# ASSESSMENT OF NOVA SCOTIA (4VWX) SNOW CRAB

*Snow Crab (Chionoecetes opilio, O. Fabricius)*

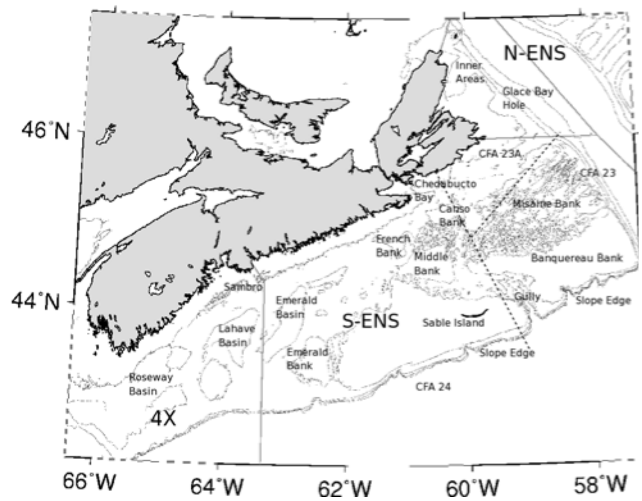



*Figure 1. Map of the Scotian Shelf and Crab Fishing Areas (CFAs). Original figure in colour.*

## 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 (CW). Additional management measures were introduced from 1994 to 1999: individual boat quotas (IBQs), 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. Advice for the next year is provided.*

*This Science Advisory Report is from the February 23, 2018, 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


- Landings in 2017 for North-Eastern Nova Scotia (N-ENS) and South-Eastern Nova Scotia (S-ENS) were 819 tonnes (t) and 6,723 t, respectively, and they were 80 t in 4X for the 2016/2017 season, representing an increase of 180% (N-ENS) and decreases of 30% (S-ENS) and 44% (4X) relative to the previous year. Total Allowable Catches (TACs) in 2017 were 825 t and 6,730 t in N-ENS and S-ENS, respectively, and 80 t for 2016/17 in 4X.
- Non-standardized catch rates in 2017 were 90 kg/trap haul in N-ENS, 94 kg/trap haul in S-ENS, and 25 kg/trap haul in 4X in 2016/2017, which, relative to the previous year, represents decreases of 18%,11% and 19%, respectively.
- Commercial catches of soft-shelled (newly moulted) crab were below 6% in N-ENS and S-ENS for the 2017 season. The shift towards earlier fishing seasons has improved soft-shell crab handling rates in both N-ENS and S-ENS, though continued diligence is important to protect incoming recruitment. Soft-shell discards in 4X are negligible, in large part due to a fall/winter fishery.
- Fishable biomass estimation was less reliable in 2014 and 2015 due to difficulties in assessment methodology. A new biomass estimation methodology was introduced in 2016 and further refined in 2017, which relates habitat and abundance with environmental and ecosystem variables while also accounting for spatial and temporal variation. Current and past biomass estimates have been determined through current methodologies to allow for direct comparison.
- Changes in the 2017 assessment further simplified model inputs (removing some ecosystem parameters) and added localized temporal smoothing. As a result, fishable biomass estimates are less variable from year to year.
- The modelled post-fishery fishable biomass index of Snow Crab in N-ENS was estimated to be 3,140 t in 2017, relative to 2,794 t in 2016. In S-ENS, the modelled post-fishery fishable biomass index was 37,640 t in 2017, relative to 40,100 t in 2018. In 4X, the modelled pre-fishery fishable biomass was 120 t for 2017/18, relative to 149 t in 2016/2017.
- In N-ENS and S-ENS, maturation of a recruitment pulse of female crab began in 2016 and continued in 2017, creating substantial increases in the abundance of mature female crab and the proportion of mature female to male crab. Area 4X also saw substantial female maturation in 2017 though at density levels lower than other areas. The majority of female crab in all areas are now mature.
- Egg production is expected to increase due to increased number of mature females and the larger egg clutch size in multiparous females.
- Moderate internal recruitment to the fishery is expected for the next year in N-ENS and S-ENS and is possible for the next 4-5 years, based on population size structure. Emigration, increased mortality, or sublegal sized terminal moult can lower expected recruitment. Area 4X internal recruitment is expected to be very minimal.
- Bycatch of non-target species is extremely low (<0.2%) 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, though it does not appear to represent more than 3% of their diet on the Scotian Shelf.
- Average bottom temperatures in the 2017 Snow Crab survey were cooler in all areas than in 2016, which varies from the general warming trend observed since the early 1990s.

Temperatures are more stable in N-ENS than S-ENS. Area 4X exhibits more erratic annual mean bottom temperatures.

- A reference points-based Precautionary Approach (PA) has been implemented in this fishery. The Limit Reference Point (LRP) is 25% of carrying capacity and the Upper Stock Reference (USR) 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 ($F_{MSY}$). Various secondary (population and ecosystem) indicators are taken into consideration for management decisions.
- The N-ENS population is considered to be in the “Healthy” zone. Current fishable biomass estimates are below the long-term mean. Recruitment is expected to continue in coming years. A moderate TAC reduction is recommended.
- The S-ENS population is considered to be in the “Healthy” zone. Fishable biomass estimates have continued to decline in spite of TAC reductions. Current fishable biomass estimates are below the long-term mean. Recruitment is expected for at least the next three to four years. A moderate TAC reduction is recommended.
- In 4X, low recruitment, high inter-annual temperature fluctuations and overall warm water temperatures create uncertainties about this population. The current assessment methodology indicates that the stock is in the “Critical” zone.

# 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 carapace width ≥ 95 mm. There is also a concerted effort to avoid areas of newly moulted (soft-shelled) crab and to discard immature males. The N-ENS and 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 North-Eastern Nova Scotia (N-ENS, CFAs 20-22), South-Eastern Nova Scotia (S-ENS, CFAs 23, 24), and 4X (Figure 1). Landings in 2017 for N-ENS and S-ENS were 819 t and 6,723 t, respectively, and they were 80 t in 4X for the 2016/2017 season (Tables 1-3, Figure 2), representing an increase of 180% (N-ENS) and decreases of 30% (S-ENS) and 44% (4X) relative to the previous year (Figures 3 and 4). TACs in 2017 were 825 t and 6,730 t in N-ENS and S-ENS, respectively, and 80 t for 2016/17 in 4X.

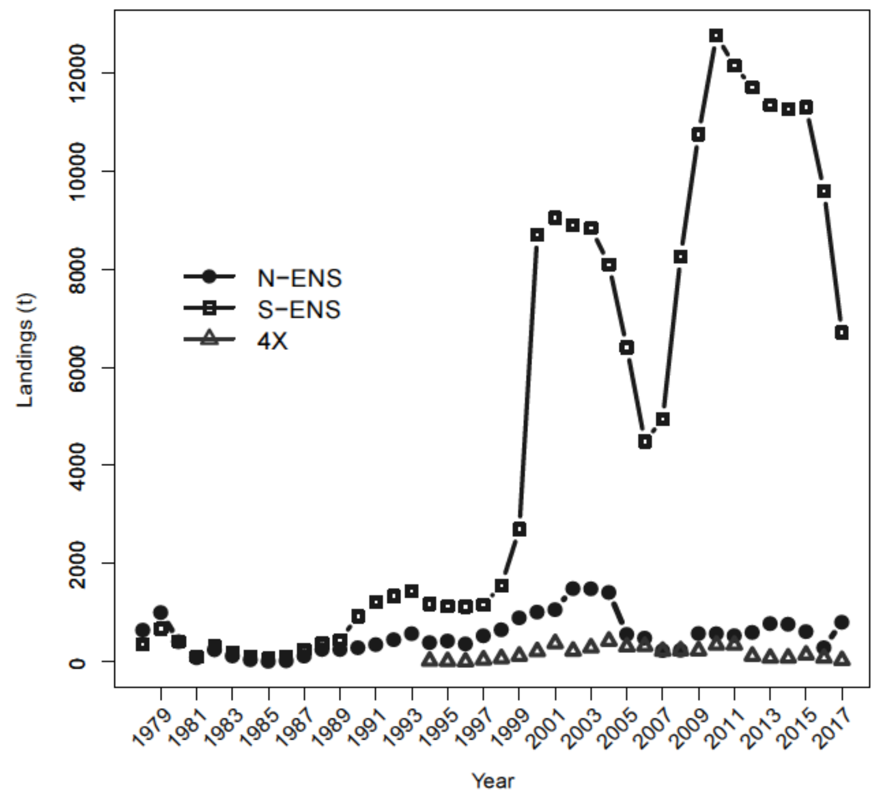



*Figure 2. Temporal variations in the landings (t) of Snow Crab on the Scotian Shelf. The landings follow the Total Allowable Catches (TACs) with little deviation, so the TACs are not shown. For 4X, the year refers to the starting year of the season.*

*Table 1. Summary of Snow Crab fisheries in North-Eastern Nova Scotia.*

| Year | Licenses | TAC (t) | Landings (t) | CPUE (kg/trap haul) | Effort (x1000 trap hauls) |
|---|---|---|---|---|---|
| 2008 | 78 | 244 | 238 | 34 | 7.0 |
| 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 | 819 | 90 | 9.0 |

*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) |
|---|---|---|---|---|---|
| 2008 | 115 | 8,316 | 8,253 | 96 | 85.9 |
| 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 | 6730 | 6,723 | 94 | 71.5 |

*Table 3. Summary of Snow Crab fisheries in 4X.*

| Season | Licenses | TAC (t) | Landings (t) | CPUE (kg/trap haul) | Effort (x1000 trap hauls) |
|---|---|---|---|---|---|
| 2006/07 | 9 | 337.6 | 317 | 28 | 11.5 |
| 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[1] | 9 | 110 | 32 | 13 | - |

Note: [1]As of February 1, 2018. Season still in progress.

