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Transparent multispecies analysis: an exploration of fisheries and survey data off the Norwegian coast and Barents Sea

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An integrated spreadsheet system was designed to combine biomass estimates for species including commercial fish species, mammals, and various other groups off the Norwegian coast and in the Barents Sea with catch data and feeding data in order to evaluate annual changes in the stocks. A time interval of two weeks was used in the simulation. No attempt was made to balance the spreadsheet; it was left transparent, with few assumptions and with results directly attributable to the data input. Eventually, the output can be used to track down important multispecies interactions and ecosystem functions. More importantly, however, the model highlights obvious gaps and deficiencies in our data and knowledge of the ecosystem, which will help to focus subsequent research.

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Introduction

There is no lack of models in fisheries science to study the population dynamics of exploited species, all of which need adequate data to give sensible results. However, it is often the case that data from commercial catches and scientific surveys suffer from both bias and imprecision (Byrne *et al.*, 1981; Nilssen *et al.*, 1986; Engås and Godø, 1989a, b). Such data inadequacy becomes easily masked when only one species is considered at a time, as though the species existed in a vacuum; additional insights from multispecies analysis would provide a check for internal consistency of data from interacting species. The educational qualities of an ecosystem approach in that respect are well exemplified by the work of Andersen and Ursin (1977).

The principal objections often raised against multispecies models is that they require inordinate amounts of data, that their internal structure is complicated, and that the results are difficult to comprehend (Gulland, 1979, 1982). There are only a few areas where there are sufficient data, and personnel, to apply elaborate multispecies assessment models such as multispecies virtual population analysis (Anon., 1989a, b). We present here a multispecies analysis of the Norwegian coast and Barents Sea ecosystem (NORFISK) that is easy to apply and has a transparent internal structure. The analysis is based on commercial spreadsheet software, and directly manipulates data tables through a minimum of simple equations, to provide the trophic relationships between the different species. The spreadsheet format ensures that all data and equations are readily accessible to the user.

We attempt to make optimum use of the available data and to restrict the necessary assumptions. The main objective at this stage concentrates on two questions: "Are the available data for the different species consistent and do these lead to a coherent picture of the community processes?", and "If not, where do the inconsistencies lie?"

Outline of NORFISK

General features

The aim of the NORFISK spreadsheet model is to simulate the changes in total biomass of species, or groups of species, off the Norwegian coast and in the Barents Sea over the course of a year. It is our expectation that over this period biomass growth will be approximately equal to biomass losses resulting from fishing, predation, and other natural mortality.

Therefore we assume that biomass will not change over the one year modelled. Biomass losses and gains are computed and recorded for each time step in the model but are not subtracted from, or added to, the biomass in each time step. The losses and gains in each time step are summed, and the total is compared with

