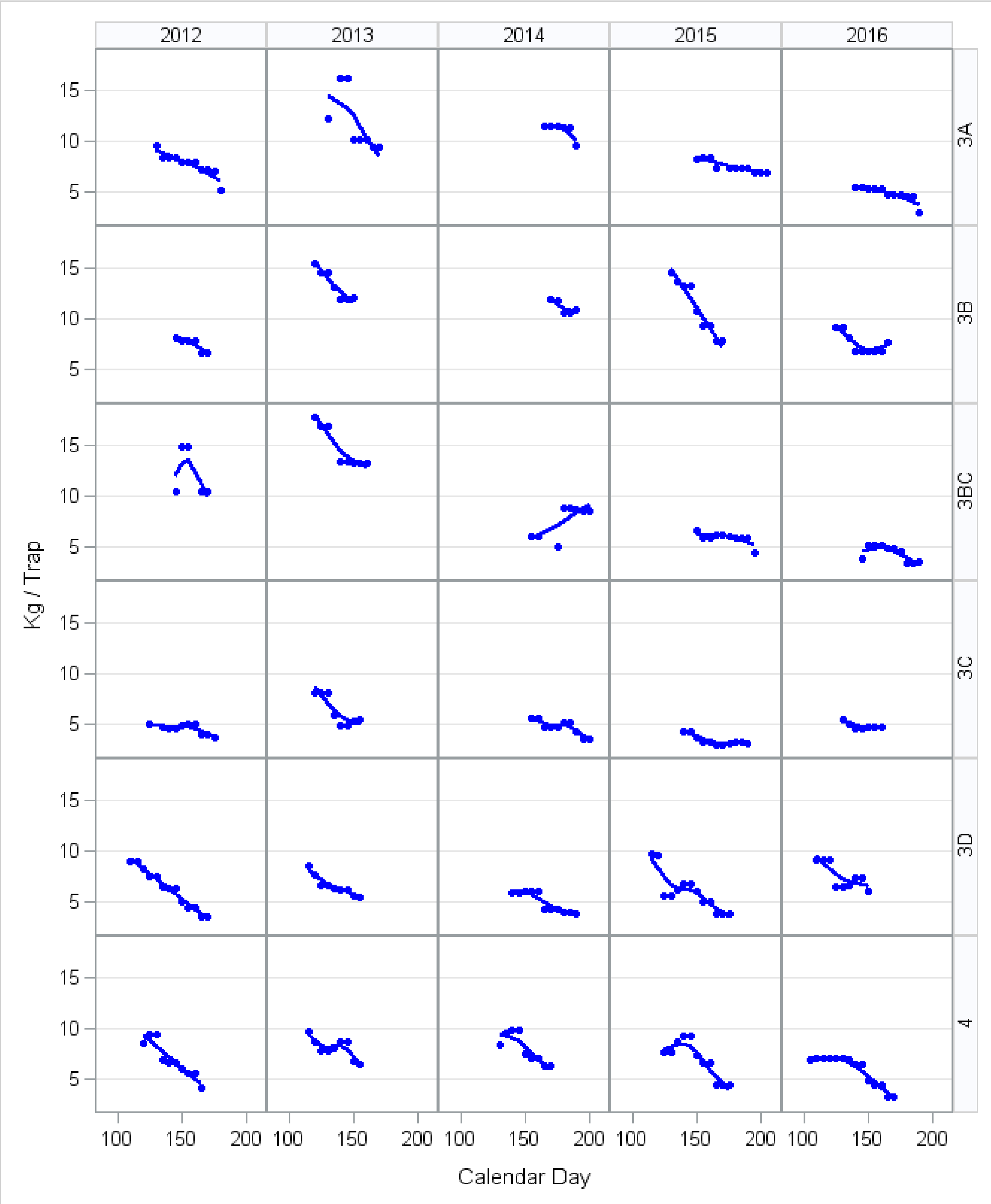

Figure 70. Trends in standardized CPUE (2012-16) throughout the season fit with loess regression curves, by CMA in Div. 3K.

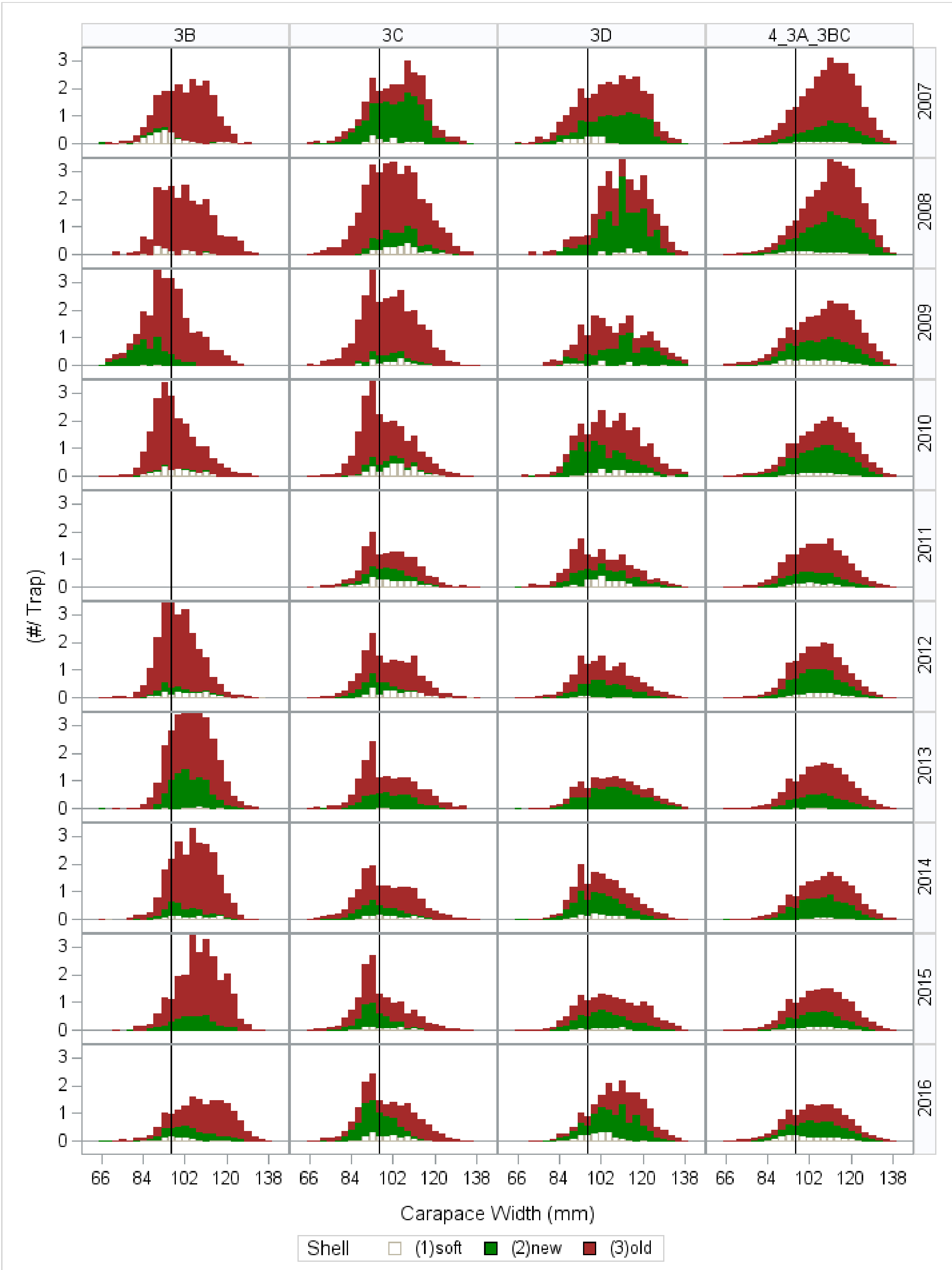

Figure 71. Trends in male carapace width distributions by shell condition from observer sampling in Div. 3K (2007-16). The vertical line indicates the minimum legal size.

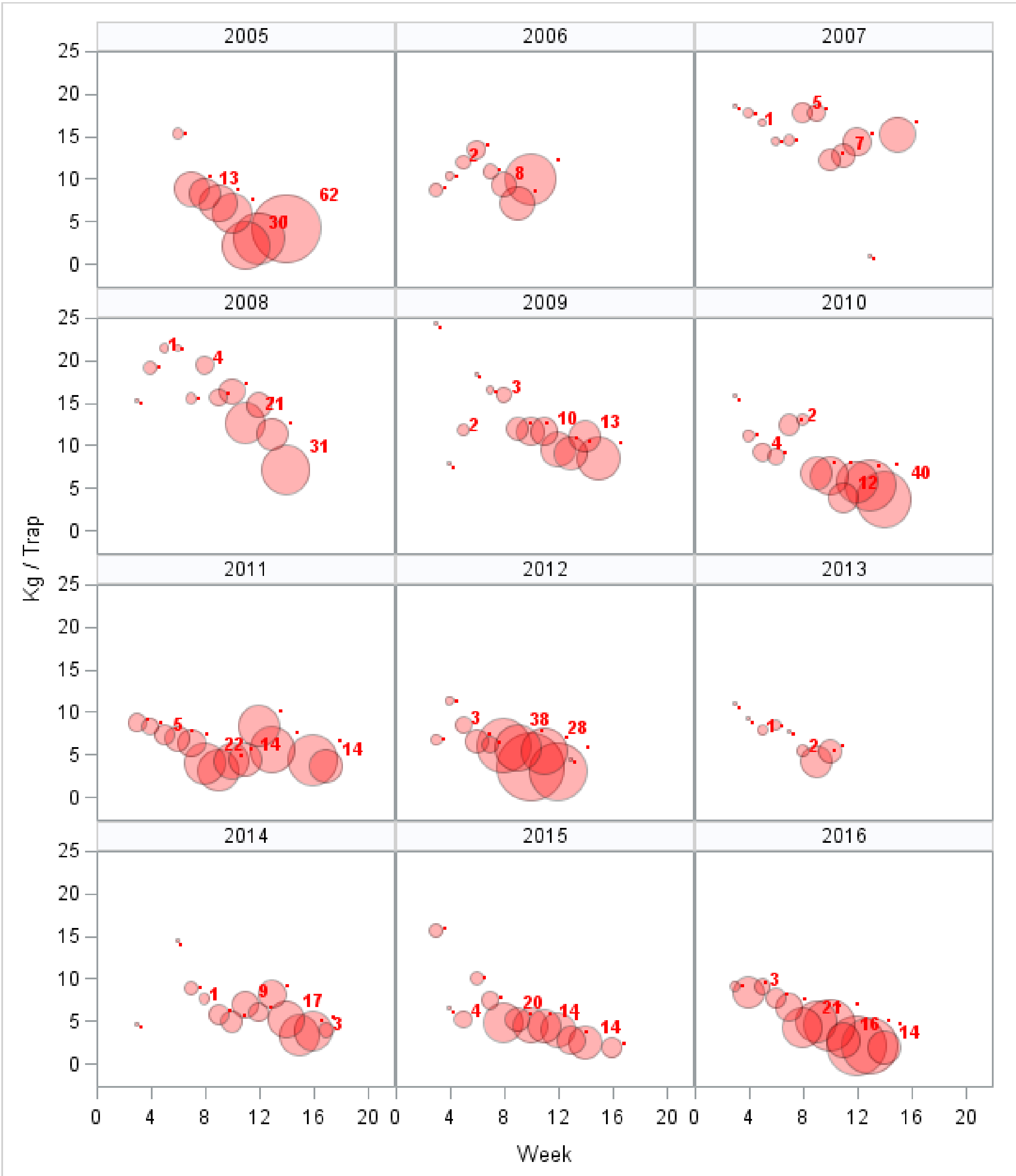

Figure 72. Trends in observed weekly catch rates versus the percentage of soft-shell crab in the catch in Div. 3K (2005-16). Bubble labels depict percentage soft-shell.

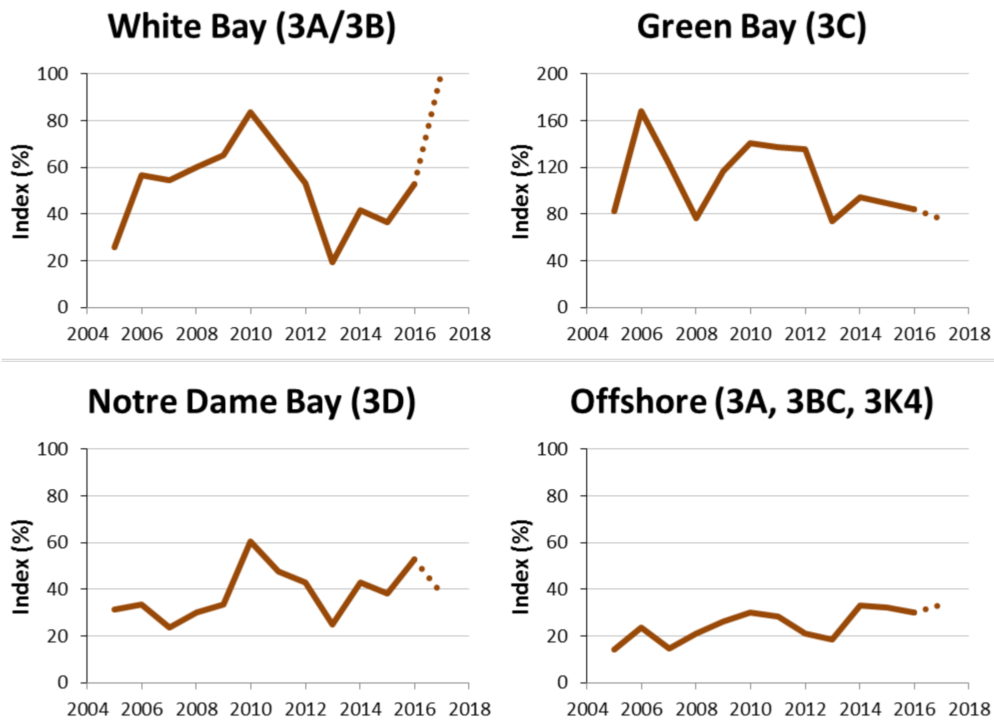

Figure 73. Trends in trap survey-based exploitation rate indices by CMA in Div. 3K. Dashed lines depict projected 2017 exploitation rate indices based on status quo landings.

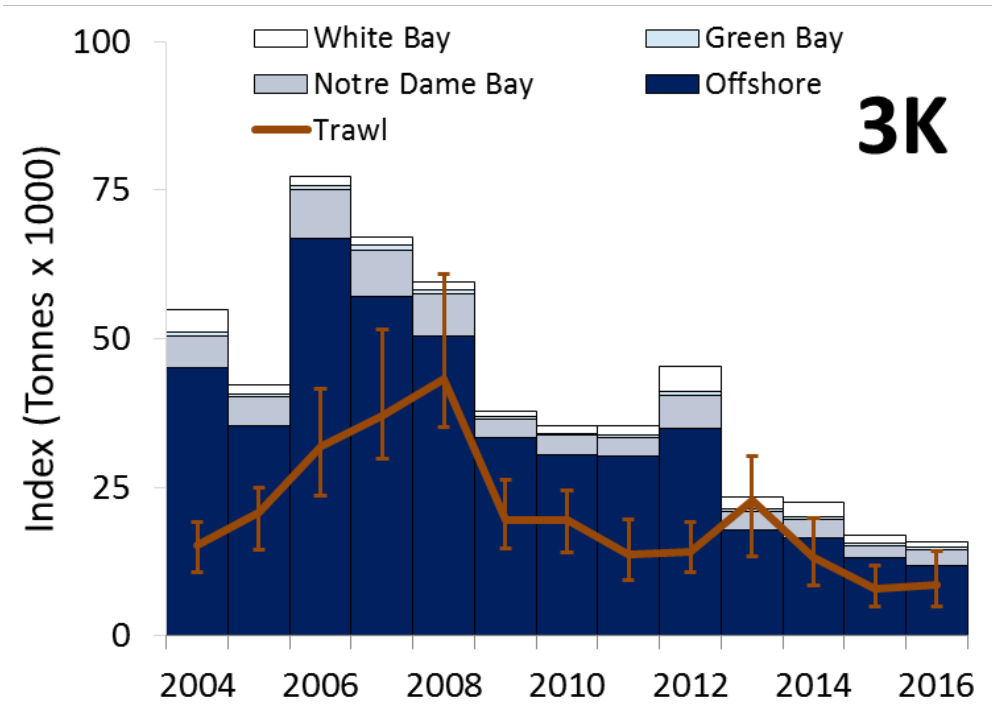

Figure 74. Trends in the trap survey-based exploitable biomass index versus the multi-species trawl survey exploitable biomass index in Div. 3K.

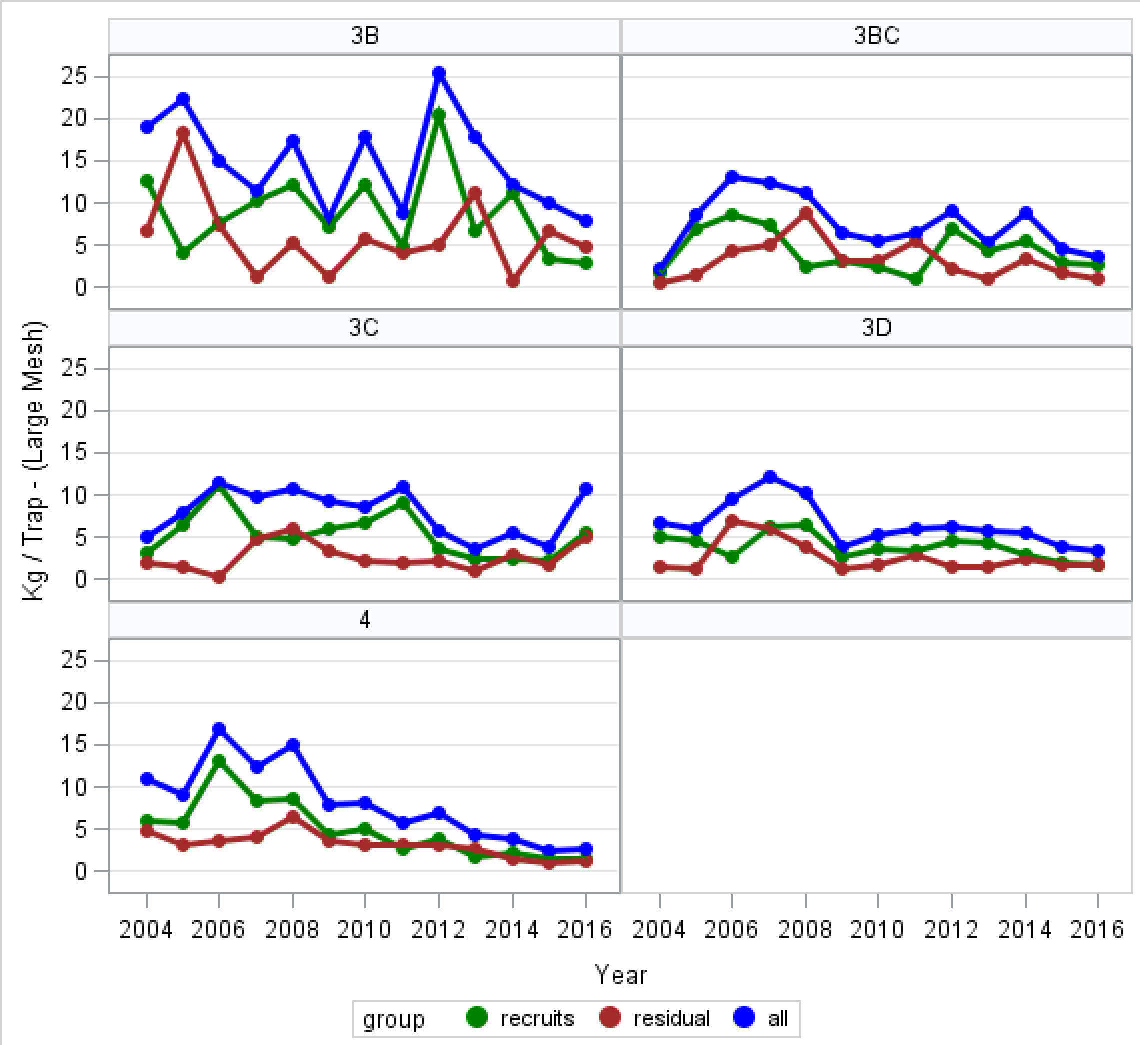

Figure 75. Trends in CPUE (Kg/Trap) by shell condition for legal-sized crab from core stations in the CPS trap survey in Div. 3K.

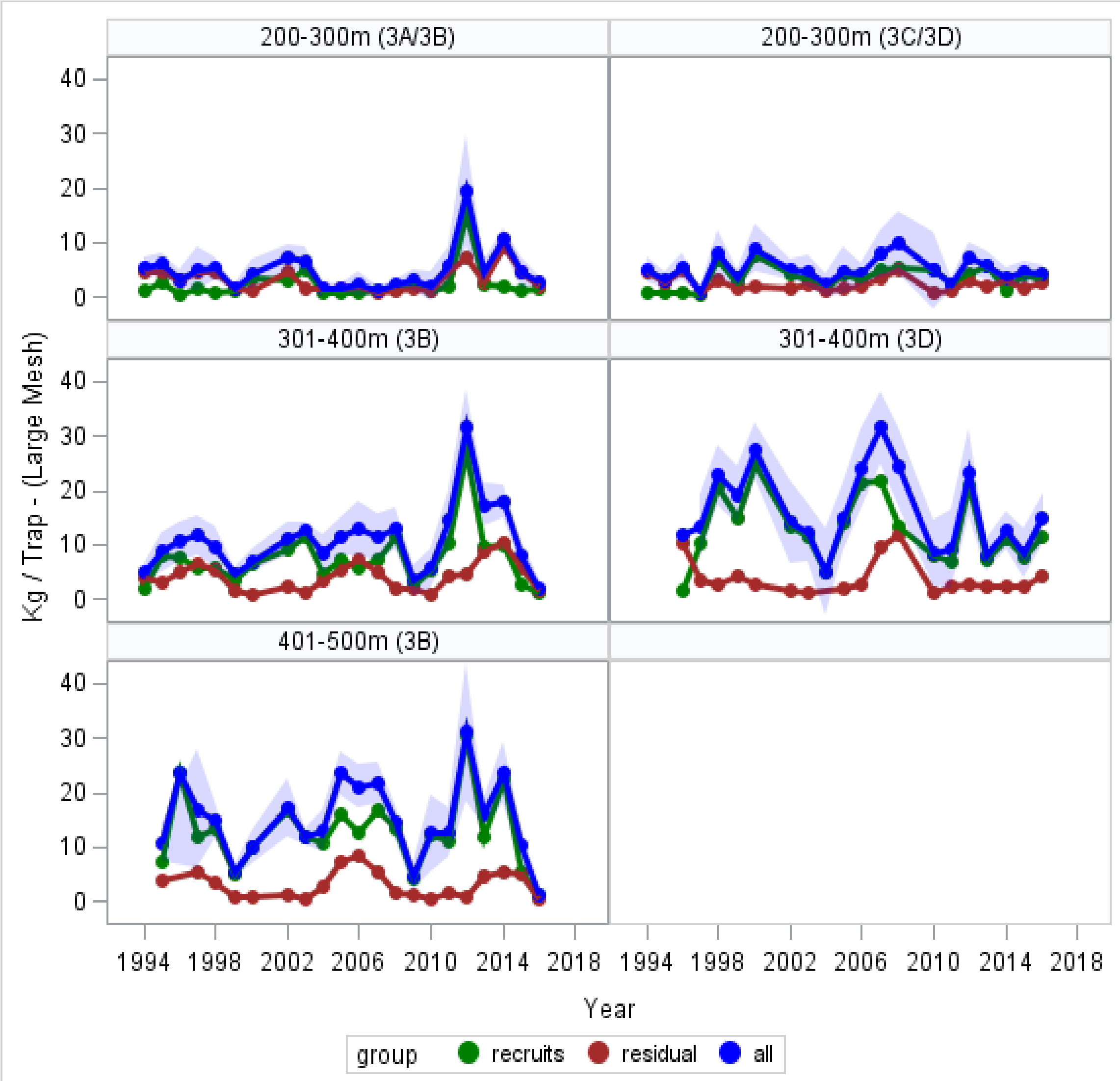

Figure 76. Trends in CPUE (kg/trap) by shell condition for legal-sized crab from DFO trap surveys in Div. 3K.

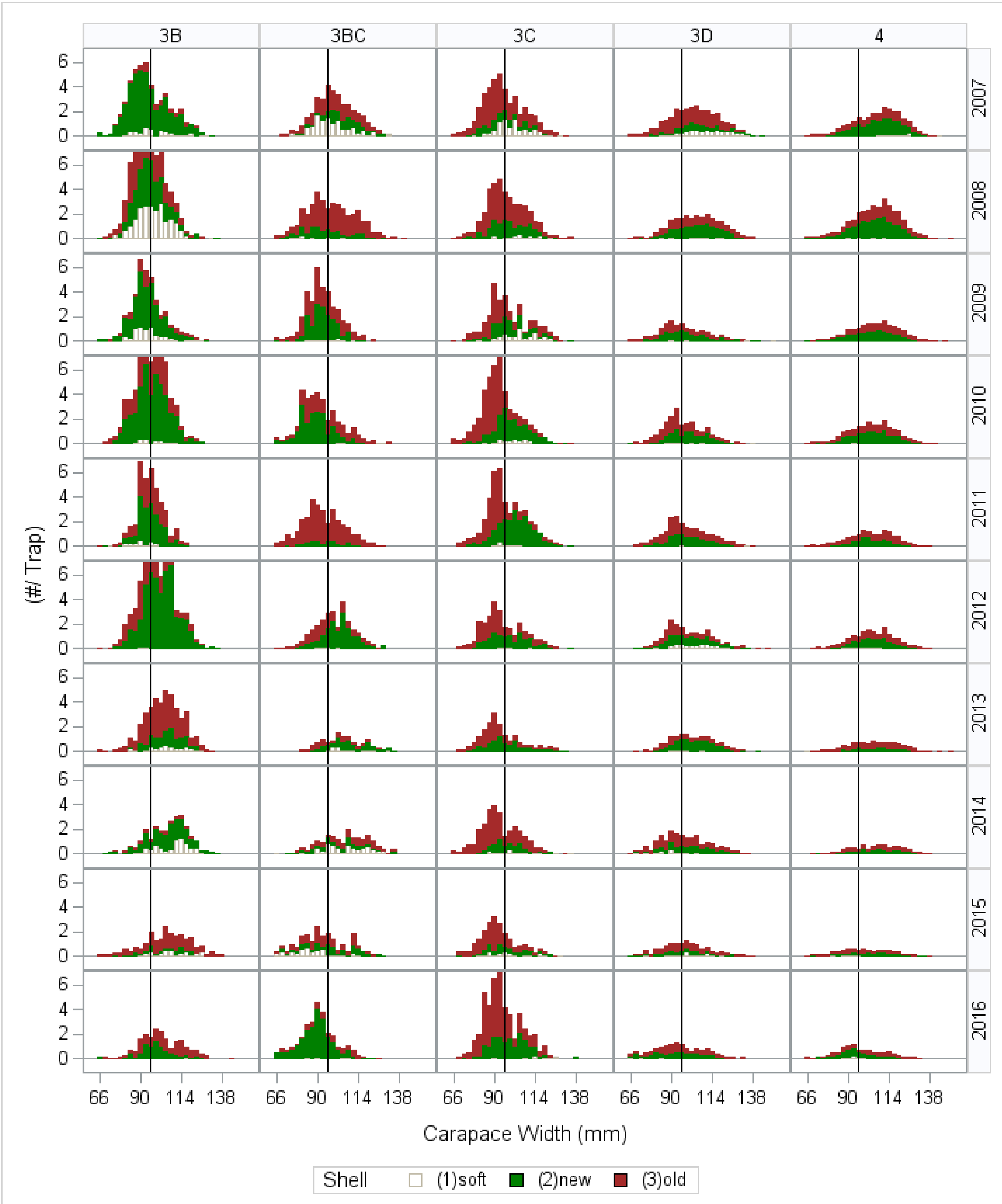

Figure 77. Trends in male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in Div. 3K. The vertical line indicates the minimum legal size.

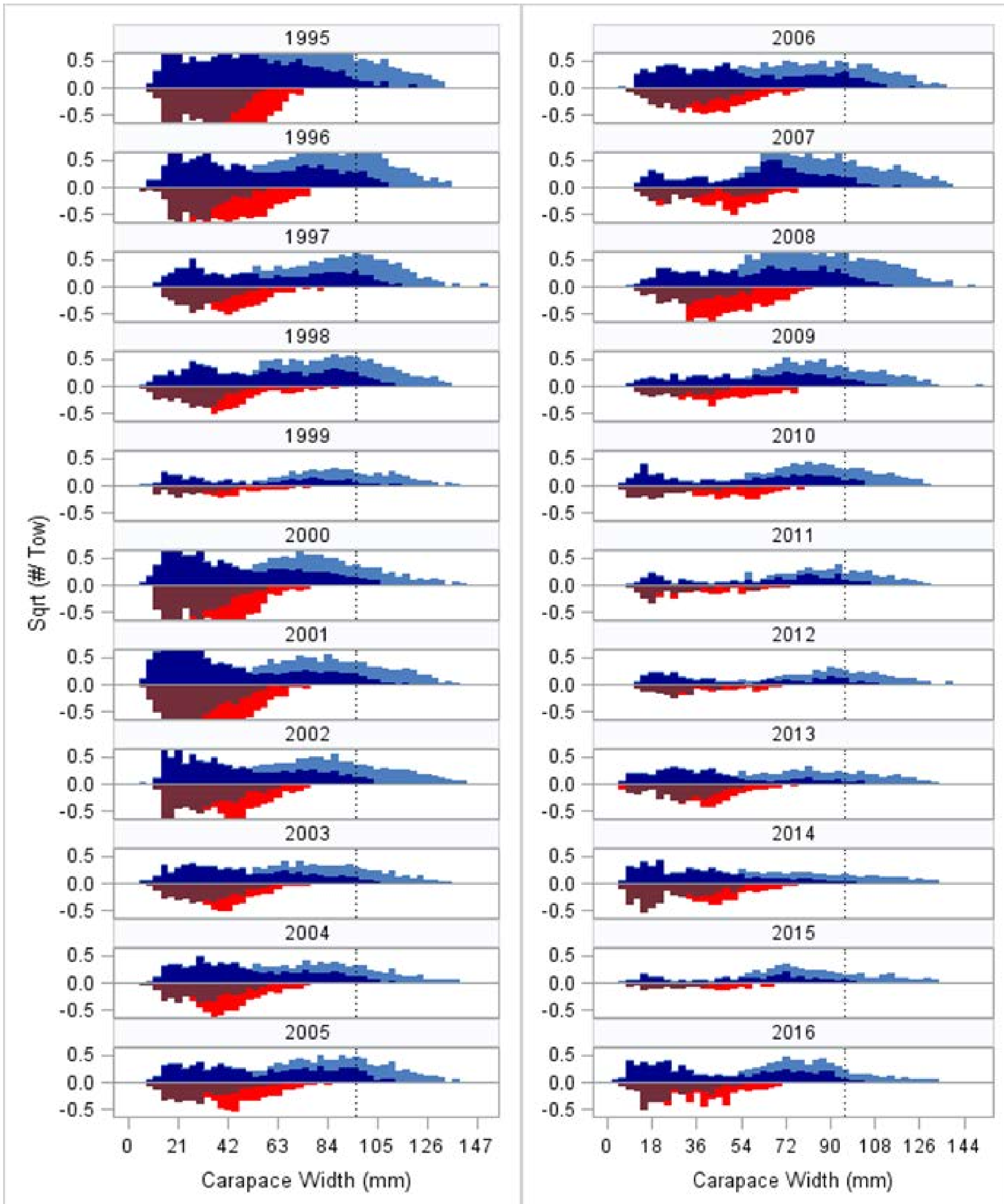

Figure 78. Abundance indices by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from the Div. 3K fall trawl survey. Dashed vertical line is legal-size.

