Fisheries and Oceans Canada | Pêches et Océans Canada
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Maritimes Region

Canadian Science Advisory Secretariat
Science Advisory Report 2017/033

ASSESSMENT OF NOVA SCOTIA (4VWX) SNOW CRAB

Snow Crab

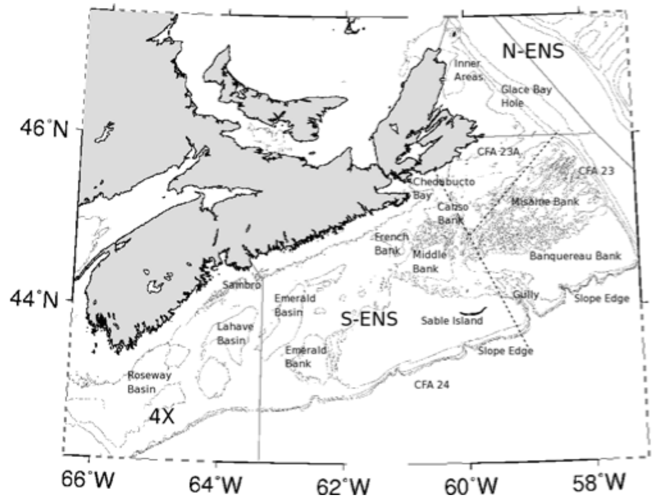


Figure 1. Map of the Scotian Shelf and Crab Fishing Areas (CFAs).

Context

Snow Crab 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).

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, 2017, 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

- Landings in 2016 for N-ENS and S-ENS were 290 t and 9,606 t, respectively, and 142 t in 4X for the 2015/2016 season. This represents a decrease of 53% in N-ENS, a decrease of 15% in S-ENS, and an increase of 73% in 4X relative to the previous year. Total allowable catches in 2016 were 286 t, 9,614 t and 150 t in N-ENS, S-ENS and 4X (2015/2016 season).
- Non-standardized catch rates in 2016 were 110 kg/trap haul in N-ENS, 106 kg/trap haul in S-ENS, and 31 kg/trap haul in 4X in 2015/2016. Relative to the previous year, this represents an increase of 7%, no change, and a decrease of 9% in N-ENS, S-ENS, and 4X.
- Commercial catches of soft shelled (newly moulted) crab were below 5% in N-ENS and S-ENS for the 2016 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 has been less reliable in 2014 and 2015 based on difficulties in assessment methodology. More robust assessment methodologies have been developed and adopted to help stabilize the biomass estimation process. Current and past biomass estimates have been determined through current methodologies to allow for direct comparison.
- The modelled post-fishery fishable biomass of Snow Crab in N-ENS was estimated to be 3,750t, relative to 2,799 t in 2015. In S-ENS, the modelled post-fishery fishable biomass was 19,835 t, relative to 25,672 t in 2015. In 4X, the modelled pre-fishery fishable biomass was 907 t, relative to 476 t in the 2015/2016 fishing season.
- The leading edge of a recruitment pulse created substantial increases in the abundance of mature female crab in N-ENS in 2016. S-ENS also showed the first increase in mature female levels since the early to mid-2000s. Large-scale maturation of female crab is expected in N-ENS and S-ENS for the next 2-3 years. Low to moderate future recruitment to the mature segment of the female population in 4X is expected in the next 1-3 years.
- Limited local recruitment into the fishery is expected for the short term in N-ENS, though the leading edge of a recruitment pulse could result in significant recruitment in 2-3 years. Male crab were observed in all size classes in S-ENS, suggesting continuing recruitment into the future. CFA 4X shows little potential for substantial internal recruitment to the fishery for the next four to five years.
- The relative proportion of CC4 (older since terminal moult) crab has increased in N-ENS in both trawl survey (48%) and commercial catches (14%) in 2016, which is indicative of an aging population. Commercial catches have shown increases in CC4 crab in S-ENS and 4X.
- Bycatch of non-target species is extremely low (<0.1%) in N-ENS and S-ENS. Area 4X bycatch levels decreased to <1%, likely due to a constriction of fishery footprint.
- Atlantic Halibut, Atlantic Wolfish and skate species appear to be the predominant predators of Snow Crab on the Scotian Shelf though Snow Crab does not appear to be an important part of their diet (<3%). Increasing population trends in these and other predators of Snow Crab could lower future recruitment to the fishable biomass.
- Average bottom temperatures in the 2016 Snow Crab survey were warmer in all areas, which continues a 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.

- 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 F_{MSY}. Various secondary (population and ecosystem) indicators are taken into consideration for management decisions.
- In N-ENS, current assessment methodologies indicate that the TAC reductions taken in the past two seasons have helped stabilize the fishable component of the population and the stock is in the Healthy Zone. Continuing low recruitment to the fishable biomass promotes a cautious harvest strategy. Based on current fishable biomass estimates an increased TAC is recommended.
- In S-ENS, current assessment methodologies indicate that the fishable biomass has been declining since 2013. Without TAC decreases relative to fishable biomass reductions, the exploitation rate (fishing mortality) has been steadily increasing since 2013. The S-ENS population is considered to be in the Healthy Zone but close to the transitional area. As recruitment is expected for at least the next three to four years, there remains scope for flexibility. A decrease in TAC is strongly recommended.
- As 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 precautionary approach towards this fishery is essential. Current assessment methodologies indicate that the stock has increased in 2016 but remains in the Cautious Zone. The erratic temperature fields and constriction of Snow Crab habitat in 4X support the continuation of a very cautious approach in harvesting strategy. In addition, recruitment into next season is uncertain leading to the recommendation of a status quo to a marginal increase in TAC.

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 on 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 may be 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 fishing season (fall to winter). Total landings increased to record-levels of approximately 10,000 tonnes (t) each year in the early 2000s and increased further to approximately 13,000 t in 2009 (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 2016 for N-ENS and S-ENS were 290 t and 9,606 t, respectively, and 142 t in 4X for the 2015/2016 season. This represents a decrease of 53% in N-ENS, a decrease of 15% in S-ENS, and an increase of 73% in 4X relative to the previous year (Tables 1-3, Figure 2). Total allowable catches in 2016 were 286 t, 9,614 t and 150 t in N-ENS, S-ENS and 4X (2015/2016 season).

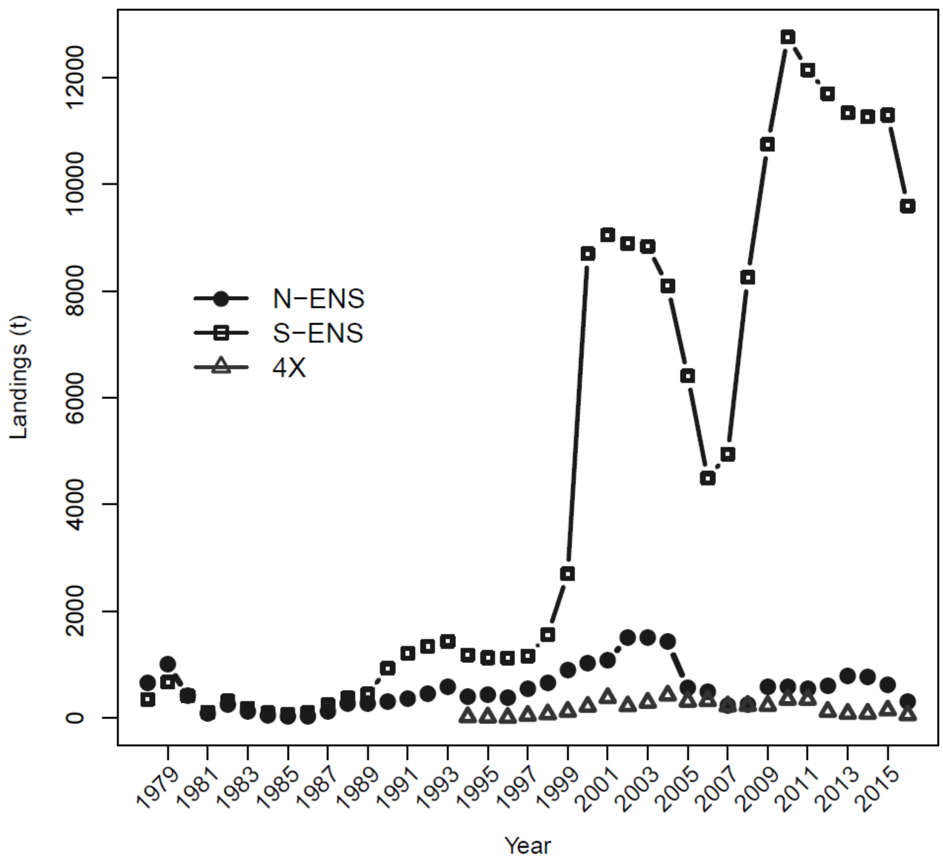


Figure 2. Temporal variations in the landings (t) of Snow Crab on the Scotian Shelf. The landings follow the Total Allowable Catches (TACs) with little deviation, so the TACs are not shown. For 4X, the year refers to the starting year of the season.

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)
2007	78	244	233	24	9.9
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

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)
2007	115	4,950	4,942	100	49.3
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

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

Season	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
2005/06	9	337.6	306	29	10.8
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[1]	9	80	55	24	2.3

Note: [1]As of February 2, 2017. Season still in progress.

