A MASS BALANCE MODEL FOR THE WEST GREENLAND MARINE ECOSYSTEM

***S. A. Pedersen*[1] *and D. Zeller*[2]**

[1]*Greenland Institute of Natural Resources*
Department of Marine Ecology and Aquaculture
Danish Institute for Fisheries Research
Kavalergården 6, DK-2920 Charlottenlund
Denmark
email: sap@dfu.min.dk

[2]*Fisheries Centre, University of British Columbia*
2204 Main Mall, Vancouver, BC, V6T 1Z4, Canada

ABSTRACT

The paper reviews the available information on fisheries, community structure and trophic relationships in the West Greenland marine ecosystem. In an attempt to evaluate the relationships between the dominant species and fisheries, a mass balance model using the Ecopath approach was constructed for the West Greenland shelf (0-1,500m) for 1997. The present report outlines the input data used to obtain a balanced Ecopath model, forming the foundation for future simulations.

INTRODUCTION

The increasing demand that management of marine resources is to be based on multispecies and ecosystem considerations has led to increased interest in improving our understanding of the more dynamic aspects and inter-relationships in marine ecosystems (Livingston and Tjelmeland, 2000; Reid *et al.*, 2000; Pauly *et al.*, 2001). This applies especially to Arctic marine systems, to which such approaches have rarely been applied.

This paper gives an overview of the exploited West Greenland marine ecosystem using Ecopath with Ecosim, a widely used software for mass-balance modeling (Christensen and Pauly, 1993; Christensen, 1995; Pauly and Christensen, 1996; Christensen and Walters, 2000). To give the reader some background knowledge of the system, we start with a short review of the exploitation of marine resources and the possible causes of species fluctuations in the system.

Exploitation of marine resources

During the twentieth century, Greenland has gradually changed from a nation of hunters to a nation of highly educated and trained people conducting a modern fishing industry. One reason for this development has been a rich cod fishery starting in the 1920s after a general warming of the Arctic (Jensen, 1939). Historically, the cod has been the most important commercial fish species in Greenland waters, with annual catches peaking at levels between 400,000 and 500,000 tonnes in the 1960s (Buch *et al.*, 1994; Horsted, 2001). During the late 1960s, the annual catches of cod and other commercially important fish species - mainly taken as by-catch in the cod fishery, e.g., redfish (*Sebastes marinus*), Atlantic halibut (*Hippoglossus hippoglossus*) and wolffish (Atlantic wolffish, *Anarhichas lupus*, and spotted wolffish, *A. minor*) declined drastically. After 1970 the catches of cod and redfish showed fluctuations at much lower levels compared to the 1960s (Figure 1). Except for a temporary improvement of the cod fishery during 1988-1990, the catches of cod, redfish, Atlantic halibut and wolffish showed decreasing trends from about 1980 to 1998 (Anon., 1999, 2000). Over the same period, however, catches (inshore and offshore combined) of two other important species, the Greenland halibut (*Reinhardtius hippoglossoides*) and the northern shrimp (*Pandalus borealis*) showed increasing trends (Figure 1). Whereas the cod catches have been taken mainly in offshore areas (outside the 3-mile limit) by an international bottom trawl fishery, the catches of Greenland halibut have been taken predominantly in the inshore areas (inside the 3-mile limit) by national fleets using longlines and gillnets, with the former being the traditional gear (Smidt, 1969; Riget and Boje, 1989). The offshore fisheries for Greenland halibut were below 1,600 tonnes during the period 1982-1990. In 1991 catches increased to 2,376 tonnes and were around 5,500 tonnes in the period 1992-1995, but decreased to around 4,500 in the period 1996-1998 (Jørgensen, 2000a). The peak in the catch statistic for Greenland halibut in 1975 are due to 20,000 tonnes reported by the former USSR from an offshore bottom trawl fishery.

The fishery for northern shrimp, *Pandalus borealis*, in West Greenland waters began in 1935 as a local fishery in a fjord south of the Sisimiut (Holsteinsborg) settlement, but was interrupted during World War II. After 19 46, several grounds with exploitable shrimp resources were found in inshore areas along the west coast of Greenland. From 1950 the inshore fishery expanded rapidly, Disko Bay being the most important area (Figure 2). Total catches from the inshore fishery ranged from 7,000 to 8,000 tonnes in the years from 1975 to 1987, but have increased in recent years to more than 21,000 tonnes in 1992. Inshore catches decreased to 9,515 tonnes in 1998 and increased again to 17,000 tonnes in 1999. During the 1990s inshore catches have accounted for about 25% of the total catch in NAFO Subarea 1. An offshore shrimp fishery in the Davis Strait began about 1970. The nominal catch of shrimp from Subarea 1 and the adjacent part of Subarea 0 (Div. 0A) increased from less than 1,000 tonnes before 1972 to almost 43,000 tonnes in 1976. Catches fluctuated thereafter and stabilized around a level of 54,000 tonnes during 1985-88, then increased to about 66,000 tonnes in 1992 and decreased thereafter to about 56,000 tonnes in 1998. Total catch in the offshore areas for 1999 increased again to 59,500 tonnes (Siegstad, 2000). Traditionally, a number of nations have been participating in this fishery, including Canada, Denmark, France, Faroe Islands, Greenland, Japan, Norway, Spain, West Germany and USSR. However, since 1993 only Greenland vessels are fishing shrimps in West Greenland waters.

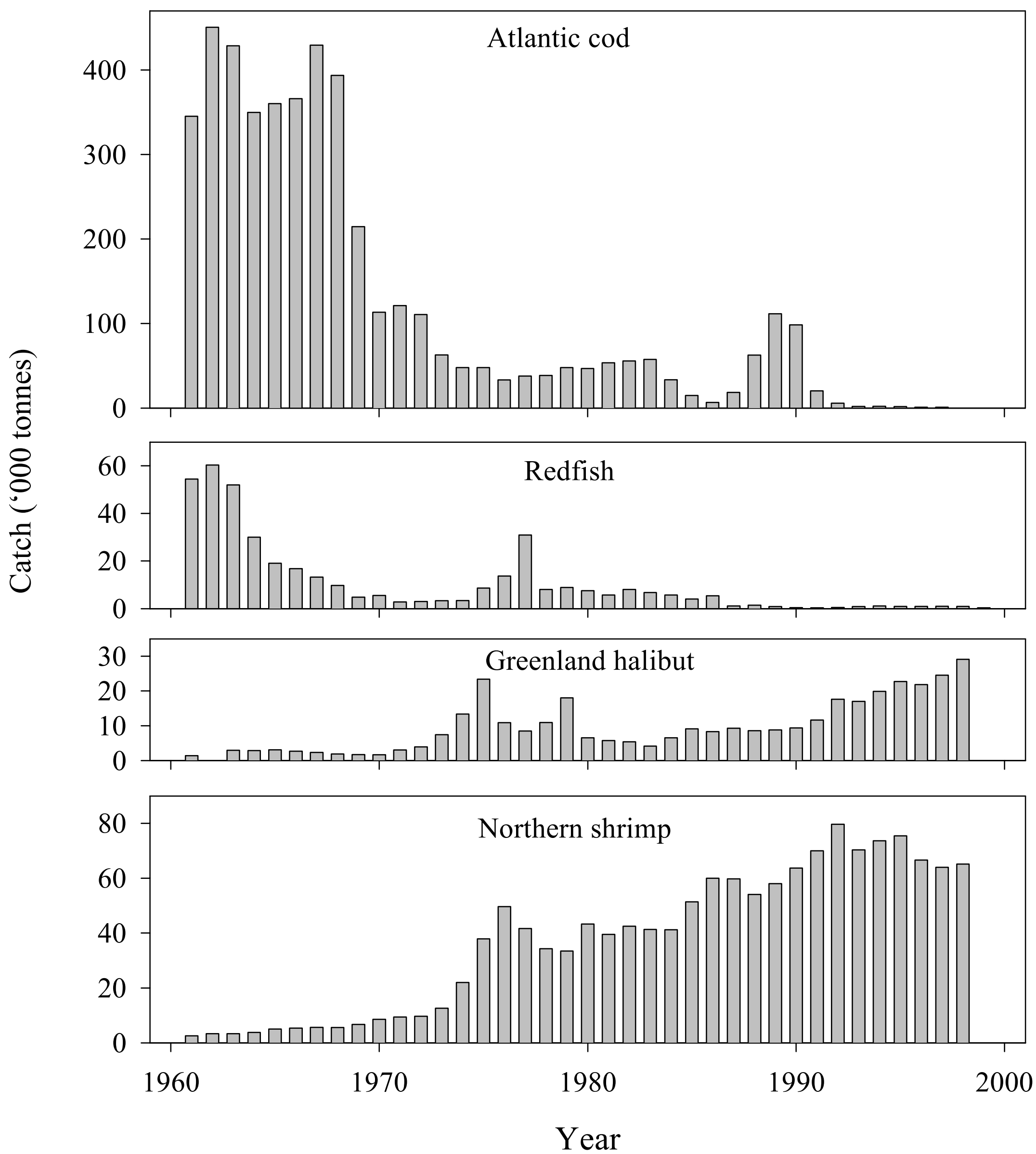

Figure 1. Catches of the four major fisheries species (Atlantic cod, Redfish, Greenland halibut and Northern shrimp) in West Greenland waters (NAFO Subarea 1 - inshore and offshore areas combined) for the period 1960-1999. Data from NAFO Statistical Bulletin and Anon. (2000), Jørgensen (2000a), Siegstad (2000), Siegstad *et al.* (2000) and Simonsen and Boje (2000). NB: 'tonnes' refers to 'metric tonnes', i.e., 1000 kg.

