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The state of the walleye pollock in the northern part of the Okhotsk Sea, North Pacific

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Abstract

Aspects of pollock biology, including growth and mortality rates are presented, based on 4 years (1991–1994) sampling of Polish commercial catches in the international waters of the Okhotsk Sea. To estimate stock dynamics, production models were fitted using Russian CPUE data, 1985–1993.

The length of fish in the catches ranged from 23 to 65 cm, with a dominant mode of 35–45 cm. Fish aged 2–22 years were recorded, with fish 4–8 years old dominating the catch. The mean age and length of the exploited fish were stable in the period analyzed. The von Bertalanffy's growth curves fitted to males and females separately showed a significantly higher asymptotic length for females. Specimens with gonads at the spawning stage were found in the catches, suggesting that the spawning ground is nearby.

Biomass estimates for the most recent years were about 10 million tons, and mean fishing mortality was 0.19. The natural mortality value obtained by the Pauly (1980) formula was 0.2. The optimum catch levels, resulting from production models, slightly exceed 2 million tons, and the optimum fishing mortalities are in the range 0.27–0.30. This is consistent with the *F*-0.1 value from the yield per recruit analysis. © 1997 Elsevier Science B.V.

Keywords: Okhotsk Sea; Population dynamics; Walleye pollock

1. Introduction

Walleye pollock (*Theragra chalcogramma*) occurs throughout the North Pacific, from the coasts of Canada through the Gulf of Alaska, the Bering Sea, the Aleutian Islands and the Sea of Okhotsk, up to the southern part of the Sea of Japan. Total pollock catches equalled 6.7 million tons in 1986–1987 (FAO, 1995), giving this species the first place in total world catches. In 1993 total pollock catches decreased to 4.6 million tons.

Most pollock live near the bottom on the continental shelf and slope, although in some areas adult fish occur in large numbers in the mesopelagic zone of deep waters. The Aleutian Basin in the Bering Sea, where pollock were found for the first time in 1979 (Okada and Yamaguchi, 1985), and deep waters of the Sea of Okhotsk (Temnykh, 1989) are among such areas.

The Sea of Okhotsk is one of the main areas of occurrence of pollock. Annual catches equalled about 1.8 million tons in recent years (Temnykh, 1991).

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Pollock biomass constituted about 80% of total fish biomass, estimated in 1988 at 14.3 million tons (Shuntov et al., 1990).

Exploitation of pollock resources in the international waters of the Sea of Okhotsk by the fleets of China, South Korea and Poland began in 1991. These waters, situated in the central part of the Sea of Okhotsk and also called the 'Peanut Hole', extend over an area of about 65 000 km (Fig. 1). Reported catches of pollock from these waters reached 698 000 ton in 1992 (Table 1).

Despite intensive investigations conducted in recent years by Russian scientists, the population structure of pollock in the Sea of Okhotsk is still not clearly understood. According to various authors, from two to ten populations may be distinguished (Temnykh, 1991). However, Temnykh points out that these different opinions are a result of there being no clear-cut definition of the term 'population'. In the northern part of the Sea of Okhotsk, Vyshegorodtsev (1987) distinguishes two isolated pollock populations: north-eastern and north-western. Fadeev (1987) recognises a number of local spawning grounds, while Vdovin and Smirnov (1992) distin-

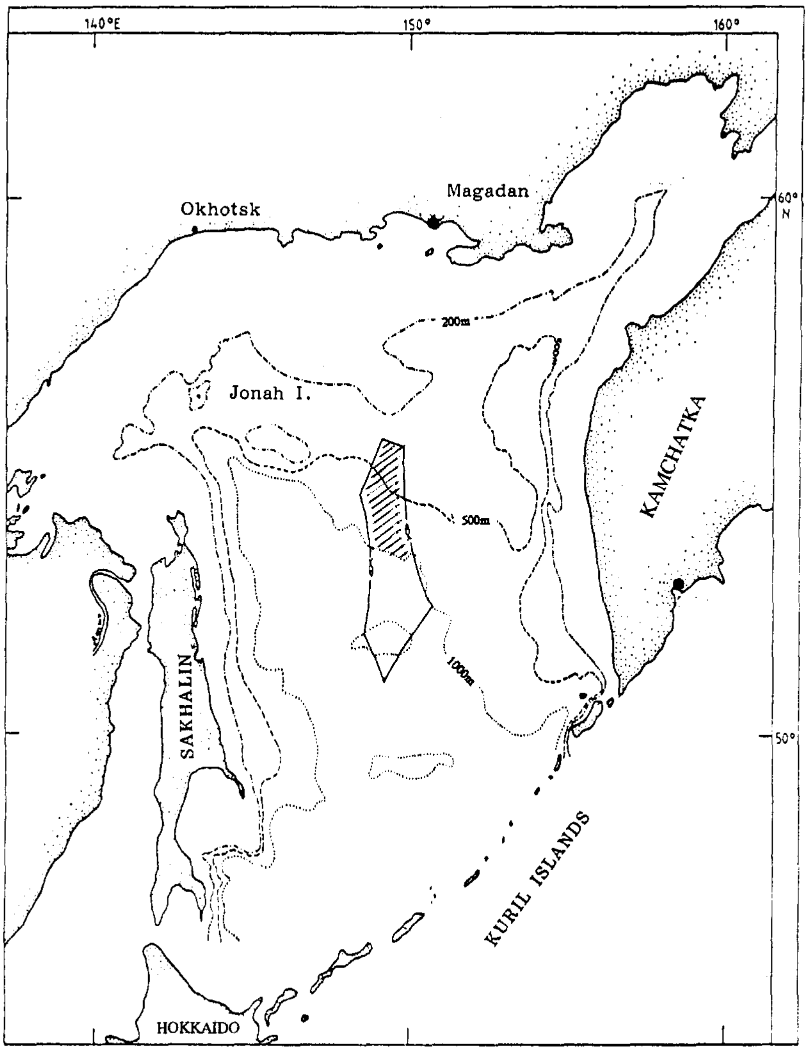

Fig. 1. The Sea of Okhotsk showing the zone of international waters (line marked by fish) and the area of studies in 1991–1994 (hatched).

Table 1
Pollock catches in the northern part of the Sea of Okhotsk in 1985–1994 (10^3 tons) (Anonymous, 1993)

Year	International waters					EEZ	
	China	Japan	Korea	Poland	Total	Russia	Total
1985	–	–	–	–	–	1515	1515
1986	–	–	–	–	–	1465	1465
1987	–	–	–	–	–	1515	1515
1988	–	–	–	–	–	1368	1368
1989	–	–	–	–	–	1442	1442
1990	–	–	–	–	–	1483	1483
1991	57	–	64	176	297	1490	1787
1992	172	–	228	298	698	1269	1967
1993	42 [a]	–	101 [a]	235	535 [b]	1104 [b]	1639 [b]
1994	nd	–	nd	270	nd	nd	nd

[a] January–March.
[b] Forecast.
nd, no data.

guish three main spawning stocks: western Kamchatka, Central and Skhalin–Iona.

