Fisheries and Oceans Canada
Pêches et Océans Canada
Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

Newfoundland and Labrador Region
Canadian Science Advisory Secretariat
Science Advisory Report 2017/023

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

Snow Crab (Chionoecetes opilio)

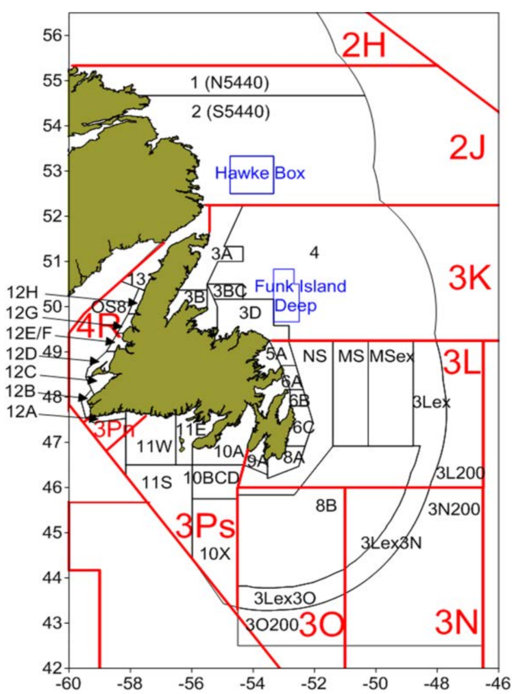

Figure 1: Northwest Atlantic Fisheries Organization Divisions (red lines), Newfoundland and Labrador Snow Crab Management Areas (black lines), and trawling and gillnetting closures (blue boxes).

Context

Snow Crab (Chionoecetes opilio) occupy a broad geographic range in the Northwest Atlantic from Greenland to the Gulf of Maine. Distribution in waters off Newfoundland and southern Labrador is widespread and continuous.

Crab harvesters use fleets of baited conical traps. The minimum legal size is 95 mm carapace width (CW). This regulation excludes females and a large proportion of adult males from the fishery thereby promoting protection of reproductive capacity in the stock.

Total Allowable Catch (TAC) management was initiated in the late 1980s. This led to the development of multiple TAC-controlled crab management areas (CMAs - Fig. 1) with about 2,600 license holders across several vessel fleets under enterprise allocation in 2016. All fleets have designated trap limits, quotas, trip limits, fishing areas within Divisions, and differing seasons. A vessel monitoring system (VMS) was fully implemented in the offshore fleets in 2004, which comprises the majority of landings.

Stock status is assessed annually within each Northwest Atlantic Fisheries Organization (NAFO) Division. Resource status is evaluated based on trends in fishery catch per unit of effort (CPUE), exploitable biomass indices, recruitment prospects, and mortality indices. Data are derived from multi-species bottom trawl surveys in Divs. 2HJ3KLNOP, Fisheries and Oceans Canada (DFO) inshore trap surveys in Divs. 3KLPs, fishery data from logbooks, observer catch-effort data, industry-DFO collaborative trap survey data, as well as biological sampling from multiple sources.

A Regional Peer Review Process meeting was held February 21-23, 2017, in St. John's, Newfoundland and Labrador (NL) to assess the status of the Snow Crab resource in NL. Participants included DFO scientists and fisheries managers, the fishing industry, the Provincial and Nunatsiavut governments, Aboriginal interests, and academia.

June 2017

SUMMARY

Divisions 2HJ3KLNOP4R

- **Landings** peaked at 53,500 t in 2009 and have since gradually declined to 42,000 t in 2016. Divisions 3LNO have accounted for about 80% of the landings in recent years.
- Fishery catch per unit of effort **(CPUE)** was at or near historical lows in most divisions in 2016.
- The overall **exploitable biomass** index has declined by 80% since 2013. All divisions are at or near their lowest observed levels of biomass, with an overall decline of 40% in 2016.
- Overall **recruitment** into the **exploitable biomass** was at its lowest observed level in 2016. No improvement or further reductions in **recruitment** are expected in the next 3-4 years. Thermal habitat, pre-recruit biomass, and predation indices collectively suggest poor broad-scale **recruitment** prospects.
- Total **mortality** in exploitable crabs has increased to be at or near time series' highs and **pre-recruit fishing mortality** rates have been at decadal highs in all divisions in recent years.
- Status quo removals would maintain **exploitation rate** indices above long-term average levels in most divisions. Divisions 3LNO, where the majority of remaining biomass occurs, will elevate to an exceptionally high level of exploitation.

Divisions 2HJ

- **Landings** have remained relatively low at less than 2,000 t since 2011. Meanwhile, **effort** has been substantially reduced and remained at or near its lowest level in the past four years.
- **CPUE** increased steadily from 2011-15 but decreased throughout the division in 2016 to a relatively low level. No improvements are anticipated in 2017.
- The trawl survey and collaborative post-season (CPS) trap survey-based **exploitable biomass** indices both increased sharply in 2014 and since declined by about half to relatively low levels.
- **Recruitment** has been relatively low throughout the 2000s. It spiked to a recent high in 2014 but subsequently decreased to more typical levels in both the trap and trawl surveys in the past two years.
- Short-term **recruitment** prospects appear poor as the pre-recruit biomass index was at or near its lowest level in the past two years.
- Despite abrupt annual fluctuations, the **pre-recruit fishing mortality** index has been increasing since 2005. It was at its highest level in a decade in 2016.
- Total **mortality** in exploitable crabs was at its highest observed level in 2016.
- While below historic peaks, the **exploitation rate** index doubled to 60% in 2016. Exploitation rates above 50% are associated with high levels of soft-shell discards. Status quo removals in 2017 would increase the exploitation rate index to 67%.

Division 3K

- **Landings** declined by 63% since 2009 to 5,600 t in 2016, a time series' low. **Effort** has remained near its lowest level for the past five years.
- **CPUE** has been low for the past six years reflecting recent lows in most management areas. It is expected to remain low in 2017.
- The post-season trawl and trap survey **exploitable biomass** indices both declined since 2008 to their lowest observed level in the past two years.
- **Recruitment** is at or near time series' lows throughout most of the division.
- **Recruitment** is expected to remain low in the short term with trawl and trap pre-recruit indices near time series' lows throughout the division.
- Maintaining current removals would leave the overall **exploitation rate** index unchanged in 2017, reflecting slight changes throughout most of the division. However, White Bay (crab management area [CMA] 3B) would double, to a historical high.

Divisions 3LNO Offshore

- **Landings** have remained at 22,000-29,000 t since 1999. **Effort** has gradually increased over this period, to a historic high in 2016.
- **CPUE** declined by a third from near a time series' high in 2013 to a two decade low in 2016. Substantial declines have occurred in all but management area MSex in recent years and further declines are anticipated in 2017.
- Both the trawl and trap surveys show considerable spatial contraction in high catch rates of exploitable crabs in recent years. The trawl survey **exploitable biomass** index, which covers the entire division, has precipitously declined since 2013 to a historic low. Both indices declined by about 50% in 2016, with the CPS trap survey index declining between 27-74% in the various management areas.
- Overall **recruitment** was at a historic low in 2016, reflecting low levels throughout most of the division.
- **Recruitment** prospects are very poor. The pre-recruit biomass index has been at its lowest level for the past three years.
- The **pre-recruit fishing mortality** index has been at or near the time series' high in the past two years.
- The **exploitation rate** index doubled to 60%, a historic high, in 2016. Status quo removals would double the index again in 2017, with increases occurring in all management areas.

Division 3L Inshore

- **Landings** increased throughout the 2000s and remained at about 8,000 t since 2013. **Effort** had oscillated without trend from 2005-16 but increased by 40% in 2016 to a time series' high.
- Overall **CPUE** was near its highest observed level during 2014-15 but abruptly declined by about 40% in 2016 to its lowest level in a decade. This reflected decreases ranging from 20-48% in the various management areas.
- The post season trap survey **exploitable biomass** index changed little from 2004-15 but declined by a third in 2016. This reflected decreases ranging from 12-46% in the various management areas.
- Overall recruitment into the **exploitable biomass** has steadily declined since 2010 to a time series low. **Recruitment** indices from DFO and CPS trap surveys in all management areas were at or near their lowest levels in 2016.
- **Recruitment** is expected to remain low in most management areas in the short-term as inferred from pre-recruit indices from DFO and CPS trap surveys. However, improvements appear likely for Bonavista Bay (CMA 5A).
- The overall trap survey-based **exploitation rate** index increased gradually from 2006-16 to a time series' high. Maintaining status quo removals would increase the exploitation rate by 52% in 2017. This reflects projected increases of 14-85% in all management areas, which would each remain near or achieve new time series' highs.

Subdivision 3Ps

- **Landings** declined from a recent peak of 6,700 t in 2011 to a time series low of 1,200 t in 2016. **Effort** reached a historic high in 2014 and has since decreased by half, with only 40-60% of the TAC taken in the past two years.
- **CPUE** has steadily declined since 2009 to a record low in 2016, reflecting precipitous declines throughout most of the Subdivision in recent years.
- The **exploitable biomass** index declined by 88% since 2010 to a time series low in 2016.
- Overall **recruitment** has declined since 2009 to its lowest observed level.
- **Recruitment** is expected to remain low in the short term (2-3 years) as the pre-recruit biomass index has remained at its lowest level for four consecutive years.
- Total **mortality** in exploitable crabs declined from its highest level in 2013 to about average in 2016. Coincidentally, the **exploitation rate index** has also declined by more than half since its 2013 peak due to the substantial decline in fishing.
- The impact of maintaining the current level of fishery removals on the **exploitation rate** is unknown.
- Concern is expressed that discards comprised half the catch in 2016. The four highest levels in the **pre-recruit fishing mortality** index have occurred during the past four years. Continuing to fish under elevated mortality levels on sub-legal-sized crabs could potentially impair reproductive capacity.

Divisions 4R3Pn

- **Landings** increased from a historic low of 190 t in 2010 to between 700-900 t since 2012. **Effort** has been relatively unchanged since 2012.
- Overall **CPUE** has been low throughout the time series relative to most other divisions. However, most management areas within Divisions 4R3Pn experienced catch rates near time series' highs during 2012-14. CPUE has declined back to low levels in most management areas in the past two years but remains relatively strong in CMAs 12C and 12G.
- The post-season trap survey **exploitable biomass** index most recently peaked in 2011 and has since gradually declined, reflecting patterns in most surveyed areas.
- Overall **recruitment** most recently peaked in 2012 and has since declined to low levels in all surveyed areas.
- **Recruitment** prospects appear relatively weak for the next 2-3 years, as pre-recruit indices have been low in most surveyed areas following relatively high levels within the 2008-13 period.
- The overall **exploitation rate** index has increased since 2013 in all surveyed areas. Status quo removals would elevate the exploitation rate index to a new high, predominately reflecting a large increase in the Bay of Islands (CMAs 12EF).