In 2016, 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 were focused on the southern region of the inner gutter with limited landings from the Glace Bay Hole area in 2016 (Map 1). There was no effort on the offshore-slope areas of S-ENS in 2016.

Non-standardized catch rates in 2016 were 110 kg/trap haul in N-ENS, 106 kg/trap haul in S-ENS, and 31 kg/trap haul in 4X in 2015/2016. Relative to the previous year, this represents an increase of 7%, no change, and a decrease of 9% in N-ENS, S-ENS, and 4X. (Tables 1-3, Figure 3, Map 2).

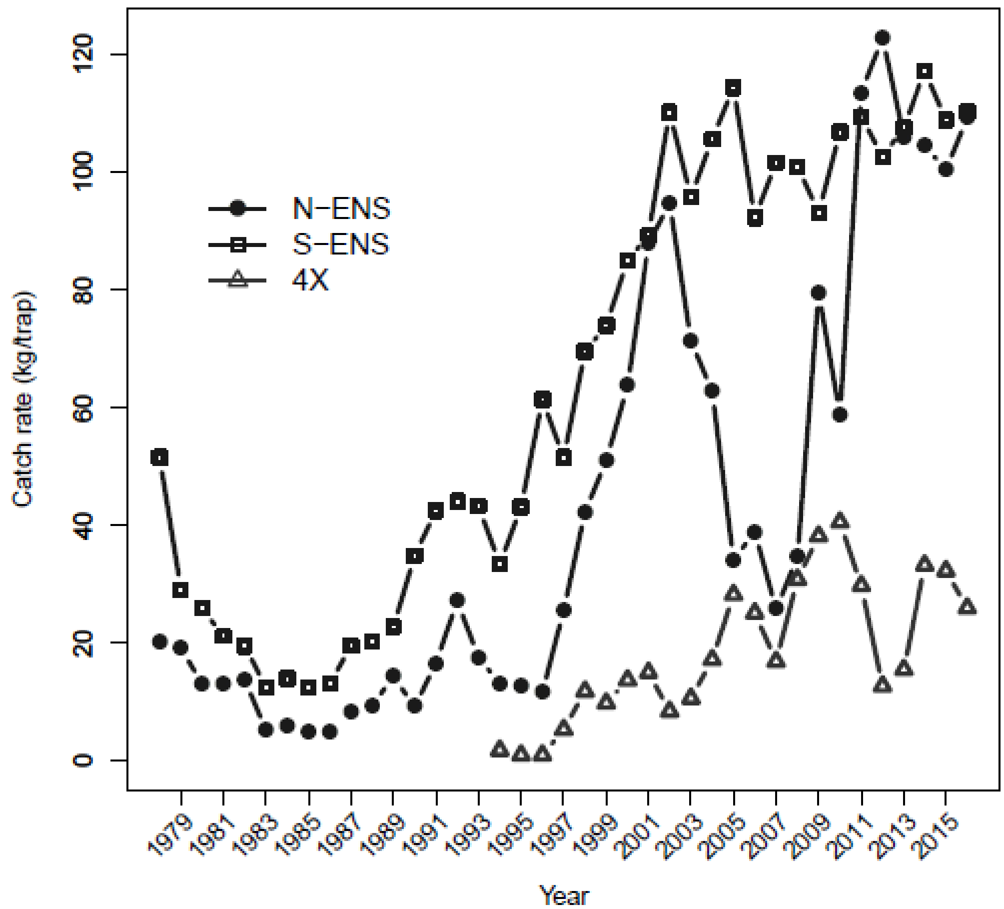


Figure 3. Temporal variations in catch rates of Snow Crab on the Scotian Shelf, expressed as kg per trap haul. Trap design and size have changed over time. No corrections for these varying trap-types nor soak time and bait-type have been made.

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 1.8% of the total catch (Figure 4), relative to 3% in 2015. This is still a substantial reduction from catches prior to 2008, when most (or all) of the landings came from the summer fishing season. 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 were caught during the spring season since 2009. 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 allowed catch rates (on a kg/trap basis) to remain high when the actual number of crab per trap has declined since 2011.There were few sub-legal (<95 mm CW) sized crab in N-ENS commercial catches as compared to S-ENS, which supports (based on the trawl survey) expectations of very limited recruitment to the fishery without external immigration. The relative percentage of CC4 crab has increased in N-ENS in both trawl survey (48%) and commercial catches (14%) in 2016, which is indicative of an ageing population.

In S-ENS, the occurrence of CC1 crab remains at low (<1%) levels. There was a decrease in the proportion of CC2 crab from 9% in 2015 to 3.6% in 2016, possibly indicating declining internal recruitment (Figure 4). Hard shell crab dominated the catch with 79.2% CC3 and 16.6% CC4. This relative percentage of CC4 crab increased almost 10% from 2015.

In 4X for the 2015/16 season, CC1 and CC2 crab collectively represented 9.1% of the total catch. This level is higher than traditionally observed in 4X. The commercial catches are heavily dominated by CC3 and CC4 crab, which collectively represent 91%. 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 species 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 2% 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.

The relative proportion of CC4 (older since terminal moult) crab has increased in N-ENS in both trawl survey and commercial catches. Commercial catches have shown increases in CC4 crab in S-ENS and 4X.

In N-ENS, the estimated soft shell crab discard rate (percentage of total landings) was ~1% in 2016, consistent with 2015. In S-ENS, 2016 estimated soft shell discards were 4.5% of landings, relative to 2.7% in 2015. 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.

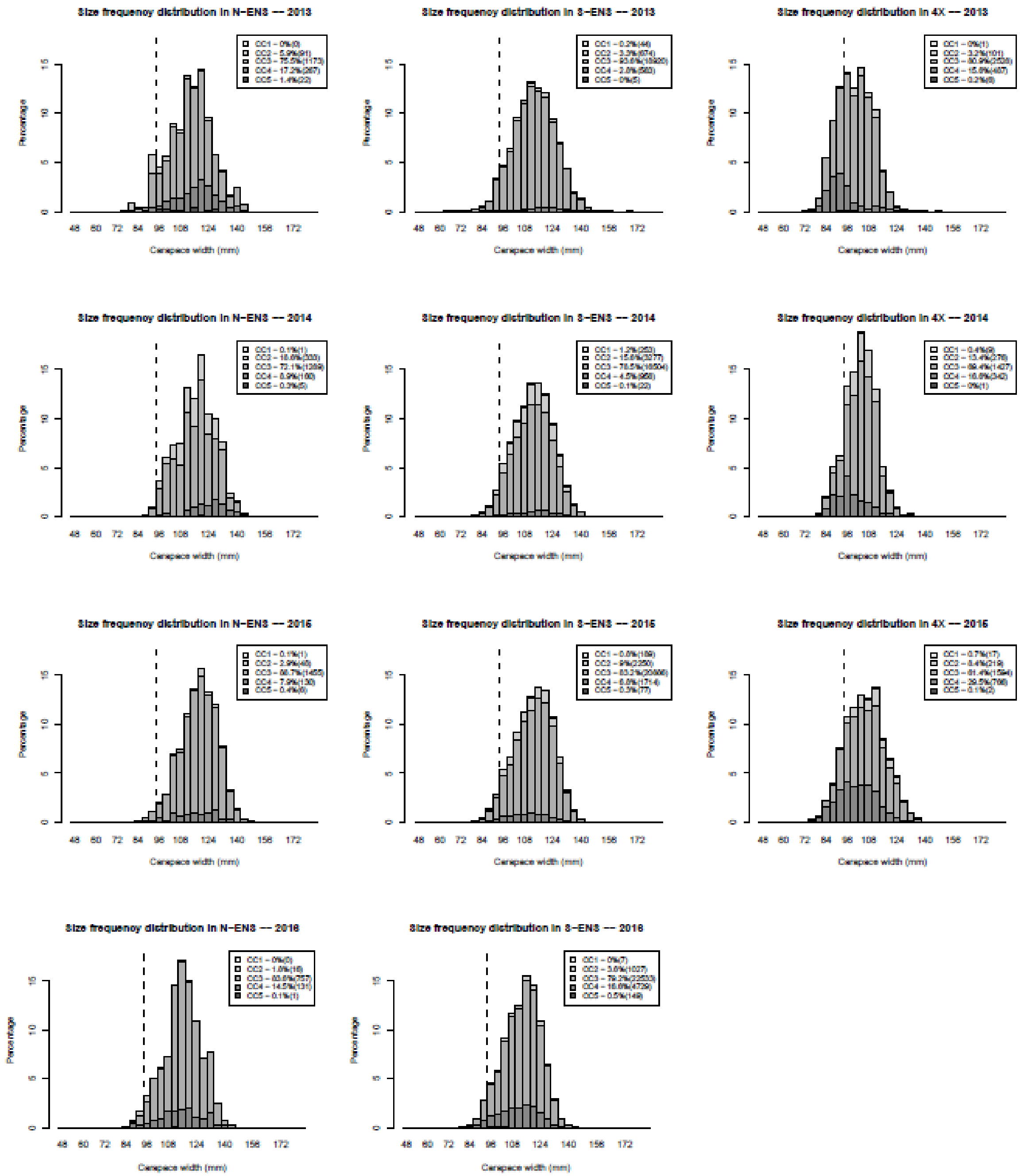


Figure 4. Size frequency distribution of all at-sea-observer monitored Snow Crab broken down by carapace condition. For 4X, the year refers to the starting year of the season. Vertical lines indicate 95 mm CW, minimum legal commercial size.

