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Impact of Cod on Dynamics of Shrimp Stock, *Pandalus borealis*, in the Barents Sea And the use of this Factor in Mutlispecies Models

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ABSTRACT

Northern shrimp (*Pandalus borealis*) is one of the important fishable invertebrates in the Barents Sea. In 1984-1985 its total catch in the ICES I, Divs.IIa and IIb was as big as 124-128 thou.t.

Investigations of the northern shrimp stock in the Barents Sea and near Spitsbergen are conducted by Russia and Norway only. In 1984-1997 similar trends as suggested by the Russian and Norwegian data were found in variation of the shrimp stock. Over this period the biomass, catch and CPUE varied nearly synchronically.

Therefore, rather interesting is the question of which factors produce the strongest impact on variation of shrimp stock in the Barents Sea. The pattern of interactions between commercial stocks in the Barents Sea is primarily determined by predation from Arcto-Norwegian cod. Russian research for 50 years indicate that the cod is also one of the most important factors which influence the variation of northern shrimp biomass. In years when the biomass of cod is high the shrimp frequency of occurrence in cod stomach declines. In addition, a reverse correlation has been found between the abundance of commercial cod stock and shrimp biomass in 1982-1998.

The analysis of the Russian-Norwegian cod stomach data base has shown that cod at age 3-6 produce the strongest impact on shrimp stock, the cod prefers to feed on shrimp with the total length of 5-10 cm.

The established relationships are used to assess the dynamics of shrimp stock by VPA and production models.

INTRODUCTION

Russian and Norwegian surveys of shrimp stock in the Barents Sea and near Spitsbergen have shown that the difference between minimal and maximum shrimp biomass is 3 to 4 times (Aschan et al., 1995). What are the major mechanisms behind such fluctuations? Could they be possibly related to the strength of shrimp year classes or the impact of oceanographic or biotic factors?

This paper reviews the relationship between the dynamics of shrimp stock and cod predation since it is exactly this species which primarily defines the pattern of interactions between commercial species of fish and invertebrates in the Barents Sea (Ajiad et al., 1992; Bogstad et al., 1998; Nilssen et al., 1994).

MATERIAL AND METHODS

Catch data on northern shrimp for ICES SA I, Divs. IIa and IIb have been borrowed from ICES Statistical Bulletins, estimates of abundance and biomass of commercial cod stock at age 3-15 from ICES Arctic Fisheries Working Group

(Anon., 1999), materials on shrimp frequency of occurrence in cod stomach were gathered by PINRO research surveys in 1957-1997.

On the average 29 thou.cod fished in ICES I, Divs IIa and IIb were examined for diet yearly. The shrimp frequency of occurrence was calculated as percentage of cod stomachs containing shrimp
to the total number of stomachs with food.

The paper uses stomach content data from more than 86 thou.cod gathered in 1990-1996 and pooled into a joint data base by PINRO (Russia) and IMR (Norway). To process the data MAGE programme developed by the Institute of Marine Research (Bergen) was used where at the output all prey species were divided between specific size groups. Total length of shrimp from cod stomachs was measured from a postorbital hollow to the tip of telson (Rasmussen, 1953). By the total (cummulative) percent a sum of yearly percent of shrimp biomass consumed by cod of a given age group of the total biomass of shrimp consumed in a given year was meant.

Biomass and abundance of shrimp in the Barents Sea and near Spitsbergen were assessed in 1984-1998 following the agreed Russian-Norwegian methodology (Aschan et al., 1995).

Single-species VPA (SSVPA) and multi-species VPA (MSVPA) could in our view along with other methods be used to assess the northern shrimp stock. To apply these methods a target species should be structured by age groups. However, it is rather difficult to read the age of northern shrimp P.borealis from the northern Barents Sea where the major part of this stock is distributed. Therefore, it was assumed that the age structure of shrimp varies only slightly between years and corresponds conventionally to the following size groups: shrimp with a carapace of less than 9.8 mm - 1 year old, 9.8-12.4 mm - 2 years, 12.5-16.5 mm - 3 years, 16.6 - 19.25 mm - 4 years, 19.26-21.5 mm - 5 years and larger than 21.53 mm - 6 years. These size groups were established on the basis of a real size distribution of shrimp in one of the areas of the Barents Sea near the Kola peninsula.

A consumption of shrimp by cod per annum was assessed based on cod abundance, ration and proportion of shrimp in its diet. This approach is used by both Norwegian experts and PINRO scientists (Russia). We used a modified dos Santos model to assess the food consumption by cod:

$$R_s = \frac{Ln2 * w_s * e^{ct}}{H_s * (2 * w/W)^b},$$

where $-R_s$ - daily consumption of prey species s, g

w_s - weight of prey species s in stomach, g,

T - water temperature, C°,

H_s - theoratical coefficient of digestion rate expressed as the time of 50% digestion (in hrs) of a portion of prey species s by fish of the same weight at temperature C°,

w - total weight of stomach content, g

W - weight of fish, g,

b and c - coefficients.

