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Abundance, dynamics and production properties of populations of edible bivalves *Mizuhopecten yessoensis* and *Spisula sachalinensis* related to the problem of organization of controllable submarine farms at the Western shores of the Sea of Japan

A. N. GOLIKOV and O. A. SCARLATO

Zoological Institute of the Academy of Sciences of the USSR; Leningrad, USSR

KURZFASSUNG: **Bestandsgrößen, Dynamik und Produktionseigenschaften von Populationen der eßbaren Muscheln *Mizuhopecten yessoensis* und *Spisula sachalinensis* im Hinblick auf das Problem der Organisation von kontrollierbaren submarinen Farmen an den Westküsten des Japanischen Meeres.** Die Lebensgeschichte, Ökologie, Populationsdynamik und Produktionsleistungen von zwei Muschelarten, *Mizuhopecten yessoensis* (JAY) und *Spisula sachalinensis* (SCHRENCK), werden im Hinblick auf ihre verbesserte Nutzung durch Kulturmaßnahmen beschrieben. Die beiden Arten sind Borealformen und leben im oberen Sublitoral des südwestlichen Japanischen Meeres. *M. yessoensis* gehört zur Epifauna; die Vertikalverteilung dieser durch Schwimmen zur aktiven Ortsänderung befähigten Art wechselt mit der Jahreszeit und dem Reifezustand. Die Bestandsstärke wird wesentlich vom Vorhandensein von Algen und Seegras bestimmt, auf denen sich die Jungtiere nach der Metamorphose anheften können. *S. sachalinensis* gehört zur Endofauna; Größe des Bestandes und Vertikalverteilung hängen besonders von den Witterungsbedingungen ab, da ein erheblicher Teil der Jungtiere vom Wellenschlag ausgespült und an den Strand geworfen wird. Die Untersuchungen über Populationsdynamik und Produktionsleistungen basieren auf regelmäßigen quantitativen Bestandsaufnahmen durch Schwimmtaucher, die während der Jahre 1962 bis 1966 zu allen Jahreszeiten durchgeführt wurden. Die Analyse der Größen- und Gewichtszusammensetzung der Populationen gestattet quantitative Aussagen über die Lebensdauer der beiden Arten, über das nach Jahreszeiten und Altersgruppen verschiedene Größen- und Gewichtswachstum sowie über die Produktionsleistungen.

INTRODUCTION

The maximal possible use of the biological resources of oceans and coastal waters for the benefit of mankind is one of the major tasks of the International Biological Program. The increase in size of fishing fleets equipped with modern fishing gear has considerably augmented the catches of economically useful marine organisms; however, in the long run, such intensive fishing will lead to a sharp decrease in the number of edible organisms available in the sea and to a depletion of nutritive protein reserves, even in marine ecosystems with most abundant life. Therefore, marine biologists face the problem of finding ways to artificially increase the individual numbers of edible species and to develop suitable methods of cultivating marine organisms by making use of natural hydrobiological processes which take place in the marine environment.

The marine biologist must study the biological structure of sea areas with the most abundant life, the regularities in the distributions of the most important biocenoses, and detailed aspects of the ecology of the species which are of interest from an economical point of view. Such studies will provide a sound basis for solving the problem outlined above. Of primary importance is the analysis of the structure of populations and their seasonal dynamics influenced by abiotic and biotic conditions, as well as the investigation of the reproductive properties of the species studied.

The laboratory of Marine Investigations of the Zoological Institute of the Academy of Sciences of the USSR is devoted to the study of the marine fauna and its evolution and to solving theoretical problems of general hydrobiology; on the basis of the information attained, the Laboratory simultaneously attempts to work out the theoretical fundament for increasing the productivity of marine organisms of economical importance in natural ecosystems and the prerequisites for developing submarine agriculture. In recent years some biocenoses of practical importance on the shores of Southern Primorje (Sea of Japan) and Southern Sakhalin (Sea of Japan and Okhotsk Sea) were studied, employing quantitative diving methods (SCARLATO et al. 1964, GOLIKOV & SCARLATO 1965). Some results of these studies have been published concerning the problems of hydrobiology (GOLIKOV 1965, 1966, SCARLATO et al. 1967, GOLIKOV & SCARLATO 1967a, 1968) and the biology of molluscs, including edible species (SCARLATO & GOLIKOV 1965, GOLIKOV & SCARLATO 1966, 1967b).

In the present paper the authors are attempting to depict some aspects of ecology, seasonal abundance dynamics, and reproductive properties of two species of edible molluscs, *Mizuhopecten yessoensis* (JAY) and *Spisula sachalinensis* (SCHRENCK), and offer some preliminary suggestions on methods to artificially increase their quantity at the Western shores of the Sea of Japan.