In 2017, the spatial distribution of landings was focused primarily on midshore and offshore areas in S-ENS, although effort was observed in the nearshore, especially in the spring. In N-ENS, the distribution of landings was focused on the southern region of the inner gutter with increased landings from the Glace Bay Hole area in 2017 (Map 1). There was no effort on the offshore-slope areas of S-ENS in 2017.

Non-standardized catch rates in 2017 were 90 kg/trap haul in N-ENS, 94 kg/trap haul in S-ENS, and 25 kg/trap haul in 4X in 2016/2017, which, relative to the previous year, represents decreases of 18%,11% and 19%, respectively (Tables 1-3, Figure 3, Map 2).

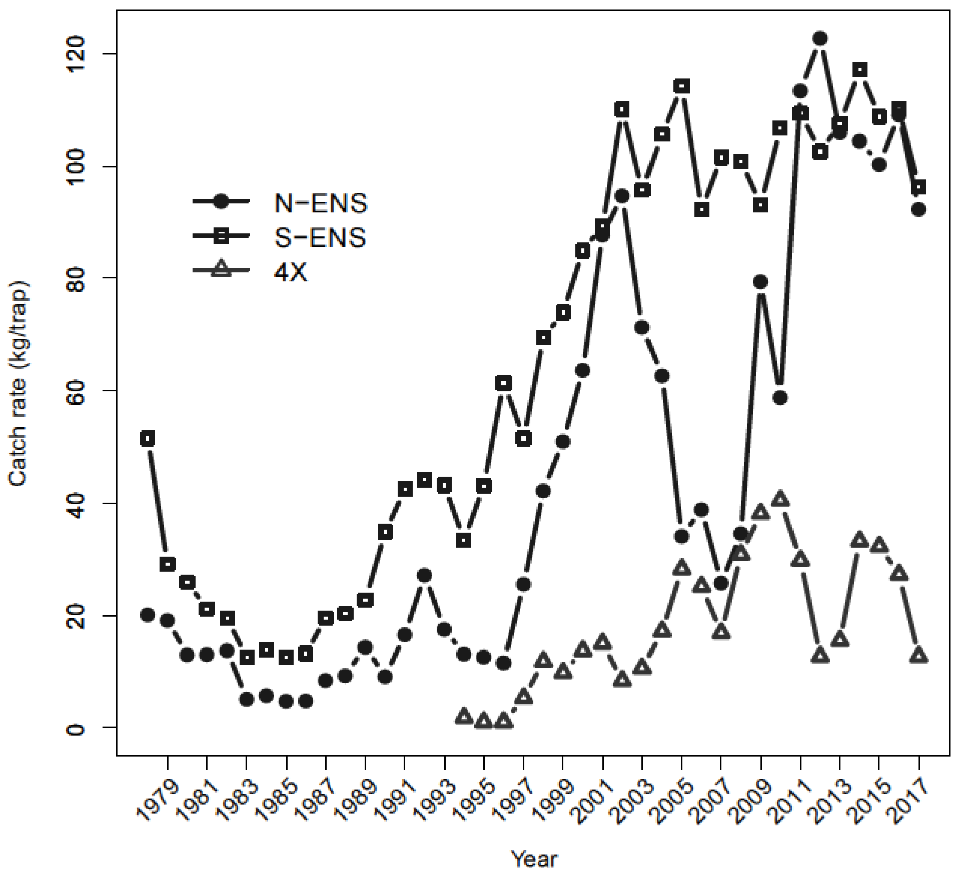



*Figure 3. Temporal variations in catch rates of Snow Crab on the Scotian Shelf, expressed as kg per trap haul. Trap design and size have changed over time. No corrections for these varying trap-types nor soak time and bait-type have been made.*

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. The oldest carapace condition CC5 signifies extensive shell decay where there is no expectation of survival into the next year.

In N-ENS, CC1 and CC2 crab collectively represented approximately 11.5% of the total catch (Figure 4), relative to 1.8% in 2016. Observed CC1 and CC2 crab were caught in the summer fishery. This is still a substantial reduction from soft-shell catches prior to 2008, when only the summer fishery existed. The spring season (2008-present) was adopted to reduce fishing intensity in the summer season and also 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. Lower spring landings in N-ENS occurred in 2014 and 2015 due to ice conditions. The mean size of animals caught in N-ENS has been increasing since 2008 suggesting higher survival of immature crab (lack of handling mortality of soft-shelled crab) and a decreased dependence on newly recruited animals. The increasing mean size of N-ENS has also bolstered catch rates (on a kg/trap basis). This increased appearance of CC1 and CC2 supports the previous year's trawl survey evidence of the very leading edge of a recruitment pulse entering the fishery. There was an increase in the proportion of the CC4 crab in the observed component of the fishery, which further supports the lack of recruitment previous to 2017.

In S-ENS, the occurrence of CC1 crab remains at low (<1%) levels (Figure 4). There was an increase in the proportion of CC2 crab from 3.6% in 2016 to 6.3% in 2017. Hard shelled crab dominated the catch with 77.5% CC3 and 15.9% CC4.

In 4X for the 2016/17 season, CC1 and CC2 crab collectively represented approximately 18% of the total catch (Figure 4). This level is higher than traditionally observed in 4X. The commercial catches are heavily dominated by CC3 and CC4 crab, which collectively represent 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 ENS as its fishing season is disjunct from that of N-ENS and S-ENS. This fall/winter 4X fishery continues to show negligible levels of soft crab.

Senescent (CC5) crab represented less than 1.5% of the total observed catch in all areas. The abundance estimates of CC5 male crab have been stable in the long-term record and below the detection limit on the Scotian Shelf surveys.

In N-ENS, the estimated soft-shell crab discard rate (percentage of total landings) was 5% in 2017, an increase from 1% the previous year. In S-ENS, 2017 estimated soft-shell discards were 1.5% of landings, relative to 4.5% in 2016. The shift towards earlier fishing seasons has improved soft-shell crab handling rates in both N-ENS and S-ENS, though continued diligence is important to protect incoming recruitment. Soft-shell discards in 4X are negligible, in large part due to a fall/winter fishery.

