ASSESSMENT OF NEWFOUNDLAND AND LABRADOR (DIVISIONS 2HJ3KLNOP4R) SNOW CRAB IN 2022

*Snow Crab (*Chionoecetes opilio*)*

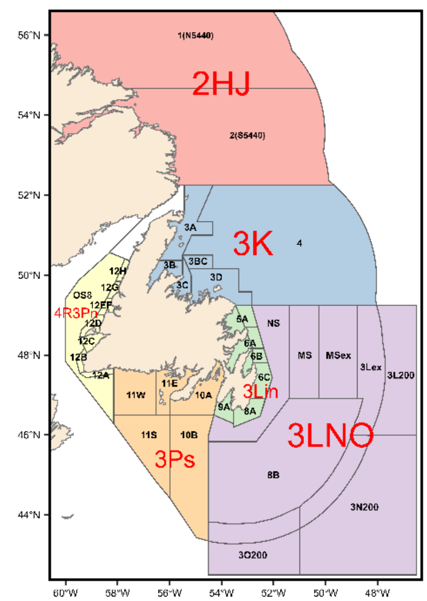

Figure 1: Map of Assessment Divisions (colours) and NL Snow Crab Management Areas (black).

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) which 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 which led to the development of multiple TAC-controlled Crab Management Areas (CMA, Fig. 1) with approximately 2,250 license holders across numerous fleet sectors under enterprise allocation in 2022. 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 (AD) comprised of combinations of the Northwest Atlantic Fisheries Organization (NAFO) Divisions (Div.). 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 Div. 2HJ3KLNOP, Fisheries and Oceans Canada (DFO) inshore trap surveys in NAFO Div. 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 20–21, 2023 Stock Assessment of Snow Crab in 2HJ3KLNOP4R. 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 2HJ3KNLNOP4R

- The DFO trawl survey did not take place in 2022, therefore the trap survey time series was used to assess status in 2022.
- The overall exploitable biomass increased from historic lows in 2016–18 to near the long-term average in the past two years.
- Fishery Exploitation Rate Indices (ERIs) were moderate to low in most Assessment Divisions (ADs) in recent years. Status quo removals would reduce or maintain the exploitation rate in all ADs in 2023.
- With status quo removals in 2023, all ADs are projected to be in the Healthy Zone of the Precautionary Approach (PA) Framework, except 2HJ, which is projected to be in the Cautious Zone. Recent and ongoing data deficiencies result in the exclusion of 4R3Pn from the PA Framework.
- Both pre-recruit catch indices and model predictions of exploitable biomass based on climate variables indicate that productivity for the next three to five years may remain similar to current levels.
- There has been particular concern about the stock in AD 2HJ in recent years. Fishery and biomass indicators suggest some improvements in 2022, but some key indicators could not be updated in this assessment.

Environment and Ecosystem

- The Newfoundland and Labrador (NL) Climate Index has shown a warming trend since 2018, with a record warm year in 2021.
- Overall conditions of the past three years are indicative of improved productivity at the lower trophic levels along the NL bioregion (2HJ3KLNOPs). This includes earlier phytoplankton blooms, higher chlorophyll concentrations, and increased zooplankton biomass with a higher abundance of larger, more energy-rich *Calanus* copepods.
- The ecosystems in the NL bioregion continue 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. In the most recent years with data available (2019–21), ecosystem indicators (e.g., biomass trends, stomach content weights) appeared to be improving, but the lack of surveys in 2022 prevented the evaluation of these trends in the current assessment.
- Predation mortality of Snow Crab declined across ecosystem units from the peak values observed in the mid-late 2010s. The most recent values of the fish predation mortality index (2019–21) 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 cannot be determined, but presently 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, ongoing 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 2021) and, by inference, older 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 pre-recruits until the following fishery when as hard-shelled crab, 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 bycatch, but within several years a directed trap fishery developed in inshore areas along the northeast coast of Div. 3KL. The minimum legal mesh size of traps is 135 mm (5 ¼”) to allow small crab to escape. Under-sized and soft-shelled males that are retained in the traps are returned to the sea, but the post-release mortality rate is unknown.

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 Div. 3K and 3L, and new fisheries started in Div. 2J, Subdivision (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 2,250 license holders in 2022.

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 the intent to reduce catch of soft-shelled crab. A protocol was initiated in 2004 that resulted in closure of localized areas when soft-shelled crab exceeds 20% of the legal-sized catch. In Div. 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 Div. 2HJ3KLNOP4R (Fig. 2) increased steadily from 1989 to a peak of 69,100 t in 1999, largely due to expansion of the fishery to offshore areas. Landings decreased by 20% to 55,400 t in 2000 and changed little until they decreased to 44,000 t in 2005, primarily due to a sharp decrease in landings 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. Landings have continued to increase since then and were just under 50,000 t in 2022.

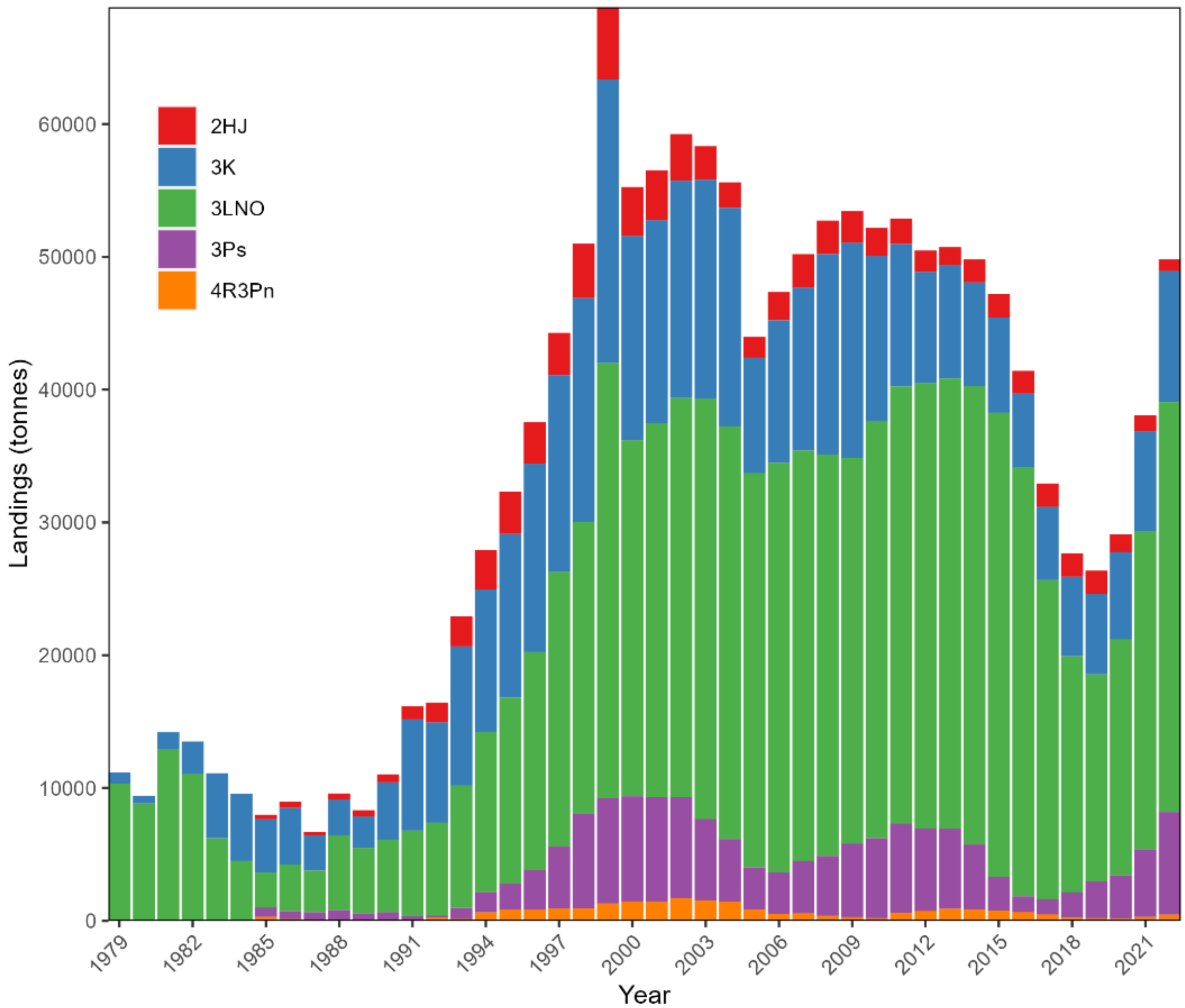

Figure 2: Annual landings (tonnes) of Snow Crab by AD (3LNO = 3LNO Offshore + 3L Inshore) (1979–2022).

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 Div. 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).