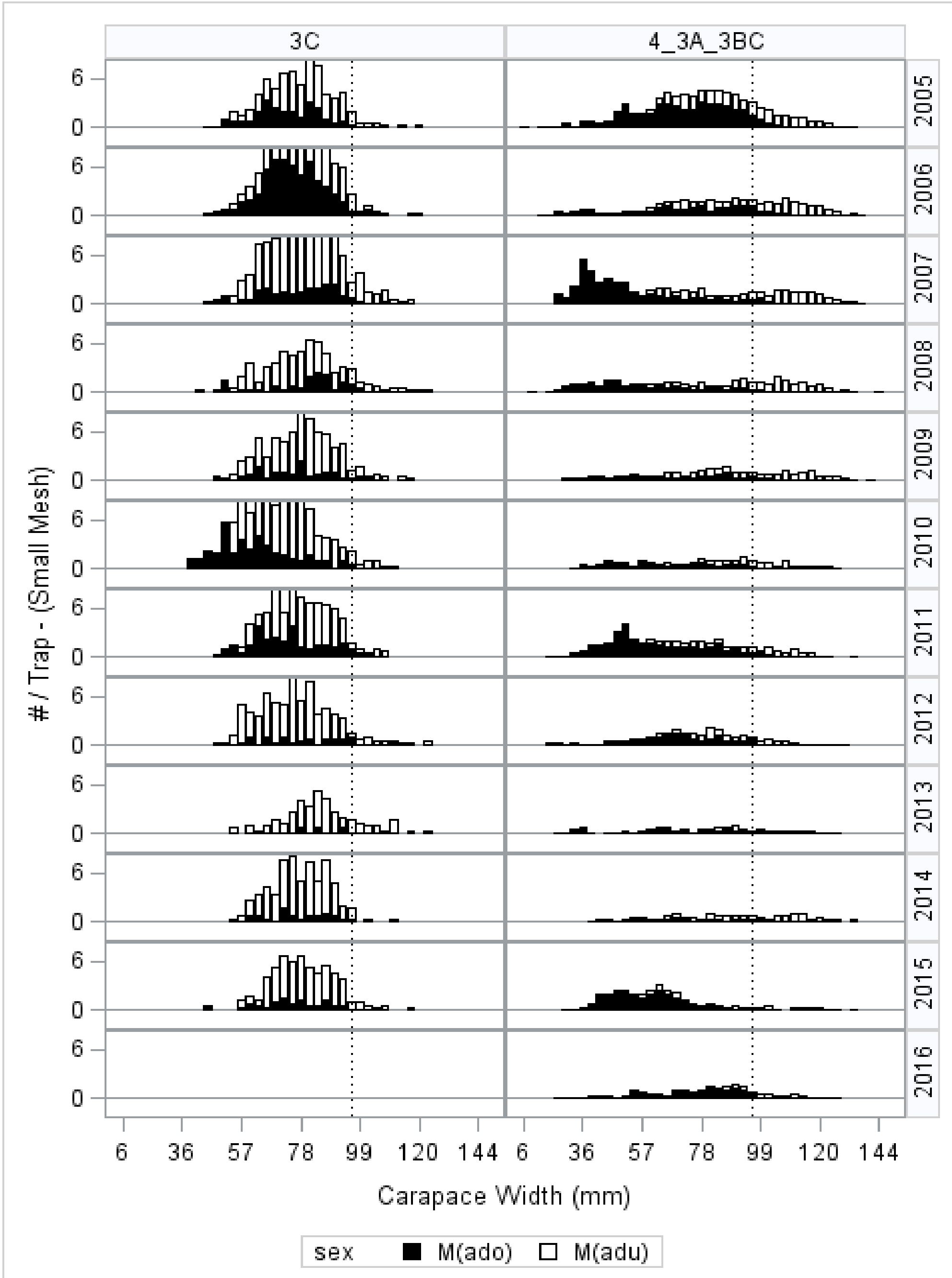

Figure 79.Trends in male carapace width distributions by maturity (black - juveniles plus adolescent males, white – adult males) from small-mesh traps in the CPS CMAs 3A/3BC/3C/4 survey (2005-16). The vertical dotted line indicates the minimum legal size.

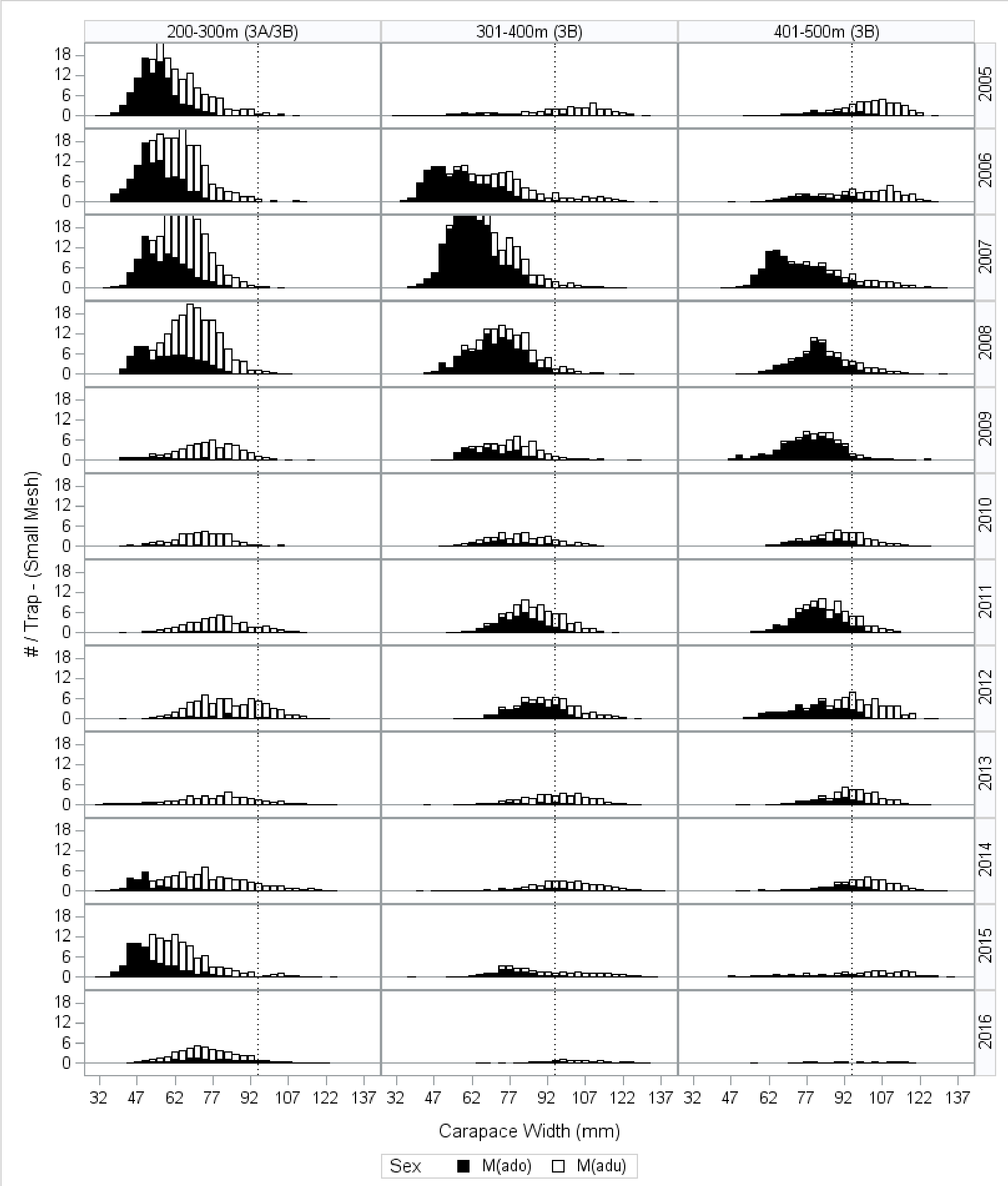

Figure 80.Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh in the DFO CMAs 3A/3B trap survey (2005-16). The vertical dotted line indicates the minimum legal size.

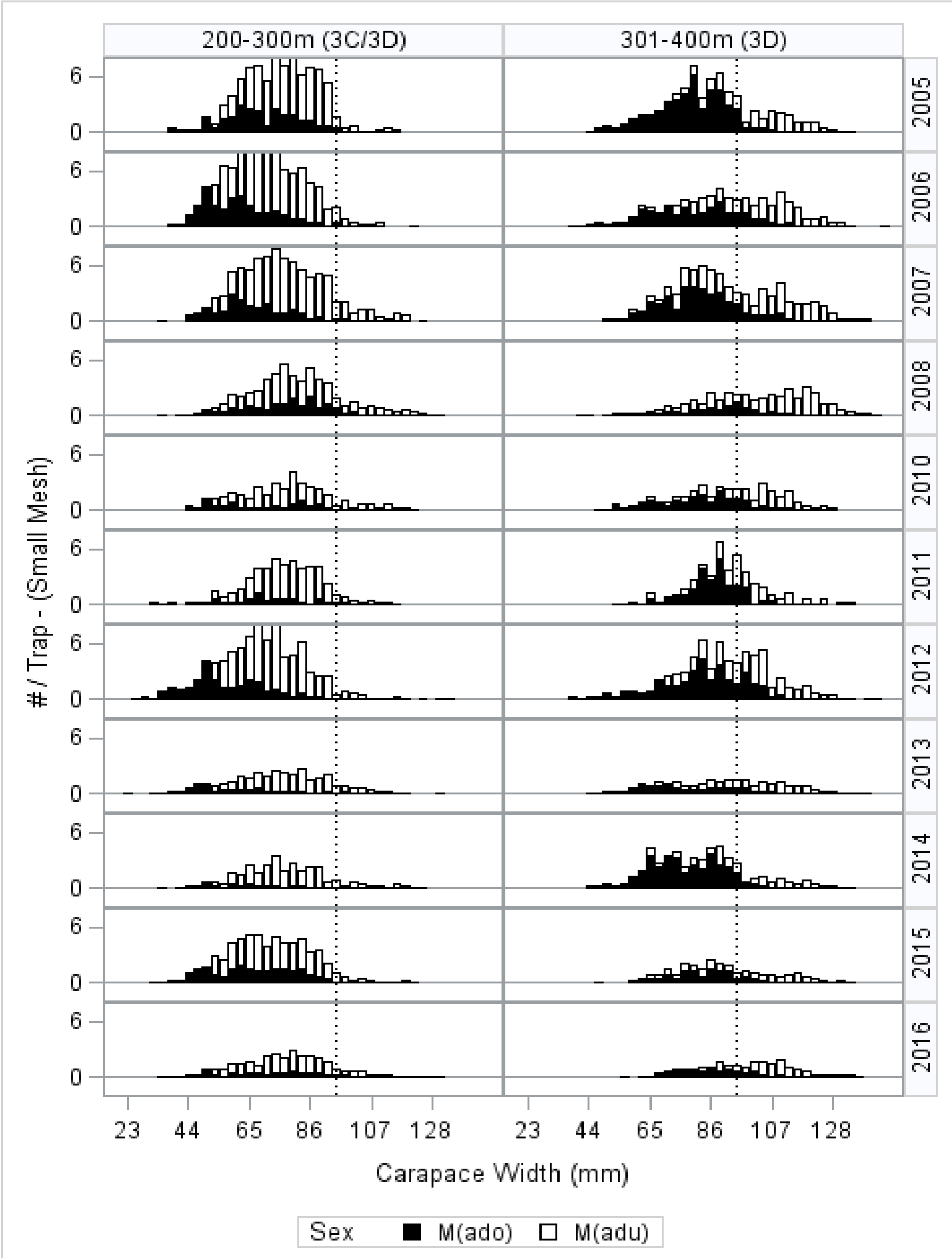

Figure 81.Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh in the DFO CMAs 3C/3D trap survey (2005-16). The vertical dotted line indicates the minimum legal size.

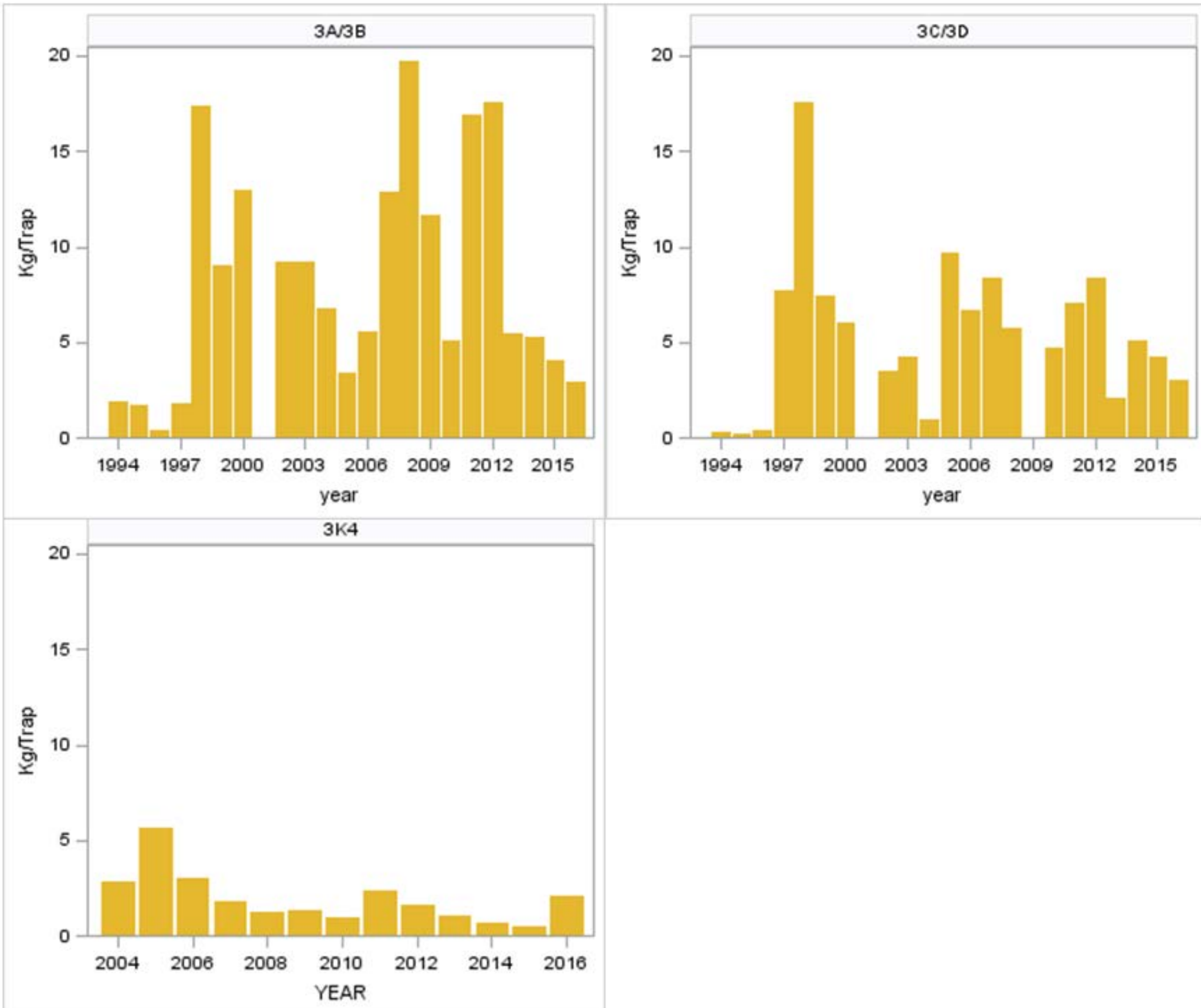

Figure 82. Pre-recruit abundance indices from small-mesh traps in DFO (top panels) and CPS (bottom panel) trap surveys in Div. 3K.

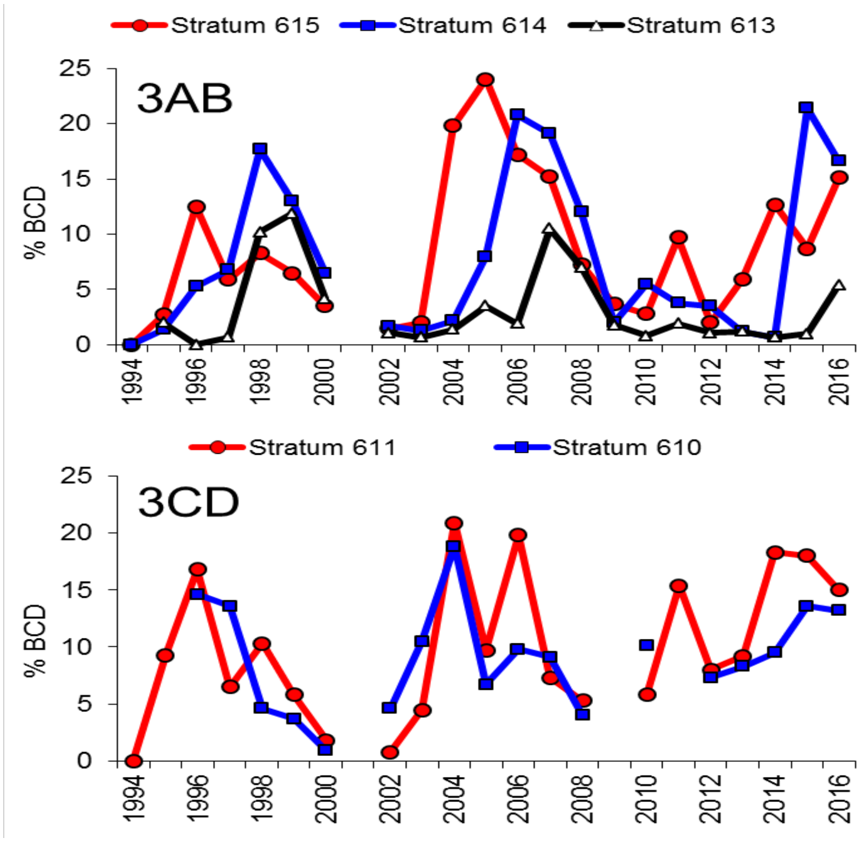

Figure 83. Prevalence of BCD in new-shelled males from Div. 3K DFO inshore trap surveys by stratum in CMA 3A/White Bay (3AB) and Green/Notre Dame Bays (3CD).

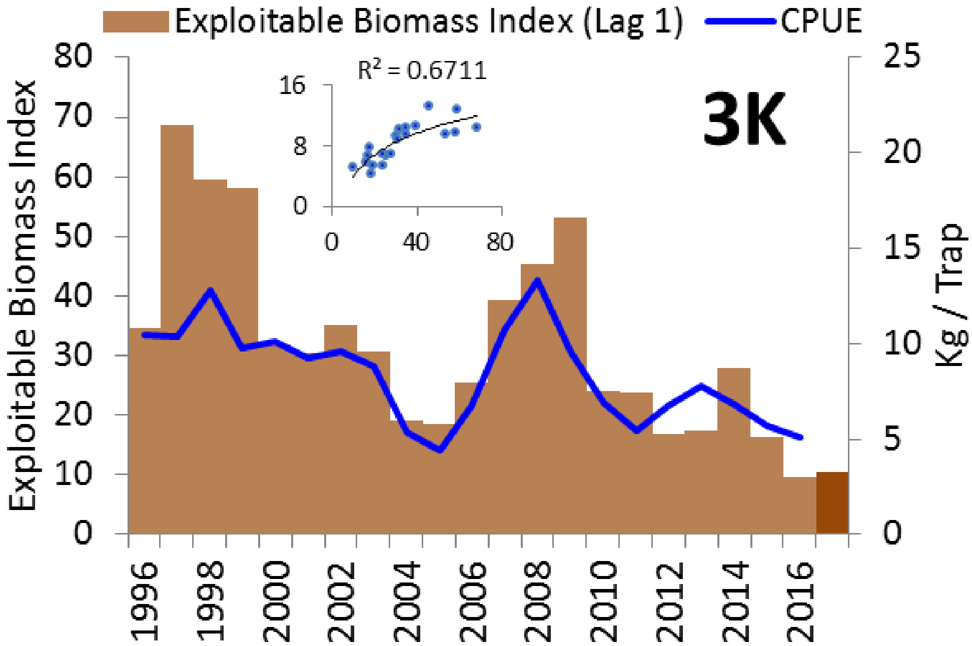

Figure 84. Standardized CPUE versus trawl survey exploitable biomass index lagged one year in Div. 3K. Dark bar in 2017 depicts most recent biomass estimate from the 2016 fall survey.

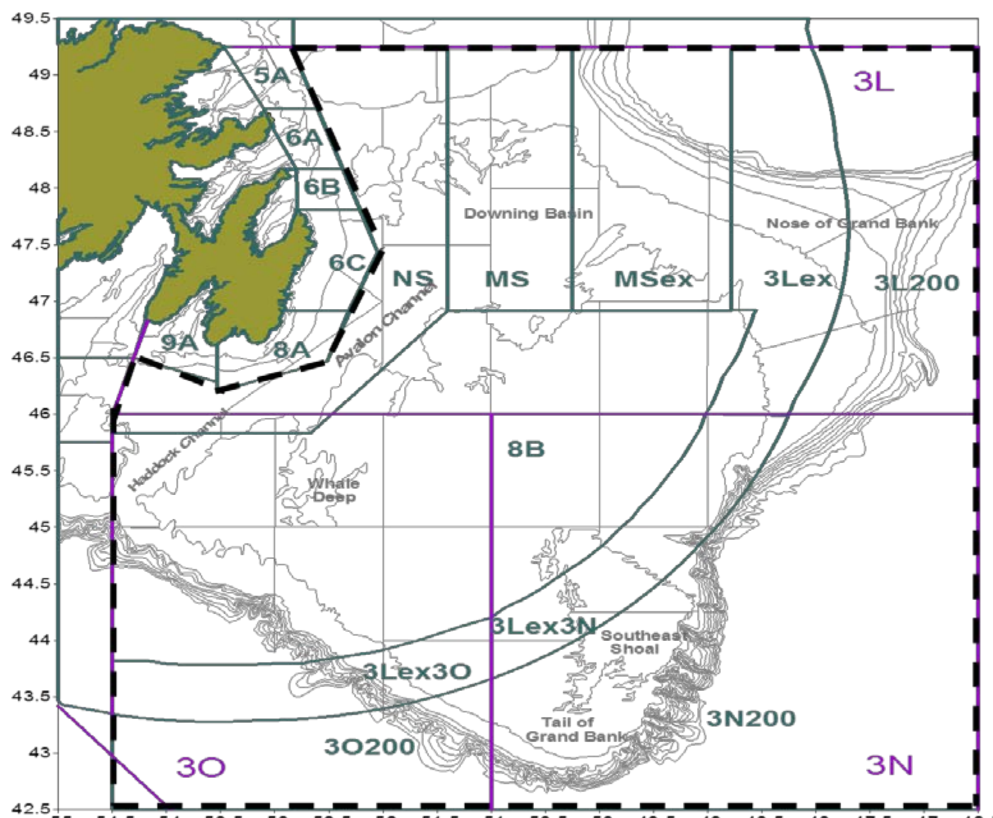

Figure 85. Map of Divs. 3LNO showing crab management areas and important bathymetric features. Dashed perimeter indicates offshore areas.

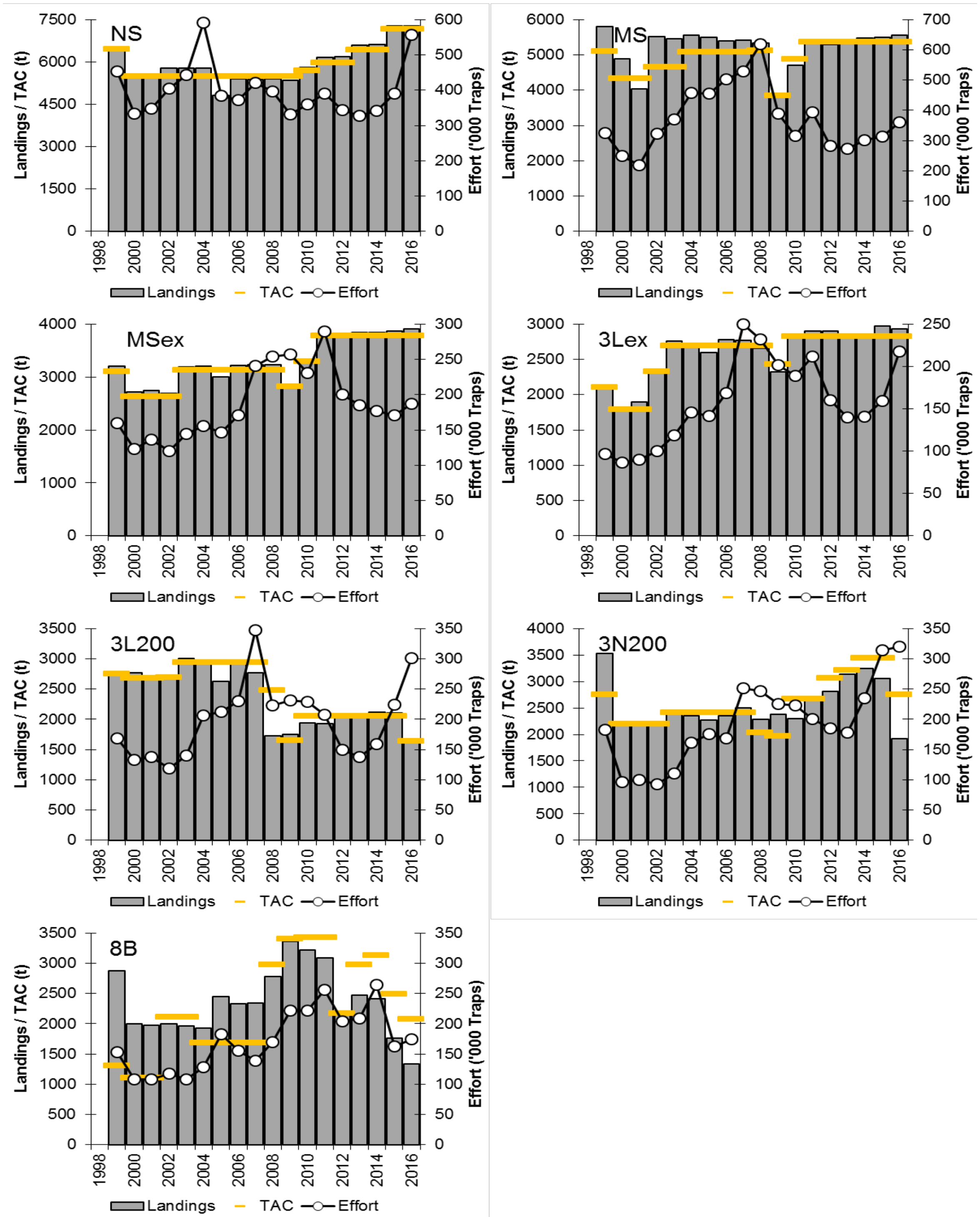

Figure 86. TAC, landings, and estimated effort for CMAs in Divs. 3LNO Offshore. 2016 effort is preliminary.

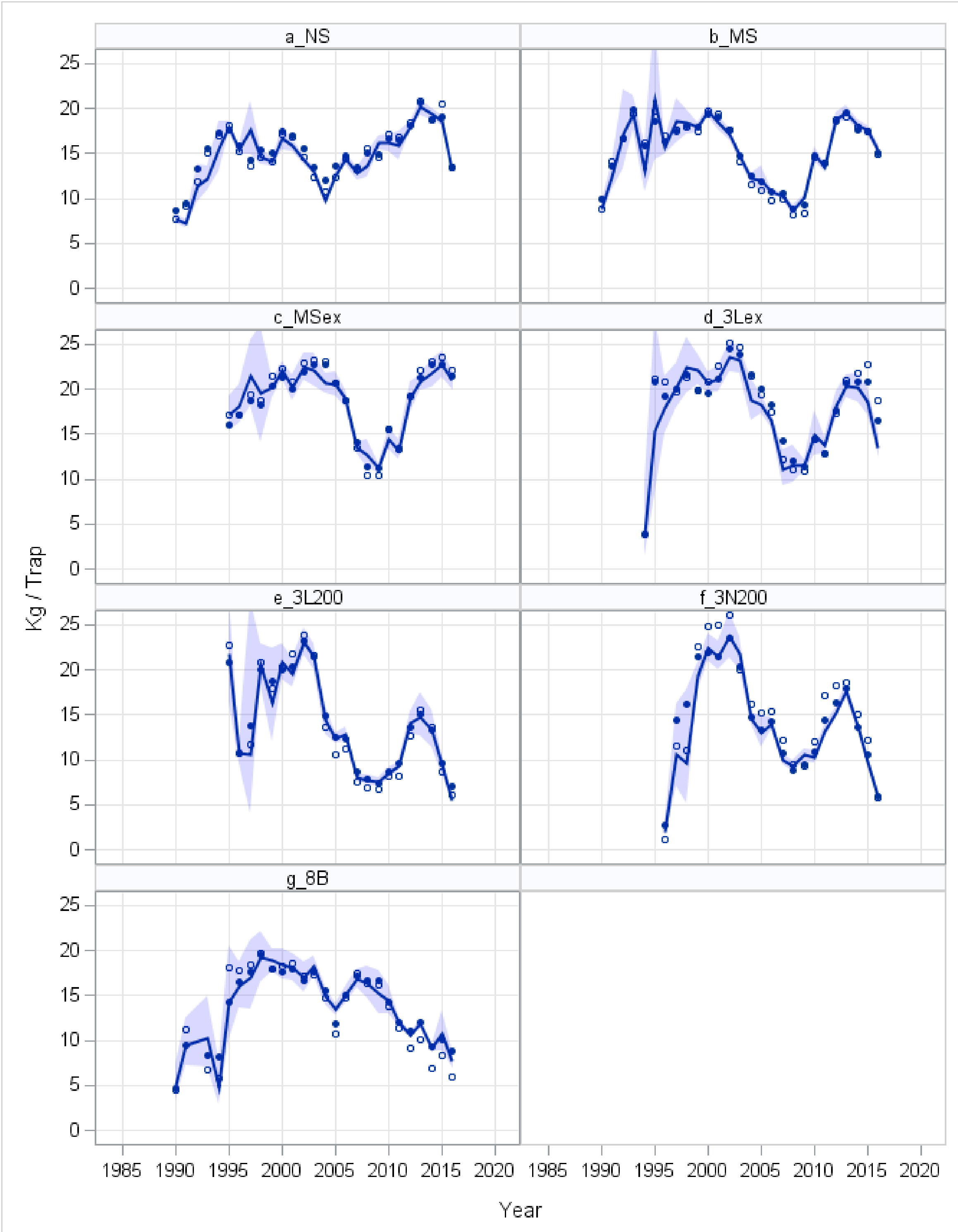

Figure 87. Trends in standardized catch per unit effort (CPUE, Kg/Trap) for CMAs in Divs. 3LNO Offshore. Open circles are medians and closed circles are means.