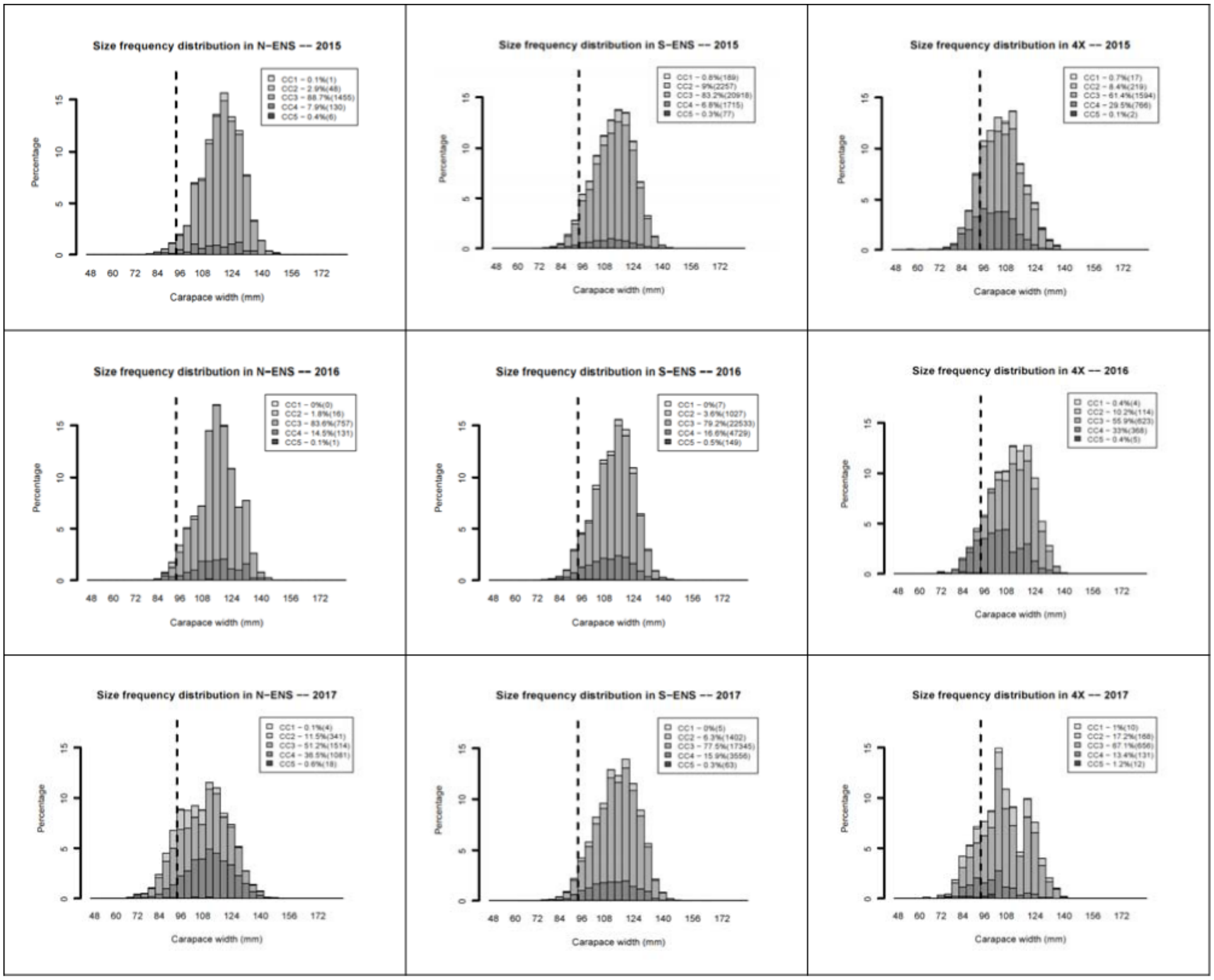



*Figure 4. Size frequency distribution of all at-sea-observer monitored Snow Crab broken down by carapace condition. For 4X, the year refers to the ending year of the season. Vertical lines indicate 95 mm CW, minimum legal commercial size.*

# 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, larger than 95 mm CW. The fishable biomass index is estimated from the area expanded trawl survey results taking into consideration environmental and ecosystem information to define Snow Crab habitat. Fishable biomass estimation was less reliable in 2014 and 2015 due to difficulties in assessment methodology (DFO 2015). A novel modelling approach (lattice-based models, “**lbm**”) was developed specifically for the Scotian Shelf Snow Crab assessment and introduced in the 2016 Snow Crab assessment. This method incorporated relationships between Snow Crab habitat and abundance with environmental (temperature, substrate and depth) and ecosystem (species composition, diversity and metabolic rates) variables while also accounting for spatial and temporal variation. The lbm approach was further refined for the 2017 assessment into a space-time modelling (“**stmv**”). This refinement simplified model inputs and add localized temporal smoothing. Results from

**stmv** were less erratic than those of **lbm**. 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.

The modelled post-fishery fishable biomass index (from the logistic population model) of Snow Crab in N-ENS was estimated to be 3,140 t in 2017, relative to 2,794 t in 2016.

In S-ENS, the modelled post-fishery fishable biomass index was 37,640 t in 2017 relative to 40,100 t in 2016.

In 4X, the modelled pre-fishery fishable biomass was 120 t , relative to 149 t in 2016/2017. 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.

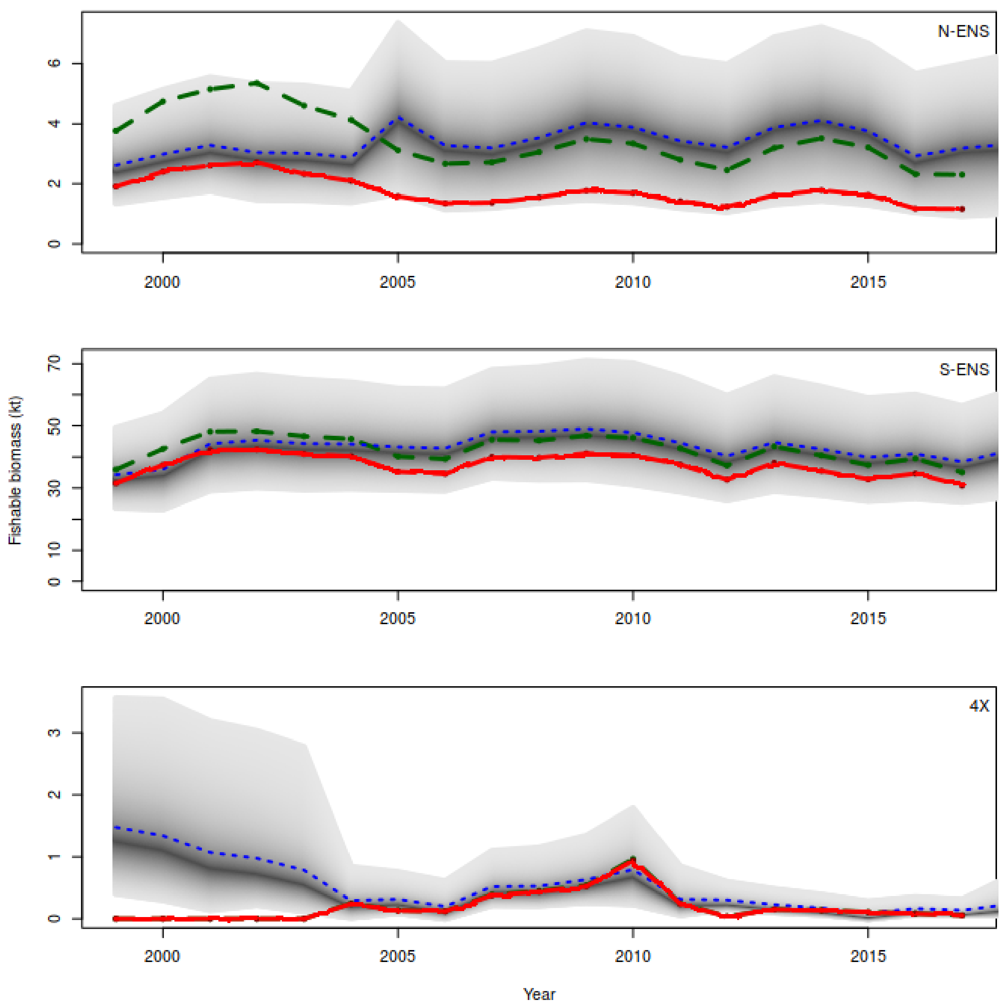



*Figure 5. Time series of fishable biomass from the logistic population models. The fishable biomass index is shown in red dashed lines. The q-corrected (model catchability coefficient (CI) fishable biomass index is shown in green dashed lines. The posterior mean fishable biomass estimates from the logistic model are shown in blue stippled lines. The density distribution of posterior fishable biomass estimates are presented with 95% CI (grey) with the darkest area being medians.*

### Recruitment

Quantitative determination of recruitment levels into the fishable biomass is confounded by a number of factors. These include terminal molt (and the timing offset of molting in spring and the survey in the fall), as well as the inability to age crab and predict absolutely at what age male crab will terminally molt. Based on size-frequency histograms of the male Snow Crab population, moderate internal recruitment (that is, recruitment from within the same fishing area) to the fishery is expected for the next year in N-ENS and S-ENS (Figure 6). Internal recruitment is 4X is expected to be very minimal. Immigration of crab from outside a given area can represent recruitment to its fishery although this is unreliable based on the episodic nature of immigration. Erratic temperature fields in 4X create strong uncertainties for the future.

In terms of size structure (Figure 6) in N-ENS and S-ENS, the presence of small immature male Snow Crab spanning almost all size ranges (30-95 mm CW) observed by the survey also suggests that internal recruitment to the fishery is possible for the next 4 to 5 years. The survival of these small animals is essential for the fishery to realize this recruitment. Any mortality (i.e. predation, environmental, disease, etc.), emigration or sub-legal sized terminal moult can impact this recruitment potential. Area 4X shows minimal potential for internal recruitment to the fishery for the next 2-3 years as very few crab in the 70-100 mm size range were captured by the trawl survey.

