THE CONSTRUCTION OF A MULTI-SPECIES MODEL FOR THE BARENTS SEA WITH SPECIAL REFERENCE TO THE COD-CAPELIN INTERACTIONS

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ABSTRACT

The predominant fish species in the ecosystem of the Barents Sea are: cod (Gadus morhua), capelin (Mallotus villosus), haddock (Melanogrammus aeglefinus) and redfish (Sebastes spp.). Both cod and capelin are known to migrate strongly, with both a seasonal cycle and a residual migration which is dependent on the ambient physical conditions. Cod is believed to be the main fish predator on capelin, and capelin is believed to be the main forage fish for cod. These two species were therefore a natural starting point for the building of a multispecies model of the Barents Sea.

The modelling of the time varying geographical overlap of the species is a key point to the model. This is achieved by partitioning the sea into eight regions and describing the migration by matrices giving the fraction of a given stock migrating from one area to another in the course of a month. Values of the matrices are estimated from the overall knowledge of fish migration and from survey data. In parallel with the modelling work, an extensive stomach sampling scheme is carried out onboard the research vessels during surveys in the area. A data base of stomach content is established and will be used to determine the preference matrices and the predation pressure.

The first runs of the capelin-cod model give promising results. Even in its preliminary stage the model appears to be a useful tool in evaluating migration dependent effects and important cod-capelin interactions. In the future we hope to be able to link the residual migrations to environmental parameters.

INTRODUCTION

The Barents Sea is the nursery and feeding area of a number of large fish stocks among which arctic cod, haddock, redfish, herring (*Clupea harengus*), capelin and polar cod (*Boreogadus saida*) are the most important from a commercial point of view (Table 1). In recent years a considerable fishery for deep sea shrimp (*Pandalus borealis*) has also developed (Table 1). Bergstad, Jørgensen and Dragesund (1985), Dragesund and Gjøsæter (1985) and Loeng (1985) have described the circulation patterns and the ecological features of the area, including distribution patterns, reproduction, recruitment, growth and stock size fluctuations of the most important species.

The fish stocks in the Barents Sea are presently assessed by single species models. Except for capelin for which a special model has been developed, traditional models are applied. Growth, natural mortality, maturity ogives and recruitment are input parameters estimated from long term means or recent observations. In the capelin model, maturity is a function of length, and growth in length of recruiting year classes is made dependent on year class strength. Also a stock-recruitment model has been incorporated for estimating sustainable yield. Natural mortality is, however, assumed constant.

The main weakness with these models is that although changes in important populations parameters can be taken into account when they are observed, they can not, or only partially, be explained or predicted by the model.

Taking for example the capelin model, changes in growth can to some extent be related to year class strength, and year class strength can to some extent be related to spawning stock. However, observed recruitments show rather large deviations from the established stock-recruitment curve.

Partly such deviations may originate from changes in the physical environment, but it is also possible that changes in for example stock size of other species in the system could explain some of the variance. It is the latter possibility which will be explored in a multispecies model.

Generally, multispecies models can potentially explain more of the variations observed in critical populations parameters as growth, natural mortality and recruitment.

Specifically, the multispecies model for the Barents Sea will be used for studying questions like the following: To what extent is recruitment and natural mortality of capelin dependent on the size and composition of the cod stock? Is there a relation between stock size of herring and recruitment to the capelin stock? To what extent is growth of cod dependent on the size and composition of the capelin, herring and shrimp stocks? Is the size of the shrimp stock partially determined by the size of the cod stock? What effects has predation from marine mammals on the commercially important fish stocks?

Table 1. Total catch (in 1000 tonnes) of the most important fish stocks which have the Barents Sea as a feeding and nursery area.

Year	Arctic cod *G. morhua*	Haddock *M. aeglefinus*	Herring *C. harengus*	Capelin *M. villosus*	Polar cod *B. saida*	Redfish *S. marinus* *S. mentella*	Deep sea shrimp *P. borealis*
1961	781	193	497	230		64	0
62	909	187	551	0	2	35	0
63	778	146	670	30	0.2	41	0
64	437	98	1117	20	3	66	0
65	444	118	1325	224	3	39	0
66	483	160	1723	389	3	34	0
67	572	136	1131	409	5	24	0
68	1073	181	273	537	5	18	0
69	1197	130	24	679	137	31	0
1970	993	87	20	1314	243	35	0
71	689	78	6	1393	346	58	0
72	565	266	0	1593	171	46	0
73	792	323	0	1336	82	59	5
74	1102	221	0	1149	123	96	5
75	829	176	0	1417	63	278	5
76	867	137	0	2545	12	317	8
77	905	110	0	2940	7	185	22
78	698	96	0	1894	0.9	124	36
79	440	104	0	1738	0.2	113	32
1980	380	88	0	1648	0.1	102	41
81	399	78	0	2006	0.1	101	38
82	364	47	0	1746	90	130	47

Since predation is strongly fish size or age dependent, the stocks going into the multispecies model should be broken down by age and size groups. Further, since large variations are observed in fish distribution between seasons, and also between years, and since the degree of overlap in geographical distribution of a predator and its prey is critical for quantifying the predation mortality, fish distribution and migration should be a part of the model.

CIRCULATION PATTERN, DISTRIBUTION AND MIGRATION

The hydrographic conditions of the sea are regulated by the meteorological conditions in the region and by the circulation patterns. These are shown in Fig. 1 where also the transition zone between warm and cold water masses, the Polar front, is indicated. Besides being of great significance for the environmental conditions for the fish, the current system also serves as a carrier of spawning products. The spawning grounds of most of the fish stocks in the Barents Sea are situated along the coasts of western and southern Norway and for some stocks extending eastward along the coast of USSR. After spawning the adult fish return to the feeding areas further north and east. Generally, spawning takes place in spring (February-May) and eggs, larvae and fingerlings are being transported north- and eastwards to the nursery areas during April-September. Once being transported into the Barents Sea as larvae the fish will remain there until it reaches maturity. It will, however, undertake seasonal migrations which are closely related to the seasonal variations in the environment and to the availability of prey organisms within the area. Fig. 2 shows the main distribution patterns and the migration routes for some stocks (Loeng 1985), yet it should be noted that large deviations from these patterns have been observed. In the continuation we will describe these features in more detail for the two stocks which are the most important commercial ones; arctic cod and capelin.

Arctic Cod

The distribution - and migration patterns of Arctic cod have been described and discussed by numerous authors. Bergstad *et al.* (1985) and Loeng (1985) have reviewed the information and given relevant references.

The mature fish, 65 cm or more in length and being 6-8 years or older, starts the spawning migration in November-December. Spawning occurs in March-April along the western and northern coast of Norway, Lofoten being the most significant spawning area. The spent fish return to the Barents Sea and Spitsbergen areas in May-June and mix with immatures during the summer feeding season in June-October.

