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

Canadian Science Advisory Secretariat
Maritimes Region | Science Advisory Report 2019/053

ASSESSMENT OF SCOTIAN SHELF SNOW CRAB

Snow Crab (Chionoecetes opilio, O. Fabricius)

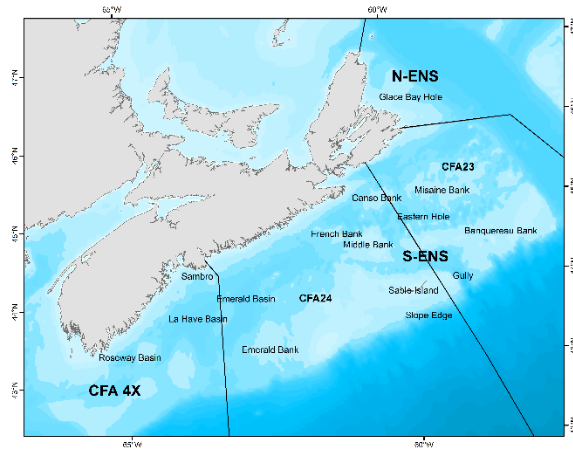


Figure 1. Map of the Scotian Shelf and Crab Fishing Areas (CFAs).

Context:

Snow Crab (Chionoecetes opilio, O. Fabricius) have been a dominant macro-invertebrate in the Scotian Shelf Ecosystem (SSE) since the decline of the groundfish. They are observed in large numbers in deep, soft-bottom substrates ranging from 60 to 280 m and at temperatures generally less than 6°C. The SSE Snow Crab are in the southern-most extreme of their spatial distribution in the Northwest Atlantic.

The fishery has been in existence since the early 1970s in Nova Scotia. The management of the Snow Crab fisheries in the SSE was initially based on effort controls (season, license, trap limits) from 1982 to 1993 with harvesting during June–November of hard shelled males larger than 95 mm Carapace Width. Additional management measures were introduced from 1994 to 1999: individual boat quotas, Total Allowable Catches (TACs), 100% dockside monitoring, mandatory logbooks, and at-sea monitoring by certified observers. In 2005, many Crab Fishing Areas (CFAs) and subareas were merged with the resulting divisions being North-Eastern Nova Scotia (N-ENS) (CFAs 20–22), South-Eastern Nova Scotia (S-ENS) (CFAs 23, 24), and 4X (Figure 1). Spring fishing efforts in N-ENS and S-ENS now represent a large portion of overall landings.

In support of the fishery, Fisheries and Oceans Canada (DFO) Maritimes Fisheries and Aquaculture Management requests from DFO Science an annual assessment of resource status. An assessment of the status of 4VWX Snow Crab is based on fishery independent surveys using indicators of abundance, reproductive potential, recruitment, and exploitation rates. Ecosystem and environmental indicators are also incorporated into the assessment. Commercial catch rates and other fishery statistics are reported.

This Science Advisory Report is from the February 27, 2019, Stock Assessment of Scotian Shelf Snow Crab. Additional publications from this process will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- In 2018, Snow Crab landings for North-Eastern Nova Scotia (N-ENS) and South-Eastern Nova Scotia (S-ENS) were 742 t and 6,064 t, respectively, and were 55 t in 4X for the 2017/2018 season, representing decreases of 9% (N-ENS), 10% (S-ENS) and 31% (4X) relative to the previous year. Total Allowable Catches (TACs) in 2018 were 786 t, 6,057 t, and 110 t in N-ENS, S-ENS, and 4X, respectively.
- Non-standardized catch rates in 2018 were 62 kg/trap haul in N-ENS, 116 kg/trap haul in S-ENS, and 12 kg/trap haul in 4X in 2017/2018, which, relative to the previous year, represents a decrease of 31% (N-ENS), an increase of 23% (S-ENS), and a decrease of 52% (4X).
- Commercial catches of soft-shelled (newly moulted) Snow Crab were 25% in N-ENS and <2% in S-ENS for the 2018 season. This is an increase from 5% in N-ENS and consistent in S-ENS from the previous season. Soft-shelled crab catches for N-ENS were almost exclusively from the summer fishery. Soft-shelled crab discards in 4X are negligible, in large part due to a fall/winter fishery.
- A novel modelling approach has been developed for Scotian Shelf Snow Crab, incorporating environmental and ecosystem variables while accounting for spatial and temporal variability. The resulting abundance estimates currently show unrealistically low inter-annual variability.
- Abundance estimates and landings are used to fit a logistic population model that provides the modelled fishable biomass and reference points.
- The modelled post-fishery fishable biomass index of Snow Crab in N-ENS was estimated to be 3,203 t in 2018, relative to 3,358 t in 2017. In S-ENS, the modelled post-fishery fishable biomass index was 33,190 t in 2018, relative to 32,040 t in 2017. In 4X, the modelled fishable biomass was 403 t in 2018, relative to 354 t in 2017.
- Hyper-stable inter-annual fishable biomass estimates (incongruous with other data sources such as length frequencies, catch rates, and survey catch densities) are minimally informative to harvest strategies.
- In all crab fishing areas, maturation of a recruitment pulse of female crab since 2016 has created substantial increases in the abundance of mature female crab and the proportion of mature female to male crab. The majority of female crab in all areas are now mature. Egg production is currently high.
- Moderate internal recruitment to the fishery is expected for the next year in N-ENS and S-ENS and is possible for the next 3–4 years, based on population size structure. Emigration, increased mortality, or sublegal sized terminal moult can lower expected recruitment. Internal recruitment in 4X is expected to be minimal.
- Bycatch of non-target species is extremely low (<0.4%) in all Snow Crab fishing areas.
- Based on stomach sampling, Atlantic Halibut, Atlantic Wolffish, Thorny Skate, and other skate species appear to be the predominant predators of Snow Crab on the Scotian Shelf. Continuing increases in Halibut biomass lowers both the abundance and reproductive potential of Snow Crab on the Scotian Shelf.
- Average bottom temperatures in the 2018 Snow Crab survey were near the long-year median in all areas. A general warming trend has been observed since the early 1990s on the Scotian Shelf. Temperatures are more stable in N-ENS than S-ENS. Annual mean bottom temperatures in 4X are more erratic.

- A reference points-based Precautionary Approach has been implemented in this fishery. The Limit Reference Point is 25% of carrying capacity and the Upper Stock Reference is 50% of carrying capacity. The Target Removal Reference is 20% of the fishable biomass in each area and the Removal Reference is not to exceed fishing mortality at Maximum Sustainable Yield . Various secondary (population and ecosystem) indicators are taken into consideration for management decisions.
- In N-ENS, the harvest strategy for the past two seasons appears to have been overly aggressive, with declining catch rates and increasing soft-shelled crab catches. A more conservative harvest approach, that lowers exploitation in N-ENS, could stabilize catch rates, protect incoming recruitment essential to the fishery, and allow commercial biomass to rebuild.
- In S-ENS, substantial TAC reductions over the past three seasons have helped maintain stable fishery performance. Geometric mean catches from the survey are stable and, based on stock structure, increased recruitment to the fishery is likely to occur for the upcoming season. A moderately more aggressive harvest strategy would be appropriate under these conditions.
- In 4X, low recruitment, high inter-annual temperature fluctuations, and overall warm water temperatures create uncertainties about this population. A zero TAC was set for the 2018/2019 fishing season due to low commercial biomass. Catches from the Snow Crab survey indicate that 4X commercial biomass levels remain low but have improved.

BACKGROUND

Species Biology

Snow Crab (*Chionoecetes opilio*, O. Fabricius) is a subarctic species with a distribution from northern Labrador to near the Gulf of Maine. Habitat preference is for soft mud bottoms. Smaller crabs are found in more complex habitats with shelter. Commercial sized crab (male, >95 mm Carapace Width; CW) in large numbers are found at depths from 60 to 280 m and temperatures from -1 to 6°C in the Scotian Shelf Ecosystem (SSE). Temperatures greater than 7°C are known to be detrimental to Snow Crab. The primary food items of crab are shrimp, fish (Capelin and Lumpfish), starfish, sea urchins, worms, detritus, large zooplankton, other crabs, molluscs, sea snails, and sea anemones. Predators of Snow Crab are Atlantic Halibut, skates (especially Thorny Skate), Atlantic Cod, seals, American Plaice, squids, and other crabs. Crab in the size range of 3 to 30 mm CW are particularly vulnerable to predation, as are soft-shelled crab in the spring moulting season. Snow Crab have been a dominant macro-invertebrate in the SSE since the decline of groundfish abundance during the late 1980s and early 1990s. The SSE Snow Crab are in the southern-most extreme of their spatial distribution in the northwest Atlantic and, as such, are one of the Snow Crab populations most susceptible to increasing ocean temperatures.

Fishery

The Snow Crab fishery in eastern Canada began in 1960 with incidental bycatches by groundfish draggers near Gaspé, Quebec. Its development was slow until the 1980s, when it began expanding rapidly to become one of the largest fisheries in Canada in terms of landings and landed value. On the Scotian Shelf, the fishery has been in existence since the early 1970s. The Scotian Shelf Snow Crab fishery lands only males with CW ≥ 95 mm. There is also a concerted effort to avoid areas of newly moulted (soft-shelled) cfrab and to discard immature males. The North-Eastern Nova Scotia (N-ENS) and South-Eastern Nova Scotia (S-ENS) fisheries are conducted within a calendar year. The 4X fishery is conducted over a fall to winter fishing season spanning calendar years. Total landings increased to record-levels of approximately 10,000 tonnes (t) each year in the early 2000s and increased further to approximately 14,000 t in 2010 (Figure 2). Landings and Total Allowable Catches (TACs) have been declining since that time. In 2005, many Crab Fishing Areas (CFAs) and subareas were merged, with the resulting divisions being N-ENS (formerly CFAs 20–22), S-ENS (CFAs 23 and 24), and 4X (Figure 1). In 2018, Snow Crab landings for N-ENS and S-ENS were 742 t and 6,064 t, respectively, and were 55 t in 4X for the 2017/2018 season (Tables 1–3, Figure 2), representing decreases of 9% (N-ENS), 10% (S-ENS), and 31% (4X) relative to the previous year (Figures 3 and 4). The TACs in 2018 were 786 t, 6,057 t and 110 t in N-ENS, S-ENS and 4X, respectively. The TAC was not reached in N-ENS or 4X. The Snow Crab fishery in 4X has a zero TAC for the 2018/19 season due to low commercial crab abundance.