In N-ENS and S-ENS, maturation of a recruitment pulse of female crab began in 2016 and continued in 2017, creating substantial increases in the abundance of mature female crab (Figure 7) and the proportion of mature female to male crab (Figure 8). Area 4X also saw substantial female maturation in 2017 though at density levels substantially lower than other areas. The majority of female crab in all areas are now mature.

### Reproduction

Mature female Snow Crab abundance has increased after 10 years of a declining trend in N-ENS and S-ENS and is expected to continue rising for the next year (Figure 7). Associated egg production is expected to increase 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 be male-dominated in N-ENS and S-ENS though the broad-scale maturation of female crab has begun to increase these sex ratios over the past 2 years. Area 4X traditionally shows a more balanced sex ratio than N-ENS and S-ENS (Figure 8), potentially resulting from higher mortality of male crab in this area. The current low density of mature female crab in 4X may hinder localized egg production, although snow crab in the 4X area will likely benefit from increased egg production in the other areas due to their down current location for larval drift.

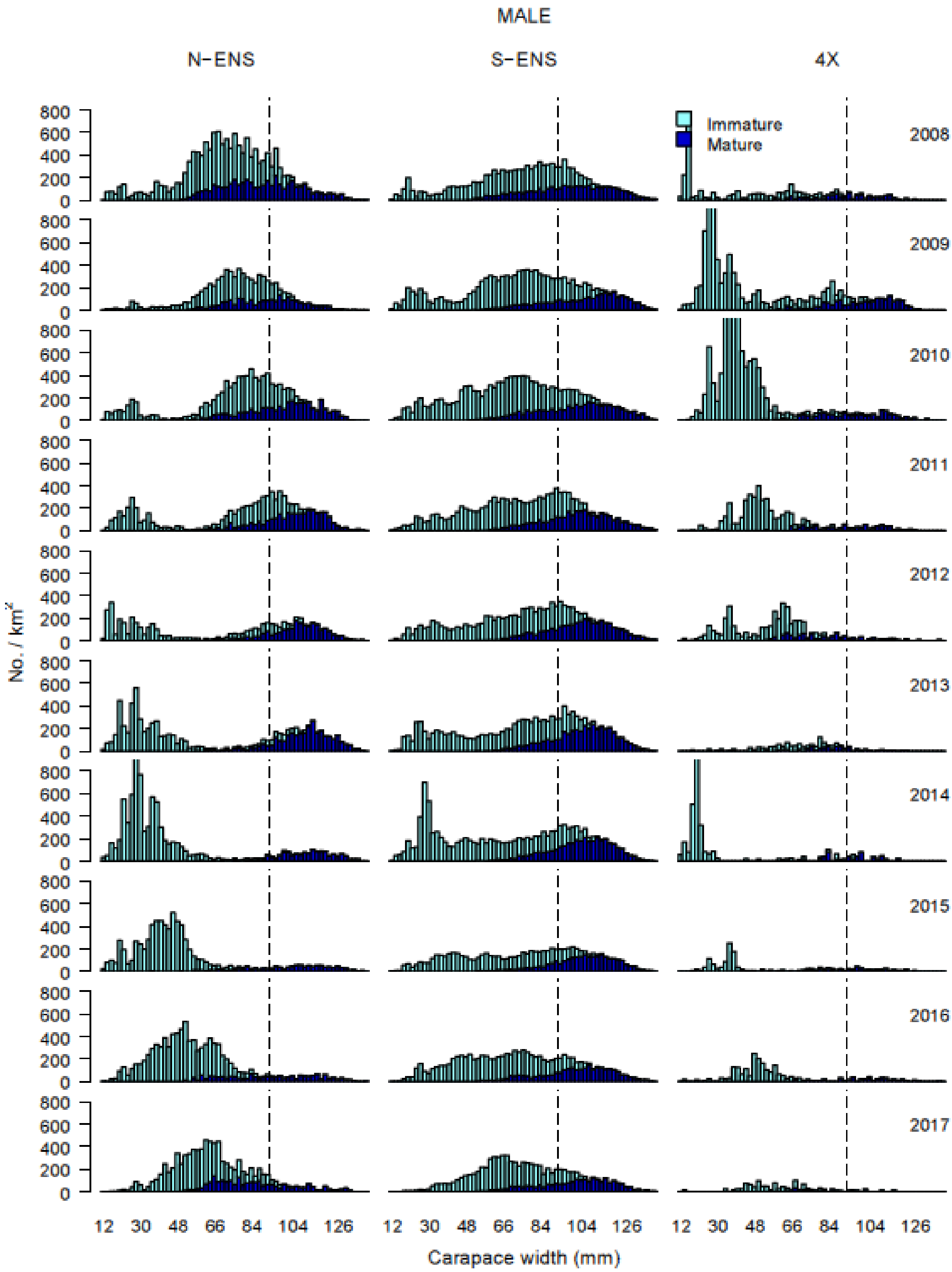



*Figure 6. Size-frequency histograms of carapace width of male Snow Crabs. Note the relatively uniform distribution of adolescent crab across all size classes in S-ENS as compared to other areas and previous patterns in S-ENS. This figure provides information about the relative numbers within a given year. The vertical line represents the legal size (95 mm).*

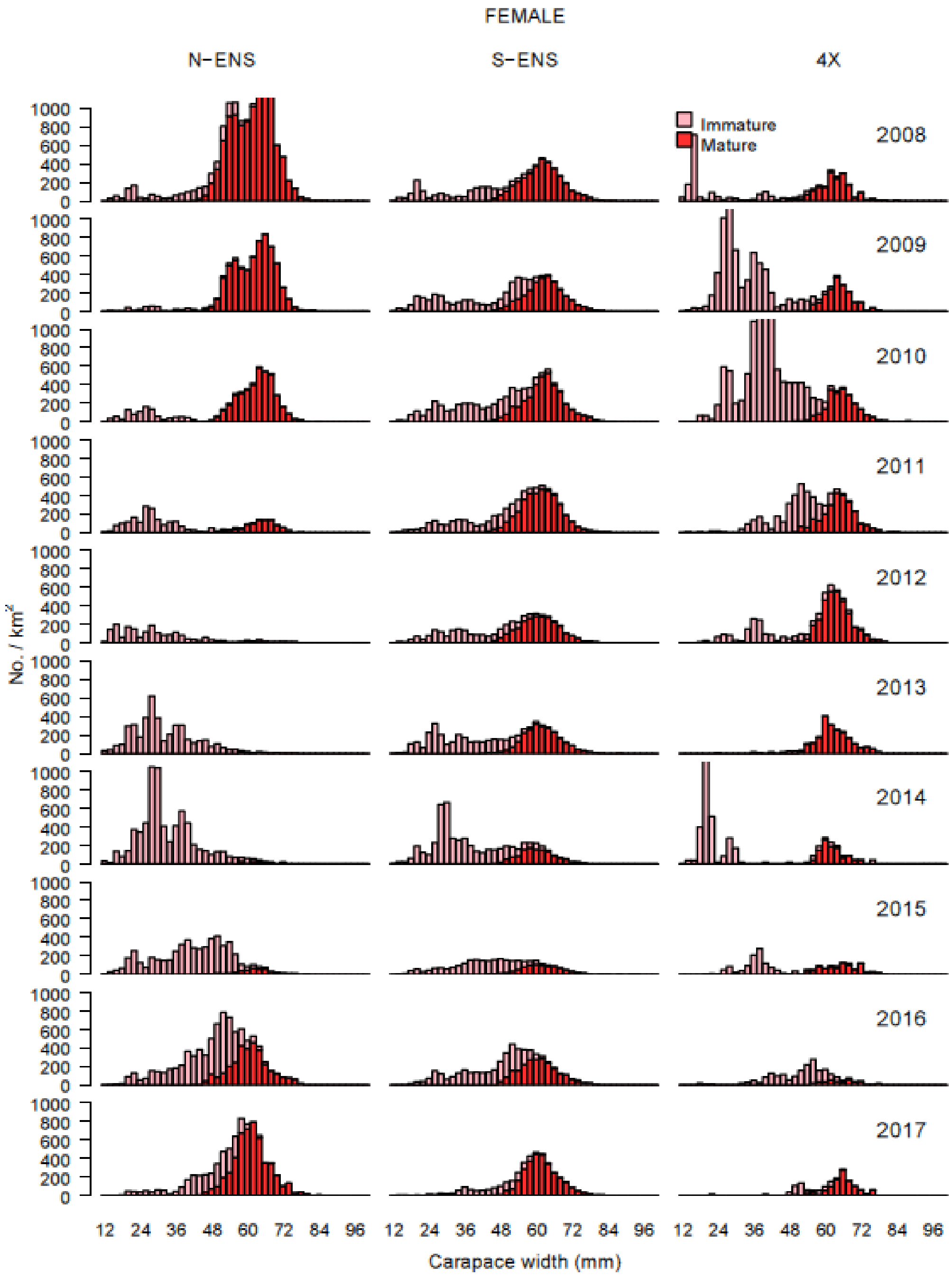



*Figure 7. Size-frequency histograms of carapace width of female Snow Crabs. This figure provides information about the relative numbers within a given year.*