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 and hard shelled (with a durometer measure of 68 or greater). 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 has been unstable in 2014 and 2015 due to difficulties in assessment methodology. In 2014, 5-year means of potential habitat were used to characterize the potential Snow Crab habitat in each area rather than year-specific estimates. In 2015, modeling was based solely on the geometric mean Snow Crab catches from the Snow Crab survey stations in each area. In this assessment, a new version of the methodology was used to predict Snow Crab habitat and abundance across the Scotian Shelf. This method incorporates 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. Current and past biomass estimates have been determined through the current methodologies to allow for direct comparison. The resulting annual estimates of fishable biomass are then used to fit a logistic population model that provides the modelled fishable biomass and reference points.

The modelled post-fishery fishable biomass of Snow Crab in N-ENS was estimated to be 3,750 t, relative to 2,799 t in 2015 (Table 4).

In S-ENS, the modelled post-fishery fishable biomass was 19,835 t, relative to 25,672 t in 2015 (Table 5).

In 4X, the modelled pre-fishery fishable biomass was 907 t, relative to 476 t in 2015/2016 fishing season (Table 6). The 4X biomass estimate is generally more uncertain, as it fluctuates more dramatically than other areas, probably a result of migration in and out of the area.

Table 4. Biomass and fishing mortality estimates of Snow Crab in North-Eastern Nova Scotia.

Year	Biomass (kt)	95% Confidence Interval		Fishing Mortality	Exploitation Rate
2007	3.59	2.31	6.30	0.06	0.06
2008	1.36	0.86	5.40	0.16	0.15
2009	4.60	2.95	7.19	0.12	0.11
2010	4.42	2.90	7.10	0.12	0.12
2011	4.88	3.24	7.55	0.10	0.10
2012	5.93	3.93	8.70	0.10	0.09
2013	6.08	3.90	8.95	0.12	0.11
2014	2.39	1.55	5.19	0.28	0.24
2015	2.80	1.81	5.48	0.20	0.18
2016	3.75	2.45	6.50	0.07	0.07

Table 5. Biomass and fishing mortality estimates of Snow Crab in South-Eastern Nova Scotia.

Year	Biomass (kt)	95% Confidence Interval		Fishing Mortality	Exploitation Rate
2007	38.99	26.57	59.73	0.12	0.11
2008	31.67	21.48	49.27	0.23	0.21
2009	25.30	17.15	39.86	0.35	0.30
2010	24.66	16.71	38.56	0.42	0.34
2011	25.76	17.48	40.28	0.39	0.32
2012	39.58	26.32	60.32	0.26	0.23
2013	38.21	25.53	58.56	0.26	0.23
2014	25.82	17.51	40.31	0.36	0.30
2015	25.67	17.29	39.80	0.36	0.31
2016	19.83	13.34	31.93	0.39	0.33

Table 6. Biomass and fishing mortality estimates of Snow Crab in 4X.

Year	Biomass (kt)	95% Confidence Interval		Fishing Mortality	Exploitation Rate
2007	0.79	1.22	1.87	0.17	0.15
2008	0.12	0.20	0.35	0.76	0.53
2009	1.09	1.76	2.61	0.12	0.12
2010	0.50	0.88	1.47	0.33	0.28
2011	0.67	1.07	1.70	0.28	0.24
2012	1.12	1.67	2.43	0.07	0.07
2013	0.61	0.97	1.51	0.08	0.08
2014	0.14	0.22	0.36	0.32	0.27
2015	0.27	0.48	0.80	0.26	0.23
2016	0.59	0.91	1.39	0.06	0.06

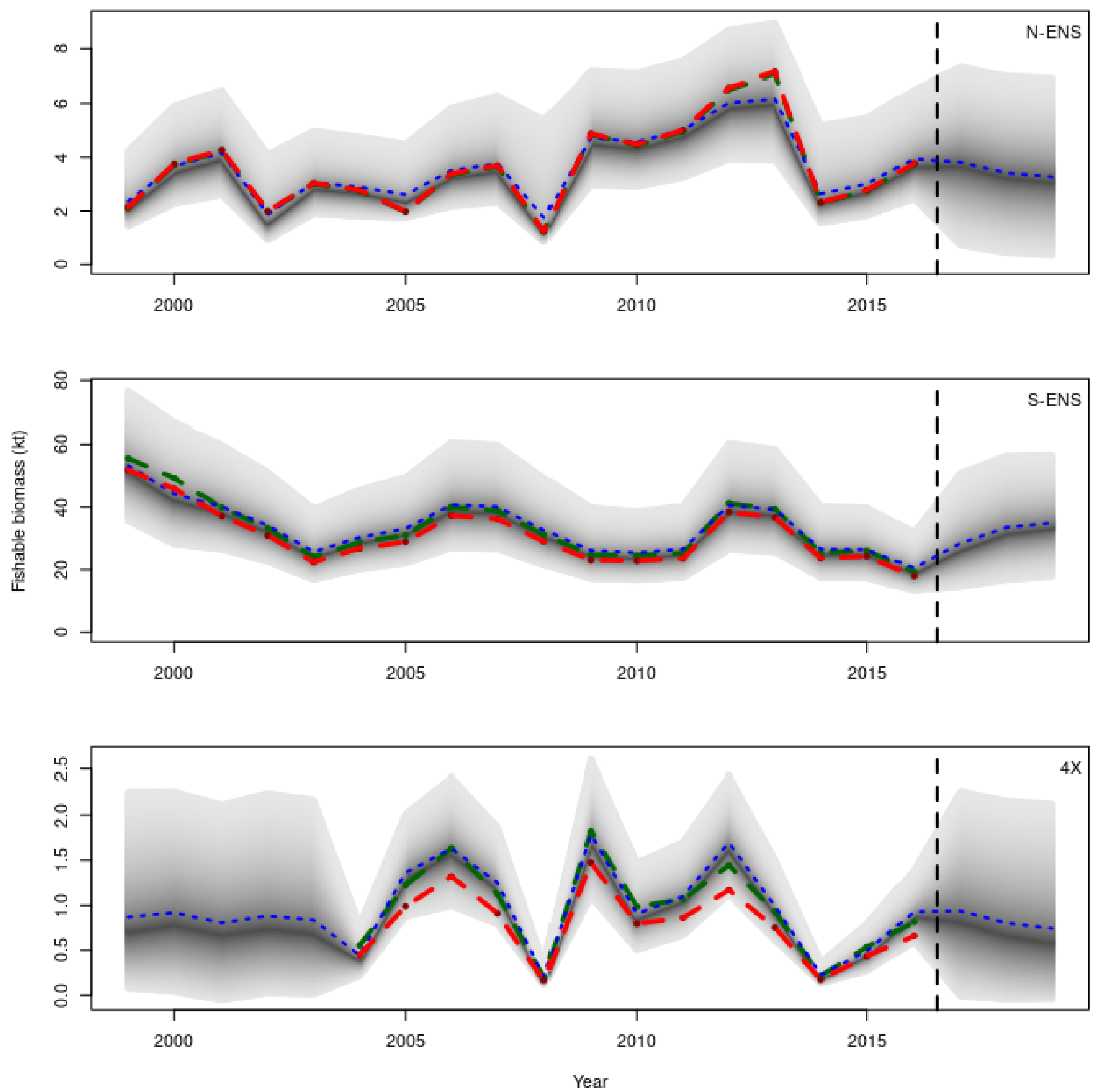


Figure 5. Time series of post-fishery fishable biomass from the logistic population models. The fishable biomass index is shown in red dashed lines. The posterior mean fishable biomass estimated from the logistic model are shown in blue stippled lines. The density distribution of posterior fishable biomass estimates are presented (gray) with the darkest area being medians and the 95% Confidence Index. A 3-year projection assuming a constant exploitation strategy of 20% is also provided.

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 moulting 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, limited internal recruitment to the fishery is expected for the next year in N-ENS and 4X (Figure 6). Internal recruitment in S-ENS is expected to remain at moderate levels. Immigration of crab from outside a given area can represent recruitment to its fishery though is unreliable based on its episodic nature.

Limited local recruitment into the fishery is expected for the short term in N-ENS, though the leading edge of a recruitment pulse could result in significant recruitment in 2-3 years (Figure 6). Male crab were observed in all size classes in S-ENS, suggesting continuing recruitment into the future. Area 4X shows little potential for substantial internal recruitment to the fishery for the next 4 to 5 years. Movement is likely an important source of crab in this area, and a lack of any commercial fishing effort in the western portion of CFA 24 hold potential benefits for 4X. Erratic temperature fields in 4X create strong uncertainties for the future.

The leading edge of a recruitment pulse created substantial increases in the abundance of mature female crab in N-ENS in 2016 (Figure 7). S-ENS also showed the first increase in mature female levels since the early to mid-2000. Large-scale maturation of female crab is expected in N-ENS and S-ENS for the next 2-3 years. Low to moderate future recruitment to the mature segment of the female population in 4X is expected in the next 1-3 years.