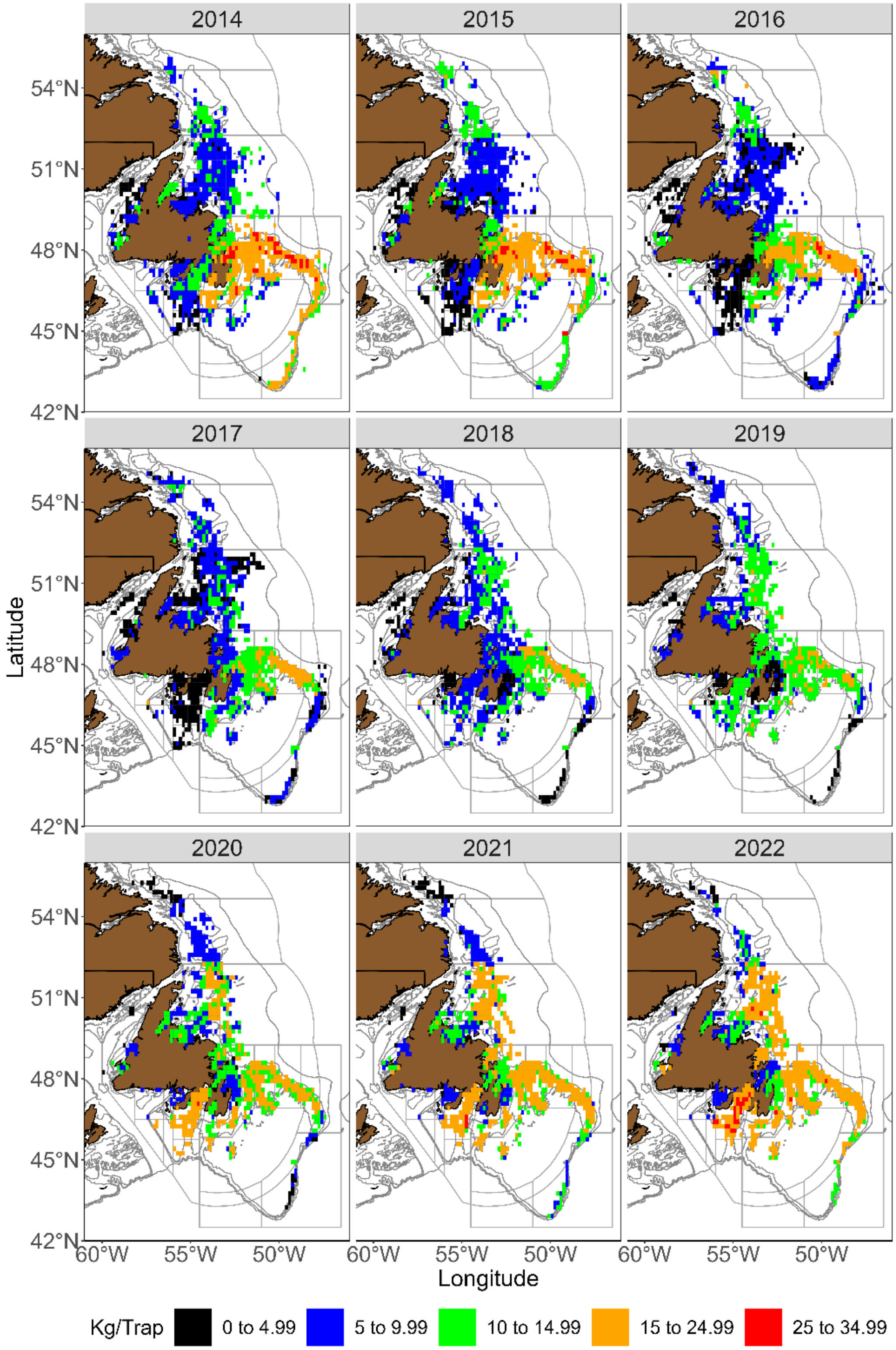

Figure 3: Locations of fishery sets and catch rates (kg/trap) from fishery logbooks (2014–22). Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

Overall effort increased to near 3.4 million trap hauls in 2022 (Fig. 4). Overall fishery CPUE was at a time-series low in 2018 but has greatly increased since then and was near the time-series high in 2022 (Fig. 4).

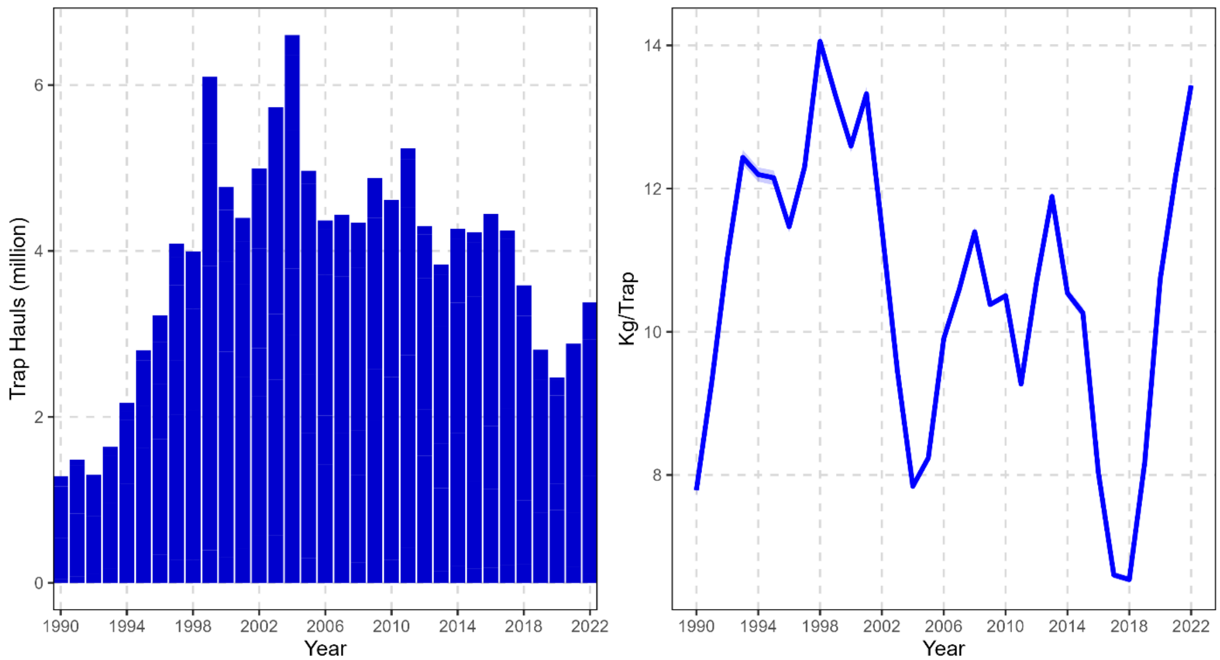

Figure 4: Left: Estimated number of trap hauls per year for the fishery in Div. 2HJ3KLNOP4R (1990–2022). Right: Standardized fishery CPUE (kg/trap) for Div. 2HJ3KLNOP4R (1990–2022). Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

ASSESSMENT

The boundaries of the 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, Div. 3LNO Offshore, representing the Grand Bank, is assessed as a unit (AD 3LNO) because the resource is managed at that unit. AD 3L Inshore (3Lin) is assessed separately because of differences in data availability, as the DFO trawl survey does not extend to inshore waters and 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 and Subdivision level, respectively.

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 AD 2HJ, 3K, and 3LNO Offshore and spring in AD 3Ps, two collaborative trap surveys covering all ADs, DFO inshore trap surveys in AD 3K, 3Lin, and 3Ps, fishery data from logbooks, and at-sea observer (ASO) catch-effort data. The multispecies bottom trawl surveys did not take place in 2022, however the time series is still used in some portions of the assessment.

The spring and fall bottom trawl surveys are based on a depth-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 AD 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 AD 3K, 3Lin, 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 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 to early-fall 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, since the previous assessment, a comparative index from all stations has also been calculated and both time series have been presented. A stratification scheme conforming to the limited historic survey footprint that was used for estimating biomass indices from this survey in the past was used on the core station time series, while spatial expansion of survey catch rates over the majority of the continental shelf area was used for the time series of all stations. Only the core stations have been consistently surveyed in AD 4R3Pn, therefore only the core station time series is presented for that AD. The CPS survey also includes small-mesh traps to provide data on recruitment prospects. Historically, small-mesh traps were deployed on select stations, but expanded to include most stations in recent years; therefore, only data from 2018 onward are used in this assessment.

A third trap survey series used in the assessment is the Torngat Joint Fisheries Board-DFO collaborative trap survey. This 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 derived using ogive mapping 'ogmap' (Evans et al. 2000) to spatially expand survey catch rates over the continental shelf area. Biomass estimates are not 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 for the smallest crab sizes, but retention efficiency is below 100% (q<1) even at the largest sizes. Besides crab size, trawl efficiency is also affected by substrate type and depth (Dawe et al. 2010), and therefore 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 capture efficiencies are unknown and vary between individual configurations. 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 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 scalar 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 scalar, as most surveys occur in late-summer or fall (2HJ3KLNO trawl surveys, CPS survey, Torngat 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 occurs in the time-series *S* for the trawl surveys from year to year, because an additional year has little influence on the time-series median. Standardized biomass indices were calculated as raw exploitable biomass estimates divided by *S*. For the shorter trap surveys, there has been variability in the catchability scalars which have been influenced by a contracting fishery in some ADs since 2018. Consequently, the time series was divided into two series (pre-2018 and post-2018). The scalars for pre-2018 were determined using linear regressions while for the post-2018 series, the median difference between logbook and survey-based biomass estimates over the time series was used for ADs without trawl surveys. For ADs with trawl surveys (all but AD 3Lin and 4R3Pn), the trap survey biomass estimates were scaled to the trawl survey estimates based on average ratios over the 2018–22 period.

Trawl and trap surveys also provide data on recruitment (i.e., crab just entering into the exploitable biomass), pre-recruitment, and mature females. Recruitment prospects for the upcoming fishery are inferred from catch rates of new-shelled legal-sized Snow Crab (immediate recruits) and pre-recruitment is based on adolescent (non-terminally-molted) males >75 mm CW. Pre-recruits would be expected to be recruited into the exploitable biomass in approximately two to three years.

