How sustainable are emerging low-trophic level fisheries on the Scotian Shelf?

by
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Abstract

After the collapse of the groundfishery, low-trophic level fisheries have been rapidly expanded in the last 20 years on the Scotian Shelf and now represent substantial economic value. Concern has been raised, however, whether management of these emerging fisheries is sustainable given the lack of basic knowledge about the species populations, fisheries and ecosystem roles. In this thesis, I evaluated the knowledge base, fisheries regulations, and relative abundance of sea urchin (*Strongylocentrotus droebachiensis*), Jonah crab (*Cancer borealis*), periwinkle (*Littorina littorea*), and rockweed (*Ascophyllum nodosum*) in NAFO Division 4X, to determine the sustainability of their fisheries. In the emerging fisheries, only 39% of knowledge factors necessary to develop sustainable management were reported compared to 62% in Atlantic cod (*Gadus morhua*). On average, only 29% of knowledge factors about the population, 37% about ecosystem knowledge, and 63% about the fishery were reported for the developing fisheries.

All investigated fisheries showed signs of market dependency. Monitoring was typically lacking in quality and precision and management was rarely precautionary or ecosystem based. In NAFO Division 4X, all fisheries, except rockweed, showed declining landings in recent years. The sea urchin drag fishery showed signs of being less sustainable than the dive fishery with a 46% decline in CPUE over the past 10 years in LFA 38. The Nova Scotia sea urchin fishery had declining abundance due to disease. Many Jonah crab fisheries showed declining landings and CPUE in recent years, but analysis was obscured by bycatch issues in the lobster fishery and incomplete reporting. The periwinkle fishery cannot be assessed due to a complete lack of data. Rockweed harvesting in New Brunswick may be sustainable while other areas such as Annapolis Basin, St. Mary's Bay, and Lobster Bay show signs of overharvesting. In conclusion, sustainability of many of these developing fisheries cannot be ensured based on the available data and current fisheries and management practices.

Acknowledgements

I am grateful to N. Shackell for suggesting this topic and providing data and advice throughout; to R. Myers for assisting with narrowing this topic and for advice; to H. Lotze for endless advice and encouragement, providing data and literature, and revisions that significantly enhanced this thesis; to B. Worm for advice; and to J. Black, C. Frail, R. Miller, D. Pezzack, D. Ricard, D. Robichaud, G. Sharp, and J. Tremblay, for generously providing the fisheries data and background information that made this thesis possible.

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List of abbreviations and symbols used

CAFSAC	Canadian Atlantic Fisheries Scientific Advisory Committee
CFV	Commercial Fishing Vessel
CSAS	Canadian Stock Assessment Secretariat
CW	Carapace Width
CPUE	Catch per Unit Effort
DFO	Department of Fisheries and Oceans (Canada)
DSAB	Developing Species Advisory Board
FAO	Food and Agriculture Organization of the United Nations
GMBIS	Gulf of Maine Biogeographic Information System
LFA	Lobster Fishing Area
NAFO	Northwest Atlantic Fisheries Organization
nm	Nautical miles
t	Metric tonne
TAC	Total Allowable Catch
VDC	Virtual Data Centre
ZIFF	Zonal Interchange File Format

Chapter 1
Introduction

1.1 Historical background

Throughout history, overfishing may have caused more extinctions in coastal ecosystems than any other form of human disturbance (Jackson et al., 2001). Recently, the collapse of the groundfishery on the Canadian Scotian Shelf resulted in major ecosystem changes (Frank, Petrie, Choi, & Leggett, 2005; Worm et al., 2005) as well as economic challenges (Roy, 1996). One way to compensate for the groundfishery decline on the Scotian Shelf was to expand the fishery to include a number of low-trophic level marine invertebrate and plant species (Lotze & Milewski, 2004). In this thesis, I investigated whether these emerging low-trophic level fisheries on the Scotian Shelf are sustainable.

Scientists noted a mean decline in the trophic level of global fisheries landings in the second half of the twentieth century with the highest decline in the northern hemisphere (Pauly, Christensen, Dalsgaard, Froese, & Torres, 1998). In Atlantic Canada, while the groundfishery declined to a fraction of its former state, the historical maximum catch of marine invertebrate and plants in the Bay of Fundy almost doubled (Lotze & Milewski, 2004). Many low-trophic level species such as northern shrimp (*Pandalus borealis*), sea urchins (*Strongylocentrotus droebachiensis*), rock crab (*Cancer irroratus*), and Jonah crab (*Cancer borealis*) were introduced as commercial resources in the last 2 decades while fishing of other species such as periwinkle (*Littorina littorea*), which had been harvested since the early 1900s increased by over 300% in the same time period (Lotze & Milewski, 2004). Today in Atlantic Canada, the total value of the shrimp and crab landings, alone, exceeds that of the former groundfishery (Frank et al., 2005).

Low-trophic level invertebrates and plants comprise a crucial component of the marine ecosystem. Some of these species act as prey for higher trophic level species (Percy, 1996) while others provide vital habitat in the form of reproductive and foraging grounds for many fish, birds, and invertebrates (DFO, 1999; Rangeley, 2000). Plants such as rockweed provide important filtering function and nutrient storage in the coastal ecosystem thereby controlling algal blooms and water quality on which other marine species and humans depend (Worm & Lotze, 1999). Overall, targeting low-trophic level species carries with it the additional risk of impacting high-trophic level species in many forms and may lead to widespread ecosystem changes and collapse of fisheries (Pauly et al., 1998).

Concern has been raised about the deficiency of data related to low-trophic level species given their current level of fishing (DFO, 1999; Lotze & Milewski, 2004; Percy, 1996; Rice & Rivard, 2002; Smith & Sainte-Marie, 2004). Fisheries and Oceans Canada have advocated a "precautionary approach" based on scientific findings with regards to management of these low-trophic level fisheries (DFO, 2001). Since 1996, the "New Emerging Fisheries Policy" has governed the harvesting of these species and envisioned "healthy and abundant fishery resources supporting sustainable uses" (DFO, 2001). The FAO (Food and Agriculture Organization of the United Nations) (1999) suggests the use of historical data to assess the sustainability of a fishery as part of a "precautionary approach"; however, most attention toward collecting baseline data within Canada has been focused on higher trophic level fish species (Rice & Rivard, 2002). Significant gaps in knowledge exist with regards to the inter-relationships of these low-trophic level species and their environment as well as their resilience to fishing (Percy, 1996; Ugarte & Sharp, 2001).

Given that the main threat to coastal species may be overfishing (Jackson et al., 2001), and the fishing of many of these new low-trophic level species has been rapidly expanded (Lotze &

Milewski, 2004), diligence had best be taken to avoid overfishing these species. Concern has been raised about simultaneously expanding the harvests of multiple ecologically fundamental low-trophic level species with insufficient population data (Lotze & Milewski, 2004). Pauly et al. (1998) has documented the unsustainable nature of a global trend associated with fishing down food webs in which catches first increases, but then stagnate or decline. With this in mind, Pauly et al. (1998) makes the prediction that if this trend continues, the future of global marine fisheries may be bleak.

1.2 Sustainability

Resilience, which is a key aspect of assessing the sustainability of a marine fishery, has been defined in a number of ways. Pimm (1984) defined resilience by the speed with which a system at a near equilibrium state could return to its equilibrium after a disturbance. Ecological resilience refers to a measure of the ability of a system to absorb disturbances and endure (Holling, 1973). The system may return to an alternative stable equilibrium and still be considered resilient under this definition (Peterson, Allen, & Holling, 1998). For the purpose of this thesis, I will consider a species population to be resilient to fishing, and a fishery as sustainable, when it can sustain a certain catch level over time without collapsing, given current fishing disturbance and current ecological conditions.

Caddy (2004) notes that since invertebrate species exhibit a greater diversity of life-history characteristics than finfish, a wider range of measurements than the typical catch, biomass, and fishing mortality should be used when assessing the sustainability of their fisheries. Smith and Sainte-Marie (2004) note that many scientists identify reproduction and recruitment as key elements in determining the resilience of invertebrate species to fishing, especially when coupled with an analysis of environmental conditions. Siddeek et al. (2004) point out that current reference point models for invertebrates fail to incorporate the ecological and economical selectivity by which some invertebrates are harvested. A number of scientists have suggested specific indicators of resilience for the low-trophic level species involved in this study. For example: Cousens (1981) suggests vegetative growth, reproductive growth, and reproductive effort as key factors in the resiliency of rockweed to harvesting since age-structure modeling is not often possible. Botsford et al. (2004) indicate that for sea urchins, the use of lifetime egg production would be an ideal, albeit difficult to implement, indicator of resilience. Perry et al. (1999) summarize many of these diverse characteristics in a list of scientific information required to develop precautionary management strategies for new and developing fisheries. In this thesis, I will use this list as a basis on which to compare the knowledge base for a set of emerging fisheries on the Scotian Shelf.

1.3 Management of developing fisheries

Hilborn and Sibert (1988) outline a typical pattern for the sustainable management of a developing fishery. They describe how, in a developing fishery, effort and catch continue to increase until catch begins to drop. At that point, effort must be reduced if the fishery is to be sustainable. Catch per unit effort (CPUE) would be expected to decrease during the initial phases of the developing fishery and then stabilize as effort is reduced to a sustainable level. Hilborn and Sibert (1988) describe the reasons for this initial decrease in CPUE as threefold: initial fishing of the stock reduces intraspecific competition providing extra production for harvest; a virgin stock will contain many large and old individuals that will persist at the point of maximum biological yield of the fishery; and during the initial development stage, less productive species or substocks will be overfished as a non-renewable portion of the fishery. These authors note that in some circumstances these decreased catch rates at a sustainable level of fishing will not constitute an economically feasible fishery. Further, Hilborn and Sibert (1988) point out that since the optimum catch and effort cannot be determined for a given developing fishery until that optimal catch and effort have been exceeded, it is crucial to carefully gather data during the development stage to make an accurate assessment of optimum or sustainable catch and effort.

1.4 Research aims

In this research I aimed to document recent fishing trends and abundance of 4 low-trophic level species on the southwestern Scotian Shelf with the goal of determining the sustainability of these fisheries given current management practices and ecological conditions. Further, I compared the knowledge base of these fisheries to evaluate the proportion of factors related to their sustainability and resilience that are reported in Stock Status Reports and Research Documents. This work may provide a model for studying and comparing the sustainability of and knowledge about other low-trophic level developing fisheries in this region as well as other regions experiencing similar fishing trends.

Chapter 2
Methods

2.1 Overall description of methods

This study aimed to investigate what we can tell about the sustainability of 4 low-trophic level developing fisheries given current states of knowledge, current management regulations, and possible indicators of relative abundance. Research for this project was comprised of 3 sections. In the first section, I examined the state of knowledge regarding 4 developing fisheries and compared them to a potentially more carefully managed species. In the second section, I examined current management regulations in place for these fisheries. In the third section, I examined detailed trends in landings, effort, and relative abundance given the available data.

This study focused on NAFO (Northwest Atlantic Fisheries Organization) Division 4X, the southwestern Canadian Scotian Shelf (Fig. 1). The Scotian Shelf supports a rich diversity of marine species (Shackell & Frank, 2003) and many valuable fisheries. Division 4X consists of the southern coast of New Brunswick, including the Bay of Fundy, and the coast of Nova Scotia south of Halifax. It extends south to the parallel of 39° north latitude and west to the 65°40' west longitude (NAFO, n.d.).

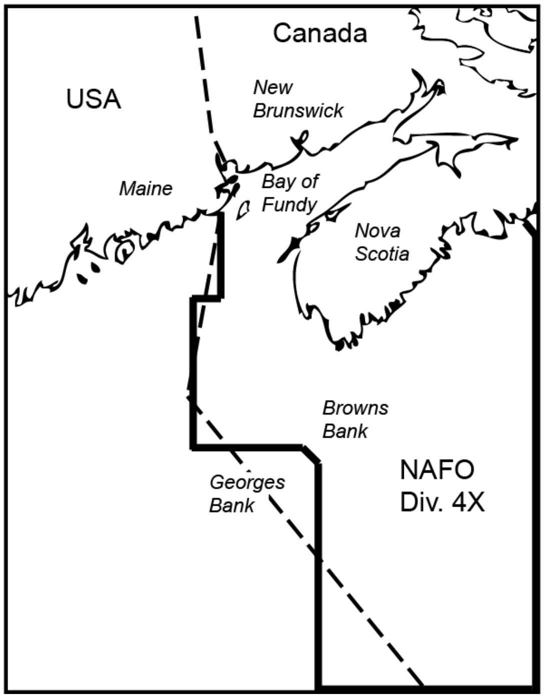

Figure 1: Northwest Atlantic Fisheries Organization Division 4X. Adapted from DFO (2005).

For this thesis, 4 species were chosen: Jonah crab (*Cancer borealis*), sea urchin (*Strongylocentrotus droebachiensis*), periwinkle (*Littorina littorea*), and rockweed (*Ascophyllum nodosum*). These species provide a mixed sample from the expanding low-trophic level fisheries on the Canadian Scotian Shelf. They possess varying life-history characteristics, have different functions in the food-web and ecosystem, and are subject to different fishing practices (see Section 2.2).

Sources of information related to regulations and fishery knowledge were limited to relevant and published DFO (Department of Fisheries and Oceans Canada) Stock Status Reports and CSAS (Canadian Stock Assessment Secretariat) Research Documents. This decision was made in order to follow a consistent approach in the comparison of all fisheries studied. In addition, it was hypothesized that addressing knowledge represented in DFO Stock Status Reports and CSAS

Research Documents was useful in itself since one would expect that individuals interested in the management of these fisheries would read these published documents as their primary source of information regarding the fishery. One would also expect these Stock Status Reports and Research Documents to be representative of the relevant information regarding the fishery and involved species that is considered in the fishery's management.

Sources of information related to catch and effort measurements were extended to include data to 2005 where possible. Since several fisheries only developed recently, it was aimed at including the longest time series possible. Data was obtained from CSAS Research Documents, CAFSAC (Canadian Atlantic Fisheries Scientific Advisory Committee) Advisory Documents, and DFO Stock Status Reports, databases, and scientists.

2.2 Description of species

The green sea urchin (*Strongylocentrotus droebachiensis*) is distributed throughout the Northern polar region and in North America as south as New Jersey (Mortensen, 1907). It is found at depths of up to 200 meters on rocky bottoms (Miller & Nolan, 2000). Green sea urchins are mainly herbivorous and usually consume algae but also slow moving or sessile animals such as mussels and barnacles (Himmelman & Steel, 1971). High densities of sea urchins are found at algae grazing fronts (Meidel & Scheibling, 1998) and sea urchins are often the dominant herbivore on coral reefs (Andrew et al., 2002). They are preyed on by purple sea stars, lobsters, rock crabs, herring gulls, and common eiders and also by other species when no other prey are available (Himmelman & Steel, 1971). Green sea urchins are dioescious animals that are usually found in 1:1 sex ratio (Meidel & Scheibling, 1998). They mature at approximately 23 mm and spawn in March or April, rebuilding their gonads in summer and fall (Miller & Mann, 1973). They produce planktonic larvae that persist for several weeks (Strathmann, 1978) and because of their high fecundity, green sea urchins often make the greatest contribution to the larval pool in kelp beds (Meidel & Scheibling, 1998). In Nova Scotia, sea urchins are fished by divers, and in New Brunswick, sea urchins are fished by both divers and bottom draggers. See Section 2.8.1 for further details on the sea urchin fisheries.