Ecosystem Perspective

- The ecosystem changes observed in the late 1980s and early 1990s involved the collapse of the finfish community, and the increase in shellfish. Consistent signals of finfish rebuilding appeared in the mid-late 2000s, which coincided with the decline in shellfish. Despite the observed increases in finfish, overall ecosystem biomass is still significantly below pre-collapse levels.
- Finfish biomass has been relatively stable in 2010-15, but recent surveys are suggesting a downward trend. This is most evident on the Grand Bank (Divisions 3LNO). Overall, it appears that the conditions that led to the start of finfish rebuilding have weakened. This may be linked to the simultaneous reductions in capelin and shrimp availability, as well as other changes in ecosystem conditions.
- Predation mortality on Snow Crab has increased since the late 2000s and early 2010s in most divisions, and shows important differences in magnitude across ecosystem units. Southern Newfoundland (Subdivision 3Ps) has predation levels an order of magnitude higher than other areas. Still, predation mortality in the Grand Bank (Divisions 3LNO) and Newfoundland Shelf (Divisions 2J3K) has coarsely increased five-fold over the last 4 to 5 years.
- Trends in predation mortality suggest that this factor may already be an important driver for Snow Crab in Southern Newfoundland (Subdivision 3Ps), and it may become one in other areas in the short to medium term.

BACKGROUND

Species Biology

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

Crabs grow by molting, in late winter or spring. Females cease molting after sexual maturity is achieved at about 40-75 mm CW and do not contribute to the exploitable biomass. However, sexually mature (adolescent) males generally molt annually until their terminal molt, when they develop enlarged claws (adults), which likely enhances their mating ability. Males molt to adulthood at any size above about 40 mm CW, and so only a portion of any cohort will recruit to the fishery at 95 mm CW. Age is not determined, but Snow Crab are believed to recruit to the fishery at about 8-10 years of age in warm areas (Divisions [Divs.] 2J3K4R3Pn) and at slightly older ages in cold areas (Divs. 3LNOPs), due to less frequent molting at low temperatures (Dawe et al. 2012).

Snow Crab is a stenothermal species and temperature has a profound effect on production, early survival, and subsequent recruitment to fisheries (Foyle et al. 1989; Dawe et al. 2008; Marcello et al. 2012). Cold conditions during early life history are associated with increased fishery catch per unit of effort (CPUE) and survey biomass indices several years later. Low temperature also promotes relatively small size at terminal molt (Dawe et al. 2012), resulting in an increased portion of crabs failing to recruit to the fishery. However, the positive effect of cold water on early survival is clearly stronger than the negative effect on size-at-terminal molt.

Adult legal-sized males remain new-shelled with low meat yield throughout the remainder of the year of their terminal molt. They are considered to be pre-recruits until the following year when they begin to contribute to the exploitable biomass as older-shelled adults. Males may live a maximum of about 6-8 years as adults after the terminal molt.

Snow Crab undertake an ontogenetic migration from shallow cold areas with hard substrates to warmer deeper areas with soft substrates. Large males are most common on mud or mud/sand, while smaller crabs are common on harder substrates. Some crabs also undertake a migration in the spring for mating and/or molting. Although the dynamics of spring migrations are not fully understood, they are generally from deep to shallow areas. The Snow Crab diet includes 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 (crab management area [CMA] 6A, Fig. 1) in 1967. Initially, crabs were taken as gillnet by-catch, but within several years a directed trap fishery developed in inshore areas along the northeast coast of Divs. 3KL. The minimum legal mesh size of traps is 135 mm (5 ¼”) to allow small crab to escape. Under-sized and new-shelled males that are retained in the traps are returned to the sea and an unknown proportion dies.

Until the early 1980s, the fishery was prosecuted by approximately 50 vessels limited to 800 traps each. In 1981, fishing was restricted to the Northwest Atlantic Fisheries Organization (NAFO) Division adjacent to where the license holder resided. During 1982 to1987, there were major declines in the resource in traditional areas in Divs. 3K and 3L, while new fisheries started in Div. 2J, Subdivision [Subdiv.] 3Ps, and offshore Div. 3K. A Snow Crab fishery began in Div. 4R in 1993.

Licences supplemental to groundfishing 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), introduced in 1995, were converted to licenses in 2003. There are now several fleet sectors and about 2,600 license holders.

In the late 1980s, quota control was initiated in all management areas of each Division. Current management measures include trap limits, individual quotas, trip limits, fishing areas within divisions, and differing seasons. The fishery has started earlier during the past decade and is now prosecuted predominately in spring, resulting in reduced incidence of soft-shelled crabs. A protocol was initiated in 2004 that results in closure of localized areas when the percentage of soft-shelled crabs within the legal-sized catch exceeds 20%. In Divs. 3LNO Offshore and 3L Inshore, the closure threshold was reduced to 15% in 2009. Mandatory use of the electronic 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. In recent years, landings most recently peaked at 53,500 t in 2009 and have since gradually declined to 42,000 t in 2016. Divisions 3LNO have accounted for a steadily increasing percentage of the catch, from about half in 2009 to 80% in recent years.

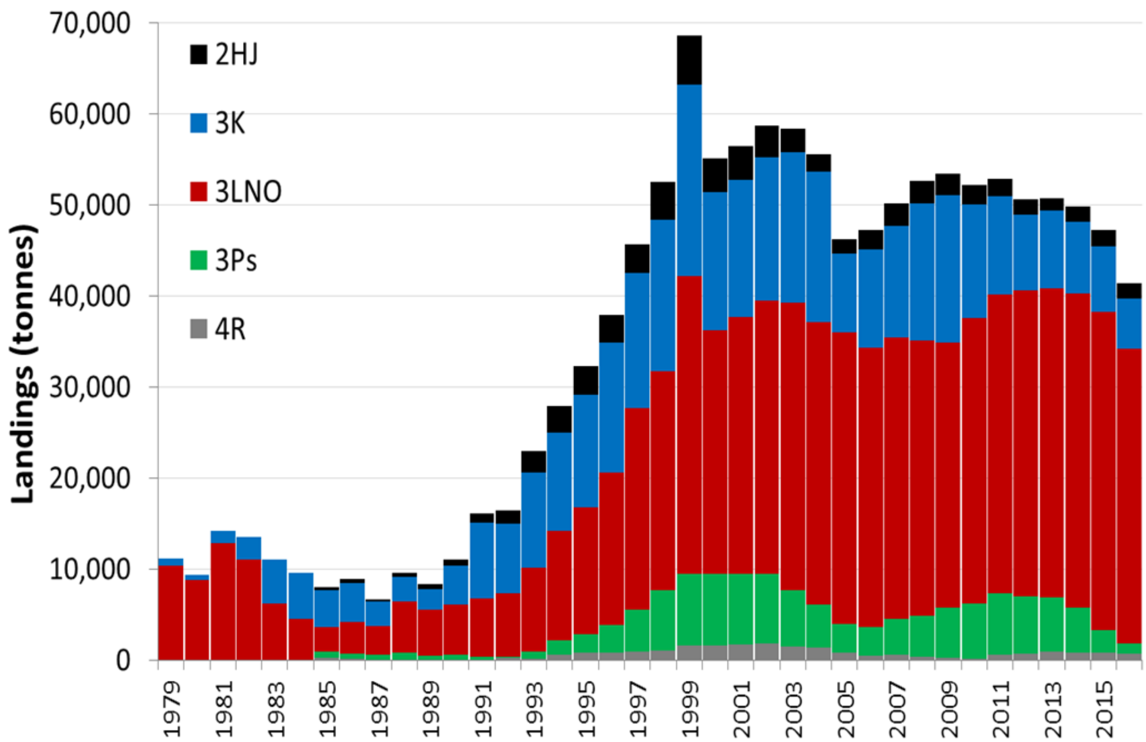

Figure 2: Annual landings by NAFO Division.

Effort increased since the 1980s and has been broadly distributed throughout most divisions in recent years (Fig. 3). Fishery CPUE is typically highest in Divs. 3LNO, adjacent to the southeast portion of the island of Newfoundland and extending east across the Grand Bank (Fig. 3). All Divisions experienced fishery catch rates at or near historical lows in 2016 (Fig. 4).

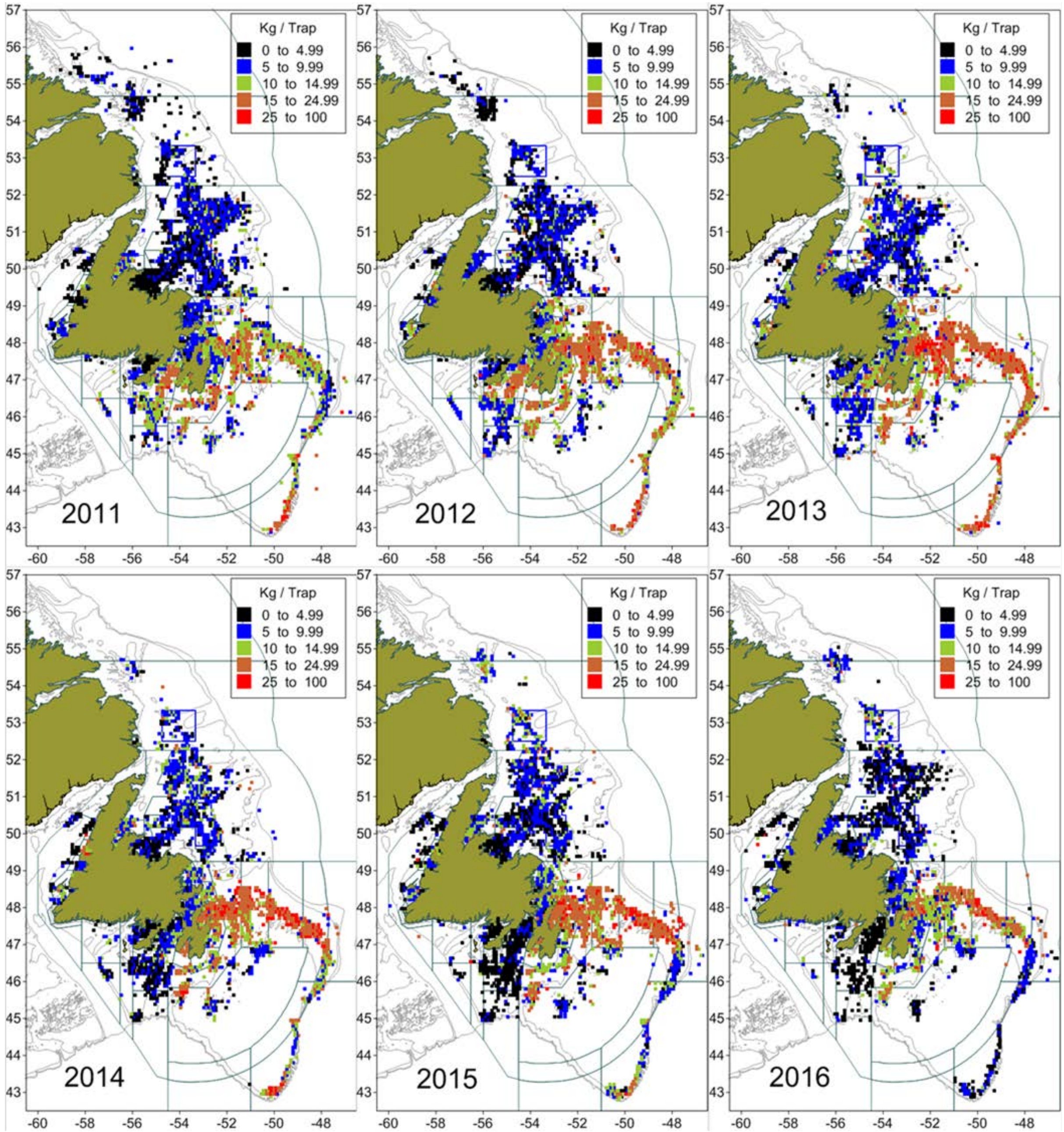

Figure 3: Spatial distribution of commercial fishing effort and CPUE during 2011-16.

