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INTERACTIONS BETWEEN COD (Gadus morhua) AND DEEP SEA SHRIMP (Pandalus borealis) IN THE BARENTS SEA

by

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ABSTRACT

For some of the most important deep sea shrimp (Pandalus borealis) areas in the Barents Sea the content of shrimp in cod (Gadus morhua) stomachs during the first part of each year in the period 1984-1990 is analysed. Total weight, frequency of occurence and length distribution of shrimp in the cod stomachs as well as possible switching between shrimp and capelin (Mallotus villosus) is studied. The results are compared with shrimp stock parameters (biomass and number indices and length distribution) in the same period and areas. At the end of 1986 the capelin stock was seriously depleted and the shrimp stock indices decreased by almost 70% from 1984 to 1986. No sign of switching from capelin to shrimp was found, and the average stomach content of shrimp decreased by up to 50% in the same period. From 1986 to 1987 the shrimp stock indices increased by 50% and there was a marked increase in the stomach content of shrimp. The length distributions of shrimp in trawl samples and in cod stomachs had a relatively similar shape in the period, with the top point in the trawl sample distribution at a slightly larger length.

INTRODUCTION

After 1970 there was a large expansion in the fishery for deep sea shrimp (Pandalus borealis) in the Northeast Arctic, and the fishery became economically very important. The catches increased almost every year from about 9.000 tonnes in 1975 to more than 120.000 tonnes in 1984 and 1985. However in 1986 the catches dropped to about the half and has been on that level since (Anon. 1984, 1991a).

Since 1982 the Barents Sea and Svalbard region has been covered annually by a stratified trawl survey for shrimps. The results of the investigations in the Barents Sea indicate that the stock was at it's highest level in 1984. In 1986 the stock was reduced to about 31 % of the 1984-level, and in 1990 it had increased to 47 % of the highest level (Hylen and Ågotnes 1990; Anon. 1991a).

Cod (Gadus morhua) is an important predator on shrimp in the Barents Sea (Bax et al. 1989, Mehl 1989). From 1983 to 1986 the Northeast Arctic cod stock (3+) increased by almost 100 % from about 750.000 tonnes to 1.5 million tonnes and then started to decrease and was at the 1986-level in 1988 (Anon. 1991a, 1991b). Capelin (Mallotus villosus) is one of the main prey items for cod in the Barents Sea (Ponomarenko and Ponomarenko 1975; Mehl 1989). The stock started to decrease from 1984 and was seriously depleted the autumn 1986 and stayed at a very low level the 2-3 following years (Anon. 1987, 1991a).

In this paper we have looked at cod stomachs sampled in 1984-1990 and tried to find any relation between the content of shrimp (and capelin) in the period and the development of the shrimp-, cod- and capelin stocks.

MATERIALS AND METHODS

The stomach content data used in the analysis have been collected during a stomach sampling program in connection with the construction of a multispecies model for the Barents Sea (Mehl 1986, 1989). The data are retrieved from the joint Soviet-Norwegian stomach content data base (Mehl and Yaragina 1991) and are aggregated by predator size group, season, area (Fig. 1) and year. Three sizegroups are used (30-39 cm, 40-49 cm and 50-59 cm), and the season is February - May. Table 1 presents the number of stomachs by predator sizegroup and year. Total wet weight of the stomach content and of shrimp and capelin, frequency of occurence (f.o.o.) of shrimp and the length distribution of shrimp in the stomachs are used in the further analysis.

The shrimp stock data have been collected during the annual stratified trawl survey for shrimps in April - May. A "Campelen Super" 1800 meshes shrimp trawl was used as survey gear. The mesh size decrease from 80mm in the front part to 35mm in the cod end, lined inside with a net of 4m in length and 8mm mesh size. Trawling distance was 3.0 nautical miles at a speed of 3 knots. As an average, the horisontal opening of the trawl was measured to 11.7m during towing (Teigsmark and Øynes 1982) and the headline was between 4 and 5m above the bottom. The method used to calculate the abundance indices is based on stratified swept-area considerations described in Dalen et al. (1983) using 11.7m as the sweeping-width of the trawl. This method differs little from the method normally used when shrimp abundance estimates are made (Teigsmark and Øynes 1981) and the results are comparable.

Fig. 1 shows the strata used in the estimates. For each stratum a swept-area estimat in numbers and biomass is calculated, as well as weigthed mean carapace-length distribution. In the presentation data from all strata are combined in the same large area as are used in the aggregation of stomach data (Fig. 1). To compare the length of shrimp in the stock and the stomachs, the carapace-length is multiplied by 5.3 to give total shrimp length (Rasmussen 1953).

Further analysis was done using linear models with f.o.o and average weight of shrimp in the cod stomachs as variables. Predator sizegroup was used as covariate.