The Jonah crab (*Cancer borealis*) in eastern North America is found from the Bermudas and Nova Scotia to Florida (MacKay, 1943) at depths of up to 750m (Squires, 1966). In the Bay of Fundy, Jonah crabs are usually found at depths of 50 to 300 meters (Robichaud, Lawton, & Strong, 2000). They are found both on rocky substrates (Jeffries, 1966) and silt or clay bottoms (Musick & McEacheran, 1972). In the Gulf of Maine, male Jonah crabs can reach a carapace width of up to 180 mm, although females usually do not reach a carapace width of over 150 mm (Robichaud, Frail et al., 2000). Moriyasu et al. (2002) found gonadal and morphometric maturity for male Jonah crabs on the Scotian Shelf to occur at 69 and 128 mm carapace width respectively. Female Jonah crabs brood their eggs on swimmerets on their abdomens and produce larvae that develop through 5 planktonic stages before setting on the bottom (Adams, Reeves, & Miller, 2000). Jonah crabs are fished with offshore lobster traps, modified lobster traps, or conical traps in the Gulf of Maine, the Scotian Shelf, and in offshore waters. See Section 2.8.2 for further details on the Jonah crab fisheries.

The common periwinkle (*Littorina littorea*) is abundant along the Atlantic coast (La Roque, 1953). In North America, periwinkles are found from Labrador to New Jersey (La Roque, 1953). While there is evidence that periwinkles existed around Halifax for at least 700 years (Clark & Erskine, 1961) they were not considered abundant in the Maritimes until the mid nineteenth century (Whiteaves, 1901). On the Maritime coast, *Littorina littorea*, 1 of 3 periwinkle species in the area, possesses a dark brown or grey shell with 7 to 8 whorls (Davis, 1971) of typically 2 to 26 millimeters in height (Gardner & Thomas, 1987). It is a herbivorous animal that feeds mostly on seaweeds, small algae, and detritus (Davis, 1971). It lives primarily on rocky shores in the intertidal area almost to the high tide water level (Bousfield, 1960) and possesses a soft foot that is used for moving and gripping rock (Davis, 1971). In the Bay of Fundy periwinkles can be found down to at least 40 meters below sea level (Gowanloch & Hayes, 1927). They are generally not well adapted to withstanding exposure to air (Davis, 1971). There is evidence of some migration by periwinkles into the subtidal zone in the winter (Gendron, 1977). They are dioescious animals that lay eggs in capsules that float in the water as part of plankton (Davis, 1971). Free swimming larvae are produced that settle and develop on shore (Davis, 1971). In the Bay of Fundy, *Littorina littorea* have a relatively short lifespan of approximately 3 to 4 years because of predation and extreme conditions in the winter (Gardner & Thomas, 1987). Periwinkles are harvested throughout the Maritimes mostly through hand gathering as part of an artisan fishery. See Section 2.8.3 for further details on the periwinkle harvest.

Rockweed (*Ascophyllum nodosum*) is the dominant brown seaweed in the intertidal zone along the Atlantic Maritimes coast (Ugarte & Sharp, 2001). Although it is found solely along North Atlantic coasts, its range extends from the Artic Circle to New Jersey in North America (Baardseth, 1970). Primarily an intertidal species, rockweed attaches to stable rocks or substrate, has shoots that float because of gas bladders, and forms a mostly continuous cover in the center of its distribution (Baardseth, 1970). In more exposed areas, *Ascophyllum nodosum* is replaced by its main competitor, *Fucus vesiculosus* (Sharp, 1986) and there is evidence that *Ascophyllum nodosum* is particularly sensitive to pollution (Baardseth, 1970). *Ascophyllum nodosum* is a dioescious organism that reproduces primarily vegetatively through basal shoots (Baardseth, 1970). Depending on wave exposure, annual vegetative biomass varies from 20% to 40% (Cousens, 1984). *Ascophyllum nodosum* germlings grow slower than the germlings of their main competitor, *Fucus vesiculosus*, and are vulnerable to grazers and waves resulting in intermittent recruitment (Baardseth, 1970). In the Maritimes, rockweed is harvested by hand sickle and cutter rake, although mechanical harvesting was common in the past. See Section 2.8.3 for further details on the rockweed harvest.

2.3 Knowledge analysis

The state of knowledge of each of the low-trophic level fisheries investigated was compared to a potentially more carefully managed species, Atlantic cod (*Gadus morhua*). Atlantic cod has been the subject of intense research for some time (Hutchings & Myers, 1994). Knowledge related to the sustainability of the fishery was therefore expected to be high and was used as a reference point to compare the state of our knowledge of the developing low-trophic level fisheries in this study.

Based on Perry et al. (1999), I developed a list of basic biological, fisheries, and ecosystem knowledge that may be required to develop a precautionary management plan for developing fisheries (Appendix A). The original table of biological and fisheries information by Perry et al. (1999) was designed to be applied to the development of a management plan for an individual species population. Since the intent of this study was to provide a quantitative comparison of the state of knowledge of a set of fisheries, more specific knowledge categories were created so that each factor could be designated as present or absent for a given fishery. For certain knowledge factors where known information might have been either basic or detailed (for example, recruitment rates), multiple categories were created to take this into account.

For each of the 4 species in this study, as well as for Atlantic cod, I rated the availability of the knowledge factors as documented in the latest DFO Stock Status Reports and CSAS Research Documents for areas within the southwestern Scotian Shelf. Reported knowledge varied between DFO assessment areas for the sea urchin and Jonah crab fisheries. My analysis therefore separated reported knowledge for individual species into Lobster Fishing Areas (LFAs) as managed by DFO (Fig. 2).

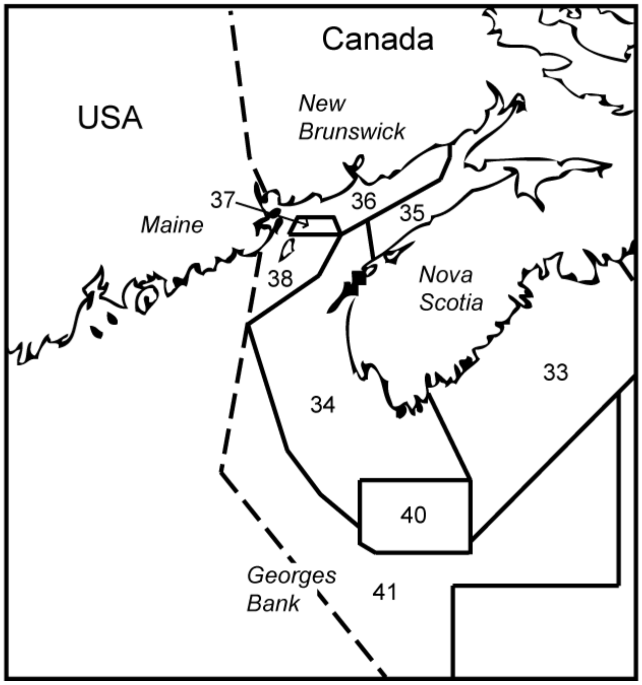

Figure 2: DFO Lobster Fishing Areas used for assessment of sea urchin and Jonah crab fisheries. Adapted from DFO (2005).

A knowledge factor was rated as present if the most recent respective documents acknowledged or demonstrated adequate understanding to use that knowledge factor to contribute to a prediction of the sustainability of that fishery and develop a precautionary management plan. If a knowledge factor was deemed irrelevant to a certain fishery it was removed from the evaluation of that fishery. While there were admittedly many instances when a known factor was not reported in Stock Status Reports or Research Documents because it was deemed 'common knowledge', an exhaustive review of literature related to each knowledge factor was beyond the scope of this study.

After evaluating the presence of the knowledge factors for each fishery, the total proportions of known and relevant information for each fishery were calculated. Knowledge factors were then separated into the following groups: factors related to population abundance and distribution, factors related to fishery information, and factors related to ecosystem information, and these groups were compared separately.

2.4 Regulations analysis

In the second section of this study, I compiled a table of regulations used in the management of these fisheries at the time of the last DFO Stock Status Reports and CSAS Research Documents. When necessary, respective management scientists at DFO were consulted to determine regulations unspecified in Research Documents or Stock Status Reports.

I expected this information to be of use in evaluating the sustainability of the fisheries and comparing management trends within the developing fisheries. Although an analysis of current (2005-06) management regulations would have been ideal, it was beyond the scope of this thesis. In addition, I expected it to be useful to compare established regulations with the availability of relevant knowledge from the same time period as determined in the first part of this study.

The management regulations that I compiled were the following: gear regulations, effort restrictions, quotas, seasons, permitted fishing areas, minimum size restrictions, regulated reporting, regulated monitoring, the presence of fishery independent surveys, minimum landings requirements, interspecies consideration regulations, habitat protection regulations, and whether there was a regulated area set aside for scientific research or reference.

2.5 Catch per unit effort analysis

Effort and landings data were compiled, where available, for each of the 4 species in this study. Data was collected from CAFSAC advisory documents, CSAS Research Documents, DFO Stock Status Reports, DFO ZIFF (Zonal Interchange File Format) catch-effort databases, as well as from personal communication with DFO scientists involved with the various fisheries who gathered landings and effort data from recent log book entries. CPUE (catch per unit effort) was calculated from the collected landings and effort data. CPUE, landings, and effort were then plotted against time on the same figure to facilitate an analysis of each of the fisheries and to derive estimates of relative abundance. Where appropriate, linear regression was performed on the CPUE data with respect to time and the coefficient of determination, R^2, and p-value were determined. The data was assessed for normality and homoskedasticity with a Kolmogorov-Smirnov and Breusch-Pagan test respectively. Throughout this study, statistical analysis was performed with an alpha level of 0.01.

Where available, landings and effort data was collected by LFA (Fig. 2). Within LFA 41, fisheries data was subdivided into lobster assessment areas (Fig. 3). Biomass estimates for rockweed within NAFO Division 4X were divided into a separate set of areas (Fig. 4) and then combined to estimate an exploitation rate.

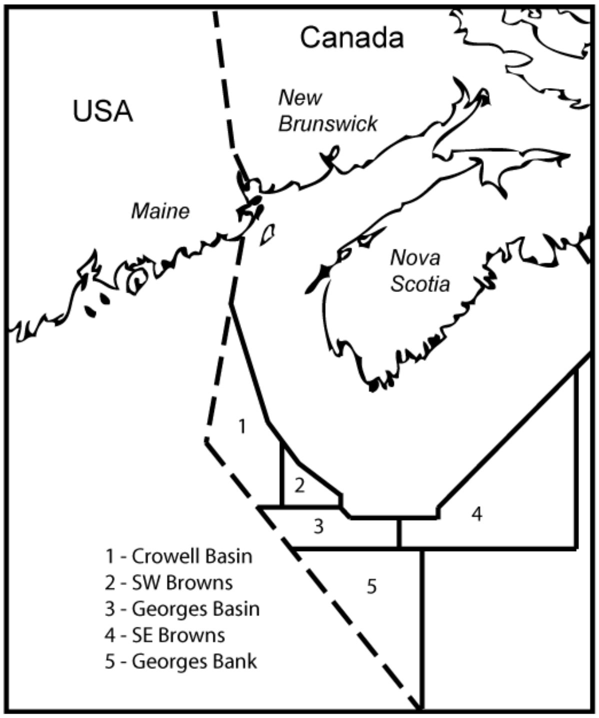

Figure 3: DFO lobster assessment areas within LFA 41 used for assessment of Jonah crab fisheries. Adapted from DFO (2005) and Robichaud et al. (2000).

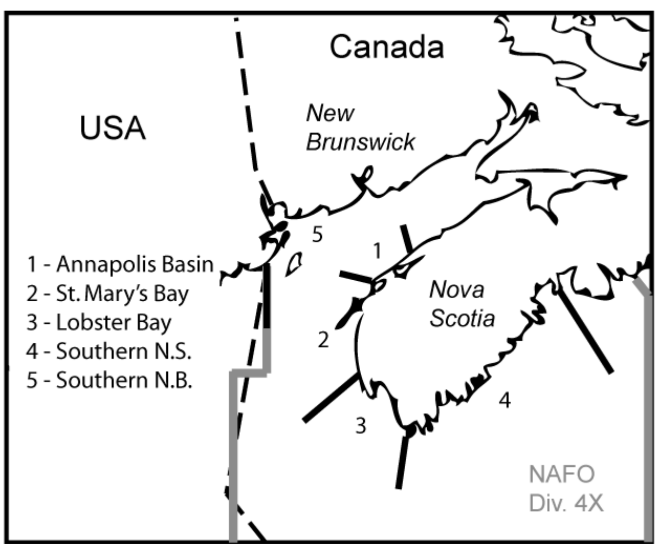

Figure 4: DFO and CAFSAC rockweed assessment areas used for estimation of exploitation rate. Adapted from DFO (2005) and DFO (1998b).

Results

2.6 Overall description of fishery landings and market trends

All 4 fisheries in this study experienced rapid growth in both landings and total fishery value between 1980 and 1995 (Fig. 5). All fisheries, with the exception of the rockweed fishery, showed peak landings and values between 1995 and 2000 followed by a decline. Of the 4 developing fisheries investigated in NAFO Division 4X, the sea urchin fishery yielded the maximum peak value at just over $5 million in the year 2000. The Jonah crab fishery yielded the next highest peak value of nearly $3 million in the year 2001. Rockweed peaked at just over $1 million in 2001 and periwinkle peaked at over $300,000 in 1997. Value per kg of periwinkle and sea urchin reached a peak as of the latest available data at approximately $1.80 and $2.80 kg^{-1} respectively. The value of Jonah crab peaked in 2000 at $2.20 kg^{-1} in 1994, declined, and then reached a second peak of $1.75 kg^{-1} in 2000. From 1998 until the end of the available value data in 2001, periwinkle landings appeared to decline while value per kg of periwinkle increased to a maximum of $1.80; however, care should be taken in interpreting these values because of frequent unreported landings and sales (G. Sharp, pers. comm). Between 1999 and 2001, the end of available and reliable data, sea urchin landings decreased by about 37% while the value per kg of sea urchin continued to increase by about 25%.