Many authors agree that the population structure of pollock is very complex and little understood because spawning grounds are not isolated during spawning (Temnykh, 1991) and because of mixing of fish during feeding migrations (Temnykh, 1989, 1990, 1991; Vdovin and Smirnov, 1992). The figure presented by Vdovin and Smirnov (1992) suggests that mixing of fish takes place in the central part of the Okhotsk Sea, including the area of international waters.

There was no unanimous opinion on the presence of pollock in the deep water of the Okhotsk Sea. Fadeev and Suchkova (1987) excluded the deep-water part of the Sea of Okhotsk even as a feeding area for pollock. Other authors (Temnykh, 1989; Vdovin and Smirnov, 1992) stated that the feeding area of adult pollock covers practically the entire sea, including deep waters. Temnykh (1990) states that about 16% of total pollock biomass in the Sea of Okhotsk may be found in the deep-water area.

This paper presents some aspects of the biology of pollock, and estimates of growth and mortality of pollock exploited in the international waters of the Okhotsk Sea in 1991–1994. Also, the dynamics of the pollock biomass in the northern part of the Okhotsk Sea is estimated using production models based on Russian CPUE data.

2. Materials and methods

Investigations were carried out on Polish commercial vessels fishing for pollock in the international waters of the Sea of Okhotsk in the period 1991–1994. In 1991 the investigations were conducted in the second half of the year, and in the remaining years during the first half of the year. A total of about 150000 pollock specimens were sampled for length distribution, and over 9000 fish were subjected to a detailed biological analysis, of which 6039 were aged.

Each sample for length distribution consisted of about 800 pollock individuals randomly collected from the haul. The fish, divided by sex, were measured from the tip of the snout to the fork of the caudal fin (fork length), to the nearest centimetre below. Each detailed biological analysis consisted of 100 fish, of which 80 were sampled randomly and 20 were selected from the least numerous, extreme length classes. Each fish was measured, weighed to an accuracy of 10 g, and sex and gonad maturity stage, according to the 8-stage Maier scale (FAO, 1965), were determined (Stage I, virgin; Stage II, maturing virgin and recovering spent; Stage III, developing; Stage IV, developed; Stage V, gravid; Stage VI, spawning; Stage VII, spent; Stage VIII, resting). The age of the fish was determined from otoliths, according to the method accepted at a meeting of a special Working Group for pollock age determination, held in September 1990 at the Sea Fisheries Institute in Gdynia (Anonymous, 1990). The length distribution in the catch was used to convert the age distribution in the biological samples (in which 20% of fish was not randomly collected) to the age distribution in the catch, and to calculate length and weight at age (so-called age–length key).

To describe the growth of pollock, von Bertalanffy's model was used.

$$l(t) = L_{\inf}\left(1 - \exp\left(-K(t - t_0)\right)\right)$$

where l is length, t is age and $L_{\inf}$, K and t_0 are parameters. The parameters were determined by minimization of the sum of squared differences between the observed length and the modelled length. The calculations were performed separately for males and females, using data from 1991–1994.

Three methods were used to estimate the total mortality coefficient, Z:

- analysis of the catch curve;
- the formula of Beverton and Holt (1956);

$$Z = K(L_{inf} - l_{mean})/(l_{mean} - l_c)$$

where l_c is the length at which all fish are fully exploited and l_{mean} is the mean length of fish equal to or longer than l_c.

- comparison of CPUE in numbers at age of the Polish fleet in the first half of 1993 and 1994.

In the first and second methods the data from 1991–1994 were used, and the analyses were made separately for males and females. The first fully exploited age was assumed to be 5 years for males and 6 years for females. Having the mean length of fish at age, l_c was taken to be 38 and 40 cm for males and females, respectively.

To evaluate the natural mortality, M, the Pauly (1980) formula was applied.

$$\ln M = -0.0066 - 0.279 \ln L_{inf} + 0.654 \ln \times K + 0.463 \ln T$$

where T is mean annual surface water temperature.

The yield per recruit model of Beverton and Holt (1957) was used to determine values of F-0.1 and F_{max}.

Finally, stock-production models were applied to estimate the maximum sustainable yield (MSY) and the dynamics of the stock biomass. This approach also gives the estimates of fishing mortality, F. The basis for the analysis was Russian data on catch per tow for 1985–1993 (Table 2) (Anonymous, 1993). With these data and the total international catch, the index of the fishing effort was calculated. The Schaefer (1954) model

$$dB/dt = rB(B_{inf} - B) - qfB$$

and the Fox (1970) model

$$dB/dt = rB(\ln B_{inf} - \ln B) - qfB$$

were fitted, where B is biomass, t is time, f is fishing effort, and parameters r, B_{inf} and q denote intrinsic growth rate, asymptotic biomass and catchability coefficient, respectively. The procedure for the estimation of the parameters of the model was that

Table 2
CPUE values for pollock in the northern part of the Sea of Okhotsk in 1985–1994 (Anonymous, 1993)

Year	International waters					EEZ Russia	
	China	Korea		Poland		t/d	t/tow
	t/d	t/d	t/h	t/d	t/h		
1985	–	–	–	–	–	48.2	18.0
1986	–	–	–	–	–	55.4	19.2
1987	–	–	–	–	–	55.6	19.6
1988	–	–	–	–	–	56.9	19.3
1989	–	–	–	–	–	65.5	23.0
1990	–	–	–	–	–	77.7	27.4
1991	50.1	56.0	4.3	40.6	4.0	70.2	26.4
1992	57.1	55.6	3.7	38.6	2.6	63.7	23.3
1993	87.1 [a]	60.0 [a]	4.8 [a]	40.5	3.0	61.5 [b]	25.2
1994	nd	nd	nd	42.1	3.6	nd	nd

t/d, tons per day; t/h, tons per hour; t/tow, tons per tow.
[a] January–March.
[b] Forecast.
nd, no data.

presented by Rivard and Bledsoe (1978) for non-equilibrium conditions. This was based on the Fletcher (1978) restructuring of the Pella and Tomlinson (1969) model

$$dB/dt = gmB/B_{inf} - gm(B/B_{inf})^n - qfB$$

where

$$g = n^{n/(n-1)}/(n-1)$$

m denotes maximum productivity and n is a parameter determining the curvature of the model. Putting $n = 2$ and $n = 1.01$ gives the Schaefer model and an approximation of the Fox model, respectively. The full general production model of Pella and Tomlinson (1969) was not applied as the data series was too short to fit a model with an additional parameter (n). The unknown parameters B_{inf}, m and q were estimated by minimization of the sum of the squared relative residuals of catches (Rivard and Bledsoe, 1978)

$$SS(B_{inf}, m, q) = \sum_{t=1985}^{1993} \left[(Y_m(t) - Y_o(t))/Y_m(t) \right]^2$$

where Y_m denotes the catches resulting from the assumed model and Y_o denotes the observed catches. The value of the biomass at the beginning of 1985