Trends in exploitation rate were inferred from changes in the ERI, defined as landings divided by the exploitable biomass index from the most recent 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 time. 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. The logbook dataset is normally most incomplete in the current assessment year, resulting from a time lag associated with compiling data from the most recent fishery, thus the terminal points are considered preliminary.

Resource Status

Landings & Effort

In AD 2HJ, landings remained near 1,700 t from 2014–19, but have since declined, due to TAC reductions. Landings were 895 t in 2022 (Fig. 5). Effort remained moderately consistent for the last decade, at around 200,000 trap hauls per year, but declined to just over 100,000 trap hauls in 2022 (Fig. 6). In AD 3K, landings have increased since 2017 to around 9,800 t in 2022, while effort increased to around 800,000 trap hauls. In AD 3Lin, landings declined by 67% from a time-series high (8,390 t) in 2015 to a low of 2,750 t in 2019. Landings have since increased to around 4,300 t in 2022 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) but have since increased to around 26,600 t in 2022. Effort increased to around 1.6 million trap hauls in 2022. In AD 3Ps, landings continued to increase from a time-series low of around 1,200 t in 2017 to around 7,700 t in 2022, while effort increased to nearly 400,000 trap hauls. In AD 4R3Pn, landings steadily declined from 2013 to a time-series low of 160 t in 2020 but have since increased to 460 t in 2022. Effort increased to nearly 50,000 trap hauls.

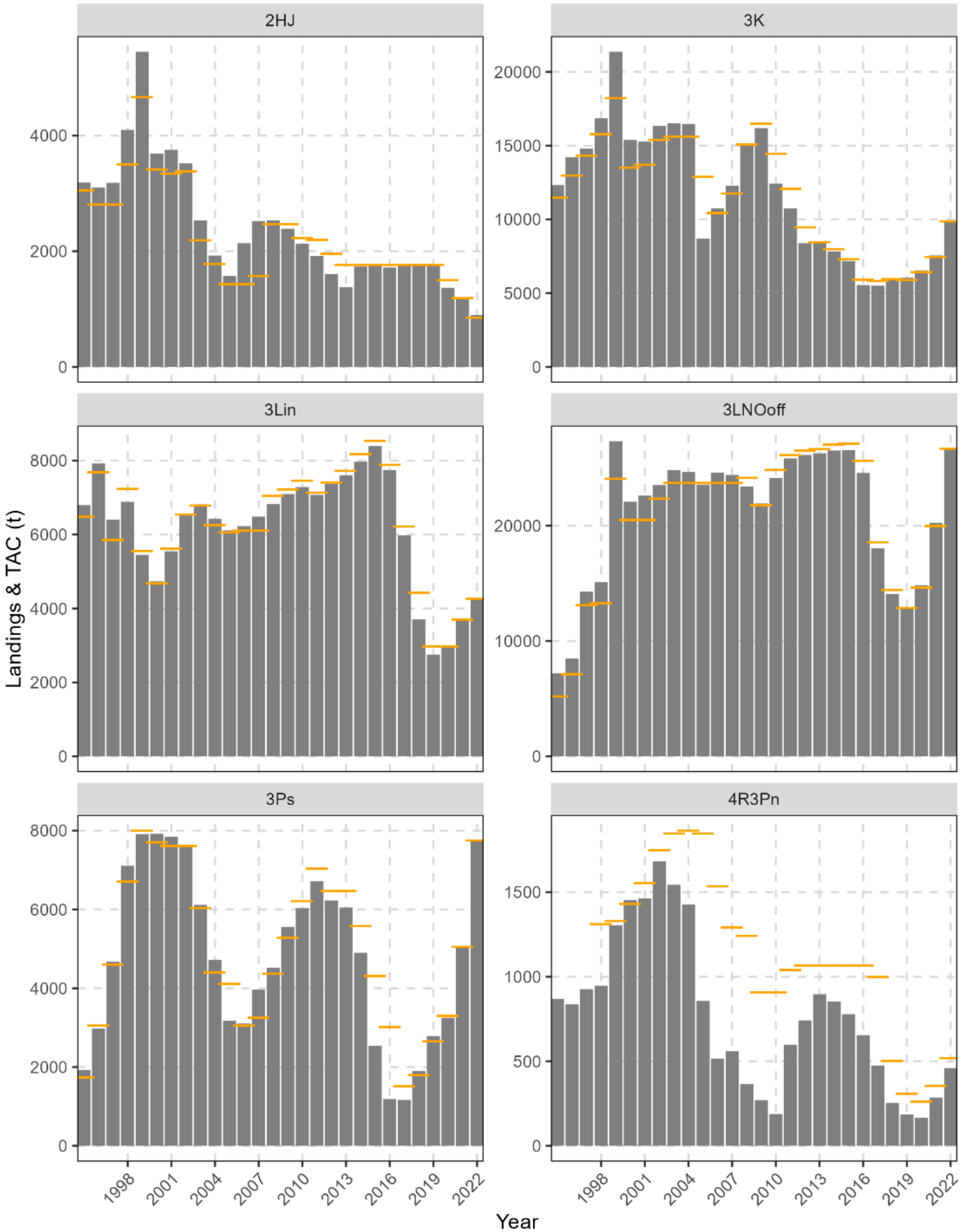

Figure 5: Annual landings (gray bars) and TAC (yellow lines) by AD (1995–2022).

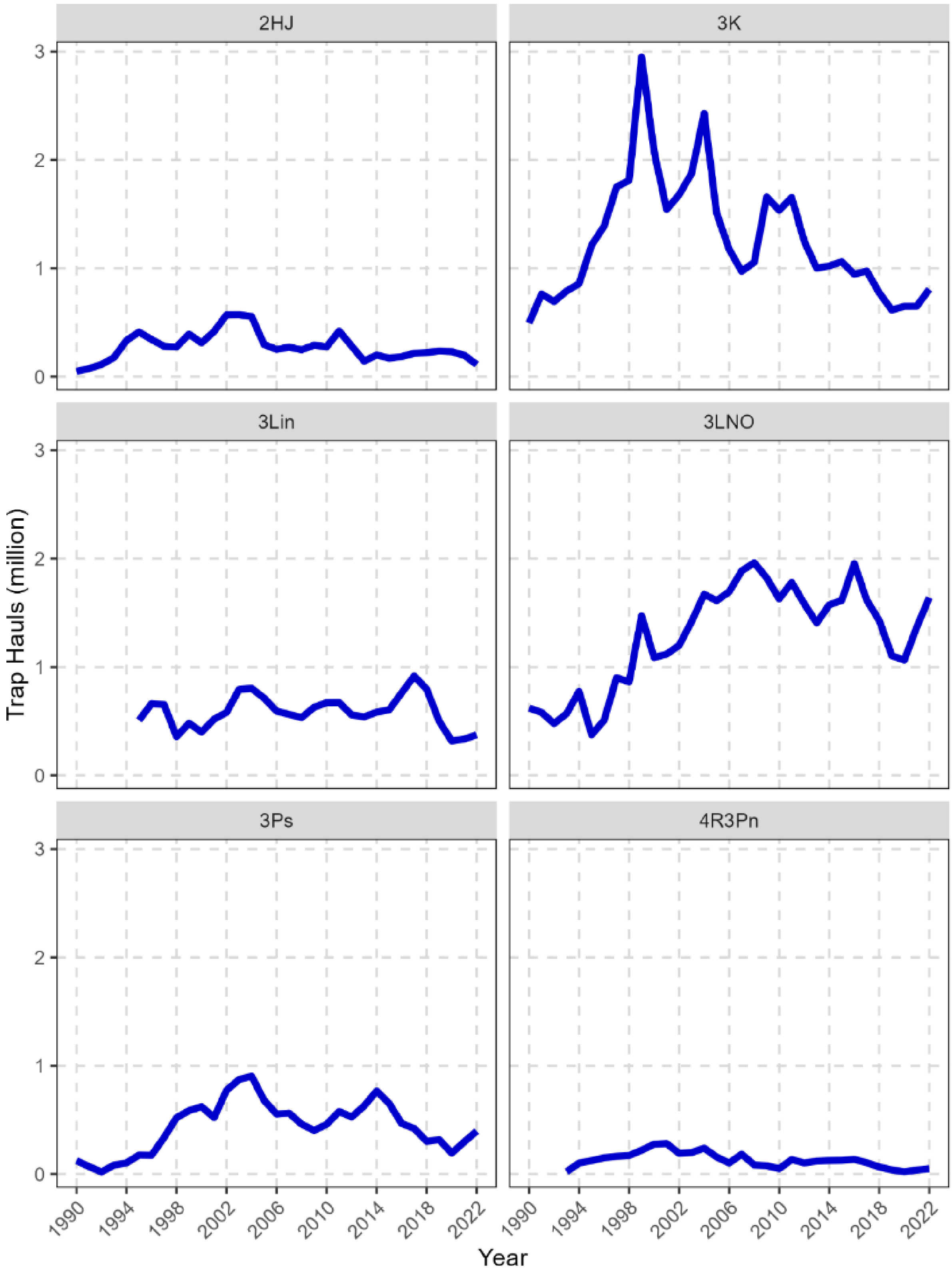

Figure 6: Annual effort (trap hauls) by AD from fishery logbook data (1990–2022). Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

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 increased to over 7 kg/trap in 2022 but remains below the time-series average (Fig. 7). In AD 3K, standardized CPUE increased to above the time-series average exceeding 11 kg/trap in 2022. In AD 3Lin, standardized CPUE was near time-series average levels of about 11 kg/trap in 2022. Logbook returns were lower than usual in this AD in 2022, with around 65% of the landings accounted for in the logbooks at the time of the assessment. In AD 3LNO Offshore, standardized CPUE increased to above the time-series average exceeding 15 kg/trap in 2022. In AD 3Ps, standardized CPUE was at a time-series high of around 19 kg/trap in 2022. In AD 4R3Pn, standardized CPUE was at a time-series high of over 8 kg/trap in 2022, however, logbook returns were very low in this AD, with only 58% of the landings accounted for in the logbooks at the time of the assessment.