RESULTS

Figures 2-4 presents the cod's stomach content (total weight, weight of capelin and shrimp and f.o.o. of shrimp) by predator size group and year. For all size groups the total stomach content weight was highest in the first part of the period, reached it's lowest level in 1988 and than started to increase. It should be noted that the data for 1990 are still incomplete. There seems to be a close relation between the total stomach weight and the content of capelin. When the stomach weight is high, capelin usually make up the largest part of the content, e.g. in 1985. From 1986 until 1988 the content of capelin was dramatically reduced and the total stomach weight decreased almost correspondingly. In 1984 the weight of shrimp and capelin in the stomachs was almost the same in the two largest size groups, while cod in the smallest sizegroup had more than twice as much capelin as shrimp in the stomachs. The weight of shrimp in the stomachs decreased from 1984 to 1986 in all sizegroups by up to 50%. From 1986 to 1987 the content of shrimp increased by about 50% in all sizegroups, than decreased somewhat and started to increase again from 1989. The f.o.o. of shrimp in the stomachs has had the same development as the weight of shrimp except from 1984 to 1985 when the f.o.o. had a more pronounced decrease.

Fig. 5 shows the development of the shrimp stock in biomass and numbers from 1984 to 1990. Except from the beginning and end of the period, increase and decrease in biomass and numbers have approximately been of the same magnitude. The stock decrased by almost 50% from 1984 to 1985. The stock continued to decrease from 1985 to 1986, but the reduction was smaller than the previous year. The stock reduction stopped in 1986-87 at about 30% of the 1984-level. From 1986 to 1987 the stock increased by about 50%, was stabel in 1987, decreased slightly in 1988 and increased by about 50% from 1989 to 1990. The stock was now on average at about 50% of the 1984-level.

In Fig. 6 the length distribution (by numbers) of shrimp in the cod stomachs is shown. Because the shrimps are measured in rather wide sizegroups (Mehl 1986) the distribution is somewhat rough and unprecise. The top and the shape of the distribution seems to have changed little from year to year. In all years except 1984 the top of the distribution was at about 8cm. In 1984 there also was a peak at about 3 - 4cm, but measured in weight, the top would have been about the same as in the other years.

Fig. 7 presents the length distribution (total length) by numbers in the shrimp stock (trawl samples) by year. The general trend is that from 1984 to 1986 the reduction in numbers was largest in the upper part of the length distribution. From 1986 to 1987 there was a marked increase in the lower part of the length distribution, and a further increse in the number of smaller and medium sized shrimps took place from 1989 to 1990. The top of the distribution was at about 11cm in 1984 and at about 9cm in 1987.

The frequency of occurence was analysed in a linear model using shrimp stock size and cod sizegroup as independent variables. The parameters in the following model was estimated:

$$F = \beta_i + \alpha \cdot S$$

where F is the f.o.o. of shrimp while S is the shrimp stock size (in numbers) and i denotes cod sizegroup. The results are shown in Table 2 and Fig. 8. A fit with $R^2 = 0.74$ was obtained.

DISCUSSION

The relative short time series 1984-1990 gives little opportunity to use statistical methods for analysis. A visual comparison of Figs. 2-4 and Fig. 5 gives an impression of similar developement of average weight of shrimp in cod stomachs and the development of the shrimp stock. One exception is the observation from 1988. The reason for this could be that 1988 has no stations with sampling of cod stomachs in April-May when the most important shrimp areas in the Barents Sea are surveyed and the content of shrimp normally is at the highest in our time interval (February-May).

From the figures it can also be seen that the f.o.o. of shrimp in cod stomachs has the same trend as the shrimp stock biomass. When the biomass decreases, shrimp becomes available for fewer cod and the other way around. The f.o.o decreased somewhat more than the weight of shrimp in cod stomachs from 1984 to 1985, but this is probably just sampling variance. There is no reason why those cod still finding shrimp should eat more when the shrimp stock is reduced by 50%.

The linear model analysis of the f.o.o. (Table 2) gave a relative high degree of fit for this kind of data. The ß's show that the f.o.o. increases with increasing cod size. There are several reasons for this. Large cod is not as numerous as smaller ones and it is therefore more likely that a higher proportion of the large cod finds shrimp, given the sizegroups are seperated and all sizegroups has the same preference for shrimp. Large cod is a better swimmer and covers a larger area than small ones. Besides, medium cod sizegroups are often more pelagic than larger ones (Hylen et al. 1986), while shrimp of the size found in cod stomachs is most abundant near the bottom (unpubl. survey data). Note that of the 7 observations (years) in this material, only 3 observations lie outside the relative narrow interval 2400-2700 (10^7) for the independent variable shrimp stock size.

The data was also tried analysed with linear models with average weight of shrimp in cod stomachs as the dependent variable. The independent variables were average weight of capelin in cod stomachs, shrimp stock biomass and shrimp stock numbers. No significant correlation with the dependent variabel was found. We belive that this is mostly due to the (relative) low number of observations and the poor samling coverage of cod stomachs in 1988.