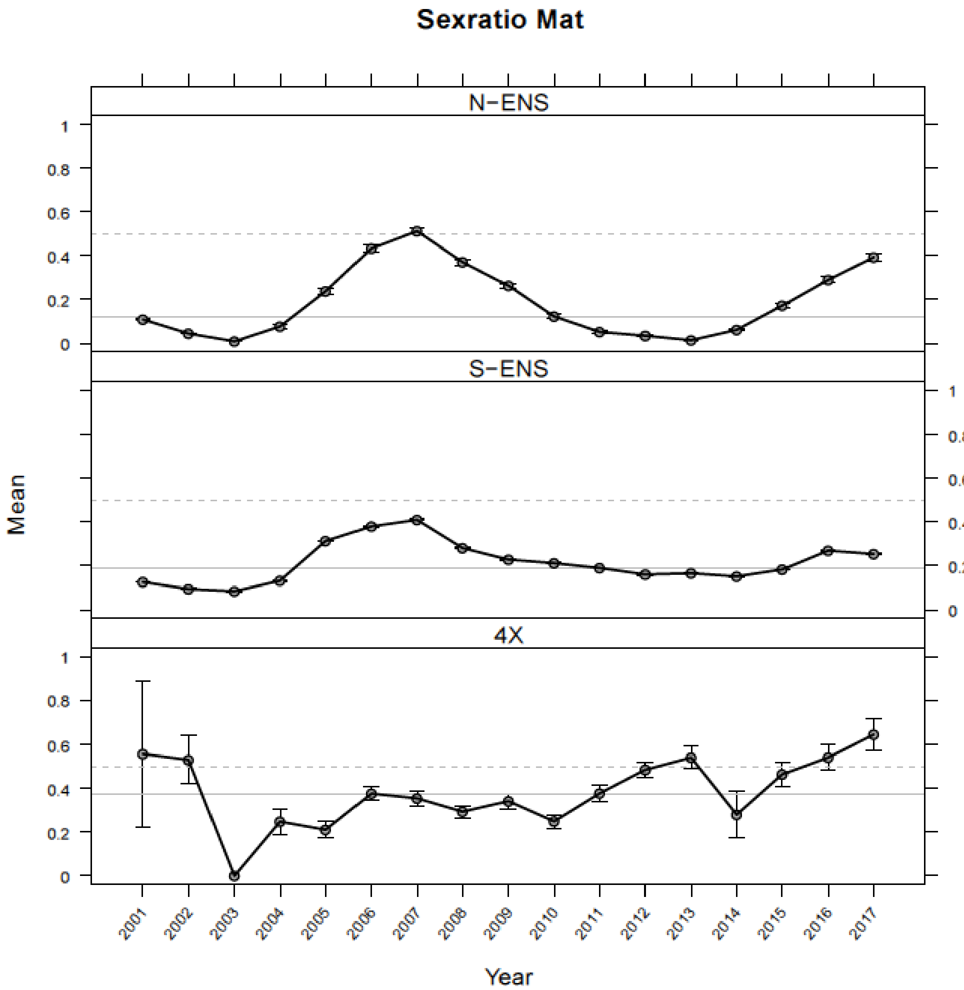



*Figure 8. Sex ratios (proportion female) of mature Snow Crab. Since 2000, the Scotian Shelf is generally male dominated.*

### Fishing Mortality

The abundance estimate of CC5 male crab has been stable in the long-term record and below the detection limit on the Scotian Shelf. Their low representation in the survey data and the fishery-observed data may be indicative of high mortality rates of the fishable biomass (fishery-based and/or natural).

The N-ENS fishing mortality (F) in 2017 was estimated to have been 0.18 (exploitation rate 0.16), a decrease from 0.33 in 2016 (Figure 9), and below the long-term mean.

The S-ENS fishing mortality (F) in 2017 was estimated to have been 0.25 (exploitation rate 0.22), a moderate increase from 0.23 in 2016 (Figure 9), and above the long-term mean. 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) and there are reports of illegal landings in this area.

The 4X fishing mortality (F) in 2016/2017 was estimated to have been 0.36 (exploitation rate 0.30), a sharp increase from 0.22 in 2015/2016 (Figure 9), and above the long-term mean. Localized exploitation rates are likely to be higher, since the computed exploitation rates incorporate biomass from throughout the 4X area and not just the fishery grounds.

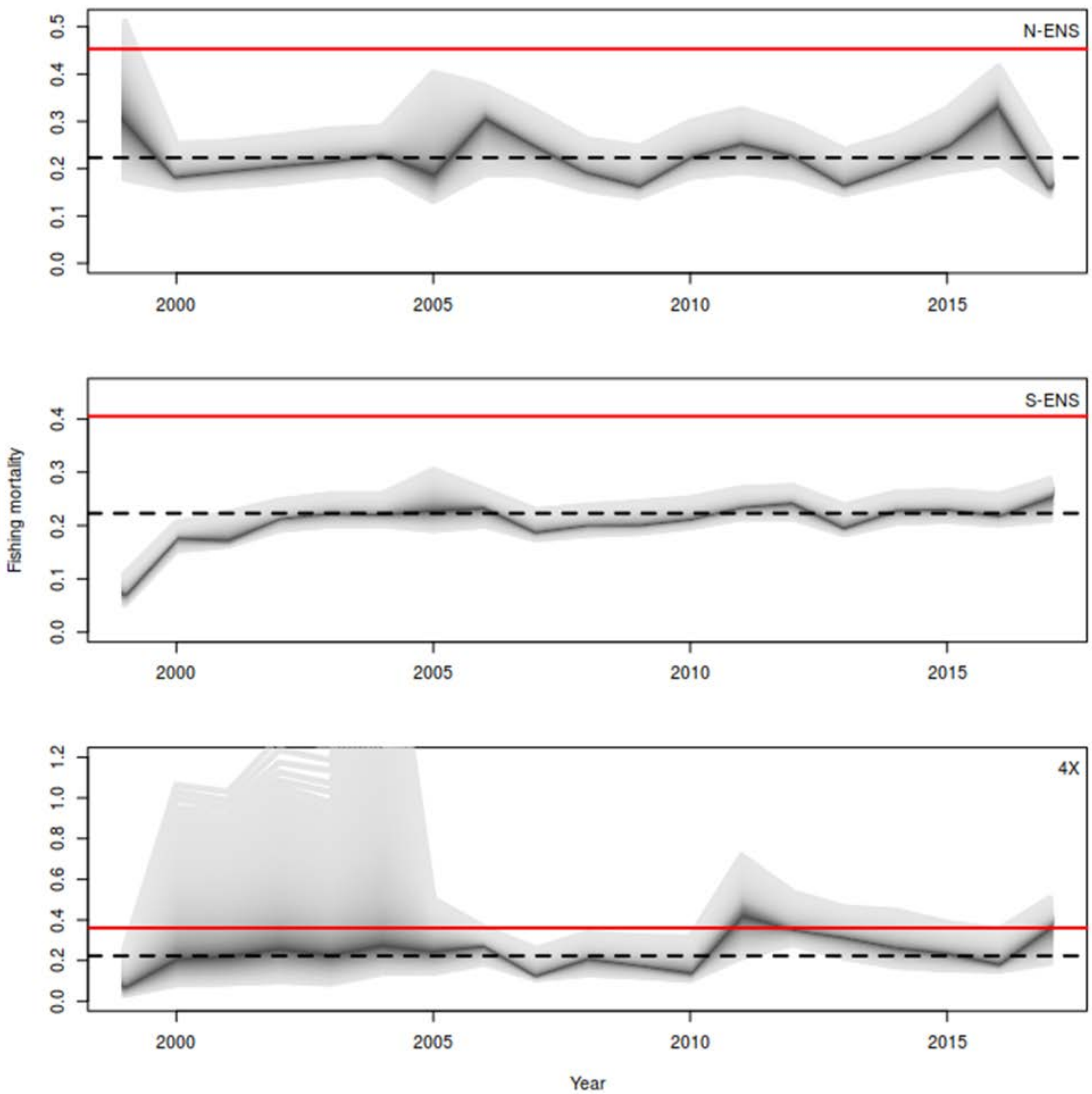



*Figure 9. Time-series of fishing mortality from the logistic population models for N-ENS, S-ENS and 4X, respectively. Posterior density distributions are presented in gray, with the darkest line being the median with 95% Confidence Interval. The red solid line is the estimated fishing mortality at maximum sustainable yield and dark stippled line is the 20% harvest rate.*

## Ecosystem Considerations

A multivariate summary of key environmental (climatic), social, economic and fishery-related indicators suggests that a suite of coherent changes have occurred on the Scotian Shelf since the early 1990s (Choi et al. 2005; Cook et al. 2015). The first axis of variation accounted for approximately 22% of the total variation in the data and was dominated by the influence of declines in mean body size of organisms in the groundfish surveys, socio-economic indicators of ocean use by humans and associated changes in their relative abundance, landings and landed values of groundfish (declining), invertebrates (increasing), declines in sharks and large demersals and landings of pelagic fish, and oil and gas exploration and development (increasing). Nova Scotia Gross Domestic Product (GDP) and population size were also influential factors that have been increasing. Further, the physiological condition of many groups of fish has been declining as has been the number of fish harvesters in Nova Scotia. The temporal differences along this axis of variation indicates that coherent systemic changes of socio-economic and ecological indicators occurred in the early-1990s, with some return to historical states evident.

