

their behavior in October. Following the arrival of cold water, herring migrated westward, forming non-mobile stocks at the depth of 180-250 m between the Cape of Goven and the Cape of Golenischev in December (Fig. 66).

Since 1993, there has been no single abundant cohort produced by the population. Due to natural

mortality, and fishing, the stock abundance of the Korf-Karaginsky herring has decreased. Moreover, at the present time, hydrological conditions can hardly provide the required biomass of forage zooplankton. This should prolong the feeding period until mid October and expand the feeding area.

## **Survival of yellowfin sole (*Limanda aspera* Pallas) in the northern part of the Tatar Strait (Sea of Japan) during the second half of the 20<sup>th</sup> century**

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The northern part of the Tatar Strait is one of the traditional areas where yellowfin sole (*Limanda aspera* Pallas) dominate, averaging 60% of flounder abundance. The commercial fishery of flounder stocks began in 1943. In 1944, their catch reached the historical maximum – 10.1 thousand tons, but during the following year it reduced up to 7.4 thousand tons, and a catch per unit of effort (CPUE) decreased almost 2 times. Since 1945, the fishery ceased and until the beginning of the 1950s, the flounder catch did not exceed 0.1 – 1.0 thousand tons a year. Regular scientific research on this species was not conducted until 1956. Nevertheless, the data collected on the size composition of flounder catches during 1946, and some similar data since 1956, indicated overfishing in the mid-1940s (Tarasyuk, 1994A). After the 1950s, catch varied from 5.45 thousand tons in 1955 to 0.35 thousand tons in 1979. In the last ten years of the century, the catch constituted 0.4 – 2.0 thousand tons per year.

Age structure of the yellowfin sole population is characterized by an extended age distribution. Fish at age 4 to 18 occur in catches. Age-7 yellowfin sole are usually a modal age group, as their average long-term age value is 8.8. Body weights of yellowfin sole change according to the equation of allometric growth. A coefficient of allometry exponent in the equation is 3.1315, and the scale coefficient is 0.0073 when body weight is measured in grams and length (AC) in cm.

Yellowfin sole from the shelf zone of western Sakhalin cease annual increments at age 8-9+. The instantaneous natural mortality rates vary by age decreasing from 0.22 to 0.12 beginning in age-4 to age-6-8 individuals, respectively, and then gradually increasing to 0.60 at age 15. The broods become fully available to the fishery beginning at age 8.

### **Methods**

Data on the age structure of catches, annual catches, catch per unit of effort, natural mortality by age, rate of maturation, and average body weight by age during the period of 1956-2000 were processed using a method of virtual populations (VPA), with the help of program developed at the Fishery Laboratory Lowestoft (Darby and Flatman 1994). The Loric-Shepherd method was used for adjusting fishing mortality coefficients (Pope and Shepherd 1985).

Further processing of VPA results was done to reveal the causes determining brood year abundances. The abundance estimates of broods at age 4 were used as the index of recruitment. A cohort survival rate at age 4 was estimated as a quotient between the number of age 4 fish obtained from the VPA method, and the number at age 0. The spawning stock was calculated as the total number of the age groups taking into account the rate of maturation, less a year catch, since the fishery in this region is the most intensive before

the beginning of spawning. The number at age 0, or a start number of generation was determined from the number of spawners in the year of reproduction, considering the fecundity and age, and assuming under equal sex ratio from the catches.