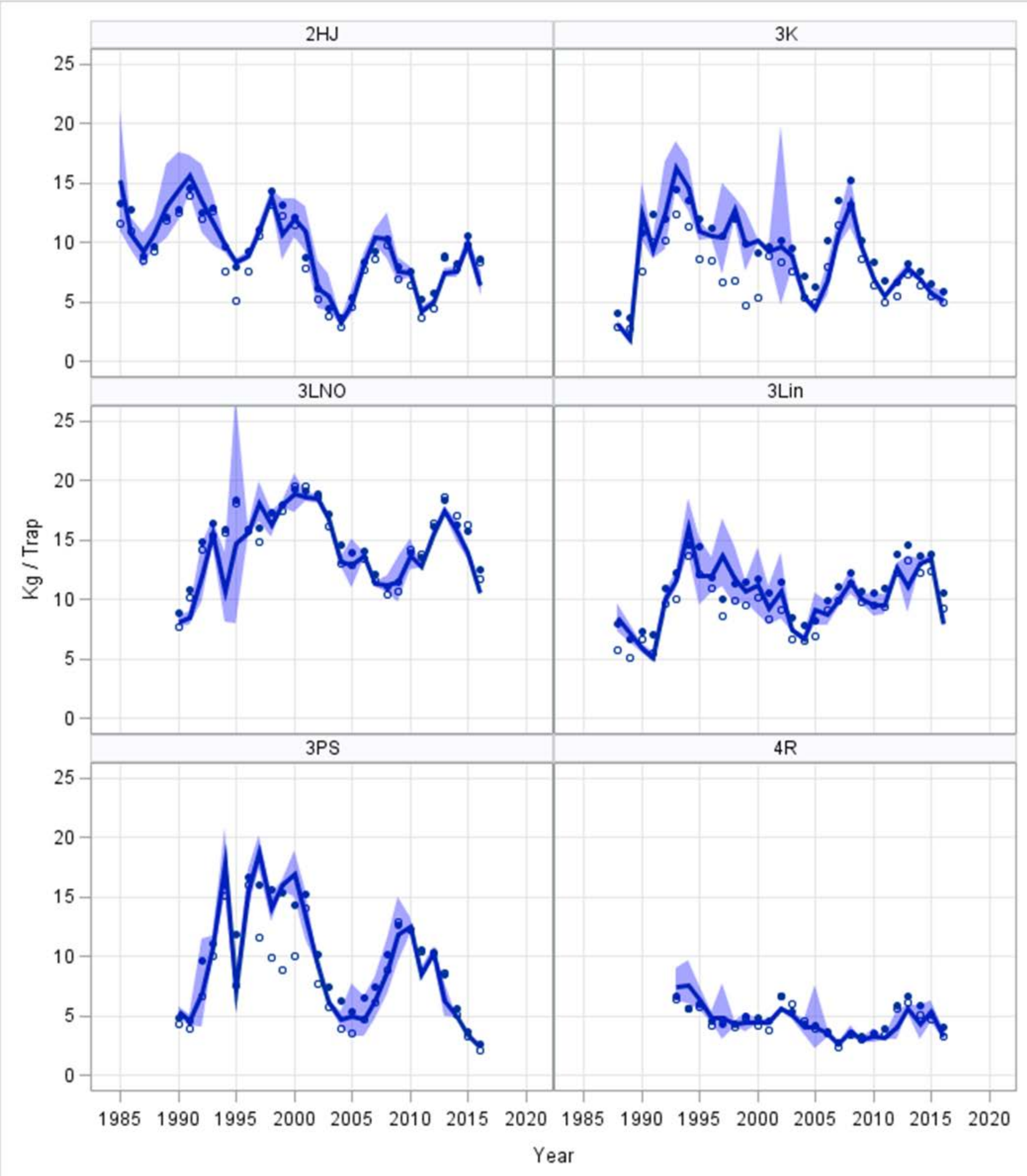

Figure 4: Standardized CPUE by assessment division. Open circles depict median catch rates and closed circles depict mean catch rates. Solid line is predicted CPUE and band is 95% confidence intervals.

The fishery is sometimes delayed in certain areas and years due to ice conditions (Divs. 2HJ and 3K) and price disputes. Late fishing seasons are believed to contribute to a high incidence of soft-shelled immediate pre-recruits in the catch. Severe ice conditions can affect the spatial distribution of fishing effort and fishery performance. Such severe ice conditions delayed the start of the 2014 and 2015 fisheries in Divs. 2HJ and 3K.

ASSESSMENT

Resource status was evaluated based on trends in fishery CPUE, survey exploitable biomass indices, fishery recruitment prospects, and mortality indices. Information was derived from multi-species bottom trawl surveys conducted during fall in Divs. 2HJ3KLNO and spring in Subdiv. 3Ps. A Campelen shrimp trawl has been used in these multi-species surveys beginning in 1995. Fisheries have begun earlier since the mid-2000s and now overlap with the timing of the spring trawl surveys in Subdiv. 3Ps. Information was also available from a fall Industry-DFO collaborative post-season (CPS) trap survey in Divs. 2J3KLO4R which was initiated in 2003. Fall post-season surveys provide the most recent data available for the annual assessment. Information is also utilized from DFO inshore trap surveys in Divs. 3KLPs, fishery data from logbooks and observer catch-effort data, as well as biological sampling data from multiple sources. Bottom temperature data from a frequently sampled oceanographic monitoring station outside St. John’s harbour (Station 27) were used to develop ocean climate indices toward inferring mid- and long-term recruitment prospects.

The resource is assessed by NAFO Division. However, Div. 2H is combined with Div. 2J 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 because the resource is managed at that unit. Div. 3L Inshore is assessed separately due to differences in data availability, with the trawl survey not normally extending into inshore bays. Finally, Subdiv. 3Pn is combined with Div. 4R to conform with management boundaries.

Generally, more data are available for offshore than inshore areas in most divisions with trawl survey data used only for offshore areas because these surveys have not consistently extended into inshore areas. However, in Subdiv. 3Ps, the spring trawl survey covers much of the inshore fishing areas, and in Divs. 2HJ virtually all the crab habitat is covered by the trawl survey. Observer coverage and sampling has also been more extensive in offshore management areas of most NAFO Divisions than in inshore areas.

The spring (Subdiv. 3Ps) and fall (Divs. 2HJ3KLNO) bottom trawl surveys are used to predict changes in biomass and recruitment for the upcoming fishery in the same year (spring Subdiv. 3Ps) or the following year (fall Divs. 2HJ3KLNO). These surveys, based on a stratified random sampling scheme, provide an index of exploitable biomass that is expected to be available for the upcoming fishery. This exploitable biomass index is based only on adults of legal size (≥ 95 mm CW). It is used together with an exploitable biomass index (all legal-sized crabs) from the CPS trap survey to evaluate trends in biomass available to the fishery. In Div. 3L Inshore and Divs. 4R3Pn no trawl survey is conducted and the CPS trap survey exploitable biomass index is compared with commercial CPUE and catch rates from inshore DFO trap surveys, where available (Div. 3L Inshore).

Trawl and trap survey biomass indices are derived using ogive mapping (‘Ogmap’) (Evans et al. 2000). Biomass estimates are not absolute because the capture efficiency of Snow Crab by the survey trawl is unknown but low, and the effective fishing area of a baited trap is not known. Trawl efficiency is directly related to substrate type and crab size, and so varies considerably spatially. Efficiency is lower and more variable on hard substrates than on soft substrates. Trawl survey catch rates are also affected by the diurnal cycle, being higher during dark periods. Other potential factors affecting trawl catchability include vessel and gear configuration. Trap effective fishing areas could potentially be affected by numerous factors including bait type, quantity, and quality, soak times, gear spacing, currents, and crab density. For the trawl survey, raw Ogmap exploitable and pre-recruit biomass estimates were adjusted by a catchability factor (Q) in each division. This Q was determined through logbook catch rate Delury depletion models, with each year in the time series scaled up by a common Q calculated as the ratio of annual trawl survey biomass to Delury logbook biomass in each division. For trap surveys, the effective fishing area of a trap was estimated at 0.01 km^2 to enable spatial expansion and biomass estimation in Ogmap.

Bottom trawl surveys also provide data on recruitment. Recruitment prospects for the upcoming fishery (in the next year) are inferred from biomass indices or catch rates of new-shelled legal-sized adults (immediate pre-recruits) from post-season or in-season trawl surveys. Trawl and trap surveys also provide indices of pre-recruit biomass, based solely on adolescent (non-terminally-molted) males larger than 75 mm CW. The adolescents of these groups would recruit in the short term (about 2-3 years).

Trawl surveys also provide abundance indices for males of all sizes. The abundance index for the smallest crabs consistently captured (about 12-30 mm CW) may indicate recruitment prospects about 6-7 years later, depending on NAFO Division. Longer-term recruitment prospects are inferred from the relationship of exploitable biomass indices (CPUE and survey) with a 'habitat index' several years earlier (Dawe et al. 2008, Marcello et al. 2012). The habitat index presented is a three-year running average of spring (March-June) bottom temperatures at Station 27. The thermal habitat index has remained tightly coupled with lagged biomass in all divisions since the mid-1990s, when finfish abundances and consequently predation pressure have been low. In future, if top-down pressures from fishing and predation increase, the reliability of the thermal habitat index as a leading indicator of Snow Crab stock status could diminish.

The CPS trap survey, based on a fixed-station grid design, is more spatially limited than the trawl survey as it targets only portions of commercial fishing grounds. A set of core stations was selected from this survey for calculating catch rates (number/trap) of legal-sized adults. These core stations represented those that were common to most years, especially recent years. A stratification scheme, developed for this assessment, was used for estimating biomass indices. The survey also includes small-meshed traps, deployed on select stations, to provide data on recruitment prospects.

Total mortality in the exploitable biomass is calculated from shell condition-specific biomass estimates from trawl surveys. The index of total annual mortality (A) is calculated as:

$$A = \sum_{p=2}^{\bar{x}} \frac{\left(Bnew(t-1) + Bold(t-1)\right)}{Bold\ (t)}$$

Where *Bnew* is biomass of soft + new-shelled crabs and *Bold* is the biomass of intermediate + old-shelled crabs, with *t* representing the current year and *t-1* representing the previous year. A smoothed two period moving average (p=2) is used to interpret trends to account for potential year effects in the trawl survey.

Fishery-induced mortality is a function of the proportion of the exploitable population that is harvested and the proportion of the pre-recruit population that dies as a result of being caught, handled, and released. Trends in exploitation rate are inferred from changes in the exploitation rate index (ERI), defined as landings divided by the exploitable biomass index from the most recent trap or trawl survey. Natural mortality rates are unknown.