As the shrimp stock decreased from its maximum in 1984, both in 1985 and 1986, and this coincided with the decrease in the capelin stock size (and the reduction in stomach content of capelin) it is difficult to find signs of switching between the two prey species in the diet. The figures 2-4 indicates however a switching to shrimp in 1987, especially compared with 1985. Both years have a similar shrimp stock size (Fig. 5). In 1985 when the capelin stock still was at a relative high level (Anon. 1991a) the stomach content of capelin was high, while in 1987 the capelin stock was depleted and the average weight of capelin in cod stomachs was at a minimum. For all sizegroups the average weight of shrimp in the stomachs is higher in 1987 than in 1985.

It seems as if the size of the shrimp stock has an effect on the cod's predation on shrimp. When the shrimp stock decreases, the content of shrimp in cod stomachs also decreases, and the other way around, especially if other main prey species are scarce. But what about the effect of the cod's predation on the shrimp stock? The shrimp stock started to decline already in 1984, 1-2 years before the cod's main prey, capelin, was seriously depleted. The cod stock was on a historically low level in 1983 (Anon. 1991a). In 1986 the cod stock (3+) had almost doubled (Anon. 1991a, 1991b) and the stomach content of shrimp increased from 1986 to 1987, but still the shrimp stock increased by almost 50% in the same period. Based on this it is doubtful that predation from cod was the only main cause to the large reduction in the shrimp stock from 1984 to 1986.

On the other hand the cod stock's predation must have a strong effect on the shrimp stock. In all of the years 1984-1989 the estimates of the Northeast Arctic cod stock's predation of shrimp exceeded the catches, in some years it exceeded the stock estimates (Mehl 1989, Bogstad and Mehl 1991). Bax _et al_. (1989) found an unrealistic high loss of shrimp biomass due to fish predation, cod being the most important predator. It should however be noted that not all of the Barents Sea is covered during the shrimp surveys and that the pelagic registrations not are included in the estimates. Especially for the second part of 1984 the consumption estimate was very high (Mehl 1989) and the cod's predation may have contributed to the quick reduction of the shrimp stock.

The length distribution of shrimp from the trawl samples (Fig. 7), indicates that the larg reduction in numbers from 1984 to 1986 took place among large shrimps of about 9-12 cm total length. That it also why the stock decreased more in biomass than in numbers in the same period. Mehl (1989) estimated that in 1984-1986 72-82% of the cod's consumption of shrimp was on size group 5-9 cm, which is in accordance with the somewhat rough length distribuion in Fig. 6. Bowering _et al_. (1984) also found smaller shrimps in cod stomachs than in trawl catches. It is therefore likely that the high catches (with similar length distribution as in Fig. 7) in 1984 and 1985 were responsible for most of the reduction of large shrimp in the stock. The cod's consumption has on the other hand influenced the recruitment to the larger (and commercially important) lengthgroups in the shrimp stock. The same was found by Boddeke (1971) and Bowering _et al_. (1984).

Other causes to the reduction of the shrimp stock estimates in 1984-1986 might be predation from other species than cod, migration and poor recruitment. According to Bax _et al_. (1989) cod was responsible for about 50% of the predation on shrimp in 1984/85. Other predators are flatfish (Pleuronectidae), redfish (_Sebastes_ spp.), Greenland halibut (Reinhardtius hippoglossoides), haddock and sea mammals, but we have no evidence of increased predation pressure from these species during the period. Surveys in areas outside the shrimp survey area in the Barents Sea showed a similar decline of the shrimp biomass both east and west of the shrimp survey area (Tveranger and Øynes 1985). The reduction in the cod stock's consumption of shrimp in the same period (Mehl 1989; Bogstad and Mehl 1991) is based on stomach data from a much wider area than the shrimp survey area. Migration therefore probably contributed little to the reduction of the shrimp stock in 1985 and 1986. Shrimp yearclasses 1979-1981 were found to be weak (Tveranger and Øynes 1985), and this would have effected the recruitment to the exploitable part of the stock in the period.

The cod and shrimp stocks in the Barents sea probably have mutual influences on each other. But both relative short time series and scarce data on absolute stock abundances, stomach contents and consumption rates in the same periods and areas make it difficult to do any precise analysis of the stock interactions and their effects.

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Table 1. The number of cod stomachs sampled in shrimp areas in the Barents Sea in February-May 1984-1990 by predator sizegroup and year.

