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Science Advisory Report 2022/054

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

*Snow Crab (*Chionoecetes opilio*)*

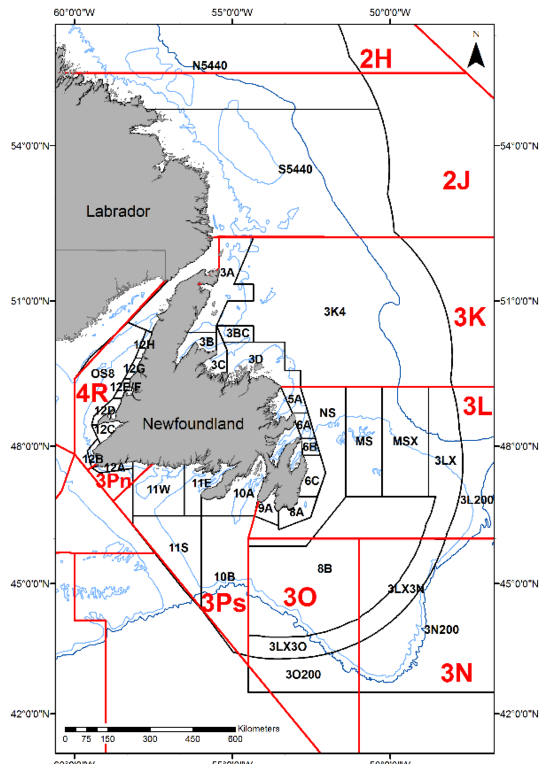

Figure 1: Map of NAFO Divisions (red) and NL Snow Crab Management Areas (black).

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 approximately 2,300 license holders across numerous fleet sectors under enterprise allocation in 2021. 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 (Divs). 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 NAFO Divs. 2HJ3KLNOP, Fisheries and Oceans Canada (DFO) inshore trap surveys in NAFO Divs. 3KLPs, fishery logbooks, at-sea observer measurements, collaborative trap surveys, as well as biological sampling from multiple sources.*

This Science Advisory Report is from the February 22-25, 2022 regional advisory meeting on the Stock Assessment of 2HJ3KLNOP4R Snow Crab. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

Overall – Divisions 2HJ3KLNOP4R

- The overall exploitable biomass increased from historic lows in both trawl and trap surveys over the past four years; however, this increase was not seen in Assessment Division (AD) 2HJ.
- Fishery Exploitation Rate Indices (ERIs) were near time-series lows in all ADs in 2021 except 2HJ and 4R3Pn, where exploitation was over 50%. Status quo removals would further reduce the exploitation rate in all ADs in 2022, except 2HJ, where it would remain over 60% of the exploitable biomass index.
- With status quo removals in 2022, all ADs are projected to be in the Healthy Zone of the provisional Precautionary Approach Framework (PAF), except 2HJ, which is projected to be in the Cautious Zone. Recent and ongoing data deficiencies result in the exclusion of 4R3Pn in the provisional PAF.
- Pre-recruit abundance indices remain generally favourable for the fishery in the next two to four years, but there are indications that these indices may have peaked.
- In 2021, there was reduced Fisheries and Oceans Canada (DFO) trawl survey coverage in ADs 2HJ and 3K. This may have resulted in overestimation of the exploitable biomass index, particularly in 2HJ.
- The DFO trawl survey was not conducted in AD 3LNO in 2021. The Collaborative Post-Season (CPS) survey was used as an exploitable biomass index. This approach was supported by comparative model analyses.
- There is particular concern about the stock in AD 2HJ. Exploitation rates have been persistently high and the residual biomass is very low. Total mortality in males is high with large declines in male size-at-maturity. There have been declines in mature female abundance and short-term recruitment prospects are poor.

Environment and Ecosystem

- The Newfoundland and Labrador (NL) Climate Index indicated that 2021 was one of the warmest years on record, continuing the ongoing warming trend since 2018.
- The spring phytoplankton bloom was earlier than average in 2021 on the NL Shelf (North Atlantic Fisheries Organization [NAFO] Divisions 2GHJ3K) and in the Gulf on St. Lawrence (3Pn4R), and mostly near normal on the Grand Banks (3LNOPs). Since the mid-2010s, the zooplankton community has been transitioning to a state with a higher proportion of larger copepod species (*Calanus finmarchicus*) with a positive impact on overall zooplankton biomass and, potentially, energy transfer to upper trophic levels.

- The ecosystems in the NL bioregion continues to experience overall low productivity conditions, with total biomass well below pre-collapse levels. While the fish community has returned to a finfish-dominated structure, groundfish rebuilding stalled in the mid-2010s, where biomass declines were observed. However, ecosystem indicators (e.g., biomass trends, stomach content weights) in recent years appear to be improving.
- Predation mortality of Snow Crab declined across ecosystem units from the peak values observed in the mid-late 2010s. The current predation rate index was highest in 2J3K and lowest in 3LNO, with intermediate values in 3Ps.

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 (~four 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, but at-present Snow Crab are believed to recruit to the exploitable biomass at eight to ten years (Sainte-Marie et al. 1995, Comeau et al. 1998). However, on-going work suggests these are 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 catch per unit effort (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 pre-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 approximately 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 die.

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 approximately 2,300 license holders in 2021.

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 2021, landings increased to 38,000 t.

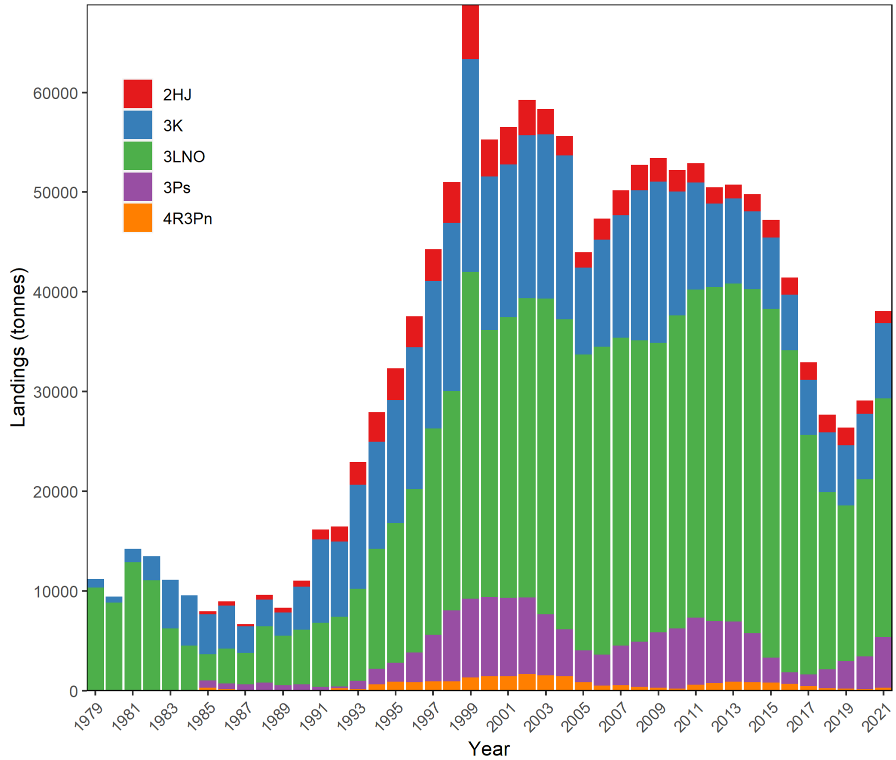

Figure 2: Annual landings (tonnes) of Snow Crab by AD (3LNO = 3LNO Offshore + 3L Inshore) (1979–2021).

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 Div. 3L; however, in recent years, Div. 3K and Subdiv. 3Ps have also had high levels of fishery CPUE (Fig. 3).

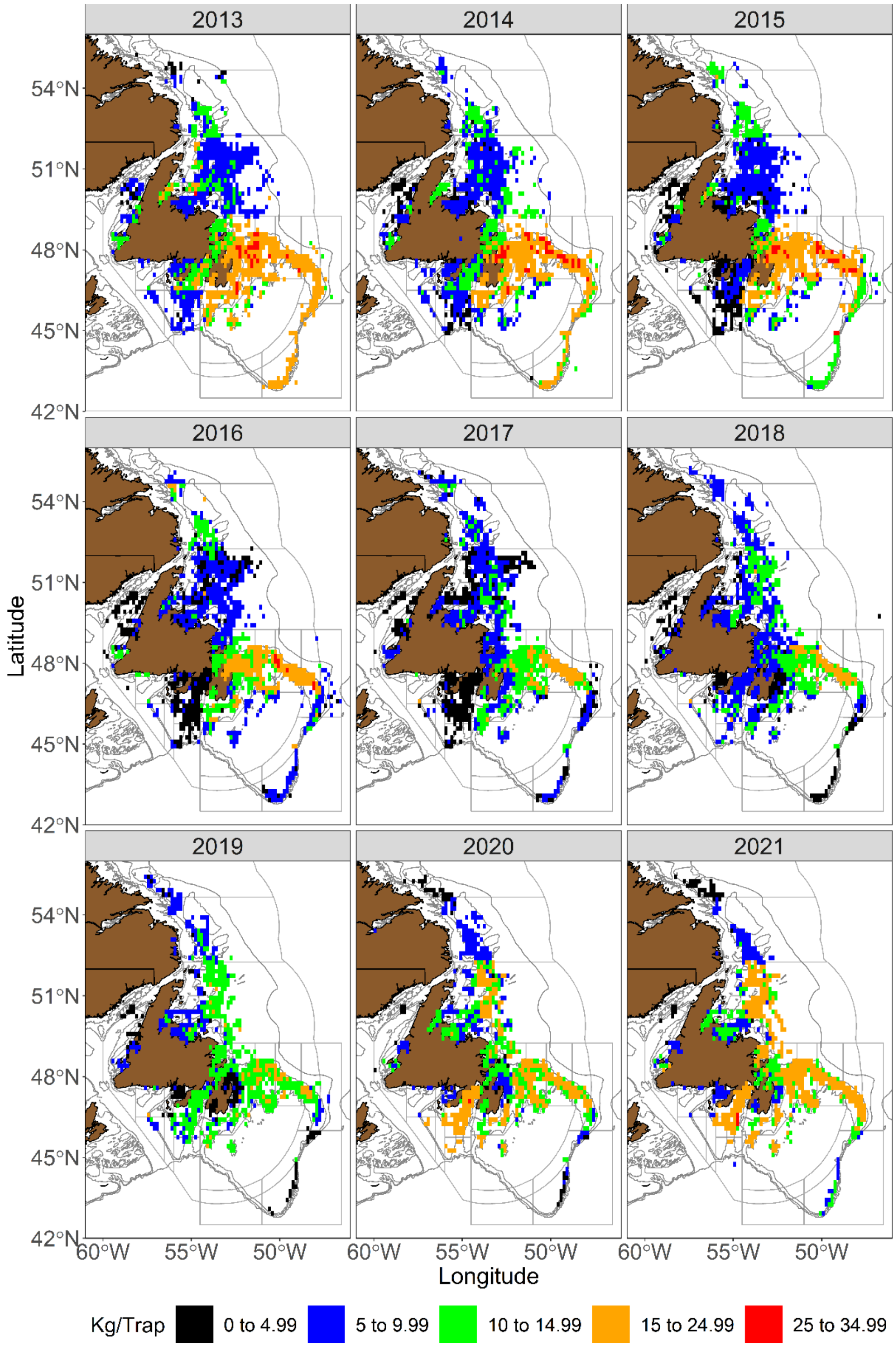

Figure 3: Locations of fishery sets and catch rates (kg/trap) from fishery logbooks (2013–21).

Overall effort increased slightly in 2021, but remains under 3 million trap hauls (Fig. 4). Overall fishery CPUE was at a time-series low in 2018, but has greatly increased since then and was above the time-series average level in 2021 (Fig. 4).