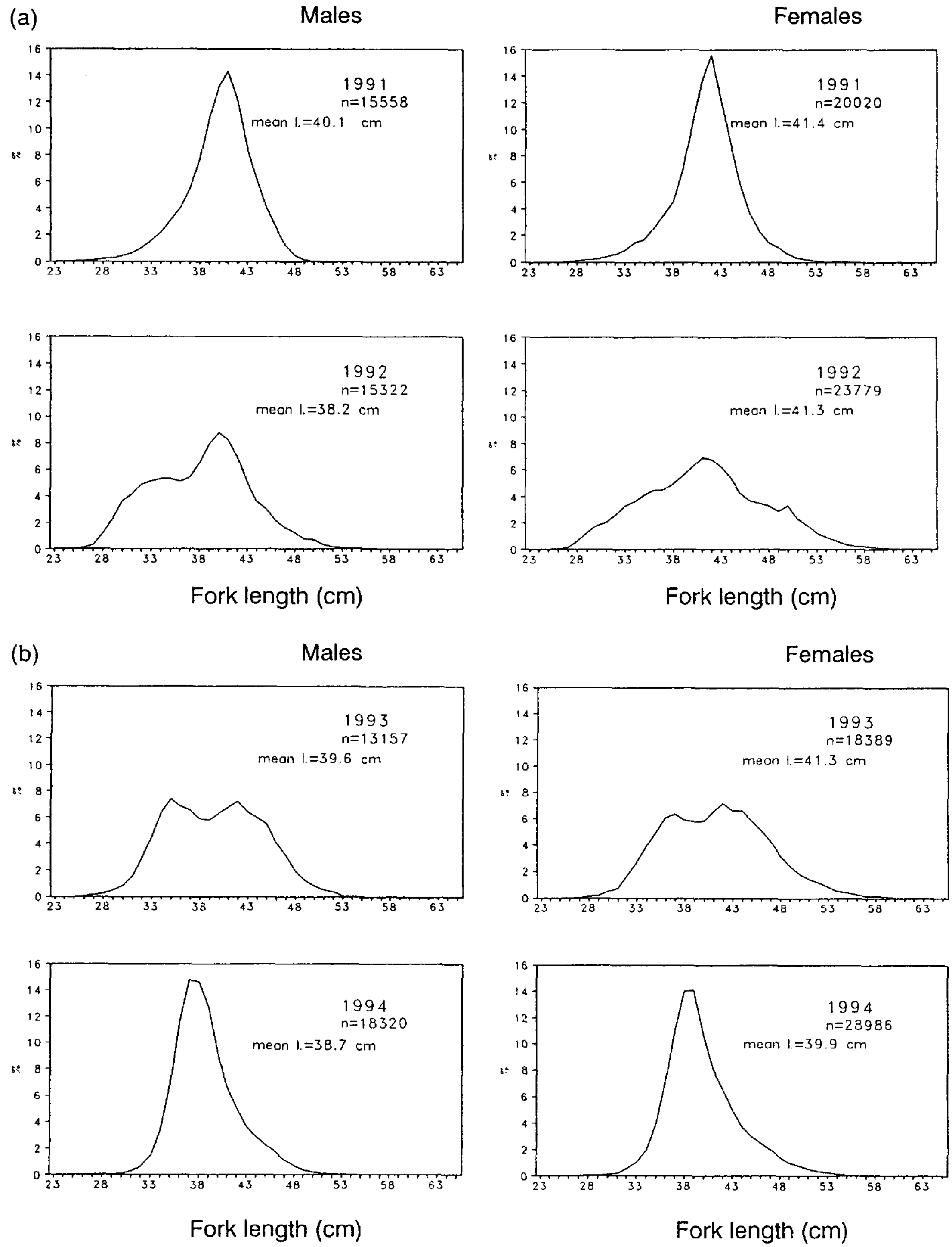

Fig. 2. Length distribution of pollock in Polish catches in international waters of the Sea of Okhotsk in 1991–1994 (n denotes the number of fish measured).

was taken as 6.605 million tons, which is the estimate of biomass on the basis of a Russian ichthyoplankton survey (Anonymous, 1993).

3. Results

3.1. Catches and CPUE

Until 1984, fishing for pollock in the Sea of Okhotsk was mainly conducted off southwestern Kamchatka, round the Kuril Islands, and between the islands of Sakhalin and Hokkaido, i.e. in the southern part of the Okhotsk Sea. In 1984 the USSR fleet also began fishing in the northern part of the Sea of Okhotsk, annually catching about 1.4–1.5 million tons. The Japanese catches in 1987–1990 in the northern part of the Okhotsk Sea were negligible. In 1991, the fleets of China, South Korea and Poland began exploiting pollock stocks in international waters.

In 1992, total pollock catches in the northern part of the Sea of Okhotsk equalled 1 967 000 tons, including 698 000 tons in international waters and 1 269 000 tons caught by Russia in its own economic zone (Table 1). In 1993, pollock catches were lower than in 1992 because of voluntary reductions (by 25%) of fishing effort made by the countries fishing in international waters.

The CPUEs attained by the Russian fleet in the northern part of the Sea of Okhotsk in 1985–1990 were very high, ranging from 48 to 78 tons per day (Table 2). Beginning in 1991, i.e. the year when fishing operations for pollock in international waters began, CPUE values in the Russian economic zone remained at a level of 62–70 tons per day for 3 years. They were higher than CPUEs attained in international waters, where the average CPUE of the fleets of China and South Korea was 50–60 tons per day. The CPUEs of the Polish fleet in 1991–1994 remained at a stable level of about 40 tons per day (Table 2). The CPUEs of the Russian fleet in tons per tow exhibited a pronounced upward trend from 18–19 tons in 1984–1985 to 23–27 tons in 1989–1993.

The marked differences between Polish CPUE data from international waters and the Russian CPUE data from the shelf area are to a large extent caused by different methods of fish processing. Polish factory trawlers are mainly processing fish for fillets, and the maximum production of the fish factory on a vessel is about 45 tons per day. There are no such marked differences between Russian CPUE on the shelf and Chinese or Korean CPUE in international waters, as the processing methods are similar in these fleets.

The CPUE values in tons per hour fished are available only for the fleets of South Korea and Poland. They ranged from 2.6 to 4.8 tons per hour, depending on the year. After a decrease of CPUE in 1992, the CPUE increased during the next 2 years (Table 2).

