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Research Reports

Ecosystem Models of Newfoundland and Southeastern Labrador: Additional information and analyses for 'Back to the Future'

ECOSYSTEM MODELS OF NEWFOUNDLAND AND SOUTHEASTERN LABRADOR: ADDITIONAL INFORMATION AND ANALYSES FOR 'BACK TO THE FUTURE'

Edited by
Johanna J. Heymans

A Research Report from the
Coasts Under Stress and CDEENA projects.

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2003 Fisheries Centre Research Reports 11(5), 79 pp

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Director's Foreword

The fisheries of eastern Canada, particularly around Newfoundland, have experienced massive change in the last decades, but these only accentuated changes initiated much earlier, when Europeans crossed an ocean to exploit the rich cod resources around that land they had newly found. At first the fisheries appeared sustainable. With hindsight, this is not surprising, as they reached only the shallow part of the distribution of cod, leaving its deeper parts to provide the recruitment needed to sustain the fisheries. This equilibrium of sorts lasted for centuries. However, we are an ingenious species with infinite needs, and we developed gears capable of reaching deeper into this resource. A number of local stocks were thus extinguished in the late 19th century. Still, it is only in the 20th century that the precarious equilibrium between cod, their ecosystem and us was definitely altered: trawlers came into the picture, and their active movement led to catches that far exceeded those of previous, passive gear, which depended on the behaviour of shallow water cod (traps, lines, etc.)

Trawling came to Newfoundland in the form of large industrial fleets from Europe. Catches rose in the 1970s to unprecedented heights. Many were worried, and they were relieved when the declaration of an exclusive economic zone by Canada forced the departure of these fleets. This should have enabled a return to the previous sustainable fisheries, but that opportunity was missed: a new national, heavily subsidized fleet was built and it destroyed the stock, forcing the imposition of a moratorium in 1992, and a complete closing of the fishery in 2003. The trawl fishery has gone on and now exploits shrimp and snow crab and some say it is as profitable as ever, though they forget to account for the loss of jobs in the previous cod fishery.

There is now a widespread call for ecosystem-based fishery management to mitigate this exemplary case of 'fishing down marine food webs'. Implementing this will require considering trophic interactions into stock evaluations, i.e., ensuring some sort of balance between target species, their prey and their predators. The contributions included in this volume, most by Dr. Sheila J.J. Heymans, its editor, describe the process by which models of the Newfoundland ecosystems were constructed or updated as required for such ecosystem-based fisheries management. This process has begun only recently and still involves considerable uncertainly and gaps that will have to be filled. Thus, the models so far available explain only part of the historic changes that occurred in that ecosystem. Future research will have to expand on these descriptions and expand on their analysis.

What this volume shows is that already now, enough data are available for coherent pictures of ecosystem change to emerge. In addition, the models that were constructed have allowed the testing of hypotheses on the manner in which fisheries ecosystems react to stress. I therefore hope that this process will continue and draw in more of those who work on these systems, or their components.

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Director, UBC Fisheries Centre

PREFACE

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The *Coasts Under Stress* project conducts interdisciplinary research of the East and West coast of Canada. The project aims to combine formal scientific and humanist analysis with the experiences of coastal people. As part of *Coasts Under Stress*, the aim of *Back to the Future* is to describe the changes in the ecosystem over time, and link these changes to both human and natural phenomena. This report is the fourth in a series of background reports for the *Back to the Future* project. It was compiled to give an update of revisions to, and analyses done on, the Newfoundland models (NAFO Divisions 2J3KLNO) since the previous publication of these models by Heymans and Pitcher (2002b; a) and Bundy *et al.* (2000).

The Newfoundland models revised here cover the 1985-87 and 1995-97 periods. The report includes two chapters on historical reconstruction, one on local knowledge and three chapters documenting the changes made to the contemporary models of the ecosystem and analysis of these models. These chapters:

- Describe the estimation of First Nations fishing prior to European contact, that was used in the construction of both the historic models;
- Provide a micro-level historical reconstruction of Newfoundland fisheries from 1891 to 2000;
- Document the evolving use of local ecological knowledge in Newfoundland;
- Document the changes made to the 1985-87 and 1995-97 models;
- Compare the new models to previously published models and the 1450 and 1900 models using information theory (Heymans and Pitcher, 2002a); and
- Present a first attempt at fitting the 1985-87 model to time series.

The information on Newfoundland given in this report is also used extensively by the Comparative Dynamics of Exploited Ecosystems in the Northwest Atlantic Project (CDEENA), specifically to compare the Newfoundland ecosystem to the Eastern Scotian Shelf and Gulf of St. Lawrence ecosystems. The aim of CDEENA was to do a comparative study of changes in the structure and function of Northwestern Atlantic shelf ecosystems to determine how these may have affected the efficiency of the systems. This was done by identifying and filling some critical data gaps and developing models to investigate ecosystem-level hypotheses such as the effects of environmental variation, predation and fishing effects on cod. The models described in this report was therefore used for testing some of these hypotheses, as is seen in the preliminary results in the sixth paper given here, as well as comparisons across space and time (as seen in chapter five).

Finally, various suggestions have been made to improve the historical models of Newfoundland. These include 1) reducing the biomass estimates of seals for the 1900. New information has been obtained from Garry Stenson (DFO Newfoundland, *pers. comm.*). 2) Newer information on the biomass of whales and turtles (Tony Pitcher, UBC Fisheries Centre, *pers. comm.*). 3) The assumption made for First Nation needs of 1 kg food per person per day (Heymans, 2003) is probably too low, and should be increased to at least 2kg. 4) It would be more realistic if we tried to constrain primary production in the 1450 and 1900 models, as the values originally needed were probably too high. Unfortunately, at this time it is not possible to implement these improvements.

REFERENCES:

Bundy, A., Lilly, G. R., and Shelton, P. A., 2000. A mass balance model of the Newfoundland-Labrador Shelf. 1-157 pp

Heymans, J. J. 2003. First Nations Impact on the Newfoundland Ecosystem During Pre-Contact Times. pp. 4-11 In: Heymans J.J. (Ed.) Ecosystem models of Newfoundland and Southeastern Labrador: Additional information and analyses for 'Back to the Future'. Fisheries Centre Research Report 11(5), Vancouver, BC.

Heymans, J. J., and Pitcher, T. J., 2002a. A model of the Marine Ecosystem of Newfoundland and Southern Labrador (2J3KLNO) in the Time Periods 1985-1987 and 1995-1997. pp. 5-43, In: Pitcher, T.J., Heymans, J.J. and Vasconcellos, M. (Eds.) Ecosystem models of Newfoundland for the time periods 1995, 1985, 1900 and 1450. Fisheries Centre Research Reports, 10(5). Vancouver, BC.

Heymans, J. J., and Pitcher, T. J., 2002b. A Picasso-esque view of the marine ecosystem of Newfoundland and Southern Labrador: Models for the time periods 1450 and 1900. pp. 44-71, In: Pitcher, T.J., Heymans, J.J. and Vasconcellos, M. (Eds.) Ecosystem models of Newfoundland for the time periods 1995, 1985, 1900 and 1450. Fisheries Centre Research Reports, 10(5). Vancouver, BC.

FIRST NATIONS IMPACT ON THE NEWFOUNDLAND ECOSYSTEM DURING PRE-CONTACT TIMES

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ABSTRACT

Historical and archeological information about the First Nations People of Newfoundland and Labrador is used to estimate their approximate numbers, diet, fisheries and harvesting impacts on the marine ecosystem. Estimates of First Nations numbers at first contact include approximately 700 Beothuk and 300 Inuit. It is assumed that they consumed approximately 365 tonnes of food a year, and that their diet included approximately 60% marine organisms, of which salmon, seals and seabirds were the most important.

INTRODUCTION

The construction of an ecosystem model of Newfoundland (NAFO divisions 2J3KLNO) prior to European contact is dependent on information of First Nations, who they were, how many of them there were, what they ate and how much of it they required. These questions are answered below as well as possible based on information from historical notes in the literature (Tuck 1976; Marshall 1996; Montevecchi and Tuck 1987) and on the internet at (www.heritage.nf.ca/home. html).

This paper is therefore a synthesis of the information available on the First Nations of Newfoundland and southern Labrador, and is used to estimate the impact that they may have had on the marine ecosystem of Newfoundland. The paper is divided into sections answering each question and a summary of the results and conclusions.

WHEN IS 'PRE-CONTACT'?

Quinn (1979a) suggest that the first discovery of land across the ocean was made by Norse explorers, first in Greenland and then in 'Vinland', which could have been Newfoundland. The richness of the seas around Newfoundland were only made public by Zuan Caboto (later known as John Cabot) when he returned from his New World voyage in 1497 (Pope 1997; Nuffield 1996). John Cabot sailed from Bristol to North America in 1497 (Pope 1997), but whether other Europeans explored the region before the Norse, is not demonstrated (Anon, 2000b). Pope (1997) quotes Zuan Caboto as saying the sea was:

> *swarming with fish, which can be taken not only with the net, but in baskets let down with a stone.*

On Sebastian Cabot's world map of 1544 was written:

> *this land was discovered by John Cabot the Venetian, and Sebastian Cabot his son, in the year of the birth of our Saviour Jesus Christ 1494.*

which was explained as a misreading of 'IIII' in MCDXCIIII for 'VII' (Pope 1997). Quinn (1979a) agrees that the first successful expedition was in 1497, with the 1495 or 1496 expedition being unsuccessful.

The Portuguese and French were also exploring and charting North America (Quinn, 1979a). In 1501, Gaspar de Côrte Real passed through the Strait of Belle Isle, where he landed and captured fifty men and women, which he brought back to Portugal (Marshall 1996), while the French were experienced Newfoundland pilots by 1511 (Quinn, 1979a). Quinn (1979b) suggest that very little concrete evidence of Portuguese activity is available before 1560. Thirty-seven years after Cabot claimed Newfoundland for England, Jacques Cartier discovered the mouth of the St. Lawrence River (Nuffield 1996).

All these speculations, facts, historical notes, etc. suggest that pre-contact could be any time before 1500, definitely pre-Cabot (i.e. pre-1497), but as Cabot did not meet the people of the new world on that voyage, and feared contact (Pope 1997), the model was built for *circa* 1500. Dunfield (1985) suggests that the Basques were known to have been fishing in the Labrador Sea off southwestern Greenland from 1400 to 1420, but Loring (1992, and references therein) suggest that the French, Portuguese and Basques only started fishing in the New World after Cabot brought back news of its riches. Thus very little (if any) Basque fishing should be added to our model.

WHO WERE THE FIRST NATIONS IN NEWFOUNDLAND AND LABRADOR DURING PRE-CONTACT TIMES?

Earliest traces of prehistoric people in Labrador have been dated between 7000 and 6000 BC (Tuck 1976). Renouf (1999) indicates the progression of aboriginal cultures on Newfoundland, from the Maritime Archaic

Time Line	Archeological culture		
Present			
Ad 1500		Beothuk / Little Passage Complex / Beaches Complex	Recent Indian
AD 1000			
AD 500	Dorset Eskimo / Paleo-Eskimo	Cow head complex	
AD 1			
500 BC	Groswater		
1000 BC			
1500 BC			
2000 BC		Maritime Archaic Tradition	
2500 BC			
3000 BC			
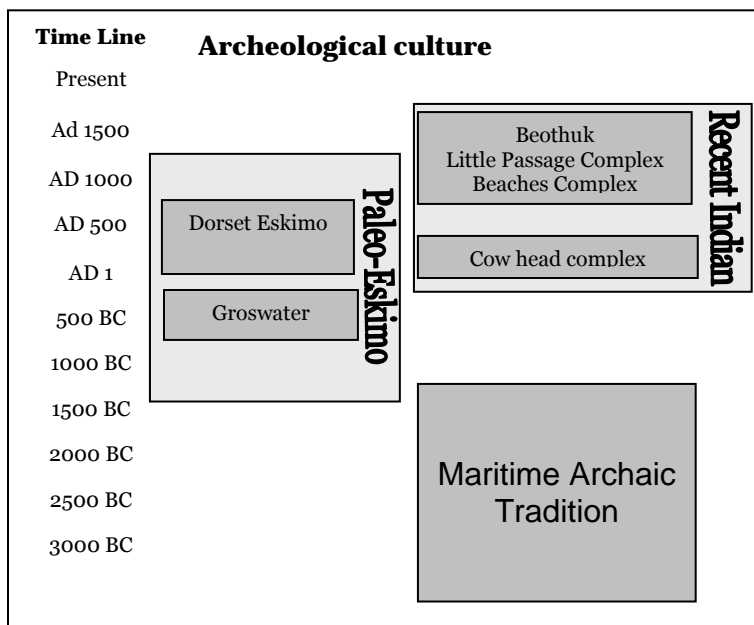
Figure 1: Archaeological Culture (redrawn from (Pastore, 1998) and illustration by Duleepa Wijayawardhana based upon data supplied by Dr. Ralph Pastore, Memorial University of Newfoundland, St. John's, Newfoundland).

Indians (c. 3500-1000 BC), followed by the Groswater Palaeo-Eskimos (c. 800 BC – AD 1), Dorset Eskimos (c. AD1 – AD 800), Recent Indians (c. AD1 – AD 1500) and Beothuk Indians (from European contact, AD 1500 - AD 1829). These dates correspond broadly with the schematic representation of archaeological culture redrawn in Figure 1 from Pastore (1998b).

Maritime Archaic Indians (3500 –1000 BC)

The "Southern branch" Maritime Archaic people were the first humans to colonize the Island of Newfoundland (Marshall 1996). By at least 5,500 years ago they had established themselves on the Northern Peninsula and within a millennium their campsites were found on the Newfoundland coastline. However, despite the apparent success of the Maritime Archaic Indians in Labrador, and the apparently well adjusted nature of their culture in Newfoundland, the residents of the Island of Newfoundland disappear from the archaeological record about 3,000 years ago (Tuck, 1998). They subsisted largely on marine mammals, birds and fish and had a marked preference for water-birds such as loons, gannets, cormorants, eiders, mergansers, gulls, and great auks (Montevecchi and Tuck 1987). Great auk remains far outnumbered those of all other species, comprising 48% of the avian elements identified to species at the Port au Choix site (Montevecchi and Tuck 1987).

Palaeo-Eskimos (2000 BC – AD 1200)

The earliest Palaeo-Eskimos that inhabited the Canadian Arctic were dated by Tuck (1976) from 2000 BC to AD 1200. Pastore (1998a) suggest that although there were Palaeo-Eskimos in northern Labrador and Newfoundland from 1500 BC to 1000 BC, the population in Labrador appears to have experienced a decline, perhaps because of competition from Maritime Archaic Indian peoples. Tuck (1976) suggests that they did not migrate south of Hamilton Inlet and about 1500 BC they disappeared altogether. Around 1000 BC there is evidence of a rapid population growth in Newfoundland and Labrador, due to the emergence of a new culture which archaeologists call the 'Groswater', after Groswater Bay on the coast of central Labrador. Their sites were situated on headlands where they could hunt sea mammals, and they relied heavily on harp seals, with sea birds, ducks, small game and caribou also being important (Renouf 1999). One possible reason for their success could be the demise of the Maritime Archaic people in Newfoundland around 1000 BC. By about AD 1 the Groswater people disappeared from the island of Newfoundland, and not long after they vanished from Labrador (Pastore 1998a).

The next arrivals in Newfoundland where the Dorset Palaeo-Eskimos, who arrived in Labrador around 700 BC (Tuck 1976) and in Newfoundland by AD 1 (Renouf 1999). Their numbers in Newfoundland increased dramatically from about AD 1-500, with their extinction well before AD 1000 (Tuck 1976). Pastore (1998a) suggest that they were the most abundant Aboriginal people ever to occupy the island, that they disappeared from the island approximately 1200 years ago, and from northern Labrador sometime between 1000 and 500 years ago. Pastore (1998a) suggest that Dorset extinction in Newfoundland was probably due to factors such as a repeated failure in either the caribou or the harp seal hunt. Renouf (1999) suggests that the reliance on marine resources was intensified in the Dorset period, when they targeted harp seals, probably due to the failure of the caribou hunt.

Labrador Thule (AD 1250 – AD 1550)

The Thule were the most recent arrivals (around AD 1500) to Labrador (Tuck 1976). They are known to ethnologists as the Labrador Eskimo, and to themselves as Inuit, or "true men" (Tuck 1976). By about AD 1500, the Thule settlers had reached Saglek, and by perhaps AD 1550 the Labrador Inuit had established their settlements in the Nain-Hopedale region of Labrador (Pastore 1998c). They fished mainly for whales and seals on the northern and southern shores of Labrador (Brice-Bennett 1997), and appear to have followed the whales and seals as far south as the Strait of Belle Isle. However, according to Kennedy (1999), our knowledge of historic Inuit occupation and land use south of Groswater Bay (situated in NAFO Division 2J) remains incomplete and controversial. Professor Peter Pope (Archaeology Department, Memorial University of Newfoundland, *pers. comm.*) suggests that archaeologists and ethnologists from Quebec believe that the Inuit were present near the Strait of Belle Isle by the sixteenth century, and therefore we include them in our First Nations *circa* 1500. This is confirmed by Loring (1992).

Newfoundland Mi'kmaq (Micmac)

Newfoundland Mi'kmaq oral tradition holds that the Mi'kmaq were living in Newfoundland prior to European contact. According to the Newfoundland and Labrador Heritage website (Pastore 1997b), there is some historical evidence that the Mi'kmaq were living in Newfoundland by the 16th century. However, there is no prehistoric evidence of Mi'kmaq settlement on Newfoundland. Montevecchi and Tuck (1987) suggest that Newfoundland might have been part of their traditional hunting, trapping, and fishing territory. Hunting, fishing, and gathering berries was a necessary part of most families' lives, but they did not participate in large marine fishing activities (Pastore, 1997b). Thus, the Mi'kmaq are not included as fishers in the model.

Recent Indians (50 BC - AD 1500)

The Recent Indian period overlaps with Dorset Palaeo-Eskimos, and is divided into the Cow Head complex (AD 1 - 1000), the Beaches complex (AD 100 – 1100) and the Little Passage complex (AD 1000 – 1500) (Marshall 1996 and *pers. comm.*; Renouf 1999). Pastore (1998b) suggest that the Little Passage complex people are the direct ancestors of the Beothuk. The Recent Indians were less reliant on marine exploitation than the Palaeo-Eskimos, although they were still marine oriented (Renouf 1999).

Beothuk (AD 1500 – AD 1829)

The Beothuk are believed to have developed their culture *in situ* in Newfoundland (Marshall 1996). They are the direct descendents of the Little Passage people (Ingeborg Marshall, Institute of Social and Economic Research, Memorial University of Newfoundland, *pers. comm.*). They were the first native people of North America to be seen by European explorers (Tuck 1976). Linguistic studies indicate that the Beothuk language was part of the Algonkian family (Marshall 1996, quoting John Hewson's work at Memorial University of Newfoundland).

The Beothuk coexisted with the migratory European fisheries. Pastore (1997a) suggests that they benefited from by scavenging from the migratory fisheries during the winter. However, the beginning of year-round European settlement in the 17th century (Peter Pope, Archaeology Department, Memorial University of Newfoundland, *pers. comm.*) meant the onset of drastic change (Pastore 1997a). As the French established a base at Placentia, and English settlement extended from Conception Bay to Trinity Bay and then Bonavista Bay, the Beothuk withdrew from the areas settled by the English due to hostile acts by the settlers. Lacking the contacts with traders, missionaries and Indian agents that were characteristic of the mainland experience, the Beothuk became increasingly isolated (Pastore, 1997a). According to Cridland (1998), the Beothuk spent the spring and summer on the coast collecting large quantities of food supplies. The extension of European settlements denied the Beothuk free access to these coastal resources and prevented them from collecting and preserving the surplus of marine foods that they had traditionally relied on for their subsistence. European encroachment also forced the Beothuk to retreat to interior regions which did not offer sufficient resources to sustain them through the winter (Ingeborg Marshall, Institute of Social and Economic Research, Memorial University of Newfoundland, *pers. comm.* and Cridland, 1998).

HOW MANY FIRST NATIONS PEOPLE WERE THERE?

From the information summarized above, it is assumed that the First Nations that fished in the 2J3KLNO study site in 1450 were mainly
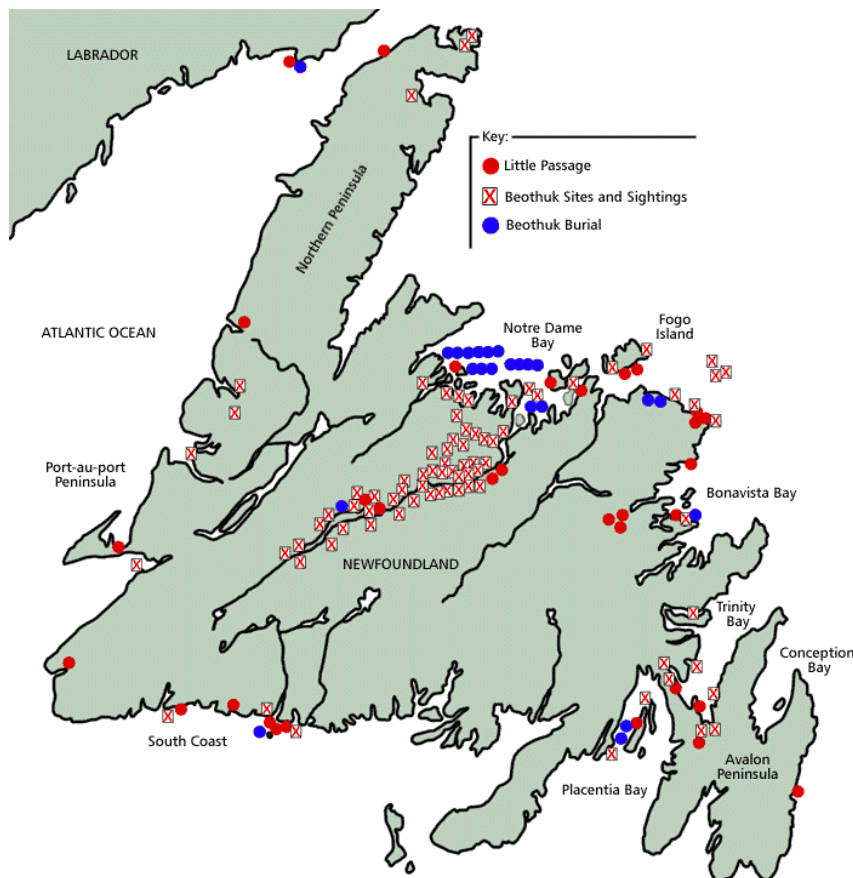
Figure 2: Map showing Little Passage Campsites, Beothuk campsites and sightings and Beothuk burials (from (Marshall, 1998) and illustration by Duleepa Wijayawardhana, 1998 and based on a map by Cliff George). Little Passage campsites = shaded circle; Beothuk campsites and sightings = cross; Beothuk burials = solid circle.

archaeologists generally believe the original Beothuk population consisted of about 500 – 1000 people.

The number of Beothuk in the model is contingent on what proportion of the population were dependent on the east coast. Figure 2 indicates that most of the archaeological sites were found on the Exploits river, which drains to the east. According to Marshall (Institute of Social and Economic Research, Memorial University of Newfoundland, *pers. comm.*) however, the Beothuk would have used the whole island prior to European contact. For now we assume that they mainly obtained their food from the East coast. The First Nations utilizing the study area thus included mostly Beothuk, probably also some Inuit and maybe some Mi'kmaq, and it was assumed that the total population utilizing the coastline of 2J3KLNO did not exceed 1000 people.

Beothuk, while the Innu, Inuit and Mi'kmaq were not using much of the resources in that area. Marshall (1996) suggests that the Beothuk were the only permanent residents of Newfoundland. Other groups, such as the Mi'kmaq may have traveled now and then to certain areas in Newfoundland to exploit resources. They probably fished for salmon in the freshwater streams, but would have taken smaller quantities than the Beothuk (Ingeborg Marshall, Institute of Social and Economic Research, Memorial University of Newfoundland, *pers. comm.*). The Inuit of Labrador probably lived further north and traveled to the Northern Peninsula and Notre Dame Bay, so their catch was limited. The Innu crossed over to Newfoundland's Northern Peninsula to hunt for furs, although fishing was not practiced to any degree (Ingeborg Marshall, Institute of Social and Economic Research, Memorial University of Newfoundland, *pers. comm.*). Pastore (1997a) suggest the number of Beothuk in Newfoundland at the time of first contact would have ranged between 600 and 800 people, while Marshall (1996) states that

WHAT WAS CAUGHT IN FISHERIES BY FIRST NATIONS PRE-1450?

Pearson (1972) writes that a traveler/fishers who visited Newfoundland in 1583 commented:

> *For the most part their (*the natives'*) food is fish rather than anything else, and especially salmon, which they have great abundance; and although there are many kinds of birds and fruits there, yet they make no account of anything but fishes.*

Various reports on the food available to the First Nations are given in the literature, and are summarized in Marshall (1996).

What species were caught?

The Beothuk were hunters, gatherers and fishers, and exploited terrestrial and marine resources (Marshall 1996). Their most important staple foods were caribou, seal and salmon, and in response to the migratory nature of these species they moved in an annual cycle from inland locations to the coast and *vice versa* (Marshall

1996). According to Cridland (1998) their predecessors, the Little Passage Complex People, focused on inner coastal marine resources, but not on any one marine species. They made use of beaver, red fox, black bear, wolf, pine martin, river otter, caribou, harbour seal, harp seal, whales, Canada goose, common eider, double-crested cormorant, common raven, gulls, red-breasted merganser, auk, black guillemot, rainbow smelt, Atlantic cod, shorthorn sculpin, longhorn sculpin, soft-shell clam and blue mussels (Cridland 1998).

According to Howley (1915), seals were used extensively by Beothuk. Pastore (1997a) states that harp seals and harbour seals were regularly hunted, while Ryan (1994) found that they utilized the flesh, skin and oil of seals for food, clothing, housing, heat and light. Loring (1992) indicated that walrus was an important prey species throughout the prehistoric sequence in Labrador and walrus remains have been uncovered at Maritime Archaic, Paleo-Eskimo and Neo-Eskimo (Inuit) sites. The Beothuk also hunted for porpoise with their canoes (Marshall 1996). Faunal analysis from Boyd's Cove and other archaeological sites indicate that their diet also included other aquatic species such as salmon, smelts, sculpin, goosefish, sea raven, dogfish, winter flounder, clams, mussels, scallops, oysters, lobster and other inshore fish (Howley 1915; Marshall 1996; Pastore 1997a).

The birds they utilized include the great auk, cormorant, loon, sandpiper, jaeger, black guillemot, murre, greater scoup, old squaw, eider duck, Canada goose, gull, ptarmigan and bald eagle (Marshall 1996). According to Montevecchi and Tuck (1987), the Beothuk hunted birds extensively and analysis of the vertebrate material at a 17th century Beothuk occupation site at Boyd's Cove in Notre Dame Bay, revealed that a third of the remains were avian (Pastore 1985). The Beothuk canoed to Funk Island, 60 kilometers off the east coast of Newfoundland, to collect the eggs of the great auk (Montevecchi and Tuck, 1987).

Most of these species, as well as the land animals, were not available at all times of the year, which meant that the would-be hunters had to time their movements. Pastore (1992) and Marshall (1996) present diagrams (reproduced here as Table 1) documenting the time of year when Newfoundland's food resources were available, showing that during some seasons, people may have had to depend on stored foods. From this it is obvious that the Beothuk utilized a large number of species over the year, and that they would have relied on all of these species to live. They had to be at specific outer islands and headlands in late winter/early spring to hunt harp seals, at a certain stream for two weeks in May to catch smelt, at a major salmon river for a salmon run, etc. (Pastore, 1997a). In the winter they camped in the interior, in the summer they made their way to Cape St. John and Cape Freels via the Exploits River. In the autumn they migrated inland to intercept the caribou migration (Montevecchi and Tuck 1987).

What gear was used?

The First Nations probably constructed nets of various types, built traps, weirs, hand nets, and scoop nets, speared fish, developed an ancient form of angling and used certain natural toxins to stun fish (Rostlund 1952). For hunting seals the Beothuk used a special sealing harpoon (Marshall 1996). According to the captive Shanawdithit this harpoon was called *a-a-duth* (Howley 1915). She also reported that her people considered it "the greatest good luck to kill a whale" though she did not say how this was done (Pastore, 1997a). The Beothuk shot large birds with arrows, and used blunt, knobbed arrows for smaller species, while using decoys to catch waterfowl (Marshall 1996). As a consequence, aboriginal fishing prior to AD 1500 included whaling, harpooning, fishing salmon with spears, or with the aid of fish weirs, trap and fish nets (hand nets, seine nets and scoop nets).

How much was caught by First Nations?

Estimating how much of the marine ecosystem was utilized by First Nations is not an easy task. Rostlund (1952) estimated salmon catches for the East Coast of the United States to be between 6,350 and 6,800 tonnes per year, or an average of 102 kg/km² in the occurrence area, covering only the coast. Dunfield (1985) applied Rostlund's base calculation to the total area of salmon occurrence in eastern North America, and estimated 65,770 tonnes per year were obtained. However, applying these estimates to the catch of salmon by First Nations in Newfoundland is not meaningful, as the population of Newfoundland was very small. Dunfield (1985) suggested that:

> *although the natives relied heavily on the fish resource, they did not overexploit it, since their relatively small numbers along the vast eastern seaboard guaranteed only periodic, insignificant, and rapidly recoverable depressions in the total resource.*

The calculation of First Nations catch was based

Table 1. Diagram of the Beothuk's seasonal exploitation of aquatic food resources (Redrawn from Marshall 1996).

Species	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Harp Seal	####	####	####	███	███							####
Harbour Seal				####	####	####	####	####	####	####	####	####
Hooded & Bearded seal		####	####	####								
Ringed seal			####	####								
Grey seal	-------	####	####	####	####	####	####	####	-----	------	------	------
White beaked dolphin, minke whale, harbour porpoise		-----	####	####	####							
Pilot whale, white-sided dolphin						------	####	####	####	####		
Arctic char						------	------	------	####	####	------	
Salmon							███	███	####	-----		
Ouaniche, trout	-----	-----	-----	-----	####	####	####	####	####	####	-----	-----
Eel	-----	-----	-----	-----		####	####	####	####	####	-----	-----
Cod & flatfish (inshore)				####	####	####	####	####				
Cod, south coast	####	####	####	####	####	####	####	####	####	####	####	####
Smelt		-----	-----	███	-----						####	####
Capelin					-----	███	███	-----				
Herring	####	####	####	####	####	####	-----	-----	####	####	####	####
Mackerel						-----	####	####	####	-----		
Squid						####	####	####	####	####	####	
Lobster, crabs				####	####	####	####	####	####	####	####	
Clams, mussels, periwinkles	-----	-----	-----	-----	####	####	####	####	####	####	####	-----
Common murre, great auk, Atlantic puffin, kittiwake, gulls, black guillemot					####	####	####	####				
Gannets, cormorants	-----	-----	-----	-----						-----	-----	-----
Bird eggs					███	███						
Overwintering thickbilled murres, dovekies	####	####	####	####							####	####
Geese, ducks, inland nesting birds					####	####	####	####				
Overwintering sea ducks	####	####	####	####	####				####	####	####	####
Ptarmigan	####	####	####	####							####	####

Available in small quantities or special places -----
Available ####
Major harvesting time ███

on their physiological needs. The First Nations population at first contact is estimated at 1000 people (approximately 700 Beothuk and 300 Inuit).

If we assume that they consume approximately 1 kg of food each per day[1], including any trading that might have been done by the Inuit, the requirements for First Nations were approximately 365 tonnes of food per year. The annual diet of Beothuk was estimated at 35% caribou, 15% salmon, 15% seals, 10% birds, 5% beavers, 5% berries and roots, and 15% "Other seafood" (see Table 2). When taking into consideration the Inuit's preference for seals and reduced salmon availability in Labrador, the ratios were changed to include these values in the Total First Nation catch figures (Table 2).

[1] It has been pointed out that this might be too small, and that an estimate of 2-4 kg per person per day would be more appropriate – Ed.

These estimates are based on preliminary indications from Ingeborg Marshall (Institute of Social and Economic Research, Memorial University of Newfoundland, *pers. comm.*), and should be confirmed by any other archaeological data. The estimates of 'Other seafood' in the First Nations diet were calculated in the ratio of their biomass, as

Table 2: Estimates of food consumption by First Nations in Newfoundland.

Food	Beothuk (%)	Beothuk & Inuit (%)	Total Tonnes
Caribou*	35	30	109.5
Berries and plants	5	5	18.2
Beavers	5	5	18.3
Salmon & char	15	15	54.8
Seals	15	20	73.0
Birds	10	10	36.5
Other seafood	15	15	54.8
Total	100	100	365.0

* also includes small fur bearers

Table 3. Estimates of 'other seafood' in the diet of First Nations in Newfoundland, and the approximate catch based on their biomass estimates (obtained mostly from the balanced 1900 model).

Compartment	Biomass (t•km⁻²)	Adapted % percentage	Catch (t•year⁻¹)
Whales	0.042	0.5	0.5	0.274
Plaice	2.792	2.7	2.5	1.369
Yellowtail	1.864	1.8	2.0	1.095
Winter	0.192	0.2	0.5	0.274
Greenland cod	0.503	0.5	0.5	0.274
Mackerel	0.001	<0.1	4.0	2.190
Capelin	16.080	15.8	15.0	8.213
Herring	4.925	4.8	4.0	2.190
Small pelagics	1.685	1.3	1.0	0.548
Small crabs	21.752	17.2	10.0	5.475
Lobster	0.0112	<0.1	10.0	5.475
Other inverts	23.048	18.2	20.0	10.950
Bivalves	53.086	42.0	30.0	16.425
Total	126.440	100.0	100.0	54.750

estimated for the 1900 model by Ecopath (see Heymans and Pitcher 2002), except for the biomass of whales which was taken from the pre-contact model. The percentage of winter flounder, mackerel and lobster was increased as their biomass estimates were underestimated in the 1900 model. Thus the adapted percentages were used to calculate the catch by First Nations around 1500 (Table 3).

CONCLUSIONS

Pre-contact is defined as the period around 1450, and the First Nations people that fished in the study site during pre-contact times were mainly the 700 Beothuk that lived in the area, while the impact of the Innu and Mi'kmaq was not as important. The Inuit lived further north, but approximately 300 Inuit were included in the diet construction and increased the catch of seals by First Nations. It was assumed that they fished for whales, seals, salmon, capelin, smelts, flounder, mackerel, mussels, clams, lobster and crabs. They also utilized seabirds such as geese and cormorants and used bird eggs. I have made a first estimate of catch by First Nations on the pre-contact model of Newfoundland by using their perceived biomass.

ACKNOWLEDGEMENTS

REFERENCES

Anon. 2000. European Exploration: From Earliest Times to 1497. In. Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Armitage, P. 1997. The Innu. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Brice-Bennett, C. 1997. The Inuit. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Cridland, J. 1998. Late Prehistoric Indian Subsistence In Northeastern Newfoundland: Faunal Analysis of Little Passage Complex Assemblages from the Beaches and Inspector Island Sites. Masters of Arts. Memorial University of Newfoundland, St. John's, Newfoundland.

Crosby, A. W. 1986. Ecological Imperialism: The biological expansion of Europe, 900-1900. Cambridge University Press, Cambridge.

Dunfield, R. W. 1985. The Atlantic Salmon in the History of North America. Department of Fisheries and Oceans, Ottawa.

Heymans, J. J., and Pitcher, T. J., 2002. A Picasso-esque view of the marine ecosystem of Newfoundland and Southern Labrador: Models for the time periods 1450 and 1900. pp. 44-71, In: Pitcher, T.J., Heymans, J.J. and Vasconcellos, M. (Eds.) Ecosystem models of Newfoundland for the time periods 1995, 1985, 1900 and 1450. Fisheries Centre Research Reports, 10(5). Vancouver, BC.

Howley, J. P. 1915. Drawings by Shanawdithit. The Beothuks or Red Indians: The Aboriginal Inhabitants of Newfoundland. In: David Cantwell (www.cs.mun.ca/~david12/).

Kennedy, J. C. 1999. The Métis. In. Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Loring, S.G. 1992. Princes and princesses of ragged fame: Innu archaeology and ethnohistory in Labrador, Ph.D. thesis, Department of Anthropology, University of Massachusetts, 607 pp.

Marshall, I. 1996. A history and Ethnography of the Beothuk. McGill-Queen's University Press, Montreal, 640 pp.

Marshall, I. 1998. Distribution and Size of the Beothuk Population, Leadership and Communal Activities. In. Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Montevecchi, W. A., and L. M. Tuck. 1987. Newfoundland Birds: Exploitation, study, conservation. Nuttall Ornithological Club, Cambridge, Massachusetts.

Nuffield, E.W. 1996. The discovery of Canada. Haro Books Vancouver, Hignell, Canada, pp. 222.

Pastore, R.T. 1985. Excavations at Boyd's Cove – 1984: a preliminary report, p. 322-337. In J.S. Thompson and C. Thompson (eds.), Archaeology in Newfoundland and Labrador 1984. Newfoundland Museum, St. John's.

Pastore, R. T. 1992. Shanawdithit's People: The Archaeology of the Beothuks. Atlantic Archaeology Ltd., St. John's, Newfoundland.

Pastore, R. T. 1997a. The Beothuk. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Pastore, R. T. 1997b. The Mi'kmaq (Micmac). In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Pastore, R. T. 1998a. Palaeo-Eskimo Peoples. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Pastore, R. T. 1998b. The Recent Indians of the Island of Newfoundland. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Pastore, R. T. 1998c. The Thule. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Pearson, J.C. 1972. The fish and fisheries of colonial North America. Dept. of the Interior, US Fish and Wildife Service, Washington.

Pope, P.E. 1997. The Many Landfalls of John Cabot. University of Toronto Press, Toronto, pp. 244.

Quinn, D.B. 1979a. New American World. A Documentary History of North America to 1612. Volume 1: America from Concept to Discovery, Early Exploration of North America. Arno Press, New York, pp. 486.

Quinn, D.B. 1979b. New American World. A Documentary History of North America to 1612. Volume 4: Newfoundland from Fishery to Colony. Northwest Passage Searches. Arno Press, New York, pp. 486.

Renouf, M. A. P. 1999. Prehistory of Newfoundland hunter-gatherers: extinctions or adaptations? World Archaeology, 30(3):403-420.

Rostlund, E. 1952. Freshwater fish and fishing in native North America. (University of California Publications in Geography, Vol. 9) University of California Press, Berkeley.

Ryan, S. 1994. The Ice Hunters: A history of Newfoundland Sealing to 1914. Breakwater, St. John's NF.

Tanner, A. 1999. Innu History. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Tuck, J.A. 1976. Newfoundland and Labrador Prehistory. Van Nostrand Reinhold Ltd.

Tuck, J. A. 1997. Intermediate Indians. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Tuck, J. A. 1998. Maritime Archaic Tradition. In: Heritage Site of Newfoundland and Labrador, Memorial University of Newfoundland.

Wallace, R. 1974. A Viking Village in America. Nature-Science Annual, New York, Time-Life Books.

Waring, G.T., 1984. Age, growth, and mortality of the little skate off the northeast coast of the United States. Trans. Am. Fish. Soc. 113:314-321.

Micro-level Historical Reconstruction of the Newfoundland Fisheries between 1891-2000: Findings and Issues

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Abstract

Fishing has been the mainstay of the communities of Bonne Bay, Newfoundland for over one hundred years. The continuous fishing pressure exerted on the fish stocks within the bay has lead to many changes in the fishery. This paper illustrates the necessity of reconstructing the past on a micro-scale to study these changes. It highlights the feasibility of micro-level reconstructions as well as their challenges and problems. This type of reconstruction can lend insight into the many social forces that help to shape the fishery and aid in the explanation of the 'Fishing Down' dynamics often identified using mass balance models.