Reproduction

Mature female Snow Crab abundance has begun to increase after 10 years of a declining trend in N-ENS and S-ENS and is expected to continue rising for the next 2-4 years (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 broad-scale maturation of female crab has begun to increase these sex ratios. 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 lack of female crab maturing in 4X may hinder localized egg production though will likely benefit from egg production in the other areas due to their down current location for larval drift.

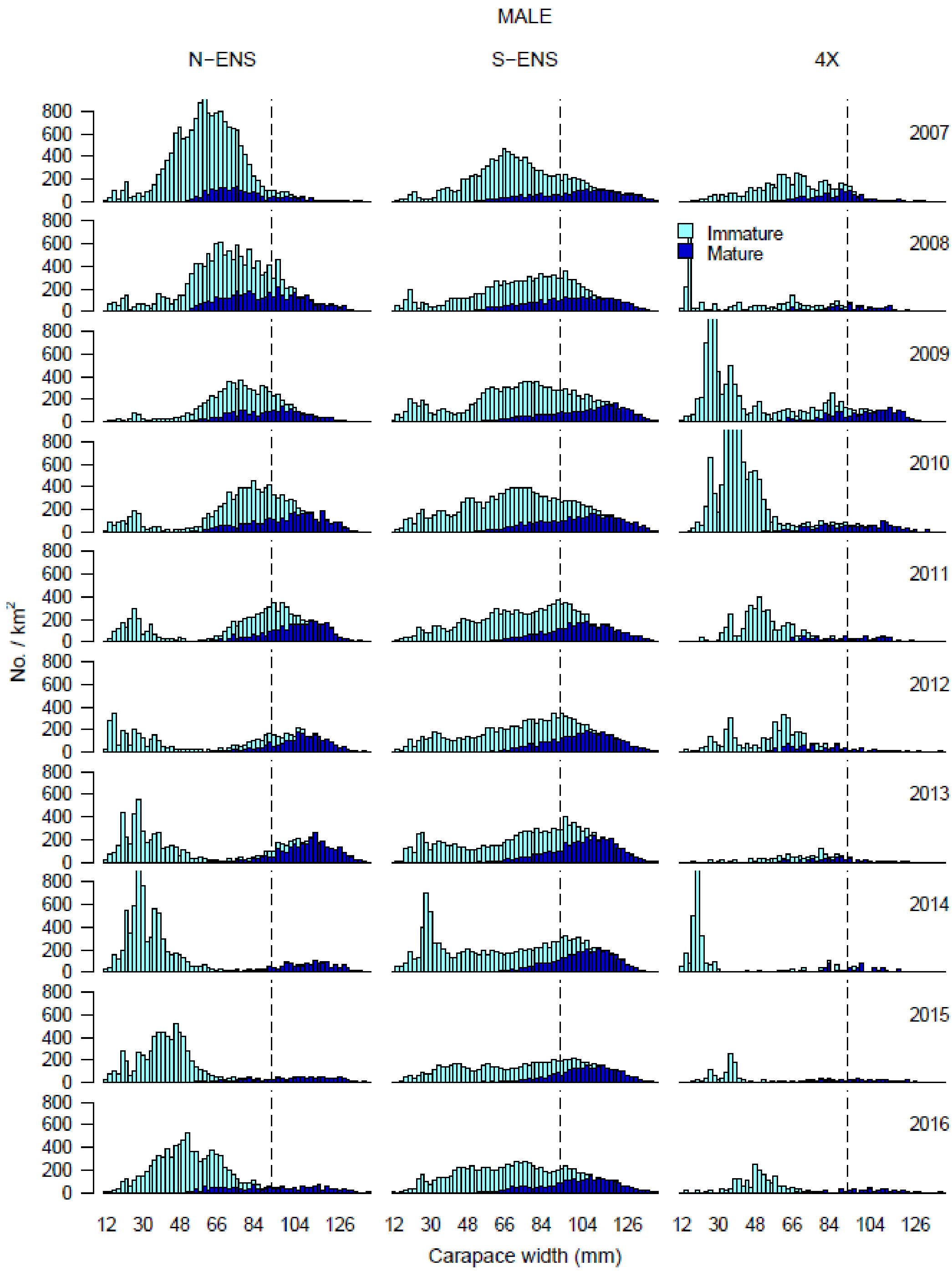


Figure 6. Size-frequency histograms of carapace width of male Snow Crabs. Note the relatively uniform distribution of adolescent crab across all size classes in S-ENS as compared to other areas and previous patterns in S-ENS. This figure provides information about the relative numbers within a given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

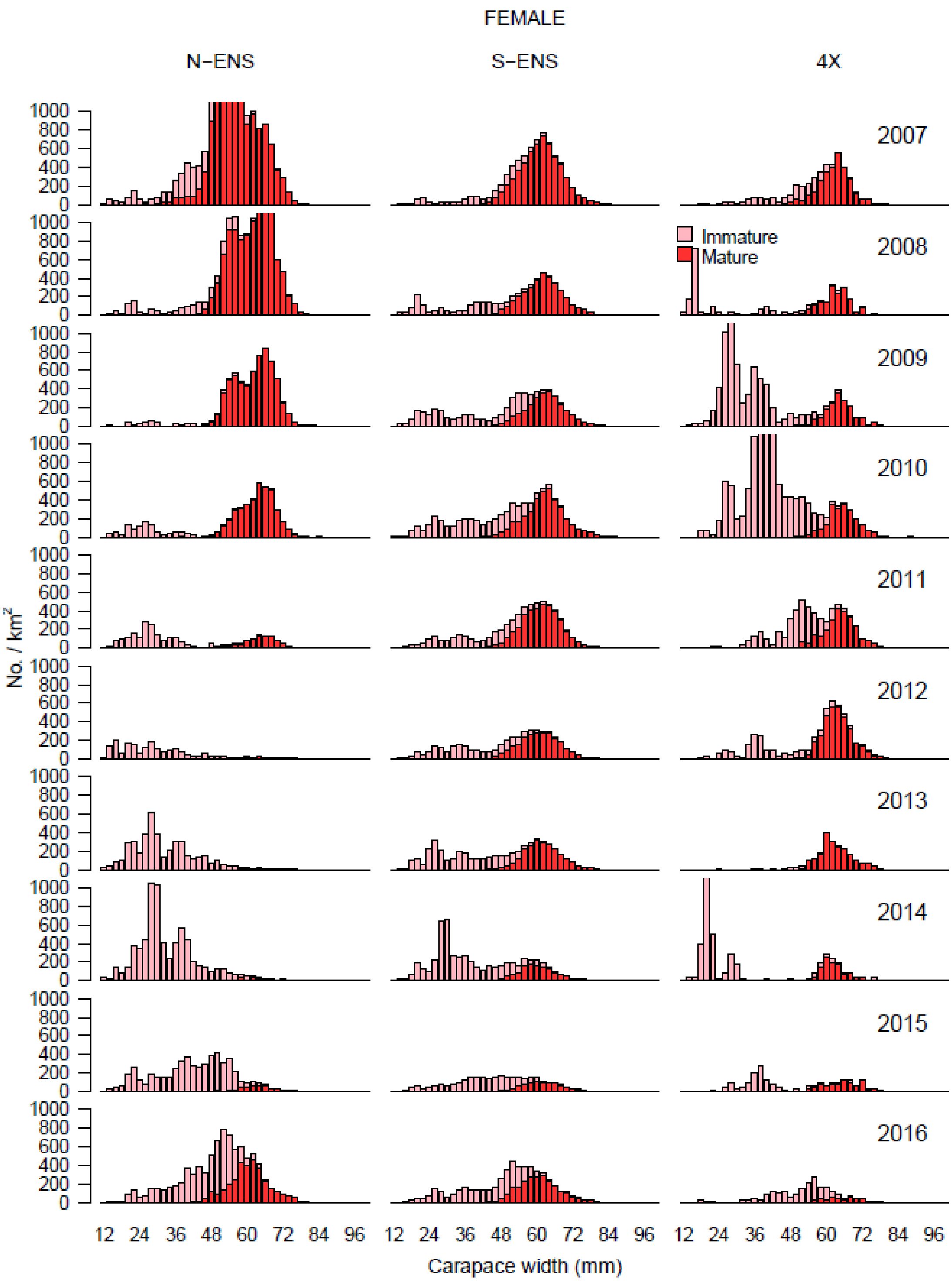


Figure 7. Size-frequency histograms of carapace width of female Snow Crabs. This figure provides information about the relative numbers within a given year.