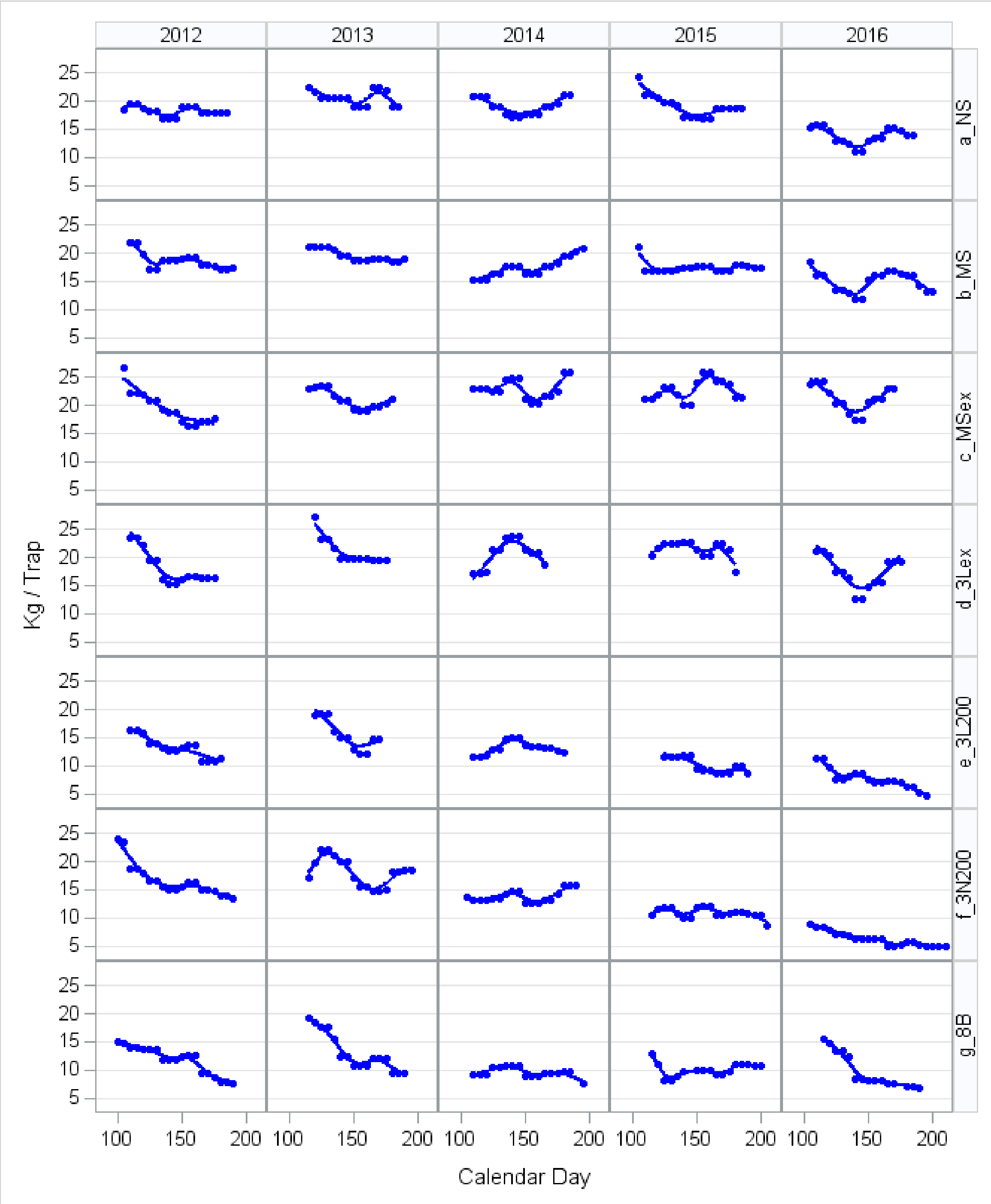

Figure 88. Trends in standardized CPUE (2012-16) throughout the season fit with loess regression curves, by CMA in Divs. 3LNO Offshore.

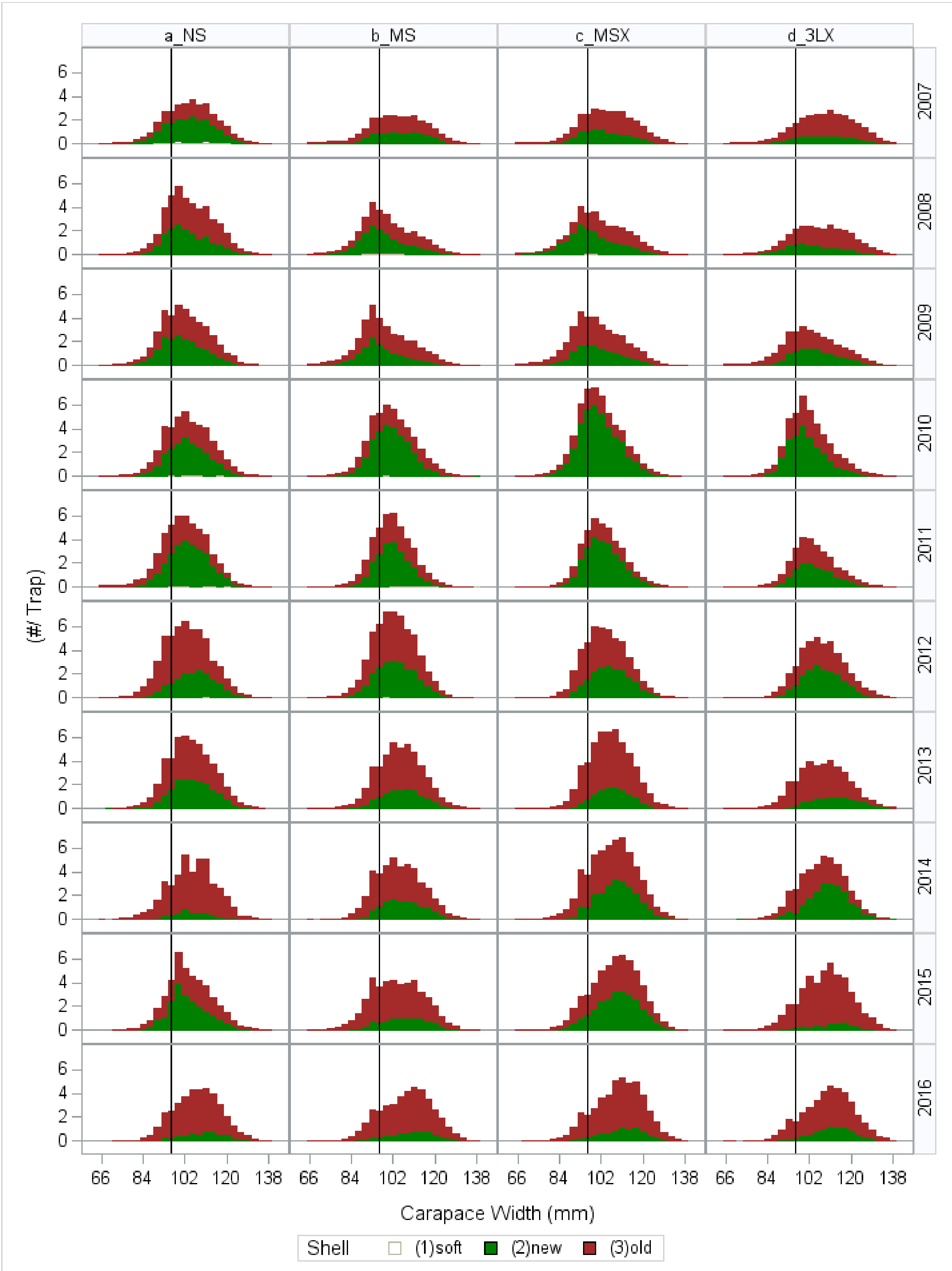

Figure 89. Trends in male carapace width distributions by shell condition from observer sampling in CMAs NS, MS, MSex and 3Lex (2007-16). The vertical line indicates the minimum legal size.

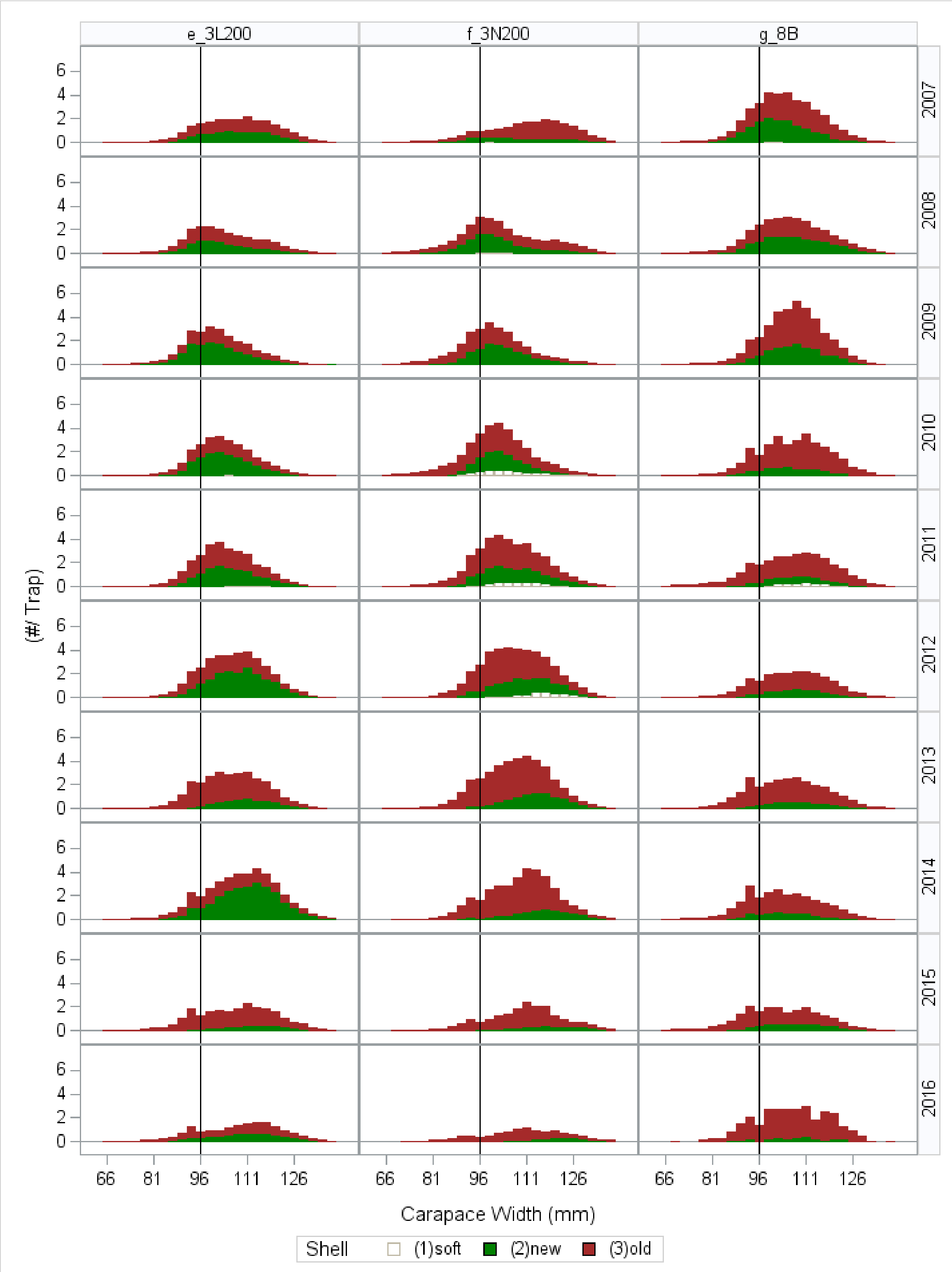

Figure 90. Trends in male carapace width distributions by shell condition from observer sampling in CMAs 3L200, 3N200 and 8B (2007-16). The vertical line indicates the minimum legal size.

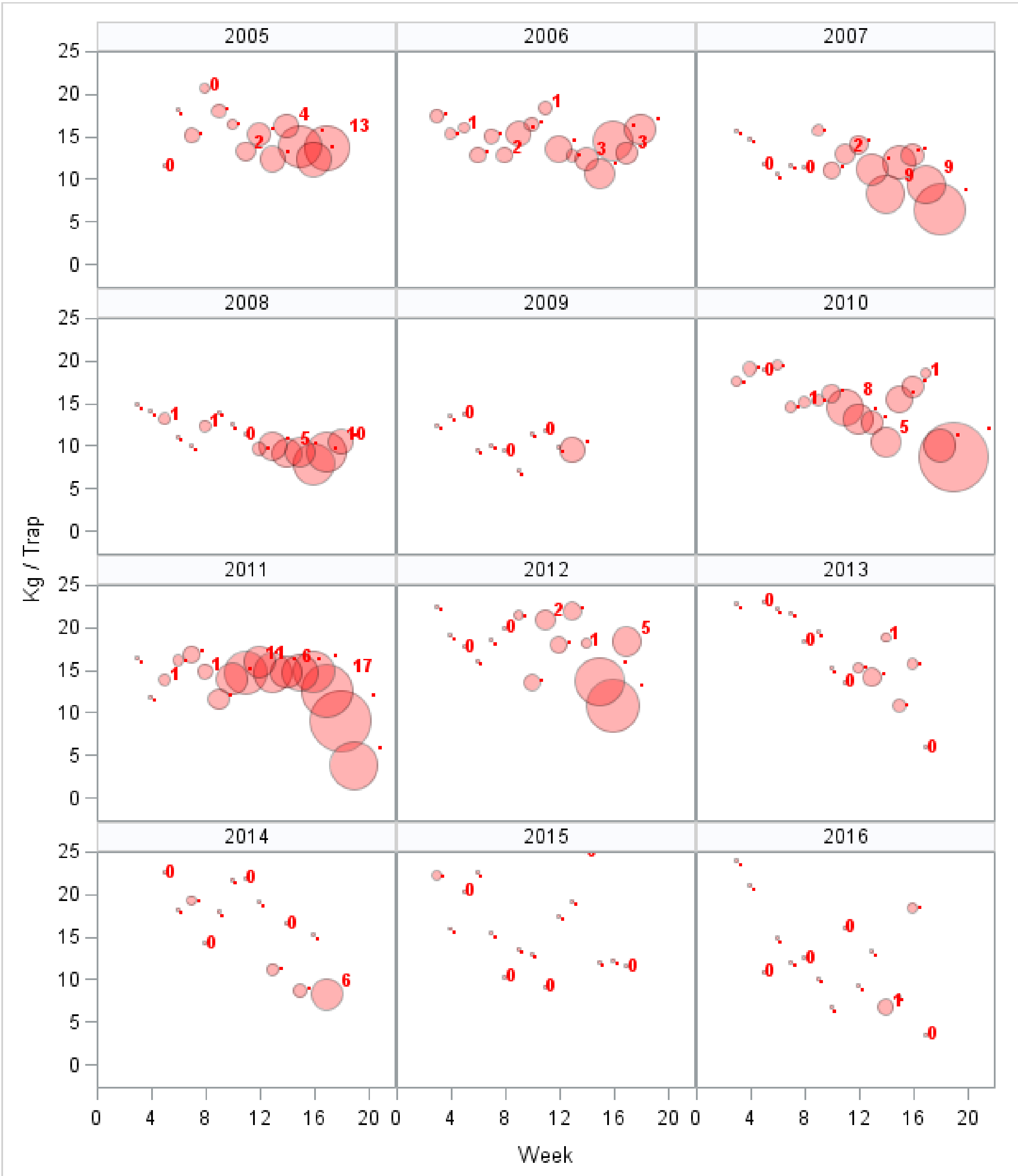

Figure 91. Trends in observed weekly catch rates versus the percentage of soft-shell crab in the catch in Divs. 3LNO (2005-16). Bubble labels depict percentage soft-shell.

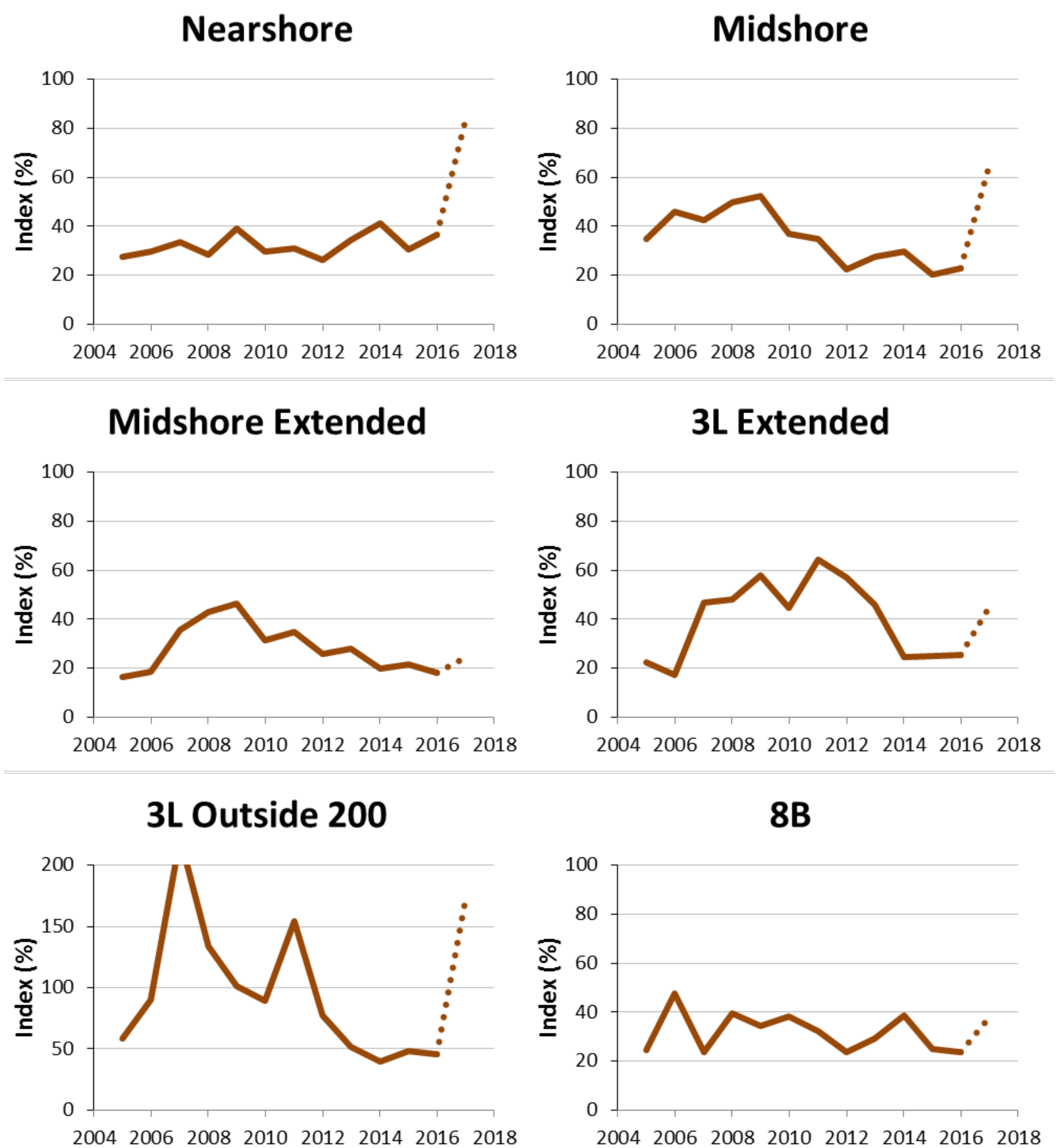

Figure 92. Trends in trap survey-based exploitation rate indices by CMA in Divs. 3LNO Offshore. Dashed lines depict projected 2017 exploitation rate indices based on status quo landings.

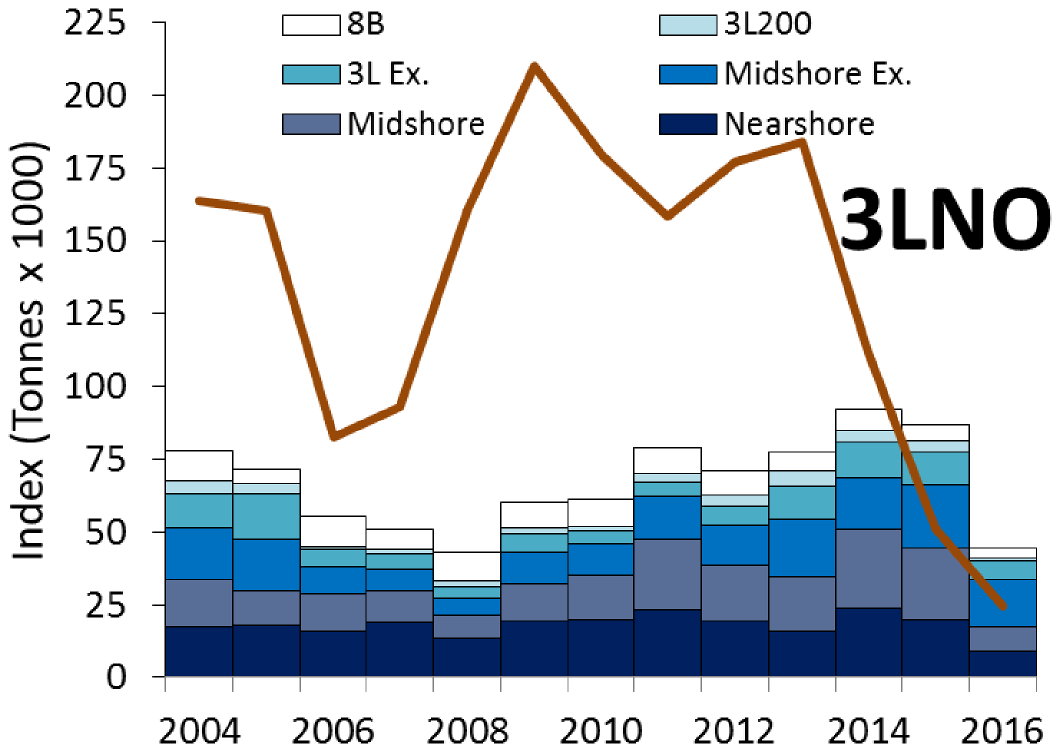

Figure 93. Trends in the trap survey-based exploitable biomass index versus the multi-species trawl survey exploitable biomass index in Divs. 3LNO Offshore.

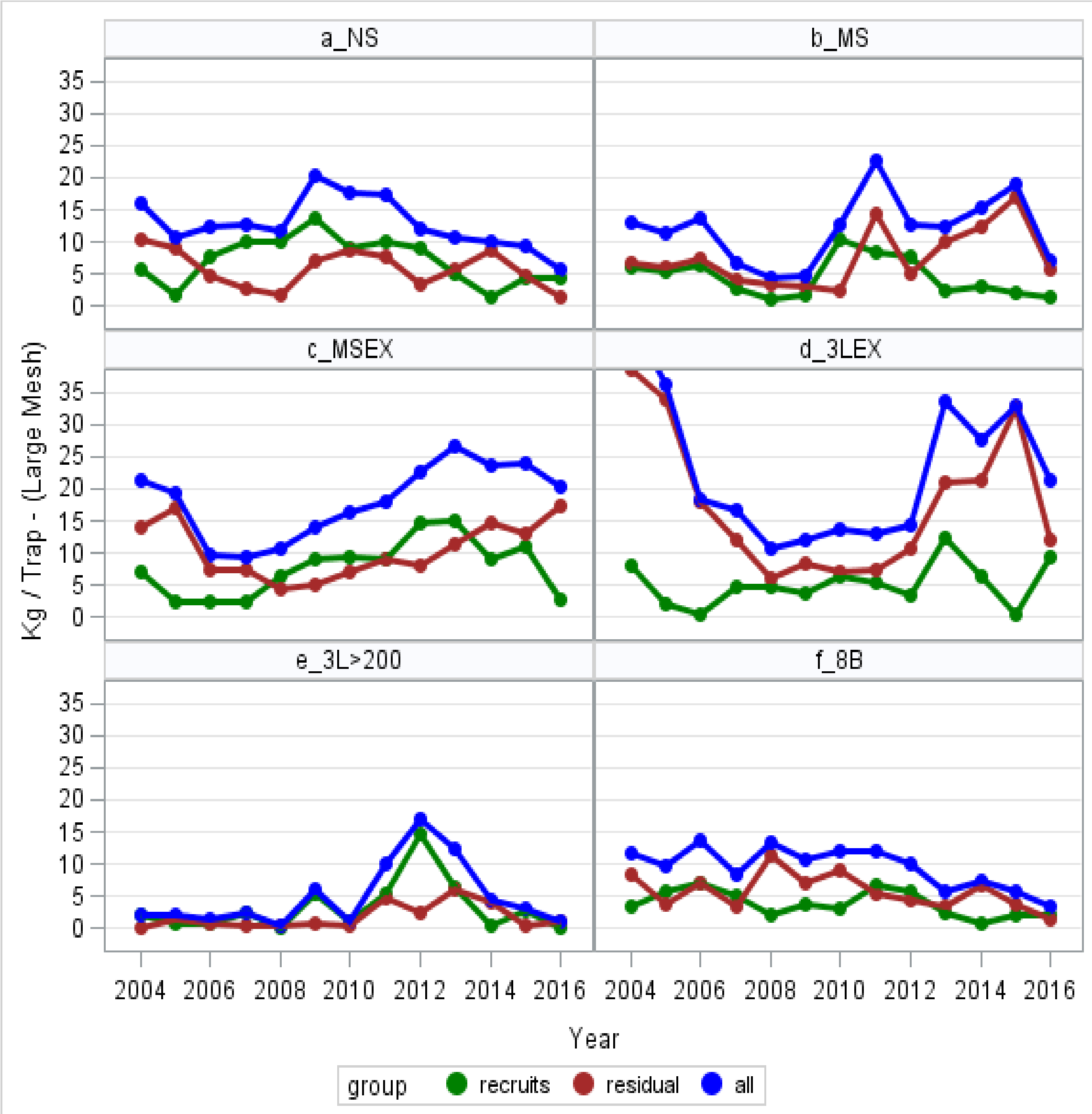

Figure 94. Trends in CPUE (kg/Trap) by shell condition for legal-sized crab from core stations in the CPS trap survey in Divs. 3LNO Offshore.

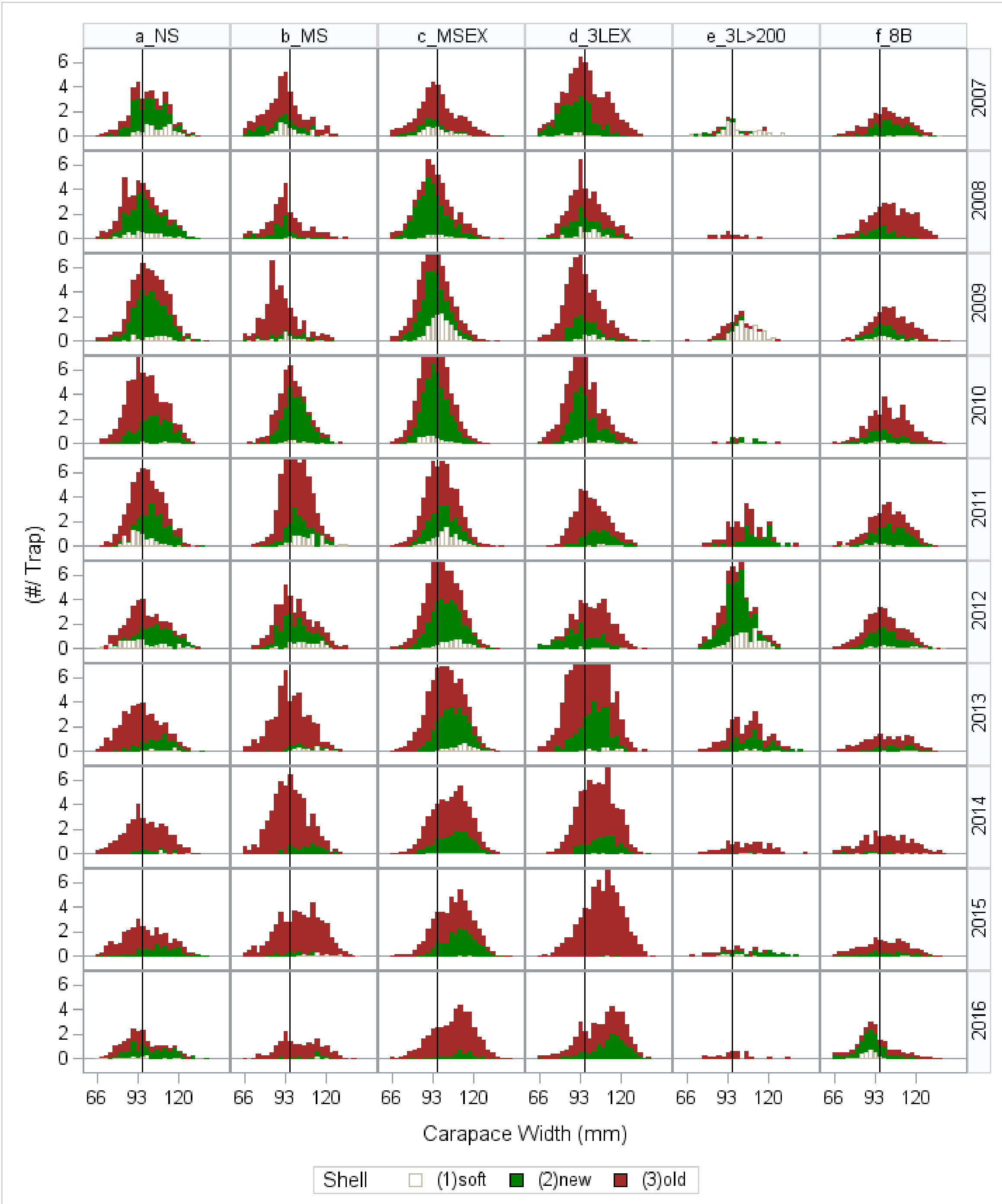

Figure 95. Trends in male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in Divs. 3LNO Offshore (2007-16). The vertical line indicates the minimum legal size.

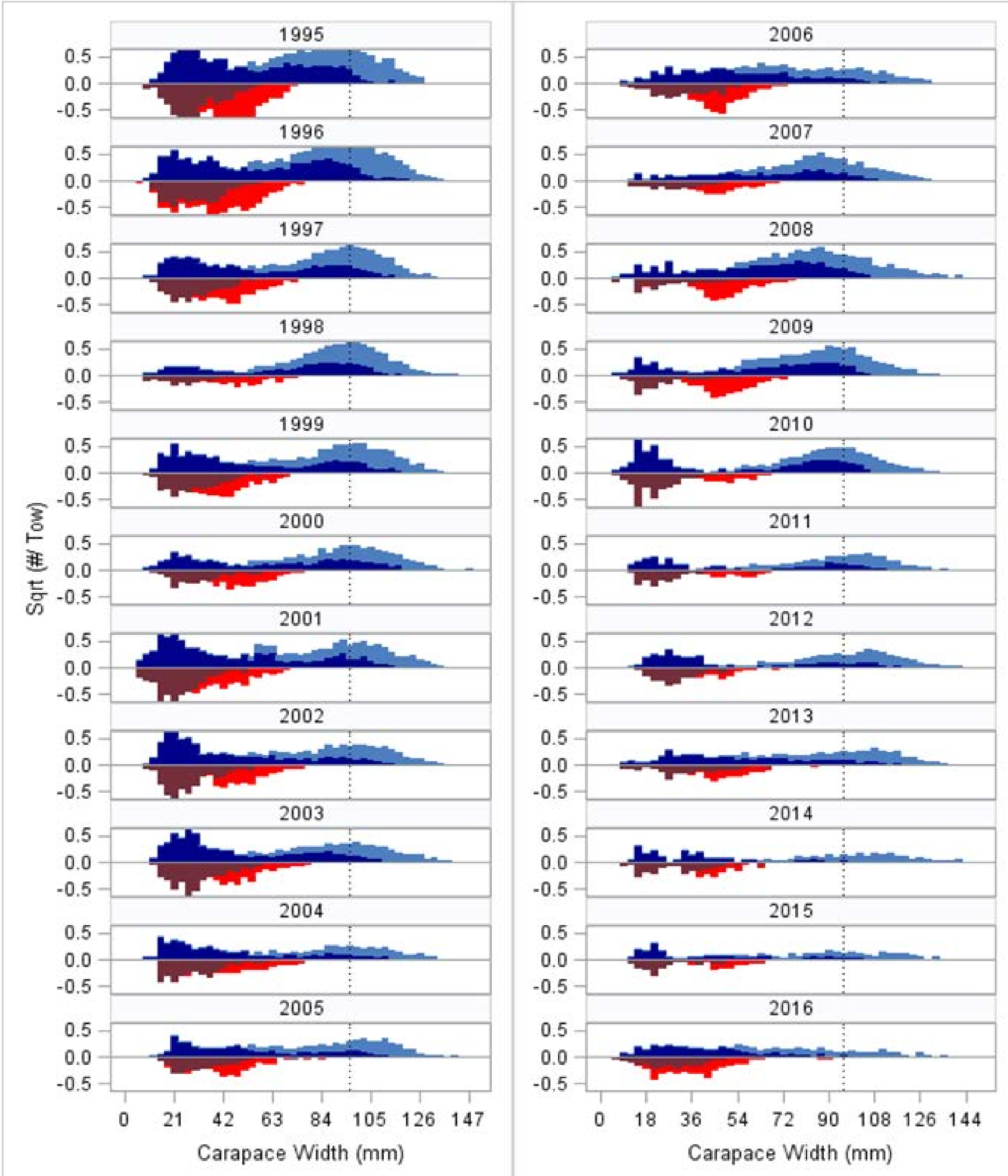

Figure 96. Abundance indices by carapace width for juveniles plus adolescent males (light blue), adult males (dark blue), immature females (dark red), and mature females (red) from the Divs. 3LNO fall trawl survey. Dashed vertical line is legal-size.