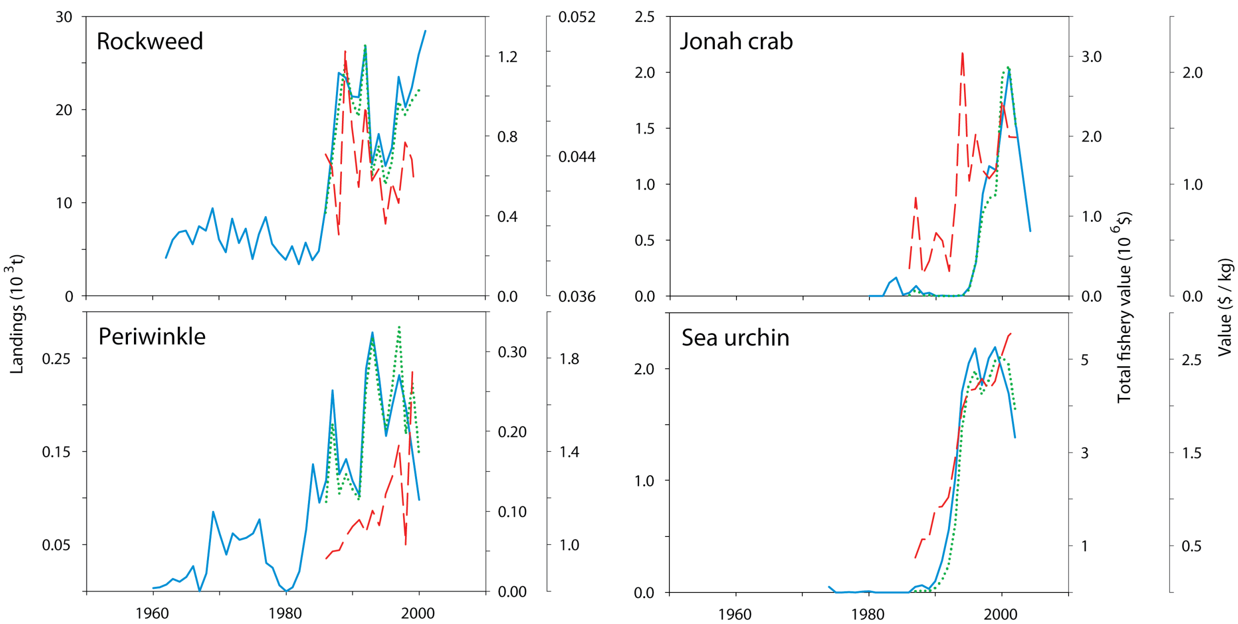

Figure 5: Landings (thick solid line), total fishery value (dotted line), and value of landings per kg (dashed line) within NAFO Division 4X for 4 developing low-trophic level fisheries. Jonah crab, periwinkle, and sea urchin data from DFO Maritimes VDC (Virtual Data Centre) NAFO database 1960-1985; rockweed data from Sharp and Pringle (1990) 1962-85; data for all species for 1986-2004 from DFO Annual Fisheries Statistics (L. Sonsini, pers. comm).

The market driven nature of the rockweed harvest is evident given a review of historical records (Fig. 6). Demand remained low and harvesting remained minimal despite the common use of mechanized harvesting from 1970 onward [Fig 4. Phase A] (Sharp & Semple, 1991). In 1986 the Norwegian mechanized suction harvester was introduced increasing the CPUE by a factor of 4 and increasing mechanized landings to 80% of the total yield (Sharp & Semple, 1991). Demand for rockweed also increased and rockweed processing progressed from a 6 to 7 months per year operation to a year round operation (Sharp & Semple, 1991) Consequently the area harvested was rapidly expanded (CAFSAC, 1992a), the value of rockweed increased from $40 to $50 per tonne in a single year, and rockweed landings increased more than fivefold by 1992 [Fig

4. Phase B]. At this point, a number of areas showed signs of overharvesting (Sharp & Semple, 1997). Around 1993 1 of the 2 major processors stopped buying rockweed and the industry reverted to hand harvesting methods (DFO, 1998b). Annual landings fell by almost half from approximately 27,000 t to 14,000 t [Fig 4. Phase C]. Shortly thereafter, the New Brunswick rockweed harvest expanded to southern New Brunswick and a new rockweed buyer was established in Nova Scotia (DFO, 1998b). Landings more than doubled within 6 years to a maximum of over 28,000 t in 2001 Fig 4. Phase [D]. Since 2001, landings have exceeded 30,000 t in both 2003 and 2004, and, in general, the value of rockweed per tonne has continued to increase (G. Sharp, pers. comm).

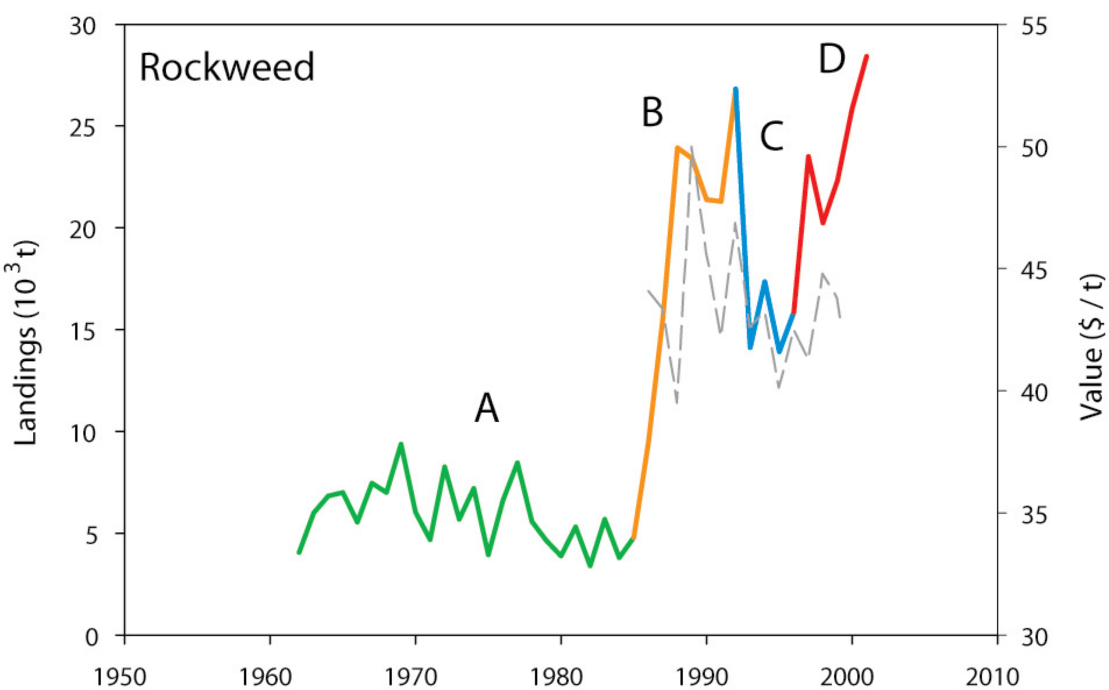

Figure 6: Tonnes of rockweed harvested per year (solid bold line) and value of rockweed per tonne harvested (dashed light line) throughout NAFO Division 4X. 1962-85 data from CAFSAC (1992a) and representing the Scotia-Fundy region, 1986-2004 data from DFO Annual Fisheries Statistics and representing NAFO Division 4X specifically (L. Sonsini, pers. comm).

2.7 Knowledge analysis

The percentage of all known factors reported in recent DFO documents that was deemed relevant to the sustainable development of each fishery was highest in rockweed and in the comparison fishery, NAFO Division 4X/5Y Atlantic cod (Fig. 7). In contrast, the lowest percentage of reported known factors was found in the offshore (LFA 41) Jonah crab fishery where less than ¼ of the evaluated knowledge factors were reported in the relevant DFO reports. All other considered invertebrate fisheries had considerably less factors reported as known compared to Maritimes rockweed and Division 4X/5Y Atlantic cod. Combined, 39% (SE=5%) of the knowledge factors for developing fisheries were reported compared to 62% for Atlantic cod.

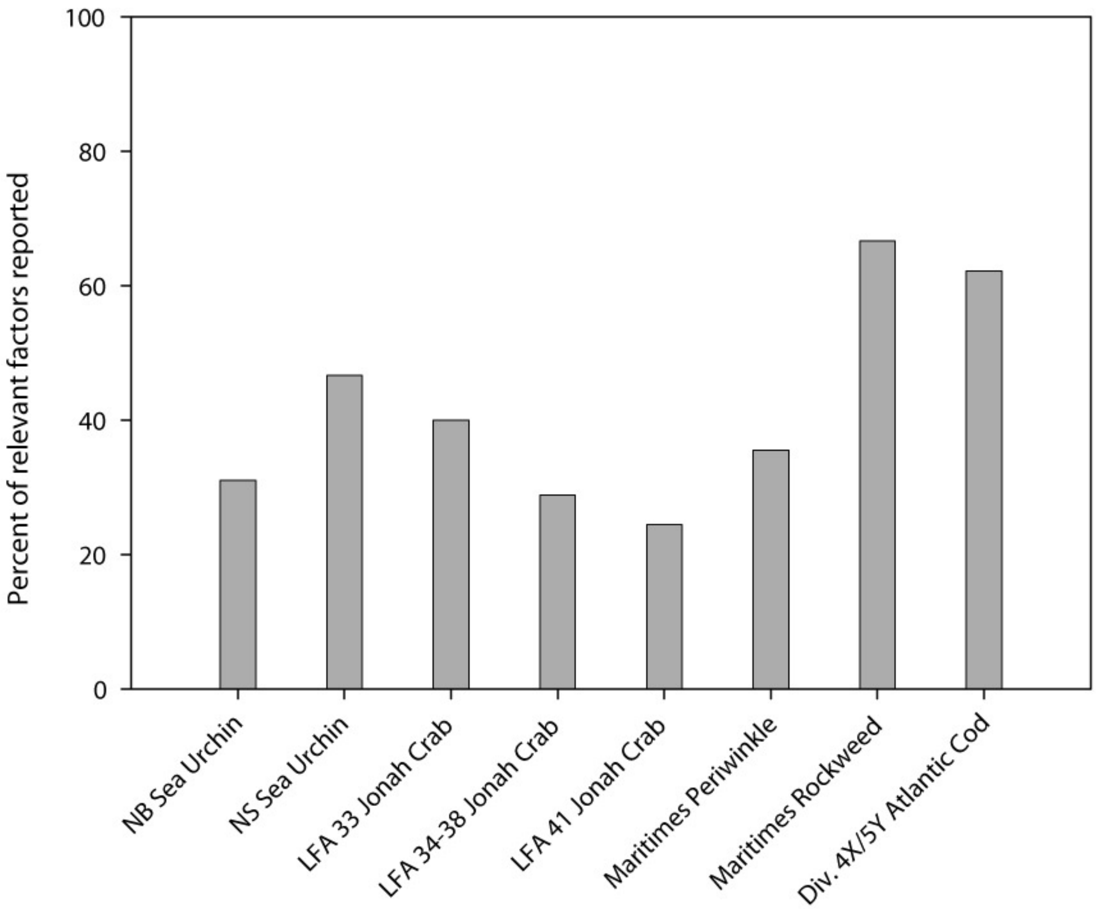

Figure 7: Reporting in DFO Stock Status Reports and CSAS Research Documents of population and life-history characteristics, fisheries characteristics, and ecosystem characteristics important for developing sustainable management of invertebrate and low-trophic level fisheries. Knowledge factors adapted from Perry et al. (1999).

Discrepancies could be seen in the groups of knowledge factors reported for each of the investigated fisheries (Fig. 8). Less than ¼ of the information about population and life-history characteristics that could be useful in developing a sustainable fishery was reported as known for any of the sea urchin or Jonah crab fisheries (Fig. 8, white bars). More fishery related information was reported as known than any other category of knowledge for all but the periwinkle and Nova Scotian sea urchin fisheries (Fig. 8, grey bars). For the Jonah crab fisheries, the most was reported known about fishery characteristics for LFA 33, while the least was reported as known about fishery characteristics for the offshore LFA 41. While the majority of the ecosystem information related to the Nova Scotian sea urchin fishery and the periwinkle fishery respectively was reported as known, there was not any reporting of the ecosystem knowledge factors evaluated in this study for the Jonah crab fisheries in LFA 34 to 38 and in LFA 41 (Fig. 8, hatched bars). For the comparison fishery, NAFO Division 4X/5Y Atlantic cod, the percentage of reported known information for both the population characteristics and fishery characteristics was among the highest while less than ⅕ of the relevant information about the ecosystem was reported as known. The highest percentage of evaluated information about the ecosystem was reported for the Nova Scotia sea urchin fishery. Rockweed had the most even distribution of knowledge with approximately ⅔ of the relevant information reported as known in each of the categories evaluated. Combined, developing fisheries had 29% (SE=7%) of population and life-history characteristics reported compared to 65% for Atlantic cod; 63% (SE=7%) of fishery characteristics reported compared to 83% for Atlantic cod; and 37% (SE=13) of ecosystem factors compared to 14% for Atlantic cod.

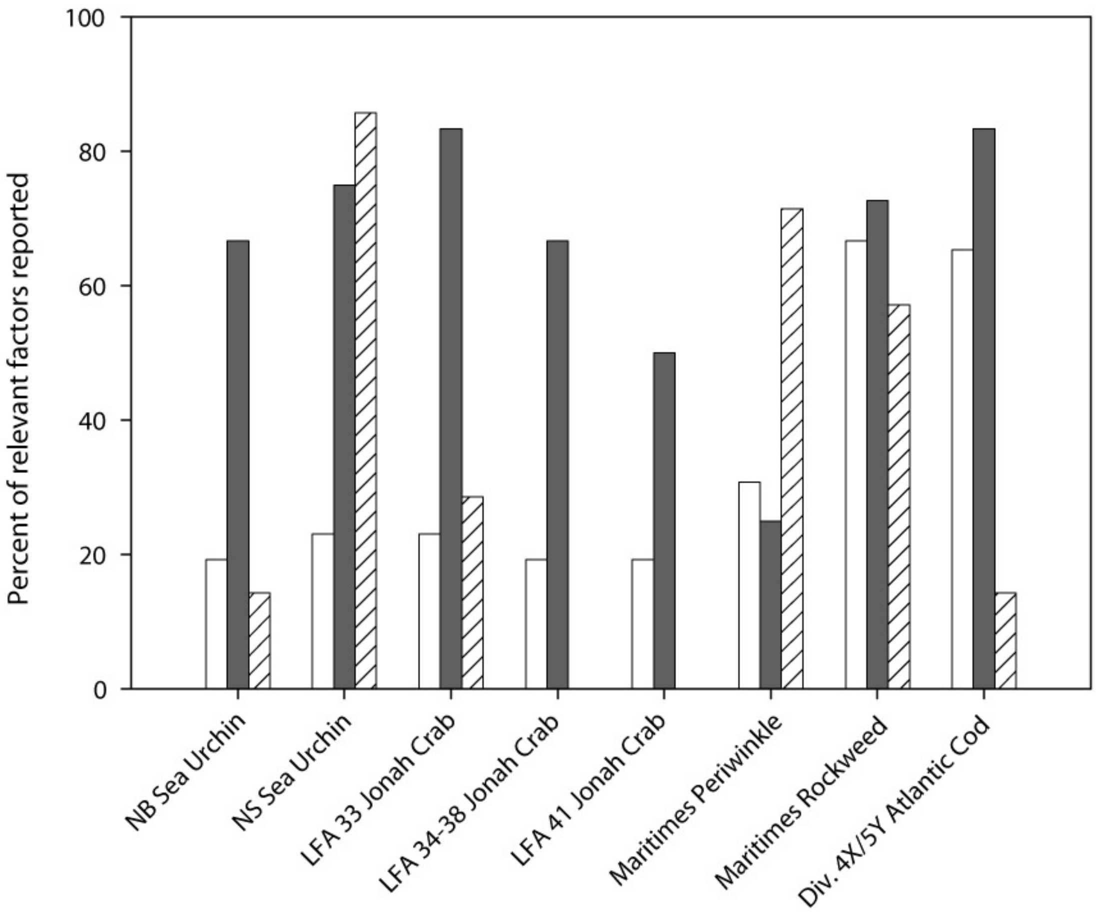

Figure 8: Reporting in DFO Stock Status Reports and CSAS Research Documents of population and life-history characteristics (white bars, n=26), fisheries characteristics (grey bars, n=12), and ecosystem characteristics (hatched bars, n=7) important for developing sustainable management of invertebrate and low-trophic level fisheries. Knowledge factors adapted from Perry et al. (1999).