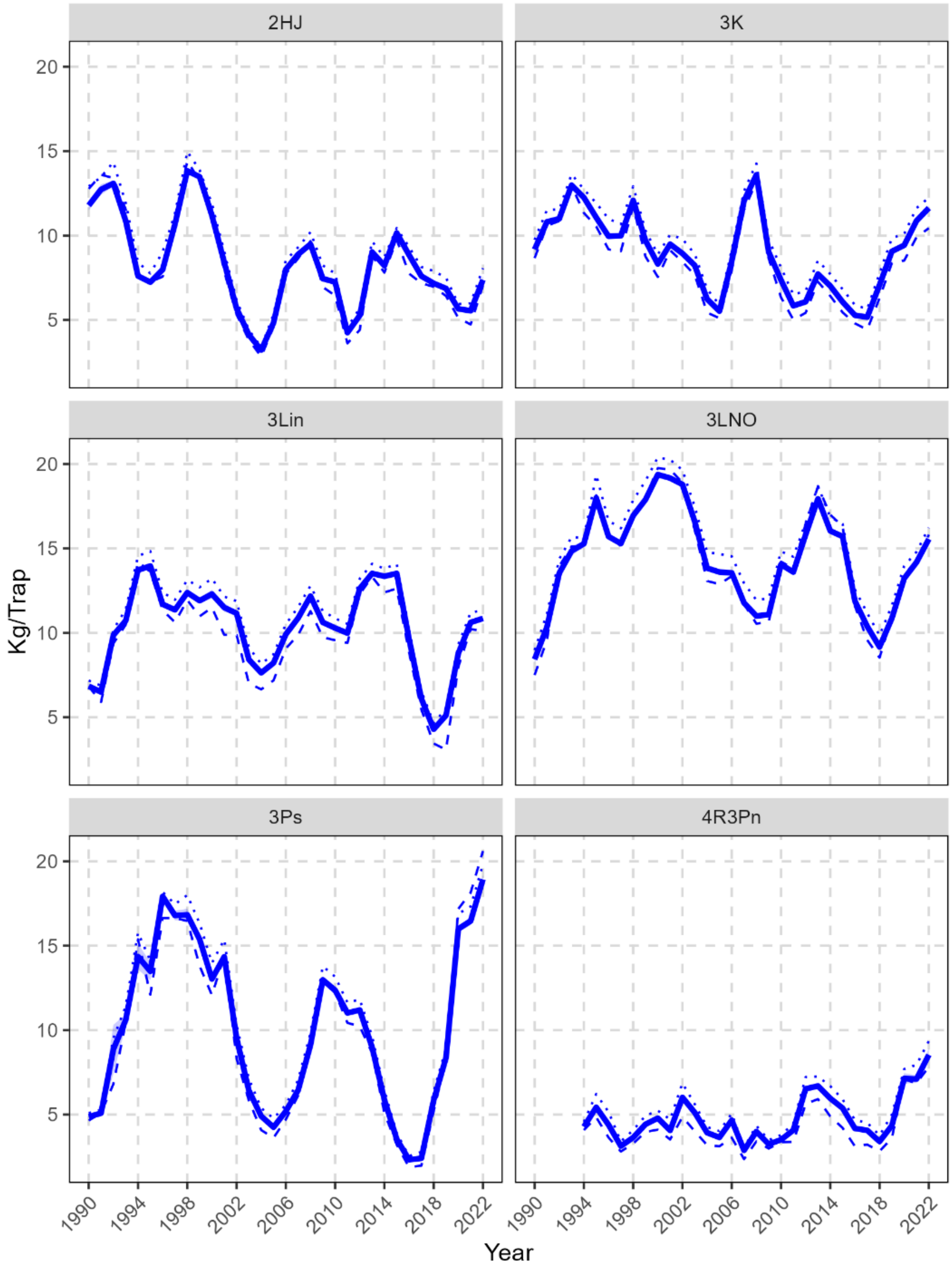

Figure 7: Fishery CPUE (kg/trap) by AD from fishery logbook data (1990–2022). Solid line is standardized CPUE, and shaded band is 95% confidence intervals (CIs). Dotted lines are raw means and dashed lines are raw medians. Data in the most recent year considered preliminary due to delays in logbook returns and data entry.

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, but has increased since then. There have been gaps in the trawl survey time series in the last three years, therefore the stock-level trawl exploitable biomass index has not been updated. 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. The trap survey exploitable biomass index declined to a time-series low in 2017–18, but has continued to increase since then. In the absence of updated trawl survey indices, trap survey indices will be used to infer trends.

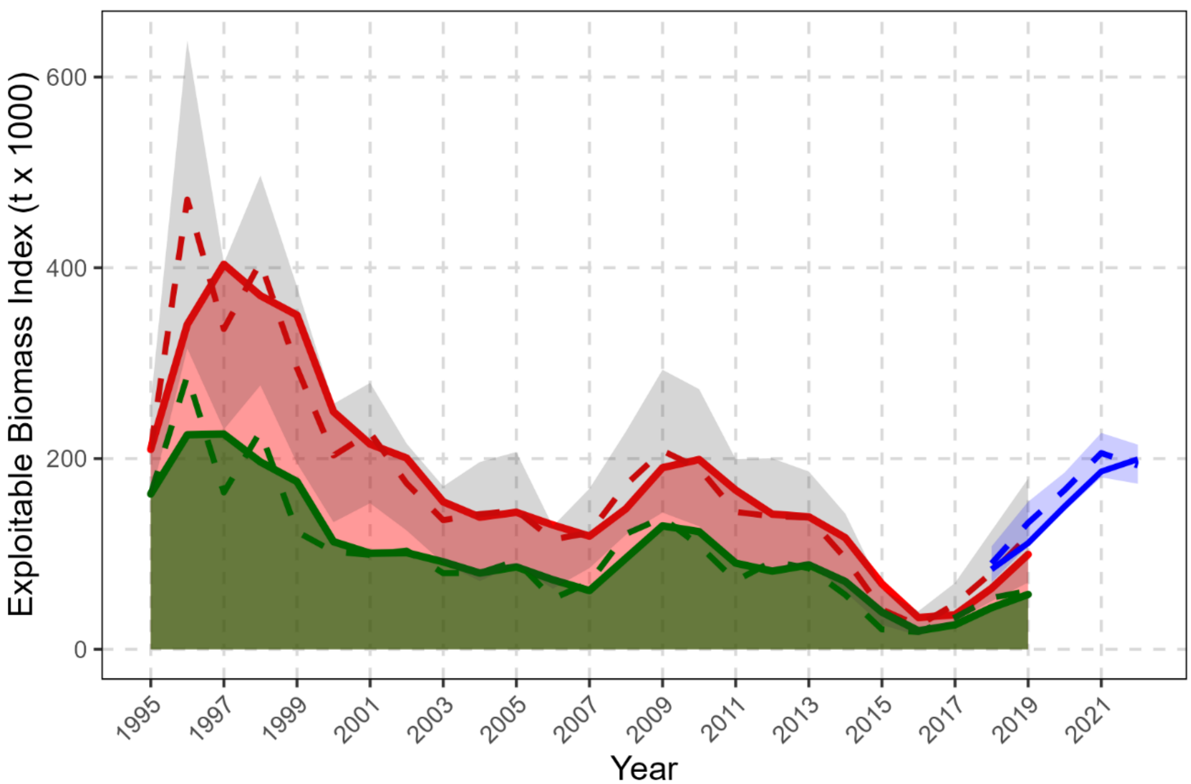

Figure 8: Annual trawl survey-based exploitable biomass index by shell condition (red = residuals, green = recruits) (1995–2019) and trap survey-based exploitable biomass index (blue) (2018–2022). Solid line = two-year moving average of exploitable biomass, dashed line = annual estimate, and grey or blue shaded band = 95% CIs of annual estimate.

In AD 2HJ, the trap survey exploitable biomass index increased slightly in 2022, but remains low for the time series (Fig. 9). In AD 3K, the trap survey exploitable biomass index has been increasing since the time-series low in 2018, but remained at a similar level in 2021 and 2022. In AD 3Lin, the trap survey exploitable biomass index increased over the last three years. In AD 3LNO Offshore, the trap survey exploitable biomass index has been increasing since the time-series low in 2018, but remained at a similar level in 2021 and 2022. The survey was not completed correctly in CMA Nearshore (CMA NS) in 2022, therefore the AD-level exploitable biomass index does not include data from that area. In AD 3Ps, the trap survey exploitable biomass index increased to a time-series high level in 2022. In AD 4R3Pn, the trap survey exploitable biomass index increased over the past four years to near a time-series high in 2022.