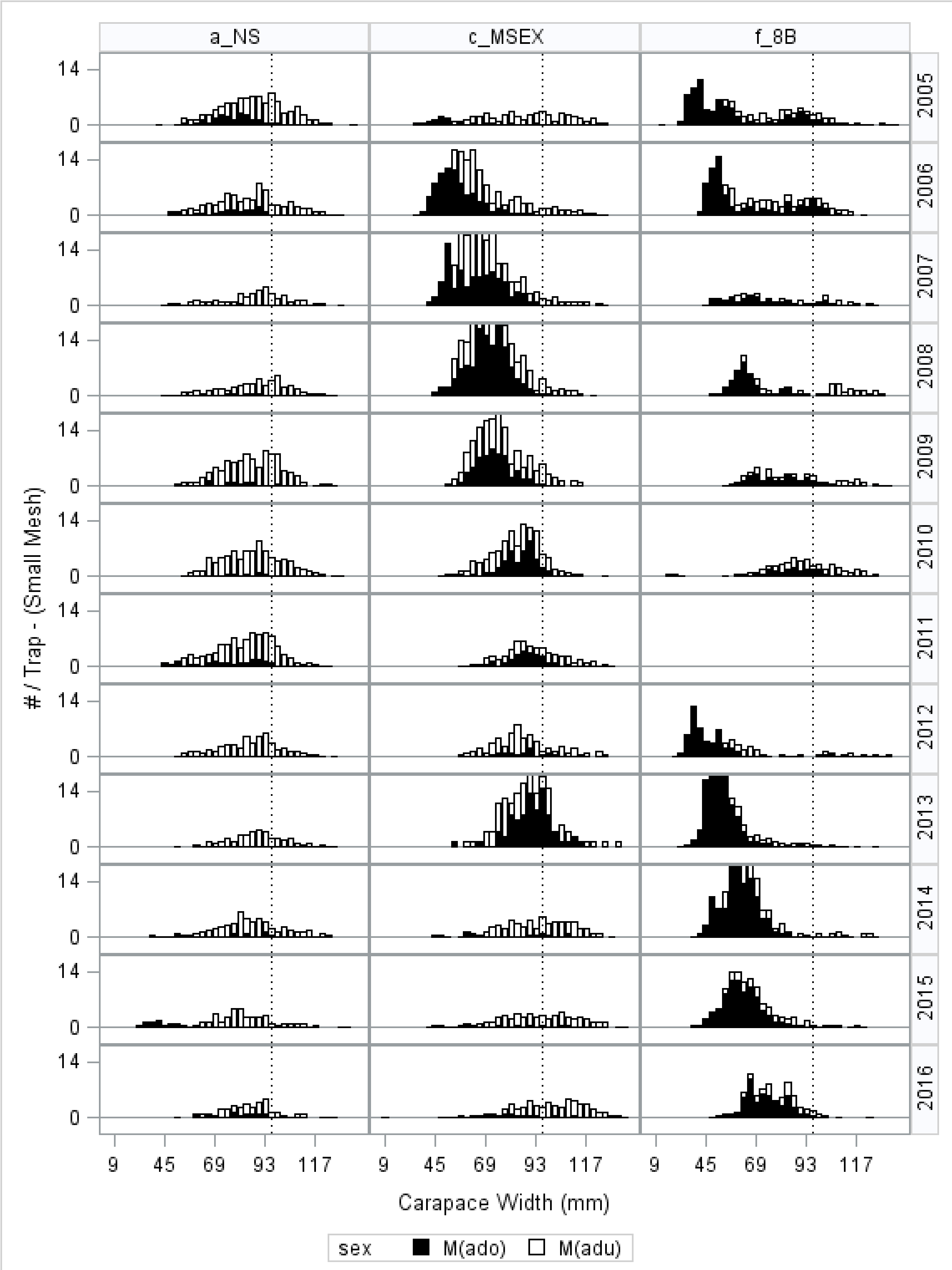

Figure 97. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the CPS CMAs NS/MSex/8B survey (2005-16). The vertical dotted line indicates the minimum legal size.

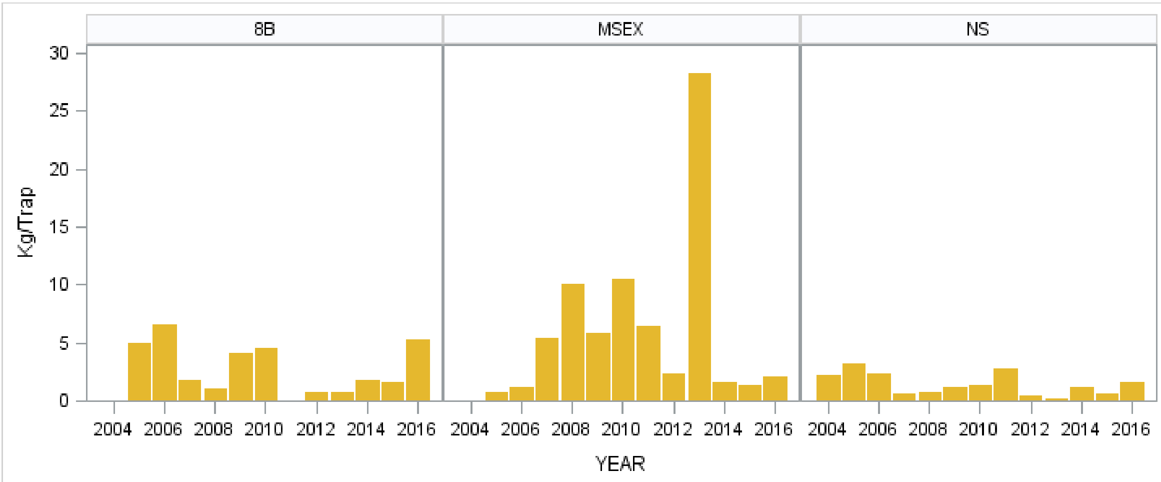

Figure 98. Pre-recruit abundance indices from small-mesh traps in the CPS survey in CMAs 8B/MSex/NS.

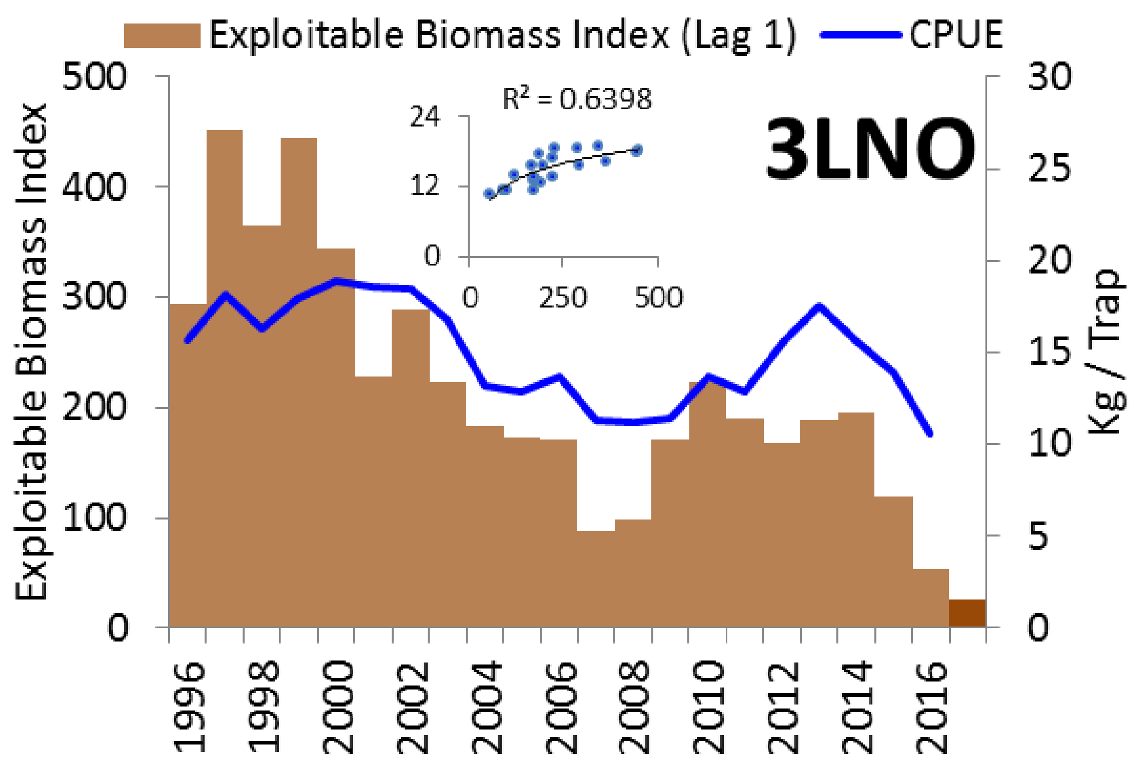

Figure 99. Standardized CPUE versus trawl survey exploitable biomass index lagged one year in Divs. 3LNO. Dark bar in 2017 depicts most recent biomass estimate from the 2016 fall survey.

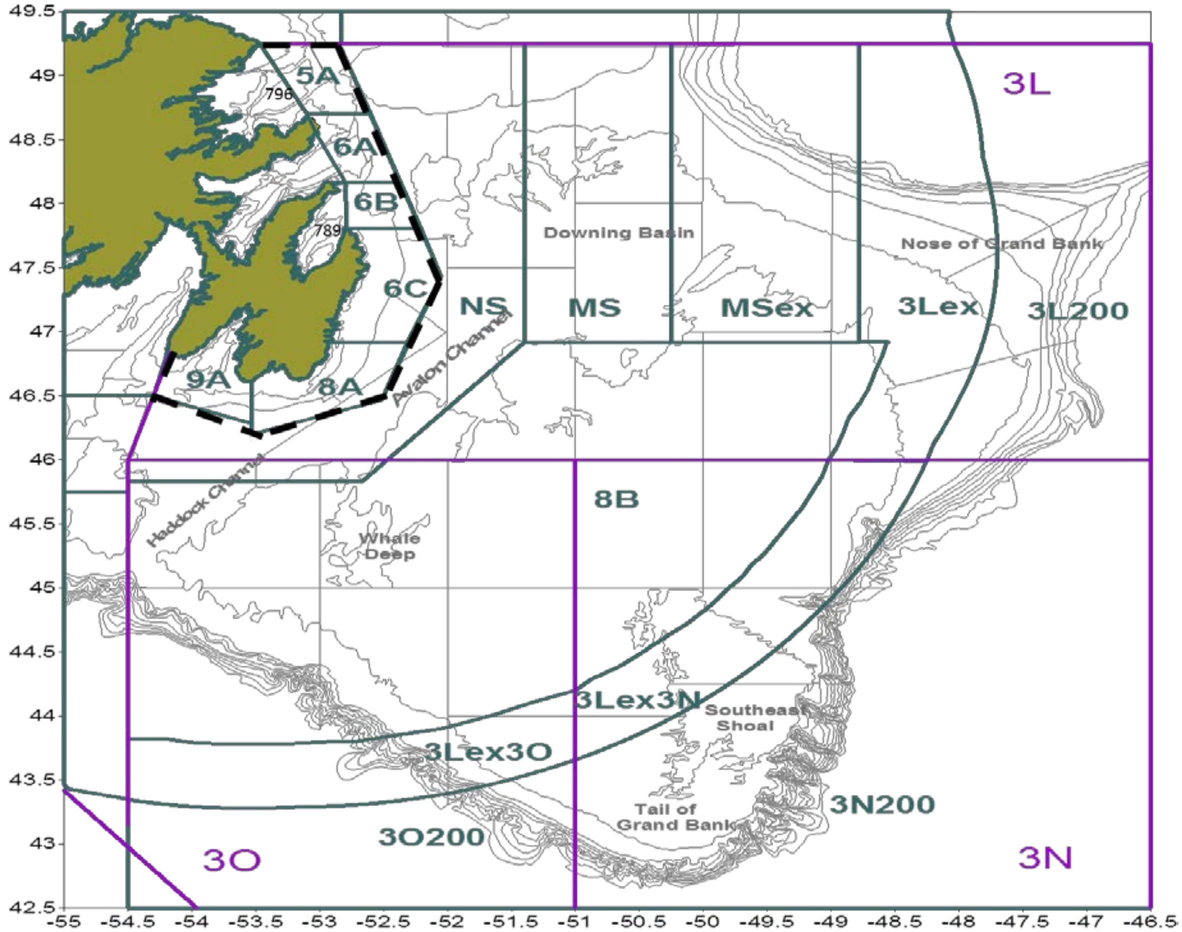

Figure 100. Map of Divs. 3LNO showing crab management areas and important bathymetric features. Dashed perimeter indicates Div. 3L Inshore areas.

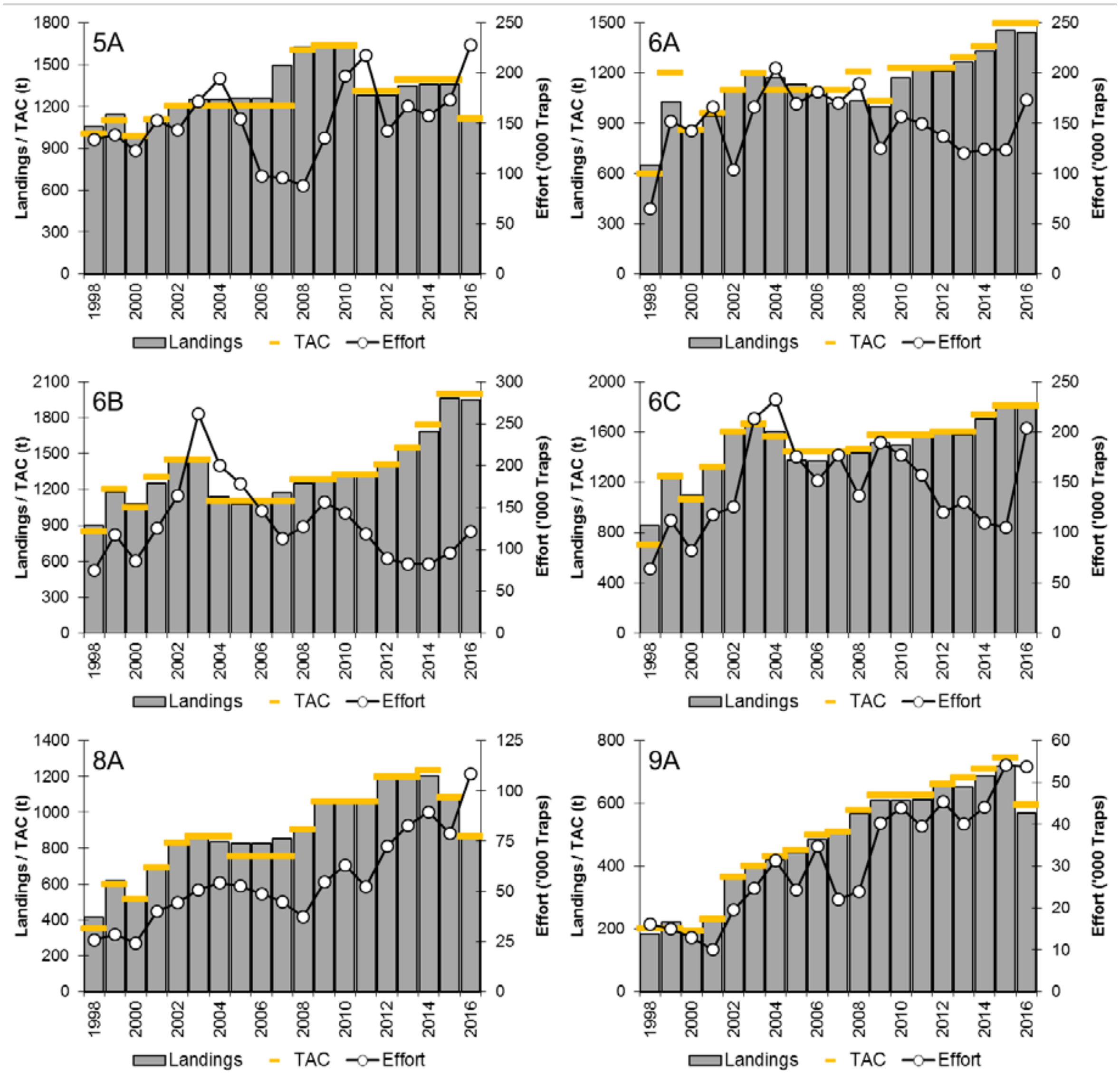

Figure 101. TAC, landings, and estimated effort by CMA in Div. 3L Inshore. 2016 effort is considered preliminary.

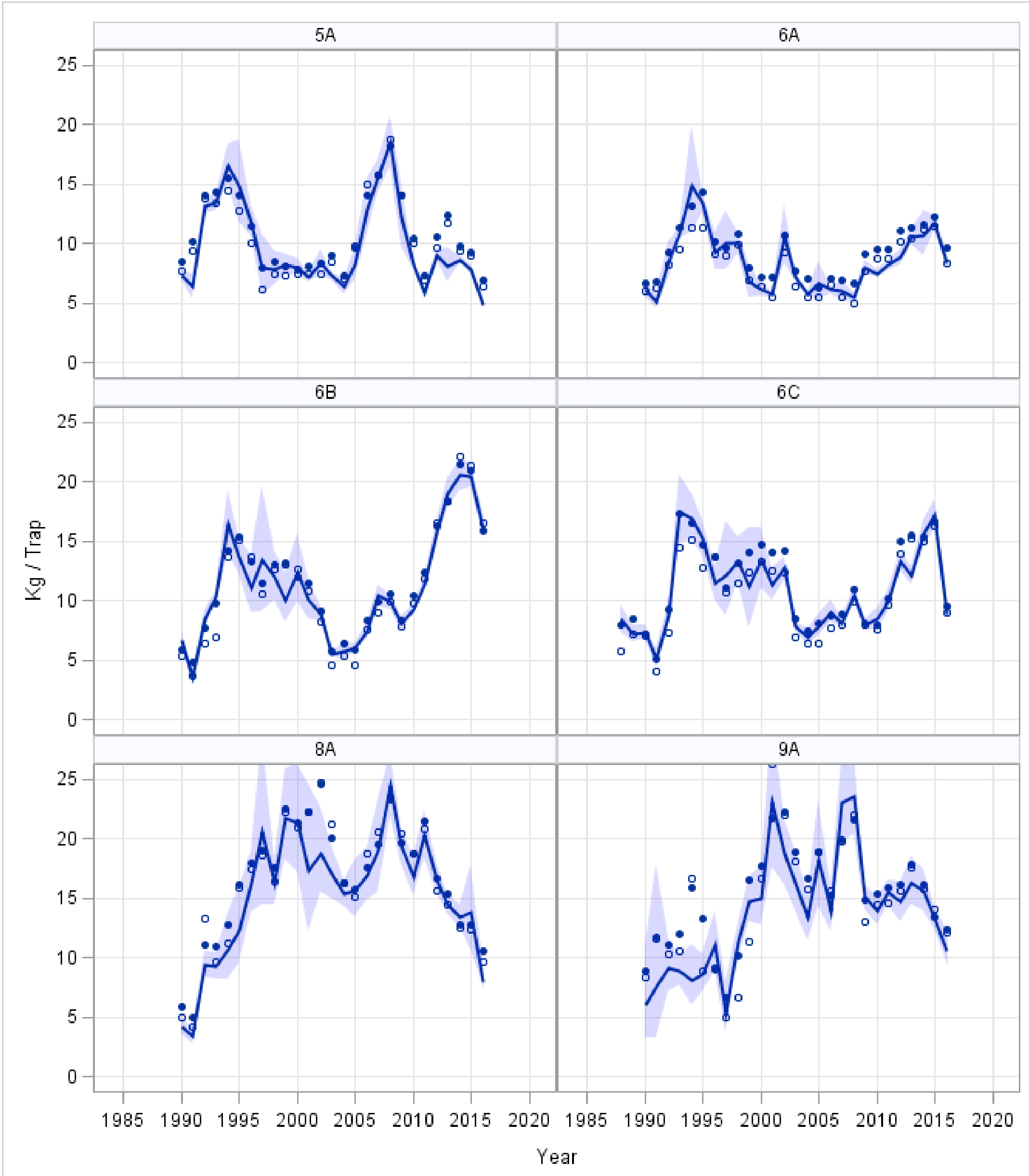

Figure 102. Trends in standardized catch per unit effort (CPUE, Kg/Trap) for CMAs in Div. 3L Inshore. Open circles are medians and closed circles are means.

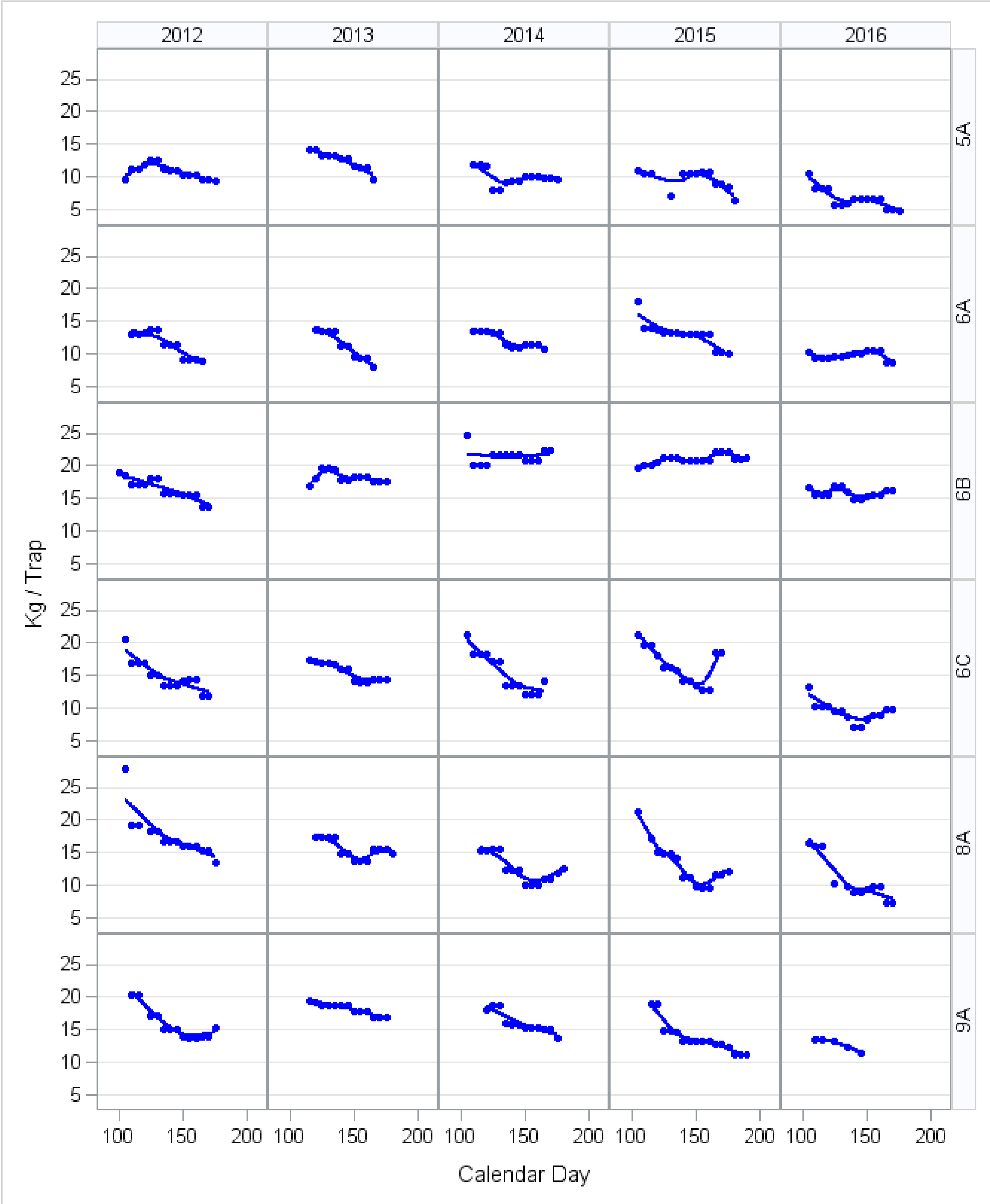

Figure 103. Trends in standardized CPUE (2012-16) throughout the season fit with loess regression curves, by CMA in Div. 3L Inshore.

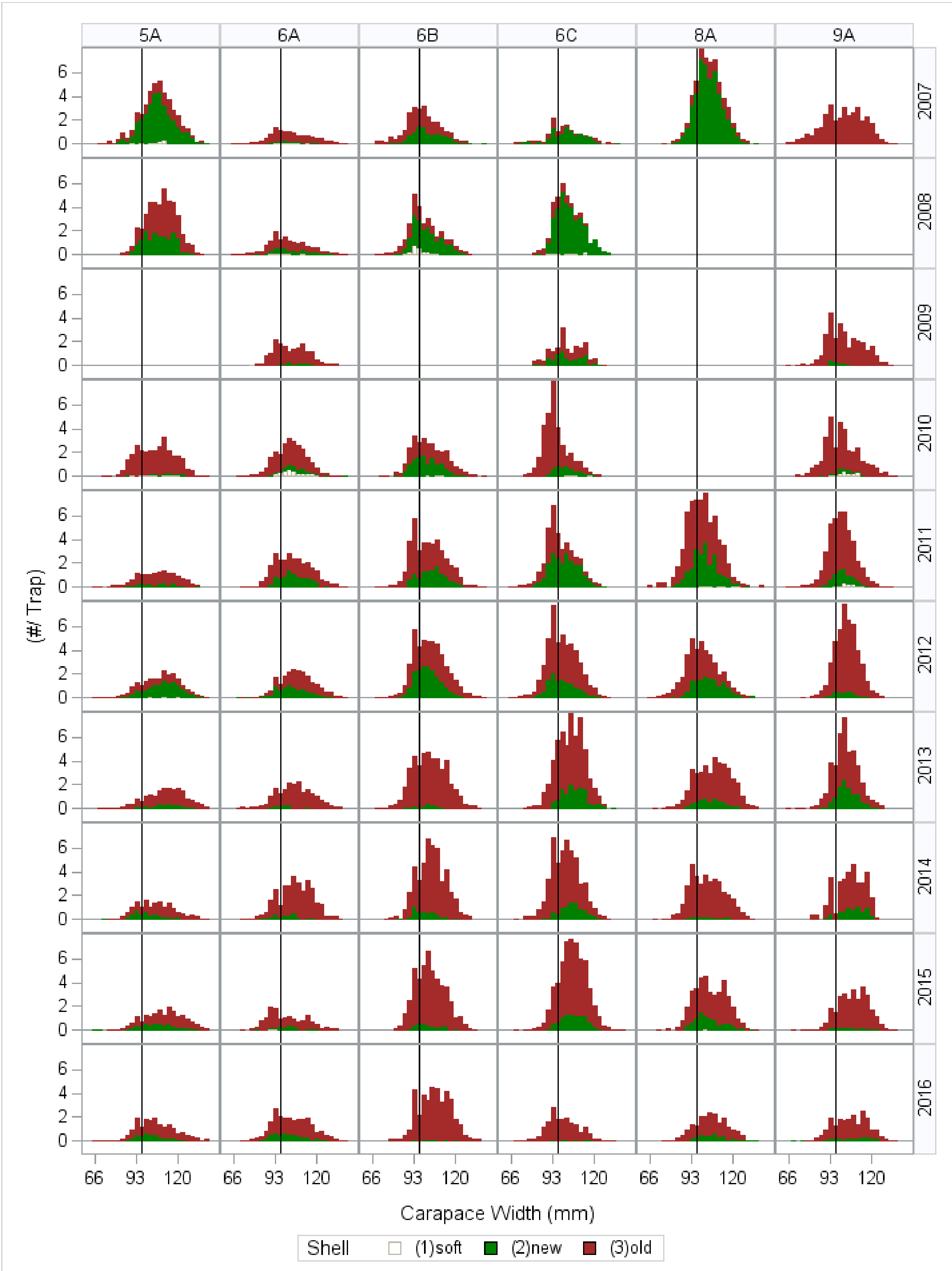

Figure 104. Trends in male carapace width distributions by shell condition from observer sampling in Div. 3L Inshore (2007-16). The vertical line indicates the minimum legal size.