MATERIAL AND METHODS

The material was collected in all seasons of the year by the quantitative diving method in Posjet Bay from 1962 until 1966. In order to analyse the population composition of the species studied as a function of the different seasons, all individuals collected from plots of known dimensions were measured and the individual numbers per size-group determined. Considering the fact that the species studied, as well as other marine invertebrates of temperate and cold latitudes, have a limited period of time for spawning and larval development, principally determined by temperature (ORTON 1920, RUNNSTRÖM 1929, and others), natural size-age groups could be distinguished which corresponded to different generations. Subdividing natural populations into size-groups before analysis (made by some other authors) masks the real structure of a population and does not permit to reveal its generation discreteness. By counting the number of size-age groups in a population (each of these groups corresponding to a generation) one can easily determine the age of individuals of different size and hence the predominating life span of individuals of the species under these conditions. The weight of individuals of a certain size was determined by direct weighing and checked by the formula:

$$W = qL^b,$$

where W is the weight of an individual, q the initial ordinate value, L the linear size of an individual, and b the angular coefficient. This formula, after logarithmic treatment, may be presented as a straight line equation. It reflects the parabolic dependence between the linear size of an individual and its weight. On the basis of the analysis of the size-generation structure of a population plotting population density on the ordinate and shell size on the abscissa the growth curve of individuals of the population was determined. Weight growth characteristics and calculated alterations in the quantity of each generation with age, were used for determining population growth production. Taking into consideration the stationary character of the populations of the species studied, population growth (production) is expressed in the weight increase of all specimens of the population per year at the time of analysis of its state and may be described by the formula:

$$Pg = N_0 (W_1 - W_0) + N_1 (W_2 - W_1) \ldots + N_n (W_{n+1} - W_n),$$

where Pg is population production, N number of individuals of a certain age, $W_{n+1} - W_n$ weight increase of individuals of a certain size per year (or ΔW). The population production was calculated following the analysis of size-weight and age compositions for each season of a year. The average annual population growth production was determined by averaging the calculated growth rates over all 4 seasons employing the formula:

$$Pg\ av = \frac{P_{g1} + P_{g2} + P_{g3} + P_{g4}}{4}$$

This method of estimating annual population production allows one to neglect seasonal changes in growth rates and to ascertain the condition which the population has attained within a year at the time of observation.

The amount of living substance formed and retained in the population (except for the individuals eliminated) calculated on the basis of the same principles employed to assess population growth; however, we did not estimate the yearly growth potential of a generation but the actual amount of young which remained, (including individuals less that 1 year old) and the yearly weight increase of older individuals present. This value, designated as supporting production, was calculated according to the formula:

$$P_s = B_0 + B_1 + N_2 (W_2 - W_1) \ldots + N_n (W_n - W_{n-1}),$$

where P_s ist the supporting production, B_0 and B_1 are biomasses of young and of individuals less than 1 year old. The average annual supporting production is considered to be the sum of a year's productive processes at the time of each seasonal sampling divided by the number of seasons:

$$P_s\,av = \frac{P_{s1} + P_{s2} + P_{s3} + P_{s4}}{4}$$ *

The availability of material at all the seasons has allowed us to trace the quantitative dynamics of the species considered here and of some other edible mass species of molluscs, to study the variations in their growth rate and in their distribution patterns at different seasons, to ascertain the times of spawning and settling of the young, and the seasonal dynamics of the productive process. On the following pages we present pertinent information on the two edible molluscs *Mizuhopecten yessoensis* and *Spisula sachalinensis*.

RESULTS

Mizuhopecten yessoensis (JAY)

Pecten yessoensis JAY (1856: 293, Pl. 3, Fig. 3, 4, Pl. 4, Fig. 1, 2); SCHRENCK (1867: 484, Taf. 20, Fig. 1–4); BAZIKALOVA (1930, 1934); RAZIN (1934: 48); BAZIKALOVA (1950); MARKOVSKAYA (1951); IVANOV (1955: 162); SCARLATO (1955: 190, Pl. 50, Fig. 8).

Pecten (Patinopecten) yessoensis SCARLATO (1960: 115, Fig. 58, Pl. 14, Fig. a, b).

Patinopecten yessoensis GOLIKOV & SCARLATO (1967b: 96, Pl. 8, Fig. 3); TAKEO (1967).

Mizuhopecten yessoensis MASUDA (1963).

At the shores of the Southern Primorje (Sea of Japan) this edible low-boreal species inhabits mainly depths of 0.5 to 25 m on the sand and silt-sand bottom (often with stone and shell admixtures). In summer time, when surface water layers warm to 15°–20° C, the scallops are found at depths of 0.5 to 12 m and are most abundant in a depth ranging from 1.5 to 4 m; their young settle at the same depths on the fronds of seaweed. In autumn, before the first frosts, the molluscs leave the shallow inshore waters and move to depths of 3 to 25 m, being most abundant at 6 to 8 m. By this time, their quantity considerably decreases, due mainly to elimination of the young. In winter, their activity is greatly reduced and they accumulate at 3.5 to 6.5 m depths. Their number decreases still more at the beginning of spring due to a general rise in the death-rate (Fig. 1). When spring approaches and the surface layers of the water warm to 6°–8° C, the molluscs become active and spread to depths from 0.5 to 8 or 9 m, being found usually at depths of 3 to 7 m. Because of the pre-spawning aggregations of mature individuals in the most favourable plots their population density somewhat increases at this time.