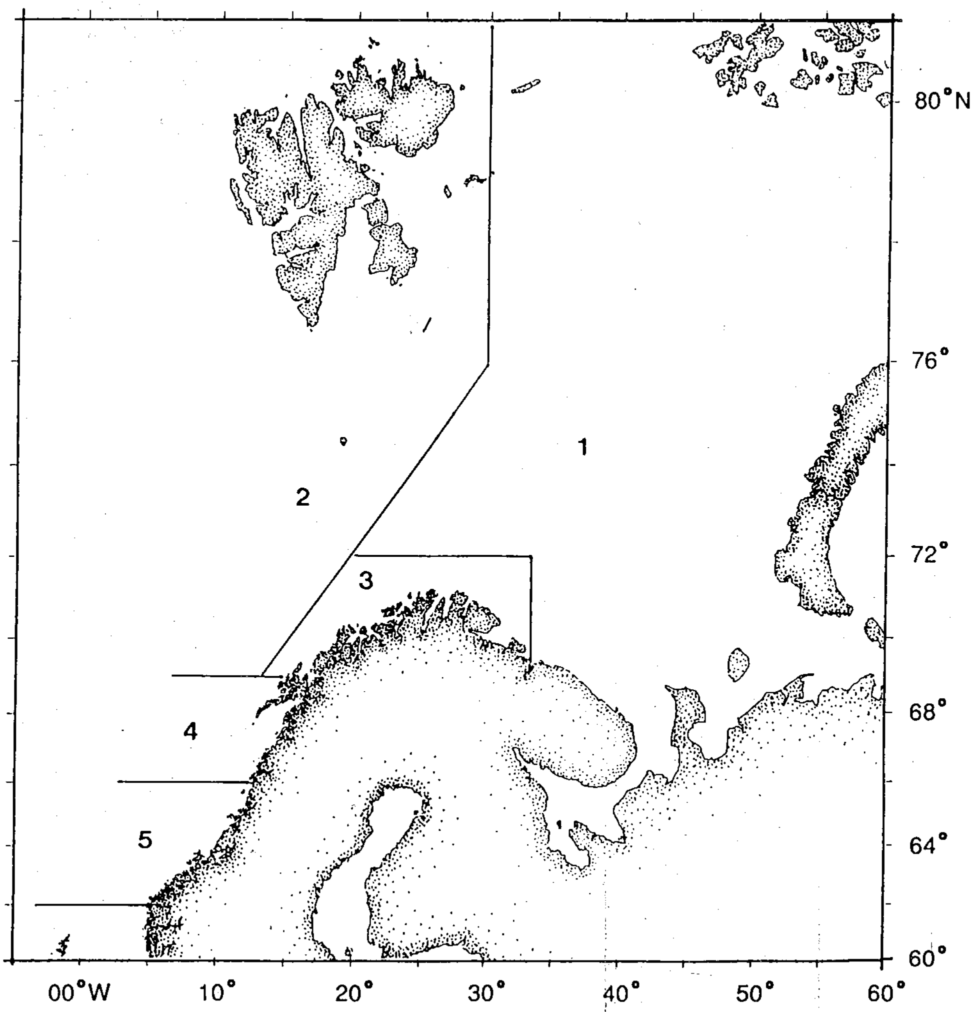

Figure 1. Areas used in the NORFISK spreadsheet of the Norwegian and Barents Seas.

the input (constant) biomass at the end of the simulation.

Species included

Capelin and herring are the major pelagic species, and cod and haddock the major demersal ones in the area of study. A total of nineteen groups are included in NORFISK. Nine species of fish (herring, capelin, blue whiting, polar cod, redfish, Greenland halibut, cod, haddock, and saithe) form individual groups, and three further groups consist of the flatfish, other predators, and other prey, respectively. Shrimp are included as one group, squids as another, seals as a third, and whales as a fourth. The last two groups are zooplankton and benthos. No data were included for birds.

Spatial resolution

The region considered has been split into five contiguous areas around the Norwegian coast extending from 62°N along the western and northern coasts of Norway, including the Barents Sea (Fig. 1). The study area is 1 500 000 km^2.

Temporal resolution

For the present purpose data have been compiled for a single year running from May 1984 to April 1985. This represents a time when both capelin and herring were abundant, and when the cod stock in the Barents Sea was growing. The model has a two-week time step.

Migration

Many of the species considered are highly migratory, and are present in different quantities in each area in different seasons. This greatly affects the predation pressure that they exert in the different areas. The proportions of the stocks in each area by two-week period are not known quantitatively. However, the start- and end-points of the annual migration periods are known. On the basis of data from surveys and commercial catches, the relative distribution of the biomass during the spawning and feeding season was estimated. Using these pieces of information, the biomass by two-week period was redistributed by linear interpolation. Finally, point estimates of the total biomass present in the system at the beginning of the year are available from routine fish stock assessment.

The migrations of herring, capelin, cod, haddock, saithe, seals, and whales are modelled in NORFISK. For other species there are insufficient data available on the seasonal distribution to model their migration. Whales are treated differently, because they are considered not to be inside the model area for the whole year. They are present only from May to August (unpubl. data, Institute Marine Research, Bergen).

Input data

Catch data for fishing areas off the Norwegian coast are available at different levels of spatial and temporal resolution. Domestic catches are provided for Norwegian and ICES statistical areas by month. Foreign catches are only available as annual totals by ICES area. The correspondence between Norwegian, ICES, and model areas is as follows:

Model area	ICES area	Norwegian area
1	I	1, 2, 10, 11, 13–19, 24
2	IIb	12, 20–23
3		3, 4, half of 5
4	IIa	0, half of 5
5		6, 7

The following assumptions were made to apportion the catches into two-week periods. It was assumed that Norwegian monthly catches were spread evenly over the entire month. Foreign catches, which were reported as an annual total, were split by assuming that foreign catches of cod, haddock, saithe, redfish, and Greenland halibut had the same distribution over time as Norwegian trawl catches. The catch of shrimp was considered equally distributed from March to December, while catches of flatfish were considered equally distributed over the whole year. In the case of herring, 60% of the catch was assumed to be taken from January to April, and 40% from August to November. International capelin catches were assumed to follow the same distribution as Norwegian capelin catches. Catches of polar cod were considered equally distributed from June to December. There was no foreign catch of blue whiting.