Coefficient H_s has been assumed the same for all size groups of shrimp and equal to 533 g/hr. To assess the shrimp stock, with the consumption known, we use the virtual population analysis method (VPA) having slightly modified it (Tretyak, Korzhev, 1989). Total natural mortality is given as a sum of two components: M2 - mortality from predation by cod and M1 - residual natural mortality. Unlike standard VPA a total of catch and consumtion by cod is used in calcultion instead of catch.

It is assumed that predation by cod is a main component of the total natural mortality of shrimp. A residual natural mortality M1 can then be assumed close to zero, for instance 0.01 for all size-age groups. To estimate start values of the coefficient (F+M) an XSA method has been used (extended survival analysis).

A fundamental difference of MSVPA from the SSVPA model, described above, is that in MSVPA only catch is used as input information, while predation by cod is assessed by the model itself. To assess predation an approach based on the weight proportions of prey in predator stomach is used. The model enables (with certain assumptions) to assess the shrimp stock and measure the impact of cod on its dynamics. In the MSVPA model the total shrimp biomass by the model is run against biomass estimates provided by trawl surveys. Therefore, this assessment can not be taken as absolutely unbiased.

This paper also presents assessment of shrimp biomass dynamics by Stefansson model (Stefansson et al., 1994).

Each of the methods has its uncertainties, therefore, it is extremely exciting to compare results produced by each model.

RESULTS AND DISCUSSION

Northern shrimp fishery in the Barents Sea and near the Spitsbergen archipelago is conducted by various nations. However, the greatest part of catch of shrimp in these areas is taken by Norway and Russia (USSR before).In recent years there were two periods of high catch and two with low catch of shrimp (Fig.1). There could be different reasons behind these variations in landings. However, fluctuations of shrimp biomass and associated synchronous variations of catch per effort were apparently major reasons for variation of catch (Figs.1,2).

Assessment of shrimp stock by Russia and Norway using stratified trawl survey has in general shown similar trends in variation of shrimp stock (Fig.2). The difference in absolute values between Russian and Norwegian assessments is due to different coefficients of catchability of research trawls.

Multi-year studies of cod diet by Russia have shown that the stomachs of this species predominantly contain those prey which prevail in a given area at a given time (Ponomarenko, Yaragina, 1978).

The role of shrimp in cod diet has changed significantly since the 30's. In the 30's the proportion of shrimp in cod diet was very small, less than 1% by occurrence frequency and 5% by weight in stomach (Zatsepin, Petrova, 1939). From 1947 to 1983 an upward trend in occurrence frequency of shrimp in cod diet was observed (Ponomarenko, Yaragina, 1984). Maximum occurrence was recorded in 1981-1984 (Fig. 3). Thereafter, it began to decrease and by mid-90's the occurrence frequency of shrimp in cod stomach stabilized at 20-25%. A comparison of yearly mean occurrence frequency with the cod biomass in 1947 to 1997 has shown a close reverse relationship between them (Fig.3). It should be noted that when the cod stock is low fluctuations of shrimp frequency of occurrence in its stomach are greater then when it is at a high level. (Fig.3, bottom).

Shrimp biomass estimates provided by trawl surveys enabled to compare the dynamics of shrimp stock variations with the abundance of commercial cod stock in the Barents Sea in 1982-1998 (Fig.4). It was found, that in this comparison too there is a certain antiphase between cod and shrimp.

Due to the appearance of several weak year classes of cod in the late 70's - early 80's (1976-1981) the predation of cod on shrimp apparently lessened and the shrimp stock grew accordingly. In the 80's two more minima of the commercial cod stock were recorded (1983-1984 and 1988-1989) corresponding to two maxima of the shrimp stock biomass (Fig.4). In the beginning of the 90's several strong year classes of cod apeared which possibly contributed to the decline of shrimp biomass.

The analysis of the joint Russian-Norwegian cod stomach data base has revealed that despite a more important role of shrimp in the diet of cod of younger age, major part of the consumed shrimp biomass is taken by cod aged 3-6 (Fig.5), and the cod prefers to prey on shrimp of 5 to 10 cm (Fig.6).

Runs of the SSVPA model have shown that in 1984-1997 the biomass of shrimp varied from 0.6 in 1986, 1987 to 1.76 mill.t in 1992 (Fig.7), and estimated shrimp biomasses were always higher than the biomass values provided by the Russian trawl surveys. A biomass variation curve shows a minimum in 1986-1989 when the capelin stock, a major prey for cod in the Barents Sea was in bad shape, and a maximum in 1991-1993 when this stock improved.

Shrimp catch and consumption of shrimp by cod were used to calculate fishing mortality and predation mortality rates (Table 1). Mean natural mortality caused by cod predation is usually much higher than fishing mortality. Therefore, a major role in shrimp abundance dynamics may be played by variations in cod predation. However, our assessment has shown that shrimp catch is only 3-4 times less than the consumption of shrimp by cod. In individual years these parameters are comparable (Table 1). Therefore, unregulated fishery for shrimp in the Barents Sea may have adverse impact on this stock.