Introduction

Located at the juncture of the north flowing "warm, nutrient-rich Gulf Stream" and the south flowing cold-water, oxygen-rich Labrador Current, lies the province of Newfoundland and Labrador (Felt and Locke 1995). The meeting of the Gulf and Labrador currents allows an abundance of fish and other marine organisms to thrive off the Newfoundland and Labrador coast. The abundance of marine life and the natural coastal resources played a crucial role in shaping Newfoundland's identity (Felt and Locke, 1995). From the times of the indigenous peoples of Newfoundland and Labrador, to the Vikings, to Christopher Columbus, to European settlement and finally to the present day, it was the ocean that supplied people's food, livelihood, and economic well-being (Gough, 1993). However, the current state of health of the coastal waters of Newfoundland and Labrador and the World threatens this balance.

Overall reductions in complexity and restructuring of our coastal ecosystems have been observed. Fisheries on the East Coast of Canada have seen catastrophic collapses of groundfish stocks such as the Atlantic cod (*Gadus morhua*). "Understanding the causes of variations in the abundance of upper trophic level animals is key to their long-term sustainability and that of the ecosystems in which they live" (MacKenzie *et al.* 2002). Changes in fish populations may be understood through studying how fish populations varied over time and understanding changes in effort.

Micro-scale historical reconstructions of landings and trends, indicate ecosystem change. and examining many data sources may lead to changes within the management framework. "Historical reconstructions of ecosystem and social changes in resource-dependent communities help our understanding of regional (and broader) changes in fish populations, and inform discussions about the need for improved stewardship and its importance for current and future human populations..." (Neis *et al.* 1996).

Dimensional Approach to the 'Fishing-Down' Hypothesis

The model of fisheries exploitation known as the 'fishing-down' hypothesis (Pauly *et al.* 1998) describes the manner in which a community shifts effort from a depleted resource to another more plentiful one (Webb, *unpublished MS*). These 'new' resources may be located in different regions and most likely are located a greater distance from shore than the population that was depleted or may be a previously under-utilized species (Webb, *unpublished MS*).

This trend can be described as a shift from an 'upper' level to a 'lower' level of the food web. The hypothesis describes a transition from long-lived, higher trophic level, piscivorous bottom fish toward short-lived, low trophic level invertebrates and planktivorous pelagic fish. It is characterized at first by increased landings, then a transition to stagnating or declining catches (Pauly *et al.* 1998). It can be seen through changes identified in spatial, temporal, or ecological dimensions, as well as through changes in intensification and expansion of the fishery. Such shifts imply major changes in the structure of marine food webs (Pauly *et al.* 1998).

Through micro-scale historical reconstruction, it may be possible to determine whether the 'fishing down' hypothesis is applicable on a much smaller scale than it is typically applied. For example, Pauly *et al.* (1998) examined fishing down marine webs on a global scale. They found that for the northern temperate areas (including the Northeast Atlantic), mean trophic levels at the global scale, had decreased over the past twenty years. Also, trophic levels have

declined at a rate of 0.1 per decade while at the same time landings have not increased substantially. Therefore, by testing the fishing down hypothesis, it may be possible to explain ecosystem changes and restructuring in relation to social changes seen within individual communities.

METHODS

For this micro-level reconstruction the Bonne Bay and headland area were chosen (Figure 1). Bonne Bay is located on the West Coast of Newfoundland, inside the boundaries of Gros Morne National Park (GMNP) and within the East Coast study area of Coasts Under Stress.

The Newfoundland census of 1891, 1901, 1911, and 1921 provided much of the historical population and fishing data for the late 1800s and early 1900s. Through the census, the time frame for the start of the reconstruction was determined based on the period when the main fishing communities were first established. In the 1891 census, the first permanent communities were settled and reliable population counts were available. To determine changes in populations, census data were gathered and compiled on the communities of Gad's Harbour, Neddie's Harbour, Norris Point, Rocky Harbour, Trout River, and Woody Point (Figure 1). These six communities were among the first to be settled in Bonne Bay and as such have long fishing histories that lend themselves well to this type of research. The data collected from the census were examined to reveal fishing trends, species fished and their relative importance, and changes within each fishery both temporally and spatially.

Unlike the early Newfoundland census (1891-1921), census data from 1935 onward, lacked the same in-depth fishing information. Beginning in 1935, Newfoundland began to use the Dominion of Canada Census form which failed to focus on fishing within individual communities, providing instead numbers for Newfoundland as a whole, therefore, losing vital fishing information on smaller regions and communities. The remaining fishery data were collected from CAFSAC Reports, NAFO Reports, Canadian Stock Assessment Secretariat Reports, DFO Documents, DFO Management Plans, Fisheries Research Board of Canada Reports, and Statistics Canada Reports.
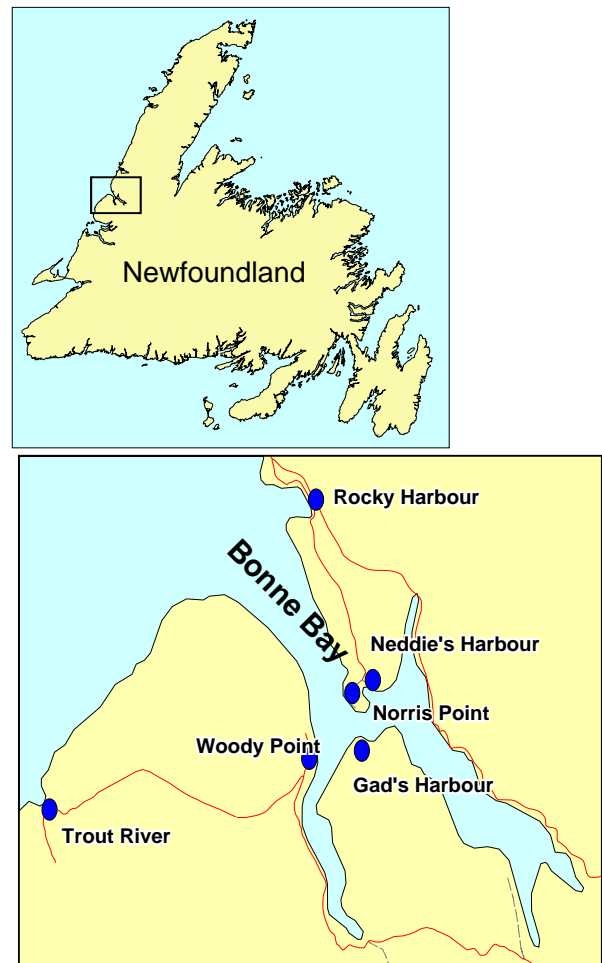
Figure 1: Map of Bonne Bay, Newfoundland enlarged from the inset of Newfoundland map (top). This figure shows the location of communities selected for reconstruction analysis.

Over time, many different systems have evolved to transfer knowledge between generations and have become known as Traditional Ecological knowledge (TEK) and Local Ecological Knowledge (LEK) (Hipwell 1998). These knowledge systems provide the researcher with a holistic perspective (Svensson 1991) that can be used to study and advocate changes to an ecosystem while contributing to understanding what the overall effects on the system might be (Bear 2000).

First hand information and knowledge was collected through interviews with retired fishers from the Bonne Bay region. Interviews with retired fisher people yielded Local Ecological Knowledge (LEK) and Traditional Ecological Knowledge (TEK) on the local fisheries of Bonne Bay. This type of information is important because "fishers have a detailed knowledge of their resources, their environment, and their fishing practices" (Neis *et al.* 1999) and this type of information generates a "wealth of empirical

knowledge" (Johnson 1992), complementary to scientific knowledge (Bear 2000). TEK and LEK also aid the acquisition of 'baseline' data. It is not also possible to acquire 'extensive year-round data' for particular species. This type of information does however, accumulate within TEK and LEK systems.

The interviewees were chosen based on a list provided by the local fisheries officer and the fisheries committee of recently retired fishers. At least one interview from each of the selected communities was completed. The interviewees were selected either randomly from the provided list and/or singled out as a local expert and recommended by other interviewees.

The interviews followed a semi-structured format allowing for both closed questions requiring precise answers and open questions allowing for opinions and stories. Interviewees were asked about the number and type of boats owned/fished (in chronological order starting with the earliest), the types of gear and boats used, and species fished during the course of their fishing career. The interviewees were also questioned about the sizes of catches and individual fish species over time, and locations and times where they fished.

The aim was to generate an idea of the changes in catch sizes, in the size of fish caught and in individual effort the fishers expended to reach and maintain those levels. These answers along with collected fishing data would help to reconstruct the fishery, identify ecosystem changes, and determine whether 'fishing-down' was occurring.

RESULTS

A slow progressive evolution towards a fishery with a high level of effort by the fishers not reflected in the landings was shown in the micro-scale reconstruction. As fishing effort increased, some landings remained at previous levels, while others experienced a decline. This troubling trend is seen all across Newfoundland and Labrador and around the world (Pauly *et al.* 1998).

Historical Statistics

Most historical data and statistics were taken from the Newfoundland census between 1891-1921 (Figure 2). The main fisheries for the Bonne Bay area, as indicated by the information on total landings available through the census, were of Atlantic cod (*Gadus morhua*), lobster (*Homarus americanus*), and herring (*Clupea harengus harengus*) (Figure 2).

While there are many gaps, the available census data show an overall decrease in lobster landings for those census years in all communities (Figure 2). Trout River exemplifies this decrease, seeing its landings drop from 88.7 tonnes in 1891 to 20.2 tonnes as converted from 1 case = 230 lbs. (Templeman, 1941) in 1921; while the number of fishermen in the community increased from 29 to 62 over the same period.

The census data between the years 1891-1921, showed peak herring landings for communities in 1911 (Figure 2). The landings from the 1920 season recorded in the 1921 census show a return to the levels seen prior to the census of 1911 (Figure 2). Trout River, Woody Point and Rocky Harbour, all saw the highest landings (1 tierce = 300 lbs., Anon, 1955-1976). This was most likely due to the fact that since these communities were located on the outside or near the outside of the bay, they had the greatest access to migrating herring.

Census data regarding the cod fishery showed that all communities experienced an overall increase in landings. The communities of Trout River and Rocky Harbour saw the largest landings (Figure 2). Given their location on the outside of the mouth of the bay (Figure 1), these communities have access for a longer period of time to harvest migrating cod.

Census information also gives insight into the growth of the fisheries of Bonne Bay. For example, the census of 1891 and 1921 show the increase in the number of fishers in all of the communities that were selected. The 1891 and 1921 census showed that the number of individuals in the fishery for the entire bay increased from 92 in 1891 to 252 by 1921, an increase of 36.5% over a thirty year period.

The census data revealed the overall trends within the fishery of Bonne Bay. The data showed the great importance in terms of landing of cod followed by lobster. The reconstruction also illustrated the decline in lobster landings.
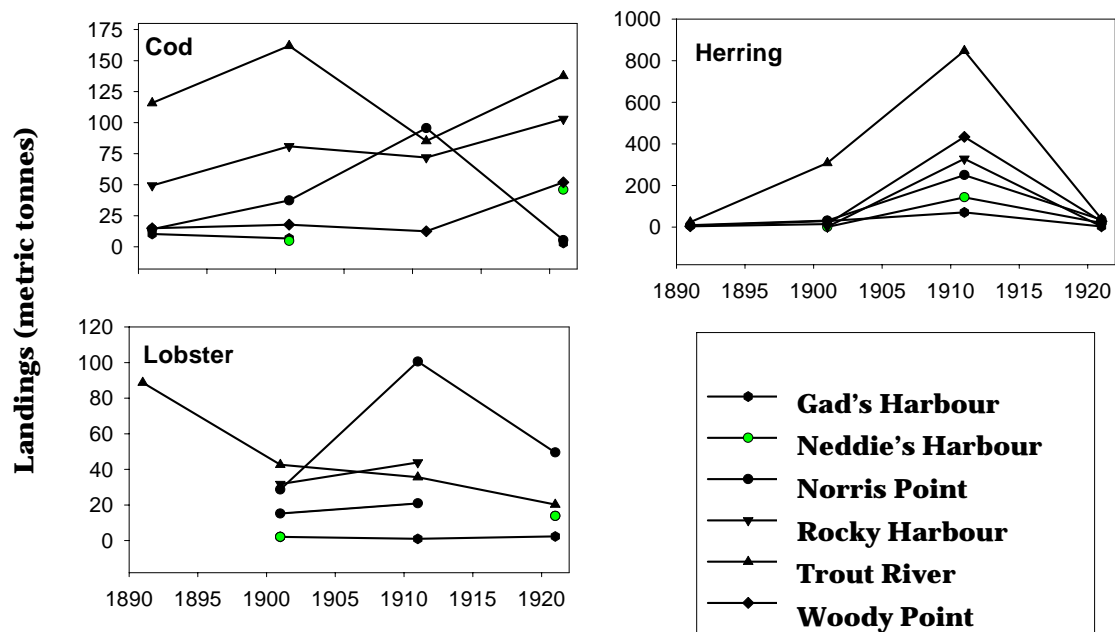
Figure 2: Landings (tonnes) of cod, herring, lobster from the census of 1891, 1901, 1911, and 1921 for six communities in Bonne Bay (i) Cod is the main fishery for all communities, with Trout River and Rocky Harbour seeing the largest landings (ii) Herring is an important fishery for the community of Trout River; with all communities seeing large landings for the 1910 fishing season (iii) Lobster landings appear to be low to decreasing for all communities

Other Sources of Data

Prior to the establishment of the Government of Canada's Department of Fisheries and Oceans, the Newfoundland Government failed to "systematically collect" data on the fishery, landings and gear. With several governmental agencies charged with data collection during this period, gaps in data, failure of data collection, and spatial irregularities are common problems. Within the changes to Newfoundland's management framework, the data collected can, at the very least, reveal trends in order to identify changes over time. For example, comparison of data collected under Newfoundland Statistical Area 'M" and NAFO Area 4R can help to reveal changes that occurred between 1955 and 2000 (Figure 3).

By the 1950's, landings were recorded by Statistical areas. Newfoundland Statistical Area 'M', which included Bonne Bay (Figure 4), showed cod landings rising from 438 tonnes to 1320 tonnes for that period, with the greatest increase occurring in the 1960's. Lobster landings during this period were low but relatively stable, the fishery was believed to be in the midst of a decline in the 1950-60's due to high exploitation rates at that time. Halibut landings fluctuated but reached their peak landings in 1964 at 52 tonnes. The pelagic bait fishery for herring grew during the period from 23 tonnes in 1955 to 1201 tonnes in 1968. This increase in landings was a result of the crisis in the Pacific and European herring stocks. Capelin still supported a traditional bait fishery and experienced fluctuating landings ranging from 254 tonnes to 35 tonnes between 1958 and 1968. While salmon was not a large commercial fishery, the landings peaked in 1959 with 18 tonnes, however, by 1968 the landings were at the lowest level, 4 tonnes. Salmon landings fluctuated widely during this period with landings ranging from 254 tonnes in 1955 to 201 tonnes by 1970.

Mackerel and squid still existed mainly as bait fisheries with negligible landings between 1955 and 1968. However, by 1960, the management framework had changed and data were collected within the NAFO framework. Data were collected for NAFO Area 4R, which encompassed the entire West coast of Newfoundland and was a much larger area as evidenced by the large increase in the size of recorded landings.

During this period, cod continued to be the major fishery of Newfoundland. The fishery saw its highest landings recorded in 1983 with 55,843 tonnes. However, landings had fallen to 15,147 tonnes by 1992. Lobster landings increased to a peak by 1989 with 1,629 tonnes landed. Halibut saw peak landings in 1966 with 312 tonnes landed. Between 1966 and 2000, landings for halibut fell to 66 tonnes.

The collapse of the Pacific and European herring fisheries in the 1960s, lead to exploitation of Newfoundland herring stocks (Comeau and Bellefontaine 1981). The NAFO 4R herring stocks were previously under-fished. With increased effort, landings peaked in 1991 at 26,437 tonnes. These stocks have shown decreases in landings with only 12,026 tonnes in 2000.

The decrease in recent years has been attributed to poor recruitment (Anonymous 2002). The salmon fishery peaked in 1977 with 201 tonnes landed; however, by 2000 landings had dropped to 4 tonnes. In recent years, the government closed rivers and bought back licences from fishers in an attempt to protect the stock. Capelin experienced a growth during the 1980's with increased demand from the Asian market place due to the crisis in the Japanese capelin stocks. The landings peaked in 1989 with 8,512 tonnes landed. However, landings have been dropping in the 1990's, with 5,121 tonnes landed.

Mackerel was not considered a major fishery until the 1980's. Landings for mackerel peaked in 1991 with 7,541 tonnes landed, after which they began to decline, with only 1,823 tonnes landed in 2000. With the problems of the other fisheries worsening, new fisheries were beginning to be explored. In the mid 1980's, the experimental snow crab fishery began. The landings for the crab fishery are still increasing and by 2000, had reached 1,611 tonnes.
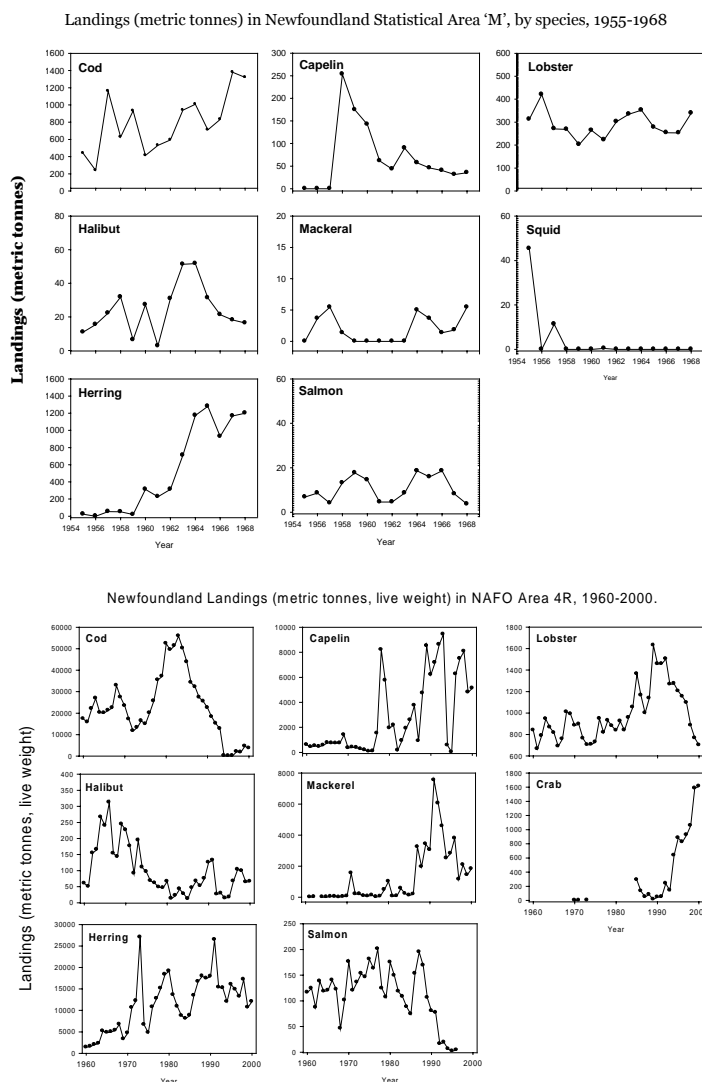
Figure 3: Comparison of Newfoundland Statistical Area 'M' (above) and NAFO 4R (below) Landings between 1955 – 2000.

Traditional and Local Ecological Knowledge

The Traditional Ecological Knowledge (TEK) and Local Ecological Knowledge (LEK) collected through interviews revealed that the effort of fishers has increased with time. This has been through using larger boats and faster engines. Also, effective effort increased through the use of tools such as Global Positioning System (GPS), haulers and bottom sounding technology.

The effect of these technological advances was revealed with TEK and LEK. These improvements allowed fishers to fish longer with more gear, essentially increasing the overall effort of each fisher. However, landings did not increase as expected. Instead they remained at similar levels or in the case of some fishers and species, landings

actually decreased with effort increase. This disturbing trend indicated significant changes in the effort required in some fisheries. The LEK and TEK illustrated that more effort was involved in maintaining fishing levels.

DISCUSSION

Over the past century, increased levels of effort and declining landings have become a reality for fish harvesters. Fisheries on the West Coast of Newfoundland have seen significant changes and are experiencing the restructuring of the coastal ecosystem. Through the micro-scale historical reconstruction of Bonne Bay fisheries, these changes and mechanisms for the restructuring of the coastal ecosystem can be seen in the 'fishing down' of the fisheries within the area.

The 'fishing down' hypothesis describes how a community shifts effort from a depleted resource to another more plentiful one. In the case of Bonne Bay, the application of this hypothesis was successful. Through various methods, these shifts were clearly seen. Through interviews and fisheries data these shifts are more easily seen in recent years. After the collapse and closure of the North Atlantic cod stocks in 1992, increased landings were seen for lobster, mackerel and snow crab. In the cases of mackerel and snow crab, these were never major fisheries until the collapse of the ground fish stocks, coupled with the decline of the halibut fishery in the 1960's and the decline of the pelagic bait fishery for herring in recent years.

Information types and Associated Problems

Various sources of information are required in order to properly reconstruct histories on a micro-scale. However, it is key to keep in mind, that all sources of information and data have their drawbacks and problems. Therefore, it is crucial to utilize these resources with caution.

The Newfoundland census is a commonly used and heavily relied upon historical data and statistical source. The historical statistics contained within the census, while useful, have shortcomings. Generally, random samples are chosen to model and study an entire population or measures of the whole population provided by the government are used (Webb, *unpublished MS*). However, in historical work, this is not always possible or reliable. During the 1800's and early 1900's, there was an obvious lack of training for enumerators, standard methods of reporting were non-existent and there was no government body whose function was to solely collect and verify data (Webb, *unpublished MS*). These problems call into question the validity of the data. Acknowledging these shortfalls, historical data can still be used to reveal and study trends.

Another problem encountered while using the census was the switch to the Canadian Dominion Bureau of Statistics methodology for the decennial census in 1935 (Webb, *unpublished MS*). The new forms failed to collect data pertaining to fish landings, gear, etc. Therefore, the 1935 and subsequent census were of minimal use as a historical source for fishing information.

There are problems with all data, especially historical data. However, in micro-scale historical reconstructions imperfect data is often the only source of information and must be incorporated. Therefore, when examining various sources of information and data, their associated problems/disadvantages must be kept in mind. It is crucial that researchers examining and utilizing historical sources are aware of the shortfalls of each information source.

In historical reconstructions, one source of information that is often tapped is TEK/LEK. This information source while extremely useful has problems of its own.

Importance of TEK/LEK

While most fisheries research and management is done on a large spatial scale, trends identified at those levels are not always reflected on a smaller scale. Therefore, by comparing larger scale data and with other sources of data such as TEK and LEK, trends can be seen on larger management scales and at the community level.

In micro-level historical reconstructions, poor fit of data is inevitable due to temporal and spatial changes over time. These challenges are most often encountered due to changes in methods of data collection as well as changes in the management framework in which the data is collected. With any change, temporal and spatial 'holes' may emerge that can be difficult to bridge.

The most obvious spatial and temporal issues deal with historical changes in the management framework. In the case of Newfoundland, the earliest fisheries data were collected in the form of the census of the Dominion of Newfoundland whereby information was collected by communities and Districts (Bonne Bay lay within the St. Barbe District; Figure 4).

Then in 1954, Newfoundland coastal waters were divided into Statistical Areas with Bonne Bay lying within Statistical Area 'M' stretching from Cape St. Gregory to Point Riche. With the inception of North American Fisheries Organization (NAFO), management areas changed yet again. After the change in 1977, Bonne Bay was now located in the NAFO area 4R. This management unit stretched from Port Aux Basque to the tip of the Northern Peninsula. With each change in management units (Census District, Newfoundland Statistical Area 'M', and NAFO 4R), units became larger than before (Figure 4).

As the framework for management changed over time, the areas managed and in which data collection occurred, were becoming larger. This was an obvious problem when trying to reconstruct a fishery at a micro-scale (i.e. one bay). The ever increasing size makes comparison of data a greater problem. For example, landings were often classified by species only without reference to the approximate location of capture. The failure of historical data sources such as the census, to collect this information hampers efforts to accurately reconstruct fishing behaviour in the bay. Without establishing these spatial changes over time it may not be possible to fully and completely understand which fish were caught where. Therefore, spatial changes over time may be lost and a critical shift/change in the fishery in the bay may not be identified.

TEK and LEK have many benefits that make their inclusion in the management framework important. For this reconstruction, TEK and LEK were used to determine whether changes seen within larger management scales were also seen within the local fisheries. This allows for greater and better management at the local level as well as including fishers in the management of their own stocks.

Overall, these problems make identification of temporal, spatial, and ecological changes more difficult. Without discovering these changes, important shifts in the fishery may not be identified or understood. These problems outline the need for micro-level research to discover what is ongoing at a more focused level than is currently done. Through the analysis at this level, better management may result.

Summary of Discussion

In researching historical trends, many different data sources, each with their own strengths and
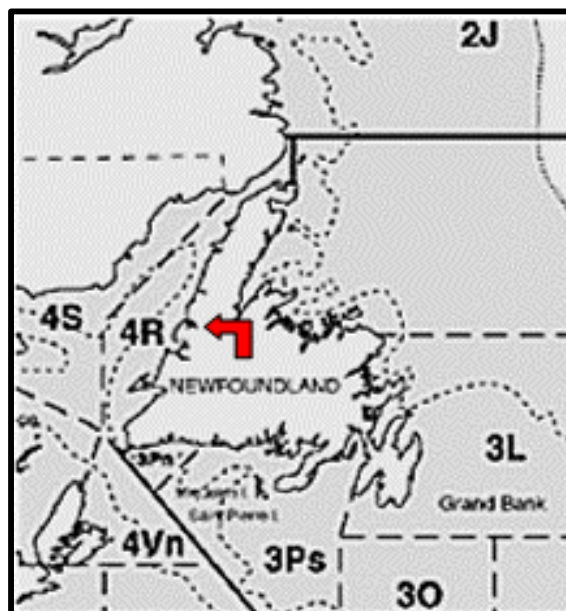
Figure 4: The geographic range Newfoundland Statistical Area 'M' (1954-1968) extending from Cape St. Gregory to Point Riche and encompassing Bonne Bay as indicated by the arrow in the top figure (Scattergood and Tibbo 1959). NAFO Area 4R (below) ranges from the tip of the Northern Peninsula to Port Aux Basque, with Bonne Bay indicated by the arrow.

weaknesses, are used. Therefore, the researcher must be fully aware of the constraints of the data in order to properly use the information. It is also evident that there are many problems with the information available that make it difficult to reconstruct the past on a micro-scale. The methods with which that data are collected today still make it difficult to reconstruct on a micro-scale. There are little data available on such small localized levels.

Collection methods change over time, as does the intended use of the data. As such, data were originally intended for use in a certain fashion and were collected accordingly. This could make applying the data accurately for new uses very difficult. A prime example looks at the changes between the census of 1921 and 1935. For the 1935 census, the Newfoundland Government began to the use the census format employed by the Dominion of Canada. This change in data collection facilitated in the loss of Newfoundland Fisheries information. Census data collected from 1935 onward no longer held valuable fishing information such as the number and types of nets used for particular fisheries. Therefore, census data was no longer a useful source of fisheries information. This is very problematic considering that the main source of governmental fishing data before Confederation was found in the Newfoundland census (Webb, *unpublished MS*).

Within historical work, patchiness in the spatial and temporal scale coverage is a constant problem, often making a complete picture difficult if not impossible to attain. Areas lacking in empirical data could possibly be covered through employing Traditional Ecological Knowledge (TEK) and Local Ecological Knowledge (LEK). If the period for which information is lacking dates farther back than TEK and LEK can reach, then new sources of data have to be discovered. However, it might never be possible to complete the historical reconstruction.

CONCLUSIONS

Through the use of micro-level reconstruction, it is possible to extend the temporal period for which we have both catch and catch-rate data by using other previously under-used data sources. This type of reconstruction also fits well within the micro-scale of Local Ecological Knowledge (LEK) and Traditional Ecological Knowledge (TEK) held within resource based communities. Micro-scale data and historical reconstructions can be aggregated into a larger framework to match larger spatial scales. Finally, these types of reconstructions can be used to illustrate 'Fishing Down' dynamics, observed globally and identified by Pauly *et al.* (1998).

REFERENCES

Anon., 2002. West coast of Newfoundland Atlantic herring (Division 4R). Stock Status Report B4-01. Department of Fisheries and Oceans.

Anon., 1955-1976. Fisheries Statistics Newfoundland. Dominion Bureau of Statistics: Industry Division; Ottawa.

Bear, C. 2000. Ecological knowledge: key informant approaches for the Gulf of St. Lawrence lobster fisheries. In Exploring and reconciling competing systems of ecologically-formed knowledge: lessons from Maritime Canada and North Atlantic Fisheries. Ecological Knowledge Working Seminar II. St. Francis Xavier University.

Comeau, P.A., and Bellefontaine, N.A. 1981. Harvesting of herring in Atlantic Canada waters. Department of Fisheries and Oceans, Maritimes Region

Felt, L.F., and Locke, L.W. 1995. The Collapse of Newfoundland's Fishery and Beyond p.197-236 In: Arnarson, R. and Felt, L.F. (Eds). *The North Atlantic Fisheries: Successes, Failures, and Challenges.*

Gough, J. 1993. Fisheries management in Canada: a historical sketch. p.5-53. In: Parsons, L.S. and Lear, W.H. (Eds.) *Perspectives on Canadian Marine Fisheries Management* Can. Bull. Fish. Aquat. Sci. No. 226

Hipwell, B. 1998. Integrating Local and Traditional Ecological Knowledge into Fisheries Management in Canada: Final Report. Integrated Coastal Zone Management; Marine Ecosystems Conservation Branch; Fisheries and Oceans Canada (www.ncr.dfo.ca/oceanscanada/newenglish/library/pdf/hipwell.pdf)

Johnson, M. 1992. Lore: Capturing Traditional Environmental Knowledge. Dene Cultural Institute, International Development Research Centre: Hay River, North West Territories.

MacKenzie, B.R., Alheit, J., Conley, D.J., Holm, P. and Kinze, C.C. 2002. Ecological hypotheses for a Historical reconstruction of upper trophic level biomass in the Baltic Sea and Skagerrak. Can. J. Fish. Aquat. Sci. 59: 173-190.

Neis, B., Felt, L., Schneider, D.C., Haedrich, R.L., Hutchings, J., and Fischer, J. 1996. Northern cod stock assessment: what can be learned from interviewing resource users? DFO Atlantic Fisheries Research Document 96/45.

Neis, B., Schneider, D.C., Felt, L., Haedrich, R.L., Fischer, J. and Hutchings, J.A. 1999. Fisheries assessment: What can be learned from interviewing resource users? Can. J. Fish. Aquat. Sci. 56: 1949-1963

Pauly, D., Christensen, V., Dalsgaard, J.,Froese, R. and Torres, F.Jr. 1998. Fishing down marine food webs. Science. 279: 860-863.

Scattergood, L.W. and Tibbo, S.N. 1959. The herring fishery of the Northwest Atlantic. Fisheries Research Board of Canada, Ottawa; Bulletin No. 121

Svensson, T. G. 1991. Sami Ethnicity and Policy – Conflict and Compromise Regarding Development in the North. Nomadic Peoples 28(1991): 123-137

Templeman, W. 1941. The Newfoundland Lobster fishery; an account of statistics, methods, and important laws. Dept. of Natural Resources, Research Bulletin No.11, St. John's, Newfoundland.

Webb, J. Unpublished MS. Limitations of historical data for testing the "Fishing Up" hypothesis. Memorial University of Newfoundland and Labrador.

FROM LOCAL KNOWLEDGE TO SCIENCE AND BACK: EVOLVING USE OF LOCAL ECOLOGICAL KNOWLEDGE IN FISHERIES SCIENCE

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ABSTRACT

Researchers studying resource use have become increasingly aware of the value of including local ecological knowledge in historical and scientific studies. With respect to fisheries science, local ecological knowledge has provided a considerable amount of information relevant to stock assessment. Literature reviews of the history of stock assessment show that the predominance of local ecological knowledge or science as the main source of information in stock assessment tends to follow a similar pattern over time across several fisheries. Local ecological knowledge collected through interviewing gives us valuable data on non-commercial and underutilized species, in addition to data to be used in the assessment of commercial species. This data are crucial in the study of ecosystems as whole units. While the spatial scale of local ecological knowledge is far less than that of traditional fisheries science, aggregation may allow for its use in larger scale ecosystem modelling and fisheries assessment in general.

INTRODUCTION

Many marine ecosystems are overfished and some fish stocks have collapsed. At this time, it is important to scrutinize the strengths and weaknesses of management and assessment practices of the past to avoid further misinterpretations and oversights. Gathering information on the fishery from individuals other than fisheries managers, scientists or politicians is important to this process. Local ecological knowledge (LEK) has been used recently in the reconstruction of the history of fisheries. LEK, while quite different from scientific and historical data, can compliment existing data by filling in detailed spatial information. This results in a description of the fishery that concurs with the experience of many fish harvesters.

Hutchings (1996) points out ways that local ecological knowledge can be useful in scientific assessments. Local familiarity with the dates of fish caught in fixed gear can indicate seasonal and directional movements of fish populations. Fish harvesters can provide information on aspects of stock structure including movement patterns, spawning grounds, juvenile habitat, and spatial patterns in fish morphology. Also he notes that catch rates may mirror local changes in fish abundance (Hutchings 1996).

Neis *et al.* (1999) expand on the potential for the inclusion of resource user data in fisheries assessment. When collected in a systematic way, local ecological knowledge provides significant information on stock distinctiveness, fishing efficiency and catch per unit of effort (CPUE). Local taxonomy relating to cod, collected during the interview process, reflects a familiarity with stock structure including seasonal locations, direction and timing of movements, as well as spawning behaviour. Tracing career history with a resource user enables quantification of fishing efficiency, specifically capacity, gear quantity, engine power and trip time; thus offering a more exact indication of increases in fishing effort. The negative trend in catch per unit of effort on a decadal scale, as indicated by fish harvesters, provides a clearer picture of stock status than information on the landings alone (Neis *et al.* 1999).

Local ecological knowledge has the potential for other uses in fisheries. The main source of data used in the assessment of a fish stock varies over time. In tracing the history of a fishery there is a general lack of fish harvester data used in recent stock assessment; it is interesting to note that local ecological knowledge is the major information source in stock assessment at earlier stages within these histories. The flow or trend in the source of data for stock assessment can be compared across species to determine if that flow is consistent with the progression of fisheries in general. To address the question of change in sources of information in fisheries management, we used graphical techniques.

Local ecological knowledge applies to more than commercial species. Useful information relating to underutilized species, important forage species and many aspects of the environment can be assembled through interviewing or other methods. This information is valuable from a conservation perspective, as well as, in evaluating

the overall health of the ecosystem. Data collected on the Atlantic sturgeon (*Acipenser oxyrinchus*) during interviews undertaken by *Coasts Under Stress* researchers will allow for well-founded inferences on populations of a non-commercial species.

METHODS

The reconstruction of sources of information in stock assessment for Atlantic snow crab (*Chionoecetes opilio*) and herring (*Clupea harengus harengus*) fisheries was based mainly on a literature review. Documents such as stock assessments, management plans, and other research documents were collected, with the end result being a brief history and a time line of the main sources of data throughout the history of the fishery. To illustrate the change in flow of information over time, timelines were positioned in a triangular diagram of three axes indicating the relative contributions from science, local ecological knowledge, and/or economics. For example, in the early stages of a fishery, when logbooks are the main source of data, the block of time would be nearest the corner of the triangle labelled TEK/ LEK, or traditional/ local ecological knowledge. The block of time included in an Integrated Management Plan would lie in the centre of the triangle, since input into stock assessment should be coming from all stakeholders (Figures 1 and 2).

After constructing these diagrams, we distinguished the different types of input from fish harvesters. For instance, when a resource user completes entries in a logbook, they are providing straightforward information such as where they fished, the species caught, and the weather conditions, and do not necessarily provide opinions on the state of the fishery or the environment. When fish harvesters are interviewed, or take part in a meeting, they may have more opportunity to speak freely, offering opinions and impressions and systematic understanding of local conditions, thus providing more than baseline data. To illustrate this difference in the schematic diagrams, two symbols were used: a book representing a logbook and a microphone, representing an interview or other opportunity for fish harvesters to offer more than data. A third symbol, a small fish, was added to indicate fish harvesters and scientists working together. Finally, a ship was added as a fourth symbol to illustrate scientific surveys (see Key, Appendix 1).

Interviews were carried out using the career history format, whereby resource users reconstruct their experience within the context of licenses, vessels, gear and equipment used, thus increasing the likelihood of accurate responses. Interviews were semi-structured, i.e., they were guided by a schedule that is easily modified to allow the resource user to steer the conversation. Copies of nautical charts, commonly used by fishers, were provided to interviewees, on which they could indicate areas fished, spawning grounds, etc. (Neis *et al.* 1999).

RESULTS

Snow crab fishery of Newfoundland

Snow crab is a relatively new fishery in Newfoundland. Substantial landings, particularly off the east coast of the island have occurred since the late 1970s, with a slight dip in the late 1980s (Taylor and O'Keefe 1999). Total landings for the province were as high as 13,178 tonnes in 1982, as low as 6,591 tonnes in 1987, and have remained well over 28,000 tonnes since 1994 (Taylor and O'Keefe 1999).

Catch History

The Newfoundland snow crab fishery, initially a bycatch in Trinity Bay, began in 1968 with effort only in the deep bays within 30 km of the coast (Taylor *et al.* 1994). Offshore areas east of the Avalon Peninsula (3L) were first fished in 1978 and as effort increased, landings increased until they peaked at 8,609 tonnes in 1981 (Taylor *et al.* 1994). Landings declined from 1982 to a low of 74 tonnes in 1985, and new areas were added from here (Taylor *et al.* 1994). In 1985 supplementary fisheries for snow crab were implemented in 2J, 3K, and 3Ps, to help the incomes of groundfish operators (Anon. 1999a). Area 2J has seen steady increases from 645 tonnes in 1990 to 4,061 tonnes in 1998. Area 3K has proved quite lucrative with landings greater than 11,000 tonnes since 1994, while 3Ps dropped as low as 121 tonnes in 1992; then, it reached 6,624 tonnes in 1998 (Taylor and O'Keefe 1999). Landings from 3L, combined with 3MNO have recovered from a dip in the late 1980s to over 12,000 tonnes since 1994 (Taylor and O'Keefe 1999). While trends in landings are similar in all divisions, 75% of all landings in 1998 came from the northeast coast, 3KL (Anon. 1999a).

A- Newfoundland

TEK/LEK

Economics

Scientific
Knowledge

D- Western Cape Breton

TEK/LEK

Economics

Scientific
Knowledge

B– Gulf of St. Lawrence

TEK/LEK

Economics

Scientific
Knowledge

E- Eastern Cape Breton

TEK/LEK

Economics

Scientific
Knowledge

C– Prince Edward Island

TEK/LEK

Economics

Scientific
Knowledge

F- NAFO Division 4X

TEK/LEK

Economics

Scientific
Knowledge

Figure 1: Shift in sources of information in Eastern Canadian Snow Crab Fisheries (see Key, Appendix 1).