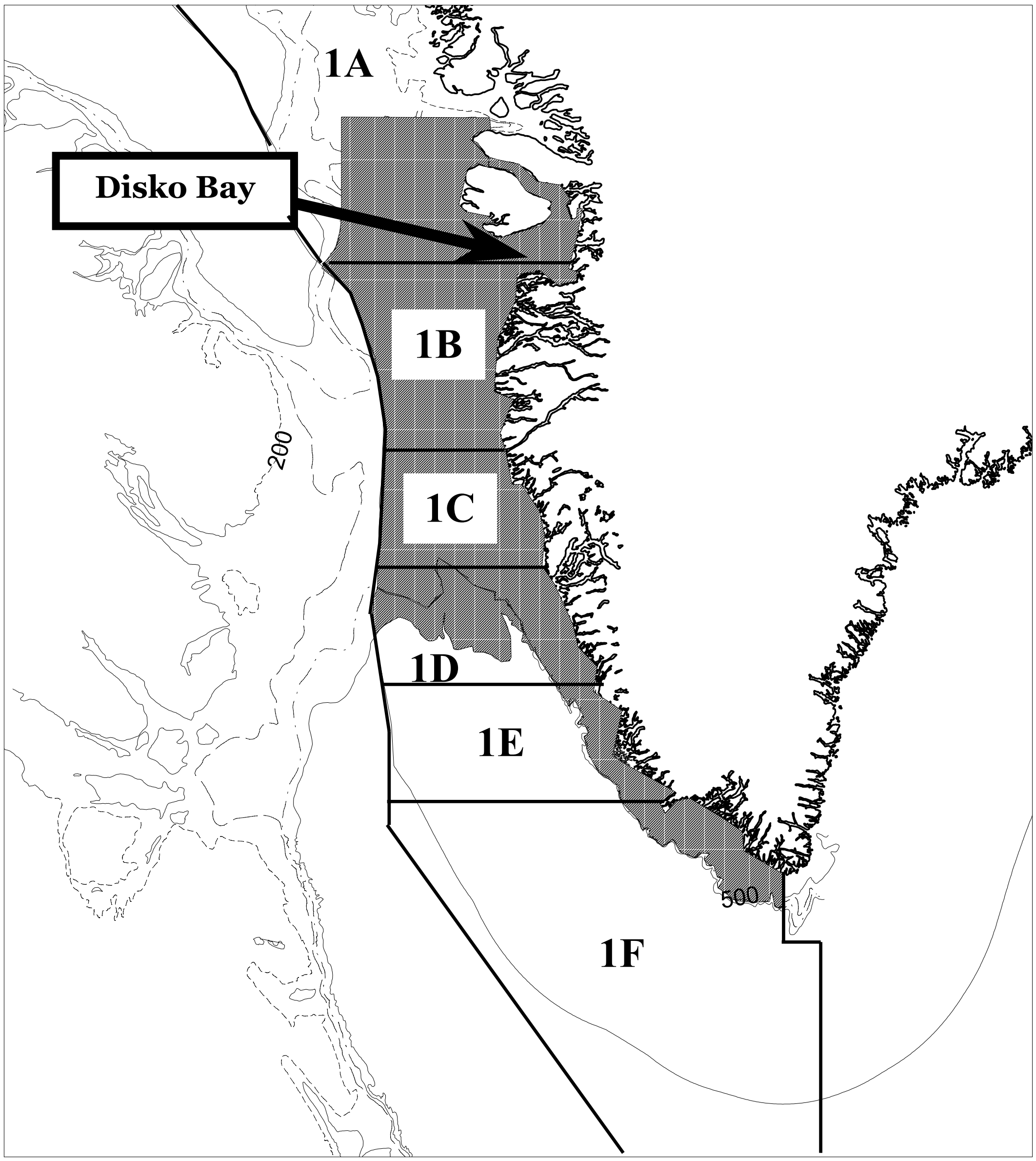

Figure 2. Map of West Greenland marine environment. The area represented by the Ecopath model is shaded gray, with depths from 0-1,500m, and a surface area of approximately 240,000 km². NAFO statistical areas mentioned in the text (1A-1F) are indicated.

It is important to keep in mind that the above descriptions of the fish and shrimp catches only represent the reported landings. In addition one would have to add an unknown amount of unreported fish and shrimp catches discarded at sea. The West Greenland sea has often been observed as "red" due to large amounts of dead redfish floating on the sea surface, especially in the 1950s and 1960s (S.A. Horsted, former Director of the Greenland Fisheries Research Institute, pers. comm.). Several of the fishing fleets did not utilize redfish and large amounts of redfish were discarded or died due to contact with the fishing gear. In the West Greenland shrimp fishery discarding of shrimp of 2 grams and above has been prohibited since 1985. However, in practice there is large scale discarding of small, low value shrimp (Siegstad, 1993).

In addition to the fisheries yields from the West Greenland marine ecosystem, one has to add the hunting (and consumption) of more than 40,000 seals, several hundred whales and several hundred-thousand seabirds per year on average. The seal hunt targets primarily ringed seals (*Phoca hispida*) and harp seals (*Phoca groenlandica*), but also takes other species including the walrus (*Odobenus rosmarus*) (Kapel, 1993, 1994; Born *et al.*, 1994). The whale hunt is mainly on fin whales (*Balaenoptera physalus*), minke whales (*B. acutorostrata*), white whales (*Delphinapterus leucas*), narwhals (*Monodon monocerus*) and occasionally others (Kapel, 1979; Heide-Jørgensen, 1994). The seabird hunt is primarily on thick-billed murre (*Uria lomvia*), king eider (*Somateria spectabilis*) and common eider (*S. mollissima*) (Evans, 1984; Falk and Durinck, 1992; Frimer, 1993; Mosbech *et al.*, 1998).

Possible causes of species fluctuations

The decline in recent years in catches and abundance indices of cod and other, mainly boreal fish species on the one hand, and the increasing annual catches of northern shrimp and Greenland halibut on the other, raises several questions. For example, to what extent are these changes due to environmental variation, or fishing, or both? How does fishing activities affect the ecosystem? Who eats who in the marine ecosystem and what is the role of species interactions in the observed changes in catches and biomass?

Historically, the occurrence of cod in Greenland waters shows very large fluctuations in abundance as well as in geographical distribution (Horsted, 1989; Buch *et al.*, 1994). Changes in the temperature conditions in West Greenland in the 20th century generally coincide with changes in the cod fishery, indicating the existence of a relatively strong climatic effect on the cod stock. A general warming of the northern hemisphere around 1920 evidently lead to the establishment of a self sustaining and very abundant West Greenland cod population, which from about 1930 to the late 1960s produced good year classes at relatively short intervals. No good year classes were produced by the West Greenland population after the late 1960s due to generally lower and more fluctuating water temperatures in the West Greenland area. All important cod year classes in West Greenland from 1970 to the present time seem to have been of Icelandic origin. The latest of these, the 1984 and 1985 years classes sustained relatively high catches during 1988-1990 but evidently left West Greenland thereafter (Buch *et al.*, 1994; Rätz, 1999; Anon., 2000). At present cod is very sparse in both offshore and inshore areas of West Greenland, and the ICES Advisory Committee on Fisheries Management recommend no fishing until a substantial increase in recruitment and biomass is evident (Anon., 1998, 2000). In addition it is recommended to reduce the by-catch and discard of cod in the shrimp fishery since simulations using a recruitment model indicated a significant adverse effect of even low fishing mortality of pre-recruits on the potential stock recovery (Anon., 2000).

Data from an annual groundfish survey for cod on the southwest Greenland shelf (0-400 m depth) performed by Germany from 1982-1998, showed a dramatic decline in overall biomass and abundance indices of the mainly boreal fish species (cod, long rough dab (*Hippoglossoides platessoides*), redfish (*Sebastes marinus*), Atlantic wolffish and spotted wolffish) in coherence with an increased abundance of starry ray (*Raja radiata*) (Rätz, 1992, 1999). According to Rätz (1992), both of these changes could be associated with changes in water temperature and fishing effort, and they were interpreted as symptoms of ecosystem stress.

The distribution area of northern shrimp coincides with important nursery areas for several fish species. A large number of fish, mainly redfish, Greenland halibut, and polar cod (*Boreogadus saida*), but also starry ray, long rough dab and others are caught and discarded in the West Greenland shrimp fishery (Pedersen and Kanneworff, 1995; Kingsley *et al.*, 1999; Engelstoft and Jørgensen, 2000). The juveniles of these fish species are spawned on spawning grounds up-current from the shrimp grounds and drift by sea currents to the nursery areas (Smidt, 1969; Riget and Boje, 1989; Pedersen, 1990; Buch *et al.*, 1994). There are large annual fluctuations in the year-class strength and biomass indices of a number of fish species on the offshore West Greenland shrimp grounds (Pedersen and Kanneworff, 1995; Engelstoft and Jørgensen, 2000). Although little quantitative information on the by-catch and discards of fishes in the West Greenland shrimp fishery is available, the considerable fishing effort of the Canadian and Greenland shrimp fisheries in the Davis Strait of 250,000 hours of trawling in 1992 declining to 177,000 hours in 1999 (Siegstad, 2000) seems to affect the demersal fish community by diminishing the recruiting year-classes (Pedersen and Kanneworff, 1995).