## Results

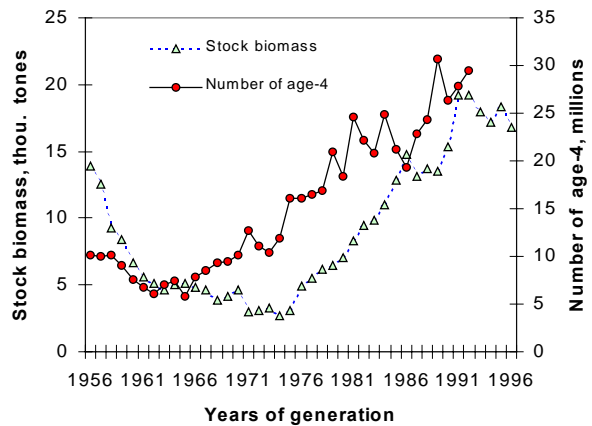
The biomass of the commercial part of the stock calculated by VPA changed significantly during the period of observation. In 1956, it constituted 13.9 thousand tons, reduced to the minimum 2.8 – 3.1 thousand tons in 1971 – 1975, and then began to increase to the maximum 19.2 thousand tons in 1991 – 1992. At the end of the century yellowfin sole stock reduced a little (Fig. 67). The commercial stock varied by 6.9 from 1956-2000. Spawning stock also varied within the wide limits: from the minimum 11.7 million fish in 1970 to 68.8 million fish in 1996, a factor of 5.8. The cohort size at age 4 varied from 6.09 million to 30.62 million fish in the 1962 and 1989 brood years, respectively, a factor of 5.0.

A potential population fecundity or cohort strength at age 0 varied from 4.0 to 25.4 trillion eggs according to changes in spawning stock and its age structure. Survival from age 0 to 4 averaged one individual from 3,000 eggs. This index ranged widely, up to 7.5.

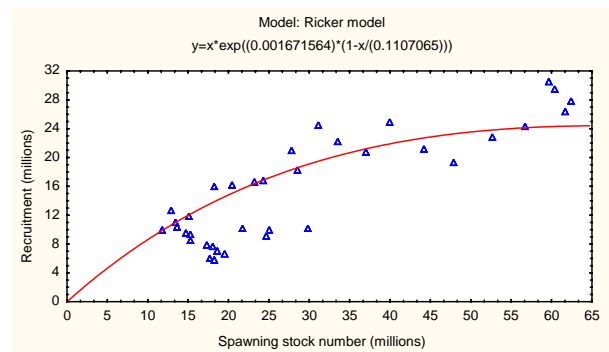
Figure 68 shows the stock recruitment relationship and the estimated Ricker's model. A correlation coefficient with the amount of spawning stock was significant (0.79,  $p < 0.05$ ) for abundance of broods. The portion of the explained dispersion after calculating the coefficients of non-linear regression for the Ricker's model was 63.08%.

The survival rate for generations was well-correlated with the numbers of age group 0; the correlation coefficient was 0.61 ( $p < 0.05$ ). Use of the equation of exponential growth approximated the relationship between those indices, with 37.16% dispersion explained. Based on the estimated curve, survival practically does not change at the initial number of brood more than 7 million individuals, and keeps at a stable level providing a minimum survival for population. Reduction in the number of eggs laid

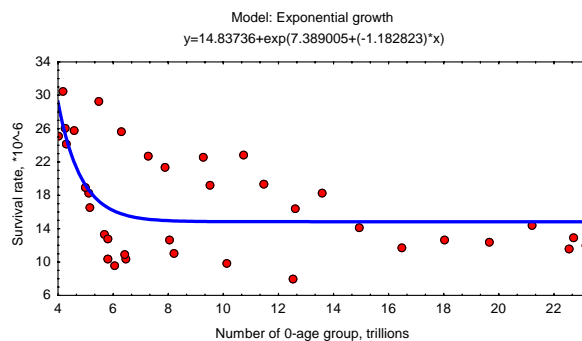
brings about a sharp increase in survival, varying about twofold (Fig. 69). This suggests a density dependent mortality.



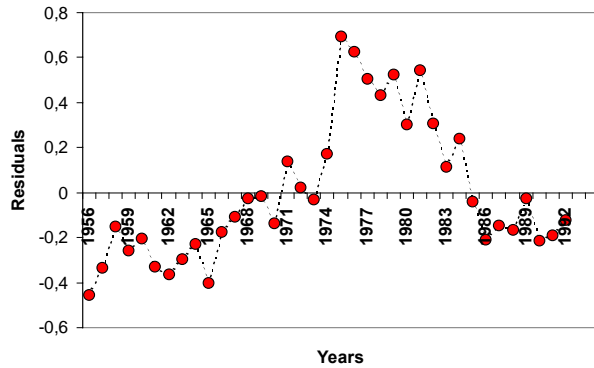
**Fig. 67** Dynamics of biomass of the spawning stock and number of broods at age 4 from this stock generation for the Tatar Strait yellowfin sole population.