A- Eastern Newfoundland
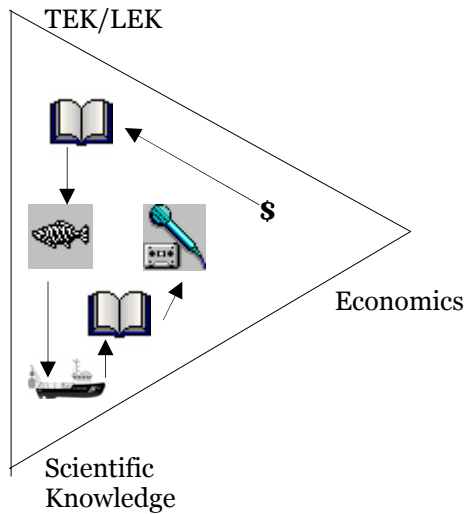
C- Several British Columbia Fisheries
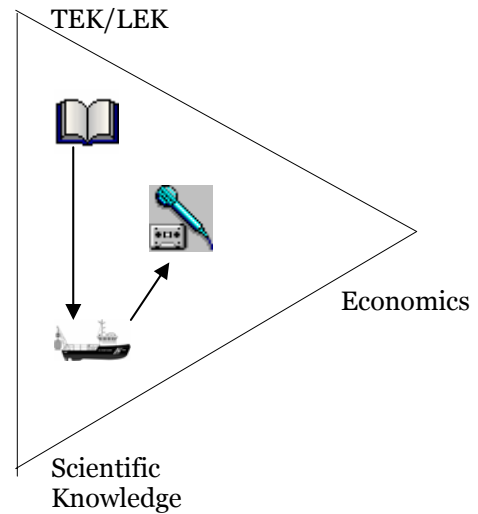
B- Western Newfoundland
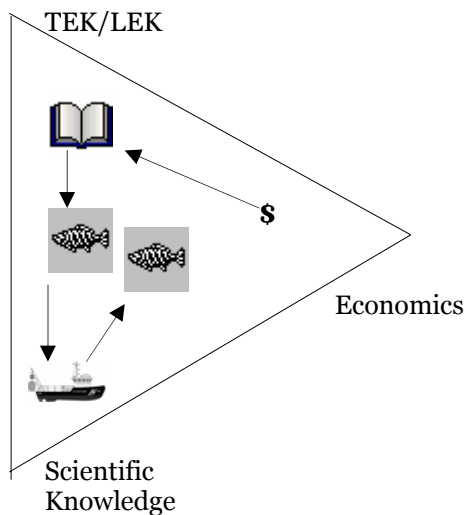
D- Nova Scotia/ Bay of Fundy
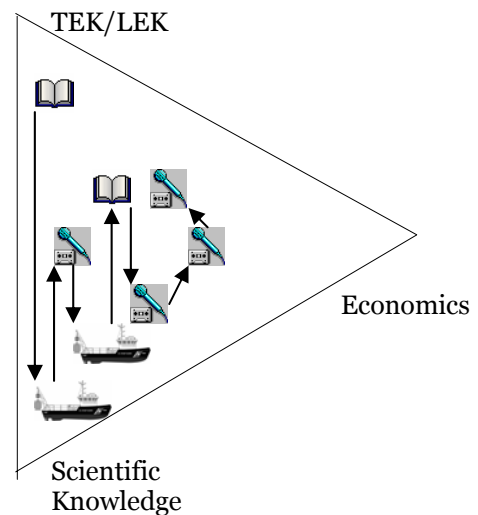
Figure 2: Shift in sources of information in selected Canadian Herring Fisheries (see Key, Appendix 1).

Snow crab landings were first recorded from the west coast of Newfoundland in 1996 when 1,032 tonnes were reported, 708 tonnes and 720 tonnes were landed in 1997 and 1998 respectively (Taylor and O'Keefe, 1999). The fishery here really began in 1987, though landings were negligible through 1991, and the fishery ceased in 1992 due to high occurrences of soft-shelled crabs (Mallet *et al.* 1993).

Management History

Throughout the 1970s, 1980s, and into the 1990s, the snow crab fishery was carried out on a competitive basis, individual quotas were not implemented until 1995 (Anon. 1999a).

Scientists carried out inshore trap surveys within bays around the east coast of the island through the 1980s to get an indication of relative year class strength. More extensive bottom trawl surveys began in 1995, obtaining information such as geographical distribution, sexes, and sizes (Anon. 1999a).

In 1994, fishers in area 3K instituted dockside monitoring, and all of the NAFO divisions followed in 1995; logbooks were also required for validation (Taylor and O'Keefe 1999). All costs

and certification of dockside monitoring are covered by fishers, either individually or as fleets; the industry also pays for 10% of observer coverage (Anon. 1999a).

The Integrated Management Plan (1999) outlines long-term objectives such as maintaining reproductive capacity of the population, minimizing sources fishery induced mortality, and maintaining stable or increasing quotas. To achieve these objectives and maintain conservation and protection requirements, DFO relies on dockside monitoring, adequate at-sea observer coverage, and accurate logbook completion; in addition, measures to discourage cheating (highgrading, etc.) are also important (Anon. 1999a).

While the rest of the Atlantic region provides a minimum percentage of allowable soft-shelled crab in the catch, the Newfoundland plan imposes an annual closure from August 15-September 15, to protect the newly molted crabs (Anon. 1999a).

History of Information Source and Use

Figure 1(A) illustrates the major shifts in the source of information for the snow crab fishery in this region. Logbooks were submitted by fishers through the 1970s, 1980s and 1990s (Taylor and O'Keefe 1989 and 1998). Catch per unit effort (CPUE) data, as well as landings, were used through Leslie analysis (Leslie and Davis 1939) to calculate catchability of commercial size crabs and exploitation rates (Taylor and O'Keefe 1989). Leslie analysis has been shown to be invalid when estimating such a highly aggregated population and more direct methods employed during post-season trawling are now used (Dawe *et al.* 1999). Fishers' logs are still required for catch and effort information (Taylor and O'Keefe 1998).

To start the Integrated Management Plan process, meetings were held in 1999 with committees representing all sectors of the fishery submitting written proposals to DFO on snow crab management. These meetings were followed by a workshop, out of which the management plan was born (Anon. 1999a). Consensus was reached on many issues, though workshop participants agreed that final allocations should rest with DFO (Anon. 1999a). One of the most important pieces of such a process is to clearly define the roles and responsibilities of all participants involved, particularly the role of DFO (Anon. 1999a).

Snow crab fishery of the Southern Gulf of St. Lawrence (Area 12)

The snow crab fishery of the south-western Gulf of St. Lawrence developed very quickly through the 1970s to peak landings in the early 1980s (Hare and Dunn 1993). This area experienced record low landings just over 7,500 tonnes and under 7,000 tonnes respectively in 1989 and 1990 (Hébert *et al.* 2000). However, the fishery in this area has become tremendously valuable, contributing $5.3 million to a fund for suffering groundfish-only license holders in 1994 (Loch *et al.* 1994); landings throughout the late 1990s were consistently over 15,000 tonnes, with a drop to 11,136 tonnes in 1998 and 12,682 tonnes in 1999 (Hébert *et al.* 2000).

Catch History

Exploratory surveys for snow crab began in 1965 after landings had been reported as bycatch in other commercial fisheries (Hare and Dunn 1993). The fishery spread from Nova Scotia in 1965, to New Brunswick and Quebec in 1966 where the new species fit nicely into existing groundfish operations (Hare and Dunn 1993). The fishery grew quickly from 15,700 tonnes landed in 1979 to above 30,000 tonnes in 1982, but this growth largely unregulated. In 1975 soft-shelled crab landings were far greater than permitted under modern limits and in 1977, many fishers were reported to be operating well in excess of trap limits recommended by the Gulf Snow Crab Advisory Committee (Hare and Dunn 1993).

Landings through the mid 1980s remained high steadily above 11,000 t, but dropped slightly in 1989 and 1990 to 7,882 tonnes and 6,950 tonnes respectively; both seasons saw closures due to high soft-shelled crab percentages (Hébert *et al.* 2000). It was suggested that the accumulated biomass of older crab had been caught or had disappeared through natural causes, therefore making a higher percentage of younger and possibly soft-shelled crabs available to recruit to the fishery (Loch *et al.* 1994). 1989 also saw the midshore fleet reach its peak size (Anon. 1997a). Through the early 1990s, the stock recovered modestly and the catch rose to over 12,000 tonnes after 1991 (Hare and Dunn 1993). Landings through the 1990s remained steady, peaking at 19,995 tonnes in 1994 with a low of 11,136 tonnes in 1998 (Hébert *et al.* 2000).

The mid 1990s saw greater demands for access to the fishery, and in 1995 two new exploratory zones were added to the region, Area E

(Laurentian Channel) and Area F (Magdalen Islands/ Cape Breton) (Hébert *et al.* 2000). Landings in these new zones have been moderate, remaining above 150 tonnes in Area E 1995-1999 and above 250 tonnes in Area F (Hébert *et al.* 2000).

Management History

The Atlantic Crab Association formed in 1996 and served until 1973 but imposed very few regulations. The Gulf Snow Crab Management Advisory Committee was established in 1974, and imposed some management measures such as limited entry licensing (Hare and Dunn 1993). Since 1978, the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) has provided advice on stock status and fisheries management. However, throughout most of the 1980s, the unemployment benefits of processing plant workers appeared to be the main concern in management (Hare and Dunn 1993). In 1985, plant workers frustrated with new DFO regulations that limited their work season, initiated demonstrations, vandalizing trucks and new processing equipment (Hare and Dunn, 1993). Fishers did not exactly follow rules either, commonly keeping dual records and sorting and discarding their catch at sea (Hare and Dunn 1993).

Proir to 1988, biomass estimates were derived indirectly using Leslie analysis whereby data from logbooks were used to determine catchability (Hébert *et. al.* 1999). Post season bottom trawl surveys began in 1988, sampling 225 randomly selected stations and collecting data on age, sex, and geographic distribution of the crab populations (Loch *et al.,* 1994); this method was looked upon much more favourably as there was a high degree of uncertainty placed upon Leslie analysis in the snow crab fishery (Hébert *et al.* 1999). In 1989, individual vessel quotas were established as well as 100% fisheries observer coverage at port (Hare and Dunn 1993).

The DFO Science branch considered the entire southern Gulf as a single stock in the early 1990s (Anon. 1997a). In 1997, Areas 25/26 (inshore PEI) were incorporated into the Area 12 management unit (Hébert *et al.* 2000). Also in 1997, an Integrated Management plan was released for the southern Gulf, intended to promote and ensure the conservation and protection of the resource. The plan, running to 2002, addressed aboriginal allocations, measures to accommodate the aging snow crab cohorts in the stock, illegal landings, highgrading, resource sharing and quota enforcement (Anon. 1997a).

Logbook use, 100% dockside monitoring; mandatory use of biodegradable escape mechanisms on traps to avoid ghost fishing; a 10% dockside sampling program; and 20% fishery officer surveillance by sea and air are all enforcement measures outlined in Area 12 (Anon. 1997a). The management plan also attempted to outline more clearly the roles played in snow crab management by all of the participants, particularly DFO (Anon. 2000a).

History of Information Source and Use

Figure 1(B) illustrates the shift in sources of information in the Area 12 snow crab fishery. Logbooks remain a management tool in this region, and valuable data on effort, landings, position and trap type are collected from these fishers' logs (Chiasson *et al.* 1995).

Relations between resource users and management in the southern Gulf of St. Lawrence are for the most part cordial and positive and most recent assessment activities are conducted in collaboration with local fishers, the industry, processors and government officials (Loch *et al.* 1994).

Chiasson *et al.* (1992) completed surveys with New Brunswick crab fishers, addressing the idea of increases in technology and their effect on the snow crab fishery. The fishers in the area agree that increased control over the fishery would be the best way to conserve stocks; they suggested looking at boat quotas, trap numbers, and ghost fishing more carefully (Chiasson *et al.* 1992).

The Integrated Management plan process combines all participants in the snow crab fishery including fishers, plant workers, provincial representatives, aboriginal groups, etc. in making recommendations to the Minister (Anon. 1997a). The planning process is also an initial stage in the development of a larger co-management scheme whereby the industry will be encouraged to have a greater involvement in the fisheries management (Anon. 1997a).

Snow crab fishery of Prince Edward Island

Prince Edward Island was a late arrival in the Gulf of St. Lawrence snow crab fishery, with negligible landings and/or lack of participation until the mid 1980s (Hare and Dunn 1993). Peak landings occurred in 1986 at 1,200 tonnes dropping to near 500 tonnes in the early 1990s, and steadily climbing to approach 1,000 tonnes in the late 1990s, when the PEI inshore zones were assimilated into the southern Gulf fishery and

landings are reported as a grand total (Loch *et al.* 1994).

Catch History

The Gulf of St. Lawrence exploratory snow crab fishery extended to PEI in 1966 (Hare and Dunn 1993). There was a lack of interest in the snow crab fishery in PEI due to low market prices for crab and consistent groundfish catch rates, and the fishery halted in 1969 (Hare and Dunn 1993).

In 1985, an exploratory fishery was reintroduced and landings for the year totalled 891 t, valuing $2.3 million; 14 inshore exploratory licenses were issued in 1986 and landings that year were 1,200 tonnes (Hare and Dunn 1993). In 1987, 16 exploratory licenses became permanent in status, but catch was already declining (Hare and Dunn 1993).

After 1989, midshore fishers were restricted from the inshore zone, and in 1990, two zones, Areas 25 and 26 were reserved exclusively for PEI fishers (Loch *et al.* 1994). In 1989, landings were extremely low due to an early closure resulting from high incidence of soft shelled crab in the fall season (Loch *et al.* 1994). Quotas were consistently full and continually increasing from 500 tonnes in 1990, up to 800 tonnes in 1993 and 1,000 tonnes in 1994, when the fishery was again closed due to high percentages of soft shelled crab in the catch (Loch *et al.* 1994). Landings in 1997 and 1998 were 696 tonnes and 592 tonnes respectively (Hébert *et al.* 2000).

Management History

Logbook data were originally utilized to estimate exploitation rates using Leslie analysis, but after 1988 bottom trawl surveys were initiated to provide a more direct estimate of biomass; logbook data remain useful in examining effort and landings (Hébert *et al.* 1999).

The Gulf Snow Crab Management Advisory Committee recommended limited entry licensing based upon past participation in 1974. PEI supported this recommendation on the condition that their fishers were considered exempt due to a lack of participation in the snow crab fishery at the time (Hare and Dunn 1993). In 1980, again while not participating in the fishery, PEI called for the establishment of an exclusive 20 mile inshore zone for its traditional fishers in response to increased midshore landings. Midshore fishers began recognizing the risk of overexploitation, called for more control instead of increased effort, and successfully sought a court injunction

preventing PEI fishers from obtaining 16 requested exploratory licenses in 1984 (Hare and Dunn 1993).

In 1997, the southern Gulf portion of management Area 12 and Areas 25/26 were integrated to form one management unit (Hébert *et al.* 2000). DFO Science advised that there were no biological distinctions between the various crab fisheries and would subsequently provide an overall exploitable biomass (Loch *et al.* 1994).

PEI fishers remained mostly frustrated with their lack of access to the snow crab fishery throughout most of the 1980s and 1990s (they would have preferred more access to Area 12). However, they participated in an at-sea observer control program, then in its infant stages, during the early 1990s (Loch *et al.* 1994). An at-sea observer could serve a dual role in sampling or in enforcement for soft-shelled crab landings or discarding at sea (Anon. 1997a). In addition, since 1997 traditional PEI inshore fishers have agreed to share the cost of snow crab management with DFO (Hébert *et al.* 2000).

Recent management strategies were previously discussed in southern Gulf / Area 12 section. The shifts in sources of information in the PEI snow crab fishery are illustrated in Figure 1(C).

Snow crab fishery of Cape Breton

The snow crab fishery of Cape Breton is fairly complex as it consists of seven zones, from Area 18 in the southwest around to Area 24 in the southeast (Biron *et al.* 2000b). Catches off western Cape Breton have remained steady near 2,000 tonnes through the late 1980s and all of the 1990s (DeGrâce *et al.* 2000), while landings off eastern Cape Breton have varied through the late 1970s, 1,634 tonnes in 1979, dropping low in the mid 1980s, 89 tonnes in 1985, and back up above 1,500 tonnes since 1991 (Biron *et al.* 2000b).

Catch History in western Cape Breton

Initially snow crab exploratory surveys were concentrated around the north coast of Cape Breton in 1967, by fishers based in Cheticamp (Loch *et al.* 1994). Crab fishing did not become popular immediately due to poor market prices (Hare and Dunn 1993). Through the mid to late 1970s the fishery developed in spite of gear conflicts evident when midshore boats moved inshore in the fall, waiting for the southern Gulf cod migration. In 1977, inshore landings totalled 516 tons; and increased to 1,941 tons in 1978,

valuing approximately $ 6.8 million (Hare and Dunn 1993).

Also in 1978, the federal government declared Area 19 (northwestern Cape Breton) exclusive to inshore fishers from the island. This management zone experienced growth with landings increasing from 900 tonnes in 1979 to 1,390 tonnes in 1990; in 1992 a 1,686 tonnes quota was established and was fully utilized through 1994 (Loch *et al.* 1994). A phase of good recruitment has been evident here in the late 1990s with catches remaining steadily above 1,300 tonnes (DeGrâce *et al.* 2000).

Southwestern Cape Breton saw similar developments. The fishery began in 1979 and exclusive inshore Area 18 was established in 1984 (Hare and Dunn 1993). Trends in landings here were slightly different than Area 19 with a 835 tonnes quota in 1981, dropping to 626 tonnes by 1986, and up again to 674 tonnes in 1988 (Loch *et al.* 1994). In 1991 an additional spring quota of 200 tonnes was set to encourage a spring fishery in addition to 674 tonnes for the fall. A quota of 749 tons was set for 1992 continuing to 1995 and all quotas have been fully used (Loch *et al.* 1994). However this area experienced a slight downturn with landings only reaching quota levels in 1996 and 1999, with 306 tonnes and 407 tonnes respectively. The zone has been plagued with frequent closures due to high percentage of soft-shelled crab in the landings (DeGrâce *et al.* 2000).

Catch History in Eastern Cape Breton

Snow crab landings off eastern Cape Breton were relatively high in the late 1970s and similar management zones, Area 20 near the northeast tip to Area 24 in the south and mainland Nova Scotia, were established (Tremblay *et al.* 1994). This area experienced large declines in the early 1980s possibly because of rapid removal of accumulated biomass in a region with little new production due to less than ideal habitat (Tremblay *et al.* 1994). Increases in all areas were observed in 1987 reaching all time highs in the early 1990s. This increase was suggested to be linked to an increase in biomass, expanded fishing area, increased effort due to higher market prices and perhaps a reduction in predation by groundfish (Tremblay *et al.* 1994). The late 1990s saw continued growth in the fishery with 3,598 tonnes landed in 1999 (Biron *et al.* 2000b).

Management History in western Cape Breton

Area 19 is a rigorously managed crab fishing zone, and has an Integrated Management Plan issued in 1996 and which ran to 2001. This zone was among the first in Atlantic Canada to establish individual quotas (IQs) as a management tool in the early 1980s (Anon. 1996). These IQs were lowered in 1984 to increase the number of participants in the fishery and new license holders were gradually added as the zone experienced steady recruitment, including temporary and eventually commercial licenses in 1996 for aboriginal fishers (Anon. 1996). High market prices increased the number of fishers looking for access (DeGrâce *et al.* 2000).

Some of the main management issues in Area 19 include the protection of new recruits to the fishery, determining fishable biomass, and measures to share the resource (Anon. 1996). At-sea observers, covering just 0.61% of the fishery in 1999 (DeGrâce *et al.* 2000) were employed to take samples and monitor the condition of the catch. Dockside monitoring by a third party is also mandatory for all landings (Anon. 1996). Trawl surveys started in 1988 (Hébert *et al.* 2000) and were originally funded by DFO, but have been funded more recently by fishers from the area, who have realized that accurate biomass estimates directly affect them (Anon. 1996). The post season trawl surveys are also used to establish individual quotas (DeGrâce *et al.* 2000). Before the trawl surveys, recommendations on the fishery were completely based upon Leslie analysis, as in the rest of the Atlantic region (Biron *et al.* 1999). As the value of the fishery rises, so too do the demands for sharing of the resources, and all parties concerned make an attempt to ensure long term stability of the resource while attempting to accommodate the entire fishing community (Anon. 1996). Logbook submissions are also mandatory (DeGrâce *et al.* 2000).

Area 18 has management tools in place as did northwestern Cape Breton during the development of its snow crab fishery. Between 1991-1997, individual boat quotas were set based upon biomass estimates from a post season trawl survey (DeGrâce *et al.* 2000). The survey was not carried out after the 1997 season and quotas for 1998-1999 were established upon information from the fishery such as catch per unit effort and the amount of soft-shelled crab in the landings (DeGrâce *et al.* 2000). While any stock assessment advice during this period was taken with caution, the percentage of soft-shelled crab exceeded the total allowable amount (20% on two

consecutive two-day samples) several times and the fishery was closed and reopened on three occasions in 1998 (DeGrâce *et al.* 2000). In 1999, the post season trawl survey resumed and biomass estimates were considered more reliable (DeGrâce *et al.* 2000). Fishers logbooks submissions and at-sea sampling are also carried out in this area, and the combination of this information with direct abundance estimates are believed to be a powerful tool for stock assessment (DeGrâce *et al.* 2000).

Management History in eastern Cape Breton

Data are collected in logsheets from crab vessels as well as sales slips from crab buyers (Tremblay *et al.* 1994). At-sea samples were also collected regularly in Area 23 and irregularly in Areas 20-22 and 24 through the early years of the fishery (Late 1970s). After the downturn in the early 1980s, sampling was reduced to a few samples per season and in the 84/85 season only Area 23 was sampled (Tremblay *et al.* 1994). Reduced resources in the early 1990s prevented more extensive sea sampling as the fishery expanded (Tremblay *et al.* 1994). The mid-1990s saw substantial changes in management including mandatory logbook use (for effort and landings data), 100% dockside monitoring, fishery closure if soft-shelled landings reached 10%, at-sea monitoring, as well as a biodegradable panel on traps to help prevent ghost fishing (Biron *et al.* 2000b). Fishers in the area also volunteered more measures such as shortening the season, not fishing on Sundays and a reduction of the trap limit (Biron *et al.* 2000b).

In 1997, Individual Quotas were lowered to bring First Nations allocations to full quota status, and the first large-scale trawl was conducted prior to the season; this was unusual, as the rest of the Gulf employs post season surveys (Biron *et al.* 2000b). The trawl survey expanded from 150 stations in 1997 to 274 in 1999 (Biron *et al.* 2000b). In 1998, an industry-designed northern and southern partition of the fleet was incorporated into management, restricting fishers to one area. DFO-Science supports this distinction, stating that it better reflects the biological distribution of the stocks and recommends the use of these zones to manage in the future rather than the existing management zones (Biron *et al.* 2000b).

History of Information Source and Use

The flow of information sources for stock assessment in Cape Breton snow crab fisheries is illustrated in Figure 1 (D & E). In Cape Breton,

fishers are satisfied with current management practices set out by DFO. Usually dissatisfaction is noticed only when fishers without licenses request access to the snow crab fishery and are denied (Loch *et al.* 1994).

Logsheet returns as a percentage of all active fishers in eastern Cape Breton ranged from 35% in 1981 to 100% in 1978 and 1985, with a mean of 81% (Tremblay *et al.* 1994).

The Integrated Management Plan process attempts to include representatives from all sectors of the fishery. The Area 19 Snow Crab Working group is composed of licensed crabbers, processors/buyers, DFO, aboriginal bands, and representatives of 'core' fishers not holding licenses (Anonymous 1996). The voluntary management measures suggested by harvesters in eastern Cape Breton also indicate that fishers understand conservation concerns and want to be involved in some of the decision making (Biron *et al.* 2000b). Also, on the east coast of Cape Breton, studies are examining the depth and surficial geology of that coast in relation to crab populations, and DFO-Science staff have gathered information by meeting one on one with fishers in an interview setting to determine what they were looking for when searching for snow crab fishing grounds (Biron *et al.* 2000b).

Snow crab fishery of NAFO Division 4X

The snow crab fishery off southwestern Nova Scotia is the newest in the Atlantic region. In 1994, 130 kg landings were reported by exploratory fishers, increasing to 18 tonnes in 1995, 11 tonnes in 1996, down to 2 tonnes in 1997, but back up to 42 tonnes and 91 tonnes in 1998 and 1999 respectively (Biron *et al.* 2000a). Harvesting, in the most southerly limit for the distribution of the snow crab, began with only 4 licenses (Biron *et al.* 2000a). Increased data collection from the area is required so that justifiable catch limits can be recommended. Regulations have yet to be put into place; logbooks have been submitted since 1996 and a small percentage of landings are monitored dockside but there needs to be 100% dockside coverage, an observer program, and a defined season (Biron *et al.* 2000a).

History of Information Source and Use

In 1996, the exploratory fishers began submitting logbooks, but a full-scale survey was not performed until 1999. The exploratory trap survey carried out in 1999, consisted of DFO-Science biologists working aboard commercial vessels

(Biron *et al.* 2000a). This allowed fishers to witness the collection of data and firsthand knowledge of conservation concerns. The trap survey does not employ kriging (a statistical method in which an abundance estimate of an unsampled area can be inferred from several adjacent sampled areas) and therefore, biomass estimates in this region remain indirect (Biron *et al.* 2000a).

There has been a shift of knowledge in 4X (Figure 1F). Logbook submissions from exploratory fishers provided the main source of information when the fishery started in this region. In 1999, rather than extending an existing trawl survey, scientists began boarding commercial vessels to assess the stock and include fishers in the process. One would hope that if DFO begins a seasonal survey trawl in this area, traditional sources of information would continue to be used.

Herring fishery of east coast of Newfoundland

There are five main herring stock complexes, predominantly spring spawning, distributed along the east coast of Newfoundland (Anon. 1999b). Historically, these have supported commercial, food, and bait fisheries. Landings are reported back as far as 1834 and have ranged from 8,143 tonnes in 1862, to 76,225 tonnes in 1946 (Hourston and Chaulk 1968), and as low as 2,500 tonnes in 1996 (Winters *et al.* 1985).

Catch History

During the late 1940s, herring landings from Newfoundland averaged 55,000 tonnes (Anon. 1984). This was largely due to post Second World War II food requests from Europe. Though not much came from the east coast, about 7,000 tonnes of the maximum 85,000 tonnes total came from the province (Winters and Moores 1977). Through the 1950s and 1960s landings from the east coast were between 1,000 tonnes and 2,000 t, mainly for bait and feed (Winters and Moores 1977).

The southeast coast fishery came into prominence during the 1960s, while the northeast coast followed in the mid 1970s (Anon. 1999b). Landings through the 1970s were high (25,000 t) and attributable to a very strong 1968 year class, and the collapse of the North Sea and west coast of Canada herring stocks (Anon. 1999b).

All eastern stock areas were closed during the early 1980s due to poor recruitment after the 1968 year class (Wheeler and Chaulk 1987). They

were reopened in 1986 when a significant year class (that of 1982) became available (Anon. 1999b).

Herring roe on kelp, a significant fishery in British Columbia and mainly serving Asian markets, is at its early stages in Newfoundland, with 200 tonnes available within the current management plan to develop this fishery sector (Anon. 1999b).

Landings through the 1990s have been less than 5000 tonnes mainly due to poor market prices and reduced quotas, though 1997 saw a slight upturn, with landings of 7,900 tonnes (Wheeler *et al.* 1999).

Management History

The main quota areas are: southern Labrador (FA 2); White Bay-Notre Dame Bay (FA 3 & 4); Bonavista Bay-Trinity Bay (FA 5 & 6); Conception Bay-Southern Shore (FA 7 & 8); St. Mary's Bay-Placentia Bay (FA 9 & 10); and Fortune Bay and Pass Island to Cinq Cerf Bay (FA 11) (Anon. 1999b). Fixed gear fishers may fish only in their fishing area of residence, while mobile gear fishers may fish adjacent fishing areas also, areas 3-8 for more northern residents and 9-10 for those living in more southern bays (Anon. 1999b).

Quota regulations were placed in northeastern Newfoundland, initially on only a few gear types, then eventually on all gear types in 1980 (Anon. 1984). Southeastern areas had quotas slightly earlier in 1973 (Anon. 1984). Quotas were set to conserve the resource and maintain the spawning biomass (Anon. 1984).

Herring stocks were mostly unregulated through the early 1970s, thus providing more incentive for fishers to move in from outside the area, where early management initiatives had already started (Winters and Moores 1977).

The fishery was driven mainly by market conditions since the early 1980s, though effort is still controlled by a rarely met biological TAC (Anon. 1999b).

In 1995, new entrants were not permitted into the herring fishery (Anon. 1999b). In 1998, 2,189 fishers were licensed to harvest herring on a commercial basis, 1,951 for fixed gear, 238 for purse seine, along with 3,300 bait permits allowing the harvest of herring for use in other high value commercial fisheries (Anon. 1999b).

The Small Pelagics Advisory Committee, comprised of government and industry representatives, meets annually soliciting opinions on management measures, and providing recommendations for the coming seasons fishery (Anon. 1999b).

Five type of abundance indices were available in recent herring assessments: research gillnet catch rates; acoustic survey biomass estimates; commercial gill net catch rates; gill net fisher observations; and purse seine fisher observations (Anon. 1999b). The acoustic survey biomass estimates extend back to the early 1980s and purse seine observations are available since 1996 (Anon. 1999b). The research gill net program was terminated in Conception Bay- Southern Shore in 1997 & 1998, due to budget cuts (Wheeler *et al.* 1999).

For the most part, surveys to assess the abundance of herring are carried out independently of the fishery. Commercial fishers are contracted as 'index fishers' to collect samples and provide accurate daily logs (Wheeler *et al.* 1999). In 1998 23 fishers participated in the program (Wheeler *et al.* 1999). The 'index fishers program' has been ongoing since 1980 whether the fishery has opened or not, and has allowed the fishers to gain insight into the work of fisheries biologists, and provided biologists with knowledge of day-to-day issues of fishers as they pursue their livelihood (Wheeler *et al.* 1988).

Harvester observations are obtained through questionnaires in which herring abundance was estimated by the fishers. This is a fairly new initiative to increase collaboration between science and fishers and allow the latter a direct view at the assessment process (Anon. 1999b).

The Integrated Management Plan process has been applied to the herring fishery in this area. Its main objectives are to ensure conservation and protection of the herring stocks, to permit the continuation of the herring bait fishery, to develop an index fishery program whereby commercial fishers are used to enhance data collection, provide a greater industry/science cooperative effort, and to promote improved reporting practices to improve the quality and quantity of available data (Anon. 1999b). The multi-year management plan idea can be advantageous in providing stability to the fishing industry where processors and fishers may prepare for the long term; alternatively, the possibility of in-season adjustments is more difficult, even with annual consultations (Anon. 1999b).

Vessels are required to carry an at-sea observer when requested by DFO (Anon. 1999b). Air surveillance and vessel patrols are employed to enforce conservation and protection issues, such as the bycatch of salmon and groundfish in the traps, and under sized herring in the catch (Anon. 1999b).

Biological samples are collected every year by fishers as well as researchers. Samples are frozen and sent for analysis to the Northwest Atlantic Fisheries Centre. The aim is to have one sample per 500 tonnes of landings, by bay, month and gear type (Wheeler *et al.* 1999). In 1996, 96% of the catch was covered by the sample, mainly due to the high degree of cooperation from the fishers (Wheeler *et al.* 1999).

History of Information Source and Use

Figure 2(A) shows the shifts in sources of information for herring stock assessment in this region. Logbook use is a condition of license for vessel operators in this area (Anon. 1999b). Log use has been ongoing since the early history of the fishery though it was sporadic. Before 1900, the main source of 'catch' data was annual exports compiled in House of Assembly journals (Hourston and Chaulk 1968). Since 1965, logbook records and processing plant turnout data have been more readily available, including information on location and time of capture (Hourston and Chaulk 1968). Logs must provide information on catch and fishing activity (Anon. 1999b). Fishers submitting logs have been provided with a summary of the fishery in their area by personnel of the Pelagic section of DFO, once the data has been coded and analyzed (Wheeler *et al.* 1999).

The commercial gillnet logbook program started in 1996 and so far returns have been low, making it difficult to identify trends (Wheeler *et al.* 1999). In the first year, the returns accounted for 30% and 15% of the catch in White Bay- Notre Dame Bay and Bonavista Bay- Trinity Bay, respectively (Wheeler *et al.* 1999).

The commercial gillnet questionnaire also began in 1996, allowing fishers to contribute knowledge on abundance, fleet characteristics, as well as biological events like spawning. Almost 95% of all fishers were contacted by telephone in the 1996 fishery and 94% in 1997 (Wheeler *et al.* 1999). Each year three attempts were made to contact the remaining fishers (Wheeler *et al.* 1999).

The contribution of fishers to fisheries research through the questionnaires and index fishery

program is valuable, though it is important to remember that it must be combined with other assessment tools (Wheeler *et al.* 1988).

Herring fishery of west coast of Newfoundland

The herring fishery of western Newfoundland is comprised of two spawning stocks, though they are difficult to examine independently (McQuinn and Lefebvre 1997). Herring landings over the years have changed in response to the changes in effort placed upon the stock. Recently, TACs are very rarely met, as stocks are near the point of collapse, particularly spring spawners (McQuinn and Lefebvre 1999).

Catch History

Western Newfoundland herring stocks are comprised of spring and fall spawners (Moores and Winters 1984). Landings in the region remained near 15,000 tonnes during the late 1940s, though they were as high as 80,000 tonnes (Moores and Winters 1984). Through the 1950s and 1960s there has been a slight decline to around 6,000 tonnes for several years (Iles 1993). Through the 1970s the main fishery for herring existed out of Bonne Bay (Moores and Winters 1984). Landings through that decade ranged from 4,102 tonnes in 1970 to 26,701 tonnes in 1973 and to 14,811 tonnes in 1978 (McQuinn and Lefebvre 1995). Gillnet catch rates calculated from logbooks from index fishers and from industry records declined since 1987 (Anon. 2001a), however landings have varied, and appear to be climbing again into the 1990s; 21,400 tonnes in 1986, 15,100 tonnes in 1987 and 19,400 tonnes in 1993 (McQuinn and Lefebvre 1995). While landings have remained above 10,000 tonnes through out the 1990s (Anon. 2001a), in the last few years the spring spawning stock has been in danger of collapse (McQuinn *et al.* 1999).

Management History

Total allowable catches have been in effect since 1977 and since 1981 there have been allocations to the fixed and mobile gear sector (McQuinn and Lefebvre 1997). Since 1988, between 90 and 98% of the catch has been by purse seine (McQuinn and Lefebvre 1995), though approximately 45% of the TAC remains allocated for fixed gear (McQuinn and Lefebvre 1997). The advised target fishing level was reached only in 1991 (McQuinn and Lefebvre 1997).

Abundance estimates for herring are often carried out independently of the fishery, such as index

fishers and chartered commercial vessels (McQuinn and Lefebvre 1999). Biological samples of the commercial catch are collected by index fishers and by at-port samplers. These samples are frozen and sent to Mont-Joli, Quebec for analysis (McQuinn and Lefebvre 1997).

Distributional information is available from bottom trawl surveys and tagging studies are carried out in this region to help better define the management unit (McQuinn and Lefebvre, 1995). Acoustic surveys are also carried out in the area, normally every second year; these began in 1989 (McQuinn and Lefebvre, 1995).

History of Information Source and Use

Figure 2(B) show the shift in sources of information for stock assessment in this fishery. Logbook data mainly from index fishers has been regularly collected since 1984 and questionnaires are also used in the area (McQuinn and Lefebvre 1997). More recently, logbook return has been down and the information collected from the logs is not as reliable (McQuinn and Lefebvre 1997). The 1995 and 1997 acoustic surveys have been carried out in close collaboration with the seine fleet from the west coast (McQuinn *et al.* 1999).

Herring fishery of British Columbia (Prince Rupert, Central Coast and Queen Charlotte Regions)

Pacific herring (*Clupea harengus pallasi),* has been fished off British Columbia (BC) since 1877 (Anon. 2000b). It is exclusively a spring spawner and ranges from Korea to southern California (Stocker 1993).

Catch History

The herring fishery in BC began at the turn of the century (Anon. 2001b). The fishery expanded to the 1930s with demand for dry-salted product from China and from World War I relief (Anonymous 2000b), followed by a reduction fishery in the 1940s (Anon. 2001b). The 1960s saw the fishery collapse due to extensive overfishing and the commercial fishery closed in 1967 (Anon. 2001b). By the mid 1970s the stock had recovered and the fishery reopened gradually, a small roe fishery began in 1972, followed by other sectors throughout the 1970s (Anon. 2001b).

After the collapse of stocks in their countries, European herring fishers, came to British Columbia looking for fish, but by this time stocks had been fished out (Anon. 2000b). The

European fishers remained in the area until their stocks rebuilt in the late 1970s (Anon. 2000b).

The Prince Rupert herring fishery did very well in the 1950s and 1960s with landings averaging over 21,000 tonnes (Anon. 2001b). The 1970s, 1980s and 1990s have not seen average catches climb above 5,000 tonnes (Anon. 2001b). The Central Coast herring fishery had a similar pattern as Prince Rupert, with landings over 20,000 tonnes into the 1960s and drastically reduced through the 1970s to the 1990s though slightly higher, averaging nearer 7,000 tonnes per year (Anon. 2001c). Herring catches were first reported from the Queen Charlotte Islands in 1937, but due to its remote location, the fishery was intermittent until the 1950s (Anon. 2001d). Landings in the 1950s averaged 13,200 t, the 1960s and 1970s averaged 9,000 tonnes and 7,500 tonnes respectively and landings have averaged approximately 4,000 tonnes per year through the 1980s and 1990s (Anon. 2001d).

Management History

Quotas were used as far back as the 1930s though they were not very effective as extensions were nearly always granted (Stocker 1993). Enforceable quotas were first put into place in the region in 1988, though the catch has been more dependent on markets since then (Anon. 2000b).

The Prince Rupert herring fishery closed in 1953 and 1958 due to industry disputes and again in 1967 in an effort to rebuild the stocks (Anon. 2001b). The Central Coast fishery closed in 1979 and 1980 and has rebuilt into the 1990s (Anon. 2001c). The Queen Charlotte Islands fishery closed in 1994 and remained closed to commercial fishers until 1997. A small aboriginal food fishery was in place during this time (Anon. 2001d).

Management plans for each fishery sector are released in BC; there is a separate plan for roe on kelp, as well as food and bait. The main objectives of the 2000-2001 Food and Bait Herring Management Plan are to conserve and protect stocks and their habitat, to meet federal Crown obligations regarding aboriginal fisheries, and to develop sustainable fisheries through partnership and co-management so that many may share in decision making, responsibility, costs and benefits (Anon. 2000b). The management plans also serve to consider social, cultural and economic value of the fishery as well as health and safety (Anon. 2000b).

Management in BC is somewhat intensive and demands much of the scientists involved (Stocker 1993). The roe fishery demands extra attention as it is often conducted on or very near spawning grounds (Stocker 1993). Assessment is based upon two models, age structure and escapement, both measured by scientists with little involvement of fishers (Stocker 1993). Biological samples are normally collected pre-fishery by chartered vessels, dockside monitoring companies and DFO research vessels (Stocker 1993). Much like Nova Scotia, where in-season management is developing, DFO-Science must provide information in an accurate and timely manner (Stocker 1993).

Dockside monitoring is mandatory in British Columbia, and all vessels must carry a DFO approved observer at all times while carrying out fishing operations (Anon. 2000b). An accurate written log must be completed and mailed within seven days of offloading as a condition of license (Anon. 2000b).

History of Information Source and Use

There is a Herring Management Working Group in British Columbia, that works on in-season management strategies, restrictions on fishing periods, as well as quotas. The coordinator of this group must seek consensus from all sides of the herring industry before any decisions or recommendations are made (Stocker 1993). The general flow in the sources of information in these fisheries can be seen in Figure 2(C).

Herring fishery of coastal Nova Scotia/ Bay of Fundy

The Scotia Fundy herring fishery is the largest in the western Atlantic, and is predominantly made up of purse seiners (Stephenson *et al.* 1999). Landings in the region, since the early 1960s have been consistently above 100,000 t, with the largest peaks in the late 1960s and early 1970s as foreign interest in the area increased (Stephenson *et al.* 1998). Non quota catches during this time were often well above 50,000 tonnes before the 200 mile limit was introduced (Anon. 1981).

Catch History

The early importance of herring after European colonization was as a convenient source of bait for the important cod fisheries (Iles 1993). A meal industry developed through the 1950s, providing feed for the poultry industry and 60,000 tonnes were removed in 1966 to use exclusively for meal (Iles 1993). There was increased exploitation in

this region, along with the rest of the Atlantic region; foreign and Pacific Canadian herring fishers began harvesting here once their local stocks had collapsed in the late 1960s (Iles 1993).

