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Newfoundland and Labrador Region
Canadian Science Advisory Secretariat
Science Advisory Report 2022/012

ASSESSMENT OF NEWFOUNDLAND AND LABRADOR (DIVISIONS 2HJ3KLNOP4R) SNOW CRAB

*Snow Crab (*Chionoecetes opilio*)*

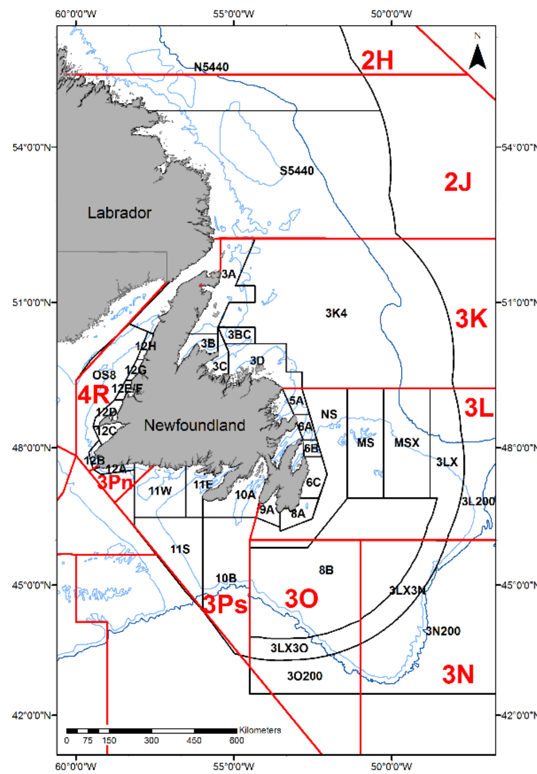

Figure 1: Map of NAFO Divisions (red) and NL Snow Crab Management Areas (black).

Context:

*Snow Crab (*Chionoecetes opilio*) occupy a broad geographic range in the Northwest Atlantic from Greenland to southern Nova Scotia. Distribution in waters off Newfoundland and southern Labrador is widespread and continuous with the genetic stock spanning throughout the region.*

Crab harvesters use long-lines ("fleets") of baited conical traps. The minimum legal size of crab is 95 mm carapace width (CW). This regulation excludes females and a large proportion of adult males from the fishery thereby partially safeguarding stock reproductive capacity.

Total Allowable Catch (TAC) management was initiated in the late-1980s. This led to the development of multiple TAC-controlled Crab Management Areas (CMAs, Fig. 1) with about 2,340 license holders across numerous fleet sectors under enterprise allocation in 2020. All fleets have designated trap limits, quotas, trip limits, dedicated fishing areas within CMAs, and pre-determined fishing seasons.

Stock status is assessed annually within Assessment Divisions (ADs) comprised of combinations of the Northwest Atlantic Fisheries Organization (NAFO) Divisions. Resource status is evaluated based on trends in exploitable biomass indices, recruitment prospects, and mortality indices, as well as fishery catch per unit of effort (CPUE). Data are derived from multispecies bottom trawl surveys in

Divs. 2HJ3KLNOP, Fisheries and Oceans Canada (DFO) inshore trap surveys in Divs. 3KLPs, fishery logbooks, at-sea observer measurements, collaborative trap surveys, as well as biological sampling from multiple sources.

A Regional Peer Review Process meeting was held February 16-18, 2021, to assess the status of the Snow Crab resource in Newfoundland and Labrador (NL).

SUMMARY

Overall – Divisions 2HJ3KLNOP4R

- **Landings** increased from a 25 year low in 2019 (26,400 t) to 29,100 t in 2020. All Assessment Divisions (ADs), except ADs 2HJ and 4R3Pn, experienced increased landings in 2020.
- **Effort** was at or near decadal lows in all ADs during 2020, except AD 2HJ.
- Fishery **CPUE** increased to or remained near time-series averages within each AD during 2020, with the exceptions of ADs 3Ps and 4R3Pn, where it was near time-series highs.
- The overall **exploitable biomass** has increased in both trawl and trap surveys during the past 3 years from historic lows. In 2020, the largest increases occurred in ADs 3K and 3LNO Offshore in the trawl survey, and AD 3Ps in the trap survey. In 2020 there was no trawl survey in AD 3Ps.
- Fishery **Exploitation Rate Indices** (ERIs) were near time-series lows in all ADs in 2020 except AD 2HJ where it remained high at around 50%. Status quo removals would further reduce exploitation rates in all ADs in 2021, with the exception of AD 2HJ, where it would remain very high at around 75% of the exploitable biomass index.
- Total **mortality** in exploitable crab has decreased in all ADs in recent years. It remains highest in AD 2HJ and lowest in AD 3LNO Offshore. There is no updated total mortality estimate for AD 3Ps in 2020 but the relatively high presence of old-shelled crab in trap survey data suggests total mortality remains low.
- Recent climate conditions and pre-recruit abundance indices suggest favourable prospects for **recruitment** into the exploitable biomass over the next 2-4 years in most ADs.
- With status quo removals in 2021 all ADs are projected to be **above the Limit Reference Points** (LRPs).

Environment

- Cold bottom conditions are linked with a positive North Atlantic Oscillation (NAO) and are associated with habitat for the early benthic stages of Snow Crab. The recent NL climate has experienced these colder conditions between the mid-1980s and the mid-1990s, and from about 2012 to 2017. Since Snow Crab exploitable biomass is highly correlated with a 6-8 year lagged NAO index, this period suggests improved environmental prospects for Snow Crab in the short term. However, the last 3 years (2018-20) have shown a trend towards warmer and potentially less favorable environmental conditions.
- Chlorophyll concentrations and zooplankton biomass were below normal in the early and mid-2010s, increasing to values above the long-term (1999-2020) average since 2016-17. Additionally, there have been changes in zooplankton community structure over the past decade (less large energy rich, and more small less energy rich copepods) although the abundance of large calanoid copepods has increased to above-normal levels in some areas since 2017. Additionally, changes in zooplankton seasonality (weaker spring and stronger

summer and fall zooplankton signals) may change the quality and timing of food availability for upper trophic levels.

- Ecosystem conditions in the NL bioregion continue to be indicative of limited productivity of the fish community, with total biomass levels much lower than prior to the collapse in the early-1990s. After some recovery since then, total biomass declined in the mid-2010s. While there have been improvements since the lows in 2016-17, especially in the Grand Bank ecosystem unit, current total biomass has not yet returned to the 2010-15 level. The improvements in 2019-20 have favored shellfish, leading to a subtle increase in their dominance in the community structure.
- The predation index indicates that current predation rate on Snow Crab appears of similar level in the Newfoundland Shelf (Divs. 2J3K) and Southern Newfoundland (Subdiv. 3Ps). These are an order of magnitude higher than the estimated level for the Grand Bank (Divs. 3LNO). Predation mortality remains among the highest in recent years. While overall predation has shown important declines from the peaks observed in 2016-18, this pattern is not homogenous within regions. Considering that the rebuilding of groundfish biomass appears to have stalled, the declines in predation pressure could potentially improve the prospects for Snow Crab in the coming years.

Assessment Division 2HJ

- Exploitation rates have been persistently high and the residual biomass is very low. Total mortality in males is high and there have been concerning declines in mature female abundance. There have been large declines in male size-at-terminal molt and short-term recruitment prospects are poor.
- Finfish predation mortality has increased rapidly in 2015-16 in NAFO Div. 2J and remains at high levels, with 2020 being the highest in the time-series.
- Recent and ongoing data deficiencies in most assessment metrics are increasingly affecting stock assessment methods.

Assessment Division 3K

- There are conflicting signals between the status of the exploitable biomass from trawl and trap surveys, with a much greater increase in the trawl survey even considering the delayed response of trap surveys to changes in stock size.
- Male size-at-terminal molt has declined in recent years and may dampen recruitment prospects moving forward.
- The exploitation rate is at a historic low for AD 3K.

Assessment Division 3L Inshore

- The spatiotemporal variability in stock status among management areas in recent years has diminished, with most CMAs rebounding from the recent time-series lows.

Assessment Division 3LNO Offshore

- This AD is the major contributor to overall stock status trends. Projected improvements in the exploitable biomass are consistent in most CMAs.

Assessment Division 3Ps

- There was no trawl survey in AD 3Ps in 2020 due to the global pandemic.
- The large increase in the fishery CPUE and trap survey exploitable biomass appear to be concentrated in the major fishing grounds.

Assessment Division 4R3Pn

- Recent and ongoing data deficiencies in most assessment metrics are increasingly affecting stock assessment, which is impacting the inclusion of AD 4R3Pn in the Department's developing PA Framework. Notwithstanding, there were some recent signs of improvement in recruitment and biomass in the major fishing areas in AD 4R3Pn.

BACKGROUND

Species Biology

The Snow Crab life cycle features a planktonic larval period after spring hatching, involving several stages before settlement. Benthic juveniles of both sexes molt frequently and may become sexually mature at approximately 40 mm CW (~4 years of age).

Snow Crab grow by molting in late winter or spring. Females cease molting after sexual maturity is achieved at 35-75 mm CW and do not contribute to the exploitable biomass. Sexually mature (adolescent) males generally molt annually until their terminal molt, when they develop enlarged claws (adults) that likely enhance their competitiveness for mating. Males molt to adulthood at any size larger than approximately 40 mm CW, and only a portion of any cohort will recruit to the fishery at 95 mm CW.

Age is not determined, however at-present Snow Crab are believed to recruit to the exploitable biomass at 8-10 years (Sainte-Marie et al. 1995, Comeau et al. 1998). However, on-going work suggests these may be underestimates in NL populations where skip-molting is relatively frequent, with age at legal-size higher in cold areas like NL due to less frequent molting at low temperatures (Dawe et al. 2012). Moreover, high population densities are associated with larger size-at-terminal molt (Mullowney and Baker 2020) and by inference higher age-at-terminal molt. After recruiting to the exploitable biomass as soft-shelled crab, it takes almost a full year for shells to become filled with meat and the crab to be of commercial quality.

Snow Crab is a stenothermal species and temperature and associated climatic mechanisms affect production, early survival, and subsequent recruitment to fisheries (Foyle et al. 1989, Dawe et al. 2008, Marcello et al. 2012). Cold conditions during early-mid life stages are associated with increased survey biomass indices and fishery CPUE several years later.

Adult legal-sized males remain soft- or new-shelled throughout the remainder of the year of their terminal molt. They are considered to be immediate recruits until the following fishery when as hard-shelled crab full of meat they begin to contribute to the exploitable biomass as recruits. Males may live a maximum of about six to eight years as adults after the terminal molt, but such longevity is not thought to be common, particularly in heavily exploited areas.

Snow Crab undertake an ontogenetic migration from shallow cold areas with hard substrates to warmer deeper areas with soft substrates (Mullowney et al. 2018a). Large males are most common on mud or mud/sand in deep areas, while smaller Snow Crab are common on harder substrates typically associated with shallow areas. Some Snow Crab also undertake a migration in the winter or spring for mating and/or molting. Although the dynamics of winter and spring migrations are not fully understood, they are known to be associated with different mating periods for first-time spawning (primiparous) and multiple-time spawning (multiparous) females and are generally from deep to shallow areas. Snow Crab are opportunistic feeders, with their diet including fish, clams, polychaete worms, brittle stars, shrimp, Snow Crab, and other crustaceans. Predators include various groundfish, other Snow Crab, and seals.

The Fishery

The fishery began in Trinity Bay (CMA 6A, Fig. 1) in 1967. Initially, Snow Crab were taken as gillnet by-catch, but within several years a directed trap fishery developed in inshore areas along the northeast coast of Divs. 3KL. The minimum legal mesh size of traps is 135 mm (5 ¼") to allow small crab to escape. Under-sized and new-shelled males that are retained in the traps are returned to the sea and an unknown proportion dies.

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. During 1982-87, there were major declines in 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.

Licenses supplemental to groundfish fisheries were issued in Div. 3K and Subdiv. 3Ps in 1985, in Div. 3L in 1987, and in Div. 2J in the early-1990s. Since 1989, there has been a further expansion in the offshore fishery. Temporary permits for inshore vessels <35 feet (<10.7 m) were introduced in 1995 and subsequently converted to permanent licenses in 2003. There are now several fleet sectors and about 2,340 license holders in 2020.

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, dedicated fishing areas within CMAs, and differing seasons. The fishery has started earlier during the past decade and is now prosecuted predominately in spring, where possible, with an intent to reduce incidence of soft-shelled crab in the catch. A protocol was initiated in 2004 that results in closure of localized areas when soft-shelled crab exceeds 20% of the legal-sized catch. In Divs. 3LNO, the closure threshold was reduced to 15% in 2009. 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.

Landings for Divs. 2HJ3KLNOP4R (Fig. 2) 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. Landings remained near 50,000 t from 2007-15, but steadily declined to a 25 year low of 26,400 t in 2019. In 2020, landings increased slightly to 29,100 t.

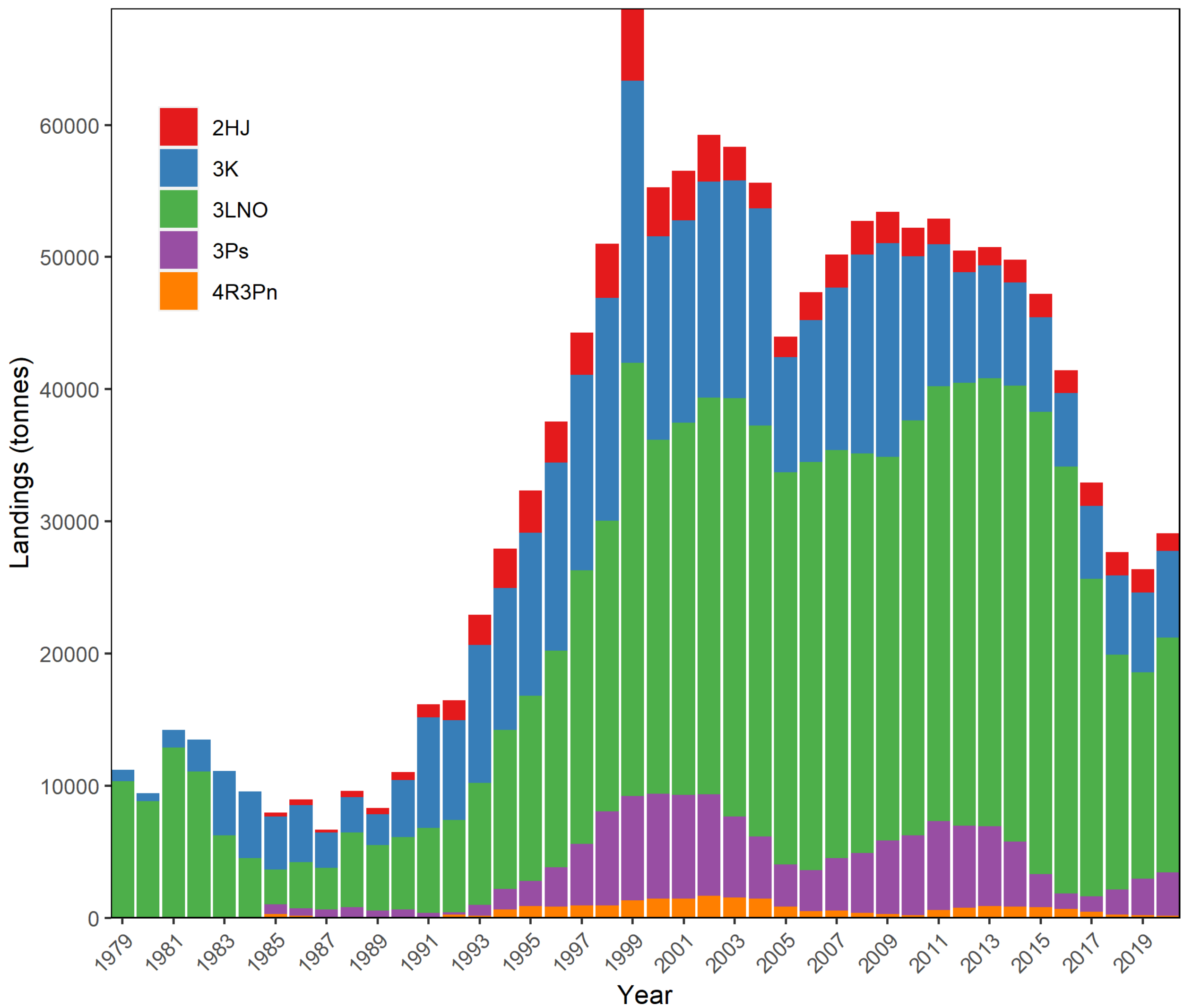

Figure 2: Annual landings (tonnes) of Snow Crab by Assessment Division (3LNO = 3LNO Offshore + 3L Inshore) (1979-2020).