Part of the catch is handled and released. Many of the discards are assumed to be pre-recruits. The ratio of the part discarded to the part kept, referred to as the pre-recruit fishing mortality index, represents an unknown mortality on pre-recruit crabs. The total catch (T) of undersized crabs (adolescent plus adult) is estimated by multiplying the total landings of all crabs by the ratio of undersized to landed crabs in observed catches. The fraction (U) that is handled and released is estimated as T divided by the trawl survey estimate of undersized crabs in the previous survey. The fraction U is then considered the same as the corresponding fraction for adolescents only. U is probably overestimated because the trawl misses many of the crabs, especially smaller crabs, in its path.

Resource Status

Landings

Landings most recently peaked at 53,500 t in 2009 and have since gradually declined to 42,000 t in 2016. Divs. 3LNO have accounted for a steadily increasing percentage in recent years, from about half in 2009 to 80% in recent years (Fig. 2).

In Divs. 2HJ, landings have remained relatively low at less than 2,000 t since 2011 (Fig. 5). In Div. 3K, they declined by 63% since 2008 to 5,600 t in 2016, their lowest level in two decades. In Divs. 3LNO Offshore, landings have remained at 22,000-29,000 t since 1999. In Div. 3L Inshore, they increased gradually throughout the 2000s and remained at 8,000 t since 2013. In Subdiv. 3Ps, landings declined from a recent peak of 6,700 t in 2011 to a time series low of 1,200 t in 2016, while in Divs. 4R3Pn they increased from a historic low of 190 t in 2010 to between 700-900 t since 2012.

Effort

Effort increased since the 1980s and has been broadly distributed in recent years (Fig. 3).

In Divs. 2HJ, effort has been substantially reduced and been at its lowest level during the past four years (Fig. 5). In Div. 3K, it has remained near its lowest level for the past four years. In Divs. 3LNO Offshore, effort has gradually increased since 2009 to a historic high in 2016. In Div. 3L Inshore effort had oscillated without trend from 2005-2016 but increased by 40% in 2016 to a time series high. In Subdiv. 3Ps, effort reached a historic high in 2014 and has since decreased by half, with only 40-60% of the TAC taken in the past two years. Finally, in Divs. 4R3Pn, effort has been relatively unchanged since 2012.

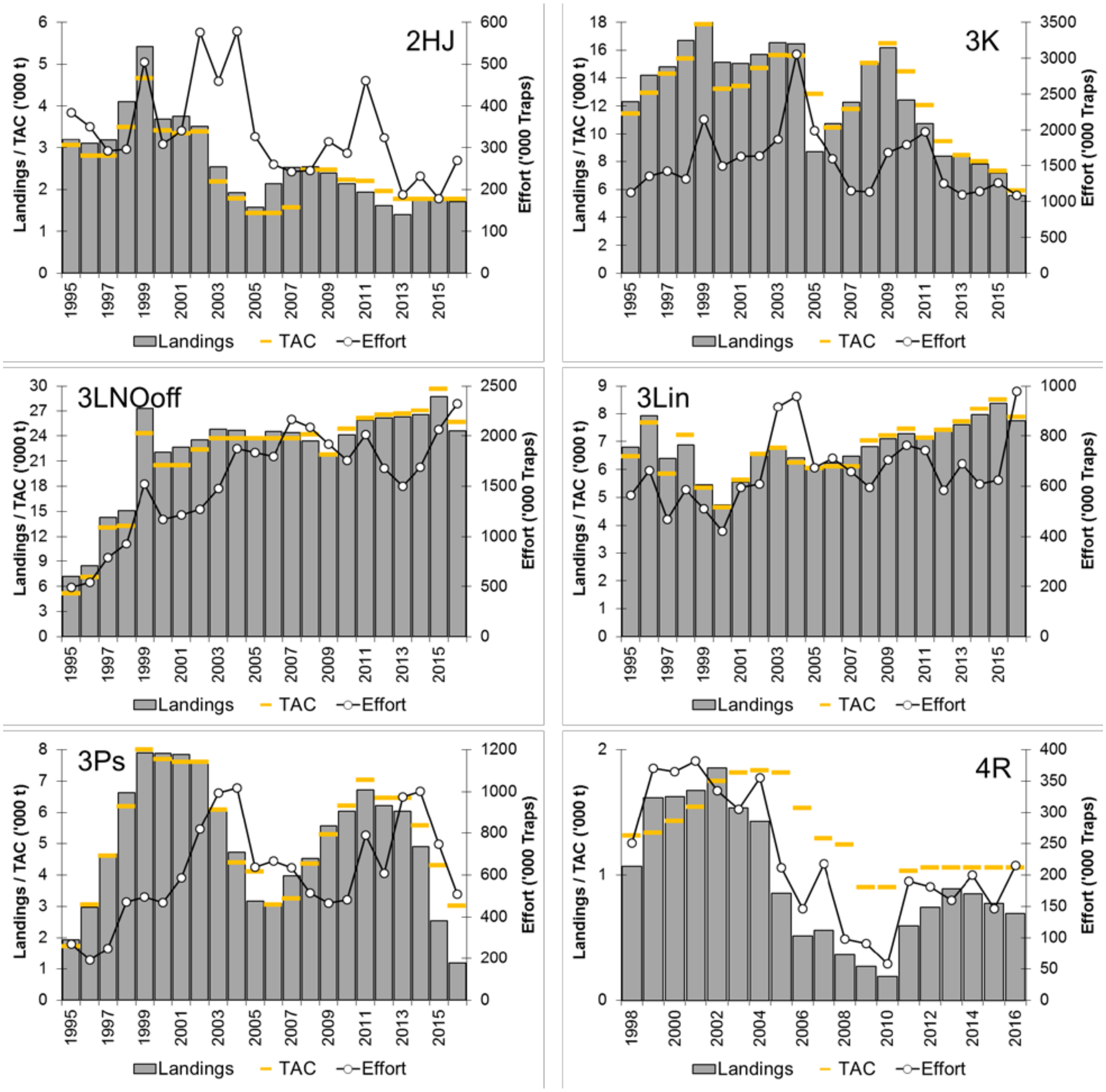

Figure 5: Annual landings, TAC, and estimated effort by assessment Division.

CPUE

CPUE increased steadily in Divs. 2HJ from 2011-2015 but decreased throughout the division in 2016 to a relatively low level (Fig. 4). In Div. 3K, it has been low for the past six years, reflecting recent lows in most management areas, and it is expected to remain low in 2017. In Divs. 3LNO Offshore, CPUE declined by a third from near a time series high in 2013 to a two decade low in 2016. Substantial declines have occurred in all but management area MSex in recent years and further declines are anticipated in 2017. In Div. 3L Inshore, CPUE was near its highest observed level during 2014-2015 but abruptly declined by about 40% in 2016 to its lowest level in a decade. This reflected decreases ranging from 20-48% in the various management areas. In Subdiv. 3Ps, CPUE has steadily declined since 2009 to a record low in 2016, reflecting precipitous declines throughout most of the Subdivision in recent years. Finally, in Divs. 4R3Pn, overall CPUE has been low throughout the time series relative to most other divisions (Figs. 3 & 4). However, most management areas within Divs. 4R3Pn experienced catch rates near time series' highs during 2012-2014. CPUE has declined back to low levels in most management areas in the past two years but remains relatively strong in CMAs 12C and 12G.

Exploitable Biomass

Multi-species trawl surveys indicate that the exploitable biomass was highest at the start of the survey series (1995-1998) (Fig. 6). It declined from the late 1990s to 2003 and then varied without trend until 2013. However, it has declined by 80% since 2013, with an overall decline of 40% in 2016.

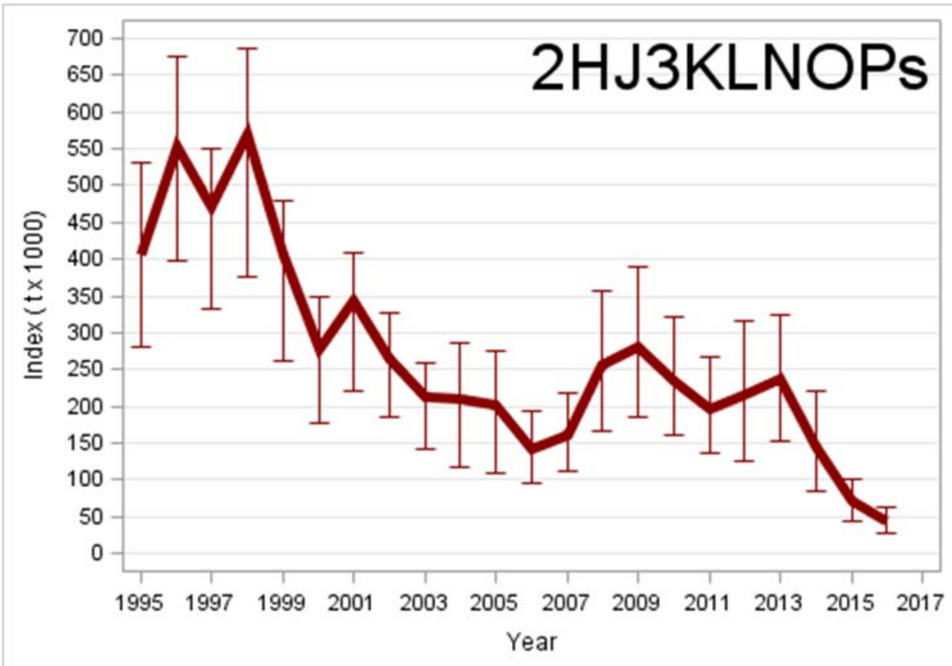

Figure 6: Overall trawl survey exploitable biomass index for Divs. 2HJ3KLNOPs. Index is the sum of annual point estimates and confidence intervals for individual assessment divisions.

All divisions are currently at or near their lowest observed levels of biomass (Fig. 7). In Divs. 2HJ, the trawl survey and collaborative post-season trap survey-based exploitable biomass indices both increased sharply in 2014 and since declined by about half to relatively low levels. In Div. 3K, the post-season trawl and trap survey exploitable biomass indices both declined since 2008 to their lowest observed level in the past two years. In Divs. 3LNO Offshore, both the trawl and trap surveys show considerable spatial contraction in high catch rates of exploitable crabs in recent years. The trawl survey exploitable biomass index, which covers the entire division, has precipitously declined since 2013 to a historic low. Both indices declined by about 50% in 2016, with the CPS trap survey index declining between 27-74% in the various management areas. In Subdiv. 3Ps, the exploitable biomass index declined by 88% since 2010 to a time series low in 2016.