The roe fishery has been the most important market component in recent years (Power and Stephenson 1990).

Management History

In 1968, a Ministry task force was appointed to test the validity of the estimates of the resource potential on which an extensive expansion to the east coast fishery was planned and in 1969 meetings were held in Halifax where the first quantitative evidence was presented suggesting that the Atlantic resource could not sustain heavy fishing pressure indefinitely (Iles 1993). From these meetings an Atlantic Herring Coordinator position was created, which was eventually incorporated into DFO due to departmental reorganization in 1972 (Iles 1993).

In 1971, the Atlantic Herring Management Committee was created to deal with scientific, economic and social aspects of management and recognize their interdependence. Throughout the 1970s and into the 1980s, this committee made recommendations on quotas, closure of spawning grounds and license issues (Iles 1993).

After 1977, the main assessment and management issues were addressed by CAFSAC (Iles, 1993). In 1981, the Atlantic Herring Management Committee was replaced by four federal departmental regions for eastern Canada where there would be more direct access and interaction within the local fisheries; eventually known as Small Pelagics Advisory Committees (Iles 1993).

Tagging programs have been in place in all of eastern Nova Scotia to obtain information on stock intermixing and herring migration; this was implemented by the Pelagics Research Council (Paul 1999). Tagging is normally done on specific trips rather than during fishing, and is normally more efficient that way (Paul 1999).

In-season management practices encourage surveying by the commercial fleet to ensure that effort is being distributed appropriately among the stock components (Anon. 2001e). In-season management requires improved data collection enabling modifications to management decisions to involve participants in the fishery (Stephenson *et al*. 1998).

In-season management decisions have been delegated to a Monitoring Working Group, formed in 1995, since it demands a high level of commitment, involvement and cooperation to obtain and report results in a rapid fashion (Anon. 1997b). The greater amount of work involved with in-season management is an advantage for the Nova Scotia herring fishery simply due to the increasing amount of information available (Anon. 1997b). It is important that the increased amounts of information be useful, so more and more rigorous survey designs are developed every year (Anon. 1997b). Longer term issues like economic viability and equitable distribution of fishing rights, which have fallen a little by the way-side due to the intensive in-season concentrations, are expected to emerge as the process continues (Stephenson *et al*. 1999).

'Survey, assess, then fish' is a protocol followed in this area, and is especially applicable to harvesting on or near spawning aggregations (Stephenson *et al*. 1998). Spatial patterns of the catch are determined from logbook information (Stephenson and Power 1990).

Conservation objectives in this region include maintaining the reproductive capacity in each management unit, to prevent growth overfishing and to maintain ecosystem integrity/balance (Stephenson *et al*. 1998).

The Bras D'Or Lakes region of Nova Scotia is one of particular interest due to the delicate nature of the stocks here and studies have been initiated to observe eggbeds, spawning and larval habitats (Denny *et al*. 1998). In 1996, there was field sampling, spawning ground surveys as well as a one on one interview survey of active fishers in the region (Denny *et al*. 1998). Landings in this area are determined by examining the records at ports (Denny *et al*. 1998). In response to the fragile nature of the Bras D'Or Lakes region strict regulations are added at every stage in the management process, such as enlarging the closed spawning areas and reducing the overall effort (Denny *et al*. 1998).

Government scientists are sometimes unsure of landings in this region, due to poor documentation of landings used for bait. However, after 1998 bait fishers were required to submit logbooks (Denny *et al*. 1998). There is little attention paid to developing management regimes that are capable of taking account of and reacting to uncertainty (Stephenson *et al*. 1999). There are countless areas where there is room for improvement in this herring fishery including

stock size estimation where larval abundance surveys are highly imprecise and stock structure estimation when assessments often concentrate upon spawning grounds, rather than entire stock region (Stephenson *et al.* 1999).

In 1997 an Integrated Management Plan was introduced for the region. Its main principles involve conservation of the resource and preservation of all its spawning components, as well as addressing the broad economic interests of fishers, processors and the interdependence of local communities on herring stocks throughout the region (Anon. 1997c). The management plan specifies allocations for particular gear types, dockside monitoring procedures and tagging programs (Anon. 1997c). The Scotia-Fundy Fisheries Herring Purse Seine Monitoring Committee, representing all aspects of the industry and DFO, takes a major role in this management plan, testing the practical application of co-management between DFO and the industry. The committee makes recommendations on a wide variety of issues such as conservation measures, license conditions, and research priorities. The committee member are also involved in decision making based on up to date information on the size of fish in the catch, the distribution of the catch, as well as physiological condition of the herring (Anon. 1997c).

A second Integrated Management Plan was released in 1999. This document outlined similar principles, although rules on enforcement were laid out more clearly and included reporting requirements, anti-dumping regulations, bycatch concerns, and gear regulations (Anon. 1999c).

History of Information Source and Use

This region has had many shifts in the main source of information used in stock assessment (Figure 2D). During the early 1970s, the Minister invited fishers to take part in developing proposals within the management constraints of the time. This was revolutionary as it was the first time fishermen were admitted as equal partners to the management forum (Iles 1993). The fishers felt that the only way to encourage cooperation was to devise a scheme that would equally apply to all fishers (Iles 1993).

In 1985, a detailed purse seine logbook was introduced and used through 1989. Returns were very good as completion of the logs was a condition of license (Stephenson *et al.* 1990). Before this, misreporting was fairly common; interestingly, misreporting decreased throughout

the season as it became clearer that TACs would not be met (Stephenson *et al.* 1987a). The main use of the logbooks is to track the progress of the fishery, the total catch and effort, but they are also useful in documenting the market and fish conditions (Power and Stephenson 1990).

In 1996 the Pelagics Research Council was created by the herring and mackerel fishing industry, because the fishers in question were interested in improving their involvement in research. They created a Science and Technology Internship program whereby people within the industry gain experience with techniques such as sampling, data recording, improved resource documentation, tagging, improved acoustic survey methods as well as ecology (Stephenson *et al.* 1998).

In 1997, new license conditions bait fishers to complete log records. Weekly logs had to be submitted annually and for commercial food fishers, daily logs had to be submitted weekly (Clark *et al.* 1999). Among the bait fishers, the minimum is usually all that is included in the logs, and fishers have offered no comments (Denny *et al.* 1998).

In 1998, 245 fixed gear herring fishers were interviewed in person, from 11 Nova Scotia counties, and asked mainly about changes in gear use over time (Clark *et al.* 1999).

Acoustic surveys to assess abundance are conducted on commercial vessels, and are occasionally supplemented by research vessels (Anon. 2001e).

Workshops take place in this region so participants from all sides of the fishery may contribute to discussions on conservation and management. Through the late 1990s there were several including, Maritimes Region Herring Workshop, Atlantic Zonal Herring Workshop and Herring Stock Assessment and Research Priorities Workshop, all in 1997 (Stephenson *et al.* 1998).

In-season management in Nova Scotia involved increased activity and industry involvement in decision-making, sampling and resource evaluation. Fishers and processors gained awareness and appreciation of biological and management issues and have shown enthusiasm about the reduction in the gap between the 'regulator' and the 'regulated' (Stephenson *et al.* 1999).

Local Ecological Knowledge

An example of the value of local ecological knowledge filling in some gaps in scientific information comes out of *Coasts Under Stress* research done in Labrador and on the Northern Peninsula of Newfoundland. Twenty-six interviews from retired fish harvesters made available a great deal of information on the Atlantic sturgeon. The Atlantic sturgeon is not a targeted species hence little government data exists, aside from some bycatch information. During interviews, harvesters were asked to indicate on a map (Figure 3) where they had seen sturgeon; they were also asked about sizes and the presence of young fish in their cod traps and other fishing gears. Two concentrations of juveniles were found; one near Gilbert bay, Labrador and one near Bonne Bay indicating the possible presence of two populations (Neis *et al.* 2001).

DISCUSSION

Information Flow

Figures 1 and 2 illustrate a very similar pattern. It is interesting that two fisheries, for quite different species, one of which being considerably 'older' than the other, show the same general pattern in information flow, as also indicated by the supporting literature. Early involvement of local fish harvesters as the source of data for stock assessment, is typically replaced by a governmental/scientific survey, upon which decisions about stock size are made. Finally, local experience is considered again in stock assessment and hence management. This pattern is also seen for Atlantic cod and other commercial species.

When searching for the 'ideal' fisheries management scenario, one would hope that all stakeholders within a fishery could have an equal opportunity to participate. In the 1970s, when Nova Scotia herring harvesters were invited by the Minister to take part in proposal writing within the management process, the fish harvesters felt that co-operation would be encouraged if the management and assessment scheme applied to all fishers equally (Iles 1993).

A series of workshops were held to develop an Integrated Management Plan for snow crab in Newfoundland. The workshops were attended by representatives from all fisheries sectors, most of whom agreed that final allocations of the crab stock ought to rest with DFO (Anon. 1999a).
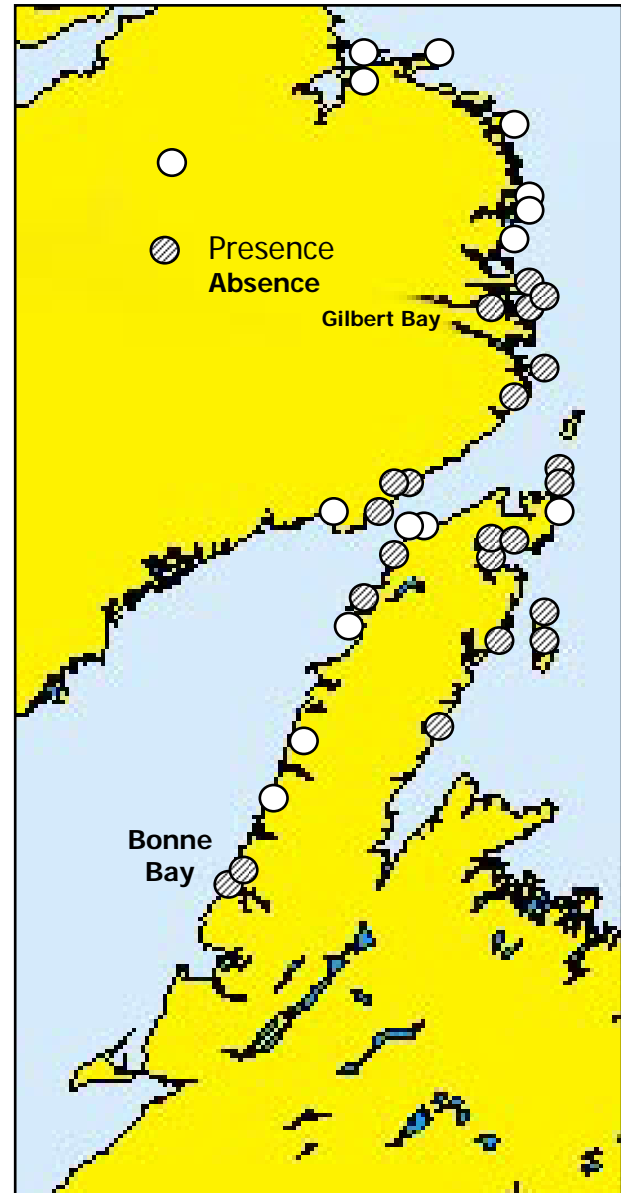
Figure 3: Map indicating presence or absence of Atlantic sturgeon as indicated by interviewed fish harvesters. Two possible populations can be seen near

It appears that the needed combination of fish harvesters and government science may not necessarily mean equal participation and input, but can increase understanding and awareness. Government sponsored acoustic surveys for herring onboard commercial vessels is an example of an exercise to increase such awareness (Anon. 2001e).

The scientific knowledge for each of these fisheries is rather sparse. Haedrich *et al.* (1998) provide numerous examples of how the scientific study of a species typically lags well behind the development of the fishery. The roundnose grenadier (*Coryphaenoides rupestris*) had nearly

been fished out in the North Atlantic during the late 1970s, almost ten years before there were any important biological papers and studies done on this species (Haedrich *et al.* 1998). In collecting stock status reports and historical reviews, etc. for snow crab and herring fisheries, just over sixty reports were found for both fisheries in all areas combined, many of which were updates of the previous years' status reports and offered little new information. While one probably wouldn't say that the science in each of these fisheries is weak, it could certainly be stronger, particularly with respect to the social concerns surrounding snow crab and herring.

Snow crab has become one of the most commercially important fisheries in Newfoundland since the Northern Cod Moratorium. It would seem obvious that stakeholders within the snow crab fishery would insist upon the very best research possible to back up the enormous financial hope placed upon the sustainability of this fishery. Herring has been fished in Atlantic Canada since the late 1800s and put to use in a wide variety of ways; this combined with its importance as a forage fish in the ecosystem, should necessitate clear biological studies to assess the health of this fishery.

Piecing together the source of data in stock assessment throughout the history of a fishery can have limitations. As previously mentioned, there is not much literature available which actually discusses stock assessment for these and other species, and it sparser as one looks back farther in time. This is a problem with much historical reconstruction, and in many cases data are not available simply because it was not recorded in the first place. Meagre data must also be spread over larger geographical areas than it was originally intended, increasing the likelihood of invalid assumptions about many features of the fishery in a particular area.

Sturgeon Distribution

If we are fortunate, fisheries management in the near future will consider the ecosystem as the most important management unit. While concerns about commercial species will probably always fuel the political aspects of fishery science, there is an increasing understanding of the importance of trophic interactions within the environment, and hence the study of under-utilised species is becoming more important.

Information collected during interviews about the Atlantic sturgeon, particularly the existence of possible spawning grounds, are data that would
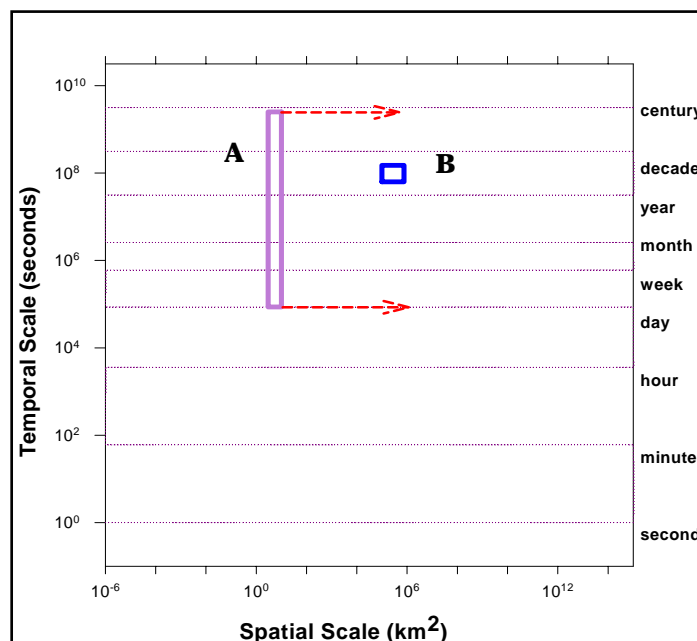
Figure 4: 'Scaling up' local ecological knowledge for possible use in ecosystem modelling. (A) Represents one interview, spanning up to 80 years, but covering less than 10 km² in area. (B) Represents an ecosystem model, spanning 2-5 years and covering a spatial area of up to 750,000 km². Arrows demonstrate how LEK could be aggregated to increase spatial scale.

not be held by government scientists. Data collected from resource users will be necessary to effectively reconstruct the local history of under-utilised species and supplement survey data for commercial species.

LEK and its application to BTF

Back to the Future work tends to be on large spatial scales. Ecosystem modelling in Northern British Columbia and on the Newfoundland and Labrador Shelf, among other areas, is very valuable to support the understanding of trophic interactions in those areas, within the context of very different fishing pressures during different periods of time.

The spatial scale of local ecological knowledge is quite narrow, but rather than dismiss such knowledge for use in ecosystem models, one can ask whether interview data could be aggregated to extend spatial scale.

Figure 4 illustrates the disparity in the spatial scales of local ecological knowledge compared with that of typical *Back to the Future* ecosystem models. While the extension of temporal scale is not as significant, the possible extension of spatial scale could be very useful. One retired fisher

could hold knowledge spanning more than fifty years of the fishing experience in a harbour or headland. It is conceivable that the familiarity of this harvester could be combined with that of adjacent harvesters to broaden the area over which the local ecological knowledge exists. At the very least, LEK could be added into ecosystem models, along with typical research data.

CONCLUSIONS

Local ecological knowledge is extremely important to the study of resource use, particularly in fisheries science. There have been many examples of fisheries reaching critically troubled states using complex stock assessment. Including knowledge from the people with the closest experience with the fishery with traditional assessment methods provides a far more tenacious picture of the state of the ecosystem in question.

Local ecological knowledge, collected through several methods, offers data on the movement of fish populations, stock structure and fish abundance (Hutchings, 1996). Semi-structured interviews allow for information collection on fish stock distinctiveness, movements and spawning behaviour, along with catch per unit of effort to indicate stock size more clearly (Neis *et al.* 1999).

The source of information used in stock assessment can be traced over the history of a fishery. Local ecological knowledge tends to dominate data used in stock assessment at the early stages of a fishery, and is commonly being used in establishing management schemes more recently, following a period of fisheries science that considered trawl survey data only. This trend is common to the fisheries of several commercial species, specifically snow crab and herring.

Critical data concerning aspects of non-commercial species can also be collected from resource users, and in fact exists in few other sources. Population structure of species like the Atlantic sturgeon, is important to consider when assessing the health of the entire marine ecosystem.

Local ecological knowledge may eventually be aggregated to extend its spatial scale, hence allowing it to be used in larger scale fisheries science applications, much like those of the *Back to the Future* research project.

REFERENCES

Anon. 1981. The management and utilization of Atlantic herring and mackerel in the 1980s- a discussion paper. DFO.

Anon. 1984. Future management of the herring fisheries of the Newfoundland and Labrador Region- A discussion paper.

Anon. 1996. Fisheries Management Plan. Area 19 snow crab 1996 to 2001. DFO. Integrated Fisheries Management Plan.

Anon. 1997a. Fisheries Management Plan. Area 12, 25-26 snow crab 1997-2002. DFO. Integrated Fisheries Management Plan.

Anon. 1997b. In-season management in the 4WX herring fishery. DFO Maritimes Regional Fisheries Status Report 97/2E.

Anon. 1997c. Fisheries Management Plan. Scotia-Fundy Fisheries Integrated Herring Management Plan 1997-1998. DFO. Integrated Fisheries Management Plan.

Anon. 1999a. Fisheries Management Plan. Newfoundland and Labrador snow crab fishery 1999-2001. DFO. Integrated Fisheries Management Plan.

Anon. 1999b. Fisheries Management Plan. Scotia-Fundy Fisheries Integrated Herring Management Plan 1999-2001. DFO. Integrated Fisheries Management Plan.

Anon. 1999c. Fisheries Management Plan. East and southeast coast of Newfoundland herring (NAFO divisions 2J3KLPs) 1999- 2000. DFO Integrated Fisheries Management Plan.

Anon. 2000a. East and Southeast Newfoundland Atlantic Herring. DFO Science Stock Status Report B2-01.

Anon. 2000b. Pacific Region 2000/2001 Management Plan-Food and Bait Herring. DFO Management Plan.

Anon. 2001a. 4VWX herring. DFO Science Stock Status Report B3-03.

Anon. 2001b. West coast of Newfoundland Atlantic Herring (4R)- Update 2000. DFO Science Stock Status Report B4-01.

Anon. 2001c. Prince Rupert Herring. DFO Science Stock Status Report B6-01(2001).

Anon. 2001d. Central Coast Herring. DFO Science Stock Status Report B6-02 (2001).

Anon. 2001e. Queen Charlotte Islands Herring. DFO Science Stock Status Report B6-03 (2001).

Biron, M., M. Moriyasu, E. Wade, P. DeGrâce, R. Campbell and M. Hébert. 1999. Assessment of the 1998 snow crab (*Chionoecetes opilio*) fisheries off eastern Nova Scotia (Areas 20 to 24 (and 4X)). DFO CSAS Res. Doc. 99/12.

Biron, M., R. Campbell and M. Moriyasu. 2000a. Historical review (1994-1998) and assessment of the 1999 exploratory snow crab (*Chionoecetes opilio*) fishery off southwestern Nova Scotia (NAFO Division 4X). DFO CSAS Res. Doc. 2000/018.

Biron, M., E. Wade, M. Moriyasu, P. DeGrâce, R. Campbell and M. Hébert. 2000b. Assessment of the 1999 snow crab (Chionoecetes opilio) fishery off eastern Nova Scotia (Areas 20 to 24). DFO CSAS Res. Doc. 2000/017.

Chiasson, Y.J., M. Hébert and M. Moriyasu. 1992. A retrospective look at the development and expansion of the Southwestern Gulf of St. Lawrence snow crab, *Chionoecetes opilio*, fishery. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1847.

Chiasson, Y., M. Hébert, P. DeGrâce, R. Campbell, E. Wade and M Moriyasu. 1995. Snow crab stocks in the southern Gulf of St. Lawrence. Can. Man. Rep. Fish. Aquat. Sci. No. 2314.

Clark, K.J., D. Rogers, H. Boyd and R.L. Stephenson. 1999. Questionnaire survey of the coastal Nova Scotia herring fishery. DFO CSAS Res. Doc. 99/137.

Dawe, E.G., D.W. Kulka, H.J. Drew, P.C. Beck and P.J. Veitch. 1999. Status of the Newfoundland and Labrador snow crab resource in 1998. DFO CSAS Res. Doc. 99/136.

DeGrâce, P., M. Hébert, E. Wade, A. Hébert, D. Giard, T. Surette, M. Biron and M. Moriyasu. 2000. Assessment of the 1999 snow crab (*Chionoecetes opilio*) fisheries off western Cape Breton (Areas 18 and 19). DFO CSAS Res. Doc. 2000/015.

Denny, S., K.J. Clark, M.J. Power and R.L. Stephenson. 1998. The status of the herring in the Bras D'Or Lakes in 1996-1997. DFO CSAS Res. Doc. 98/80.

Haedrich, R.L., N.R. Merrett and N. O'Dea. 1998. Can ecological knowledge catch up with deep-water fishing? ICES CM O:37, Deepwater Fish and Fisheries.

Hare, G.M. and D.L. Dunn. 1993. A retrospective analysis of the Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) fishery. Can. Bull. Fish. Aquat. Sci. 226: 177-192.

Hébert, M., E. Wade, P. DeGrâce, A. Hébert, M. Biron and M. Moriyasu. 1999. The 1998 assessment of snow crab, *Chionoecetes opilio*, stock in the southern Gulf of St. Lawrence (Areas 12-25/26, 18, 19, E and F). DFO CSAS Res. Doc. 99/11.

Hébert, M., A. Hébert, E. Wade, T. Surette, D. Giard, P. DeGrâce, M. Biron and M. Moriyasu. 2000. The 1999 assessment of snow crab, *Chionoecetes opilio*, stock in the southwestern Gulf of St. Lawrence (Areas 12-25/26, E and F). DFO CSAS Res. Doc. 2000/014.

Hourston A.S. and R. Chaulk. 1968. Herring landings and catches in Newfoundland and their implications concerning the distribution and abundance of the stocks. Fish. Res. Brd. Can. Tech. Rep. No. 58.

Hutchings, J. A. 1996. Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock collapse. Can. J. Fish. Aquat. Sci. 53: 943-962.

Iles, T.D. 1993. The management of the Canadian Atlantic herring fisheries. Can. Bull. Fish. Aquat. Sci. 226: 123-150.

Leslie, P.M. and D.H.S. Davis. 1939. An attempt to determine the absolute number of rats in a given area. J. Anim. Ecol. 8: 94-113.

Loch, J.S., M. Moriyasu and J.B. Jones. 1994. An improved link between Industry, Management and Science: a case history- the southern Gulf of St. Lawrence snow crab fishery. ICES C.M. 1994/T: 46.

Mallet, P., R. Campbell and M. Moriyasu. 1993. Assessment of the 1992 snow crab (*Chionoecetes opilio*) exploratory fishery in Bay of Islands, western coast of Newfoundland. Can. Man. Rep. Fish. Aquat. Sci. No. 2189.

McQuinn I.H., and L.Lefebvre. 1995. A Review of the west coast of Newfoundland (NAFO division 4R) herring fishery data (1973 to 1994). DFO Atl. Fish. Res. Doc.95/56.

McQuinn, I.H. and L.Lefebvre. 1997. An assessment of the west coast of Newfoundland (NAFO division 4R) herring stocks (1973 to 1994). DFO Atl. Fish. Res. Doc. 97/116.

McQuinn, I.H. and L.Lefebvre. 1999. An evaluation of the western Newfoundland herring acoustic abundance index from 1989-1997. DFO CSAS Res. Doc. 99/120.

McQuinn, I.H., M. Hammill and L.Lefebvre. 1999. An assessment and risk projections of the west coast of Newfoundland (NAFO division 4R) herring stocks (1965 to 2000). DFO CSAS Res. Doc. 99/119.

Moores, J.A. and G.H Winters. 1984. Migration Patterns of Newfoundland west coast herring, *Clupea harengus,* as shown by tagging studies. J. Nrthw. Alt. Fish. Sci. 5: 17-22.

Neis, B. , D.C. Schneider, L. Felt, R.L. Haedrich, J. Fischer and J.A. Hutchings. 1999. Fisheries assessment: what can be learned from interviewing resource userd? Can. J. Fish. Aquat. Sci. 56: 1949-1963.

Neis. B., C. Palmer, D. Ings, K. Gosse and H. Chaffey. 2001. CUS Arm 2 Presentation. Taxonomy Interviews.

Paul, S.D. 1999. Report of the 1998-1999 4VWX herring and mackerel tagging program and plans for 1999-2000. DFO CSAS Res. Doc. 99/138.

Power, M.J. and R.L Stephenson.1987. An analysis of logs from the 4X summer purse seine fishery. DFO CAFSAC Res. Doc. 87/77.

Power, M.J. and R.L. Stephenson. 1990. Logbook analysis for the 4WX herring purse seine fishery, 1985-1989. DFO CAFSAC Res. Doc. 90/53.

Stephenson, R.L., D.J. Gordon and M.J. Power. 1987a. Herring of the outer Scotian Shelf and Georges Bank: History of the fisheries, recent developments and management considerations. DFO CAFSAC Res. Doc. 87/76.

Stephenson, R.L., M.J. Power and T.D. Iles. 1987b. Assessment of the 1986 4WX herring fishery. DFO CAFSAC Res. Doc. 87/75.

Stephenson R.L., K rodman, D.G Aldous and D.E. Lane. 1999. An inseason approach to management under uncertainty: the case of the SW Nova Scotia herring fishery. ICES Journal of Marine Science, 56: 1005-1013.

Stephenson, R.L. and M.J. Power. 1990. A summary of the 4Vn herring fishery. DFO CAFSAC Res. Doc. 90/51.

Stephenson, R.L., M.J. Power and W.H. Dougherty. 1990. Assessment of the 1989 herring fishery. DFO CAFSAC Res. Doc. 90/50.

Stephenson, R.L, M.J. Power, K.J. Clark, G.D. Melvin, F.J. Fife and S.D. Paul. 1998. 1998 evaluation of 4VWX herring. DFO CSAS Res. Doc. 98/52.

Stocker, M. 1993. The management of the Pacific herring fishery. Can. Bull. Fish. Aquat. Sci. 226.: 267-293.

Taylor, D.M. and P.G. O'Keefe. 1989. Assessment of the Newfoundland snow crab, *Chionoecetes opilio*, fishery- 1988. CAFSAC Res. Doc. 89/69.

Taylor, D., P.G. O'Keefe and C. Fitzpatrick. 1994. A snow crab, *Chionoecetes opilio* (Decapoda, Majidae), fishery collapse in Newfoundland. Fishery Bulletin 92: 412-419.

Taylor, D.M. and P.G. O'Keefe. 1998. Assessment of the 1997 Newfoundland and Labrador snow crab fishery. DFO CSAS Res. Doc. 98/140.

Taylor, D. and P.G. O'Keefe. 1999. Assessment of the 1998 Newfoundland and Labrador snow crab fishery. DFO CSAS Res. Doc. 99/143.

Tremblay, M.J., M.D. Eagles and R.W. Elner. 1994. Catch, effort and population structure in the snow crab fishery off eastern Cape Breton, 1978-1993: a retrospective. Can. Tech. Rep. Fish. Aquat. Sci. 2021.

Wheeler, J.P. and R. Chaulk. 1987. Newfoundland east and southeast coast herring- 1986 assessment. DFO CAFSAC Res. Doc. 87/60.

Wheeler, J.P., G.H. Winters, and R. Chaulk. 1988. Newfoundland east and southeast coast herring-1987 assessment. DFO CAFSAC Res. Doc. 88/74.

Wheeler, J.P., B. Squires and P.Williams. 1999. Newfoundland east and southeast coast herring- an assessment of stocks to the spring of 1998. DFO CSAS Res. Doc. 99/13.

Winters, G.H. and J.A Moores. 1977. Assessment of yield potential of eastern Newfoundland herring stocks. DFO CAFSAC Res. Doc. 77/12.

Winters, G.H., E.L. Dalley and J.A. Moores. 1985. Fortuity disguised as fisheries management: the case history

of Fortune Bay herring. Can. J. Fish. Aquat. Sci. 42(Sup. 1): 263-274.

Appendix 1: Key to Figures 1 and 2

$ The dollar sign illustrates an information source that is mostly economical, such as export data.

 The logbook symbol illustrates fishers' logs or other types of directed input.

 The ship illustrates a government science directed survey**.**

 The fish symbol represents government science and resource users working together, such as a science survey onboard a commercial vessel.

 The microphone symbol illustrates an interview or input from fish harvesters which is more free flowing.

REVISED MODELS FOR NEWFOUNDLAND FOR THE TIME PERIODS 1985-87 AND 1995-97

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ABSTRACT

This paper updates the models for Newfoundland (NAFO Div. 2J, 3K, 3L, 3N and 3O) for 1985-87 and 1995-97. Data obtained from previous models, DFO-Newfoundland, stock status report, and other literature, were used to update the 1985-87 and 1995-97 models for this area. Comparisons between the Newfoundland, Eastern Scotian Shelf, northern Gulf of St. Lawrence and southern Gulf of St. Lawrence models were used to calibrate some of the values used in the Newfoundland models. The models were finally reduced to 30 compartments for comparison between the Newfoundland, Eastern Scotian Shelf and Gulf of St. Lawrence.

INTRODUCTION

Five mass-balance trophic models of Newfoundland (NAFO Div. 2J, 3K, 3L, 3N, and 3O) have been constructed since 2000 (Bundy *et al.* 2000; Heymans and Pitcher, 2002b; a), covering four different time periods: 1450; 1900; 1985-87 (called '1985') and 1995-97 (called '1995'). The last two models are updated in this paper using the model structure given in Heymans and Pitcher (2002a) and data from Bundy *et al.* (2000) as well as new data obtained from DFO Newfoundland and the literature.

The first model constructed for 1985 by Bundy *et al.* (2000) consists of 31 compartments, and made use of the extensive knowledge of the three authors. The second model, constructed by Heymans and Pitcher (2002a), consists of 50 compartments, and was constructed in a similar fashion to their model for 1995. The models constructed by Heymans and Pitcher (2002a) for 1985 and 1995 both used diet and biomass estimates obtained from George Lilly *(pers. comm.,* DFO-Newfoundland), without the changes made by Bundy *et al.* (2000) for catchability and using the same SAUP database (Anon 2003a) for catches in both models. In this paper, the biomass, P/B and Q/B ratios and catch estimates used by Bundy *et al.* (2000) were substituted for those compartments also occurring in the 1985 model (Heymans and

Pitcher 2002a) and the model was rebalanced. New estimates of P/B and Q/B obtained from the literature, stock status reports, and DFO scientists were used to update the 1995-97 model.

These models were also reduced to 30 compartments for comparison with other models constructed for the Gulf of St. Lawrence and the Eastern Scotian shelf by Bundy (*in press*), Morissette *et al.* (2003), Savenkoff *et al.* (*in press*) and Bourdages *et al.* (*in press*).

METHODOLOGY

1985-1987:

For comparative purposes with other models on the East Coast of Canada an estimate of bacterial respiration was added as alternative input to the model. According to Silverman *et al.* (2000), the burial rate of detritus in Eastern Canadian waters is approximately equivalent to 4.5% of primary production, or 113 $t•km^{-2}•year^{-1}$ in 1985. By adding this burial of detritus to the detritus consumed and subtracting that from the egestion, a respiration estimate of 755 $t•km^{-2}•year^{-1}$ for bacteria in the detritus was calculated for this model.

The biomass estimated by Bundy *et al.* (2000) for adult and juvenile cod, American plaice and Greenland halibut were substituted for that estimated by Ecopath in Heymans and Pitcher (2002a). Similarly, the biomass estimates of skates, redfish, capelin, sandlance, Arctic cod, shrimp, large and small zooplankton used by Bundy *et al.* (2000) were substituted into the Heymans and Pitcher (2002a) model. Bundy *et al.* (2000) estimate that the biomass of large crustaceans (including adult and juvenile crabs and lobster) is 3.55 $t•km^{-2}$, large crabs 0.175 $t•km^{-2}$ and lobster 0.005 $t•km^{-2}$, thus the biomass of small crabs would be 3.37 $t•km^{-2}$.

Additionally, the annual P/B estimates of various species were changed to be similar to those given by Bundy *et al.* (2000): adult and juvenile cod (0.65 and 0.6), adult and juvenile American plaice (0.54 and 0.63), adult and juvenile Greenland halibut (0.3 and 0.87), redfish (0.33), skates (0.29) and small pelagics (0.28). Consumption/Biomass ratios for some species were also substituted for values obtained from Bundy *et al.* (2000): adult and juvenile plaice (1.262 and 3.736), juvenile Greenland halibut (3.401), capelin (6.4), small pelagics (1.767) and transient pelagics (3.33).

Subsequent to comparing the Newfoundland models to those constructed for the Eastern Scoatian Shelf and the Gulf of St. Lawrence by the CDEENA project (Bundy *in press*, Morissette *et al.* 2003, Savenkoff *et al. in press* and Bourdages *et al. in press*), some other changes were made to the P/B and Q/B ratios:

- The annual P/B and Q/B estimates of juvenile demersals and juvenile piscivorous demersals were both set to be similar to that of the small demersals (0.564 and 4.5 respectively);

- For adult piscivorous demersals the annual P/B ratio seemed to be very low. It was taken from Bundy *et al.* (2000), but here we used their natural mortality (0.1 year^{-1} from Appendix Table A1 in Heymans and Pitcher 2002b) plus fishing mortality instead. The annual P/Bs for 1985 and 1995 were then 0.6 and 0.2 respectively. However, the 1985 value was very high, and as we have no estimate of catchability, we reduce it to 0.3 during that period;

- The annual gross efficiency (GE) of dogfish was too high, so their Q/B was reduced to 2.6 obtained for BC waters (Jones and Geen 1977);

- The annual GE of small zooplankton was too high, so we set it at 0.3 and let the model estimate the Q/B ratio;

- The annual Q/B and P/B estimates for large and small crabs were assumed to be the same as that of lobster in the model of Heymans and Pitcher (2002a). However, after comparison to the estimates for the Gulf of St. Lawrence models (Morissette *et al.* 2003 and *in press*), these values were reduced. The annual P/B estimates for large and small crabs were 0.16 and 0.3 respectively (with the range between 0.2 and 0.429) and the Q/B estimates for large and small crabs were 1.2 and 1.5 respectively;

- The annual P/B and Q/B estimates for grey seals were substantially higher than the other models. Grey seals are known not to frequent the Newfoundland ecosystem anymore, although they were found there around the time of European contact. We therefore use the annual P/B (0.12) and Q/B (11.8) estimates of grey seals from the Eastern Scotian Shelf model (Bundy *in press*).

The catch estimates of groups that were similar to the two models used by Bundy *et al.* (2000) were also substituted into the model constructed by Heymans and Pitcher (2002a). The catch estimates in Heymans and Pitcher (2002a) were obtained from the SAUP catch database (Anon 2003a), which is divided into gear types. However, the total catch estimates obtained from

that database were different from those given in Bundy *et al.* (2000). For cod, flounders, redfish, capelin, herring, lobster, snow crab, bivalves and shrimp, the total catch given in Bundy *et al.* (2000) was therefore prorated to the gear types used in Heymans and Pitcher (2002a). Bundy *et al.* (2000) also estimates the discards of cod at 9,563 tonnes, which was not included in the Heymans and Pitcher (2002a) model. In addition, the discards of yellowtail flounder (516 tonnes), witch flounders (20 tonnes) and redfish (1,199 tonnes) given in Bundy *et al.* (2000) were added to the catch of bottom trawlers.

The catch of Greenland halibut in the Heymans and Pitcher (2002a) model is similar to the total catch plus discards (of juveniles from shrimp trawlers) in the Bundy *et al.* (2000) model. The discards are thus taken from the bottom trawler catch and added to the discards of juveniles. For American plaice, Bundy *et al.* (2000) had a similar catch for adults as in Heymans and Pitcher (2002a), but an additional 0.025 t•km^{-2}.y^{-1} of juvenile plaice was discarded in their model. The catch of mackerel given by Bundy *et al.* (2000) was less than the catch obtained from the SAUP database (Anon 2003a), but was only for area 2J3KL, so the SAUP catch was kept in the model.

The large demersal fish group of Bundy *et al.* (2000) was divided into large demersal bentho-pelagic piscivores and other large demersals by Heymans and Pitcher (2002a). The total catch for these two groups were higher than the catch obtained by Bundy *et al.* (2000), but discards were not included. Thus, the 21,604 tonnes estimated by Bundy *et al.* (2000) was prorated by group and gear, with the discards (4,285 tonnes) added to the bottom trawl fleet. There was also a small discard (44.1 tonnes) of small demersals by the shrimp fleet (Bundy *et al.*, 2000), that was added to the Heymans and Pitcher (2002a) model. For all other groups the catch obtained from the SAUP database (Anon 2003a) was kept in this updated model, either because these groups were not defined in Bundy *et al.* (2000), or because it was not possible to assign the catch to the same groups. The total catch including discards given by Bundy *et al.* (2000) was 643,005 tonnes (1.3 t•km^{-2}•year^{-1}), while that obtained from these changes to the Heymans and Pitcher (2002a) model was 647,017 tonnes (also approximately 1.3 t•km^{-2}•year^{-1}). Table 1 shows the updated catch and discard by gear type.

The diets obtained from the unbalanced Heymans and Pitcher (2002a) model (Appendix B Table 2) were used, and changed to balance the model. In

that report (page 23) changes were made to the diet matrix to expand the consumption of salmon, large crabs and lobsters. These changes were also incorporated into the model. The predators of salmon were expanded to include cetaceans (0.1%), grey seals (0.2%), piscivorous birds (0.04%), skates (0.1%) and transient pelagics (0.1%). Large crabs were consumed by grey (0.1%), harp (0.01%) and hooded (0.1%) seals and large cod (0.1%). Lobsters were consumed by walrus (0.01%), large cod (0.01%), skates (0.01%), large demersal piscivores (0.1%) and other large demersal fish (0.01%).

Finally, the diet of sandlance in the Heymans and Pitcher (2002a) model was obtained from Bundy *et al.* (2000), which had used data from the 1970s for the Eastern Scotian Shelf. However, newer data for Georges Bank in the 1980s and the Eastern Scotian Shelf in the 1990s were obtained from Bundy (*in press*) and included here. The 1985 diet included benthic invertebrates (3.9%), large zooplankton (20.9%), small zooplankton (71.2%) and detritus (4%).