Importantly, temperature-related changes were generally orthogonal (independent) to the first axis of variation. The second (orthogonal) axis of variation, accounting for 10% of the total variation, was strongly associated with the cold intermediate layer temperature and volume, bottom temperatures and variability in bottom temperatures, bottom oxygen concentrations and sea ice coverage.

### Environmental Variability

Average bottom temperatures in the 2017 Snow Crab survey were cooler than 2016 values in all areas (Figure 10), which varies from the general warming trend observed since the early 1990s. Temperatures are more stable in N-ENS than S-ENS. Area 4X exhibits the most erratic annual mean bottom temperatures.

Overall, the potential Snow Crab habitat in the SSE for 2017 was below the long-term mean. All areas have potential habitat at the lowest level observed in the past 20 years (Figure 11).

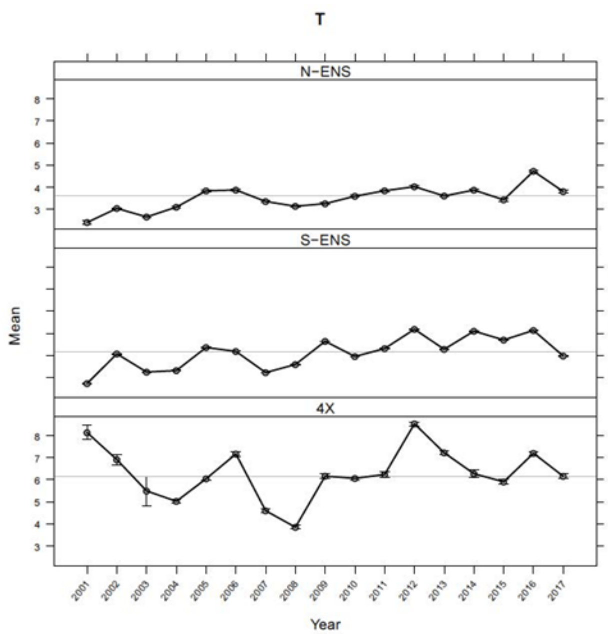



*Figure 10. Annual variations in bottom temperature observed during the Snow Crab survey. The horizontal line indicates the long-term median temperature within each subarea. Error bars are standard errors.*

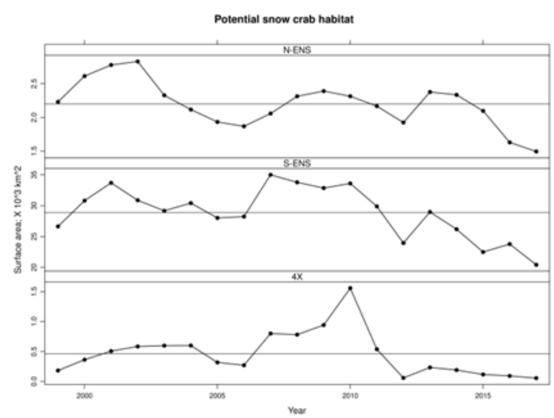



*Figure 11. Annual variations in the surface area of potential Snow Crab habitat. The horizontal line indicates the long-term median surface area within each subarea. The estimates for the period from 1998 to the present are based upon Snow Crab surveys while those prior to 1998 are projected using incomplete data (and so less reliable).*

### 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 that 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 resultant release from predation upon the immature and soft-shelled crabs, may have been an important determinant of the rise to dominance of Snow Crab in the SSE in the early 2000s. Based on stomach sampling, Atlantic Halibut (Figure 12), Atlantic Wolffish, Thorny Skate (Figure 13), and other skate species, appear to be the predominant predators of Snow Crab, though it does not appear to represent more than 3% of their diet on the Scotian Shelf. 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.

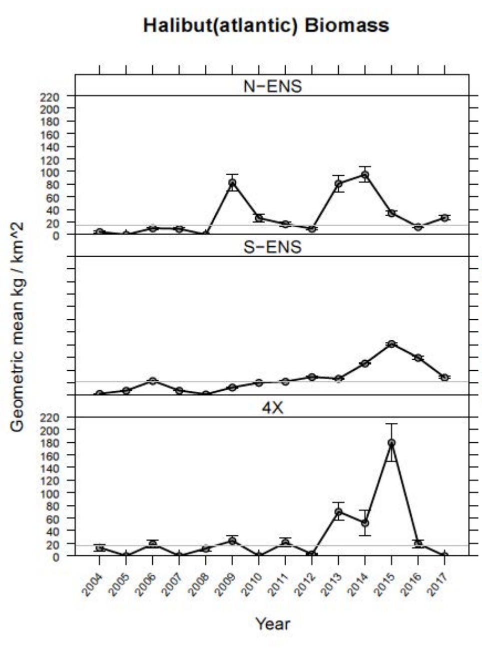



*Figure 12. Atlantic Halibut biomass trend from annual Snow Crab survey. Horizontal lines indicates the long-term median within each subarea. Vertical lines are 95% confidence intervals estimated by bootstrapping.*

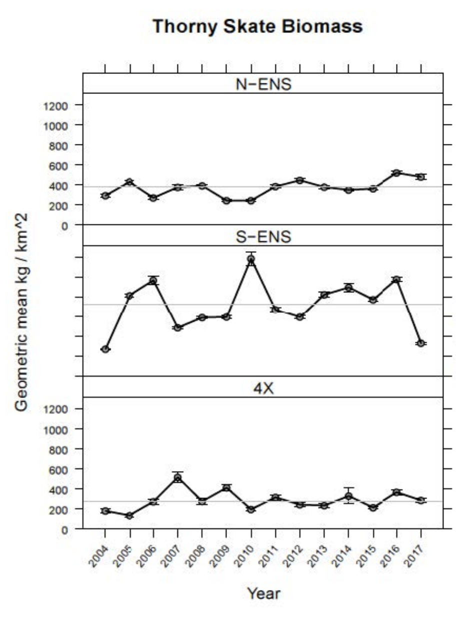



*Figure 13. Thorny Skate biomass trend from annual Snow Crab survey. Horizontal lines indicates the long-term median within each subarea. Vertical lines are 95% confidence intervals estimated by bootstrapping.*

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, it should also be emphasized that high concentrations of Snow Crab are found in the immediate vicinity of Sable Island, an area where the abundance of Grey Seals is extremely high. The evidence indicating that seals have a negative influence upon the Snow Crab population, therefore, seems to be minimal. In fact, it is quite possible that 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 also protect them from potential predators of crab (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 males stabilize the Snow Crab population by maintaining and occupying prime crab habitat. Large mature males keep at bay potential competitors such as other crab species or even groundfish, serve as strong mates for the current population pulse of mature females, and are protectors of the smaller females. Their over-exploitation can have numerous negative biological consequences. An important consequence of the extended period of low proportions of mature females to mature males (Figure 7) observed in the early 2000s and early 2010s throughout the Scotian Shelf is that 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, suggestive of little competitive interactions. 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 those of lobster.

#### Human Influences

Oil and gas development/exploitation continues to occur on the Scotian Shelf near to, or upstream of, 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 are still not known (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 has supported a precautionary approach long before its formal implementation. 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 2017-2019 (CNSOPB 2017).