The state of shrimp stock is basically determined by two factors: recruitment and cod predation. Calculations have shown that from 15% to 58% of shrimp stock are eaten by cod both in terms of the total biomass and each individual age group (Table 2). Thus, the cod prey on shrim of all age groups.

To assess the northern shrimp stock using catch per effort, recruitment indices and cod predation a production model by Gunnar Stefansson was applied (Stefansson et al., 1994). This is a parametric model where estimated absolute values of biomass are dependent on initial biomass (B_o) in a start year. Runs were performed for minimal, average and maximum B_o. In this paper B_o is assumed to be close to maximum (Fig.8). The significance of estimates of model parameters has been checked against F-criterion which reflects the variations of standard error (SSE) under different model parameters.

CONCLUSIONS

Biomass, catch and CPUE of shrimp *Pandalus borealis* in the Barents Sea varied nearly synchronically.

On the basis of multi-year studies of cod diet it can be inferred that cod predation is one of important factors impacting on the dynamics of northern shrimp stock in the Barents Sea.

The abundance of commercial cod stock on the one hand and biomass o f shrimp and its occurrence frequency in cod stomach on the other are in antiphase against each other.

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Table 1

Mortality rate of the shrimp P.borealis in the Barents Sea from cod predation

AGE	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1	0,17	0,14	0,15	0,18	0,29	0,46	0,54	0,44	0,34	0,27	0,30	0,32	0,48	0,60	0,76	0,90	0,73
2	0,08	0,08	0,09	0,11	0,17	0,22	0,25	0,19	0,17	0,16	0,16	0,18	0,23	0,27	0,35	0,47	0,40
3	0,15	0,14	0,13	0,16	0,24	0,39	0,55	0,44	0,35	0,29	0,27	0,28	0,41	0,51	0,75	1,04	0,83
4	0,13	0,12	0,12	0,14	0,22	0,36	0,46	0,37	0,30	0,25	0,24	0,26	0,37	0,45	0,64	0,90	0,72
5	0,28	0,25	0,23	0,27	0,40	0,70	0,98	0,82	0,67	0,55	0,49	0,50	0,73	0,94	1,38	1,99	1,58
6	0,24	0,22	0,22	0,26	0,38	0,67	0,76	0,61	0,51	0,47	0,48	0,48	0,68	0,79	1,06	1,50	1,28

Fishing mortality rate of the shrimp P.borealis in the Barents Sea

AGE	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00
3	0,03	0,05	0,10	0,13	0,15	0,04	0,03	0,04	0,04	0,07	0,05	0,06	0,04	0,02	0,06	0,034	0,01
4	0,10	0,07	0,20	0,33	0,48	0,24	0,07	0,12	0,11	0,18	0,16	0,15	0,17	0,07	0,06	0,25	0,05
5	0,09	0,15	0,17	0,34	0,85	0,53	0,36	0,21	0,23	0,30	0,24	0,28	0,26	0,22	0,10	0,332	0,08
6	0,16	0,05	0,13	0,09	0,25	0,43	0,38	0,55	0,17	0,27	0,18	0,17	0,19	0,13	0,08	0,642	0,22
Mean for age 2-5																	
	0,05	0,07	0,12	0,20	0,37	0,20	0,12	0,09	0,10	0,14	0,11	0,12	0,12	0,08	0,06	0,15	0,04

Table 2

Proportion of shrimp consumed by cod of the total Barents Sea shrimp stock

AGE	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1	0,15	0,13	0,13	0,16	0,24	0,36	0,41	0,35	0,28	0,23	0,25	0,27	0,37	0,44	0,52	0,58	0,52
2	0,08	0,07	0,08	0,10	0,15	0,19	0,22	0,17	0,15	0,14	0,15	0,16	0,20	0,23	0,29	0,37	0,33
3	0,14	0,12	0,11	0,13	0,19	0,31	0,41	0,34	0,29	0,24	0,22	0,23	0,32	0,39	0,51	0,63	0,56
4	0,11	0,10	0,10	0,11	0,15	0,25	0,35	0,29	0,25	0,19	0,19	0,20	0,28	0,34	0,45	0,54	0,50
5	0,23	0,20	0,18	0,19	0,21	0,36	0,55	0,52	0,44	0,36	0,33	0,33	0,45	0,54	0,71	0,80	0,77
6	0,19	0,19	0,18	0,21	0,27	0,36	0,44	0,37	0,37	0,32	0,34	0,34	0,43	0,50	0,63	0,68	0,66
Biomass	0,16	0,15	0,15	0,17	0,20	0,30	0,38	0,36	0,31	0,26	0,25	0,25	0,34	0,40	0,53	0,58	0,54