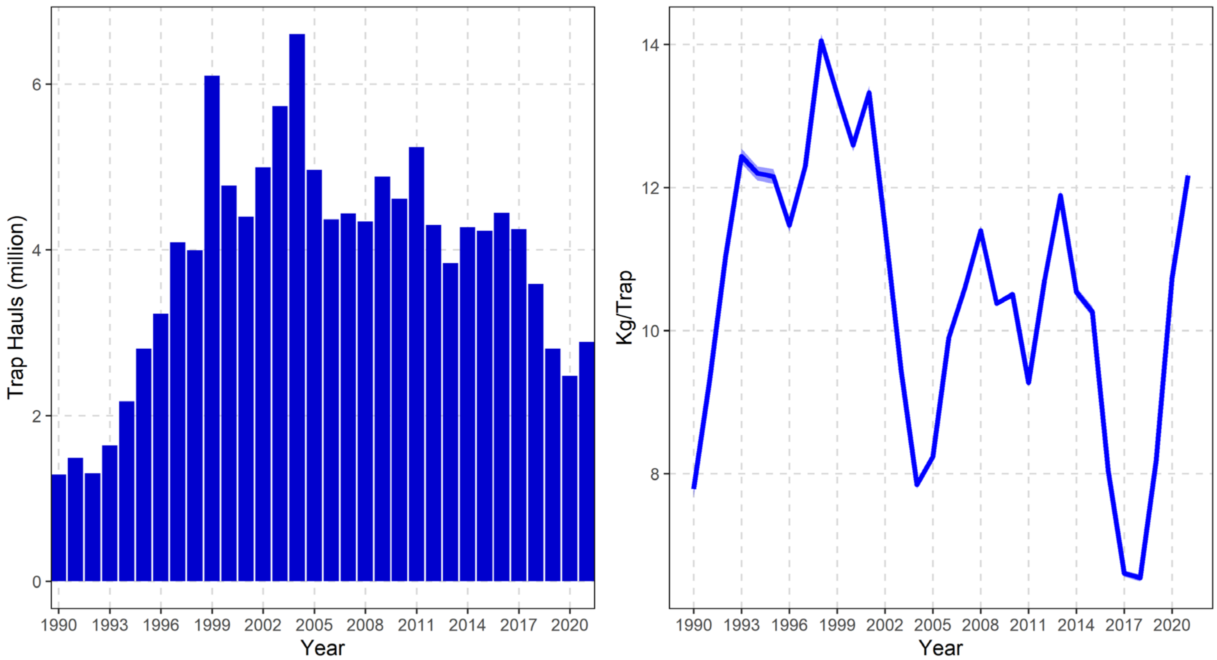

Figure 4: Left: Estimated number of trap hauls per year for the fishery in Divs. 2HJ3KLNOP4R (1990–2021). Right: Fishery CPUE (kg/trap) for Divs. 2HJ3KLNOP4R (1990–2021). Solid line is standardized CPUE and shaded band is 95% confidence intervals.

ASSESSMENT

The numerous CMAs have no biological basis and the resource is assessed at larger-scale 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 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.

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 in AD 3Ps) or the following year (fall in ADs 2HJ, 3K, and 3LNO Offshore). A Campelen 1800 shrimp trawl has been used for these 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.

DFO Inshore trap surveys are conducted in ADs 3K, 3L Inshore, and 3Ps from May to October. The survey takes place in Fortune Bay and St. Mary's Bay in late-spring and early-summer; Bonavista Bay and Trinity Bay in mid-summer; and White Bay, Notre Dame Bay and Conception Bay in late-summer and fall. These surveys also follow a depth-stratified random survey design and utilize large-mesh and small-mesh traps alternating within each fleet of gear.

The industry-DFO Collaborative Post-season (CPS) trap survey occurs late-summer or early-autumn each year and covers all areas except CMA 2JN and Div. 2H. It was historically based on a fixed-station grid design and was more spatially limited than the trawl survey as it targeted only portions of commercial fishing grounds. To improve its representativeness for the stock assessment, the CPS survey has transitioned to a more random stratified spatial design since 2018, and is now a 50% fixed and 50% random station design, covering both a horizontally and vertically broader area of the continental shelf than the historic design. Historically, a set of core stations was selected from this survey for calculating catch rates (kg/trap) of legal-sized adults; however in the present assessment, a comparative index from all stations was calculated and presented. Furthermore, a stratification scheme conforming to the limited historic survey footprint that was used for estimating biomass indices from this survey in the past was abandoned this year in accordance with the broader spatial distribution of the survey in recent years that allowed spatial expansion of survey catch rates over the majority of the continental shelf area. The CPS survey also includes small-mesh traps, historically deployed on select stations but expanded to include most stations in recent years, to provide data on recruitment prospects.

A third trap survey series used in the assessment is the Torngat Joint Fisheries Board-DFO collaborative trap survey. This survey is a fixed station survey covering the northern portion of Div. 2J and a 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-mesh traps at every station to provide data on recruitment prospects.

Exploitable biomass indices are based only on male Snow Crab of legal size (≥95 mm CW). Trawl and trap survey exploitable biomass indices are used together to evaluate trends in biomass available to the fishery. In ADs 3L Inshore and 4R3Pn, no trawl survey is conducted, therefore the trap survey exploitable biomass index is used. This is a less preferred approach because trends in trap survey indices have tended to lag behind trawl survey indices by a year or two showing changes in stock size (Mullowney et al. 2018b). Among other possibilities, this is thought to have reflected the spatially-restricted nature of the historic CPS survey design which almost exclusively targeted the densest aggregations of exploitable crab.

Due to vessel disruptions, there was no trawl survey in AD 3LNO and reduced coverage in ADs 2HJ and 3K in 2021 and consequently no updated trawl exploitable biomass index for AD 3LNO. In an attempt to determine the impacts of the reduced coverage on the exploitable biomass estimates in ADs 2HJ and 3K, 25 test datasets were generated mimicking the 2021 coverage/strata for the time-series. These 25 test datasets were compared to the exploitable biomass estimates presented in the previous assessment. To address the missing trawl survey in AD 3LNO, a comparative model analysis of seven biomass estimation approaches was performed to estimate the 2021 trawl survey exploitable biomass index for AD 3LNO. These estimates were both consistent with one another and comparable to the exploitable biomass index measured in the trap survey; therefore, the trap survey exploitable biomass index was used in the trawl time-series for AD 3LNO in 2021.

Trawl and trap survey exploitable biomass indices are derived using ogive mapping (‘Ogmap’) (Evans et al. 2000) to spatially expand survey catch rates over the continental shelf area. Neither trawl nor trap biomass estimates are deemed absolute because the capture efficiency of Snow Crab by the survey gears is not known. For the trawl, the gear efficiency is known to be low, particularly at smallest sizes, but even at largest sizes retention efficiency is below 100% (q<1). 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. Traps also have unknown and variable capture efficiencies. Effective Fishing Areas (EFAs) of survey traps could potentially be affected by numerous factors including bait type, quantity, and quality, soak times, gear spacing, ocean currents, and crab density. For biomass estimation, the EFA parameter of survey traps, analogous to the swept area parameter for survey trawls, was estimated at 0.01 km^2 to enable spatial expansion and biomass estimation in Ogmap.

For the trawl and AD-level trap surveys, raw Ogmap exploitable biomass estimates were adjusted by a catchability scalar (*S*) in each AD. This scalar was determined through a common baseline source, logbook catch rate Delury depletion models, with a scaling factor determined each year in the respective survey time-series’ when depletion estimates were deemed valid. It is important to note that the Delury fisheries depletion biomass estimates are applicable to the beginning of the season (spring), therefore a one year lag was applied to most survey estimates in calculating the annual scaling factors, as most surveys occur in late-summer or fall (2HJ3KLNO trawl surveys, CPS survey, Torngat survey). This method of scaling survey biomasses into a common unit is subject to considerable variability in calculating annual scaling factors so a constant *S* was applied to the time-series for each survey. For the trawl surveys, the *S* was calculated as the median ratio of annual survey biomass to Delury logbook biomass in each AD, with the one-year temporal lags applied where necessary. Due to considerable time-series length, little change occurred in the time-series *S* factors for the trawl survey as an additional year would have little influence on the time-series median. For the trap surveys, the trap scalars were previously calculated using the same method as the trawl survey, however, in the current assessment the *S* applied to the time-series was calculated using linear regressions rather than a time-series median. This change in methodology was due to the change in the CPS trap survey design and the incorporation of stations covering a much larger area which resulted in a temporal shift in the calculated annual scalars associated with broadening survey coverage. The use of linear regressions normalized the error structure of survey catchability around a central tendency during this shifting period of areal survey coverage.

Trawl and trap surveys also provide data on recruitment (i.e., 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 North Atlantic Oscillation (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 the NAO with subsequent exploitable biomass at a wide range of temporal lags conforming to early-mid ontogeny of crab is consistent with the notion of strong effects of climate in regulating Snow Crab success in early-mid life stages (Dawe et al. 2008, Marcello et al. 2012). In the previous 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 (December-March) were used as predictor variables in a generalized additive model to predict forthcoming biomass potential at the stock (Divs. 2HJ3KLNOP4R) level. This model was not updated in 2021 due to the absence of trawl data for AD 3LNO.

Total annual mortality rates in any given year t (A_t) were calculated as a three-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 were 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).

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.

Estimates of Snow Crab consumed by fish predators were generated by combining three sources of information from trawl survey data: biomass estimates for fish predators, estimations of total food consumption by unit of biomass for those predators, and fractionation of that consumption using diet compositions to define the proportion of Snow Crab in the diet. The resulting index is not a precise estimate of consumption, but intended to generate a plausible envelope for the order of magnitude for consumption. Estimates of absolute consumption of Snow Crab by all piscivore and large benthivore fishes are presented as the median (point estimate) and range from all consumption models considered, along with a predation mortality index (predation estimate/total Snow Crab survey biomass).

Resource Status

Landings & Effort

In AD 2HJ, landings remained near 1,700 t from 2014–19, but declined to around 1,200 t in 2021 (Fig. 5). Effort has remained moderately consistent in this AD, at around 200,000 trap hauls per year (Fig. 6). In AD 3K, landings increased in 2021 to around 7,500 t, while effort remained near the two-decade low of 600,000 trap hauls in 2021. In AD 3L Inshore, landings declined by 67% from a time-series high in 2015 to a low of 2,750 t in 2019. In 2021, landings increased to around 3,700 t and effort remained near the time-series low of 300,000 trap hauls. In AD 3LNO Offshore, landings were at the lowest level in two decades in 2019 (around 13,000 t) due to reductions in the TAC, but increased in 2021 to around 20,200 t. Effort in 3LNO Offshore expanded rapidly from 1992 to the mid-2000s and has oscillated at a similar level of about 1.5–2 million trap hauls per year until decreasing to approximately one million trap hauls in 2019. Effort increased to about 1.4 million trap hauls in 2021. In AD 3Ps, landings increased from a time-series low in 2017 to around 5,000 t in 2021 while effort remained consistent at about 300,000 trap hauls. In AD 4R3Pn, landings steadily declined from 2013 to a time-series low in 2020, but increased to around 300 t in 2021. Effort has been low in recent years with less than 100,000 trap hauls per year.

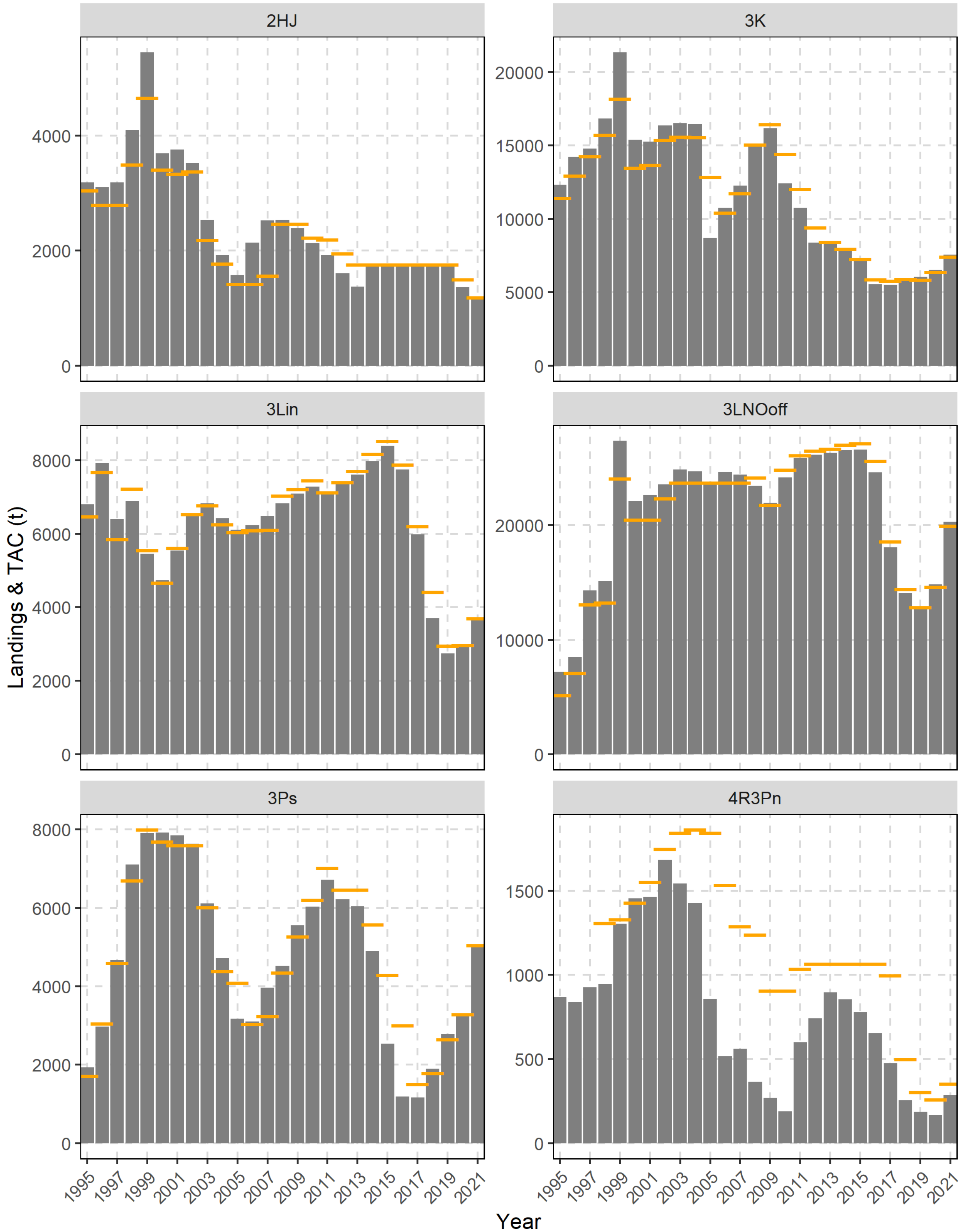

Figure 5: Annual landings (gray bars) and TAC (yellow lines) by AD (1995–2021).