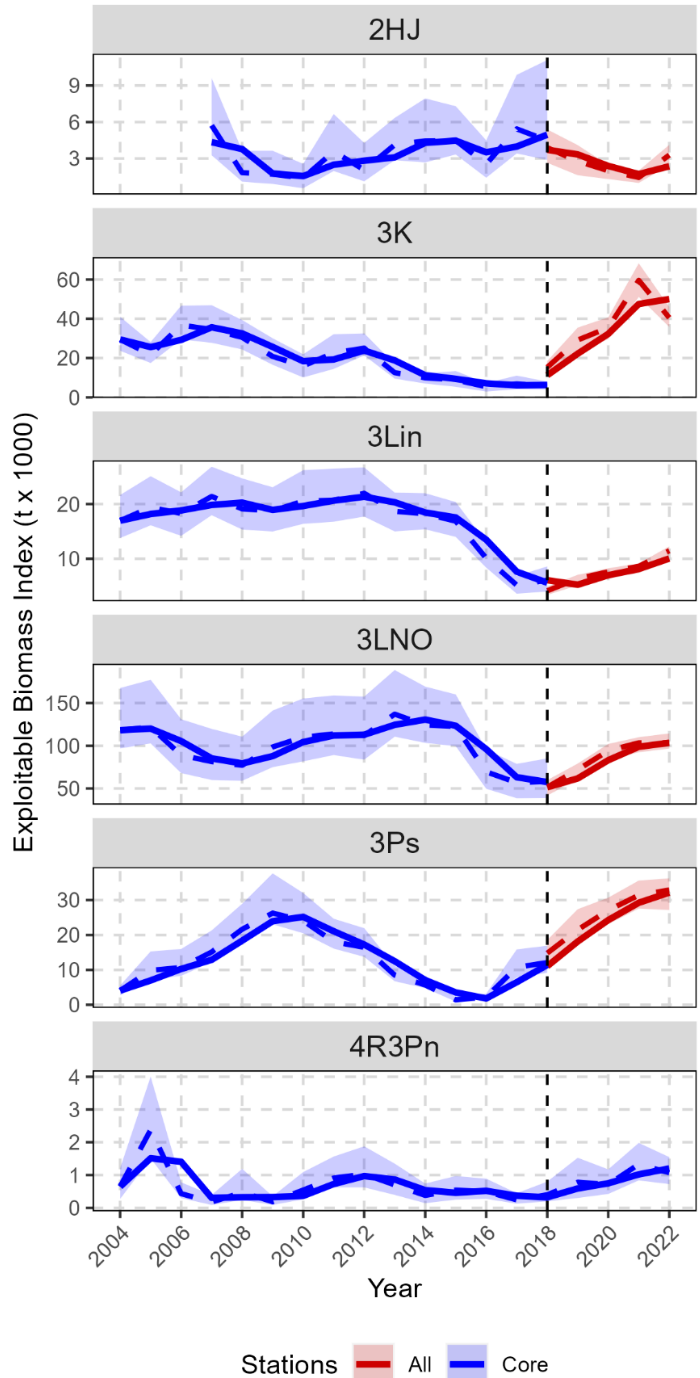

Figure 9: Trap survey exploitable biomass index by AD (2004–22). Dashed line shows annual estimate, shaded area represents the 95% CIs, and solid line is two-year moving average of the estimate. Red represents using stations covering the entire trap survey area and blue represents using stations only within core polygons. Dashed vertical line denotes the first year of the trap survey redesign.

Mortality

Trends in total mortality generally reflect those of fishing-induced mortality, as measured by ERIs. The trawl survey time series is usually used to infer trends in exploitation in AD 2HJ, 3K, and 3LNO Offshore. 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. However, with the redesign of the trap survey and consequent agreement in exploitable biomass index between trawl and trap surveys, the recent trap-based ERIs will be used in the absence of 2022 trawl survey data. In AD 2HJ, the trap survey-derived ERI increased in 2022; however, under status quo removals in 2023 the ERI is projected to decrease (Fig. 10). In AD 3K, the trap survey-derived ERI decreased in 2022 and under status quo removals in 2023 the ERI is projected to remain at a similar level. In AD 3Lin, the trap survey-derived ERI remained at a similar level in 2022; however, under status quo removals in 2023 the ERI is projected to decrease. In AD 3LNO Offshore, the trap survey-derived ERI remained at a similar level in 2022 and no change is projected under status quo removals in 2023. In AD 3Ps, the trap survey-derived ERI increased in 2022; and under status quo removals in 2023 the ERI is projected to remain at that level. In AD 4R3Pn, the trap survey-derived ERI increased in 2022; however, with status quo removals in 2023 the ERI is projected to decrease.

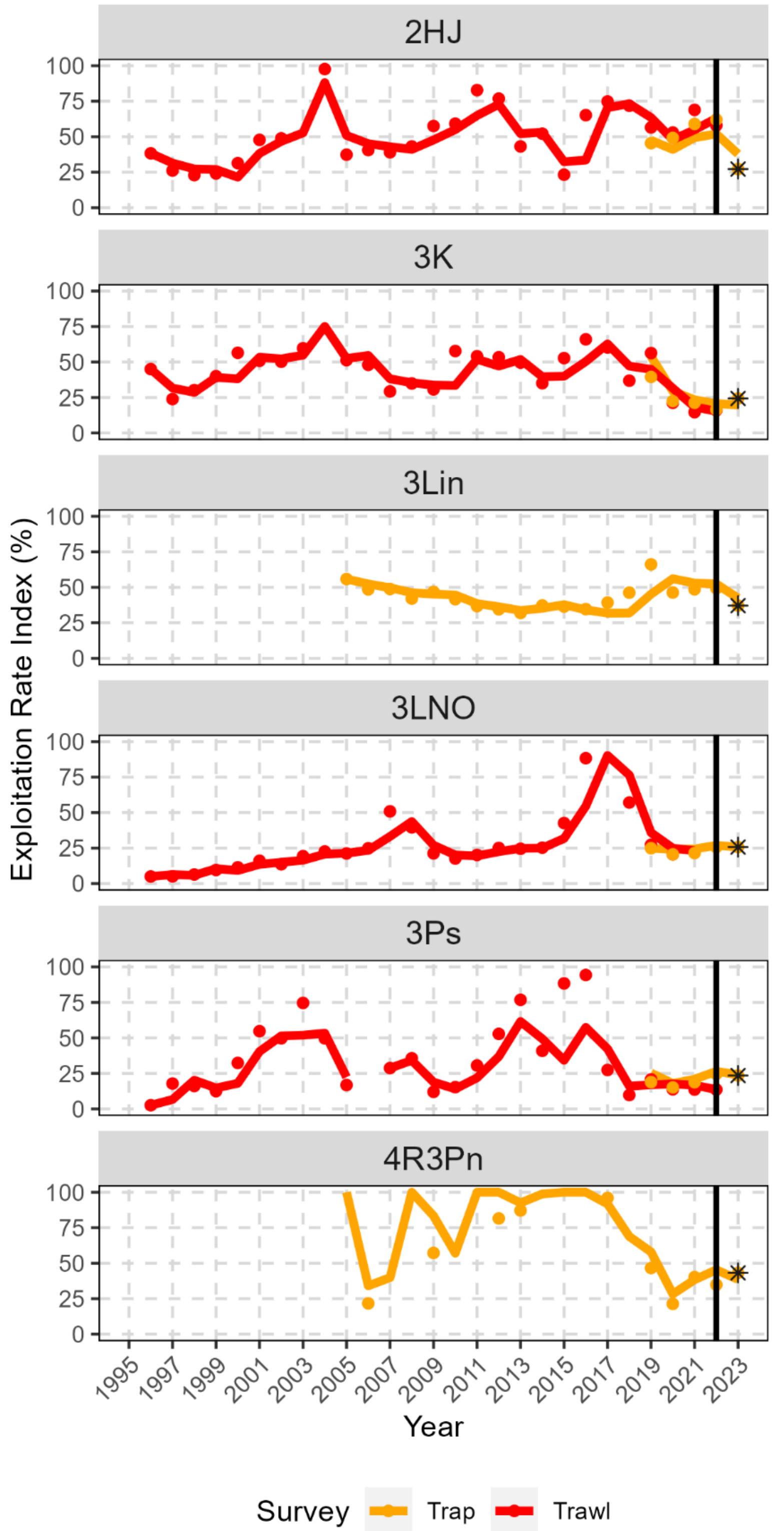

Figure 10: Trends in the trawl-derived (red) and trap-derived (orange) annual (points) and 2-year moving average (solid line) ERI (%) by AD (1996–2023); 2023 points (*) depict projected annual ERIs under status quo removals in the 2023 fishery.

Recruitment

In the absence of 2022 trawl data, recruitment into the exploitable biomass was examined from catch rates of new-shelled exploitable crab from the CPS trap surveys. Crab captured as soft- or new-shelled in the current survey represent recruitment into the exploitable biomass, while the residual biomass is comprised of intermediate- to very old-shelled crab. Increases in the catch rates of recruit crab were seen in AD 2HJ, 3Lin, and 3Ps in 2022, suggesting potential improvements in the fishery in 2023 (Fig. 11). Declines in recruit crab catch rates were seen in AD 3K, 3LNO Offshore, and 4R3Pn in 2022. The trap survey sampling was incomplete for the large-mesh traps in CMA NS in AD 3LNO Offshore, therefore results include little information from CMA NS.