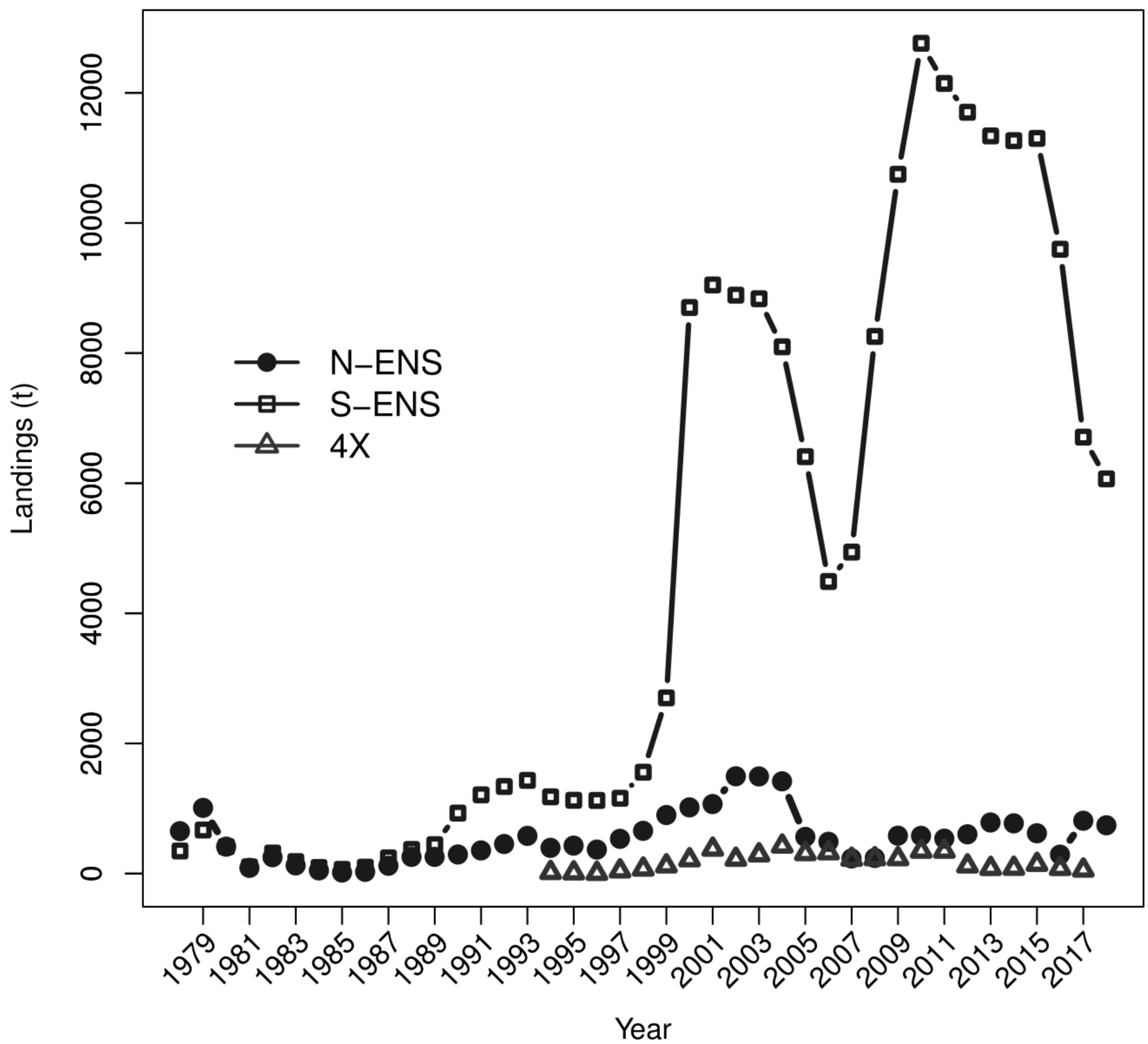


Figure 2. Temporal variations in the landings (t) of Snow Crab on the Scotian Shelf. The landings follow the Total Allowable Catches (TACs) with little deviation, so the TACs are not shown. For 4X, the year refers to the starting year of the season.

Table 1. Summary of the Snow Crab fishery in North-Eastern Nova Scotia.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
2009	78	576	579	76	7.6
2010	78	576	576	55	10.5
2011	78	534	536	110	4.8
2012	78	603	603	117	5.1
2013	78	783	783	106	7.4
2014	78	783	778	104	7.4
2015	78	620	619	103	6.0
2016	78	286	290	110	2.6
2017	78	825	813	90	9.0
2018	78	786	742	62	12.0

Table 2. Summary of Snow Crab fisheries in South-Eastern Nova Scotia.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
2009	116	10,800	10,645	90	118.8
2010	116	13,200	13,150	103	128.3
2011	116	12,120	12,135	106	118.8
2012	116	11,707	11,733	98	120
2013	116	11,311	11,309	104	108.7
2014	116	11,311	11,267	112	100.2
2015	116	11,311	11,292	106	106.5
2016	116	9,614	9,606	106	90.6
2017	116	6,730	6,719	94	71.5
2018	116	6,057	6,064	116	52.3

Table 3. Summary of the Snow Crab fishery in 4X.

Season	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
2007/08	9	230	220	18	12.1
2008/09	9	230	229	28	8.0
2009/10	9	230	229	36	6.4
2010/11	9	346	345	38	9.0
2011/12	9	346	344	29	11.8
2012/13	9	263	118	13	9.6
2013/14	9	80	79	15	5.1
2014/15	9	80	82	34	1.7
2015/16	9	150	142	31	4.6
2016/17	9	80	80	25	3.2
2017/18	9	110	55	12	4.6
2018/19[1]	9	0	-	-	-

Note: [1] No fishery (0 TAC) due to low commercial biomass. Dash (-) represents no data.

In 2018, the majority of N-ENS landings came from the inner grounds, not the Glace Bay Hole (Figure 1). In S-ENS, a general inshore migration of spatial landings patterns was observed from the 2017 season. In 4X, the limited landings (2017/2018) were focused toward the 4X/CFA 24 line (Map 1). There were no landings on the continental slope areas of S-ENS in 2018.

Non-standardized catch rates in 2018 were 62 kg/trap haul in N-ENS, 116 kg/trap haul in S-ENS, and 12 kg/trap haul in 4X in 2017/2018, which, relative to the previous year represents a decrease of 31% (N-ENS), an increase of 23% (S-ENS) and a decrease of 52% (4X) (Tables 1–3, Figure 3, Map 2).

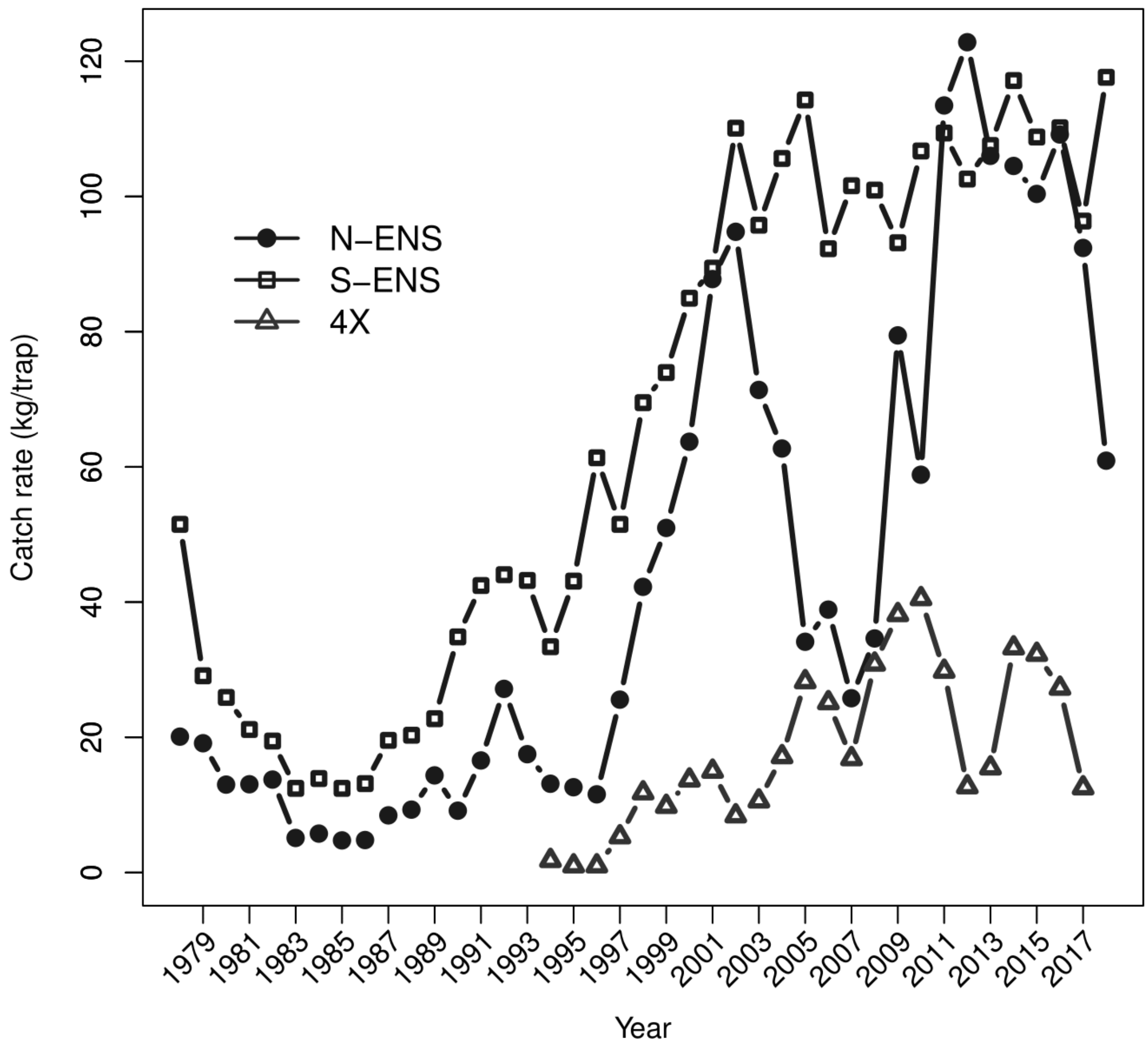


Figure 3. Temporal variations in catch rates of Snow Crab on the Scotian Shelf, expressed as kg per trap haul. Trap design and size have changed over time. No corrections for these varying trap-types, soak time, or bait-type have been made.

Carapace Condition (CC) defines the approximate age (since terminal moult) of the terminally moulted crab based on the relative development and subsequent decay of the carapace. Carapace Condition 1 signifies a newly moulted crab, soft-shelled, with no epibiont (e.g., barnacles) growth. Carapace Condition 2 has begun to harden but it is still considered to be soft and of no commercial value. Carapace Condition 3 and 4 represent ideal commercial Crab. The oldest carapace condition (CC5) signifies extensive shell decay with no expectation of survival into the next year.

In N-ENS, CC1 and CC2 crab collectively represented approximately 28% of the total catch (Figure 4), relative to 12% in 2017. Observed CC1 and CC2 Crab were caught almost exclusively in the summer fishery in 2017 and 2018. The spring season (2008–present) was adopted to reduce fishing intensity in the summer season and to encourage fishing during the earlier period when newly molted Crab are too weak and soft to easily enter into traps. After a successful trial in 2008, the majority of landings (>60%) from N-ENS have been caught during the spring season. The mean size of crabs caught in N-ENS had been increasing from 2008 to 2016, suggesting higher survival of immature crab (lack of handling mortality of soft-shelled Crab) and a decreased dependence on newly recruited animals. This increasing mean size of crab in N-ENS had contributed to increased catch rates (on a kg/trap basis). The mean size of the Crab caught in N-ENS has decreased the last two seasons, further exacerbating falling catch rates. Increased appearance of CC1 and CC2, decreasing Crab size, and a decrease in CC4 Crab is evidence of the leading edge of a recruitment pulse entering the fishery, following a period of little or no recruitment. The mean size of Snow Crab caught in N-ENS decreased from previous years, resulting in the increased catch of sub-legal sized male Crab.

In S-ENS, the occurrence of CC1 Snow Crab remains low, at <1% (Figure 4). The proportion of CC2 Crab in the catch remained constant from 2017, at approximately 6%. Carapace Condition 3 Crab dominated the catch (approximately 85%). A relative decrease in CC4 Crab from 2017 may reflect the reliance of the fishery on crab that have matured in the past 2 seasons, rather than an older residual biomass.

In 4X for the 2016/17 season, CC1 and CC2 Crab collectively represented approximately 17% of the total catch (Figure 4). This level is higher than traditionally observed in 4X. The commercial catches are dominated by CC3 and CC4 Crab, which collectively represent approximately 80%. An extreme warm-water event in 2012/2013 is hypopthesized to have been detrimental to the Snow Crab population in 4X. Mortality caused by this warming likely continues to influence population composition in 4X. The data from 4X are not directly comparable to N-ENS and S-ENS, as its winter fishing season is disjunct.

Senescent (CC5) Crab represented less than 1.3% of the total observed catch in all areas and less than 1% in survey catches.