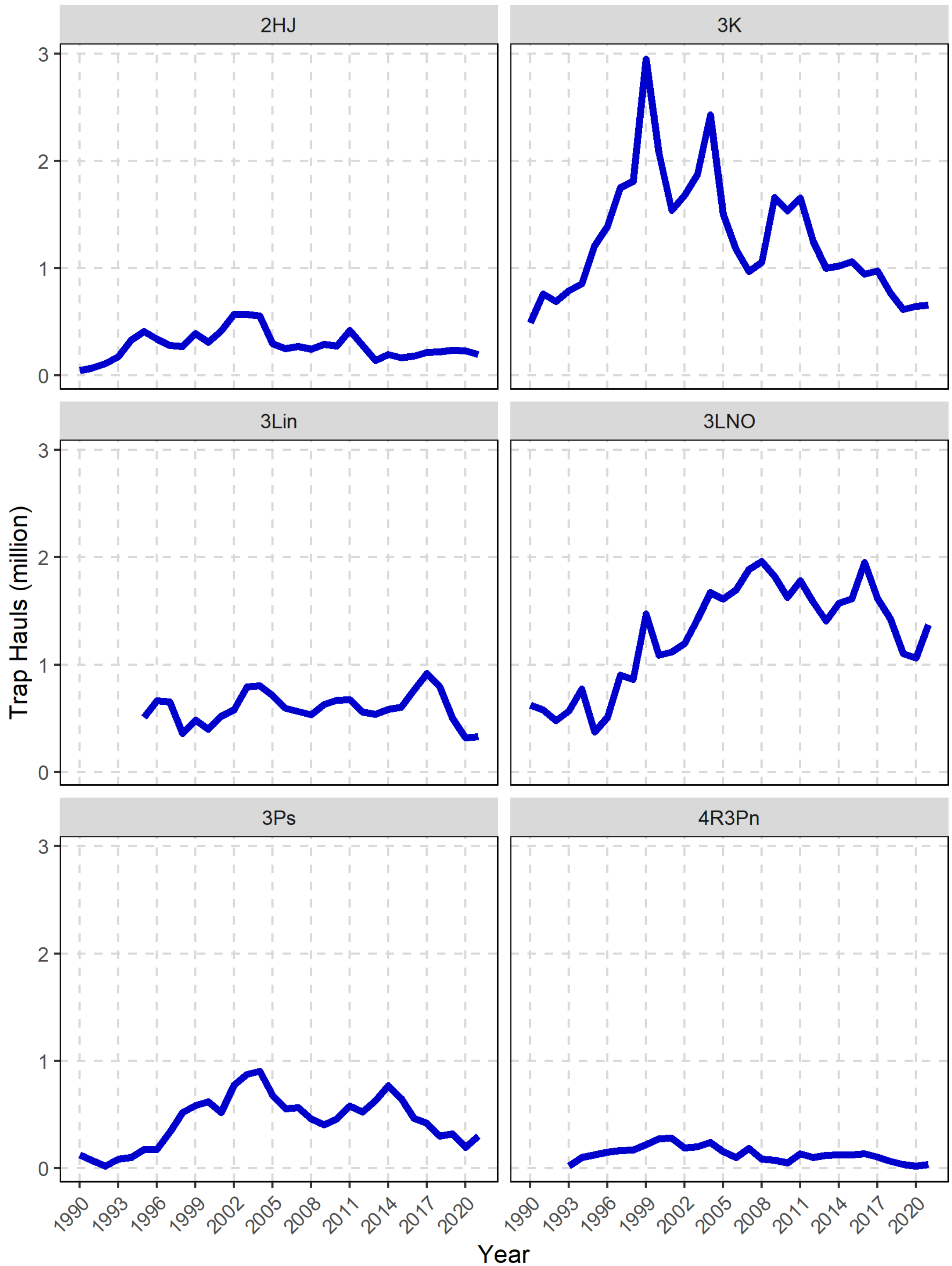

Figure 6. Annual effort (trap hauls) by AD from fishery logbook data.

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, at about 6 kg/trap, standardized CPUE was below the time-series average in 2021 (Fig. 7). In AD 3K, standardized CPUE increased from a time-series low of 5 kg/trap in 2017 to above the time-series average exceeding 10 kg/trap in 2021. In ADs 3L Inshore and 3LNO Offshore in 2021, standardized CPUE was near time-series average levels of about 11 kg/trap and 14 kg/trap, respectively. In AD 3Ps, standardized CPUE at 16 kg/trap was near time-series high in 2021. Finally, in AD 4R3Pn, standardized CPUE remained at a time-series high of 7 kg/trap in 2021.

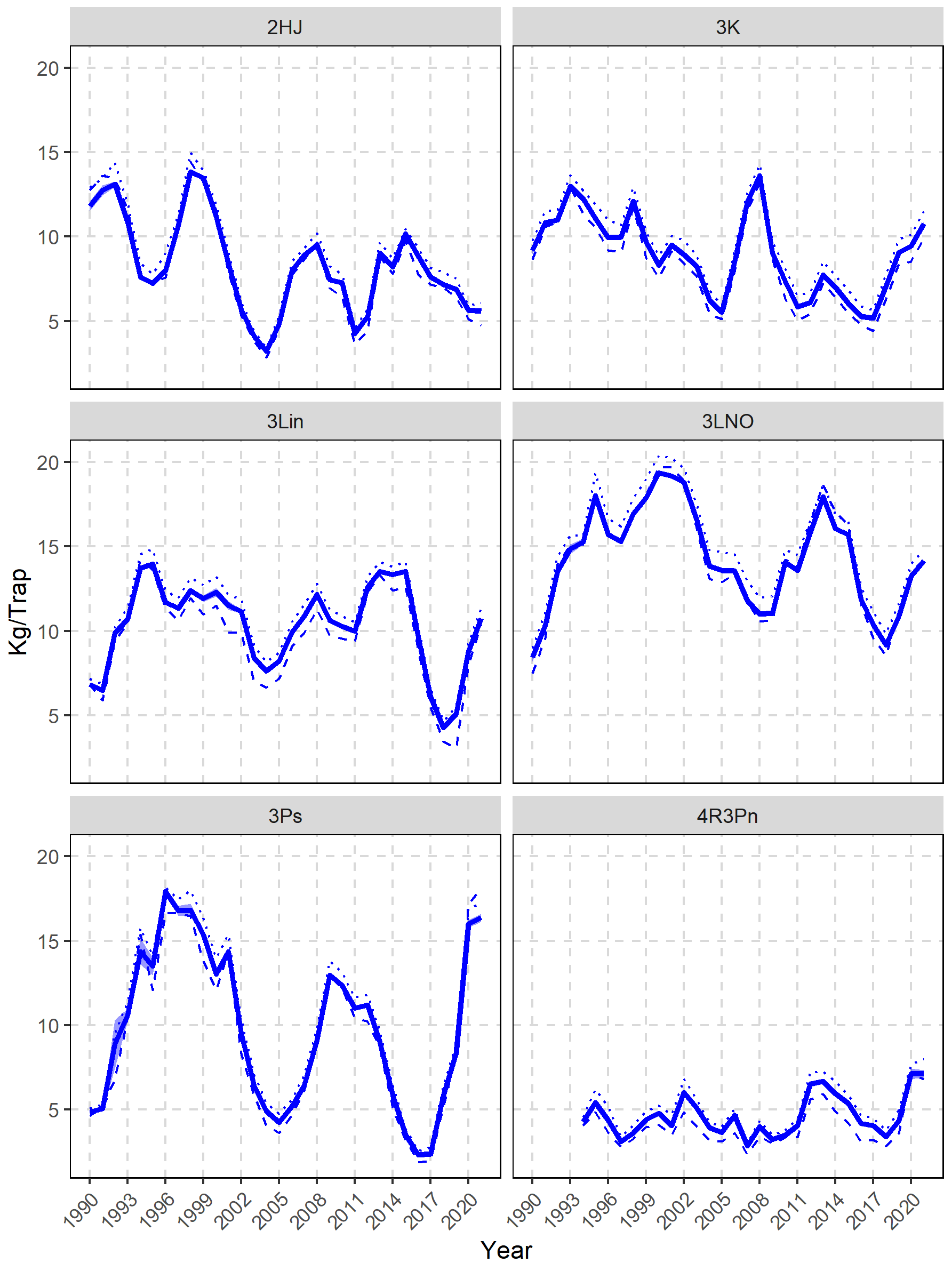

Figure 7: Fishery CPUE (kg/trap) by AD from fishery logbook data. Solid line is standardized CPUE and shaded band is 95% confidence intervals. Dotted lines are raw means and hashed lines are raw medians.

Exploitable Biomass

Multispecies trawl surveys indicate that the exploitable biomass was highest at the start of the survey series (1996–98) (Fig. 8). The index declined from a peak near 400 kt in the late-1990s to about 150 kt in 2003 and then varied without trend until 2013. From 2013–16, the exploitable biomass index declined by 80% to a historical low of about 33 kt. After increases over the past four to five years, the exploitable biomass index approached the time-series average in 2020. The trawl survey did not take place in AD 3LNO in 2021, therefore the stock level trawl exploitable biomass index was not updated. The trap survey exploitable biomass index also increased over the last four years (Fig. 8). The redesign of the CPS trap survey and subsequent incorporation of stations over a much larger area has resulted in the trap survey exploitable biomass index becoming more temporally in-line with the trawl survey exploitable biomass index (Fig. 8), rather than lagging behind the trawl trends as was evident with the previous survey design.

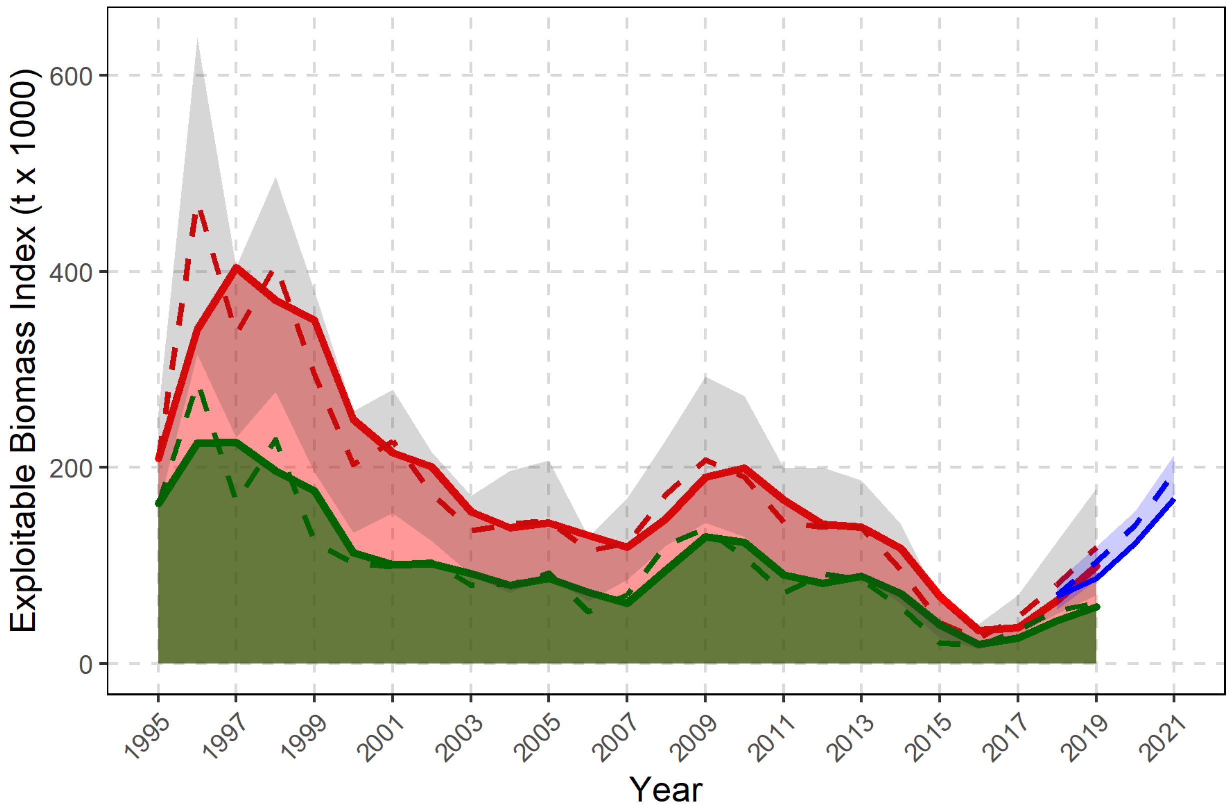

Figure 8: Annual trawl survey-based exploitable biomass index by shell condition (red = residuals, green = recruits) (1995–2019) and trap survey-based exploitable biomass index (blue) (2018–21). Solid line = two-year moving average of exploitable biomass, dashed line = annual estimate, and grey or blue shaded band = 95% confidence intervals of annual estimate.