Some groups had annual gross efficiencies (GE's) outside the 0.1 to 0.3 range that is usual for marine species:

- The annual GE of lumpfish was 0.08, while the P/B was 0.1143. We assumed a GE of 0.15 and let Ecopath estimate a new P/B of 0.206 as the fishing mortality could be underestimated;
- The annual GE of transient mackerel was 0.07 and while the Q/B of this species was obtained from FishBase we let Ecopath estimate it by assuming an GE of 0.15, which estimates a Q/B of 1.93;
- The annual GE for dogfish (0.07) was still too low, even after the Q/B was reduced. We therefore let Ecopath estimate the Q/B by assuming a GE of 0.1. The Q/B was estimated at 1.93;
- The annual GE for juvenile Greenland halibut was less than 0.1 when using the annual P/B from the unbalanced model in Bundy *et al.* (2000). However, when the balanced model's P/B of 0.87 is used the GE increases to 0.26;
- The annual GE of juvenile cod was less than 0.1, while the P/B was 0.6, from the unbalanced model in Bundy *et al.* (2000). They had increased the P/B to 1.6, which gives a GE of 0.26;
- The annual GE of adult American plaice was too high, because the Q/B of the unbalanced model in Bundy *et al.* (2000) was used. By increasing the Q/B to 2.0, similar to the balanced model, the GE decreased to 0.27;

- The annual GE of adult cod and adult Greenland halibut were 0.33 and 0.34 respectively. The Q/B of adult cod had been reduced from 3.24 in the Heymans and Pitcher (2002a) model to 2, but it is now estimated by assuming a GE of 0.25 at 2.6. The P/B of adult Greenland halibut was reduced from 0.5 to 0.3 in the balanced model of Bundy *et al.* (2000). We use the same value in balancing our GE.

Balancing the model

When the abovementioned changes were made to the model, it was unbalanced and Table 2 shows the Ecotrophic efficiencies of the unbalanced groups.

Detritus

The respiration of detritus included in this model increased its ecotrophic efficiency to above one. We therefore reduced the respiration of detritus to 680 t•km^{-2}•year^{-1} to balance. This respiration of bacteria was excluded when comparing this new model to the previous models constructed for this area (Heymans and Pitcher 2002a and b).

Shrimp

The highest ecotrophic efficiency was for shrimp, which was consumed mainly by small demersals. The Q/Bs of juvenile planktivorous and piscivorous demersals were set to be equal to that of other small demersals (4.5), which was probably too high, and was then reduced to 4.0 to reduce the consumption of shrimp by small demersals. The other species that consume large quantities of shrimp is small crab. This was then reduced to 1% (from 5%) as not all the small crabs are juvenile snow crabs. The consumption of echinoderms by small crabs was increased to 9% from 5% to compensate for this. It was decided to let Ecopath estimate the biomass of shrimp at this time - it was estimated at 1.173 t•km^{-2}.

Juvenile cod

Juvenile cod had a biomass of 0.094 t•km^{-2} and a P/B of 1.6 in this version of the model. However, Bundy *et al.* (2000) increased the biomass to 0.34 t•km^{-2} to balance, and we did the same, which reduced the ecotrophic efficiency to 1.435. To balance juvenile cod, the diet of shortfin squid was revised by reducing the percentage of cod in the diet to 10% and increasing the percentage of Arctic cod to 1%, that of small mesopelagics to 5% and Arctic squid to 11.6%.

Table 1: Catch (t•km^{-2}•year^{-1}) and discards (t•km^{-2}•year^{-1}) from for the 1985-87 model of Newfoundland (2J3KLNO).

Group Name	Seal hunt	Bottom trawl	Midwater trawl	Mobile Seine	Surround net	Gill and Entangling	Hook and Line	Traps and Liftnets	Dredges	Other gear	Discards Bottom trawl	Discards Gill entangling	Total catch + discards
Walrus													0.000000
Cetaceans													0.000000
Grey seals													0.000000
Harp seals	0.000900											0.00213	0.003030
Hooded seals	0.000179												0.000179
Ducks	0.000014												0.000014
Piscivorous Birds	0.000810												0.000810
Planktivorous Birds	0.000176												0.000176
Adult cod		0.410628	0.000733	0.000585		0.058662	0.038887	0.065689		0.008717		0.019319	0.603220
Juv. cod													0.000000
Adult American plaice		0.095589	0.000086	0.000112		0.00587	0.000276	0.000147	0.000002	0.000007			0.102089
Juv. American plaice												0.025	0.025000
Adult Greenland halibut		0.016564	0.000013			0.018409	0.000057	0.00004		0.000001			0.035084
Juv. Greenland halibut												0.002	0.002000
Yellowtail flounder		0.050621	0.000012	0.000154			0.000022			0.000002		0.001042	0.051853
Witch flounder		0.023614	0.000234	0.000017		0.000967	0.000006	0.000002		0.000002		0.00004	0.024882
Winter flounder		0.000209				0.002296	0.000042	0.000079					0.002626
Skates		0.034066	0.002661			0.000303	0.000028	0.000004					0.037062
Dogfish		0.000133	0.000117										0.000250
Redfish		0.139242	0.035547			0.000476	0.000001	0.000001		0.000001		0.002422	0.177690
Transient mackerel			0.00004		0.015886	0.001385	0.000007	0.000636		0.000332			0.018286
Adult Dem. piscivores		0.010186	0.000347	0.00005		0.00203	0.00539	0.000004		0.000009		0.003573	0.021589
Juv. Dem. piscivores													0.000000
Adult Dem. Feeders		0.024997	0.000034	0.000044		0.000402	0.000118	0.000028		0.000004		0.005083	0.030710
Juv. Dem. Feeders													0.000000
Other small demersals												0.000089	0.000089
Lumpfish													0.000000
Greenland cod						0.000005	0.000013	0.000002					0.000020
Salmon						0.001797	0.000019	0.00004		0.001692			0.003548
Capelin		0.000031	0.056516		0.023674	0.00001		0.045753					0.125984
Sandlance		0.000083											0.000083
Arctic cod													0.000000
Herring		0.000012			0.012677	0.004934	0.000002	0.000557					0.018182
Transient pelagics							0.000708			0.000007			0.000715
Small pelagics		0.000025	0.000059			0.000018	0.000014	0.000003		0.001556			0.001675
Mesopelagics													0.000000
Shortfin squid		0.000763	0.000001				0.000392	0.000006					0.001162
Arctic squid													0.000000
Large crabs						0.000024		0.014321					0.014345
Small crabs													0.000000
Lobster								0.001416					0.001416
Shrimp		0.003093											0.003093
Echinoderms													0.000000
Polychaetes													0.000000
Bivalves										0.000244			0.000244
Other benthic inverts.													0.000000
Total	0.002079	0.809856	0.096400	0.000962	0.052237	0.097588	0.045982	0.128728	0.000246	0.012330	0.058568	0.002130	1.307106

Table 2: Ecotrophic efficiencies of unbalanced groups in the 1985 model.

#	Group	Ecotrophic efficiency
10	Juvenile cod	5.553
14	Juvenile Greenland halibut	2.038
20	Redfish	2.368
31	Sandlance	1.339
40	Small crab	1.664
41	Lobster	1.544
42	Shrimp	6.836
47	Large zooplankton	1.051
48	Small zooplankton	1.316
50	Detritus	1.046

At that stage the biomass of juvenile cod was then estimated by the model at 0.377 t•km^{-2}, which is slightly higher than the 0.34 t•km^{-2} estimated by Bundy *et al.* (2000).

Juvenile Greenland halibut

Juvenile Greenland halibut biomass was 0.165 t. km^{-2}, which was lower than the 0.5 t•km^{-2} in Bundy *et al.* (2000). We let Ecopath estimate a biomass (0.3624 t•km^{-2}) by assuming an ecotrophic efficiency of 95%.

Redfish

The consumption of redfish by skates was reduced to 5% to decrease the ecotrophic efficiency of that group, and the proportion of echinoderms and bivalves was increased to 1% while that of other benthic invertebrates was increased to 9.82%. The biomass of redfish was then estimated at 2.011 t•km^{-2}, only marginally higher than the 1.876 t•km^{-2} estimated by Bundy *et al.* (2000).

Small crabs

The consumption of small crabs by juvenile planktivorous demersals was reduced to 5% (from 9%) to balance small crabs, while their consumption of bivalves increased to 7.28%. The consumption of small crabs by skates was also reduced (to 15%), while skates consumed more echinoderms (5%) and bivalves (3.6%). The P/B of small crabs was reduced to 0.3 above, but we increased it to 0.38 again (similar to lobster in Bundy *et al.* 2000) to balance small crabs.

Lobster

Lobster was balanced by removing the consumption of large cod on lobster and reducing the consumption of large demersal piscivores to 0.01% and increasing the echinoderms to 0.4%.

Sandlance

The biomass of sandlance (2.7 t•km^{-2}) was estimated in Bundy *et al.* (2000) as well as in this model (2.934 t•km^{-2}).

Large and small zooplankton

Using the biomass of large and small zooplankton the unbalanced model obtained from Bundy *et al.* (2000) gives ecotrophic efficiencies of large and small zooplankton at 1.27 and 1.37 respectively. Bundy *et al.* (2000) balanced their model with biomass estimates of 22.5 t•km^{-2} and 33.7 t•km^{-2} respectively. Using those values in our model, the ecotrophic efficiencies were reduced to 1.1 and 1.02 respectively. The main consumer of small zooplankton was large zooplankton, while capelin was an important consumer of both small and large zooplankton. The diet of capelin was adapted to be more similar to that given in Bundy *et al.* (2000) with cannibalism at 2.5%, 0.5% sandlance and large and small zooplankton at 43.4% and 53.6% respectively. At first the Q/B ratio of capelin was reduced from 6.4 to 4.3 similar to the balanced model in Bundy *et al.* (2000), however, to be consistent between ecosystems, the Q/B was kept at 6.4, and the biomass of large and small zooplankton was estimated at 27.5 t•km^{-2} and 41.78 t•km^{-2} respectively.

Final balancing

After these compartments were balanced, the detritus pool ecotrophic efficiency also increased to above 1. To balance the detritus, the respiration of detritus was reduced to 510 t•km^{-2}•year^{-1}, which reduced the ecotrophic efficiency of detritus to 0.997. Similarly, the biomass of shrimp estimated above (1.17 t•km^{-2}) was not sufficient to feed their predators. The main predator of shrimp was harp seals, and rather than change the diet of that species, I decided to look at the P/B ratio. Bundy (*in press*) used a P/B of 1.7, which is higher than the 1.45 used in Bundy *et al.* (2000), so I use this value and let Ecopath calculate the biomass at 1.15 t•km^{-2}. The new input data for the adapted model are given in Table 3, the new diet matrix in Table 4 and the data pedigree in Table 5. The pedigree of the data are coded statements categorizing the origin of the data and specifies its associated uncertainty (Christensen *et al.* 2000). The product of all the pedigree parameter specific indices gives the pedigree index, which scales from 0 for approximations up to a value of 1 precise estimates (Christensen *et al.* 2000). The Ecopath pedigree index of this model was 0.427 and the

measure of fit, which shows how well rooted the model is in local data (Christensen *et al.* 2000), was 3.24.

1995-1997

The annual Q/Bs of polychaetes and bivalves were accidentally switched in the Heymans and Pitcher (2002a) version of the 1995 model. This was corrected here, with the Q/B of polychaetes set at 22.2 year^{-1} and that of bivalves being 6.33 year^{-1}.

The biomass of hooded seals was calculated by Hammill and Stenson (2000) to increase by 4.8% over the decade from 1985 to 1997. However, Garry Stenson (*pers. comm.*, DFO Newfoundland) suggested that that increase was probably not correct, and that the population stayed the same during that decade. We thus change the biomass from 0.062 to 0.034 t•km^{-2}.

Table 3: Input parameters of the new balanced 1985 model (bold = estimated by Ecopath). Biomass estimated in t•km^{-2}.

Group name	Trophic level	Biomass	P/B	Q/B	Ecotrophic efficiency	P/Q
Walrus	3.32	<0.0001	0.0600	16.8462	**0.0000**	**0.0036**
Cetaceans	4.14	0.2510	0.1000	11.7940	**0.0000**	**0.0085**
Grey seals	4.40	<0.0001	0.1200	11.8000	**0.1404**	**0.0102**
Harp seals	4.24	0.1840	0.1020	17.4120	**0.1614**	**0.0059**
Hooded seals	4.79	0.0340	0.1090	13.1000	**0.0483**	**0.0083**
Ducks	3.00	0.0002	0.2500	54.7500	**0.3333**	**0.0046**
Piscivorous birds	4.29	0.0100	0.2500	54.7500	**0.4526**	**0.0046**
Planktivorous birds	3.53	0.0022	0.2500	54.7500	**0.3246**	**0.0046**
Adult cod	4.16	2.0400	0.6500	**2.6000**	**0.4674**	0.2500
Juv. cod	3.87	0.3774	1.6000	6.0900	**0.9667**	**0.2627**
Adult American plaice	3.64	0.9700	0.5400	2.0000	**0.2610**	**0.2700**
Juv. American plaice	3.70	0.7800	0.6300	3.7360	**0.8672**	**0.1686**
Adult Greenland halibut	4.54	0.3500	0.3000	1.4800	**0.9632**	**0.2027**
Juv. Greenland halibut	4.25	0.3624	0.8700	3.4010	**0.9500**	**0.2558**
Yellowtail flounder	3.12	**0.2145**	0.5337	3.6000	0.9500	**0.1482**
Witch flounder	3.02	**0.5503**	0.5879	2.3045	0.9500	**0.2551**
Winter flounder	3.08	**0.0481**	0.2674	1.6436	0.9500	**0.1627**
Skates	4.01	0.5200	0.2900	2.8780	**0.3083**	**0.1008**
Dogfish	4.01	**0.0207**	0.1930	**1.9298**	0.9500	0.1000
Redfish	3.68	2.0105	0.3300	2.0000	**0.9499**	**0.1650**
Transient mackerel	3.86	0.3725	0.2900	**1.9333**	**0.1713**	0.1500
Adult bentho-piscivorous demersals	4.32	**0.2316**	0.3000	**2.0000**	0.9500	0.1500
Juv. bentho-piscivorous demersals	3.97	**0.6313**	0.5640	4.0000	0.9500	**0.1410**
Adult large demersal feeders	3.35	**0.3939**	0.2717	1.7470	0.9500	**0.1555**
Juv. large demersal feeders	3.23	**1.3589**	0.5640	4.0000	0.9500	**0.1410**
Other small demersals	3.11	**0.9932**	0.5640	4.5000	0.9500	**0.1253**
Lumpfish	3.59	**0.1089**	**0.2061**	1.3743	0.9500	0.1500
Greenland cod	4.04	**0.0828**	0.1660	1.3000	0.9500	0.1277
Salmon	4.25	**0.0142**	**0.6139**	4.0928	0.9500	0.1500
Capelin	3.28	13.2890	1.1500	6.4000	**0.9564**	**0.1797**
Sandlance	3.08	2.9340	1.1500	7.6670	**0.9500**	**0.1500**
Arctic cod	3.41	2.7290	0.4000	2.6330	**0.7333**	**0.1519**
Herring	3.29	**0.9238**	0.5440	4.1000	0.9500	**0.1327**
Transient pelagics	4.08	**0.0124**	0.4000	3.3300	0.9500	**0.1201**
Small pelagics	3.42	**0.9580**	0.2800	1.7670	0.9500	**0.1585**
Mesopelagics	3.38	**1.2884**	1.4220	4.7894	0.9500	**0.2969**
Shortfin squid	4.19	**0.4533**	0.6000	**4.0000**	0.9500	0.1500
Arctic squid	3.28	**1.6680**	0.5000	**3.3333**	0.9500	0.1500
Large crabs	2.92	0.1744	0.1600	1.2000	**0.7313**	**0.1333**
Small crabs	3.07	3.3700	0.3800	1.5000	**0.9743**	**0.2533**
Lobster	2.93	0.0045	0.3800	4.4200	**0.9875**	**0.0860**
Shrimp	2.46	**1.1479**	1.7000	9.6670	0.9500	**0.1759**
Echinoderms	2.00	112.3000	0.6000	6.6670	**0.0619**	**0.0900**
Polychaetes	2.00	10.5000	2.0000	22.2220	**0.1868**	**0.0900**
Bivalves	2.00	42.1000	0.5700	6.3330	**0.0970**	**0.0900**
Other benthic inverts.	2.00	7.8000	2.5000	12.5000	**0.3948**	**0.2000**
Large zooplankton	2.56	**27.5000**	3.4330	19.5000	0.9500	**0.1761**
Small zooplankton	2.00	**41.8000**	8.4000	28.0000	0.9500	**0.3000**
Phytoplankton	1.00	26.9000	93.1000	-	**0.5472**	-
Detritus	1.00	389.0000	-	-	**0.9974**	-

Table 4: Diet matrix of balanced model for Newfoundland in 1985.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3	0.001																						
4	0.001																						
5	0.001																						
6																							
7				0.0001																			
8																							
9			0.099	0.0032	0.0141																		
10		0.0100	0.091	0.0060	0.0424		0.0057		0.0177	0.0065	0.0001	0.0043	0.0764	0.0087				0.0344	0.020	0.002		0.0537	0.0271
11				0.0108																			
12	0.010		0.007	0.0387					0.0171	0.0003	0.0009	0.0209	0.0010					0.0015				0.0674	0.034
13				0.0078	0.0922																		
14			0.001	0.0169	0.2764				0.0057	0.0023	0.0010	0.0019	0.1270	0.0055				0.0008	0.003			0.0019	0.0010
15	0.004		0.007		0.0208				0.0009		0.0001	0.0079										0.0114	0.0057
16	0.004		0.030	0.0726	0.0774				0.0001		0.0001		0.0024					0.0046				0.0038	0.0019
17	0.004		0.030	0.0001	0.0208																		
18			0.004						0.0002				0.0010									0.0038	0.0019
19		0.0012																					
20			0.006	0.0030	0.1194				0.0086	0.0001		0.0008	0.2565					0.0500	0.053	0.007		0.0232	0.0117
21			0.005				0.0004																
22		0.0150																					
23	0.002	0.0150	0.041				0.0036		0.0001	0.0001								0.0417	0.0125			0.1301	0.0656
24		0.0150		0.0065	0.0129																		
25	0.010	0.0150	0.026	0.0060	0.0386		0.0036		0.0247	0.005	0.0044	0.0057	0.0696	0.0004				0.1120	0.035	0.001		0.1473	0.0743
26	0.016		0.003	0.0129			0.0036		0.0145	0.0188	0.0049	0.0147	0.0158	0.0072		0.009	0.0710	0.0278	0.010			0.1021	0.0515
27		0.0060	0.015				0.0036		0.0003														
28	0.002	0.0020	0.004	0.0011			0.0036		0.0003														
29		0.0010	0.002				0.0004											0.0010					
30	0.044	0.4884	0.012	0.4541	0.0060		0.7929		0.597	0.4297	0.2973	0.3357	0.3829	0.8337	0.0394			0.1251	0.151	0.007	0.50	0.1215	0.0613
31		0.0519	0.450	0.1459			0.0566		0.1047	0.0309	0.1687	0.0905		0.0002	0.0404			0.1251	0.050	0.004	0.05	0.175	0.0882
32			0.002	0.1113	0.0724		0.068		0.0218	0.0322	0.0006	0.0037	0.0267	0.0498				0.0008	0.001		0.05		
33		0.0539	0.075	0.0102	0.0699		0.0109		0.005	0.0159									0.070		0.05		
34			0.005		0.0080		0.0004						0.0004										
35		0.0549	0.043		0.0290		0.006												0.020			0.0213	0.0107
36		0.0300	0.01	0.0004			0.017		0.0016	0.0005			0.0089	0.0085				0.0077	0.050	0.233		0.0372	0.0188
37			0.03	0.0075	0.0494		0.006		0.0012				0.0006					0.0591	0.025			0.0076	0.0415
38		0.0539		0.0004	0.0494		0.0109		0.0026	0.0019	0.0006	0.0001	0.0125	0.0311				0.0008	0.100	0.012			
39			0.001	0.0001	0.0001				0.0010														
40	0.120			0.0002					0.0496	0.0236	0.0486	0.0249				0.001	0.0018	0.1500				0.0107	0.0589
41	0.0001																	0.0001				0.0001	
42	0.120			0.0690			0.0068		0.037	0.0787	0.0029	0.0127	0.0133	0.0222		0.021		0.0136	0.175	0.035		0.0214	0.1173
43	0.050								0.0043	0.0002	0.2976	0.1118		0.0001	0.0734	0.006	0.1023	0.0500				0.004	0.0172
44	0.100								0.0059	0.017	0.0165	0.1106			0.4043	0.66	0.1318	0.0561	0.025			0.0032	0.0175
45	0.300					0.9			0.0198	0.0047	0.0599	0.0217			0.0298	0.011	0.0563	0.0360					
46	0.200					0.1			0.0120	0.139	0.0751	0.1398	0.0019	0.0035	0.3702	0.291	0.6368	0.0982	0.025		0.30	0.0104	0.0569
47		0.1039		0.0153				0.9569	0.0466	0.1924	0.0206	0.0923	0.0031	0.0291	0.0426	0.001		0.0023	0.175	0.538	0.05	0.0405	0.2226
48	0.010	0.0829						0.0431		0.0002		0.0001						0.0013		0.161		0.0026	0.0145

Table 4: Diet matrix of balanced model for Newfoundland in 1985 (continued)

	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
3																									
4																									
5																									
6																									
7																									
8																									
9																									
10	0.0017	0.0009				0.0022					0.0010			0.1000											
11																									
12	0.0010	0.0005																							
13																									
14						0.0011																			
15																									
16																									
17																									
18	0.0003	0.0002																							
19																									
20	0.0185	0.0093									0.0020														
21																									
22																									
23	0.0003	0.0002									0.0120			0.0003											
24																									
25	0.0004	0.0002	0.002		0.01						0.0120			0.0003											
26	0.0013	0.0007	0.008		0.20						0.0110			0.0003											
27																									
28											0.0010														
29											0.0010														
30	0.0306	0.0154	0.02	0.100	0.40	0.4828	0.025		0.038		0.0749		0.01	0.3590											
31	0.0120	0.0061	0.01	0.001	0.05	0.1831	0.005				0.0859			0.1260											
32			0.005	0.002	0.05				0.002					0.0100											
33	0.0001		0.002	0.002	0.02	0.1155					0.1149			0.0580											
34																									
35	0.008	0.004	0.001	0.002							0.1149														
36	0.0543	0.0274				0.1924					0.1149		0.05	0.0500											
37	0.0001	0.0001			0.01						0.0564														
38	0.0038	0.0041		0.002	0.01	0.0044					0.0564		0.04	0.1161											
39																									
40	0.0875	0.0500	0.010		0.06											0.001		0.01							
41	0.0001																								
42	0.0784	0.0842	0.020	0.010	0.12	0.006					0.0120					0.020	0.01	0.02							
43	0.3189	0.3423	0.100	0.010	0.02											0.303	0.09	0.30							
44	0.0873	0.0937	0.200	0.010	0.01						0.0030					0.303	0.10	0.30	0.015						
45	0.0271	0.0728	0.050		0.01											0.120	0.25	0.12							
46	0.1865	0.2002	0.470	0.010	0.02			0.039		0.100	0.0190					0.120	0.15	0.12	0.015						
47	0.0744	0.0799	0.050	0.801	0.02	0.0125	0.434	0.209	0.640	0.513	0.2947	0.75	0.45	0.1800	0.5	0.020	0.20	0.02	0.120					0.05	
48	0.0073	0.0078	0.050	0.050			0.536	0.712	0.320	0.387	0.0130	0.25	0.45		0.5	0.010	0.15	0.01	0.24					0.48	
49																			0.085					0.37	1
50						0.040										0.103	0.05	0.10	0.525	1	1	1	1	0.10	

Table 5: Data pedigree for the 1985 model.

Group name	Biomass	P/B	Q/B	Diet	Catch
Walrus	3	2	9	19	-
Cetaceans	4	3	12	19	-
Grey seals	3	2	2	21	-
Harp seals	6	13	12	21	25
Hooded seals	5	9	12	21	25
Ducks	4	2	2	20	25
Piscivorous birds	4	2	2	20	25
Planktivorous birds	4	2	2	20	25
Adult cod	5	11	9	21	25
Juv. cod	4	2	10	20	-
Adult American plaice	5	11	13	21	25
Juv. American plaice	5	3	12	21	25
Adult Greenland halibut	5	11	13	21	25
Juv. Greenland halibut	1	2	9	21	25
Yellowtail flounder	1	9	9	20	24
Witch flounder	1	9	9	20	24
Winter flounder	1	9	9	20	24
Skates	5	9	10	20	24
Dogfish	1	9	10	20	24
Redfish	4	9	12	20	24
Transient mackerel	5	9	12	19	24
Adult bentho-piscivorous demersals	1	3	9	20	24
Juv. bentho-piscivorous demersals	1	10	3	20	-
Adult large demersal feeders	1	9	9	20	24
Juv. large demersal feeders	1	10	3	20	-
Other small demersals	2	9	9	20	-
Lumpfish	1	9	9	20	-
Greenland cod	1	9	9	20	24
Salmon	1	1	9	20	24
Capelin	2	9	2	20	25
Sandlance	1	9	2	19	24
Arctic cod	2	9	2	20	-
Herring	1	9	9	19	24
Transient pelagics	1	9	12	19	24
Small pelagics	1	9	12	19	24
Mesopelagics	1	9	9	19	-
Shortfin squid	2	3	1	20	24
Arctic squid	1	9	1	19	-
Large crabs	5	9	2	20	24
Small crabs	5	9	2	20	-
Lobster	5	9	2	20	24
Shrimp	1	2	2	19	25
Echinoderms	5	10	2	19	-
Polychaetes	5	10	2	19	-
Bivalves	5	10	2	19	24
Other benthic inverts.	5	10	2	19	-
Large zooplankton	1	12	11	19	-
Small zooplankton	1	12	11	19	-
Phytoplankton	4	9	-	-	-
Detritus					

1	Estimated by Ecopath	2	From other model
3	Guestimate	4	Approximate or indirect method
5	Sampling based low precision	6	Sampling based high precision
7	Locally based low precision	8	Locally based high precision
9	Empirical relationship	10	Similar group, similar system
11	Similar group, same system	12	Same group, similar system
13	Same group, same system	14	Similar system, low precision
15	Same system, low precision	16	Similar system, high precision
17	Same system, high precision	18	General knowledge of related group
19	General knowledge of same group	20	Qualitative diet composition study
21	Quantitative but limited study	22	Qualitative, detailed
23	FAO statistics	24	National statistics
25	Local study, low precision	26	Local study, high precision

The biomass of capelin estimated from the area swept by the groundfish trawlers (0.096 t•km^{-2}) is probably underestimated as this species is not predominantly demersal. In contrast, Anderson *et al.* (2001) estimate that the average biomass of capelin in 2J3KLNO for 1995 to 1997 by IYGPT trawl, to be between 725,000 tonnes and 1,800,000 tonnes, using catchabilities (q) of 10%

- 25%. The lower catchability was used, but it still estimates a very small biomass (3.7 t•km^{-2}) for capelin.

Some of the annual Q/B ratios in the 1995 model were assumed to be similar to that of the 1985 model:

- The annual Q/B of adult cod was too high in the Heymans and Pitcher (2002a) model, and we let Ecopath estimate it by assuming a GE of 0.25, which estimates a Q/B of 2.69;
- Adult American plaice Q/B was reduced to 1.262 year^{-1}, similar to the unbalanced model of Bundy *et al.* (2000) and the new 1985 model;
- For adult piscivorous demersals the P/B ratio seemed to be very low. It was taken from Bundy *et al.* (2000) but we used their natural mortality of 0.1 year^{-1} obtained from Appendix Table A1 in Heymans and Pitcher (2002b) plus fishing mortality. The P/B was then 0.206. Their Q/B (1.4 year^{-1}) was estimated by assuming a GE of 0.15;
- Adult planktivorous demersal Q/B was similar to the 1.747 year^{-1} obtained in 1985;
- The P/B and Q/B estimates of juvenile demersals and juvenile piscivorous demersals were both set to be similar to that of the small demersals (0.564 and 4.5 year^{-1} respectively);
- Other small demersal Q/B was similar to the 4.5 year^{-1} obtained in 1985;
- Small pelagic Q/B was reduced to 1.767 year^{-1}, similar to the 1985 model.

Some of the annual P/B ratios in the 1995 model were assumed to be similar to that used in 1985:

- Similar to the 1985 model, the P/B estimates for large and small crabs were 0.16 and 0.3 respectively (range 0.2-0.429) and the Q/B estimates for large and small crabs were 1.2 and 1.5 respectively;
- The annual P/Bs of small pelagics, sandlance and Arctic cod were assumed to be the similar (0.28, 1.15 and 0.4) to that of the 1985 model;
- The annual P/B of yellowtail flounder (0.53), witch flounder (0.59), winter flounder (0.27), skates (0.29), dogfish (0.19), redfish (0.33), transient mackerel (0.3), adult planktivorous demersals (0.27), other small demersals (0.56), lumpfish (0.11) and Greenland cod (0.17) were assumed to be similar to that of the 1985 model. The biomass estimates of these groups were not q-adjusted, and very little information is available on their natural mortalities, so we assume that the total mortality of each group stayed constant over time;

- The stock status report for American plaice (Anon 2000) suggest that the total mortality for this group has consistently stayed above 0.7, probably due to an increase in natural mortality. The annual P/Bs of American plaice in 1985 were 0.54 and 0.63 respectively for adults and juveniles. Instead we use a value of 0.7 for adults and the same ratio of adult:juvenile mortality to calculate a juvenile plaice P/B of 0.82;
- From the NAFO stock report on Greenland halibut (Bowering 2002), the abundance at age for 1996 and 1997 was used to calculate an annual Z for adult and juvenile Greenland halibut. This was estimated to be 0.75 and 0.61 for adults and juveniles respectively;
- According to George Lilly (DFO-Newfoundland *pers. comm.*) the bulk of the cod biomass was in the inshore in the 1990s, and their Z markedly different between the onshore and offshore. The offshore Z was higher and mostly consisted of natural mortality. In contrast, the inshore fish have been surviving to older ages, and the M of exploitable sizes was around 0.5 in the inshore (G. Lilly, DFO-Newfoundland *pers. comm.*). Fishing mortality was low until 1997 due to the moratorium, so for adult cod, the average Z (0.67 year^{-1}) obtained from the stock status report (Anon 2003b) for 1995 was used as the upper limit of their P/B, while a value of 0.5 (natural mortality) was the lower limit;
- For juvenile cod we assumed that the 1985 P/B (1.6 year^{-1}) was the lower limit for the 1995 model, and increased it for balancing purposes;
- The annual P/B of capelin was calculated at 1.6 by using a GE of 0.25;
- The annual P/B and Q/B estimates for grey seals were substantially higher than the other models. Grey seals are not known to frequent the Newfoundland ecosystem anymore, although they were found there around the time of European contact. We therefore use the P/B (0.12 year^{-1}) and Q/B (11.8 year^{-1}) estimates of grey seals from the Eastern Scotian Shelf model (Bundy *in press*);
- The annual Q/B ratios for harp and hooded seals were very high, and were recalculated. The average consumption by harp seals for
- 1995 to 1997 (2,803,140 tonnes) was obtained from Garry Stenson (DFO-Newfounland *pers. comm.*) and divided by the average biomass (200,475 tonnes) to give a Q/B of 13.98 year^{-1}. For hooded seals the consumption for 1996 (182,488 tonnes) were obtained from Hammill and Stenson (2000) and divided by

the average biomass (16,830 tonnes for 1995 to 1997) to give a Q/B of 10.8 year^{-1}.

The total catch of cod was updated with information on catches from Lilly *et al.* (2001) for 2J3KL and Healey *et al.* (2002) for catches in 3NO. These total catches were then prorated to gear types as per the catches used in Heymans and Pitcher (2002a) – see Table 6.

The biomass estimates and diets of fish obtained from George Lilly (DFO-Newfoundland, *pers. comm.*) and used in the unbalanced model in Heymans and Pitcher (2002a) were re-entered (diets from Appendix B Table B1), and changed to balance the model. The same changes were made to the diets of the predators of salmon, large crabs and lobster as to the 1985 model.

The diet of sandlance in the Heymans and Pitcher (2002a) model was obtained from Bundy *et al.* (2000), which had used data from the 1970s for the Eastern Scotian Shelf. However, newer data for the Eastern Scotian Shelf in the 1990s were obtained from Bundy (*in press*) and included here: redfish (0.2%), shrimp (13.4%), benthic invertebrates (0.04%), echinoderms (0.5%), large zooplankton (72.2%), small zooplankton (9.7%) and detritus (4%) (Bundy *in press*).

Some groups had annual gross efficiencies (GE's) that were not within the 0.1 to 0.3 range that is usual for marine species. Inputs for these groups were therefore adapted as follows:
- The annual GE's of both adult American plaice (0.56) and adult Greenland halibut (0.51) were too high. We therefore reduced both these GE's to be the same as the 1985 model (0.27 and 0.203 respectively) and let Ecopath estimate new Q/B's of 2.6 and 3.7;
- The annual GE of lumpfish was 0.08, while the P/B was 0.114. We assumed a GE of 0.15 and let Ecopath estimate a new P/B of 0.21 as the fishing mortality could be underestimated;
- The annual GE of transient mackerel was 0.07 and while the Q/B of this species was

Table 6: Catch of cod during 1995 to 1997 by gear type in 2J3KLNO.

Gear	Catch (tonnes)
Bottom trawls	135.0
Mid-water trawls	1.6
Gillnets and entangling nets	551.0
Hooks and lines	145.0
Traps and lift nets	6.0
Other gear	95.0
Total	988.6

obtained from FishBase, we let Ecopath estimate it (2.0) by assuming a GE of 0.15;
- The annual GE for dogfish (0.07) was still too low, even after a reduced Q/B was used (2.6, which was obtained for BC waters Jones and Geen 1977); we therefore let Ecopath estimate the Q/B by assuming a GE of 0.1. The Q/B was estimated at 1.93.

Balancing the model

Table 7 documents the model imbalance in terms of the ecotrophic efficiencies.

Greenland cod

The first group to be balanced was Greenland cod, which had an ecotrophic efficiency of 1,017. The biomass of Greenland cod was very low (0.000087 t•km^{-2}), mainly because they occur more inshore and are not readily caught by trawlers. Thus, their catchability would be very low. We therefore assume an ecotrophic efficiency of 0.95 and let Ecopath estimate the biomass at 0.102 t•km^{-2}.

Small crabs

The consumption of small crabs by juvenile planktivorous demersals was reduced to 1% (from 9%) to balance small crabs, while their consumption of bivalves increased to 7.28% and their consumption of polychaetes increased to 13.4%. The consumption of small crabs by skates was also reduced (to 15%), while skates consumed more echinoderms (5%) and bivalves (3.6%). The biomass of 'small crabs was a tentative biomass for recruits from the snow crab population. However, 'small crabs' also include 'other crabs', so we let Ecopath estimate the biomass (1.9 t•km^{-2}) by using an ecotrophic efficiency of 0.95. This biomass is much lower than the 3.4 t•km^{-2} estimated for the 1985 model.

Mesopelagics

Similar to Greenland cod, the catchability of mesopelagics with the Campelen trawl is probably very small, and the ecotrophic efficiency of this group was 32.8. We let Ecopath estimate the biomass (0.569 t•km^{-2}) by assuming an ecotrophic efficiency of 0.95.

Table 7: Ecotrophic efficiencies of unbalanced groups in the 1995 model.

Group name	Ecotrophic efficiency
Juvenile cod	27.563
Juvenile American plaice	1.276
Witch flounder	32.100
Dogfish	2.541
Redfish	3.576
Adult bentho-piscivorous demersals	14.899
Adult large demersal feeders	2.360
Other small demersals	3.902
Lumpfish	5.227
Greenland cod	1017.410
Capelin	1.406
Sandlance	7.685
Arctic cod	9.709
Herring	3.415
Small mesopelagics	32.766
Large crabs	2.317
Small crabs	65.335

Witch flounder

The main predators on witch flounder are harp and hooded seals. In the diet of harp seals Heymans and Pitcher (2002a) assumed that all flounders consumed were witch flounder. However, this assumption was refined, so that the 7.3% of flounders in the diet of harp seals are now 3% and the percentage of witch flounder is 2.3%. This decreased the ecotrophic efficiency of witch flounder from 32.1 to 14.9. The biomass of witch flounder was very low, from the Campelen trawl survey, and we then estimate a new biomass of 0.376 t•km^{-2} by setting the ecotrophic efficiency to 0.95.

Juvenile cod

Using the Campelen-adjusted biomass and P/B obtained from the 1985 model, the ecotrophic efficiency of juvenile cod was 27.6. To balance the juvenile cod, the diet of shortfin squid was revised by reducing the percentage of cod in the diet to 5% and increasing the percentage of Arctic cod to 1%, that of small mesopelagics to 5% and Arctic squid to 10%. In addition to these changes, information obtained from Mauer and Bauman (1984) suggest that shortfin squid also consume polychaetes and gammarid amphipods, so they were added to the diet of shortfin squid (at 3.3% each). The smaller percentage of cod in the diet of squid is realistic as the cod population was mainly inshore in this time period, and shortfin squid is more of a deepwater species. This decreased the ecotrophic efficiency to 14.9. We then increased their P/B to 2.0 and let Ecopath estimate the biomass (0.17 t•km^{-2}), which is much smaller than

the 0.4 t•km^{-2} estimated in the 1985 model, although still quite conceivable.

Adult demersal piscivores

Adult demersal piscivores are only consumed by cetaceans, and only consist of 1.5% of their diet. However, their low biomass (0.015 t•km^{-2}) compared to that of the 1985-87 model pushed their ecotrophic efficiency to 14.9. As there is no catchability for the trawler used in the survey, we let Ecopath estimate the biomass of this group (0.235 t•km^{-2}). This increased the juvenile cod and mesopelagics biomass estimates needed to feed this group, to 0.193 t•km^{-2} and 0.658 t•km^{-2} respectively.

Arctic cod

The ecotrophic efficiency of Arctic cod was 10.3. However, the catchability of this species would probably be very low in the Campelen trawl, and we therefore let Ecopath estimate the biomass required to feed its predators, including their main predator - harp seals. The biomass was estimated at 1.49 t•km^{-2}.

Sandlance:

Sandlance ecotrophic efficiency was 9.4 and their main predator was harp seals. Thus, we let Ecopath estimated the biomass of sandlance at 2.24 t•km^{-2}.

Small demersals

The ecotrophic efficiency of small demersals was 6.6, and that was mainly due to consumption by harp seals; thus we let Ecopath estimate the biomass at 0.88 t•km^{-2}.

Lumpfish

The main predators of lumpfish are piscivorous fish and cetaceans, and the demands of their predators increased their ecotrophic efficiency to 5.3. The biomass of this species was estimated at 0.11 t•km^{-2} by assuming an ecotrophic efficiency of 0.95.

Redfish

Redfish ecotrophic efficiency was 4.0 when the biomass was 0.38 t•km^{-2}. As in the 1985 model, the consumption of redfish by skates was reduced to 5% to decrease the ecotrophic efficiency of that group, and the proportion of bivalves was increased to 3.6% while that of other benthic invertebrates was increased to 9.8%. To balance

redfish, their consumption by adult Greenland halibut was reduced to 15.3%, and their consumption of skates and adult American plaice both increased from 0.01% to 1%. The benthic invertebrates were also increased from 0.2% to 3.3, and 1% was added to echinoderms and bivalves. The biomass of redfish was then estimated at 1.19 t•km^{-2}. This caused the mesopelagics to be unbalanced, so their biomass was re-estimated at 1.0 t•km^{-2}.

Herring

The ecotrophic efficiency of herring in this model was 3.4, mainly due to the consumption by harp seals and cetaceans. According to the Stock Status Report for herring (Anon 2002). the White Bay – Notre Dame Bay and Bona Vista Bay populations of herring are currently not doing very well. The mean weight at age have decreased since the 1980s and it resulted in increased fishing mortality (Anon 2002). I therefore increase the P/B of herring to 2 – to be more similar to that of capelin and small cod – and let Ecopath estimate the biomass at 0.44 t•km^{-2}, approximately half the biomass in 1985.