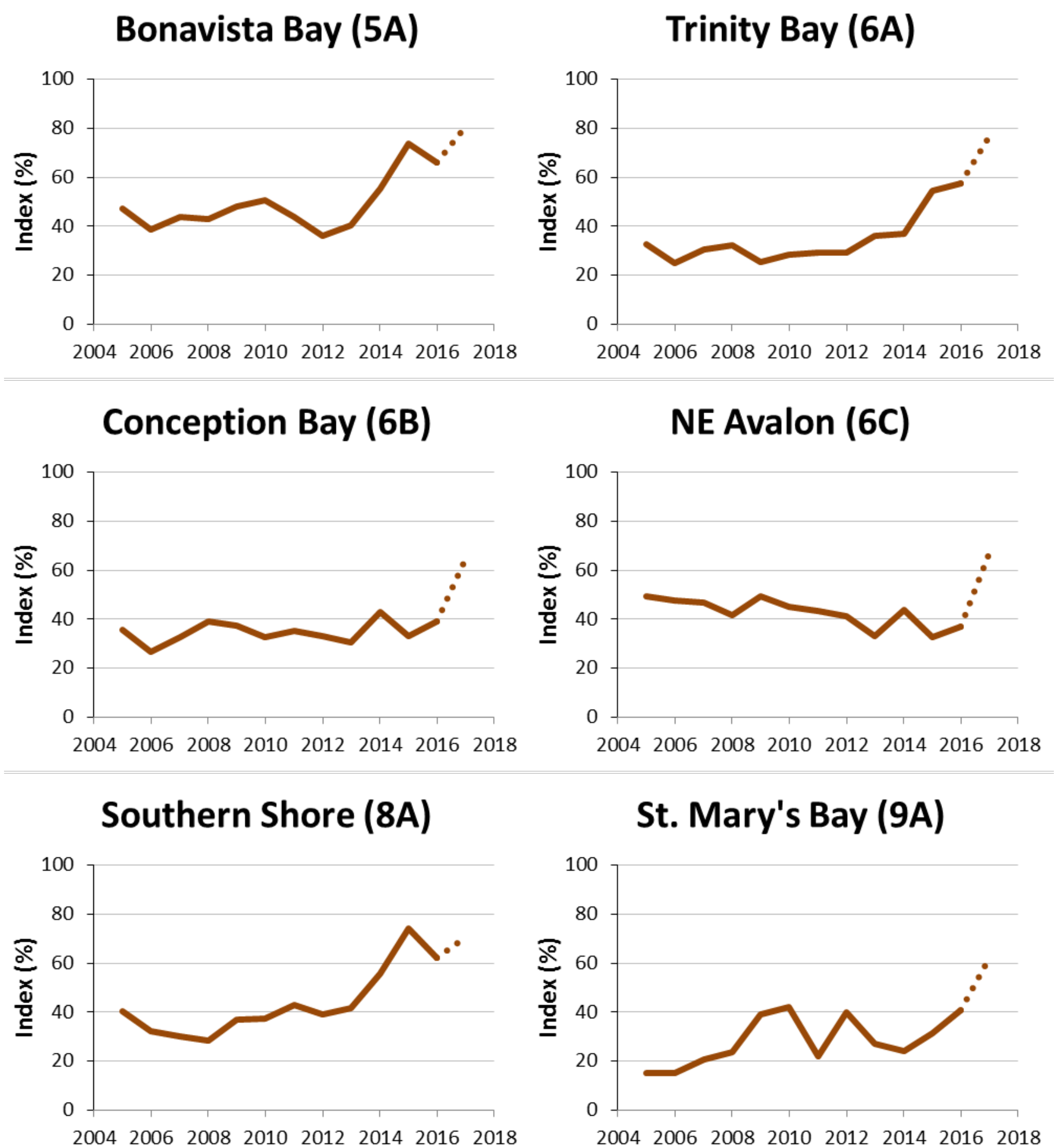

Figure105. Trends in trap survey-based exploitation rate indices by CMA in Div. 3L Inshore. Dashed lines depict projected 2017 exploitation rate indices based on status quo landings.

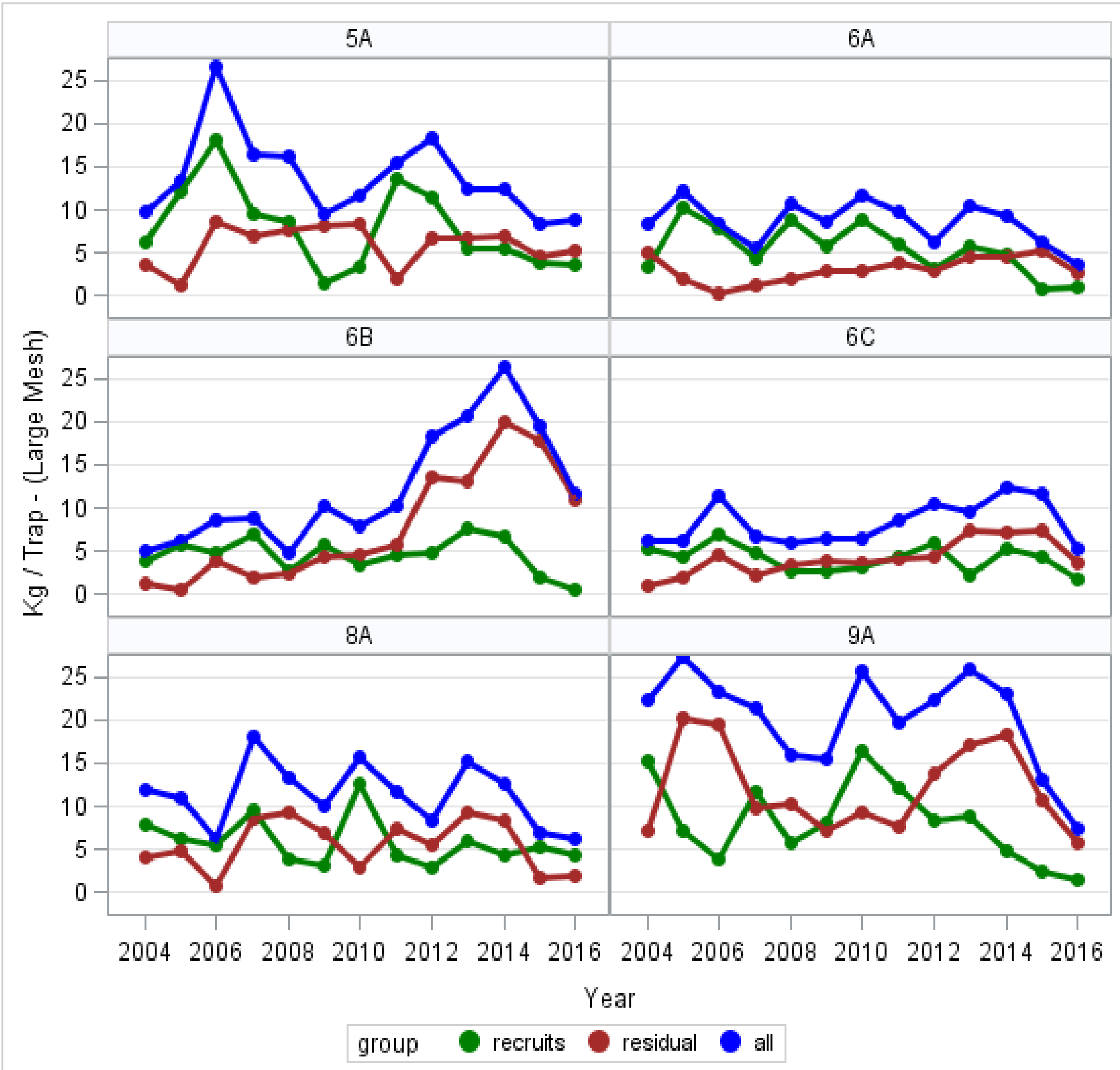

Figure 106. Trends in CPUE (Kg/Trap) by shell condition for legal-sized crab from core stations in the CPS trap survey in Div. 3L Inshore.

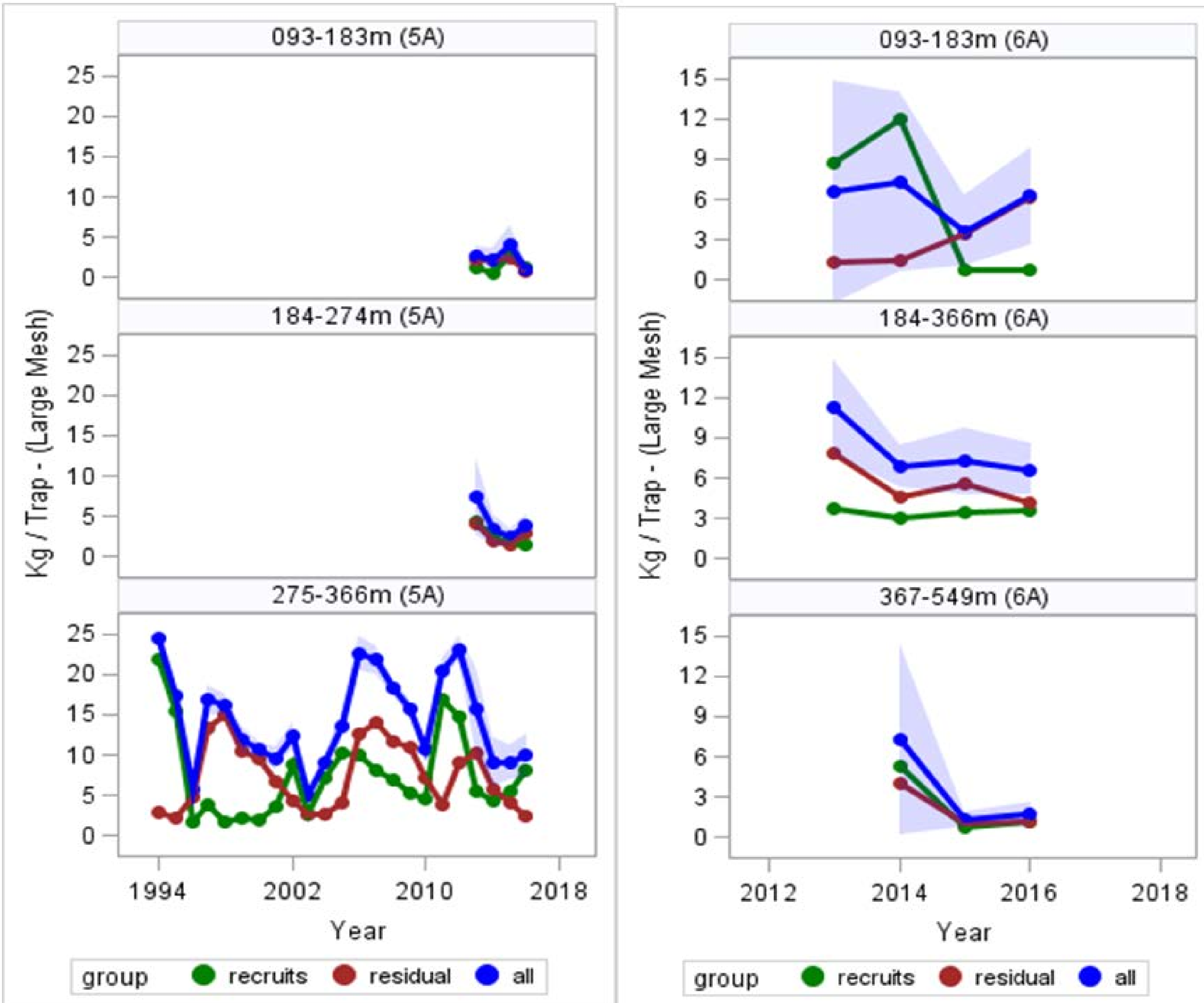

Figure 107. Trends in CPUE (Kg/Trap) by shell condition for legal-sized crab from DFO trap surveys in CMAs 5A and 6A.

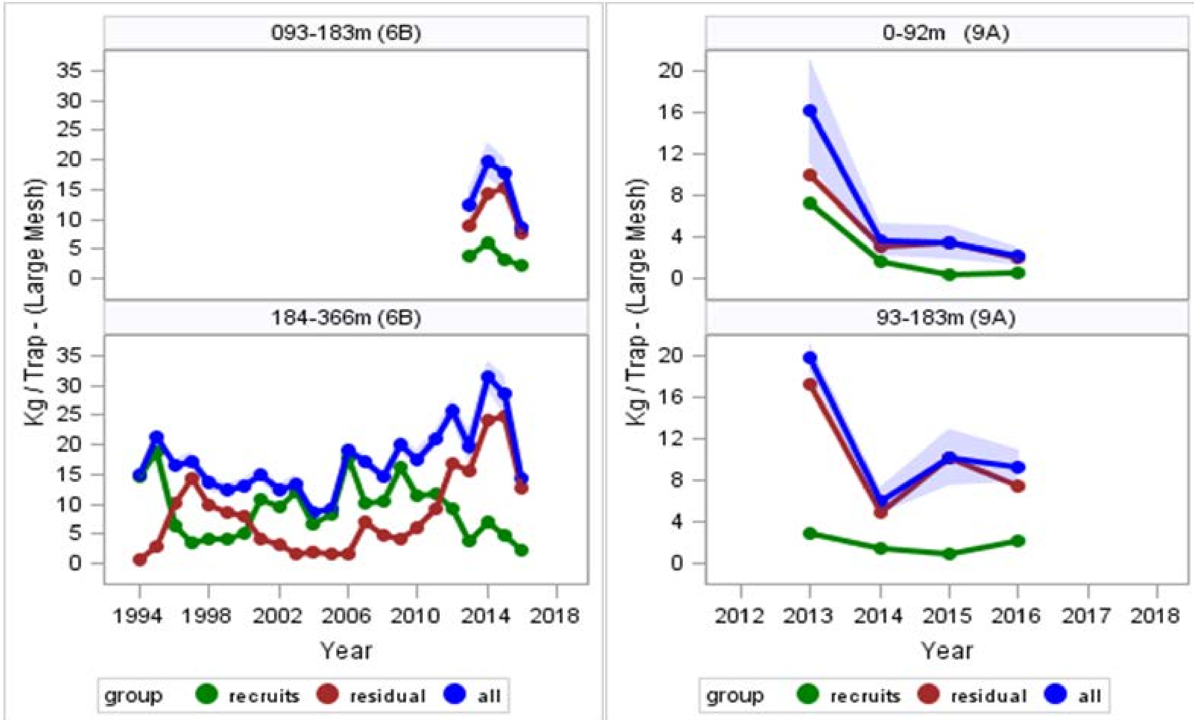

Figure 108. Trends in CPUE (Kg/Trap) by shell condition for legal-sized crab from DFO trap surveys in CMAs 6B and 9A.

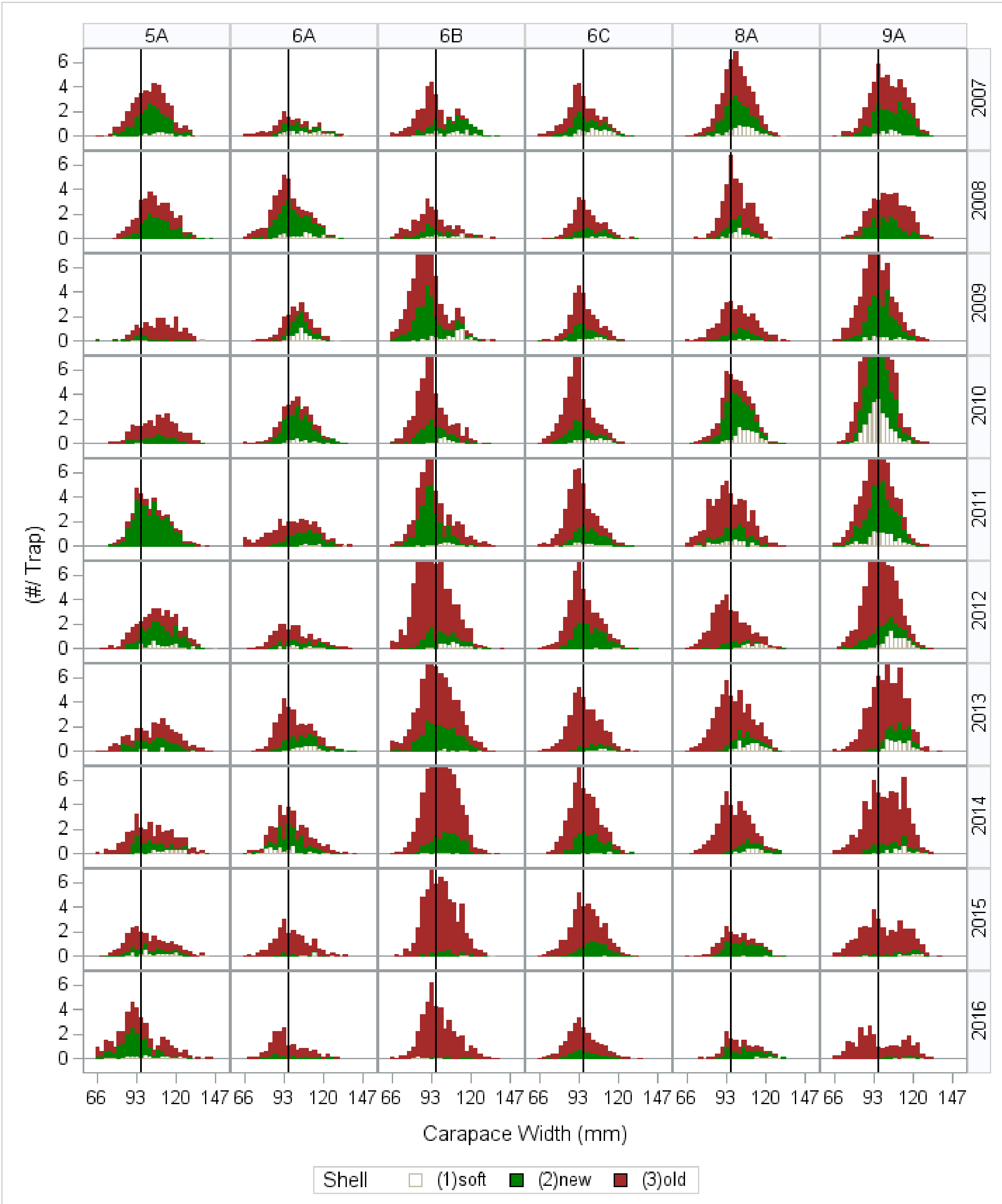

Figure 109. Trends in male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in Div. 3L Inshore. The vertical line indicates the minimum legal size.

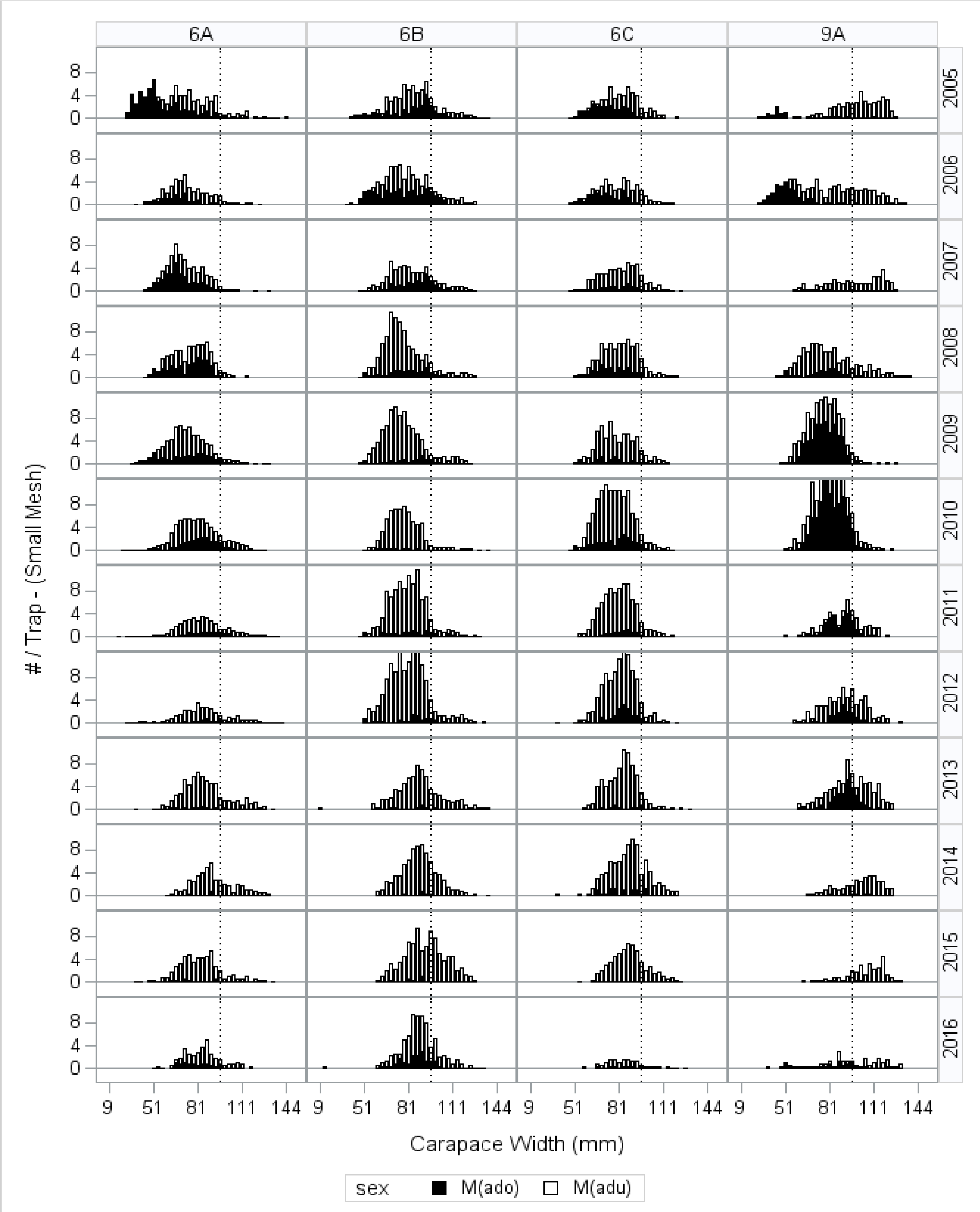

Figure 110. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the CPS 3L Inshore survey (2005-16). The vertical dotted line indicates the minimum legal size.

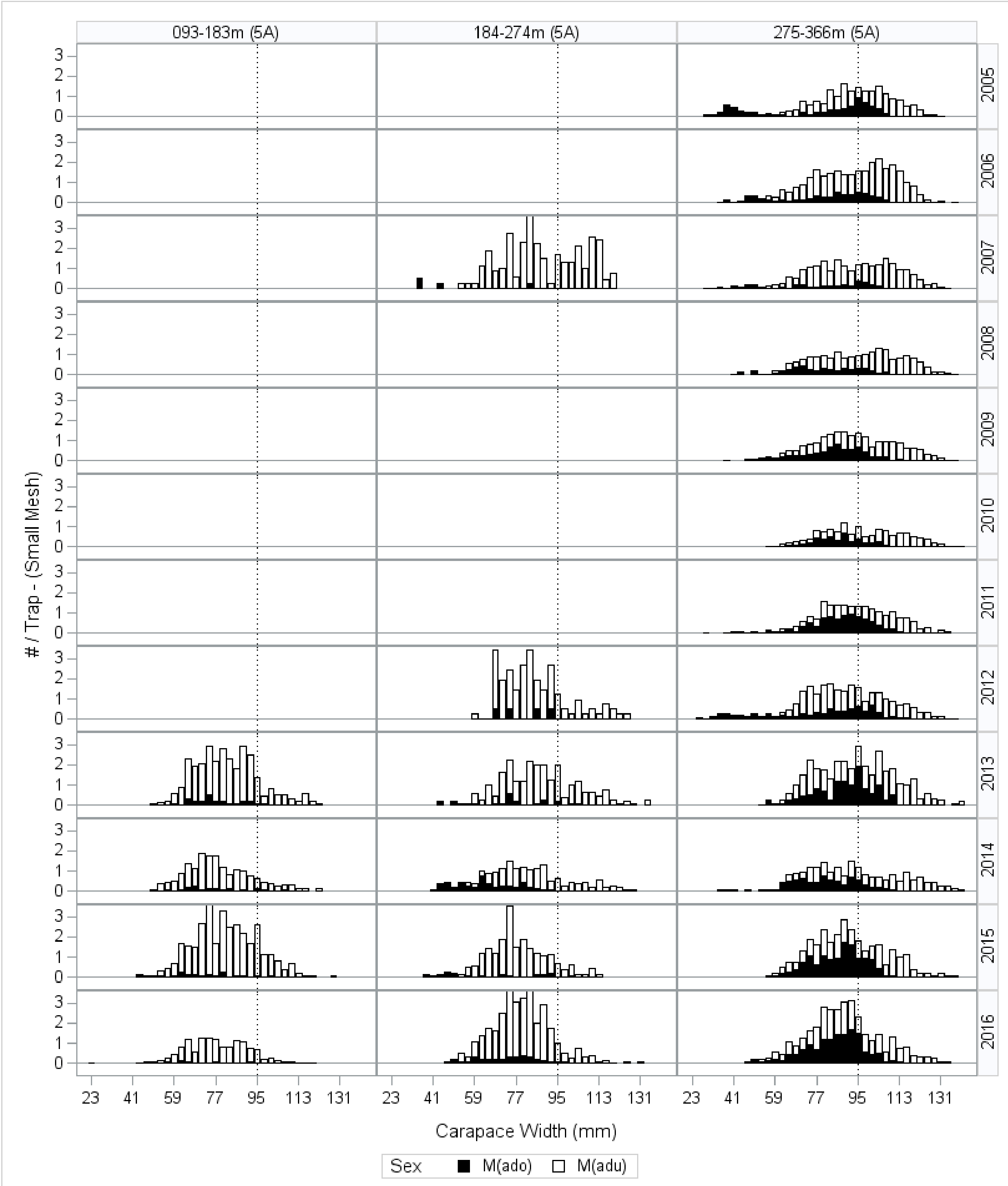

Figure 111. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the DFO 5A trap survey (2005-16). The vertical dotted line indicates the minimum legal size.

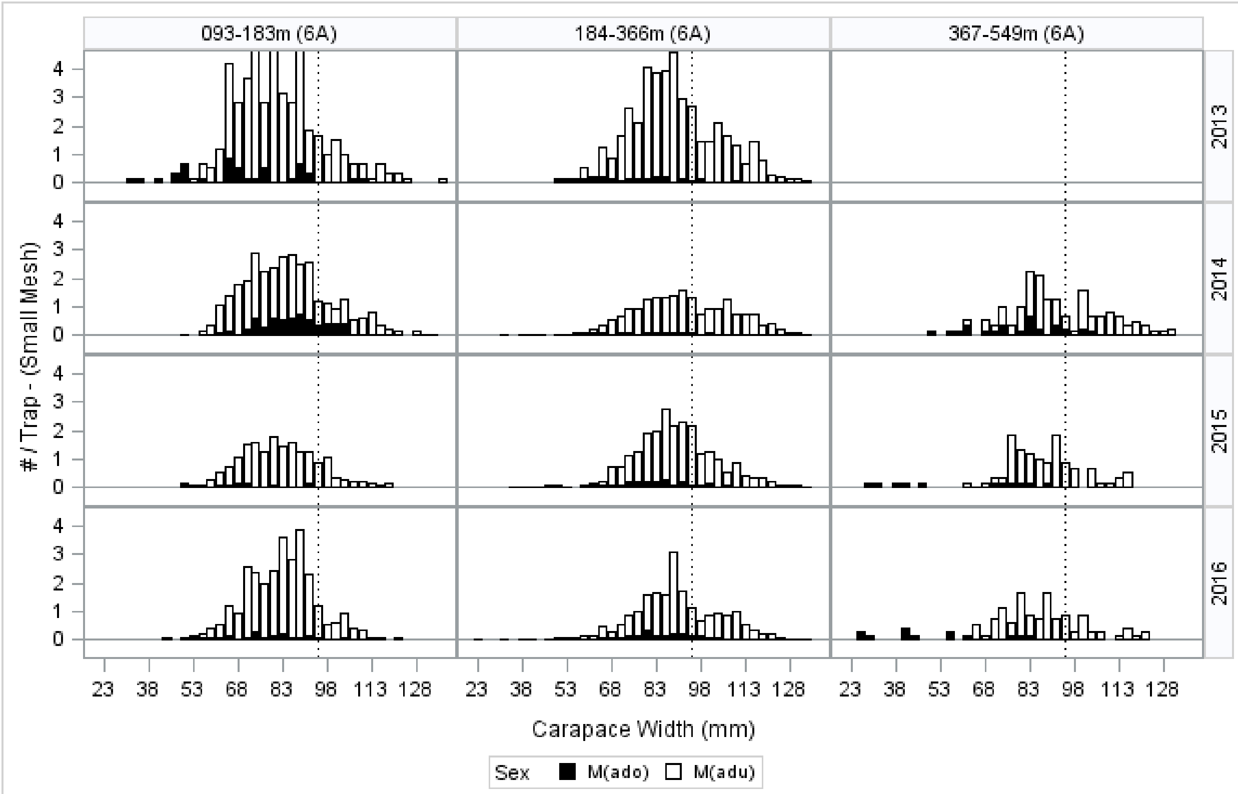

Figure 112. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the DFO 6A trap survey (2013-16). The vertical dotted line indicates the minimum legal size.

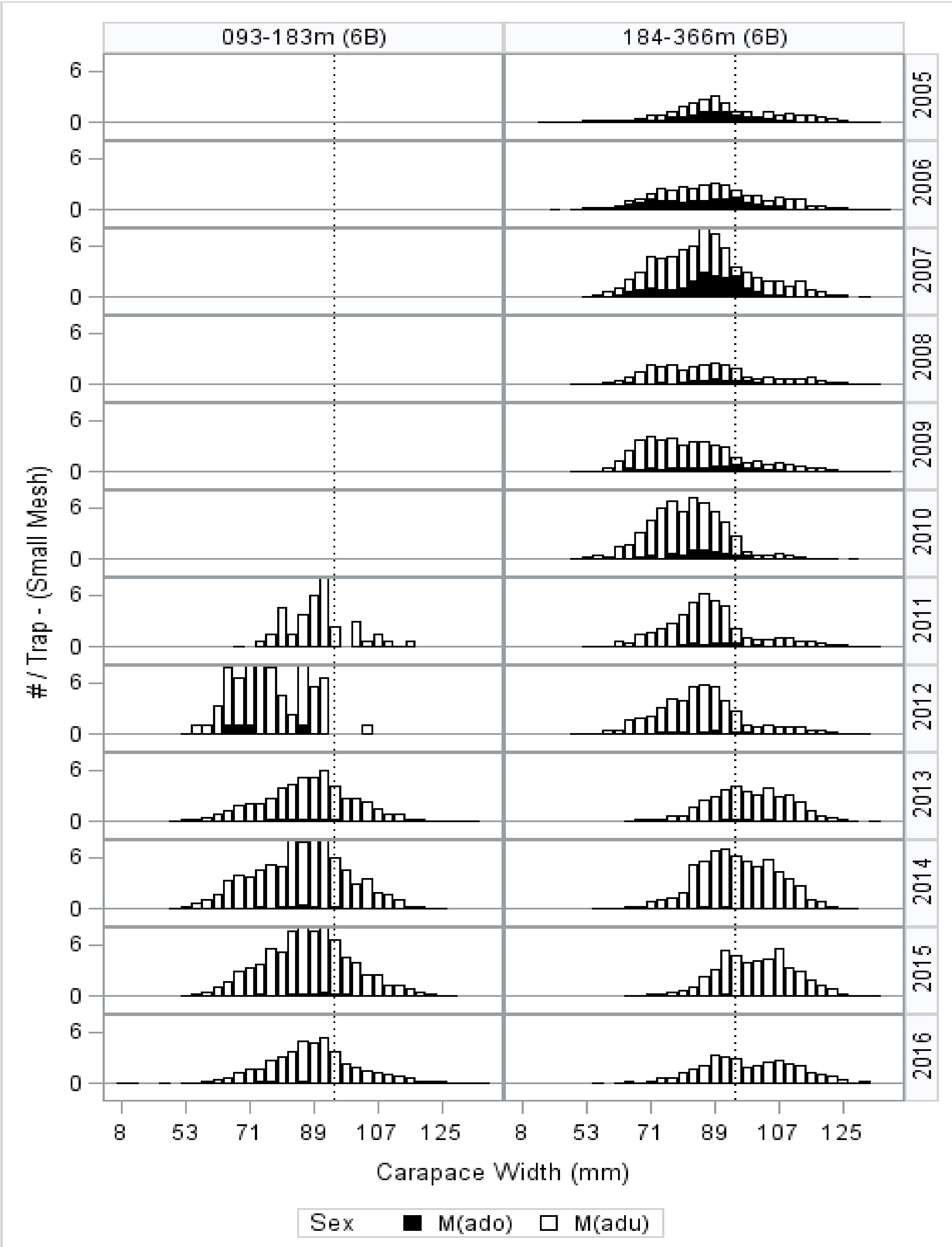

Figure 113. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the DFO 6B trap survey (2005-16). The vertical dotted line indicates the minimum legal size.