The spatial distribution of the fishery grew as licences and landings increased throughout the 1980s-90s. The resource is now deemed fully-exploited, with fishing effort typically spanning from the fringes of the Makkovik Bank off central Labrador in the north to the far offshore slope edges of the Grand Bank in Divs. 3LNO in the south, to near the border of Quebec in the westernmost portions of Div. 4R (Fig. 3). Fishery CPUE is typically highest in Divs. 3LNO and occasionally off the south coast in Subdiv. 3Ps. In recent years, Div. 3K has also had high levels of fishery CPUE (Fig. 3).

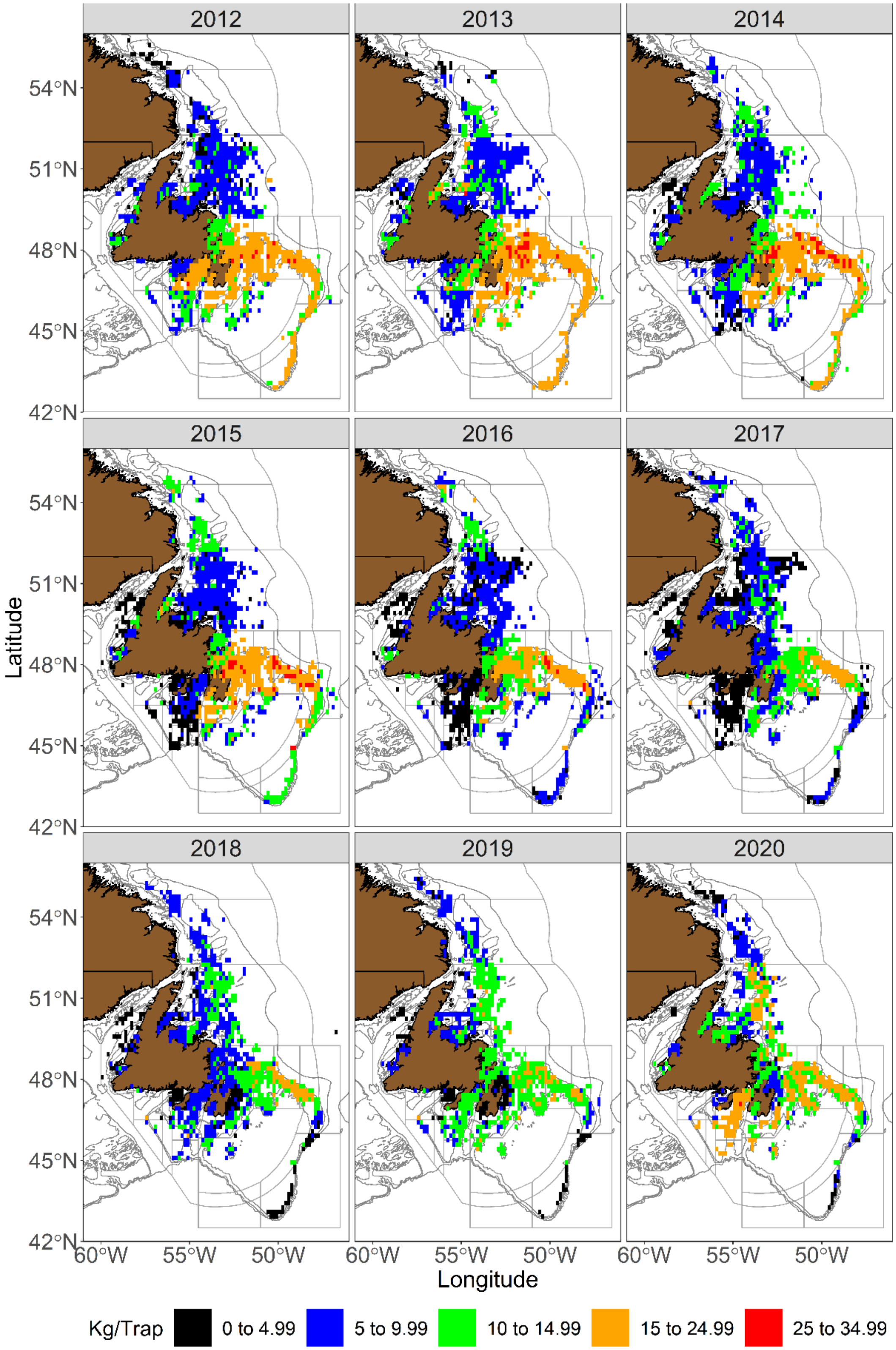

Figure 3: Locations of fishery sets and catch rates (kg/trap) from fishery logbooks (2012-20).

Overall effort decreased in 2020 to under 2.5 million trap hauls which is the lowest level in two decades (Fig. 4). Overall CPUE was at a time-series low in 2018, but returned to near the time-series average level in 2020 (Fig. 5).

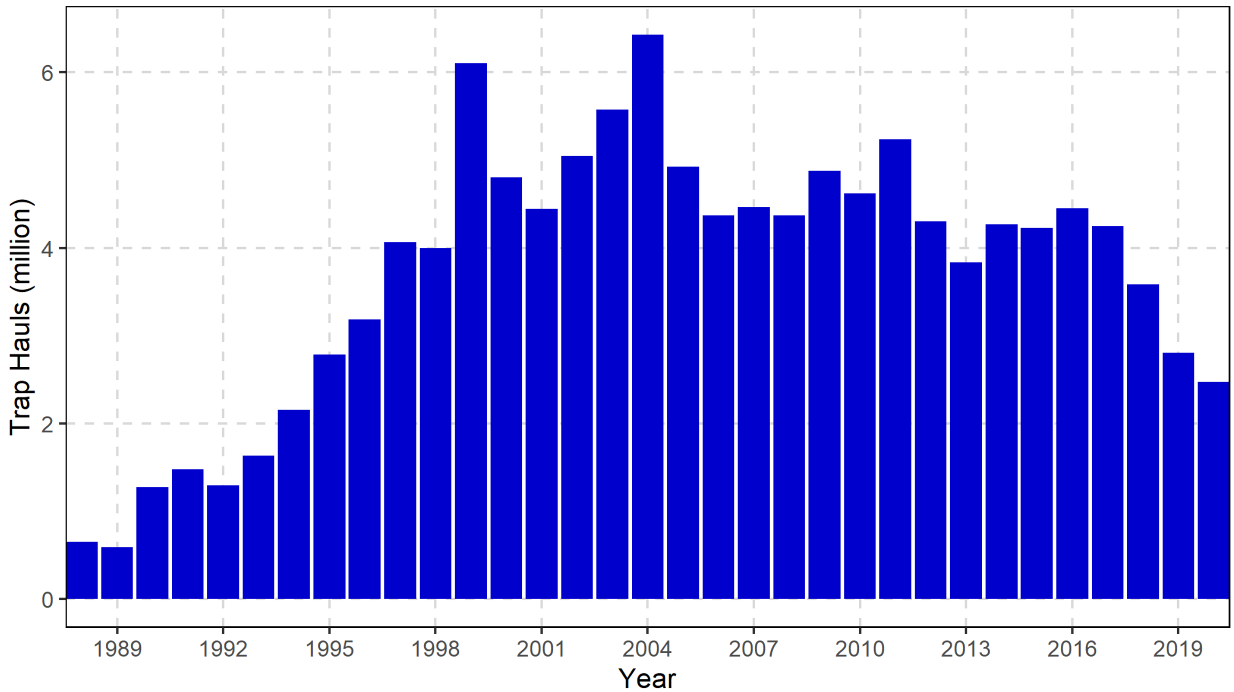

Figure 4: Estimated number of trap hauls per year for the fishery in Divs. 2HJ3KLNOP4R.

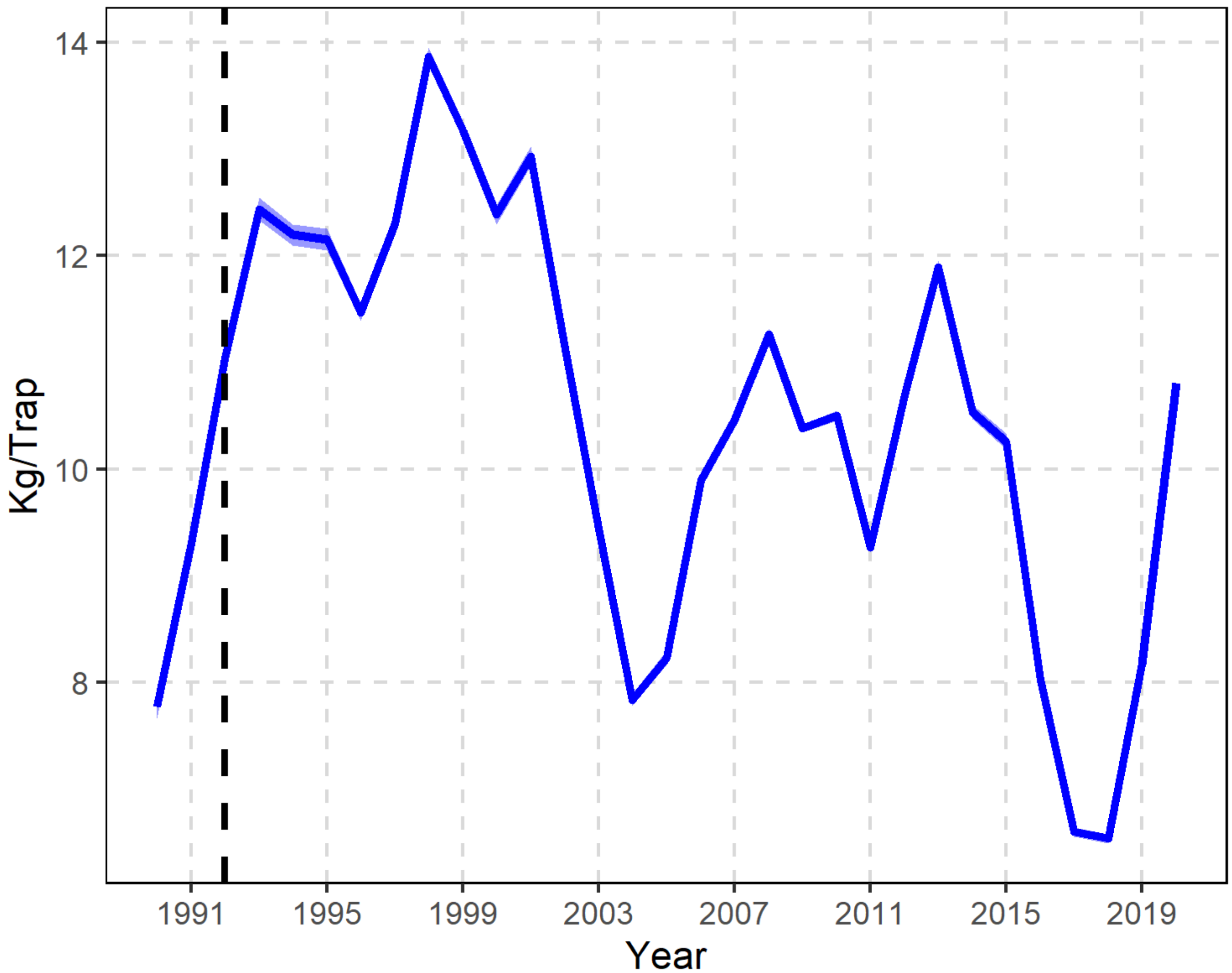

Figure 5: Fishery CPUE (kg/trap) for Divs. 2HJ3KLNOP4R. Solid line is standardized CPUE and shaded band is 95% confidence intervals. Vertical dashed line represents the beginning of the cod moratorium in most Divisions.

ASSESSMENT

The numerous CMAs have no biological basis and the resource is assessed at larger-scale Assessment Divisions (ADs), which are comprised of combinations of NAFO Divisions. Div. 2H is combined with Div. 2J (AD 2HJ) as the resource extends only into the southern portion of Div. 2H and is managed at a spatial scale that extends over the Divisional boundary line. Similarly, Divs. 3LNO Offshore, representing the Grand Bank, is assessed as a unit (AD 3LNO) because the resource is managed at that unit. AD 3L Inshore is assessed separately because of differences in data availability, with the trawl survey not normally extending to inshore bays. Finally, Subdiv. 3Pn is combined with Div. 4R (AD 4R3Pn) to conform to management boundaries. Div. 3K (AD 3K) and Subdiv. 3Ps (AD 3Ps) are assessed at the NAFO Division or Subdivision level.

Resource status was evaluated based on trends in survey exploitable biomass indices, fishery CPUE, fishery recruitment prospects, and mortality indices. Information was derived from multiple sources: multispecies bottom trawl surveys conducted during fall in ADs 2HJ, 3K, and 3LNO Offshore and spring in AD 3Ps, two collaborative trap surveys covering all ADs, DFO inshore trap surveys in ADs 3K, 3L Inshore, and 3Ps, fishery data from logbooks, and at-sea observer catch-effort data.

Bottom temperature data from various surveys were incorporated into a Snow Crab thermal habitat index, defined as the areal extent of water below 2°C in each AD. Cool conditions (a high index) are deemed favourable for long-term production potential in the stock.

Generally, more data are available for offshore than inshore CMAs within ADs. Trawl survey data are often only available for offshore areas because inshore areas are excluded when issues and time constraints occur in these surveys, which have become the norm in recent years. However, in AD 3Ps, the spring trawl survey covers most of the inshore fishing areas, and in AD 2HJ virtually all the Snow Crab habitat is covered by the trawl survey. Observer coverage and sampling has also been more extensive in offshore CMAs of most ADs compared to inshore areas.

The spring and fall bottom trawl surveys are based on a stratified random sampling scheme and are used to provide an index of exploitable biomass that is expected to be available for the upcoming fishery in the same year (spring AD 3Ps) or the following year (fall ADs 2HJ, 3K, and 3LNO Offshore). A Campelen shrimp trawl has been used for the multispecies surveys since 1995. Fisheries have begun earlier since the mid-2000s and now overlap with the timing of the spring trawl survey in AD 3Ps.