Investigations of selective shrimp trawls which reduce the by-catch and discard of small shrimp and fish were started in Greenland waters in 1990 (Valdemarsen *et al.*, 1993) raising the question of whether increased survival rates of fish might reduce the yield from the shrimp fishery on account of increased predation. In Greenland waters several fish species, e.g., Atlantic halibut, cod, Greenland halibut, redfish, long rough dab and starry ray have been identified as important predators on shrimp (Jensen, 1925; Horsted and Smidt, 1965; Smidt, 1969; Tiedtke, 1988; Köster and Schober, 1990; Pedersen and Riget, 1991, 1993; Grünwald, 1992, 1998; Pedersen, 1994, 1995). The northern shrimp stock off West Greenland is regarded as more stable than that of cod, because the northern shrimp are distributed in deeper water with less temperature fluctuations compared to cod, and because northern shrimp has been a common species in Greenland over a longer time period than cod (Horsted, 1989). According to Horsted (1989), it is appropriate to ask whether the present abundance of shrimp in West Greenland waters is the result of a lower stock size of one of its main predators, namely cod. The question is, however, not readily answered because another predator, Greenland halibut seems to be more plentiful when the cod stock is at a low level (Horsted, 1989).

In inshore areas off West Greenland, harp seals have been found to consume a considerable amount of fish and shrimp (Angantyr and Kapel, 1990). Thick-billed murres have been found to feed on fish, mainly capelin (*Mallotus villosus*), and crustaceans in the same area (Falk and Durinck, 1993).

Objectives

The main objective of this report was to develop a mass-balance ecosystem model (Ecopath with Ecosim, Christensen and Walters, 2000) for the West-Greenland area down to 1,500 m depth. It is anticipated that this model will be used for simulations to address issues of interest to the Greenland Institute of Natural Resources. For example, this model can be used (1) to evaluate the levels of predation and fishing mortalities and (2) to evaluate the magnitude of fishing impacts relative to climate change, and thereby possibly get new insights of how to fish the system in a sustainable, yet economically viable fashion.

MATERIALS AND METHODS

A mass balance model using the Ecopath with Ecosim approach (Christensen *et al.*, 2000) was constructed for the West Greenland shelf for 1997. The model area is 240,000 km^2 and ranges from 0-1,500 m depth (Figure 2). The biota in the study area were grouped in 22 key system components defined from the available information of biomass and commercial importance (Tables 1-3). All estimates of biomass were expressed on an area basis (tonnes·km^{-2}) and mortality rates on a yearly basis (year^{-1}) to facilitate comparisons with other systems and models.

Information on the fish community structure and biomass in the study area were obtained primarily from annual shrimp and groundfish surveys performed by the Greenland Institute of Natural Resources, and by the Institute for Sea Fisheries, Hamburg, Germany (Carlsson and Kanneworff, 2000; Engelstoft and Jørgensen, 2000; Rätz, 1999). The shrimp surveys were performed in July-August during daytime only, using the 722 GRT trawler *Paamiut*, with a 3000/20-mesh *Skjervoy* shrimp trawl (wing spread, opening and headline height: about 23 m, 280 m^2 and 16 m, respectively) with bobbin gear, a double-bag with 20 mm (stretched) mesh size in the codend and a towing speed of about 2.5 knots. The German groundfish surveys were performed during autumn because of favorable weather and ice conditions, and the lack of spawning concentrations. Those surveys were carried out by the research vessel (R/V) *Walther Herwig II* throughout most of the time period. In 1984 R/V *Anton Dohrn* was used, and she was replaced by the new R/V *Walther Herwig III* in 1994. The fishing gear used was a standardized 140-feet bottom trawl, its net frame rigged with heavy ground gear because of the rough nature of the fishing grounds. A small mesh liner (10 mm) was used inside the codend.

Bottom trawl performance, availability and catchability of shrimp and fish are highly variable (Engås and Godø, 1986, 1989a, b; Godø and Engås, 1989; Dickson, 1993). Capture efficiency of trawl gear with bobbin ground-rope can range from 0.1 to 0.5 and the efficiencies are low for small shrimp, juvenile fish, bottom fishes (e.g. starry ray), and pelagic fishes (Nilssen *et al.*, 1986; Sparholt and Vinther, 1991; Larsen *et al.,* 1993; Bech, 1994; Boje and Lehmann, 1994).

Many system groups in West Greenland waters are known to exhibit temporal trends in biomass change, and the model structure permitted us to incorporate estimates of the levels of biomass change (Table 1).

Much of the diet composition data for the present model originates from stomach contents analysis of fish stomachs sampled from the key fish species during 1990, 1991 and 1992 on the continental shelf between 61° 52' N and 69° 30' N in the Davis Strait outside the 3 nm limit off the Greenland coast in depths of 150-600 m (Pedersen and Riget, 1991, 1993; Grünwald, 1992, 1998; Grünwald and Köster, 1994; Pedersen, 1994, 1995).

Table 1. Basic parameters used to describe the 1997 West Greenland Ecopath model, with 21 functional groups. P/B and Q/B are the production/biomass and consumption/biomass ratios, respectively. Trophic level and values in brackets were estimated by the model.

Group	Habitat fraction	Biomass in habitat ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	Ecotrophic efficiency	Biomass accumulation ($t \cdot km^{-2}$ $year^{-1}$)	Trophic level
Baleen whales	1	0.458	0.030	4.00	(0.519)	0.000	3.8
Toothed mammals	1	0.049	0.060	10.00	0.900	0.000	4.4
Seals	1	0.509	0.070	15.00	0.900	0.000	4.3
Seabirds	1	0.008	1.000	99.00	(0.211)	0.000	3.9
Cod 4+	1	0.047	0.300	2.80	(0.263)	0.000	4.0
Cod juv	1	0.010	0.600	3.50	(0.657)	0.002	3.9
Grl. halibut 5+	0.218	2.141	0.700	1.80	(0.843)	0.200	4.1
Grl. halibut juv	0.52	(1.617)	0.900	3.40	0.950	0.115	4.0
Redfish > 14cm	0.52	0.070	(1.099)	2.50	0.950	0.000	3.7
Redfish juv	0.52	0.331	(1.955)	5.00	0.950	0.018	3.6
Polar cod	1	(2.513)	1.000	5.00	0.950	0.119	3.4
Thorny ray	1	0.034	0.400	1.30	(0.190)	0.000	3.0
Long rough dab	0.52	(0.105)	0.600	2.00	0.950	-0.012	3.0
Other pelagic fish	1	3.636	1.100	2.50	(0.943)	0.000	3.5
Other bottom fish	1	(1.776)	0.600	2.00	0.950	0.000	3.3
Northern shrimp	0.52	3.307	0.900	6.00	(0.916)	0.000	2.7
Benthos	1	85.000	1.500	9.75	(0.498)	0.000	2.2
Squid	1	(0.376)	2.440	6.00	0.950	0.000	3.6
Large Zooplankton	1	25.000	4.000	15.00	(0.713)	0.000	2.6
Small Zooplankton	1	15.000	20.000	50.00	(0.904)	0.000	2.0
Phytoplankton	1	20.000	50.000	-	(0.790)	0.000	1.0
Detritus	1	-	-	-	(0.904)	-	-

Table 2. Diet matrix for the West Greenland ecosystem model

	Group	Predator																			
	Prey	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	Baleen whales																				
2	Toothed mammals																				
3	Seals		0.010																		
4	Seabirds																				
5	Cod 4+																				
6	Cod juv					0.010	0.010														
7	Grl. halibut 5+		0.040																		
8	Grl. halibut juv		0.050	0.050				0.005	0.050	0.010	0.030										
9	Redfish > 14cm		0.020	0.002		0.010		0.005													
10	Redfish juv		0.010	0.005		0.050	0.050	0.020	0.050	0.030	0.030		0.050			0.010					
11	Polar cod		0.050	0.246	0.053	0.010		0.155	0.050							0.010					
12	Thorny ray																				
13	Long rough dab					0.010		0.005								0.010					
14	Other pelagic fish	0.200	0.295	0.200	0.316	0.240	0.200	0.200	0.200	0.080					0.050	0.010			0.090		
15	Other bottom fish	0.038	0.060	0.047		0.150	0.185	0.210	0.050							0.050					
16	Northern shrimp		0.020	0.020		0.200	0.100	0.150	0.200	0.200	0.030		0.100	0.100		0.050					
17	Benthos		0.050		0.053	0.119	0.205	0.150	0.100	0.050			0.500	0.650	0.060	0.650	0.200	0.070			
18	Squid		0.120	0.030	0.053	0.040		0.100	0.050	0.010	0.080				0.020	0.010			0.010		
19	Large Zooplankton	0.464	0.045	0.100	0.526	0.140	0.200		0.250	0.520	0.610	0.600	0.050		0.600	0.100	0.100	0.040	0.750	0.050	
20	Small Zooplankton	0.069				0.020	0.050			0.100	0.220	0.400			0.270		0.250	0.070	0.150	0.500	0.020
21	Phytoplankton																0.050	0.020		0.400	0.830
22	Detritus												0.300	0.250		0.100	0.400	0.800		0.050	0.150
	Import	0.229	0.230	0.300																	

Table 3. Catches and discards (t·m^{-2}) used in the Ecopath model of West Greenland waters (NAFO area 1) for 1997. Catches are separated by the three main fisheries, with other gear types combined.