Mizuhopecten yessoensis begins to spawn at the end of May at a water temperature of about 8° to 12° C and continues until August. Fertility is very high; a female gonad contains 20 to 30 million eggs.

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* The principles of calculating the population growth and supporting production of populations of poikilotherm animals on the basis of the analysis of their size-generation composition are expounded in a paper by GOLIKOV (in press).

The larvae settle and complete their metamorphosis at the end of June or the beginning of July. The young settle on the fronds of seaweed, chiefly *Sargassum (S. pallidum, S. kjellmanianum)* and leaves of sea grass *(Zostera asiatica)* mostly at depths of 1 to 3 m, with 7 to 15 specimens per m². On the artificial substrate-collectors

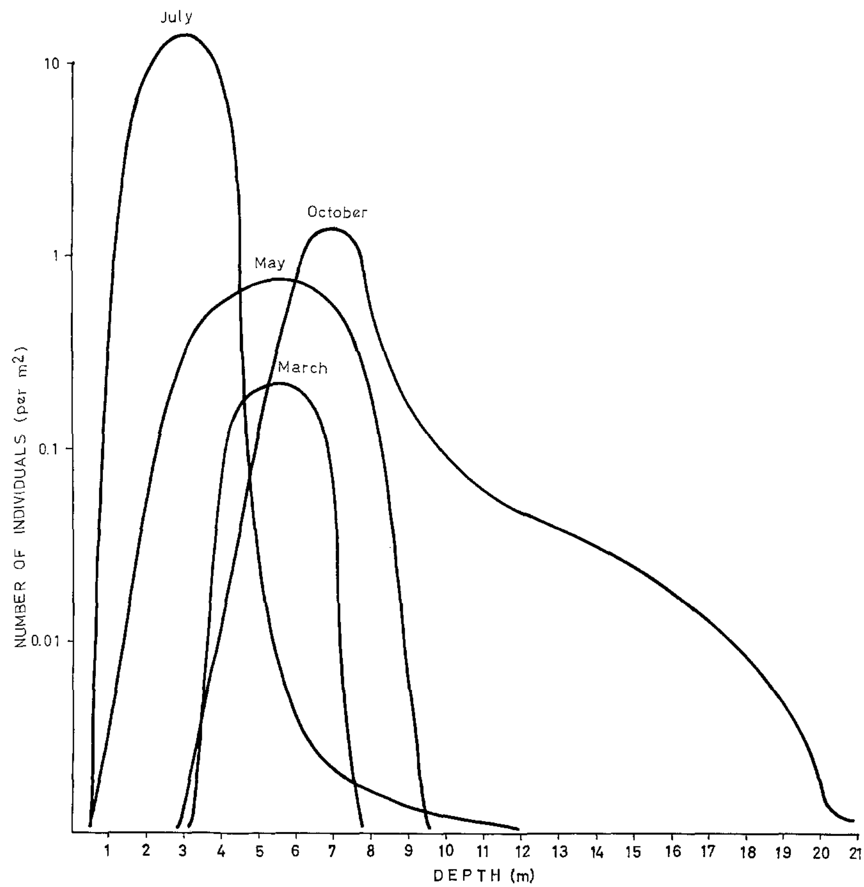

Fig. 1: *Mizuhopecten yessoensis.* Distribution and abundance in the Posjet Bay (Sea of Japan) during different seasons. Logarithmic data have been adopted on the ordinate in order to reduce graph height

(cotton nets, unravelled sisal ropes, birch brooms), placed on rafts at similar depths, 1 to 2 thousand larvae settle per m² substrate surface. The settled larvae grow rapidly and gradually move to the base of the plant or to the lower end of the artificial substrate.

About a month after settling the *Mizuhopecten yessoensis* larvae detach from the plants (or from suspended artificial substrates) and begin a bottom mode of life. At the beginning of September the shell of a young mollusc is 20 mm high and by the middle of October it attains 30 mm. The growth rate of the mollusc slackens considerably during the cold part of the year. A scallop shell attains a height of 45 to 50 mm in one year. The growth rate noticeably falls with age. Growth rate is particularly small in winter, when a sexually mature mollusc grows about 0.12 mm per month (Fig. 2).