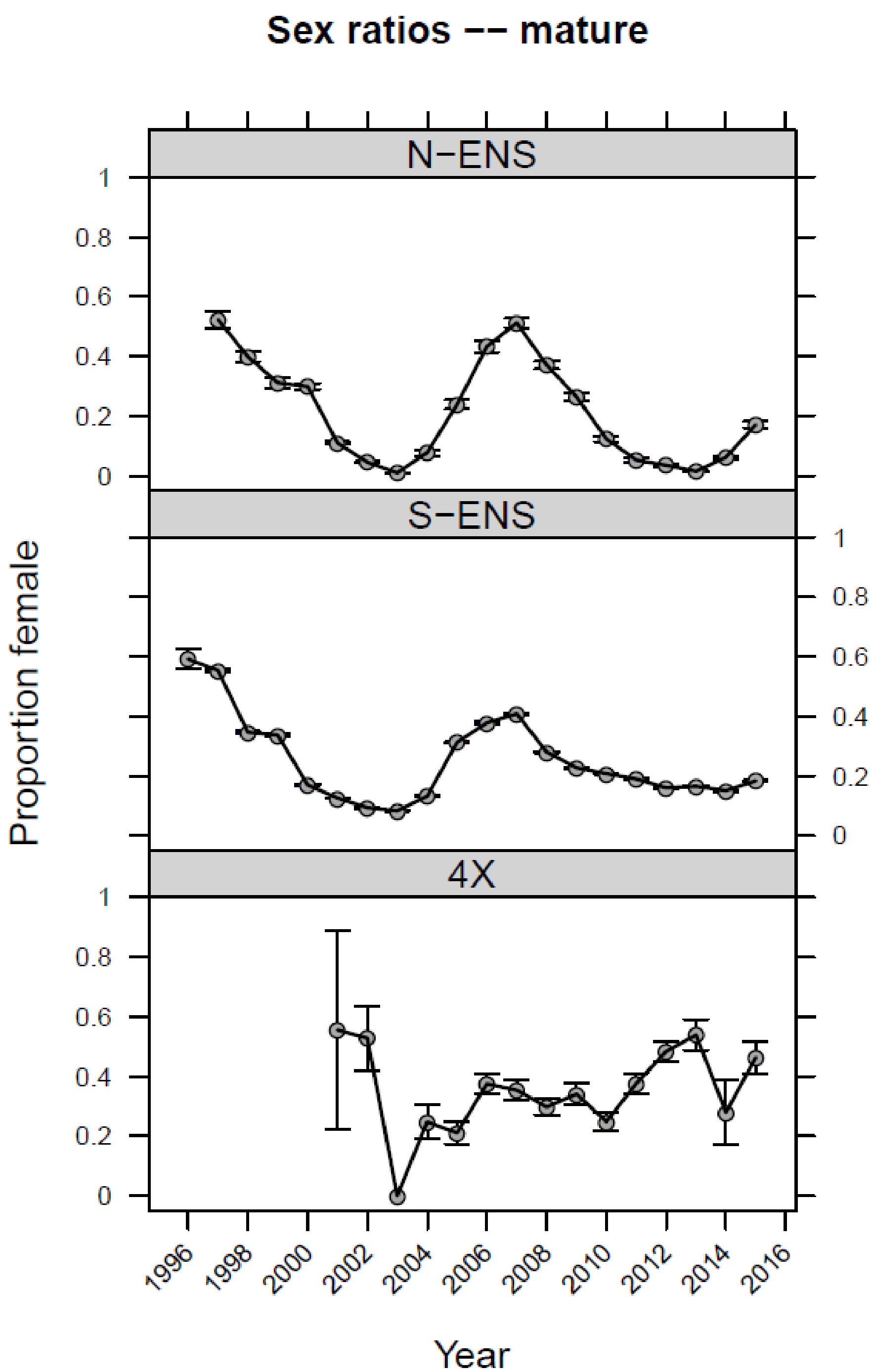


Figure 8. Sex ratios (proportion female) of mature Snow Crab. Since 2000, the Scotian Shelf is generally male dominated.

Fishing Mortality

The abundance estimates 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).

In N-ENS, fishing mortality (F) has been estimated to have been in the range of 0.06 to 0.64 (exploitation rate 0.06 to 0.48), peaking in 2002 (Figure 9). In 2016, F is estimated to have been above 0.07 (exploitation rate 0.07), a sharp decrease from 0.20 in 2015 and 0.28 in 2014 as a result of decreased TAC implemented because of concerns that the stock had entered the Cautious Zone.

Fishing mortality for S-ENS has historically ranged from 0.05 to 0.42 (exploitation rate 0.05 to 0.34), peaking in 2010 (Figure 9). In 2016, F was estimated to have been 0.39 (exploitation rate 0.33). 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.

In 4X, F has historically ranged from 0.06 to 0.76 (exploitation rate 0.06 to 0.53), peaking in 2008 (Figure 9). In 2015/2016, F was 0.26. Realized 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.

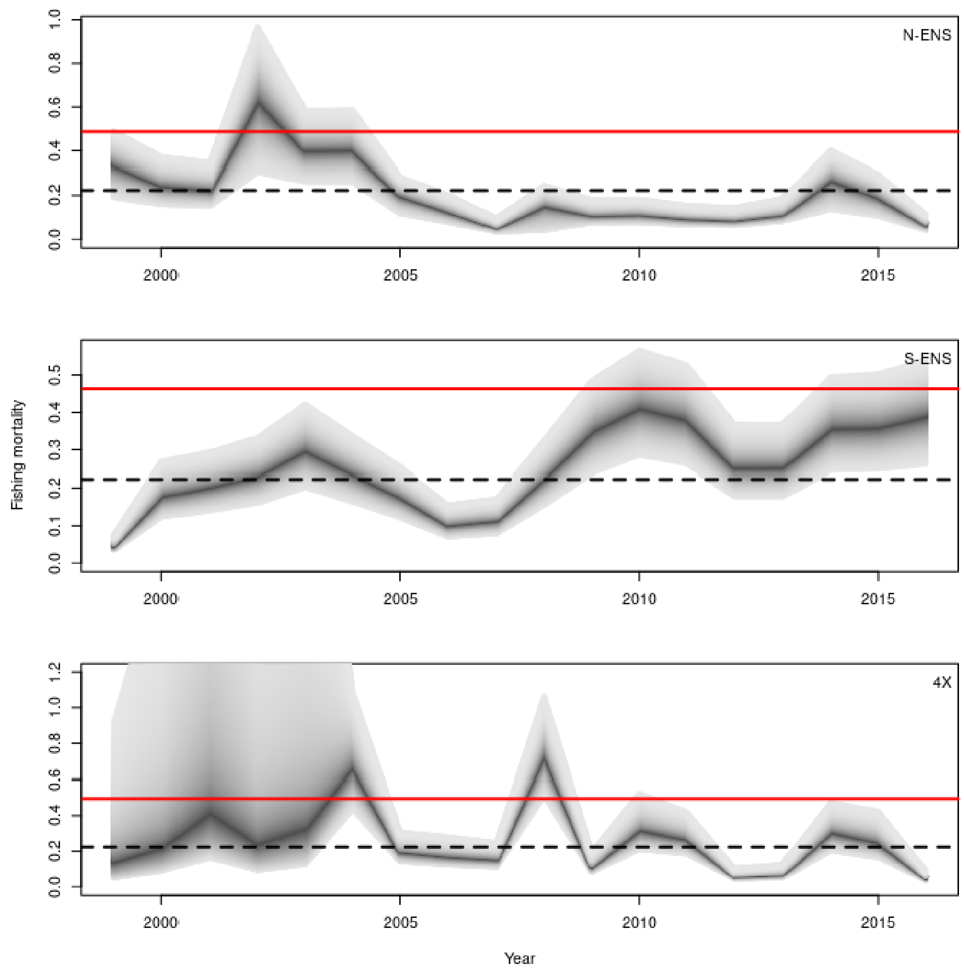


Figure 9. Time-series of fishing mortality from the logistic population models for N-ENS, S-ENS and 4X, respectively. Posterior density distributions are presented in gray, with the darkest line being the median with 95% Confidence Interval. The red solid line is the estimated fishing mortality at maximum 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 last updated in 2014 (Figure 10) suggests that a suite of coherent changes have occurred on the Scotian Shelf since the early 1990s. The first axis of variation accounted for 21.9% of the total variation in the data (Figure 11). It was dominated by the influence of declines in mean body size of organisms in the groundfish surveys and socio-economic indicators of ocean use by humans and associated changes in their relative abundance. These include landings and landed values of groundfish (declining), invertebrates (increasing), landings of pelagic fish (declining), sharks and large demersals (declining), 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 have 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 (Figure 11).

Importantly, temperature-related changes were generally orthogonal (independent) to the above axis of variation (not shown). This 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.