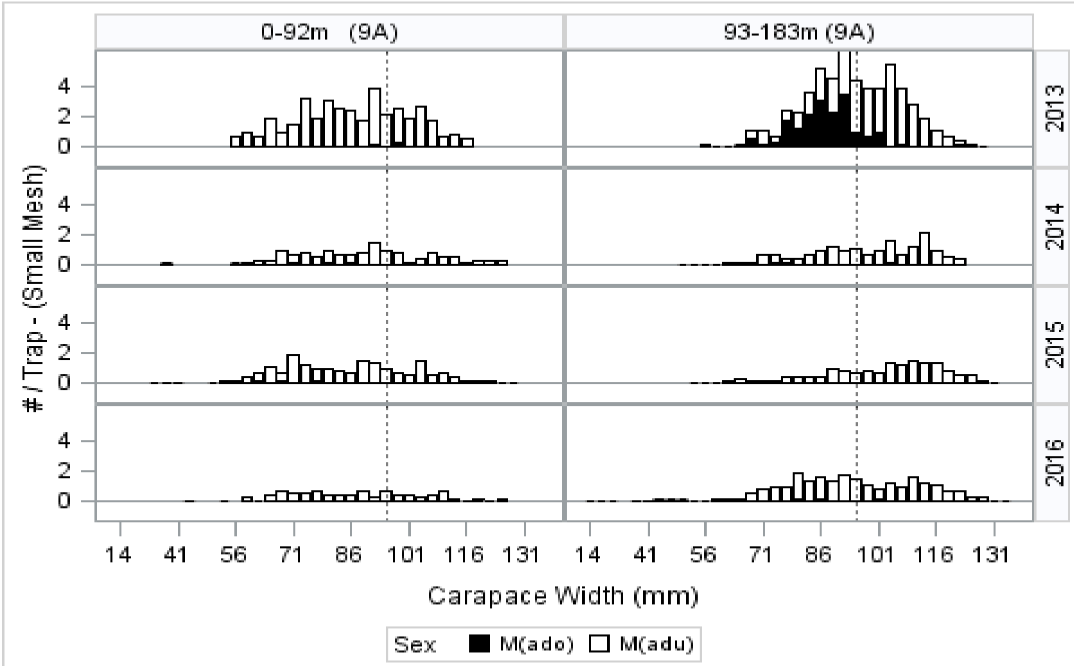

Figure 114. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the DFO 9A trap survey (2013-16). The vertical dotted line indicates the minimum legal size.

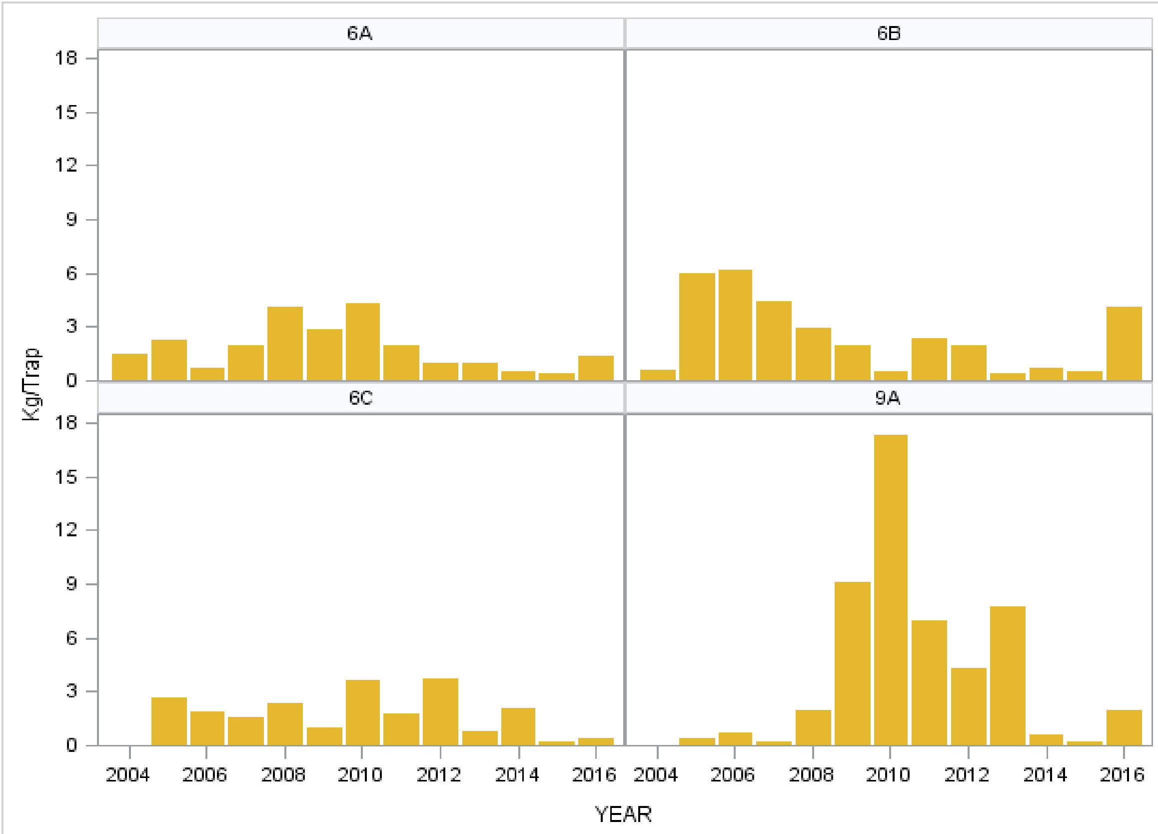

Figure 115. Pre-recruit abundance indices from small-mesh traps in CPS trap surveys in Div. 3L Inshore.

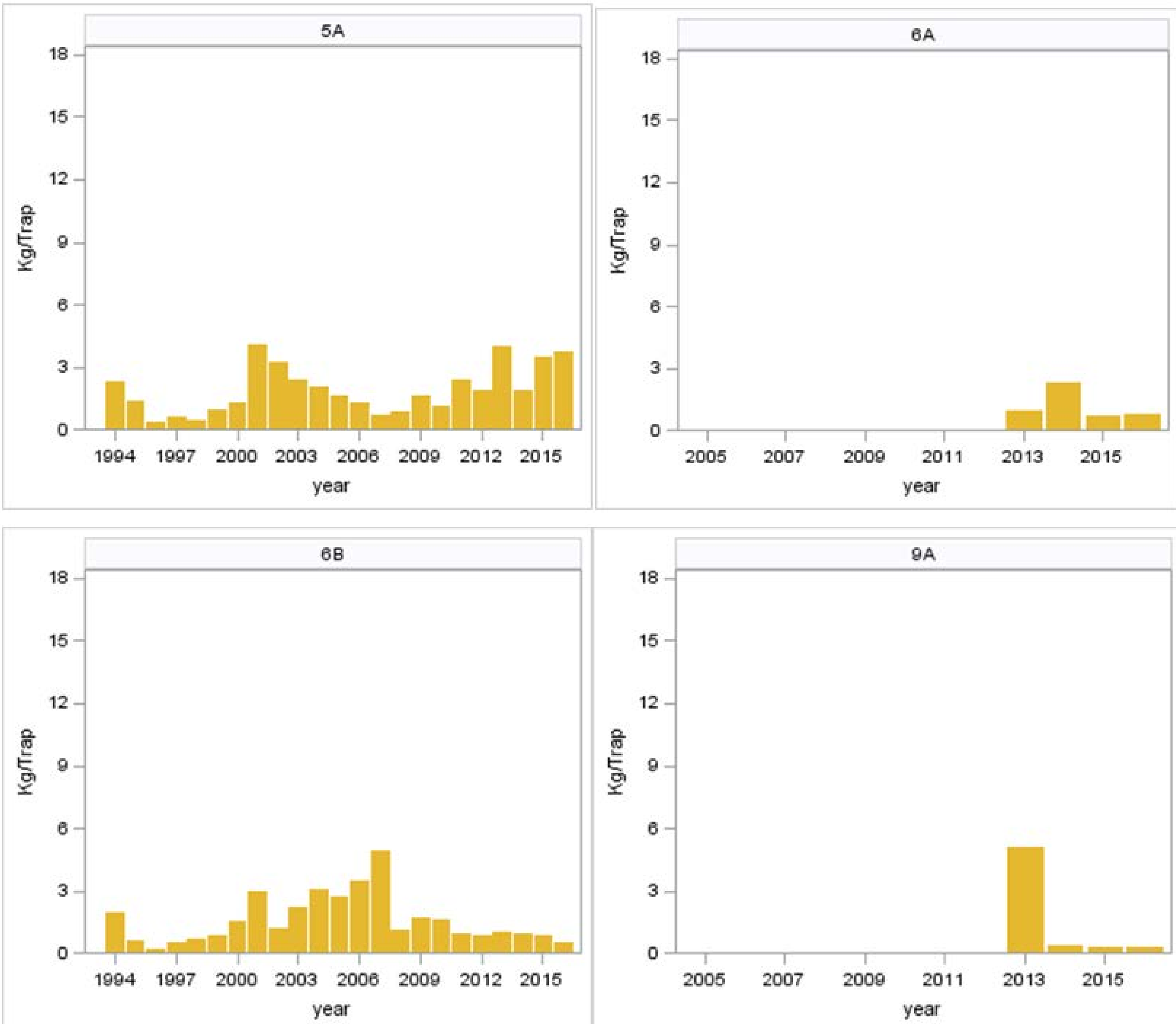

Figure 116. Pre-recruit abundance indices from small-mesh traps in DFO trap surveys in Div. 3L Inshore.

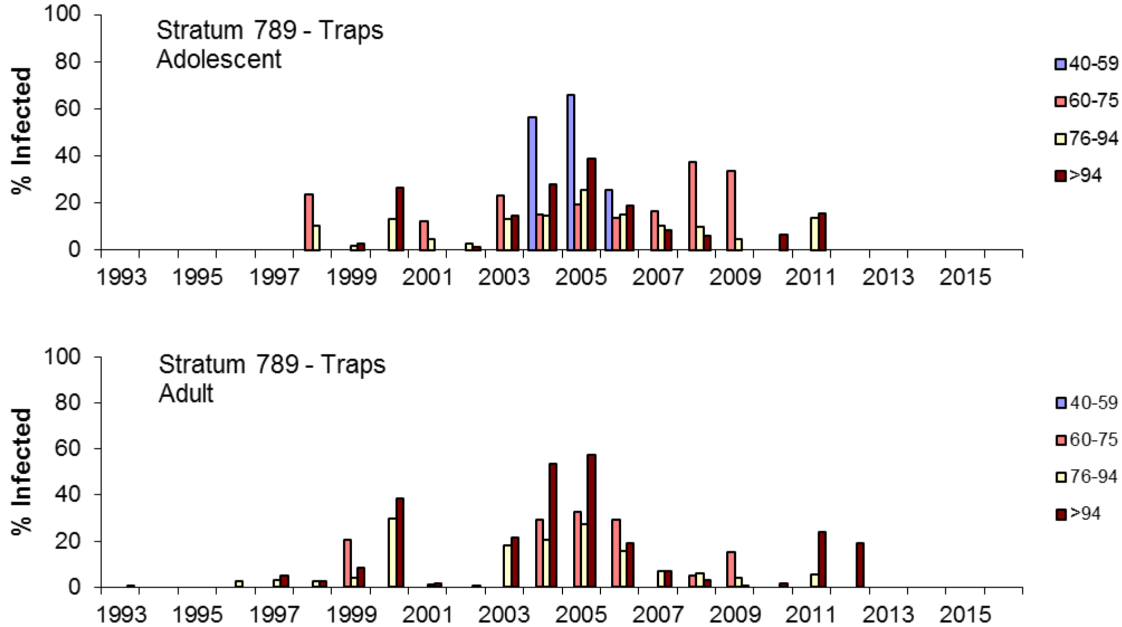

Figure 117. Prevalence of BCD in male crab by carapace width group and maturity from DFO Conception Bay (CMA 6B) trap surveys.

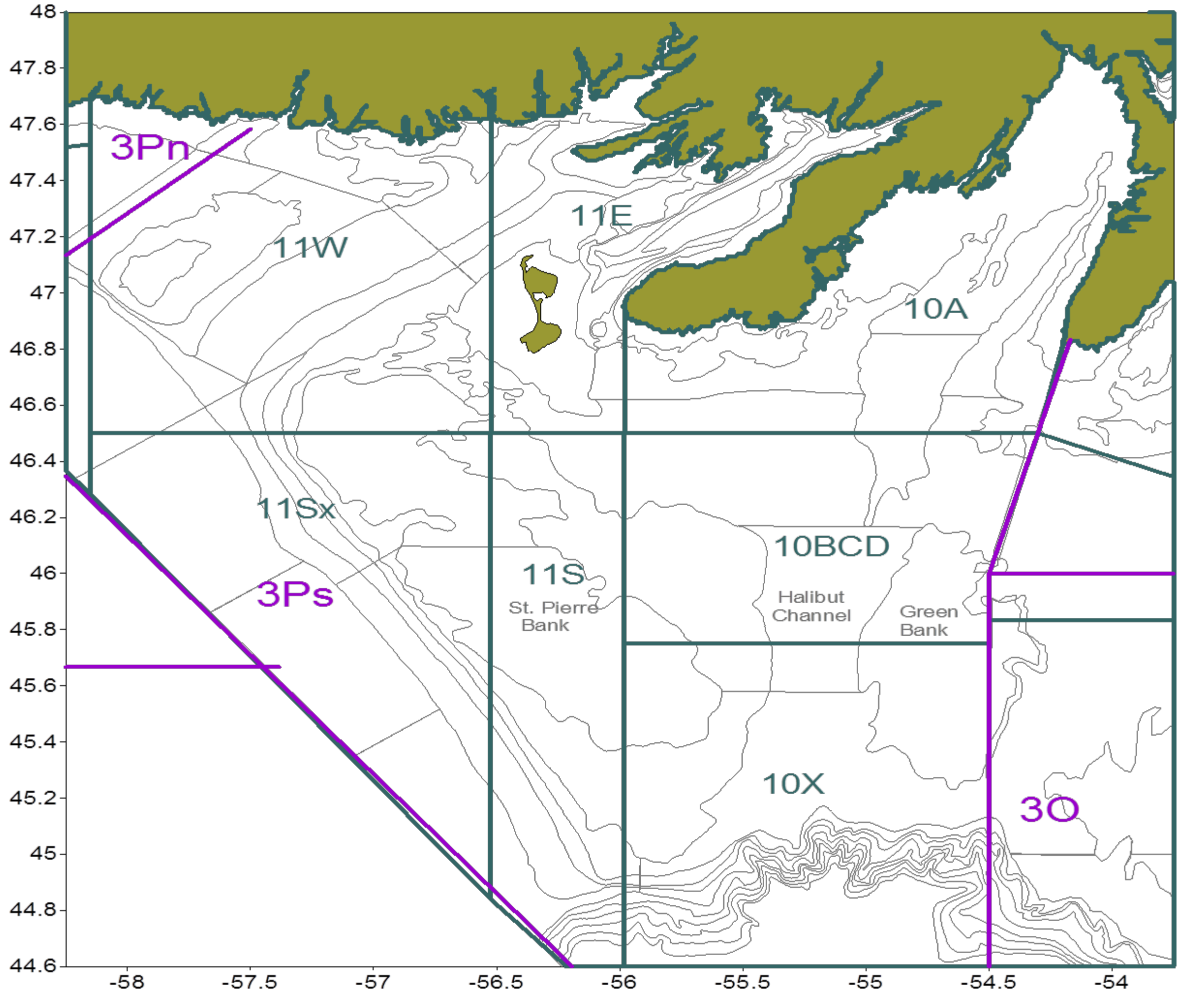

Figure 118. Map of Subdiv. 3Ps showing crab management areas and important bathymetric features. Dashed perimeter indicates offshore areas. Note merger of CMAs 11Sx and 11S in 2015.

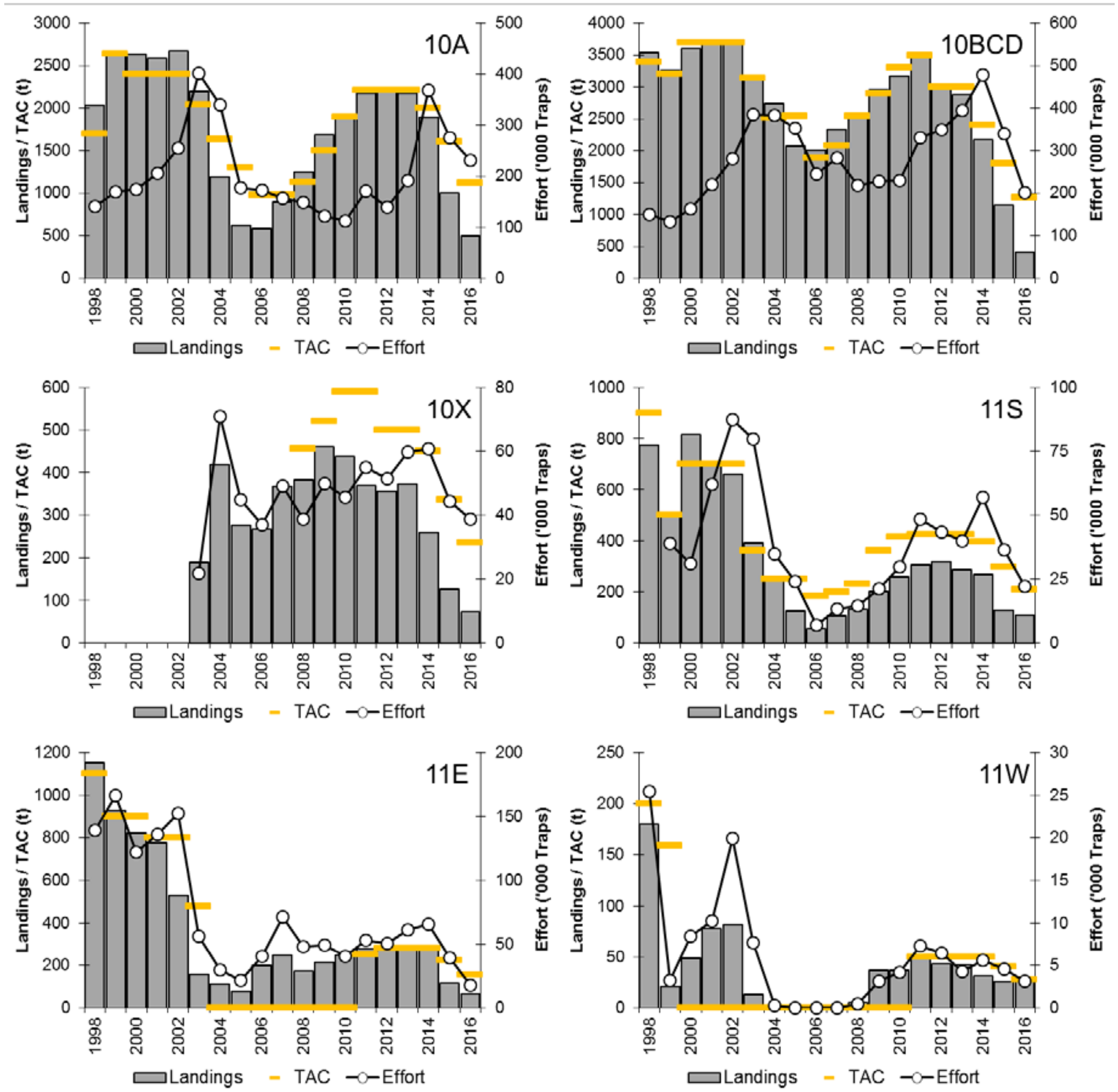

Figure 119. TAC, landings, and estimated effort for CMAs in Subdiv. 3Ps. 2016 effort is considered preliminary.

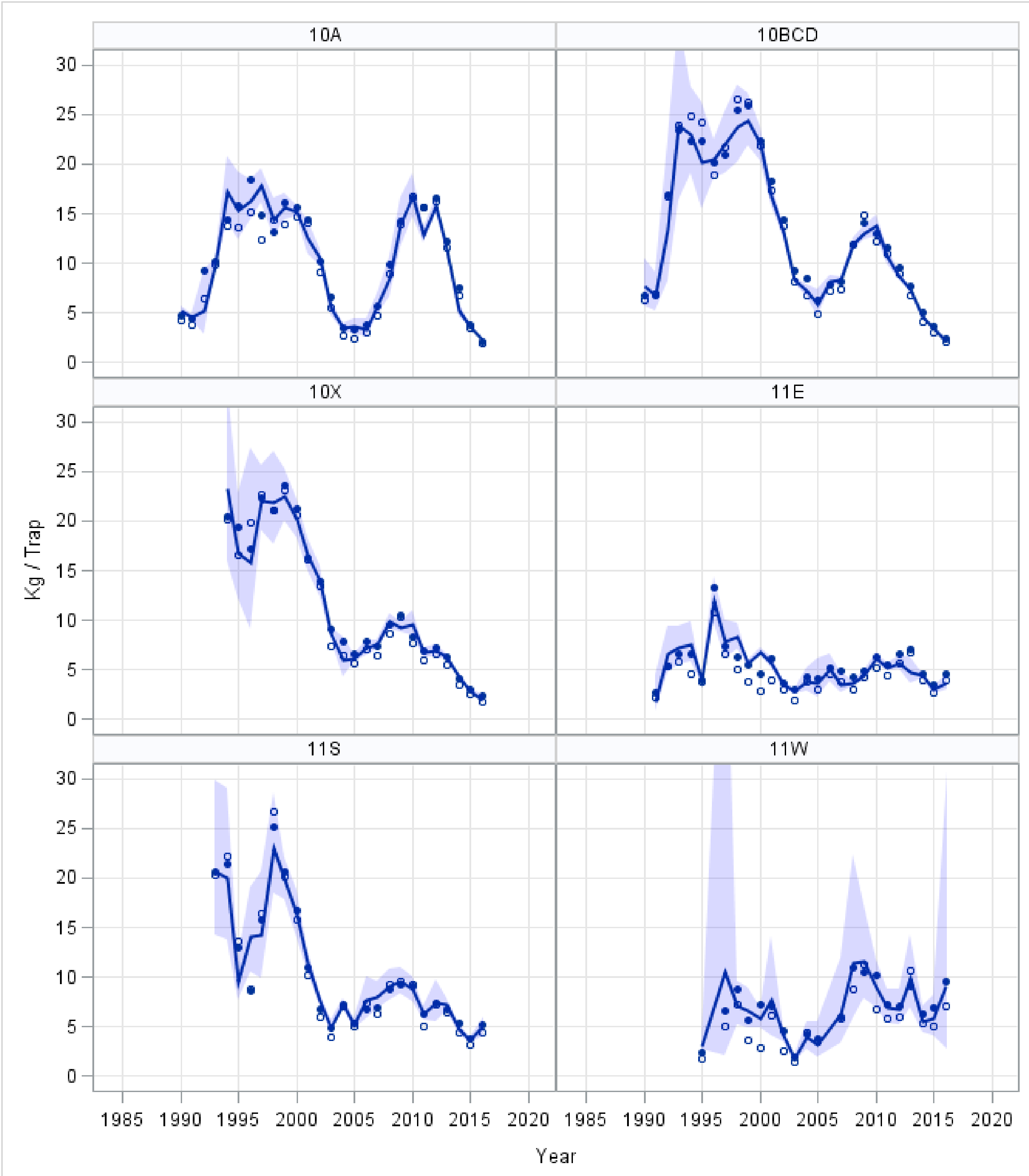

Figure 120. Trends in standardized catch per unit effort (CPUE, Kg/Trap) for CMAs in Subdiv. 3Ps. Open circles are medians and closed circles are means.

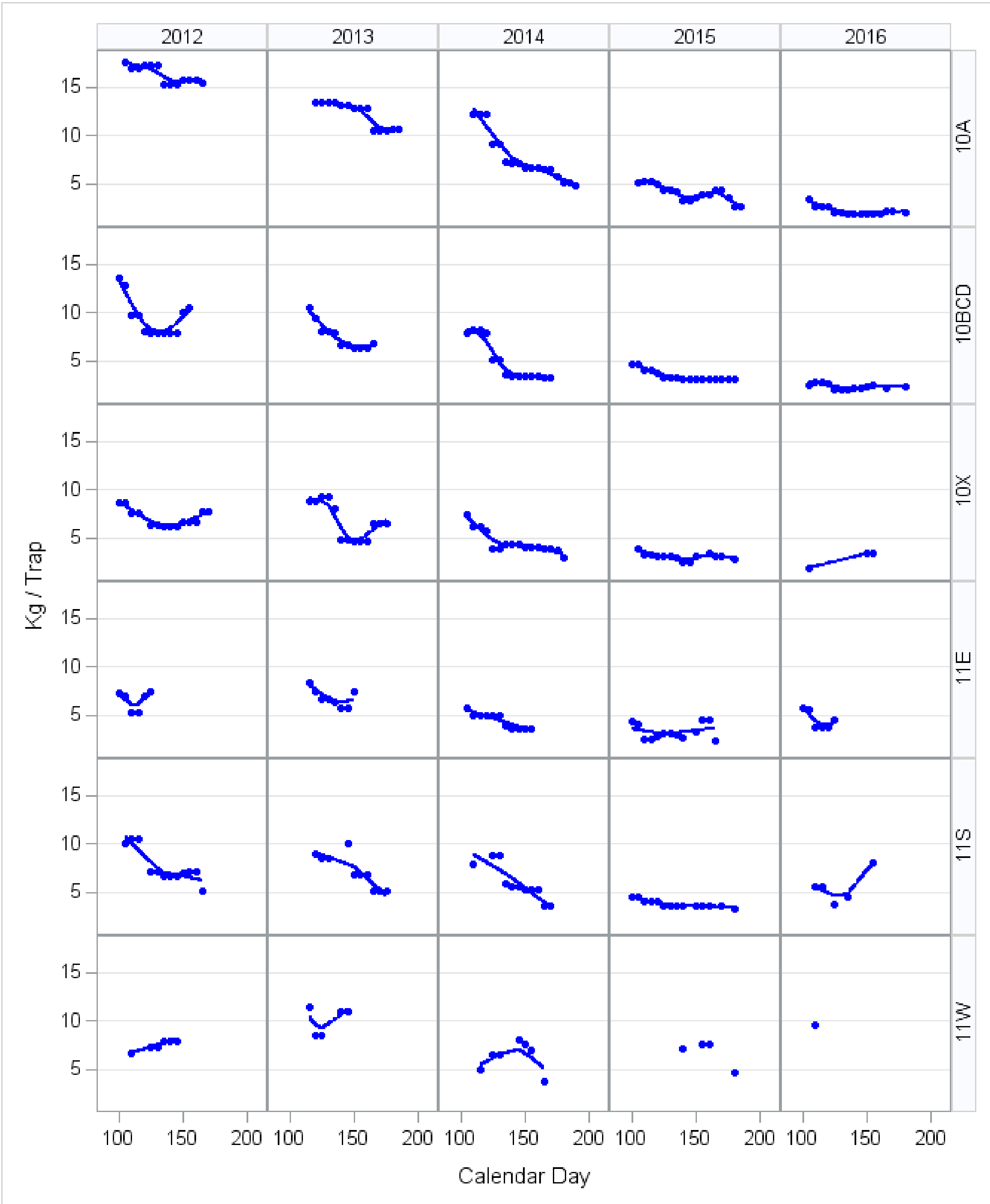

Figure 121. Trends in standardized CPUE (2012-16) throughout the season fit with loess regression curves, by CMA in Subdiv. 3Ps.

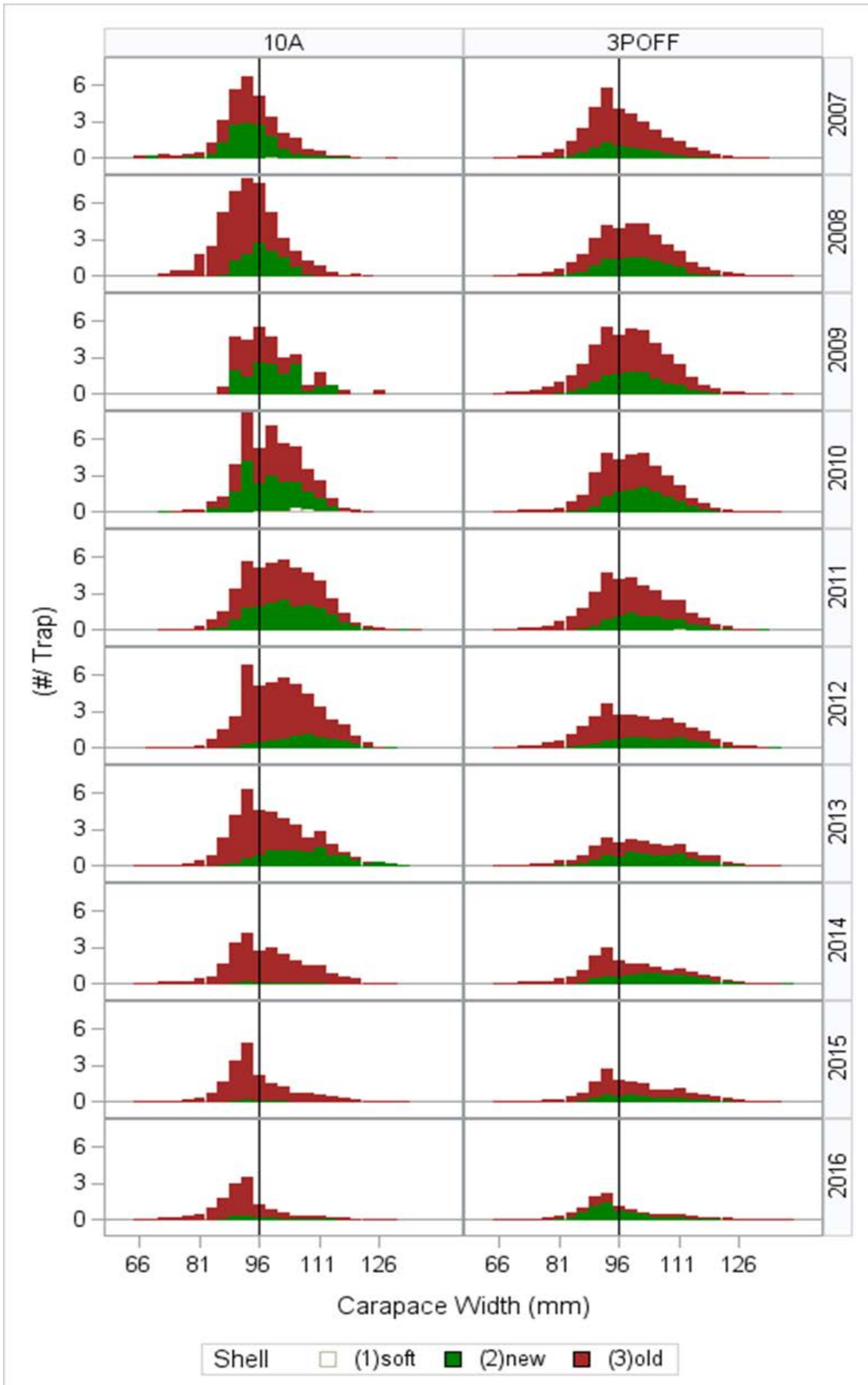

Figure 122. Trends in male carapace width distributions by shell condition from observer sampling in Subdiv. 3Ps (2007-16). The vertical line indicates the minimum legal size.

Figure 123. Trends in observed weekly catch rates versus the percentage of soft-shell crab in the catch in Subdiv. 3Ps (2005-16). Bubble labels depict percentage soft-shell.