Biomass estimates of the commercial fish stocks, seals, and whales at the beginning of 1985 by Norwegian statistical area were taken, or interpolated, from published and unpublished data reports. Biomass estimates of non-commercial species represent the best guesses of the authors, based on survey experience, and published data from other areas.

Further data were required for species whose migration is modelled. These data, taken from survey reports of the Institute of Marine Research, were the distribution of the biomass during spawning and/or the most southerly distribution of the species, and the time that the southerly spawning migration began, peaked, and ended. The January biomasses provide the northernmost distribution of biomass.

Whales are modelled as being inside the area only from May to August, and thus they exert no predation pressure during eight months of the year.

Diet composition data were taken from published stomach content analyses (Mehl, 1986; Burgos and Mehl, 1987), from unpublished records (including those of PINRO, Murmansk), and from published reports for other areas. Two separate sets were prepared for the period January to April, and the rest of the year on the basis of stomach collections in 1984 and 1985. Diet composition data were specific to each area in the model. Diets for some species were derived from the literature or even from comparison of similar species.

Several biomass parameters are needed to initiate the model. One important parameter is that determining food requirements. These are divided into the food required for maintenance and food required for growth. Equations estimating these parameters as a function of body weight (W) and temperature were fitted to values reported in the literature (Sunnanå, unpubl. manus.). An approximate value for maintenance ration (MR) at 5°C for individual fish is:

$$MR = 2.0 \times W^{0.67}$$

This formula was applied to the average weight-at-age composition of the population to arrive at a maintenance ration for the biomass of the population per unit biomass per two-week period.

A different equation was used for marine mammals:

$$MR = 1.5 \times W^{0.75}$$

Food requirements for growth were calculated from realized growth rate. The following formula for individual growth in weight (W) has been applied:

$$W = a \times t_b$$

$$dW/dt = b/t \times W$$

where t is age and a and b are parameters.

These equations have been fitted to weight-at-age for the population and the resulting values averaged over all

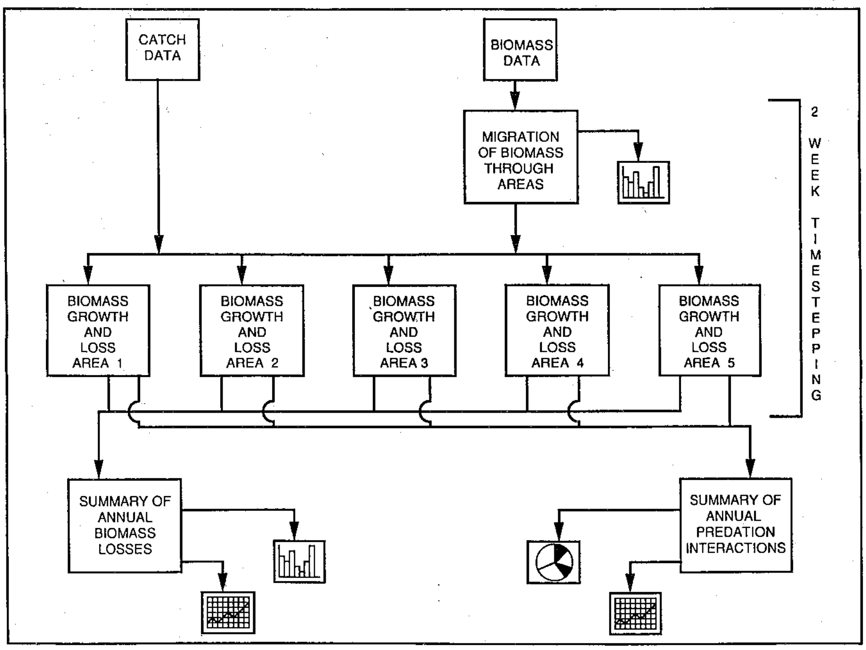

Figure 2. Schematic of the NORFISK spreadsheet showing data inputs, processing, and outputs.

ages in the population to estimate relative maximum growth in biomass per time unit.

The food requirement for growth was set at 1.7 times biomass growth. This value, together with the food requirements for maintenance, produces daily food requirements in accord with published values.