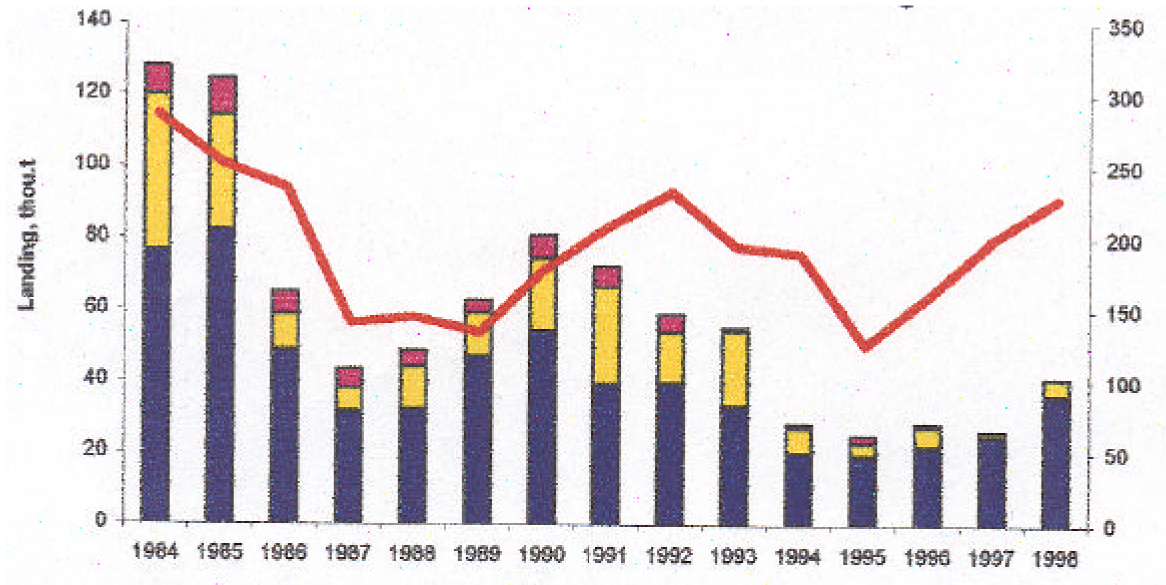


Fig. 1. Shrimp *Pandalus borealis* landings by Norwegian (blue), Russian (yellow), other countries (red) and catch per effect (kg/h) on Russian shrimp fishery (red line) in the Barents Sea and Svalbard Region.

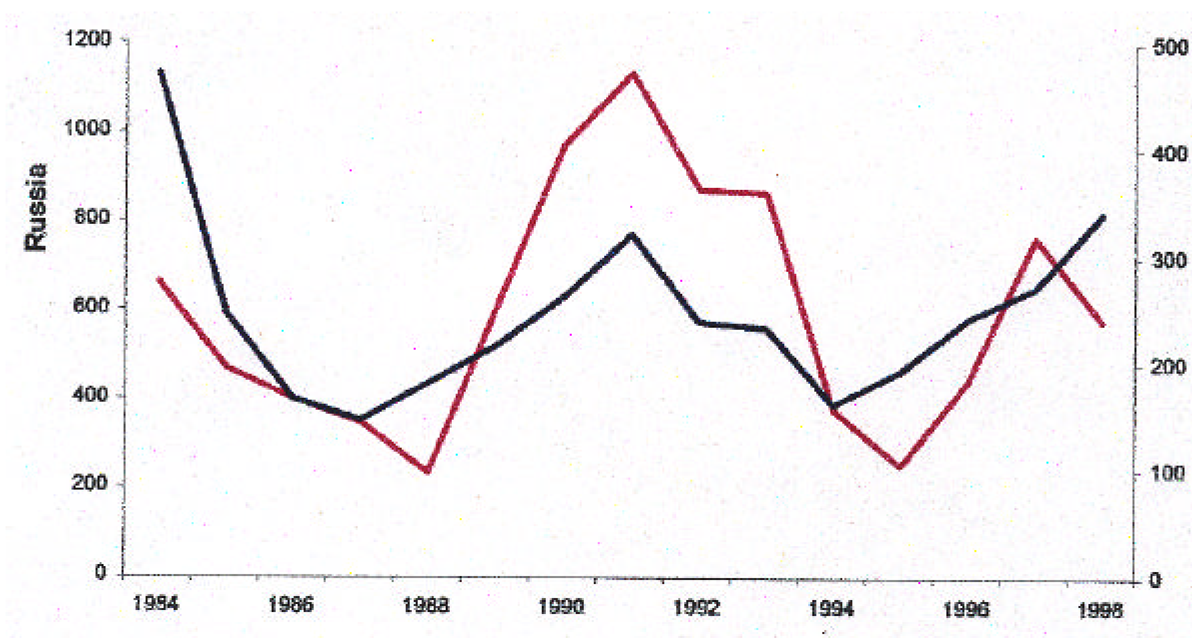


Fig. 2. Biomass of shrimp in the Barents Sea by Russian (red) and Norwegian (blue) data, thou. t.