2.8 Regulations analysis

2.8.1 Sea urchin fisheries

There are 3 main regulatory areas for sea urchin fisheries within the southwestern Scotian Shelf (Table 1). Management regulations for the 2 New Brunswick sea urchin fisheries differ greatly from the management regulations for the Nova Scotian sea urchin fisheries. In general, the New Brunswick fisheries rely on a typical TAC (total allowable catch) structure and permit bottom dragging in addition to dive harvesting, while the Nova Scotian fisheries are run under an area licensed habitat-based management scheme and operate entirely as dive harvests.

The New Brunswick sea urchin fishery is divided into 2 main regulatory areas, LFA 38, Grand Manan, and LFA 36, the remaining area of the New Brunswick side of the Bay of Fundy including both mainland coast and coastal islands, each with its own regulations (Fig. 2) (DFO, 2000e). Fishers from both LFAs are also permitted to harvest sea urchins in LFA 37, which is a small LFA between LFA 36 and 38 (Fig. 2). As of the year 2000, LFA 36 permitted harvesting by bottom dragging and diving while all LFA 38 licenses where for dragging. Drag fishers are permitted to switch from dragging to diving licenses, but not vice versa (D. Robichaud, pers. comm). The maximum drag width was greater in LFA 36 at 3.05m. Both fisheries require sorting and culling to be performed at sea between sunrise and sunset. Based on an estimated biomass of 12,245 t and 29,879 t in LFA 36 and 38 respectively, a total allowable catch of 900 t (6.8% exploitation rate) and 979 t (3.3% exploitation rate) was enforced for LFA 36 and 38 respectively. The harvesting season is shorter in LFA 38 compared to LFA 36 (Table 1). Both LFAs enforced a 50 millimeter diameter size limit, which corresponded to harvesting sexually mature sea urchins between 10 and 15 years and older. Both LFAs required logbooks and had dockside monitoring in place. Although there was a diver based survey carried out from 1992 to 1994, there have been no regularly performed fishery independent surveys for sea urchins in southwestern New Brunswick.

The only interspecies consideration requirement was the avoidance of scallop conservation zones and no area was protected for research purposes (DFO, 2000e).

The Nova Scotian sea urchin fishery is a dive fishery managed based on a restricted zone area based system (DFO, 2000b). When entering the fishery, fishers must first fish competitively on a section of the coast, usually a county, with a 4 t quota. After meeting specified guidelines they can apply for a restricted zone. Restricted zone are surveyed initially and then every few years and licenses are conditional on maintaining the urchin-algae feeding front. Urchin biomass is not monitored; instead, the number of licenses and the state of the habitat within are used as indicators of the state of the fishery (DFO, 2000b).

Table 1: Management regulations for green sea urchins (*Strongylocentrotus droebachiensis*) within NAFO Div. 4X as reported in most recent DFO Stock Status Reports and CSAS Research Documents

Management Control	LFA 36 Sea Urchin	LFA 38 Sea Urchin	N.S. Sea Urchin
Reference	(DFO, 2000e)	(DFO, 2000e)	(DFO, 2000b; Miller & Nolan, 2000)
Gear	Dragging or diving (suction harvesting)	Dragging	Diving only
Effort	Dragging: maximum width 3.05 m Diving: maximum 4 divers and 2 skiffs within 457 m of mother boat Sorting and culling done at sea, sunrise to sunset	Dragging: maximum width 1.83 m Diving: none Sorting and culling done at sea, sunrise to sunset	4 divers per boat
Quota	TAC of 900 t, based on estimated legal biomass of 12,245 t from 1992-94 survey (6.8%) Overall fishery quota	TAC of 979 t, based on estimated legal biomass of 29,879 t from 1992-94 survey (3.3%) Non-transferable individual quotas, dockside monitoring	None - partly self regulated by restricted licenses
Seasons	October 1 to May 15	November 1 to April 15	None
Licensed Areas	None	None	Exploratory: usually 1 county, multiple licenses per area Restricted: a few miles of coast, 1 license per area
Minimum Size, Reasoning	50 mm diameter (10-15 years old)	50 mm diameter (10-15 years old)	50 mm diameter (sexually mature at 7-23 mm)
Reporting	Mandatory logbook	Mandatory logbook	Mandatory catch reporting, voluntary science logs
Monitoring	Dockside monitoring	Dockside monitoring	Catch monitored 20% of time
Fishery independent surveys	Diver based survey from 1992-94 No regular surveys	Diver based survey from 1992-94 No regular surveys	None

Management Control	LFA 36 Sea Urchin	LFA 38 Sea Urchin	N.S. Sea Urchin
Minimum Landings	None	None	4 t/yr for exploratory licences None for permanent licences
Interspecies Consideration	No dragging allowed near scallop conservation zones	No dragging allowed near scallop conservation zones	None, partly encouraged by restricted licenses
Habitat Protection	None	None	None, partly encouraged by restricted licenses
Protected Area for Scientific Research	None	None	None

2.8.2 Jonah crab fisheries

Regulations for Jonah crab fisheries in NAFO Division 4X can be divided into 4 groups: LFA 33, LFA 34 and 35, LFA 36 and 38, and the offshore LFA 41 (Table 2). All fisheries were for male crab only.

In LFA 33, top entry traps and modified lobster traps were permitted with a 375 trap maximum (DFO, 2000d). The fishers had to fish in a zone from 12-50 nm (nautical miles) offshore and the season extended from June 15 to November 15. A minimum CW (carapace width) of 130 mm was initially established in 1997-98. A trial lowering to 121 mm in 1998-99 resulted in only a small increase in landings but a significant increase in female discards and a recommendation to increase the minimum CW (DFO, 2000d).

LFA 34 and 35 Jonah crab fisheries developed under a different Developing Species Advisory Board (DSAB) than LFA 36 and 38 (DFO, 2000a). Only in LFA 34 and 38 were commercially viable populations found. Fishing in both LFA 34 and 35 was limited to the lobster off-season, whereas fishing in LFA 36 and 38 was permitted year round. Modified lobster traps and conical traps were permitted in LFA 34 and 35, whereas only conical traps were permitted in LFA 36 and 38. In LFA 34 and 35, each licensed fisher had to land at least 10,000 kg to maintain his/her license, while in LFA 36 and 38, each fisher had to make at least 15 trips and land at least 30% of the average landings for all fishers in the LFA. For all of these LFAs, Jonah crab bycatch in the lobster fisheries was only occasionally reported on a voluntary basis and there were indications that this bycatch exceeded the directed landings as of 1999 (DFO, 2000a).

In 1995, the offshore Jonah crab fishery developed as a bycatch component of the lobster fishery (DFO, 2000c). Licenses were limited to 8 fishing vessels, landings were limited to 720 t/yr so as not to exceed the lobster fishery, and the fishery extended year round (DFO, 2000c).

Although a mandatory logbook existed, all traps used were standard offshore lobster traps and fishers were not required to record whether crabs were landed as bycatch or from directed effort (D. Pezzack, pers. comm).

Table 2: Management regulations for Jonah crab (C*ancer borealis*) within NAFO Div. 4X as reported in most recent DFO Stock Status Reports and CSAS Research Documents. CW = carapace width, CFV = Commercial Fishing Vessel, nm = nautical miles.

Management Control	LFA 33 Jonah Crab	LFA 34, 35 Jonah Crab	LFA 36, 38 Jonah Crab	LFA 41 Jonah Crab
Reference	(Adams et al., 2000; DFO, 2000d)	(DFO, 2000a; Robichaud, Lawton et al., 2000)	(DFO, 2000a; Robichaud, Lawton et al., 2000)	(DFO, 2000c; Robichaud, Frail et al., 2000)
Gear	Top entry traps or modified lobster traps with maximum 102 mm high entrance	Modified lobster traps, maximum of 48 mm wide rectangular entrance	Conical traps only, minimum of 2 circular openings of 63.5 mm diameter	Offshore lobster trap
	Minimum of 44.5 mm high escape gap	Conical traps, minimum of 2 circular openings of 79 mm diameter		
Effort	375 trap maximum	375 trap maximum	200 traps in LFA 36, 300 in LFA 38	Limited to 8 offshore lobster vessels
Quota	None	None	None	720 t/yr (so as not to exceed lobster fishery)
Seasons	June 15 - November 15	1 week after closure of spring lobster season to 1 week before the opening of the fall lobster season	Open	Year round, begins on October 16
Licensed Areas	12-50 nm offshore	None	None	None
Minimum Size, Reasoning	1997-98 130 mm, 1998-99 121 mm CW, males only	130 mm CW, males only	121 mm CW, males only	130 mm CW, males only

Management Control	LFA 33 Jonah Crab	LFA 34, 35 Jonah Crab	LFA 36, 38 Jonah Crab	LFA 41 Jonah Crab
Reporting	Mandatory logbook: weight of landed crab, number of traps set, location, date, depth, soak time	Mandatory logbook: traps hauled, soak days, weight landed, depth, date, location, trap type	Mandatory logbook: traps hauled, soak days, weight landed, depth, date, location, trap type	Mandatory logbook: trip number, vessel name, CFV number, vessel captain, number of crew, trap type and entry design, trap size, date, location, depth range, number of days gear set, traps hauled, estimated weight of crabs and lobsters retained
Monitoring	Dockside monitoring, at sea sampling	Dockside monitoring, at sea sampling	Dockside monitoring, at sea sampling	Mandatory dockside monitoring on all trips, at sea sampling
Fishery independent surveys	None	None	None	None
Minimum Landings	Unknown	10,000 kg	15 trips and land at least 30% of average landings (weight) for all fishers in LFA	None
Interspecies Consideration	Some bycatch reported	Some lobster bycatch reported	Some lobster bycatch reported	None
Habitat Protection	None	None	None	None
Protected Area for Scientific Research	None	None	None	None

2.8.3 Periwinkle and rockweed harvests

In the Maritimes, periwinkles have been primarily harvested through hand gathering as part of an unlicensed artisan fishery with largely unreported landings and sales (DFO, 1998a) (Table 3). The area harvested has been largely tide dependant, although ATVs (All Terrain Vehicles), boats, lights, and diving equipment have provided further access to the resource (DFO, 1998a). There have been no comprehensive surveys of periwinkles in the Maritimes (DFO, 1998a). Proposed integration of licenses, regulations, and enhanced reporting in recent years has largely failed because of the established casual and transient nature of the harvest (G. Sharp, pers. comm).

Rockweed has been harvested by a number of mechanical methods, by boat with cutter rakes, and on foot by sickle (Ugarte & Sharp, 2001) (Table 3). Mechanical harvesting reached its peak in the early 1980s and by 1994 all harvesters had reverted to cutter rakes or sickles (Ugarte & Sharp, 2001). This reversion to hand harvesting was the result of a number of industry related sociological pressures, mainly influenced by the increased employment offered through hand harvesting methods (G. Sharp, pers. comm). Both open and exclusive licenses exist and an exploitation rate of 17% exploitation is aimed for (DFO, 1998b). Regulations and reporting tend to be less strict in Nova Scotia and some areas are still experiencing pulse harvesting (repeated overexploitation) (G. Sharp, pers. comm). The southern New Brunswick area was sectioned into 64 sectors of which 8 were set aside as closed to harvesting (DFO, 1999). A number of harvestable biomass surveys have been performed, although detailed survey data does not exist for all harvested areas in the Maritimes (DFO, 1998b) and much of the detailed surveying has been performed by the rockweed industry and later reviewed by DFO (G. Sharp, pers. comm).

Table 3: Management regulations for Periwinkle (*Littorina littorea*) and Rockweed (A*scophyllum nodosum*) within NAFO Div. 4X as reported in recent DFO Stock Status Reports and CSAS Research Documents. References as noted in second row unless otherwise indicated.

Management Control	Maritimes Periwinkle	Maritimes Rockweed
Reference	(DFO, 1998a)	(DFO, 1998b, 1999; Sharp & Semple, 1997)
Gear	Hand gathered, some diving, experimental diver operated suction harvesting	Hand harvesting: cutter rake by boat and sickle by foot along shoreline Mechanical harvesting in past
Effort	None	None
Quota	None	17% of local biomass in New Brunswick, less regulation in Nova Scotia (G. Sharp, pers. comm)
Seasons	None	None
Licensed Areas	None	Open areas: open with federal marine plants license Exclusive license areas: 1 license per area
Minimum Size, Reasoning	None	Must leave minimum of 13.5 cm
Reporting	Limited reporting	Mandatory reporting
Monitoring	None	Strict monitoring in New Brunswick, provincial regulator monitoring in Nova Scotia (G. Sharp, pers. comm)
Fishery independent surveys	None besides limited selected sites	Some, majority of surveys harvest related (G. Sharp, pers. comm)
Minimum Landings	None	None
Interspecies Consideration	None	None
Habitat Protection	None	None
Protected Area for Scientific Research	None	8 sectors (of 64) closed to harvesting in southern New Brunswick

2.9 Abundance analysis

2.9.1 Nova Scotia sea urchin fisheries

The overall catch per license increased dramatically in the first few years of the opening of the commercial sea urchin fishery in Nova Scotia (Fig. 9). While catch per license varied from year to year within each evaluated area, the overall catch per license in Nova Scotia remained relatively constant after the initial variability. Effort data after 1999 was unavailable and deemed unreliable as a measure of abundance because of a mass die-off from disease experienced in recent years (R. Miller, pers. comm). As of 2004, landings had decreased to ⅕ of their peak value in 1996.