Eggs and fry are transported north- and eastwards in the surface layers, 0-50 m in depth, during spring and summer. In October-November the 0-group, now being 6-10 cm in length, descend towards deeper waters and occur in numbers in bottom trawl hauls at the end of the year.

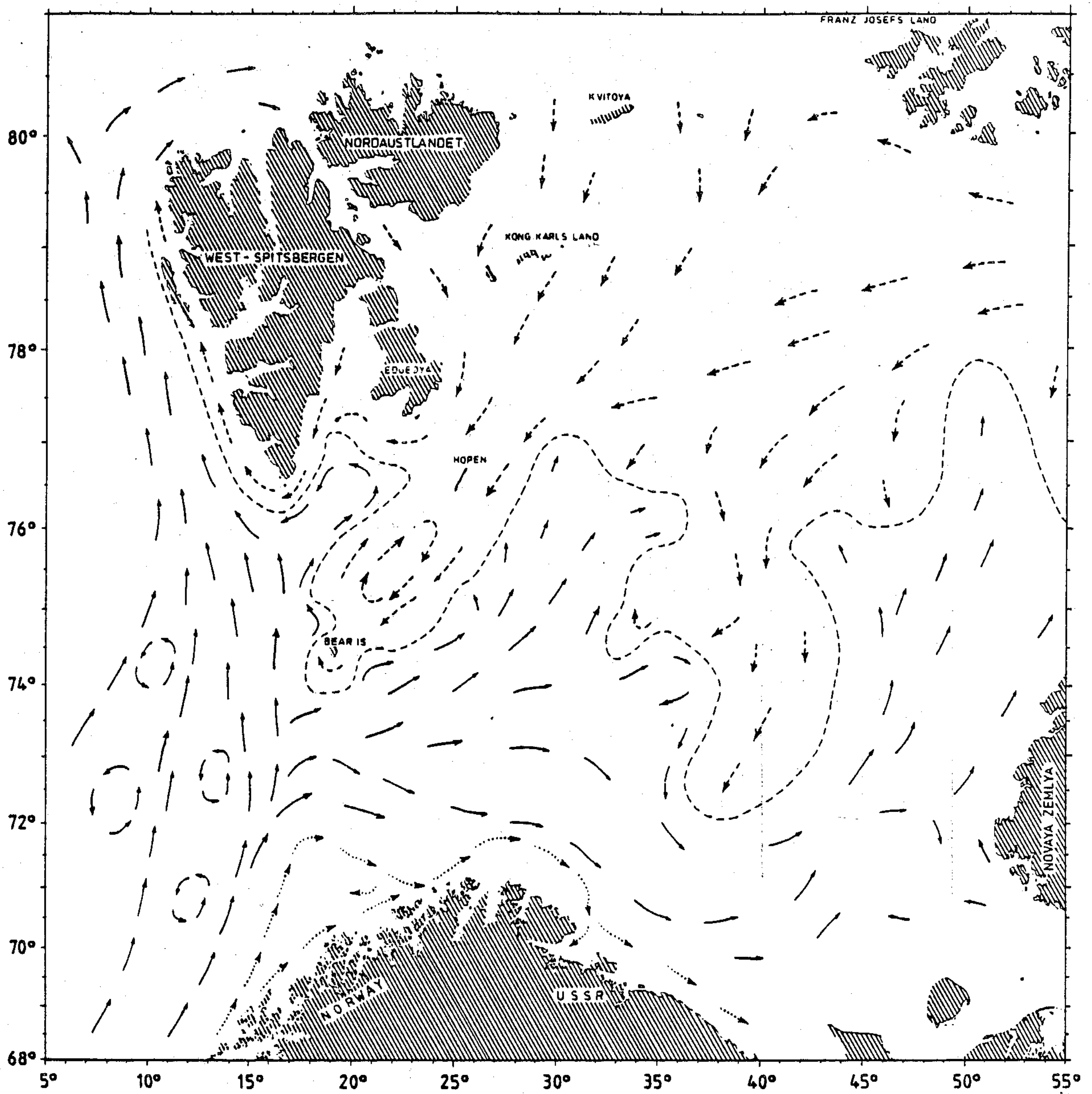


Fig. 1. Surface currents in the Barents Sea. —>: Atlantic Currents, •••>: Coastal currents, --->: Arctic currents. (After Loeng 1985).

During its first years of life (age 1 and 2) the fish do not undertake large seasonal movements. Unless large environmental changes take place the cod remains throughout the year in (or close to) the areas where it settled down as 0-group.

At an age of 3-4 years, being 30-45 cm in length, migration become pronounced and the movements of the fish are now closely related to the seasons. In January-March large amounts of these age-groups migrate west- and southwest wards in the Barents Sea feeding intensively on schools of capelin which approaches the coast for spawning. During March-May these concentrations reaches the coast of Finnmark where they appear in the so called "Finnmark spring fishery". An east- and northward migration takes place during May-September. Thus, the distribution area in the Barents Sea of these age groups shows regular seasonal displacements, reaching its south- and westernmost extension in March and north- and easternmost extension in September. In the Bear Island - Spitsbergen area there is a corresponding southward (winter) - northward (summer) migration and to a large extent a deep water (winter) - shallow water (summer) movement associated with the cooling and heating of the shallow areas of the Spitsbergen Bank.

When 5-6 years in age, being 50-65 cm long, the seasonal migrations of the fish are similar to the 3-4 year olds but the displacements are larger. The largest immature individuals participate in the spawning migration but stop before the spawning grounds are reached ("dummy runs").

On the basis of the description given above the following migration scheme have been adopted for a given yearclass of arctic cod (Fig. 3):

1. All age groups have their south- and westernmost distribution in March and their north- and easternmost distribution in September.

2. The seasonal displacements of the distribution areas increase gradually with age: The 1-year olds migrates little while the movements of the adults (7+) are quite large.

3. The geographical distributions in September are almost similar for all age groups while the March-distributions are quite different, the spawners now being farthest to the south and west while the 1-group is farthest north and east.