Undersea cables have been identified by fishers as another source of concern, in particular, the Emera Maritime Link subsea cables in N-ENS. Two subsea High Voltage DC Cables now span approximately 180 km from Cape Ray, Newfoundland, to Point Aconi, Nova Scotia to potentially transport electricity from the Lower Churchill Hydro-electric project. These two cables, spaced by at least twice the water depth, may create a barrier to normal Snow Crab movement through static magnetic fields, increased temperature, and induced electrical fields or the physical barriers created as a result of trenching activities and substrate disturbance. Once energized, Emera will conduct a survey in crab habitat to confirm the Electric and Magnetic Field (EMF) intensity around the cables. At present, there is no information that can be presented to definitively 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 pior to 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, estimates of bycatch were 0.03% of Snow Crab landings (5.7% observer coverage in 2017; 5% target). Area 4X shows higher (relative to ENS) bycatch rates at 0.2% of Snow Crab landings (6.2% observer coverage in 2016/2017; 10% target). 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 adjust 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, though 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 very minimal.

## Sources of Uncertainty

Two primary sources of uncertainty exist with this fishery: 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.

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 and Protection and 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 and the potential source of uncertainty it raises for future productivity and the impacts on the stock assessment results.

Quantified uncertainties, in the form of confidence intervals, are provided from the assessment model but do not include errors propagated from the spacetime modelling that produced the fishable biomass index. These errors have not been calculated but could be used to inform observation errors in the assessment model once they are available.

## CONCLUSIONS AND ADVICE

High catches of soft-shell crab are a potential issue in N-ENS and S-ENS (but not in 4X due to their offset fishing season), 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 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 soft-shell handling and should continue whenever possible in future years.

A reference points-based Precautionary Approach (PA) has been implemented in this fishery. The LRP is 25% of carrying capacity and the USR 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 ($F_{MSY}$). Various secondary (population and ecosystem) indicators are taken into consideration for management decisions (Figure 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 has been nearly eliminated, helping to protect recruitment. The previous assessment’s modelling approach provided biomass estimates for N-ENS that fluctuated wildly by year and were higher than previously estimated. This assessment’s further refinement in modelling approach has moderated the inter-annual variations to more believable estimates. With this refinement, modelled fishable biomass index estimates are lower than estimated in the past assessment suggesting that the almost 300% increase in TAC in 2017 was overly aggressive.

The N-ENS population is considered to be in the “Healthy” zone (FB > USR, Figure 15). Current fishable biomass estimates are below the long-term mean. Recruitment is expected to continue in coming years but past expectations of recruitment in N-ENS have not always materialized, likely due to emigration, high predation or other sources of mortality. A moderate TAC reduction is recommended.

### 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 continued uncertainty in world markets and the more volatile state of global Snow Crab populations.

For many years, a high productivity regime for Snow Crab created a situation where removals from the fishable biomass (both natural and fishery-related) were more than replenished annually. S-ENS pre-fishery “target” exploitation rates were often higher than post-fishery “realized” exploitation rates. More recently, reduced recruitment and less favorable environmental / ecosystem conditions have seen removals outstrip recruitment to the fishable biomass. The TAC reductions in the past two seasons have not lowered estimates of fishing mortality. In spite of these TAC reductions, the fishable biomass index has continued declining. This requires adopting a more conservative approach to target exploitation rates.

The S-ENS population is considered to be in the “Healthy” zone (Fishable Biomass (FB) > USR, Figure 15). Current fishable biomass estimates are below the long-term mean. As recruitment is expected for at least the next three to four years, there remains scope for flexibility. A moderate TAC reduction is recommended.

### 4X

As Area 4X is the southern-most area of Snow Crab distribution, existing in more “marginal” environments relative to the “prime” areas of S- and N-ENS, an explicitly PA towards this fishery is essential. Low recruitment, high inter-annual temperature fluctuations and overall warm water temperatures create uncertainties about this population. The extreme warm bottom temperature event of 2012/2013 was very detrimental to the Snow Crab populations in 4X. Indeed, they have yet to recover to previous abundance levels. The previous assessment methodology provided fishable biomass index estimates that appear to be unrealistically erratic and, for 4X, overly optimistic based on the current modelling approach as well as fishery performance.

Current assessment methodologies indicate that the stock is in the “critical” zone (FB < LSR, Figure 15).

## MANAGEMENT CONSIDERATIONS

### Capture of Immature Crab

The continuation of 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 area closures and at-sea observer monitoring of soft-shell incidence helping to maximize the potential yield per animal to the biomass.

Harvest Control Rules (HCR) have been developed that link the biomass reference points to the exploitation reference points (DFO 2013a; Figure 14). In the Cautious and Healthy zones, actual target harvest rates are shaped by a suite of secondary indicators that provide more complete information on the entire stock’s health. These secondary indicators are used to inform management decisions under the HCR linking the stock references to harvest strategies.

Secondary indicators include expected recruitment, spawning stock biomass, size and age structure of various stock components, sex ratios, environmental variables, fishery performance and others. 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).

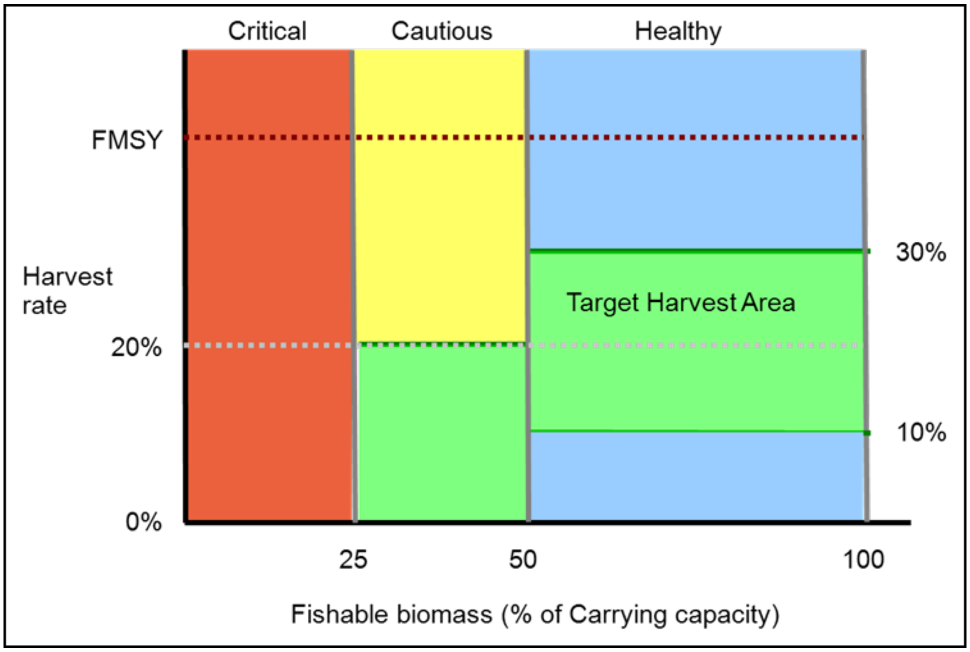



*Figure 14. Harvest control rules for the Scotian Shelf Ecosystem Snow Crab fishery.*