The simulations on potential impacts of reduced survey coverage in ADs 2HJ and 3K in 2021 showed that the reduced surveys may have affected precision in biomass estimation but conclusions that the biomass remained low in 2HJ and high in 3K were not affected (Fig. 9).

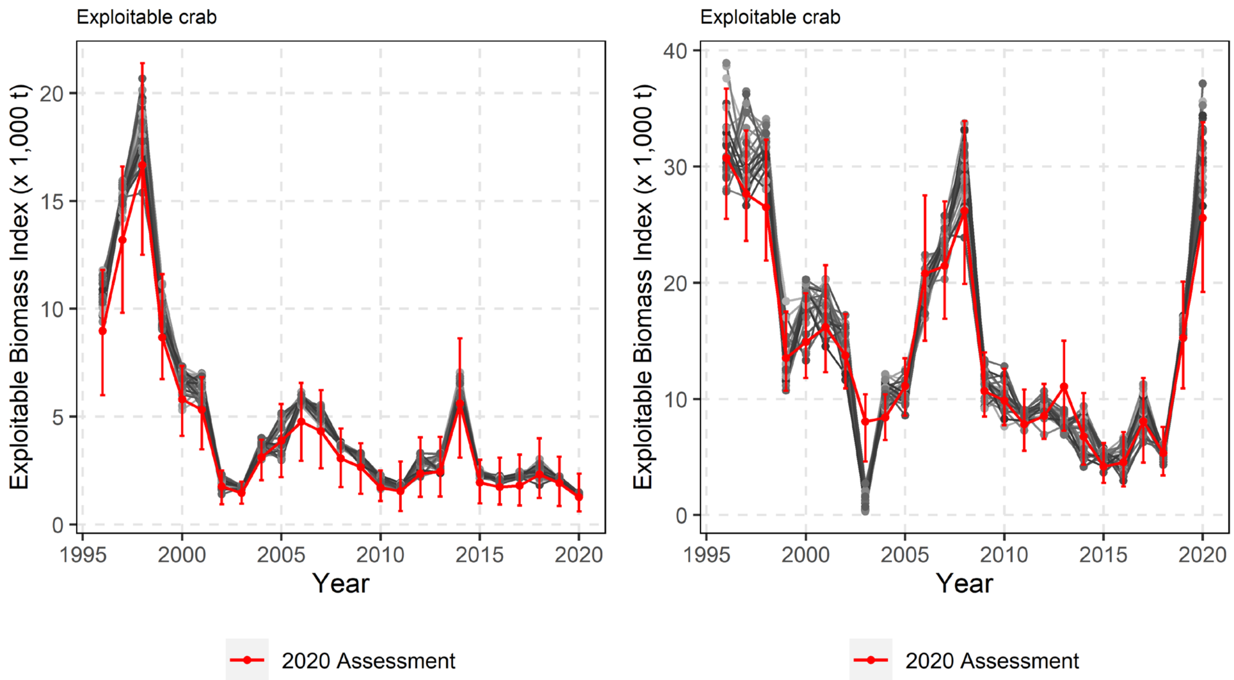

Figure 9: Exploitable biomass estimates for 25 test datasets with 2021 trawl survey coverage (gray lines) and the time-series exploitable biomass estimates presented at the previous stock assessment (red lines) in ADs 2HJ (left) and 3K (right). Exploitable biomass estimates are not Delury adjusted.

In AD 2HJ, the trawl exploitable biomass index remained low and the trap exploitable biomass index decreased in 2021 (Fig. 10). Due to the reduced trawl coverage in AD 2HJ in 2021, the trawl exploitable biomass index may be overestimated in 2021 (Fig. 9). In AD 3K, the trawl exploitable biomass index increased over the last three years to near time-series high levels. Unlike AD 2HJ, simulations of the effect of reduced survey coverage in recent years was not directionally consistent (Fig. 9). Increases in the exploitable biomass index from the trap survey were also seen in the last three years in this AD (Fig. 10). In AD 3L Inshore, the trap survey exploitable biomass index increased over the last three years, but remained below the time-series average in 2021. In AD 3LNO Offshore, both the trawl and trap exploitable biomass index increased from a time-series low in 2016–17; however, there was no trawl survey in AD 3LNO in 2021, therefore the trap survey was used to infer trends. In AD 3Ps, the exploitable biomass index increased in 2021 to a decadal high in both the trawl and trap survey. In AD 4R3Pn, the trap exploitable biomass index increased over the past three years to near time-series highs.

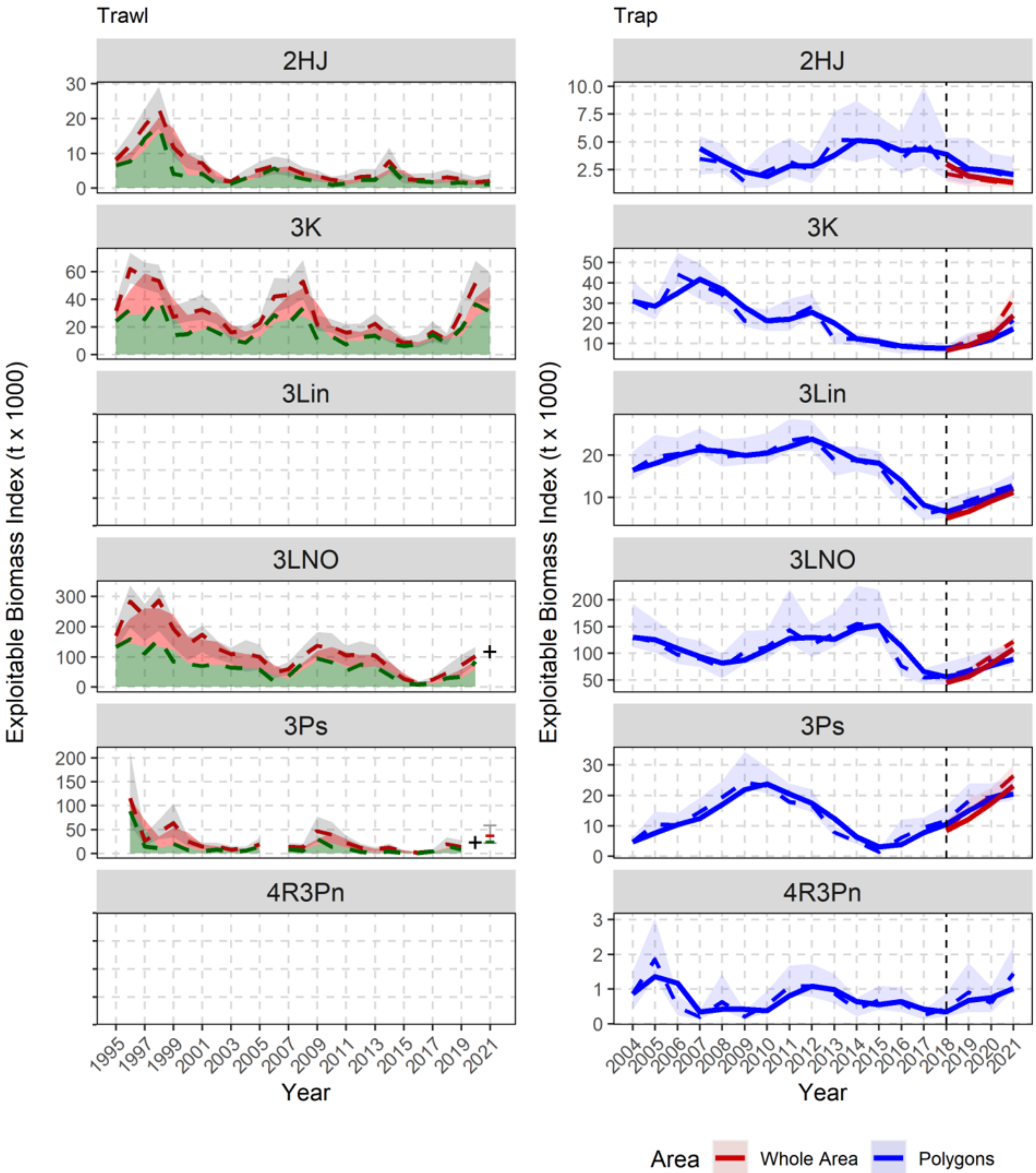

Figure 10: Annual trawl exploitable biomass index by shell condition (red = residuals, green = recruits) by AD (1995–2021). Solid line = two-year moving average of exploitable biomass, dashed line = annual estimate, and grey band = 95% confidence intervals of annual estimate. "+" denotes years without a trawl survey where an estimate was calculated from other data sources. Right: Trap survey exploitable biomass index by AD. Dashed line shows annual estimate, shaded area represents the 95% confidence intervals, and solid line is two-year moving average estimate. Red represents using stations covering the entire trap survey area and blue represents using stations only within core polygons. Dashed vertical line denotes the first year of the trap survey redesign.

Mortality

Total mortality in exploitable crab was high in all ADs during 2015–17 (Fig. 11). There are no indices of total mortality for ADs 3L Inshore and 4R3Pn as this calculation uses trawl survey data. There was no updated total mortality data for AD 3LNO in 2021 due to the absence of a trawl survey. In AD 2HJ, total mortality increased in 2021 and remained highest in this AD. In AD 3K, total mortality was at its highest level from 2016–18, but declined since then. 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 an increase in residual crab in 2019 and a return to a recruit-dominated exploitable biomass in 2020. In AD 3Ps, mortality was low in 2021.

Trends in total mortality generally reflect those of fishing-induced mortality, as measured by ERIs (Figs. 11 and 12). The 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 increased in 2021 (Fig. 11). Under status quo removals in 2022 the ERI would further increase. In AD 3K, the ERI declined from a decadal high in 2017 to a time-series low in 2021. Under status quo removals in 2022 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 2021. The ERI would further decline with status quo removals in 2022.

There are no trawl-based exploitable biomass indices available in ADs 3L Inshore and 4R3Pn from which to calculate ERIs. Accordingly, the shorter time-series of trap surveys were used as the basis (Fig. 12).The trap-based exploitable biomass index is preferred for AD 3Ps as the trawl survey occurs within season, as opposed to post-season as in the other ADs. In AD 3L Inshore, the trap survey-derived ERI increased to its highest observed level in 2018, but decreased to near time-series low levels in 2021. Status quo removals would decrease the ERI to a time-series low in 2022. In AD 3Ps, the trap survey-derived ERI increased slightly in 2021. Under status quo removals in 2022, the ERI would decline to a time-series low. In AD 4R3Pn, the trap survey-derived ERI increased to over 60% in 2021; however, with status quo removals in 2022, the ERI would decrease.