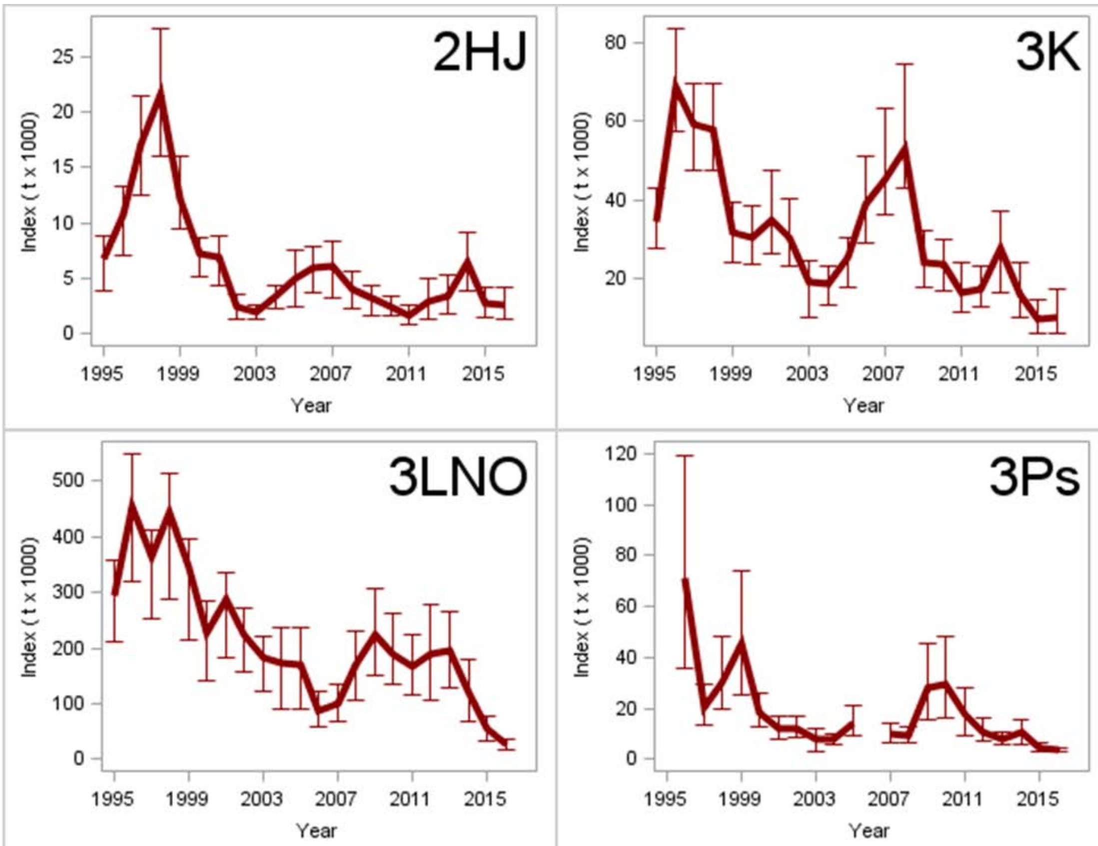

Figure 7: Trawl survey exploitable biomass indices by assessment division.

In Div. 3L Inshore, the post season exploitable biomass index changed little from 2004-15 but declined by a third in 2016. This reflected decreases ranging from 12-46% in the various management areas. In Divs. 4R3Pn, the post-season trap survey exploitable biomass index most recently peaked in 2011 and since gradually declined, reflecting patterns in most surveyed areas.

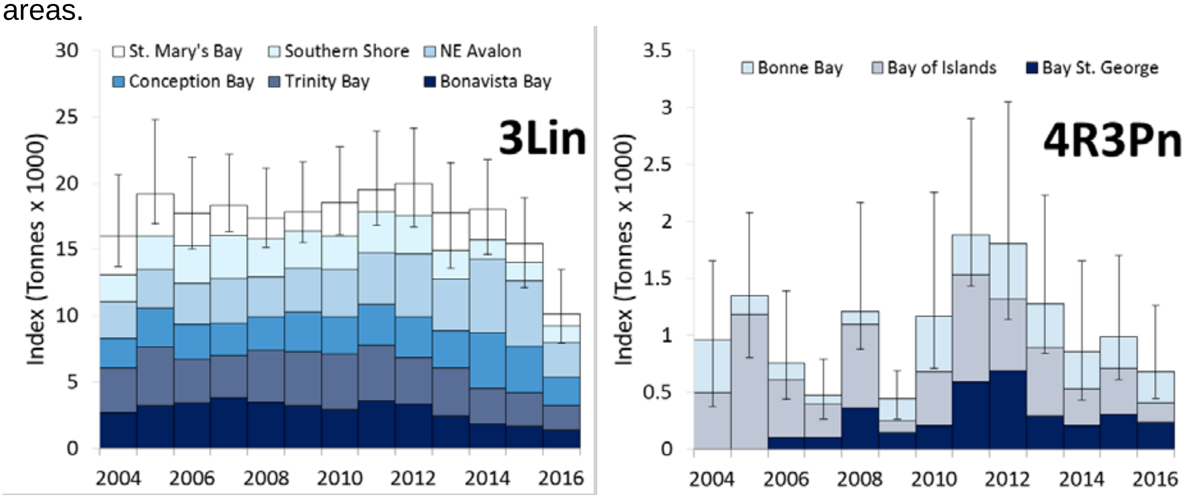

Figure 8: Trap survey exploitable biomass indices for Divs. 3L Inshore and 4R3Pn.

Mortality

Total mortality in exploitable crabs has increased to be at or near time series' highs in most divisions (Fig. 9). However, total mortality in exploitable crabs in Subdiv. 3Ps has decreased to near average levels in the past two years.

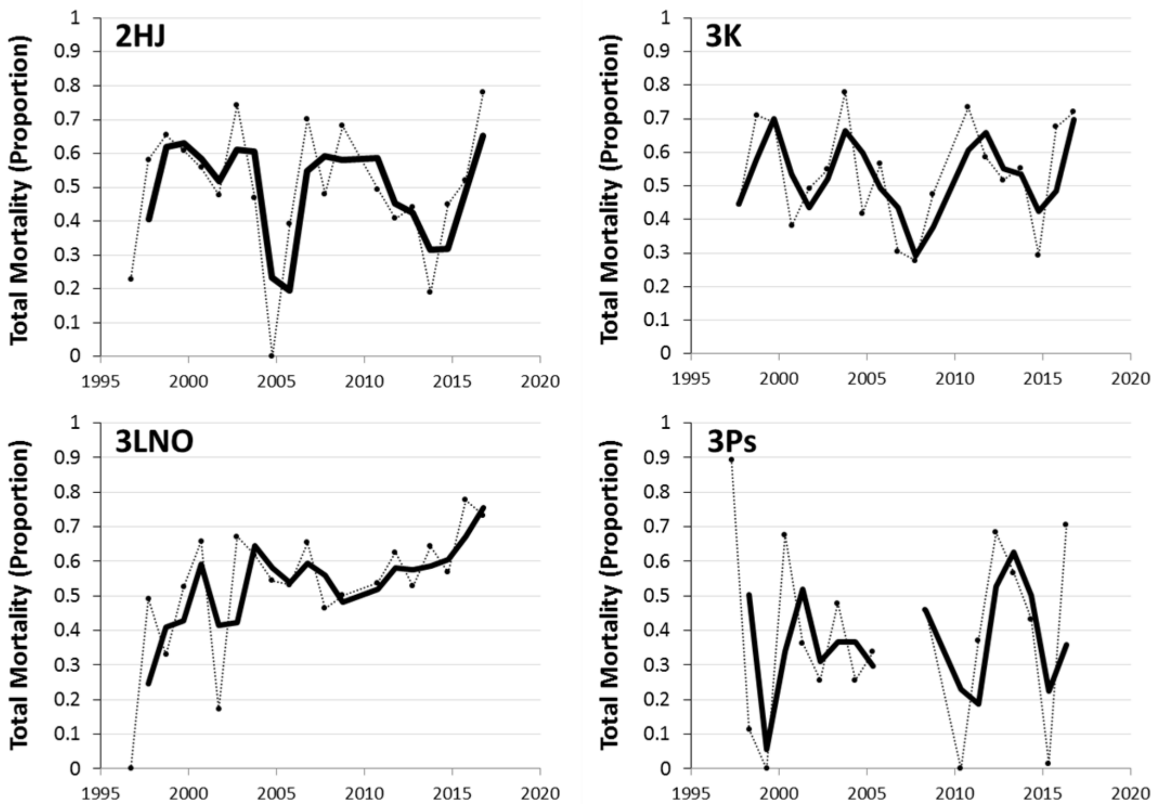

Figure 9: Trawl survey shell conditions-based index of annual total mortality in exploitable crabs, by assessment division. Annual point estimates (thin lines) versus two period moving averages (thick lines).

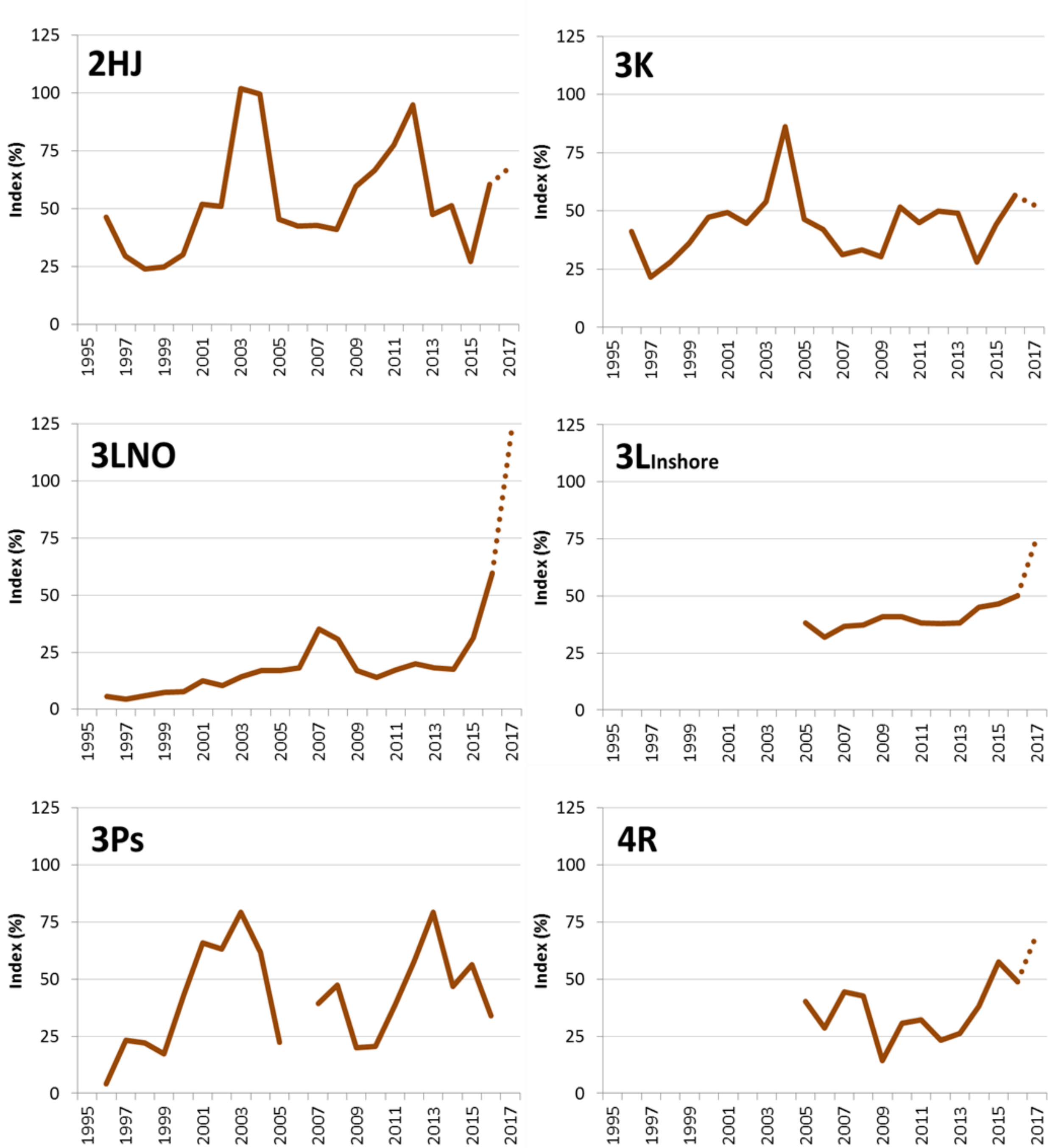

Figure 10: Trends in the exploitation rate indices by assessment division. Dashed lines depict projected 2017 exploitation rate indices based on status quo landings. Divisions 2HJ, 3K, 3LNO, and 3Ps based on trawl surveys. Divisions 3L Inshore and 4R based on trap surveys.