A last parameter is the non-predation natural mortality. Since all major species, including mammals, are included in the model this value represents largely disease, senescent mortalities, and emigration from the entire region. It has been set at the nominal value of 0.001 for each two-week period.

Spreadsheet overview

There are three stages in the analysis (Fig. 2). First, catch data and biomass data are prepared for each area by two-week interval. In the second stage, these catch and biomass data are added to the main spreadsheet by area, which computes food requirements, food composition, mortalities, and change in biomass over each two-week period (Table 1). Finally, the results from the five areas are combined to provide an overall picture of biomass flows, and the overall change in biomass over the year for each ecological entity.

Calculations are performed for each two-week period independently. First, the food requirements of each species in each area are calculated and the biomass removed by each predator is computed using the food composition tables. Then on the basis of the growth parameters, the catch data, and the losses due to predation, the change in biomass is obtained for each species in each two-week period. Any gains or losses to the biomass in one period are not transferred to the subsequent period. Thus biomass gains and losses for each period are computed from constant (input) biomass values, subject only to migration within the total modelled area.

Apart from these major computations, additional tables are produced to show the amount of each species consumed by each species during the summer and winter season, and over the entire year (Table 2). Summary statistics show for each species the mean biomass, the food intake, the biomass production, and the losses to mammals, birds, fish, non-predation mortality, and fishing, all over the entire year (Table 3). Finally, ratios of biomass production to intake, and the ratio of biomass loss to intake are calculated.

Results

For most species, the simulated annual percentage change in biomass is within the likely order of magnitude (Fig. 3). However, several groups stand out as having implausible losses in total biomass over the course of one year. Shrimps and "other prey" disappear and also polar cod and redfish show very large losses. On the other hand zooplankton exhibits an increase of 300%. Evidently, some important inputs for these groups are incorrect. In Figure 4 the causes of the biomass loss are shown, again for the five areas combined. In the case of shrimp and other prey, the major loss is due to fish, whereas polar cod and redfish suffer major predation by mammals. Figure 5 delineates the loss in shrimp further

Table 1. Example of input data for main spreadsheet of Area 1 (habitat not currently used).

	Herring	Capelin	Blue whiting	Polar cod
Biweekly growth	0.0162	0.0403	0.019	0.02
Biweekly M1	0.001	0.001	0.001	0.001
Annual catch	820	491 538	0	5227
Habitat (0 = S; 1 = B)	0	0	0	0
DFR maintenance	0.6	0.8	0.9	0.9
Ration food growth	1.7	1.7	1.7	1.7

Diet composition January to April 1985

		Species as prey			
		Herring	Capelin	Blue whiting	Polar cod
	Herring	0.0	0.0	0.0	0.0
	Capelin	0.0	0.0	0.0	0.0
P	Blue whiting	0.0	0.0	0.0	0.0
R	Polar cod	0.0	0.0	0.0	0.0
E	Redfish	0.0	0.0	0.0	0.0
D	G. halibut	0.0	0.0	0.0	0.0
A	Cod	13.4	71.7	0.0	0.0
T	Haddock	0.0	47.0	0.0	0.0
O	Saithe	0.0	0.0	0.0	0.0
R	Flatfish	0.0	0.0	0.0	0.0
S	Shrimps	0.0	0.0	0.0	0.0
	Other predators	0.0	0.0	0.0	0.0
	Other prey	0.0	0.0	0.0	0.0
	Squids	0.0	0.0	0.0	0.0
	Seals	10.0	20.0	0.0	20.0
	Whales	10.0	20.0	0.0	7.0
	Birds	0.0	0.0	0.0	0.0
	Benthos	0.0	0.0	0.0	0.0
	Zooplankton	0.0	0.0	0.0	0.0

Table 2. Example of total predation by species for the combined areas over one year.

		Species as prey			
		Herring	Capelin	Blue whiting	Polar cod
	Herring	0	0	0	0
	Capelin	0	0	0	0
P	Blue whiting	0	0	0	0
R	Polar cod	0	0	0	0
E	Redfish	0	0	0	0
D	G. halibut	0	0	0	0
A	Cod	409	1044	5	0
T	Haddock	166	118	0	0
O	Saithe	96	0	0	0
R	Flatfish	0	0	0	0
S	Shrimps	0	0	0	0
	Other predators	0	0	0	0
	Other prey	0	0	0	0
	Squids	85	0	0	0
	Seals	256	509	0	509
	Whales	1816	1374	0	481
	Birds	0	0	0	0
	Benthos	0	0	0	0
	Zooplankton	0	0	0	0
	Total loss	2827	3045	5	990

Table 3. Example of summary statistics for the combined areas over one year.