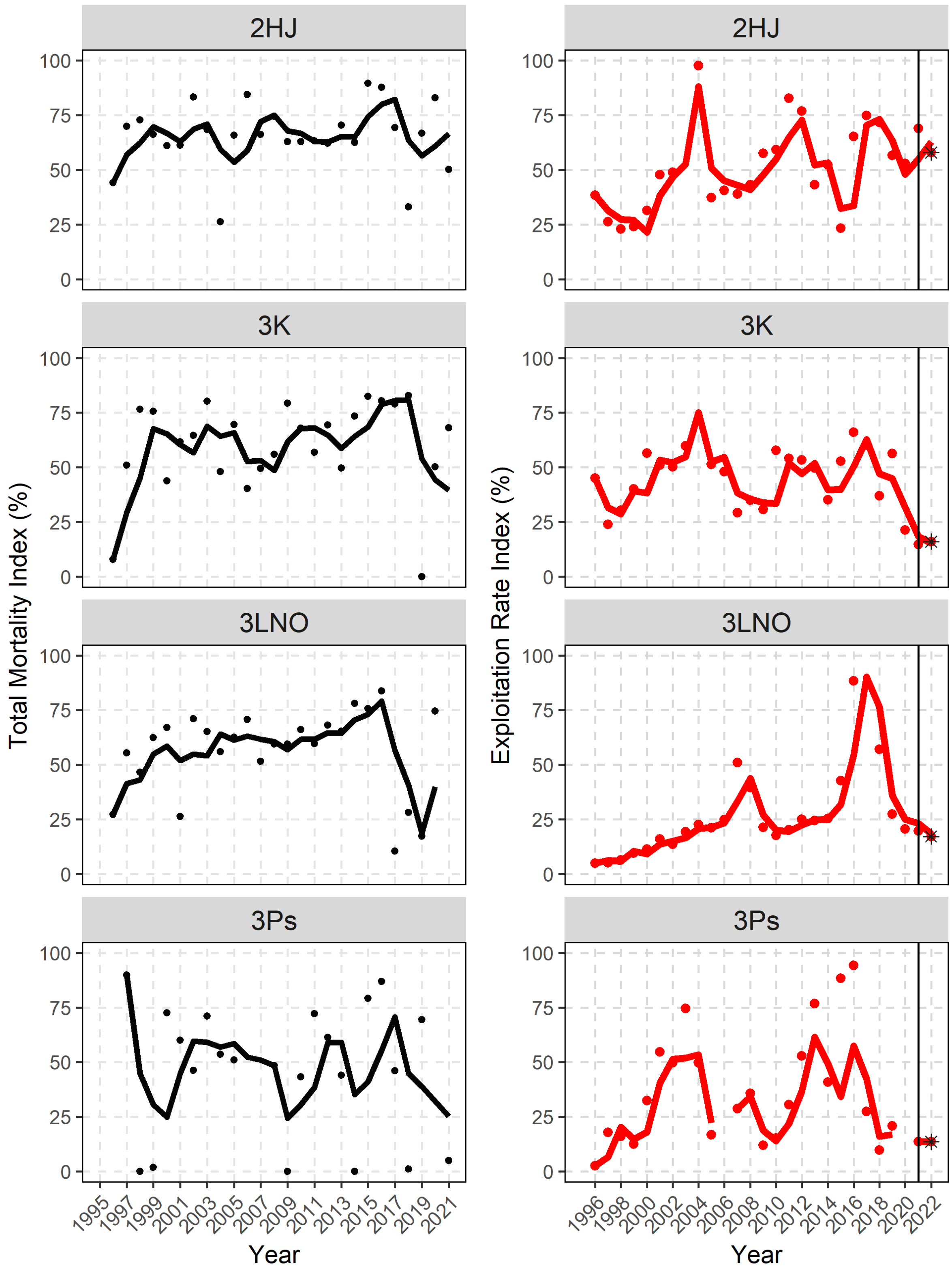

Figure 11: Left: Trends in the annual (points) and three-year moving average (solid line) total mortality index (%) of exploitable crab by AD. Note if annual mortality index was <0 it was plotted as 0 for presentation. Right: Trends in the annual (points) and two-year moving average (solid line) trawl-based ERIs (%) by AD; 2022 stars depict annual projected ERIs under status quo removals in the 2022 fishery.

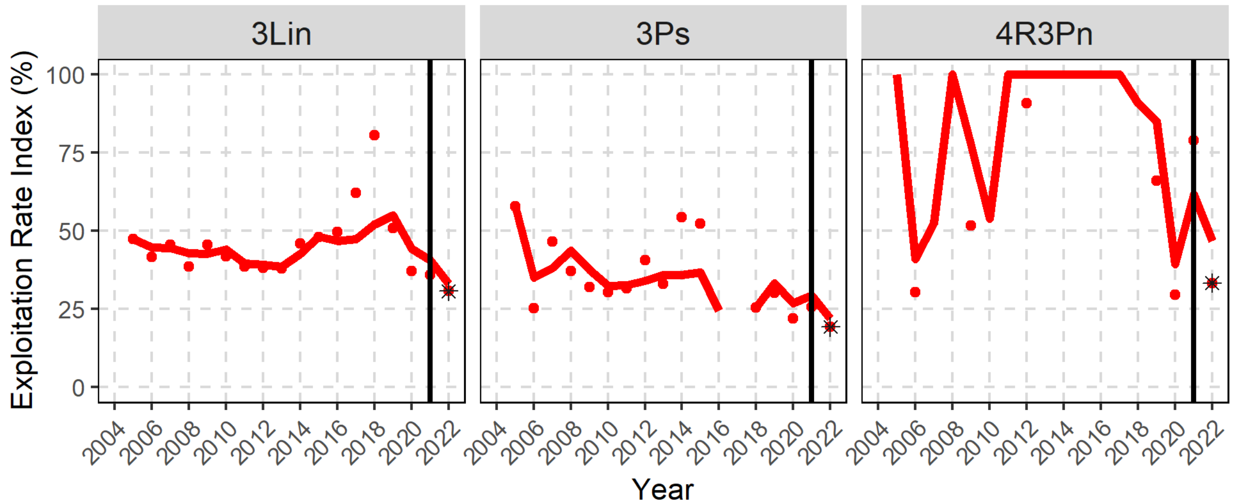

Figure 12: Trends in the annual (points) and two-year moving average (solid line) trap-based ERIs (%) by AD; 2022 stars depict annual projected ERIs under status quo removals in the 2022 fishery.

Recruitment

In most ADs, the exploitable biomass was dominated by incoming recruits (Fig. 10). In AD 2HJ, recruitment into the exploitable biomass changed little during the majority of the time-series. The 2021 trawl survey suggests recruitment will remain unchanged in 2022, suggesting little change in fishery prospects for 2022. In AD 3K, the post-season trawl and trap survey indices of recruitment into the exploitable biomass showed increases in 2021 (Figs. 10 and 13), suggesting potential for improvement in the fishery in 2022. In AD 3LNO Offshore, the trap survey index of recruitment into the exploitable biomass increased slightly in 2021, suggesting potential for improvement in the fishery in 2022. In AD 3Ps, recruitment into the exploitable biomass increased in 2021 from the last trawl survey in 2019, suggesting improvements for the upcoming fishery; however this increasing trend was not evident in the trap survey.

For ADs where no trawl surveys occur, the trap-derived indices are 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 four years, it remains below the time-series average (Fig. 13). In AD 4R3Pn, recruitment into the exploitable biomass was low from 2014–17, but increased to a time-series high in 2021, suggesting potential improvements in the fishery in 2022.

Pre-recruit abundance indices for trawl and trap surveys provide an index of recruitment prospects for the next two to four years; 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. Recent trends in pre-recruit indices from trawl and trap surveys suggest potential for improvements of recruitment into the exploitable biomass in forthcoming years (Fig. 14). However, pre-recruit catch rates from the trap surveys have declined in the last two years in most ADs, suggesting they may have peaked.

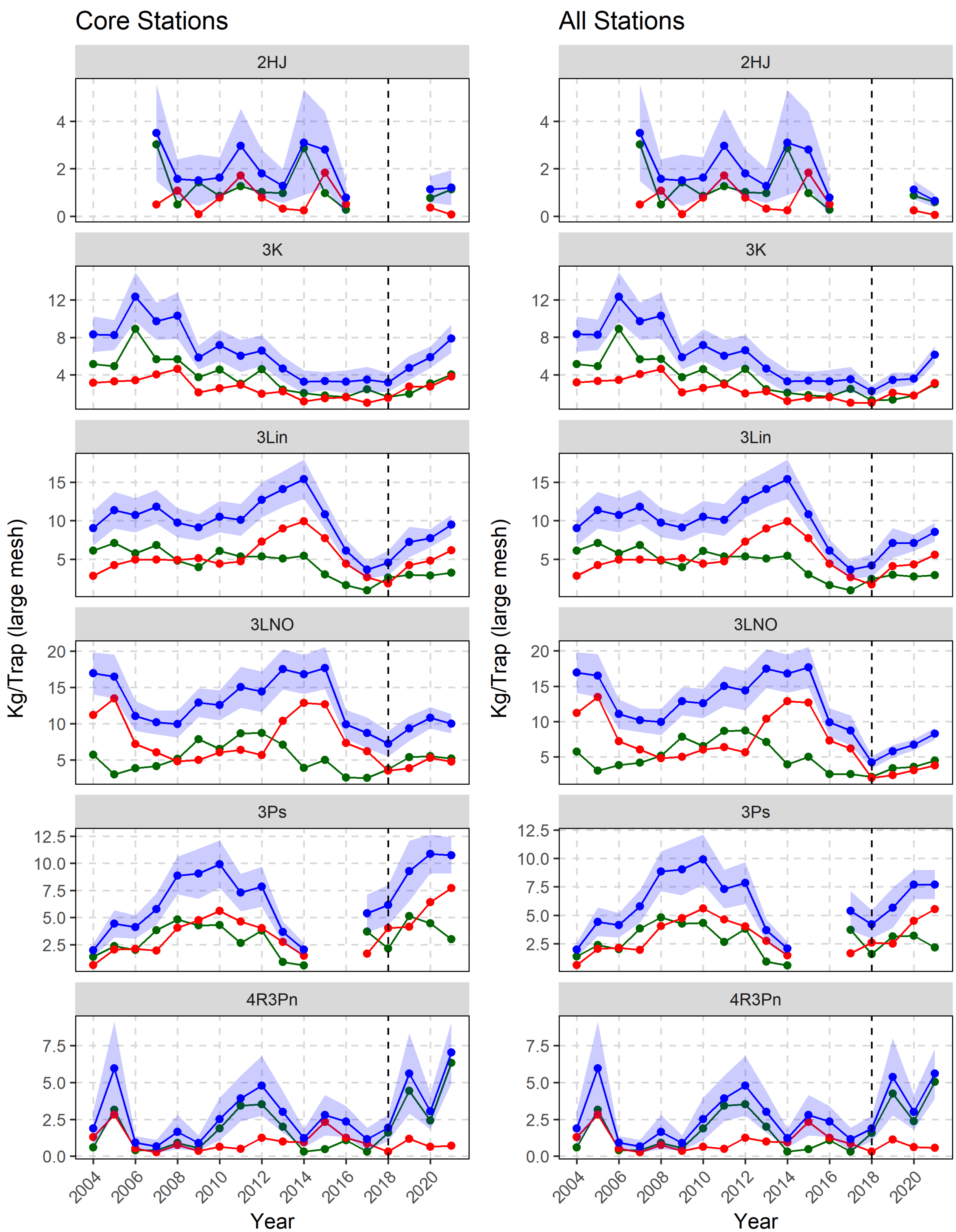

Figure 13: Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable crab from core stations (left) and all stations (right) in the CPS trap survey by AD (2004–21). Shaded area represents the 95% confidence interval. Dashed vertical line denotes the first year of the trap survey redesign.