	Catch (t·km^{-2})					Discards (t·km^{-2})		
Group	**Shrimp trawl**	**Deep water**	**Coastal gear**	**Other gear**	**Total**	**Shrimp trawl**	**Deep water**	**Total**
Baleen whales				0.0071	***0.0071***			
Toothed mammals				0.003	***0.003***			
Seals				0.0426	***0.0426***			
Seabirds				0.0017	***0.0017***			
Cod 4+				0.0037	***0.0037***			
Cod juv								
Grl. halibut 5+		0.0199	0.0358		***0.0558***			
Grl. halibut juv						0.0239		***0.0239***
Redfish > 14cm		0.0045			***0.0045***	0.0027		***0.0027***
Redfish juv						0.0240		***0.0240***
Polar cod						0.0142		***0.0142***
Thorny ray						0.0026		***0.0026***
Long rough dab						0.0018		***0.0018***
Other pelagic fish		0.00067			***0.00067***	0.0035		***0.0035***
Other bottom fish		0.01847			***0.01847***	0.0113	0.0009	***0.0123***
Northern shrimp	0.2666				***0.2666***	0.0236		***0.0236***
Benthos				0.0134	***0.0134***			
Squid						0.0009		***0.0009***
Total	***0.2666***	***0.0436***	***0.0358***	***0.0716***	***0.4176***	***0.1085***	***0.0009***	***0.1094***

Input data by Ecopath group (Tables 1-3)

Group 1. Baleen whales

The species composition of the three marine mammal groups occurring in West Greenland waters are listed in Table 4, based on Mosbech *et al.* (1998).

Table 4. List of species of marine mammals included in the model of the West Greenland marine ecosystem model, separated into their Ecopath groups.

Baleen Whales
Blue whale (*Balaenoptera musculus*)
Bowhead whale (*Balaena mysticetus*)
Fin whale (*Balaenoptera physalus*)
Humpback whale (*Megaptera novaeangliae*)
Minke whale (*Balaenoptera acutorostrata*)
Sei whale (*Balaenoptera borealis*)
Toothed Whales
Atlantic white-sided dolphin (*Lagenorhynchus obliquidens*)
Bottlenose whale (*Hyperoodon ampullatus*)
Harbour porpoise (*Phocoena phocoena*)
Killer whale (*Orcinus orca*)
Narwhal (*Monodon monoceros*)
Pilot whale (*Globicephala melaena*)
Sperm whale (*Physeter macrocephalus*)
White-beaked dolphin (*Lagenorhynchus albirostris*)
White whale (*Delphinapterus leucas*)
Seals
Bearded seal (*Erignathus barbatus*)
Harbour seal (*Phoca vitulina*)
Harp seal (*Phoca groenlandica*)
Hooded seal (*Cystophora cristata*)
Ringed seal (*Phoca hispida*)
Walrus (*Odobenus rosmarus*)

The catch of 1,710 tonnes was obtained from Mosbech *et al.* (1998) as the average annual catch for the years 1994-1996. The biomass was calculated based on summer abundance and average weights by species from Table 5.124 in Born (1999). The natural mortality estimate was based on Bundy *et al.* (2000), while the Q/B estimate was based on the Norwegian Ecopath model (Dommasnes *et al.*, this volume).

The dietary information was derived from Mosbech *et al.* (1998) and Vikingsson and Kapel (2000). As whale biomass was based on summer abundance, lower concentrations of animals were assumed for winter. Therefore, the food taken by migrant whales during winter is treated in the model as an import, and here it is assumed that approximately 20% of the diet is import.

Group 2. Toothed whales

Catches of 727 tonnes were averaged data for the years 1994-1996 based on Mosbech *et al.* (1998). The biomass was calculated based on summer abundance and average weights by species. Exceptions are narwhale and white whale, for which $^1/_3$ of the estimated winter abundance was used from Table 5.124 in Born (1999). P/B and Q/B were based on the Norwegian Ecopath model (Dommasnes *et al.*, this volume).

The dietary information was derived from Mosbech *et al.* (1998) and Born (1999). As most whale biomass was based on summer abundance, lower concentrations of most animals were assumed for winter. Therefore, the food taken by migrant whales during winter is treated in the model as an import, and here it is assumed that approximately 20% of the diet is import.

Group 3. Seals

The reported seal catches of 10,221 tonnes represent an average for the years 1994-1996 (Mosbech *et al.*, 1998). Biomass was calculated based on summer abundance and average weights by species from Table 5.124 in Born (1999).

P/B was based on an assumed total mortality of 7% based on data from the Global Marine Mammal database of the *Sea Around Us* project (see Pauly *et al.*, 1998; Trites and Pauly, 1998). Q/B was based on the Norwegian Ecopath model (Dommasnes *et al.*, this volume). The diet composition for seals was based on Mosbech *et al.* (1998) and Kapel (2000).

Group 4. Seabirds

The main species of seabirds occurring in West Greenland are listed in Table 5 (Mosbech *et al.*, 1998). The catch of seabirds of 405 tonnes was derived from Mosbech *et al.* (1998). Biomass estimate was calculated from population size estimates (pairs) and average weight by species (and sex) described in Mosbech *et al.* (1998).

P/B was derived from the total mortality estimate based on information in Sakshaug (1995). Q/B was based on the Norwegian Ecopath model (Dommasnes *et al.*, this volume). The diet composition for seals was based on Mosbech *et al.* (1998).

Table 5. Main species of seabirds found around West Greenland.

Birds
Arctic tern (*Sterna paradisaea*)
Black guillemot (*Cepphus grylle*)
Black-legged kittiwake (*Rissa tridactyla*)
Common eider (*Somateria mollissima*)
Glaucous gull (*Larus hyperboreus*)
Great black-backed gull (*Larus marinus*)
Great cormorant (*Phalacrocorax carbo*)
Great shearwater (*Puffinus gravis*)
Harlequin duck (*Histrionicus histrionicus*)
Iceland gull (*Larus glaucoides*)
Ivory gull (*Pagophila eburnea*)
King eider (*Somateria spectabilis*)
Long-tailed duck (*Clangula hyemalis*)
Mallard (*Anas plathyrhynchos*)
Northen fulmar (*Fulmarus glacialis*)
Puffin (*Fratercula arctica*)
Purple sanpiper (*Calidris maritima*)
Razorbill (*Alca torda*)
Red-breasted merganser (*Mergus serrator*)
Thick-billed murre (*Uria lomvia*)
White-tailed eagle (*Haliaeetus albicilla*)

Group 5. Atlantic Cod 4+ (Gadus morhua)

This group consists of adult Atlantic cod of 4 years and older, considered to be > 35 cm (Bundy *et al.*, 2000). The 1997 catch of 891 tonnes of adult cod was based on the ICES working group report (Anon., 2000). Biomass was derived from Anon. (2000), based on the annual groundfish survey, and predicted inshore biomass from pound net catches.

The total mortality estimate was based on Sakshaug (1995), and was considered lower than in comparable areas (Bundy *et al.*, 2000; Dommasnes *et al.*, this volume) as no targeted fisheries exists for cod, and catches are essentially incidental by-catches in other gears and the shrimp fishery. Thus, the P/B was estimated at 0.4 year^{-1}.

For cod from West Greenland (mean length: 45 cm) feeding mainly on northern shrimp, Köster and Schober (1990) found a gastric evacuation rate of 0.22 g/h at a mean temperature of 3.5^{o}C. From this information an estimate of annual Q/B can be calculated to 2.8 (Christensen *et al.*, 2000).

The diet composition used as input for cod was obtained from stomach content analysis and the literature (Tiedtke, 1988; Köster and Schober, 1990; Schnack *et al.,* 1993; Grundwald and Köster, 1994; E. Grünwald, pers. comm.).

Group 6. Cod (juvenile)

Following Bundy *et al.* (2000), juvenile Atlantic cod were defined as of age 0, 1, 2 and 3, and being < 35 cm. There is no known catch of juvenile cod (Anon., 2000). Biomass estimates are from Anon. (2000) based on groundfish survey. The estimates are clearly underestimates, due to the survey sampling gear used, and due to additional inshore juvenile cod biomass of uncertain amount. Therefore, we decided to increase the initial estimate (0.001 t/km^{2}) to account for the uncertainties.

Total mortality estimate was based on Bundy *et al.* (2000), and Q/B was based on the Norwegian Ecopath model (Dommasnes *et al.*, this volume). The diet composition data was based on Bundy *et al.* (2000).

Group 7. Greenland halibut 5+ (Reinhardtius hippoglossoides)

Adult Greenland halibut consisted of 5 years and older fish. The 1997 deep-water and inshore catches of adult Greenland halibut of 14,000 tonnes were obtained from Jørgensen (2000a) and Simonsen and Boje (2000).

The biomass estimate was based on Jørgensen (2000b). The Jørgensen estimate is most likely an underestimate as it is based on 'trawlable biomass' in NAFO areas 1C & 1D. The estimate was doubled to account for additional, un-surveyed inshore component (e.g. Disko Bay and fjords), which forms part of major coastal fisheries (Simonsen and Boje, 2000).