Shrimp

The ecotrophic efficiency of shrimp was 2.6 and their main predators were sandlance, harp seals, small crabs and juvenile planktivorous demersals. The sandlance diet was obtained from Bundy (*in press*) and was originally for the Eastern Scotian Shelf. I decreased shrimp in the diet of sandlance from 13.4% to 5% and increased echinoderms to 3.9%, while increasing the small zooplankton from 9.7% to 14.7%. This reduced the ecotrophic efficiency to 1.7. Similar to the 1985 model, the Q/Bs of juvenile planktivorous and piscivorous demersals were set to be equal to that of other small demersals (4.5 year^{-1}), which might be too high, and was then reduced to 4.0 to reduce the consumption of shrimp by small demersals. I then let Ecopath estimate the shrimp biomass (1.9 t•km^{-2}) by assuming an ecotrophic efficiency of 0.95.

Dogfish

The ecotrophic efficiency of dogfish was 2.5, and as cetaceans were there only predators, we let Ecopath estimate the biomass at 0.017 t•km^{-2}.

Adult planktivorous demersals

The ecotrophic efficiency of this group was 2.4 with a biomass of 0.119 t•km^{-2}. The biomass was estimated at 0.29 t•km^{-2} using an ecotrophic efficiency of 0.95.

Large crabs

The ecotrophic efficiency of large crabs (2.3) was high mainly due to the high fishing mortality rate of 0.364, compared to the P/B ratio of 0.16 year^{-1}. I therefore set the GE to 0.25 and let Ecopath estimate a P/B of 0.3. This value is in the range of 0.2 to 0.429 obtained by Morissette *et al.* (2003). The ecotrophic efficiency of large crabs was still higher than one, and we let Ecopath estimate the biomass (0.23 t•km^{-2}) by assuming an ecotrophic efficiency of 0.95.

Capelin

The ecotrophic efficiency of capelin was 1.55 and their biomass was 3.67 t•km^{-2}, it is calculated at 6.04 t•km^{-2} when assuming an ecotrophic efficiency of 0.95. This caused the large zooplankton to become unbalanced, with an ecotrophic efficiency of 1.006. We estimated the biomass of large zooplankton at 19.9 t•km^{-2}.

Juvenile American plaice

The ecotrophic efficiency of juvenile American plaice was 1.46, their biomass 0.273 t•km^{-2}, and their main predator was harp seals. The stock status report for American plaice (Anon 2000) suggest that the total mortality for this group has consistently remained above 0.7, probably due to an increase in natural mortality. I had used the adult:juvenile P/B ratio in 1985 to calculate the juvenile P/B for the 1995 model. However, the biomass of plaice has not recovered, so I could not estimate a much higher biomass. I therefore set the GE to 0.3 and let Ecopath estimate the P/B at 1.12. However, the ecotrophic efficiency of American plaice was still 1.07, and Ecopath estimates a marginally higher biomass (0.307 t•km^{-2}) when the ecotrophic efficiency was set to 0.95.

Final balancing

Balancing the juvenile cod and herring increased their GE's to above 30%. Setting the GE of juvenile cod to 30% calculated a P/B of 1.8 instead of the 2.0 assumed when balancing juvenile cod. For herring, a GE of 0.25 estimated a P/B of 1.03 instead of the 2.0 assumed when balancing, and Ecopath estimated a herring biomass of 0.85 t•km^{-2} when an ecotrophic efficiency of 0.95 was assumed.

The phytoplankton biomass and primary production for 1995 had changed due to updated information. Using satellite data for Newfoundland obtained from the Bedford Institute of Oceanography, and the same methodology as in Bundy *et al.* (2000), a phytoplankton biomass (35.6 t•km⁻²) and P/B (52.9) were calculated for 1998-1999, and used here for the 1995 model.

The detritus pool changes due to the change in primary production. The detritus biomass was estimated using an empirical relationship derived by Pauly *et al.* (1993):

$$\log_{10}D = -2.41 + 0.954\log_{10}PP + 0.863\log_{10}E$$

where D is detritus standing stock (gC·m⁻²), PP is primary productivity (gC·m⁻²·year⁻¹) and E is the euphotic depth (m). Primary production was 1,882 t•km⁻²•year⁻¹, or 209 tonnes (dry weight)•km⁻²•year⁻¹, which gives a detritus biomass of 181 t•km⁻².

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Table 8: Input data for the 1995-97 model. (bold = estimated by Ecopath). Biomass estimated in t•km⁻².

Group name	Trophic level	Biomass	P/B	Q/B	Ecotrophic efficiency	P/Q
Walrus	3.32	<0.001	0.060	16.846	**0.000**	**0.004**
Cetaceans	4.14	0.251	0.100	11.794	**0.002**	**0.008**
Grey seals	4.54	<0.001	0.120	11.800	**0.140**	**0.010**
Harp seals	4.27	0.405	0.102	13.983	**0.433**	**0.007**
Hooded seals	4.75	0.034	0.109	10.843	**0.517**	**0.010**
Ducks	3.00	0.000	0.250	54.750	**0.247**	**0.005**
Piscivorous birds	4.29	0.014	0.250	54.750	**0.240**	**0.005**
Planktivorous birds	3.53	0.003	0.250	54.750	**0.241**	**0.005**
Adult cod	4.19	0.080	0.673	**2.692**	**0.869**	0.250
Juv. cod	3.87	0.193	**1.827**	6.090	**0.992**	0.300
Adult American plaice	3.64	0.340	0.700	**2.593**	**0.263**	0.270
Juv. American plaice	3.73	**0.307**	**1.121**	3.736	0.949	0.300
Adult Greenland halibut	4.32	0.366	0.749	**3.689**	**0.322**	**0.203**
Juv. Greenland halibut	4.23	0.522	0.607	4.480	**0.943**	**0.135**
Yellowtail flounder	3.13	0.330	0.534	3.600	**0.778**	**0.148**
Witch flounder	3.02	0.376	0.588	2.304	**0.945**	**0.255**
Winter flounder	3.08	**0.548**	0.267	1.644	0.950	**0.162**
Skates	4.05	0.208	0.290	2.878	**0.624**	**0.101**
Dogfish	4.02	0.017	0.193	**1.930**	**0.972**	0.100
Redfish	3.69	1.193	0.330	2.000	**0.928**	**0.165**
Transient mackerel	3.86	**0.002**	0.300	**2.000**	0.950	0.150
Adult bentho-piscivorous demersals	4.37	0.235	0.206	**1.373**	**0.951**	0.150
Juv. bentho-piscivorous demersals	3.99	**0.429**	0.564	4.000	0.950	**0.141**
Adult large demersal feeders	3.36	0.295	0.272	1.747	**0.948**	**0.156**
Juv. large demersal feeders	3.19	**1.585**	0.564	4.000	**0.951**	**0.141**
Other small demersals	3.11	0.876	0.564	4.500	**0.908**	**0.125**
Lumpfish	3.59	0.105	0.210	1.400	**0.946**	0.150
Greenland cod	4.05	0.094	0.166	1.300	**0.946**	**0.128**
Salmon	4.30	**0.008**	0.614	4.093	0.951	0.150
Capelin	3.26	6.041	**1.600**	6.400	**0.953**	0.250
Sandlance	3.39	2.242	1.150	7.667	**0.966**	**0.150**
Arctic cod	3.41	1.488	0.400	2.633	**0.977**	**0.152**
Herring	3.29	0.845	**1.025**	4.100	**0.949**	0.250
Transient pelagics	4.10	**0.011**	0.400	3.330	**0.954**	**0.120**
Small pelagics	3.42	**0.914**	0.280	1.767	**0.950**	**0.158**
Mesopelagics	3.38	1.001	1.422	4.789	**0.931**	**0.297**
Shortfin squid	4.11	**0.423**	0.600	**4.000**	0.951	0.150
Arctic squid	3.28	**1.604**	0.500	**3.333**	0.950	0.150
Large crabs	2.92	0.232	**0.300**	1.200	**0.954**	0.250
Small crabs	3.08	1.942	0.300	1.500	**0.938**	**0.200**
Lobster	2.93	**0.003**	0.380	4.420	0.949	**0.086**
Shrimp	2.46	1.859	1.450	9.667	**0.962**	**0.150**
Echinoderms	2.00	112.300	0.600	6.667	**0.063**	**0.090**
Polychaetes	2.00	10.500	2.000	22.222	**0.179**	**0.090**
Bivalves	2.00	42.100	0.570	6.333	**0.073**	**0.090**
Other benthic inverts.	2.00	7.800	2.500	12.500	**0.320**	**0.200**
Large zooplankton	2.56	**20.320**	3.433	19.500	0.950	**0.176**
Small zooplankton	2.00	30.367	8.400	**28.000**	**0.892**	0.300
Phytoplankton	1.00	35.600	52.900	-	**0.530**	-
Detritus	1.00	181.000	-	-	**0.992**	-

Outputs from detritus include burial and respiration as well as detritus consumed by organisms. The burial (113 t•km^{-2}•year^{-1}) was assumed to be similar to that calculated for the 1985-87 model. The respiration of bacteria (420 t•km^{-2}•year^{-1}) was estimated by maximizing the ecotrophic efficiency, and was excluded for comparison with the 1450 and 1900 model, but included in comparison to other Western Atlantic ecosystems (CDEENA). The balanced model inputs are given in Table 8 and the new diets in Table 10 at the end of this paper. The pedigree of the 1995 model is given in Table 11. The overall Ecopath pedigree index was 0.396 and the measure of fit was 2.95.

Model aggregations

The models updated and described here were used in the CDEENA (Comparative Dynamics of Exploited Ecosystems in the Northwest Atlantic) project for comparison with the other ecosystems in the Northwest Atlantic: the Eastern Scotian Shelf (Bundy *in press*) and Gulf of St. Lawrence models (Morissette *et al.* 2003, Savenkoff *et al. in press* and Bourdages *et al. in press*). For comparison with these ecosystems, the updated models of Newfoundland were reduced to 30 compartments.

The aggregations were done by using the estimated biomass, P/B and Q/B ratios in the models above, with no values estimated by Ecopath. The walrus and grey seals groups were excluded as neither of these groups are currently present in the ecosystem. Then the groups were aggregated two at a time, without re-balancing at each step. The diets were recalculated from the diet matrix of the 50 compartment model by aggregating the rows (prey) that were aggregated in the new groups. The columns (predator diets) were then recalculated using the formula:

$$F_{ia} = (\sum F_{ij} * Q_j) / \sum Q_j$$

Where F_{ia} is the flow of prey to the new aggregated predator group 'a', F_{ij} is the flow of prey to all the predators in the new aggregated group 'a', Q_j is the consumption (in t•km^{-2}•year^{-1}) for all the groups in the new aggregated group 'a'. The final 30 compartments and the groups that were aggregated to form them are given in Table 9. The new input data and diets for 1985 are given in Tables 12 and 13, while the new inputs and diets for 1995 are given in Tables 14 and 15 respectively. The comparison of information indices given by these models to those of the 50 compartment models is described in the next paper (Heymans 2003).

Table 9: Aggregated groups for the 30 compartment models of Newfoundland in 1985 and 1995 and groups contained therein.

#	New group	Aggregated groups
1	Cetaceans	Cetaceans
2	Harp seals	Harp seals
3	Hooded seals	Hooded seals
4	Birds	Ducks, piscivorous birds+planktivorous birds
5	Large cod	Cod (> 35 cm)
6	Small cod	Cod (≤ 35 cm)
7	Large A. plaice	American plaice (> 35 cm)
8	Small A. plaice	American plaice (≤ 35 cm)
9	Large G. halibut	Greenland halibut (> 40 cm)
10	Small G. halibut	Greenland halibut (≤ 40 cm)
11	Yellowtail flounder	Yellowtail flounder
12	Other flounders	Witch and winter flounder
13	Skates	Skates
14	Redfish	Redfish
15	Large demersals	Demersals planktivores > 30 cm, Demersal piscivores > 40cm, lumpfish, Greenland cod, salmon
16	Small demersals	Small Demersals, Piscivorous ≤ 30 cm, Planktivorous ≤ 40 cm
17	Forage fish	Capelin and Arctic cod
18	Small pelagics	Small Pelagics, small mesopelagics, herring, sandlance, Arctic squid
19	Large pelagics	Transient pelagics, transient mackerel, dogfish
20	Squid	Shortfin squid
21	Large crustaceans	Crabs (large and small), lobsters
22	Shrimp	Shrimp
23	Echinoderms	Echinoderms
24	Polychaetes	Polychaetes
25	Bivalve Molluscs	Bivalve Molluscs
26	Other benthic invertebrates	Other benthic invertebrates
27	Large zooplankton	Large zooplankton
28	Small zooplankton	Small zooplankton
29	Phytoplankton	Phytoplankton
30	Detritus	Detritus

Table 10: New diet matrix for the Newfoundland model in 1995.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22
3	0.001																				
4	0.001																				
5	0.001																				
6																					
7																					
8																					
9			0.100	0.0070	0.014																
10		0.010	0.091	0.0090	0.042		0.006		0.026	0.008	0.000	0.001	0.030	0.005				0.034	0.020		0.054
11				0.0110																	
12	0.010		0.007	0.0390					0.026	0.000	0.000	0.001	0.010					0.002			0.068
13				0.0050	0.092																
14			0.001	0.0150	0.274				0.002	0.001	0.000	0.001	0.070	0.006				0.001	0.003		0.002
15	0.004		0.007	0.0200	0.021				0.003		0.000	0.001									0.011
16	0.004		0.030	0.0300	0.078				0.001				0.000					0.005			0.004
17	0.004		0.030	0.0230	0.021				0.001												
18			0.004						0.001				0.010								0.004
19		0.001																			
20			0.006	0.0020	0.120				0.005	0.000		0.001	0.080					0.050	0.053		0.023
21			0.005				0.001														
22		0.015																			
23	0.002	0.015	0.041				0.004			0.000								0.042	0.013		0.130
24		0.015		0.0020	0.013								0.005								
25	0.010	0.015	0.026	0.0040	0.039		0.004		0.022	0.003	0.007	0.010	0.271	0.050				0.112	0.035		0.147
26	0.016		0.003	0.0180			0.004		0.011	0.014	0.002	0.023	0.002	0.009		0.009	0.071	0.028	0.010		0.102
27		0.006	0.015				0.004		0.001												
28	0.002	0.002	0.004	0.0010			0.004		0.000												
29		0.001	0.002				0.001											0.001			
30	0.044	0.489	0.012	0.4370	0.006		0.793		0.435	0.331	0.145	0.258	0.340	0.750	0.039			0.125	0.151	0.50	0.122
31		0.052	0.451	0.1470			0.057		0.245	0.118	0.268	0.160		0.002	0.040			0.125	0.050	0.05	0.175
32			0.002	0.0540	0.073		0.068		0.008	0.011	0.000	0.002	0.010	0.050				0.001	0.001	0.05	
33		0.054	0.075	0.0840	0.070		0.011		0.040	0.015									0.070	0.05	
34			0.005		0.008		0.001														
35		0.055	0.043		0.029		0.006		0.001										0.020		0.021
36		0.03	0.010	0.0004			0.017		0.001	0.002			0.030	0.015				0.008	0.050		0.037
37			0.030	0.0070	0.050		0.006		0.002				0.022	0.015				0.059	0.025		0.008
38		0.054		0.0004	0.050		0.011		0.001	0.001	0.001	0.000	0.055	0.031				0.001	0.100		
39			0.001	0.0001	0.001				0.001												
40	0.120								0.054	0.079	0.056	0.035				0.001	0.002	0.150			0.011
41	0.001																	0.000			0.000
42	0.120			0.0650			0.007		0.024	0.044	0.001	0.014	0.011	0.035		0.021		0.014	0.175		0.021
43	0.050								0.007	0.001	0.311	0.085	0.010	0.000	0.073	0.006	0.102	0.050			0.003
44	0.10								0.009	0.018	0.011	0.085			0.404	0.660	0.132	0.056	0.025		0.003
45	0.30				0.9				0.042	0.019	0.093	0.033	0.010		0.030	0.011	0.056	0.036			
46	0.20				0.1				0.006	0.133	0.077	0.130	0.033	0.004	0.370	0.291	0.637	0.098	0.025	0.30	0.010
47		0.104		0.0190				0.957	0.030	0.204	0.027	0.160	0.001	0.029	0.043	0.001		0.002	0.175	0.05	0.041
48	0.010	0.083						0.043		0.000		0.001						0.001			0.003
49																					
50																					

Table 10: New diet matrix for the Newfoundland model in 1995 (continue)

	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
3																										
4																										
5																										
6																										
7																										
8																										
9																										
10	0.027	0.002	0.0009				0.002					0.001			0.05											
11																										
12	0.034	0.001	0.0005																							
13																										
14	0.001						0.001																			
15	0.006																									
16	0.002																									
17																										
18	0.002	0.000	0.000																							
19																										
20	0.012	0.019	0.009						0.002			0.002														
21																										
22																										
23	0.066	0.000	0.000									0.012			0.000											
24																										
25	0.074	0.000	0.000	0.002		0.010						0.012			0.000											
26	0.052	0.001	0.001	0.008		0.200						0.011			0.000											
27																										
28												0.001														
29												0.001														
30	0.061	0.031	0.015	0.020	0.100	0.400	0.483	0.005		0.038		0.075		0.01	0.359											
31	0.088	0.012	0.006	0.010	0.001	0.050	0.183	0.005				0.086			0.126											
32				0.005	0.002	0.050				0.002					0.010											
33		0.000		0.002	0.002	0.020	0.116					0.115			0.058											
34																										
35	0.011	0.008	0.004	0.001	0.002							0.115														
36	0.019	0.054	0.027				0.192					0.115		0.05	0.050											
37	0.042	0.000	0.000			0.005						0.057														
38		0.004	0.004		0.002	0.005	0.004					0.057		0.04	0.100											
39																										
40	0.059	0.088	0.010	0.010		0.060											0.001		0.01							
41		0.000																								
42	0.117	0.078	0.084	0.020	0.010	0.120	0.006		0.050			0.012					0.020	0.05	0.02							
43	0.017	0.319	0.342	0.100	0.010	0.020			0.039								0.303	0.05	0.30							
44	0.018	0.087	0.134	0.200	0.010	0.015						0.003			0.033		0.303	0.10	0.30	0.015						
45		0.027	0.073	0.050		0.005											0.120	0.25	0.12							
46	0.057	0.187	0.200	0.472	0.010	0.020			0.000		0.100	0.019			0.033		0.120	0.15	0.12	0.015						
47	0.223	0.074	0.080	0.050	0.801	0.020	0.013	0.439	0.722	0.640	0.513	0.295	0.75	0.45	0.180	0.5	0.020	0.20	0.02	0.120					0.05	
48	0.015	0.007	0.008	0.050	0.050			0.551	0.147	0.320	0.387	0.013	0.25	0.45		0.5	0.010	0.15	0.01	0.240					0.48	
49																				0.085					0.37	1
50									0.040								0.103	0.05	0.1	0.525	1	1	1	1	0.1	

Table 11: Data pedigree for the 1995 model.

Group name	Biomass	P/B	Q/B	Diet	Catch
Walrus	3	2	9	19	-
Cetaceans	4	3	12	19	-
Grey seals	3	2	2	21	-
Harp seals	6	13	12	21	25
Hooded seals	5	9	12	21	25
Ducks	4	2	2	20	2
Piscivorous birds	4	2	2	20	2
Planktivorous birds	4	2	2	20	2
Adult cod	5	11	9	21	25
Juv. cod	1	9	10	20	24
Adult American plaice	5	11	9	21	24
Juv. American plaice	1	3	9	21	24
Adult Greenland halibut	5	11	9	21	24
Juv. Greenland halibut	1	3	9	21	24
Yellowtail flounder	4	9	9	20	24
Witch flounder	1	9	9	20	24
Winter flounder	1	9	9	20	24
Skates	1	9	10	20	24
Dogfish	1	9	9	20	24
Redfish	1	9	12	20	24
Transient mackerel	1	9	9	19	24
Adult bentho-piscivorous demersals	1	9	9	20	24
Juv. bentho-piscivorous demersals	1	10	10	20	-
Adult large demersal feeders	1	9	2	20	24
Juv. large demersal feeders	1	10	10	20	-
Other small demersals	1	9	9	20	-
Lumpfish	1	9	9	20	-
Greenland cod	1	9	9	20	24
Salmon	1	1	9	20	24
Capelin	1	9	2	20	24
Sandlance	1	9	2	19	-
Arctic cod	1	9	2	20	-
Herring	1	9	9	19	24
Transient pelagics	1	9	12	19	24
Small pelagics	1	9	12	19	24
Mesopelagics	1	9	9	19	24
Shortfin squid	1	3	1	20	24
Arctic squid	1	9	1	19	-
Large crabs	1	10	2	20	24
Small crabs	1	10	2	20	25
Lobster	1	9	2	20	24
Shrimp	1	9	2	19	24
Echinoderms	2	10	2	19	-
Polychaetes	2	10	2	19	-
Bivalves	2	10	2	19	24
Other benthic inverts.	2	10	2	19	24
Large zooplankton	1	12	11	19	-
Small zooplankton	2	12	9	19	-
Phytoplankton	4	4	-	-	-
Detritus	3	2	9	19	-

1	Estimated by Ecopath	2	From other model
3	Guestimate	4	Approximate or indirect method
5	Sampling based low precision	6	Sampling based high precision
7	Locally based low precision	8	Locally based high precision
9	Empirical relationship	10	Similar group, similar system
11	Similar group, same system	12	Same group, similar system
13	Same group, same system	14	Similar system, low precision
15	Same system, low precision	16	Similar system, high precision
17	Same system, high precision	18	General knowledge of related group
19	General knowledge of same group	20	Qualitative diet composition study
21	Quantitative but limited study	22	Qualitative, detailed
23	FAO statistics	24	National statistics
25	Local study, low precision	26	Local study, high precision

Table 12: New 30 compartment model for Newfoundland. Biomass estimated in t•km⁻². (Bold estimated by Ecopath)

Group name	Trophic level	Biomass	P/B	Q/B	Ecotrophic efficiency	P/Q
Cetaceans	4.11	0.251	0.100	11.794	**0.000**	**0.009**
Harp seals	4.25	0.184	0.102	17.412	**0.161**	**0.006**
Hooded seals	4.76	0.034	0.109	13.100	**0.048**	**0.008**
Birds	4.14	0.012	0.250	54.750	**0.428**	**0.005**
Large cod	4.18	2.040	0.650	2.600	**0.467**	**0.250**
Small cod	3.87	0.377	1.600	6.090	**0.967**	**0.263**
Large A. plaice	3.67	0.970	0.540	2.000	**0.261**	**0.270**
Small A. plaice	3.71	0.780	0.630	3.736	**0.868**	**0.169**
Large G. halibut	4.53	0.350	0.300	1.480	**0.963**	**0.203**
Small G. halibut	4.25	0.362	0.870	3.401	**0.950**	**0.256**
Yellowtail flounder	3.12	0.215	0.534	3.600	**0.950**	**0.148**
Other flounders	3.03	0.598	0.562	2.251	**0.950**	**0.250**
Skates	4.01	0.520	0.290	2.878	**0.308**	**0.101**
Redfish	3.64	2.011	0.330	2.000	**0.950**	**0.165**
Large demersals	3.75	0.831	0.266	1.764	**0.950**	**0.151**
Small demersals	3.33	2.983	0.564	4.167	**0.950**	**0.135**
Forage fish	3.29	16.018	1.022	5.758	**0.942**	**0.178**
Small pelagics	3.19	7.772	0.876	5.109	**0.950**	**0.172**
Large pelagics	3.87	0.406	0.288	1.976	**0.231**	**0.146**
Squid	4.18	0.453	0.600	4.000	**0.950**	**0.150**
Large crustaceans	3.06	3.549	0.369	1.489	**0.969**	**0.248**
Shrimp	2.46	1.148	1.700	9.667	**0.950**	**0.176**
Echinoderms	2.00	112.300	0.600	6.667	**0.062**	**0.090**
Polychaetes	2.00	10.500	2.000	22.222	**0.187**	**0.090**
Bivalve Molluscs	2.00	42.100	0.570	6.333	**0.097**	**0.090**
Other benthic invertebrates	2.00	7.800	2.500	12.500	**0.395**	**0.200**
Large zooplankton	2.56	27.480	3.433	19.500	**0.950**	**0.176**
Small zooplankton	2.00	41.755	8.400	28.000	**0.950**	**0.300**
Phytoplankton	1.00	26.860	93.100	-	**0.547**	-
Detritus	1.00	389.000	-	-	**0.997**	-

Table 13: Diet matrix of balanced 30 compartment model of Newfoundland in 1985.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2														
3														
4		0.000												
5		0.003	0.014											
6	0.010	0.006	0.042	0.005	0.018	0.007	0.000	0.004	0.076	0.009			0.034	0.002
7		0.011												
8		0.039			0.017	0.000	0.001	0.021	0.001				0.002	
9		0.008	0.092											
10		0.017	0.276		0.006	0.002	0.001	0.002	0.127	0.006			0.001	
11			0.021		0.001		0.000	0.008						
12		0.073	0.098		0.000		0.000		0.002				0.005	
13					0.000				0.001					
14		0.003	0.119		0.009	0.000		0.001	0.257				0.050	0.007
15	0.039	0.008	0.013	0.006	0.001								0.001	
16	0.030	0.019	0.039	0.009	0.039	0.024	0.009	0.020	0.085	0.008		0.013	0.182	0.001
17	0.488	0.565	0.078	0.698	0.619	0.462	0.298	0.339	0.410	0.884	0.039		0.126	0.007
18	0.245	0.157	0.148	0.082	0.114	0.049	0.169	0.091	0.021	0.040	0.040		0.134	0.249
19	0.001		0.008	0.001					0.000					
20		0.008	0.049	0.005	0.001				0.001				0.059	
21		0.000	0.001		0.051	0.024	0.049	0.025				0.001	0.150	
22		0.069		0.006	0.037	0.079	0.003	0.013	0.013	0.022		0.020	0.014	0.035
23					0.004	0.000	0.298	0.112		0.000	0.073	0.012	0.050	
24					0.006	0.017	0.017	0.111			0.404	0.629	0.056	
25				0.012	0.020	0.005	0.060	0.022			0.030	0.014	0.036	
26			0.001		0.012	0.139	0.075	0.140	0.002	0.004	0.370	0.311	0.098	
27	0.104	0.015		0.168	0.047	0.192	0.021	0.092	0.003	0.029	0.043	0.001	0.002	0.538
28	0.083			0.008		0.000		0.000					0.001	0.161
29														
30														

Table 13: Diet matrix of balanced 30 compartment model of Newfoundland in 1985 (continued)

	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1														
2														
3														
4														
5														
6	0.018	0.006			0.001	0.100								
7														
8	0.022	0.007												
9														
10	0.001	0.000			0.000									
11	0.004	0.001												
12	0.001	0.000												
13	0.001	0.001												
14	0.016	0.006			0.003									
15					0.000									
16	0.136	0.043			0.005	0.001								
17	0.115	0.028	0.026	0.002	0.506	0.369								
18	0.136	0.047	0.005	0.014	0.129	0.350								
19														
20	0.003	0.009			0.004									
21	0.049	0.037					0.000							
22	0.054	0.068			0.009		0.010							
23	0.153	0.189					0.099							
24	0.044	0.116			0.001		0.109	0.015						
25	0.013	0.050					0.244							
26	0.093	0.269		0.032	0.272		0.149	0.015						
27	0.131	0.098	0.450	0.339	0.069	0.180	0.192	0.120					0.050	
28	0.009	0.024	0.519	0.591	0.001		0.144	0.240					0.480	
29								0.085					0.370	1.0
30				0.023			0.052	0.525	1.0	1.0	1.0	1.0	0.100	

Table 14: New 30 compartment model for Newfoundland in 1995. Biomass estimated in t•km^{-2}. (Bold estimated by Ecopath)

Group name	Trophic level	Biomass	P/B	Q/B	Ecotrophic efficiency	P/Q
Cetaceans	4.14	0.251	0.100	11.794	**0.002**	**0.008**
Harp seals	4.27	0.405	0.102	13.983	**0.433**	**0.007**
Hooded seals	4.77	0.034	0.109	10.843	**0.517**	**0.010**
Birds	4.14	0.017	0.250	54.750	**0.240**	**0.005**
Large cod	4.20	0.080	0.673	2.692	**0.869**	**0.250**
Small cod	3.88	0.193	1.827	6.090	**0.991**	**0.300**
Large A. plaice	3.64	0.340	0.700	2.593	**0.263**	**0.270**
Small A. plaice	3.73	0.307	1.121	3.736	**0.950**	**0.300**
Large G. halibut	4.35	0.366	0.749	3.689	**0.322**	**0.203**
Small G. halibut	4.24	0.522	0.607	4.480	**0.947**	**0.135**
Yellowtail flounder	3.13	0.330	0.534	3.600	**0.781**	**0.148**
Other flounders	3.06	0.924	0.398	1.913	**0.948**	**0.208**
Skates	4.03	0.208	0.290	2.878	**0.628**	**0.101**
Redfish	3.68	1.193	0.330	2.000	**0.906**	**0.165**
Large demersals	3.76	0.736	0.232	1.546	**0.949**	**0.150**
Small demersals	3.27	2.890	0.564	4.152	**0.938**	**0.136**
Forage fish	3.27	7.529	1.363	5.656	**0.955**	**0.241**
Small pelagics	3.36	6.606	0.897	4.906	**0.952**	**0.183**
Large pelagics	4.05	0.030	0.276	2.448	**0.961**	**0.113**
Squid	4.12	0.423	0.600	4.000	**0.954**	**0.150**
Large crustaceans	3.07	2.177	0.300	1.472	**0.941**	**0.204**
Shrimp	2.46	1.859	1.450	9.667	**0.961**	**0.150**
Echinoderms	2.00	112.300	0.600	6.667	**0.063**	**0.090**
Polychaetes	2.00	10.500	2.000	22.222	**0.179**	**0.090**
Bivalve Molluscs	2.00	42.100	0.570	6.333	**0.073**	**0.090**
Other benthic invertebrates	2.00	7.800	2.500	12.500	**0.320**	**0.200**
Large zooplankton	2.56	20.320	3.433	19.500	**0.950**	**0.176**
Small zooplankton	2.00	30.367	8.400	28.000	**0.892**	**0.300**
Phytoplankton	1.00	35.600	52.900	-	**0.530**	-
Detritus	1.00	181.000	-	-	**0.992**	-

Table 15: Diet matrix of balanced 30 compartment model of Newfoundland in 1995.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2														
3														
4														
5		0.007	0.014											
6	0.010	0.009	0.042	0.00487	0.026	0.008	0.000	0.001	0.030	0.005			0.034	0.002
7		0.011												
8		0.039			0.026	0.000	0.000	0.001	0.010				0.002	
9		0.005	0.092											
10		0.015	0.274		0.002	0.001	0.000	0.001	0.070	0.006			0.001	
11		0.020	0.021		0.003		0.000	0.001						
12		0.053	0.099		0.001				0.000				0.005	
13					0.001					0.010				
14		0.002	0.120		0.005	0.000		0.001	0.080				0.050	0.007
15	0.039	0.003	0.013	0.00681	0.001				0.005				0.001	
16	0.030	0.022	0.039	0.00973	0.033	0.017	0.009	0.033	0.273	0.059		0.041	0.182	0.001
17	0.489	0.491	0.079	0.698	0.443	0.342	0.145	0.260	0.350	0.800	0.039		0.126	0.007
18	0.245	0.232	0.149	0.0827	0.287	0.136	0.269	0.160	0.085	0.048	0.040		0.134	0.249
19	0.001		0.008	0.00065										
20		0.007	0.050	0.00487	0.002				0.022	0.015			0.059	
21		0.000	0.001		0.055	0.079	0.056	0.035				0.002	0.150	
22		0.065		0.00568	0.024	0.044	0.001	0.014	0.011	0.035		0.010	0.014	0.035
23					0.007	0.000	0.311	0.085	0.010	0.000	0.073	0.055	0.050	
24					0.009	0.018	0.011	0.085			0.404	0.391	0.056	
25				0.0119	0.042	0.019	0.093	0.033	0.010		0.030	0.034	0.036	
26				0.00132	0.006	0.133	0.077	0.130	0.033	0.004	0.370	0.467	0.098	
27	0.104	0.019		0.168	0.030	0.204	0.027	0.160	0.001	0.029	0.043	0.000	0.002	0.538
28	0.083			0.00755		0.000		0.001					0.001	0.161
29														
30														

Table 15: Diet matrix of balanced 30 compartment model of Newfoundland in 1995 (continued)

	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1														
2														
3														
4														
5														
6	0.016	0.004			0.009	0.050								
7														
8	0.020	0.005												
9														
10	0.001	0.000			0.001									
11	0.003	0.001												
12	0.001	0.000												
13	0.001	0.000												
14	0.015	0.006		0.001	0.025									
15					0.001									
16	0.131	0.031			0.043	0.001								
17	0.124	0.025	0.008	0.001	0.135	0.369								
18	0.124	0.043	0.005	0.013	0.379	0.334								
19														
20	0.003	0.006			0.040									
21	0.049	0.017					0.000							
22	0.056	0.068		0.027	0.084		0.047							
23	0.149	0.216		0.021			0.073							
24	0.043	0.139			0.013	0.033	0.118	0.015						
25	0.013	0.055					0.238							
26	0.091	0.269		0.011	0.037	0.033	0.147	0.015						
27	0.151	0.091	0.457	0.624	0.228	0.180	0.184	0.120					0.05	
28	0.011	0.023	0.530	0.281	0.007		0.137	0.240					0.48	
29								0.085					0.37	1
30				0.021			0.055	0.525	1	1	1	1	0.10	

REFERENCES

Anderson, J. T., Davis, D. J., Dalley, E. L., and Carscadden, J. E., 2001. Abundance and Biomass of Juvenile and Adult Capelin in the Newfoundland Region (NAFO 2J3KL) Estimated from the Pelagic Juvenile Fish Surveys, 1994-1999. DFO Research Document, St. John's, Newfoundland, 1-12 pp.

Anon, 2000. American plaice in Subarea 2 and Division 3K. DFO Newfoundland Region, St. John's, Stock Status Report, A2-11. 1-5 pp

Anon, 2002. East and Southeast Newfoundland Atlantic Herring. DFO Newfoundland and Labrador Region, St. John's, Stock Status Report, B2-01. 1-21 pp.

Anon, 2003a. Global landings database, Sea Around Us Project Fisheries Centre, University of British Columbia, Vancouver, www.seaaroundus.org.

Anon, 2003b. Northern (2J+3KL) Cod. DFO - Newfoundland and Labrador Region, St. John's, Stock Status Report, 2003/018. 1-15 pp

Bourdages, H., C. Savenkoff, S.-P. Despatie, J.M. Hanson, L. Morissette, R. Méthot, and D. Swain, in press. Data gathering and input parameters to construct ecosystem models for the southern Gulf of St. Lawrence (mid-1980s and mid-1990s). Canadian Technical Report of Fisheries and Aquatic Sciences.

Bowering, W. R., 2002. Greenland halibut (Reinhardtius hippoglossoides) in NAFO Subarea 2 and Divisions 3KLMNO: Stock Trends Based on Canadian Research Vessel Survey Results During 1978-2001. NAFO, St. John's Newfoundland, Scientific Council Report, 02/24. 1-40 pp

Bundy, A., Lilly, G. R., and Shelton, P. A., 2000. A mass balance model of the Newfoundland-Labrador Shelf. 1-157 pp

Bundy, A. in press. Mass balance ecosystem models of the eastern Scotian Shelf ecosystem before and after the groundfish collapse in 1993. DFO Technical Report.

Christensen, V., Walters, C. J., and Pauly, D., 2000. Ecopath with Ecosim, Help system., UBC Fisheries Centre, Vancouver, BC.

Hammill, M. O. and Stenson, G.B. 2000. Estimated prey consumption by harp seals (Phoca groenlandica), hooded seals (Cystophora cristata), grey seals (Halichoerus grypus) and harbour seals (Phoca vitulina) in Atlantic Canada." Journal of Northwest Atlantic Fisheries Science 26: 1-23.

Healey, B. P., Stansbury, D. E., Murphy, E. F., and Shelton, P. A., 2002. An Update on the Status of the Cod stock in NAFO Divisions 3NO. NAFO, St. John's Newfoundland, Scientific Council Research Document, NAFO SCR Doc. 02/57. 1-15 pp

Heymans, J. J. 2003. Comparing the Newfoundland models using information theory. pp. 63-72 In: Heymans J.J. (Ed.) Ecosystem models of Newfoundland and Southeastern Labrador: Additional information and analyses for 'Back to the Future'. Fisheries Centre Research Report 11(5), Vancouver, BC.

Heymans, J. J., and Pitcher, T. J., 2002a. A model of the Marine Ecosystem of Newfoundland and Southern Labrador (2J3KLNO) in the Time Periods 1985-1987 and 1995-1997. pp. 5-43, In: Pitcher, T.J., Heymans, J.J. and Vasconcellos, M. (Eds.) Ecosystem models of Newfoundland for the time periods 1995, 1985, 1900 and 1450. Fisheries Centre Research Reports, 10(5). Vancouver, BC.

Heymans, J. J., and Pitcher, T. J., 2002b. A Picasso-esque view of the marine ecosystem of Newfoundland and Southern Labrador: Models for the time periods 1450 and 1900. pp. 44-71, In: Pitcher, T.J., Heymans, J.J. and Vasconcellos, M. (Eds.) Ecosystem models of Newfoundland for the time periods 1995, 1985, 1900 and 1450. Fisheries Centre Research Reports, 10(5). Vancouver, BC.

Jones, B.C. and Geen, G.H. 1977. Food and feeding of spiny dogfish, Squalus acanthias, in British Columbia, Canada waters. J. Fish. Res. Bd. Can. 34: 2067-2078.Lilly, G. R., Shelton, P. A., Brattey, J., Cadigan, N. G., Healey, B. P., Murphy, E. F., and Stansbury, D. E., 2001. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO, Canadian Science Advisory Secretariat, St. John's NFL, Research Document, 2001/044. 1-149 pp

Lilly, G. R., Shelton, P. A., Brattey, J., Cadigan, N. G., Healey, B. P., Murphy, E. F., and Stansbury, D. E., 2001. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO, Canadian Science Advisory Secretariat, St. John's NFL, Research Document, 2001/044. 1-149 pp.

Maurer, R.O. and R.E. Bowman. 1984. Food Consumption of Squids (Illex illecebrosus and Loligo pealei) off the Northeastern United States. Northwest Atlantic Fisheries Organization: Scientific Council Studies, Special Session on Squids, Hodder, V.M., (ed.) 9: 117-124.

Morissette, L., Despatie, S.-P., Savenkoff, C. and M. O. Hammill 2003. Constructing an Ecopath model for the Northern Gulf of St. Lawrence: data gathering and input parameters. Canadian Technical Report of Fisheries and Aquatic Sciences 2497, 102 pp.

Pauly, D., Soriano-Bartz, M.L. and Palomares, M.L.D. 1993. Improved construction, parametrization and interpretation of steady-state ecosystem models. Pages 1-13 in Pauly,D. and Christensen, V. (eds) Trophic Models of Aquatic Ecosystems. ICLARM Conference Proceedings 26: 390 pp.

Savenkoff, C., H. Bourdages, L. Morissette, D. Chabot, M.O. Hammill, and M. Castonguay, in press. Data gathering and input parameters to construct ecosystem models for the northern Gulf of St. Lawrence (mid-1990s). Can. Tech. Rep. Fish. Aquat. Sci. XXX: viii+89 p.

Silverman, N., Sundbay, B., Mucci, A., Zhong, S., Arakaki, T., Hall, P., Ladén, A., and Tengberg, A. 2000. Reminieralization of organic carbon in eastern Canadian continental margin sediments. Deep-Sea Research II, 47:699-731.