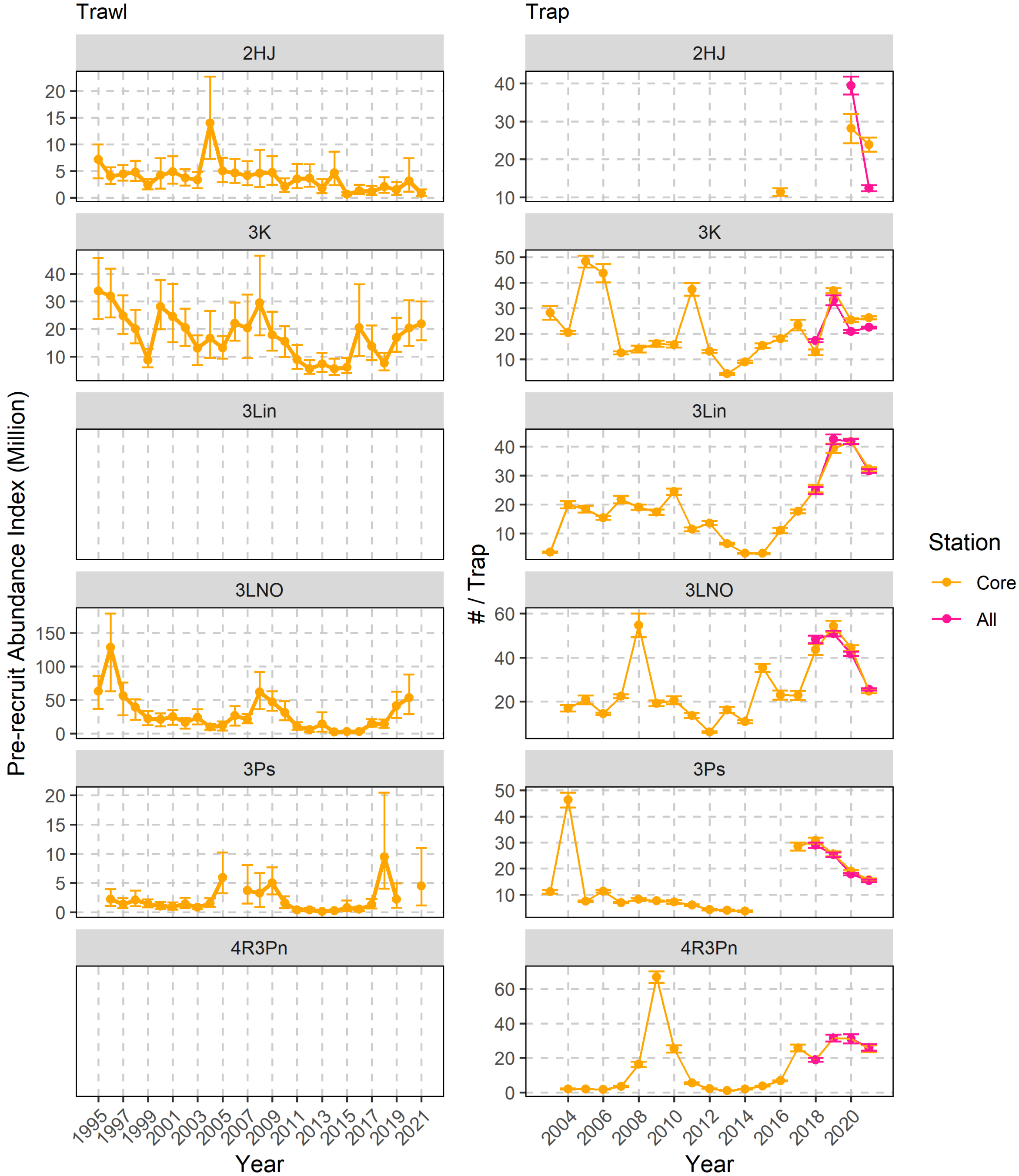

Figure 14: Left: Trawl survey pre-recruit abundance index (millions) by AD (1995–2021). Note: No trawl survey in AD 3LNO in 2021. Right: Annual CPUE (#/trap) of pre-recruits from small-mesh traps at core stations (orange) and all stations (pink) in the CPS trap survey by AD (2004–21).

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. 15). However, the last four years have shown an overall trend towards warmer and potentially less favourable environmental conditions for future productivity, indicating that productivity may be reaching a peak. It was particularly warm in 2021, with the NL Climate Index (Cyr and Galbraith 2020) indicating it was one of the top three warmest years in the 70 year time-series.

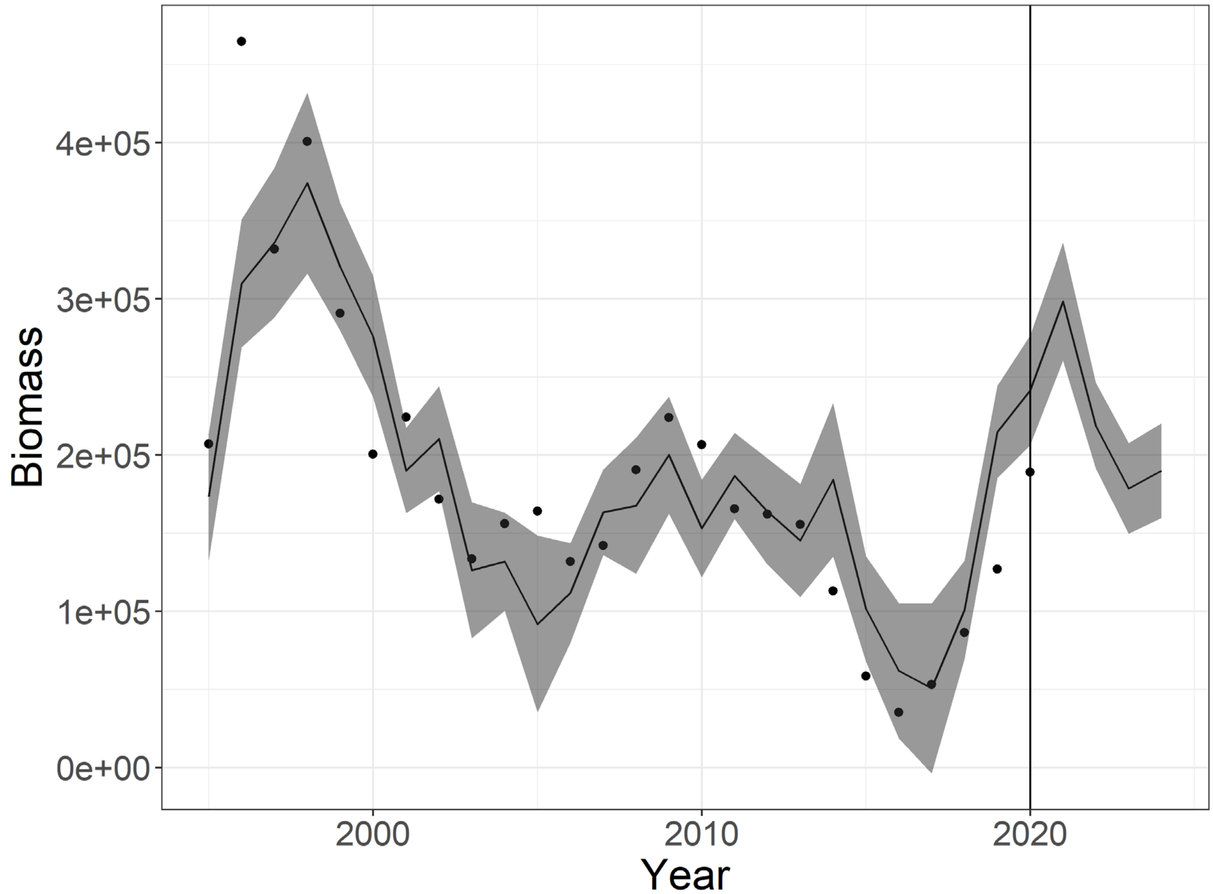

Figure 15: Stock-level exploitable biomass index in relation to lagged indices of the AO and ENSO defined as an average of monthly values from five to seven years ago and four to six years ago, respectively. Points are survey exploitable biomass + landings, solid line is the model fit, and shaded band is the 95% confidence intervals.

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 highlighted that other factors such as top-down forcings from heavy exploitation and increased predation have increased in importance. In the most recent two years, substantially decreased fisheries exploitation rates have been associated with current improvements in the exploitable biomass.

While the predation mortality index remained among the highest in recent years, there have been declines from the peaks of 2016–18 (Fig. 16). The predation mortality index remained among the highest levels in 2J3K and 3LNO, but declined to its lowest value in over 25 years in 3Ps. Within 2J3K, predation mortality was substantially higher in 2J than in 3K. The regulating effect of predation is thought to be most important on small to intermediate-sized crab (Chabot et al. 2008), thus, a delay would be expected between decreases in the predation mortality index and recruitment into the exploitable biomass. In most ADs in recent years, a decline in predation mortality coupled with current decreased fisheries exploitation rates and increased pre-recruit abundance indices indicates a positive outlook in the next two to four 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 fish biomass levels remain much lower than prior to the collapse in the early-1990s. However in recent years, ecosystem indicators such as biomass trends and stomach content weights appear to be improving. Improvements extend into the bases of the food-web, with a return to more average conditions in zooplankton community structure in recent years, which may have a positive impact on energy transfer to higher trophic levels.

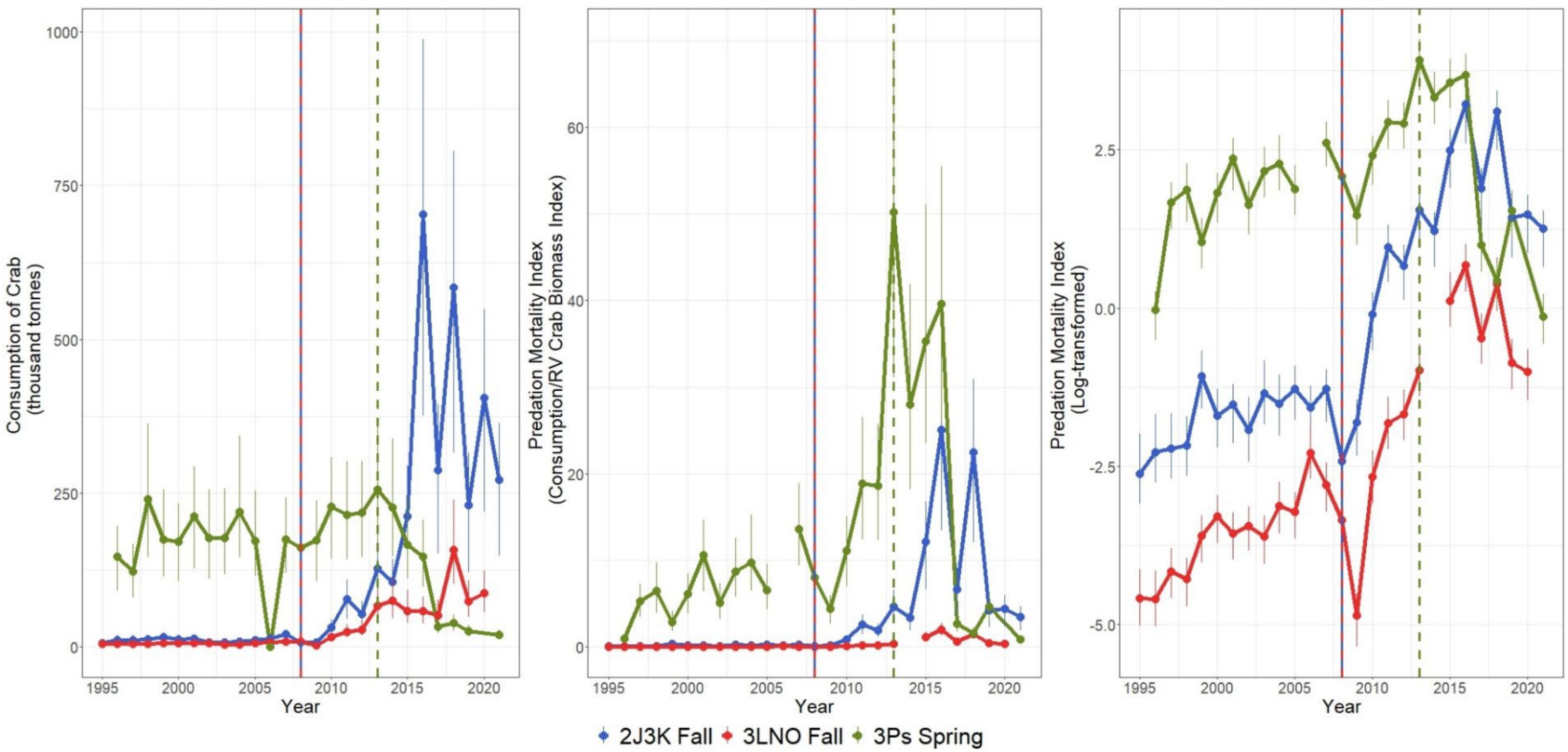

Figure 16: Consumption of Snow Crab by finfish predators (left) and predation mortality index (middle and right) by Ecosystem Production Unit (EPU) and year.

Outlook

There were improvements in the exploitable biomass index in all ADs except 2HJ in 2021, which is likely to continue in the short-term. The stock has continued to increase from record low levels, but has not returned to high levels of the past. There were indications that several ecosystem-related factors may have encouraged this growth including cool bottom water temperatures from 2012–17 and a slight decline in predation in most areas, associated with substantial reductions in fishing mortality. However, the last four years have shown an overall trend towards warmer, potentially less favourable environmental conditions for future productivity and indications in the trap survey data that abundance indices of pre-recruits may have peaked (Fig. 14). Overall there have been sustained signals of increased abundances of pre-recruit and small-sized crab in recent years (Fig. 17), indicating a positive outlook for the foreseeable future if fishing pressure levels allow 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 occurred in recent years (Fig. 18). Recent work concluded that a combination of cold conditions and a low population density of large males contributed to this decline in male size-at-terminal molt, with the low density of large males resulting from persistently high fishing pressure (Mullowney and Baker 2020). A decline was also seen in AD 3K, resulting in a time-series low in 2017. However, the male size-at-terminal molt increased in the last three years in AD 3K to a level in line with AD 3LNO Offshore. Male size-at-terminal molt will be particularly important to monitor in 2HJ moving forward as this AD represents the furthest upstream component of the Snow Crab resource in Atlantic Canada and persistent decreased size-at-terminal molt could negatively impact stock and subsequently fishery productivity not only in AD 2HJ, but throughout the stock range.