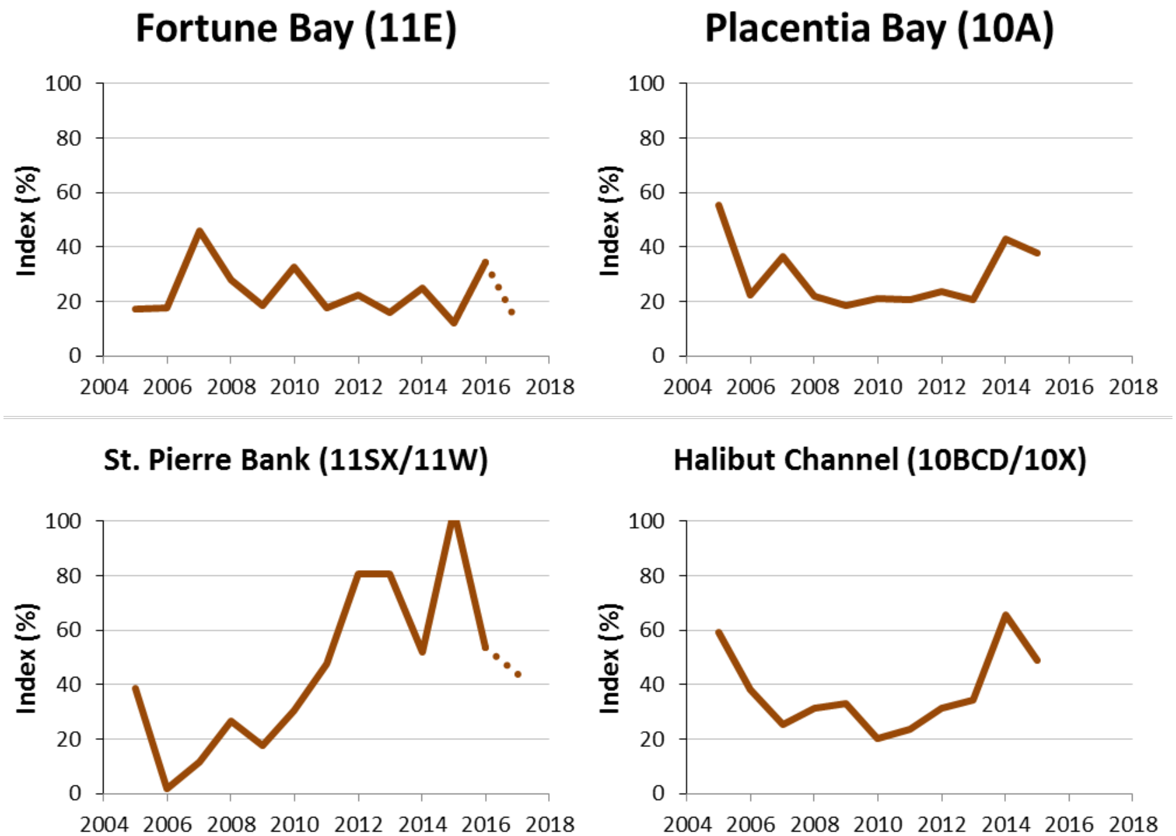

Figure 124. Trends in trap survey-based exploitation rate indices by CMA in Subdiv. 3Ps. Dashed lines depict projected 2017 exploitation rate indices based on status quo landings.

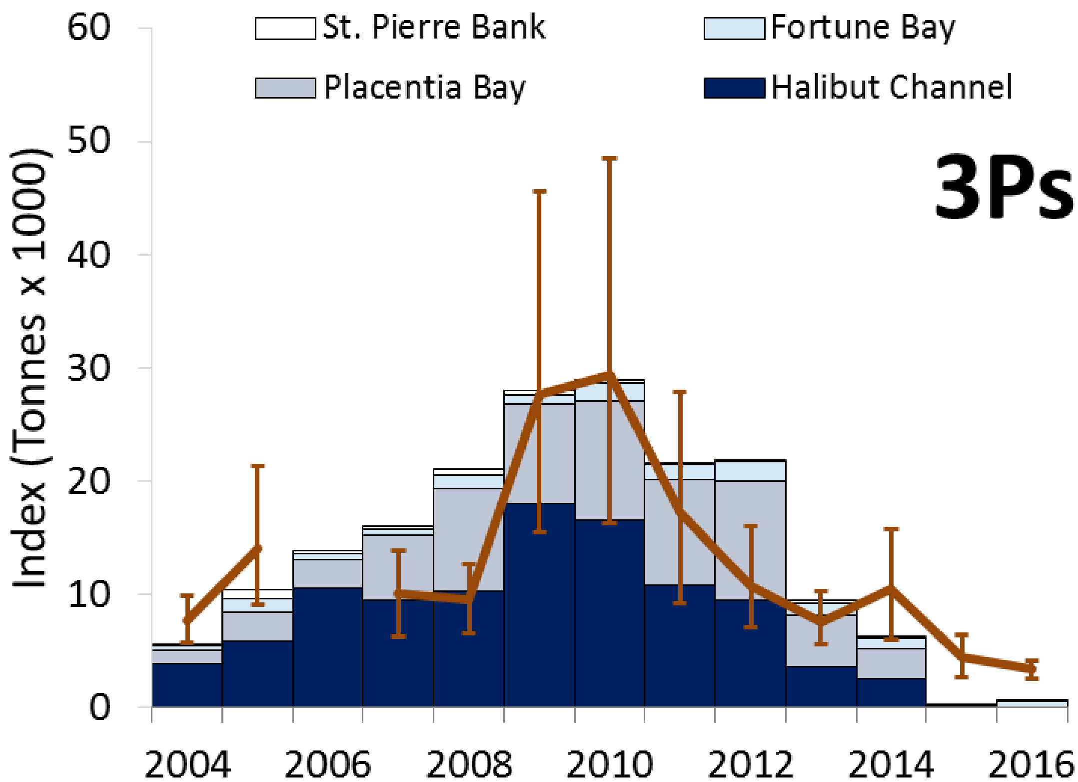

Figure 125. Trends in the trap survey-based survey exploitable biomass index versus the multi-species trawl survey exploitable biomass index in Subdiv. 3Ps. No CPS survey conducted in Placentia Bay or Halibut Channel in 2015-16.

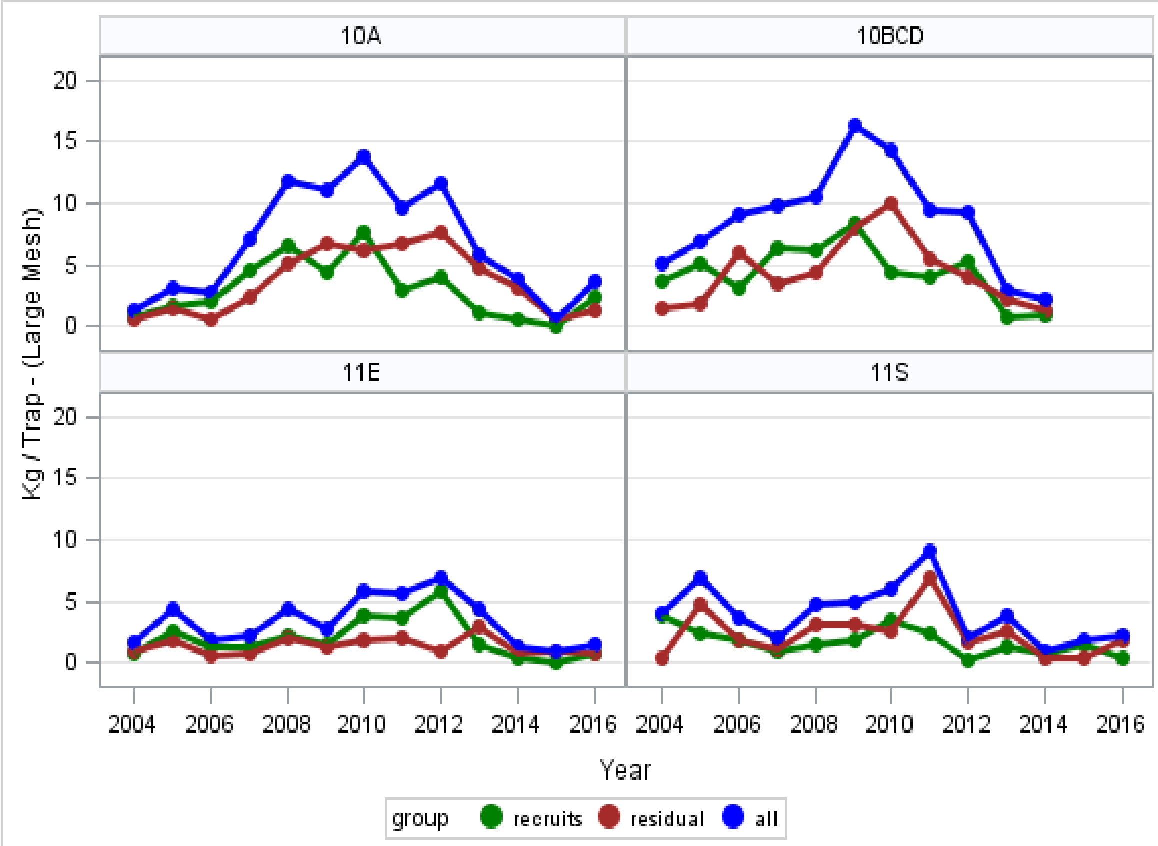

Figure 126. Trends in CPUE (Kg/Trap) by shell condition for legal-sized crab from core stations in the CPS trap survey in Subdiv. 3Ps.

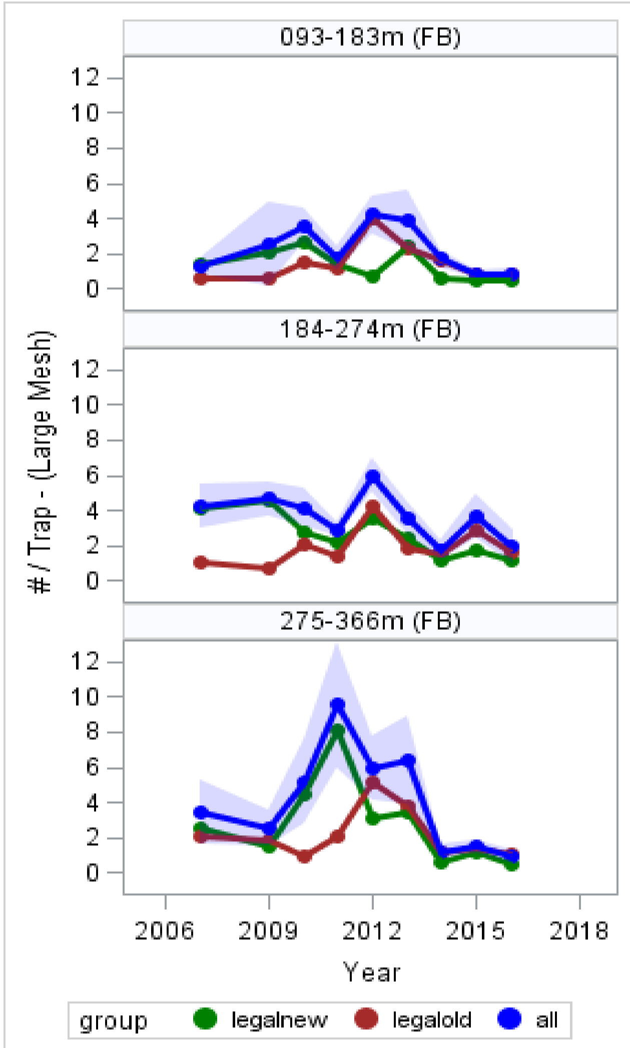

Figure 127. Trends in CPUE (Kg/Trap) by shell condition for legal-sized crab from the DFO trap surveys in CMA 11E.

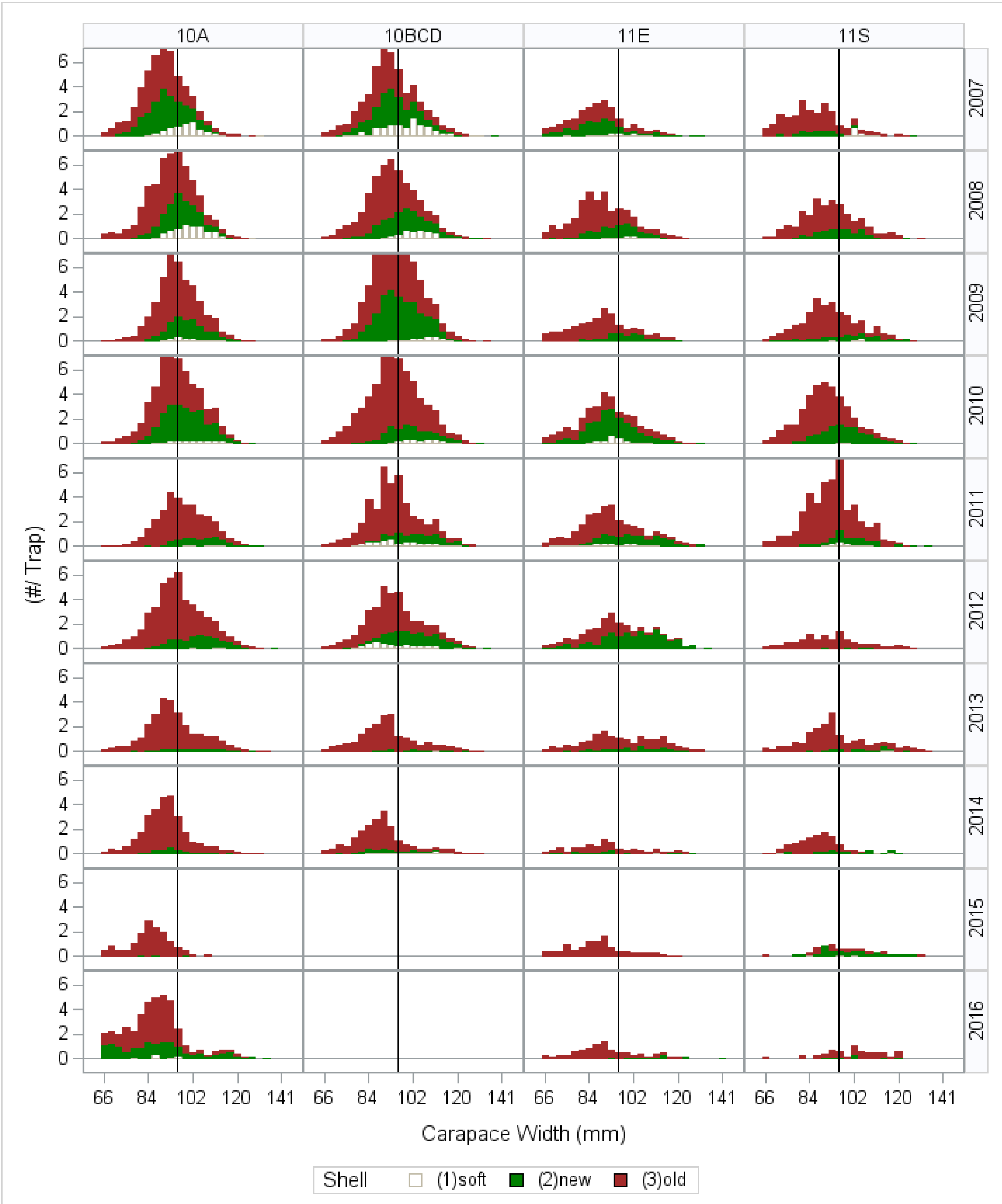

Figure 128. Trends in male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in Subdiv. 3Ps. The vertical line indicates the minimum legal size.

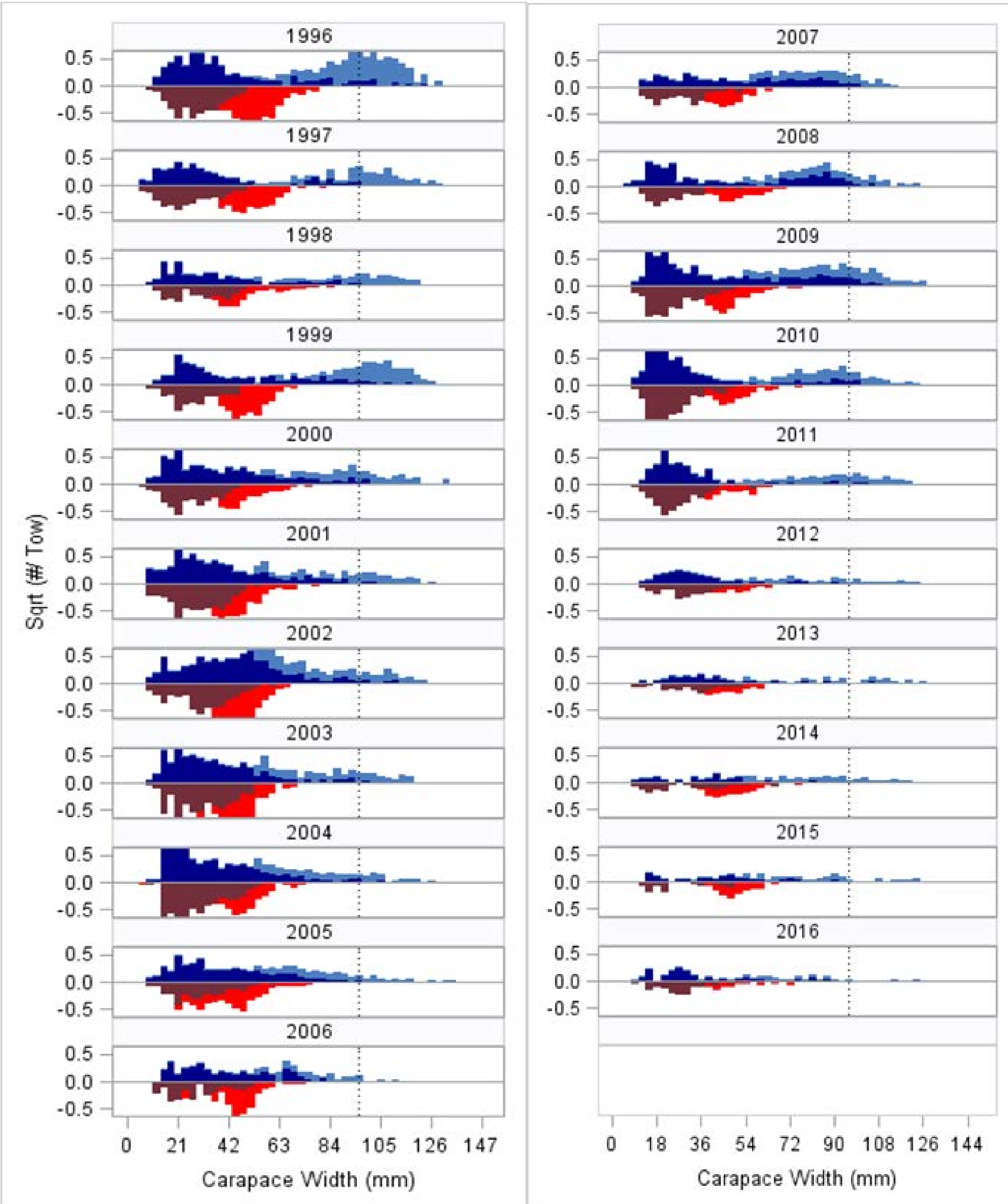

Figure 129. Abundance indices by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from the Subdiv. 3Ps spring trawl survey. Dashed vertical line is legal-size.

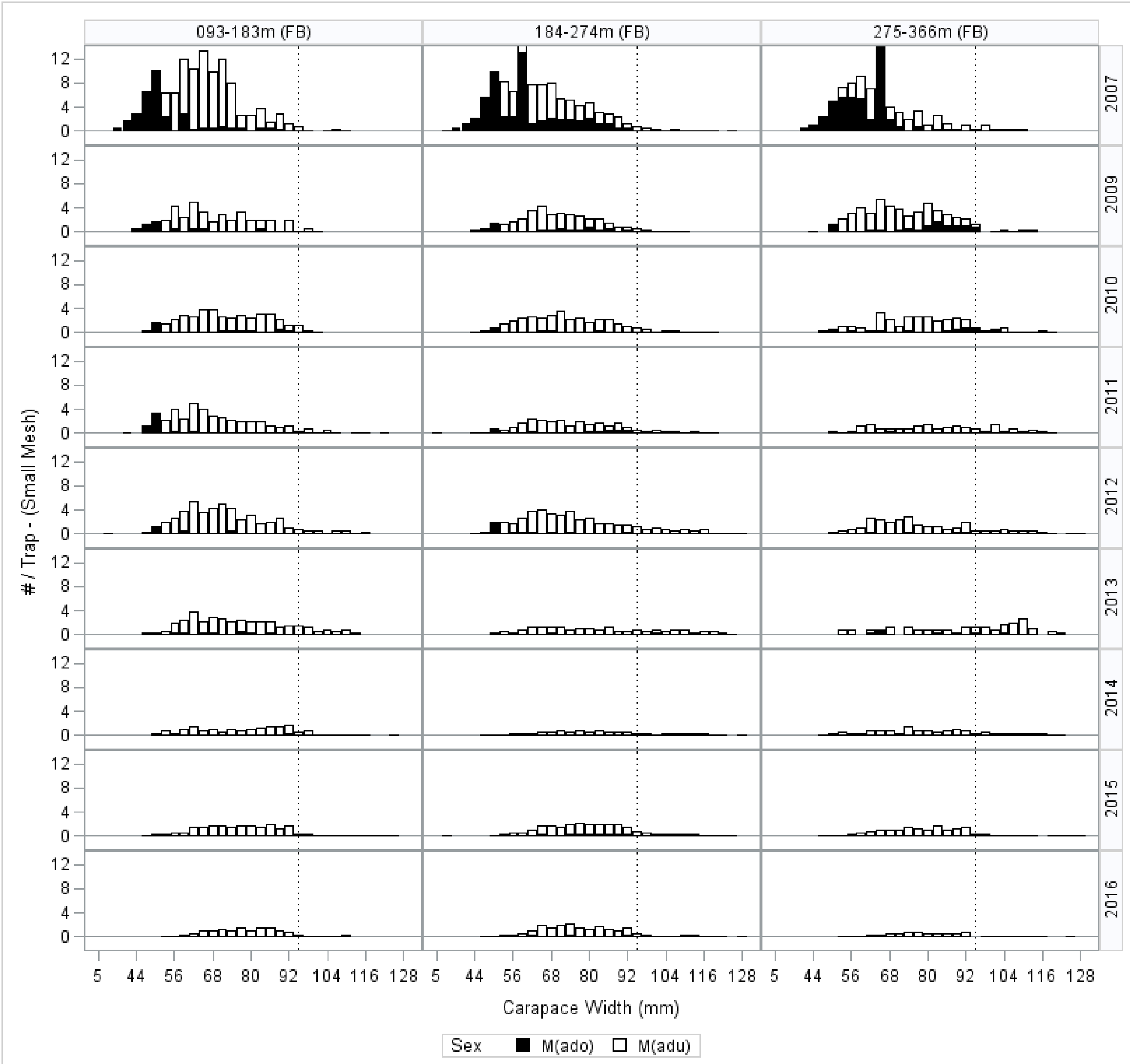

Figure 130. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the DFO CMA 11E trap survey (2007-16). The vertical dotted line indicates the minimum legal size.

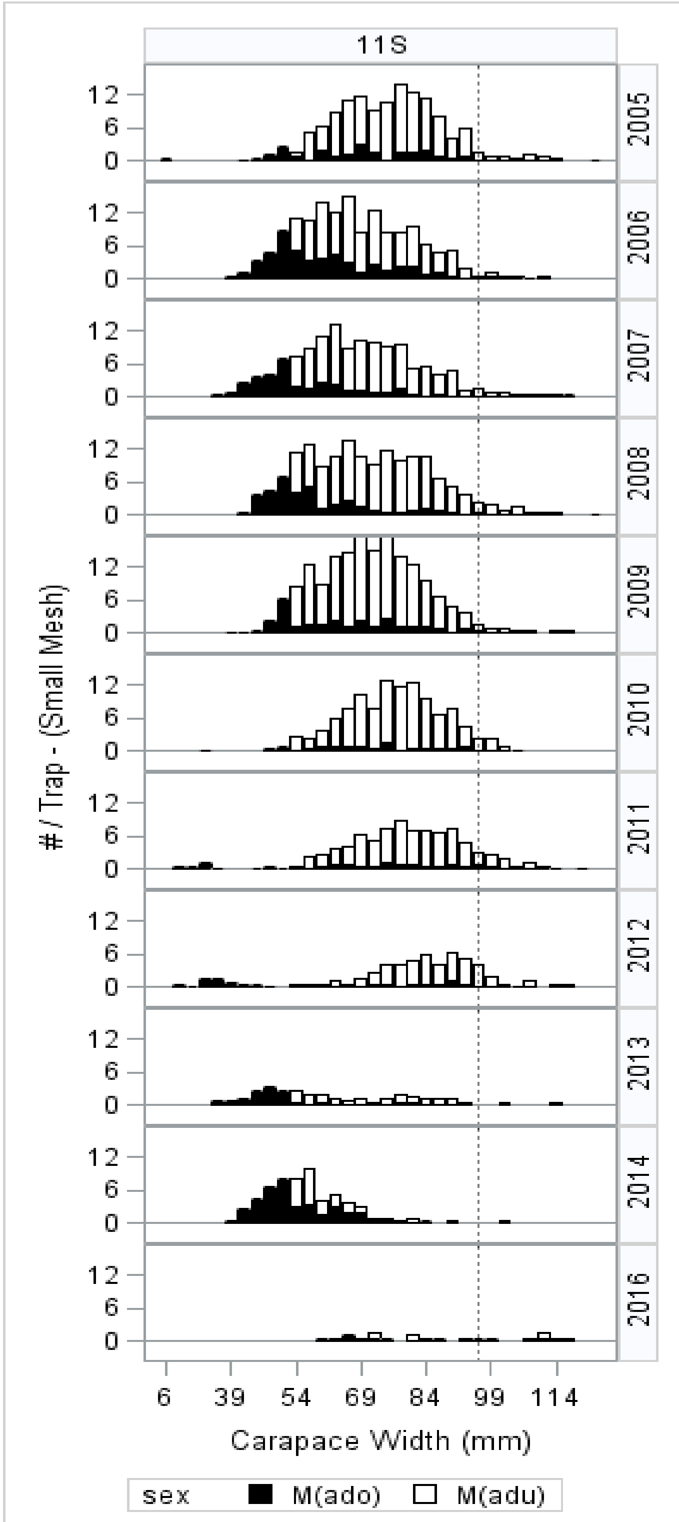

Figure 131. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the CPS CMA 11S trap survey (2005-16). The vertical dotted line indicates the minimum legal size.

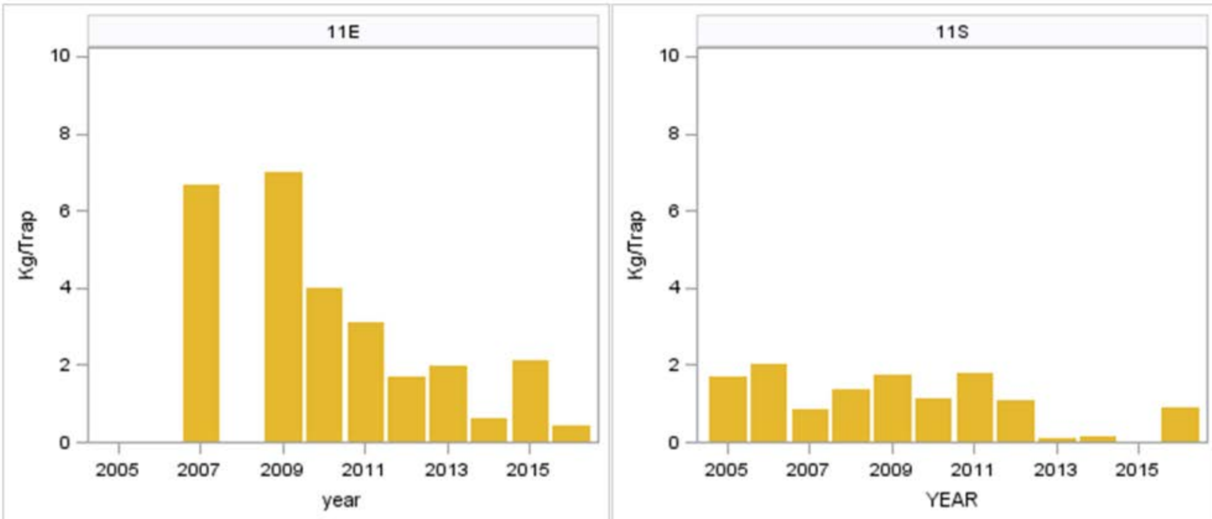

Figure 132. Pre-recruit abundance indices from small-mesh traps in DFO (left panel) and CPS (right panel) trap surveys in Subdiv. 3Ps.

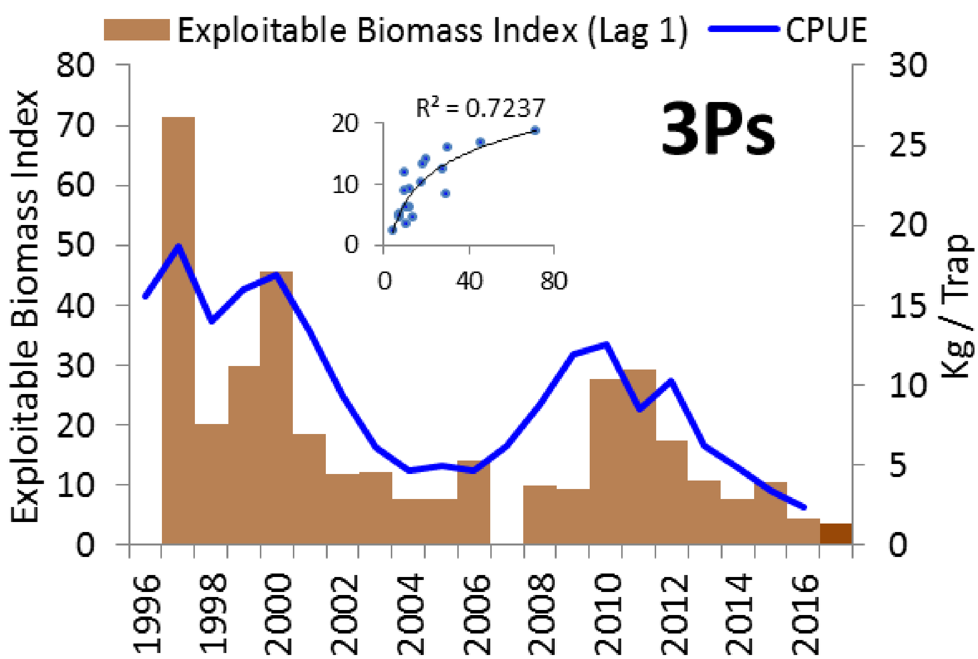

Figure 133. Standardized CPUE versus trawl survey exploitable biomass index lagged one year in Subdiv. 3Ps. Dark bar in 2017 depicts most recent biomass estimate from the 2016 spring survey.