Trends in total mortality in exploitable crabs have generally reflected trends in exploitation rates in recent years. In Divs. 2HJ, the exploitation rate index doubled to 60% in 2016 but remains below historical peaks (Fig. 10). Status quo removals in 2017 would increase the exploitation rate index to 67%. Historically, exploitation rates above 50% in the index in Divs. 2HJ have been associated with high levels of soft-shell discards. In Div. 3K, the exploitation rate index was at its second highest level in the time series in 2016 (Fig. 10). Maintaining current removals would leave the exploitation rate index unchanged in 2017, reflecting slight changes throughout most of the division. However, the exploitation rate in White Bay (CMA 3B) would double, to a historical high. In Divs. 3LNO Offshore, the exploitation rate index doubled to 60%, a historic high, in 2016. Status quo removals would double the index again in 2017, with increases in all management areas. In Div. 3L Inshore, the trap survey-based exploitation rate index increased gradually from 2006-16 to a time series high and maintaining status quo removals would increase the exploitation rate by 52% in 2017. In Subdiv. 3Ps, the exploitation rate index declined by more than half since its 2013 peak due to the substantial decline in fishing. The impact of maintaining current removals is unknown, as projections are not possible because the survey is conducted in the spring. Finally, in Divs. 4R3Pn, the overall exploitation rate index has increased since 2013 in all surveyed areas and status quo removals in 2017 would elevate the exploitation rate index to a new high, predominately reflecting a large increase in the Bay of Islands (CMAs 12EF).

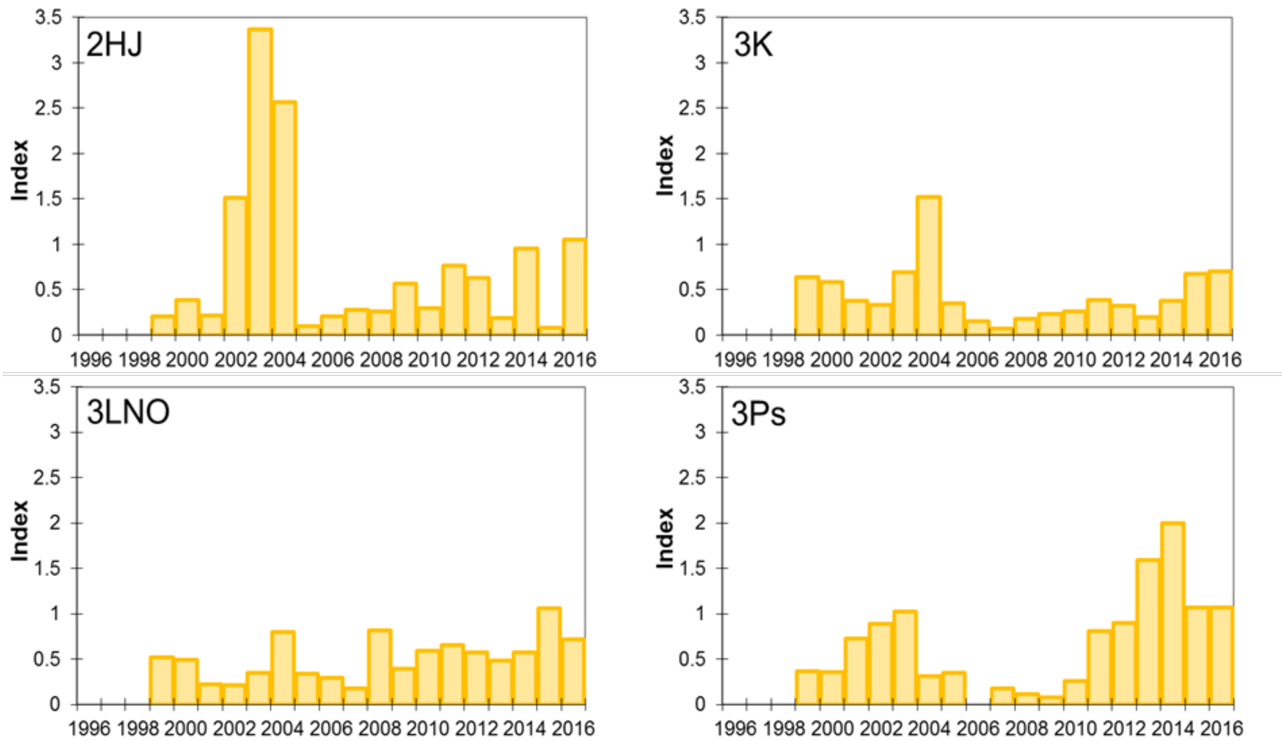

Figure 11: Trends in the pre-recruit fishing mortality rate index by assessment division.

Pre-recruit fishing mortality rates have been at decadal highs in all divisions in recent years (Fig. 11), suggesting increased wastage of pre-recruits in the fishery. In Divs. 2HJ, the index has been increasing since 2005 to its highest level in a decade in 2016. Similarly, in Div. 3K the index increased since 2007 to a decadal high in 2016. In Divs. 3LNO Offshore, the pre-recruit mortality index has been at or near time series' highs in the past two years, while in Subdiv. 3Ps the four highest levels of the pre-recruit fishing mortality index have occurred during the past four years and continuing to fish under elevated mortality levels on sub-legal-sized crabs could impair reproductive capacity.

Recruitment and Outlook

Overall recruitment into the exploitable biomass was at its lowest observed level in 2016. No improvement or further reductions in recruitment are expected in the next 3 - 4 years. In Divs. 2HJ, recruitment has been relatively low throughout the 2000s. It spiked to a recent high in

2014 but subsequently decreased to more typical levels in both the trap and trawl surveys in the past two years. In Divs. 3K and 3LNO Offshore, recruitment was at or near time series' lows in 2016, reflecting lows throughout those divisions. In Div. 3L Inshore, recruitment indices from DFO and CPS trap surveys in all management areas were at or near their lowest levels in 2016. In Subdiv. 3Ps, recruitment is expected to remain low in the short term (2-3 years) as the pre-recruit biomass index has remained at its lowest level for four consecutive years. Finally, in Divs. 4R3Pn, overall recruitment most recently peaked in 2012 and has since declined to low levels in all surveyed areas.

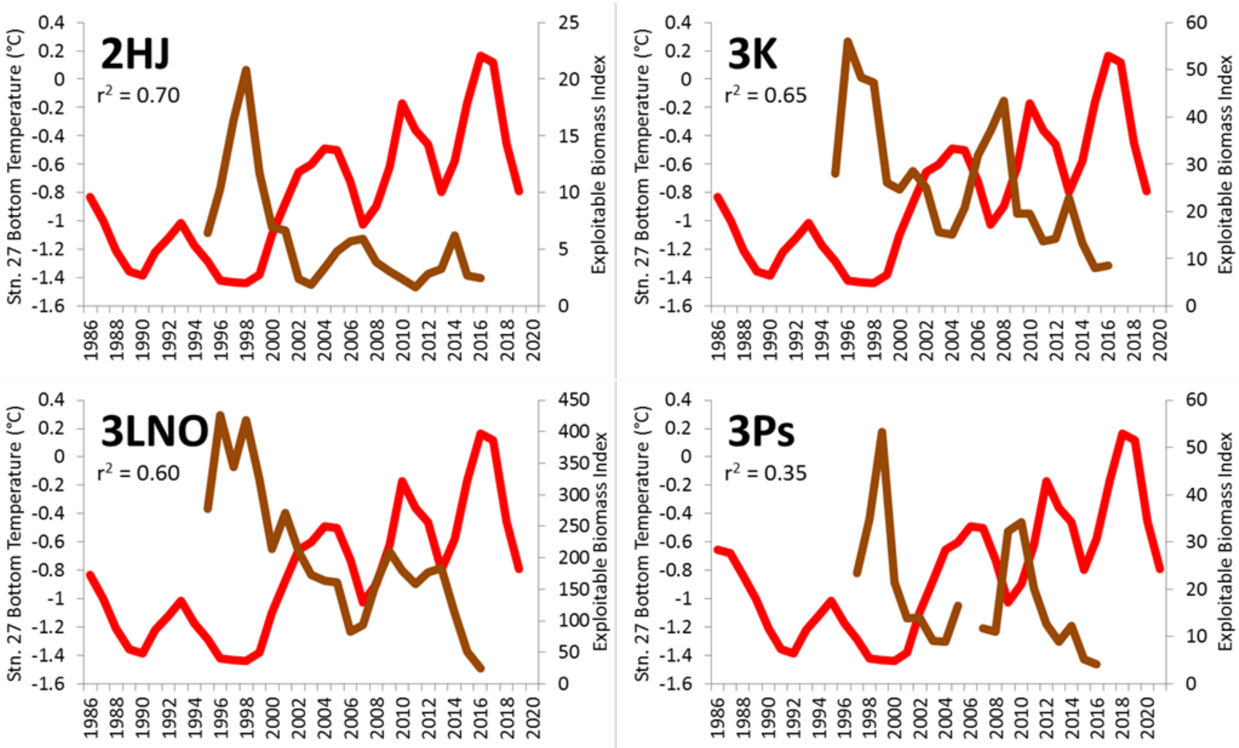

Figure 12: 3-year moving average, ending in the terminal years, of spring (March-June) bottom temperatures at Station 27 (red line) versus exploitable biomass indices (brown line) by assessment division. Temperature index lagged by three years in Divs. 2HJ, 3K, and 3LNO, and five years Subdiv. 3Ps.

A thermal habitat index defined as a three year moving average of bottom temperature from the Station 27 oceanographic monitoring station relates negatively to exploitable biomass indices in all divisions (Fig. 12) and suggests further reductions or no improvements are likely to occur in the exploitable biomass in all divisions in the next 3-4 years.

Thermal habitat (Fig. 12), pre-recruit biomass (Figs. 13 and 14), and predation (Fig. 15) indices collectively suggest poor broad-scale recruitment prospects.