In N-ENS, the estimated soft-shelled Crab discard rate (percentage of total landings as determined by at-sea observer sampling) was 25% in 2018, an increase from 5% in 2017, and is the highest level in 10 years. The soft-shelled Crab catches occurred during the summer fishery where soft-shelled Crab discard rate was estimated to be 48%. These newly moulted Crab are not commercially harvested and are highly susceptible to handling damage/mortality. Maximizing spring fishing efforts will limit this source of Snow Crab mortality, which is incidental to the fishery removals in N-ENS. In S-ENS, the 2018 estimated soft-shelled Crab discards were <2% of landings, and is consistent with the 2017 estimate. Soft-shelled discards are negligible in 4X, due to season timing.

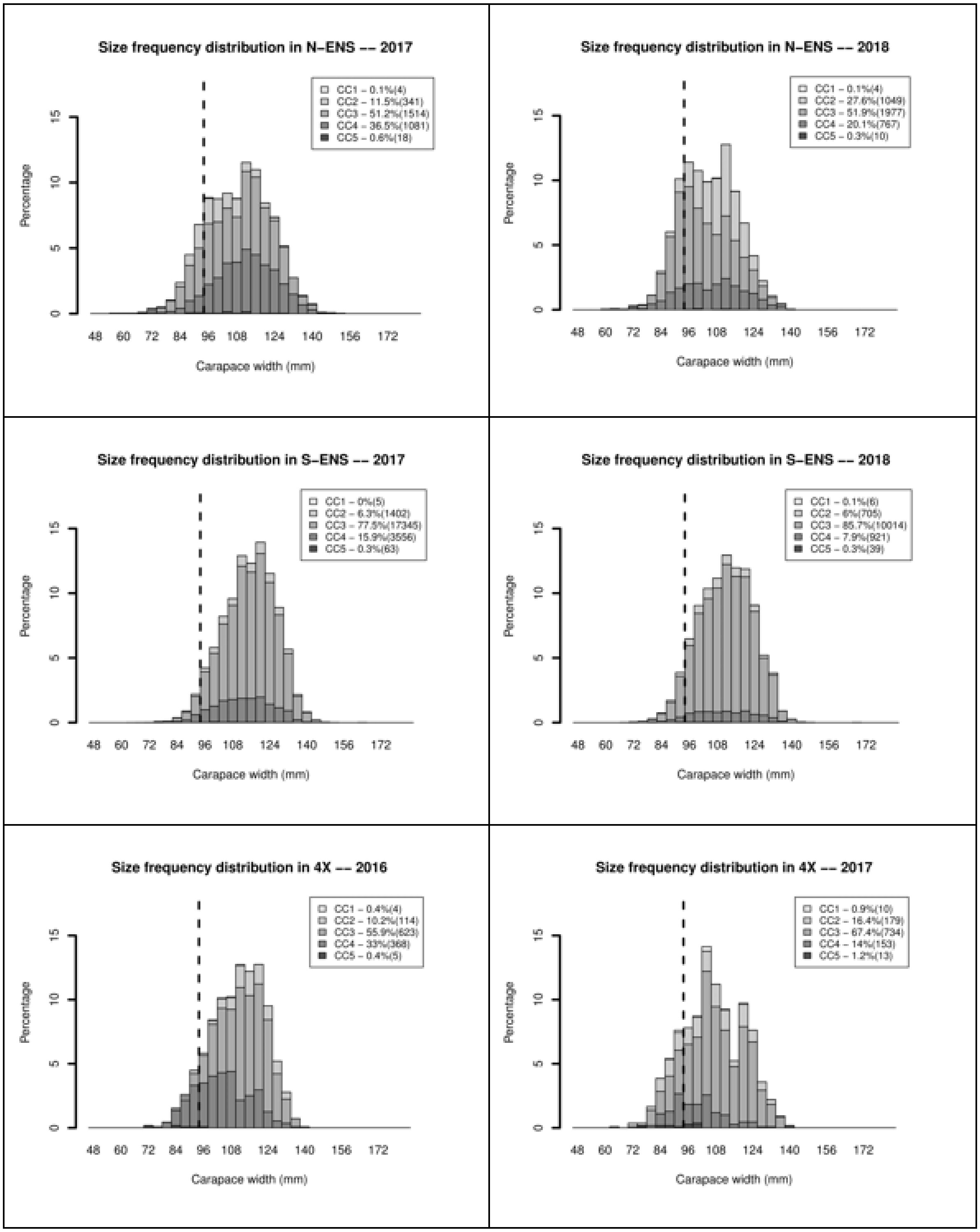


Figure 4. Size frequency distribution of at-sea observer monitored Snow Crab broken down by Carapace Condition (CC). For 4X, the year refers to the starting year of the season. Vertical lines indicate 95 mm carapace width, the minimum legal commercial size.

ASSESSMENT

Stock Trends and Current Status

Fishable Biomass

The fishable biomass (Figure 5, Map 3) is defined as that segment of the Snow Crab biomass that is male, mature, and >95 mm CW. The fishable biomass index is estimated from the area expanded trawl survey results, incorporating environmental and ecosystem information to define Snow Crab habitat. A novel modelling approach (**stmv-**spatio-temporal modelling of variability) has been developed and implemented for the Scotian Shelf Snow Crab assessment since 2016. This method incorporates relationships between Snow Crab habitat and abundance, with environmental (temperature, substrate and depth) and ecosystem (species composition and diversity) variables, while also accounting for spatial and temporal variation. Current and past biomass estimates have been determined through the current methodologies to allow for direct comparison. The resulting annual estimates of fishable biomass from **stmv** are then used to fit a logistic population model that provides the modelled fishable biomass and reference points. Current results of this **stmv** approach have produced biomass estimates that show little inter-annual variability and are considered to be unrealistically stable. This hyper-stability of abundance estimates is not supported in other stock indicators such as survey catch densities (Figure 6), length frequencies (stock size composition; Figure 7), and fishery data (such as catch rates and relative occurrence of carapace conditions in the catch). Modelled parameter estimates such as fishable biomass and fishing mortality that result from **stmv** are therefore minimally informative to harvest strategies.

The modelled post-fishery fishable biomass index (from the logistic population model) of Snow Crab in N-ENS was estimated to be 3,203 t in 2018, relative to 3,358 t in 2017. In S-ENS, the modelled post-fishery fishable biomass index was 33,190 t in 2018, relative to 32,040 t in 2017.In 4X, the modelled fishable biomass was 403 t in 2018, relative to 354 t in 2017. The 4X biomass estimate is generally more uncertain, as this area exhibits more extreme temperature fluctuations than other areas, potentially resulting in increased migration in and out of the area.

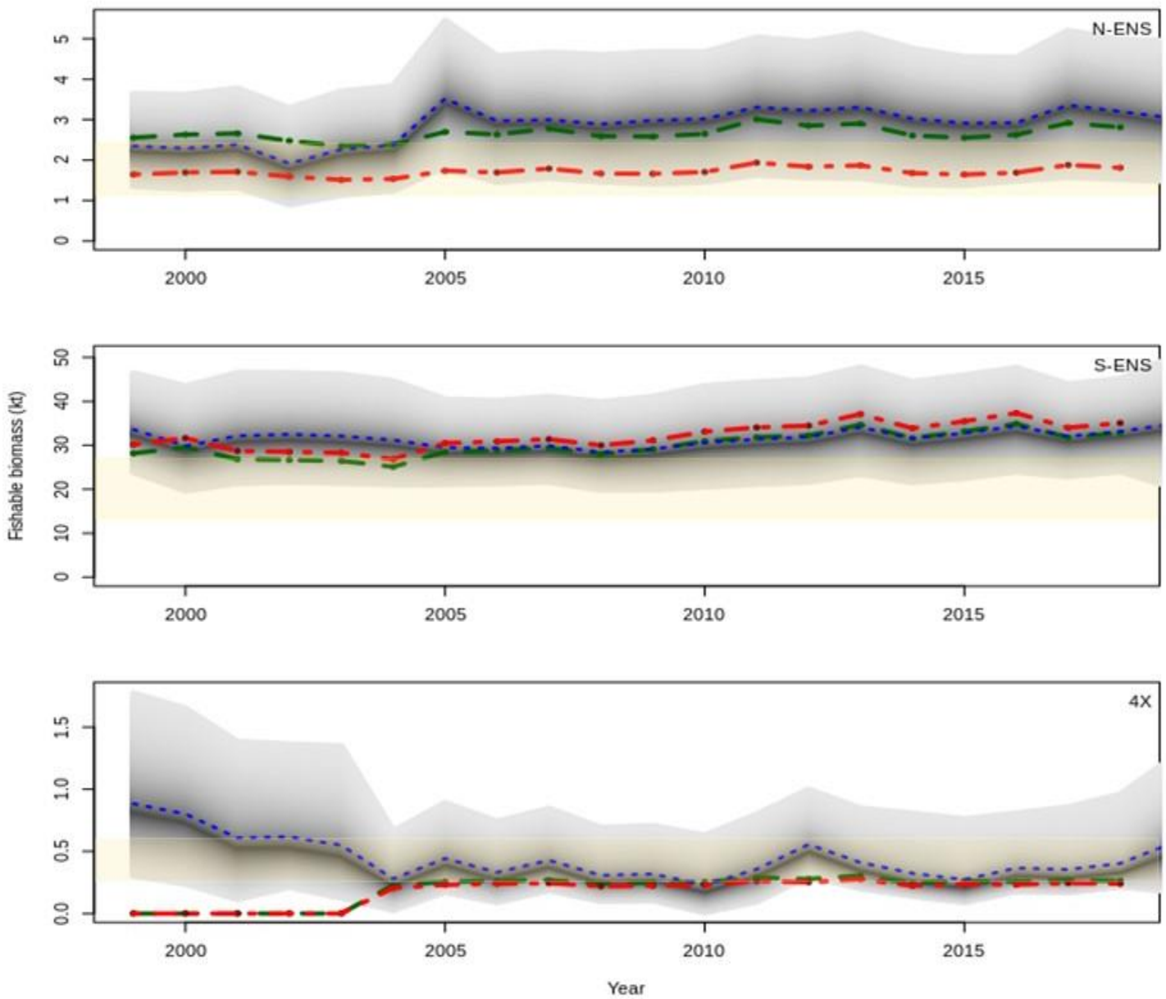


Figure 5. Time series of fishable biomass from the logistic population models. The fishable biomass index is shown in red dashed lines. The q-corrected (model catchability coefficient) fishable biomass index is shown in green dashed lines. The posterior mean fishable biomass estimates from the logistic model are shown in blue stippled lines. The density distribution of posterior fishable biomass estimates are presented with 95% Confidence Interval (grey). The "Cautious Zone" from the Harvest Control Rules is shown in yellow.