In order to fully understand and describe the migrations which a yearclass of cod will exert during its life time, two additional factors should be considered: The passive transportation of the 0-group during the first 6 months of the fish life and the migrations which are linked to the anomalies of the environmental conditions in the area. Variations in the transport of the larvae and 0-group may cause large variations in the locations of the settling down areas which are the starting areas of the migration scheme outlined above. Changes in the environmental conditions may lead to

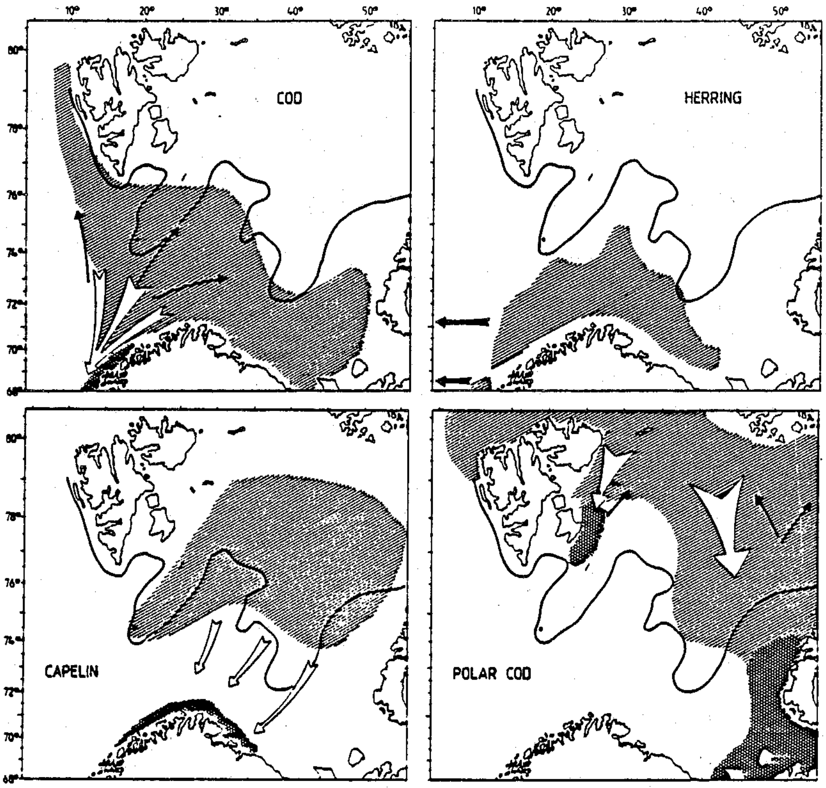


Fig. 2. Distribution of feeding cod, young herring, capelin and polar cod in the Barents Sea (hatched area) and their spawning areas (double hatched area). Open arrows indicate spawning migration, black arrows feeding migration, while the hatched arrows indicate the emigration of herring to the Norwegian Sea. The continuous line shows the approximate position of the Polar front (After Loeng 1985).

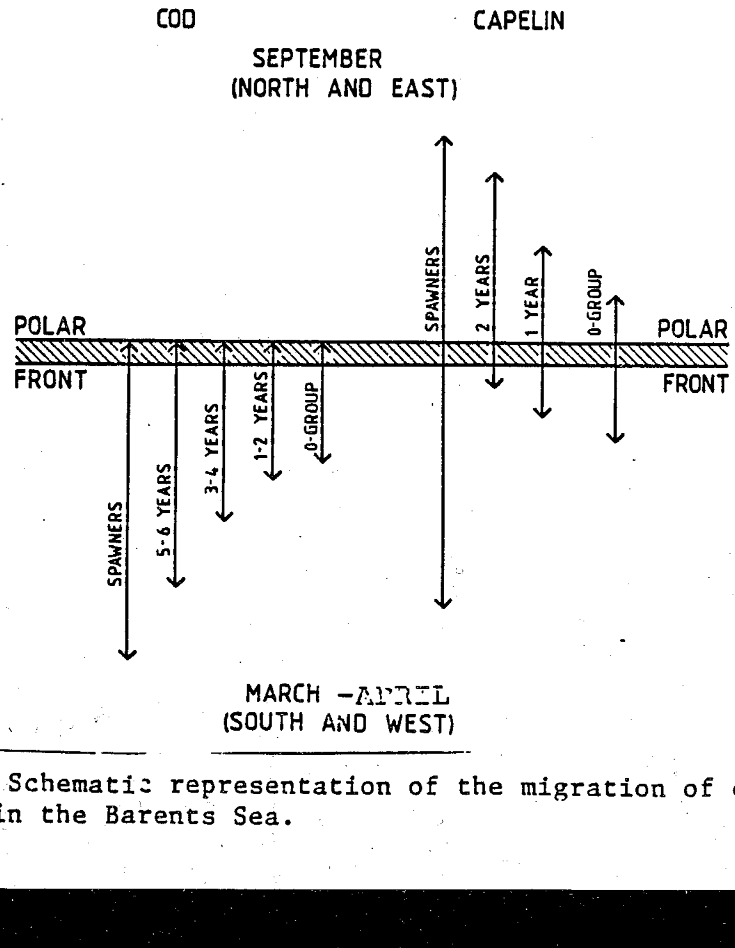


Fig. 3. Schematic representation of the migration of cod and capelin in the Barents Sea.

large displacements of the whole stock on a time scale which differs completely from the regular seasonal pattern.

Capelin

The distribution and migration patterns of capelin in the Barents Sea have been described and discussed by many authors. Dragesund and Gjøsæter (1985) and Loeng (1985) have reviewed the information and given relevant references.

The mature fish, 14 cm or more in length and 3-5 years old, spawn at the bottom off the coasts of northern Norway and USSR in March-May. Hatching occurs 40-60 days after spawning (depending on temperature). The larvae ascend towards the surface layers, 0-50 m and are spread over vast areas in the Barents Sea within a few months. Capelin suffer a mass mortality during the weeks after spawning and spent fish are seldomly observed outside the spawning grounds.

The main features of the geographical distribution differ from those described for cod (Fig. 2). The adult stock feeds in the northern parts of the sea during summer and autumn, in waters with temperatures between $-1^{o}C$ and $+2^{o}C$, while the younger fish, age groups 0 and 1, inhabits somewhat warmer waters in more central areas. In late autumn and winter, the fish being on spawning migration towards the coast, migrates across the areas inhabited by the immatures. Simultaneously there is a south- and westerly displacement of the immatures associated with the cooling of the watermasses. The extremes in the extension of the distribution areas of all age groups occur in April-May and September-October as for cod; maximum extensions to the north and east in September, and to the south and west in April-May. Fig. 3 shows a sketch of the general migration scheme adopted for capelin.

As for cod, this scheme will be modified by the drift of the larvae and by migrations which are linked to the anomalies in the environmental conditions. Large variations have been observed in the geographical distribution of the 0-group from one year to another, and large scale changes in water temperature seem to generate significant displacements of the distribution areas of the fish. In turn, such displacements also influence the migration routes of the spawners, as well as the location of the spawning grounds (Ozhigin and Luka 1984).

THE CONSTRUCTION OF A MULTISPECIES MODEL

During the period January-June the geographical distribution of capelin and cod have a considerable overlap, whereas during July-December there is little or no overlap of the two distributions. In order to be able to quantify the cod-capelin interaction the amount of capelin and cod being in the same area must be quantified. Thus, the time-varying overlap of the species is an important part of a multispecies model for the region. The overlap model must serve two purposes:

The actual overlap must be evaluated historically, in order to assess parameters like natural mortality (capelin) and consumption-growth relations (cod).