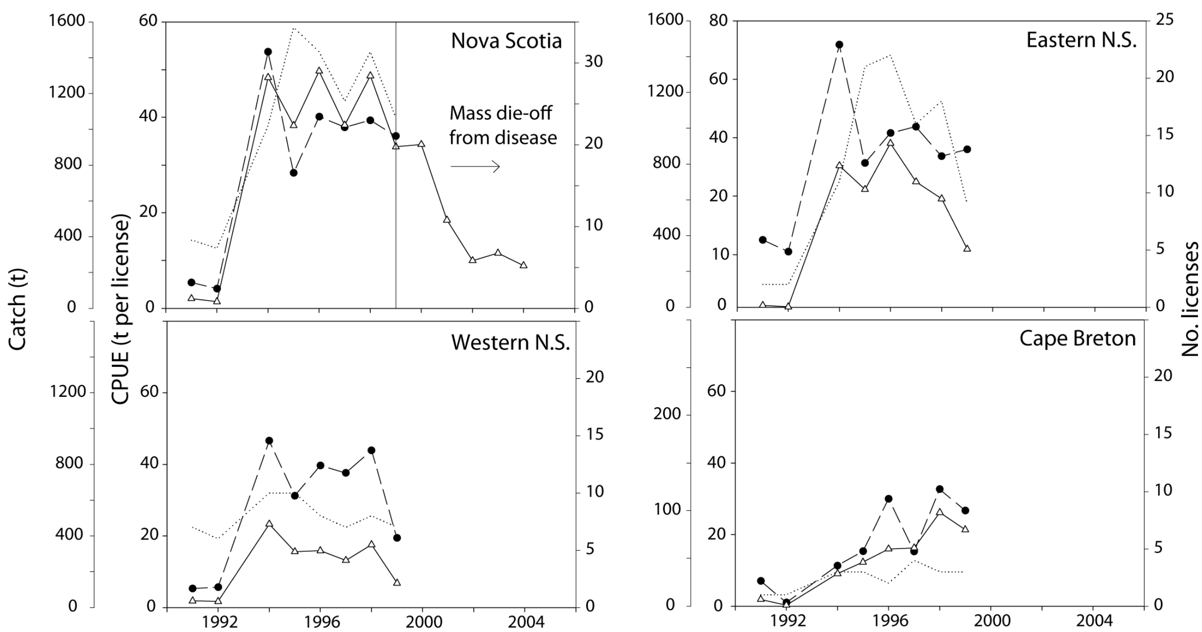

Figure 9: Sea urchin catch (open triangles, solid lines), number of licenses (no symbols, dotted lines), and CPUE (solid circles, dashed lines) for Nova Scotia dive fisheries plotted by year. 1991 to 1999 data from CSAS Research Document (Miller & Nolan, 2000), 2000 to 2004 season data from DFO Annual Fisheries Statistics (R. Miller, pers. comm).

2.9.2 New Brunswick sea urchin fisheries

The LFA 36 sea urchin fishery expanded until landings reached a total of approximately 970 t in the 1996-97 season (Fig. 10). Since the then, the proportion of catch attributed to bottom dragging in LFA 36 has decreased with time. As of the 2004-05 season, bottom dragging accounted for approximately ⅕ of the total sea urchin landings in LFA 36. Landings specific to diving and dragging were unavailable prior to the 1996-97 season. Catch per day dived and dragged has in general increased slightly throughout the lifetime of the fishery with the exception of a spike in CPUE for the dive fishery around the 1995-96 season. The general decrease in dragging landings is reflected by a decrease in dragging effort and the general increase in diving landings is reflected by an increase in diving effort. This may be partly because fishers can switch from dragging to diving licenses but not vice versa, conflict issues with lobster traps in some areas, and the greater area accessible to divers (D. Robichaud, pers. comm).

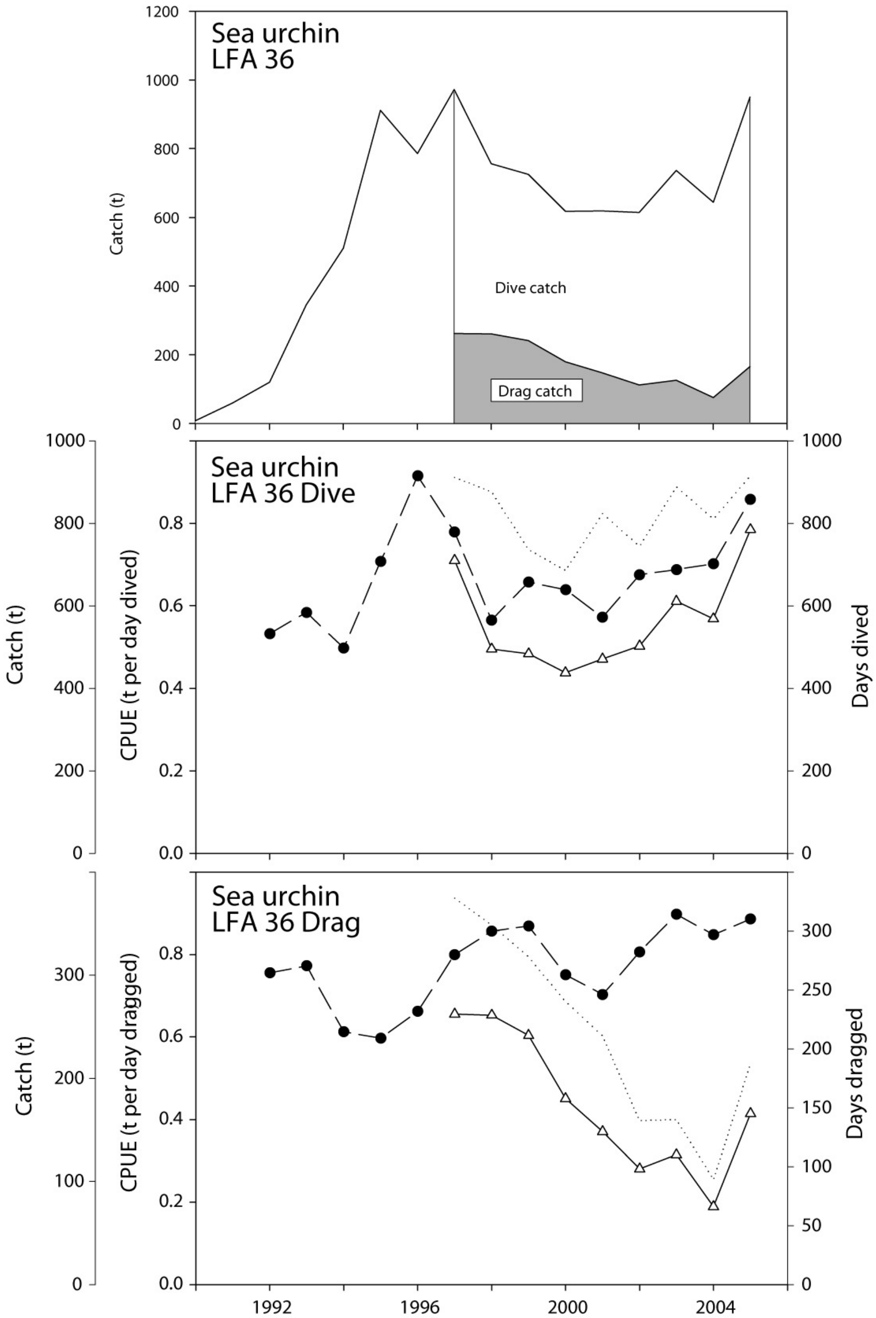

Figure 10: Sea urchin catch (open triangles, solid lines), effort (no symbols, dotted lines), and CPUE (solid circles, dashed lines) for LFA 36 dive and drag fisheries plotted by season (year indicates last year of season). 1991-92 to 1996-97 season data from DFO Stock Status Report (DFO, 2000e), 1997-98 data from DFO Annual Fisheries Statistics (D. Robichaud, pers. comm).

In contrast to LFA 36, LFA 38 saw an increasing proportion of effort attributed to draggers until the 1996-97 season, after which all remaining dive fishers converted to drag licenses (DFO, 2000e). In LFA 38, CPUE has experienced a relatively steady decline since the 1995-96 season (Fig. 11). As of the 2004-05 season, the catch per day dragged was almost ½ of what it was at its peak 10 years before. A linear regression of CPUE against time from the 1996-97 season onward indicated that approximately 89% of the variation in LFA 38 sea urchin CPUE could be accounted for by time (R^2=0.89, y=-0.055x+110.45, p=0.0001). The data passed normality and constant variance tests.

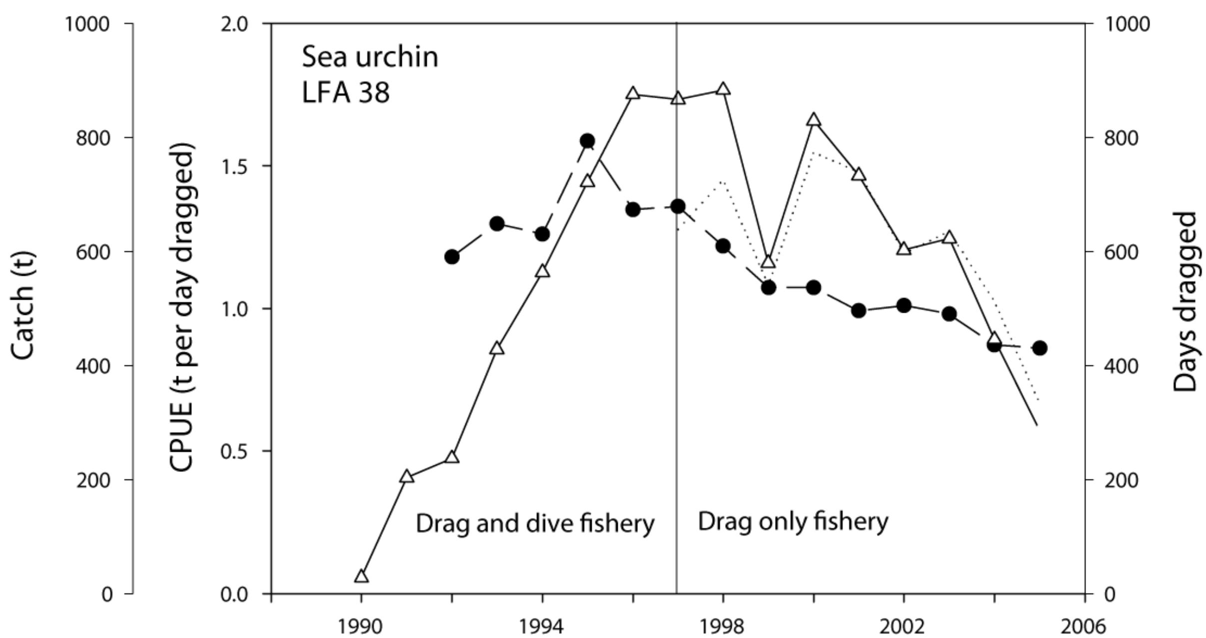

Figure 11: Sea urchin catch (open triangles, solid line), days dragged (no symbols, dotted line), and CPUE (solid circles, dashed line) for LFA 38 fishery plotted by season (year indicates last year of season). Landings prior to 1996-97 season include dive and drag landings. Linear regression of CPUE against time from 1995-96 to 2004-05 shown (R^2=0.89). 1989-90 to 1996-97 season data from DFO Stock Status Report (DFO, 2000e). 1997-98 data from DFO Annual Fisheries Statistics (D. Robichaud, pers. comm).

2.9.3 Jonah crab fisheries

An analysis of the NAFO Division 4X Jonah crab fisheries, excluding LFA 33 because of incomplete data (C. Frail, pers. comm), shows that effort and landings peaked around the 1999-2000 and 2000-01 seasons while CPUE has in general shown a declining trend since the beginning of the commercial fishery (Fig. 12). A linear regression performed on the CPUE data with respect to time indicated that 66% of the variation in CPUE could be explained by time (R^2=0. 66, y=-0.25x+502.35, p=0.008). The data was normally distributed and possessed constant variance.

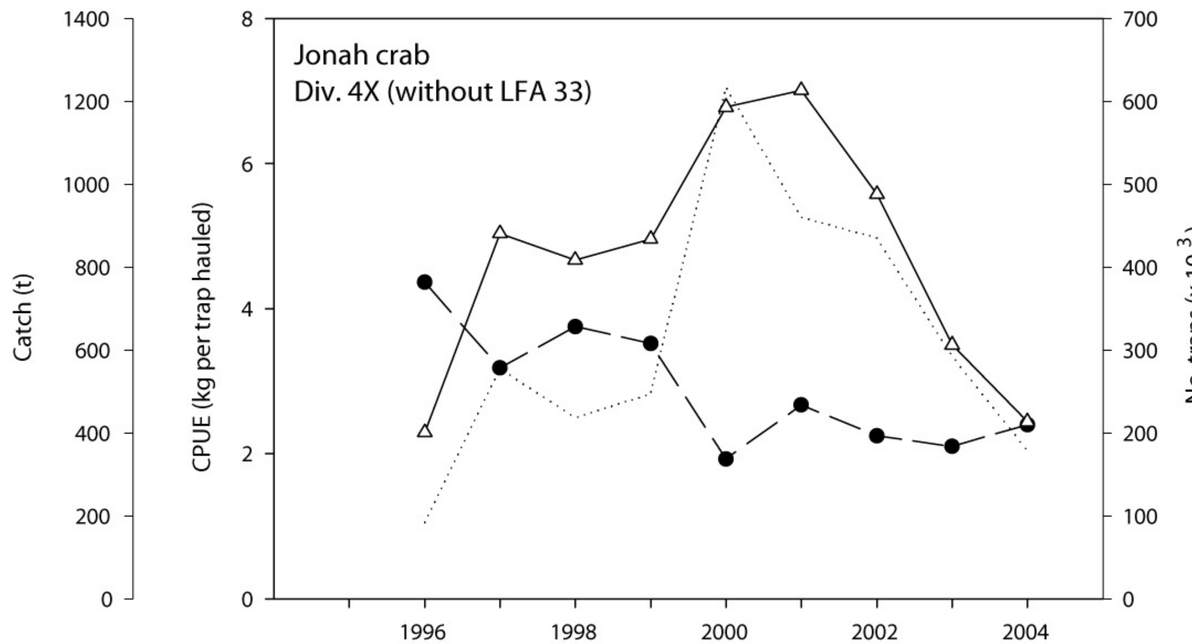

Figure 12: Jonah crab catch (open triangles, solid line), number of thousand traps set (no symbols, dotted line), and CPUE (solid circles, dashed line) for NAFO Division 4X (includes LFA 34, 38, 41) by season (year indicates last year of season). All data from 1994-95 season to 1998-99 season from CSAS Research Documents (Adams et al., 2000; Robichaud, Frail et al., 2000; Robichaud, Lawton et al., 2000). For 1999-2000 season to 2004-05 season: LFA 33 and 41 data from DFO Annual Fisheries Statistics (C. Frail, pers. comm), LFA 34 and 38 data from DFO Annual Fisheries Statistics (D. Robichaud, pers. comm).

In LFA 33, CPUE remained relatively constant between the 1996-97 and 2000-01 seasons while landings and effort increased approximately by a factor of 4 (Fig. 13). Since this peak, landings declined by approximately 100 t/yr by the 2003-04 season before increasing again in the 2004-05 season. As effort data for Jonah crabs has been inconsistently recorded for LFA 33 since the 2001-02 season, an analysis of CPUE was difficult given the short available time series.

The LFA 34 CPUE peaked in the 1998-99 season at just over 6 kg per trap hauled, landings peaked the following season at approximately 280 t, and effort peaked the season after that at approximately 60,000 traps hauled (Fig. 13). Since those peaks, landings and effort have declined to approximately 58 t and 16,000 traps hauled respectively. CPUE declined from its peak in the 1998-99 season to a low of 3.3 kg per trap hauled in the 2001-02 season and remained relatively stable thereafter.

Around Grand Manan, LFA 38, data suggests that the fishery is characterized by a sharp increase in landings and effort in the 1999-2000 season followed by an increase in effort with decreasing landings, and finally decreasing effort and a continued decrease in landings (Fig. 13). CPUE follows a downward trend throughout most of the fishery. A linear regression performed on the CPUE data with respect to time indicated that 70% of the variation in CPUE could be explained for by time (R^2=0.70, y=-0.25x+513.41, p=0.001). The CPUE data was normally distributed and possessed constant variance.