The industry-DFO Collaborative Post-season (CPS) trap survey, which takes place in all areas except Div. 2H, has historically been based on a fixed-station grid design and is more spatially limited than the trawl survey as it targets only portions of commercial fishing grounds. A set of core stations was selected from this survey for calculating catch rates (kg/trap) of legal-sized adults. A stratification scheme conforming to the limited survey footprint was used for estimating biomass indices. This survey has transitioned from this fixed station design to a more random stratified design in recent years to result in a 50% fixed and 50% random station design. While a time-series is being established, only the core stations will be used in the current assessment. This survey also includes small-meshed traps, deployed on select stations, to provide data on recruitment prospects. The Torngat Joint Fisheries Board-DFO collaborative trap survey is a fixed station survey in the southern portion of Div. 2H chosen to target sampling within the deep channels where the fishery occurs as well as in the shallow peripheries around the fishing grounds. This survey also includes small-meshed traps at every station to provide data on recruitment prospects.

The exploitable biomass index is based only on male Snow Crab of legal size (≥95 mm CW). It is used together with an exploitable biomass index from the trap surveys to evaluate trends in biomass available to the fishery. In ADs 3L Inshore and 4R3Pn, no trawl survey is conducted, so the trap survey exploitable biomass index is used. This is less preferred because trends in trap survey indices tend to lag behind trawl survey indices by a year or two in showing changes in stock size (Mullowney et al. 2018b). Due to COVID-19 global pandemic disruptions, there was no spring trawl survey in 2020 and consequently no updated trawl exploitable biomass index for AD 3Ps. Trap survey exploitable biomass index was primarily used for this AD for 2020; however to display the overall trawl exploitable biomass index trends, an estimate for the AD 3Ps trawl exploitable biomass index was derived by exploring the relationship between trap and trawl exploitable biomass indices from 2004-19. The equation of this trendline was used to calculate an estimate for the 2020 trawl exploitable biomass index from the 2020 trap exploitable biomass index.

Trawl and trap survey exploitable biomass indices are derived using ogive mapping (‘Ogmap’) (Evans et al. 2000). Biomass estimates are not absolute because the capture efficiency of Snow Crab by the survey trawl is known to be low, particularly at smallest sizes, but even at largest sizes retention efficiency is below 100% (q<1). The effective fishing area of baited traps is unknown. Besides crab size, trawl efficiency is also affected by substrate type and depth (Dawe et al. 2010), and so varies considerably spatially. Efficiency is lower and more variable on hard (typically shallow) substrates than on soft (typically deep) substrates. Trawl survey catch rates also appear affected by the diurnal cycle, being higher during dark periods when crab appear most active. Other potential factors affecting trawl catchability include vessel and gear configuration. Trap effective fishing areas could potentially be affected by numerous factors including bait type, quantity, and quality, soak times, gear spacing, ocean currents, and crab density. For the trawl and AD-level trap surveys, raw Ogmap exploitable biomass estimates were adjusted by a catchability factor (q) in each AD. This q was determined through logbook catch rate Delury depletion models, with each year in the time-series scaled by a time-series q, calculated as the median ratio of annual survey biomass to Delury logbook biomass in each AD. For trap surveys, the effective fishing area of a trap was estimated at 0.01 km^2 to enable spatial expansion and biomass estimation in Ogmap.

Bottom trawl surveys also provide data on recruitment, defined as crab just entering into the exploitable biomass. Recruitment prospects for the upcoming fishery are inferred from biomass indices or catch rates of new-shelled legal-sized Snow Crab (immediate recruits) from post-season or in-season trawl and trap surveys. Trawl and trap surveys also provide indices of pre-recruit abundance, based solely on adolescent (non-terminally-molted) males 65-94 mm CW. The adolescents of these groups would be expected to be recruited into the exploitable biomass in approximately two to four years.

Trawl surveys also provide abundance indices for the smallest Snow Crab consistently captured (approximately 15-50 mm CW) which may indicate recruitment prospects approximately five to seven years later, depending on AD. Longer-term recruitment prospects have previously been inferred from the relationship of exploitable biomass indices with the annual average of monthly directional anomalies of the NAO index. The NAO is an index of the relative strength of atmospheric forcing in the Northern Atlantic and its impacts have a strong impact on the ocean climate of the NL shelf, with positive phases associated with generally cool conditions. The strong correlation of NAO with subsequent exploitable biomass at these lags is consistent with the notion of strong effects of climate in regulating Snow Crab success in early life stages (Dawe et al. 2008, Marcello et al. 2012). For the present assessment similar, but stronger, lagged correlations with the exploitable biomass index were found with the Arctic Oscillation (AO) and El Niño Southern Oscillation (ENSO). The best-fit lagged correlations of the AO and ENSO during winter months (DJFM) were used as predictor variables in a generalized additive model to predict forthcoming biomass potential at the stock (Divs. 2HJ3KLNOP4R) level.

Total annual mortality rates in any given year t (A_t) were calculated as a 3-year moving average of stage-specific biomass indices of exploitable Snow Crab:

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

where,

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

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

t-1 = denotes survey of previous year

Trends in exploitation rate are inferred from changes in the exploitation rate index (ERI), defined as landings divided by the exploitable biomass index from the most recent trap or trawl survey, with biomass indices smoothed as a two-year moving average to account for year effects in survey performance. Natural mortality rates are unknown, but predation is highest on smaller crab (e.g. <50 mm CW) (Chabot et al. 2008).

Finally, fishery CPUE is used as an index of fishery performance. Annual CPUE (kg/trap) is based on logbook information on catch and effort for individual or daily set hauls and is standardized using a linear mixed model incorporating main and random effects of time (calendar day and year) and space (CMA nested in AD), as well as trap soak times. The CPUE model also includes a weighting factor accounting for the importance of the grid cell (10’ x 10’ nautical mile) where the set occurred, defined as the number of years the cell has been fished.

Resource Status

Landings & Effort

In AD 2HJ, landings remained near 1,700 t from 2014-19, but declined to around 1,400 t in 2020 (Fig. 6). Effort has remained fairly consistent in this AD (Fig. 7). In AD 3K, landings increased slightly in 2020 to around 6,500 t, while effort increased slightly from a two-decade low in 2019. In AD 3L Inshore, landings declined by 67% from a time-series high in 2015 to 2,750 t in 2019. In 2020, landings increased to 2,949 t and effort declined from the time-series high in 2017 to a time-series low. In AD 3LNO Offshore, landings were the lowest level in two decades in 2019 due to reductions in the TAC, but increased in 2020 to 14,839 t. Effort expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level until decreasing in 2019. Effort was at its lowest level in over 20 years in 2020. In AD 3Ps, landings increased from a time-series low in 2017 to 3,249 t in 2020. Effort declined in 2020 to the lowest level in over 20 years. Finally, in AD 4R3Pn, landings have steadily declined since a recent peak in 2013 and were at a time-series low of 167 t in 2020, while effort has declined near time-series low level.

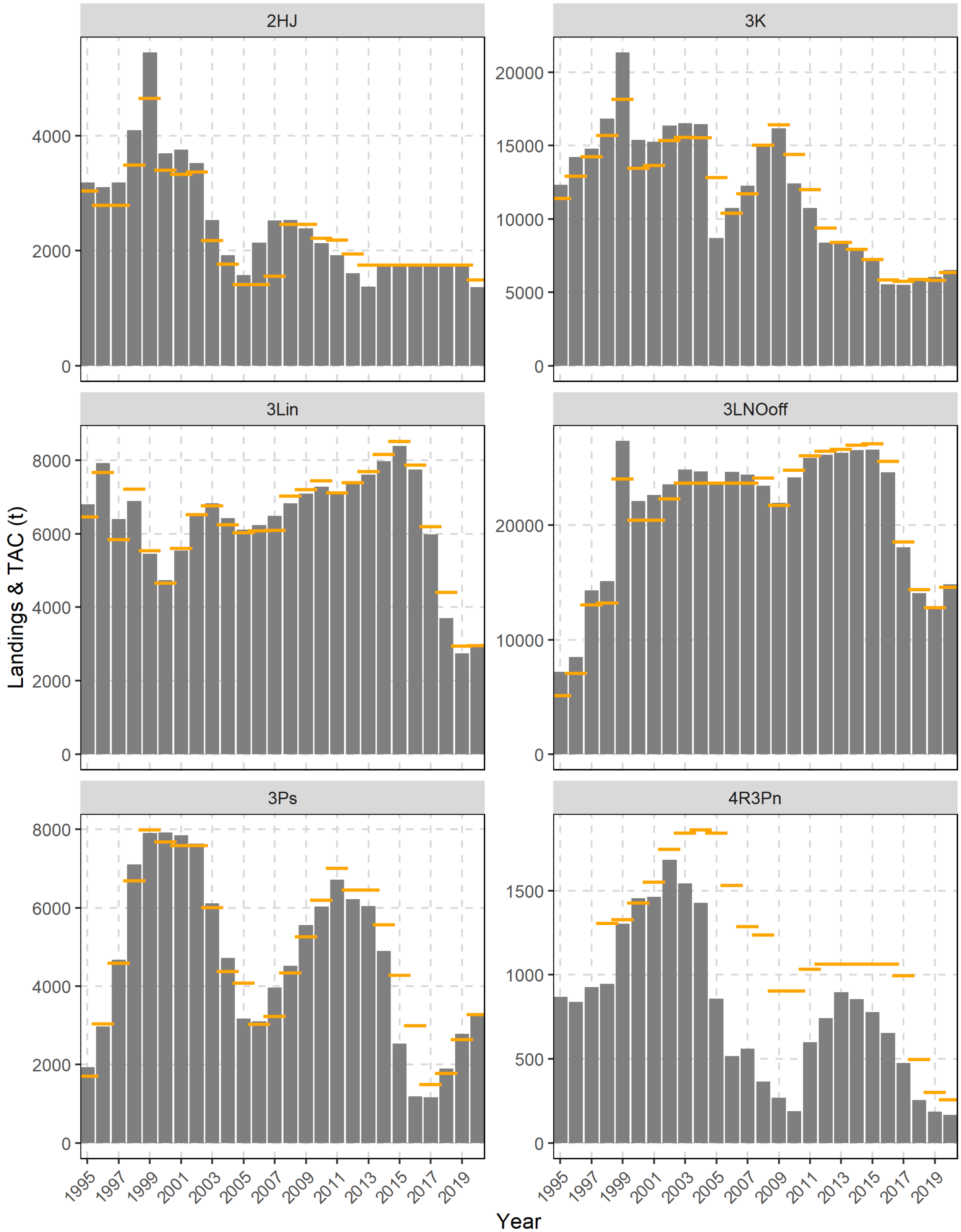

Figure 6: Annual landings and TAC by Assessment Division. Solid gray bars are landings and horizontal yellow lines are the TAC.

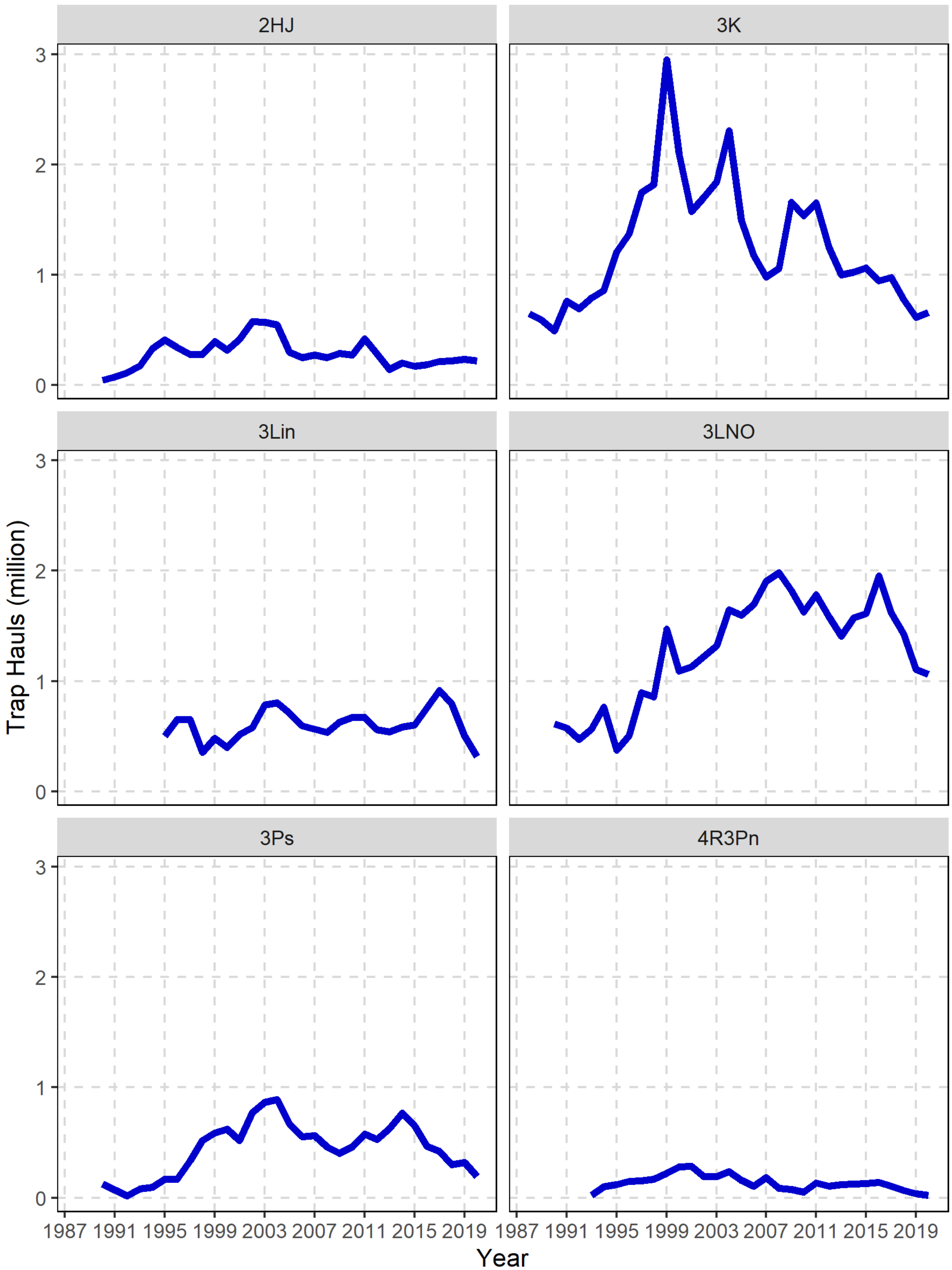

Figure 7: Annual effort (trap hauls) by Assessment Division from fishery logbook data.

CPUE

Fishery CPUE trends lag behind survey biomass trends by one to two years in most ADs, thus the fishery is typically delayed in reflecting stock status. In AD 2HJ, standardized CPUE was below the time-series average in 2020 (Fig. 8), with particularly low standardized CPUE in CMA 2JN. Logbooks returns were much lower than usual in this AD in 2020, with only 58% of the landings accounted for in the logbooks at the time of the assessment. In AD 3K, standardized CPUE increased from a time-series low in 2017 to above the time-series average in 2020. In AD 3L Inshore, standardized CPUE doubled in 2020 from its lowest level in the time-series in 2018. In AD 3LNO Offshore, standardized CPUE returned to near time-series average in 2020 from a historic low level in 2018. In AD 3Ps, standardized CPUE doubled from 2019-20 to near the historic high levels of 1996-98. Finally, in AD 4R3Pn, standardized CPUE increased to a time-series high in 2020; however, logbook returns were very low in this AD, with only 37% of the landings accounted for in the logbooks at the time of the assessment.

Exploitable Biomass

Multispecies trawl surveys indicate that the exploitable biomass was highest at the start of the survey series (1996-98) (Fig. 9). It declined from the late-1990s to 2003 and then varied without trend until 2013. From 2013-16, it declined by 80%. There have been modest increases over the past 3-4 years and the exploitable biomass index was nearing the time-series average in 2020. Meanwhile, the trap survey index declined by nearly 60% in 2017 and 2018 to a time-series low. It has increased in the past two years, but remains below the time-series average (Fig. 10).