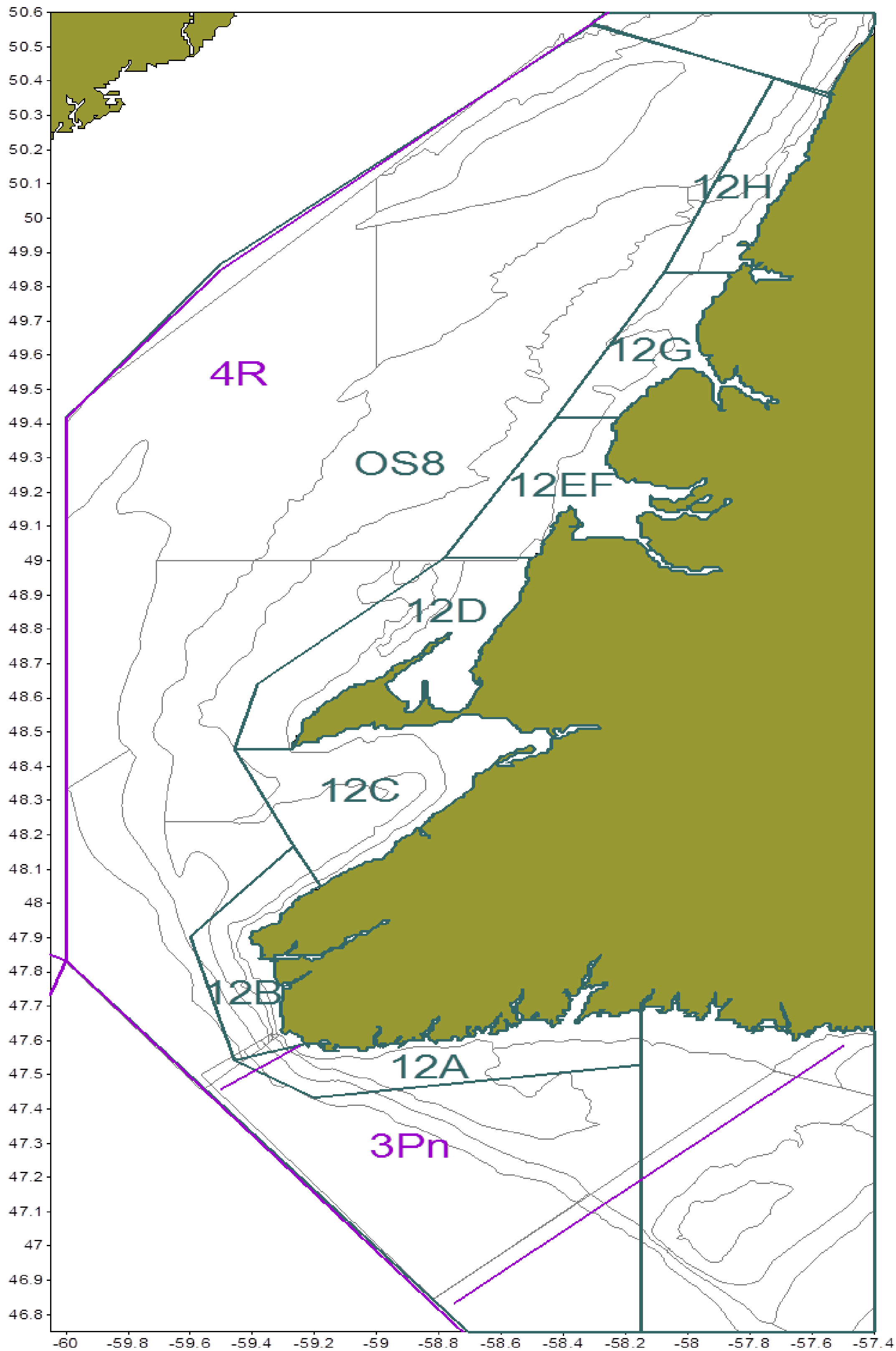

Figure 134. Map of Div. 4R and Subdiv. 3Pn showing crab management areas and important bathymetric features.

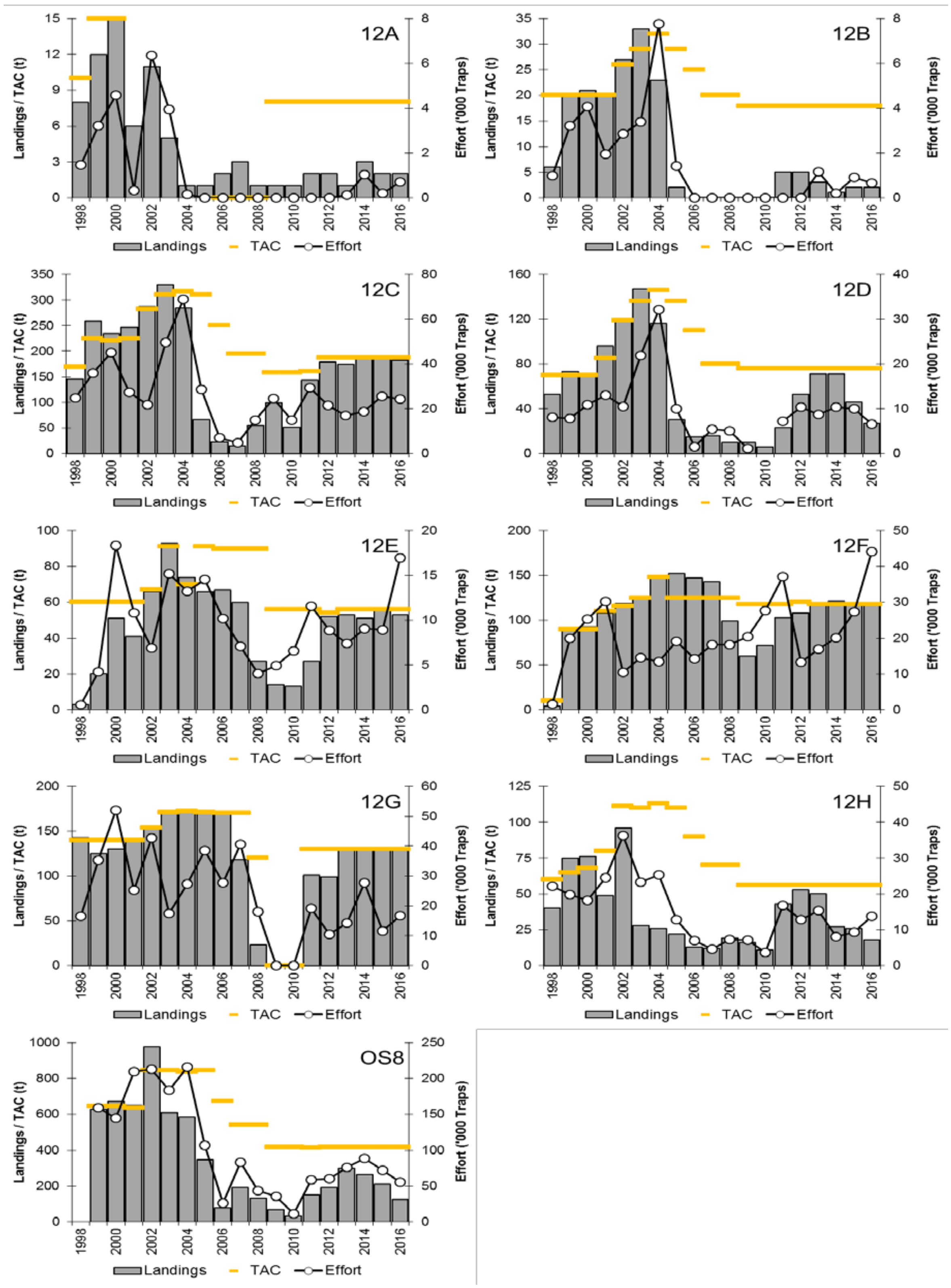

Figure 135. TAC, landings, and estimated effort for CMAs in Div. 4R and Subdiv. 3Pn. 2016 effort is considered preliminary.

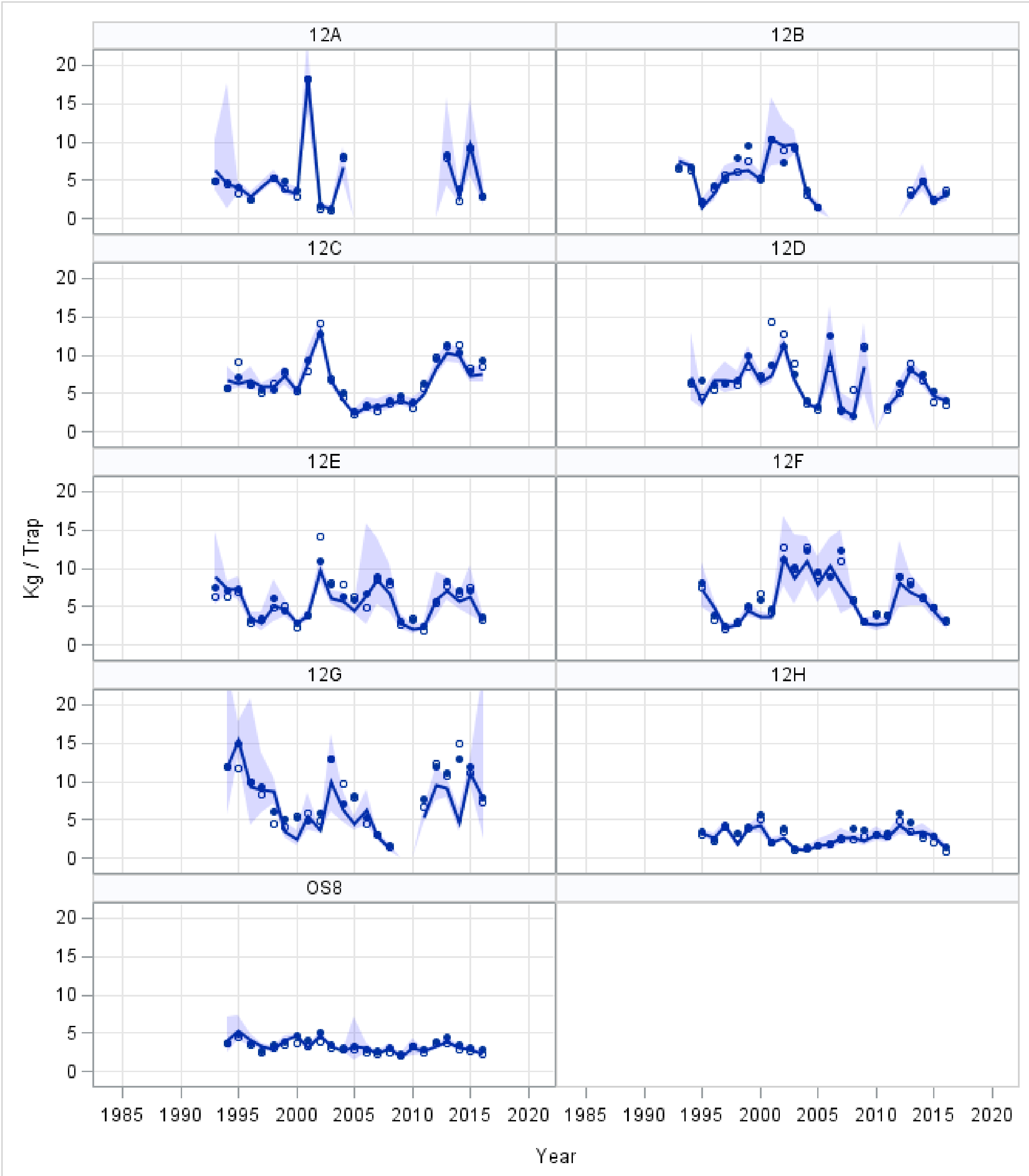

Figure 136. Trends in standardized catch per unit effort (CPUE, Kg/Trap) for CMAs in Div. 4R and Subdiv. 3Pn. Open circles are medians and closed circles are means.

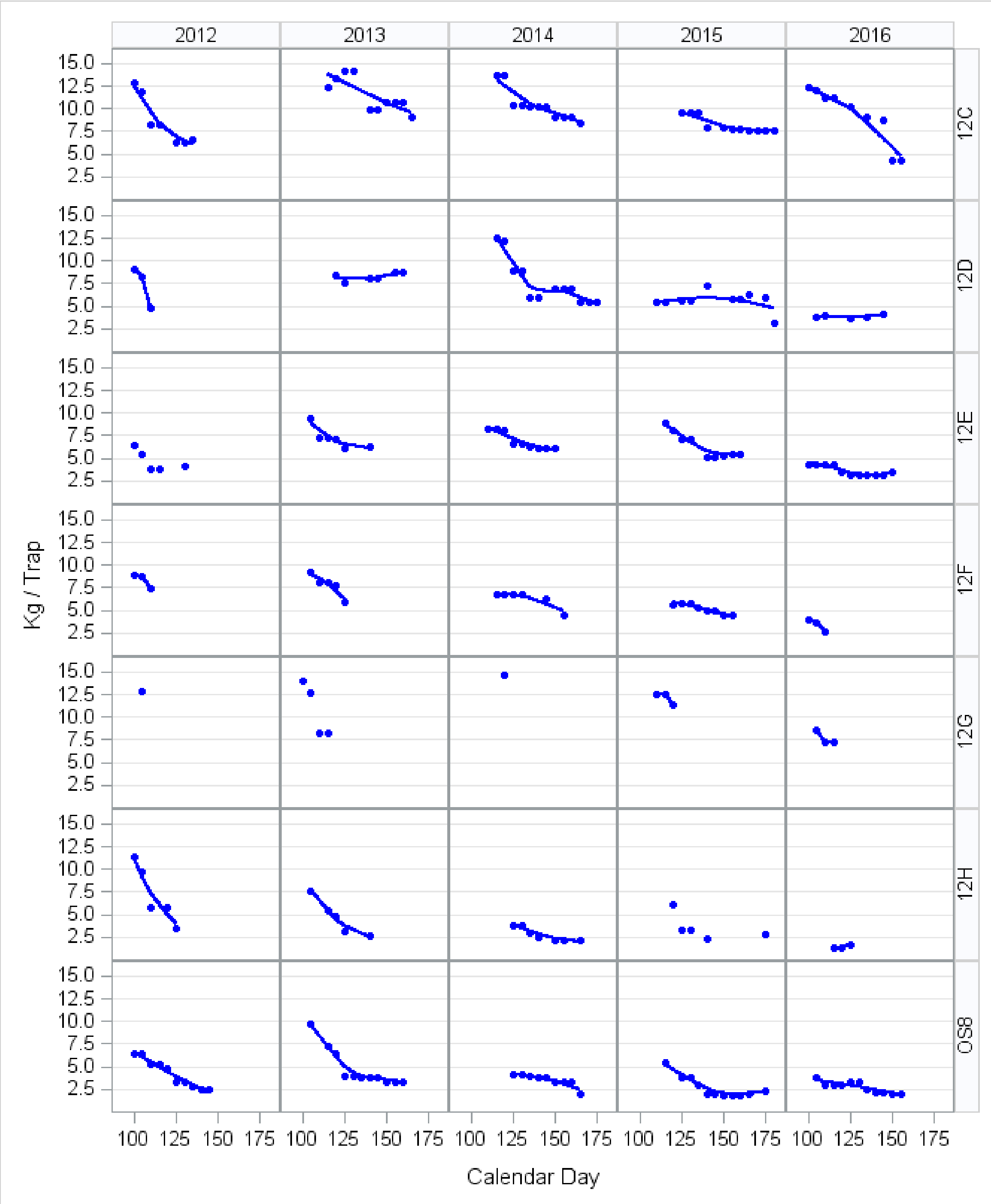

Figure 137. Trends in standardized CPUE (2012-16) throughout the season fit with loess regression curves, by CMA in Div. 4R.

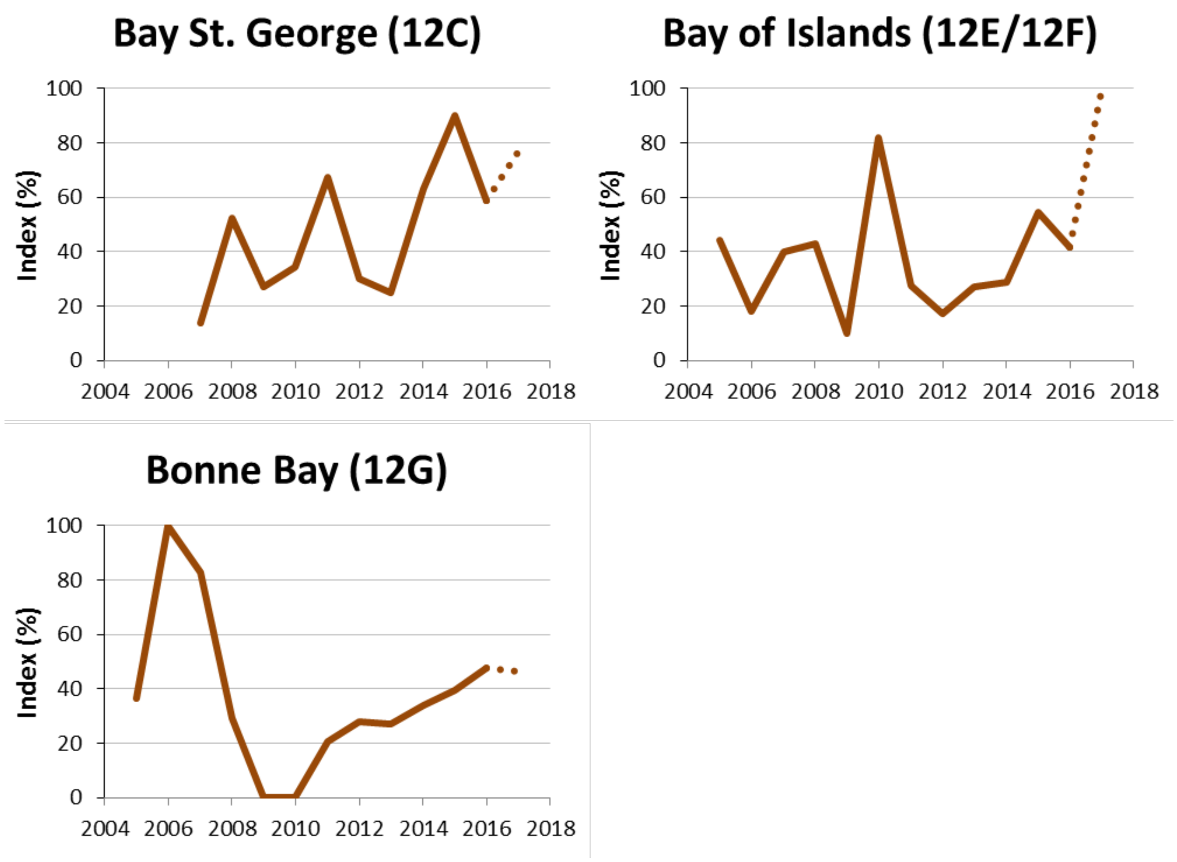

Figure 138. Trends in trap survey-based exploitation rate indices by CMA in Div. 4R. Dashed lines depict projected 2017 exploitation rate indices based on status quo landings.

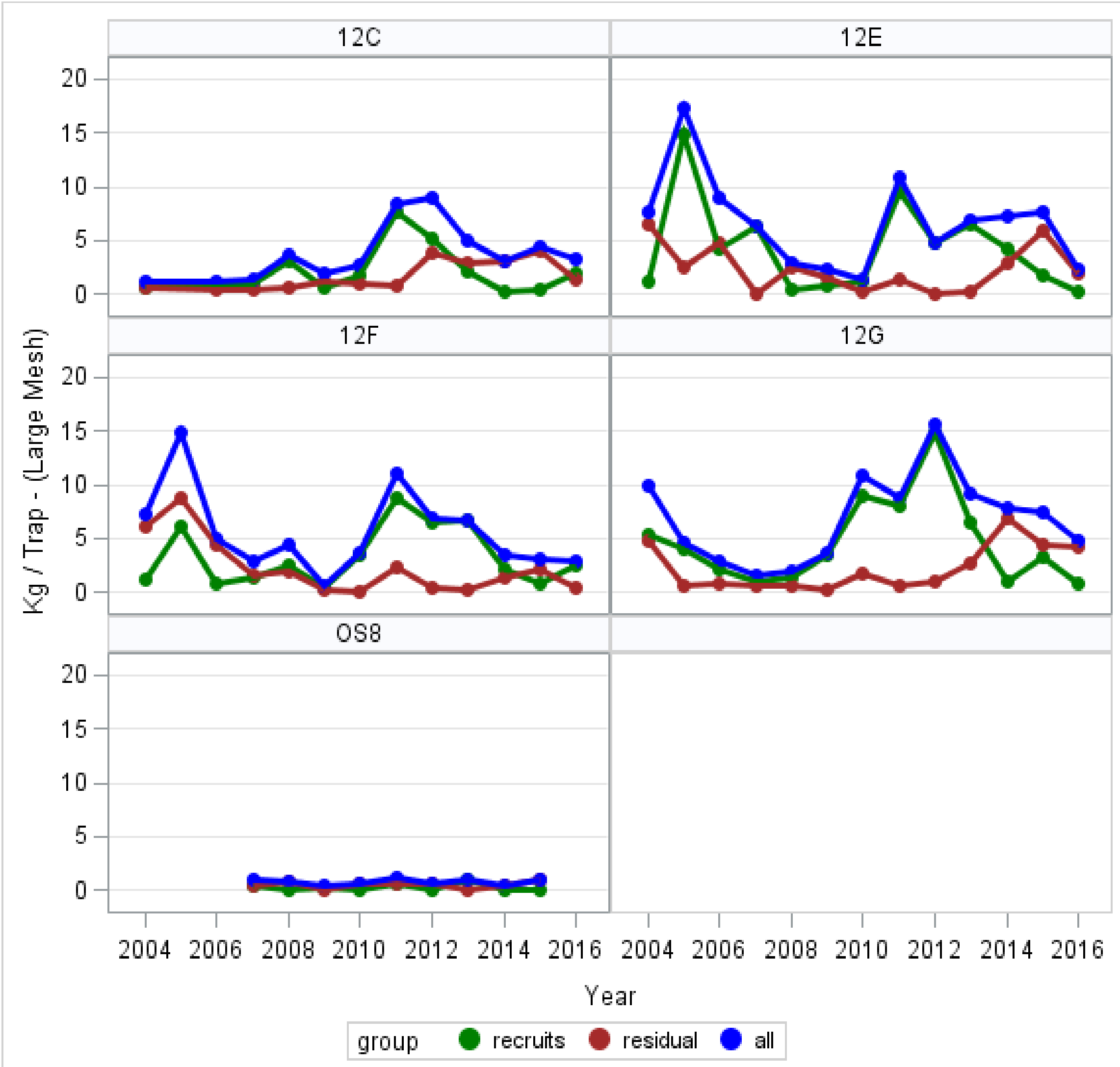

Figure 139. Trends in CPUE (Kg/Trap) by shell condition for legal-sized crab from core stations in the CPS trap survey in Div. 4R.

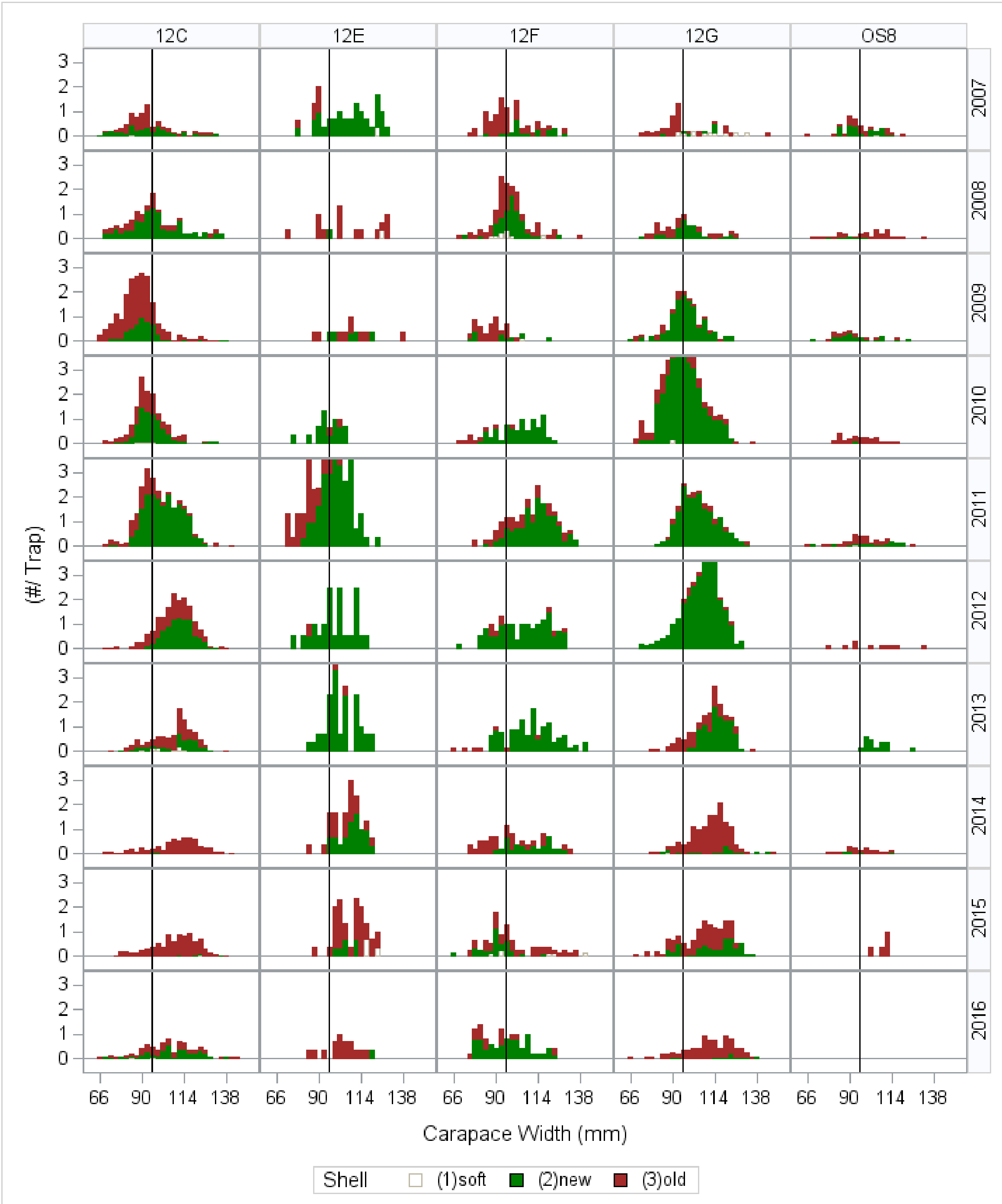

Figure 140. Trends in male carapace width distributions by shell condition from large-mesh traps at core stations in the CPS trap survey in Div. 4R. The vertical line indicates the minimum legal size.

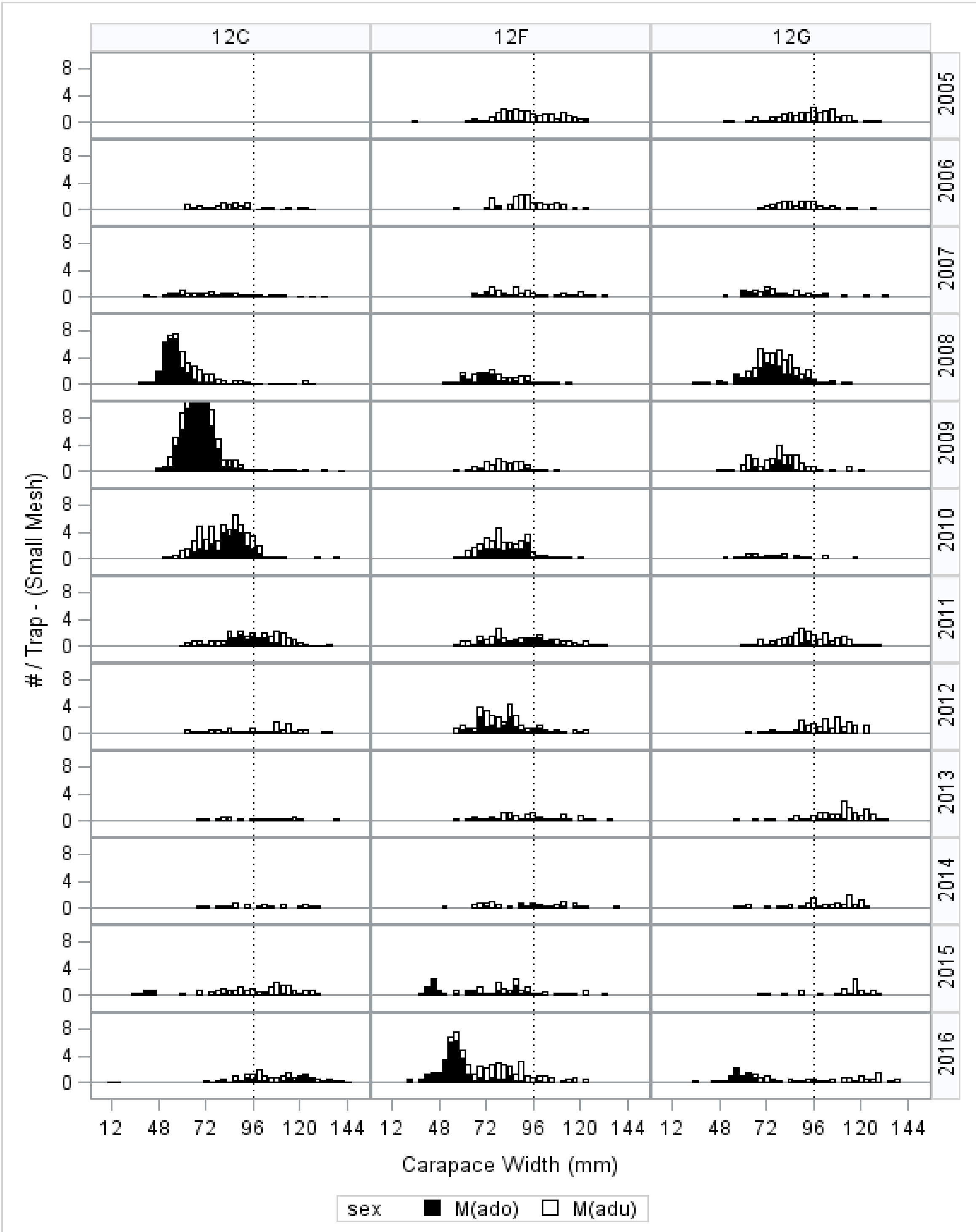

Figure 141. Trends in male carapace width distributions by maturity (black – juveniles plus adolescent males, white – adult males) from small-mesh traps in the CPS CMAs 12C/F/G survey (2005-16). The vertical dotted line indicates the minimum legal size.

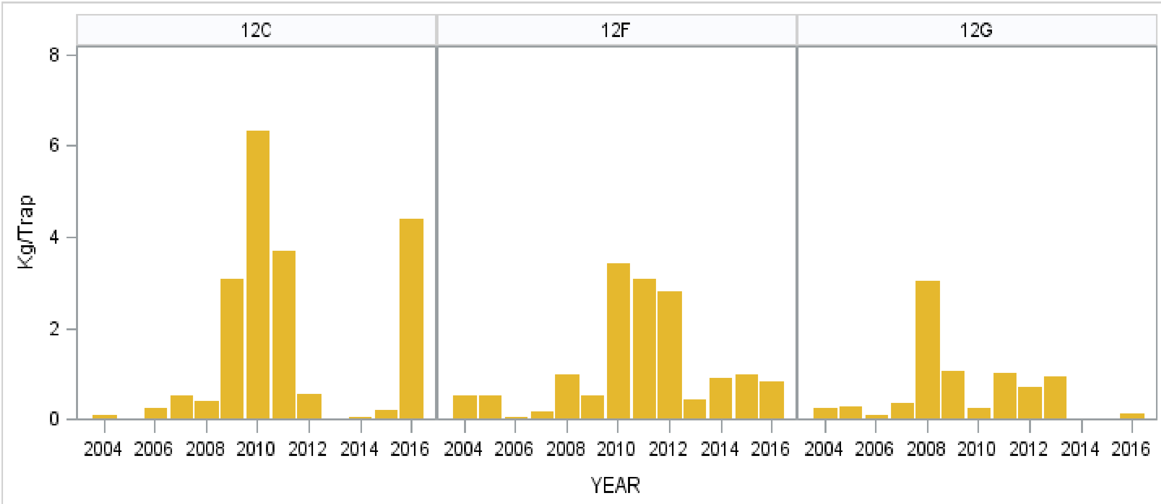

Figure 142. Pre-recruit abundance indices from small-mesh traps in CPS trap surveys in Div. 4R.