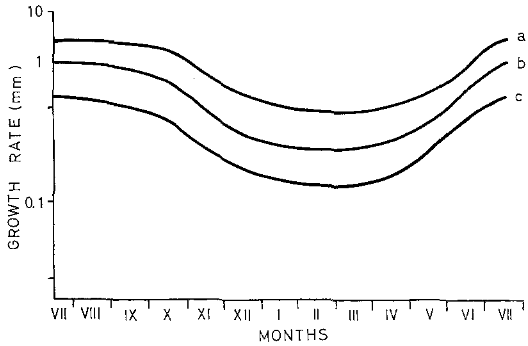

Fig. 2: *Mizuhopecten yessoensis.* Alterations in growth rate as a function of season; *a* growth rate of individuals less than 1 year old; *b* less than 2 to 3 years old. *c* Growth rate of mature individuals (4 years or older)

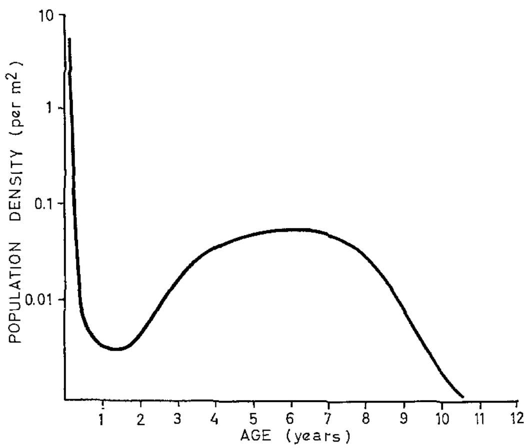

Fig. 3: *Mizuhopecten yessoensis.* Distribution and abundance as a function of age

Mizuhopecten yessoensis attains sexual maturity after 3 years, when their shell height is 95 to 100 mm. Up to this age the young scallops live dispersed; they do not aggregate. After maturity the scallops aggregate in the most favourable areas where they reveal patchy aggregation with significantly increased population densities. This type of distribution is maintained over all seasons up to the end of the life span (Fig. 3). The life span of *M. yessoensis* is 10 years (Fig. 4). The majority of individuals in a population are less than 9 years old (with shell heights up to 160 mm). The most densely populated areas are inhabited by young individuals still attached to plants and by scallops more than 3 years old with shells higher than 100 mm.

The highest death-rate after metamorphosis occurs during the first months of life. Only about 4 % of the settled young reach the age of about 6 months (Fig. 5). In the older age-groups the highest death-rate occurs in winter; the highest growth-rate of

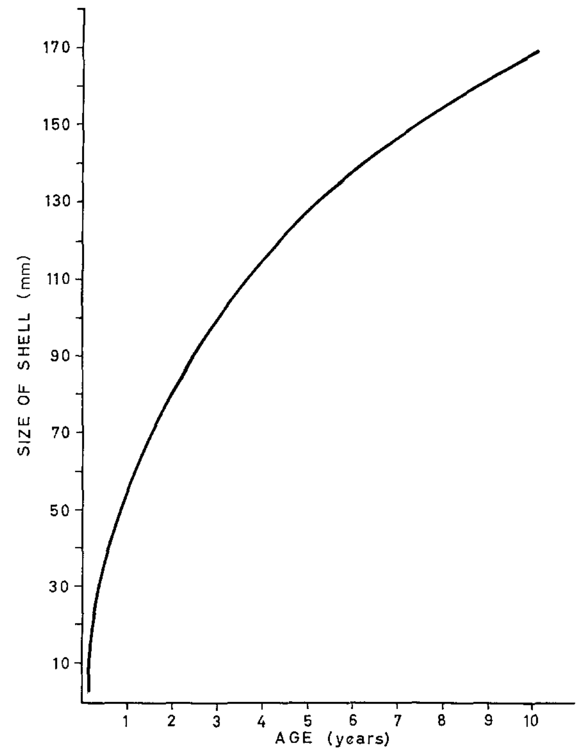

Fig. 4: *Mizuhopecten yessoensis.* Growth as a function of shell size

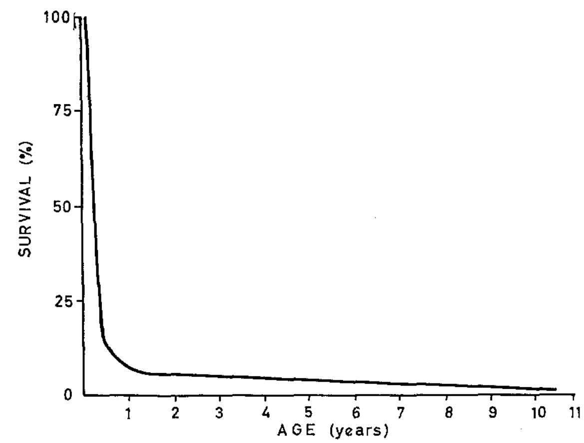

Fig. 5: *Mizuhopecten yessoensis.* Survial as a function of age

all age-groups was observed in late spring, summer and early autumn (Fig. 6). The average annual growth production of *Mizuhopecten yessoensis* (calculated on the basis