In AD 2HJ, the exploitable biomass index has changed little during the past decade; however, the trawl exploitable biomass index decreased slightly in 2020 (Fig. 11). Despite consistency across the two surveys, stock status interpretation has been compromised in recent years by incomplete trap surveys from 2017-19 (Fig. 12) and reduced coverage of the fall multispecies trawl survey in 2019. In AD 3K, the trawl exploitable biomass index increased greatly in 2020 to near time-series high levels. This large increase is not reflected in the trap survey, which shows a modest increase from the 2018 low level. In AD 3L Inshore, the trap survey exploitable biomass index has increased slightly in the last two years, but remained below the time-series average in 2020. In AD 3LNO Offshore, the trawl exploitable biomass index has increased in the last three years from a time-series low in 2016-17. The trap exploitable biomass index has also shown an increase in the last 2-3 years, but remains well below the time-series average. In AD 3Ps, the trap exploitable biomass index showed further increases in 2020, nearing time-series high levels. Finally, in AD 4R3Pn, the trap exploitable biomass index has increased over the past 2-3 years to around the time-series average.

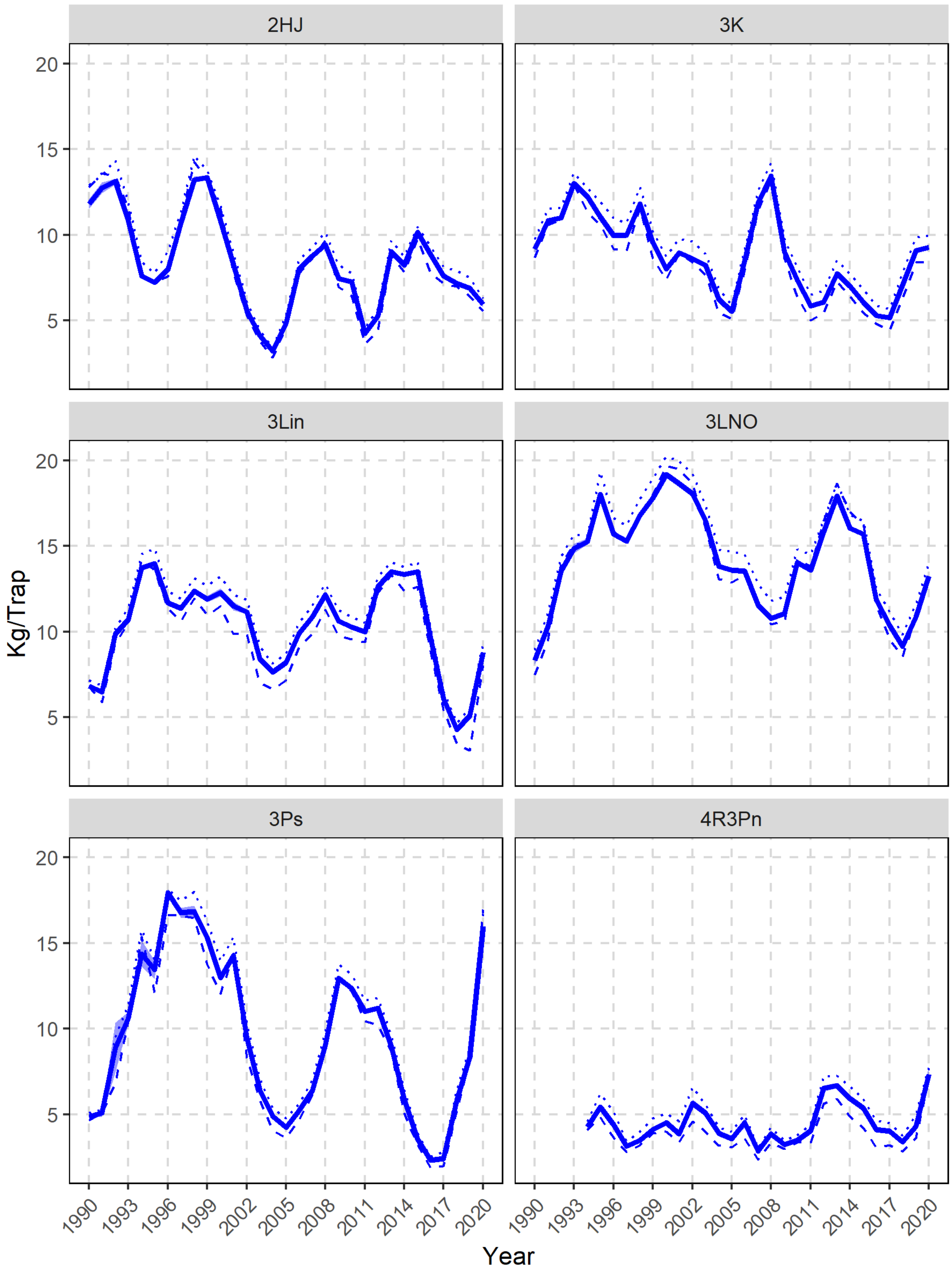

Figure 8: Fishery CPUE (kg/trap) by Assessment Division from fishery logbook data. Solid line is standardized CPUE and shaded band is 95% confidence intervals. Dotted lines are raw means and hashed lines are raw medians.

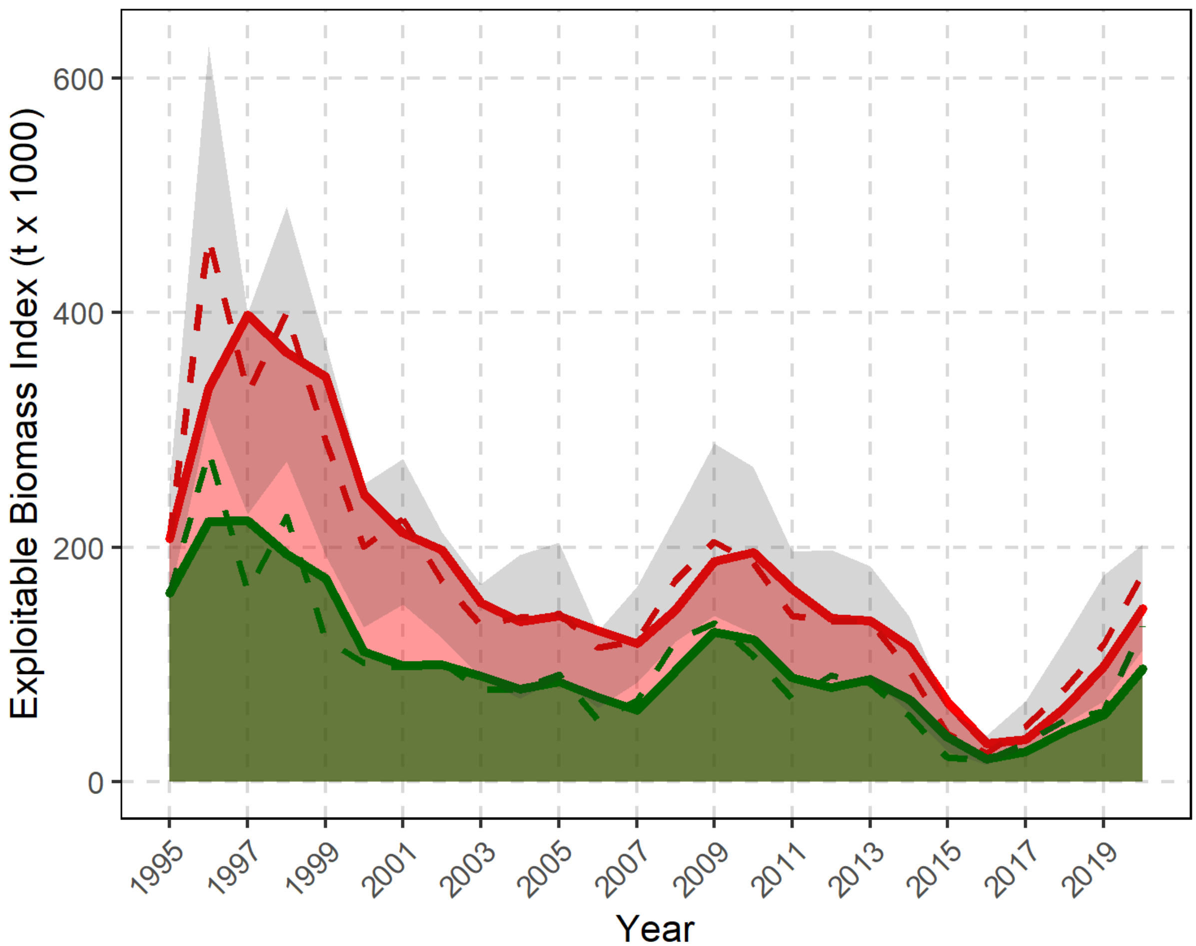

*Figure 9: Trawl survey exploitable biomass indices (t * 1000) by shell condition for combined Assessment Divisions. Soft and new-shell crab represent recruitment (green) and intermediate and old-shell crab represent residual biomass (red). Dashed lines shows annual estimates and solid lines are two-year moving average estimates. Shaded grey 95% confidence intervals apply to annual estimates.*

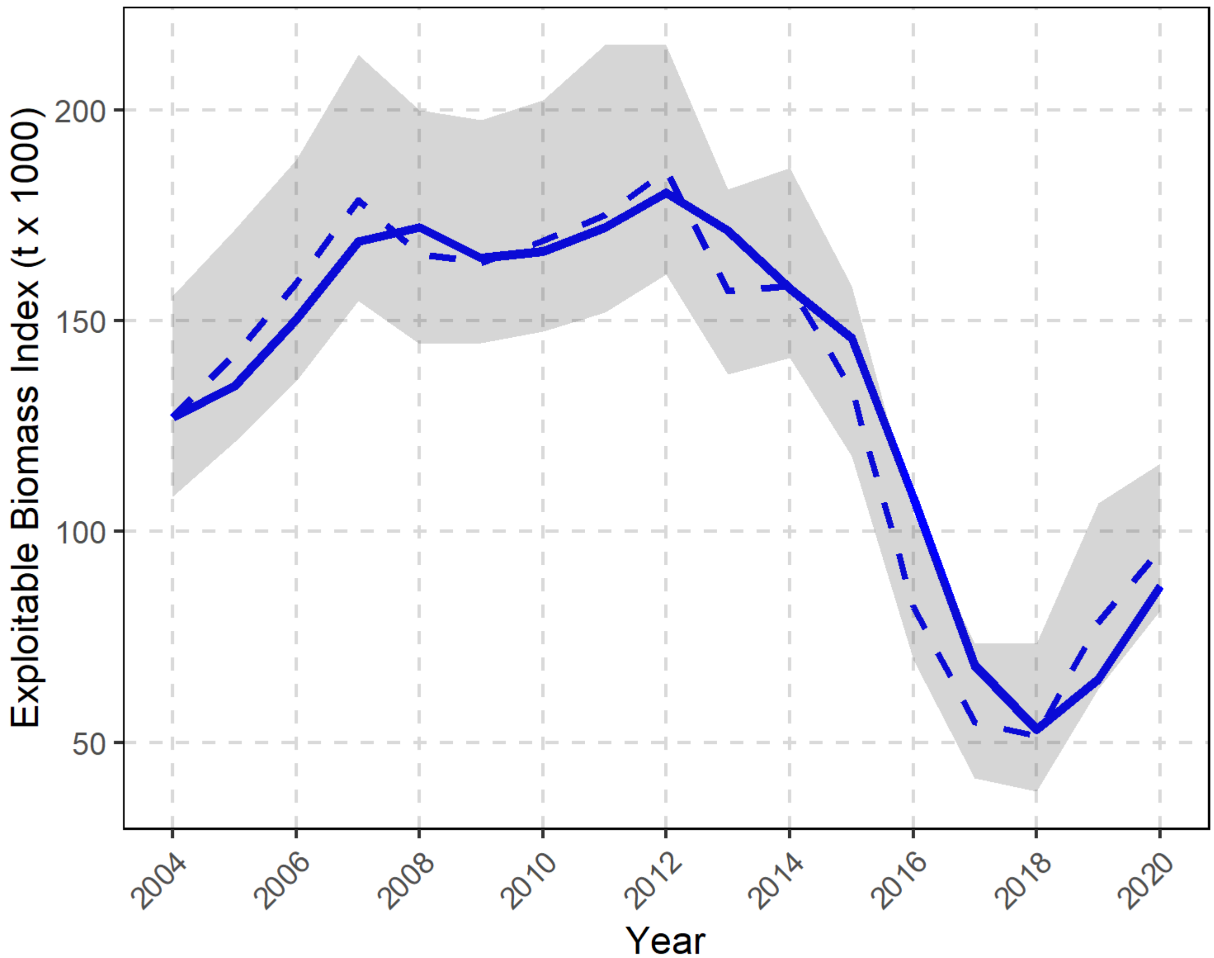

*Figure 10: Trap survey exploitable biomass index (t * 1000) for combined Assessment Divisions. Dashed line shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate.*

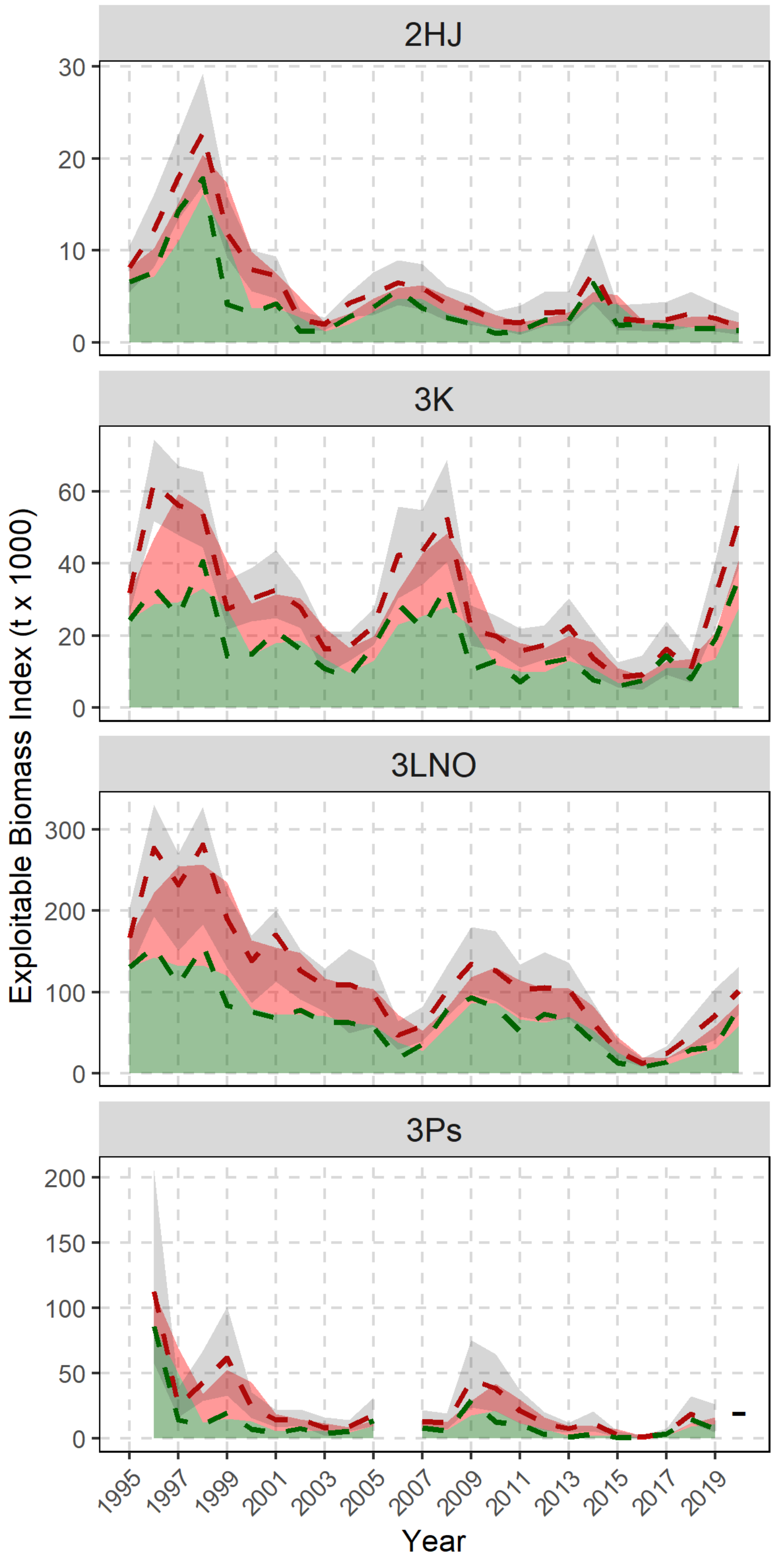

*Figure 11: Trawl survey exploitable biomass indices (t * 1000) by shell condition for trawl-surveyed Assessment Divisions. Soft and new-shell crab represent recruitment (green) and intermediate and old-shell crab represent residual biomass (red). Dashed lines show annual estimates and solid lines are two year moving average estimates. Shaded grey 95% confidence intervals apply to annual estimates.*