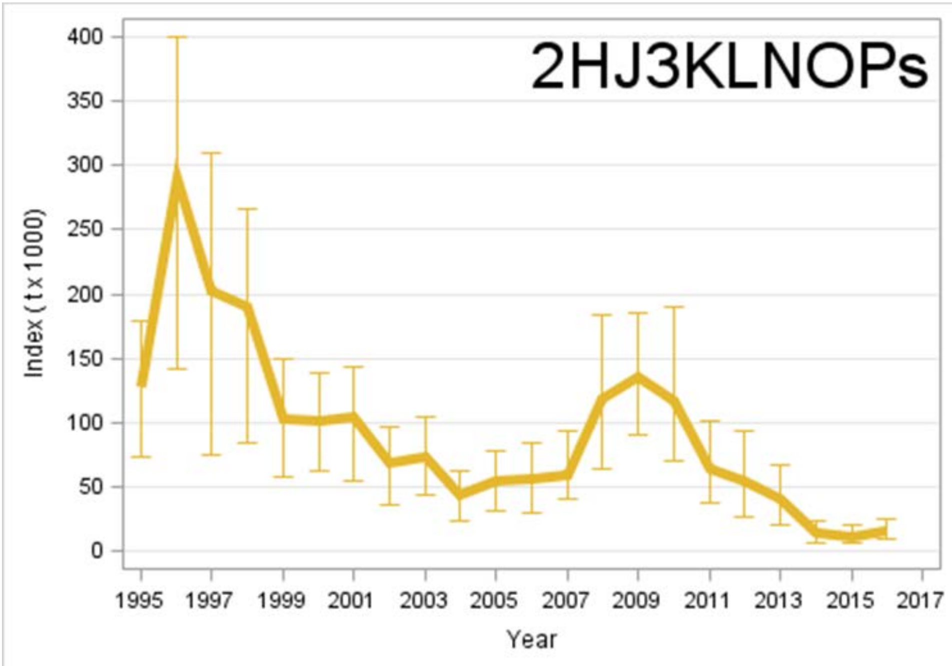

Figure 13: Overall trawl survey pre-recruit biomass index for Divs. 2HJ3KLNOPs. Index is the sum of annual point estimates and confidence intervals for individual assessment Divisions.

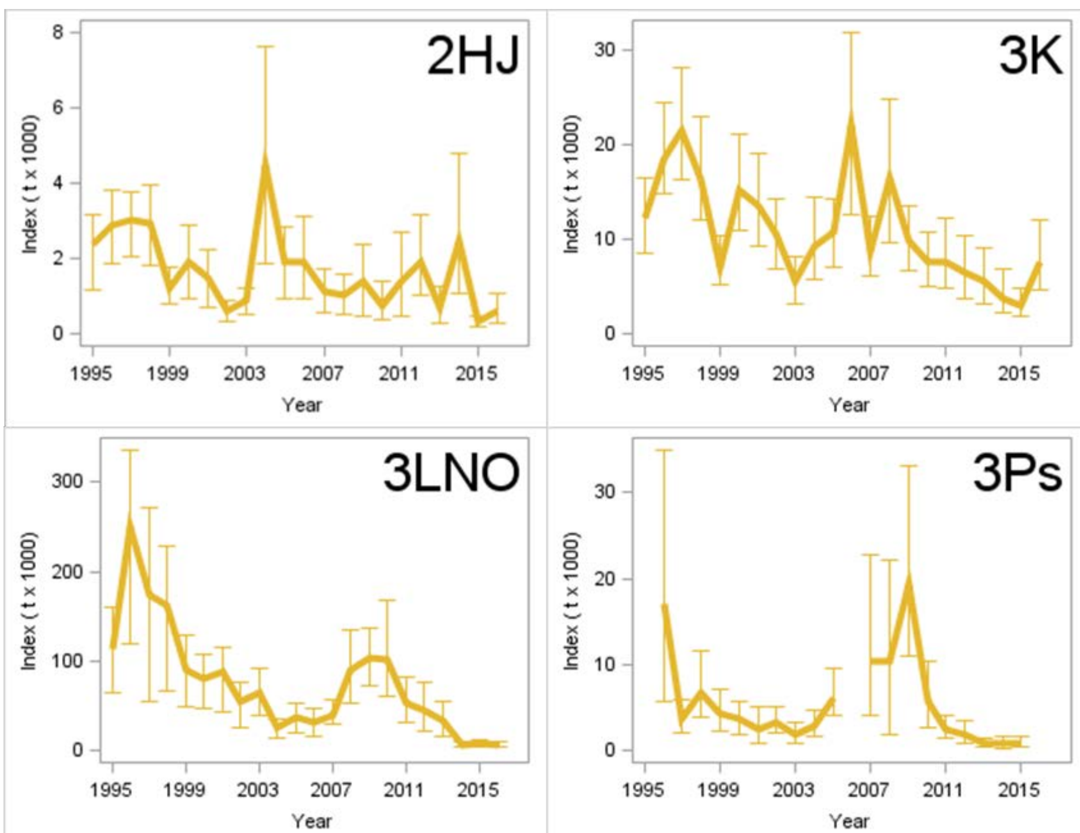

Figure 14: Trawl survey pre-recruit biomass indices by Division.

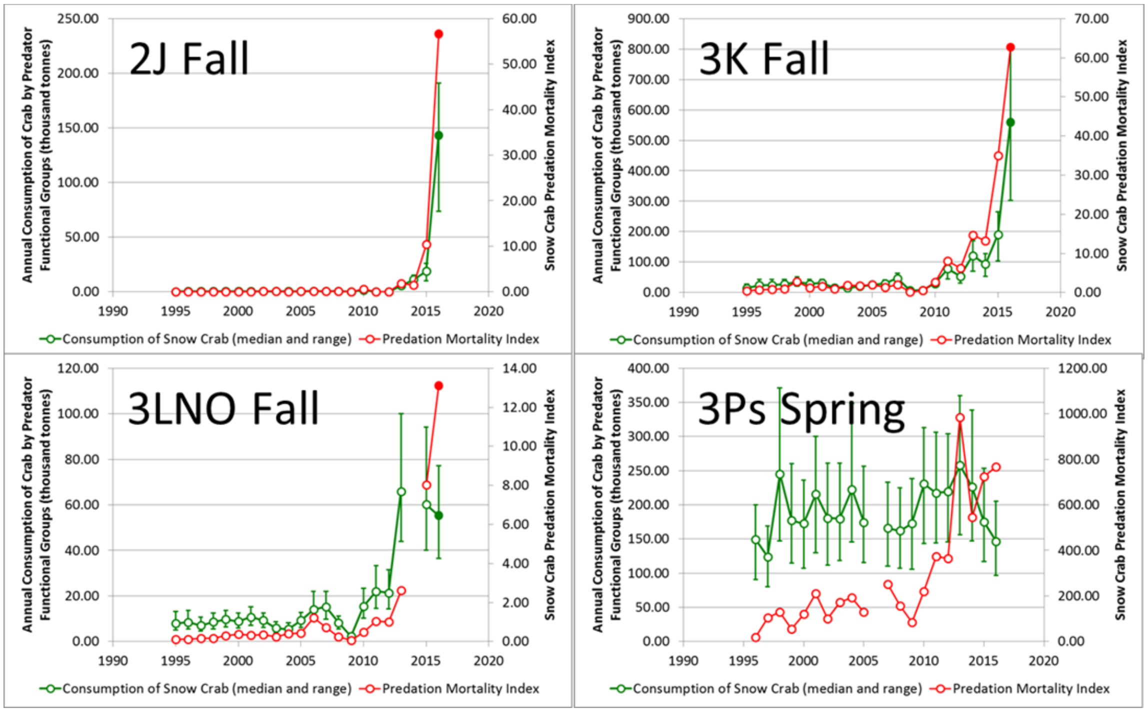

Figure 15: Consumption of Snow Crab by predators by assessment division. Green represents estimated consumption and red is an index of predation mortality. Solid symbols in 2016 denote preliminary data, with only cod and turbot stomachs processed to date.

Ecosystem Perspective

Trends in predation mortality suggest that this factor may already be an important driver for Snow Crab in Southern Newfoundland (Subdiv. 3Ps), and it may become one in other areas in the short to medium term. Predation mortality on Snow Crab has increased since the late 2000s and early 2010s in most divisions (Fig. 15), and shows important differences in magnitude across ecosystem units. Southern Newfoundland (Subdiv. 3Ps) has predation levels an order of magnitude higher than other areas. Still, predation mortality in the Grand Bank (Divs. 3LNO) and Newfoundland Shelf (Divs. 2J3K) has coarsely increased five-fold over the last 4 - 5 years.

Since the collapse of most of the finfish community in the early 1990s, the Snow Crab resource appears to have largely been under bottom-up temperature control (Fig. 12). The resource was most productive throughout the 1990s, but productivity has diminished coincident with warming over the past decade (Mullowney et al. 2014). Besides exerting a direct impact on early-life survival, a shift toward warmer conditions now appears to be affecting the Snow Crab resource indirectly, in the form of increased predation as finfish populations respond positively to warming.

Although impacts of predation on the fishery in most areas would be expected to be minimal at present (with finfish predation predominately occurring on small Snow Crab below about 40 mm CW [Chabot et al. 2008]) with the Snow Crab resource in decline, increased top-down controls in the forms of predation and fishing are likely to become more important in regulating the resource and consequently impact the fishery in the coming years.

Although a small pulse of young crabs (i.e. < 30 mm CW) has emerged in some divisions in recent years (i.e. Divs. 2HJ and 3K), overall, virtually all population components are at low levels relative to historical levels in all divisions (Fig. 16). Most data suggest that overall, short, medium, and long-term prospects appear relatively weak.