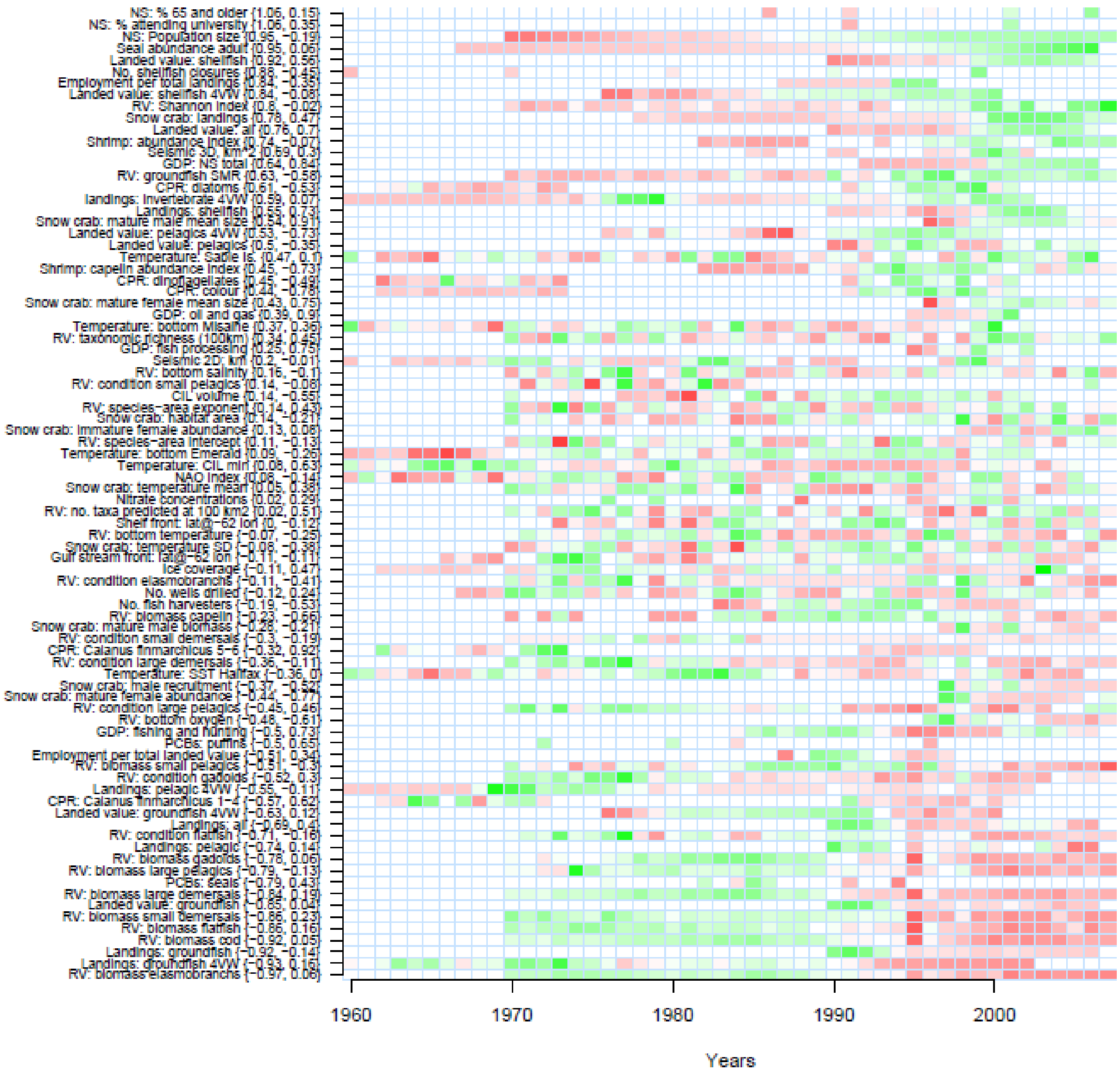


Figure 10. Sorted ordination of anomalies of key social, economic and ecological patterns on the Scotian Shelf relevant to Snow Crab. Red indicates below the mean and green indicates above the mean. Last updated to 2014 (DFO 2015). Original in colour.

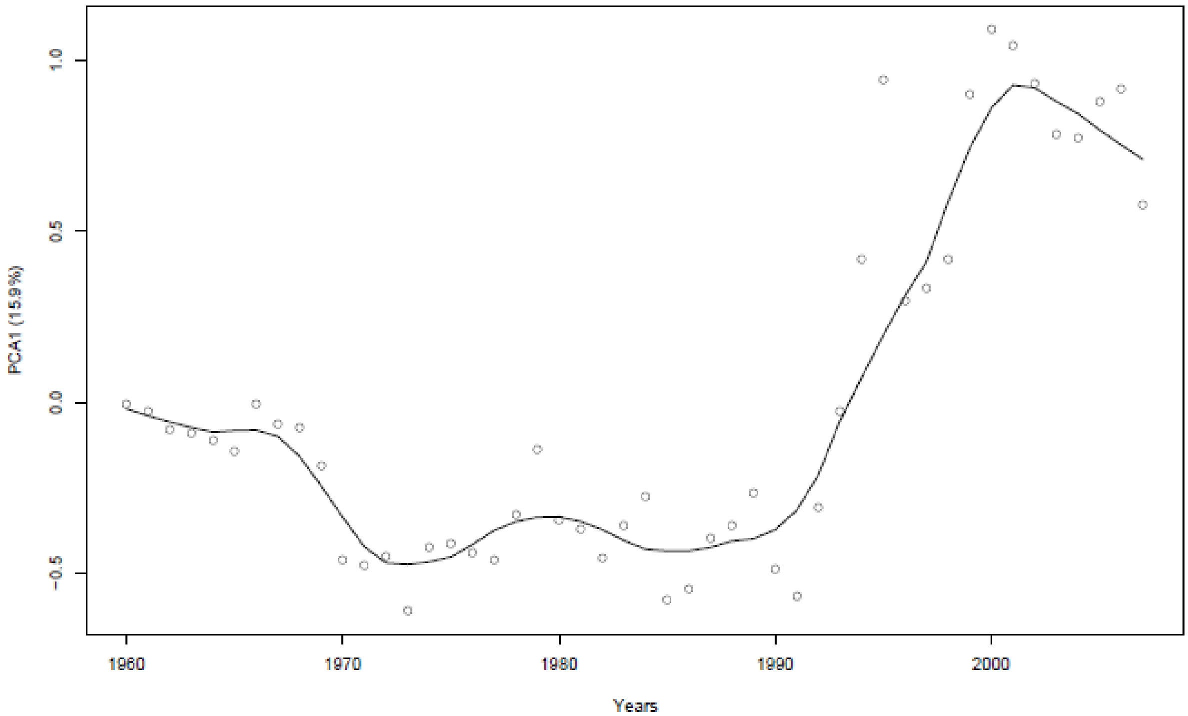


Figure 11. First axis of variation (Principle component axis 1) in ordination of anomalies of social, economic and ecological patterns on the Scotian Shelf. Last updated to 2014 (DFO 2015).

Environmental Variability

Temperature variations within the areas of potential habitat appeared to be robust throughout the historical record (Figure 12). Average bottom temperatures in the 2016 Snow Crab survey were warmer in all areas, which continues a 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.

The surface area of potential Snow Crab habitat in 4X and S-ENS has decreased in each of the past 4 years (Figure 13), whereas the potential habitat in N-ENS has been relatively stable in the past 3 years after a decline from 2013. The surface area of potential Snow Crab habitat is below the mean of the time series in all areas.

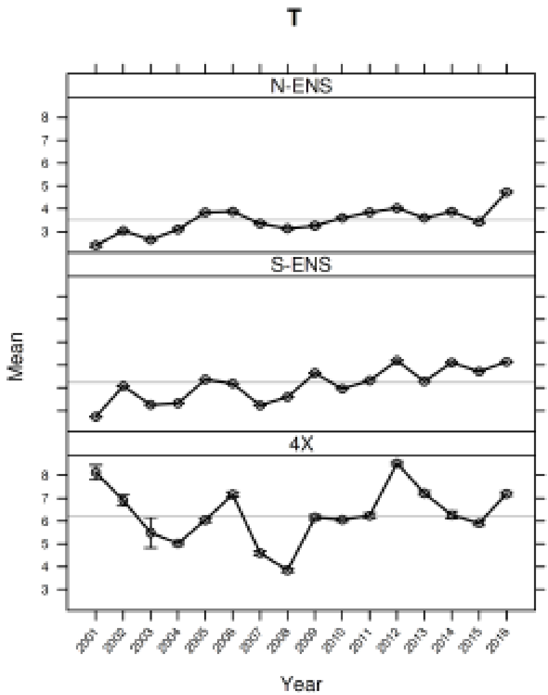


Figure 12. Annual variations in bottom temperature observed during the Snow Crab survey. The horizontal line indicates the long-term median temperature within each subarea. Error bars are standard errors.

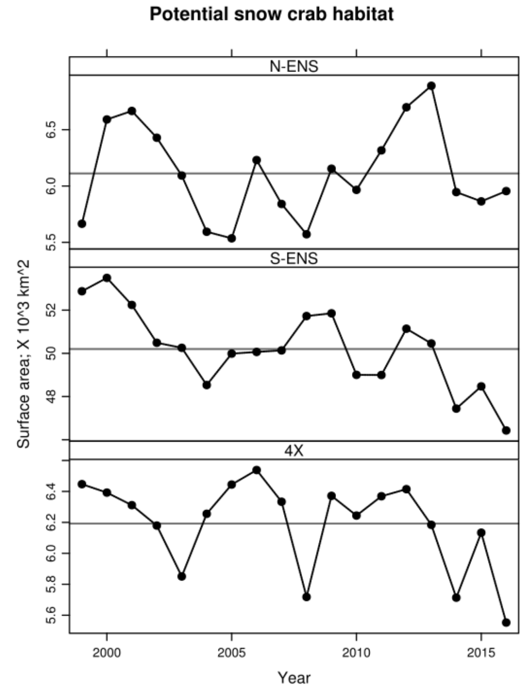


Figure 13. Annual variations in the surface area of potential Snow Crab habitat. The horizontal line indicates the long-term median surface area within each subarea. The estimates for the period from 1998 to the present are based upon Snow Crab surveys while those prior to 1998 are projected using incomplete 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. 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 yet 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 (Figure 10), 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 14), Atlantic Wolfish,Thorny Skate (Figure 15), and other skate species, appear to be the predominant predators of Snow Crab, though it does not appear to represent more than 2.2% of their diet on the Scotian Shelf. Increasing population trends in predator species could result in increased predation may lower future recruitment to the fishable biomass and affect movement patterns of Snow Crab.