The P/B ratio was based on data from Simonsen and Boje (2000). For Greenland halibut Q/B was assumed to be 1.8 year^{-1} (FishBase 1999). This seems to be a reasonable level although in the lower end of the estimates presented by Yang and Livingston (1988). They estimated daily rations between 0.66 and 1.17% body weight per day. The diet components for Greenland halibut were based on stomach content analysis (Orr and Bowering, 1997).

Offshore fishery
Subarea 1: Div. 1B-1F. The offshore fishery in Div. 1B-1F increased from about 900 tonnes in 1987 to about 1,500 tonnes in 1988 and catches remained at that level until 1992 when they increased to 5,550 tonnes. Catches remained at that level until 1995, but decreased to 4,800 tonnes in 1997. Offshore, 3,703 tonnes were taken by mainly Norwegian and Greenlandic trawlers while 1,090 tonnes were taken by Norwegian and Greenlandic longliners. Inshore

catches amounted to 7 tonnes. Almost all the fishery takes place in Div. 1D in the second half of the year.

Subarea 1: Div. 1A. There has been practically no offshore fishing for Greenland halibut in Div. 1A. In 1993, 34 tonnes were taken by a Japanese trawler; in 1994, 18 tonnes by a Greenlandic longliner; in 1995, 13 tonnes by a Japanese trawler. No fishing was carried out in the area in 1996-97.

Inshore fishery
The main fishing grounds for Greenland halibut in Div. 1A are located inshore. The inshore catches in Div. 1A were around 7,000 tonnes in the late-1980s have increased steadily since, and were almost 20,000 tonnes in 1997. Catches were rather evenly distributed over the year but with a tendency toward higher catches in July and August.

For recruitment, the inshore stock depends on immigration from the offshore nursery grounds and the spawning stock in Davis Strait. Only sporadic spawning seems to occur in the fjords, hence the stock is not considered self-sustainable. This connection between the offshore and inshore stocks implies that reproductive failure in the offshore spawning stock for any reason will have severe implications for the recruitment to the inshore stocks.

Subarea 1: Div. 1A This fishery is mainly a traditional fishery, typically in the inner parts of the ice fjords at depths between 500 to 800 m. Longlines are set from small boats below 20 GRT, or in winter through the ice. In the middle of the 1980s gillnets were introduced to the inshore fishery, and were used more commonly in the following years. In 1989 gillnets and longlines accounted equally for the catches, but since then the annual proportion of catches from each gear has varied considerably. The minimum mesh size allowed was 110 mm (half meshes). Authorities have in recent years tried to discourage the use of gillnets, which has led to an increased proportion of longline catches. Gillnets are banned since the year 2000. There are no regulations on longline fisheries. Longline catches comprised 74% of the total in 1996 and 76% in 1997. There are no quota regulations on the fishery, but from 1998 a license is required to land commercial catches.

Commercial processors pay more for 'large fish' (over 3.3 kg), so 'small fish' are sometimes discarded. Size composition data from the landed catch are therefore biased with respect to the fishable stock.

Group 8. Greenland halibut juveniles

This group comprises juvenile Greenland halibut of ages 0-4 years. In 1997 5,726 tonnes of juvenile Greenland halibut was caught as by-catch by the shrimp fishery, and was discarded. This estimate was based on shrimp survey by-catch data (Kingsley *et al.*, 1999; Engelstoft and Jørgensen, 2000).

A reliable estimate of juvenile biomass was not available, and it was estimated by the model, while P/B and Q/B were based on Bundy *et al.* (2000). The diet components for Greenland halibut were based on stomach content analysis (Bowering *et al.*, 1984; Pedersen and Riget, 1993; Pedersen, 1994; Jørgensen, 1997).

Group 9. Redfish larger than 14 cm (Sebastes spp.)

Two species of redfish are found commonly in West Greenland waters and are pooled here: *Sebastes marinus* and *S. mentella*. The catch by the deep water fisheries of slightly more than 1,000 tonnes in 1997 was based on Siegstad *et al.* (2000). The biomass estimate was based on deep water groundfish survey data (Rätz and Stransky, 2000) for a survey area of 59,205 km^2, with both *S. mentella* and *S. marinus* pooled. This estimate is assumed to be representative for scaling up to the larger model area (240,000 km^2).

Total mortality is unknown, and P/B was estimated by the model, while Q/B was derived from an estimate in FishBase (1999). The diet compositions used as input for adult and juvenile redfish was obtained from stomach content analysis and the literature (Pedersen and Riget, 1993; Pedersen, 1994).

Group 10. Redfish juvenile

Juvenile redfish are caught as incidental by-catch (approximately 5,700 tonnes) by the shrimp fishery, and was estimated from shrimp survey by-catch information (Kingsley *et al.*, 1999). The basic biomass estimate was based on shrimp survey data (Kinglsey *et al.*, 1999; Engelstoft and Jørgensen, 2000), and was doubled to account for gear selectivity.

No information was available for P/B, and the parameter was allowed to be estimated by the model. By applying the Winberg equation to mean weights of the Barents Sea deep-water redfish, Dolgov and Drevetnyak (1990, 1992) calculated the annual rations (% of body weight) to vary from 470-599% in juvenile redfish to 125-142% at age 19. Therefore, 5.0 year^{-1} seems to be a reasonable level of Q/B for the small redfish in this study. See adult redfish for diet sources.

Group 11. Polar cod (Boreogadus saida)

There is no targeted fishery for polar cod, but approximately 3,400 tonnes are taken as by-catch by the shrimp fishery (Kinglsey *et al.*, 1999). No reliable estimate of biomass for the model area was available, and the parameter was estimated by the model.

P/B was based on the Norwegian Ecopath model (Dommasnes *et al.*, this volume). Results from evacuation experiments with polar cod indicate that a reasonable level of Q/B for the fish sizes in the present study is about 5.0 $year^{-1}$ (J.S. Christiansen, University of Tromsø, Norway, pers. comm.). The diet compositions used as model input for polar cod were based on information from Jensen (1992).

Group 12. Thorny ray (Raja radiata)

There is no targeted fishery for thorny ray, but approximately 620 tonnes are taken as by-catch by the shrimp fishery (Kinglsey *et al.*, 1999; Siegstad and Rätz, 2000). The basic biomass estimates of Kinglsey *et al.* (1999), Engelstoft and Jørgensen (2000) and Rätz and Lloret (1999) were doubled to account for sampling uncertainty.

P/B was approximated from F = 0.2 $year^{-1}$ (Kingsley *et al.*, 1999; Engelstoft and Jørgensen, 2000; Rätz and Lloret, 1999) and M = 0.2 $year^{-1}$ (FishBase, 1999). The consumption/biomass ratio was based on information from Bundy *et al.* (2000). The diet composition information was based on data by Pedersen (1995).

Group 13. Long rough Dab (Hippoglossoides platessoides)

There is no targeted fishery for this species, but there is a small by-catch in the shrimp fishery (Kingsley *et al.*, 1999; Siegstad and Rätz, 2000). No reliable estimates of biomass were available and this parameter was estimated by the model. The P/B estimate was based on Rätz and Lloret (1999), and the Q/B value was taken from FishBase (1999). The diet of this species consist mainly of benthic organisms, northern shrimp and detritus (Grünwald, 1992).

Group 14. Other pelagic fish

This groups represents several species, including *Ammodytes dubius*, *A. marinus*, *Mallotus villosus*, *Stomias boa*, *Benthosema glaciale*, *Alepocephalus* sp., *Arctogadus glacialis*, *Paralepsis coregonoides*, *Chauliodus sloani*, *Serrivormer beani*, as well as other myctophids and paralipids.

A small by-catch is taken as part of the shrimp and deep water fishery (Pedersen and Kanneworff, 1995; Kingsley *et al.*, 1999; O.A. Jørgensen, Greenland Institute of Natural Resources, pers. comm.). The biomass estimate was based on information from P. Kannerwolff (Greenland Institute of Natural resources, pers. comm.) and S.A. Horsted (Former Director of Greenland Fisheries Research Institute, pers. comm.).

P/B and Q/B: The values used were estimated by V. Christensen (University of British Columbia, pers. comm.) based on other Ecopath models from the North Atlantic area. The diet composition for these species was assumed to comprise mainly plankton, other pelagic species, squid and some benthos.

Group 15. Other bottom fish

This group includes numerous species, including *Anarhichas denticulatus*, *A. lupus*, *A. minor*, *Artediellus* sp., *Aspidophoroides monopterygius*, *Bathylagus* sp., *Brosme brosme*, *Careproctus reinhardti*, *Centroscyllium fabricii*, *Cottunculus microps*, *Cottunculus* sp., *Cyclopterus lumpus*, *Eumicrotremus derjugini*, *Eumicrotremus spinosus*, *Gadus ogac*, *Icelus* sp., *Leptagonus decagonus*, *Leptoclinus maculatus*, *Liparis* sp., *Liparis tunicata*, *Lycodes esmarki*, *Lycodes* sp., *Macrourus berglax*, *Melanogrammus aeglefinus*, *Myoxocephalus scorpius*, *Myxine glutinosa*, *Onogadus argentatus*, *O. ensis*, *Paraliparis* sp., *Raja* sp., *R. fyllae*, *R. lintea*, *Somniosus microcephalus*, *Synaphobranchus kaupi*, *Triglops* sp., *T. murray*, *T. nybelini*, *T. pingeli*, stichaeids and lumpenids (Pedersen and Kanneworff, 1995; Rätz, 1999).