	Predator size group (cm)		
Year	30-40	40-50	50-60
1984	151	74	93
1985	168	256	135
1986	120	101	82
1987	214	179	66
1988	171	372	181
1989	220	244	210
1990	101	69	60
Sum	1145	1295	827

Tabel 2. Results of frequency of occurence (f.o.o.) modelled as a linear function of predator sizegroup and shrimp stock size

Source	DF	SS	MS
Model	4	1.1340	0.2835
Error	17	0.0441	0.0026
Total	21	1.1781	

$F=109.34$ $p=0.0001$ $R^2=0.7359$

Parameters	Estimate	T	p	Std error of estimate
$ß_1$ (30-40cm)	$8.19\ 10^{-3}$			$3.42\ 10^{-2}$
$ß_2$ (40-50cm)	$7.96\ 10^{-3}$			$3.42\ 10^{-2}$
$ß_3$ (50-60cm)	$1.31\ 10^{-3}$			$3.42\ 10^{-2}$
α	$5.55\ 10^{-5}$	5.19	0.0001	$1.07\ 10^{-5}$

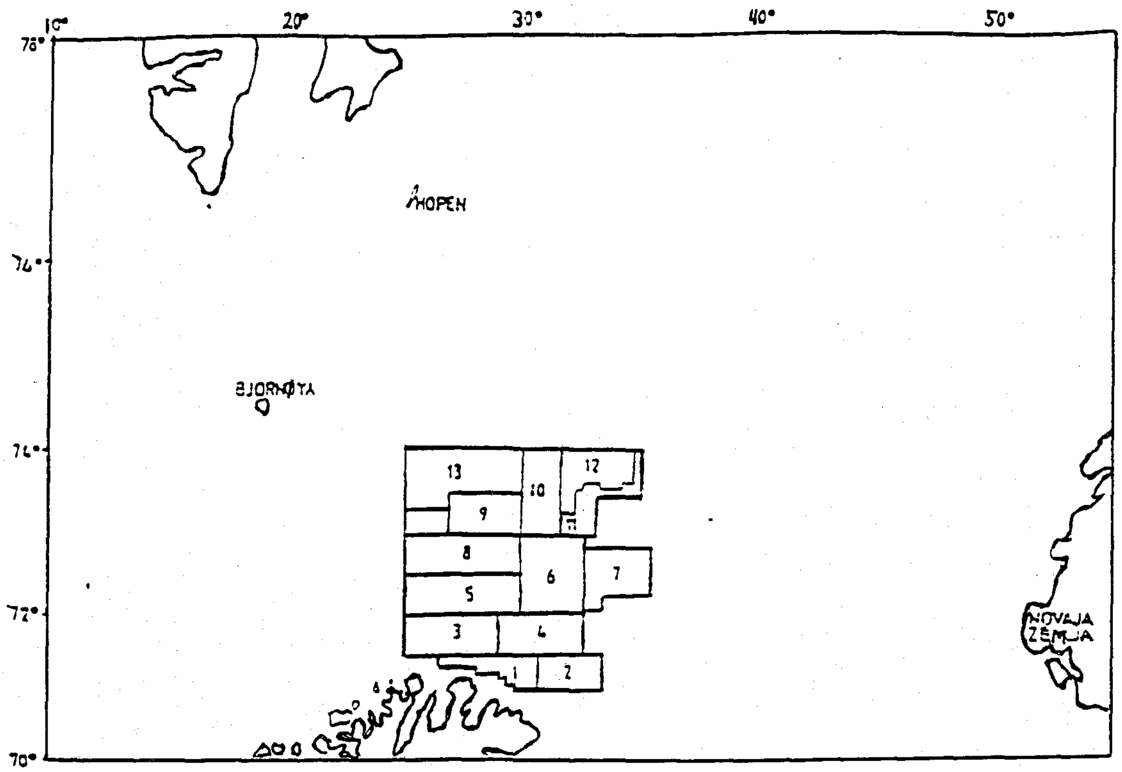

Figure 1. The area with strata used for aggregation of cod stomach data and shrimp stock estimates in the Barents Sea.