In the offshore Jonah crab fishery, LFA 41, available data indicate that landings remained relatively steady around 700 t per season from the 1996-97 season to the 2000-01 season before landings began to decrease to a low of 170 t in the season with the latest available data, 2003-04 (Fig. 13). Effort rose to a peak in the 1999-2000 season of 600,000 traps hauled before declining to just over 100,000 traps hauled as of 2003-04. In general, the data indicates a decrease in catch per unit of recorded effort throughout the LFA 41 Jonah crab fishery. A linear regression performed on the CPUE data with respect to time indicated that 77% of the variation in CPUE could be explained for by time (R^2=0.77, y=-0.28x+553.40, p=0.0004). The data was normally distributed and possessed constant variance. Although difficult to verify, the effort data in LFA 41 may be increasingly inflated, however, because of the reporting structure for Jonah crabs in this fishery (D. Pezzack, pers. comm). Logbook entries do not indicate whether a landed crab was the result of directed effort or bycatch and a growing percentage of crabs are being caught as bycatch in the lobster fishery since the value of Jonah crabs has decreased recently (D. Pezzack, pers. comm). The declining CPUE trend may therefore not be indicative of declining abundance.

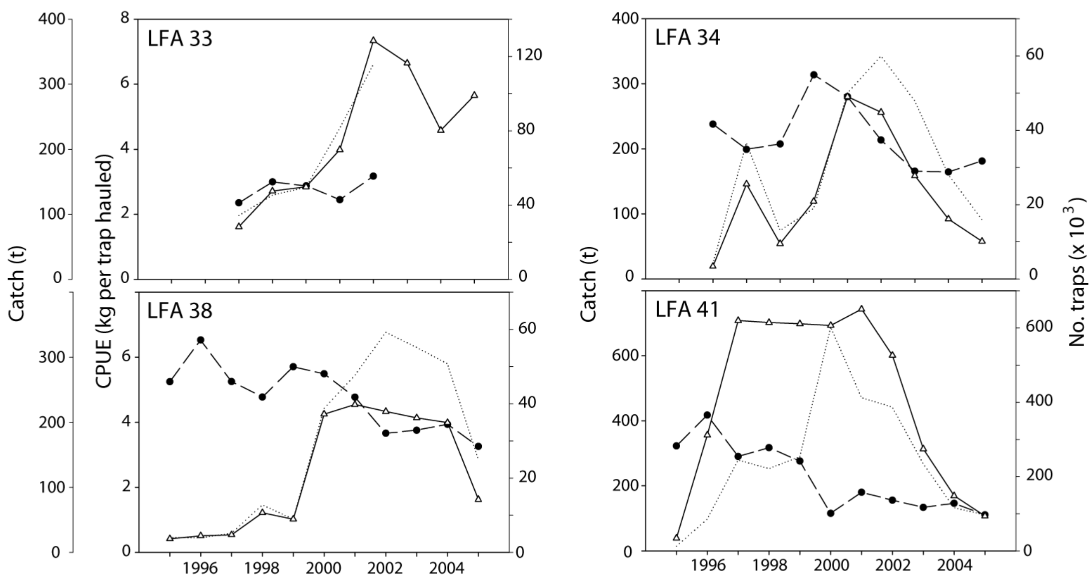

Figure 13: Jonah crab catch (open triangles, solid lines), number of thousand traps set (no symbols, dotted lines), and CPUE (solid circles, dashed lines) for Jonah crab fisheries in LFAs 33, 34, 38, and 41 plotted by season (year indicates last year of season). All data from 1994-95 season to 1998-99 season from CSAS Research Documents (Adams et al., 2000; Robichaud, Frail et al., 2000; Robichaud, Lawton et al., 2000). For 1999-2000 season to 2004-05 season: LFA 33 and 41 data from DFO Annual Fisheries Statistics (C. Frail, pers.

comm), LFA 34 and 38 data from DFO Annual Fisheries Statistics (D. Robichaud, pers. comm).

With LFA 41, available data indicate that landings, effort, and CPUE have followed different trends in different regions of the offshore Jonah crab fishery (Fig. 14, see Fig. 3 for map). Initially, CPUE and landings were highest in Georges Bank, followed by Crowell Basin, and SE Browns. Reported landings and effort have in general declined in all assessment areas since the 2001-02 season possibly because of a declining value of Jonah crab in recent years, which may have resulted in less directed effort (D. Pezzack, pers. comm).

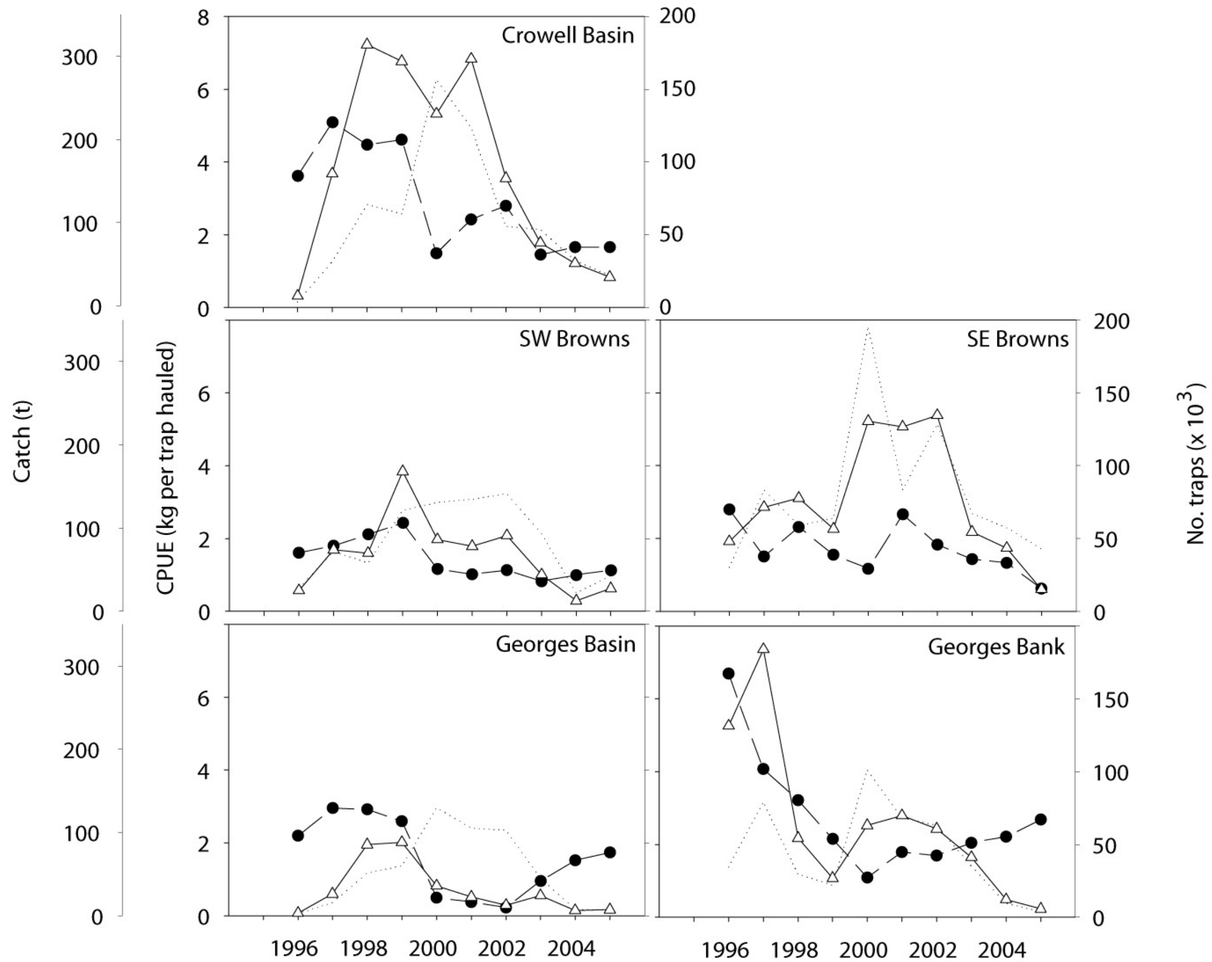

Figure 14: Jonah crab catch (open triangles, solid lines), number of thousand traps set (no symbols, dotted lines), and CPUE (solid circles, dashed lines) for Jonah crab fisheries in LFAs 41 plotted by season (year indicates last year of season) and separated by assessment area. All data from 1994-95 season to 1998-99 season from the CSAS Research Document (Robichaud, Frail et al., 2000). Data from 1999-2000 season to 2004-05 season from DFO Annual Fisheries Statistics (C. Frail, pers. comm).

Jonah crabs have been assessed as part of DFO Groundfish Research Trawl Surveys since 1999 (Fig. 15). When trawl survey data from the main Jonah crab fisheries within NAFO Division 4X was combined, the maximum standardized number per tow occurred in the year 2003 and the minimum standardized number per tow occurred in 2001. Year 2004 data was excluded due to anomalous species counts and concerns with standardization of the data for many of the crab fisheries from those surveys (J. Tremblay, pers. comm). There was a substantial drop in standardized number per tow in LFA 41 from 1999 to 2000 (Fig. 15), which corresponded with a drop in CPUE (Fig. 13). Otherwise, the standardized number of Jonah crabs per tow for the investigated areas varied considerably and did not show any clear trend from 1999 to 2005. The groundfish trawl surveys were not designed to catch invertebrates or to be separated into LFAs; therefore, it is not clear the degree to which they reflect relative abundance (J. Tremblay, pers. comm).

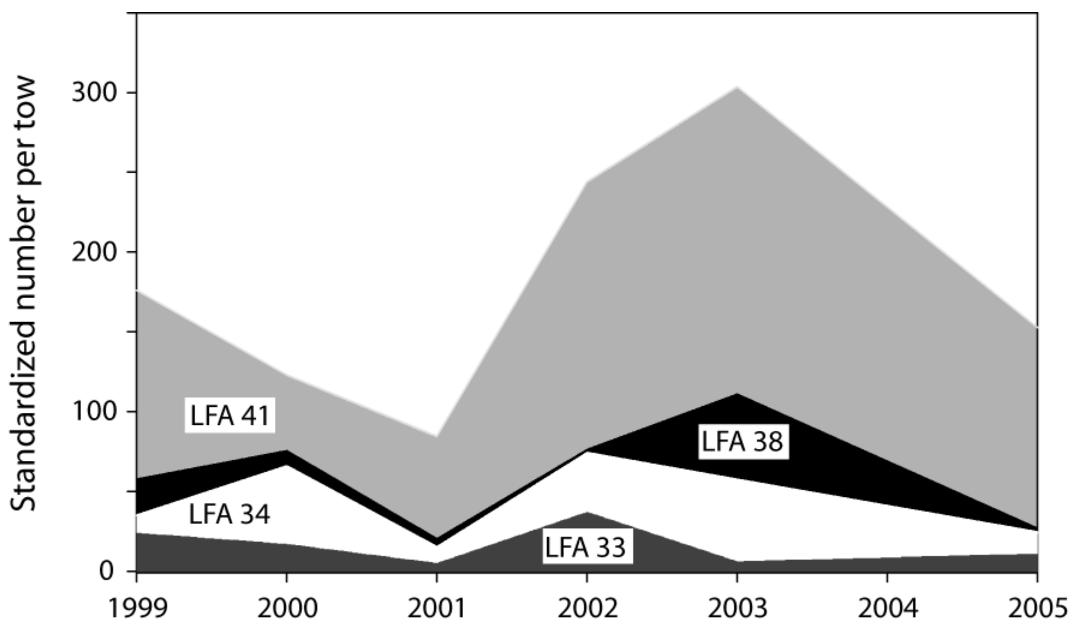

Figure 15: Standardized number per tow for Jonah crab for the main Jonah crab fisheries in NAFO Division 4X. Data from DFO Annual Groundfish Trawl Survey Reports (J. Black, pers. comm).

To assess the spatial distribution of Jonah crabs, the average number of crabs caught in summer DFO Groundfish Research Trawl Surveys was mapped for the available years of 1999 to 2001 (Fig. 16). Distribution appeared to vary considerably between years and regions within NAFO

Division 4X. The trawl surveys indicate a lack of Jonah crab abundance in LFA 35 and 36 (Fig. 16) where fishers failed to find commercially viable concentrations (DFO, 2000a). There was a high average number of Jonah crabs per standard tow in Crowell Basin (see Fig. 3 for map) in 1999 (Fig. 16), which may have corresponded to the high CPUE in this area at the time (Fig. 14). Trawl survey data indicated a decrease in abundance in Crowell Basin (Fig. 16) from 1999 to 2000 and this corresponded with a decline in CPUE (Fig. 14).

There are, however, several limitations to making these sorts of correlations. In LFA 41, crab CPUE data was compiled by season, which started each year on October 16th, and extended year round. The second calendar year of each season, as shown in Fig. 13, therefore, corresponded to the year of the summer trawl survey, but this fishery data encompassed a greater temporal scale than the summer trawl survey. Further, these groundfish trawl surveys were not designed with invertebrates or LFAs in mind and there relation to relative abundance is, therefore, not clear (J. Tremblay, pers. comm).

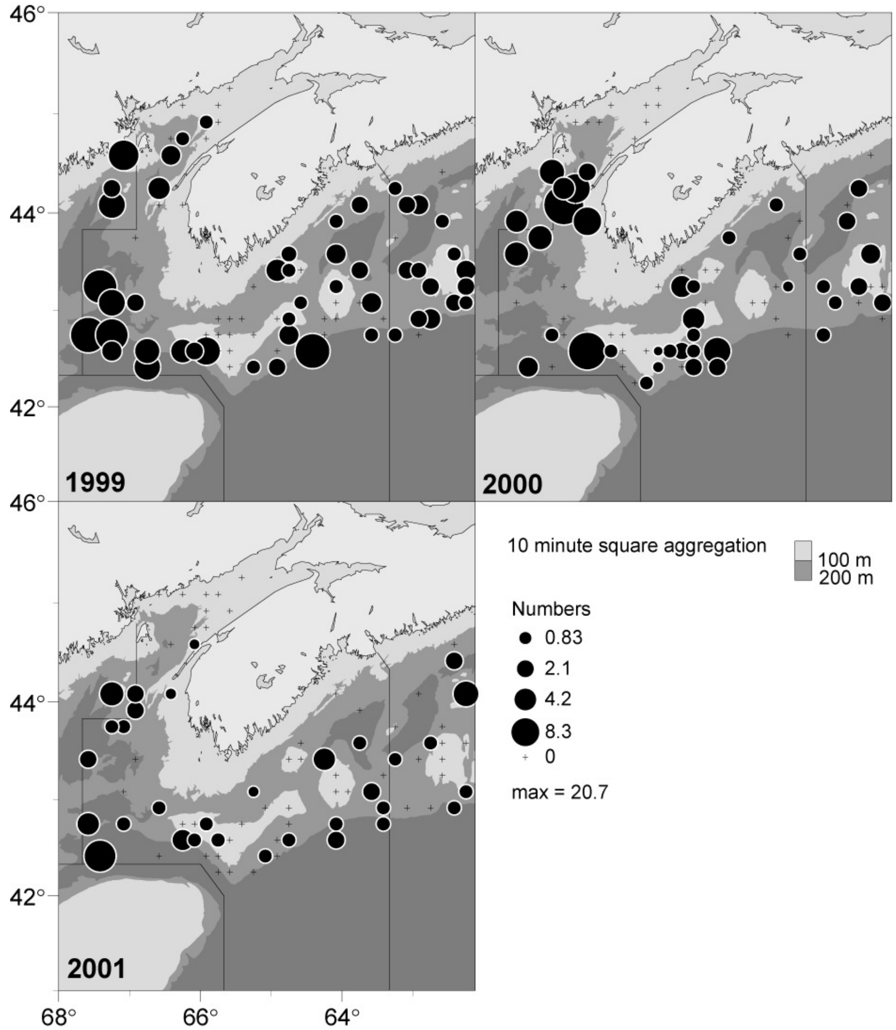

Figure 16: Average number of Jonah crab per standard summer tow on the southwestern Scotian Shelf from 1999 to 2001. Data from and figure adapted from DFO Groundfish Research Trawl Surveys (GMBIS (Gulf of Maine Biogeographic Information System) Electronic Atlas, 2002) .