The 1997 catch of 4,435 tonnes was obtained from Siegstad and Rätz (2000) and roughly estimated discards from the shrimp fishery (Kingsley *et al.*, 1999). No reliable biomass estimate could be obtained for this group, and the parameter was estimated by the model. P/B and Q/B values were estimated by V. Christensen (pers. comm.). The data on diet for this group were estimated from Pedersen and Riget (1991), Rodriguez-Marin *et al.* (1994) and Torres *et al.* (2000).

Group 16. Northern shrimp (Pandalus borealis)

The fishery for northern shrimp is presently the largest fishery in West Greenland waters, with a 1997 catch of 64,000 tonnes (Siegstad, 2000), and a discard of approximately 5,600 tonnes (Kingsley *et al.*, 1999). The biomass estimate from Carlsson and Kanneworff (2000) based on survey data was doubled to account for an unknown fraction of shrimp present in the water-column.

The P/B estimate of 0.9 year^{-1} was based on Rønnow (1992), and a personal communication from D.G. Parsons (Science Branch, Dept. of Fisheries and Oceans, St. John's, Newfoundland, Canada), who considers this level of total mortality to be reasonable for the West Greenland shrimp populations. A Q/B value of 6 year^{-1} was assumed for the consumption/biomass ratio. The diet of northern shrimps consists mainly of detritus, zooplankton and some benthos (Shumway *et al.* 1985; Hopkins *et al.*, 1989; Ivanova, 2000).

The shrimp stock off West Greenland is distributed in NAFO Div. 0A and Subarea 1 (*www.nafo.ca/imap/map.htm*) and the entire shrimp stock is assessed as a single population. The Greenland fishery exploits the stock in Subarea 1 (Div. 1A to 1F) in offshore and inshore areas (primarily Disko Bay). The Canadian fishery has been restricted to Div. 0A since 1981.

Two Greenlandic fleet components exploit the stock in Subarea 1: an offshore fleet, which at present consists of 13 large factory trawlers (1,500-3,000 GRT) and a small vessel fleet composed of about 100 vessels below 80 GRT. The offshore fleet component is restricted to offshore areas and by quotas. Internal Transferable Quotas (ITQ) were introduced as a management tool in 1991. With a few exceptions vessels below 80 GRT were unrestricted by areas and quotas until 1997 when catch regulations were introduced also for this fleet component. Since 1986 logbooks have been mandatory for vessels above 50 GRT. Since 1997 logbooks are available for all vessels.

The Canadian fleet exploits the stock component in Div. 0A. Seventeen companies are currently licensed to fish in the area, but in recent years only 6-7 vessels (2,000-4,000 GRT) have participated. Catches are restricted by quotas. Vessel logs are available since 1979.

Overall catches increased until 1992, then decreased from 1993 to 1997. The nominal catch of shrimp in the offshore areas of Subarea 1 and the adjacent part of Subarea 0 (Div. 0A) increased from less than 1,000 tonnes before 1972 to almost 43,000 tonnes in 1976. Catches fluctuated thereafter and stabilized around a level of 54,000 tonnes during 1985-88, then increased to 66,000 tonnes in 1992 and decreased thereafter to 51,000 tonnes in 1997. The Canadian fishery in Div. 0A amounted to about 2,500 tonnes in 1995 and 1996, declined to 500 tonnes in 1997 and 875 tonnes has been reported up to October 1998. Historically, the fishing grounds in Div. 1B have been the most important. Since 1989, a gradual southward shift in the offshore fishery has taken place, and since 1990 catches in Div. 1C and 1D have exceeded those from Div. 1B. At the end of the 1980s, exploitation began in Div. 1E and 1F, and catches from these areas now account for about 20% of the total catch. The distribution of the fishery has not changed since 1996. The West Greenland inshore shrimp fishery was relatively stable from 1972 to 1987 with estimated catches of 7,000-8,000 tonnes annually (except for 10,000 tonnes in 1974). Inshore catches in recent years have increased to over 20,500 tonnes in 1992, but decreased to 13,500 tonnes in 1997. During the 1990s inshore catches have accounted for about 25% of the total catch in Subarea 1.

Group 17. Benthos

This group contains all benthic invertebrates, including echinoderms, polychaetes, molluscs and miscellaneous crustaceans, nematodes and other meiofauna (Bundy *et al.*, 2000).

The catch of approximately 3,200 tonnes was obtained from the NAFO catch time series (*www.nafo.ca*), and comprises mainly snow crab (*Chionoecetes opilio*) and Iceland scallop (*Chlamys islandica*). The biomass estimate was based on information from macrobenthos investigations carried out by the Institut für Meereskunde, University of Kiel, Germany, by Schnack *et al.* (1993) and E. Grünwald (pers. comm.), and assumed to be representative for the whole model area.

P/B and Q/B were based on the Norwegian Ecopath model (Dommasnes *et al.*, this volume). The benthic group was assumed to feed primarily on detritus and plankton, and to a smaller extend on other benthos (Bundy *et al.*, 2000).

Group 18. Squids

The main species of cephalopods included in this group is *Gonatus fabricii*. There is no targeted fishery for squid in the waters off West Greenland, and only small quantities are taken as by-catch by the shrimp fishery (Kingsley *et al.*, 1999). No reliable estimate of biomass was available, and this parameter was estimated by the model.

P/B and Q/B were based on the Norwegian Ecopath model (Dommasnes *et al.*, this volume). It was assumed that the diet of squid consists to 90% of zooplankton, with the rest being other pelagic fish and cephalopods (Kristensen, 1984).

Group 19 and 20. Large and Small Zooplankton

Large zooplankton consists mainly of animals of or larger than 1 mm, while small zooplankton are components smaller than 1 mm (Pedersen and Smidt, 2000). The biomass of zooplankton were assumed to be similar to the levels as estimated in northern Norway (Hopkins *et al.*, 1989; Bax and Elliassen, 1990). Other parameters were estimated based on information from Dommasnes *et al.* (this volume) and V. Christensen (pers. comm.).

Group 21. Phytoplankton

In Disko Bay (Figure 2), Andersen and Born (1999) measured about 90 C g m^{-2} $year^{-1}$ – which is approximately 1000 g m^{-2} $year^{-1}$ wet weight. No other information on phytoplankton biomass or production exists for this area, and the assumed values are based on estimates made for northern Norwegian waters (Hopkins *et al.*, 1989; Bax and Elliassen, 1990).

Model balancing

An ecosystem model of the West Greenland waters ≤ 1,500 m depth as constructed and balanced based on data for the year 1997. Balancing required only moderate changes to initial input data, primarily the percentage distributions within the diet matrix. This model, based on the input parameters summarized in the present report, should be considered a preliminary version, and may be altered should other data become available.

CONCLUSIONS

The primary purpose of this report was to document the input data assembled for an ecosystem model of the West Greenland marine waters. In the future, the model will be used to examine specific questions of interest to the Greenland Institute of Natural Resources. Clearly, the presently used input data should be amended as more precise estimates become available.

No signs of overfishing have been detected for the offshore West Greenland shrimp stock, despite the steady catch increase over the last three decades (Siegstad, 2000). For the year 2001 the NAFO Scientific Council noted that all available indices of size and age composition were favorable, and considered that the stock can sustain an increased catch compared to previous years (*www.nafo.ca*). The increase in the West Greenland shrimp catches may well have been possible because of the generally lower abundance of the offshore West Greenland cod population after the 1970s and its virtually disappearance in 1992. In the same period other shrimp predators also showed decreasing trends e.g., redfish, Atlantic halibut, wolffishes (Rätz, 1999). As marine resources are of major importance to the Greenland economy, the present model can assist in evaluating the effects of various management scenarios on marine resources. Future simulations could also address potential ecosystem level effects and changes due to large scale climatic change.

ACKNOWLEDGMENTS

We would like to acknowledge the Pew Charitable Trusts, Philadelphia, USA, for the funding of the *Sea Around Us* project at the University of British Columbia, Canada. Thanks to Dr. J. S. Christiansen, NCFS, University of Tromsø, Norway, for information on consumption and evacuation in Polar cod and to E. Grünwald, Institut für Meereskunde, Kiel University, Germany, for information on stomach content in cod and mean wet weight of macrobenthos off West Greenland.

References

Andersen, O.N. and Born, E.W. 1999 . De lavere trofiske niveauer. In: Grønlands Økologi – en grundbog. (The Ecology of Greenland – basics). Ed. by Born and Böcher. Grønlands Miljø- og Naturforvaltning. Atuakkiorfik Undervisning, Nuuk 1999. 431 p. (Danish, available in English in 2001).

Angantyr, L. A. and Kapel, F.O. 1990. Harp seal feeding habits in Greenland, - our present knowledge, April 1990. Greenland Fisheries Research Institute Technical Report. 45pp + appendices.

Anon. 1998. Report of the North-western working group. ICES CM/ACFM:19. Part 1 and 2. 350 pp.

Anon. 1999. NAFO Scientific Council Meeting Reports 1998. 257 pp.

Anon. 2000. Report of the North-western working group. ICES CM 2000/ACFM:15. Part 1 and 2. 328 pp.