3.2. Length distribution of pollock

Pollock ranging from 23 to 65 cm occurred in Polish commercial catches during the study period. Fish with a length of 35–45 cm predominated (Fig. 2). The proportions of these length classes in each year of exploitation were: 1991, 88%; 1992, 62%; 1993, 69%; 1994, 87%. Fish of lengths below 32 cm

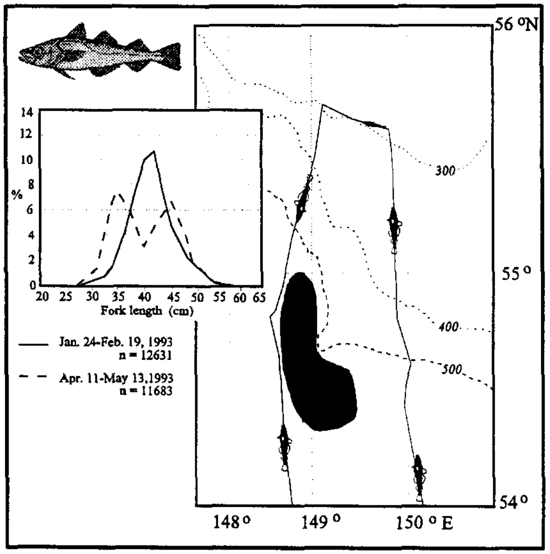

Fig. 3. Length distribution of pollock caught in the same area but during different periods in 1993 (the black area is the sampling area in the periods 24 January to 19 February and 11 April to 13 May 1993; the line marked by fish indicates international waters; n denotes the number of fish measured).

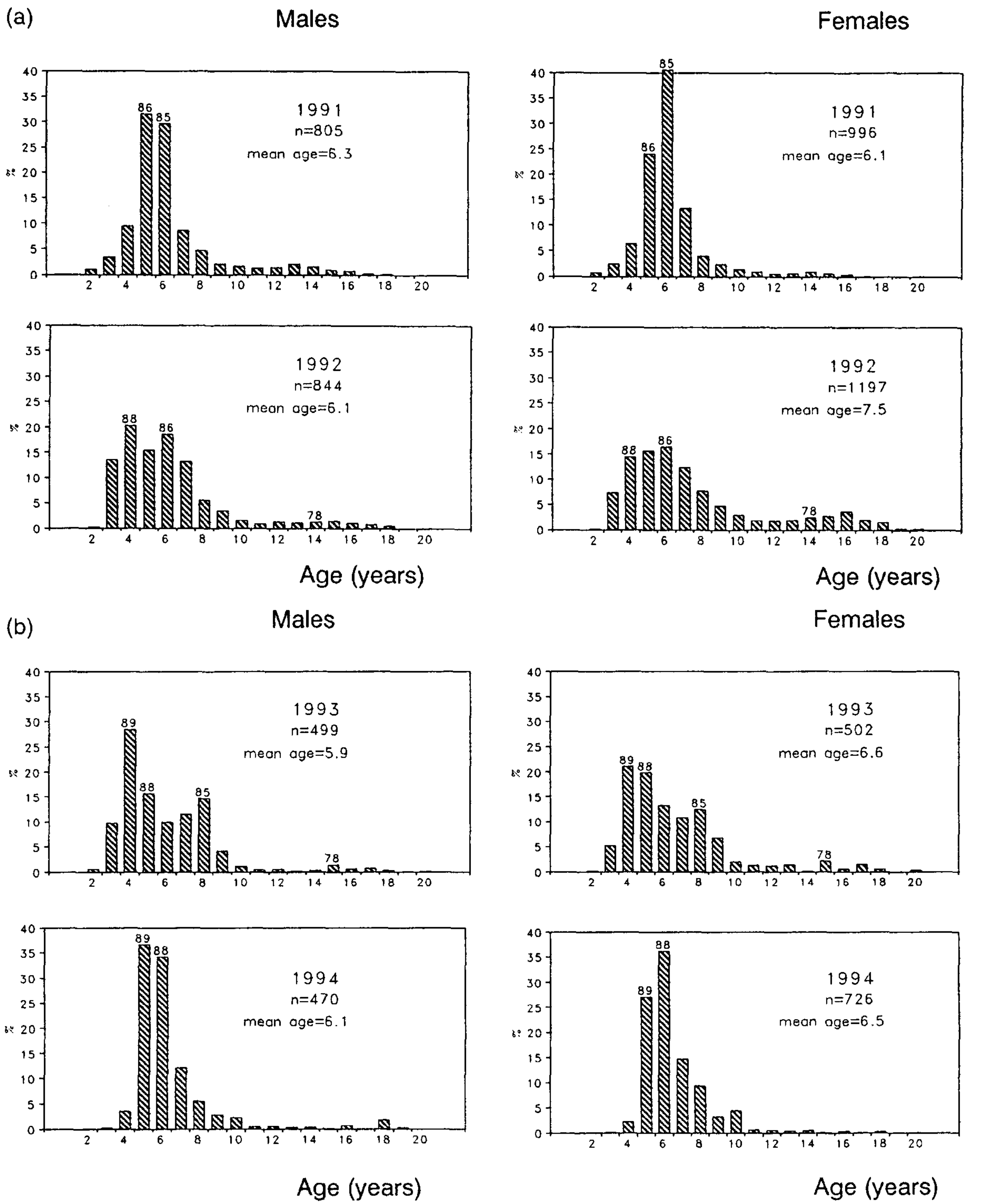

Fig. 4. Age distribution of pollock in Polish catches in international waters of the Sea of Okhotsk in 1991–1994 (n denotes the number of fish sampled).

constituted only 1.3% of the catches in 1991, 8.3% in 1992, 2.3% in 1993 and 0.3% in 1994. Single specimens of pollock with a length of over 65 cm also occurred in the catches. The highest recorded length was 75 cm. The mean length of pollock during the 4-year study remained at a stable level of about 40 cm.

Pollock length distribution curves differed considerably in shape in most years. The length distributions for males were generally similar to those for females, but the distribution curves of females were shifted towards greater lengths. As a result, the mean length of females was greater than that of males by about 1.5 cm.

The pollock length distributions may differ considerably even when sampling site and time are similar. An example of the variability of pollock length distributions is shown in Fig. 3. Catches were taken in the same area but with a time lapse of 2 months, which resulted in the shape of the curves being completely different.

3.3. Age composition of pollock

The age composition of pollock in Polish catches taken in international waters is shown in Fig. 4. Fish aged 2–22 years occurred in these catches. Fish age 2 years were very scarce, as were fish older than 17 years. During the 4 years fish aged 4–8 years predominated. In 1992, fish aged 12–18 years constituted 13% of the catches. In the remaining years the proportion of these age-groups in the catches was lower.

In 1991, two year-classes (1985 and 1986) dominated the stock and constituted about 60% of catches by number. In 1992, there were strong year-classes in 1988 and 1989. The catches in 1992 were based on a similar proportion of five year-classes (1985–1989). In 1993 the strong year-classes of 1989 and 1988 began to dominate and their share in the number of catches increased to about 70% in 1994. The age composition of the catch is well reflected in the length distribution (Fig. 2). The strong 1988 and 1989 year-classes are seen as the left-hand peak in length distributions from 1992 and 1993, and the single peak in the 1994 length distribution.