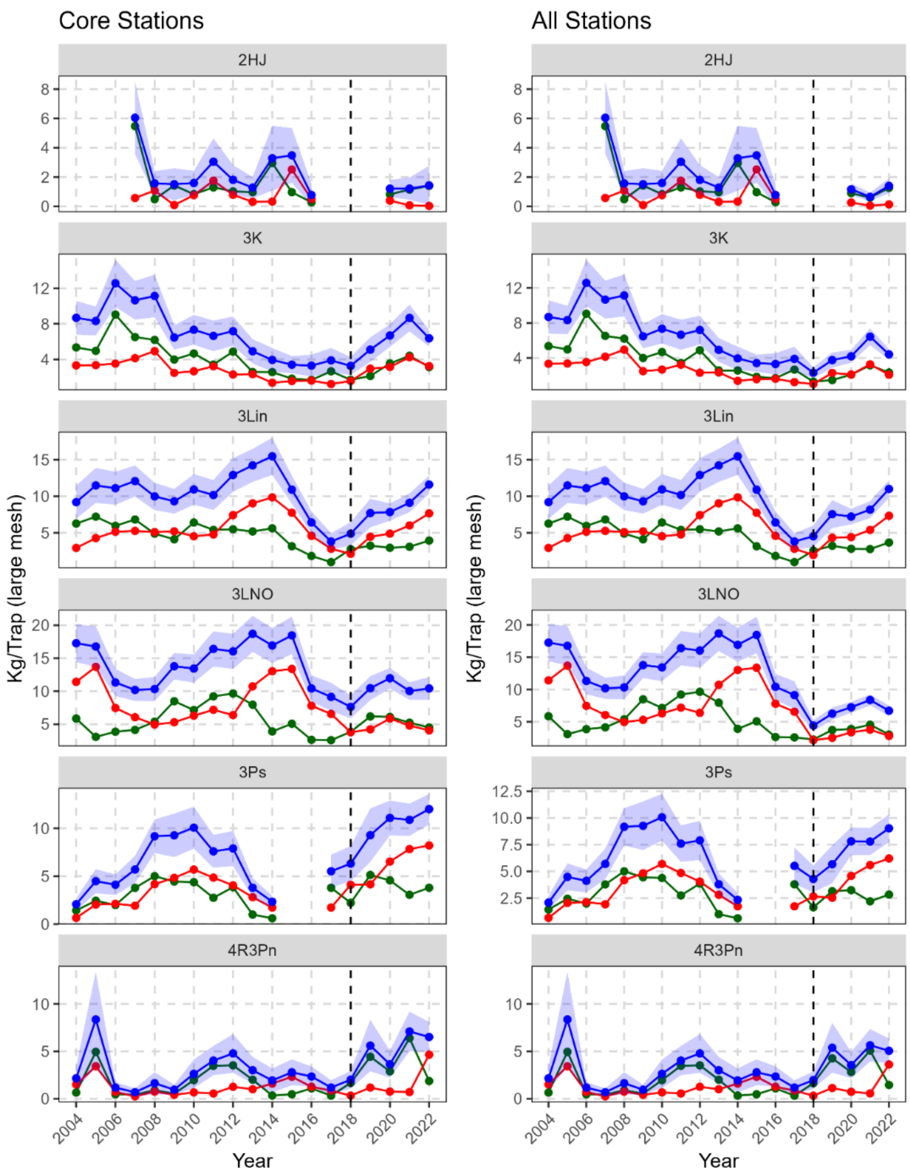

Figure 11: Trends in CPUE (kg/trap) by shell condition (blue = total, red = residuals, green = recruits) for exploitable crab from core stations (left) and all stations (right) in the CPS trap survey by AD (2004–22). Shaded area represents the 95% CI. Dashed vertical line denotes the first year of the trap survey redesign.

Trends in pre-recruitment were examined from catch rates of >75 mm CW adolescent males in the trawl and small-mesh trap time series and provide an index of recruitment prospects in the short-term (~2–3 years). However, the proportion of these adolescents measured in the 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 the trawl and trap surveys suggest a moderate level of pre-recruit abundance in all ADs, except 2HJ, where both surveys have shown a declining trend in recent years (Fig. 12).

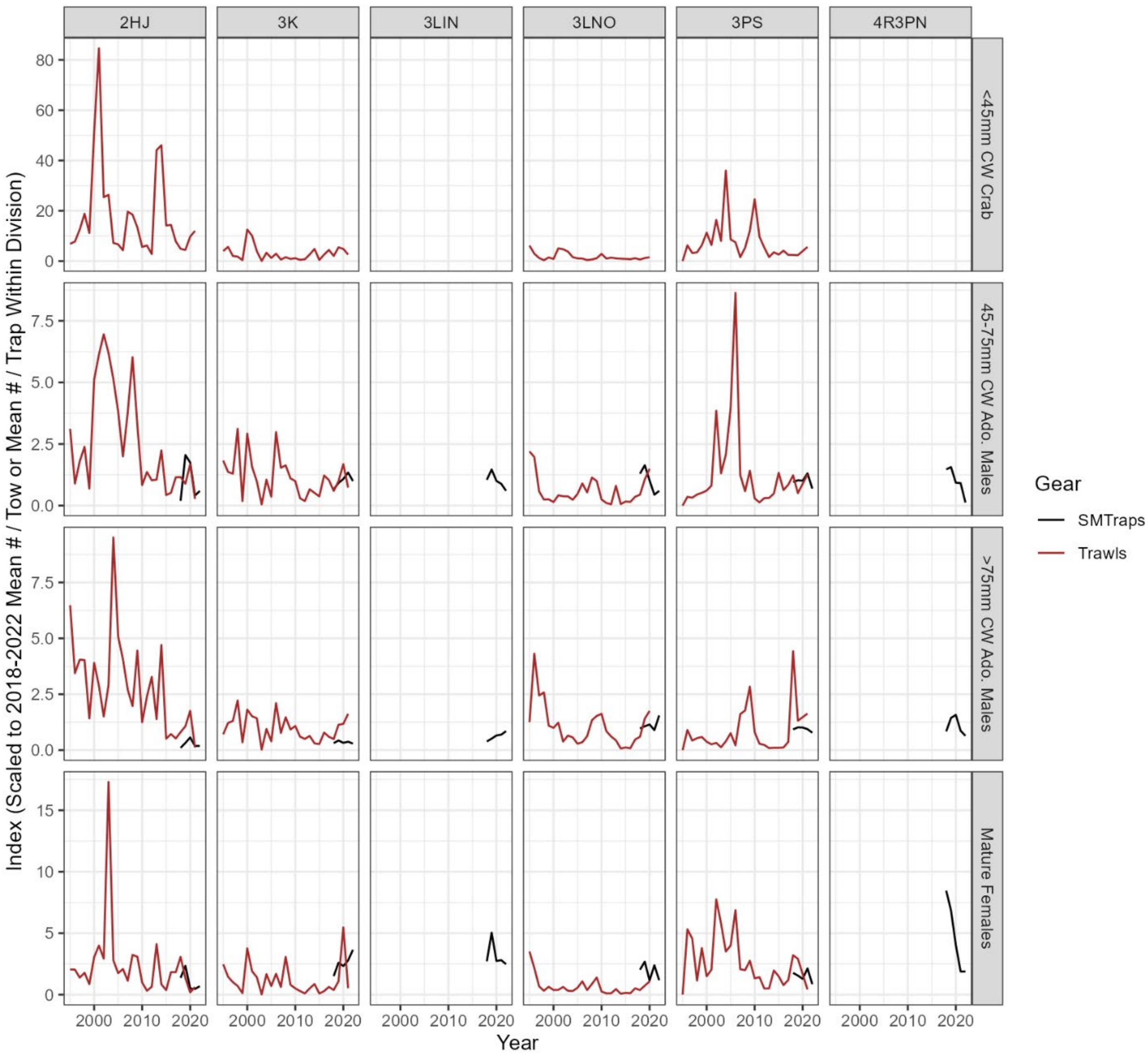

Figure 12: Indices of small crab, pre-recruit crab (>75 mm CW adolescent males), and mature female crab from the trawl and small-mesh trap surveys (1995–2022).

Ecosystem Perspective

Increased bottom temperature has been shown to relate positively to size and negatively to abundance in regulating stock productivity and ultimately biomass. Cold bottom temperatures appear to promote terminal molt at small sizes in Snow Crab, resulting in relatively low recruitment and yield-per-crab from a given year class (Dawe et al. 2012). However, recruitment is more strongly affected by the positive effects of cold environmental conditions on year class production (Dawe et al. 2008; Marcello et al. 2012) than it is by the negative effects of cold conditions on size-at-terminal molt. This is consistent with positive benefits of cold conditions in promoting early- to mid-life survival and subsequently increased densities of crab in the population. The last five years have shown an overall trend towards warmer and potentially less favourable environmental conditions for future productivity. It was particularly warm in 2021, with the NL Climate Index (Cyr and Galbraith 2020) indicating it was one of the two warmest years of the time series (Cyr et al. 2022); 2022 was in the top ten warmest years. Bottom temperature is not the only climatic factor important for Snow Crab productivity; the Arctic Oscillation and sea ice extent are important variables in predicting abundances of different life stages. The model presented at the assessment suggests productivity may remain at similar levels over the next five years (Fig. 13).