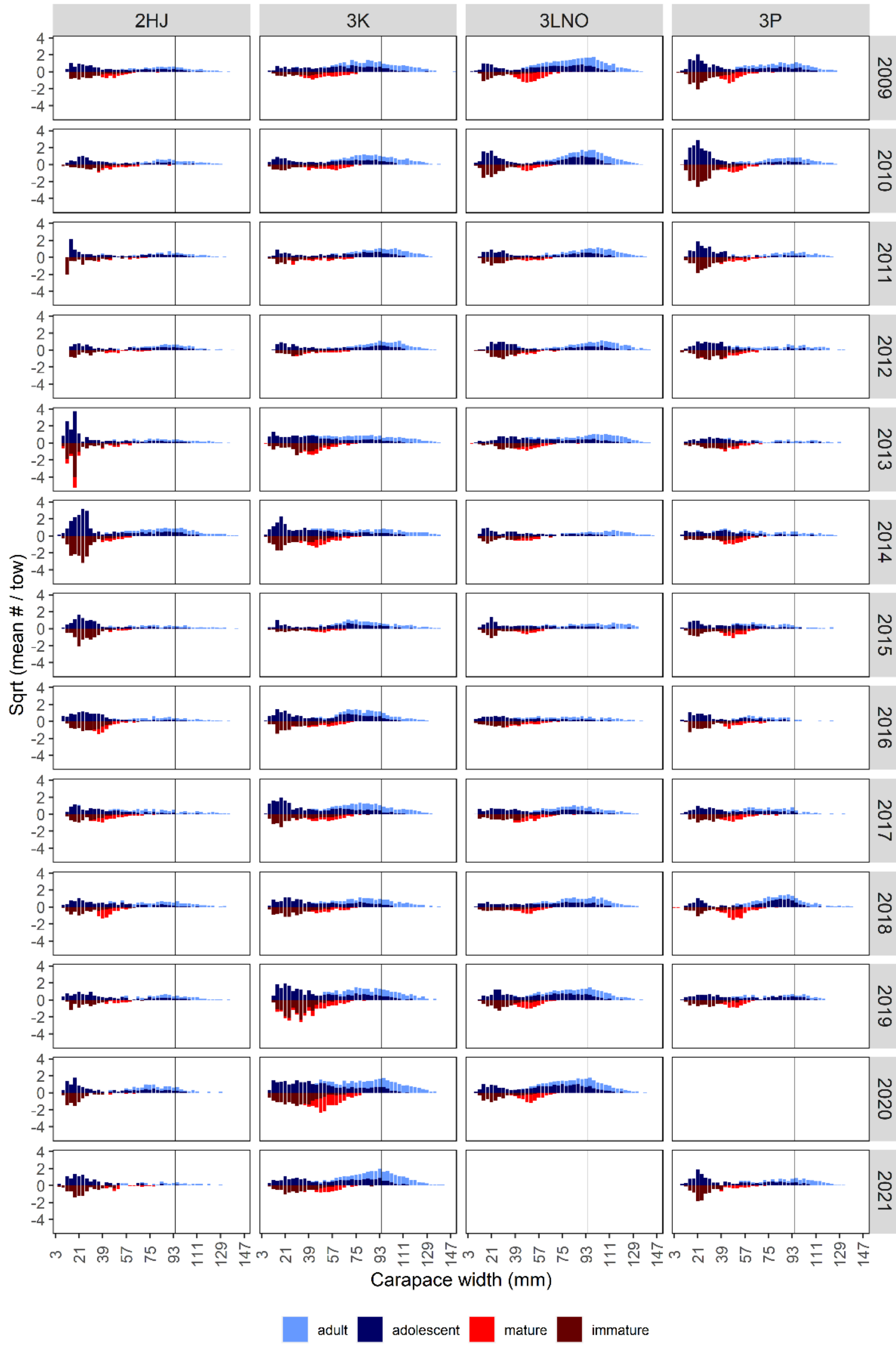

Figure 17: Abundance indices by CW for juveniles + adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (AD 3Ps) and fall (ADs 2HJ, 3K, and 3LNO) trawl surveys. Information on females, while displayed on the negative y-axis, represent positive abundance indices. Vertical line is legal size. Data standardized by vessel.

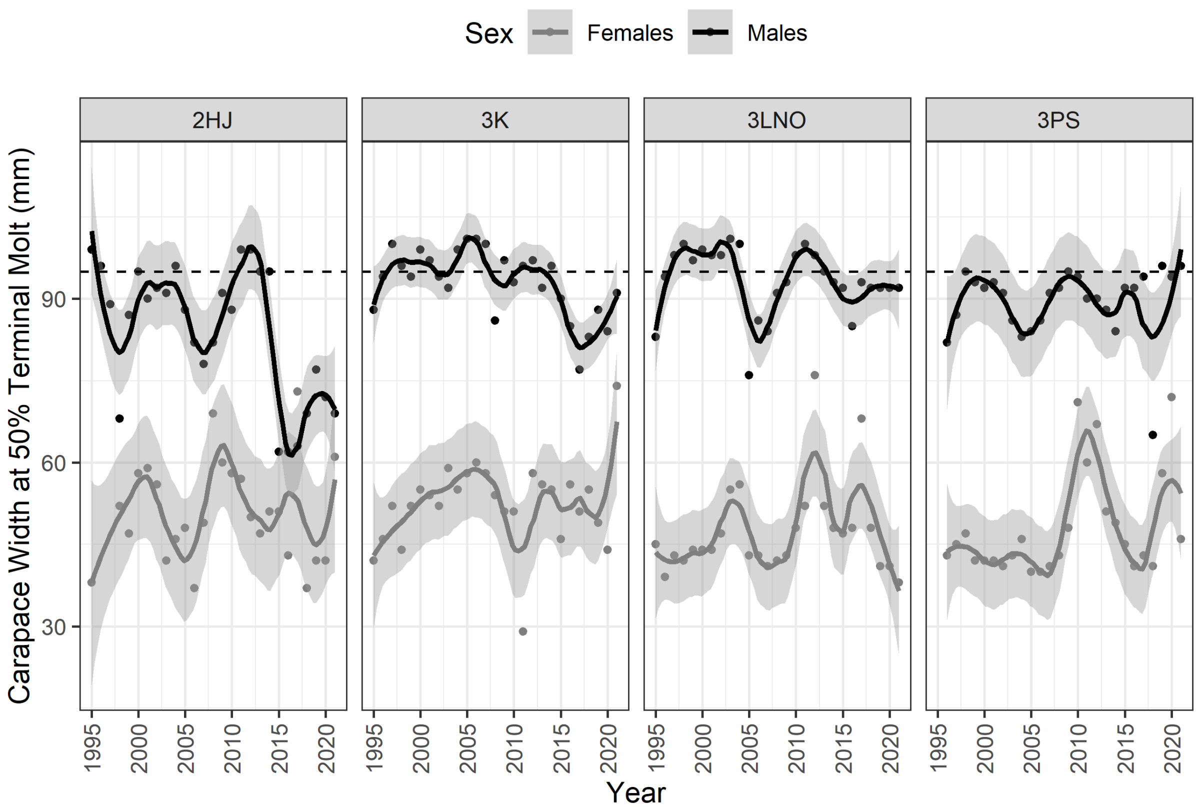

Figure 18: Annual estimates of size at which 50% of male (black) and female (grey) Snow Crab undertook their terminal molt by AD and year. Error bands are 95% confidence intervals of a loess regression fit (lines) to annual estimates from GAM (points). The horizontal dashed line is the minimum legal 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 PAF for the NL Snow Crab resource and fishery that was based on three key metrics of stock health: (1) predicted CPUE, (2) predicted discards, and (3) proportion of females with full egg clutches (Mullowney et al. 2018b).

Using generalized additive models that were peer-reviewed in a previous assessment, the framework projects forward one year anticipated fishery CPUE and discard rates. The adopted parts of the framework include the LRPs, differentiating the Critical from Cautious Zones. 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. Discussions have been productive and progress is ongoing, but the HCRs have not been finalized at the time of publishing. A scoring system has been developed to incorporate the stock status of the three metrics into one stock health score (Fig. 19; Fig. 20).

In 2022, all ADs are projected to be in the Healthy Zone in the provisional PA Framework, except AD 2HJ which is projected to be in the Cautious Zone (Fig. 21). These projections assume status quo landings. Recent and ongoing data deficiencies resulted in the exclusion of AD 4R3Pn in the provisional PA Framework.

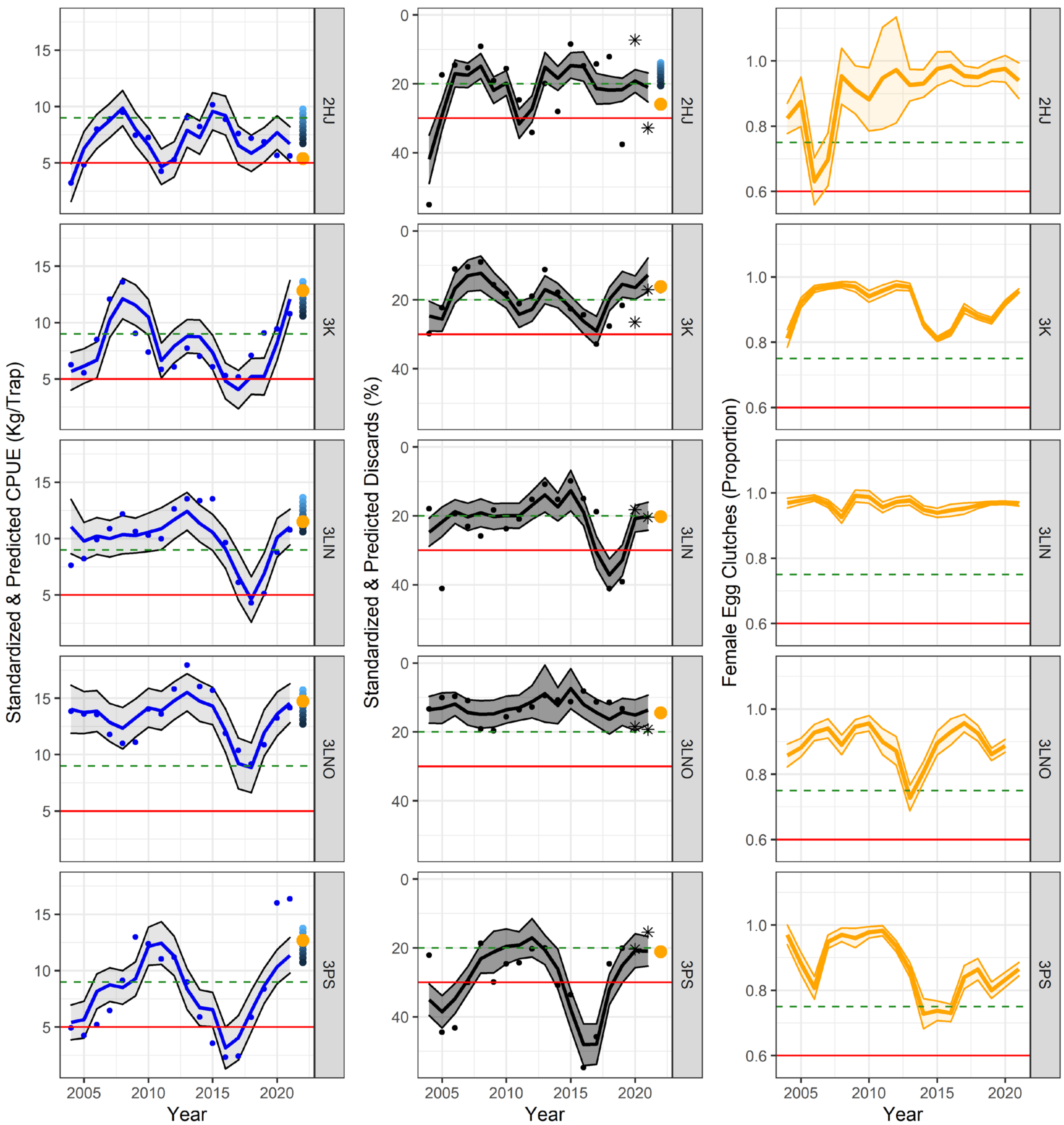

Figure 19: Trends in predicted CPUE (left), predicted % discards (middle), and observed proportion of females with full egg clutch (right) (solid lines), as well as standardized CPUE and % discards (points) in the provisional PA Framework, by AD. The red horizontal line is the LRP and the dashed green horizontal line is the provisional USR. The shaded areas represent prediction intervals (CPUE and discards) or 1 standard deviation (egg clutches). The orange points in 2022 represent predicted values under status quo landings in the forthcoming fishery. The vertical blue shades in 2022 are the predicted values under varying levels of ERI (light to dark blue: ERI = 5–42%). Stars in % discards panel in 2020 and 2021 represent the mean % discards from at-sea observer data and a reference fleet from logbook data.