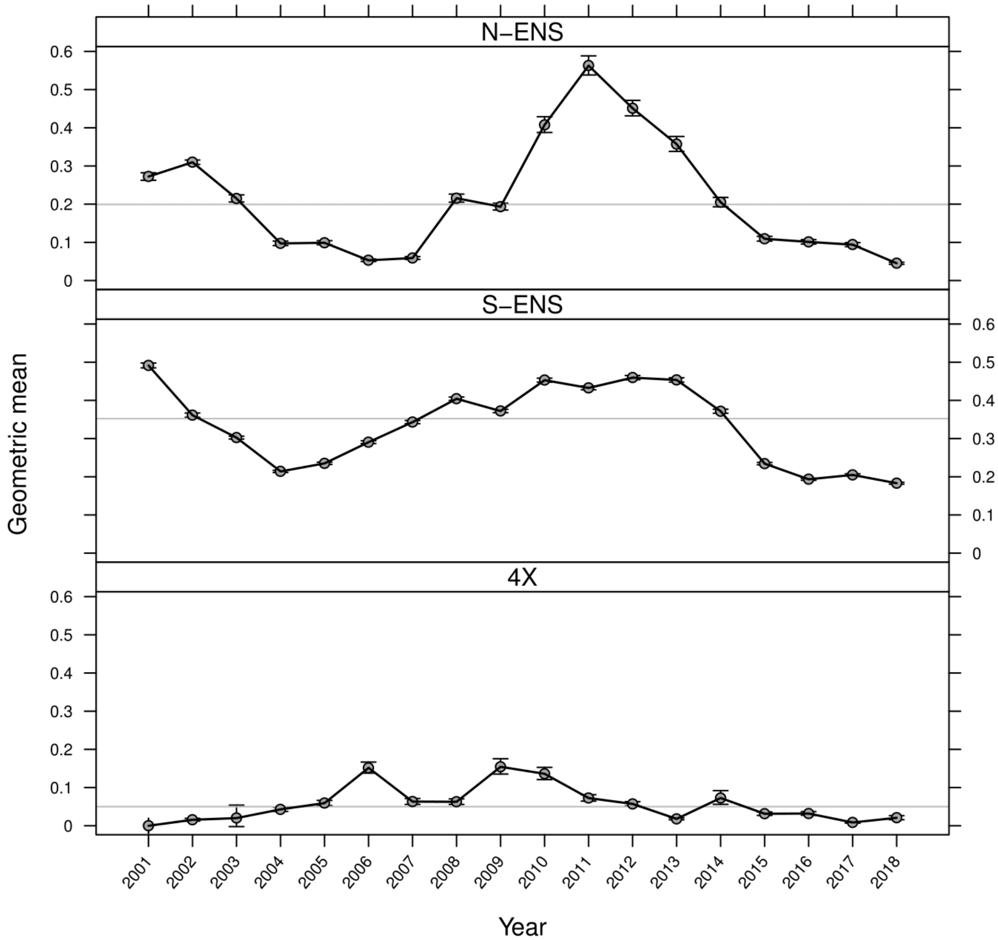


Figure 6. Time series of trends in the geometric mean of fishable biomass (t/km²) obtained from the annual Snow Crab survey. Error bars are the 95% Confidence Interval about the geometric mean.

Recruitment

Quantitative determination of recruitment levels into the fishable biomass is confounded by a number of factors. These include terminal molt (the timing offset of molting in spring and the survey in the fall), and the inability to age Crab and predict the age that male Crab will terminally molt. Based on size-frequency histograms of the male Snow Crab population, moderate internal recruitment (from within the same fishing area) to the fishery is expected for the next year in N-ENS and S-ENS (Figure 7). Internal recruitment in 4X is expected to be minimal. Immigration of Crab from outside a given area can represent recruitment to its fishery, although this is unreliable, based on its episodic nature. Erratic temperature fields in 4X create strong uncertainties for future recruitment.

In the survey, the presence of small immature male Snow Crab in N-ENS and S-ENS (Figure 7), spanning almost all size ranges (30–95 mm CW), also suggests that internal recruitment to the fishery is probable for the next 3–4 years, though potentially at decreasing rates due to the lower numeric densities of smaller animals. The survival of small Crab is essential for the fishery to realize this recruitment. Any mortality (e.g. predation, environmental, and disease), emigration, or sub-legal size moulting will impact this recruitment potential. Based on size frequency distributions from the trawl survey, 4X shows limited potential for internal recruitment to the fishery for the next 2–3 years.

In N-ENS and S-ENS, maturation of a recruitment pulse of female Crab began in 2016 and continued into 2018, creating substantial increases in the abundance of mature female Crab (Figure 8) and the proportion of mature female to male Crab (Figure 8). In 4X, there were increases in mature female Crab in 2017 and 2018. The majority of female Crab in all areas are now mature. Based on population size structure, mature female abundance is expected to decline for the next 4–5 years in all areas.

Reproduction

In all CFAs, mature female Snow Crab abundance has increased for the past three years (Figure 8). Associated egg production is expected to be high due to increased number of mature females, as well as larger egg clutch size in multiparous females from subsequent breeding events (Figure 8). Concentrations of mature females now exist in all areas (Map 4). Sex ratios (proportion female) continue to generally be male-dominated in N-ENS and S-ENS, though the broad-scale maturation of female Crab has increased the mature sex ratios (proportion female) over the past 3 years. The sex ratio is more balanced in 4X than in N-ENS and S-ENS (Figure 9), potentially resulting from higher mortality of male Crab in this area.

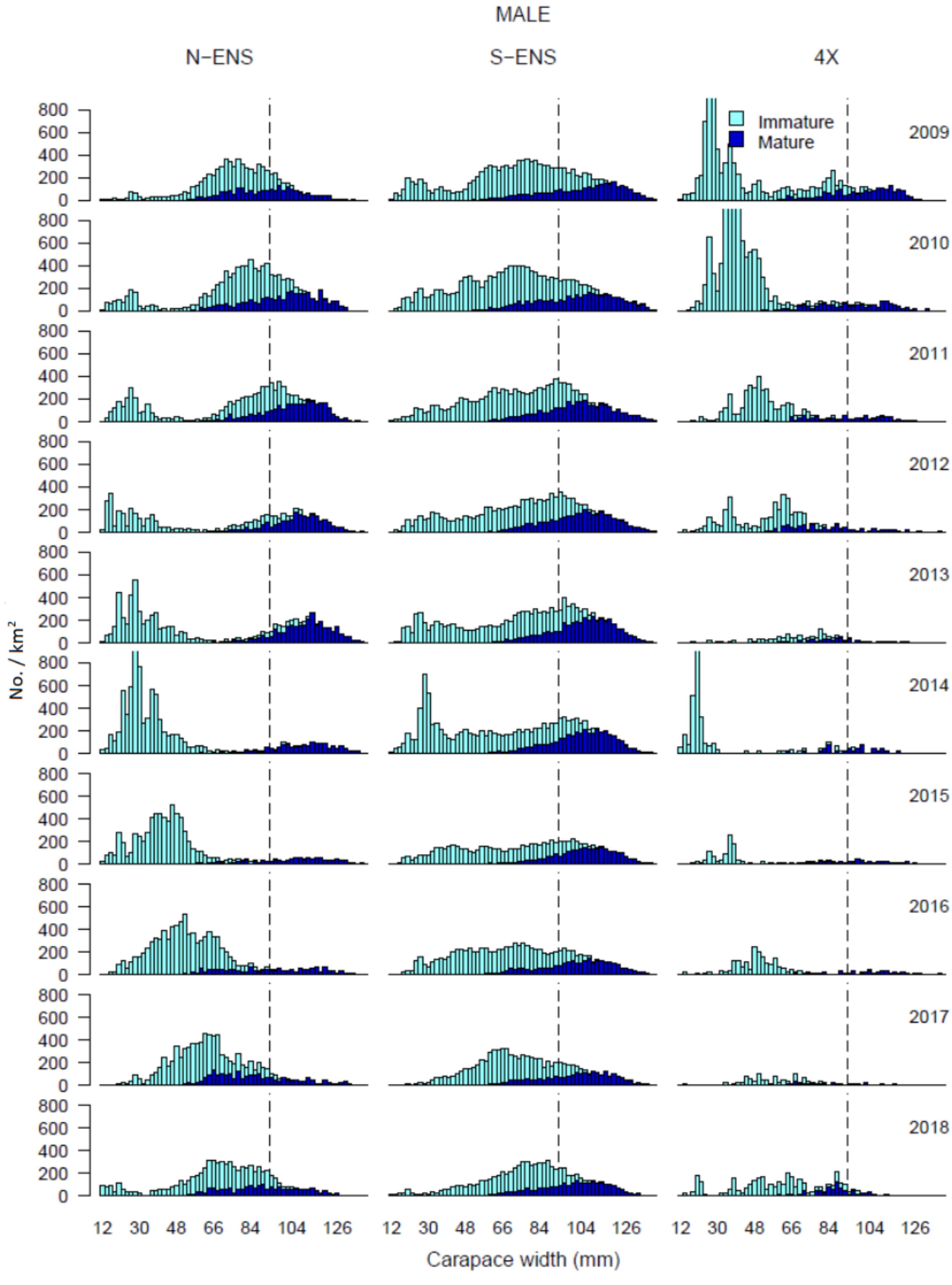


Figure 7. Size-frequency histograms of carapace width of male Snow Crab. This figure provides information about the relative numbers within a given year. The vertical line represents the legal size (95 mm).

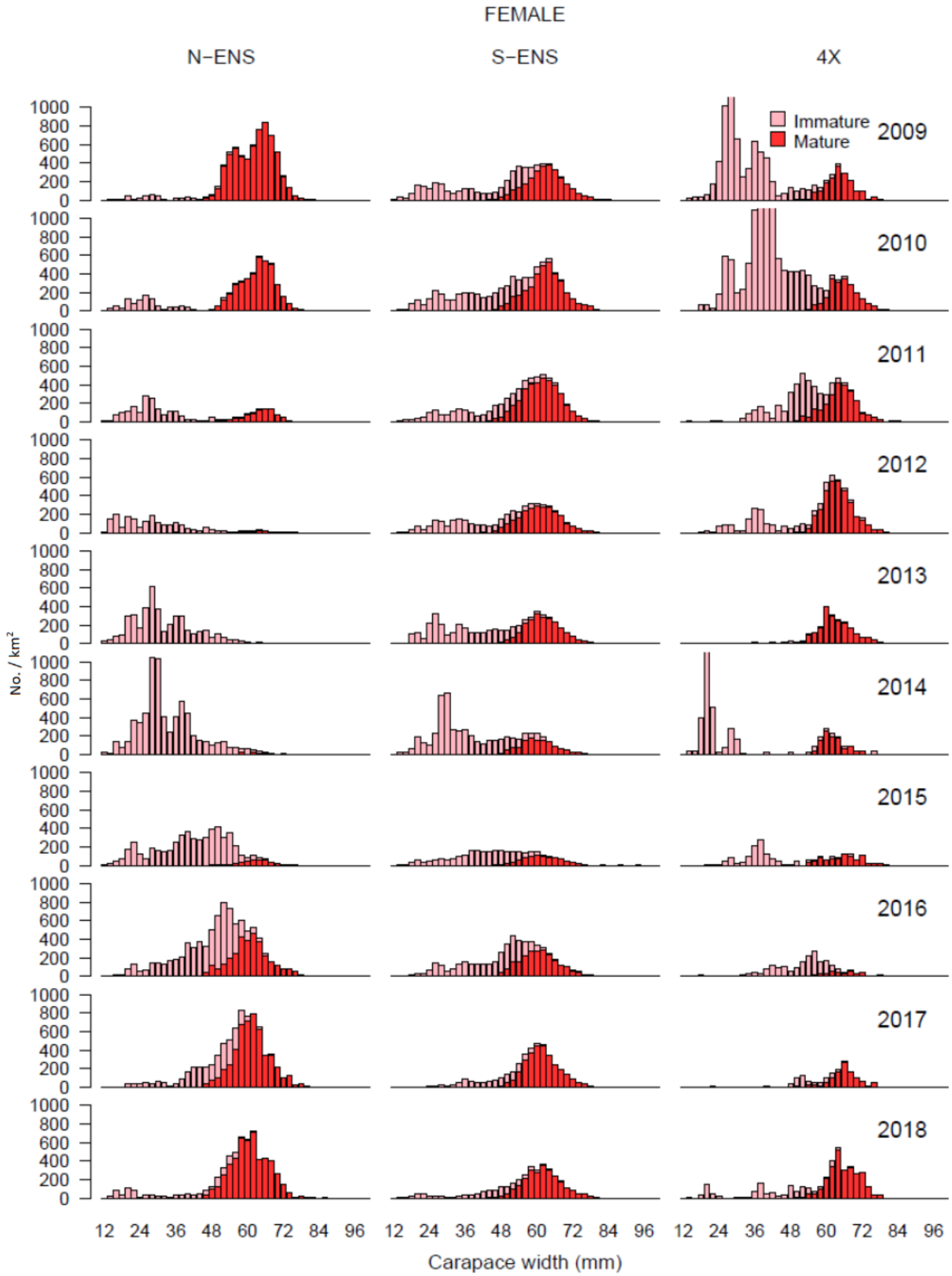


Figure 8. Size-frequency histograms of carapace width of female Snow Crab. This figure provides information about the relative numbers within a given year.