**Fig. 68** Ricker's "stock-recruitment" model fit to the 1956-1992 observed data.



**Fig. 69** Exponential model of the relation between survival rate and number of broods at age 0.



**Fig. 70** Dynamics of standardized residuals of the survival rate regression by the birth years of broods.

The observed deviations from the exponential growth curve have causes other than the initial density of a population. The standardized residuals indicated a maximum of survival appears from 1974 to 1984, and low survival from the mid-1950s through the mid-1960s, 1985 through 1992 is characterized as slightly less than average.

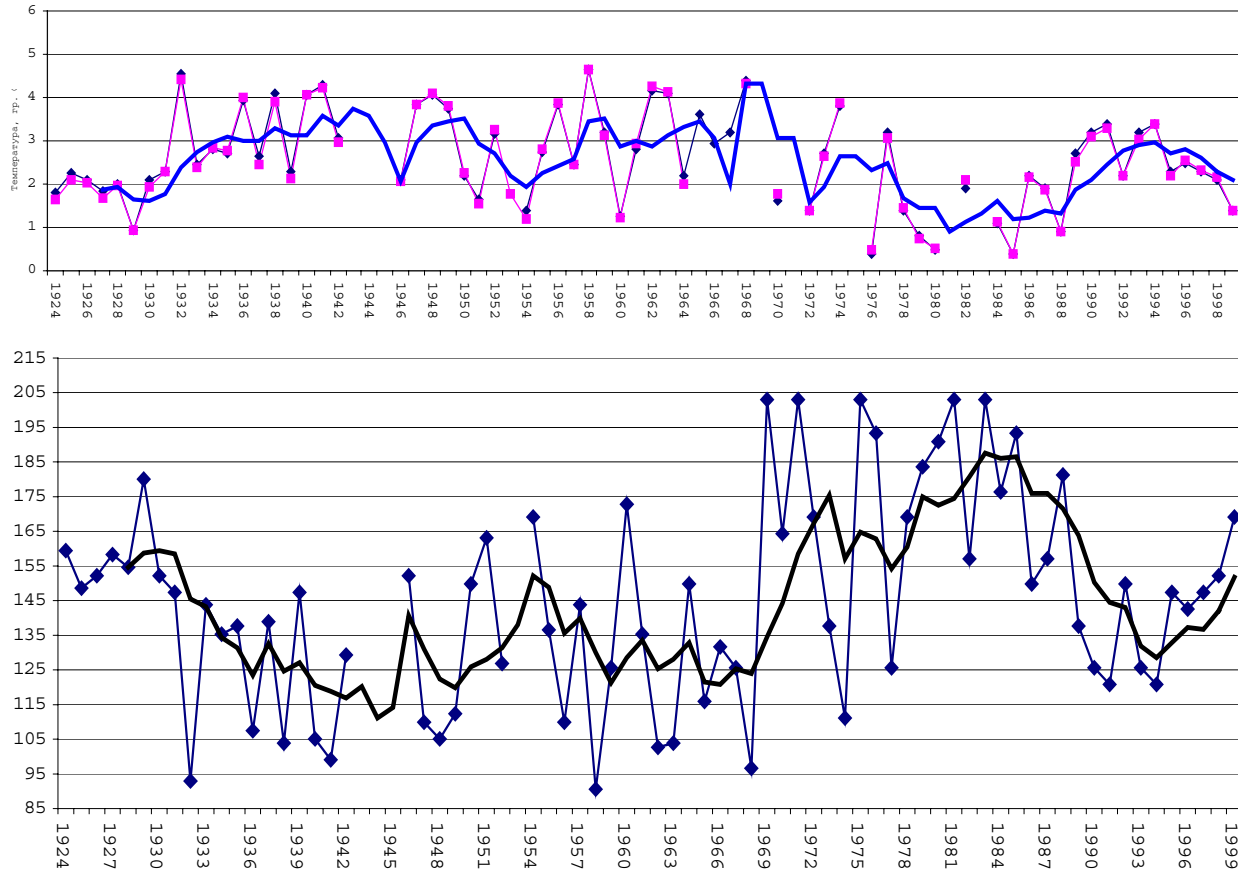
A temporal series of the regression residuals on fish density demonstrates the potential climatic causes affecting a survival. According to the data of coastal hydrometeorological stations (Kholmsk GMS), a maximum heating of the surface water in the northern part of the Sea of Japan occurred in the early to mid 1970s, whereas the 1980s were characterized as cold years. Nevertheless, temperature conditions in the coastal zone may non-adequately characterize biota during early stages of the yellowfin sole ontogenesis when a brood abundance is formed. The longest oceanographic time-series observations in Tatar Strait are standard transects: Antonovsky and Cape Slepikovsky. The temperature regime in this region strongly depends upon the Tsushima Current. Its strengthening during the autumn in a warm year forms a stable water column until the beginning of winter. This is evident in the dynamics of May temperature in the layer 50-100 m (Kantakov 2000; Fig. 71). The layer temperature, smoothed by a 5 point moving averages, has decreased from the mid-1970s to the late 1980s, whereas the mid-1950s to the mid-1970s was characterized by higher temperatures. A correlation of initial estimates of the layer