Zone	Egg Clutch	pDiscards	pCPUE
Healthy	1	2	4
Cautious	0.5	1	2
Critical	0	0	0

Zone	Points
Healthy	5.5 to 7
Cautious	2.5 to 5
Critical	0 to 2

Figure 20: Scoring system for determining stock health score from three stock status metrics (Egg Clutch = proportion of females with a full egg clutch, pDiscards = predicted % discards, and pCPUE = predicted CPUE).

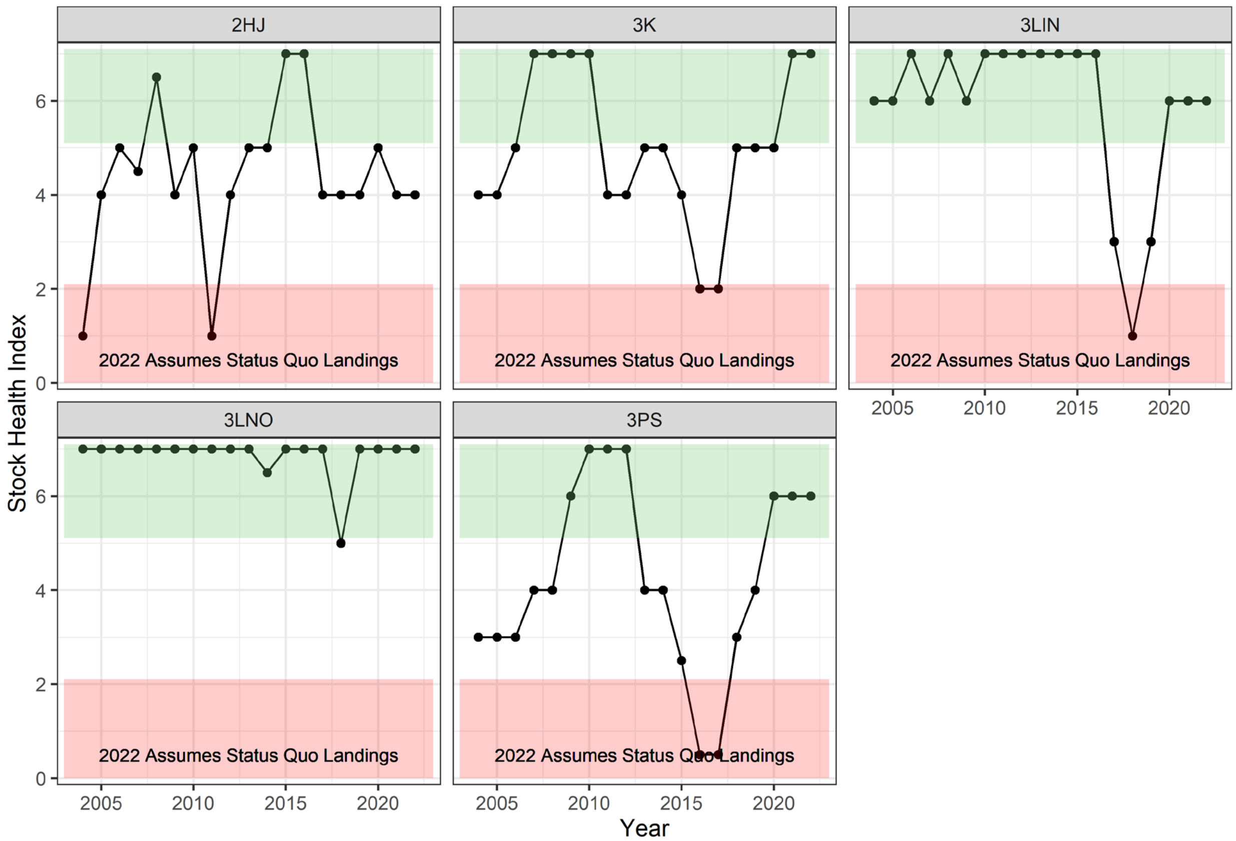

Figure 21: Projected stock status (black point) by AD in the provisional Snow Crab Precautionary Approach Framework from 2004–22. The green, white, and red shaded areas represent the Healthy, Cautious, and Critical Zones, respectively.

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 do not sample inshore areas in some NAFO Divisions and there have been missed and reduced trawl surveys in recent years, including reduced coverage in 2HJ3K in 2019 and 2021 and 2H in 2020, and no survey in 3Ps in 2020 or 3LNO in 2021. Depending on the degree of completion of the trap or trawl survey, some years are completely removed from the time series for some ADs, while in cases of reduced trawl survey coverage, analyses have been undertaken to attempt to determine the possible trajectory of the impact (i.e., overestimation, underestimation, variable/unclear) on the exploitable biomass estimation.

Trawl efficiency is directly related to substrate type and crab size, and 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. As well, 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-mesh 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-mesh 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 traps, 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). Molt frequency is also affected by density of large males, with terminal molt at small sizes more common in low density situations (Mullowney and Baker 2020).

Long-Term Recruitment

There is much 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. In most years the logbooks account for between 85–95% of the landings at the time of the assessment in all ADs, except 4R3Pn which typically has lower returns. 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 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 crab 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 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. In 2021, observer coverage was improved in some ADs from pandemic-related low and/or absent coverage in 2020, however use of the at-sea observer data was limited overall. 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 solely on the post-season trap survey biomass index. This index may be biased by annual changes in the distribution of crab or fishing effort inside versus outside the limited survey areas.

Predation mortality indices should be interpreted with caution as they are calculated using total Snow Crab biomass, while the influence of predation is exerted primarily on small-sized crab.

Ecosystem Change

Prolonged ocean 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. If temperatures continue to warm as expected under greenhouse gas scenarios, the prognosis for Snow Crab would be poor. 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

Exploitable biomass and recruitment indices have remained low for many years. There was a low residual biomass and high total mortality of exploitable crab in this AD. The DFO trawl survey had reduced coverage in 2HJ in 2021, such that the exploitable biomass index may have been an overestimation. The ERI was high throughout most of the time-series relative to other ADs within NL, as well as other fished Snow Crab stocks globally. Status quo removals in 2022 would further increase the ERI to above 60% of the exploitable biomass. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Cautious Zone in 2022. In addition to low residual biomass and high fishing pressure, there have been declines in the male size-at-terminal molt and mature female abundance index in AD 2HJ. These declines are very concerning and could dampen recruitment if a higher proportion of males reach their terminal molt below exploitable size and declines in mature females result in lower egg production.

Assessment Division 3K

The exploitable biomass index increased over the last three years and was dominated by recruits, suggesting improvements in the coming year. Total mortality of exploitable crab has declined in recent 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 has been at a much lower level since 2020. Status quo removals in 2022 would maintain the ERI at the time-series low. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2022.

Assessment Division 3L Inshore

The exploitable biomass index increased over the last three years, but remained below the time-series average. Recruitment has remained steady for the last four years, above the low in 2017. There may be improvements coming in the AD, with high pre-recruitment indices in 2019 and 2020 indicating improvements in two to four years. The overall ERI has declined from recent high levels to a more moderate level of exploitation. Status quo removals in 2022 would reduce the ERI to a time-series low. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2022.

Assessment Division 3LNO Offshore

The trawl survey was not conducted in 3LNO Offshore in 2021; however, the trap survey-based exploitable biomass index increased in 2021. There has been an increasing trend in the exploitable biomass index in both the trawl and trap surveys for the last three to four years. There was no updated value for total mortality in 2021. While there may be improvements coming in the AD in the short-term, trap-survey pre-recruit indices have decreased in the last two years and there was no updated pre-recruit information from the trawl survey to inform trends. This AD had a period of high ERI from 2014–17, but the ERI declined significantly in the last four years. Status quo removals in 2022 would further reduce the ERI. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2022.

Assessment Division 3Ps

The exploitable biomass index increased in 2021 to a decadal high. There may be improvements coming in the AD, with increases in recruitment and pre-recruitment indices in the trawl survey indicating improvements in the short-term, but the level of improvements from these indices in two to four years is uncertain. The pre-recruit index in the trap survey has shown a declining trend in the last three years. The ERI declined in 2021 and status quo removals in 2022 would maintain the ERI at this low level. Following the provisional PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2022.

Assessment Divisions 4R3Pn

The exploitable biomass index increased over the past three years and was dominated by recruits, suggesting improvements in the coming year. The overall ERI increased in 2021, however with status quo removals in 2022, the ERI would decline to near time-series lows. Completion of the trap survey outside the major fishing areas has been poor, therefore stock status was attributable primarily to CMAs 12C and 12EF. Recent and ongoing data deficiencies do not allow inclusion of this AD into the provisional 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. Incidence of BCD was low in 2019 and 2020, but there was a higher incidence of BCD in sub-legal-sized crab in 2021 in AD 3K, where surveys indicate it has been most persistent. 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 the last three years.

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 and remained near this low level in 2021. 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 possibly 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 (Mullowney et al. 2021). 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 not impacted. 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, 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, it was abandoned in some areas in past years. 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.

Snow Crab in NL are part of a larger genetic stock unit in Canadian Atlantic waters, ranging from southern Labrador to the Scotian Shelf (Puebla et al. 2008). The NL Snow Crab resource is assessed at the AD level, but managed at the spatially smaller CMA level. To both assess and manage a natural resource at scales that do not conform to biologically meaningful units increases the likelihood of providing inaccurate advice and making decisions based on sub-optimal information. The probability of accurately and precisely forecasting stock health separately in the numerous CMAs in a given year is relatively low, particularly considering transboundary movements.

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Kristin Loughlin	DFO-NL – Science
Travis Van Leeuwen	DFO-NL – Science
Hilary Rockwood	DFO-NL – Centre for Science Advice
Dale Richards	DFO-NL – Centre for Science Advice
Janet Lucas-Cantwell	DFO-NL – Centre for Science Advice
Diane Johnston	DFO-NCR – Centre for Science Advice
David Small	DFO-NL – Resource Management
Laurie Hawkins	DFO-NL – Resource Management
Mark Simms	DFO-NL – Resource Management
Martin Henri	DFO-NL – Resource Management
Ryan Critch	DFO-NL – Communications
Aaron Adamack	DFO-NL – Science
Atef Mansour	DFO-NL – Science
Brian Healey	DFO-NL – Science
Brittany Pye	DFO-NL – Science
Darrell Mullowney	DFO-NL – Science
Darren Sullivan	DFO-NL – Science
David Belanger	DFO-NL – Science
Elaine Hynick	DFO-NL – Science
Elizabeth Coughlan	DFO-NL – Science
Erika Parrill	DFO-NL – Science
Frederic Cyr	DFO-NL – Science
Jessica Desforges	DFO-NL – Science
Julia Pantin	DFO-NL – Science
Kate Charmley	DFO-NL – Science
Katherine Skanes	DFO-NL – Science
Krista Baker	DFO-NL – Science
Mariano Koen-Alonso	DFO-NL – Science
Robert Deering	DFO-NL – Science
Sanaollah Zabihi-Seissan	DFO-NL – Science
Steve Snook	DFO-NL – Science
Will Coffey	DFO-NL – Science
Stephanie Boudreau	DFO-Gulf – Science
Lottie Bennett	DFO-NCR – Science
Sarah Loboda	DFO-Quebec – Science

Name	Affiliation
Anna Tilley	Fisheries, Forestry and Agriculture NL
Andrew Careen	Fish, Food and Allied Workers Union
April Wiseman	Fish, Food and Allied Workers Union
Brian Careen	Fish, Food and Allied Workers Union
Chad Strugnell	Fish, Food and Allied Workers Union
Darren Boland	Fish, Food and Allied Workers Union
Erin Carruthers	Fish, Food and Allied Workers Union
Jim Chidley	Fish, Food and Allied Workers Union
Miranda McGrath	Fish, Food and Allied Workers Union
Trevor Jones	Fish, Food and Allied Workers Union
Derek Butler	Association of Seafood Producers
Todd Broomfield	Nunatsiavut Government
Rob Coombs	Nunatukavut Community Council
Craig Taylor	Torngat Secretariat
Ron Johnson	Torngat Fish Co-op
Martial Laurans	French Research Institute for Exploitation of the Sea
Scott Grant	Memorial University – Marine Institute

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This Science Advisory Report is from the February 22-25, 2022 regional advisory meeting on the Stock Assessment of 2HJ3KLNOP4R Snow Crab. 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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Center for Science Advice (CSA)
Newfoundland and Labrador Region
Fisheries and Oceans Canada
PO Box 5667
St. John’s, NL, A1C 5X1

E-Mail: DFONLCentreforScienceAdvice@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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