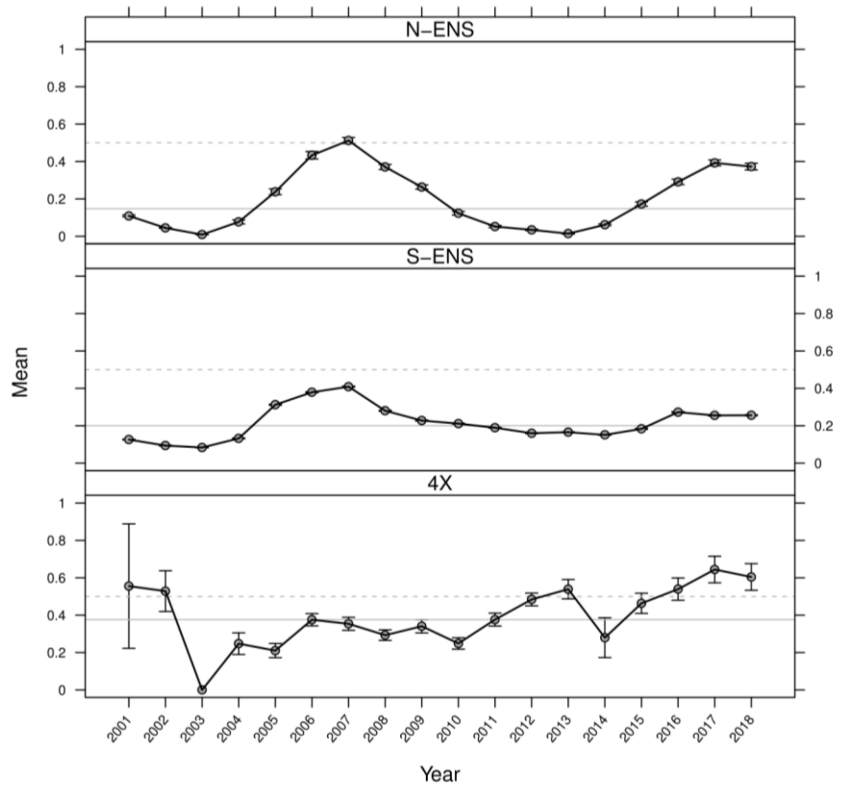


Figure 9. Sex ratios (proportion female) of mature Snow Crab. Since 2000, the Scotian Shelf is generally male dominated. Dashed line shows equal proportions. Solid grey line represents the long-term mean.

Fishing Mortality

Current abundance estimates show unrealistically low inter-annual variability. As such, the following associated fishing mortality estimates are minimally informative.

The N-ENS fishing mortality (*F*) estimate for 2018 is 0.24 (exploitation rate 0.21), an increase from 0.17 in 2017 (Figure 10).

The S-ENS *F* estimate for 2018 is 0.22 (exploitation rate 0.20), a decrease from 0.26 in 2017 (Figure 10). Localized exploitation rates are likely higher, as not all areas where biomass estimates are provided are fished (e.g., continental slope areas and western, inshore areas of CFA 24).

The 4X *F* estimate for 2017/2018 is 0.23 (exploitation rate 0.21), a decrease from 0.26 in 2016/2017 (Figure 10). Localized exploitation rates are likely to be higher, since the computed exploitation rates incorporate biomass throughout 4X and are not limited to the fishery grounds.

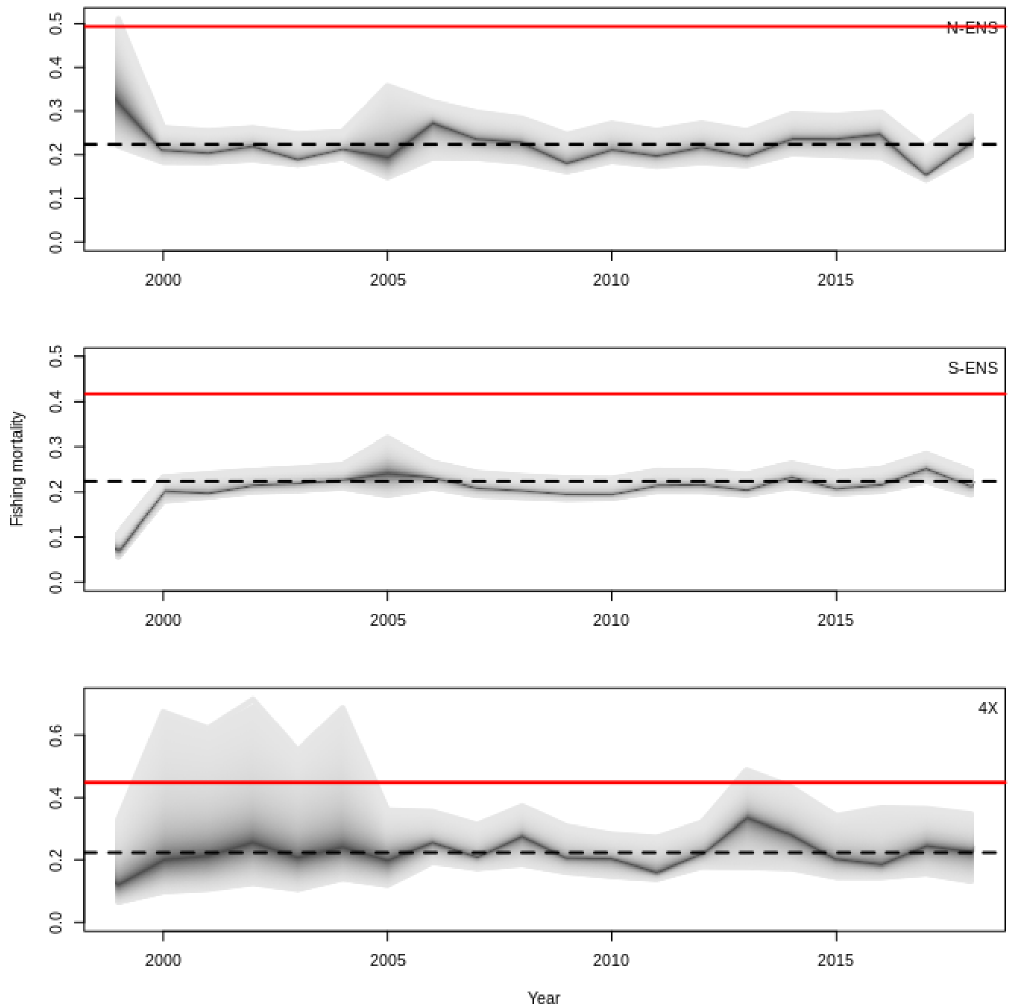


Figure 10. Time series of fishing mortality from the logistic population models for N-ENS, S-ENS, and 4X, respectively. Posterior density distributions are presented in gray, with the darkest line being the median with 95% Confidence Interval. The solid (red) line is the estimated fishing mortality at maximum sustainable yield and the stippled (black) line is the 20% harvest rate.

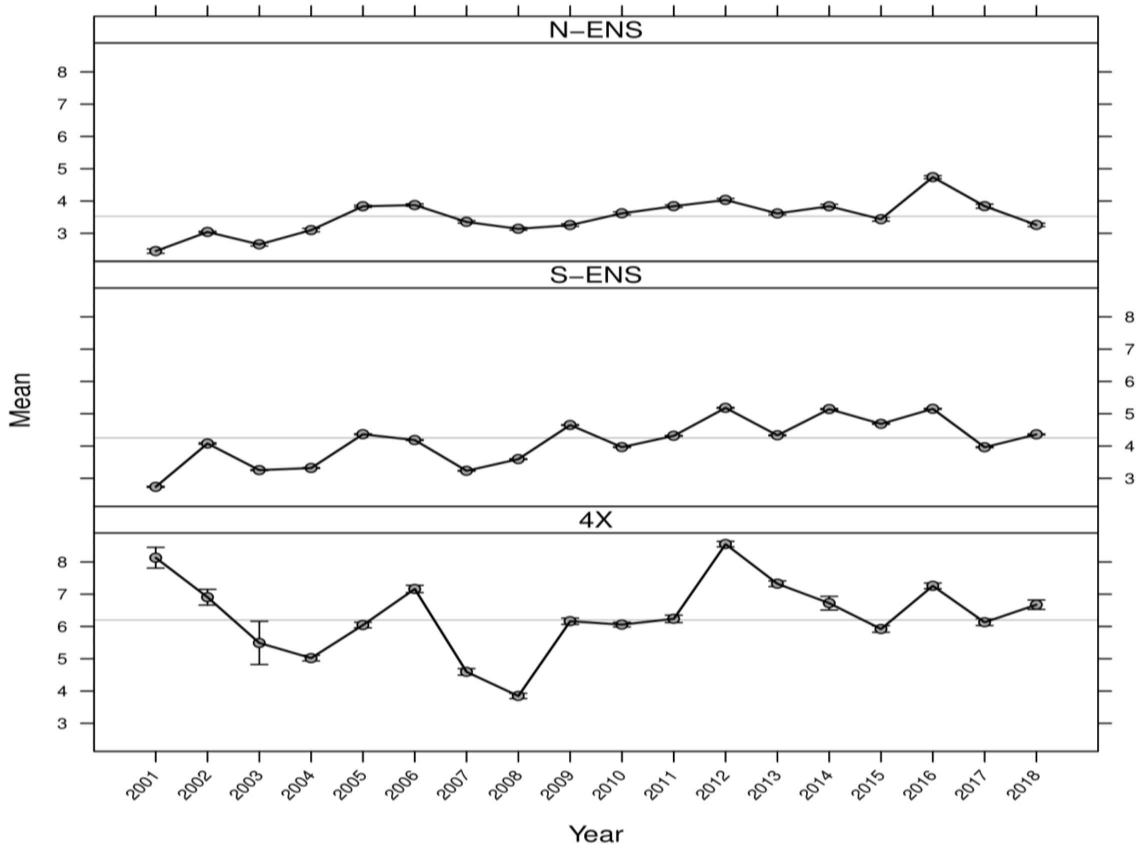


Figure 11. Annual variations in bottom temperature observed during the Snow Crab survey. The horizontal (black) line indicates the long-term median temperature within each subarea. Error bars are standard errors.

Ecosystem Considerations

Environmental Variability

Average bottom temperatures in the 2018 Snow Crab survey were near the long-term median in all areas (Figure 11). A general warming trend has been observed since the early 1990s on the Scotian Shelf. Temperatures are more stable in N-ENS than S-ENS; 4X exhibits the most erratic annual mean bottom temperatures.

Bottom-up (Resource Limitation)

Food items such as Northern Shrimp are found in concentrations below the long-term average in most core areas of S-ENS (based on Snow Crab trawl survey; Map 5).

Near the ocean surface, there has been a trend towards increased ocean colour, which is an index of chlorophyll concentrations. Additionally, deeper phytoplankton blooms have occurred that are not captured through satellite ocean colour measurements. Therefore, total primary production may be increasing (in the form of diatoms and dinoflagellates). This is likely enhanced by the reduction in abundance of *Calanus finmarchicus*, an important zooplankton link in the pelagic food web. Whether this elevated primary production reaches the detrital system is not known.