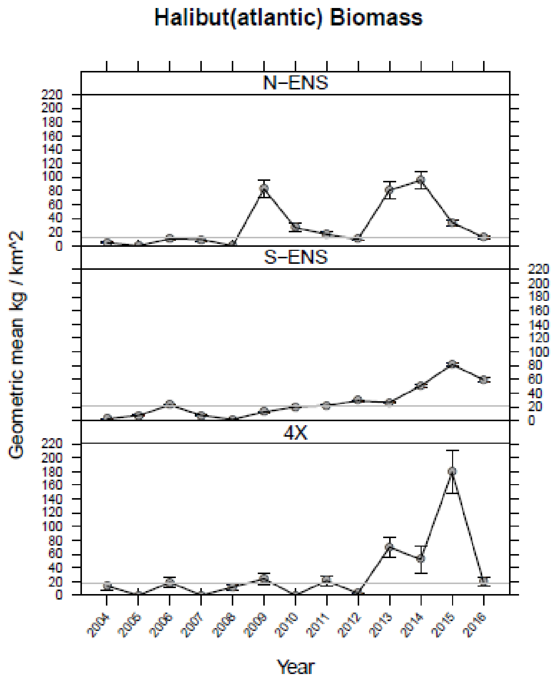


Figure 14. Atlantic Halibut biomass trend from annual Snow Crab survey. Horizontal lines indicates the long-term median within each subarea. Vertical lines are 95% confidence intervals estimated by bootstrapping.

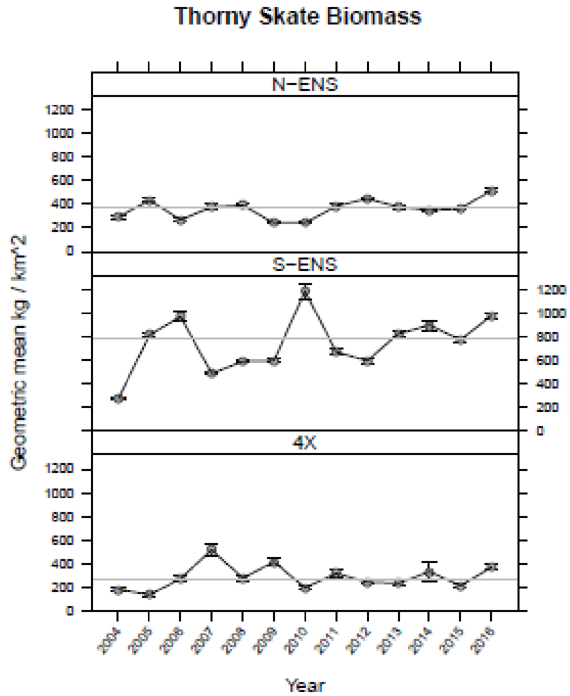


Figure 15. Thorny Skate biomass trend from annual Snow Crab survey. Horizontal lines indicates the long-term median within each subarea.Vertical lines are 95% confidence intervals estimated by bootstrapping.

Seals are considered by fishers to be a predator of Snow Crab, and their continued increase in abundance (Figure 10) 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 ratios 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.

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, 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.

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.

Undersea cables have been identified by fishers as a source of concern, in particular, the Maritime Link subsea electrical transmission cables in N-ENS. These two cables, spaced by up to 200 m, 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. At present, there is no information that can be presented to definitively describe their effects upon Snow Crab. Additional tagging efforts continue to be applied in this area to better understand Snow Crab movement pior to installation of the cable(s).

St Ann's Bank has been identified for designation as a Marine Protected Area (MPA) (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 in the long-term record. Estimates of bycatch in this fishery are extrapolated from at-sea observer estimates. In ENS, estimates of bycatch were 0.02% of Snow Crab landings (7.2% and 5.9% observer coverage in N-ENS and S-ENS, respectively). Area 4X shows higher (relative to ENS) bycatch rates at 0.35% of Snow Crab landings (9.2% observer coverage in 2015/2016). 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 fin fish 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.

Bycatch 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.

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 only increases the potential for such illegal activities. By addressing this issue, 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 16).

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 (2008). The capture of soft-shelled crab has been nearly eliminated, helping to protect recruitment. Fishable biomass declined rapidly from 2013 to 2014 without significant reductions in TAC, placing the stock in the Cautious Zone (FB > USR, Figure 17) although the stock remains in the Healthy Zone (FB >

USR, Figure 17). Over the past few years the harvest strategy adopted by fishers in N-ENS has been more conservative, with exploitation rates being closer to those historically adopted in S-ENS.

Fishable biomass estimation has been less reliable in 2014 and 2015 based on difficulties in the assessment methodology. Newly implemented, more robust assessment methodologies indicate that the TAC reductions taken in the past two seasons have helped stabilize the fishable component of the population and the stock is in the Healthy Zone (FB > USR, Figure 17). Recruitment to the fishable biomass is expected to continue being very low for the coming season supporting a cautious harvest strategy. Based on current fishable biomass estimates an increased TAC 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 other Atlantic Canadian Snow Crab populations.

Fishable biomass estimation has been less reliable in 2014 and 2015 based on difficulties in assessment methodology. Newly implemented, more robust assessment methodologies indicate that the fishable biomass has been declining since 2013. Without TAC decreases relative to fishable biomass reductions, the exploitation rate (fishing mortality) has been steadily increasing since 2013. The S-ENS population is considered to be in the Healthy Zone but close to the transitional area between the Healthy and Cautious Zone (FB > USR, Figure 17). As recruitment is expected for at least the next three to four years, there remains scope for flexibility. A decrease in TAC is strongly recommended.

4X

As 4X is the southern-most area of Snow Crab distribution, existing in more “marginal” environments relative to the “prime” areas of S-ENS and N-ENS, an explicitly PA towards this fishery is essential. Further, the lower recruitment into the fishable biomass and the large inter-annual temperature variations (especially in 2012) increases the uncertainty associated with this area. Indeed the speculated increases in mortality associated with the warm temperature event in 2012, most likely occurred as all measures of Snow Crab productivity decreased in the area. In the past, S-ENS has been assumed to provide a buffer for 4X via immigration as evidenced by a large portion of commercial biomass in 4X being proximal to the S-ENS line.

Fishable biomass estimation has been less reliable in 2014 and 2015 based on difficulties in assessment methodology. Newly implemented, more robust assessment methodologies indicate that the stock has increased in 2016 but remains in the Cautious Zone (FB > USR, Figure 17). The erratic temperature fields and constriction of Snow Crab habitat in 4X support the continuation of a very cautious approach in harvesting strategy. In addition, recruitment into next season is uncertain leading to the recommendation of a status quo to a marginal increase in TAC.

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 and should be reiterated:

- 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 (Figure 16). 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, all fishing activities cease with the belief that this will allow the stock to rebuild.

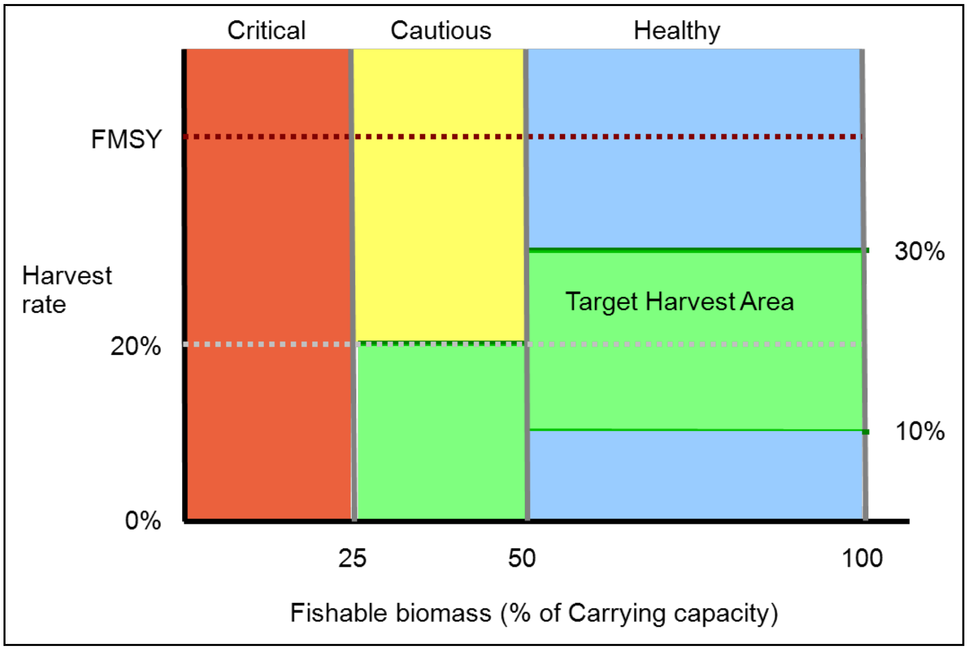


Figure 16. Harvest control rules for the Scotian Shelf Ecosystem Snow Crab fishery.