Bax, N. and Eliassen, J. E. 1990. Multispecies analysis in Balsfjord, Northern Norway: solution and sensitivity analysis of a simple ecosystem model. Journal du Conseil International pour l'Exploration de la Mer, 47: 175-204.

Boje, J. and Lehmann, K. M. 1994. Selectivity in shrimp trawl codend from an alternate haul experiment. ICES C.M. 1994/B: 12, 8 pp.

Born, E. W, Heide-Jørgensen, M. P. and Davis, R.A. 1994. The Atlantic walrus (*Odobenus rosmarus*) in West Greenland. Meddr. Grønland, Biosci, 40: 1-33.

Born, E. W. 1999. Havpattedyr *In* Grønlands Økologi – en grundbog (The Ecology of Greenland – basics). Ed. by Born and Böcher. Grønlands Miljø- og Naturforvaltning. Atuakkiorfik Undervisning, Nuuk 1999. 431 p. (In Danish, available in English in 2001).

Bowering, W. R., D. G. Parsons and G. R. Lilly. 1984. Predation on shrimp (*Pandalus borealis*) by Greenland halibut (*Reinhardtius hippoglossoides*) and Atlantic cod (*Gadus morhua*) off Labrador. ICES C.M. 1984/G:54, 30 pp.

Buch, E., Horsted, S. A. and Hovgård, H. 1994. Fluctuations in the occurrence of cod in Greenland waters and their possible causes. ICES Marine Science Symposia, 198: 158-174.

Carlsson, D.M. and P. Kanneworff. 2000. Stratified-random trawl survey for Northern shrimp *(Pandalus borealis*) in NAFO Subarea 0 & 1 in 2000. NAFO Scientific Council Report No. 78, serial No. N4335, 28 pp.

Christensen, V., and Walters, C. J. 2000. Ecopath with Ecosim: methods, capabilities and limitations. p. 79-105 In: Methods for evaluating the impacts of fisheries on the North Atlantic ecosystems. Ed. by Pauly, D., and Pitcher, T. Fisheries Centre Research Reports 8(2).

Christensen, V., Walters, C. J. and Pauly, D. 2000. Ecopath and Ecosim: A user's guide, October 2000 Edition. Fisheries Centre, University of British Columbia Vancouver, Canada and ICLARM, Penang, Malaysia. 130 pp. (available from: *www.ecopath.org*)

Dickson, W. 1993. Estimation of the capture efficiency of trawl gear. II: Testing a theoretical model. Fisheries Research, 16: 255-272.

Dolgov, A.V. and Drevetnyak, K.V. 1990. Estimation of rations and food consumption of deep-water redfish (*Sebastes mentella*) from the Norwegian-Barents Sea stock. ICES CM 1990/G:11, 15 pp.

Dolgov, A.V. and Drevetnyak, K.V. 1992. Food requirements of the Barents Sea *Sebastes mentella*. In: Interrelations between fish populations in the Barents Sea. S. Proceedings of the fifth PINRO-IMR Symposium Murmansk, 12-16 Ed. by Bogstad, B. and Tjelmeland, August 1991: 193-204.

Engelstoft, J. J. and Jørgensen, O. 2000. Biomass and Abundance of Demersal Fish Stocks off West Greenland Estimated from the Greenland Shrimp Survey, 1988-1999. NAFO Scientific Council Report No. 22, serial No. N4251, 20 pp.

Engås, A. and Godø, O.R. 1986. Influence of trawl geometry and vertical distribution of fish on sampling with bottom trawl. Journal of Northwestern Atlantic Fisheries Science 7: 35-42.

Engås, A. and Godø, O.R. 1989a. The effect of different sweep lengths on the length composition of bottom-sampling trawl catches. Journal du Conseil International pour l'Exploration de la Mer, 45: 263-268.

Engås, A. and Godø, O.R. 1989b. Escape of fish under the fishing line of a Norwegian sampling trawl and its influence on survey results. Journal du Conseil International pour l'Exploration de la Mer, 45: 269-276.

Evans, P.G.H. 1984. The seabirds of Greenland: Their status and conservation. In: Status and conservation of the World's seabirds, pp 49-84. Ed. by Croxall, J.P., Evans, P.G.H. and Schreiber, R.W. International Council for Bird Preservation Technical Publication No. 2, Cambridge.

Falk, K. and Durinck, J. 1992. Thick-billed murre hunting in West Greenland, 1988-89. Arctic, 45: 167-178.

Falk, K. and Kampp, K. 1992. Havfugle ved Vestgrønland - en opdateret oversigt/Sea birds at West Greenland - an updated review. Report, Ornis Consult/Zoologisk Museum, Copenhagen: 24 pp. + maps. (in Danish).

Falk, K. and Durinck, J. 1993. The winter diet of thick-billed murres, *Uria lomvia*, in western Greenland, 1988-1989. Canadian Journal of Zoology, 71: 264-272.

FishBase 1999. A global information system on fishes. *www.fishbase.org*

Frimer, O. 1993. Occurrence and distribution of king eider (*Somateria spectabilis*) and common eider (*S. mollissima*), West Greenland. Polar Research, 12: 111-116.

Godø, O. R. and Engås, A. 1989. Swept area variation with depth and its influence on abundance indices of groundfish from trawl surveys. Journal of Northwestern Atlantic. Fisheries Science, 9: 133-139.

Godø, O. R. and Westpestad, V. G. 1993. Monitoring changes in abundance of gadoids with varying availability to trawl and acoustic surveys. ICES Journal of Marine Science, 50: 39-51.

Grünwald, E. 1992. Nahrungsökologie der Doggerscharbe (*Hippoglossoides platessoides* Fabr.) im Seegebiet vor West-Grönland. Diplomarbeit, Institut für Meereskunde, University of Kiel. 99 pp. (In German).

Grünwald, E. 1998. Nahrungsökologische Untersuchungen an Fischbeständen im Seegebiet vor Westgrönland. Doctoral thesis, Christian-Albrechts-Universität, Kiel. 208 pp. (In German).

Grünwald, E. and Köster, F 1994. Feeding habits of Atlantic cod in West Greenland waters. ICES CM 1994/P:5, 19 pp.

Heide-Jørgensen, M. P., Lassen, H., Teilmann, J. and Davis, R.A. 1993. An index of relative abundance of wintering Belugas, *Delphinapterus leucas*, and Narwhals, *Monodon monoceros*, off West Greenland. Canadian Journal of Fisheries Science, 50(11): 2323-2335.

Heide-Jørgensen, M. P. 1994. Distribution, exploitation and population status of white whales (*Delphinapterus leucas*) and narwhals (*Monodon monocerus*). Meddr. Grønland, Bioscience, 39:133-148.

Hopkins, C. C. E., Grotnes, P. E. and Eliassen, J.-E. 1989. Organization of a fjord community at 70° north: The pelagic food web in Balsfjord, Northern Norway. Rapports et Procès-Verbaux des Réunions du Conseil International pour l' Exploration de la Mer. 188: 146-153.

Horsted, S. A. 1989. Some features of oceanographic and biological conditions in Greenland waters. In: Proceedings of the sixth conference of the comité arctique international 13-15 May 1985, 456-476. Ed. by Louis Rey and Vera Alexander. E. J. Brill. Leiden, New York, København, Köln.

Horsted, S. A. 2001. A Review of the Cod Fisheries at Greenland, 1910-1995. Journal of Northwest Atlantic Fisheries Science 28: 1-109.

Horsted, S. A. and Smidt, E. 1965. Remarks on effects of food animals on cod behavior. ICNAF Special Publication No. 6: 435-437.

Ivanova, I. V. 2000. About *Pandalus borealis* (Krøyer, 1848) nutrition on Flemish Cap. NAFO Scientific Council Report No. 65, serial No. N4307. 8 pp.

Isaksen, B., Valdemarsen, J.W. and Larsen, R.B. 1990. Reduction of fish bycatch in shrimp trawl using a solid separator grid in the aft belly. ICES C.M. 1990/B:47, 13 pp.

Jensen, Ad. S. 1925. On the fishery of the greenlanders. Meddelelser fra Kommissionen for Havundersøgelser. Serie: Fiskeri, Bind VII, Nr. 7. København. C.A. Reitzel, Boghandel. 39 pp.

Jensen, Ad. S. 1939. Concerning a change of climate during recent decades in the Arctic and subarctic regions, from Greenland in west to Eurasia in the east, and contemporary biological and geophysical changes. Det Kgl. Danske Videnskabernes Selskab. Biologiske Meddelelser XIV,8. København. Munksgaard. 75 pp. with 2 charts.

Jensen, D. 1992. Polar cod from the Davis Strait and Arctic Canada. Master thesis, University of Copenhagen 1992. 114 pp. (in Danish).

Jørgensen, O. A. 1997. Pelagic occurrence of Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum), in West Greenland waters. Journal Northwestern Atlantic Fisheries Science, 21: 39-50.

Jørgensen, O. A. 2000a. Assessment of the Greenland Halibut Stock Component in NAFO Subarea 0 + Div. 1A Offshore + Divisions 1B-1F. NAFO Scientific Council Report No. 38, serial No. N4267. 20 pp.

Jørgensen, O. A. 2000b. Survey for Greenland Halibut in NAFO Divisions 1C-1D, 1999. NAFO Scientific Council Report No. 10, serial No. N4232. 26 pp.