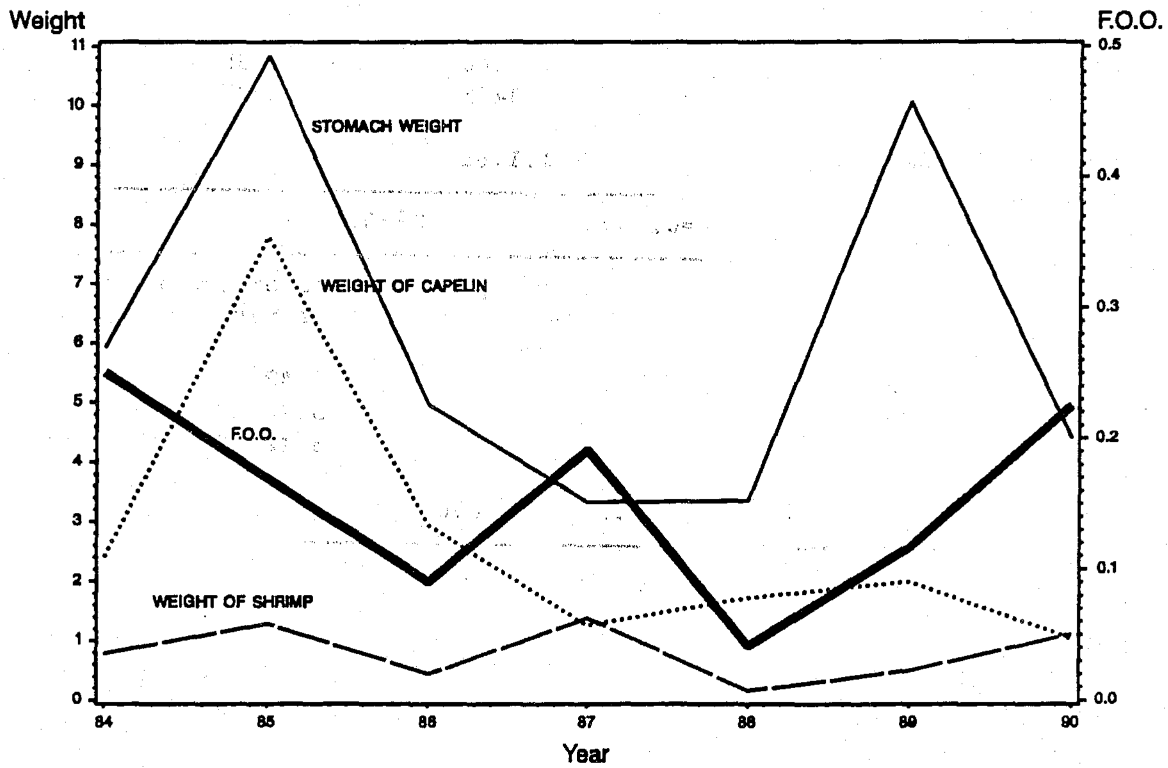

Figure 2. The development of the total stomach content, weight of capelin and shrimp and frequenvy of occurence of shrimp in cod stomachs sampled in the Barents Sea in 1984 - 1990. (Cod length between 30 and 40 cm)

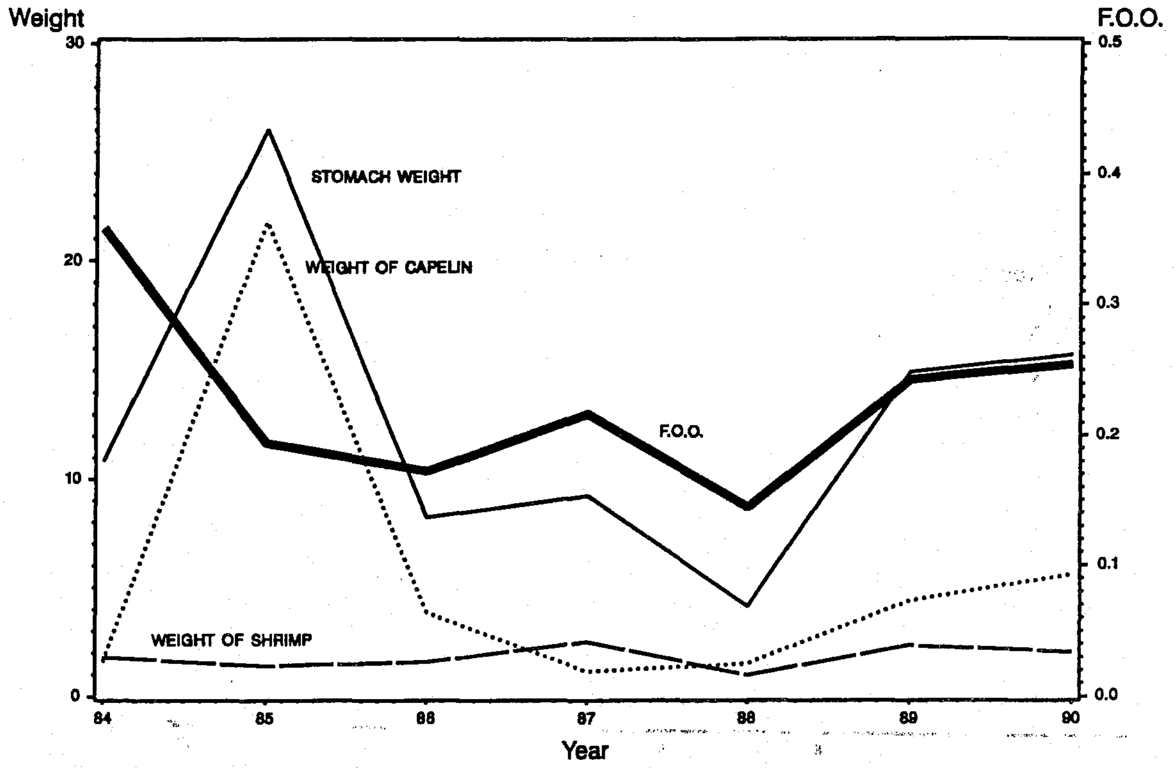

Figure 3. The development of the total stomach content, weight of capelin and shrimp and frequenvy of occurence of shrimp in cod stomachs sampled in the Barents Sea in 1984 - 1990.(Cod length between 40 and 50 cm)