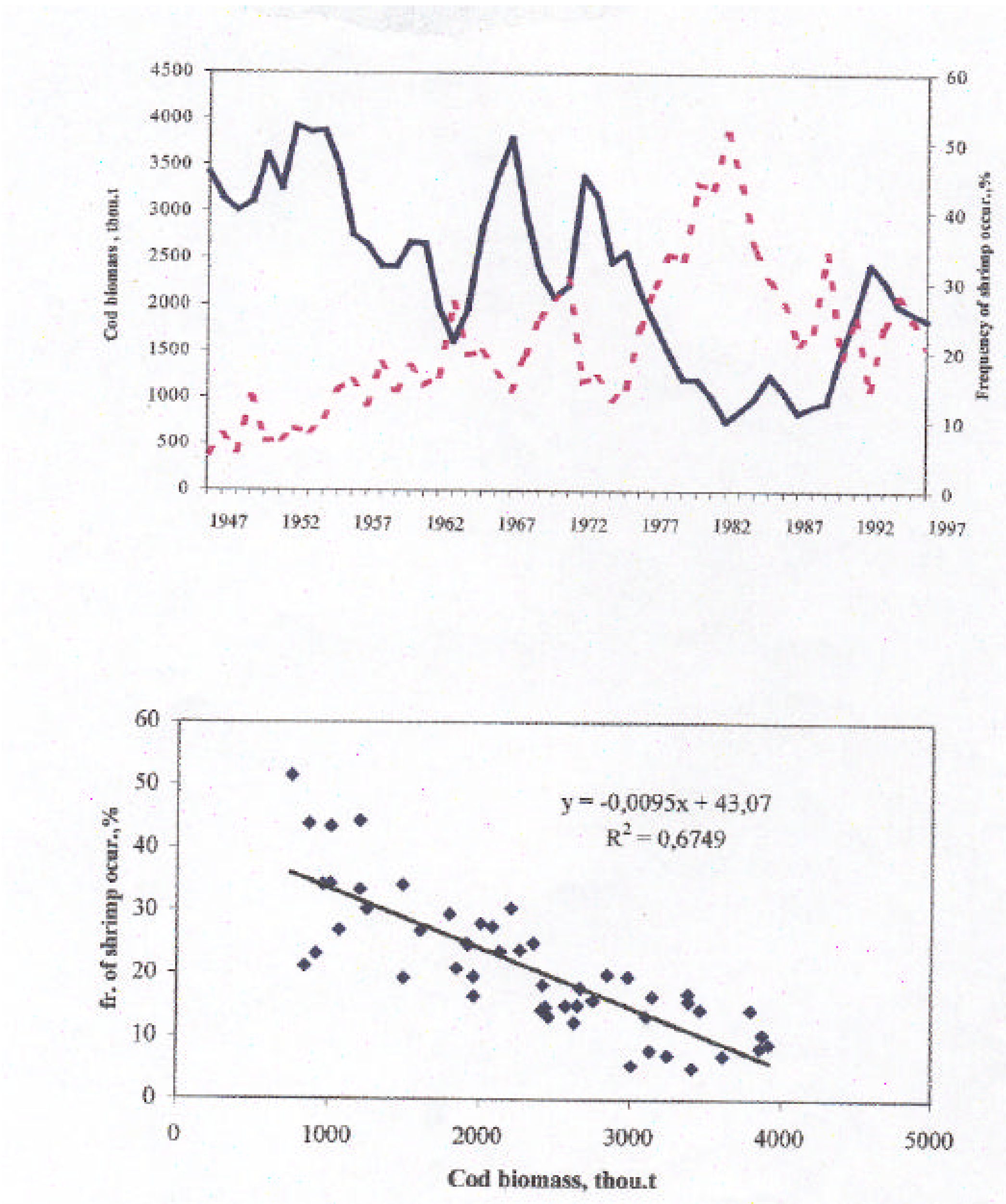


Fig. 3. Dynamics of Northeast Arctic cod biomass (fish at age 3 – 15 solid line) and frequency of shrimp occurrence in cod stomachs in 1947-1997 (%, stroke line).