COMPARING THE NEWFOUNDLAND MARINE ECOSYSTEM MODELS USING INFORMATION THEORY

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ABSTRACT

In this paper, Ecopath models of Newfoundland were compared using information theory indices and summary statistics. Four time periods were compared: 1450, 1900, 1985 and 1995, with both 1985 and 1995 having three models each: the initial models, the updated models, and the aggregated 30 compartment models. Furthermore, the 50 compartment models were also compared with and without the inclusion of bacterial respiration in the detritus. These models all show signs of "fishing down the food web" with the Finn cycling index and Finn mean path length both increasing over time, while the internal flow overhead increased. This indicates that the system had become less stable and more stressed over time. However, there were some indications of the impending collapse with the gross efficiency of the fishery and the predatory cycling index being highest in the 1985 model, while the systems entropy and throughput cycled including detritus, were at their lowest at that time. The inclusion of bacterial respiration changed the contribution of respiration and export to the throughput, as well as their contribution to the overhead and relative overhead ratios. The reduction of the 50 compartment models to 30 compartment models reduced the systems omnivory index, and increased the connectance in these systems, while changing the average mutual information and the total primary production to total respiration ratios.

INTRODUCTION

This paper is a first look at the differences in the emergent properties of the ecosystem models constructed for Newfoundland over the four time periods: 1995-1997 (called '1995'), 1985-1987 (called '1985'), 1900-1905 (called '1900') and for pre-European contact (called '1450'). These models are static representations of the ecosystem over time using the best available data (Heymans 2003). The ecosystem was first described by Bundy *et al.* (2000), and then by Heymans and Pitcher (2002a) for the later time periods and by Heymans and Pitcher (2002b) for the historical models. The contemporary models were then updated and aggregated in the present

report by Heymans (2003). For comparison with other models in the CDEENA project, the models described by Heymans (2003) were adapted to incorporate the respiration of bacteria in detritus. These models are compared in this paper using Network analysis indices (*sensu* R.E. Ulanowicz) as well as the summary statistic indices of the models available in Ecopath. Network analysis is a suite of algorithms devised by R.E. Ulanowicz and co-workers (Ulanowicz 1986 and 1987; Ulanowicz and Puccia 1990; Ulanowicz and Kay 1991) from information theory, then incorporated into Ecopath by D. Pauly (Christensen and Pauly 1992).

METHODOLOGY

Eleven different models of the Newfoundland ecosystem have been constructed up to this time. The models were for four time periods and the most recent models for each time period were compared here using the summary statistics of the newly updated (Heymans 2003) contemporary models and the two historic models (Heymans and Pitcher 2002b). The contemporary models were also compared with other models constructed by Bundy *et al.* (2000) and Heymans and Pitcher (2002a and b) as well as the aggregated models for the contemporary times (Heymans 2003).

The summary statistics used for comparison include: the sum of all consumption, sum of all exports, sum of all respiratory flows, sum of all flows into detritus and sum of all production. All these statistics are given in t•km^{-2}•year^{-1} and are calculated as the sum of each index in each compartment. Other summary statistics include the mean trophic level of the catch, the gross efficiency, net primary production (t•km^{-2}•year^{-1}), total primary production/total respiration, net systems production (t•km^{-2}•year^{-1}), total primary production/total biomass, total biomass/total throughput, total biomass excluding detritus and total catches (both in t•km^{-2}•year^{-1}).

The models were also subjected to Network analysis in Ecopath. The network analysis indices of importance for comparison of ecosystem are the total systems throughput (t•km^{-2}•year^{-1}), ascendency, overhead and development capacity (in flowbits), average mutual information, relative ascendency, relative overhead, internal relative ascendency, statistical entropy, connectance index and the system omnivory index. From cycling analysis, the indices of importance are the Finn cycling index (%), Finn's mean path length, throughput cycled excluding detritus, predatory

cycling index (%), throughput cycled including detritus, and Finn's straight-through path length (with and without detritus). These indices are defined below.

Definitions of indices used for comparison

- The <u>mean trophic level of the catch</u> (TL_{catch}) is calculated by the sum of the catch of each group times its trophic level divided by the total catch, and has been shown to decline between 0.03 and 0.1 per decade in Canada and globally (Pauly *et al.* 2001);
- The <u>net systems production</u> (NSP) is the difference between total primary production and total respiration and is an indication of immaturity when it is high; a mature system will have a low NSP (Christensen *et al.* 2000a);
- The <u>gross efficiency</u> (GE) is defined as the catch divided by the net primary production and this index will be high for fisheries that harvest low TL fish, while under-exploited systems and systems where mostly apex predators are harvested will have a low GE (Christensen *et al.* 2000a);
- The <u>total systems throughput</u> (TST) is the sum of all the flows in the ecosystem (Finn 1976);
- The <u>ascendency</u> (A) is the product of the total systems throughput and a factor that represents the coherence of the flows, or the average mutual information of the flow structure (Ulanowicz and Puccia, 1990);
- The upper bound to A is the <u>development capacity</u> (C), which is a measure of the network's potential for competitive advantage over other real or putative network configurations (Ulanowicz and Puccia 1990). The development capacity (C) is the product of the TST and the diversity of the individual flows (Ulanowicz and Puccia 1990);
- The systems <u>overhead</u> (O) is complementary to the ascendency and gauges all the inchoate (unclear), inefficient, and redundant degrees of freedom that the system retains (Ulanowicz 2000);
- The <u>relative ascendency</u> (A:C) shows the relative organization and specialization of the system (Ulanowicz 1986);
- The <u>relative overhead</u> (O:C) is proposed here as a index of the resilience of the system as the overhead is a prerequisite of system resilience, creativity, and persistence (Ulanowicz 1997).
- The <u>internal relative ascendency</u> ($A_i:C_i$) is the relative ascendency calculated over the internal exchanges only, i.e., no inputs or exports from the system are included. According to (Ulanowicz 1986) the growth and development of networks are best characterized using this ratio;
- The <u>average mutual information</u> (AMI) measures the organization with which exchanges among components are transacted. A rise in AMI signifies that the system is developing further constraints to channel flows along more specific pathways (Ulanowicz and Abarca-Arenas 1997);
- The <u>statistical entropy</u> (H) is the ratio of development capacity to total systems throughput. It is an indication of the uncertainty of the system and represents the total number and diversity of flows in a system given the same amount of throughput (Mageau *et al.* 1998);
- The <u>connectance index</u> (CI) is the number of connections in the ecosystem as a proportion of the total possible trophic connections (Ulanowicz 1986) and shows the transfers among the living compartments (Baird *et al.* 1991);
- The <u>system omnivory index</u> (SOI) is the average group omnivory index weighted by the logarithm of the total food consumption. A group's omnivory index is calculated as the variance of the trophic levels of a consumer's preys (Christensen and Pauly 1992). The SOI is a measure of how the feeding interactions are distributed between trophic levels (Vasconcellos *et al.* 1997);
- The <u>Finn cycling index</u> (FCI) quantifies the relative amount of cycling in the ecosystem and is an indication of the stress and structural differences in different ecosystems (Finn 1976);
- The <u>Finn mean path length</u> (FPL), or average path length (Heymans and Baird 2000) is the average number of compartments through which an inflow into the system passes (Finn 1976). The FPL is sensitive to the number of compartments in the model, but if the systems have the same number of compartments this sensitivity would be avoided (Heymans and Baird 2000);
- The <u>predatory cycling index</u> (PCI) is the percentage of throughput cycled after detritus has been removed (Christensen *et al.* 2000b).

RESULTS

Comparing the four time periods

The models used for this comparison are those described by Heymans and Pitcher (2002b) for 1450 and 1900 and the updated models (without

respiration by bacteria) described by Heymans, (2003). The biomass estimates obtained from the balanced models are given in Figure 1. Figure 1 shows that in most instances the biomass was highest in the 1450 model, and decreased over time to the latest model (1995). The biomass of species that went locally extinct (such as grey seals and walrus) are close to zero (Figure 1).

The trophic flow pyramids of the four systems (Figure 2) show flows by trophic level from TL II to the top consumers (Christensen *et al.* 2000a). The volume of each compartment is proportional to its flow throughput and its top-angle is inversely proportional to the geometric mean trophic transfer efficiency between the trophic levels observed in the system (Christensen *et al.* 2000b). The mean trophic transfer efficiency decreased over time from 17.2% in 1450 to 14.6% in 1995.

Results from the Network analysis done on the four models are given in Table 1. The total system's throughput and its parts (viz., the sum of all the consumption, respirations, production, exports and flow to detritus) all tend to decrease from their highest values in 1450, through lower values in 1900 and 1985, to the lowest values in 1995. Similarly, the reduction in the trophic level of the catch, net primary production, net systems production, total primary production/total biomass and total biomass excluding detritus are reduced from their highest values in 1450, to the

lowest in 1995. In contrast, the total biomass/total throughput increases from 1450 to 1995.

The gross efficiency and the total catch increased from 1450 to 1985, after which it decreased again to 1995, while the total primary production/total respiration decreased from 1450 to 1985 and then increased to 1995.

Of the Network analysis indices, the development capacity, ascendency and overhead follow the same reduction trends as the total system throughput from 1450 to 1995. Similarly, the throughput cycled (excluding detritus) and the Finn's straight through path length without detritus decreased over that time.

In contrast, the systems omnivory index, internal relative ascendency, relative overhead, Finn cycling index, Finn mean path length and Finn straight through path length with detritus show the inverse trend, by increasing from 1450 to 1995. The connectance index and throughput cycled including detritus decreased from 1450 to 1985, after which it increased to 1995, and the predatory cycling index, and entropy both show an increase from 1450 to 1900, then a decrease to 1985 and another increase to 1995. Finally, the average mutual information was stable for 1450 and 1900 but reduced to the same value in 1985 and 1995.
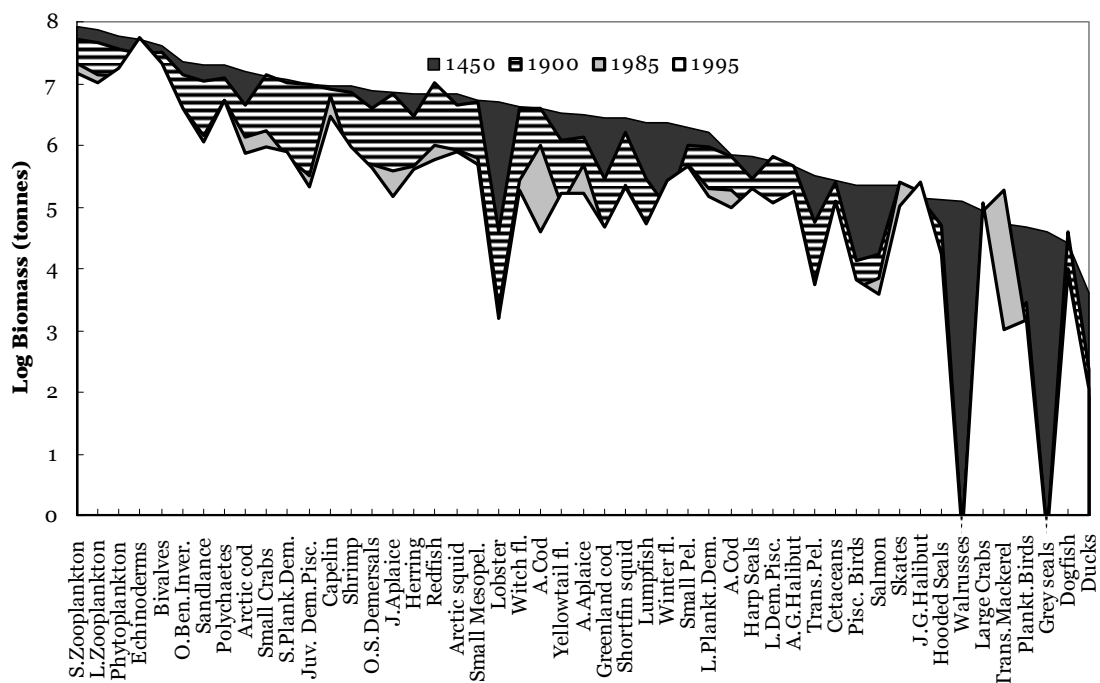
Figure 1: Biomasses (log scale) estimated for the four Newfoundland models constructed by Heymans and Pitcher (2002b) and Heymans (2003).
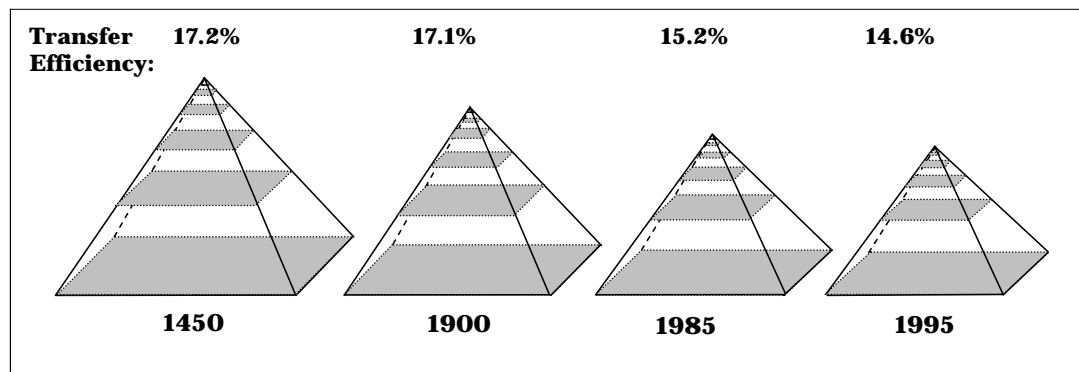
Figure 2: Fishing down the foodweb in the Newfoundland ecosystem as shown by the flow diagrams of the ecosystem over time. Note the decline of the mean trophic transfer efficiency.

Comparison with other models

The Network analysis indices of the eleven models constructed for the four time periods were compared here. These include the models constructed by Bundy *et al.* (2000) and Heymans and Pitcher (2002a and b) and the models reduced to 30 compartments by Heymans (2003). In addition, the 50 compartment models updated by Heymans (2003), were also restructured to include the respiration of bacteria in detritus, for comparison with other models in the CDEENA project. The results from these models are all given in Table 2.

The 30 and 50 compartment models (with the respiration of bacteria included) are very similar in all respects except for the systems connectance, systems omnivory indices and the trophic level of the catch in 1995 (Table 2). Both these indices are dependent on the number of compartments in the model as more compartments would have more connections and there would be less omnivory when compartments are combined and diets consolidated.

The main difference between the models with and without bacterial respiration is in the exports and respiration but it is also echoed in a reduction in the systems information and an increase in the systems overhead, mainly due to the increase in respiration overhead (Table 2). This increase in overhead also increases the relative overhead, which shows that it is not possible to compare the models with and without detritus respiration using these indices.

Of the models given in Table 2, it is therefore only possible to compare the 1450, 1900 and 50 compartment models without added bacterial respiration for all indices. Of these models (Heymans and Pitcher, 2002b; a; Heymans, 2003) the main changes made were in the

systems, as many changes were made to the Q/B and P/B ratios of the systems. In the 1995 model the total systems throughput was nearly halved mainly due to the reduced primary production.

The mean trophic level of the fishery was marginally reduced in the 1985 model and increased in the 1995 model due to the changes in the catch instituted in Heymans (2003). However, this did not change in interpretation of the temporal differences in this index.

Other than these changes, the differences in the models instituted by Heymans (2003) also changed the overall summary statistics. The reduction in primary production in the new 1995 models (with and without bacterial respiration) decrease the total systems throughput, calculated total net primary production, total PP/total respiration, total PP/total biomass and net systems production dramatically. Some key Network analysis indices change enough to make a difference to the interpretation of the system. These changes are underlined in Table 2 and include reductions in the connectance index (CI) and the average mutual information (AMI), for both the new 1985 and 1995 models.

The decrease in the throughput decreases the ascendency, overhead and capacity estimates in 1995, while it increases the relative overhead due to increased internal overhead. In addition the predatory cycling index decreased in the 1985 model, but increased in the 1995 model. The systems omnivory index (SOI), throughput cycled excluding detritus, and the Finn cycling index (FCI) all increased for both the 1985 and 1995 models.

Table 1: Results of Network analysis of the four Newfoundland models constructed by Heymans and Pitcher (2002b) and Heymans (2003).

Parameter	1450	1900	1985	1995
Sum of all consumption (t•km^{-2}•year^{-1})	11412	7571	3245	2727
Sum of all exports (t•km^{-2}•year^{-1})	4251	2469	515	432
Sum of all respiratory flows (t•km^{-2}•year^{-1})	6727	4525	1986	1451
Sum of all flows into detritus (t•km^{-2}•year^{-1})	7893	5082	1920	1828
Sum of all production (t•km^{-2}•year^{-1})	13380	8530	3110	2362
Mean trophic level of the catch	4.04	3.92	3.85	3.17
Gross efficiency (catch/net p.p.)	0.00000	0.00013	0.00052	0.00015
Calculated total net primary production (t•km^{-2}•year^{-1})	10979	6994	2501	1883
Total primary production/total respiration	1.63	1.55	1.26	1.30
Net system production (t•km^{-2}•year^{-1})	4251	2469	515	432
Total primary production/total biomass	10.52	10.10	8.05	6.58
Total biomass/total throughput	0.034	0.035	0.041	0.044
Total biomass (excluding detritus) (t•km^{-2})	1043	693	311	286
Total catches (t•km^{-2}•year^{-1})	0.004	0.878	1.307	0.280
Total system throughput (t•km^{-2}•year^{-1})	30282	19647	7666	6438
Connectance Index	0.234	0.231	0.232	0.234
System Omnivory Index	0.122	0.129	0.143	0.144
Ascendency (flowbits)	40283	26076	9910	8317
Overhead (flowbits)	89345	58131	22782	19323
Development Capacity (flowbits)	129628	84206	32692	27641
Information	1.33	1.33	1.29	1.29
Relative overhead (O/C)	68.92	69.03	69.69	69.91
Systems entropy (C/T)	4.28	4.29	4.26	4.29
Internal ascendency (A_i/C_i)	17.30	17.70	19.60	20.30
Throughput cycled excluding detritus (t•km^{-2}•year^{-1})	108.51	70.54	29.56	20.44
Predatory cycling index (% of throughput w/o detritus)	0.75	0.74	0.77	0.73
Throughput cycled including detritus (t•km^{-2}•year^{-1})	1073	775	554	559
Finn's cycling index	3.54	3.95	7.22	8.69
Finn's mean path length	2.759	2.809	3.066	3.419
Finn's straight-through path length without detritus	2.139	2.079	1.910	1.903
Finn's straight-through path length with detritus	2.661	2.698	2.844	3.121

The new connectance indices for both 1985 and 1995 (CI) are similar to those of the 1450, 1900 and 1985 models in both Heymans and Pitcher (2002a and b), but less than the 1995 CI's in Heymans and Pitcher (2002a). The CI's of the Bundy *et al.* (2000) model and the two 30 compartment models for 1985 and 1995 are much higher than any of the other CI's.

The high CI's in these models are probably due to the fact that the model consists of less compartments {31 for the Bundy *et al.* (2000) model}, and therefore the total number of trophic connections is much lower than in the 50 compartment models. It is therefore not viable to compare this index when models with different compartments are used.

Similar to the systems omnivory index (SOI) in the Heymans and Pitcher (2002a) model of 1985, the new 1985 model's SOI is still higher than that of the 1450 and 1900 models, and higher than that of the Bundy *et al.* (2000) model (Table 2). The SOI of the new 1995 model is much higher than that obtained from the Heymans and Pitcher (2002a) 1995 model, but similar to that of the 1985 models.

The average mutual information (AMI) of the new 1985 model is lower than that in Bundy *et al.* (2000) model and the Heymans and Pitcher (2002a and b) models for 1985, 1900 and 1450. In addition, the models that include bacterial respiration have even more reduced information in both 1985 and 1995. The new models have therefore, less constraint to channel flows along more specific pathways (Ulanowicz and Abarca-Arenas 1997), and by including the bacterial respiration the constraint was reduced further. Similarly, the new 1995 model AMI is lower than that of the Heymans and Pitcher (2002a) model for the same time period, indicating that their constraints of channelling flows have been reduced further.

The predatory cycling index (PCI) in the two 1985 models {the new 1985 model constructed by Heymans (2003) and the Heymans & Pitcher (2002a) model} are relatively similar. In contrast, the new PCI's in the 1995 model (Heymans 2003) are substantially higher than that of the Heymans and Pitcher (2002a) model, but still lower than any other of the time periods.

Table 2: Comparison of the differences in Network analysis indices obtained from the Heymans and Pitcher (2002a) models (H&P), vs. that of the model obtained from Bundy *et al.* (2000) (Bundy) and the model described by Heymans (2003) (with and without respiration by bacteria in detritus, '50 w R' and '50 w/o R') and the 30 compartment models (30 comp). Changes in the indices that change the interpretation of the results are underlined.

Parameter	1450	1900	1985					1995			
			Bundy	H&P	50 w/o R	50 w R	30 comp	H&P	50 w/o R	50 w R	30 comp
Sum of all consumption *	11,415	7,572	2,519	2,789	3,245	3,245	3,245	3,196	2,727	2,727	2,727
Sum of all exports *	4,251	2,469	972	831	515	5	5	2,630	432	12	12
Sum of all respiratory flows *	6,728	4,526	1,528	1,669	1,986	2,496	2,496	1,828	1,451	1,871	1,871
Sum of all flows into detritus *	7,894	5,083	2,362	2,238	1,920	1,920	1,920	4,534	1,828	1,828	1,828
Total system throughput *	30,288	19,649	7,381	7,528	7,666	7,666	7,666	12,189	6,438	6,438	6,438
Sum of all production *	13,384	8,530	2,987	3,061	3,110	3,110	3,110	4,961	2,362	2,362	2,362
Mean trophic level of the catch	4.04	3.92	3.83	3.88	3.85	3.85	3.85	3.11	3.17	3.16	3.21
Gross efficiency (catch/net p.p.)	0.00000	0.00013	0.00052	0.00046	0.00052	0.00052	0.00052	0.00006	0.00015	0.00015	0.00015
Calculated total net p.p. *	10,979	6,994	2,501	2,501	2,501	2,501	2,501	4,458	1,883	1,883	1,883
Total p.p./total respiration	1.632	1.545	1.636	1.498	1.259	1.002	1.002	2.439	1.298	1.006	1.006
Net system production *	4,251	2,469	972	831	515	5	5	2,630	432	12	12
Total p.p./total biomass	10.5	10.1	8.7	8.1	8.0	8.0	8.0	13.6	6.6	6.6	6.6
Total biomass/total throughput	0.034	0.035	0.039	0.041	0.041	0.041	0.041	0.027	0.044	0.044	0.044
Total biomass excluding detritus †	1,043	693	287	308	311	311	311	328	286	286	286
Total catches (t/km²/year)	0.004	0.878	1.299	1.148	1.307	1.307	1.307	0.280	0.280	0.278	0.278
Connectance Index	0.234	0.231	0.289	0.234	0.232	0.232	0.321	0.236	0.234	0.234	0.329
System Omnivory Index	0.122	0.129	0.125	0.138	0.143	0.143	0.123	0.111	0.144	0.144	0.136
Ascendency (Flowbits)	40,292	26,078	9,795	9,940	9,910	8,096	8,072	16,018	8,317	6,881	6,859
Overhead (Flowbits)	89,365	58,137	19,878	21,705	22,782	24,627	24,410	27,704	19,323	20,838	20,675
Capacity (Flowbits)	129,656	84,215	29,672	31,645	32,692	32,723	32,482	43,722	27,641	27,719	27,535
Information	1.330	1.327	1.327	1.321	1.293	1.056	1.053	1.314	1.292	1.069	1.065
Relative overhead (O/C)	68.92	69.03	66.99	68.59	69.69	75.26	75.15	63.36	69.91	75.17	75.09
Throughput cycled excl. detritus *	108.5	70.5	20.7	25.2	29.6	29.6	30.4	5.8	20.4	20.4	21.0
Predatory cycling index	0.75	0.74	0.78	0.83	0.77	0.77	0.80	0.19	0.73	0.73	0.76
Throughput cycled incl. detritus *	1,073	775	514	520	554	554	555	597	559	559	560
Finn's cycling index	3.54	3.95	6.96	6.90	7.22	7.22	7.24	4.90	8.69	8.69	8.70
Finn's mean path length	2.76	2.81	2.95	3.01	3.07	3.07	3.07	2.73	3.42	3.42	3.42
Internal flow/C (%)	64.0	64.2	64.7	65.2	65.6	65.6	65.6	64.7	68.4	68.2	68.2
Export/C	9.30	8.80	9.60	8.40	6.20	0.20	0.20	13.30	6.10	0.40	0.40
Respiration/C	26.7	27.0	25.7	26.4	28.2	34.2	34.2	22.0	25.5	31.4	31.4
Internal overhead	46.7	46.5	45.2	46.1	46.1	46.0	46.0	45.2	48.1	47.9	47.9
Export overhead	2.90	3.10	4.30	3.80	3.10	0.10	0.10	4.70	3.30	0.30	0.30
Respiration overhead	19.3	19.5	17.5	18.6	20.5	29.1	29.0	13.4	18.6	26.9	26.9

* = t•km⁻²•year⁻¹   † = t•km⁻²

$* = t \cdot km^{-2} \cdot year^{-1}$ $\dagger = t \cdot km^{-2}$

The lower PCI's in the 1995 models are probably due to the low throughput cycled excluding detritus in those models. The difference in primary production also changed the Finn cycling index (FCI) of the new 1995 model to be higher than that of the 1985 models, which is an indication of continued stress in the system. The FCI remains much higher in all three the 1985 models than it was in 1900 or 1450.

The system's overhead increased in the new 1985 model and decreased in the new 1995 model. The systems overhead gauges the inefficient and redundant degrees of freedom that the system retains (Ulanowicz 2000). The overhead is partitioned into four categories: inputs, internal flow, exports and dissipation (respiration) (Mageau *et al.* 1998). The internal overhead is an indication of the internal redundancy (excluding the export and respiration redundancy) in the system and this index is similar in the 1985 models. The internal overhead is higher in the new 1995 model than in the Heymans & Pitcher (2002a) model or in any of the other models.

The contribution of respiration, exports and internal flow to the absolute overhead, as well as the proportion they contribute to the overhead, are shown in Figure 3. From Figure 3A and B it is evident that the contribution of internal flow to the overhead was reduced until 1985, while the contribution of respiration had increased and the contribution of export stayed relatively constant. After the collapse, the contribution of internal flow increased while that of respiration decreased.

It might be more useful to exclude the overhead on export from the calculation of a proposed resilience index, as the export in this ecosystem was obviously not sustainable after 1985 and it does not seem to change much. The relative overhead of the ecosystem as well as the contribution that respiration and internal flow make to the relative overhead and the proportion of their combined contribution are plotted in Figure 4.

The contribution of respiration plus internal flow seems to follow the same trend as the relative overhead. Both the total relative overhead and the 'respiration + internal flow' seem to stay constant over the first two models and then increase to 1985 and again marginally to 1995. However, the proportion that is respiration and internal flow show a steady decline from 1450 to 1900, to 1985 and finally to 1995. It might therefore be a better indication of the resilience of the system.

DISCUSSION

The Newfoundland model shows 'fishing down the food web' (Figure 2) over the four time periods with a decrease in the trophic level of the fishery over time. This is also reflected by a decrease in the mean trophic transfer efficiency (Figure 2), the throughput cycled (excluding detritus), the Finn straight through path length (without detritus) and the average mutual

B

Export — Respiration — Internal flow

A

Export — Respiration — Internal flow
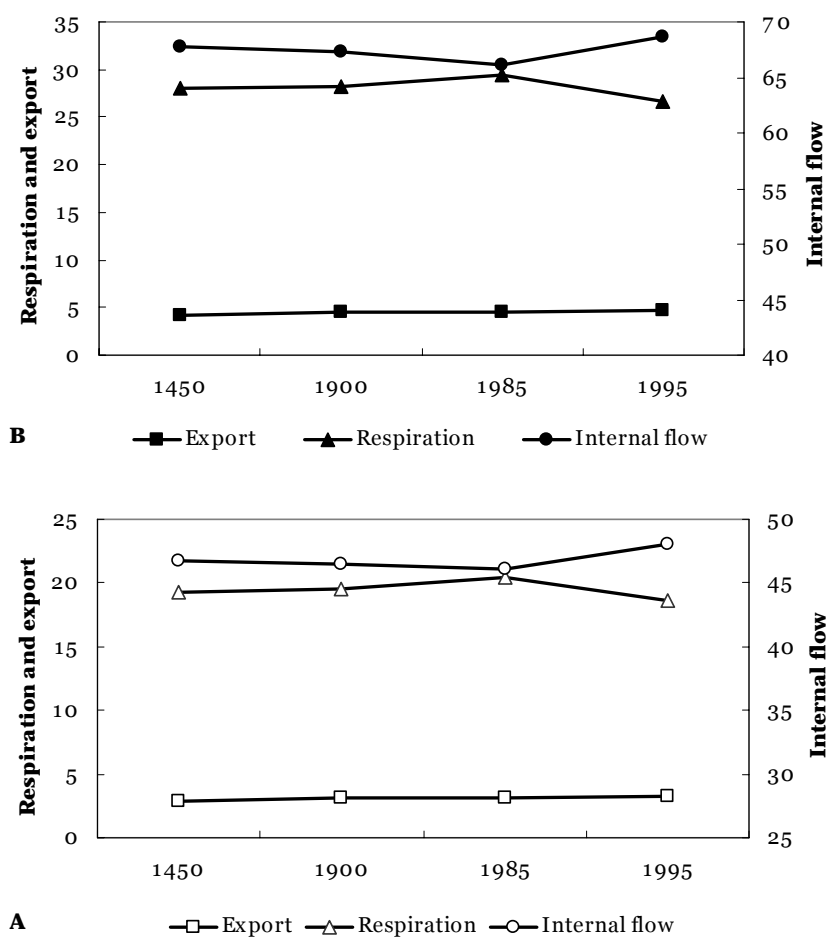
Figure 3: Comparison of the factors contributing to relative overhead in the four ecosystems as a breakdown of their overhead (A), and as the proportion that they contribute to the relative overhead (B).

information (AMI) over the four models (Table 1). According to Ulanowicz (1997) the AMI increases in an efficient system, notwithstanding Latham and Scully (2002) who suggest that the maturity of a system is represented by a low AMI. Thus, the system seems to have lost efficiency and maturity over time.

The large reduction in biomass over the 20th century reduced the total biomass and the total system's throughput (TST) more than fourfold from the 1450 and 1900 models to the 1995 model (Table 1). This reduction in biomass and throughput caused a decrease in most system indices, such as calculated net primary production, net system production and the total primary production/ total biomass ratio.

The reduction in total system's throughput over the four time periods caused a reduction in ascendency, overhead and development capacity, as well as a reduction in the throughput cycled excluding detritus and the Finn's straight through path length without detritus. In contrast to these declines, the total biomass/total throughput ratio, systems omnivory index, internal ascendency, relative overhead, Finn cycling index, Finn's mean path length, and Finn's straight through path length with detritus all show an increase over the four time periods.

 The indices that show any change in trend over time are the gross efficiency, total primary production / respiration, connectance, predatory cycling index and throughput cycled including detritus. The gross efficiency (GE) increases to a maximum in 1985, and is reduced in 1995. The GE is calculated as the total catch divided by net primary production, and as the catch is the highest in 1985, while the net primary production is relatively close to that of 1995, this index shows that the system was very efficient at that time. A high GE is linked to low TL fisheries, while a low GE is either caused by low exploitation or high TL fisheries. The GE of 1900 is similar to that obtained for 1995, but

for two very different reasons. In 1900, the higher trophic level of the mainly cod and whale fisheries decreased the GE, even though the catch was very high, while in 1995 the catch was lower, but so was the TL of the catch.

Indices of system's stability and stress include the Finn cycling index, the predatory cycling index and Finn mean path length. These indices are inversely correlated with the recovery time and stability of an ecosystem (Vasconcellos *et al.* 1997). Of these indices, the Finn cycling index and Finn mean path length both increase over time, which indicates that the system is becoming less stable and more stressed. However, the predatory cycling index does not show a clear trend over time. It is highest in 1985, indicating that the recycling through living compartments was highest at that time. Similarly, throughput cycled (including detritus) was lowest in 1985, which reflects that the system was very efficient, not just in terms of catches (gross efficiency) but also in terms of cycling in the living compartments. This efficiency was short lived, as the predatory cycling index and gross efficiency of the system declined substantially after the collapse.

Interestingly enough, the systems entropy (H) is lowest in the 1985 model. The systems entropy represents the total number and diversity of flows in a system and would increase as a given amount of throughput is partitioned among a greater number of exchange pathways associated with an
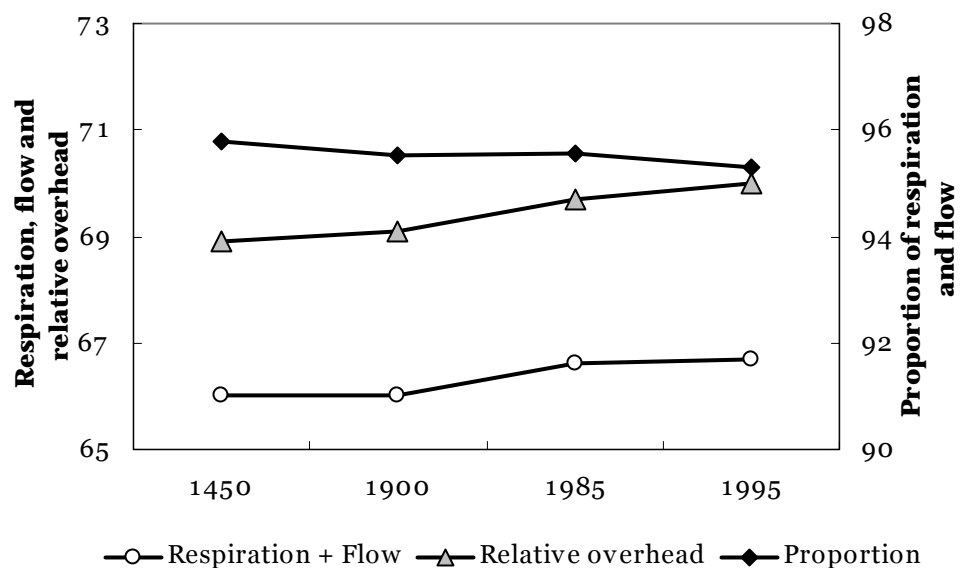
Figure 4: The relative overhead, contribution of respiration and internal flow to the relative overhead (primary y axis) and the proportion of respiration and internal flow to the relative overhead (secondary y axis) in the four models.

increase in diversity (Mageau *et al.* 1998). Thus, the number of exchange pathways and diversity of the system was decreased in 1985.

It therefore seems that there were some indications of stress and instability by 1985, although indices such as the Finn cycling index and Finn mean pathway both show that the system has increased in stress and instability since then. In addition, the proposed index of resilience, or the proportion that internal flow and respiration makes to the overhead, decreased over the four time periods.

CONCLUSIONS

The Newfoundland ecosystem has been severely stressed over the past century, with 'fishing down the food web' (Pauly *et al.* 2001) being evident. This stress appears to increase over the four time periods, although the gross efficiency, predatory cycling and systems entropy all show that the 1985 system was under more pressure. This is also evident by the low internal overhead at that time. In contrast, if the effect of export on the calculation of relative overhead is excluded, the proportion of overhead due to internal flow and respiration show a decreasing trend as expected from a 'resilience index'.

The various models described for Newfoundland show very similar trends in systems indices with some interesting differences. In general, the 1985 models (Bundy *et al.* 2000; Heymans and Pitcher 2002a; Heymans 2003) are very similar with regards to information theory indices. In contrast, the new 1995 model (Heymans 2003) is different in some important features, mainly due to the different primary production in the newest models. This caused a decrease in the total system's throughput, and an increase in the Finn cycling index, Finn mean path length and relative overhead.

The overall conclusion when comparing the four time periods is that there was a change with regard to the relative overhead, stress and instability of the system. The new 1985 model (Heymans 2003) is still similar to the previous models in that fishing was highest in 1985, the gross efficiency of the system was highest and the predatory cycling index was highest. A possible indication of the impeding catastrophe in the 1985 model could be found in these indices as well as the reduction in internal overhead and the proportion of both internal flow and respiration to the overhead. "Fishing down the food web" is

still evident whichever models are used for the 1985 and 1995 time periods.

REFERENCES

Baird, D., McGlade, J. M., and Ulanowicz, R. E. 1991. The comparative ecology of six marine ecosystems. Philosophical Transactions of the Royal Society of London, B., 333:15-29.

Bundy, A., Lilly, G. R., and Shelton, P. A., 2000. A mass balance model of the Newfoundland-Labrador Shelf. 1-157 pp

Christensen, V., and Pauly, D. 1992. ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. Ecological Modelling, 61:169-185.

Christensen, V., Walters, C., and Pauly, D., 2000a. Ecopath with Ecosim: A User's guide. Fisheries Centre, University of British Columbia and ICLARM, Vancouver, BC and Penang, Malaysia, 1-131 pp

Christensen, V., Walters, C. J., and Pauly, D., 2000b. Ecopath with Ecosim, Help system., UBC Fisheries Centre, Vancouver, BC.

Finn, J. T. 1976. Measures of ecosystem structure and function derived from analysis of flows. Journal of theoretical Biology, 56:363-380.

Heymans, J. J. 2003. Revised models for Newfoundland and southern Labrador (2J3KLNO) for the time periods 1985-87 and 1995-97. pp. 40-62 In: Heymans J.J. (Ed.) Ecosystem models of Newfoundland and Southeastern Labrador: Additional information and analyses for 'Back to the Future'. Fisheries Centre Research Report 11(5), Vancouver, BC.

Heymans, J. J., and Baird, D. 2000. Network analysis of the northern Benguela ecosystem by means of NETWRK and ECOPATH. Ecological Modelling, 131:97-119.

Heymans, J. J., and Pitcher, T. J., 2002a. A model of the Marine Ecosystem of Newfoundland and Southern Labrador (2J3KLNO) in the Time Periods 1985-1987 and 1995-1997. pp. 5-43, In: Pitcher, T.J., Heymans, J.J. and Vasconcellos, M. (Eds.) Ecosystem models of Newfoundland for the time periods 1995, 1985, 1900 and 1450. Fisheries Centre Research Reports, 10(5). Vancouver, BC.

Heymans, J. J., and Pitcher, T. J., 2002b. A Picasso-esque view of the marine ecosystem of Newfoundland and Southern Labrador: Models for the time periods 1450 and 1900. pp. 44-71, In: Pitcher, T.J., Heymans, J.J. and Vasconcellos, M. (Eds.) Ecosystem models of Newfoundland for the time periods 1995, 1985, 1900 and 1450. Fisheries Centre Research Reports, 10(5). Vancouver, BC

Latham, L. G. I., and Scully, E. P. 2002. Quantifying constraint to assess development in ecological networks. Ecological Modelling, 154:25-44.

Mageau, M. T., Costanza, R., and Ulanowicz, R. E. 1998. Quantifying the trends expected in developing ecosystems. Ecological Modelling, 112(1):1-22.

Pauly, D., Palomares, M. L. D., Froese, R., Sa-a, P., Vakily, M., Preikshot, D., and Wallace, S. 2001. Fishing down Canadian aquatic food webs. Canadian Journal of Fisheries and Aquatic Sciences, 58(1):51-62.

Ulanowicz, R. E., 1986. Growth and Development: Ecosystems Phenomenology. toExcel Press, Lincoln, NE.203 pp.

Ulanowicz, R. E., 1987. NETWRK 4.2a: A package of Computer Algorithms to analyze Ecological Flow networks. University of Maryland, Solomons, UMCEES Report, 82-7.

Ulanowicz, R. E., 1997. Ecology, the Ascendent Perspective. Complexity in Ecological Systems Series, Columbia University Press, New York.201 pp.

Ulanowicz, R. E., 2000. Toward the Measurement of Ecological Integrity. In: Ecological integrity: integrating environment, conservation, and health. pp. 99-113, Ed. by D. Pimentel, L. Westra, and R. F. Noss, Island Press, Washington DC,

Ulanowicz, R. E., and Abarca-Arenas, L. G. 1997. An Informational Synthesis of Ecosystem Structure and Function. Ecological Modelling, 95:1-10.