	Herring	Capelin	Blue whiting	Polar cod
Biomass	2370	2257	120	122
Intake	6974	10878	495	521
% Body weight/day	0.8	1.3	1.1	1.2
Growth	1356	3994	75	84
Losses				
Mammals	2072	1883	0	990
Birds	0	0	0	0
Fish	671	1162	5	0
Other	85	0	0	0
Fishing	59	1498	1	6
Total	2886	4543	6	996
Loss/biomass	1.2	2.0	0.0	8.1
Loss/intake	0.4	0.4	0.0	1.9
Growth/intake	0.2	0.4	0.2	0.2

as being attributable to cod, and the loss in "other prey" to cod, saithe, and other predators.

Discussion

The NORFISK model is only a crude representation of the system in the area studied. Many input data are not specific to the area, and temperature effects have not been included. However, the model does suggest the major biomass flows within the area, and, as importantly, indicates where the available data are implausible. The advantage of the model is its simplicity (or transparency), which enables initial evaluations and recommendations to be made from data which often fit the modelled biomass dynamics poorly.

It is apparent from the results that the role of both shrimp and other prey in the diet of fish in this region requires better data, or that the abundance and growth dynamics of these species are poorly understood. Observations on the biomass dynamics of Balsfjorden (Bax and Eliassen, 1990) and the German Wattenmeer (Bax and Weber, unpublished data) have indicated that survey data frequently fail to account for a sufficient abundance of shrimp to satisfy the estimated predation pressure.

The "other prey" category is always difficult to estimate, being composed of a diverse assortment of species, most of them of no commercial value. The biomass of these poorly sampled species necessary to satisfy the feeding requirements of the predator species may provide a more precise estimate than traditional survey techniques.

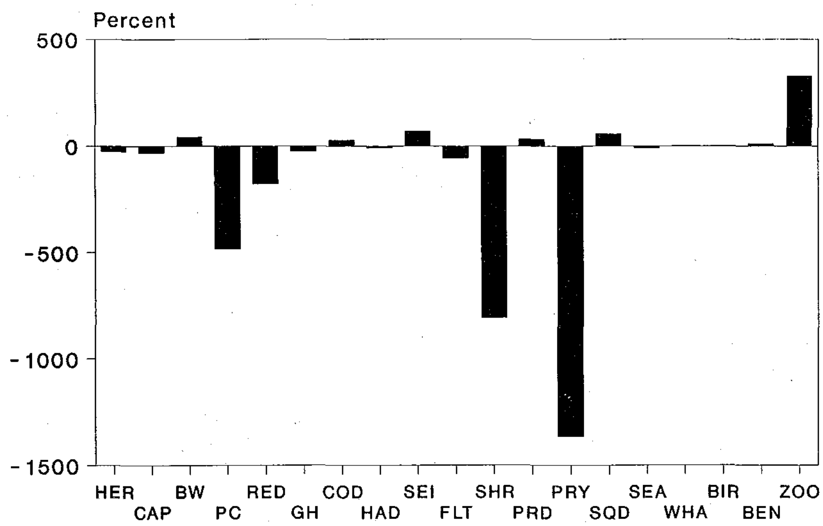

Figure 3. Annual percentage change in biomass, by species, for all areas combined from May 1984 to April 1985.