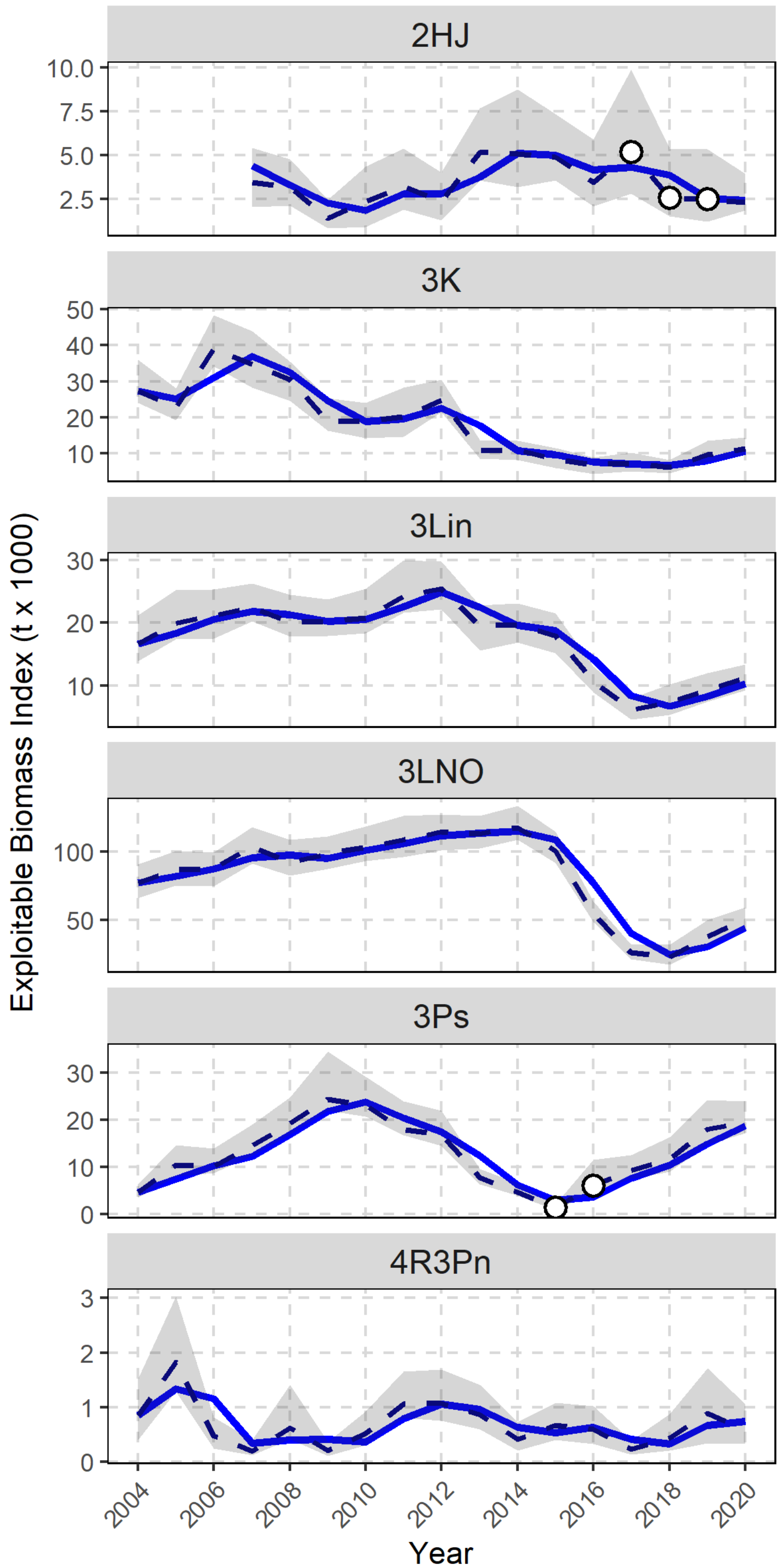

*Figure 12: Trap survey exploitable biomass index (t * 1000) by Assessment Division. Dashed line shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate. White dots depict incomplete surveys.*

Mortality

Total mortality in exploitable crab was very high in all ADs during 2015-17 (Fig. 13). There are no indices of total mortality for ADs 3L Inshore and 4R3Pn as this calculation uses trawl survey data. There is no updated total mortality data for AD 3Ps in 2020 because there was no trawl survey in that AD in 2020. In AD 2HJ, total mortality increased in 2020 and remains highest in this AD. In AD 3K, total mortality was at its highest level from 2016-18, but has declined greatly in the last two years. In AD 3LNO Offshore, total mortality declined from its highest observed level in 2016 to a time-series low in 2019. There was an increase in total mortality in 2020 due to the increase in residual crab in 2019, but a return to the exploitable biomass dominated by recruits in 2020.

Trends in total mortality generally reflect those of fishing-induced mortality, as measured by ERIs. ADs currently experiencing notable recovery in the exploitable biomass (i.e. 3K and 3LNO Offshore) are associated with reduced total mortality rates and reductions in exploitation rates, while ADs remaining at low levels with little signs of recovery (i.e. 2HJ) are associated with persistent high total mortality and exploitation rates. Evidence suggests that reducing exploitation rates constitutes an effective strategy toward promoting recovery of the exploitable biomass. This is further reinforced by the presence of stronger residual components to the exploitable biomass in less heavily exploited areas.

In AD 2HJ, the ERI declined to near the time-series average in 2020 (Fig. 13). This was due to a TAC reduction in 2020 along with the full TAC not being caught in CMA 2JN. Under status quo removals in 2021 the ERI would increase to near the time-series high level. In AD 3K, the ERI declined from a decadal high in 2017 to a time-series low in 2020. Under status quo removals in 2021 the ERI would further decrease. In AD 3LNO Offshore, the ERI increased by a factor of five from 2014-17, but decreased to below the time-series average in 2020. The ERI would further decline with status quo removals in 2021.

There are no trawl-based biomass indices available in ADs 3L Inshore and 4R3Pn from which to calculate ERIs. Accordingly, the shorter time-series of trap surveys are used as the basis (Fig. 14).The trap-based exploitable biomass index is also used for AD 3Ps as the trawl survey takes place within season, as opposed to post-season as in the other ADs. In AD 3L Inshore, the overall trap survey-derived ERI increased to its highest observed level in 2018, but decreased to near time-series low levels in 2020. Status quo removals would decrease the ERI to a time-series low in 2021. In AD 3Ps, the trap survey-derived ERI increased slightly in 2019, but decreased to a time-series low in 2020. Under status quo removals in 2021, the ERI would decline further. In AD 4R3Pn, the trap survey-derived ERI declined to a time-series low in 2020. Status quo removals in 2021 would maintain the ERI at a similar level.

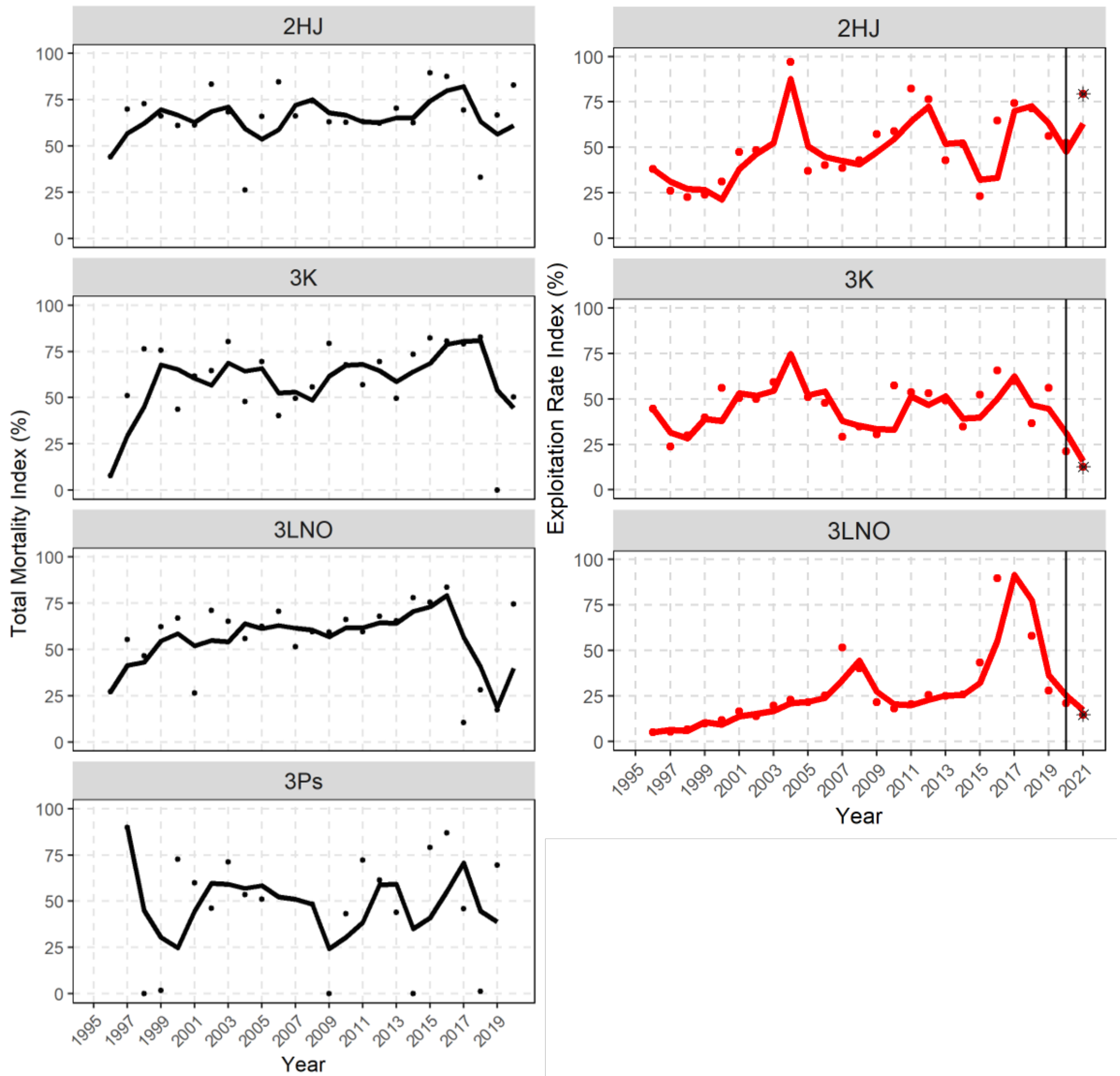

Figure 13: Left: Trends in the annual (points) and 3-year moving average (solid line) total mortality index (%) of exploitable crab by Assessment Division. Note if annual mortality index was <0 it was plotted as 0 for presentation. Right: Trends in the annual (points) and 2-year moving average (solid line) trawl-based ERIs (%) by Assessment Division; 2021 stars depict annual projected ERIs under status quo removals in the 2021 fishery.

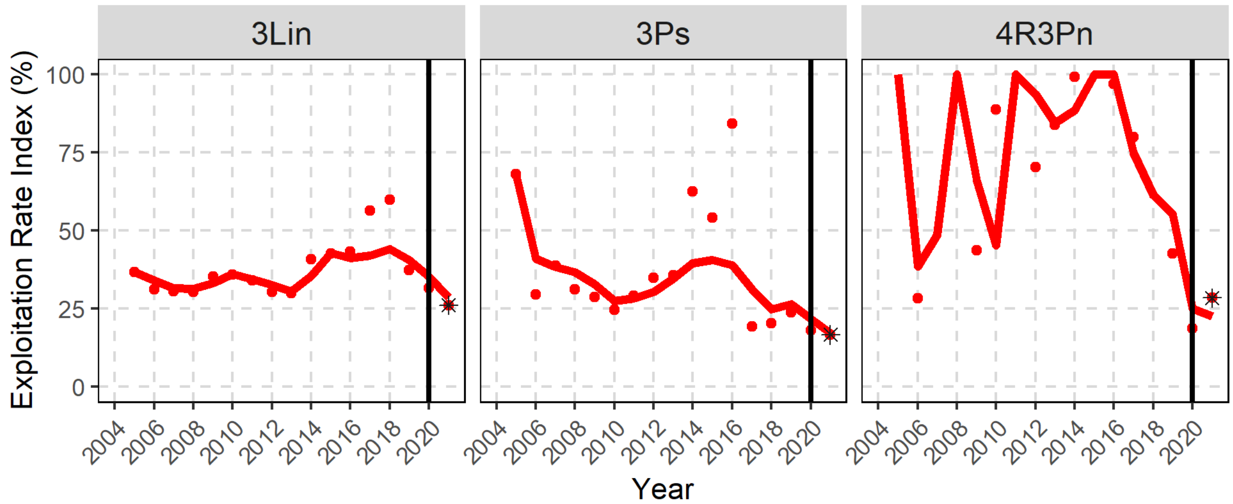

Figure 14: Trends in the annual (points) and 2-year moving average (solid line) trap-based ERIs (%) by Assessment Division; 2021 stars depict annual projected ERIs under status quo removals in the 2021 fishery.

Recruitment

Overall recruitment into the exploitable biomass increased in 2020, nearing the time-series average (Fig. 9). In most ADs, the exploitable biomass is presently dominated by incoming recruits (Fig. 11). In AD 2HJ, recruitment into the exploitable biomass has changed little during the majority of the time-series. The 2020 trawl survey suggests recruitment will remain unchanged in 2021 which suggests little change in fishery prospects for 2021. In AD 3K, the post-season trawl and trap survey indices of recruitment into the exploitable biomass showed increases in 2020 (Figs. 11 and 15), suggesting potential for improvement in the fishery in 2021. In AD 3LNO Offshore, the post-season trawl and trap survey indices of recruitment into the exploitable biomass showed increases in 2020, suggesting potential for improvement in the fishery in 2021.