2.9.4 Periwinkle harvests

Data that may provide evidence toward changes in abundance over time for periwinkle (*Littorina littorea*) is limited. There has been no comprehensive assessment of periwinkle biomass in the Maritimes (DFO, 1998a). Since the periwinkle harvest is not licensed, landings often go unreported through unofficial cash sales, CPUE varies greatly by harvester, and effort may respond on a weekly basis to changes in periwinkle market value (DFO, 1998a, G. Sharp, pers. comm), reliable fishery statistics are not available.

In 1998, the Department of Fisheries and Oceans (1998a) made an approximate estimation of *Littorina littorea* biomass in the Bay of Fundy, where most of the Maritimes periwinkle harvest occurs, including estimated *Littorina littorea* biomass within rockweed canopies, of 5,000 t. Based on the NAFO Division 4X landing statistics shown in Figure 3, the peak reported harvest of approximately 280 t in 1993 would correspond to an approximate 6% exploitation rate.

2.9.5 Rockweed harvests

Comprehensive effort data for rockweed is not publicly available, and landings (Fig. 5) and area harvested (Sharp & Semple, 1997) have varied considerably over time. Further, methods of harvesting have changed from mostly mechanical harvesting in the early 1980s to entirely hand harvesting methods by 1994 (Ugarte & Sharp, 2001). For these reasons, an analysis of CPUE was not included in this thesis.

An approximation of rockweed exploitation rate in NAFO Division 4X was possible. Sharp and Semple (1991) estimated the harvestable biomass of rockweed in southern Nova Scotia, Annapolis Basin, and Lobster Bay (see Fig. 4 for map) to be 7,600 t, 1,872 t, and 57,532 t respectively. CAFSAC (1992b) estimated the rockweed biomass in southwestern New Brunswick to be approximately 140,000 t of which 77,000 were later estimated as in harvestable areas (Sharp & Semple, 1997). These areas comprise the bulk of the rockweed harvesting in NAFO Division 4X with the exception of St. Mary's Bay. Harvesting had recently begun in St. Mary's Bay and reached a peak of 2,277 t in 1992 followed by a decline to 12 t in 1996 (DFO, 1998b). This area has been data deficient and biomass estimates are not available (Sharp & Semple, 1997).

Combined, there was approximately 144,000 t of known harvestable rockweed in NAFO Division 4X in 1991-92. Given the peak harvest in 1992 (Fig. 5 & 6) of 24,520 (after removing the landings for St. Mary's Bay for which biomass is not known) the exploitation rate in NAFO Division 4X was approximately 17% of the harvestable stock in 1992. Assuming there has been no change in biomass since then, landings from St. Mary's Bay have remained minimal, and current landings are approximately 30,000 t/yr (G. Sharp, pers. comm), the present exploitation rate is approximately 20%.

While the target exploitation rate has been set at 17%, rates have varied considerably by area (DFO, 1998b). In some areas, biomass removal has approached 95% while other areas have remained untouched (Sharp & Semple, 1991). Some areas continue to be competitively pulse harvested while others experience responsible area based management (G. Sharp, pers. comm).

Chapter 3
Discussion

3.1 Overview

In this thesis, I analyzed knowledge, regulations, and relative abundance in order to draw conclusions about the sustainability of developing fisheries on the Scotian Shelf. I concluded that we may be observing a declining abundance of sea urchins and possibly Jonah crabs around Grand Manan. There are indications that the drag sea urchin fishery around Grand Manan may be less sustainable than the mostly dive sea urchin fishery in nearby LFA 36, although diving could be masking a decrease of abundance in this area. Although carefully managed, disease has severely impacted the Nova Scotian sea urchin population and fishery. Reporting structure in the offshore and Gulf of Maine Jonah crab fishery has made assessment difficult. The periwinkle fishery is unregulated, monitoring is sparse, and surveys are not available making an analysis of relative abundance difficult. Harvesting of rockweed appears to be sustainable in some areas while other areas have shown evidence of overharvesting. The effect of this harvest on the abundance of associated species is largely unknown. In all these fisheries, abundance cannot be conclusively assessed with the available data.

3.2 Lack of data and knowledge

A general theme throughout the investigated fisheries was a problem with the quality, precision, and availability of fisheries data. A review of recent DFO Stock Status and Habitat Status Reports reveals that management scientists have raised such concerns for all the investigated fisheries including the Nova Scotian (DFO, 2000b) and New Brunswick (DFO, 2000e) sea urchin fisheries; the inshore Gulf of Maine (DFO, 2000a), Scotian Shelf (DFO, 2000d), and offshore

(DFO, 2000c) Jonah crab fisheries; the New Brunswick Rockweed harvest (DFO, 1999) and the Maritimes periwinkle fishery (DFO, 1998a). Further, greater transparency in the source of available data and consistent reporting would aid in analysis.

The discrepancy observed between the reporting of knowledge in developing fisheries compared to Atlantic cod (Fig. 7) was likely underestimated. It was observed that many knowledge factors that have been incorporated into Atlantic cod management were omitted from recent Stock Status Reports and Research Documents in favour of recent research. I suspect this is owing to the volume of reports that have been published for this species and the degree of established 'common knowledge' assumed for this fishery.

Given low-trophic level species' ecological and economic value, we need to be putting the same effort into monitoring them as we are putting into predatory fish stocks such as Atlantic cod. Fishery statistics are published annually for species such Atlantic cod. Annual or biannual assessments of developing fisheries had best be incorporated if we are to ensure their sustainability. Further, these assessments need to incorporate data from other trophically and ecologically related species and populations to move beyond single species assessments.

Regularly performed fishery independent surveys could greatly increase the ability to assess relative abundance and manage these fisheries in a sustainable manner. Fishery related data is fraught with numerous inherent biases and the incorporation of fishery independent data can be vital to optimal management (Chen, Chen, & Stergiou, 2003; Hilborn & Walters, 1992). Only Jonah crabs have been counted on the Scotian Shelf as part of the DFO Groundfish Research Trawl Surveys since 1999; however, because of the short time series available to date, meaningful conclusions were not evident (Fig. 15 & 16). In addition, since these surveys were not designed with invertebrates in mind, their validity in indicating relative abundance for Jonah crabs is uncertain (J. Tremblay, pers. comm). Hilborn and Sibert (1988) note that failing to carefully monitor abundance from a virgin stock state through the early portion of the development of a fishery results in the loss of vital information about the species population and ecosystem response to fishing.

A dive survey was performed in areas of New Brunswick for sea urchins from 1992-94 (DFO, 2000e) but regularly performed dive surveys have not been performed since. Given indications of declining CPUE in some of these fisheries (Fig. 11), fishery independent data would be critical to drawing conclusions regarding abundance and making meaningful changes to regulations.

There have been no comprehensive surveys of periwinkles within the Maritimes (DFO, 1998a). Fishery independent information regarding the state of this population and its associated ecology is non-existent making any assessment of the sustainability of this fishery difficult.

Rockweed biomass in the Maritimes has been assessed a number of times but not comprehensively in all areas (Sharp, 1986; Sharp & Semple, 1991). Recent biomass estimates of specific locations have been partly reliant on surveys performed by rockweed harvesting companies and later reviewed by DFO; however, issues remain with regularly assessing rockweed biomass in certain areas such as St. Mary's Bay (Sharp & Semple, 1997). While such assessment of biomass has proved useful in management, increased frequency and precision could greatly increase the possibility for sustainable management.

3.3 Issues with management and regulations

3.3.1 Market dependency

In all of the investigated fisheries, landings and effort showed signs of market dependency. The relation between value and landings appeared strongest in the sea urchin industry (Fig. 5), which globally is tightly connected with market demand (Berkes et al., 2006), and also with the value of the Japanese Yen (Botsford et al., 2004). Since 1999, landings from many of the sea urchin fisheries in NAFO Division 4X have declined for reasons related to both declining CPUE and increasing disease, while the value per kg of sea urchins has continued to increase. Pressure to overharvest sea urchins is likely to increase as urchin value rises and landings decrease and may contribute to an acceleration of declining abundance in vulnerable areas. The Jonah crab fisheries were developed largely because of rising market demand for crab following the collapse of the Alaskan crab stocks in the early 1980s (Robichaud, Frail et al., 2000). Fishing effort has decreased substantially in recent years largely because of decreasing market demand (D. Pezzack, pers. comm). Rockweed has been heavily influenced by market demand with landings halving and doubling in a few years according to demand (Fig. 6). Periwinkle harvesting has been known to fluctuate on a week by week basis depending on market demand (G. Sharp, pers. comm). The ecological effects of market driven rapid increases in harvesting of low-trophic fisheries are largely unknown because of a lack of monitoring and the relative novelty of many of these fisheries. Given the important ecological role formed by many of these species, however, the potential effects could be disastrous.

3.3.2 Management of new versus developing fisheries

The green sea urchin fisheries in New Brunswick and Nova Scotia began from a near virgin stock around 1989. The directed Jonah crab fisheries throughout NAFO Division 4X began between 1995 and 1997 after many years of limited bycatch in the lobster fishery and a trial directed fishery in some areas in the early 1980s (Adams et al., 2000). These 2 fisheries are in contrast to the periwinkle and rockweed harvests, which were established on a smaller scale prior to a rapid expansion in the mid 1980s. While population and ecosystem effects of a rapid fishery expansion might be similar between a new and a minimally established fishery beyond the initial fishing down period, management principles might vary greatly. In established fisheries, fishing methods and market structure may be entrenched and participants in the fishery may be resistant to change. Consideration of such sociological factors had best be included when considering changes to management schemes.

Issues with managing new versus developing fisheries have been evident in the fisheries investigated. Such difficulties have been particularly evident in failed attempts to regulate the periwinkle fishery because of the established casual and transient nature of the fishery (G. Sharp, pers. comm). In the rockweed industry some harvesters have become accustomed to competitive pulse harvesting and have been resistant to change (G. Sharp, pers. comm). The Nova Scotian sea urchin restricted zone based management system has largely been successful because of its status as a new and developing fishery. If fishers had been previously established, it might have been difficult to enforce habitat based management as has generally been successfully done. The Jonah crab fishery, although a relatively new fishery, has been linked with the lobster fishery in terms of involved fishers, gear, and fishing areas. It has therefore faced some of the same regulatory problems one would expect of a minimally established fishery. Reporting structure has been heavily influenced by the established lobster fishery and DFO (2000a; 2000c) has often found it inadequate in drawing conclusions about relative abundance.

3.3.3 The precautionary approach

With the possible exception of the Nova Scotian sea urchin fishery and some areas of the rockweed harvest, the development of low-trophic level fisheries on the Scotian Shelf show signs of being experimental at best and opportunistic at worst. Fishing effort in these fisheries was expanded with only rudimentary understanding of possible population and ecosystem effects and could therefore be termed experimental; however, without reliable and precise fishery independent measurements of abundance we may have lost vital knowledge about the response of these populations and ecosystems to increased fishing. I would suggest that carrying out precautionary management that ensures “healthy and abundant fishery resources supporting sustainable uses” as outlined in the “New Emerging Fisheries Policy” (DFO, 2001) could be difficult, if not impossible, with current monitoring.

Gear regulations may be further impinging on a precautionary approach to management of some of these fisheries. Given the plentitude of scientific and anecdotal evidence demonstrating the disastrous impacts of dragger fishing gear on marine habitat and biodiversity (for ex. Messieh, Rowell, Peer, & Cranford, 1991; Watling & Norse, 1998), the use of such gear is incongruent with a precautionary approach and inherently unsustainable. Further, a bottom dragging fishery that has experienced a steady reduction in CPUE to half of its peak in fewer than 10 years despite reductions in effort, as may have occurred in the Grand Manan sea urchin fishery (Fig. 11), can hardly be considered precautionary.

3.3.4 Ecosystem based management

Ecosystem based management is an integral component of developing sustainable fisheries (Pauly et al., 2002). Such an approach would likely incorporate into management: trophic interactions, evaluations of the impact of various gears on habitat, and marine reserves of suitable location and size (Pauly et al., 2002). Rarely have such evaluations been incorporated into the management of developing fisheries on the Scotian Shelf.

Of the fisheries investigated, only in the Nova Scotian sea urchin fishery have trophic interactions been explicitly incorporated into management. Sea urchins tend to be the dominant herbivore in their marine ecosystems (Andrew et al., 2002) and serve as prey to many species (Himmelman & Steel, 1971). Incorporation of trophic interactions into the management of the

New Brunswick sea urchin fisheries would therefore seem necessary to ensure sustainability. Likewise, the sustainability of the Jonah crab and particularly of the periwinkle and rockweed harvests could improve greatly if trophic interactions were incorporated into management.

A number of the developing fisheries on the Scotian Shelf have failed to take into account gear impact on habitat. The failure to take into account the impact of bottom dragging gear on habitat in the New Brunswick sea urchin fisheries is in conflict with ecosystem based management. Urchin harvesters in LFA 36 are permitted to switch their dragging licenses to diving licenses but not vice versa and this regulation may be partly responsible for the decrease in dragging in this area (D. Robichaud, pers. comm). Traps used in the Jonah crab fishery are assumed to have minimal impact on habitat (DFO, 2000d). While hand gathering of periwinkles is unlikely to severely impact habitat, these harvesters often access the shoreline by all-terrain vehicles (DFO, 1998a), which may impact the coastal ecosystem.

The impact of gear on rockweed habitat is of particular importance since rockweed provides reproductive and foraging habitat for a multitude of bird, fish, and invertebrates (Rangeley, 2000) as well as maintaining water quality through its filtering function and nutrient storage (Worm & Lotze, 1999). Rockweed has been harvested by cutter rake, hand sickle, and by mechanized harvesters (Sharp & Pringle, 1990). CAFSAC (1992b) found the exploitation rate to be highest for the hand sickle (90% mean exploitation rate) and lowest for the cutter rake (25% mean exploitation rate), but the cutter rake was found to remove the highest percentage (41%) of whole plants, which would retard the recovery of the rockweed habitat (Sharp, 1981). Areas with 95% exploitation rates have been found to take up to 10 years to recover (Sharp & Pringle, 1990), so a 90% exploitation rate incurred by hand sickles could impact habitat recovery. Mechanized harvesting of rockweed has been permitted in the past and there has been a push from industry in recent years to revert to back to these methods (G. Sharp, pers. comm). While local exploitation rates may be lower with mechanized harvesting, the ease with which mechanized harvesting allows high volume harvesting and therefore greater impact on habitat should be considered. While much research has gone into evaluating the impact of rockweed harvesting gear technology, regulations could go further toward integrating such knowledge.