In using a multispecies model for prediction on a medium-range time basis (5-10 years) possible shifts in the annual overlap time function must be forecasted.

In order to build an overlap model, migration models for both species must then first be constructed. Then the overlap model is a consequence of the combined effect of the migration models.

Construction of Migration Models

In contrast to the ordinary fluid description of migration, leading to the integration of two (space) dimensional partial differential equations, we will divide the Barents Sea into a few areas and describe the migration by means of the proportions of fish in each area migrating to each of the other areas. The mathematical formulation is:

$$\frac{dN}{dt} = M\,N$$

where: N = a population vector, one element for each area.
M = a matrix describing the change of N due to migration in the coarse one time-step (month).

The Barents Sea is divided into 8 areas as shown in Fig. 4. The matrix M then becomes an 8 by 8 matrix. A migration matrix for northwards migrating immature capelin (July) is shown in Table 2.

The division is chosen so that the model can describe:

The increase in length and weight of capelin from east to west as measured in September.

The division of the capelin spawning migration into eastern and western parts clearly different with respect to age and length distribution.

The increase in age of cod from east to west as measured in January-March.

In addition, the spawning area of cod in Lofoten and southwards is included.

Estimation of the Migration Model

The data sources available for constructing migration models for the species capelin and cod are:

Capelin: Annual acoustic survey in September since 1973.

Annual acoustic survey in June-July 1973-1979.

Table 2. Migration matrixs for immature capelin (July).

		FROM AREA							
		1	2	3	4	5	6	7	8
	1								
	2								
	3								
TO AREA	4		0.4						
	5			0.4					
	6				0.2				
	7				0.2	0.2			
	8					0.2			

Biological sampling during the fishery January-April and August-December.

Cod: Barents Sea:

Annual acoustic surveys in January-March since 1978
Annual trawl surveys in February since 1981

Spitsbergen area:

Annual trawl survey in September since 1981

In addition to these surveys which cover the complete geographical distributions of the two stocks, information from a number of surveys covering parts of the stocks in various seasons have been utilized.

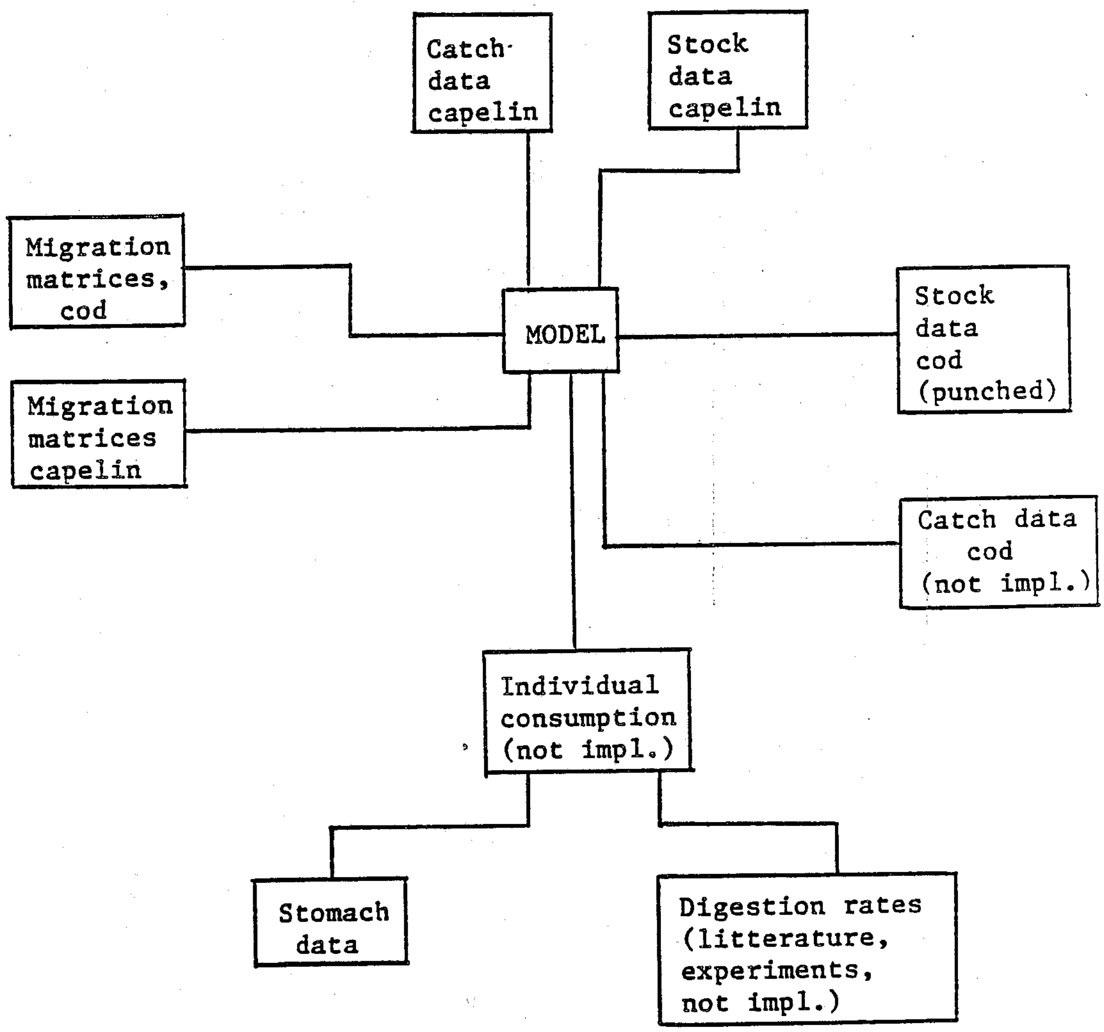
Direct updating of the migration models can only be made by the use of surveys that yield the complete geographical distributions of both stocks simultaneously. So far no such surveys have been carried out but considerable use can be made of other data sources. This can be illustrated by an example from the capelin migration dynamics:

In the autumn, the capelin is distributed over areas 4, 5, 6, 7 and 8. The age- and length distribution of the capelin is different in all these areas. During the course of the spawning migration the mature capelin ends up in the areas 2 and 3 in March. The model prediction of the age distribution is dependent on the initial observed age distribution in areas 4-8 as well as on the migration matrix elements.

The age distribution observed in March in areas 2 and 3 will generally differ widely. Some values of the migration matrix elements will make the model predict age distributions close to the observed age distribution, some will not.