For ADs where no trawl surveys occur, the trap-derived indices are solely used. In AD 3L Inshore recruitment into the exploitable biomass steadily declined to a time-series low in 2017. While recruitment has been at an increased level for the past three years, it remains below the time-series average level (Fig. 15). In AD 3Ps, recruitment into the exploitable biomass declined slightly in 2020, but remains near time-series high levels. This suggests continued improvements in the fishery in 2021. In AD 4R3Pn, recruitment into the exploitable biomass was low from 2014-17, but increased to a time-series high in 2019. Recruitment decreased slightly in 2020, but remains near a time-series high level, suggesting potential improvements in the fishery in 2021.

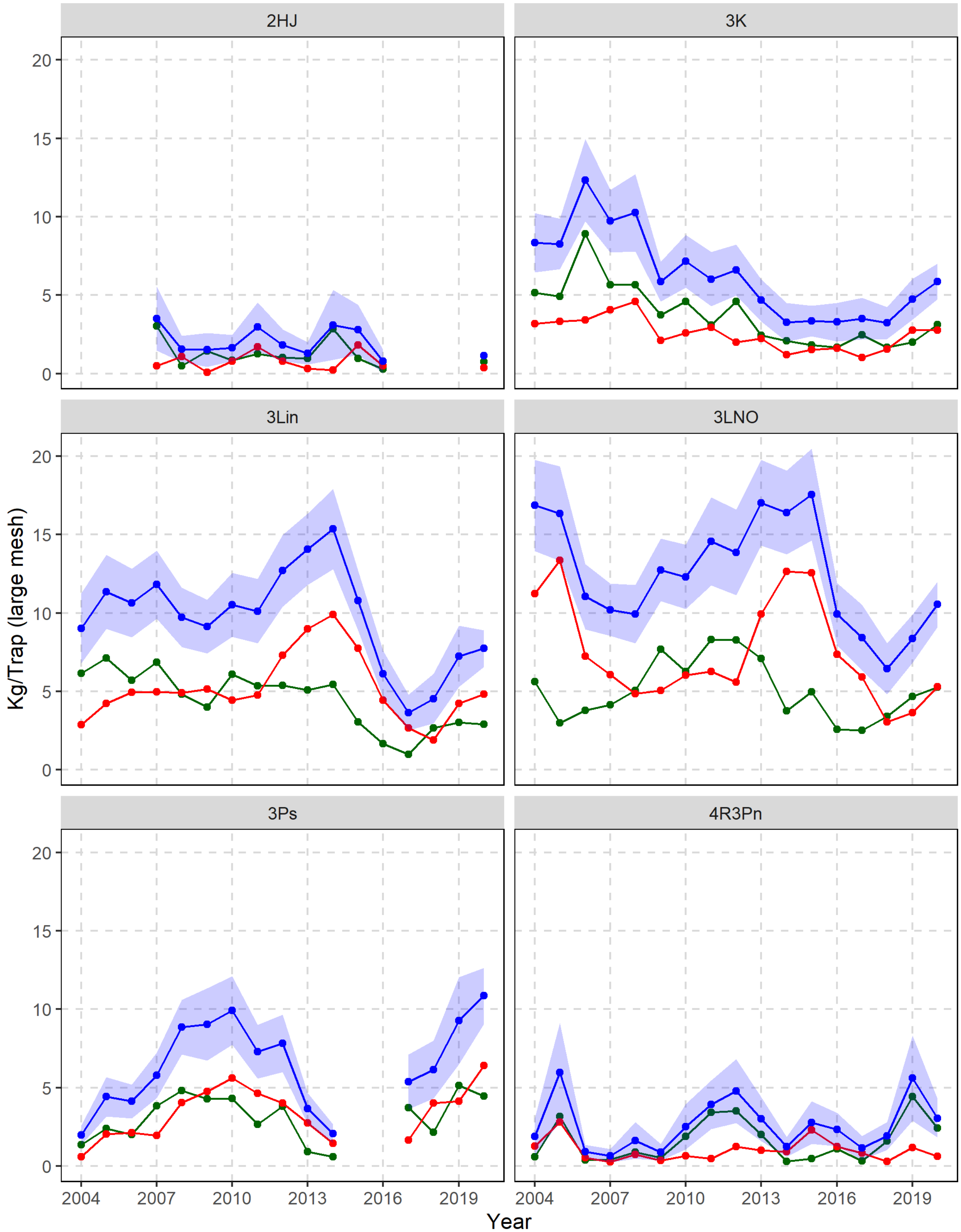

Figure 15: Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable crab from large-mesh traps at core stations in the CPS survey by Assessment Division (2004-20). Shaded area represents the 95% confidence interval.

Pre-recruit abundance indices for trawl and trap surveys provide an index of recruitment prospects for the next two to four years. In reality however, the proportion of the 65–94 mm CW adolescents measured by these surveys that reach the exploitable biomass depends on several factors including mortality and the size at which crab terminally molt. The overall abundance of pre-recruits in the stock increased to above the time-series average in 2020 and was at a decadal high level. Both surveys are suggesting the potential for improvements of recruitment into the exploitable biomass in forthcoming years (Figs. 16-17). While there have been decreases or little change in the pre-recruit abundance indices from trap surveys in most ADs in 2020, these indices remain near high levels. In ADs where exploitable biomass levels remain low and there is an increased potential of recruitment into the biomass, a scenario of increased soft-shell crab incidence may occur in the fishery over the next couple of years if measures to ensure efficient transition of these crab into the exploitable biomass are not taken.

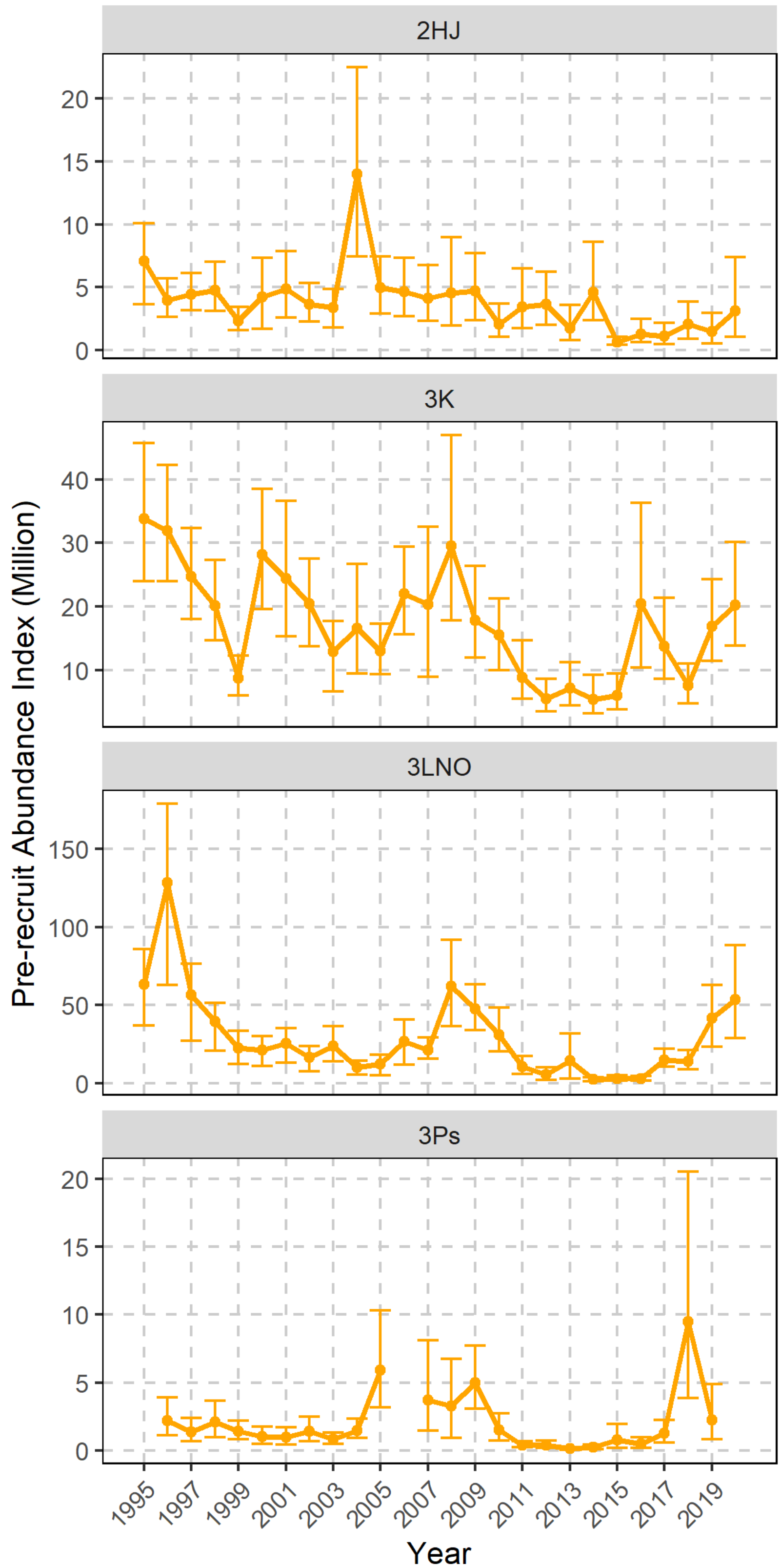

*Figure 16: Overall trawl survey pre-recruit abundance index (t * million) by Assessment Division (1995-2020). Note: No trawl survey in AD 3Ps in 2020.*

Figure 17: Annual CPUE (#/trap) of pre-recruits from small-mesh traps at core stations in the CPS trap survey by Assessment Division (2004-20).

Ecosystem Perspective

Overall, broad-scale climate indices appear favourable for improved recruitment to occur in most major areas of the stock range in the short-term (Fig. 18). For those areas with updated data, the thermal habitat index (defined as the areal extent of <2°C bottom water) declined in recent years (Fig. 19), indicating warming conditions. The last three years have shown an overall trend towards warmer and potentially less favourable environmental conditions for future productivity.

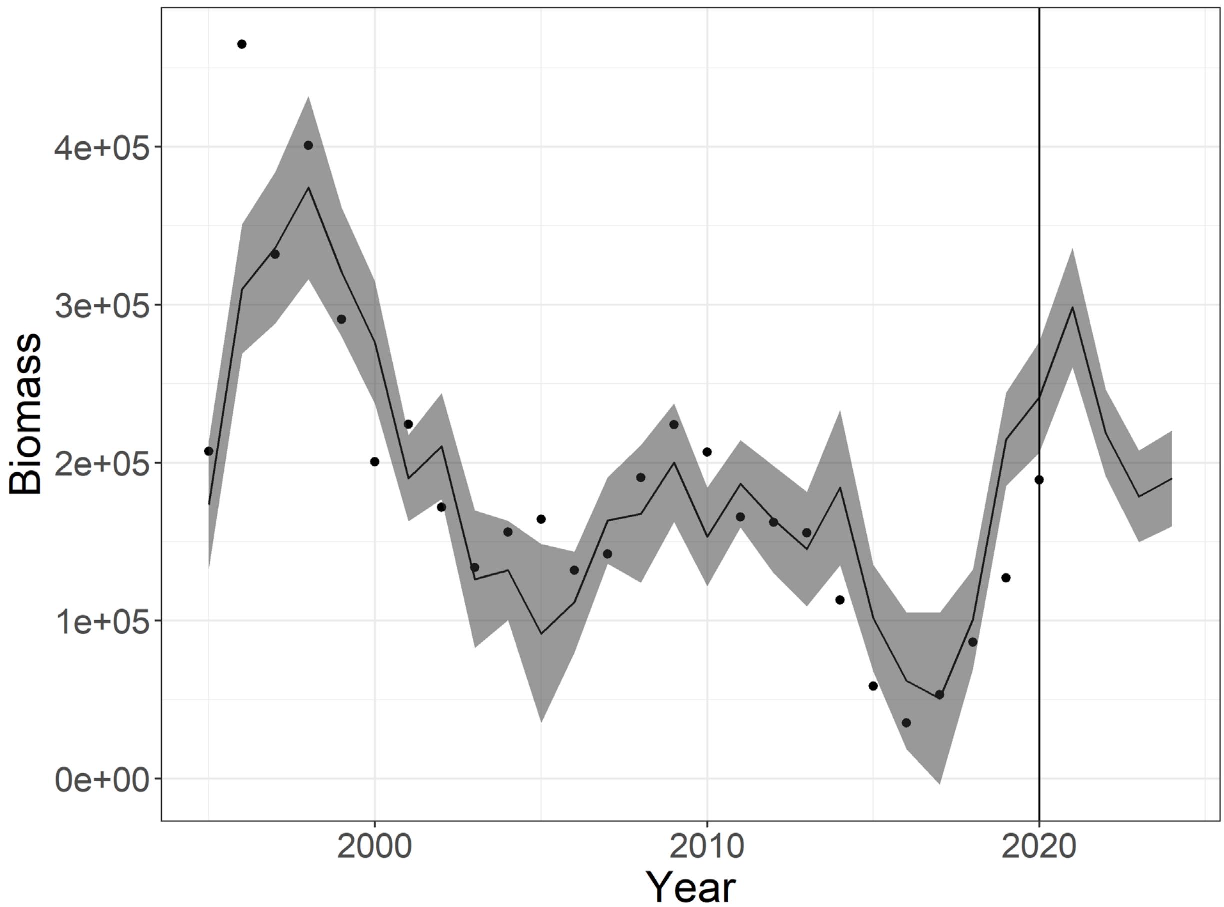

Figure 18: Stock-level exploitable biomass index in relation to lagged indices of the AO and ENSO defined as an average of monthly values from five to seven years ago and four to six years ago, respectively. Points are survey exploitable biomass + landings, solid line is the model fit, and shaded band is the 95% confidence intervals.

Figure 19: Snow Crab thermal habitat indices by Assessment Division and year (1980-2020). Note: f = fall and s = spring data. Light green lines are annual values and dark green lines are loess regression curves.

Since the collapse of most of the finfish community in the early-1990s, the Snow Crab resource appeared to have largely been under bottom-up temperature control for much of the past two decades (Mullowney et al. 2014). However, recent assessments have highlighted that other factors such as top-down forcings from heavy exploitation and increased predation have increased in importance.

While predation mortality remains among the highest in recent years, there have been declines from the peaks of 2016-18. However, this pattern is not seen in all areas, with predation mortality maintained at a high level in AD 2J (Fig. 20). Given that the regulating effect of predation is thought to be most important on small to intermediate-sized crab (Chabot et al. 2008), a delay would be expected between the time the predation mortality index decreases and crab become available to the fishery. A decline in predation mortality coupled with now decreased fisheries exploitation rates and increasing pre-recruit abundance indices in most ADs (Figs. 16-17) indicates a positive outlook in the next two to seven years if fishing pressure levels remain low enough to allow the crab to continue to recruit into the exploitable biomass.