Kapel, F. 1979. Exploitation of large whales in West Greenland in the Twentieth Century. Report of the International Whaling Commission No. 29. (SC/30/Doc 23): 197-214.

Kapel, F. 1993. A note on the variations in the catch of seals and purchase of seal skins in Greenland, 1971-1992 *In* Document presented at joint ICES/NAFO Working Group on Harp and Hooded Seals, 1993. 7 pp.

Kapel, F.O. 2000. Feeding habits of harp and hooded seals in Greenland waters. NAMMCO Science Publication 2: 50-64.

Kingsley, M.C.S., Kanneworff, P. and Carlsson, D.M. 1999. By-catches of Fish in the West Greenland Shrimp Survey: an Initial Analysis. NAFO SCR Document no. 111, serial No. N4191, 7 pp

Kristensen, T.K. 1984. Biology of the squid *Gonatus fabricii* (Lichtenstein, 1818) from West Greenland waters. Meddelelser om Grønland, Bioscience, 13:1-17.

Köster, F.W. and Schober, W. 1990. Cod stomach sampling in West Greenland waters 1989 - Some preliminary results. NAFO Scientific Council Report no. 33, serial No. N1750. 13 pp.

Larsen, R.B., Kristjansson, J. and Marteinsson, J.E. 1993. Vertical size distribution of shrimps (*Pandalus borealis*) in the water column 0 to 8 m off the seabed. ICES Marine Science Symposium, 196: 207-210.

Livingston, P. A., and Tjelmeland, S. 2000. Fisheries in boreal ecosystems. ICES Journal of Marine Science, 57: 619–627.

Mosbech, A., Boertmann, D., Nymand, J., Riget, F., and Acquarone, M. 1998. The marine environment in Southwest Greenland. National Environmental Research Institute, Denmark. NERI Technical Report no. 236, 205 pp.

Nilssen, E. M., Larsen, R.B., and Hopkins, C.C.E. 1986. Catch and size-selection of *Pandalus borealis* in a bottom trawl and implications for population dynamics analyses. ICES CM 1986/K:4, 12 pp.

Orr, D. C. and Bowering, W. R. 1997. A multivariate analysis of food and feeding trends among Greenland halibut (*Reinhardtius hippoglossoides*) samples in Davis Strait, during 1986. ICES Journal of Marine Science, 54: 819-829.

Pauly, D., Trites, A. W., Capuli, E., and Christensen, V. 1998. Diet composition and trophic levels of marine mammals. ICES Journal of Marine Science, 55: 467-481.

Pauly, D., Palomares, L, 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

Pedersen, S. A., 1990. Redfish (*Sebastes* spp.) in Greenland waters/"Rødfisk (*Sebastes* spp.) ved Grønland". Rapport til Grønlands Hjemmestyre fra Grønlands Fiskeri-undersøgelser. 103 pp (in Danish).

Pedersen, S. A. 1994. Shrimp trawl catches and stomach contents of redfish, Greenland halibut and starry ray from West Greenland during a 24-hour cycle. Polar Research, 13: 183-196.

Pedersen, S. A. 1995. Feeding habits of starry ray (*Raja radiata*) in West Greenland waters. ICES Journal of Marine Science, 52: 43-54.

Pedersen, S. A. and Riget, F. 1991. Preliminary studies on feeding habits of demersal fish species in West Greenland waters with special emphasis on predation on shrimp. NAFO Scientific Council Report No. 47, serial No. N1930.

Pedersen, S.A. and Riget, F. 1993. Feeding habits of redfish (*Sebastes* spp.) and Greenland halibut (*Reinhardtius hippoglossoides*) in West Greenland waters. ICES Journal of Marine Science, 50: 445-459.

Pedersen, S.A. and Kanneworff, P. 1995. Fishes on the West Greenland shrimp grounds, 1988-1992. ICES Journal of Marine Science, 52: 165-182.

Pedersen, S.A. and Smidt, E.L.B. 2000. Zooplankton distribution and abundance in West Greenland waters,1950-1984. Journal of Northwestern Atlantic Fisheries Science, 26, 45-102.

Reid, P. C., Battle, E. J. V., Batten, S. D., and Brander, K. M. 2000. Impacts of fisheries on plankton community structure. ICES Journal of Marine Science, 57: 495–502.

Rätz, H.J. 1992. Decrease in the fish biomass of West Greenland (Subdivisions 1B-1F), continued. NAFO Scientific Council Report No. 40, serial No. N2088.

Rätz, H. J., 1999. Structures and changes of the demersal fish assemblage off Greenland, 1982-96. NAFO Science Council Studies, No. 32: 1-15.

Rätz, H.J., and Stransky, C. 1999. Assessment of Redfish *(Sebastes marinus, S. mentell*a) in NAFO Subarea 1 and ICES Div. XIVb Based on Survey Indices, 1982-98. NAFO Scientific Council Report No. 20, serial No. N4070. 22 pp.

Riget, F. and J. Boje 1989. Fishery and some biological aspects of Greenland halibut (*Reinhardtius hippoglossoides*) in West Greenland waters. NAFO Scientific Council Studies No. 13: 41-52.

Rodriguez-Marin, E., Punzón, A., Paz, J. and Olaso, I. 1994. Feeding of most abundant fish species in Flemish Cap in summer 1993. NAFO Scientific Council Report No. 35, serial No. N2403, 33 pp.

Rønnow, B. 1992. Analysis of the catch curves for *Pandalus borealis* in Disko Bay, West Greenland. NAFO Scientific Council Report No. 54, serial No. N2107.

Sakshaug, E. 1995. A synopsis of the biomass distribution and energetics of the pelagic ecosystem of the Barents Sea. ICES C.M. CM 1995/Mini:3. 11 pp.

Schnack, D., Köster, F. W., Rätz, H. -J., Wieland, K., Fürderer, H., Grünwald, E., Zarkeschwari, N. 1993. Wissenschaftliche Grundlagen für Ökosystem-orientiertes Fischereimanagement in Gewässern vor Grönland. Berichte aus dem Institut für Meereskunde an der Christian-Albrechts-Universität, Kiel, No. 234. 134 pp.

Shumway, S. E., Perkins, H. C., Shick, D.F. and Stickney, A.P. 1985. Synopsis of biological data on the pink shrimp, *Pandalus borealis* Krøyer, 1838. NOAA Technical Report NMFS 30 (FAO Fisheries Synopsis No. 144). 57 pp.

Siegstad, H. 1993. An estimate of shrimp discard from factory trawlers in Davis Strait 1992. NAFO Scientific Council Report No. 79, serial No. N2264, 8 pp.

Siegstad, H. 2000. Preliminary Assessment of Shrimp (*Pandalus borealis*) in Davis Strait, 2000 (Subareas 0+1). NAFO Scientific Council Report No. 84, serial No. N4341. 22 pp.

Siegstad; H. and Rätz, H. J. 2000. Stock Status Update of Other Finfish in NAFO Subarea 1 NAFO Scientific Council Report No. 27, serial No. N4256. 5 pp.

Siegstad; H., Rätz, H. J. and Stransky, C. 2000. Stock Status Update of Redfish in NAFO Subarea 1. NAFO Scientific Council Report No. 28, serial No. N4257. 7 pp.

Simonsen and Boje 2000. An Assessment of the Greenland Halibut Stock Component in NAFO Division 1A Inshore. NAFO Scientific Council Report No. 47, serial No. N4278. 36 pp.

Smidt, E. L. B. 1969. The Greenland Halibut *Reinhardtius hippoglossoides* (Walb.). Biology and exploitation in Greenland waters. Meddelelser fra Danmarks Fiskeri og Havundersøgelser N.S., (København). 6(4): 79-148.

Sparholt, H. and Vinther, M. 1991. The biomass of starry ray (*Raja radiata*) in the North Sea. ICES Journal of Marine Science, 47: 295-302.

Tiedtke, J. E. 1988. Qualitative und quantitative Untersuchungen des Mageninhaltes vom Kabeljau (*Gadus morhua* L.) aus westgrönlandischen Gewässern. Mitteilungen aus dem Institut für Seefischerei der Bundesforschungsanstalt für Fischerei, Hamburg. No. 43. 106 pp. (in German).

Torres, P., Rodriguez-Marin, E. and Loureiro, I. 2000. Preliminary Results From Feeding Analysis for the Most Abundant Demersal Fishes in Flemish Cap During Summer (1993-2000). NAFO SCR. Document No. 60, serial No. N4302. 9 pp.

Trites, A. W., and Pauly, D. 1998. Estimating mean body masses of marine mammals from maximum body lengths. Canadian Journal of Zoology, 76: 886-896.

Valdemarsen, J.W., Lehman, K., Riget, F. and Boje, J. 1993. Grid devices to select shrimp size in trawls. ICES C.M. 1993/B: 35.

Vikingsson, G. A. and Kapel, F. O. 2000. Introduction. *In* Minke whales, harp and hooded seals: Major predators in the North Atlantic Ecosystem, pp 5-8. Ed. by G. A. Vikingsson and F. O. Kapel. NAMMCO Science Publications, No. 2.

Yang, M. S. and Livingston, P. A. 1988. Food habits and daily ration of Greenland halibut, *Reinhardtius hippoglossoides*, in the eastern Bering Sea. Fishery Bulletin, 86(4):675-690.