The three year-classes of 1985, 1988 and 1989 were most visible during the 4 years of pollock exploitation. The mean age of pollock ranged from 6.2 to 6.4 years, with the exception of 1992, when, because of the considerable proportion of older fish in the catches, it equalled 7 years.

Table 3
The parameters of the von Bertalanffy growth equation of pollock with their standard errors and the value of r^2

Parameter	Males	Females
L_{inf} (cm)	48.4 ± 0.5	53.3 ± 0.5
K	0.231 ± 0.021	0.177 ± 0.011
t_0	-1.56 ± 0.39	-1.93 ± 0.30
r^2	0.92	0.97

3.4. Growth of pollock

The parameters of von Bertalanffy's growth model with their standard errors are presented in Table 3. Fig. 5 shows the shape of the theoretical growth curve and the observed length. The approximate 95% confidence limits of the asymptotic length (estimate $\pm$ 1.96 $\times$ standard error) of males and females do not overlap, indicating a significantly higher asymptotic length for females. The K value of males is

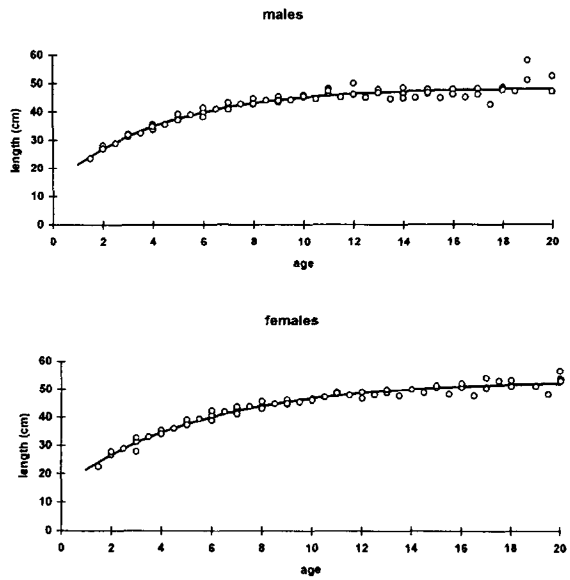

Fig. 5. Growth of pollock modelled by von Bertalanffy's equation and the observed length in 1991–1994 for males and females (each open circle represents the observed mean length at age in one of the years in the period specified).

higher than that of females, but the approximate 95% confidence limits of both values slightly overlap.

3.5. Gonad maturity of pollock

In 1993 and 1994, observations of pollock gonad maturity were conducted in the first half of the year (January–June), covering the pre-spawning, spawning and feeding periods. In both years the development of the gonads was similar. In January and February, the gonads of the majority of fish were developed (Fig. 6). In March, gonads matured rapidly and a considerable number of fish reached the gravid stage, while some specimens were even at the spawning or spent stages. Peak spawning of pollock caught in open waters took place in April, and the main spawning ground is probably situated nearby. The spawning period of pollock is extended in time. Specimens with gonads at the spawning stage were encountered as late as May or even June. Young fish with gonads at the maturing virgin stage were observed in all samples.

3.6. Total, natural and fishing mortality

The estimates of total mortality resulting from the catch curves (Fig. 7) are presented in Table 4. The 1991 catch curve gave $Z=0.36$ for males (age 5–18) and $Z=0.52$ for females (age 6–20). The exclusion of points representing ages 17 and 20 (which seem to be outliers in female catch curves) produced $Z=0.41$ for females. These estimates would represent the total mortality at the beginning of exploitation in international waters if the stock

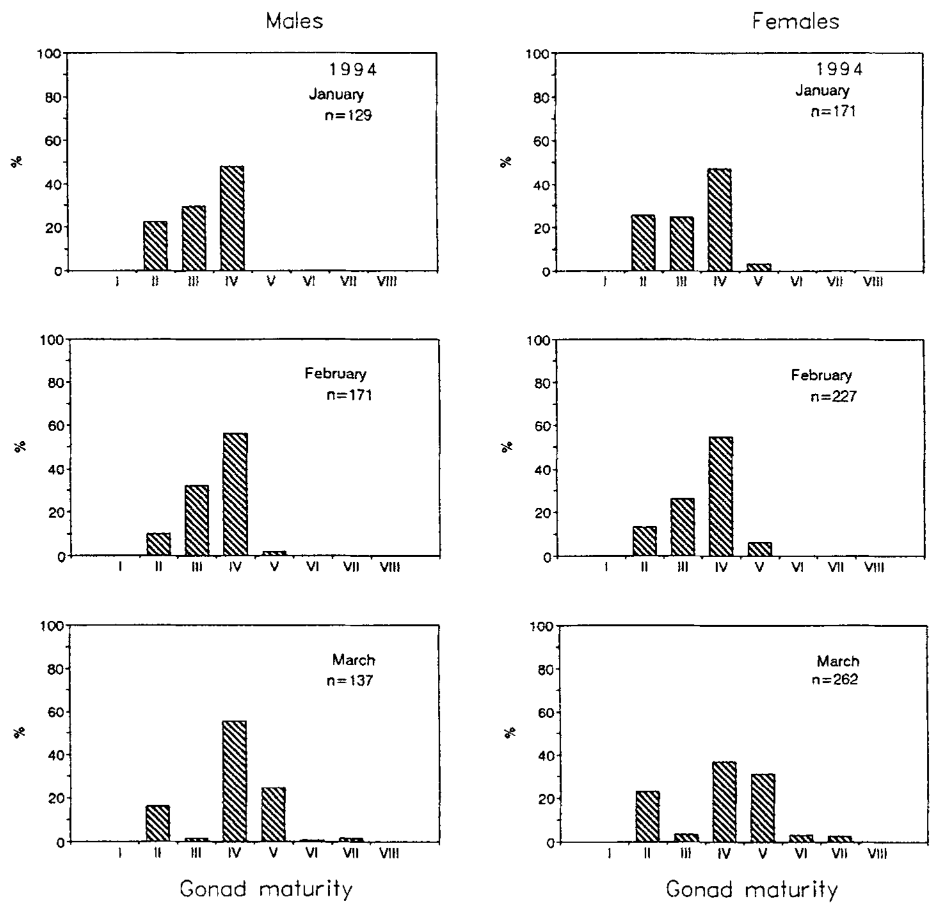

Fig. 6. Gonad maturity stages of pollock according to the Maier scale from January to June 1994 (n denotes the number of fish sampled).