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

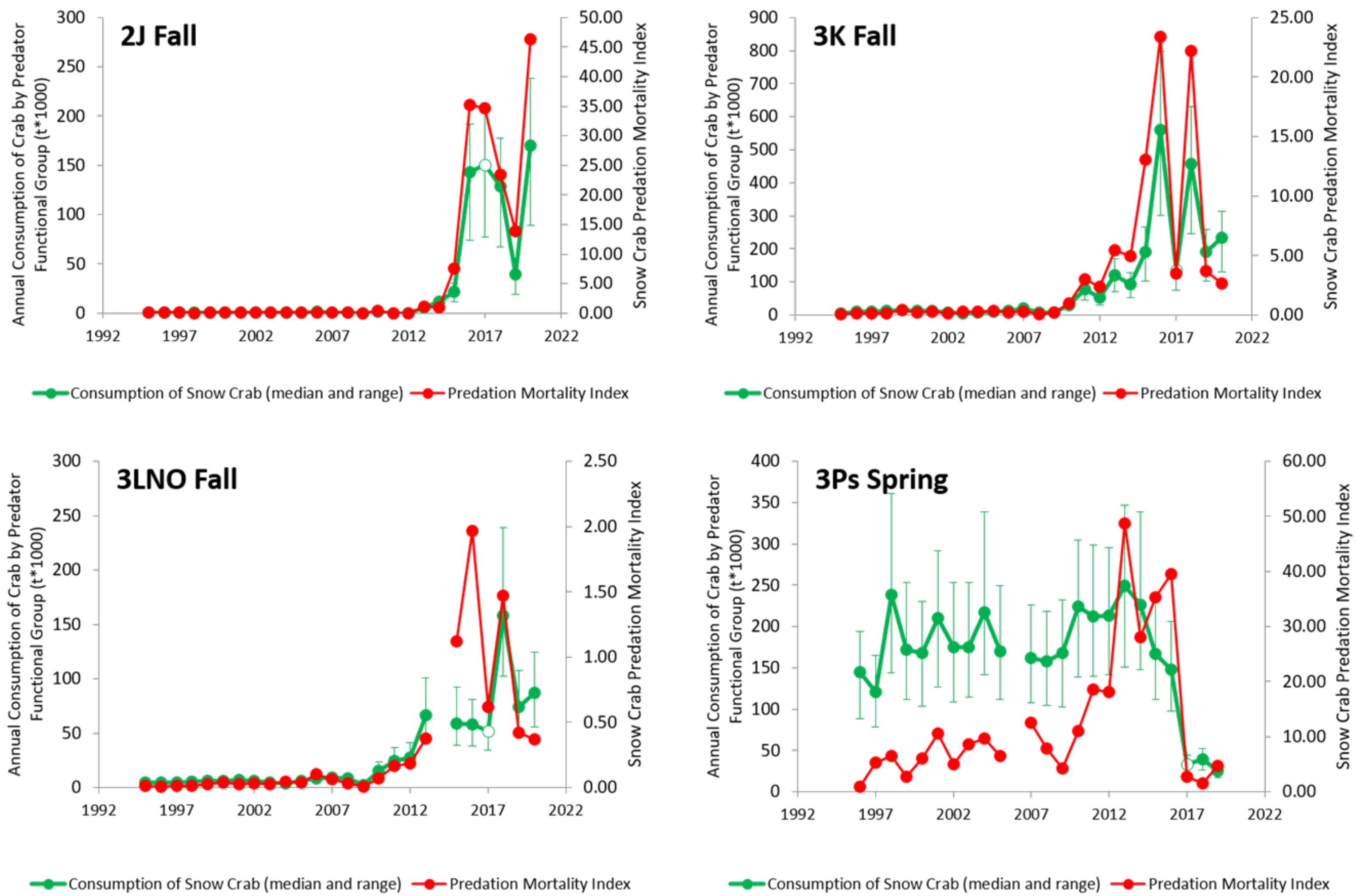

Figure 20: Consumption of Snow Crab by finfish predators by Assessment Division and year. Green represents estimated consumption and red is an index of predation mortality.

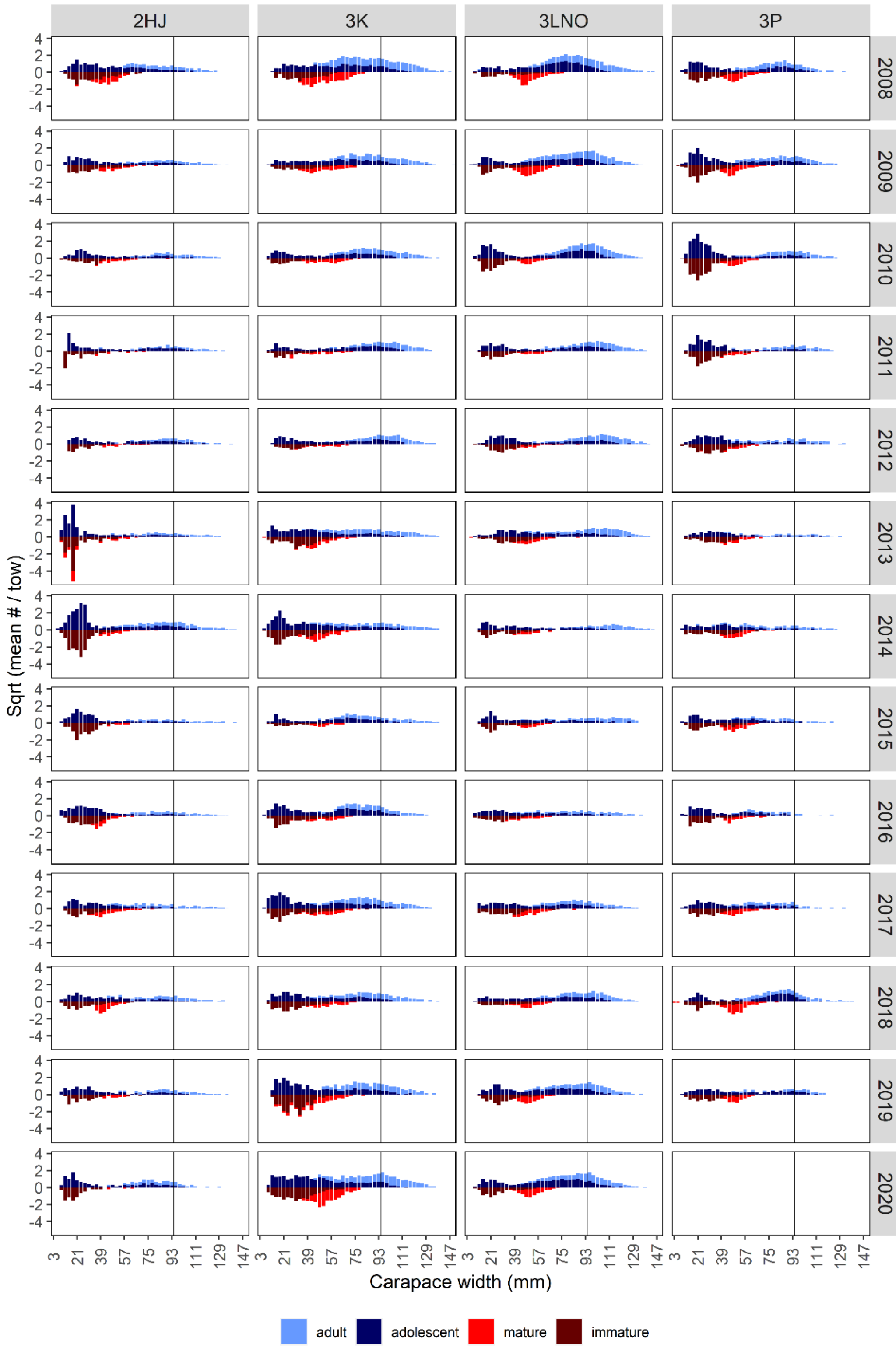

Figure 21: Abundance indices by CW for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (AD 3Ps) and fall (ADs 2HJ, 3K, and 3LNO) trawl surveys. Information on females, while displayed on the negative y-axis, represent positive abundance indices. Vertical line is legal-size. Data standardized by vessel.

Outlook

There have been improvements in the exploitable biomass index in all ADs except 2HJ in 2020, which are likely to continue in the short-term. This stock is continuing to increase from record low levels, however has not returned to high levels of the past. There are indications that several ecosystem-related factors may be encouraging both short- and long-term growth of the stock, including cool bottom water temperatures in previous years and a slight decline in predation in most areas. There are also signals of increased abundances of pre-recruit and small-sized crab (Fig. 21), indicating a positive outlook in the next two to seven years if fishing pressure levels allow the crab to recruit into the exploitable biomass.

In AD 2HJ, along with persistently high fishing pressure and low residual biomass, a sharp decline in male size-at-terminal molt has occurred in recent years (Fig. 22). Recent work concludes that a combination of cold conditions and low population density of large males contributed to this decline in male size-at-terminal molt (Mullowney and Baker 2020). This occurrence has also been seen in AD 3K, but to a lesser degree than AD 2HJ. The emergence or potential reversal of this phenomenon in all ADs will be important to monitor moving forward as persistent decreased size-at-terminal molt would negatively impact stock and subsequently fishery productivity.

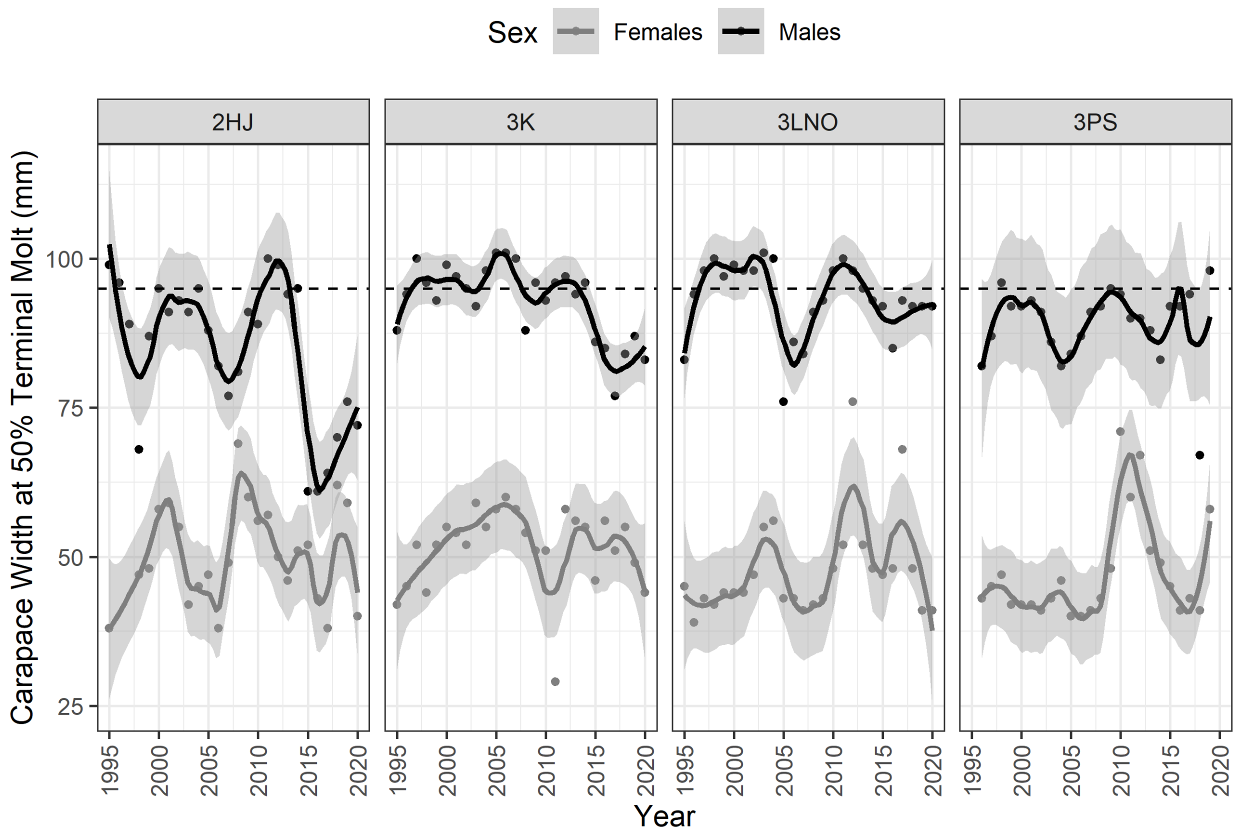

Figure 22: Annual estimates on size at which 50% of male (black) and female (grey) crab undertook their terminal molt by AD and year. Error bands are 95% confidence intervals of a loess regression fit (lines) to annual estimates from GAM (points). Horizontal dashed line shows minimum legal size.

Precautionary Approach

In June 2018, DFO Science held a CSAS Regional Peer Review process to develop a Precautionary Approach (PA) Framework for Snow Crab in the NL Region. The key objective of the meeting was to define Limit Reference Points (LRPs) consistent with the PA for NL Snow Crab based on the best scientific information available. DFO Science proposed a PA Framework for the NL Snow Crab resource and fishery (Mullowney et al. 2018b). The framework uses generalized additive models, peer-reviewed in a previous assessment, to project forward one year anticipated fishery CPUE and discard rates. The adopted parts of the framework include the LRPs, differentiating the Critical from Cautious Zones, and the Upper Removal Reference (URR). Harvest Control Rules (HCRs) and Upper Stock References (USRs) were proposed but not adopted into the framework.

In early-2020, members of the harvesting sector submitted an alternative PA Framework for Snow Crab to be reviewed. Following peer-review this alternate PA Framework was not accepted and the DFO Science LRPs remained in place. A working group was reestablished to bring forward a series of recommendations to DFO on the USRs and HCRs, but no formal recommendations have been made at this point. Accordingly, USRs are not presented in this assessment and the overarching HCR for the framework is not defined, meaning an AD is not projected to be in a zone, rather individual metrics are either above or below the associated LRP.

In 2021, all ADs are projected to be above the LRPs for each stock status metric in the PA Framework (Fig. 23). These projections assume status quo landings.

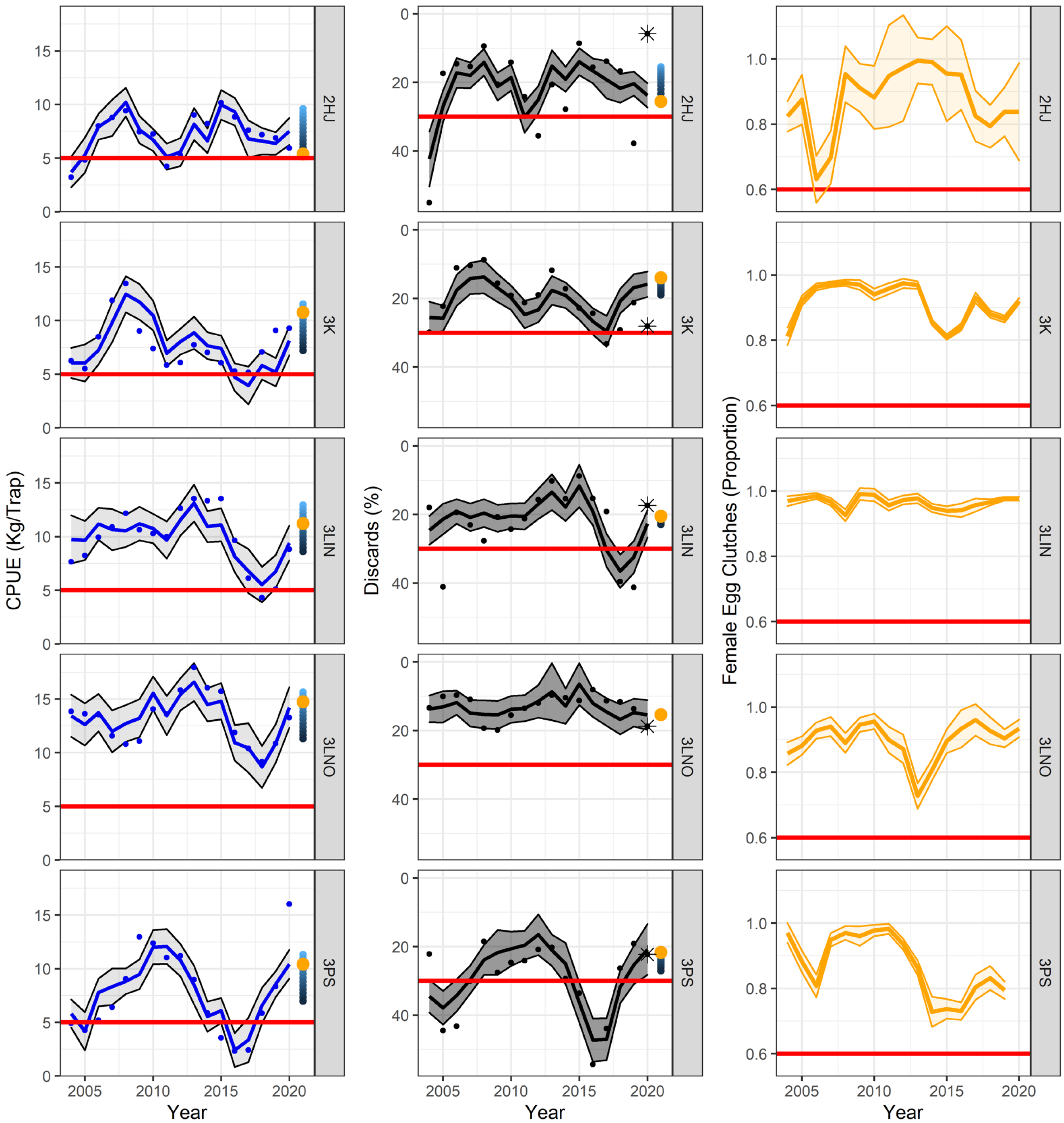

Figure 23: Trends in predicted CPUE (left), predicted % discards (middle), and observed proportion of females with full egg clutch (right) (solid lines), as well as standardized CPUE and % discards (points) in relation to LRPs (red horizontal lines) for each metric in the PA Framework, by Assessment Division. Shaded areas represent prediction intervals (CPUE and discards) or 1 standard deviation (egg clutches). Orange points represent predicted values under status quo landings in the forthcoming fishery. Vertical blue shades in 2021 are the predicted values under varying levels of ERI (light to dark blue: ERI = 0-60%). Stars in % discards panel in 2020 represent the mean % discards from at-sea observer data and a reference fleet from logbook data.