Ulanowicz, R. E., and Kay, J. J. 1991. A package for the analysis of ecosystem flow networks. Environmental Software, 6(3):131-142.

Ulanowicz, R. E., and Puccia, C. J. 1990. Mixed trophic impacts in ecosystems. Coenoses, 5(1):7-16.

Vasconcellos, M., Mackinson, S., Sloman, K., and Pauly, D. 1997. The stability of trophic mass-balance models of marine ecosystems: a comparative analysis. Ecological Modelling, 100:125-134.

FITTING THE NEWFOUNDLAND MODEL TO TIME SERIES DATA

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ABSTRACT

This paper fits the 1985-97 model to reconstructed time series data. The time series data includes biomass estimates obtained from Engels and Campelen trawls for demersal species. Catch estimates were obtained from research reports and the SAUP catch database. Changes were made to the biomass accumulation in the Ecopath base model and to the flow control "vulnerability" parameters of groups that were fitted. A forcing function was estimated and compared to the North Atlantic Oscillation. All these changes reduced difference in the sum of squares of the estimated biomass to the time series biomass from 632 to 543.

INTRODUCTION

Mass balanced Ecopath models are a first step to understanding the ecosystem of an area of interest. However, if these models are to be useful they need to be usable for simulations of past and future system interactions. In this paper the newly updated 1985-87 model of Newfoundland (Heymans 2003) was fitted to time series data obtained from trawl surveys in stock assessment reports, etc. for the time period 1985 to 2000. The fitting was done to reproduce as much of the dynamic interactions that were taking place in the ecosystem in the late 1980s and 1990s as is possible. To that end, changes were made to the flow control (vulnerability) parameters and feeding time adjustment rates. Biomass accumulation was used to reproduce the trends in biomass seen in the time series data. After these parameters were changed as much as ecologically possible, the model was fitted to the time series to find the forcing function that reduces the sum of squares of deviation of log biomasses from log predicted biomasses estimated by Ecopath with Ecosim (EwE) the most.

METHODOLOGY

The time series data were obtained from stock assessment reports for cod, Greenland halibut, crabs and shrimp. The groundfish trawl survey data obtained from Lilly (2002) were used to fit the other groundfish and pelagic species in the

model. The groundfish surveys in Newfoundland were conducted with Engel 145 high-rise otter trawls with bobbin gear until 1995. In the fall of 1995, DFO changed to a Campelen 1800 shrimp trawl using rockhopper gear and the vessel used for trawling also changed (Morgan and Brodie 2000). It was therefore necessary to convert the values from Engels to Campelen estimates.

Time series reconstructions

Cod

There are many different hypotheses for what caused the northern cod collapse (Hutchings 1996; Rose *et al.* 2000 among others). There is evidence of a southern shift in 1989-1990 (Kulka *et al.* 1995) that was thought to have been as a result of the North Atlantic Oscillation (NAO) (Rose *et al.* 2000), or because their main prey (capelin) shifted south (Frank *et al.* 1996). Rose *et al.* (2000) also suggest that there was recruitment failure in 1991 and 1992 and Rose *et al.* (1995) found that the migration patterns were changing as a consequence of density- and age-dependent effects. Overfishing from the 1950s onwards and especially in the 1980s and early 1990s led to widespread population collapse, which caused a truncated age structure (Rose *et al.* 2000). Subsequent to the moratorium, the cod population has not rebuilt, with poor recruitment, cannibalism and predation being important reasons for the lack of recovery (Lilly *et al.* 2001). Fishing, even on a small scale, is probably also a factor.

There are different catch and biomass time series data for cod in this system. The catch estimates were obtained from the Sea Around Us Project database (Anon 2003), and from stock assessment reports. The catch estimates of 2J3KL cod were obtained from Lilly *et al.* (2001) and the catch estimates of 3NO cod were obtained from Healey *et al.* (2002). The biomass estimates for the total area can be obtained from the trawl surveys (Lilly, MS) or from the stock assessment reports. Biomass estimates of cod in 2J3KL are given by Lilly *et al.* (2001), while the biomass for 3NO cod was estimated from the catch and fishing mortality in Healey *et al.* (2002) and Smedbol *et al.* (2002). A third possibility for biomass estimates is the VPA done by Ahrens (1999). The different catch and biomass estimates of cod are given in Table 1.

Differences in catch estimates impact the catch rate time series, with the SAUP catches (Anon 2003) giving lower catch rates than the stock assessment report catches.

Table 1: Biomass and catch estimates (tonnes) for adult cod for areas 2J3KLNO from various sources. SAR = Stock assessment reports (Lilly *et al.* 2001; Healey *et al.* 2002; Smebol *et al.* 2002), TS = trawl surveys (Lilly *in prep.*).

Year	Biomass			Catch	
	SAR	VPA	TS	SAUP	SAR
1985	1,183,371	1,195,460	528,964	271,309	266,090
1986	2,823,244	1,183,136	1,070,589	269,290	294,711
1987	1,232,597	985,929	704,972	275,953	270,183
1988	1,197,266	845,777	613,440	307,895	308,125
1989	1,507,607	683,662	640,448	278,329	283,847
1990	1,257,773	483,535	567,843	236,790	243,942
1991	1,003,032	278,183	327,513	163,337	197,475
1992	206,404	95,251	97,461	39,156	53,952
1993	72,257	46,715	61,206	13,939	22,936
1994	19,470	24,209	22,269	3,195	4,003
1995	21,920	25,543	37,902	259	493
1996	33,081	28,754	31,363	544	1,868
1997	30,712	31,514	33,576	907	887
1998	30,182	35,784	67,769	4,104	4,885
1999	42,142	39,500	93,919	58	9,188
2000	70,623	57,278	105,804		

Using the VPA biomass estimates (Ahrens 1999) for 2J3KL instead of the trawl survey data obtained from Lilly *et al.* (2001) would increase the catch rate for 2J3KLNO cod substantially. Similarly, the trawl survey biomass estimate gives higher catch rates than the stock assessment reports. The estimates made with VPA include an increase in natural mortality, and therefore it was decided to use the catch from the stock assessment reports [Lilly *et al.* (2001) for 2J3KL and Healey *et al.* (2002) for 3NO] and the biomass from the trawl survey data (Lilly MS).

American plaice

For American plaice, data obtained from J. Morgan (DFO-Newfoundland *pers. comm.*) for Campelen adjusted abundances for NAFO division 2J3K from 1978-2000 and weight at length for 3LNO plaice from 1990-1999, were used to calculate their biomass from 1990-1999. For 1985-1989 the average weight at length for 1990-1992 was used to calculate the biomass. The VPA analysis for plaice in area 3LNO was also obtained from J. Morgan (DFO-Newfoundland, *pers. comm.*). The total biomass calculated for NAFO division 2J3KLNO from 1985-2000 is given in Table 2. The catch, obtained from the SAUP catch database (Anon 2003), and fishing mortality of adult American plaice is also given in Table 2.

Greenland halibut

Greenland halibut biomass estimates were obtained from Bowering (2001) for NAFO divisions 2J, 3K, 3L, 3N and 3O. The Greenland halibut stock mostly resides in areas 2J and 3K, where the stock biomass was relatively stable until the mid 1980s. Subsequently, the biomass declined substantially to reach an all time low in the early 1990s with the disappearance of older fish from the population (Bowering 2001). The stock recovered from 1995 but the fishable biomass and spawning stock biomass remain well below historic highs (Bowering 2001). For areas 3L, 3N and 3O the biomass estimates were only available for 1996-1999, as the maximum survey depth prior to 1996 was 400 m. Thus, the total biomass for 2J3KLNO from 1985 to 1995 could not be estimated. Instead, the biomass of 2J3K obtained from Bowering (2001) and catch from Brodie and Power (2002) of 2J3K was used to calculate the fishing mortality for 2J3K and used as proxy for the whole area (Table 3).

Snow crab

A major decline in the snow crab catches was seen in 1982-1987 in areas 3K and 3L, and since 1989 there has been an expansion in the offshore fishing areas (Anon 1996). Estimates of biomass were obtained from the multi-species bottom trawl surveys done since 1996 (Anon 1996). Snow crab exploitable biomass (in tonnes), offshore catch (in tonnes) and fishing mortality (Table 4) were obtained from Dawe *et al.* (2001).

Table 2: Biomass, catch (tonnes) and fishing mortality estimated for adult American Plaice for areas 2J3KLNO.

Year	3LNO	2J3K	2J3KLNO	Catch	Fishing mortality
1985	140,969	135,725	276,693	48,823	0.176
1986	147,622	114,758	262,380	47,993	0.183
1987	132,454	77,728	210,183	49,154	0.234
1988	125,997	85,202	211,199	35,380	0.168
1989	117,447	99,947	217,394	40,491	0.186
1990	75,104	66,356	141,460	25,773	0.182
1991	48,704	33,050	81,754	25,942	0.317
1992	26,935	19,883	46,819	10,849	0.232
1993	16,299	24,994	41,293	7,580	0.184
1994	6,900	27,960	34,860	574	0.016
1995	8,085	17,166	25,251	573	0.023
1996	12,200	12,166	24,366	887	0.036
1997	13,136	21,923	35,059	1,369	0.039
1998	15,088	17,599	32,687	223	0.007
1999	15,833	13,395	29,228	2	0.000
2000	20,326	?	20,326	?	?

Table 3: Biomass, catch (tonnes) and fishing mortality of Greenland halibut in NAFO division 2J3K used as proxy for 2J3KLNO. The catch for 1985-1998 was obtained from SAUP database (Anon 2003), while the catch for 1999 and 2000 was obtained from Brodie and Power (2002).

Year	Biomass	Catch	Fishing mortality
1985	207,150	12,499	0.060
1986	256,853	6,796	0.026
1987	191,915	32,547	0.170
1988	170,368	8,125	0.048
1989	183,923	10,647	0.058
1990	160,914	7,822	0.049
1991	87,098	5,163	0.059
1992	62,579	3,873	0.062
1993	115,483	2,344	0.020
1994	81,766	1,241	0.015
1995	104,493	1,014	0.010
1996	184,791	3,544	0.019
1997	211,673	3,957	0.019
1998	203,693	2,621	0.013
1999	262,778	3,034	0.012
2000	?	6,997	?

Shrimp

The northern shrimp populations of Newfoundland and Labrador are managed in Shrimp Fishing Areas (SFAs) instead of NAFO divisions. The areas that correspond to our Divisions 2J3K are SFA 5 and 6. SFA 6 includes the Hopedale and Cartwright channels, which correlates to areas 2H and 2J (Parsons *et al.* 2000). NAFO division 3K is included in SFA 6 - Hawke Channel (Parsons *et al.* 2000). Northern shrimp in NAFO division 3LNO are managed by NAFO (Orr *et al.* 2000; 2002c).

The biomass estimates of northern shrimp for 1996-2000 in area 3LNO were obtained from Orr *et al.* (2002c), while that of area 3K for the same time period came from Orr *et al.* (2002b). The biomass estimates of 2J northern shrimp were taken to be that of the Cartwright channel in SFA 5 also obtained from Orr *et al.* (2002b). Catch estimates of northern shrimp in area 3LNO were obtained from Orr *et al.* (2000) and confirmed for 2000 by Orr *et al.* (2002a). For area 3K catches were obtained from Orr *et al.* (2002b). The catches of northern shrimp in 2HJ obtained from Orr *et al.* (2002b) were divided into 2J and

Table 4: Exploitable biomass (tonnes), catch (tonnes) and fishing mortality (for offshore stocks) of snow crab obtained from Dawe *et al.* (2001).

Year	Exploitable biomass	Catch	Fishing mortality
1996	65,091	27,197	0.418
1997	102,224	32,135	0.314
1998	97,285	36,695	0.377
1999	105,849	49,640	0.469
2000	60,978	38,277	0.628

2H by using the ratio of their biomass estimates (approximately 50%). The biomass, catch and fishing mortality estimated for northern shrimp in area 2J3KLNO are given in Table 5.

Other species

For all other species caught by the groundfish trawlers, the biomasses prior to 1995 were adapted for Campelen equivalents by using the conversion of 1993-94 to 1995-96 by area for the autumn survey and the conversion of 1994-95 to 1996-97 by area for the spring survey estimates. The biomass estimates adjusted for Campelen equivalents are given in Table 6. Catches, given in Table 7 of these species were obtained from the SAUP database (Anon 2003). Estimates of fishing mortality for all species are given in Table 7.

Changes to the model to incorporate multistanza methodology

Three groups were split using the multistanza methodology incorporated into Ecosim. In this new feature, mortality rates (Mo, predation, fishing) and diet composition are assumed to be similar for individuals within each stanza and the baseline estimates of total mortality rate 'Z' and diet composition for each stanza need to be entered, while the biomass, Q/B ratio, and BA for the adults only is entered. The Z entered for each stanza-group is used to replace the Ecopath P/B ratio for that group. For each of the groups you enter the von Bertalanffy growth parameter 'k', the age in months at transition, and the ratio of the weight at maturity to asymptotic weight.

Table 5: Biomass (tonnes), catch (t•year^{-1}) and fishing mortality (year^{-1}) of northern shrimp in Newfoundland.

Year	Biomass				Catch				Fishing mortality
	2J	3K	3LNO	2J3KLNO	2J	3K	3LNO	2J3KLNO	
1996	75,250	486,800	20,089	582,139	4,036	10,923	79	15,038	0.026
1997	49,100	418,900	46,202	514,202	5,665	21,246	485	27,396	0.053
1998	43,300	453,150	59,914	556,364	7,728	46,337	515	54,580	0.098
1999	56,600	510,900	53,144	620,644	7,890	51,255	827	59,972	0.097
2000	71,700	565,400	118,180	755,280	7,568	63,266	4,152	74,985	0.099

Table 6: Biomass estimates (tonnes) for all other species caught in the Campelen trawlers from 1994 and adjusted for Campelen equivalents from 1985 to 1994.

Year	Yellowtail flounder	Witch flounder	Skates	Redfish	Demersal piscivores	Demersal feeders	Small demersals	Lumpfish	Greenland cod	Capelin
1985	625,207	61,458	242,505	2,466,439	14,656	499,349	106,275	10,299	2,293	137,657
1986	451,088	45,170	210,613	1,769,734	11,190	389,073	84,643	36,382	483	1,331,710
1987	327,477	44,668	161,322	896,225	9,805	402,545	101,708	11,444	618	865,922
1988	204,986	41,079	171,834	1,859,767	10,890	459,320	48,319	38,631	948	299,855
1989	195,781	24,319	133,987	630,942	5,687	246,849	58,163	20,329	1,425	312,295
1990	221,881	49,460	214,636	1,320,790	10,719	264,874	84,882	10,622	162	622,098
1991	201,684	16,862	186,906	263,254	10,297	145,444	91,127	16,348	0	130,179
1992	120,355	14,168	113,296	183,499	6,470	79,864	55,123	6,938	0	48,872
1993	237,692	10,228	93,769	137,657	6,158	78,930	79,231	9,678	0	355,430
1994	137,479	11,556	69,612	128,951	7,741	66,299	42,686	8,144	47	63,075
1995	162,512	8,060	76,206	166,691	5,464	44,527	43,007	5,683	16	114,653
1996	145,246	10,431	73,713	113,027	5,960	61,773	60,397	10,723	92	86,049
1997	210,136	8,883	89,815	162,593	7,658	75,323	48,098	7,592	22	52,050
1998	194,458	7,889	84,097	264,199	6,468	64,085	50,859	7,898	26	123,020
1999	308,341	16,331	101,596	206,129	15,255	80,137	48,219	21,690	79	73,994
2000	310,907	9,347	114,515	192,583	21,742	79,162	51,761	9,426	9	158,697

Table 7: Catch (t•year^{-1}) and fishing mortality of all species caught by Campelen trawlers.

Year	Yellowtail flounder	Witch flounder	Skates	Redfish	Demersal piscivores	Demersal feeders	Small demersals	Lumpfish	Greenland cod	Capelin
					Catch					
1985	21,472	11,774	10,588	57,859	9,898	10,364	0	0	5	49,704
1986	20,421	11,860	14,509	72,489	6,865	15,402	0	0	16	37,698
1987	14,203	12,060	19,497	103,657	12,084	15,268	0	0	9	58,659
1988	13,540	10,306	19,140	63,539	4,888	14,677	0	0	21	98,188
1989	8,683	8,198	14,831	46,039	3,546	12,452	0	0	34	105,080
1990	8,752	8,190	14,798	36,214	4,460	8,222	6	0	240	173,697
1991	11,004	7,801	28,420	29,463	4,958	8,199	13	1	36	42,491
1992	10,755	7,619	5,147	27,273	2,441	6,283	36	0	103	19,548
1993	6,780	4,991	6,065	28,201	1,869	5,376	23	7	38	19,846
1994	231	402	8,715	7,198	957	2,395	35	0	25	961
1995	66	1,047	7,568	4,435	489	2,957	45	0	17	132
1996	233	1,683	6,847	10,098	767	4,781	0	12	20	24,312
1997	657	1,361	12,382	5,286	1,169	5,371	0	27	27	11,204
1998	3,420	8	892	8,944	549	202	28	2	0	33,578
1999	275	0	10	317	226	17	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0
					Fishing mortality (year^{-1})					
1985	0.03434	0.19158	0.03434	0.02346	0.67537	0.00000	0.00000	0.00000	0.00218	0.36107
1986	0.04527	0.26256	0.04527	0.04096	0.61351	0.00000	0.00000	0.00000	0.03316	0.02831
1987	0.04337	0.26999	0.04337	0.11566	1.23246	0.00000	0.00000	0.00000	0.01456	0.06774
1988	0.06605	0.25088	0.06605	0.03417	0.44887	0.00000	0.00000	0.00000	0.02216	0.32745
1989	0.04435	0.33710	0.04435	0.07297	0.62350	0.00000	0.00000	0.00000	0.02385	0.33648
1990	0.03944	0.16559	0.03944	0.02742	0.41610	0.00007	0.00007	0.00000	1.48095	0.27921
1991	0.05456	0.46264	0.05456	0.11192	0.48152	0.00014	0.00014	0.00006	0.00000	0.32640
1992	0.08936	0.53776	0.08936	0.14863	0.37731	0.00065	0.00065	0.00000	0.00000	0.39998
1993	0.02852	0.48796	0.02852	0.20486	0.30350	0.00029	0.00029	0.00072	0.00000	0.05584
1994	0.00168	0.03479	0.00168	0.05582	0.12363	0.00082	0.00082	0.00000	0.52933	0.01524
1995	0.00041	0.12991	0.00041	0.02661	0.08949	0.00105	0.00105	0.00000	1.09426	0.00115
1996	0.00160	0.16135	0.00160	0.08934	0.12868	0.00000	0.00000	0.00112	0.21800	0.28254
1997	0.00313	0.15321	0.00313	0.03251	0.15264	0.00000	0.00000	0.00356	1.20415	0.21526
1998	0.01759	0.00101	0.01759	0.03385	0.08488	0.00055	0.00055	0.00025	0.00000	0.27295
1999	0.00089	0.00000	0.00089	0.00154	0.01481	0.00000	0.00000	0.00000	0.00000	0.00000
2000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Cod

For cod we set the age at transition (i.e., when the cod started being caught) at 24 months, to get the same general biomass and Q/B estimated for the juveniles as in the previous model (Heymans 2003). The P/B for small and large cod (1.6 & 0.65), biomass for adults (2.0 t•km^{-2}•year^{-1}), Q/B (2.6) for adults, K (0.1 year^{-1}) and weight at maturity/asymptotic weight (0.062) were entered. A von Bertalanffy K value of 0.07 and 0.112 were given in FishBase, and we used a value of 0.1, while the weight at age 20 and weight at age 2 (Table 8) were obtained from the stock assessment report (Lilly *et al.* 2001).

Table 8: Weight at maturity (w_m) (kg) and asymptotic weight (w_∞) for cod.

Age	1985	1986	1987	Average
Age 20	19.49	15.72	15.97	17.06
Age 5	0.26	0.21	0.32	0.26
			$w_m/w_\infty =$	0.02

American plaice

American plaice was split into two groups at age 4. Females reach maturity at age 8, but males reach maturity at age 4 (Anon 2000a). I use the averages of weight at maturity for ages 4-8 to get the mean weight at maturity / asymptotic weight (Table 9) The von Bertalanffy K values of 0.09 for division 3N an 0.19 for the North Atlantic obtained from FishBase were used to assume a K of 0.1. The ratio of weight at maturity to asymptotic weight (w_m/w_∞) was calculated for the 3LNO stock for 1990 (the earliest weight at age data available from Joanne Morgan).

The biomass (0.97 t•km^{-2}•year^{-1}), P/B (0.54) and Q/B (2.0) of adults and the P/B of juveniles (0.63) obtained from Heymans (2003) were used. The P/B of juveniles were increased to 0.65 to balance the group. To balance the small plaice I decreased the proportion of small plaice in the diet of harp seals to 0.157% from 3.87%, and increased the proportion of large plaice to 3.38%. Similarly, I reduced the proportion of juvenile plaice in the diet of large cod from 1.71% to 0.7% and added 1.01% to large plaice. The small plaice in the diet of small demersal piscivores was reduced form 3.4% to 2.4% and the small planktivorous feeders was increased to 8.4%

Greenland halibut

Greenland halibut was also split into two groups at age 4. According to Bowering (2001), Greenland halibut enters the fishery at around 35 cm, and the population above 35 cm does not contribute much to the biomass. Bowering and Nedreaas (2001) show that at length 30-35, the age is 4 years. Bundy (2001) suggests a von Bertalanffy K of 0.1 and Bowering (1983) found that females mature at 12 years in 2J3KL, so the weight at maturity (age 12) and the weight of the largest age class (Table 10) were obtained for 1985-1987 from Darby *et al.* (2003).

Table 9: Weight at maturity (w_m) and asymptotic weight (w_∞) for American plaice in NAFO Div. 3LNO in 1990.

Age	Mean weight (kg)
Age 4-8	0.14
Age 20	4.41
w_m/w_∞	0.03

The biomass (0.35 t•km^{-2}•year^{-1}), P/B (0.3) and Q/B (1.48) of adults and the P/B of juveniles (0.87) from Heymans (2003) were used. Halibut was balanced by increasing the P/B of large halibut to 0.4 and that of small halibut to 1.0 to balance. The diet of hooded seals was changed to balance small halibut. Small halibut in the diet of hooded seals was reduced from 27.6% to 3% and large halibut increased from 9.2% to 14.2%; winter flounder was increased from 2.08% to 7.08%; adult planktivorous feeders to 4.29% from 1.29%; small planktivorous feeders to 7.86% from 3.86%; Arctic cod from 6.77% to 12.61% and added 3.66% to transient mackerel.

RESULTS AND DISCUSSION

Time series fitting

The time series data obtained from the reconstructions above were then put into a 'csv' file, including catch (t•km^{-2}•year^{-1}), biomass (t•km^{-2}) and fishing mortality. The file was read into Ecopath with Ecosim version 5. When the time series data were read in, the SS was 632.6.

For harp seals a biomass accumulation of 0.01 t•km^{-2}•year^{-1} was added and the vulnerabilities (v's) of their prey to harp seals (i.e., the column of the vulnerability matrix) were increased to 0.6 for all prey species. This reduced the SS to 595.2. Similarly, the v's of the prey of hooded seals were increased to 0.6 for all prey groups, which reduced the SS to 584.6.

Next the species for which there was not much time series data, i.e. shrimp, crab, capelin, etc. were fitted. For shrimp the v's of shrimp to their predators (i.e. the rows of the v matrix) were increased to 0.6, which marginally reduced the SS to 584.1. The vulnerabilities of large crab to their prey (column) were reduced to 0.1, while their vulnerability to their predators (column) were increased to 0.6. The vulnerabilities of capelin, lumpfish and small demersals to their prey (columns) were increased to 0.6 each. This decreased the SS to 582.5.

For large demersal piscivores and planktivores the feeding time adjustment rates were set to 0.2

Table 10: Weight at maturity (w_m) (kg) and asymptotic weight (w_∞) for Greenland halibut.

Age	Average	1985	1986	1987
Age 12	3.73	3.71	3.89	3.6
Age max	6.94	7.01	7.345	6.454
w_m/w_∞	0.54	-	-	-

(instead of 0.5), while all their v's on prey (column) were set back to 0.3, to reduce the SS to 579.3, while the feeding time adjustment rate for skates were set to 0.8 and the v's on their prey (column) were set to 0.6 (SS = 577.8).

For the three split groups: halibut, American plaice and cod, all changes to v's were made for both adults and juveniles. For halibut, the feeding time adjustment rates were set to 0.8, and the v's of the adults and juveniles to their prey (columns) were set to 0.1. Also, the vulnerability of both adults and juvenile halibut to harp and hooded seals were set to 0.1, which reduced the SS to 573.6. The vulnerabilities of the prey of plaice (columns) were set to 0.6, which reduced the SS to 571.9. For cod the v's of the prey (columns) of adults were set to 0.1, while for juveniles the v's of their prey were set to 0.6. The vulnerability of both adults and juveniles to harp and hooded seals were set to 0.1.

Estimating a Forcing Function

Ecosim can estimate a time series of primary production (forcing the primary producers) that would represent historical productivity changes impacting biomasses throughout the ecosystem (Christensen *et al.* 2000). The production anomaly search can be used to either search for annual relative productivity values or for a smoother long-term pattern or trend in productivity. The default is to search for annual values. But if you specify a non-zero number of 'spline pts.', the program will then use a cubic spline function to generate forcing shape number 4. A spline value of 4 was used in this case, describing a fifth order change.

The algorithm increments one PP annual value slightly, so as to calculate the Jacobian matrix of sensitivities of each of the predicted time series observations to each of the parameters. After N+1 such checks, the Jacobian matrix is used to estimate an initial best step change for each parameter, and a few more runs are used to further improve the fit (Christensen *et al.,* 2000). The user has to specify the weight that the algorithm needs to put on all the available time

Table 11: Weights put on biomass data for Ecosim estimation of primary production forcing.

| Data Type	Data weight
Capelin	0.1
Cod	1
Crab	0.5
Bentho-pelagic demersals	0.1
Large demersals	0.1
Greenland cod	0.1
Greenland halibut	1
Harp seals	1
Hooded seals	1
Lumpfish	0.1
Plaice	1
Redfish	0.5
Skates	0.5
Witch flounder	0.1
Yellowtail flounder	0.5
Small demersals	0.1

series data. The weights put on the biomasses are given in Table 11.

The forcing function estimated by Ecosim can then be compared to a known environmental variable such as the North Atlantic Oscillation (NAO). The forcing function estimated by Ecosim gives a very similar trend to the NAO (Figure 1), and so the NAO can then be added as a forcing function in Ecosim to see if it reduces the SS more. The NAO reduced the SS to 542.8, although it does not seem to explain the large decline in Atlantic cod seen from the time series data.

The changes in biomass for some key species are given in Figure 2. The time series biomass, biomass estimated after fitting the v's, biomass estimated when a forcing function was fitted, and biomass estimated when the NAO was added as a forcing function are shown. It seems that for some species, the NAO estimates biomasses close to the time series, but for the key species such as cod, neither estimating a forcing function, nor using the NAO seems to approximate the biomass shown in the survey time series. It is therefore necessary to look at addition mortality in cod to explain the reduction.
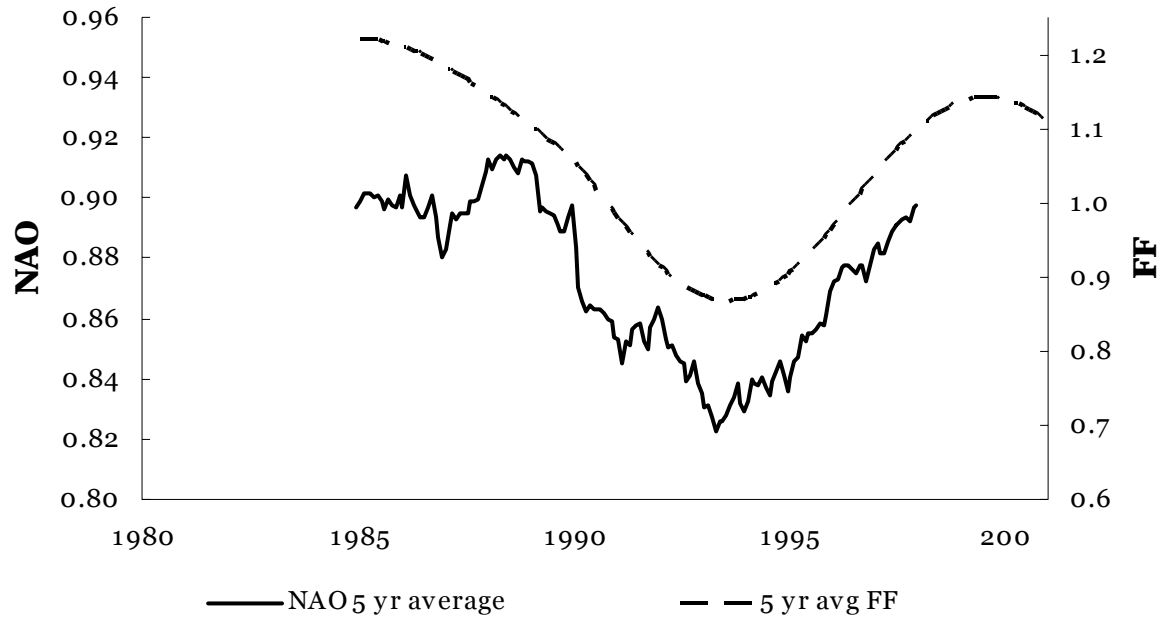
Figure 1: Forcing function estimated by Ecosim when fitting the model (FF) to the available time series data compared to the North Atlantic Oscillation index (NAO).
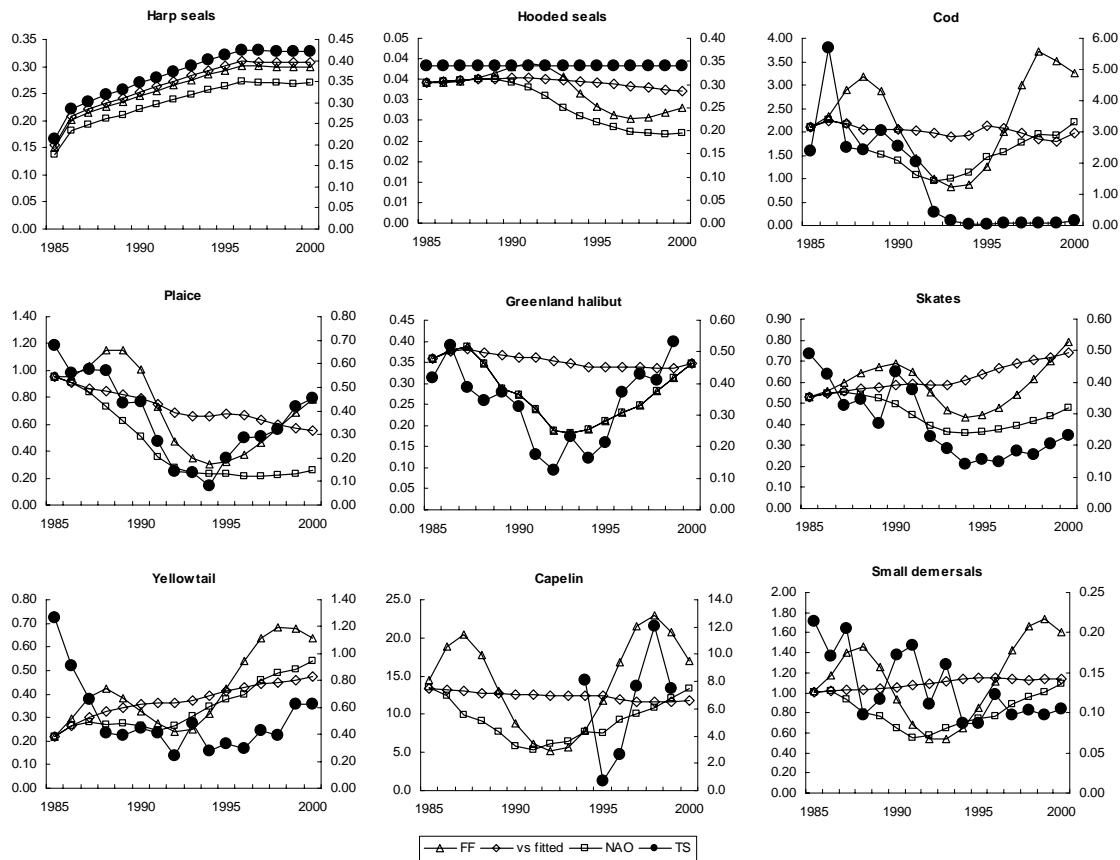
Figure 2: Differences in the biomass of key groups from time series (TS), after fitting vulnerabilities (v's fitted), estimating a forcing function (FF), and using the North Atlantic Oscillation (NAO) as a forcing function.

References

Ahrens, R.N.M. 1999. Heritable risk sensitive foraging in juvenile fish: potential implications for the dynamics of harvested populations. M.Sc. Thesis, Department of Zoology, University of British Columbia, 75 pages.

Anon, 1996. Newfoundland and Labrador Snow Crab. DFO, Stock Status Report, C2-01. 105 pp.

Anon, 2000. American plaice in Subarea 2 and Division 3K. DFO Newfoundland Region, St. John's, Stock Status Report, A2-11. 1-5 pp.

Anon, 2003. Global landings database, Sea Around Us Project Fisheries Centre, University of British Columbia, Vancouver, Canada, http://www.seaaroundus.org.

Bowering, W. R., 2001. Trends in distribution, biomass and abundance of Greenland halibut (*Reinhardtius hippoglossoides*) in NAFO Subare 2, and Divisions 3KLMNO from Canadian Research vessel surveys during 1978-99. NAFO, St. John's NF, Scientific Council Research Document, 00/12. 1-42 pp.

Bowering, W.R., 1983. Age, growth and sexual maturity of Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum), in the Canadian Northwest Atlantic.. Fish. Bull. 81:599-611.

Bowering, W. R., and Nedreaas, K. H. 2001. Age validation and growth of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum): A comparison of populations in the Northwest and Northeast Atlantic. Sarsia, 86:53-68.

Brodie, W. B., and Power, D., 2002. The Canadian fishery for Greenland Halibut in Subarea 2+ Divisions 3KLMNO, with Emphasis on 2001. NAFO, Scientific Council Reesarch Document, NAFO SCR Doc. 02/39. 1-12 pp.

Bundy, A. 2001. Fishing and ecosystems: the interplay of fishing and predation in Newfoundland-Labrador. Canadian Journal of Fisheries and Aquatic Science, 58(6):1153-1167.

Christensen, V., Walters, C., and Pauly, D., 2000. Ecopath with Ecosim: A User's guide. Fisheries Centre, University of British Columbia and ICLARM, Vancouver, BC and Penang, Malaysia, 1-131 pp.

Darby, C., Bowering, W.R., Mahé, J-C. 2003. An Assessment of Stock Status of the Greenland Halibut Resource in NAFO Subarea Divisions 3KLMNO Based on Extended Survivors Analysis with Short Medium-term Projections of Future Stock Development, NAFO SCR Doc. 03/64.

Dawe, E. G., Drew, H. J., Beck, P. C., Veitch, P. J., Warren, W. G., and Costigan, R. L., 2001. An Assessment of Newfoundland and Labrador Snow Crab in 2000. Science, Oceans and Environment, DFO, Ottawa, Stock Assessment Report, 2001/087. 1-28 pp.

Frank, K. T., Carscadden, J. E., and Simon, J. E. 1996. Recent excursions of capelin (M*allotus villosus*) to the Scotian Shelf and Flemish Cap during anomalous hydrographic conditions. Canadian Journal of Fisheries and Aquatic Science, 53:1473-1486.

Healey, B. P., Stansbury, D. E., Murphy, E. F., and Shelton, P. A., 2002. An Update on the Status of the Cod stock in NAFO Divisions 3NO. NAFO, St. John's Newfoundland, Scientific Council Research Document, NAFO SCR Doc. 02/57. 1-15 pp.

Heymans, J.J. 2003. A revised model for Newfoundland (2J3KLNO) for the time period 1985-87. Fisheries Centre Research Reports. 11(5): 40-63.

Hutchings, J. A. 1996. Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock's collapse. Canadian Journal of Fisheries and Aquatic Science, 53(5):943-962.

Kulka, D. W., Wroblewski, J. S., and Narayanan, S. 1995. Recent changes in the winter distribution and movements of northern Atlantic cod (*Gadus morhua* Linnaeus, 1758) on the Newfoundland-Labrador Shelf. ICES Journal of Marine Science, 52:889-902.

Lilly, G. R. MS. Swept area biomass estimates and diets of fish on the Newfoundland Shelf (NAFO Div. 2J3KLNO): inputs for bulk (Ecopath) modelling of the mid-1980s and late 1990s. To be published in Canadian Technical Report of Fisheries and Aquatic Sciences.

Lilly, G. R., Shelton, P. A., Brattey, J., Cadigan, N. G., Healey, B. P., Murphy, E. F., and Stansbury, D. E., 2001. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO, Canadian Science Advisory Secretariat, St. John's NFL, Research Document, 2001/044. 1-149 pp.

Morgan, M. J., and Brodie, W. B., 2000. Results of data conversions for American plaice in Div. 2J and 3K from comparative fishing trails between the Engel otter trawl and the Campelen 1800 shrimp trawl. DFO, Canadian Science Advisory Secretariat, Research Document, 2000/132. 1-25 pp.

Orr, D. C., Kulka, D. W., and Firth, J., 2002a. Groundfish By-catch in the Canadian Small (<500 Tons; LOA<100') and Large (=>500 Tons) Vessel Division 3L Shrimp Fishery, During 2000 and 2001. NAFO, St. John's Newfoundland, Scientific Council Research Document, NAFO SCR Doc. 02/6. 1-6 pp.

Orr, D. C., Parsons, D. G., Veitch, P. J., and Sullivan, D., 2002b. Northern shrimp (*Pandalus borealis*) off Baffin Island, Labrador and northeastern Newfoundland - second interim review. Canadian Science Advisory Secretariat, St. John's Newfoundland, Research Document, 2002/035. 1-50 pp.

Orr, D. C., Veitch, P. J., and Sullivan, D., 2000. An update of information pertaining to Northern shrimp (*Pandalus borealis*) and Groundfish in NAFO Division 3LNO. Northwest Atlantic Fisheries Organization, St. John's Newfoundland, Scientific Council Research Document, 00/85 Serial No. N4342.

Orr, D. C., Veitch, P. J., and Sullivan, D., 2002c. Information pertaining to the distribution of Northern Shrimp (*Pandalus boreali*s, Kroyer) in NAFO Divisions 3LNO. Northwest Atlantic Fisheries Organization, St. John's Newfoundland, Scientific Council Research Document, NAFO SCR Doc. 02/61.

Parsons, D. G., Veitch, P. J., Orr, D., and Evans, G. T., 2000. Assessment of northern shrimp (*Pandalus boreali*s) off Baffin Island, Labrador and northeastern Newfoundland. Canadian Stock Assessment Secretariat, Ottawa, Research Document, 2000/069. 1-65 pp.

Rose, G. A., deYoung, B., and Colbourne, E. B. 1995. Cod (*Gadus morhua* L.) migration speeds and transport relative to currents on the north-east Newfoundland Shelf. ICES Journal of Marine Science, 52:903-913.

Rose, G. A., deYoung, B., Kulka, D. W., Goddard, S. V., and Fletcher, G. L. 2000. Distribution shifts and overfishing the northern cod (*Gadus morhua*): a view from the ocean. Canadian Journal of Fisheries and Aquatic Science, 57:644-663.

Smedbol, R. K., Shelton, P. A., Swain, D. P., Fréchet, A., and Choulnard, G. A., 2002. Review of population structure, distribution and abundance of cod (*Gadus morhua*) in Atlantic Canada in a species-at-risk context. Canadian Science Advisory Secretariat, Ottawa, Research Document, 2002/082. 1-134 pp.