temperature with the regression residuals, the index of survival, appeared to be significant with a correlation coefficient of -0.48. A reconstructed zooplankton biomass time series for the southwestern Sakhalin coast has shown that maximum zooplankton biomass observed in cold years, and low plankton biomass occurred in warm years (Kantakov 2000; Fig. 71).

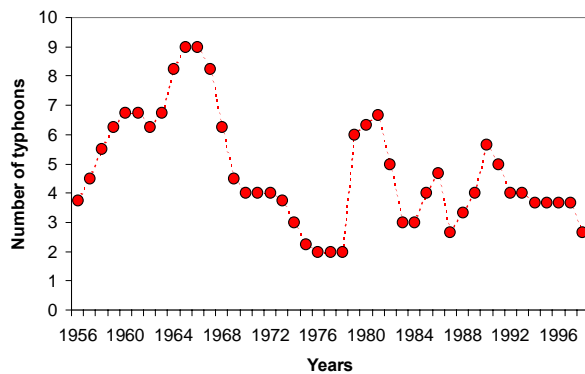
Maximum of atmospheric activity also occurred in the 1950s, when the greatest number of tropical typhoons moved through the region, whereas in the 1970s, the number of typhoons was minimum (Fig. 72). The correlation coefficient was -0.50 (Tarasyuk 1994 B).

## Discussion

The noted relationships demonstrate the influence of climatic factors on the abundance of yellowfin sole generations. To understand the mechanism of these relationships, we review the ecology of yellowfin sole spawning. They spawn in the northern part of the Sea of Japan in July-August, at the depths less than 50 m. Eggs are spawned in batches (Fadeev 1957, Ivankov *et al.* 1972). Spawned eggs are relatively small, their diameter is 0.8 – 0.9 mm. Embryos and larvae develop in the upper 50-m of water column at temperatures from 8 to 19°C (Pertseva- Ostroumova 1961). At the length of 16 - 27 mm, larvae settle on the bottom (Nikolotova 1975). The planktonic stage is about a one month, and on the whole, taking into account the duration of spawning, may continue up to 4 months (Tarasyuk 1994B). The peculiarity of yellowfin sole reproduction is the timing of their aggregations at plankton stages of development to small areas with circulation that prevents the larvae from flowing out of favorable sites (Moiseev 1952). Plankton and nektobenthic crustaceans at juvenile stages of development form the basic food for planktotrophic larvae (Nikolotova 1975). Evidently, a long stay in the upper water column, their peculiarities of feeding, and concentration in a limited area create a special vulnerability of yellowfin sole at early stages of ontogenesis to the negative affects of environment, and also a high mortality as a result of intra-population competition.