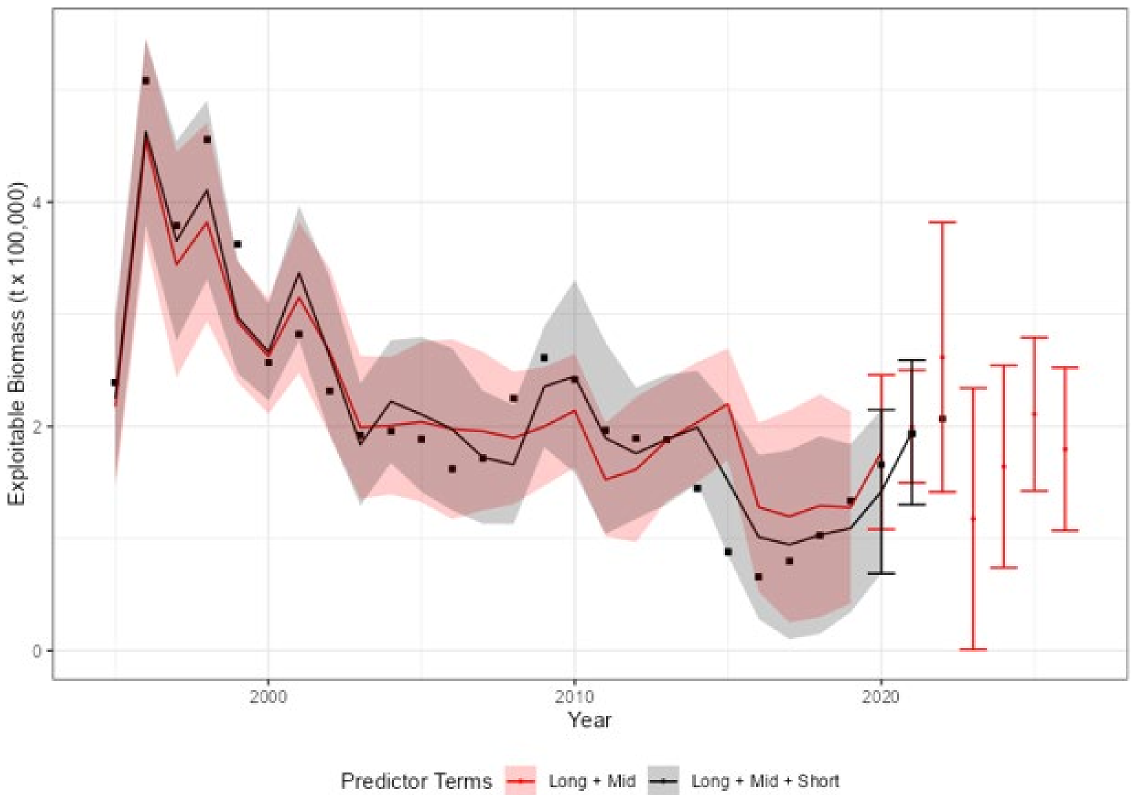

Figure 13: Short-term prediction model of exploitable biomass (1995–2026). Black squares are survey measured exploitable biomass in 2HJ3KLNOP. Black lines, points, and associated error bars are full model fits (short-, mid-, long-term effects) and red lines, dots, and associated error bars are model run with no short-term effects. Shaded areas are 95% CIs of model fits.

Until the past few years, following a regime shift culminating in a collapse of most of the finfish community in the late-1980s and early-1990s (Buren et al. 2014), the Snow Crab resource appears to have largely been under bottom-up control, in association with low exploitation rates in the largest areas of abundance (i.e., AD 3LNO Offshore) (Mullowney et al. 2014). However, recent assessments have highlighted that other factors such as top-down forcing from heavy exploitation and increased predation have grown in importance. While there have been issues in completing trawl surveys over the last two years, the available data from trap surveys, indicate that substantially decreased fisheries exploitation rates have been associated with current improvements in the exploitable biomass.

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. There have been no updates in diet information since the last assessment, where it was observed that while the predation mortality index remained among the highest in recent years, there have been declines from the peaks of 2016–18. The predation mortality index in 2019–21 was among the highest levels in 2J3K and 3LNO but declined to its lowest value in over 25 years in 3Ps by 2021. Within 2J3K, predation mortality was substantially higher in 2J than in 3K.

With respect to overall ecosystem productivity, ecosystem conditions in the NL bioregion remain indicative of a low productivity state. Total fish biomass levels remain much lower than prior to the finfish collapse in the early 1990s, however some ecosystem indicators (biomass trends and stomach content weights) appear to be improving in the most recent years for which data is available. Increased nutrients availability and phytoplankton and zooplankton biomass, along with a higher abundance of large, energy-rich *Calanus* copepods, are indicative of improved productivity at the lower trophic levels in recent years. This has the potential for positive impacts on the energy-transfer to higher trophic levels and overall ecosystem productivity.

Analyses of aggregate fishing pressure (i.e., all fisheries combined) at the ecosystem level in relation to ecosystem productivity in 2J3K and 3LNO indicate these ecosystem units have experienced significant levels of ecosystem overfishing in the past (pre-collapse), but since the mid-2000s, fisheries exploitation has remained below the level that indicates a high risk of ecosystem overfishing.

Outlook

The exploitable biomass index remained moderate to high or increased in all ADs in 2022. The stock has increased from record low levels, but has not returned to the historic high levels of the past. The growth in the overall trap-based exploitable biomass index from the low period in 2017–18 appeared to stabilize in 2022, with this index remaining at a similar level for the last two years. 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, along with substantial reductions in fishing mortality. However, the last five years have shown an overall trend towards warmer, potentially less favourable environmental conditions for future productivity and biomass trajectories suggest that productivity may remain similar to current levels.

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. No update was available for 2022, however male size-at-terminal molt will be particularly important to monitor in 2HJ moving forward.

Precautionary Approach

In June 2018, DFO Science held a CSAS Regional Peer Review process to develop a PA Framework for Snow Crab in the NL Region. The key objective of the meeting was to define 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 that was based on three key metrics of stock health:

1. predicted CPUE (pCPUE),

2. predicted discards (pDiscards), 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 the 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 re-established to bring forward a series of recommendations to DFO on the USRs and HCRs. The USRs and HCRs were developed and approved. A decision-making rule was developed to incorporate the three metrics of stock health into one stock health score (Fig. 14; Fig. 15).

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 14: Decision-making rule for Snow Crab PA Framework.

In 2023, all ADs are projected to be in the Healthy Zone in the PA Framework, except AD 2HJ which is projected to be in the Cautious Zone (Fig. 15). These projections assume status quo landings. Recent and ongoing data deficiencies resulted in the exclusion of AD 4R3Pn in the PA Framework.

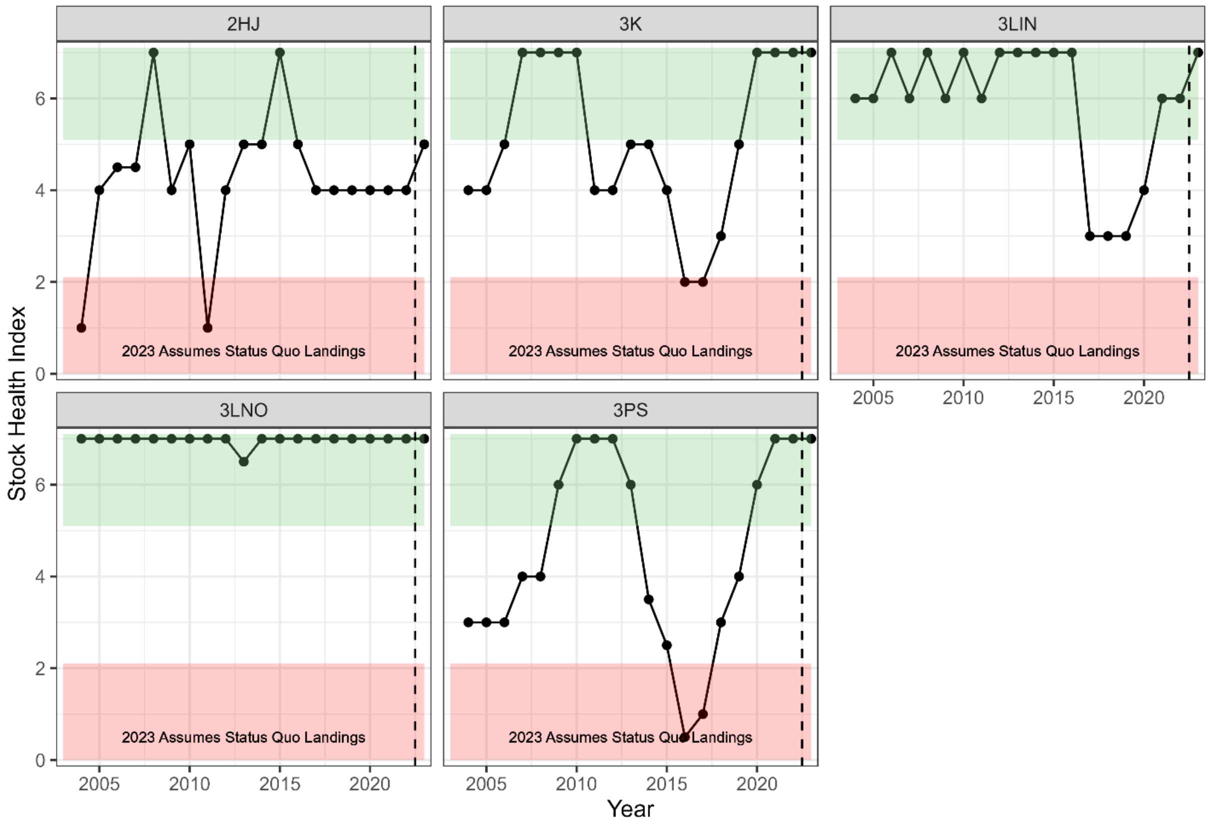

Figure 15: Projected stock status (black point) by AD in the Snow Crab PA Framework from 2004–23. The green, white, and red shaded areas represent the Healthy, Cautious, and Critical Zones, respectively.