Top-down (Predation)

The capacity of predatory groundfish to opportunistically feed upon Snow Crab, in combination with their numerical dominance prior to the 1990s, suggests they may have been an important regulating factor controlling the recruitment of Snow Crab. The demise of these predatory groundfish in the post-1990 period, and the resulting reduction of predation pressure on immature and soft-shelled Crabs, may have been an important determinant of the Snow Crab rise to dominance in the SSE in the early 2000s. Based on stomach sampling, Atlantic Halibut (Figure 12; DFO 2018), Atlantic Wolffish, Thorny Skate (Figure 13), and other skate species, appear to be the predominant predators of Snow Crab. Localized predation rates may be much higher due to relative local abundance and encounter rates. Increasing population trends in predator species could result in increased predation, potentially lowering future recruitment to the fishable biomass and affecting movement patterns of Snow Crab.

Atlantic Halibut biomass has increased almost exponentially (Figure 12; DFO 2018); consequently, the total number of Snow Crab consumed by Halibut is expected to increase. A proliferation of Halibut, particularly the largest fish with large mouth gapes, could result in the predation of larger Snow Crab, which has seldom been previously experienced. Anecdotal reports of large Atlantic Halibut with multiple mature female Snow Crab in their stomachs support this assertion. Increasing predation by Halibut lowers both the abundance and reproductive potential of Snow Crab on the Scotian Shelf.

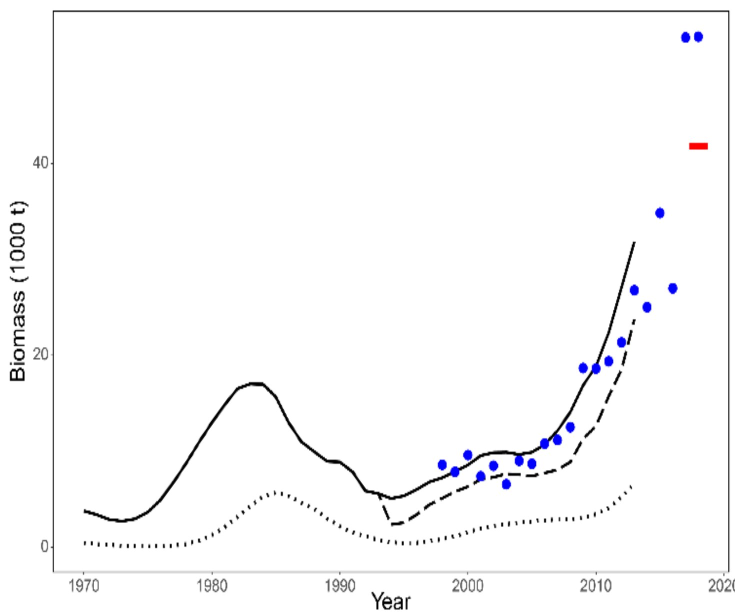


Figure 12. Atlantic Halibut biomass for the Scotian Shelf and Southern Grand Banks from the stock assessment model (black lines) and the Halibut survey (blue circles). The solid black line is total biomass, the dashed line is legal biomass, and the dotted line is spawning stock biomass. The solid red bar is the current 3-year mean of the Halibut survey biomass index.

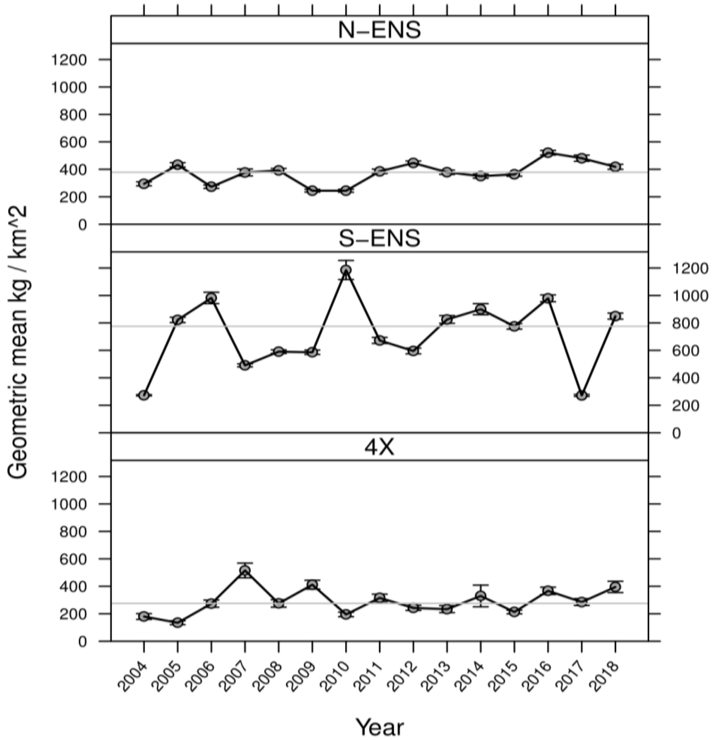


Figure 13. Thorny Skate biomass trend from annual Snow Crab survey. Horizontal lines indicate the long-term median within each subarea. Vertical lines are 95% Confidence Intervals estimated by bootstrapping.

Seals are considered by fishers to be a predator of Snow Crab, and their continued increase in abundance is a source of concern for many fishers. While seals have been observed with Snow Crab in their stomachs, high concentrations of Snow Crab are found in the immediate vicinity of Sable Island, an area with a high abundance of Grey Seals. Seals may be having a positive influence by physically importing food and food waste (organic matter) from other, more outlying areas, to the immediate vicinity of Sable Island. This would indirectly feed the Snow Crab and protect them from potential predators (in both early pelagic and benthic stages). Seal predation of groundfish would lower potential lateral competition for Snow Crab food resources.

Lateral (Competition)

Large mature male Crabs stabilize the Snow Crab population by maintaining and occupying prime Crab habitat. Large mature male Crab deter potential competitors (such as other crab species or groundfish), serve as strong mates for the current population pulse of mature females, and protect smaller females. Their over-exploitation can have numerous negative biological consequences. Extended periods of low female to male proportions (Figure 9) were observed in the early 2000s and early 2010s throughout the Scotian Shelf. Poor egg and larval production in the system likely occurred for at least a four to five year period in each case.

The diet of Snow Crab overlap in many ways with that of some groundfish species; thus, the demise of these groups in the late 1980s and early 1990s would have been doubly beneficial to Snow Crab, through the reduction in predation pressure and also resource competition. A strong negative relationship is not found between Snow Crab and other Snow Crab survey bycatch species, suggesting little competitive interaction. The potential competitors, such as Lesser Toad Crab and Jonah Crab, remain in relatively patchy distributions and, therefore, do not currently appear to pose much threat to the overall health of the Snow Crab stock. Sharp increases in near-shore Lobster populations in the past 10 years may increase resource competition (and even predation) for juvenile Snow Crab, whose habitat preferences overlap with Lobster, as does substantial increases in Halibut biomass.

Human Influences

Oil and gas development/exploitation continues to occur on the Scotian Shelf near to, or upstream from, major Crab fishing grounds and population centers in both N-ENS and S-ENS. The effects of seismic methods of exploration upon potentially vulnerable components of the Snow Crab population (eggs, larvae, soft-shelled Crab) and the long-term biological effects of development upon this long-lived species remain unknown (DFO 2004; Boudreau et al. 2009; Courtenay et al. 2009). Seismic exploration occurred in November 2005 and July 2010 immediately over the Glace Bay Hole and the shallows of the Sydney Bight (Hunt Oil 2005; Husky Energy 2010), where immature and female Crab are generally abundant. The Snow Crab fishery had adopted a precautionary approach long before the formal implementation of DFOs Precautionary Approach (PA). The uncertainties associated with oil and gas exploration and production increase the risk of destabilizing the Snow Crab population on the Scotian Shelf. Future seismic work has been proposed throughout the Scotian Shelf in 2019–2021 (CNSOPB 2019).

Undersea cables have been identified by fishers as another source of concern, in particular, the Emera Maritime Link subsea electricity cables spanning approximately 180 km from Cape Ray, Newfoundland, to Point Aconi, Nova Scotia. These two cables, spaced by at least twice the water depth, potentially create a barrier to normal Snow Crab movement through static magnetic fields, increased temperature, induced electrical fields, or the physical barriers created as a result of trenching activities and substrate disturbance. These cables were energized in January 2018. At present, there is no information to describe their effects upon Snow Crab. Additional tagging/movement studies by DFO Science and Emera have been applied in this area to better understand Snow Crab movement prior to and following installation of the cables.

St. Anns Bank was designated as a Marine Protected Area (MPA) in 2017 (Canada Gazette 2016). The presence of a refuge from fishing activities is potentially positive as it could serve as a fallow area. However, if the reserve is disproportionately beneficial to other organisms, either predators or prey of Snow Crab, the effects upon Snow Crab could be mixed. The long-term effects of the MPA cannot be determined at this point.

Bycatch/Incidental Catch

Bycatch levels in the SSE Snow Crab fishery have been extremely low over the long term. Estimates of bycatch in this fishery are extrapolated from at-sea observer estimates. In ENS in 2018, at-sea observers did not follow proper reporting protocol as it relates to bycatch observed in the fishery. As such, no reliable, species-specific estimates of bycatch in the fishery can be generated for the 2018 N-ENS and S-ENS fisheries. To best approximate total bycatch levels, the 3-year mean bycatch (0.016% of landings) was applied to the 2018 landings. In ENS, a total of 6,806 t of Snow Crab were landed in 2018 with associated estimates of bycatch (based on 3-year mean levels) at 1.1 t. Total estimated bycatch in 4X was 0.2 t associated with 55 t of Snow Crab landings (0.4%) for the 2017/18 fishing season. The majority of bycatch for all areas is composed of other invertebrate species (e.g., Northern Stone Crab, Jonah Crab and American Lobster) for which higher survival rates can be expected after being released as compared to finfish discards. In previous years, at-sea observers reported two Leatherback Sea Turtles as having been entangled in buoy lines, both released alive though bleeding. A Humpback Whale was entangled in buoy lines in 2012, which was released with little or no harm to the animal. Multiple entanglements of North Atlantic Right Whales in a neighbouring Snow

Crab area (CFA 12) during the summer of 2017 has created an increased vigilance among Snow Crab fishers to maintain fishing practices to minimize the potential for marine mammal interactions with Snow Crab fishing gear.

Mortality of Snow Crab from other fisheries is still not quantified. Trawls can increase mortality, especially upon the soft-shelled phases of Snow Crab. The lack of trawl fisheries (other than shrimp trawling), in the majority of Snow Crab habitat on the Scotian Shelf, limits this potential damage. Additional effort of high bottom contact fisheries (such as dredging) could negatively impact Snow Crab habitat.

Bottom damage from the placement of Snow Crab traps is thought to be minimal.

Sources of Uncertainty

Two primary sources of uncertainty exist with the Snow Crab population on the Scotian Shelf: environmental uncertainty associated with rapid climate change and uncertainty in the relative abundance of predators. To remain adaptive in the face of these significant uncertainties, industry and management must continue to be mindful and vigilant in maintaining a small enough fishery, and more generally a smaller human footprint, such that these larger ecosystem uncertainties will not further be exacerbated.

The development of a stock assessment model, which incorporates ecosystem considerations (such as environmental conditions and species composition), has highlighted the need for greater data density to inform the model and improve the applicability of modelled results for stock assessment purposes. The current lack of temporally and geographically intensive data has yielded model abundance results which are, at best, moderately informative as the cyclical nature of abundance trends observed in other data are not present. This disparity undermines the use of modelled results as the sole determinant of harvest strategies.

Fishery catch rates are potentially biased indicators of crab abundance. The spatial and temporal distribution of crabs and the fishing effort are not uniform, varying strongly with season, bottom temperatures, food availability, reproductive behavior, substrate/shelter availability, relative occurrence of soft and immature Crab, species composition, fisher experience, bait type, soak time, and ambient currents. Catch rates have not been adjusted for these influences. Fishery catch rates are used primarily as a measure of fishery performance.