**Fig. 71** Dynamics of the May temperature in the 50-100 m layer along the transects Antonovsky and Cape Slepikovsky (top panel) and autumn biomass of the net zooplankton (bottom panel). Zooplankton biomass is in units of mg wet weight per cubic meter. (Source: Kantakov 2000).



**Fig. 72** Frequency of tropic typhoons moving through the area of Sakhalin Island.

Comparing these relationships with the peculiarities of reproduction of yellowfin sole, we conclude that the negative influence of the initial

cohort abundance upon their survival is realized through the deterioration of feeding conditions under the increased density of larval aggregations, diet selectivity, and limited resources of food fields. The influence of tropical typhoons (more than 80 % of them occur in June-August) (Eremin and Tretyakova 1980) may result both in the negative impact of hydrodynamic wave on the embryos survival at the sensitive stages of development, and in their impact on the small-scale circulation systems, causing the appearance of cold deep water masses on the surface and carrying eggs and larvae out of zones favorable for inhabitation. In the cold year periods, zooplankton biomass in the northern Sea of Japan increases, and that reduces the level of intra-population competition for food. In turn, this favorably affects the larval survival.

## References

- Darby, C.D. and Flatman, S. 1994. Virtual Population Analysis: Version 3.1 (Windows/DOS) User Guide. Info. Tech. Ser., MAFF Direct, Fish. Res., Lowestoft, (1): 85 pp.
- Eremin, P.G. and Tretyakova, E.I. 1980. To a question about the cyclicity of typhoons above Sakhalin Region. Information Letter No. 1/90. Yuzhno-Sakhalinsk, SakhUGCS, pp. 31– 45 (in Russian).
- Fadeev, N.S. 1957. On the type of spawning and fecundity for some commercial Sakhalin flounders. Zoological Journal 36(12): 18-41 (in Russian).
- Ivankov, V.I., Ivankova, Z.G., and Volkova, T.D. 1972. Types and terms of spawning for flounders from Peter the Great Bay. Scientific Notes of DVGU 60: 49-61 (in Russian).
- Kantakov, G.A. 2000. Oceanographic Retrospective Analysis of the Zooplankton Population Inhabitation Conditions at the Southwest Sakhalin in 20<sup>th</sup> Century. In 15<sup>th</sup> International Symposium on Okhotsk Sea & Sea Ice. Okhotsk Sea & Cold Ocean Research, pp. 384-390.
- Moiseev, P.A. 1952. Some specific features of the bottom and near-bottom fish distribution in the Far East seas. Izv. TINRO 27: 129 – 137 (in Russian).
- Nikolotova, L.A. 1975. Larval feeding of the west Kamchatka flounders. Izv. TINRO 97: 51-61 (in Russian).
- Pertseva-Ostroumova, T.A. 1961. A spawning and developing patterns of the Far East flounders. M.: AS USSR Publishers. 484 pp. (in Russian).
- Pope, J.G. and Shepherd, J.G. 1985. A comparison of the performance of various methods for tuning VPA's using effort data. J. Cons. Int. Explor. Mer. 42: 129-151.
- Tarasyuk, S.N. 1994A. Results of modeling biological indices of the yellowfin flounder from the western Sakhalin waters during the initial period of fishery. In "Fishery researches in Sakhalin-Kuril region and adjoining areas". Yuzhno-Sakhalinsk, Sakhalin Region Book Publishers, pp. 33-38 (in Russian).
- Tarasyuk S.N. 1994B. On the possible causes providing the abundant broods of yellowfin flounder. In "Fishery researches in Sakhalin-Kuril region and adjoining areas". Yuzhno-Sakhalinsk, Sakhalin Region Book Publishers, pp. 23-32 (in Russian).