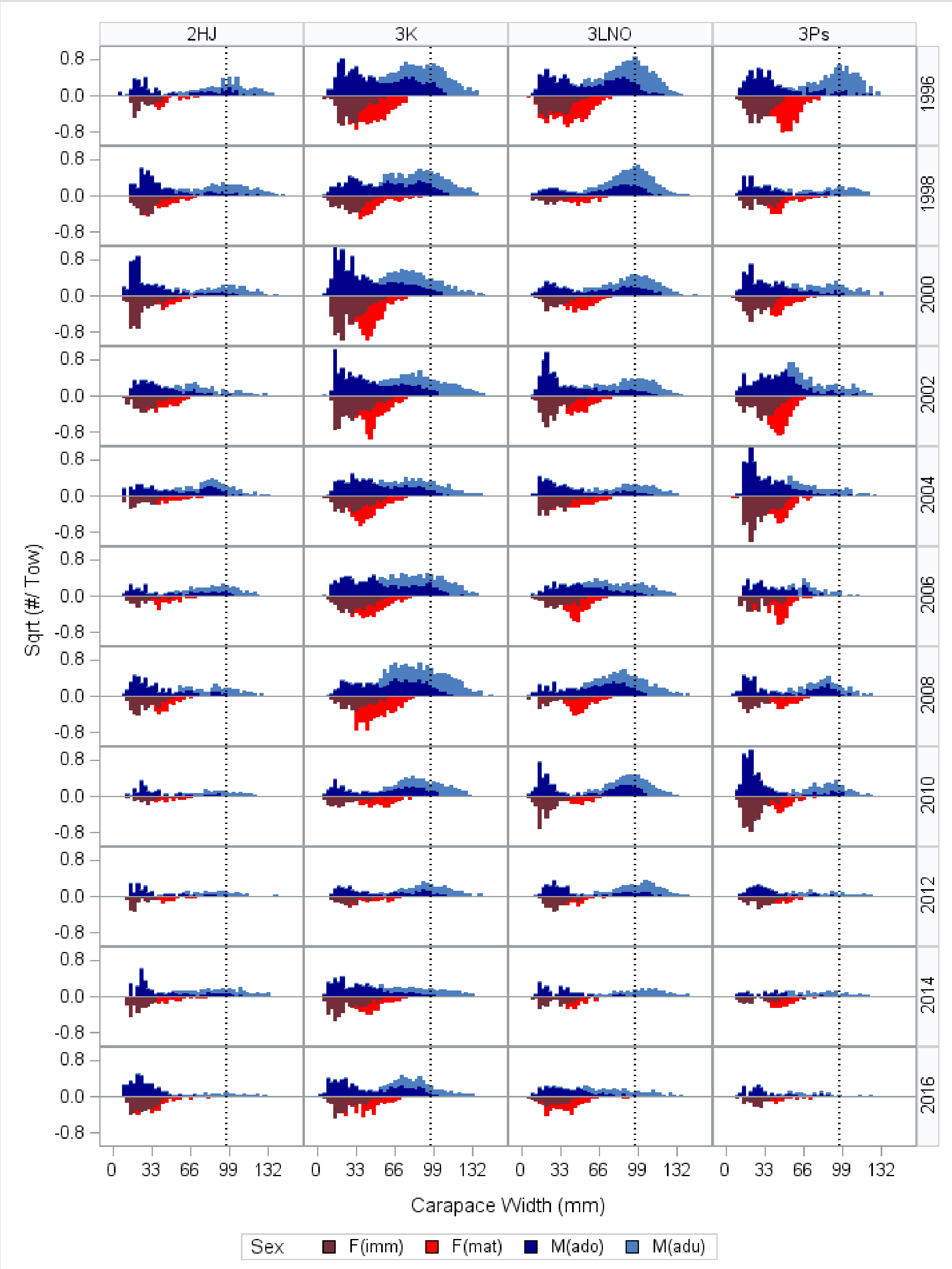

Figure 16: Abundance indices by carapace width for juveniles plus adolescent males (dark blue), adult males (light blue), immature females (dark red), and mature females (red) from spring (Subdiv. 3Ps) and fall (Divs. 2HJ3KLNO) trawl surveys. Dashed vertical line is legal-size. Data standardized by vessel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

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.

Surveys

Interpretation of trends in exploitable and pre-recruit biomass indices from surveys is highly uncertain if the survey was incomplete. The multispecies trawl surveys do not sample inshore areas in some NAFO Divisions.

It is difficult to predict recruitment from the trawl survey pre-recruit biomass index because it and the exploitable biomass index often trend together rather than at some delay. This is thought to be largely due to annual variation in survey trawl efficiency which likely affects trends in both indices. Trawl efficiency is directly related to substrate type and crab size, and so varies considerably spatially. Efficiency is lower and more variable on hard substrates than on soft substrates. Thus, annual survey catchability depends on the conditions at the positions randomly selected for the survey each year. Interpretation of indices from the spring trawl survey in Subdiv. 3Ps is more uncertain than for those from the fall surveys because they occur after a variable fraction of fishery removals.

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

Small-meshed traps are included in sampling by the CPS trap survey on 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 very limited spatial coverage by small-meshed traps, especially in shallow-water small-crab habitat, and high variability in trap catchability. Small adolescents may be particularly susceptible to trap catchability effects due to competition with larger and adult males.

Short-Term Recruitment

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

Long-Term Recruitment

There is high uncertainty about the reliability of lagged habitat indices as a leading indicator of future biomass (or CPUE), particularly under the scenario of changing oceanographic conditions and shifts in trophic control. A trend of recent warming is clearer in the northern areas (Divs. 2J and 3K) than in the southern areas (Divs. 3LNO and Subdiv. 3Ps). Continued long-term warming in all areas is inferred from multi-decadal oscillations in the ocean climate of the entire Atlantic Ocean that, in recent years, are consistent with changes observed on the NL shelf (Colbourne et al. 2011). However, there is uncertainty regarding whether such long-term oscillations will persist as they have in the past.

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. Overall, for the current assessment, 60% of the 2015 logbooks were available. The reliability of the logbook data is suspect with respect to effort (i.e. under-reporting) and areas fished. However, logbook data provide the broadest coverage and therefore the most representative fishery performance index.

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

There are concerns regarding the utility of the observer data from at-sea sampling during the fishery due to low and spatio-temporally inconsistent coverage, especially in Divs. 3L Inshore and 4R3Pn. These concerns introduce a strong bias in interpreting trends in catch rates at broad spatial scales. Observer-based indices are also biased by inconsistent sampling methods and levels resulting from changing priorities. There are also concerns relating to variability in experience of observers in subjectively assigning shell stages. This introduces uncertainty in inferring recent recruitment trends and prospects based on catch rates of new-shelled crabs.

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. An exploitation rate index is estimated for Divs. 3L Inshore and 4R3Pn based on the post-season trap survey biomass index. However, this index may be biased by annual changes in the distribution of crabs or fishing effort inside versus outside the limited survey areas. The index of pre-recruit fishing mortality is also not estimated for inshore areas due to insufficient observer data.

Ecosystem Change

Prolonged warming in waters surrounding most of Newfoundland and Labrador has promoted a general loss of productivity in cold water crustaceans such as Snow Crab and Northern Shrimp (*Pandalus borealis*) and some recovery in pelagic and groundfish species in recent years. However, the extent of community reorganization or change that will result in response to changing thermal conditions is unknown. The most recent years have been characterized by a high level of variability in ocean temperatures, which could slow or alter changes that have been occurring. Ultimately, if temperatures continue to warm, the prognosis for Snow Crab would be poor. However, rates, extent, and even direction of future climate and community changes in the marine shelf ecosystem are highly uncertain.

CONCLUSIONS AND ADVICE

Divisions 2HJ

While below historic peaks, the exploitation rate index doubled to 60% in 2016. Exploitation rates above 50% are associated with high levels of soft-shell discards. Status quo removals in 2017 would increase the **exploitation rate index** to 67%.

Division 3K

Maintaining current removals would leave the overall **exploitation rate** index unchanged in 2017, reflecting slight changes throughout most of the division. However, White Bay (CMA 3B) would double, to a historical high.

Divisions 3LNO Offshore

The exploitation rate index doubled to 60%, a historic high, in 2016. Status quo removals would double the index again in 2017, with increases occurring in all management areas.

Division 3L Inshore

The overall trap survey-based exploitation rate index increased gradually from 2006-16 to a time series high. Maintaining status quo removals would increase the exploitation rate by 52% in 2017. This reflects projected increases of 14 - 85% in all management areas, which would each remain near or achieve new time series' highs.

Subdivision 3Ps

The impact of maintaining the current level of fishery removals on the **exploitation rate** is unknown.

Concern is expressed that discards comprised half the catch in 2016. The four highest levels in the **pre-recruit fishing mortality** index have occurred during the past four years. Continuing to fish under elevated mortality levels on sub-legal-sized crabs could potentially impair reproductive capacity.

Divisions 4R3Pn

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

OTHER CONSIDERATIONS

Bitter Crab Disease (BCD)

This disease, which is fatal to crabs, occurs in new-shelled crab of both sexes, appears to be acquired during molting, and can be detected visually during autumn. Fall surveys indicate that it has been most persistent, albeit at low levels, in Div. 3K. Prevalence in small males is directly related to density (Mullowney et al. 2011) and has been low in most recent years throughout Divs. 2J3KL.

Reproductive Biology

The percentage of mature females carrying full clutches of viable eggs has generally remained high throughout the time series wherever measured. Fishery-induced mortality on mature males (including undersized males) could adversely affect insemination of females. Egg clutches have remained high but the abundance of mature females has declined wherever measured and been at very low levels during the past five years. While this is a concern, the implications for Snow Crab production are uncertain. The threshold level of mature female abundance below which larval supply would become limiting is unknown.

Management Considerations

Reproductive potential is at least partially protected by conservation measures that exclude females and males smaller than 95 mm CW, including a portion of the adult (large-clawed) males, from the fishery. Therefore, exploitation has been considered to have minimal impact on reproductive potential, relative to other fisheries.

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

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

Low and spatio-temporally variable observer coverage introduces high uncertainty in interpreting indices of biomass, recruitment, and mortality. Measures should be taken to ensure representative observer coverage and analysis so as to improve data quality from this program.

Among other uses, the 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 by closing localized areas (70 nM^2 grids) for the remainder of the season when a threshold level of 20% of the legal-sized catch is reached. It became evident during 2010-12 that this protocol, as implemented, is inappropriate and ineffectual in controlling handling mortality. This is largely due to very low observer coverage, together with the decision to treat unobserved grids as if they had no problem. In addition, failure to draw all the inferences possible from moderate-sized samples frequently resulted in failure to invoke the protocol even when it was clear that the level of soft-shelled crabs had exceeded the threshold. These shortcomings undermine the intent of the protocol. Although soft-shell incidence in the catch has been very low in all divisions for the past two years, consistent with diminishing recruitment prospects, measures should be taken to ensure representative observer coverage and analysis so as to better quantify prevalence of soft-shelled crabs in the fishery to afford better protection to recruitment if and when the situation improves.

The CPS trap survey is one of the primary data sources used to assess the resource. It operates under a compensation scenario of ‘quota-for-survey’ whereby harvesters are allocated additional quota in the following season in exchange for conducting the survey. However, the survey was incomplete this year in Subdiv. 3Ps 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. This has also occurred in other divisions in previous years. In the future, under the scenario of expected reduced exploitable biomass in most divisions, there are concerns the integrity of this survey could further deteriorate.

Precautionary Approach

Any credible precautionary approach management system should include information about resource size and renewal rate, or whether a given level of harvest is sustainable. Further, it should be concerned with what might be adjusted to protect or enhance the reproductive potential and the renewal rate.

Total mature male biomass (MMB) may provide an appropriate basis for future reference points, assuming that insemination of females and larval production may be reduced at low MMB. However, there has to date been no such effect, with the percentage of females carrying full clutches of viable eggs remaining high throughout the survey time series. Therefore there is as yet no evidence of harm to reproductive potential and consequently no basis for quantifying reference points.

The Snow Crab fishery imposes virtually no mortality on females and the smallest adult males; management measures are intrinsically conservative and promote avoidance of severe deleterious effects of fishing on recruitment when exploitation rates remain moderate to low. 'Caution' can then focus on more nuanced considerations such as exploiting large incoming recruitment peaks economically efficiently (avoiding killing them as undersized or soft-shelled, for example).

SOURCES OF INFORMATION

This Science Advisory Report is from the February 21-24, 2017 Newfoundland and Labrador Snow Crab Assessment. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2017. Assessment of Newfoundland and Labrador (divisions 2HJ3KLNOP4R) Snow Crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/023.

Aussi disponible en français :

MPO. 2017. Évaluation du crabe des neiges de Terre-Neuve-et-Labrador (divisions 2HJ3KLNOP4R). Secr. can. de consult. sci. du MPO, Avis sci. 2017/023.