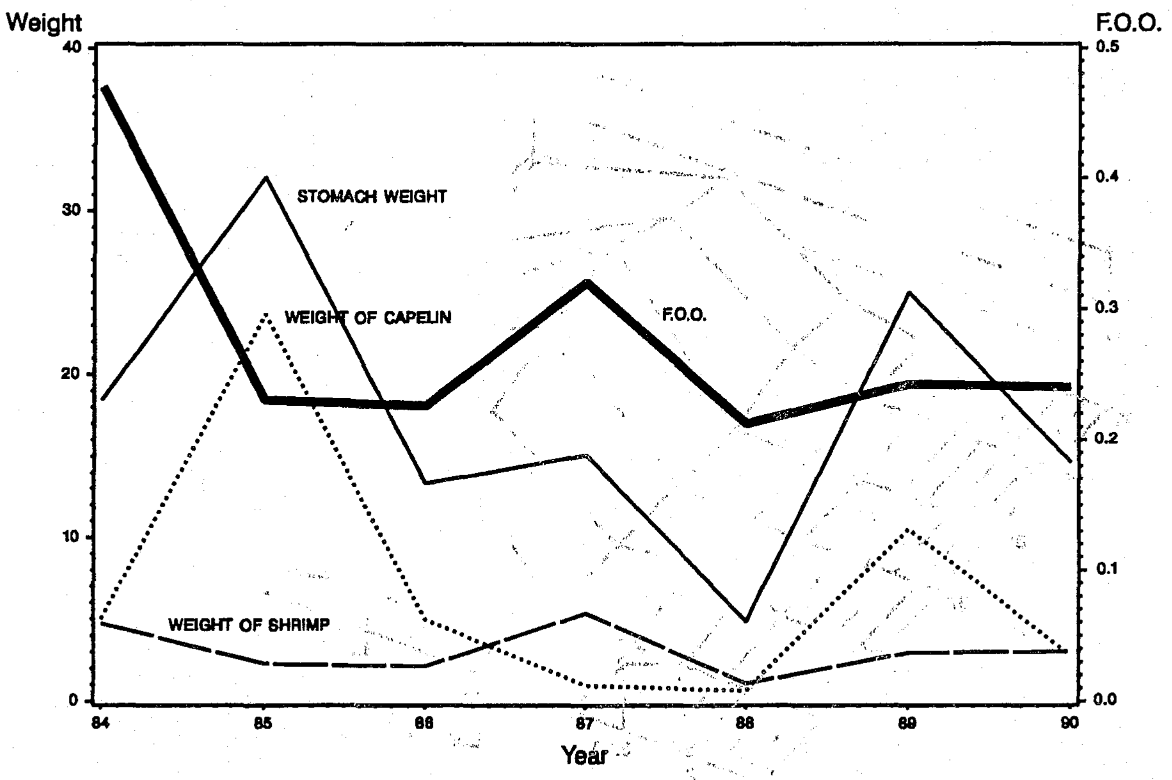

Figure 4. The development of the total stomach content, weight of capelin and shrimp and frequenvy of occurence of shrimp in cod stomachs sampled in the Barents Sea in 1984 - 1990.(Cod length between 50 and 60 cm)