Sources of Uncertainty

There are several sources of uncertainty that affect the interpretation of trends in biomass, recruitment, and mortality that represent the basis for this assessment. Uncertainties that affect post-season survey indices are more important than those that affect indices based on fishery performance because surveys are used to predict fishery performance. In contrast, past fishery performance does not predict future fishery performance.

Surveys

Interpretation of trends in exploitable biomass and pre-recruit abundance indices from surveys is highly uncertain if the survey was incomplete, such as in AD 2HJ trap surveys from 2017-19. There are consistent issues with coverage in the CPS trap survey that affect the interpretation of stock status trends, including spatial bias and abandonment of survey areas in times of poor fishery performance. As well, the multispecies trawl surveys fail to sample inshore areas in some NAFO Divisions. Additionally, the multispecies trawl survey in spring 2020 did not take place due to the COVID-19 global pandemic and in fall 2020 there was reduced coverage in NAFO Div. 2H.

Trawl efficiency is directly related to substrate type and crab size, and so varies considerably spatially. Efficiency is lower and more variable on hard substrates than on soft substrates. Thus, annual survey catchability depends on the conditions at the positions randomly selected for the survey each year. Interpretation of indices from the spring trawl survey in AD 3Ps is more uncertain than for those from the fall surveys because they occur after a variable fraction of fishery removals.

Exploitable biomass indices and pre-recruit catch rates from trap surveys are also affected by annual variation in catchability of crab. There is uncertainty in interpreting trends from the CPS survey because it has limited spatial coverage. Also, catch rates in this survey may be affected by adverse weather and other factors that affect soak time and trap efficiency.

For the present assessment, all biomass estimates were smoothed as two-year moving averages to partially account for such inconsistencies in annual survey performance.

Small-meshed traps are included in sampling by the CPS trap survey at some stations in most areas to provide an index of future recruitment based on catch rates of pre-recruits. However, there is uncertainty associated with historically limited spatial coverage by small-meshed traps, especially in shallow-water small-crab habitat, and high variability in trap catchability. Small adolescents may be particularly susceptible to trap catchability effects due to competition with larger and adult males. Recent efforts to increase the amount and distribution of small-mesh pots, as well as broader distribution of the CPS survey stations should address some of these uncertainties going forward.

Crab movements across divisional boundaries may affect the extent to which distributions during timing of various surveys are reflected in subsequent fisheries or the extent to which modes of growth progression can be followed from one year to the next. In the 2019 Snow Crab assessment, there was evidence presented of a large redistribution of exploitable crab out of AD 3K and into AD 2HJ during the previous year and back into AD 3K the following year. Such issues have the potential to greatly affect stock status interpretations at small spatial scales such as the CMAs used to manage the fishery.

Short-Term Recruitment

Predicting recruitment is complicated by variation in the proportion of pre-recruits that molt in any given year. Molt frequency is inversely related to body size and directly related to temperature such that growth is slower under cold regimes (e.g. Divs. 3LNOPs) than under warm regimes (e.g. Divs. 2J3K4R).

Long-Term Recruitment

There is high uncertainty about the reliability of qualitatively relating recent climate events to long-term recruitment potential. Strong direct linkages of future biomass to climate forcings such as the NAO (Colbourne et al. 2011) could fail if additional factors such as excessive fishing or high predation affect recruitment and yield. Moreover, under greenhouse gas-forced warming, there is uncertainty regarding whether such long-term oscillations will persist as they have in the past or how they will interact with additional forcings.

Fishery Indices

Completion and timely return of logbooks is mandatory in this fishery. Data for the current year is typically incomplete at the time of the assessment and so the associated CPUE and effort values are potentially biased and considered preliminary. For the current assessment, logbook returns were particularly poor in ADs 2HJ and 4R3Pn, with 58% and 37% of landings accounted for in the logbooks, respectively. ADs 2HJ, 3Ps, and 4R3Pn usually have lower returns (~70%) at the time of the assessment, with returns in the other ADs greater than 80%. The reliability of the logbook data can be suspect with respect to effort (i.e., under-reporting) and areas fished. However, logbook data provide the broadest coverage and therefore the most representative fishery performance index.

There is uncertainty regarding the effects of changes in some fishing practices (e.g., location, seasonality, soak time, trap mesh size, high-grading, and bait efficiency) on commercial catch rates (CPUE) and their interpretation as indicators of trends in exploitable biomass. Some of these changes (e.g., in mesh size and soak time) also affect catch rates of undersized crab and can compromise the utility of the catch rate of undersized crabs as an index of future recruitment.

Fishery catch rates are standardized in a mixed model incorporating fishing day and soak time to account for potential inaccuracies, but other factors remain that can potentially bias their utility as indices of fisheries performance. Fishery CPUE is also characterized by both a lag in response to changes in stock size and an asymptotic curve indicative of trap saturation which affects its ability to measure exploitable biomass.

There are concerns regarding the utility of the observer data from at-sea sampling during the fishery due to low and inconsistent spatio-temporal coverage, especially in ADs 2HJ, 3L Inshore, and 4R3Pn. These concerns introduce bias in interpreting trends in catch rates at broad spatial scales and introduces high uncertainty in interpreting indices of biomass, recruitment, and mortality. Observer-based indices are also biased by inconsistent sampling methods and levels resulting from changing priorities. There are also concerns relating to variability in experience of observers in subjectively assigning shell stages. This introduces uncertainty in inferring recent recruitment trends and prospects based on catch rates of new-shelled crabs. In 2020, observer coverage was particularly poor due to the COVID-19 global pandemic, which resulted in no observer coverage in ADs 2HJ and 4R3Pn. Consequently, the observer data was not presented in the current assessment. Measures should be taken to ensure representative observer coverage to improve data quality from this program.

Mortality Indices

Indices of fishery-induced mortality are subject to uncertainties associated with both survey and fishery data. Mortality indices are not estimated for years when the associated survey biomass index was not available or reliable. Total mortality estimation relies on shell-condition classifications, and such classifications may be especially difficult during spring surveys. An ERI is estimated for ADs 3L Inshore and 4R3Pn based on the post-season trap survey biomass index. However, this index may be biased by annual changes in the distribution of crab or fishing effort inside versus outside the limited survey areas.

Ecosystem Change

Prolonged warming to approximately 2010-12 in waters surrounding most of NL promoted a general loss of productivity in coldwater crustaceans, such as Snow Crab and Northern Shrimp (*Pandalus borealis*), and some recovery in pelagic and groundfish species. However, bottom conditions then cooled until approximately 2017. The extent of community reorganizations resulting from such instability and change is unknown. Ultimately, if temperatures continue to warm as expected under greenhouse gas scenarios, the prognosis for Snow Crab would be poor. However, the rates, extent, and even direction of future climate and community changes in the marine shelf ecosystem are highly uncertain. Moreover, it is uncertain the extent to which changes in zooplankton community structure will resonate through the food-web to affect future Snow Crab success.

CONCLUSIONS AND ADVICE

Assessment Division 2HJ

The exploitable biomass has consisted largely of incoming recruits for the past sixteen years with few residual crab in the population. This suggests high mortality of large adult male crab. The ERI has been high throughout most of the time-series relative to other ADs within NL, as well as other fished snow crab stocks globally, and this has been shown to be a factor contributing to reduced size-at-terminal molt in males. Status quo removals in 2021 would further increase the exploitation rate index. Following the proposed PA the stock status would be projected to be above the LRPs in 2021.

Assessment Division 3K

The exploitable biomass has increased significantly over the last two years and is dominated by recruits, suggesting improvements in the coming year. Total mortality in exploitable crab has declined in the last two years from a very high level in previous years. The ERI has been high throughout most of the time-series relative to other ADs within NL, as well as other fished snow crab stocks globally, but declined to a time-series low in 2020. Status quo removals in 2021 would reduce the ERI to a time-series low. Following the proposed PA the stock status would be projected to be above the LRPs in 2021.

Assessment Division 3L Inshore

The exploitable biomass has increased slightly overall over the last two years, but remains low. All CMAs have shown slight improvements in either 2019 or 2020. The overall ERI declined in the last two years from previous very high levels. Status quo removals in 2021 would reduce the ERI to a time-series low. Following the proposed PA the stock status would be projected to be above the LRPs in 2021.

Assessment Division 3LNO Offshore

The exploitable biomass has increased over the past three years and is dominated by recruits, suggesting improvements in the coming year. Total mortality in exploitable crab has decreased in the last three years and is the lowest in this AD. This AD had a period of high ERI from 2014-17, but the ERI has declined significantly in the last three years. Status quo removals in 2021 would reduce the ERI to below the time-series average. Following the proposed PA the stock status would be projected to be above the LRPs in 2021.

Assessment Division 3Ps

The trawl survey was not conducted in 3Ps in 2020 due to the COVID-19 global pandemic; however, the exploitable biomass index from the trap survey remained near time-series highs in 2020. The overall ERI declined in 2020 and status quo removals in 2021 would reduce the ERI to a time-series low. Following the proposed PA the stock status would be projected to be above the LRPs in 2021.

Assessment Divisions 4R3Pn

The exploitable biomass has increased over the past three years. The overall ERI has been declining since a peak in 2015 and was at a time-series low in 2020. The ERI would remain near the time-series low with status quo removals in 2021. Recent and ongoing data deficiencies do not allow inclusion of this AD into the proposed PA Framework.

OTHER CONSIDERATIONS

Bitter Crab Disease

Bitter Crab Disease (BCD) is fatal to crab and predominately occurs in new-shelled crab of both sexes. It appears to be acquired during molting and can be detected visually during autumn. Surveys indicate that it has been most persistent in AD 3K, albeit at low levels, however there has been low incidence in the last two years. Prevalence is most typical in small Snow Crab (Mullowney et al. 2011). Although BCD had been unusually high in large males in AD 3K in recent years, there were no large males observed with BCD in 2019 or 2020.

Reproductive Biology

The percentage of mature females carrying full clutches of viable eggs has generally remained high throughout the time-series wherever measured, but localized declines in heavily fished areas have been observed in recent years. Fishery-induced mortality on mature males (including undersized males) could adversely affect insemination of females in the presence of high exploitation. A current study is investigating the presence of sperm limitation in females associated with high exploitation rates of males in some areas in recent years. A decline in the abundance index of mature females to very low levels was seen in AD 2HJ in 2020, however similar low levels have been seen throughout the time-series. Careful monitoring of this trend, particularly in light of the declines in male size-at-terminal molt in this AD, will be important moving forward as this could have serious implications for reproductive potential in AD 2HJ and potentially other ADs considering upstream/downstream population connectivity.

Management Considerations

Conservation measures that exclude females and males smaller than 95 mm CW, including a portion of the adult (large-clawed) males, from the fishery are aimed to protect reproductive potential. Nevertheless, it remains unclear how the persistence of a very low exploitable biomass in areas such as AD 2HJ may impact reproductive potential at either localized or broad spatial scales (e.g., sperm limitation and reduced post-molt guarding of females in association with downstream connectivity).

Fishery-induced mortality on non-exploitable Snow Crab could possibly impair future recruitment. Pre-recruit mortality is reduced by avoidance in the fishery and, when encountered, careful handling and quick release of pre-recruits. Mortality on sub-legal-sized males, including adolescent pre-recruits, can also be reduced by increasing trap mesh size and soak time, as well as trap modifications such as escape mechanisms. Such initiatives have reportedly been increasingly implemented in recent years.

Prevalence of soft-shelled, legal-sized males in the fishery is affected by fishery timing and exploitable biomass level. Mortality on soft-shelled males can be minimized by fishing early in spring before recently-molted crabs are capable of climbing into traps. It may be further reduced by maintaining a relatively high exploitable biomass level, thereby maintaining strong competition for baited traps and low catchability of less-competitive soft-shelled immediate pre-recruits.

Among other uses, the at-sea observer program forms the basis of the soft-shell protocol, which was introduced in 2005 to protect soft-shelled immediate pre-recruits from handling mortality. It closes localized areas (70 nM^2 grids in the offshore and 18 nM^2 in inshore areas of ADs 3L Inshore, 3K, 3Ps, and 4R3Pn) for the remainder of the season when a threshold level of 20% (15% in some areas) of the legal-sized catch is soft-shelled. It became evident during 2010-12 that this protocol, as implemented, is inappropriate and ineffectual in controlling handling mortality. This is largely due to very low observer coverage, together with the decision to treat unobserved grids as if they had no problem. In addition, failure to draw all the inferences possible from moderate-sized samples frequently resulted in failure to invoke the protocol even when it was clear that the level of soft-shelled crabs had exceeded the threshold. An analysis at the 2019 Snow Crab stock assessment (DFO 2020) showed that a high proportion of cells had no ability to invoke closure due to complete absence of observer coverage in a given year. This was further compounded by low sample sizes prohibiting adherence to closure thresholds when observer coverage was present. These shortcomings undermine the intent of the protocol. Measures should be taken to ensure adequate and representative observer coverage, as well as adjust sample size thresholds to better quantify prevalence of soft-shelled crab in the fishery and therefore afford better protection to recruitment.

The CPS trap survey is one of the primary data sources used to assess the resource. It operates under a compensation scenario of 'quota-for-survey' whereby harvesters are allocated additional quota in the following season in exchange for conducting the survey. However, the survey was incomplete in AD 3Ps in 2015 and 2016 due to resource shortages and the perception that additional quota would not be catchable and therefore would not meet the costs of conducting the survey and it was abandoned. This has also occurred within other ADs such as 4R3Pn. In the future, under the scenario of low exploitable biomass in any given AD, there are concerns the integrity of this survey could further deteriorate. This survey is of great benefit to the stock assessment and deployment and sampling schemes should be strictly followed moving forward.

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SOURCES OF INFORMATION

This Science Advisory Report is from the February 16-18, 2021 Regional Advisory Meeting on the 2HJ, 3KLNOP, and 4R Snow Crab Assessment. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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