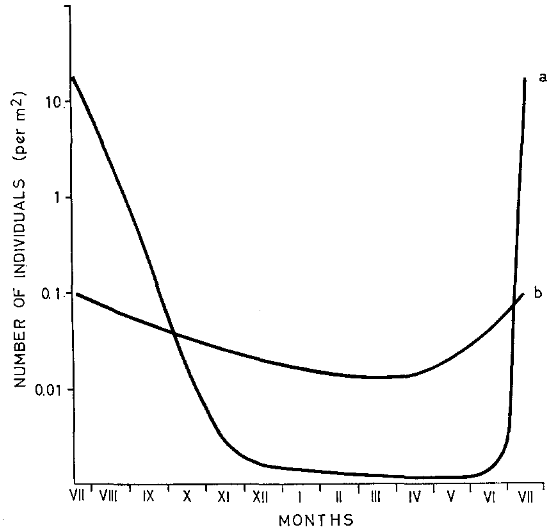

Fig. 6: *Mizuhopecten yessoensis.* Survival of different age-groups as a function of the seasons. *a* young less than 1 year old; *b mature* individuals

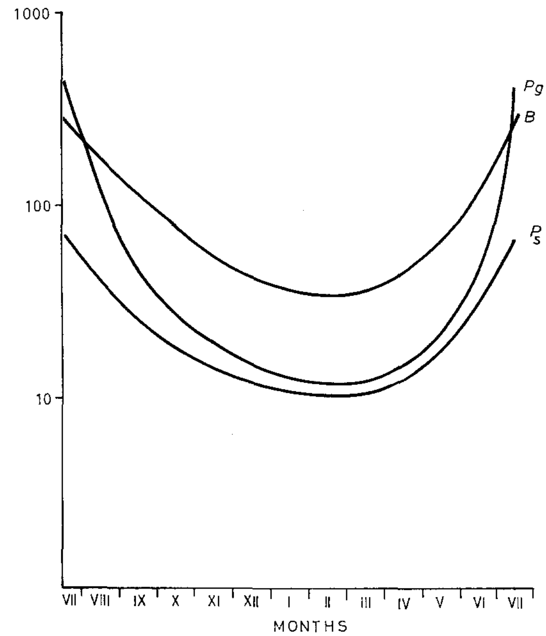

Fig. 7: *Mizuhopecten yessoensis.* Fluctuations in population (productive process) during a year at different seasons. Ordinate: logarithms of biomass value (*B*), of growth production per year at the season indicated (*Pg*), and of the supporting production per year at the season indicated (P_s)

of the principles stated in the introduction to this paper) amounts to about 130 g per m^2 and the supporting production 32 g per m^2 with $\frac{p}{B}$ indices of 1 and 0.25, respectively. The most intensive production process takes place in summer, when the growth production attains 457 g/m^2 per year ($\frac{p}{B}$-index = 1.5), and supporting production about 72 g/m^2 per year ($\frac{p}{B}$-index = 0.2) (Fig. 7). In autumn, the production capacity of a population declines sharply. Chiefly due to the elimination of the major part of the young, growth production falls to 28 g/m^2 per year ($\frac{pg}{B}$ index = 0.34), and supporting production to 19.6 g/m^2 per year ($\frac{ps}{B}$ index = 0.24). In winter, because of the greatly reduced growth rate and increased death-rate among individuals of all age-groups, production rate continues to decrease and falls to 13.7 g/m^2 per year ($\frac{pg}{B}$ index = 0.34) judged by the growth capacity of the population, and to 10.8 g/m^2 per year ($\frac{ps}{B}$-index = 0.24) judged by the remaining composition of the population at the end of the hydrological winter. In spring, because of the rapid increase in growth rate and the prespawning increase in the number of mature adults in favourable areas, population growth production increases to 23.4 g/m^2 per year ($\frac{pg}{B}$ index = 0.3) and the rate of supporting production to 19.6 g/m^2 per year ($\frac{ps}{B}$ index = 0.25). After the next spawning at the beginning of summer, the general pattern of seasonal dynamics in the production process is repeated.

Spisula sachalinensis (SCHRENCK)

Mactra sachalinensis SCHRENCK (1861: 94; 1867: 575, Taf. 23, Fig. 3–7); IVANOV (1930); RAZIN (1934: 63).

Spisula sachalinensis GOLIKOV & SCARLATO (1967b: 115, Fig. 95, Pl. 12, Fig. 2).

At the shores of the Southern Primorje (Sea of Japan) the low-boreal *Spisula sachalinensis* inhabits mainly depths of 1 to 5 m on the sandy bottom, which is sometimes slightly silted. In summer, this mollusc forms the most densely populated colonies at a depth of 2 to 4 m (Fig. 8). In autumn, after the end of the mass settling of young and during the pronounced intensification of gales, a considerable number of *S. sachalinensis*, particularly young ones which are unable to bury themselves deep enough into the bottom, are washed into the littoral and even into the supralittoral. There may be more than 50 specimens per linear metre cast ashore after strong gales. In winter, the abundance of this species decreases sharply. In the middle of March *Spisula* occurs at depths of 1.5 to 5.5 m with increased density of population at a depth of 3 m. Activity of these animals at water temperatures below zero and near to 0^0 C is sharply reduced. By the end of May depth range of distribution of the molluscs increases a little, but their numbers further decrease. At this time, *S. sachalinensis* inhabits approximately the same depths as in winter.