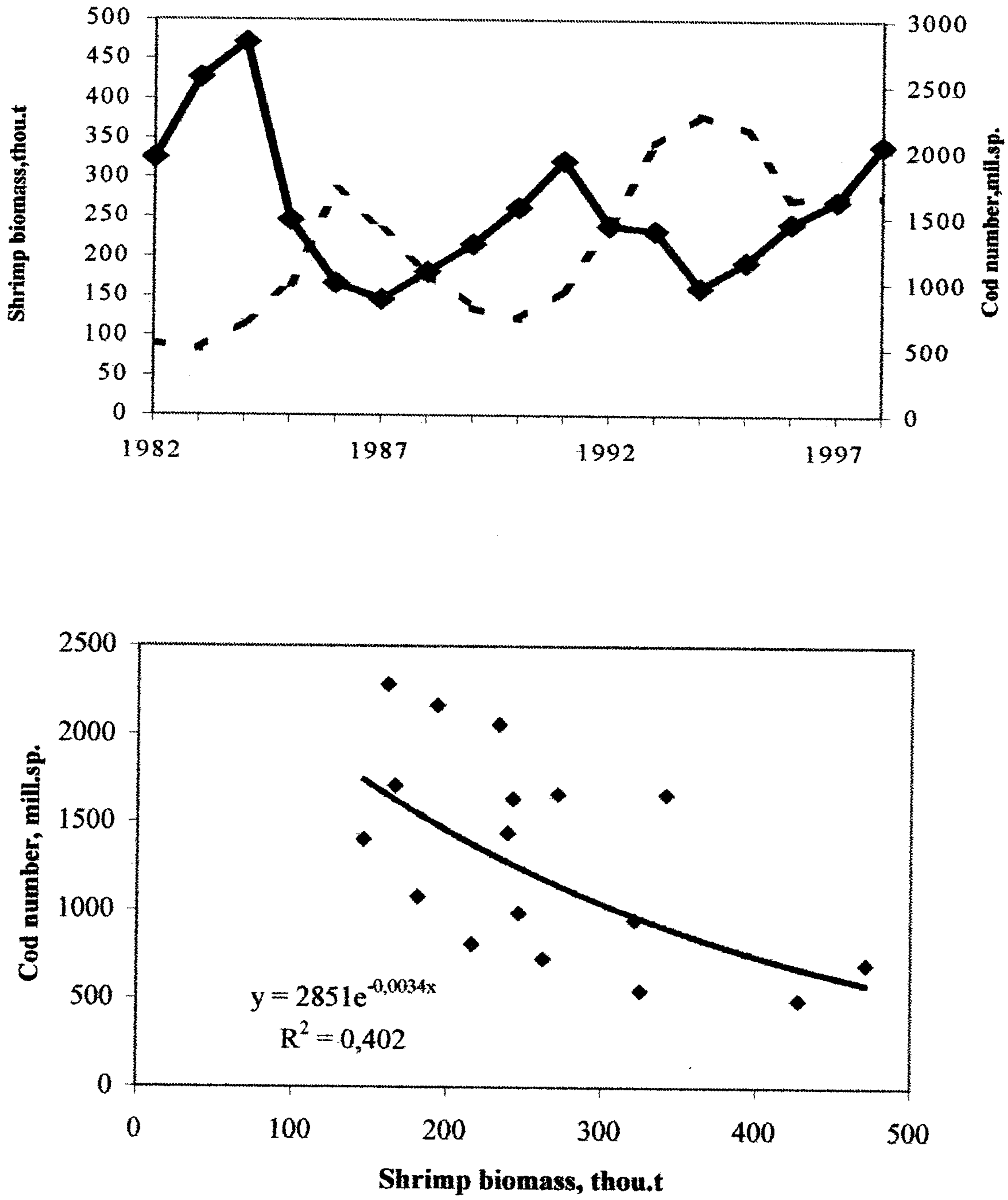


Fig. 4. Dynamics of northern shrimp biomass (Norwegian data, solid line) and Northeast Arctic cod stock abundance (fish at age 3 – 15, strike line) in 1982-1998.