Sources of Uncertainty

There are several sources of uncertainty influencing the interpretation of trends in biomass, recruitment, and mortality that represent the basis for this assessment.

Surveys

Interpretation of trends in exploitable biomass and pre-recruit indices from surveys is highly uncertain when surveys are incomplete. There have been historic occasional issues with coverage of the CPS trap survey. As well, in recent years the multispecies trawl surveys have been reduced or not conducted in multiple ADs and years and were not used to generate advice in the current assessment.

Crab movements across divisional boundaries may affect survey indices resulting in uncertainties in distributions and 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 variations 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., Div. 3LNOPs) than under warm regimes (e.g., Div. 2J3K4R). Molt frequency is also affected by density of large males, with terminal molt at small sizes more common at lower densities (Mullowney and Baker 2021).

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. However, in 2022, logbook returns were particularly low in AD 3Lin and 4R3Pn, with 65% and 58% of landings accounted for in the logbooks, respectively. 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, artificial lighting, 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 these data 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 ASO data from at-sea sampling during the fishery due to low and inconsistent spatio-temporal coverage. There is concern that current coverage introduces bias in interpreting trends in catch rates at broad spatial scales and introduces high uncertainty in interpreting indices of biomass, recruitment, and mortality. ASO-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 ASOs in subjectively assigning shell stages. In 2022, ASO coverage was improved in some ADs from low and/or absent coverage in 2020 and 2021. Measures should be taken to ensure representative ASO coverage to improve data quality from this program.

The use of fishery catch rate Delury depletion models to adjust survey-based exploitable biomass estimates requires depletion of a resource as well as similar coverage by the fishery and the survey. Years with no depletion during the fishery cannot be used for calculating the depletion catchability scalars and are omitted. In the current assessment, the potential effects of a constricting fishery in recent years, particularly in AD 2HJ, 3K, and 3Ps, on the efficacy of Delury depletion models was highlighted. There were low depletion-based biomass estimates associated with increasing divergence between the fishery and the survey footprints, which plausibly reflects localized depletion by the fishery in some areas and negligible depletion of the resource in areas no longer being fished. This was corrected by scaling the trap survey to the trawl survey in these ADs of concern; however, close examination of effects of this ongoing fishery contraction on time series catchability scalars is required in future assessments.

CONCLUSIONS AND ADVICE

For AD 2HJ, 3K, 3LNO Offshore, and 3Ps, the trap survey time series was solely used to infer trends in 2022 due to the absence of trawl data.

Assessment Division 2HJ

Exploitable biomass and recruitment indices have remained low for many years, however there were slight increases in these trap-based indices in 2022. 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. The trap-based ERI is projected to decline with status quo removals in 2023. Following the PA Framework, with status quo removals the stock status is projected to be in the Cautious Zone in 2023. In addition to low residual biomass and high fishing pressure in recent years, there have been declines in the male size-at-terminal molt and mature female abundance index in AD 2HJ (DFO 2022). Due to the absence of a trawl survey in 2022, the male size-at-terminal molt could not be updated. However, recent trends are concerning and could dampen recruitment if a higher proportion of males reach their terminal molt below exploitable size.

Assessment Division 3K

Exploitable biomass and recruitment indices have increased in the last four years, with the trap-based exploitable biomass remaining at a similar level in 2021 and 2022. There was a decrease in recruitment in the trap time series in 2022. 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, but the trawl-derived ERI has been at a much lower level since 2020. With status quo removals, the trap-based ERI is projected to remain at a low level in 2023. Following the PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2023.

Assessment Division 3L Inshore

The exploitable biomass index increased over the last three to four years. Recruitment has remained steady for the last four years. The ERI remained at a similar level in 2022; however, under status quo removals in 2023 the ERI is projected to decrease. Following the PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2023.

Assessment Division 3LNO Offshore

There has been an increasing trend in the exploitable biomass index in the trap surveys for the last three to four years, with the index remaining steady in 2022. There was a decrease in recruitment in the trap time series in 2022. The trap-based ERI is projected to remain at a low level with status quo removals in 2023. Following the PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2023.

Assessment Division 3Ps

The trap-based exploitable biomass index has continued to increase to a time-series high in 2022. Recruitment has remained around the same level for the last four years. The trap-based ERI is projected to remain at a low level with status quo removals in 2023. Following the PA Framework, with status quo removals the stock status is projected to be in the Healthy Zone in 2023.

Assessment Division 4R3Pn

The exploitable biomass index has increased over the past four years, nearing time-series high levels. There was a decrease in recruitment in 2022. The ERI increased in 2022, however it is projected to decrease with status quo removals in 2023. Completion of the trap survey outside the major fishing areas has been poor, therefore stock status was attributable primarily to CMA 12C and 12EF. Recent and ongoing data deficiencies do not allow inclusion of this AD into the PA Framework.

OTHER CONSIDERATIONS

Bitter Crab Disease

Bitter Crab Disease (BCD) is fatal to crab and predominately occurs in small, new-shelled Snow Crab of both sexes (Mullowney et al. 2011). It appears to be acquired during molting and can be detected visually in the fall. Incidence of BCD in the trawl survey 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 indicated it was most persistent. Although BCD had been unusually high in large males in AD 3K in recent years, there were no large males observed with BCD in 2019–21. Updated data from trawl surveys was not available for 2022.

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 the time series. Fishery-induced mortality of mature males (including undersized males) could adversely affect insemination of females in the presence of high exploitation. A study is currently investigating the presence of sperm limitation in females associated with high exploitation rates of males in some areas in recent years.

Management Considerations

In an aim to protect reproductive potential, conservation measures exclude females and males <95 mm CW, including a portion of the adult (large-clawed) males, from the fishery. 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 of 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 of 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 of 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 ASO 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 grids in inshore areas of AD 3Lin, 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 ASO coverage paired with the decision to treat unobserved grids as not impacted. In addition, failure to draw all possible inferences from moderate-sized samples frequently resulted in failure to invoke the protocol even when it was clear that the level of soft-shelled crab had exceeded the threshold. 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 ASO coverage in a given year. This was further compounded by low sample sizes prohibiting adherence to closure thresholds when ASO coverage was present. These shortcomings undermine the intent of the protocol. Measures should be taken to ensure adequate and representative ASO 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, the survey 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; therefore, 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
Aaron Adamack	DFO-NL – Science
Kristin Loughlin	DFO-NL – Science
Julia Pantin	DFO-NL – Science
Hilary Rockwood	DFO-NL – Centre for Science Advice
Victoria Neville	DFO-NL – Centre for Science Advice
Jodi Riggs-Power	DFO-NL – Resource Management
Kelly Firmage-O'Brien	DFO-NL – Resource Management
Laurie Hawkins	DFO-NL – Resource Management
Martin Henri	DFO-NL – Resource Management

Name	Affiliation
Ryan Critch	DFO-NL – Communications
Charmain Hamilton	DFO-NL – Science
Chelsea Malayny	DFO-NL – Science
Corey Morris	DFO-NL – Science
Darrell Mullowney	DFO-NL – Science
David Belanger	DFO-NL – Science
Elizabeth Coughlan	DFO-NL – Science
Erika Parrill	DFO-NL – Science
Frédéric Cyr	DFO-NL – Science
Hannah Munro	DFO-NL – Science
Janine O'Reilly	DFO-NL – Science
Jonathan Coyne	DFO-NL – Science
Kate Charmley	DFO-NL – Science
Khanh Nguyen	DFO-NL – Science
Krista Baker	DFO-NL – Science
Kyle Lefort	DFO-NL – Science
Mariano Koen-Alonso	DFO-NL – Science
Michael Hurley	DFO-NL – Science
Nicolas Le Corre	DFO-NL – Science
Robert Deering	DFO-NL – Science
Will Coffey	DFO-NL – Science
Ben Zisserson	DFO-MAR – Science
Lottie Bennett	DFO-MAR – Science
Vanessa Byrne	Fisheries, Forestry and Agriculture NL
Alton Rumbolt	Fish, Food and Allied Workers Union
April Wiseman	Fish, Food and Allied Workers Union
Chad Payne	Fish, Food and Allied Workers Union
Erin Carruthers	Fish, Food and Allied Workers Union
Jamie Barnett	Fish, Food and Allied Workers Union
Nelson Bussey	Fish, Food and Allied Workers Union
Tony Doyle	Fish, Food and Allied Workers Union
Renae Butler	Association of Seafood Producers
Ron Johnson	Torngat Fish Coop
Colin Webb	Nunatsiavut Government
Rob Coombs	Nunatukavut Community Council
Craig Taylor	Torngat Wildlife, Plants & Fisheries Secretariat
Colin Frank	Memorial University – Marine Institute
Alannah Wudrick	Memorial University – Marine Institute
Paul Winger	Memorial University – Marine Institute
Gemma Rayner	Oceans North

SOURCES OF INFORMATION

This Science Advisory Report is from the February 20–21, 2023 regional peer review on Stock Assessment of Snow Crab in 2HJ3KLNOP4R. 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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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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