Spisula sachalinensis begins to spawn at the end of June. At the end of July, on the bottom, young molluscs were found with a shell height of 2 to 3 mm. The highest intensity of spawning is attained at the beginning of autumn; in October, the greatest number of young, with a shell height of 1 to 14 mm, occurs on the bottom. The young settle in the same biotopes inhabited by the adults. By spring, the number of young decreases, mostly due to mortality and partly because of transition to an older age-group. The highest mortality of the adults occurs in summer, after spawning (Fig. 9).

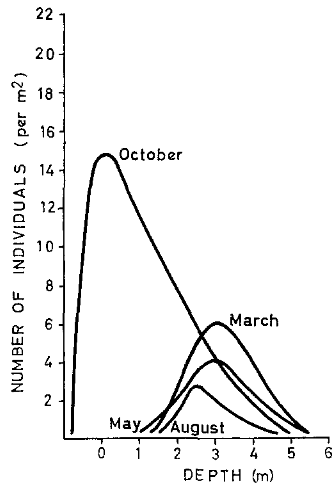

Fig. 8: *Spisula sachalinensis.* Distribution and abundance in the Posjet Bay during the different seasons

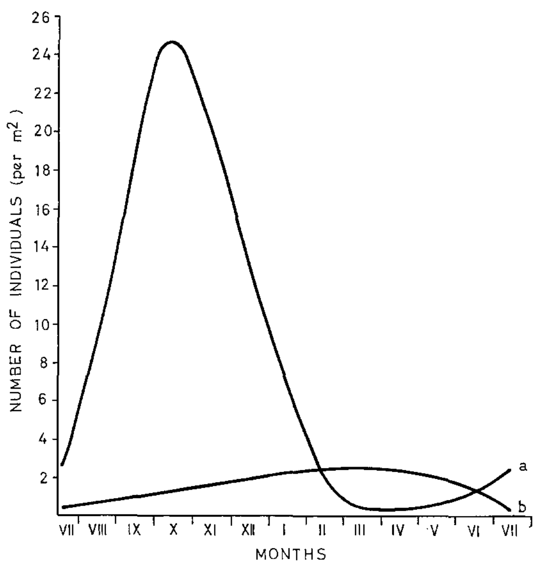

Fig. 9: *Spisula sachalinensis.* Survival of different age-groups as a function of season. *a* young less than 1 year old; *b* more than 1 year old

The lifetime of *Spisula sachalinensis* is about 8, rarely 9, years (Fig. 10). The main part of a population lives until the age of 6 years; less than 3 % reach an age of 7 or 8 years (Fig. 11). The growth rate is highest in young individuals especially during the warmest time of the year. In winter, the growth rate decreases 4 or 5 times, but slow growth is maintained (Fig. 12).

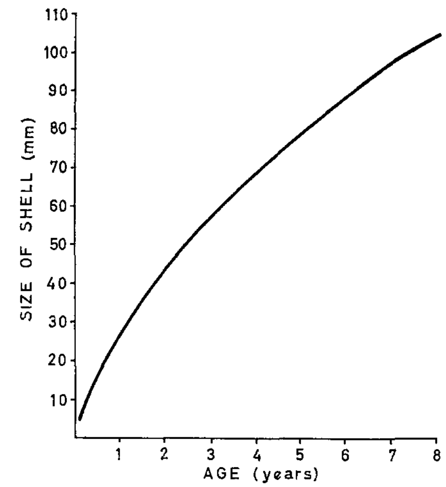

Fig. 10: *Spisula sachalinensis*. Growth rate as function of shell size

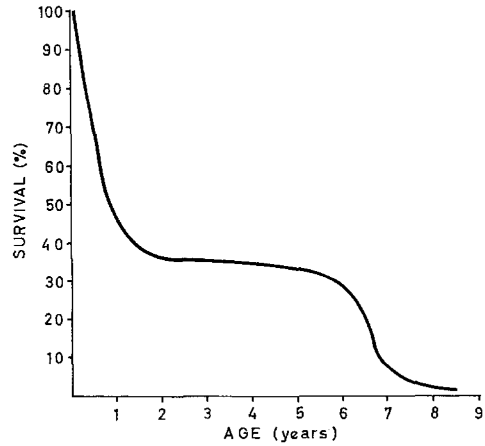

Fig. 11: *Spisula sachalinensis*. Survival as a function of age

Spisula sachalinensis becomes sexually mature at about 3 years of age; at this time shell height is about 50 to 60 mm. Up to this age the young are rather widely distributed and do not form any local patches of increased population density. After attaining sexual maturity, *S. sachalinensis* aggregates in favourable biotopes; later on the individuals occupy separate areas maintaining a sufficient overall population density (Fig. 13).