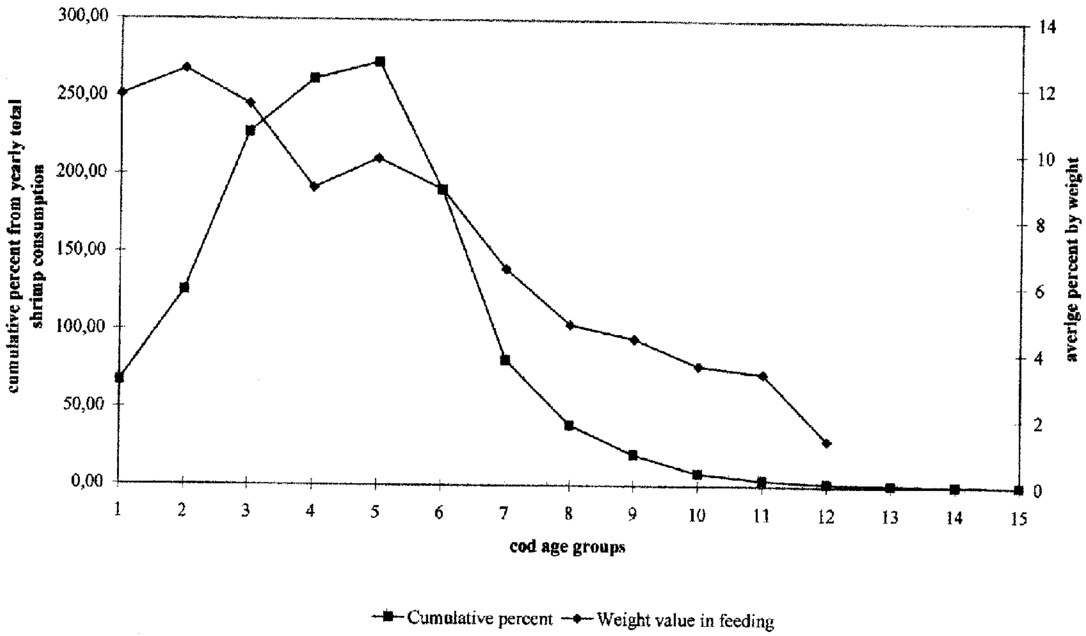


Fig. 5. Shrimp importance and consumption by different cod age groups in 1984-1996.

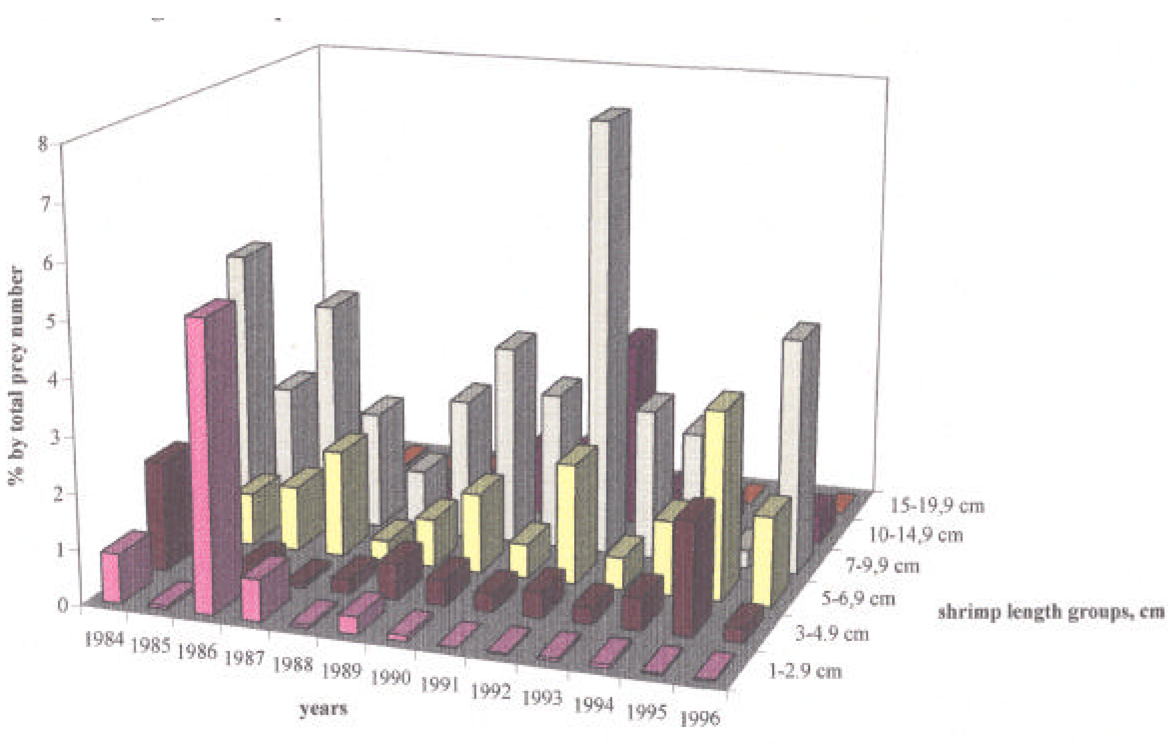


Fig. 6. Shrimp size distribution in the Barents Sea cod stomachs in 1984-1996.