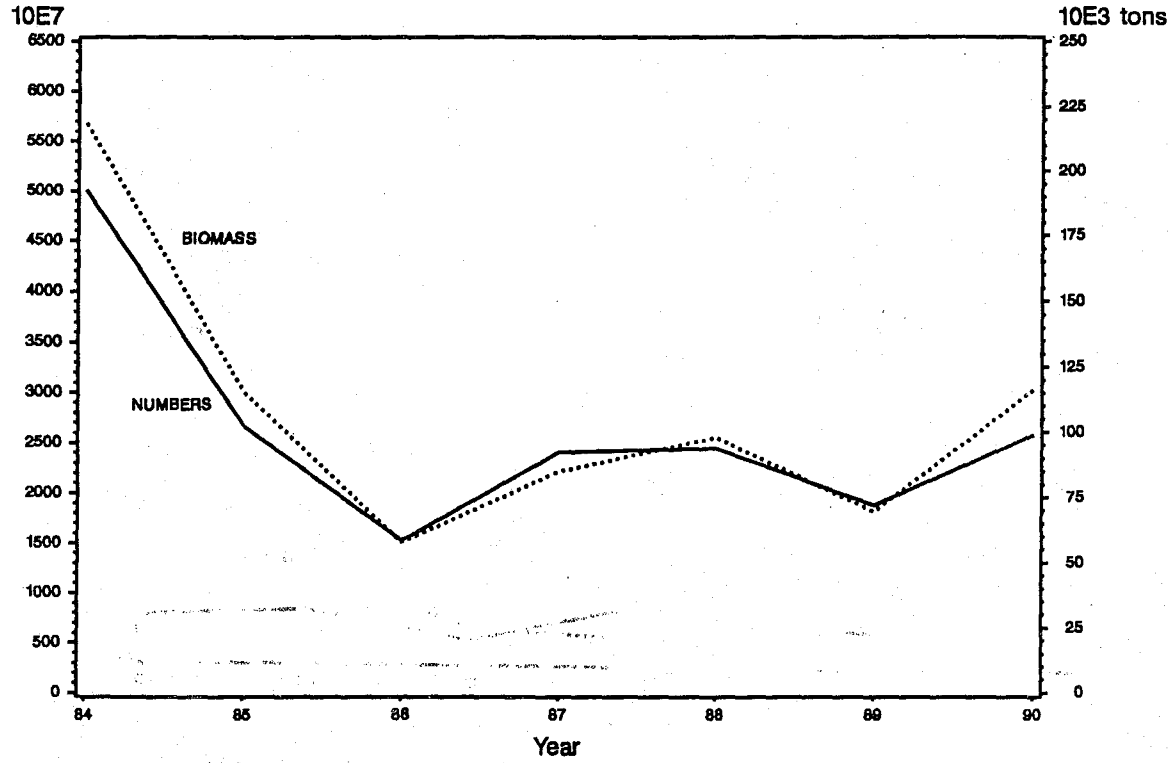

Figure 5. The development of the shrimp stock in the central part of the Barents Sea from 1984 to 1990)

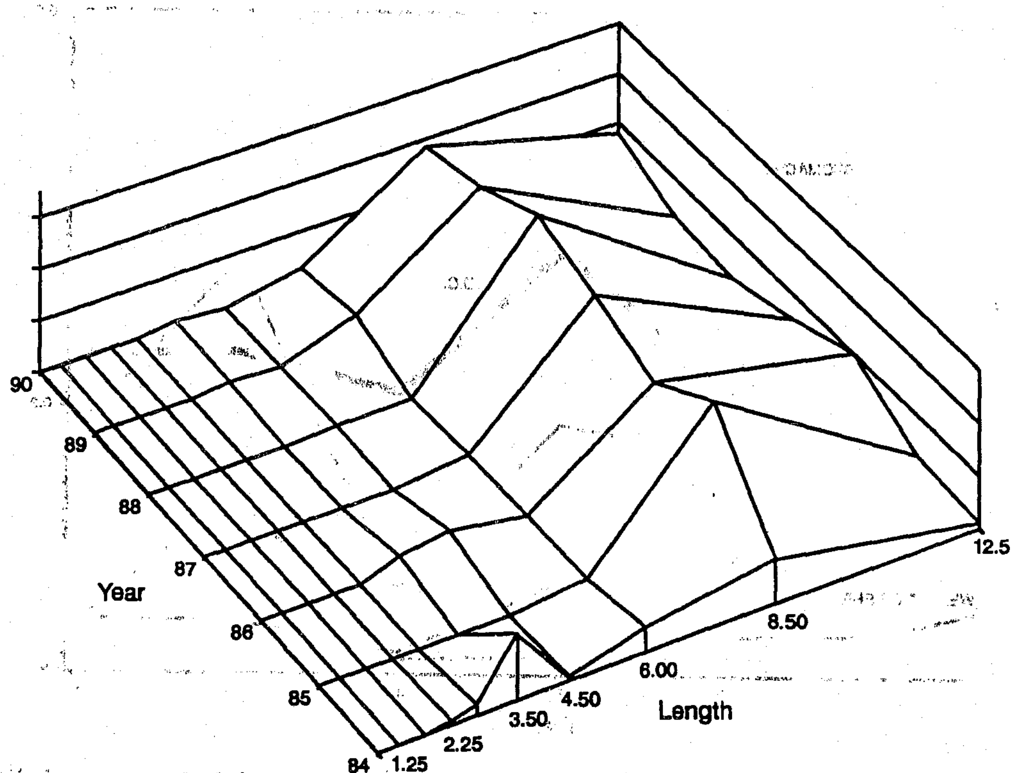

Figure 6. Length distribution of shrimp in cod stomachs sampled in the Barents Sea in 1984 - 1990.