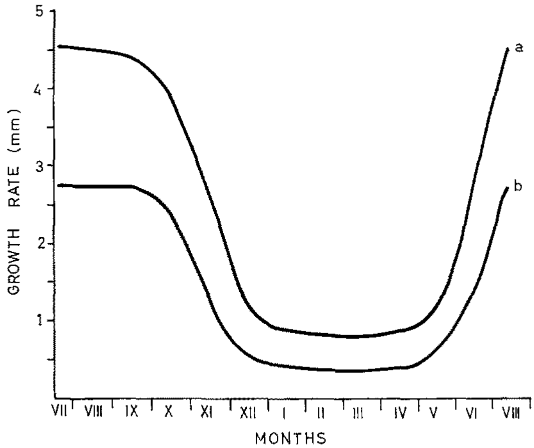

Fig. 12: *Spisula sachalinensis.* Fluctuation in growth rate as a function of age. *a* growth rate of individuals less than 1 year old; *b* of mature individuals

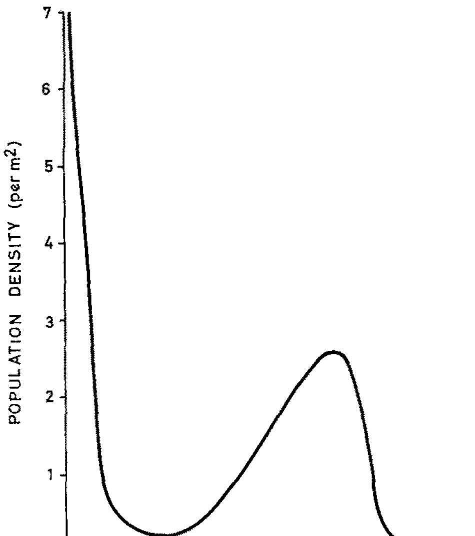

Fig. 13. *Spisula sachalinensis.* Distribution and abundance as a function of age

Calculated in the same way as for *M. yessoensis,* the average annual population growth production for *Spisula sachalinensis* amounts to 451 g/m^2, and the supporting production to 329 g/m^2 with $\frac{P}{B}$ indices of 0.55 and 0.39, respectively. The amount of biomass and the correlated population growth and supporting production attain their highest values by March, when the annual population growth production amounts to about 881 g/m² and the supporting production to about 645 g/m², with $\frac{p}{B}$ indices of 0.55 and 0.4, respectively. By May and June biomass as well as growth and supporting productions diminish, the former to 11 g/m², and the latter to 30 g/m² per year ($\frac{p}{B}$ indices = 0.1 and 0.28, respectively). By autumn, because of the mass appearance of young, the productive capacity of the population increases to 293 g/m² per year for the growth production and to 164 g/m² for the supporting production ($\frac{p}{B}$ indices = 0.82 and 0.46, respectively). Then the process repeats. In contrast to *M. yessoensis*, *S. sachalinensis* has a higher biomass production per year becaue of a considerably higher population density in winter; the annual production of this species is relatively high by March, in spite of the relatively slow turnover of organic matter during the cold period of the year.

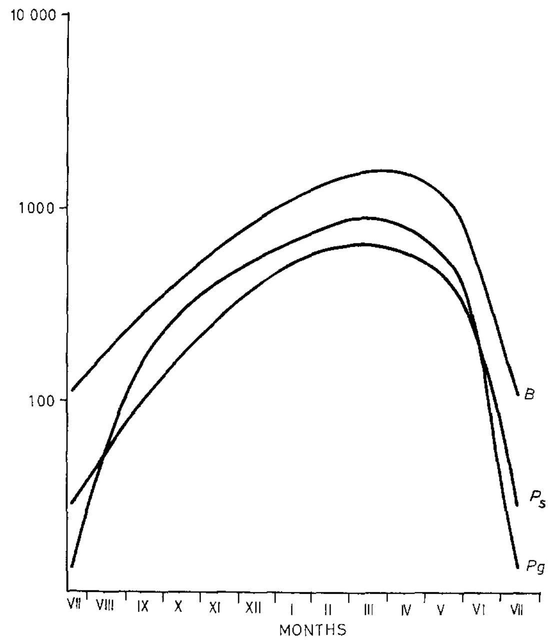

Fig. 14: *Spisula sachalinensis.* Fluctuations in the productive process of populations per year at different seasons. Ordinate: logarithms of biomass value (*B*), of growth production per year at the season indicated (*Pg*), and of the supporting production per year at the season indicated (*Ps*)

DISCUSSION

The information presented and the study of the general biological background as well as of the hydrobiological processes during the different seasons of a year in Posjet Bay and adjacent waters, have allowed us to make some suggestions for cultivating the two edible mollusc species dealt with in this paper.