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: 6.87 {5.14, 9.58} kt
- S-ENS: 57.3 {45.6, 77.9} kt
- 4X: 2.21 {1.68, 2.96} kt

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

- N-ENS: 0.487 {0.389, 0.586}
- S-ENS: 0.463 {0.366, 0.562}
- 4X: 0.494 {0.397, 0.592}

Parameter estimates for 4X should be considered highly uncertain, due to the brevity of their data series and uncertain nature of their error distributions.

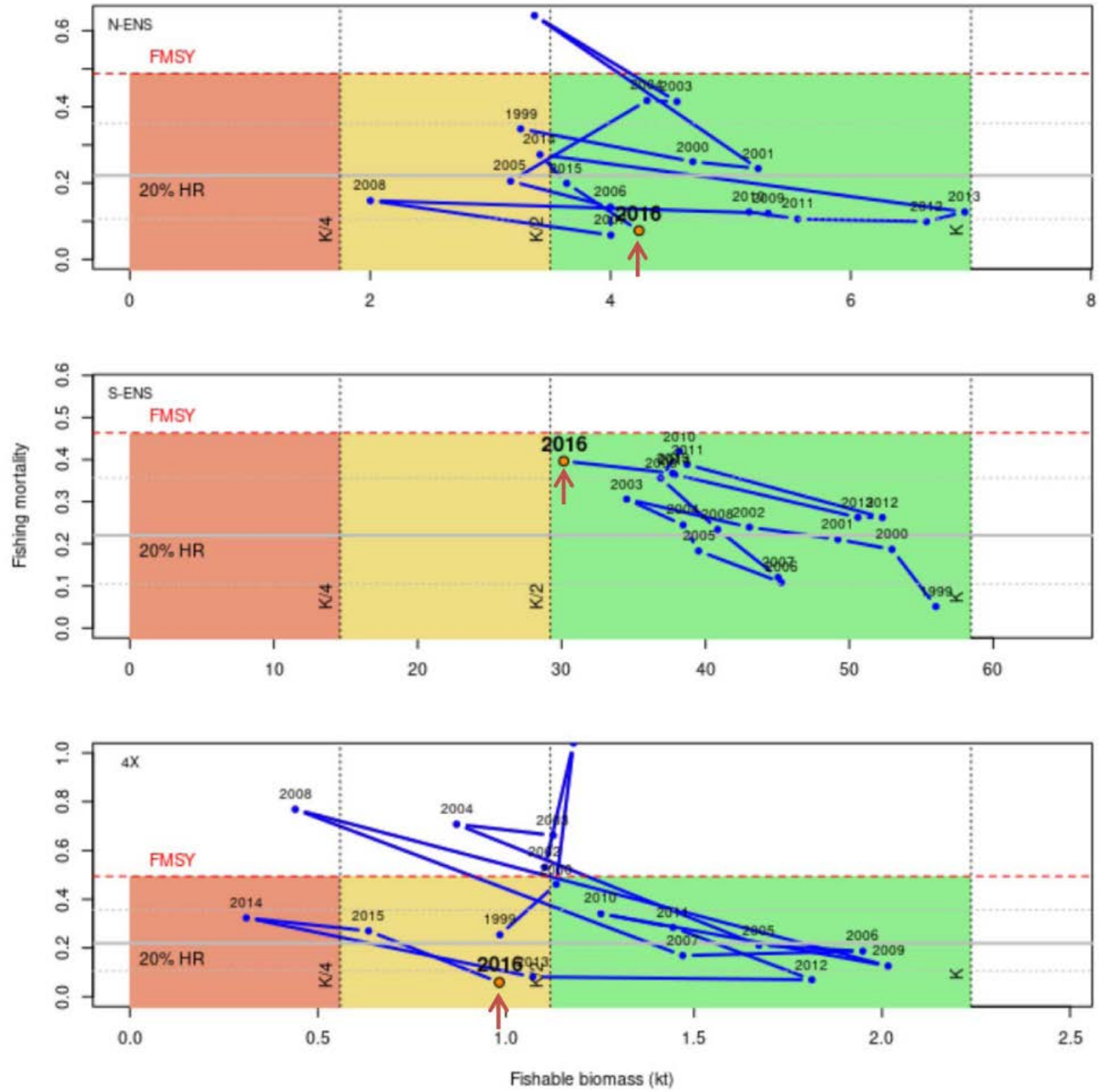
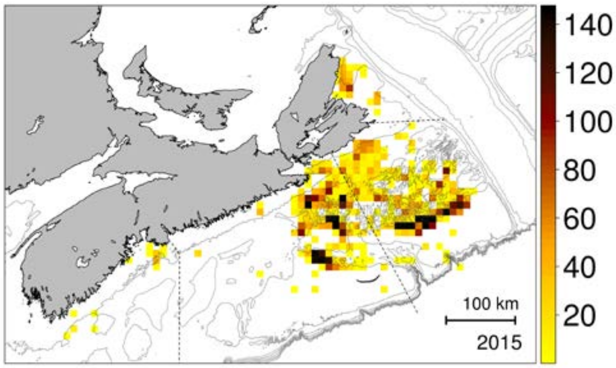
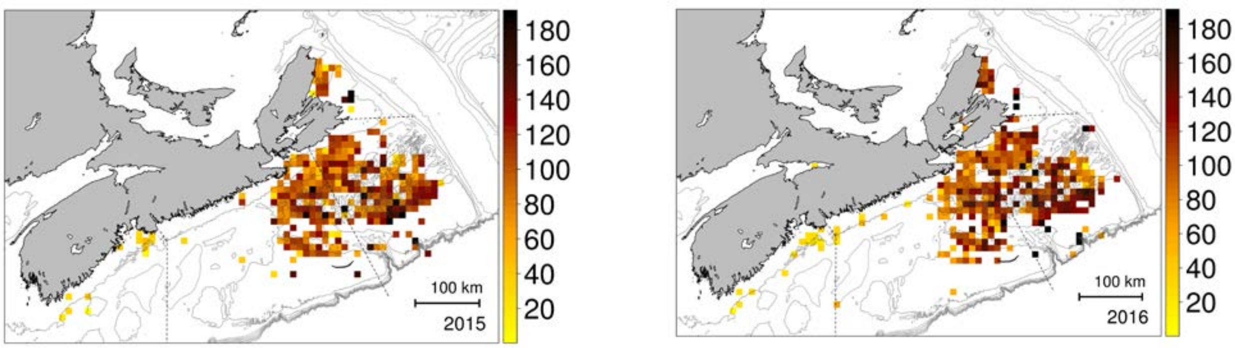


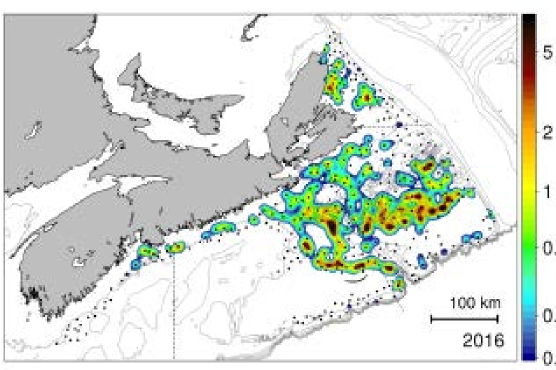
Figure 17. Time series of fishing mortality and fishable biomass for N-ENS (top), S-ENS (middle) and 4X (bottom) as obtained from the logistic population models. Red arrow indicates current (2016) year.



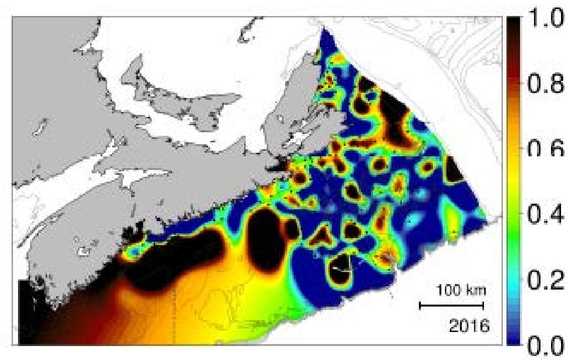
Map 1. Snow Crab landings (tons / 10 km^2 grid) from fisheries logbook data for 2015 and 2016. For 4X, year refers to the starting year. Original figure in colour.



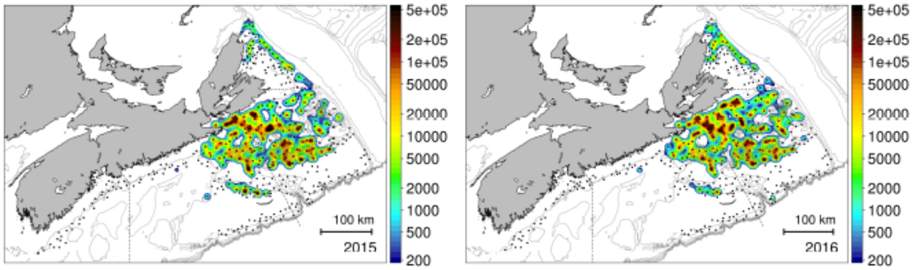
Map 2. Average catch rates (kg/trap haul) of Snow Crab on the Scotian Shelf in 2015 and 2016. Original figure in colour.



Map 3. Fishable biomass denisities (t/km^2) from the 2016 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 23, 2017, 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.

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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 completed 21-Jul-10).

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