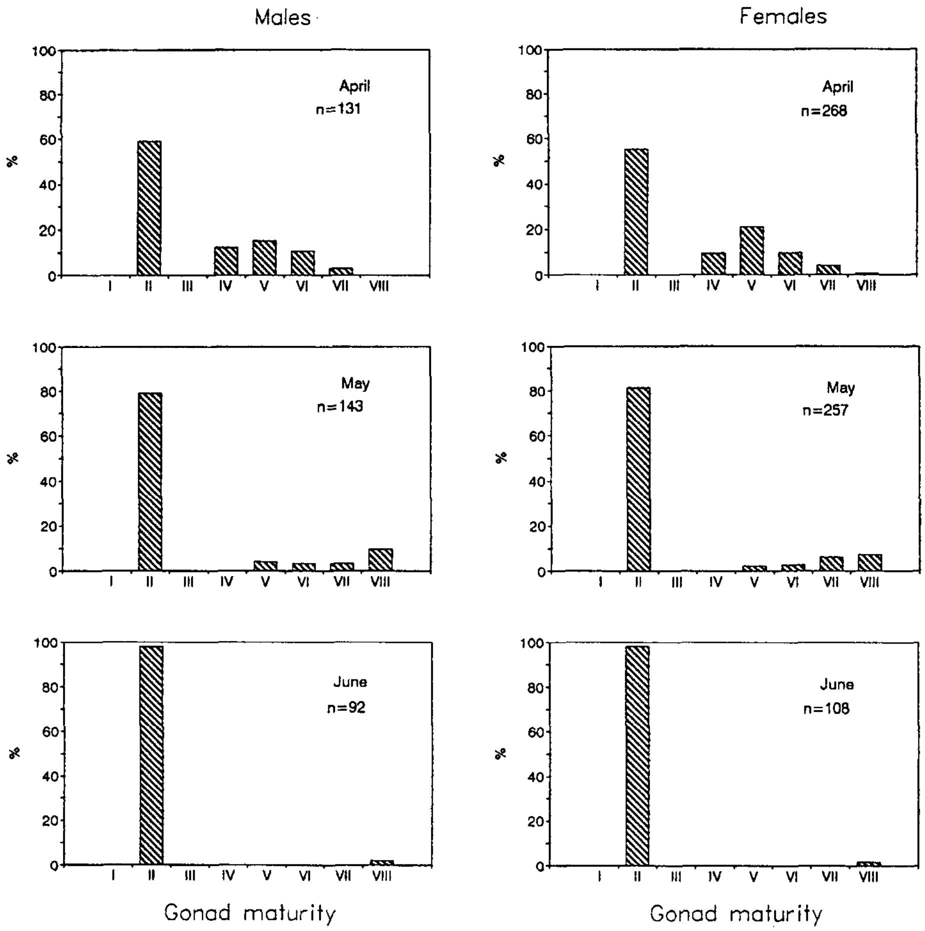

Fig. 6 (continued).

was in equilibrium in the few years before 1991. Russian CPUE values are very stable in 1985–1988 and increase in 1989–1990. This suggests a relative stability in the pollock resources over the greater part of that period, so our estimates of Z roughly reflect the true values. The data for 1991 refer to the second half of the year (while all data for 1992–1994 refer to the first half of the year), so catch curves for the first half of 1992 were also determined to give another approximation of the total mortality at the beginning of the exploitation in international waters. Assuming again that the stock was in equilibrium in the few years before 1992, the Z estimate is 0.26 for males and 0.25 for females. The mean catch curves for 1991–1994 give $Z = 0.33$ for males and $Z = 0.37$ for females. This should roughly represent the mean total mortality in 1991–1993. Two parts of the catch curves may be distinguished: a steeper one for ages 6–11 and a less steep one for ages over 11. This may suggest that the fishery in the Russian EEZ exploits younger pollock than the fishery in international waters. Moreover, younger fish are probably under-represented in international waters, and thus the total mortality determined by our method may also be underestimated.

The estimates of mean Z for 1991–1993, based on the Beverton and Holt (1956) formula (Table 5), indicate higher total mortality than the catch curve estimates. The mean Z value for males is 0.43 and that for females is 0.42. Assuming that the von Bertalanffy's parameters determined for 1991–1994 are appropriate for describing growth before 1991,

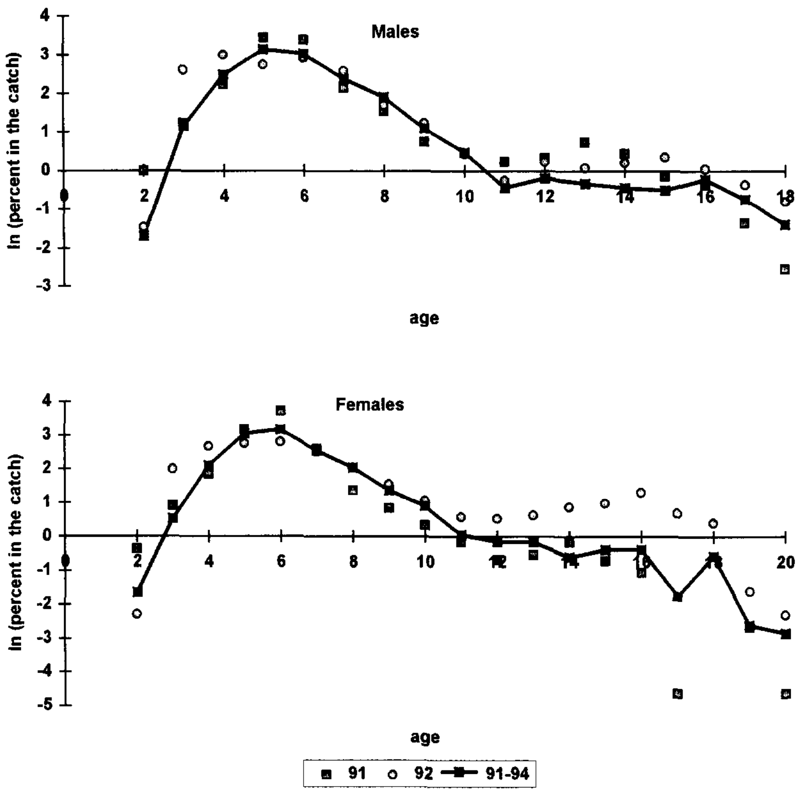

Fig. 7. Catch curves of pollock males and females in 1991 and 1992, and the mean for 1991–1994.

and that the stock was in equilibrium in the last few years before 1991, the length distribution in 1991 and 1992 may be used for an approximate determination of the total mortality at the beginning of the exploitation in international waters. The Z estimates based on the 1991 length distributions are 0.48 and 0.63 for males and females, respectively, while the values resulting from the 1992 length distribution give $Z=0.40$ and $Z=0.27$ for males and females, respectively.

The Polish CPUE in 1994 increased so much in relation to the 1993 values that the logged ratio of CPUEs in numbers at age for the same cohorts in both years produced negative estimates of mortality, so this method of deriving total mortality had to be rejected.