The hydrological conditions and biotic background are favourable for spawning and for the planktonic phase of both species. During the planktonic phase of life, the larvae of both bivalve molluscs predominate in the whole water column and there are relatively few predators. Therefore, it can be assumed that spawning conditions and the length of the planktonic period do not limit the abundance of these species. However, the amount of substrate suitable for larval settling limits, to a considerable extent, the number of larvae which can complete successful metamorphosis, e.g. in *Mizuhopecten yessoensis* and related species with a comparable ecology of their early ontogenetic stages. Indeed, seaweeds and sea grass with their phyllose structure of fronds and leaves, which are suitable for settling of scallop larvae, are distributed in a relatively narrow belt at the shores of the Southern Primorje. Probably, this is the very reason why the large swarms of scallop larvae which fail to secure a suitable substrate for settling, perish. As has been stated above, a considerable amount of scallop larvae settled on the artificial collectors placed on anchored rafts.

The second factor limiting the number of individuals of the economically important *Mizuhopecten yessoensis* is the mass consumption of settled young by the predators, especially by the sea stars *Patiria pectinifera*, *Asterias amurensis* and *Distolasterias nippon*.

Considering these facts we recommend the following measures for establishing sea farms for artificial increase of individual numbers of scallops under conditions prevailing in the Southern Primorje: (1) offering of sufficient collectors to allow maximum numbers of larvae to settle; (2) protection of growing spat and adults from predators (especially sea stars) via fences, nets, etc., removal (collection) of the predators.

The most important factor limiting the increase in numbers of individuals of *Spisula sachalinensis* is extensive water movements due to storms. While the young are still unable to bury themselves deep and fast into the sea bottom, heavy waves often cast them ashore in enormous quantities, where, owing to the unfavourable conditions, the young molluscs perish. Therefore, periodical collection of the young cast ashore during storms and their transfer to protected farm areas which favour further growth can be recommended in order to increase, artificially, the abundance of this species.

SUMMARY

1. The quantitative distribution and the size/weight structure of populations of the edible molluscs *Mizuhopecten yessoensis* (JAY) and *Spisula sachalinensis* (SCHRENK) have been studied on the shores of Southern Primorje (Sea of Japan) during different seasons of the year.
2. By counting the size-age groups (which correspond to certain generations) constituting a given population, the age of individuals of different size and the maximum individual life-time were determined.
3. The characteristics of growth (weight increase) and calculation of fluctuations in abundance of generations of different age, have enabled the authors to estimate the nett population growth production (expressed as weight increase of all specimens of a population per year at the time of control). The average annual population growth production was determined by averaging the values obtained for each of the four seasons.

4. The living matter accumulated over a year and retained by the individuals of the population, as well as the matter contained in shells, was calculated by adding up the weight of the young present at the time of control (including specimens less than 1 year old) and the annual weight increase in the older specimens available. The value obtained is designated as supporting production; it constitutes the minimum rate of production of living matter required for maintaining the size of a population at a stationary level. The average annual supporting production is the sum of the productive process for a year. It was determined by dividing the values obtained for each of the seasons by 4 (i. e. by the number of seasons).
5. The average annual population growth production of *Mizuhopecten yessoensis* in the areas studied, is 131 g/m^2, and the supporting production 32 g/m^2; the *P/B* indices are 1 and 0.25, respectively. The greatest biomasses and maximum production rates occur in summer; they decrease considerably in winter and begin to increase again in the spring.
6. The average annual population growth production of *Spisula sachalinensis* is 451 g/m^2, and the supporting production 329 g/m^2; the *P/B* indices are 0.55 and 0.39, respectively. Maximum biomass and production rates are observed at the beginning of winter because of winter aggregation of specimens in the study area; the rate of turnover of organic matter is small during the cold period. The *P/B* indices reach their highest value in autumn.
7. The hydrological conditions and the biotic background at the shores of the Southern Primorje are favourable for spawning and for the planktonic stages of both species.
8. In *Mizuhopecten yessoensis* the larvae settle on submerged plants. The factors which badly limit the abundance of this species are the shortage of substratum for settling and the predation on young settled individuals especially by sea stars. Artificial increase in abundance of the species may be accomplished by: (a) offering sufficient settling area; this can be done by placing suitable collectors in the habitat; (b) protecting the settled young from predators.
9. Abundance of *Spisula sachalinensis* is most appreciably limited by the effect of storm waves, which cast numerous young, weak individuals ashore into the intertidal zone, where they perish owing to unfavourable conditions. Collection of young individuals cast ashore and their transfer into protected farm areas favourable for growth is recommended for artificial increase in the abundance of this species.

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First author's address: Dr. A. N. GOLIKOV
Zoological Institute
Academy of Sciences of USSR
Leningrad, B-164, USSR