None of the developing fisheries on the Scotian Shelf have incorporated designated marine reserves into management in which no fishing of any kind is permitted. In southern New Brunswick, 8 of a possible 64 sectors have been reserved as unharvestable for rockweed (DFO, 1999), but are not true marine reserves. The creation of marine reserve areas restricted from fishing could be of great benefit to the sustainability of the investigated fisheries. First, by creating areas that are restricted from fishing, we would create a reference point to compare fished areas to identify changes in population, habitat, trophic level distribution, and ecosystem functions. Second, by creating areas restricted to fishing, we would provide a refuge that could replenish fished areas should overexploitation occur. Third, by selecting ecologically sensitive areas to preserve, we could conserve the integrity of vulnerable local marine species populations and ecosystems. Worm et al. (2003) describe the potential of regulating ecological hotspots in the ocean to aide in the conservation of large predatory species. Similar regulations could aide in the conservation of low-trophic level species.

Although designated marine reserves are not incorporated into the management scheme, substantial unfishable reproductive refuges are believed to exist for Nova Scotian urchins (Miller & Nolan, 2000). Rockweed has few natural reserves since any area accessible by a 5m boat can be harvested by hand (Sharp, 1986). Natural reproductive refuges for periwinkles are believed to exist because of the limited depths and locations at which periwinkle harvesting occurs (G. Sharp, pers. comm). Still, these and other fisheries could benefit greatly from designated marine reserves both incase such assumptions of reproductive refuges prove incorrect and to form areas for comparison of population and ecological characteristics overtime to fished areas.

3.4 Assessing relative abundance

This study has identified signs of declining abundance in some of the developing fisheries. For the sea urchin fisheries: in Nova Scotia, landings and likely abundance have declined due to disease; in LFA 36, landings and CPUE have been relatively stable over the past 10 years but may not be indicative of abundance; and in LFA 38, there has been a decline in landings and CPUE likely due to overfishing and destructive dragging. For the Jonah crab fisheries: in LFA 38, CPUE has declined possibly because of a decline in abundance and possibly because of changes in quality of effort or bycatch issues; for the remaining Jonah crab fisheries, abundance trends are unclear. The periwinkle and rockweed harvests are strongly market driven. Relative abundance of periwinkles in the Maritimes is unknown. Relative abundance of rockweed is steady in some areas, decreasing in other areas, and unclear in some locations.

The sea urchin fishery around Grand Manan (LFA 38), which is primarily a bottom drag fishery, has seen its CPUE decrease by almost 50% from its peak value in 10 years (Fig. 11). Further, as of the year 2000, there was anecdotal evidence from fishers around Grand Manan of serial depletion of the stocks (DFO, 2000e). Compared to nearby LFA 36, the LFA 38 fishing season was made shorter, the permitted drag width was smaller, and the exploitation rate was set lower because of signs of lower recruitment during a dive survey in 1992-94 (DFO, 2000e). Despite these regulations, the CPUE has continued to decline in LFA 38.

The sea urchin fisheries on the southwestern Scotian Shelf have been developing for approximately 16 years (Fig. 5). Given that these fisheries began with a near virgin stock, the question remains to what extent the declining CPUE seen in LFA 38 may be part of typical fishing down of the stock as described by Hilborn and Sibert (1988). CPUE has, however, failed to plateau thus far with decreased effort as must occur if the fishery is to become biologically sustainable. Further, we have failed to see similar declines in CPUE in the nearby LFA 36 urchin fishery, which is primarily a dive fishery (Fig. 10). It should be noted, however, that CPUE may not be a reliable indicator of population abundance for dive fisheries because of the non-blind nature of diving and the fact that divers will only dive if they expect the CPUE to be suitably high (Miller & Nolan, 2000). Although differences in population characteristics make a direct comparison difficult, given the established habitat destruction incurred by bottom dragging (for ex. Messieh et al., 1991; Watling & Norse, 1998), it is not unreasonable to assume that gear type may be partly responsible for the differing CPUE trends of these 2 urchin fisheries. Given the available population data, CPUE data, and fishing gear in use, the LFA 38 sea urchin fishery may be unsustainable. Although the LFA 36 fishery has not seen a decline in CPUE and has thus far appeared sustainable, the possibility of diving masking a decline in abundance and the lack of ecosystem based management leads me to conclude that the long term sustainability of this fishery is unclear.

Signs of declining abundance of sea urchin populations are not unique among global sea urchin fisheries. Sea urchin fisheries have demonstrated repeatedly to be unsustainable (Andrew et al., 2002; Berkes et al., 2006; Botsford et al., 2004). This, despite the fact that most sea urchin fisheries world wide are dive fisheries (Andrew et al., 2002). When one considers the inherent habitat destruction caused by bottom dragging (Watling & Norse, 1998), one could question the wisdom of applying this technology to the fishery of a species that has repeatedly shown to be prone to overexploitation.

In contrast to the New Brunswick sea urchin fisheries, the Nova Scotian sea urchin fisheries are managed based on a restricted zone area based management scheme (Table 1). While sea urchins are a prime candidate for ecosystem based management, the Nova Scotia sea urchin fishery is the only urchin fishery in North America that has used ecological information to develop management policy (Andrew et al., 2002). Unfortunately, the largest threat to the Nova Scotian sea urchin population is disease (Miller & Nolan, 2000). The effect of disease can be seen in recent landings statistics (Fig. 9) and as Andrew et al. (2002) note, if populations of Nova Scotian sea urchins collapse approximately every decade because of disease, then an ecosystem based management scheme that fails to take this into account is missing a key component. Overall, if it wasn't for recurring mass die-offs from disease, the ecosystem based management of the fishery could result in a sustainable fishery.

Evaluation of relative abundance in the Jonah crab fisheries was generally unclear given the available data. The declining CPUE in LFA 38 may be indicative of declining abundance or may be indicative of issues with data collection. Robichaud et al. (2000) note that all the log books may not have been received for some seasons and the data may therefore not include all landings. Reporting of bycatch of Jonah crabs in the lobster fishery was voluntary and incomplete, exceeded the directed catch as of 1999, and was not included in the landings data (DFO, 2000a). It is also possible that the quality of fishing effort has decreased with the recent decline in crab value. It is unclear whether the decline of CPUE in the offshore LFA 41 is indicative of declining abundance because of the increasing percentage of reported landings being attributed to bycatch in the lobster industry (D. Pezzack, pers. comm). In the remaining LFAs, abundance trends remain unclear. Without complete and distinguishable recording of the Jonah crab bycatch in the lobster industry, the sustainability of these fisheries will remain unclear.

Available data does not permit an estimate of relative abundance of periwinkles. Comprehensive surveys have not been performed in the Maritimes and landings are often unrecorded (DFO, 1998a). The depth of harvestable periwinkles is considered minimal and extensive refuges for this species are assumed to exist from which periwinkles tend to repopulate harvested areas (G. Sharp, pers. comm). With the available data, however, the sustainability of the Maritimes periwinkle harvest remains unclear.

Detailed biomass surveys have been performed on some areas of the rockweed harvest, which have aided in estimating relative abundance. Sharp and Semple (1997) note that competitive overharvesting had resulted in declining abundance in the Nova Scotian Annapolis Basin, St. Mary's Bay, and Lobster Bay (see Fig. 16 for map). Surveys indicated that abundance appeared more steady in southern New Brunswick where area based management is more common (Sharp & Semple, 1997). Assuming that 17% exploitation is a reasonable target to maintain abundance, my estimate of a 17% and 20% exploitation rate in NAFO Division 4X in 1992 and post 2000 respectively (Section 2.9.5), indicate that overexploitation is occuring in some areas. Since harvesting is minimal in some areas (Sharp & Semple, 1997), harvesting in other areas must continue to far exceed the targeted 17% and could be assumed to be resulting in declining abundance. Additionally, there is some concern that 17% may not be an appropriate target for some areas in which rockweed is particularly susceptible from holdfast removal (DFO, 1999). Therefore, while the rockweed harvest in some areas, most notably southern New Brunswick, may be sustainable, the harvests of other areas show signs of being unsustainable; however, the effect of the rockweed harvest on the sustainability of associated species is unclear given current monitoring. If competitive overharvesting continues in the Annapolis Basin, St. Mary's Bay, and Lobster Bay, these harvests may not be sustainable.

3.5 Sustainability

In summary, some of the developing fisheries on the southwestern Scotian Shelf appear to be sustainable, some show signs of being unsustainable, and the sustainability of many remains unclear. The Nova Scotian sea urchin fishery is well managed, but because of recurring disease may not be sustainable. The LFA 36 sea urchin fishery may be sustainable at current effort levels, although the possible relative abundance masking effects of diving, possible serial depletion, and the established unsustainability of global dive sea urchin fisheries (Andrew et al., 2002; Berkes et al., 2006) makes its long term sustainability uncertain. This fishery was more sustainable than the Grand Manan, LFA 38, drag sea urchin fishery, which is showing signs of declining abundance and serial depletion. The sustainability of the Jonah crab fisheries remains unclear because of issues with the reporting of bycatch in the lobster fishery and incomplete reporting. The sustainability of the periwinkle harvest cannot be assessed with the available data. The southern New Brunswick rockweed harvest may be sustainable, but its effect on the sustainability of associated species is unclear. Some of the rockweed harvests in Annapolis Basin, St. Mary's Bay, and Lobster Bay may be unsustainable if overexploitation continues to occur.

Chapter 4
Conclusions

Low-trophic level fisheries have been rapidly expanded in the last 20 years on the southwestern Scotian Shelf and now represent substantial economic value (Fig. 5). Despite this, only 39% of knowledge factors necessary to develop sustainable management were reported for developing fisheries compared to 62% for the Atlantic cod fishery (Fig. 6). Further, only ⅓ of the possible population and ecosystem knowledge factors and ⅔ of the possible fishery knowledge factors were reported for the developing fisheries (Fig. 7).

Developing fisheries on the Scotian Shelf show signs of tight market dependency (Fig 5 & 6) and have the potential to be boom and bust industries, but monitoring has been largely inadequate. Monitoring is often lacking in quality, precision, and availability of data, and regulations rarely follow ecosystem based management principles. A reliable measurement of fishing effort was rarely available for these fisheries, and reported landings were often incomplete. Fishery independent data has rarely been collected. None of these fisheries have marine reserves in which all fishing is banned. Only in the Nova Scotian sea urchin fishery is substantial ecological knowledge integrated into the management plan. Overall, management regulations are failing to address many of our missing knowledge factors. Some of the fisheries may be sustainable, some appear to be unsustainable, but the sustainability of most of the fisheries cannot be ensured based on the available data.

Fisheries cannot be managed politically or allowed to fluctuate solely by market demand. These fisheries were expanded rapidly without the integration of adequate monitoring tools because of political and economic pressure from collapsed higher trophic level fisheries. There are signs that we may already be seeing a decreased abundance of some of these species but because of inadequate monitoring, decisive management decisions cannot be made and ecosystem effects of this increased fishing are largely unknown. Given our history of fishery mismanagement (Jackson et al., 2001) and the state of our oceans (Pauly et al., 2003), we cannot afford to continue to manage our fisheries in such a manner. No new low-trophic level fisheries should be opened without basic population and ecosystem knowledge and a manner of monitoring these parameters over time.

With 40% of the world marine fisheries categorized as developing (FAO Marine Resources Service, 1997) and the global fishery trophic level decreasing (Pauly et al., 1998), developing low-trophic level fisheries on the Scotian Shelf are part of a global trend. Some low-trophic level fisheries have a long global history of unsustainability (Andrew et al., 2002), while the sustainability of others has yet to be established. A rapid and substantial shift in the way we manage our fisheries is necessary if we are to ensure the long term health of our marine ecosystem.

Appendix A

Factors used in knowledge analysis

Table 4: Knowledge factors related to population abundance and distribution that are important for developing sustainable management of invertebrate and low-trophic level fisheries. Used in analysis of DFO Stock Status Reports and CSAS Research Documents. See Fig. 7 and 8. Knowledge factors adapted from Perry et al. (1999).

Population abundance and distribution knowledge category	Population abundance and distribution knowledge factor
Population structure	Single widespread population or metapopulations
	Mobility and range of life-history stages
	Extent of exchange among sub-populations
Distribution in space and time	Basic knowledge of geographic range
	Detailed knowledge of geographic range
	Degree of aggregation or schooling behaviour
	Seasonal migrations/changes in availability or location
	Preferred habitats
Population size or biomass	Virgin
	Current
	Size/age structure
	Potential lifespan
Reproductive characteristics	Basic knowledge of timing of spawning/reproduction
	Detailed knowledge of timing of spawning/reproduction
	Size at maturity/spawning/reproduction
	Fecundity at size
	Spawning/reproductive area/region
	Length (time) of larval/egg phase
	Type of larval/egg phase (e.g. planktonic…)
	Lifetime egg production
	Sex ratio
	Mating system, hermaphroditism?
Productivity characteristics	Growth rates
	Basic knowledge of recruitment patterns
	Detailed knowledge of recruitment rates
	Natural mortality rates

Table 5: Knowledge factors related to fishery characteristics that are important for developing sustainable management of invertebrate and low-trophic level fisheries. Used in analysis of DFO Stock Status Reports and CSAS Research Documents. See Fig. 7 and 8. Knowledge factors adapted from Perry et al. (1999).

Fishery knowledge category	Knowledge factor
Potential fishing techniques	Gear types
	Gear selectivity
	Gear efficiency
Handling characteristics	Survival after capture and release or regrowth after harvesting
Fishing location and timing	Specific fishery areas or locations
	Fishery seasons
Fishery monitoring	Measurement of landings
	Measurement of fishing effort
	Bycatch rate of this species in other fisheries
	Bycatch rate of other species in this fishery
History	Response of species population to fishing from fisheries experience elsewhere
Goldrush potential	Potential market and value of product landed

Table 6: Knowledge factors related to ecosystem characteristics that are important for developing sustainable management of invertebrate and low-trophic level fisheries. Used in analysis of DFO Stock Status Reports and CSAS Research Documents. See Fig. 7 and 8. Knowledge factors adapted from Perry et al. (1999).

Ecosystem knowledge category	Ecosystem knowledge factor
Potential for habitat disturbances	Fishery disruption of the habitat
	Recovery times after disturbance
Potential role in the ecosystem	Strength of interaction: e.g. keystone species or weak interactor
	Predator-prey species interactions
	Competition species interactions
	Habitat provision or interaction with habitat
	Other ecosystem function: e.g. nutrient filter or storage

Data from knowledge analysis available at:
http://myweb.dal.ca/sn516781/Honours_Thesis_2006_ANDERSON_data.xls

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