Anecdotal reports from the Snow Crab industry suggest that illegal fishing activities and mis-reporting of catch is occurring, particularly in S-ENS. Such activities increase the uncertainty in the stock assessment results and hinder the steps made toward applying a precautionary approach to the management of this resource. Current strong catch rates, reduced TACs, and increased landed price for Snow Crab increase the potential for such illegal activities. By addressing this issue, DFO Conservation & Protection, in conjunction with stakeholders, would decrease this source of uncertainty.

Concerns are continually raised by the fishing industry regarding the impact of seismic and other industrial activity (such as cable trenching and installation) on local Snow Crab, as well as the potential source of uncertainty it raises for future productivity and the impacts on the stock assessment results.

CONCLUSIONS AND ADVICE

High catches of soft-shelled Crab are a concern in N-ENS and a potential issue in S-ENS, depending on the balance of spring or summer fishing activities. Timely responses from industry to avoid fishing in areas showing potential or actual high incidence of soft-shelled Crab must continue if unnecessary mortality of future recruits is to be averted. An earlier season in N-ENS and S-ENS appeared to significantly reduce the handling of soft-shelled Crab. Summer fishing activities, particularly in N-ENS, create additional handling mortality to commercial Snow Crab stocks.

A reference points-based PA has been implemented in this fishery. The LRP and USR are 25% and 50% of carrying capacity, respectively. The Target Removal Reference is 20% of the fishable biomass in each area and the Removal Reference is not to exceed fishing mortality at Maximum Sustainable Yield (F_{MSY}). Various secondary indicators (population and ecosystem) are taken into consideration for management decisions (Figures 13 and 14).

North-Eastern Nova Scotia (N-ENS)

High exploitation rates and limited recruitment, caused by handling mortality of soft-shelled Crab in the past, pushed the N-ENS fishable biomass to historic lows. The capture of soft-shelled Crab had been nearly eliminated, helping to protect recruitment. The 2018 fishing season saw substantial increases (potentially detrimental) in soft-shelled Crab catches, almost exclusively in the summer season. All efforts must be made to further reduce or eliminate summer fishing to protect incoming recruitment.

The 288% increase in TAC in 2017 and 5% reduction in 2018 appears to have been an overly aggressive harvest strategy. Catch rates have fallen steadily over the past two seasons to the lowest levels since 2011. The TAC was not reached in 2018 for the first time since the introduction of individual transferable quotas and removal of sub-area lines.

The presence of large male Crab are required for breeding and to protect both the female Crab and occupied Snow Crab habitat. Low catch rates (fishery and survey), increased incidence of soft-shelled Crab, increased predation, and the uncertainty around biomass estimates suggest extreme caution is warranted in the consideration of harvest strategies.

A more conservative harvest approach that lowers exploitation in N-ENS could stabilize catch rates, protect incoming recruitment essential to the fishery, and allow commercial biomass to rebuild.

South-Eastern Nova Scotia (S-ENS)

The long-term PA adopted by the S-ENS fishers since 2004 appears to have increased stability in commercial biomass levels. This stability is an important consideration given the changing ecosystems and the more volatile state of global Snow Crab populations.

Substantial TAC reductions over the past three seasons have helped maintain stable fishery performance (catch rates) in S-ENS, in spite of contracting habitat, reduced recruitment, and increased predation. Geometric mean catches from the survey are stable and, based on stock structure, increased recruitment to the fishery is likely to occur for the upcoming season. A moderately more aggressive harvest strategy would be appropriate under these conditions.

4X

As 4X is the southern-most extent of Snow Crab distribution in the North Atlantic, existing in more “marginal” environments relative to the “prime” areas of S- and N-ENS, an explicitly precautionary approach in this fishery is essential. Further, very low recruitment into the fishable biomass and the large inter-annual temperature variations increases the uncertainty associated with this area. The extreme warm bottom temperature event of 2012/2013 was detrimental to the Snow Crab population in 4X, which has not recovered to previous abundance levels. A zero TAC was set for the 2018/2019 fishing season due to low commercial biomass. Catches from the Snow Crab survey indicate that commercial biomass levels in 4X remain very low but have improved.

MANAGEMENT CONSIDERATIONS

Capture of Immature Crab

The continuation of the prompt and careful return of immature (small-claw, non-terminally moulted) Crab to the water is an important conservation measure that will enhance the mid-term (2–3 year) sustainability of this fishery.

Precautionary Approach

Many existing measures and fishing practices in the Scotian Shelf Snow Crab fishery are inherently precautionary:

- No removal of female Crab. Reproductive potential of spawning stock biomass is not disrupted. Most removals of males occur after mating and sub-legal mature Crab (able to reproduce) are never removed.
- Conservative exploitation strategies have generally been the norm, especially in recent years.
- Refugia from directed fishing pressures exist in the Gully MPA, along the continental slope, and much of the western inshore portion of CFA 24.
- Immature and soft-shelled (newly-moulted, easily damaged) Crab are not harvested, and handling mortality is minimized via voluntary area closures and at-sea observer monitoring of soft-shelled incidence, helping to maximize the potential yield per animal to the biomass.

Harvest control rules have been developed that link the biomass reference points to the exploitation reference points (DFO 2013a; Figures 14 and 15). The harvest strategies are further informed by secondary indicators, which include expected recruitment, spawning stock biomass, size and age structure of various stock components, sex ratios, environmental variables, and fishery performance. If a stock is determined to be in the Critical Zone, a rebuilding plan must be in place with the aim of having a high probability of the stock growing out of the Critical Zone within a reasonable timeframe. Removals from all fishing sources are kept to the lowest possible level until the stock has cleared this zone (DFO 2006, DFO 2013b).

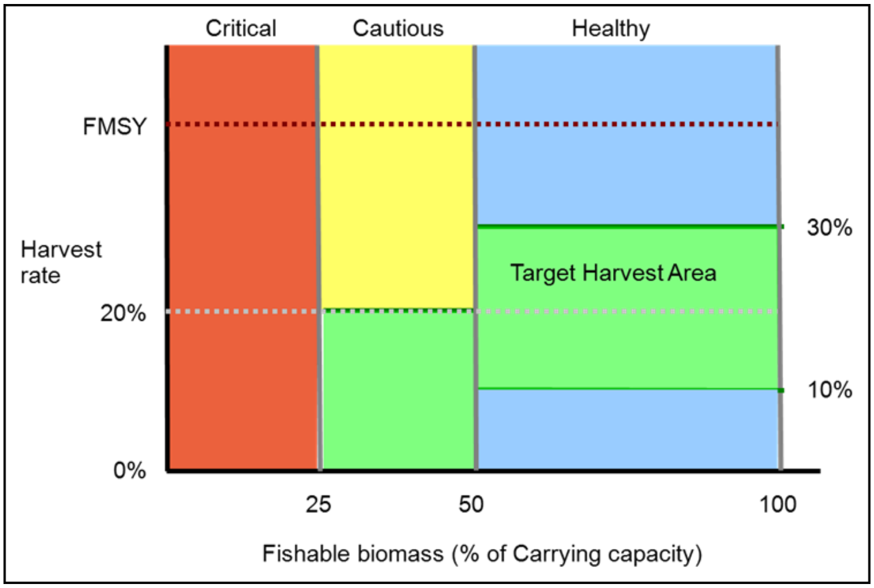


Figure 14. Harvest control rules for the Scotian Shelf Ecosystem Snow Crab fishery.

The operational reference points associated with the 4VWX Snow Crab fishery are as follows:

* **Lower Stock Reference (LSR):** 25% of carrying capacity

* **Upper Stock Reference (USR):** 50% of carrying capacity.

* **Removal Reference (RR):** not to exceed F_{MSY} (where F is the fishing mortality of the legal sized mature male population and MSY is the theoretical Maximum Sustainable Yield)

* **Target Removal Reference (TRR):** 20% of the fishable biomass (F=0.22). Secondary, contextual indicators are used to alter harvest rates between 10 and 30% of fishable biomass (FB; F=0.11 to F=0.36).

The Harvest Control Rules are, therefore, as follows:

- FB>USR: target exploitation rate of 10%–30% be utilized, based upon contextual information provided by secondary indicators
- LSR<FB<USR: target exploitation rate of 0%–20%, based upon contextual information provided by secondary indicators
- FB<LSR: fishery closure until recovery (at a minimum, until FB>LSR)

From the logistic model output the current estimates of “carrying capacity” for the fishable biomass of Snow Crab is estimated to be {and 95% CI}:

- N-ENS: 4.85 {3.76, 6.3} kt
- S-ENS: 55.7 {44.9, 69.1} kt
- 4X: 1.17 {0.89, 1.56} kt

The estimates of F_{MSY} {and 95% CI} were:

- N-ENS: 0.499 {0.266, 0.719}
- S-ENS: 0.411 {0.283, 0.583}
- 4X: 0.444 {0.286, 0.643}

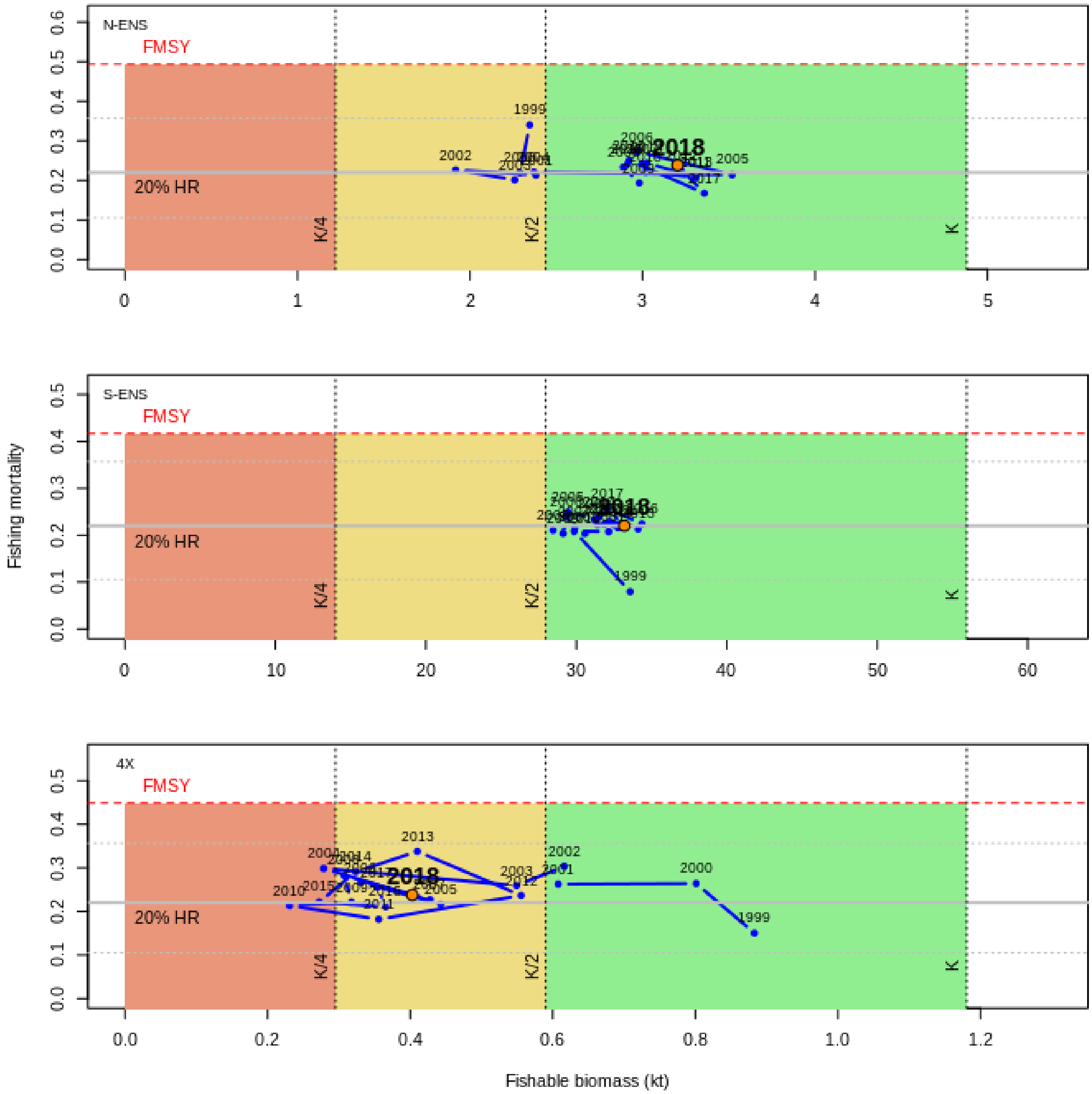
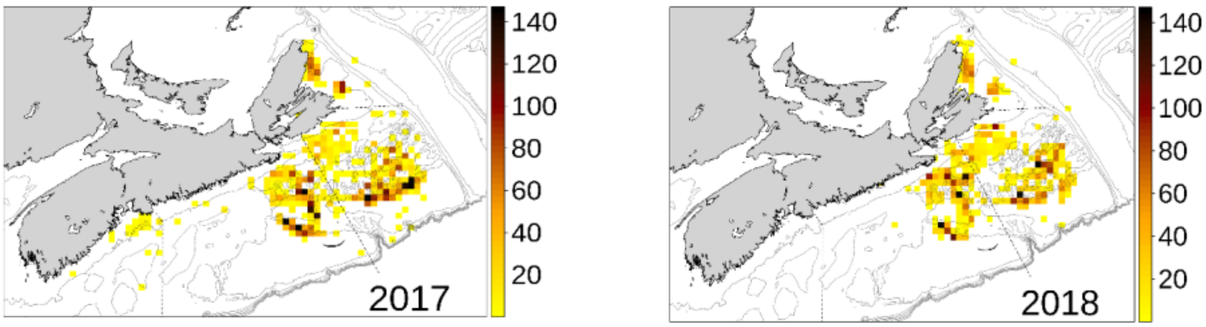
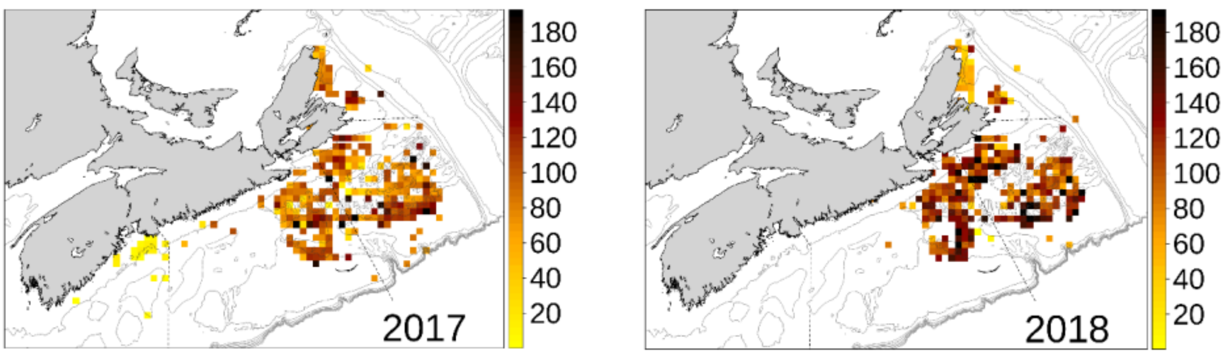


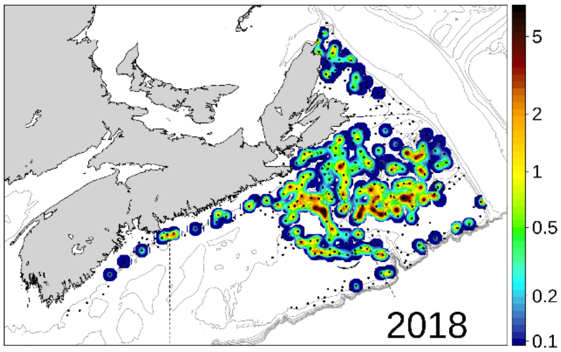
Figure 15. Time series of fishing mortality and fishable biomass for N-ENS (top), S-ENS (middle), and 4X (bottom) as obtained from the logistic population models. The large red dot indicates 2018.



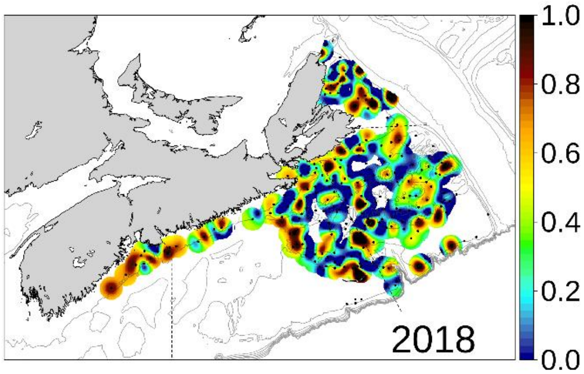
Map 1. Snow Crab landings (tons/10 km² grid) from fisheries logbook data for 2017 and 2018. For 4X, year refers to the starting year. Original figure in colour.



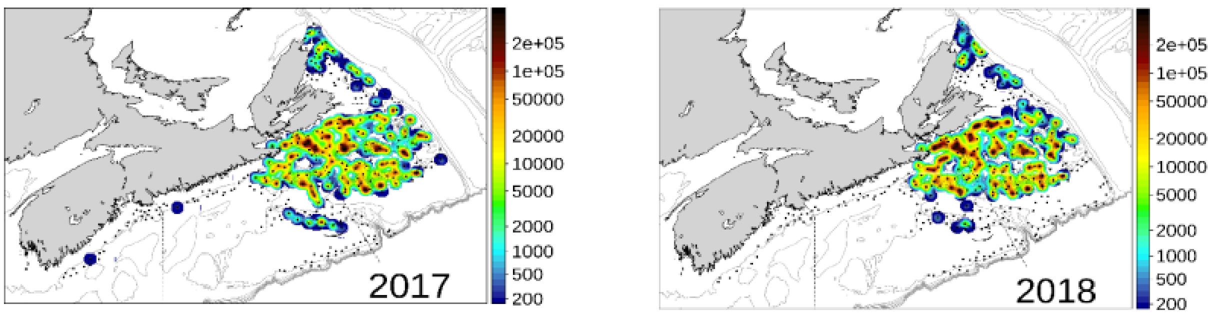
Map 2. Catch rates (kg/trap haul) of Snow Crab on the Scotian Shelf in 2017 and 2018. Original figure in colour.



Map 3. Fishable biomass densities (t/km²) from the 2018 Snow Crab survey. Original figure in colour.



Map 4. Proportion of females in the mature population. Note the heterogeneous distribution of sexes in all areas. Original figure in colour.



Map 5. Number of Northern Shrimp, a food item of Snow Crab. Original figure in colour.

SOURCES OF INFORMATION

This Science Advisory Report is from the February 27, 2019, Assessment of Scotian Shelf Snow Crab. Additional publications from this process will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Boudreau, M., Courtenay, S.C. and Lee, K. 2009. Proceedings of a Workshop Held 23 January 2007 at the Gulf Fisheries Centre; Potential Impacts of Seismic Energy on Snow Crab: An Update to the September 2004 Review. Can. Tech. Rep. Fish. Aquat. Sci. 2836: vii+31 p.

Canada Gazette. 2016. St. Anns Bank Marine Protected Area Regulations. Canada Gazette, Part I, Vol 150, Issue 51: 4143–4149.

CNSOPB (Canada-Nova Scotia Offshore Petroleum Board). 2019. Lands Management: Call for Bids Forecast Areas (2019–2021).

Courtenay, S.C., Boudreau, M., and Lee, K. (editors). 2009. Potential Impacts of Seismic Energy on Snow Crab: An Update to the September 2004 Peer Review. Environmental Studies Research Funds Report No. 178. Moncton, 181 p.

DFO. 2004. Potential Impacts of Seismic Energy on Snow Crab. DFO Can. Sci. Advis. Sec. Hab. Status Rep. 2004/003.

DFO. 2006. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.

DFO. 2013a. Integrated Fisheries Management Plan for Eastern Nova Scotia and 4X Snow Crab (*Chionoecetes Opillio*).

DFO. 2013b. Guidance for the Development of Rebuilding Plans under the Precautionary Approach Framework: Growing Stocks out of the Critical Zone.

DFO. 2018. Stock Status Update of Atlantic Halibut (Hippoglossus hippoglossus) on the Scotian Shelf and Southern Grand Banks in NAFO Divisions 3NOPs4VWX5Zc. DFO Can. Sci. Advis. Sec. Sci. Resp. 2018/022.

Hunt Oil. 2005. CNSOPB Program # NS24-H33-1P. Hunt Oil Company of Canada, Inc. 2D Seismic. Contractor Geophysical Services Incorporated. Vessel *M/V Gulf Pacific*. Start Date 03-Nov-05. Total numbers of kilometers Acquired/ Projected 920.53 km/940.25 km. Report Date 23-Nov-05 (Program terminated November 20, 2005).

Husky Energy. 2010. CNSOPB. Husky Energy 2D Seismic/Petroleum Geo-Services *M/V Harrier Explorer* July 1/10 696.36 km/597 km July 21/10 (Program terminated July 21, 2010).

APPENDIX

Participant List

Name	Affiliation
Anderson, Bob	CFA 24 (S-ENS)
Baker, Lori	Eastern Shore Fisherman's Protective Association (ESFPA)
Bennett, Lottie	DFO Maritimes / Centre for Science Advice
Brickman, David	DFO Maritimes / Ocean & Ecosystem Science
Cameron, Brent	DFO Maritimes / Population Ecology Division
Choi, Jae	DFO Maritimes / Population Ecology Division (BIO)
Cook, Adam	DFO Maritimes / Population Ecology Division (BIO)
Cormier, Paul	N-ENS Snow Crab
Crouse, Rick	Pisces Consulting
d'Entremont, Dennis	CFA 24 (S-ENS) / Canso Trawler-Mans
Donovan, Darrell	CFA 23 (S-ENS)
Glass, Amy	DFO Maritimes / Population Ecology Division (BIO)
Hayman, Timothy	DFO Maritimes / Resource Management
Kehoe, Andrew	CFA 24 (S-ENS)
Keith, David	DFO Maritimes / Population Ecology Division (BIO)
MacDonald, Gordon	CFA 23 (S-ENS) / Traditional Fleet / LFA 30 Fishermen's Association
Martin, Tim	Native Council of Nova Scotia (NCNS)
Nasmith, Leslie	DFO Maritimes / Population Ecology Division (BIO)
Nicholas, Hubert	Membertou First Nation / Fisheries
Penny, Lorne	DFO Maritimes / Resource Management, ENS
Rhyno, Tim	CFA 23
Smith, Allan	4X Snow Crab
Soomai, Suzuette	DFO Maritimes / Fisheries Management
Spinney, René	Blue Ribbon Crabbers CFA 24
Symes, Tommy	N-ENS Snow Crab
Zisserson, Ben	DFO Maritimes / Population Ecology Division (BIO)

THIS REPORT IS AVAILABLE FROM THE:

Center for Science Advice (CSA)
Maritimes Region
Fisheries and Oceans Canada
Bedford Institute of Oceanography
1 Challenger Drive, PO Box 1006
Dartmouth, Nova Scotia B2Y 4A2

Telephone: 902-426-7070
E-Mail: MaritimesRAP.XMAR@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2020. Assessment of Scotian Shelf Snow Crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/053.

Aussi disponible en français :

MPO. 2020. Évaluation du crabe des neiges en Nouvelle-Écosse. Secr. can. de consult. sci. du MPO, Avis sci. 2019/053.