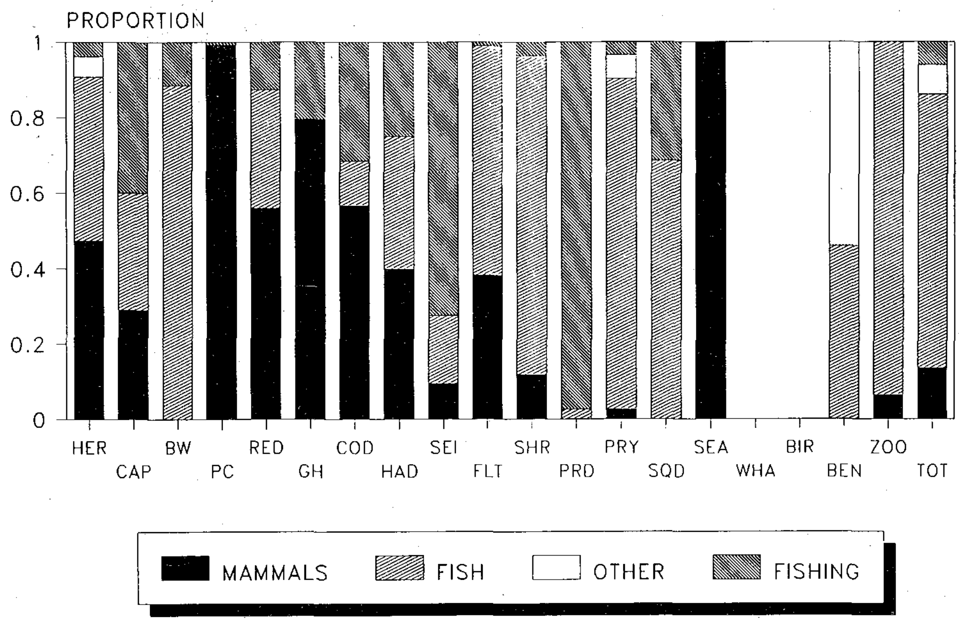

Figure 4. Proportion of the total biomass lost from May 1984 to April 1985 to mammals, fish, other species, and fishing.

The large proportion of biomass loss of polar cod and redfish going to marine mammals (Fig. 4), which of necessity occurs only in areas 1 and 2, again indicates an imbalance in the data. Either the biomasses of polar cod and redfish are underestimated, or the predation by marine mammals is overestimated. The latter could arise through incorrect estimates of the biomass of marine mammals, incorrect assessment of their migration patterns, incorrect food composition data, or through inflated estimates of their food requirements.

It is still premature to lend much credence to the results derived from this analysis; however, some general observations can be made. Disposition of biomass from the combined species is given in the final column of Figure 4. Most of the biomass in the system appears to end up as food for fish, followed by mammals, other

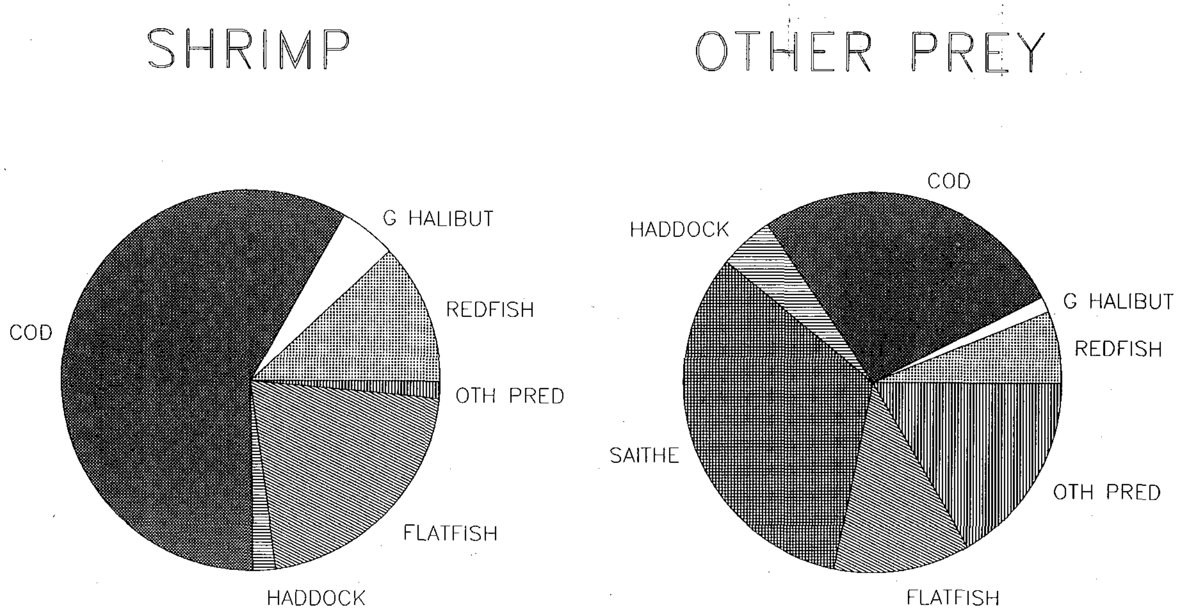

Figure 5. Disposition of shrimp and other prey biomass lost to fish predators. All time periods and areas combined (cf. Figure 4 for total fractions lost to fish predators).

species (squids, shrimp, benthos), and lastly fishing. The percentages obtained are 64, 24, 7, and 5 respectively. This result is due largely to the zooplankton, benthos, and squid groups.

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