Construction of the Data Base

In evaluating the matrix elements all kind of information must be used. This implies that there must be built an effective data base that preferably can be used interactively with the model. Also, facilities for inspecting and making trial changes to the data base must be furnished together with the actual model. The success of a complicated model is to a great extent dependent on the ease of its use. The figure below shows which data sources that are integrated with the model. The design philosophy is to use the basic data in the form they are and construct interfacing software to make them easily utilised by the model. With the exception of stomach data, only compressed data files close to the model are shown on the figure. Some of the data are not implemented yet.



THE STOMACH SAMPLING PROGRAM

One essential requirement for the multi-species model are estimates of the food consumption over the area of distribution of the stock of each age group of predatory species.
Food requirements can be estimated in two ways:

1. From information on the amount of food in stomachs and gastric evacuation rates.
2. From consideration of energy requirement.

The first approach is to be preferred, and the primary aim of the stomach sampling program is to provide detailed data on stomach content weights, composition and prey size preference for the different predator age groups per quarter. Stomach samples of cod, haddock and herring are collected during the program but here only preliminary results for cod are presented

Materials and Methods

The methods used for sampling, stomach analysis, data recording, computer input and presantation of data are mainly the same as for the North Sea "Stomach sampling project" (Anon. 1980 and 1981, Westgård 1982). Stomach samples are collected onboard Norwegian research vessels during routine surveys in the Barents Sea. The gear used is bottom trawl (shrimp trawl) and stomach samples are taken in connection with other biological sampling (otoliths etc.). The Barents Sea is divided into stratas, and one tries to get biological samples from each stratum during bottom trawl surveys. The trawl stations are randomly spread within each stratum and the sampling continues over 24 hours per day. For each station with biological sampling, up to ten stomachs for each of the lengthgroups 10-14, 15-19, 20-24, 25-29, 30-39, 40-49, 50-59, 60-69, 70-99 and > 100 cm are collected if possible. Stomachs of fish which have regurgitated are discarded from the samples. Each stomach is frozen separately, and data on each predators length, age, weight, sex and maturity stage is recorded together with station data for the total sample.

The stomach sampling started on a small schale in the 1. quarter of 1982 and continued on a full scale in 1984. Fig. 4 shows the geographical distribution of the samples from the 1. quarter of 1982 and 1984, and the text table below presents the number of fish sampled per length group during the same time period in the two years:

	10-14	15-19	20-24	25-29	30-39	40-49	50-59	60-69	70-99	Sum
1982			11	32	194	193	175	143	84	832
1984	90	86	52	102	221	155	183	124	74	1087

All together about 4000 cod stomachs were collected throughout 1984.

In the laboratory the plastic bags containing the stomachs are

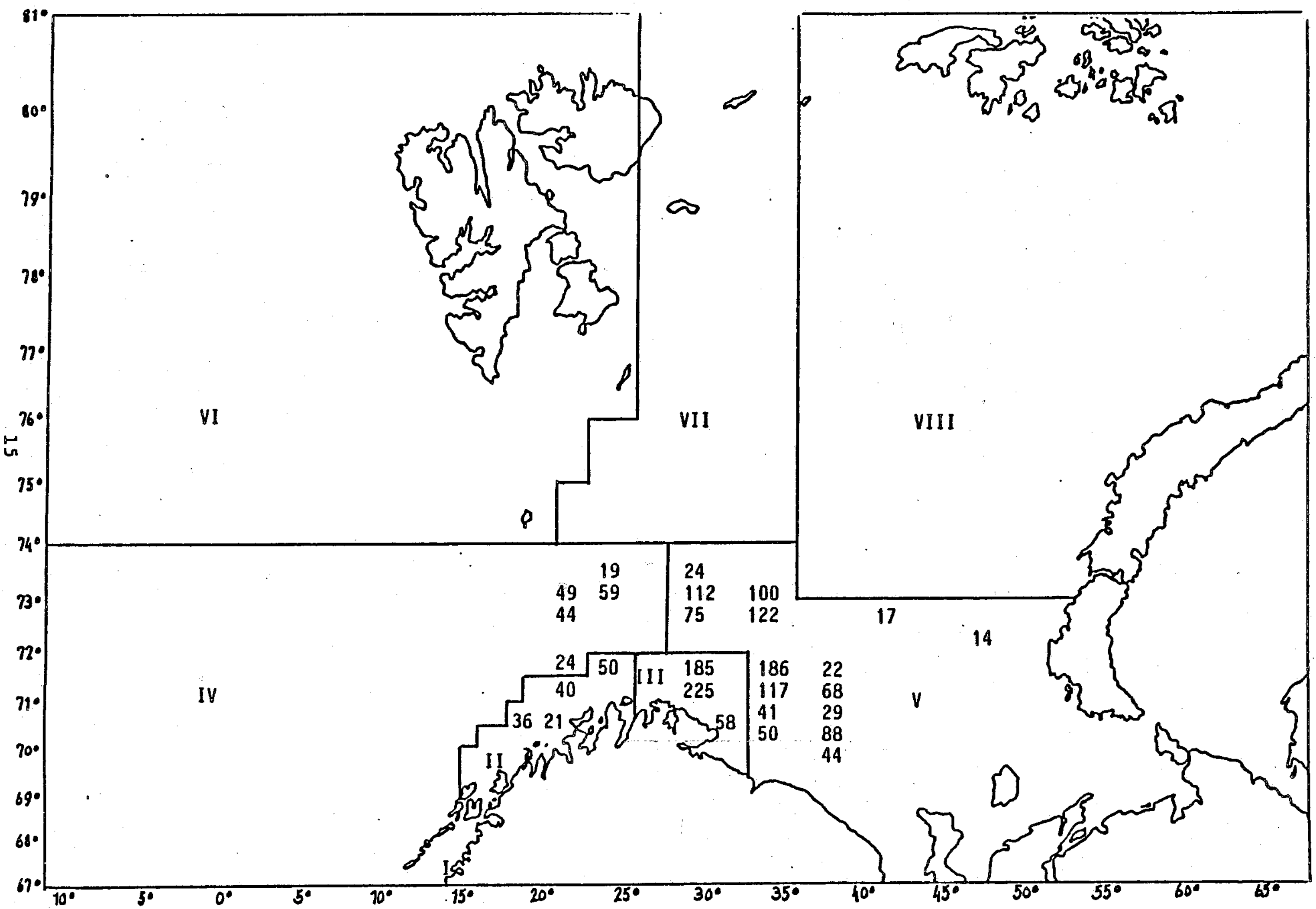


Fig. 4. The number of cod stomachs sampled in different areas of the Barents Sea during the 1. quarter of 1982 and 1984.

put in cold water, and the stomachs are opened as soon as practically possible. Fish prey and shrimps are identified to species level if possible, other prey is identifed to species level when practical (the main aim of the stomach sampling program is to estimate the consumption of different age groups of fish prey and deep sea shrimp by fish predators).