A rough evaluation of natural mortality was obtained from the Pauly (1980) formula. Taking the mean water temperature as 3.5°C (Morskoj Atlas, 1963) and using the calculated values for the parameters of the von Bertalanffy growth equation, gives an estimate of $M=0.23$ for males and $M=0.19$ for females. Thus, in the present paper M was assumed

Table 4
Estimates of the total mortality of pollock exploited in international waters, using the catch curves and their standard errors

Option	Males	r^2	Females	r^2
Data from 1991	0.36 ± 0.04	0.86	0.52 ± 0.08	0.81
Data from 1992	0.26 ± 0.04	0.81	0.25 ± 0.05	0.70
Mean 1991–1994	0.33 ± 0.04	0.87	0.37 ± 0.03	0.91

Table 5
Estimates of the total mortality of pollock exploited in international waters, calculated using the Beverton and Holt (1956) formula

Option	Males	Females
Data from 1991	0.48	0.63
Data from 1992	0.40	0.27
Mean 1991–1994	0.43	0.42

Table 6
Parameters of the production models with their standard errors, and the minimal sum of squares of residuals, SS

Parameter	Schaefer model	Fox model
m (10 ton)	2067 ± 253	2076 ± 367
B_{inf} (10 ton)	15240 ± 3573	18656 ± 8503
q	0.0026 ± 0.00024	0.0026 ± 0.00026
SS	0.035	0.036

to be 0.2. Averaging the mean total mortality for males and females in the 1991–1993 period as obtained by both methods (Tables 4 and 5) and subtracting 0.2 leads to an estimate of the mean fishing mortality for 1991–1993 of 0.19.

3.7. Biomass and the optimum catch level

To fit both the Schaefer and Fox models, several starting values for the unknown parameters were employed to increase the probability of finding a global minimum. Starting values for B_{inf} were taken as 8000, 10000, 12000 and 14000, and starting values for the maximum productivity, m, were taken as 1500, 2000, 2500 and 3000. Next a series of fits of the models were performed starting with all possible combinations of the initial parameter values given above. The best fit of the Schaefer model produced the $B_{inf} = 15240$, $m = 2067$ and $q = 0.0026$. Table 6 gives parameter values with their approximate standard errors and the sum of squared residuals. For the Fox model, the best fit was obtained with $B_{inf} = 18656$, $m = 2076$ and $q = 0.0026$. Fig. 8 shows the equilibrium catch curves and the observed catch versus fishing effort for both models. Relative residuals of the modelled catch are shown in Fig. 9. The observed catch and effort values refer to the left limb of the equilibrium catch curve, which makes it diffi-

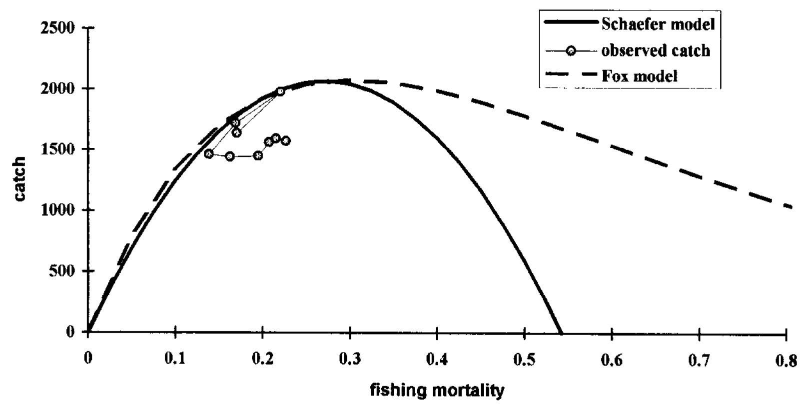

Fig. 8. The equilibrium catch (10^3 tons) for pollock on the basis of the Schaefer and Fox models and the observed catch versus fishing mortality.

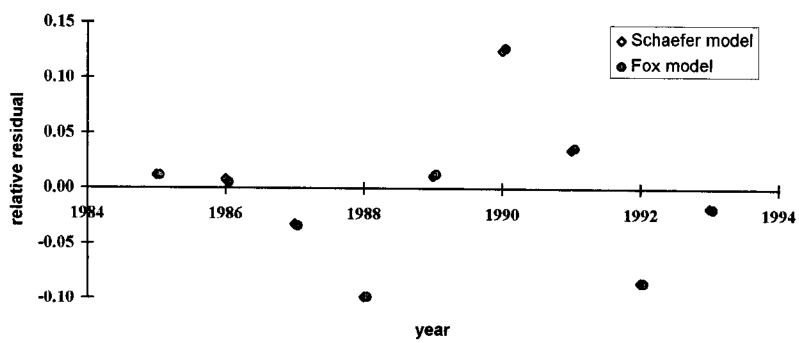

Fig. 9. The relative residuals of the catches in the Schaefer and Fox models.

Table 7
Estimates of the biomass (10^3 tons) and fishing mortality resulting from the production models, and biomass on the basis of the Russian ichthyoplankton survey

Year	Biomass		Mortality (A and B)	Biomass (ichthyoplankton survey)
	A	B		
1985	6605 [a]	6605 [a]	0.22	6605
1986	7094	7123	0.22	8762
1987	7574	7607	0.21	9103
1988	8022	8043	0.20	8263
1989	8465	8472	0.16	6585
1990	9055	9051	0.14	5293
1991	9708	9705	0.17	4720
1992	9937	9952	0.22	4796
1993	9674	9700	0.17	
1994	9904	9939		

A, Schafer model; B, Fox model.
[a] Assumed on the basis of the Russian ichthyoplankton survey.

cult to determine which model is more appropriate. In both cases, the residuals (Fig. 9) and the sum of squared residuals (Table 6) are very similar. However, the MSY and catchability values obtained are also very similar, leading to a similar management conclusion from both models. The estimated biomass according to both models (Table 7) increased from about 7 000 000 tons in 1985–1986 to almost 10 000 000 tons in 1991–1994. The values of fishing mortality based on the estimated catchability and fishing effort ranged from 0.14 in 1990 to 0.22 in 1985. Taking a natural mortality of 0.2, the estimate of the total mortality for 1991–1993 was about 0.39, which was the same as the estimate of Z for 1991–1993 obtained by using both the catch curve and the Beverton and Holt (1956) formula and referring to part of the resources exploited in international wa-

Table 8
Comparison of fishing mortality at MSY, F_{MSY} resulting from the production models and F-0.1 from the yield per recruit model

Model	F_{MSY}	F-0.1		F_{max}	
		Males	Females	Males	Females
Schaefer	0.27				
Fox	0.30				
Yield per recruit					
$t_c = 4$		0.29	0.26	2.0	1.3
$t_c = 5$		0.31	0.28	?	?

t_c, age at first capture.