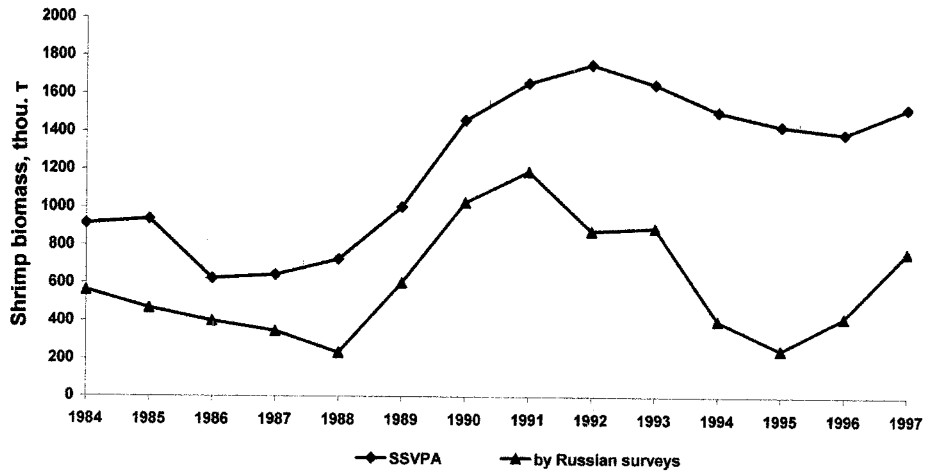
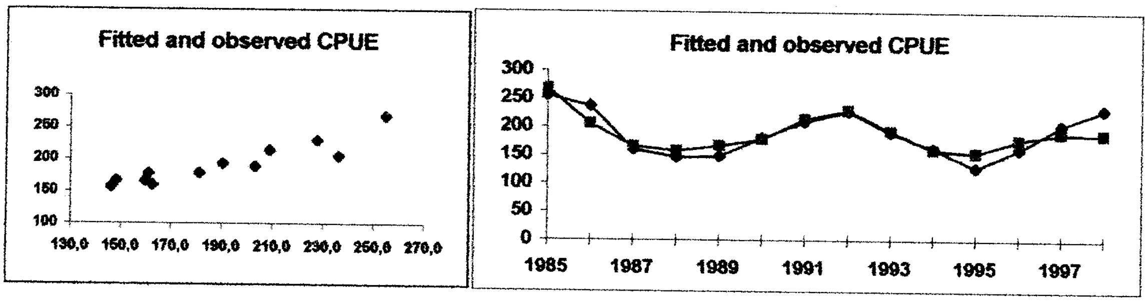
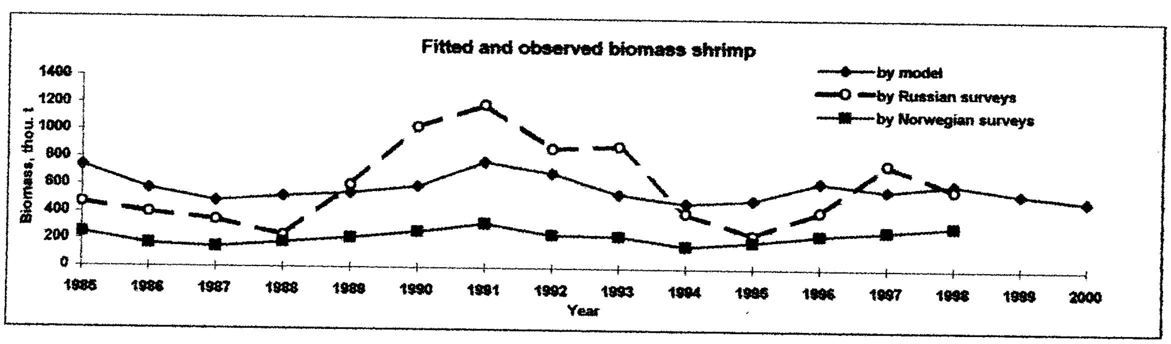


Fig. 7. Shrimp biomass in the Barents Sea by SSVPA by Russian surveys.

	U,kg/hou	R, mln	C	Cod,thou.t	B,thou.t	Uhat	Sq. error	B,thou. t survey	B,thou. t survey96	alpha	0,57500679
					969,50					beta	0,15178927
1985	254,95	2275	120	998,1	736,44	267,86	166,74	246,00	468,00	gamma	0,3140347
1986	236,18	1819	60	1488,2	570,47	205,21	959,30	166,00	399,00	delta	0,04643286
1987	159,75	1625	32	1283,5	483,08	165,43	32,21	146,00	346,00	B0	969,50
1988	146,27	2163	37	1128,5	516,70	156,98	114,76	181,00	233,00	SSE	4714,92
1989	148,17	2285	54	982,4	544,33	166,60	339,63	216,00	603,00	n	16
1990	181,12	2679	74	1132,7	593,04	178,59	6,42	262,00	1028,00	p	4
1991	208,89	3786	76	1450,6	772,32	214,39	30,20	321,00	1192,00	min. SSE	1876,59
1992	227,77	2682	59	2163,7	691,72	229,88	4,45	239,00	876,00	F	18,15
1993	190,28	2290	55	3246,6	539,59	193,34	9,35	233,00	892,00		
1994	162,58	1958	29	2209,0	475,90	159,45	9,79	161,00	404,00		
1995	128,24	2252	24	1941,6	501,32	153,44	635,12	193,00	248,00		
1996	160,96	3008	25,2	1935,4	629,78	177,60	276,98	242,00	420,00		
1997	203,00	2189	32,1	1955,6	571,49	188,62	206,78	276,00	765,00		
1998	231,00	2661	30,8	1751,6	620,39	187,15	1923,18	311,00	577,00		
1999		2000	30	1724,1	550,25	183,81					
2000		2000	28	1952,6	501,31	165,11					
2001		2000		2184,4	490,41						
2002		2000		2383,9	474,88						



The observed CPUE and the predicted CPUE by years, kg/hr



The observed and the predicted stock size of shrimp, thou. t

Fig. 8. Shrimp biomass computations, spreadsheet model.