Each recognizable prey species, genus or family are split into size classes and damp dried on bibulos paper. Numbers and total wet weight, measured to the nearest milligram, are recorded for each size class. The station-, predator- and prey data are then input to the computer. Predator and prey are coded according to the adapted NODC system (Third edition, July 1981).

In order to obtain population estimates of food consumption some weighting is required to take account of spatial differences in abundance of the various predator size classes. For each predator, the number per hour fishing per trawl station is computed.

For aggregating the information over areas and time periods a computer program has been developed, which allows different approaches and different levels of detail in output (Westgård 1982).

Preliminary results and comments

Later in the modelling prosess it will be possible to present stomach contents data both for predator size classes and age groups, and fish prey can be divided in size classes or age groups. In this paper only size classes will be used.

Table 3 and 4 present the summary output of the stomach contents by predator size class and area for the most important prey categories in the 1. quarter of 1982 and 1984. No weighting factor has been applied.

Prey spectrum

The prey spectrum of cod is broad (Table 5), but only a few groups of organisms are important. Fish were the major prey both in 1982 and 1984, contributing about 80% by weight. The dominant fish prey was capelin in both years. Other important fish prey were polar cod in 1982 and redfish in 1984. Crustaceans were the dominating invertebrate group, and shrimp the most important species, contributing 15-20% by weight in both years.

Size related variation in the cod diet

The relative importance of the various prey categories varied with cod length. Fish were the major prey for cod >20 cm, and crustaceans for smaller cod. Among the fish prey, capelin was the dominant species for all length groups in 1982, contributing about 60% by weight. Polar cod made up about 20% of the diet of cod >50 cm.

Table 3. Stomach contents composition in weight percentage for Barents Sea cod in Q1 1982 by predator size class and area (III and V).

	20-29		30-39		40-49		50-59		60-69		70-99	
Prey category	III	V	III	V	III	V	III	V	III	V	III	V
Var.evertebrates	100	10.7	12.9	1.3	11.7	0.9	10.8	0.4	39.7	0.2	53.4	0.4
Shrimp	-	27.6	81.7	27.6	81.7	23.7	80.5	8.9	55.6	10.2	39.8	7.9
Var. fish	-	2.3	-	-	-	1.6	8.5	2.6	4.7	0.8	-	-
Capelin	-	53.4	-	53.2	6.4	62.6	-	67.0	-	66.5	6.8	62.3
Polar cod	-	2.8	-	17.0	-	11.1	-	21.0	-	22.3	-	29.4
Unidentified	-	3.1	-	0.8	-	-	0.3	-	-	-	-	-
G. pr stomach	0.2	2.7	2.8	12.1	3.1	27.1	5.1	68.7	6.9	168.7	16.3	211.1
% empty	0	14.3	18.7	5.8	27.5	3.5	14.6	3.5	19.6	3.6	15.4	2.9

Table 4. Stomach contents composition in weight percentage for Barents Sea cod in Q1 1984 by predator size class and area (II+IV, III and V).

	10-14			15-19			20-24			25-29			30-39		
Prey category	II	III	V	II	III	V	II	III	V	II	III	V	II	III	V
Var.evertebr.	100	70.7	43.7	100	100	1.6	-	-	1.4	0.9	0.3	0.4	0.3	1.2	2.6
Shrimp	-	29.3	20.8	-	-	32.9	64.1	18.2	12.8	38.9	40.1	31.7	6.5	13.5	28.4
Var.fish	-	-	4.7	-	-	30.7	3.2	-	8.6	14.8	-	15.4	5.4	3.2	5.1
Capelin	-	-	-	-	-	14.0	-	-	54.6	6.1	-	31.7	72.6	6.7	23.9
Polar cod	-	-	-	-	-	-	-	-	5.5	-	-	10.2	-	-	9.7
Cod	-	-	-	-	-	-	-	-	-	-	-	-	2.3	-	-
Haddock	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Redfish	-	-	-	-	-	5.6	32.8	81.8	3.2	38.7	59.6	10.0	12.9	75.4	30.1
Unidentified	-	-	30.7	-	-	15.3	-	-	14.0	0.6	-	0.5	-	-	0.2
G. pr stomach	0.02	0.1	0.1	0.0	0.04	0.5	3.8	1.1	2.1	2.1	4.0	3.3	11.2	5.4	5.4
% empty	0	40	15.5	50	66.7	18.5	0	0	18.7	0	25	9.5	3.3	14.5	17.4

	40-49			50-59			60-69			70-99		
Prey category	II	III	V	II	III	V	II	III	V	II	III	V
Var.evertebr.	0.4	0.5	7.0	-	0.7	3.4	1.0	2.5	7.9	0.1	5.9	4.4
Shrimp	5.0	25.2	44.3	6.5	27.8	39.9	9.4	26.4	44.9	5.3	29.6	21.2
Var.fish	2.1	3.6	9.4	3.9	4.4	15.8	3.5	2.2	18.1	1.7	4.4	0.4
Capelin	69.3	5.4	-	66.6	5.1	3.9	76.7	2.7	-	81.8	3.2	1.4
Polar cod	-	-	-	-	-	5.4	1.3	-	-	-	-	-
Cod	-	-	-	-	0.9	-	-	-	-	-	-	54.3
Haddock	-	6.4	6.9	-	9.4	10.4	-	2.0	13.0	-	3.9	3.1
Redfish	23.0	57.9	31.4	23.0	51.7	18.7	8.0	64.2	13.8	11.1	53.1	15.2
Unidentified	0.2	-	0.9	-	-	2.6	0.1	-	2.3	-	-	-
G. pr stomach	29.1	11.3	10.3	29.3	17.8	20.9	38.7	26.1	16.2	74.8	34.1	69.4
% empty	2.4	5.9	6.5	4.1	5.8	7.5	3.2	0	4.8	2.8	10	0

Table 5. The total number of prey categories found in the cod stomachs in Q1 1984.