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: 5.65 {4.04, 7.91} kt

- S-ENS: 68.71 {53.26, 89.07} kt
- 4X: 1.82 {1.09, 2.89} kt

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

- N-ENS: 0.459 {0.211, 0.695}
- S-ENS: 0.397 {0.257, 0.598}
- 4X: 0.356 {0.191, 0.551}

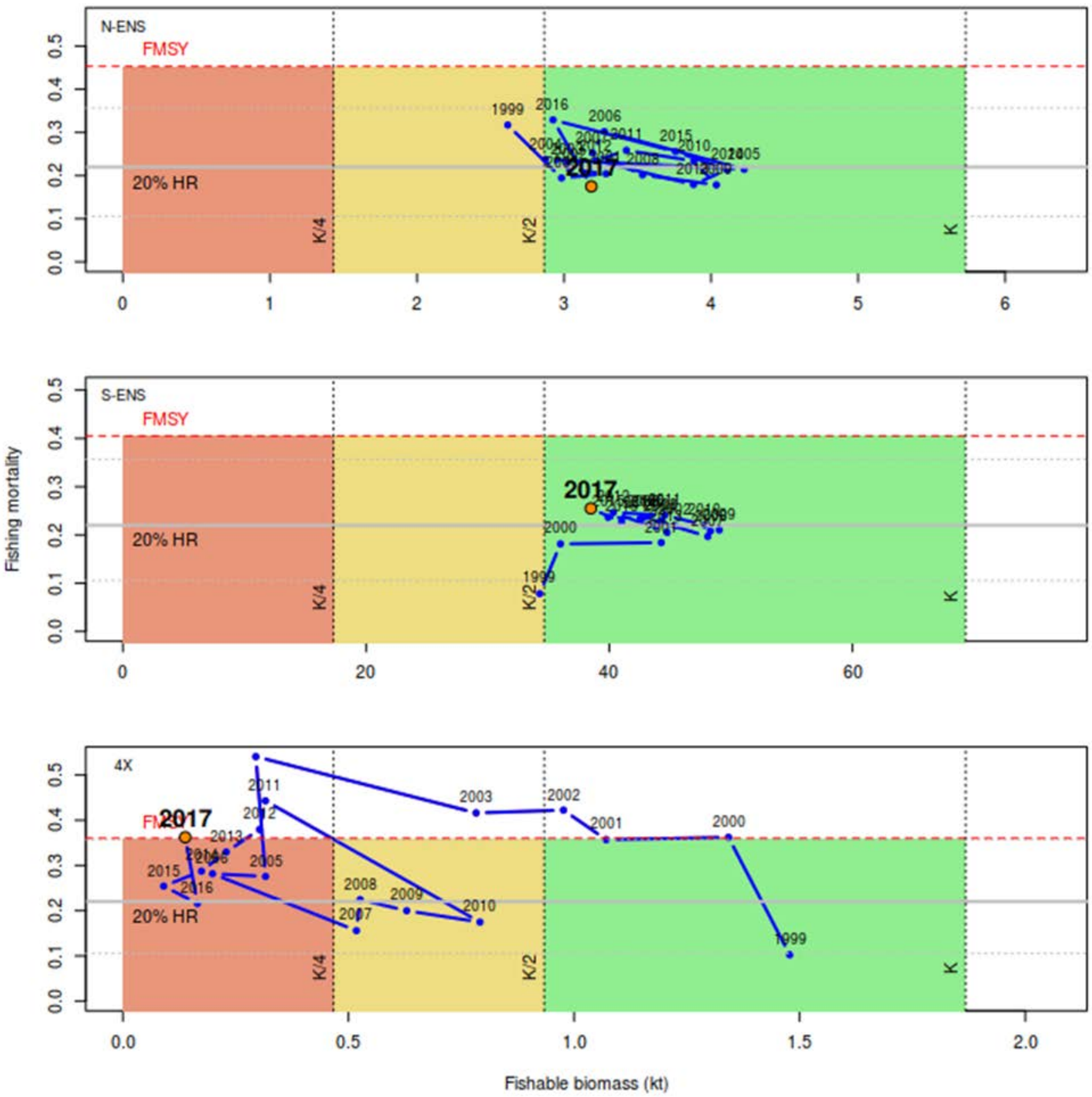
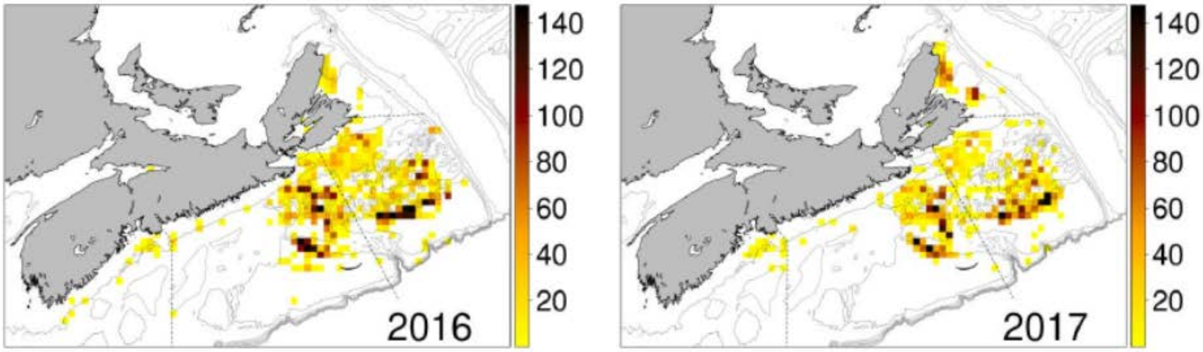
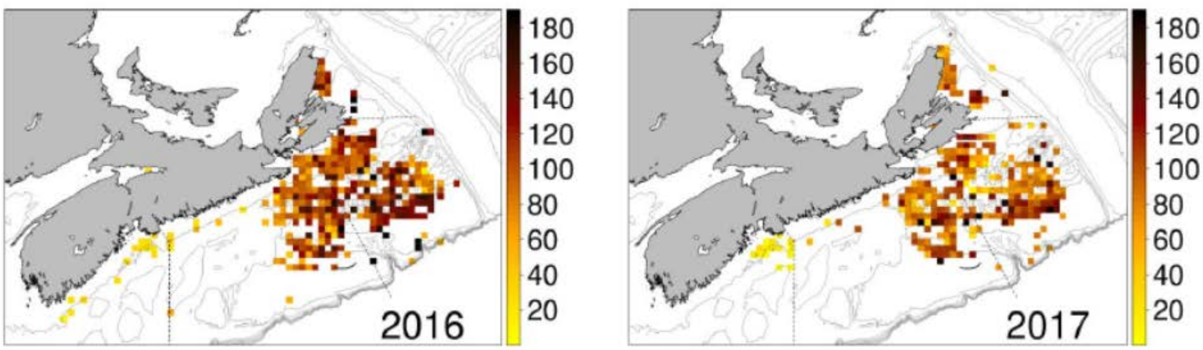


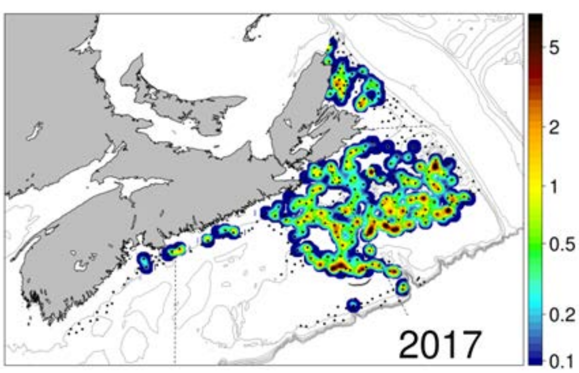

*Figure 15. Time series of fishing mortality and fishable biomass for N-ENS (top), S-ENS (middle) and 4X (bottom) as obtained from the logistic population models. The large red dot indicates current (2017) year.*



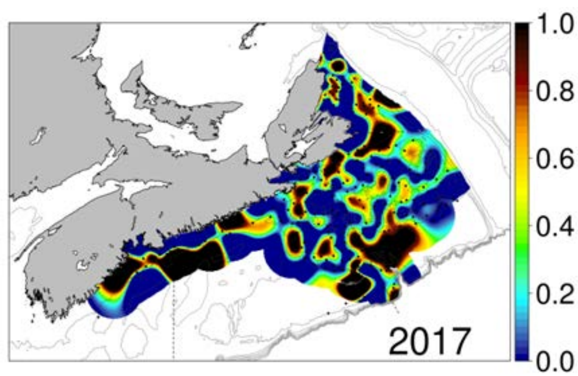

*Map 1. Snow Crab landings (tons / 10 km$^2$ grid ) from fisheries logbook data for 2016 and 2017. For 4X, year refers to the starting year. Original figure in colour.*



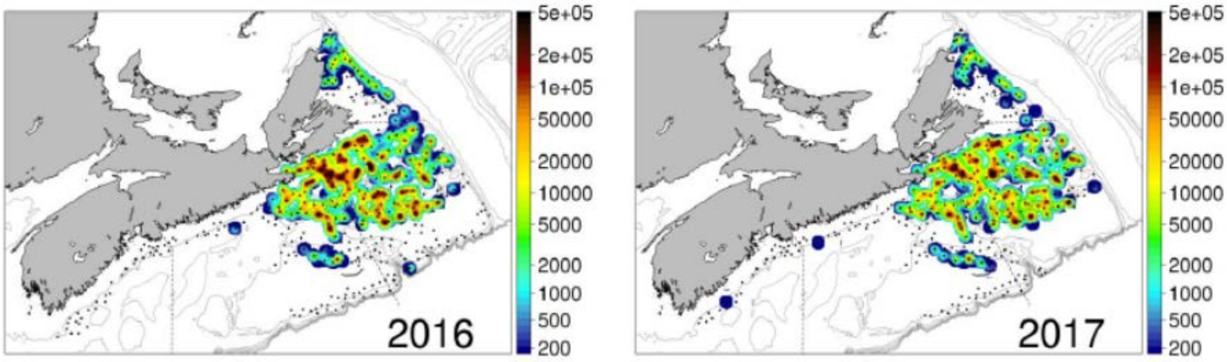

*Map 2. Average catch rates (kg/trap haul) of Snow Crab on the Scotian Shelf in 2016 and 2017. Original figure in colour.*




*Map 3. Fishable biomass denisities (t/km$^2$) from the 2017 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.*

## LIST OF MEETING PARTICIPANTS

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## SOURCES OF INFORMATION

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