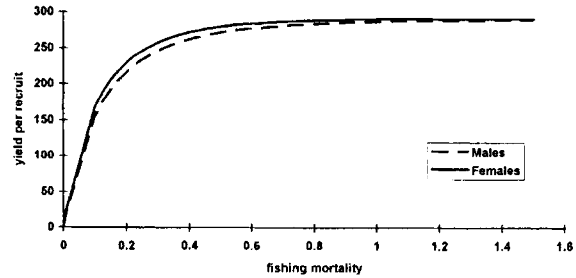

Fig. 10. The yield per recruit (g) according to the Beverton and Holt model for males and females.

ters. The optimum biomass in the Schaefer model is $B_{inf}/2$, which equals about 7 600 000 tons. The present biomass estimate of about 10 000 000 tons is higher than the optimum biomass, and the catches are about 15% lower than the MSY. In the case of the Fox model, the optimum biomass is determined from B_{inf}/e, which equals about 6 860 000 tons. The fishing mortality values producing the MSY are similar for both models: 0.27 for the Schaefer model and 0.30 for the Fox model (Table 8).

The yield per recruit curves of the Beverton and Holt (1957) model for males and females (Table 8, Fig. 10) show F-0.1 values which are consistent with the F values obtained on the basis of production models. The simulations indicate that increasing the age at first capture from 4 to 5 years would increase yield referring to F-0.1 by about 10% at the expense of increasing F-0.1 also by about 10%.

4. Discussion

The investigations conducted by the Sea Fisheries Institute in the Sea of Okhotsk in 1991–1994 were limited to the northern and central part of international waters. Pollock occur all the year round in the area in which the observations were made.

Length distributions of pollock caught in international waters, which exhibit large variability depending on the time and place of the observations, suggest that pollock stocks mix in that area. Fish caught in international waters probably consist of fish from stocks described by Vdovin and Smirnov (1992). Generally, however, the dominance of fish with a length ranging from 35 to 45 cm was most pronounced. The age structure of pollock also exhibits great variability depending on the time and place of the observations. Generally fish aged 4–8 years predominated in the catches. The Russian data from the northeastern part of the Sea of Okhotsk, from 1983 to 1987, show similar trends (Zverikova, 1990). What is characteristic, however, is the total absence of fish older than 9 years in Russian catches. It should be stressed here that Russian scientists use scales for age determination of pollock, which can produce different results, especially for older fish.

The peak of spawning is in March–April in the northeastern part of the Okhotsk Sea and in May–June in its northwestern part (Temnykh, 1990). It appears from studies in international waters that the peak of spawning for fish caught there is in April.

Temnykh (1991) states that there are no evaluations of the degree of isolation among the spawning grounds, and assumes a hypothesis that the northern part of the Sea of Okhotsk is inhabited by populations in which specimens migrate between the spawning grounds, and the degree of their mixing is limited by the distance between the spawning grounds. The proportion of 'local' specimens on each of these spawning grounds is 40–60%. Large-scale migrations are mainly undertaken by fish with lengths exceeding 40 cm. It has been confirmed (Temnykh, 1989, 1990; Vdovin and Smirnov, 1992) that pollock do occur in deep waters. However, Temnykh (1989) reports that despite the presence of mature pollock in deep waters, there is no spawning in this area. The results of our observations indicate that a part of the pollock stock does spawn in deep waters (Fig. 6).

Temnykh (1990) compares pollock migrations into the deep waters of the Sea of Okhotsk with pollock behaviour in the Bering Sea. There is a striking similarity between pollock behaviour in both of these areas. In the deep waters of the Bering Sea there is a pollock stock spawning near Bogoslof Island. Spawning specimens also occur in the international waters of the Bering Sea (Hinckley, 1987; Jackowski and Trocinski, 1989). The deep-water stock, through the process of spawning and recruitment, is to some degree connected with shelf stocks (Wespestad, 1993).

It is relatively easy to identify the specimens belonging to the deep-water stock in the Bering Sea because pollock from deep waters differ distinctly in their length composition, age structure and growth rate from pollock inhabiting the shelf. The deep waters of the Bering Sea are poor in food in comparison with shelf waters, which results in differences in fish growth. A different situation is observed in the Sea of Okhotsk, where feeding conditions in the deep part of the Okhotsk Sea, especially in summer, are very favourable (Shuntov et al., 1990; Temnykh, 1990) compared with those on the shelves. That is why fish growth in the two areas may be similar and the mixing of the stocks makes it difficult to separate the deep-water stock (if it exists) on the basis of the fish growth analysis.

The hypothesis about the existence of such a stock in the Sea of Okhotsk is mainly supported by the fact that old fish, aged up to 22 years, and spawning specimens occur in deep waters. In the Polish catches taken in 1992, pollock aged 14–18 years constituted almost 14% of all fish. In each year of the study, some fish were observed which had spawned in international waters. These are arguments in favour of the possibility of the existence of a separate, deep-water pollock stock in the Sea of Okhotsk, similar to that in the Bering Sea.

Polish biological data were collected in international waters while Russian CPUE records referred to the northern part of the Okhotsk Sea. However, the estimates of fishing mortality for 1991–1993 derived on the basis of Polish data are very similar to the values obtained based on the Russian CPUE series. Further research is needed to find out whether this agreement is accidental or whether it is a result of such a mixing of fish in international waters that samples collected in these waters approximately reflect the stock dynamics in the entire northern part of the sea.

The estimated stock dynamics should be treated with caution. Polish biological data were collected in a limited area, although in this area fish from different parts of the sea probably mix. The Russian CPUE series used in production models is rather short, and standard errors of the B_{inf} are fairly large. Data should be collected from different parts of the sea and the stock structure should be researched in more detail in order to obtain more reliable estimates of stock biomass and MSY values.

Our estimates diverge from the Russian estimates of biomass obtained on the basis of ichthyoplankton surveys in the last 4 years. The ichthyoplankton estimates of biomass (Anonymous, 1993) have their peak in 1987 (over 9 million tons) and then decline, before stabilizing at a level of 5.3–4.7 million tons in 1990–1993 (Table 7). The stock assessment method based on ichthyoplankton monitoring, in which the number of spawning specimens is determined on the basis of the number of eggs, has several disadvantages in the case of the Sea of Okhotsk. The extended spawning time (March–June), the existence of several local spawning grounds, the changeable hydrological conditions, and especially the ice cover in certain spawning areas make it difficult to estimate the stocks. Fadeev and Smirnov (1987) acknowledge that the ichthyoplankton surveys are conducted in an area where the concentrations of eggs and larvae are not known with any certainty, and egg numbers are calculated for areas whose boundaries are determined arbitrarily. The mortality of eggs is not taken into account when calculating stock biomass. They concluded that the spawning stock biomass values obtained by means of ichthyoplanktonic monitoring are distinctly underestimated.

Temnykh (1990) discussed the distribution of pollock in the Okhotsk Sea on the basis of 209 trawl hauls taken in the summer of 1988. Her estimation of the biomass was 11.2 million tons, and there were about 39 billion fish. This estimate of biomass is 40% higher than our estimate for 1988 (Table 7).

Zverikova (1990) stated that natural losses amount to about 25–26%, which is equivalent to an instantaneous coefficient of natural mortality of about 0.3. This value seems to be too high for such long-lived fish as pollock in the Okhotsk Sea, and our estimate of M at a level of 0.2 is probably more reliable.

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