Number of categories	Taxon	Weight grams per pred.	Weight %	Number per pred.	Number %	Weight grams per prey ind.
1	Porifera	0.00	0.0	0.00	0.0	0.01
2	Anthozoa	0.00	0.0	0.00	0.0	1.63
3	Polychaeta	0.00	0.0	0.00	0.1	1.15
4	Bivalvia	0.00	0.0	0.00	0.0	0.50
5	Cephalopoda	0.00	0.0	0.00	0.0	0.97
6	Rossia	0.02	0.1	0.00	0.0	21.10
7	Crustacea	0.00	0.0	0.01	0.1	0.12
8	Copepoda	0.00	0.0	0.01	0.2	0.01
9	Calanoida	0.00	0.0	0.00	0.0	0.00
10	Calanus finmarchicus	0.00	0.0	0.71	9.9	0.00
11	Cyclopoida	0.00	0.0	0.00	0.0	0.01
12	Malacostraca	0.01	0.1	0.04	0.5	0.23
13	Mysidae	0.00	0.0	0.00	0.0	0.06
14	Isopoda	0.01	0.1	0.01	0.1	2.22
15	Amphipoda	0.01	0.1	0.25	3.5	0.06
16	Hyperiidae	0.04	0.3	0.97	13.6	0.05
17	Euphausiidae	0.00	0.0	0.01	0.1	0.06
18	Meganyctiphanes norvegica	0.00	0.0	0.01	0.1	0.25
19	Thysanoessa	0.00	0.0	0.03	0.4	0.09
20	Sergestes arcticus	0.02	0.1	0.01	0.2	1.33
21	Caridea	0.07	0.5	0.07	1.0	1.05
22	Pandalus borealis	2.61	16.9	1.23	17.2	2.12
23	Pontophilus norvegicus	0.00	0.0	0.00	0.1	0.86
24	Paguridae	0.00	0.0	0.00	0.0	1.80
25	Pagurus bernhardus	0.00	0.0	0.00	0.0	1.55
26	Brachyura	0.00	0.0	0.01	0.1	0.33
27	Hyas coarctatus	0.02	0.1	0.00	0.0	6.03
28	Geryon tridens	0.08	0.5	0.01	0.1	10.77
29	Asteroidea	0.00	0.0	0.00	0.0	2.80
30	Ophiuroidea	0.00	0.0	0.00	0.0	0.17
31	Echinozoa	0.01	0.0	0.00	0.0	6.30
32	Holothuroidea	0.00	0.0	0.00	0.0	0.80
33	Ascidiacea	0.01	0.1	0.00	0.1	2.25
34	Teleostei	0.63	4.1	0.32	4.5	1.95
35	Mallotus villosus	6.71	43.5	0.96	13.5	6.97
36	Benthosema glaciale	0.00	0.0	0.00	0.0	2.40
37	Gadidae	0.08	0.5	0.01	0.1	13.62
38	Boreogadus saida	0.14	0.9	0.01	0.2	11.10
39	Gadus morhua	0.30	1.9	0.01	0.1	54.38
40	Melanogrammus aeglefinus	0.31	2.0	0.01	0.2	27.93
41	Trisopterus esmarkii	0.01	0.1	0.00	0.0	6.60
42	Lycodes vahlii	0.02	0.1	0.00	0.0	25.00
43	Sebastes	4.18	27.1	2.41	33.7	1.73
44	Anarhichas	0.00	0.0	0.00	0.0	1.10
45	Lumpenus lampretaeformis	0.01	0.1	0.00	0.0	9.40
46	Pleuronectidae	0.04	0.3	0.00	0.1	10.62
47	Hippoglossoides platessoides	0.00	0.0	0.00	0.0	1.90
48	Indeterminatus	0.06	0.4	0.00	0.0	66.90
	Sum	15.44				

In 1984 capelin contributed 40% on average for cod > 20 cm, and 1-group redfish 30% with a slight peak in the 20-50 cm range. Smaller haddock were eaten by cod >40 cm (5-10% by weight). Canibalism to any extent was only found for cod > 70 cm. For smaller cod, krill and shrimps were the dominating prey species, contributing 70-100% by weight. The percent of stomachs empty was higher for small than for large cod.

Area and year-to-year variations

For the 1. quarter of 1982 we have stomach samples from 2 of the areas, area III and V. All samples are of cod > 20 cm. In the smaller area III, shrimp was the major prey for all length groups, contributing 60% on average. Capelin contributed less than 5%. The average stomach weight was low, ranging from 0.2 g pr. stomach for the smallest cod (20-25 cm) to 16.3 g for the largest cod (70-79 cm). About 20% of the stomachs were empty.

In the larger area V, which cover most of the south-eastern Barents Sea, the picture was different. Capelin was the major prey for all length groups, contributing 50-70% by weight. Polar cod contributed 20% in the larger length groups. The average stomach contents weight ranged from 2.7 to 211.1g and only 5% of the stomachs were empty.

In the 1. quarter of 1984 samples were taken in area II, III, IV and V, and they also include length groups < 20 cm. Area II and IV are pooled because of low numbers of stomachs from those areas. The major prey there were invertebrates for small cod (<25 cm), and capelin for larger cod (>30 cm), contributing 75% by weight on average. For cod 20-30 cm, redfish made up about 30% of the stomach content. Average stomach weight ranged from 3.8 g (20-25 cm) to 74.8 g (70-79 cm), and on average 3.5% of the stomachs were empty.

In area III redfish were the dominating prey for all length groups > 20 cm, contributing 50-80% by weight. Shrimp made up 15-40% of the stomach content, and capelin less than 5%, as in 1982. Average stomach contents weight ranged from 1.1 to 34.1 g, and about 10% of the stomachs were empty.

In area V the diet was more mixed. Shrimp was the dominating prey species, contributing 2-40%, while fish were the major prey category for cod > 20 cm, contributing 50-75% by weight. The most important fish prey was redfish (20%), capelin (10%) and haddock (6%). Small cod were only eaten by the largest length group, and contributed 54% by weight in a sample of 8 stomachs. Average stomach contents weight ranged from 2.1 to 69.4 g, and 5-15% of the stomachs were empty. Fig. 5 summarises the area and year-to-year variations in the cod diet.