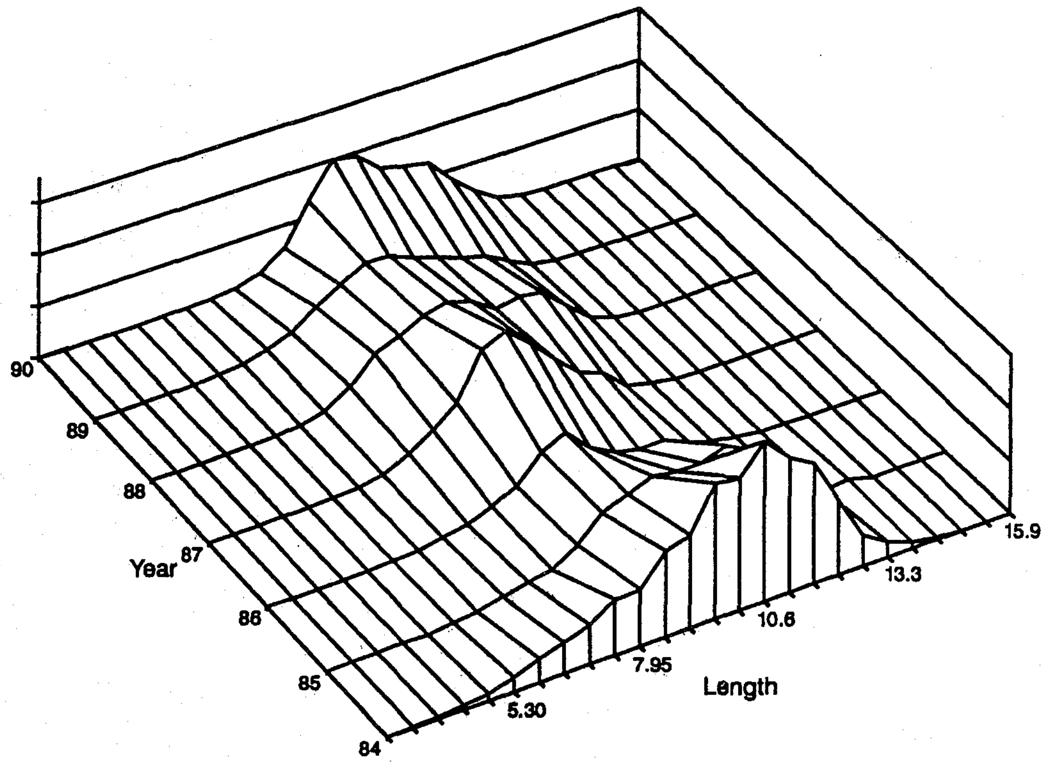

Figure 7. Length distribution (by numbers) of shrimp sampled by shrimp trawl in the Barents Sea in 1984 - 1990.

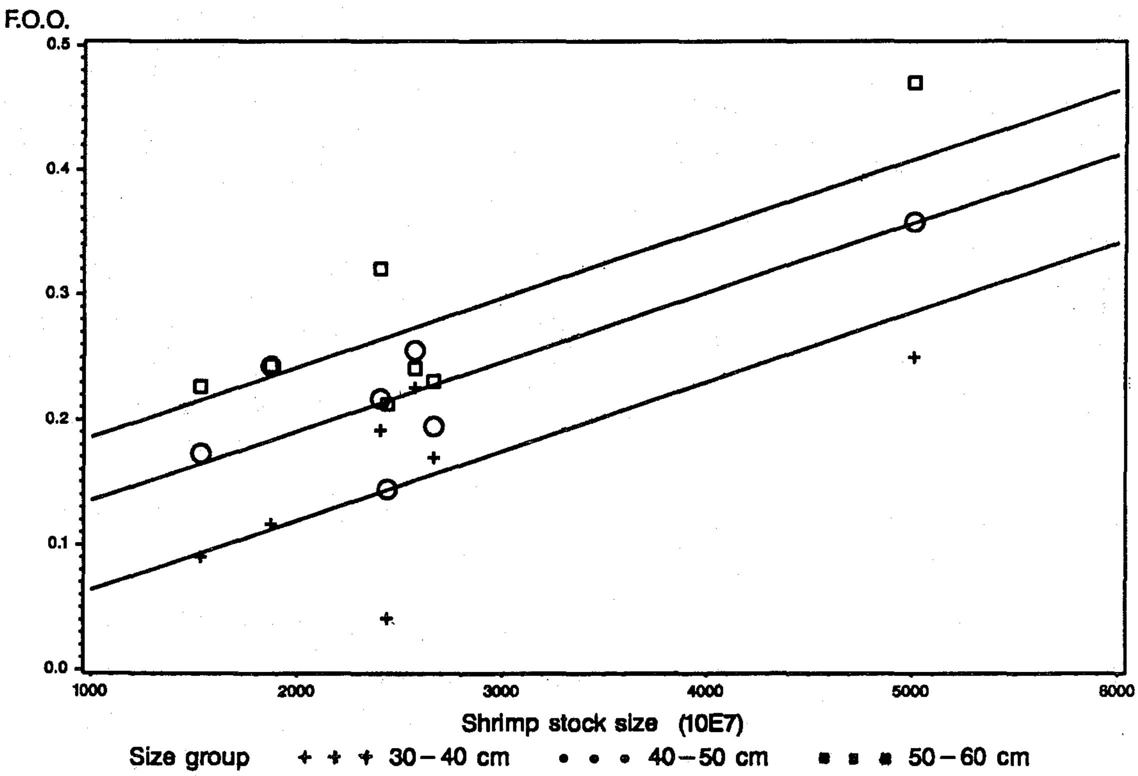

Figure 8. Frequency of occurence (F.O.O.) modelled as a linear function of predator length group and shrimp stock size.