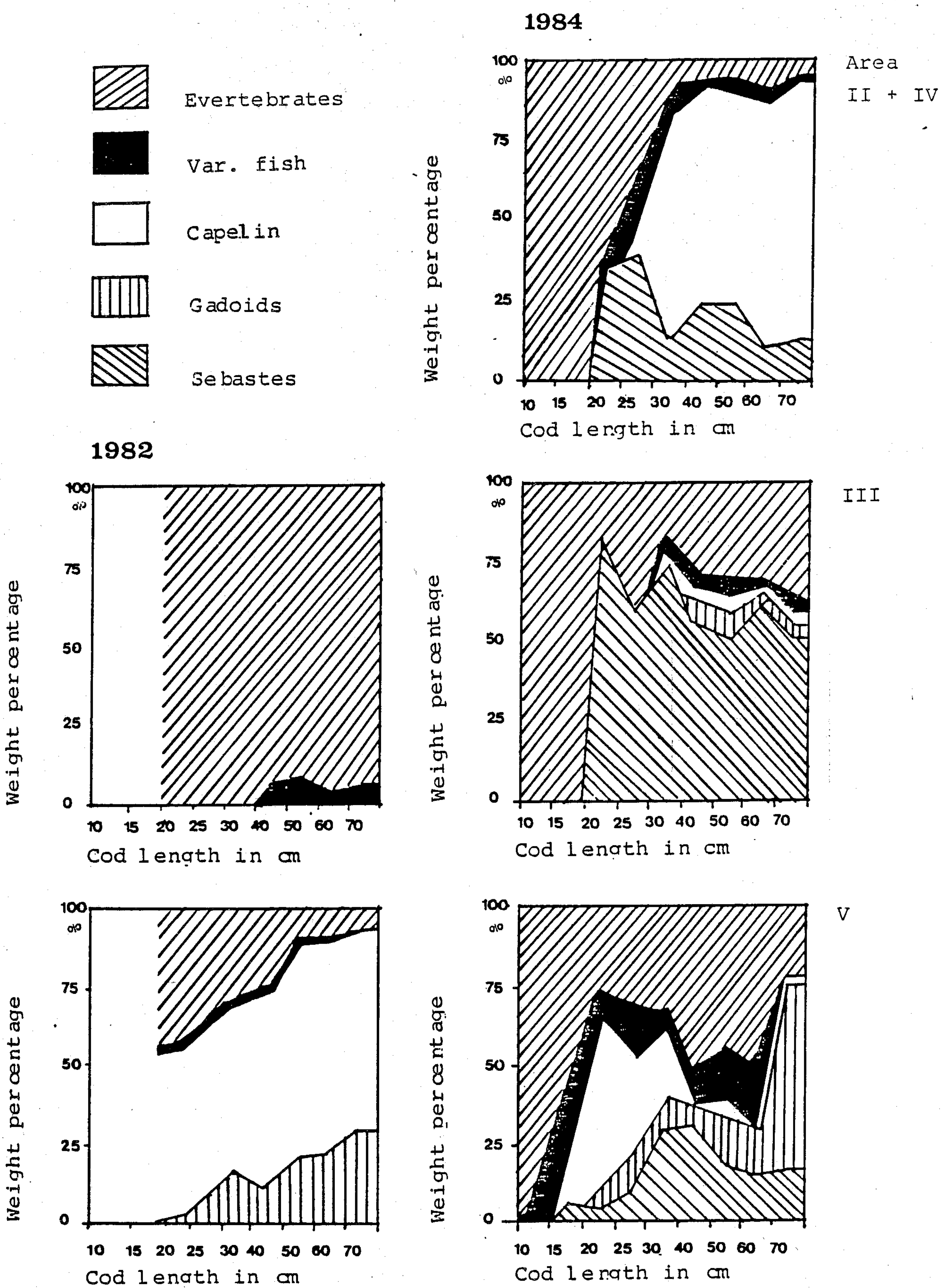


Fig. 5. The stomach contents composition in weight percentages for cod in different areas of the Barents Sea during the 1. quarter of 1982 and 1984, in relation to the length of the cod.

Comments

The diet of the Barents Sea cod shows large individual, area and year-to-year variations, as found by Brown and Cheng (1946), Ponomarenko and Yaragina (1978) and others. The general trend is that crustaceans (krill and shrimp) are the dominant food of smaller cod, and fish of the bigger ones. This general trend was also found in the North Sea (Daan 1973), in the Icelandic waters (Palsson 1981) and in the Northwest Atlantic (Minet and Perodou 1978, Langton and Bowman 1980).

For cod > 20-25 cm, the major prey in the total area during the 1. quarter of 1982 and 1984 was capelin. In areas with high percentage of capelin in the stomachs, the average stomach contents weights were the highest and the percentage of empty stomachs was low. The same was found by Lilly (1984).

The percentage of capelin in the cod stomachs was on average 20% lower in 1984 than in 1982, and the average weight of capelin in the stomachs dropped by about 75%. During the same time period the capelin stock decreased by about 50% (Anon. 1982 and 1984a). Ponomarenko and Yaragina (op. cit.) also found large year-to-year variations in the content of capelin in the cod stomachs, the content beeing highest when the year-classes of capelin were the strongest.

In the smaller area III, with important shrimp fishing grounds, shrimp dominated the diet totally in 1982 and contributed 60% by weight. In 1984 1-group redfish had taken over and made up more than 50% of the stomach content. The last year-classes of redfish is expected to be strong ones (Anon. 1983). From 1983 to 1984 the biomas of shrimp increased in this area (Hylen et. al. 1984), and one reason for this might be that cod switched from shrimp to redfish.

In area V, the stomach content of capelin dropped from 1982 to 1984 and the content of shrimp and redfish increased. But the average stomach contents weights were much lower in 1984, so there was only a partial replacement of capelin in the diet of cod, as found by Lilly (1984). The percentage of larger fish prey than capelin in the diet increased with increasing cod length. Polar cod was the most important prey species of this category in 1982, and was replaced by 1- and 2-group haddock and cod in 1984. Small cod was the major prey in the largest length group. The 1984 year-classes of both haddock and cod are strong (Anon. 1984b), and they are to a large degree distributed in area V. The amount of cannibalism is expected to depend on the availability of young cod and thus on year-class strength (Daan 1973).

In area II + IV, with important capelin spawning grounds, capelin was the major prey in 1984.

FURTHER WORK

To get estimates of the amount of food consumed by the cod stock in different time periods and areas of the Barents Sea, the stomach contents data must be combined with the rates of gastric evacuation for cod. Several authors report data for gastric evacuation or digestion times for cod (Karpevitch and Bokoff 1937, Tyler 1970, Daan 1973, Jones 1974, Bagge 1977, Holdal 1977, Braaten and Gokstad 1980 and Ursin et al. 1984). The gastric evacuation times range from 24 hours to 6 days, depending on fish size, prey species, prey size and temperature in the sea. Most of these experiments are done in other areas than the Barents Sea and with other prey species. Therefore there is a strong need for data on the Barents Sea cod's gastric evacuation rate for different cod lengths, temperatures and the most important prey species.

Until such data are available, an extract of the existing data on gastric evacuation rates for cod will be used in the model. A data file containing gastric evacuation rates for different cod lengths in different areas and time periods will be combined with the stomach contents data files to produce consumption files. The consumption data will be of the form: number of each prey category by length/age consumed per predator by age per day in the area of distribution.

From these data and data on the amount of predators and prey species estimated by the model in the area, the model then will produce preference parameters.

Stomach content data are presently collected from cod, haddock and herring, and all fish species and shrimps found in the stomachs are registered. However, only capelin and cod have so far been explicitly incorporated in the model (i.e. food from other species is treated as "other food", and the effect of predation on these species is not calculated by the model).

The work should be extended along two lines:

1. Species not presently included in the stomach sampling program, but which generates a significant predation mortality on the important commercial species, have to be taken account of in some way.

The most important ones among these are the marine mammals, especially the harp seals and minke whales. Some stomach content data from harp seals and minke whales exist, but the material is very limited. Further, the distribution of these species throughout the year is not known in sufficient detail to estimate the overlap with the various fish species at present.

2. Other important fish species like haddock, herring, polar cod and shrimps should be included in the model.

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